Multiplicative Properties of the Slice Filtration

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ABSTRACT OF DISSERTATION

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Abstract

We show that the slice filtration introduced by Voevodsky is compatible in a suitable sense with the symmetric monoidal structure in the category of motivic symmetric $T$-spectra $\text{Spt}_T^{\Sigma}(Sm|_S)_{Nis}$ constructed by Jardine. It follows from this compatibility that the zero slice of the sphere spectrum $s_0(1)$ is a ring spectrum in $\mathcal{SH}(S)$ and that for every symmetric $T$-spectrum $X$, and every $n \in \mathbb{Z}$; the $n$-slice $s_n(X)$ is a module over $s_0(1)$. In particular, if the base scheme is a field of characteristic zero, we have that all the slices $s_n(X)$ are big motives in the sense of Voevodsky.
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Introduction

Let $S$ be a Noetherian separated scheme of finite dimension, and let $\mathcal{SH}(S)$ denote the motivic stable homotopy category of Morel and Voevodsky. In order to get a motivic version of the Postnikov tower, Voevodsky [24] constructs a filtered family of triangulated subcategories of $\mathcal{SH}(S)$:

$$\cdots \subseteq \Sigma^{q+1}_{T} \mathcal{SH}^{eff}(S) \subseteq \Sigma^{q}_{T} \mathcal{SH}^{eff}(S) \subseteq \Sigma^{q-1}_{T} \mathcal{SH}^{eff}(S) \subseteq \cdots$$

(1)

The work of Neeman [18, 19], shows that the inclusion:

$$i_{q} : \Sigma^{q}_{T} \mathcal{SH}^{eff}(S) \rightarrow \mathcal{SH}(S)$$

has a right adjoint $r_{q}$, and that the following functors are exact:

$$f_{q}, s_{q} : \mathcal{SH}(S) \rightarrow \mathcal{SH}(S)$$

where $f_{q} = i_{q} r_{q}$, and for every $T$-spectrum $X$, $s_{q} X$ fits in the following distinguished triangle:

$$f_{q+1} X \rightarrow f_{q} X \rightarrow s_{q} X \rightarrow \Sigma_{T}^{1,0} f_{q+1} X$$

We say that $f_{q} X$ is the $q$-connective cover of $X$ and that $s_{q} X$ is the $q$-slice of $X$.

Let $\mathcal{SH}^{\Sigma}(S)$ denote Jardine’s motivic symmetric stable homotopy category [13], $X$ be a ring spectrum in $\mathcal{SH}^{\Sigma}(S)$, $M$ be an $X$-module, and $Y, Y', Z, Z'$ be arbitrary symmetric $T$-spectra. Our main results (see theorems 3.5.10, 3.5.14, 3.5.16 and 3.5.18) are the following:

1. For every $p, q \in \mathbb{Z}$, the smash product of symmetric $T$-spectra induces the following natural external pairing:

$$s_{p}^{\Sigma} Y \land s_{q}^{\Sigma} Z \xrightarrow{\cup_{p,q}^{\Sigma}} s_{p+q}^{\Sigma} (Y \land Z)$$
2. The zero slice of $X$, $s^0_\Sigma(X)$ is a ring spectrum in $\mathcal{SH}_\Sigma(S)$.

3. For every $n \in \mathbb{Z}$, the $n$-slice of $M$, $s^\Sigma_n(M)$ is a module over $s^\Sigma_0 X$.

4. The direct sum of all the slices of $X$, $s^\Sigma X = \bigoplus_{n \in \mathbb{Z}} s^\Sigma_n X$ is a graded ring spectrum in $\mathcal{SH}_\Sigma(S)$.

5. The direct sum of all the slices of $M$, $s^\Sigma M = \bigoplus_{n \in \mathbb{Z}} s^\Sigma_n M$ is a graded module over $s^\Sigma X$.

6. If the base scheme $S$ is a field of characteristic zero, then all the slices $s^\Sigma_n Y$ are big motives in the sense of Voevodsky.

7. The smash product of symmetric $T$-spectra induces natural external pairings in the motivic Atiyah-Hirzebruch spectral sequence generated by the slice filtration (see definition 3.5.17):

$$E_r^{p,q}(Y;Z) \otimes E_r^{p',q'}(Y';Z') \longrightarrow E_r^{p+p'+q+q'}(Y \wedge Y';Z \wedge Z')$$

To prove the results mentioned above, we need to carry out a very detailed analysis of the multiplicative properties (with respect to the smash product of spectra) of the filtration (1) considered above. It turns out that the natural framework to do this, is provided by Jardine’s category of motivic symmetric $T$-spectra [13]. Our approach consists basically of three steps:

1. First, we lift Voevodsky’s slice filtration to the usual category of $T$-spectra equipped with the Morel-Voevodsky motivic stable model structure (see section 3.2).

2. Then, using the Quillen equivalence given by the symmetrization and forgetful functors [13], we are able to promote the previous lifting to the category of symmetric $T$-spectra (see section 3.3).

3. Finally, we describe the multiplicative properties of the slice filtration using the symmetric monoidal structure given by the smash product of symmetric $T$-spectra (see section 3.4).
We use Hirschhorn’s approach to localization of model categories for the construction of the lifting of the slice filtration to the model category setting. In order to apply Hirschhorn’s techniques, it is necessary to show that the Morel-Voevodsky motivic stable model structure is cellular; for this we rely on Hovey’s general approach to spectra [11] and on an unpublished result of Hirschhorn (see theorem 2.2.4). For the description of the multiplicative properties of the slice filtration in the model category setting, we use Hovey’s results on symmetric monoidal model categories [10, chapter 4].

We now give an outline of this thesis. In chapter 1, we just recall some standard results about Quillen model categories. The reader who is familiar with the terminology of model categories may skip this chapter.

In chapter 2, we review the definitions of the Morel-Voevodsky stable model structure for simplicial presheaves and Jardine’s stable model structure for symmetric T-spectra. We also show that these two model structures are cellular, therefore it is possible to apply Hirschhorn’s technology to construct Bousfield localizations. The reader who is familiar with these two model structures may either skip this chapter or simply look at sections 2.2, 2.5 and 2.7 where we prove that the cellularity condition holds.

Finally in chapter 3, we carry out the program sketched above. In section 3.1, we review Voevodsky’s construction for the slice filtration in the setting of simplicial presheaves. In section 3.2, we apply Hirschhorn’s localization techniques to the Morel-Voevodsky stable model structure in order to construct three families of model structures, namely $R_{C_{q,eff}} Spt_T M_*$, $L_{<q} Spt_T M_*$ and $S^q Spt_T M_*$ ($q \in \mathbb{Z}$). The first family, $R_{C_{q,eff}} Spt_T M_*$ is constructed by a right Bousfield localization with respect to the Morel-Voevodsky stable model structure (see theorem 3.2.1), and it provides a lifting of Voevodsky’s slice filtration to the model category level (see theorem 3.2.23). Moreover, this family has the property that the cofibrant replacement functor $C_q$ provides an alternative description for the functor $f_q$ ($q$-connective cover) defined above (see theorem 3.2.20). In order to get a lifting for the slice functors $s_q$ to the model category level, we need to introduce the model structures $L_{<q} Spt_T M_*$ and $S^q Spt_T M_*$. The model category $L_{<q} Spt_T M_*$ is defined as a left Bousfield localization with respect to the Morel-Voevodsky stable model structure (see theorem
3.2.29); its main property is that its fibrant replacement functor \( W_q \) gives an alternative description for the cone of the natural map \( f_q X \to X \) (see theorems 3.1.18 and 3.2.52). On the other hand, the model structure \( S^q \Spt_T \mathcal{M}_* \) is constructed using right Bousfield localization with respect to the model category \( L_{<q+1} \Spt_T \mathcal{M}_* \) (see theorem 3.2.59), and it gives the desired lifting for the slice functor \( s_q \) to the model category level (see theorem 3.2.80).

In section 3.3, we promote the model structures defined above (section 3.2) to the setting of symmetric \( T \)-spectra. In this case, Hirschhorn’s localization technology applied to Jardine’s stable model structure for symmetric \( T \)-spectra allows us to introduce three families of model structures which we denote by \( R_{Ceff}^q \Spt_T^\Sigma \mathcal{M}_* \), \( L_{<q} \Spt_T^\Sigma \mathcal{M}_* \) and \( S^q \Spt_T^\Sigma \mathcal{M}_* \); where the underlying category is given by symmetric \( T \)-spectra (see theorems 3.3.9, 3.3.25 and 3.3.49). Using the Quillen equivalence [13] given by the symmetrization and the forgetful functors, we are then able to show that these new families of model structures are also Quillen equivalent to the ones introduced in section 3.2 (see theorems 3.3.19, 3.3.41 and 3.3.63). Therefore, these model structures give liftings for the functors \( f_q \) and \( s_q \) to the model category level (see corollary 3.3.5, and theorems 3.3.22(3), 3.3.67(3)), with the great technical advantage that the underlying categories are now symmetric monoidal. Hence, we have a natural framework for the study of the multiplicative properties of Voevodsky’s slice filtration.

In section 3.4, we show that the smash product of symmetric \( T \)-spectra

\[
R_{Ceff}^p \Spt_T^\Sigma \mathcal{M}_* \times R_{Ceff}^q \Spt_T^\Sigma \mathcal{M}_* \xrightarrow{\wedge} R_{Ceff}^{p+q} \Spt_T^\Sigma \mathcal{M}_*
\]

\[
S^p \Spt_T^\Sigma \mathcal{M}_* \times S^q \Spt_T^\Sigma \mathcal{M}_* \xrightarrow{\wedge} S^{p+q} \Spt_T^\Sigma \mathcal{M}_*
\]

is in both cases a Quillen bifunctor in the sense of Hovey (see theorems 3.4.4 and 3.4.12). Finally, using these bifunctors we are able to prove in section 3.5 the following results:

1. For every \( p, q \in \mathbb{Z} \), there exist the following natural external pairings induced by the smash product of symmetric \( T \)-spectra (see theorem 3.5.10):

\[
f_p^\Sigma X \wedge f_q^\Sigma Y \xrightarrow{L_{p,q}^\Sigma} f_{p+q}^\Sigma (X \wedge Y)
\]
2. If $X$ is a ring spectrum in $\mathcal{SH}(S)$ and $M$ is an $X$-module, then (see theorem 3.5.14):

(a) The zero connective cover of $X$, $f^0_0 X$ is also a ring spectrum in $\mathcal{SH}(S)$.

(b) For every $q \in \mathbb{Z}$, the $q$-connective cover of $M$, $f^q_0 M$ is a module over $f^0_0 X$.

(c) The direct sum of all the connective covers of $X$, $f^X = \bigoplus_{n \in \mathbb{Z}} f^n_0 X$ is a graded ring in $\mathcal{SH}(S)$.

(d) The direct sum of all the connective covers of $M$, $f^M = \bigoplus_{n \in \mathbb{Z}} f^n_0 M$ is a graded module over $f^X$.

(e) The zero slice of $X$, $s^0_0 X$ is also a ring spectrum in $\mathcal{SH}(S)$.

(f) For every $q \in \mathbb{Z}$, the $q$-slice of $M$, $s^q_0 M$ is a module over $s^0_0 X$.

(g) The direct sum of all the slices of $X$, $s^X = \bigoplus_{n \in \mathbb{Z}} s^n_0 X$ is a graded ring in $\mathcal{SH}(S)$.

(h) The direct sum of all the slices of $M$, $s^M = \bigoplus_{n \in \mathbb{Z}} s^n_0 M$ is a graded module over $s^X$.

3. If the base scheme $S$ is a field of characteristic zero, then for every symmetric $T$-spectrum $X$, its slices $s_n X$ are big motives in the sense of Voevodsky (see theorem 3.5.16).

4. The smash product of symmetric $T$-spectra induces (via the external pairings $\cup^c$ and $\cup^s$) natural external pairings in the motivic Atiyah-Hirzebruch spectral sequence (see definition 3.5.17 and theorem 3.5.18):

$$
E^p,q_r(Y; X) \otimes E^{p',q'} r'(Y'; X') \longrightarrow E^{p+p',q+q'} r(Y \wedge Y'; X \wedge X') \underset{(\alpha, \beta)}{\longrightarrow} \alpha \sim \beta
$$
Chapter 1

Preliminaries

All the results in this chapter are classical, cf. [20], [10], [7], [5], [4]; and are included here just to fix notation and to make this note self contained.

1.1 Model Categories

Model categories were first introduced by Quillen in [20], his original definition has been slightly modified along the years, we will use the definition introduced in [2].

Definition 1.1.1. A model category $\mathcal{A}$ is a category equipped with three classes of maps $(W, C, F)$ called weak equivalences, cofibrations and fibrations, such that the following axioms hold:

MC1 $\mathcal{A}$ is closed under small limits and colimits.

MC2 If $f, g$ are two composable maps in $\mathcal{A}$ and two out of $f, g, g \circ f$ are weak equivalences then so is the third one.

MC3 The classes of weak equivalences, cofibrations and fibrations are closed under retracts.
1.1. Model Categories

**MC4** Suppose we have a solid commutative diagram:

\[
\begin{array}{ccc}
A & \longrightarrow & X \\
\downarrow^i & & \downarrow^p \\
B & \longrightarrow & Y
\end{array}
\]

where \( i \) is a cofibration, \( p \) is a fibration, and either \( i \) or \( p \) is a weak equivalence, then the dotted arrow making the diagram commutative exists.

**MC5** Given any arrow \( f : A \to B \) in \( \mathcal{A} \), there exist two functorial factorizations, \( f = p \circ i \) and \( f = q \circ j \), where \( p \) is a fibration and a weak equivalence, \( i \) is a cofibration, \( q \) is a fibration and \( j \) is a cofibration and a weak equivalence.

A map \( j : A \to B \) will be called a **trivial cofibration** (respectively **trivial fibration**) if it is both a cofibration and a weak equivalence (respectively a fibration and a weak equivalence).

If a given category \( \mathcal{A} \) has a model structure, then we get immediately the following consequences:

**Remark 1.1.2.**

1. The limit axiom **MC1** implies that there is an **initial** and a **final** object in \( \mathcal{A} \), which we will denote by \( \emptyset \) and \( * \) respectively. We say that the category \( \mathcal{A} \) is **pointed** if the canonical map \( \emptyset \to * \) is an isomorphism.

2. The axioms for a model category are self dual, therefore the opposite category \( \mathcal{A}^{op} \) has also a model structure, where a map \( i : A \to B \) in \( \mathcal{A}^{op} \) is a weak equivalence, cofibration or fibration if its dual \( i : B \to A \) is a weak equivalence, fibration or cofibration in \( \mathcal{A} \). This implies in particular that any result we prove about model categories will have a dual version.

3. Let \( X \) be an object in \( \mathcal{A} \). Then the category \( (\mathcal{A} \downarrow X) \) of objects in \( \mathcal{A} \) over \( X \) has also a model structure, where the weak equivalences, cofibrations and fibrations are maps which become weak equivalences, cofibrations and fibrations after applying the forgetful functor \( (\mathcal{A} \downarrow X) \to \mathcal{A} \).
4. Similarly the category \((X \downarrow A)\) has a model structure induced from the one in \(A\). We will denote by \(A\ast\) the category \((\ast \downarrow A)\) of objects under the final object of \(A\).

5. Let \(A, X\) be two objects in \(A\), then the category \((A \downarrow A \downarrow X)\) of objects which are simultaneously under \(A\) and over \(X\) has also a model structure induced from the one in \(A\).

Let \(X\) be an object in \(A\). We say that \(X\) is cofibrant if the natural map \(\emptyset \rightarrow X\) is a cofibration. Similarly, we say that \(X\) is fibrant if the natural map \(X \rightarrow \ast\) is a fibration.

Consider two objects \(A, X\) in \(A\). We say that \(A\) is a cofibrant replacement for \(X\), if \(A\) is cofibrant and there is a map \(A \rightarrow X\) which is a weak equivalence in \(A\). Dually, we say that \(X\) is a fibrant replacement for \(A\), if \(X\) is fibrant and there is a map \(A \rightarrow X\) which is a weak equivalence in \(A\).

Let \(i : A \rightarrow B, p : X \rightarrow Y\) be two maps in \(A\). We say that \(i\) has the left lifting property with respect to \(p\) (or that \(p\) has the right lifting property with respect to \(i\)) if for every solid commutative diagram:

\[
\begin{array}{ccc}
A & \longrightarrow & X \\
\downarrow_i & & \downarrow_p \\
B & \longrightarrow & Y
\end{array}
\]

the dotted arrow making the diagram commutative exists.

The following are two elementary but extremely useful results about model categories.

**Proposition 1.1.3** (Retract Argument, [10]). Let \(A\) be a model category and \(f = p \circ i\) a factorization of \(f\) such that \(f\) has the left lifting property with respect to \(p\) (respectively \(f\) has the right lifting property with respect to \(i\)). Then \(f\) is a retract of \(i\) (respectively \(f\) is a retract of \(p\)).

**Proof.** By duality it is enough to show the case where \(f\) has the left lifting property with respect to \(p\).
Consider the following solid commutative diagram:

\[
\begin{array}{ccc}
A & \xrightarrow{i} & X \\
\downarrow^f & & \downarrow^p \\
B & \xrightarrow{id} & B
\end{array}
\]

By hypothesis the dotted arrow \( j \) making the diagram commutative exists. But then the following commutative diagram shows that \( f \) is a retract of \( i \).

\[
\begin{array}{ccc}
A & \xrightarrow{id} & A \\
\downarrow^f & \downarrow^i & \downarrow^f \\
B & \xrightarrow{j} & X & \xrightarrow{p} & B
\end{array}
\]

\[\square\]

**Lemma 1.1.4** (Ken Brown’s lemma, [10]). Let \( F : A \to D \) be a functor, where \( A \) is a model category. Assume that there exists a class \( V \) of maps in \( D \) which has the two out of three property, and that \( F(i) \in V \) for all trivial cofibrations \( i : A \to B \) between cofibrant objects \( A \) and \( B \) in \( A \). Then \( F(g) \in V \) for all weak equivalences \( g : A \to B \) between cofibrant objects \( A \) and \( B \) in \( A \).

**Proof.** Consider the following commutative diagram:

\[
\begin{array}{ccc}
\emptyset & \rightarrow & A \\
\downarrow & & \downarrow^{i_A} \\
B & \xrightarrow{\text{id}} & A \coprod B \\
\downarrow & & \downarrow^i \\
A & \xrightarrow{g} & B
\end{array}
\]

where we have a factorization of \((g, \text{id}) = p \circ i\), with \( i \) a cofibration and \( p \) a trivial fibration.

Since \( A \) and \( B \) are cofibrant, it follows that \( i_A \) and \( i_B \) are cofibrations. This implies that \( i \circ i_A, i \circ i_B \) are both cofibrations, and hence \( C \) is a cofibrant object in \( A \).
By the two out of three property in $\mathcal{A}$, $i \circ i_A$ and $i \circ i_B$ are weak equivalences, since $g$, $p$ and $id_B$ are weak equivalences. Therefore $i \circ i_A$ and $i \circ i_B$ are both trivial cofibrations. It follows that $F(i \circ i_A)$ and $F(i \circ i_B)$ are both in $\mathcal{V}$. But then $F(p) \circ F(i \circ i_B) = F(p \circ i \circ i_B) = F(id) = id$, and since $\mathcal{V}$ has the two out of three property, we have that $F(p)$ is in $\mathcal{V}$. Then the two out of three property for $\mathcal{V}$ implies that $F(g) = F(p) \circ F(i \circ i_A)$ is also in $\mathcal{V}$.

By duality we get immediately the following lemma:

**Lemma 1.1.5.** Let $F : \mathcal{A} \to \mathcal{D}$ be a functor, where $\mathcal{A}$ is a model category. Assume that there exists a class $\mathcal{V}$ of maps in $\mathcal{D}$ which has the two out of three property, and that $F(p) \in \mathcal{V}$ for all trivial fibrations $p : X \to Y$ between fibrant objects $X$, $Y$ in $\mathcal{A}$. Then $F(g) \in \mathcal{V}$ for all weak equivalences $g : X \to Y$ between fibrant objects $X$ and $Y$ in $\mathcal{A}$.

The retract argument has the following consequences, which give nice characterizations for the cofibrations and trivial cofibrations (respectively fibrations and trivial fibrations) in terms of a left lifting property (respectively right lifting property).

**Corollary 1.1.6.** The class of cofibrations (respectively trivial cofibrations) in a model category $\mathcal{A}$ is equal to the class of maps having the left lifting property with respect to any trivial fibration in $\mathcal{A}$ (respectively any fibration in $\mathcal{A}$). The class of fibrations (respectively trivial fibrations) in a model category $\mathcal{A}$ is equal to the class of maps having the right lifting property with respect to any trivial cofibration in $\mathcal{A}$ (respectively any cofibration in $\mathcal{A}$).

**Proof.** By duality it is enough to prove the case of cofibrations and trivial cofibrations. Suppose that $i : A \to B$ is a cofibration in $\mathcal{A}$, then the lifting axiom $\text{MC4}$ implies that $i$ has the left lifting property with respect to any trivial fibration in $\mathcal{A}$. Conversely, if $i : A \to B$ has the left lifting property with respect to any trivial fibration in $\mathcal{A}$, then the factorization axiom $\text{MC5}$ implies that $i = ql$ where $l$ is a cofibration in $\mathcal{A}$ and $q$ is a trivial fibration in $\mathcal{A}$. Since $i$ has the left lifting property with respect to $q$, the retract argument (see proposition...
1.1. Model Categories

1.1.3) implies that \( i \) is a retract of \( l \). Therefore, the retract axiom \( \text{MC3} \) implies that \( i \) is also a cofibration. The case for trivial cofibrations is similar. \( \square \)

**Corollary 1.1.7.** Any isomorphism in a model category \( \mathcal{A} \) is a cofibration, a fibration, and a weak equivalence. The class of cofibrations and the class of trivial cofibrations in \( \mathcal{A} \) are closed under retracts and pushouts. The class of fibrations and the class of trivial fibrations in \( \mathcal{A} \) are closed under retracts and pullbacks.

**Proof.** Follows immediately from the lifting property characterization (corollary 1.1.6) for cofibrations, trivial cofibrations, fibrations and trivial fibrations. \( \square \)

**Remark 1.1.8.** Let \( \mathcal{A} \) be a model category. Given any object \( X \) in \( \mathcal{A} \), we can apply the factorization axiom \( \text{MC5} \) to the natural map \( \emptyset \to X \) to get a cofibrant replacement for \( X \):

\[
\emptyset \longrightarrow QX \xrightarrow{QX} X
\]

where \( QX \) is cofibrant and \( QX \) is a trivial fibration. We also get fibrant replacements for \( X \) when we factor the natural map \( X \to * \):

\[
X \xrightarrow{RX} RX \longrightarrow *
\]

where \( RX \) is fibrant and \( RX \) is a trivial cofibration. The factorization axiom \( \text{MC5} \) implies also that these two constructions are functorial.

**Definition 1.1.9.** Let \( \mathcal{A}, \mathcal{B} \) be two model categories. A functor \( F : \mathcal{A} \to \mathcal{B} \) is called a **left Quillen functor** if it has a right adjoint \( G : \mathcal{B} \to \mathcal{A} \), and satisfies the following conditions:

1. If \( i \) is a cofibration in \( \mathcal{A} \), then \( F(i) \) is also a cofibration in \( \mathcal{B} \).

2. If \( j \) is a trivial cofibration in \( \mathcal{A} \), then \( F(j) \) is also a trivial cofibration in \( \mathcal{B} \).

The right adjoint \( G \) is called a **right Quillen functor**, and the adjunction

\[
(F, G, \phi) : \mathcal{A} \longrightarrow \mathcal{B}
\]

is called a **Quillen adjunction**.
Definition 1.1.10. Let \((F, G, \varphi) : A \to B\) be a Quillen adjunction. We say that \(F\) is a **left Quillen equivalence** if for every cofibrant object \(X\) in \(A\) and every fibrant object \(Y\) in \(B\) the following condition holds:

- A map \(f : X \to GY\) is a weak equivalence in \(A\) if and only if its adjoint \(f^\# : FX \to Y\) is a weak equivalence in \(B\).

In this case \(G\) will be called a **right Quillen equivalence**, and \((F, G, \varphi)\) a **Quillen equivalence**.

Definition 1.1.11. Let \(A\) be a model category, and let \(X\) be an object of \(A\). We say that \(\tilde{X}\) is a **cylinder object** for \(X\), if we have a factorization of the fold map

\[
\begin{array}{ccc}
X \coprod X & \xrightarrow{\nu} & X \\
i & \downarrow & \downarrow \\
\tilde{X} & \nearrow & s
\end{array}
\]

where \(i\) is a cofibration and \(s\) is a weak equivalence.

Definition 1.1.12. Let \(A\) be a model category, and let \(X\) be an object of \(A\). We say that \(\hat{X}\) is a **path object** for \(X\), if we have a factorization of the diagonal map

\[
\begin{array}{ccc}
X & \xrightarrow{\Delta} & X \times X \\
r & \downarrow & \downarrow p \\
\hat{X} & \nearrow & \hat{X}
\end{array}
\]

where \(p\) is a fibration and \(r\) is a weak equivalence.

Definition 1.1.13. Let \(A\) be a model category and consider two maps \(f, g : X \to Y\). We say that \(f\) is **left homotopic** to \(g\) \((f \xleftarrow{L} g)\) if there exists a cylinder object \(\tilde{X}\) for \(X\), together with the following factorization:

\[
\begin{array}{ccc}
X \coprod X & \xrightarrow{(f,g)} & Y \\
i & \downarrow & \downarrow H \\
\tilde{X} & \nearrow & \tilde{X}
\end{array}
\]

The map \(H\) is called a **left homotopy** from \(f\) to \(g\).
**Definition 1.1.14.** Let \( \mathcal{A} \) be a model category and consider two maps \( f, g : X \to Y \). We say that \( f \) is **right homotopic** to \( g \) \( (f \overset{r}{\sim} g) \) if there exists a path object \( \hat{Y} \) for \( Y \), together with the following factorization:

\[
\begin{array}{ccc}
    X & \overset{(f,g)}{\to} & Y \times Y \\
    \downarrow H & & \downarrow p \\
    \downarrow \downarrow & & \downarrow \downarrow \\
    \hat{Y} & & Y
\end{array}
\]

The map \( H \) is called a **right homotopy** from \( f \) to \( g \).

**Definition 1.1.15.** Let \( \mathcal{A} \) be a model category and consider two maps \( f, g : A \to B \). We say that \( f \) is **homotopic** to \( g \) \( (f \sim g) \) if \( f \) and \( g \) are both left and right homotopic.

**Definition 1.1.16** (cf. [20, I.1 definition 5]). Let \( \mathcal{A} \) be an arbitrary category and \( \mathcal{W} \) a class of maps in \( \mathcal{A} \). The **localization** of \( \mathcal{A} \) with respect to \( \mathcal{W} \) will be a category \( \mathcal{W}^{-1}\mathcal{A} \) together with a functor

\[
\gamma : \mathcal{A} \longrightarrow \mathcal{W}^{-1}\mathcal{A}
\]

having the following universal property: for every \( w \in \mathcal{W} \), \( \gamma(w) \) is an isomorphism, and given any functor \( F : \mathcal{A} \to \mathcal{D} \) such that \( F(w) \) is an isomorphism for every \( w \in \mathcal{W} \), there is a unique functor \( \theta : \mathcal{W}^{-1}\mathcal{A} \to \mathcal{D} \), such that \( \theta \circ \gamma = F \), i.e. the following diagram commutes:

\[
\begin{array}{ccc}
    \mathcal{A} & \overset{F}{\longrightarrow} & \mathcal{D} \\
    \downarrow \gamma & & \downarrow \theta \\
    \mathcal{W}^{-1}\mathcal{A} & & \mathcal{D}
\end{array}
\]

**Theorem 1.1.17** (Quillen). Let \( \mathcal{A} \) be a model category. Then there exists a category \( \text{Ho}\mathcal{A} \), which is the localization of \( \mathcal{A} \) with respect to the class \( \mathcal{W} \) of weak equivalences, and is called the **homotopy category** of \( \mathcal{A} \). \( \text{Ho}\mathcal{A} \) is defined as follows:

1. The objects of \( \text{Ho}\mathcal{A} \) are just the objects in \( \mathcal{A} \).

2. The set of maps in \( \text{Ho}\mathcal{A} \) between two objects \( X, Y \) is given by the set of homotopy classes between cofibrant-fibrant replacements for \( X \) and \( Y \):

\[
\text{Hom}_{\text{Ho}\mathcal{A}}(X,Y) = \pi_{\mathcal{A}}(RQX, RQY)
\]

and the composition law is induced by the composition in \( \mathcal{A} \).
Let $\mathrm{Ho}A_c$, $\mathrm{Ho}A_f$, $\mathrm{Ho}A_{cf}$ be the full subcategories of $\mathrm{Ho}A$ generated by the cofibrant, fibrant and cofibrant-fibrant objects of $\mathcal{A}$ respectively. In the following diagram, all the functors are equivalences of categories:

\[
\begin{array}{ccc}
\mathrm{Ho}A_c & \sim & \mathrm{Ho}A_{cf} \\
\downarrow & & \downarrow \\
\mathrm{Ho}Q & \sim & \mathrm{Ho}A_f \\
\downarrow & & \downarrow \\
\mathrm{Ho}R & \sim & \mathrm{Ho}A \\
\end{array}
\]

where the adjoints to the equivalences given above are constructed taking cofibrant, fibrant and cofibrant-fibrant replacements.

**Proof.** We refer the reader to [20, I.1 theorem 1].

**Theorem 1.1.18** (Quillen). Let $(F,G,\varphi) : \mathcal{A} \to \mathcal{B}$ be a Quillen adjunction. Then the adjunction $(F,G,\varphi)$ descends to the homotopy categories, i.e. we get an adjunction:

\[(QF, RG, \varphi) : \mathrm{HoA} \longrightarrow \mathrm{HoB}\]

Furthermore, if $(F,G,\varphi)$ is a Quillen equivalence, then $(QF, RG, \varphi)$ is an equivalence of categories.

**Proof.** We refer the reader to [20, I.4 theorem 3].

### 1.2 Cofibrantly Generated Model Categories

In this section we recall the definition of a cofibrantly generated model category.

In order to get the functorial factorizations required in axiom **MC5**, we need to introduce ordinals, cardinals, and regular cardinals. For a definition of these, see [7, chapter 10]. It will be convenient in some situations to consider an ordinal $\lambda$ as a small category, with objects equal to the elements of $\lambda$, and a unique map from $a$ to $b$ if $a \leq b$. 
1.2. Cofibrantly Generated Model Categories

**Definition 1.2.1.** Let $\mathcal{C}$ be a category that is closed under small colimits, and let $\mathcal{V}$ be a class of maps in $\mathcal{C}$. If $\lambda$ is an ordinal, then a $\lambda$-sequence in $\mathcal{C}$ is a functor $A : \lambda \to \mathcal{C}$, i.e. a diagram

$$A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda)$$

such that for every limit ordinal $\gamma < \lambda$ the induced map

$$\text{colim}_{\beta < \gamma} A_\beta \to A_\gamma$$

is an isomorphism.

The composition of the $\lambda$-sequence is the map $A_0 \to \text{colim}_{\beta < \lambda} A_\beta$.

If $A_\beta \to A_{\beta+1}$ is in $\mathcal{V}$ for any $\beta < \lambda$, we say that the $\lambda$-sequence is a $\lambda$-sequence of maps in $\mathcal{V}$, and the transfinite composition $A_0 \to \text{colim}_{\beta < \lambda} A_\beta$ is called a transfinite composition of maps in $\mathcal{V}$.

**Proposition 1.2.2.** Let $\mathcal{A}$ be a model category, then the cofibrations and trivial cofibrations in $\mathcal{A}$ are both closed under transfinite composition.

**Proof.** The cofibrations and trivial cofibrations in $\mathcal{A}$ are characterized by a left lifting property. But the universal property of the colimit clearly preserves this lifting property under transfinite composition. \hfill \Box

**Definition 1.2.3.** Let $\mathcal{C}$ be a category closed under small colimits, and let $\mathcal{V}$ be a class of maps in $\mathcal{C}$.

1. If $\kappa$ is a cardinal, then an object $D$ in $\mathcal{C}$ is $\kappa$-small relative to $\mathcal{V}$, if for every regular cardinal $\lambda \geq \kappa$ and every $\lambda$-sequence

$$A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda)$$

of maps in $\mathcal{V}$, we have a bijection of sets:

$$\text{colim}_{\beta < \lambda} \text{Hom}_\mathcal{C}(D, A_\beta) \to \text{Hom}_\mathcal{C}(D, \text{colim}_{\beta < \lambda} A_\beta)$$
2. An object $D$ in $\mathcal{C}$ is small relative to $\mathcal{V}$ if it is $\kappa$-small relative to $\mathcal{V}$ for some cardinal $\kappa$, and it is small if it is small relative to the class of all maps in $\mathcal{C}$.

**Definition 1.2.4.** Let $\mathcal{C}$ be a category, and let $I$ be a set of maps in $\mathcal{C}$.

1. We define $I$-inj as the class of maps in $\mathcal{C}$ that have the right lifting property with respect to every map in $I$.

2. We define $I$-cof as the class of maps in $\mathcal{C}$ that have the left lifting property with respect to every map in $I$-inj.

**Definition 1.2.5.** Let $\mathcal{C}$ be a category closed under small colimits, and let $I$ be a set of maps in $\mathcal{C}$, then

1. The relative $I$-cell complexes are the maps that can be constructed as a transfinite composition of pushouts of elements of $I$.

2. An object $A$ of $\mathcal{C}$ is an $I$-cell complex, if the map $\emptyset \to A$ is a relative $I$-cell complex.

3. A map is an inclusion of $I$-cell complexes if it is a relative $I$-cell complex whose domain is an $I$-cell complex.

We will denote the class of relative $I$-cell complexes as $I$-cells.

**Remark 1.2.6.** Since the left lifting property is preserved under pushouts and transfinite compositions we have that $I$-cells $\subseteq I$-cof.

**Theorem 1.2.7** (Quillen’s small object argument). Let $\mathcal{C}$ be a category closed under small colimits, and let $I$ be a set of maps in $\mathcal{C}$. Assume that the domains of all the maps in $I$ are small with respect to $I$-cells. Then for every map $f : X \to Y$ in $\mathcal{C}$, there is a functorial factorization

$$X \xrightarrow{i} E_f \xrightarrow{p} Y$$

where $i$ is in $I$-cells, and $p$ is in $I$-inj.

**Proof.** We refer the reader to [20], [7], or [10].
1.2. Cofibrantly Generated Model Categories

**Definition 1.2.8.** A model category $\mathcal{A}$ is **cofibrantly generated** if there exist sets $I$ and $J$ of maps in $\mathcal{A}$, such that:

1. The domains of all the maps in $I$ are small with respect to the $I$-cells.
2. The domains of all the maps in $J$ are small with respect to the $J$-cells.
3. The class $\mathcal{F} \cap \mathcal{W}$ of trivial fibrations in $\mathcal{A}$ is equal to $I$-inj.
4. The class $\mathcal{F}$ of fibrations in $\mathcal{A}$ is equal to $J$-inj.

In this situation, $I$ will be called the set of **generating cofibrations**, and $J$ will be called the set of **generating trivial cofibrations**.

To work with spectra, we need to start with a pointed model category. The following result will allow us to go from an unpointed cofibrantly generated model category to a pointed one.

**Theorem 1.2.9** (Hirschhorn). Let $\mathcal{A}$ be a cofibrantly generated model category with set of generating cofibrations $I$ and set of generating trivial cofibrations $J$. Then the associated pointed model category $\mathcal{A}_*$ (see remark 1.1.2) is also a cofibrantly generated model category, with set of generating cofibrations $F(I) = I_+$ and set of generating trivial cofibrations $F(J) = J_+$, where $F$ is the functor $F : \mathcal{A} \to \mathcal{A}_*$ defined on objects $A$ in $\mathcal{A}$ as the pushout in the commutative diagram:

\[
\begin{array}{ccc}
\emptyset & \longrightarrow & A \\
& \downarrow & \\
& \ast & \longrightarrow F(A) = A_+
\end{array}
\]

and on maps $i : A \to B$ in $\mathcal{A}$ as:

\[
F(A) = A \amalg \ast \xrightarrow{F(i) \amalg \text{id}} B \amalg \ast = F(B)
\]

**Proof.** We refer the reader to [6, theorem 2.7].
1.3 Cellular Model Categories

In this section we review Hirschhorn’s cellularity, which is the main property that a model category has to satisfy if we want to construct Bousfield localizations.

**Definition 1.3.1.** Let $\mathcal{C}$ be a category closed under small colimits, and let $I$ be a set of maps in $\mathcal{C}$. If $i : A \to B$ is a relative $I$-cell complex, then a **presentation** of $i$ is a pair consisting of a $\lambda$-sequence

$$A_0 \to A_1 \to \cdots \to A_\beta \to \cdots \quad (\beta < \lambda)$$

for some ordinal $\lambda$, and a sequence of ordered triples

$$\{(T^\beta, e^\beta, h^\beta)\}$$

such that:

1. The composition of the $\lambda$-sequence is isomorphic to $i$

2. For every $\beta < \lambda$
   
   (a) $T^\beta$ is a set.

   (b) $e^\beta$ is a function $e^\beta : T^\beta \to I$.

   (c) If $i \in T^\beta$ and $e^\beta_i$ is the element $C_i \to D_i$ of $I$, then $h^\beta_i$ is a map $h^\beta_i : C_i \to A_\beta$, such that there is a pushout diagram

   $$\begin{array}{ccc}
   \prod_{i \in T^\beta} C_i & \xrightarrow{\prod e^\beta_i} & \prod_{i \in T^\beta} D_i \\
   \downarrow \prod h^\beta_i & & \downarrow \\
   A_\beta & \xrightarrow{} & A_{\beta+1}
   \end{array}$$

**Definition 1.3.2.** Let $\mathcal{C}$ be a category closed under small colimits, and let $I$ be a set of maps in $\mathcal{C}$. If

$$i : A \to B, A = A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda), \{T^\beta, e^\beta, h^\beta\}_{\beta < \lambda}$$

is a presented relative $I$-cell complex, then
1. The **presentation ordinal** of \( i \) is \( \lambda \).

2. The **set of cells** of \( i \) is \( \bigsqcup_{\beta < \lambda} T^\beta \).

3. The **size** of \( i \) is the cardinal of the set of cells of \( i \).

4. If \( e \) is a cell of \( i \), the **presentation ordinal** of \( e \) is the ordinal \( \beta \) such that \( e \in T^\beta \).

5. If \( \beta < \lambda \), then the **\( \beta \)-skeleton** of \( i \) is \( A_\beta \).

The next remark follows directly from the previous definitions.

**Remark 1.3.3.** If \( \mathcal{C} \) is a category closed under small colimits, and \( I \) is a set of maps in \( \mathcal{C} \), then a presented relative \( I \)-cell complex is entirely determined by its presentation ordinal \( \lambda \), and its sequence of triples \( \{ (T^\beta, e^\beta, h^\beta) \}_{\beta < \lambda} \).

**Definition 1.3.4.** Let \( \mathcal{C} \) be a category closed under small colimits, and \( I \) a set of maps in \( \mathcal{C} \). If

\[
i : A \to B, \quad A = A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda), \quad \{ T^\beta, e^\beta, h^\beta \}_{\beta < \lambda}
\]

is a presented relative \( I \)-cell complex, then a **subcomplex** of \( i \) consists of a presented relative \( I \)-cell complex

\[
\tilde{i} : A \to \tilde{B}, \quad A = \tilde{A}_0 \to \tilde{A}_1 \to \cdots \to \tilde{A}_\beta \to \cdots (\beta < \lambda), \quad \{ \tilde{T}^\beta, \tilde{e}^\beta, \tilde{h}^\beta \}_{\beta < \lambda}
\]

such that

1. For every \( \beta < \lambda \), \( \tilde{T}^\beta \subseteq T^\beta \) and \( \tilde{e}^\beta \) is the restriction of \( e^\beta \) to \( \tilde{T}^\beta \).

2. There is a map of \( \lambda \)-sequences

\[
\begin{array}{cccccc}
A & \xrightarrow{id} & \tilde{A}_0 & \xrightarrow{\tilde{id}} & \tilde{A}_1 & \xrightarrow{\tilde{id}} & \tilde{A}_2 & \xrightarrow{\tilde{id}} & \cdots \\
\downarrow{\id} & & \downarrow{\id} & & \downarrow{\id} & & \downarrow{\id} & & \\
A & \xrightarrow{id} & A_0 & \xrightarrow{id} & A_1 & \xrightarrow{id} & A_2 & \xrightarrow{id} & \cdots \\
\end{array}
\]

such that, for every \( \beta < \lambda \) and every \( i \in \tilde{T}^\beta \), the map \( \tilde{h}_i^\beta : C_i \to \tilde{A}_\beta \) is a factorization of the map \( h_i^\beta : C_i \to A_\beta \) through the map \( \tilde{A}_\beta \to A_\beta \).
Proposition 1.3.5. Let $\mathcal{C}$ be a category closed under small colimits, and $I$ a set of maps in $\mathcal{C}$ such that the relative $I$-cell complexes are monomorphisms, then a subcomplex of a presented relative $I$-cell complex is entirely determined by its set of cells $\{\tilde{T}_\beta\}_{\beta<\lambda}$.

Proof. The definition of a subcomplex implies that the maps $\tilde{A}_\beta \to A_\beta$ are all inclusions of subcomplexes (see definition 1.2.5(3)). Since inclusions of subcomplexes are monomorphisms, there is at most one possible factorization $\tilde{h}_i^\beta$ of each $h_i^\beta$ through $\tilde{A}_\beta \to A_\beta$. \hfill $\square$

Proposition 1.3.6. Let $\mathcal{C}$ be a category closed under small colimits, and let $I$ be a set of maps in $\mathcal{C}$ such that the relative $I$-cell complexes are monomorphisms. If

$$i : A \to B, \ A = A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda), \ \{T_\beta, e_\beta, h_\beta\}_{\beta<\lambda}$$

is a presented relative $I$-cell complex, then an arbitrary subcomplex of $i$ can be constructed by the following inductive procedure:

1. Choose an arbitrary subset $\tilde{T}_0$ of $T_0$.

2. If $\beta < \lambda$ and we have defined $\{\tilde{T}_\gamma\}_{\gamma<\beta}$, then we have determined the object $\tilde{A}_\beta$ and the map $\tilde{A}_\beta \to A_\beta$. Consider the set

$$\{i \in T_\beta | h_i^\beta : C_i \to A_\beta \text{ factors through } \tilde{A}_\beta \to A_\beta\}$$

Choose an arbitrary subset $\tilde{T}_\beta$ of this set. For every $i \in \tilde{T}_\beta$ there is a unique map $\tilde{h}_i^\beta : C_i \to \tilde{A}_\beta$ that makes the diagram

$$\begin{array}{ccc} C_i & \xrightarrow{\tilde{h}_i^\beta} & \tilde{A}_\beta \\ \downarrow{\tilde{h}_i^\beta} & \downarrow & \downarrow \\ \tilde{A}_\beta & \longrightarrow & A_\beta \end{array}$$

commute. Let $\tilde{A}_{\beta+1}$ be defined by the pushout diagram

$$\begin{array}{ccc} \coprod_{i \in \hat{T}_\beta} C_i & \longrightarrow & \coprod_{i \in \hat{T}_\beta} D_i \\ \downarrow{\coprod\tilde{h}_i^\beta} & & \downarrow \\ \tilde{A}_\beta & \longrightarrow & \tilde{A}_{\beta+1} \end{array}$$
1.3. Cellular Model Categories

**Proof.** Follows immediately from the definitions and proposition 1.3.5.

**Corollary 1.3.7.** Let \( \mathcal{C} \) be a category closed under small colimits, and let \( I \) be a set of maps in \( \mathcal{C} \) such that the relative \( I \)-cell complexes are monomorphisms. Consider an arbitrary

\[
i : A \to B, \ A = A_0 \to A_1 \to \cdots \to A_\beta \to \cdots (\beta < \lambda), \ \{T^\beta, e^\beta, h^\beta\}_{\beta < \lambda}
\]

presented cell complex. Assume that \( S \) is a set and take an arbitrary family \( \{A_s\}_{s \in S} \) of subcomplexes of \( i : A \to B \), then there exists a subcomplex \( \bigcup_{s \in S} A_s \) which represents the union of the given family.

**Proof.** Follows immediately from proposition 1.3.6.

**Definition 1.3.8.** Let \( \mathcal{C} \) be a category closed under small colimits, and let \( I \) be a set of maps in \( \mathcal{C} \).

1. If \( \gamma \) is a cardinal, then an object \( A \) of \( \mathcal{C} \) is \( \gamma \)-compact relative to \( I \) if, for every presented relative \( I \)-cell complex \( i : X \to Y \), every map from \( A \) to \( Y \) factors through a subcomplex of \( i \) of size at most \( \gamma \).

2. An object \( A \) of \( \mathcal{C} \) is compact relative to \( I \) if it is \( \gamma \)-compact relative to \( I \) for some cardinal \( \gamma \).

**Definition 1.3.9.** Let \( \mathcal{A} \) be a cofibrantly generated model category with set of generating cofibrations \( I \).

1. If \( \gamma \) is a cardinal, then an object \( X \) of \( \mathcal{A} \) is \( \gamma \)-compact if it is \( \gamma \)-compact relative to \( I \) (see definition 1.3.8).

2. An object \( X \) of \( \mathcal{A} \) is compact if there is a cardinal \( \gamma \) for which it is \( \gamma \)-compact.

To complete the definition of a cellular model category, we need to introduce the concept of effective monomorphism.
1.4. Proper Model Categories

**Definition 1.3.10.** Let $C$ be a category that is closed under pushouts. The map $i : A \to B$ is an effective monomorphism if $i$ is the equalizer of the pair of natural inclusions $B \rightrightarrows B \amalg_A B$.

**Remark 1.3.11.** In the category of sets, the class of effective monomorphisms is just the class of injective maps.

**Definition 1.3.12** (cf. [7, definition 12.1.1]). Let $A$ be a model category. We say that $A$ is cellular if it satisfies the following conditions:

1. $A$ is cofibrantly generated (see definition 1.2.8) with set of generating cofibrations $I$ and set of generating trivial cofibrations $J$.

2. Both the domains and codomains of the maps in $I$ are compact (see definition 1.3.9).

3. The domains of the maps in $J$ are small relative to $I$ (see definition 1.2.3).

4. The cofibrations in $A$ are effective monomorphisms (see definition 1.3.10).

When we have a cellular model category $A$ with set of generating cofibrations $I$, the relative $I$-cell complexes will be called relative cell complexes.

**Theorem 1.3.13** (Hirschhorn). Let $A$ be a cellular model category. Then the associated pointed model category $A_*$ equipped with the model structure considered in theorem 1.2.9 is also cellular.

**Proof.** We refer the reader to [6, theorem 2.8].

1.4 Proper Model Categories

In this section we just recall the definition of proper model categories.
Definition 1.4.1. Let \( \mathcal{A} \) be a model category. We say that \( \mathcal{A} \) is left proper if the class of weak equivalences is closed under pushouts along cofibrations, i.e. in any pushout diagram

\[
\begin{array}{ccc}
A & \xrightarrow{h} & X \\
\downarrow & & \downarrow \\
B & \xrightarrow{h_*} & Y
\end{array}
\]

where \( i \) is a cofibration and \( h \) is a weak equivalence, we then have that \( h_* \) is also a weak equivalence.

Definition 1.4.2. Let \( \mathcal{A} \) be a model category. We say that \( \mathcal{A} \) is right proper if the class of weak equivalences is closed under pullbacks along fibrations, i.e. in any pullback diagram

\[
\begin{array}{ccc}
A & \xrightarrow{h^*} & X \\
\downarrow & & \downarrow \\
B & \xrightarrow{h} & Y
\end{array}
\]

where \( p \) is a fibration and \( h \) is a weak equivalence, we then have that \( h^* \) is also a weak equivalence.

Definition 1.4.3. Let \( \mathcal{A} \) be a model category. We say that \( \mathcal{A} \) is proper if it is both left and right proper.

Theorem 1.4.4 (Hirschhorn). Let \( \mathcal{A} \) be a left proper, right proper, or proper model category. Then the associated pointed model category \( \mathcal{A}_\ast \) (see remark 1.1.2) is also left proper, right proper, or proper.

Proof. We refer the reader to [6, theorem 2.8].

1.5 Simplicial Sets

Let \( \Delta \) denote the category of well ordered finite sets, i.e. the category with objects:

\[
\mathbf{n} = \{0 < 1 < \cdots < n\}
\]
where \( n \geq 0 \); and maps the weakly order preserving functions, i.e.:

\[
\text{Hom}_\Delta(m, n) = \{ f : m \to n | i \leq j \Rightarrow f(i) \leq f(j) \}
\]

There exists a canonical set of generators for the maps in \( \Delta \), called **cofaces** \((\delta^i : n \to n + 1)\), and codegeneracies \((\sigma^i : n + 1 \to n)\), defined as:

\[
\delta^i(j) = \begin{cases} 
  j, & \text{if } j < i \\
  j + 1, & \text{if } j \geq i 
\end{cases}
\]

\[
\sigma^i(j) = \begin{cases} 
  j, & \text{if } j \leq i \\
  j - 1, & \text{if } j > i 
\end{cases}
\]

The cofaces and degeneracies satisfy a list of relations called the **cosimplicial identities**:

\[
\begin{align*}
\delta^j \delta^i &= \delta^i \delta^{j-1} & \text{for } i < j \\
\sigma^j \delta^i &= \delta^i \sigma^{j-1} & \text{for } i < j \\
\sigma^i \delta^i &= id \\
\sigma^i \delta^{i+1} &= id \\
\sigma^j \delta^i &= \delta^{i-1} \sigma^i & \text{for } i > j + 1 \\
\sigma^j \sigma^i &= \sigma^i \sigma^{j+1} & \text{for } i < j
\end{align*}
\]

**Definition 1.5.1.** A simplicial set \( X \) is a contravariant functor from the category \( \Delta \) to the category of sets.

We will denote the category of simplicial sets by **SSets**, where the maps between to simplicial sets \( X \) and \( Y \) are just the natural transformations \( \eta : X \to Y \).

It follows from the cosimplicial identities that to specify a simplicial set \( X \), it is enough to give sets \( X_0, X_1, \ldots, X_n, \ldots; \) where \( X_i = X(i) \) together with **face** maps \( d_i : X_n \to X_{n-1} \) \((d_i = X(\delta^i))\) and **degeneracy** maps \( s_i : X_n \to X_{n+1} \) \((s_i = X(\sigma^i))\), satisfying the following relations which are called **simplicial identities** (these are just the duals with respect to
the cosimplicial identities):
\[
\begin{align*}
  d_i d_j &= d_{j-1} d_i & \text{for } i < j \\
  d_i s_j &= s_{j-1} d_i & \text{for } i < j \\
  d_i s_i &= id \\
  d_{i+1} s_i &= id \\
  d_i s_j &= s_j d_{i-1} & \text{for } i > j + 1 \\
  s_i s_j &= s_{j+1} s_i & \text{for } i < j
\end{align*}
\] (1.2)

There exist three particular interesting families of simplicial sets: \( \Delta^n, \partial \Delta^n \) and \( \wedge_k^n \); they are defined in the following way:

\[
\Delta^n = \text{Hom}_\Delta(-, n)
\] (1.3)

\( \partial \Delta^n \) is the subobject of \( \Delta^n \) characterized by:

\[
(\partial \Delta^n)_m = \{ f : m \to n | f \text{ is not surjective} \}
\] (1.4)

and finally \( \wedge_k^n \) is the subobject of \( \partial \Delta^n \) given by:

\[
(\wedge_k^n)_m = \{ f : m \to n | \{0 < 1 < \cdots < \hat{k} < \cdots < n\} \not\subseteq \text{im}(f) \}
\] (1.5)

where \( \{0 < 1 < \cdots < \hat{k} < \cdots < n\} \) denotes the well ordered set \( n \) with the \( k \) element removed.

We also have the dual notion of cosimplicial set:

**Definition 1.5.2.** A cosimplicial set \( X \) is a covariant functor from the category \( \Delta \) to the category of sets.

Given any category \( \mathcal{C} \), we can also define simplicial and cosimplicial objects in \( \mathcal{C} \), where a simplicial (respectively cosimplicial) object \( X \) in \( \mathcal{C} \) is just a contravariant (respectively covariant) functor from \( \Delta \) to \( \mathcal{C} \).

Let \( \textbf{Top} \) be the category of compactly generated Hausdorff topological spaces. Consider the following family of objects in \( \textbf{Top} \):
1.5. Simplicial Sets

$$|\Delta^n| = \{(t_0, t_1, \ldots, t_n) | t_i \geq 0, \sum t_i = 1\} \subseteq \mathbb{R}^{n+1}$$

We get a cosimplicial object $|\Delta^\bullet|$ in $\text{Top}$ if we define the coface and codegeneracy maps for $|\Delta^n|$ as:

$$\delta^i : |\Delta^n| \to |\Delta^{n+1}|$$

$$(t_0, t_1, \ldots, t_n) \mapsto (t_0, \ldots, t_{i-1}, 0, t_i, \ldots, t_n)$$

(1.6)

and

$$\sigma^i : |\Delta^{n+1}| \to |\Delta^n|$$

$$(t_0, t_1, \ldots, t_{n+1}) \mapsto (t_0, \ldots, t_{i-1}, t_i + t_{i+1}, t_{i+2}, \ldots, t_{n+1})$$

(1.7)

Now we are ready to define the geometric realization functor:

$$| - | : \text{SSets} \to \text{Top}$$

Let $X$ be a simplicial set, then its geometric realization $|X|$ is the following topological space:

$$|X| = \lim_{\Delta^n \to X} |\Delta^n|$$

(1.8)

where the indexing category to compute the colimit has objects given by the simplices over $X$, i.e. maps of simplicial sets $\Delta^n \to X$; and morphisms given by commutative triangles:

$$\Delta^n \xrightarrow{\theta} \Delta^m \xrightarrow{\theta^*} \Delta^n \xrightarrow{\theta^*} X$$

for $\theta : n \to m$

The geometric realization functor $| - |$ has a right adjoint:

$$\text{Sing} : \text{Top} \to \text{SSets}$$

called the singular functor and defined in the following way:

$$\text{Sing}(T) : \Delta^{op} \to \text{Sets}$$

$$n \mapsto \text{Hom}_{\text{Top}}(|\Delta^n|, T)$$

(1.9)
1.6. Simplicial Model Categories

with faces and degeneracies induced by the cofaces and codegeneracies of the cosimplical object $|\Delta^n|$.

We say that a map of simplicial sets $\theta : X \to Y$ is a weak equivalence if its geometric realization $|\theta| : |X| \to |Y|$ is a weak equivalence of topological spaces, i.e. $\pi_i(|\theta|,*)$ is an isomorphism for any $i \geq 0$, and for every choice of base point $* \in |X|$.

With all the previous definitions, we are ready to give a cofibrantly generated model category structure on the category of simplicial sets. Take $I = \{\partial \Delta^n \hookrightarrow \Delta^n\}$ and $J = \{\wedge_k^n \hookrightarrow \Delta^n\}$.

**Theorem 1.5.3** (Quillen). The category of simplicial sets $\text{SSets}$ has a cofibrantly generated model category structure, where the weak equivalences, the set of generating cofibrations $I$ and the set of generating trivial cofibrations $J$ are defined as above.

**Proof.** The proof is probably one of the most difficult ones in abstract homotopy theory. We refer the reader to [20, II.3 theorem 3], [5] or [10].

1.6 Simplicial Model Categories

Simplicial model categories were defined by Quillen in [20], we will follow the approach in [5, chapter 2] and [7, chapter 9].

**Definition 1.6.1.** Let $\mathcal{A}$ be a category. We say that $\mathcal{A}$ is simplicial if it satisfies the following axioms:

1. There exists a functor

\[ \begin{array}{ccc}
\mathcal{A}^{op} \times \mathcal{A} & \longrightarrow & \text{SSets} \\
X, Y & \longmapsto & \text{Map}(X, Y)
\end{array} \]

such that

2. The set of 0-simplices in $\text{Map}(X, Y)$ is equal to the set of maps in $\mathcal{A}$ from $X$ to $Y$, i.e. $\text{Map}(X, Y)_0 = \text{Hom}_\mathcal{A}(X, Y)$.
3. For every triple $X, Y, Z$ of objects in $\mathcal{A}$, there exists a map of simplicial sets called composition law

$$\circ_{X,Y,Z} : \text{Map}(Y, Z) \times \text{Map}(X, Y) \to \text{Map}(X, Z)$$

which is compatible with the composition in $\mathcal{A}$.

4. There exists a map of simplicial sets $i_X : * \to \text{Map}(X, X)$, for every object $X \in \mathcal{A}$.

5. There exists three commutative diagrams (cf. [7, definition 9.1.2.]), which give the associativity of the composition law, and right and left unit properties for the map $i_X$.

**Definition 1.6.2.** Let $\mathcal{A}$ be a model category, we say that $\mathcal{A}$ is a simplicial model category if it is a simplicial category (see definition 1.6.1) and satisfies the following two axioms:

**SM0** 1. For every $X \in \mathcal{A}$, the functor

$$\begin{array}{ccc}
\text{Map}(X, -) : \mathcal{A} & \to & \text{SSets} \\
Y & \mapsto & \text{Map}(X, Y)
\end{array}$$

has a left adjoint

$$\begin{array}{ccc}
X \otimes - : \text{SSets} & \to & \mathcal{A} \\
K & \mapsto & X \otimes K
\end{array}$$

such that the adjunction is compatible with the simplicial structure on $\mathcal{A}$, i.e. $\text{Map}(X \otimes K, Y) \cong \text{Map}(K, \text{Map}(X, Y))$, where the simplicial set on the right hand side is the one defined in remark 1.6.3(1).

2. For every $Y \in \mathcal{A}$, the functor

$$\begin{array}{ccc}
\text{Map}(-, Y) : \mathcal{A}^{\text{op}} & \to & \text{SSets} \\
X & \mapsto & \text{Map}(X, Y)
\end{array}$$

has a left adjoint

$$\begin{array}{ccc}
Y^\sim : \text{SSets} & \to & \mathcal{A}^{\text{op}} \\
K & \mapsto & Y^K
\end{array}$$
such that the adjunction is compatible with the simplicial structure on \( \mathcal{A} \), i.e. \( \text{Map}(X, Y^K) \cong \text{Map}(K, \text{Map}(X, Y)) \), where the simplicial set on the right hand side is the one defined in remark 1.6.3(1).

**SM7** For any cofibration \( i : A \to B \) in \( \mathcal{A} \) and fibration \( p : X \to Y \) in \( \mathcal{A} \), the map

\[
\text{Map}(B, X) \xrightarrow{(i^*, p_*)} \text{Map}(A, X) \times_{\text{Map}(A, Y)} \text{Map}(B, Y)
\]

is a fibration of simplicial sets, which is trivial if either \( i \) or \( p \) is a weak equivalence.

**Remark 1.6.3.**
1. The category of simplicial sets \( \textbf{SSets} \) has a canonical simplicial model category structure where \( \text{Map}(X, Y) \) is the simplicial set having \( n \)-simplices

\[
\text{Map}(X, Y)_n = \text{Hom}_{\textbf{SSets}}(X \times \Delta^n, Y)
\]

with faces and degeneracies induced from the cosimplicial object \( \Delta^* \).

2. The associated category of pointed simplicial sets \( \textbf{SSets}_* \) equipped with the induced model structure from \( \textbf{SSets} \) (see remark 1.1.2) has a natural simplicial model category structure.

**Lemma 1.6.4.** Let \( \mathcal{A} \) be a simplicial model category. Suppose that \( i : A \to B \), \( p : X \to Y \) are maps in \( \mathcal{A} \) and \( j : L \to K \) is a map of simplicial sets. Then the following are equivalent:

1. For every solid commutative diagram of simplicial sets

\[
\begin{array}{ccc}
L & \rightarrow & \text{Map}(B, X) \\
\downarrow_j & & \downarrow_{(i^*, p_*)} \\
K & \rightarrow & \text{Map}(A, X) \times_{\text{Map}(A, Y)} \text{Map}(B, Y)
\end{array}
\]

the dotted arrow making the diagram commutative exists.

2. For every solid commutative diagram in \( \mathcal{A} \)

\[
\begin{array}{ccc}
A \otimes K & \rightarrow & X \\
\downarrow_{i_! j_!} & & \downarrow_p \\
B \otimes K & \rightarrow & Y
\end{array}
\]

the dotted arrow making the diagram commutative exists.
3. For every solid commutative diagram in $\mathcal{A}$

\[
\begin{array}{ccc}
A & \xrightarrow{i} & X^K \\
\downarrow & & \downarrow \left((j^*, p^*)\right) \\
B & \xrightarrow{=} & X^L \times_{Y^L} Y^K
\end{array}
\]

the dotted arrow making the diagram commutative exists.

**Proof.** Follows directly from the existence of the adjunctions in axiom SM0. \qed

The following is a useful criterion to check axiom SM7.

**Proposition 1.6.5.** Let $\mathcal{A}$ be a model category with a simplicial structure (see definition 1.6.1), satisfying axiom SM0, then the following are equivalent:

1. $\mathcal{A}$ satisfies axiom SM7.

2. Suppose that $i : A \to B$ is a cofibration in $\mathcal{A}$, and $j : L \to K$ is a cofibration of simplicial sets, then the map

\[
A \otimes K \coprod_{A \otimes L} B \otimes L \xrightarrow{i \boxplus j} B \otimes K
\]

is a cofibration in $\mathcal{A}$, which is trivial if either $i$ or $j$ is a weak equivalence.

3. Suppose that $p : X \to Y$ is a fibration in $\mathcal{A}$, and $j : L \to K$ is a cofibration of simplicial sets, then the map

\[
X^K \xrightarrow{(j^*, p^*)} X^L \times_{Y^L} Y^K
\]

is a fibration in $\mathcal{A}$, which is trivial if either $p$ or $j$ is a weak equivalence.

**Proof.** Follows from lemma 1.6.4 and corollary 1.1.6. \qed

These characterizations of axiom SM7, allow to construct “simplicial” cylinder (respectively path) objects for any cofibrant (respectively fibrant) object $A$ of $\mathcal{A}$. 

**Proposition 1.6.6.** Let $\mathcal{A}$ be a simplicial model category, and let $A$ be a cofibrant object in $\mathcal{A}$. Then the following diagram represents a cylinder object for $A$

\[
\begin{array}{ccc}
A \otimes \partial \Delta^1 & \cong & A \coprod A \\
\downarrow i & & \swarrow \nabla \\
A \otimes \Delta^1 & \rightarrow & A \otimes * \cong A
\end{array}
\]

**Proof.** Proposition 1.6.5 implies that $i$ is a cofibration. In the following commutative diagram

\[
\begin{array}{ccc}
A \otimes * & \cong & A \\
\downarrow t & & \swarrow \text{id} \\
A \otimes \Delta^1 & \rightarrow & A \otimes * \cong A
\end{array}
\]

Proposition 1.6.5 implies that $t$ is a trivial cofibration, so by the two out of three property for weak equivalences we have that $s$ is a weak equivalence. It only remains to show that $A \otimes \partial \Delta^1 \rightarrow A \otimes *$ is the fold map $A \coprod A \rightarrow A$, but this follows from the next commutative diagram:

\[
\begin{array}{ccc}
A \otimes * & \rightarrow & A \otimes \Delta^1 \\
\downarrow id \otimes d_1 & & \swarrow id \\
A \otimes \partial \Delta^1 & \rightarrow & A \otimes * \\
\downarrow id \otimes d_0 & & \swarrow id
\end{array}
\]

The dual statement for path objects is the following.

**Proposition 1.6.7.** Let $\mathcal{A}$ be a simplicial model category, and let $X$ be a fibrant object in $\mathcal{A}$. Then the following diagram represents a path object for $X$

\[
\begin{array}{ccc}
X^\Delta^1 & \rightarrow & X^\Delta^1 \\
\downarrow r & & \downarrow p \\
X \cong X^* & \rightarrow & X^{\partial \Delta^1} \cong X \times X
\end{array}
\]
One of the interesting consequences we get when we have a simplicial model category $\mathcal{A}$, is that we can compute the maps in the homotopy category $\text{Ho}\mathcal{A}$ simplicially.

**Proposition 1.6.8.** Let $X, Y$ be a pair of objects in $\mathcal{A}$, where $X$ is cofibrant and $Y$ is fibrant. Then $[X, Y] = \pi_0 \text{Map}(X, Y)$, where $[X, Y] = \text{Hom}_{\text{Ho}\mathcal{A}}(X, Y)$.

**Proof.** Since $X$ is cofibrant and $Y$ is fibrant, we have that $[X, Y]$ is just the set of homotopy classes of maps between $X$ and $Y$. On the other hand, axiom SM7 implies that $\text{Map}(X, Y)$ is a fibrant simplicial set (Kan complex), so $\pi_0 \text{Map}(X, Y)$ is computed using the simplicial homotopies given by $\Delta^1 \to \text{Map}(X, Y)$, which by the adjunction are in bijection with the homotopies given by $X \otimes \Delta^1 \to Y$. But these are just homotopies between $X$ and $Y$, since proposition 1.6.6 implies that $X \otimes \Delta^1$ is a cylinder object for $X$. 

**Corollary 1.6.9.** Let $\mathcal{A}$ be a simplicial model category, and consider a couple of objects $X, Y$ in $\mathcal{A}$. Then $[X, Y] = \pi_0 \text{Map}(RQX, RQY)$.

**Proof.** By construction $[X, Y]$ is equal to set of homotopy classes of maps between $RQX$ and $RQY$. But $RQX, RQY$ are both cofibrant and fibrant objects in $\mathcal{A}$, so proposition 1.6.8 implies that this set of homotopy classes of maps is equal to $\pi_0 \text{Map}(RQX, RQY)$.

Another simple but very useful consequence of having a simplicial model category $\mathcal{A}$, is that we can also detect weak equivalences in $\mathcal{A}$ at the level of simplicial sets.

**Proposition 1.6.10.** Let $\mathcal{A}$ be a simplicial model category, and let $h: A \to B$ be a map between two cofibrant (respectively fibrant) objects in $\mathcal{A}$. Then $h$ is a weak equivalence if and only if for every fibrant (respectively cofibrant) object $X$ in $\mathcal{A}$, $h^*: \text{Map}(B, X) \to \text{Map}(A, X)$ (respectively $h_*: \text{Map}(X, A) \to \text{Map}(X, B)$) is a weak equivalence of simplicial sets.

**Proof.** By duality, it is enough to consider the case in which $A, B$ are cofibrant objects in $\mathcal{A}$. Assume that $h$ is a weak equivalence. Since weak equivalences of simplicial sets have the two out of three property, then by Ken Brown’s lemma (see lemma 1.1.4) we can assume
that $h$ is a trivial cofibration. The conclusion then follows from axiom SM7 which implies that for any fibrant object $X$ in $\mathcal{A}$, $h^* : \text{Map}(B, X) \to \text{Map}(A, X)$ is a trivial fibration of simplicial sets, so in particular $h^*$ is a weak equivalence.

For the converse, it is enough to show that $h^* : [B, X] \to [A, X]$ is a bijection for every fibrant object $X$ in $\mathcal{A}$. But since for every fibrant object $X$ in $\mathcal{A}$, $h^* : \text{Map}(B, X) \to \text{Map}(A, X)$ is a weak equivalence of simplicial sets, in particular we have that $h^* : \pi_0\text{Map}(B, X) \to \pi_0\text{Map}(A, X)$ is a bijection, and the result follows from proposition 1.6.8 since $A, B$ are cofibrant in $\mathcal{A}$ and $X$ is fibrant in $\mathcal{A}$.

\[\square\]

**Corollary 1.6.11.** Let $\mathcal{A}$ be a simplicial model category and consider a couple of objects $A, B$ in $\mathcal{A}$, and a map $h : A \to B$ between them. Then the following conditions are equivalent:

1. $h$ is a weak equivalence in $\mathcal{A}$.

2. For every fibrant object $X$ in $\mathcal{A}$, $(Qh)^* : \text{Map}(QB, X) \to \text{Map}(QA, X)$ is a weak equivalence of simplicial sets.

3. For every cofibrant object $C$ in $\mathcal{A}$, $(Rh)_* : \text{Map}(C, RA) \to \text{Map}(C, RB)$ is a weak equivalence of simplicial sets.

\[\text{Proof.} \ (1) \Leftrightarrow (2). \ We \ have \ that \ h \ is \ a \ weak \ equivalence \ if \ and \ only \ if \ every \ (or \ some) \ cofibrant \ approximation \ Qh : QA \to QB \ is \ also \ a \ weak \ equivalence. \ Since \ QA, QB \ are \ cofibrant \ the \ result \ follows \ from \ proposition \ 1.6.10. \]

$(1) \Leftrightarrow (3). \ We \ know \ that \ h \ is \ a \ weak \ equivalence \ if \ and \ only \ if \ every \ (or \ some) \ fibrant \ approximation \ Rh : RA \to RB \ is \ also \ a \ weak \ equivalence. \ But \ RA, RB \ are \ fibrant, \ so \ the \ result \ follows \ from \ proposition \ 1.6.10. \ \square$
1.7 Symmetric Monoidal Model Categories

Symmetric monoidal model categories were introduced by Hovey in [10, chapter 4]. In this section we just recall some of his definitions and results without proof.

**Definition 1.7.1.** Let $\mathcal{C}$ be a monoidal category. We say that a category $\mathcal{D}$ is a left $\mathcal{C}$-module if the following conditions are satisfied:

1. There exists a bifunctor $\otimes : \mathcal{C} \times \mathcal{D} \to \mathcal{D}$

2. For every pair of objects $X, Y$ in $\mathcal{C}$ and every object $A$ in $\mathcal{D}$ there exists a natural isomorphism $a : (X \otimes Y) \otimes A \to X \otimes (Y \otimes A)$.

3. For every object $A$ in $\mathcal{D}$ there exists a natural isomorphism $l : 1 \otimes A \to A$, where $1$ denotes the unit for the monoidal structure on $\mathcal{C}$.

4. Three coherence diagrams commute (see [10, definition 4.1.6]).

We also have right modules over a given monoidal category.

**Definition 1.7.2.** Given three categories $\mathcal{C}, \mathcal{D}, \mathcal{E}$, we define an adjunction of two variables as a bifunctor $\otimes : \mathcal{C} \times \mathcal{D} \to \mathcal{E}$ together with two extra functors $\text{Hom}_r : \mathcal{D}^{\text{op}} \times \mathcal{E} \to \mathcal{C}$ and $\text{Hom}_l : \mathcal{C}^{\text{op}} \times \mathcal{E} \to \mathcal{D}$, such that there exist the following two adjunctions:

1. $\text{Hom}_\mathcal{E}(X \otimes Y, Z) \xrightarrow{\psi_r} \text{Hom}_\mathcal{C}(X, \text{Hom}_r(Y, Z))$

2. $\text{Hom}_\mathcal{E}(X \otimes Y, Z) \xrightarrow{\psi_l} \text{Hom}_\mathcal{D}(Y, \text{Hom}_l(X, Z))$

**Definition 1.7.3.** We say that a category $\mathcal{C}$ is closed monoidal if it is a monoidal category such that the bifunctor $\otimes : \mathcal{C} \times \mathcal{C} \to \mathcal{C}$ giving the monoidal structure is an adjunction of two variables.

**Definition 1.7.4.** Given model categories $\mathcal{A}, \mathcal{B}, \mathcal{D}$ an adjunction of two variables $\otimes : \mathcal{A} \times \mathcal{B} \to \mathcal{D}$ is called a Quillen adjunction of two variables, if given a cofibration $i : A \to B$ in $\mathcal{A}$ and a cofibration $j : C \to D$ in $\mathcal{B}$, the induced map

$$i \square j : A \otimes D \coprod_{A \otimes C} B \otimes C \longrightarrow B \otimes D$$
is a cofibration in \( \mathcal{D} \) which is trivial if either \( i \) or \( j \) is a weak equivalence. In this case, we will refer to the functor \( \otimes \) as a Quillen bifunctor.

**Lemma 1.7.5** (Hovey). Let \( \mathcal{A}, \mathcal{B}, \mathcal{D} \) be three model categories and let \( \otimes : \mathcal{A} \times \mathcal{B} \to \mathcal{D} \) be an adjunction of two variables. Then the following conditions are equivalent:

1. \( \otimes \) is a Quillen bifunctor.

2. Given a cofibration \( j : C \to D \) in \( \mathcal{B} \) and a fibration \( p : X \to Y \) in \( \mathcal{D} \), the induced map

\[
(j^*, p_*) : \text{Hom}_r(D, X) \longrightarrow \text{Hom}_r(C, X) \times_{\text{Hom}_r(C, Y)} \text{Hom}_r(D, Y)
\]

is a fibration in \( \mathcal{A} \) which is trivial if either \( j \) or \( p \) is a weak equivalence.

3. Given a cofibration \( i : A \to B \) in \( \mathcal{A} \) and a fibration \( p : X \to Y \) in \( \mathcal{D} \), the induced map

\[
(i^*, p_*) : \text{Hom}_l(B, X) \longrightarrow \text{Hom}_l(A, X) \times_{\text{Hom}_l(A, Y)} \text{Hom}_l(B, Y)
\]

is a fibration in \( \mathcal{B} \) which is trivial if either \( i \) or \( p \) is a weak equivalence.

**Proof.** Follows immediately from the adjunctions that appear in the definition of an adjunction of two variables (see definition 1.7.2), and the lifting property characterization for cofibrations, fibrations, trivial cofibrations and trivial fibrations.

**Remark 1.7.6** (cf. [10, remark 4.2.3]). Let \( \otimes : \mathcal{A} \times \mathcal{B} \to \mathcal{D} \) be a Quillen bifunctor. Then if \( A \) is a cofibrant object in \( \mathcal{A} \), the functor \( A \otimes - : \mathcal{B} \to \mathcal{D} \) is a Quillen functor with right adjoint \( \text{Hom}_l(A, -) : \mathcal{D} \to \mathcal{B} \). Similarly if \( B \) is a cofibrant object in \( \mathcal{B} \), we get a Quillen functor \( - \otimes B : \mathcal{A} \to \mathcal{D} \) with right adjoint \( \text{Hom}_r(B, -) \). Finally, if \( X \) is a fibrant object in \( \mathcal{D} \), we get a Quillen functor \( \text{Hom}_r(-, X) : \mathcal{B} \to \mathcal{A}^{\text{op}} \) with right adjoint \( \text{Hom}_l(-, X) : \mathcal{A}^{\text{op}} \to \mathcal{B} \).

**Definition 1.7.7.** A **monoidal model category** \( \mathcal{A} \) is a closed monoidal category with a model category structure, such that the following conditions are satisfied:

1. The bifunctor \( \otimes : \mathcal{A} \times \mathcal{A} \to \mathcal{A} \) giving the monoidal structure is a Quillen bifunctor.
2. Let \( q : Q1 \to 1 \) be a cofibrant replacement for the unit \( 1 \). Then the natural maps 
\[ q \otimes id : Q1 \otimes A \to 1 \otimes A, \quad id \otimes q : A \otimes Q1 \to A \otimes 1 \]
are weak equivalences for any cofibrant object \( A \) in \( \mathcal{A} \).

We have an analogous definition for symmetric monoidal categories.

**Proposition 1.7.8** (Quillen). The category of simplicial sets \( \text{SSets} \) is a symmetric monoidal model category.

**Proof.** We refer the reader to [20, II.3 theorem 3].

**Proposition 1.7.9** (Hovey). Let \( \mathcal{A} \) be a monoidal model category, with unit \( 1 \) equal to the terminal object \( * \), and assume that \( * \) is cofibrant. Then the associated pointed category \( \mathcal{A}_* \) (equipped with the monoidal structure described in remark 1.1.2) is also a monoidal model category, which is symmetric if \( \mathcal{A} \) is.

**Proof.** We refer the reader to [10, proposition 4.2.9].

**Corollary 1.7.10.** The category of pointed simplicial sets \( \text{SSets}_* \) is a symmetric monoidal model category.

**Proof.** Follows immediately from propositions 1.7.8 and 1.7.9.

**Definition 1.7.11.** Let \((F,G,\varphi) : \mathcal{A} \to \mathcal{B}\) be a Quillen adjunction between two monoidal model categories. We say that \((F,G,\varphi)\) is a monoidal Quillen adjunction if \( F \) is a monoidal functor (see [10, definition 4.1.2]) and the map \( F(q_1) : F(Q1) \to F1 \) is a weak equivalence. In this situation we say that \( F \) is a left Quillen monoidal functor.

**Definition 1.7.12.** Let \( \mathcal{A} \) be a monoidal model category. A \( \mathcal{A} \)-model category is a left \( \mathcal{A} \)-module \( \mathcal{B} \) equipped with a model category structure such that the following conditions hold:

1. The action map \(- \otimes - : \mathcal{A} \times \mathcal{B} \to \mathcal{B}\) is a Quillen bifunctor.
2. If $q : Q \to 1$ is a cofibrant replacement for $1$ in $A$, then the map $q \otimes id : Q1 \otimes A \to 1 \otimes A$ is a weak equivalence for every cofibrant object $A$ in $B$.

The simplicial model categories discussed in section 1.6 are just $\text{Sset}$-model categories.

**Proposition 1.7.13** (Hovey). Let $A$ be a monoidal model category where the unit $1$ is equal to the terminal object $\ast$. Assume that $\ast$ is cofibrant. If $B$ is a $A$-model category, then the associated pointed category $B_\ast$ has a natural $A_\ast$-model category structure.

**Proof.** We refer the reader to [10, proposition 4.2.19].

**Proposition 1.7.14** (Hovey). Let $A$, $B$, $D$ be three model categories, and let $- \otimes - : A \times B \to D$ be a Quillen bifunctor. Then the total derived functors define an adjunction of two variables $\otimes^L : \text{Ho}A \times \text{Ho}B \to \text{Ho}D$, with adjoints given by $R\text{Hom}_l : (\text{Ho}A)^{op} \times \text{Ho}D \to B$ and $R\text{Hom}_r : (\text{Ho}B)^{op} \times \text{Ho}D \to \text{Ho}A$.

**Proof.** We refer the reader to [10, proposition 4.3.1].

**Theorem 1.7.15** (Hovey). Let $A$ be a (symmetric) monoidal model category. Then $\text{Ho}A$ can be given the structure of a closed (symmetric) monoidal category. The adjunction of two variables $(\otimes^L, R\text{Hom}_l, R\text{Hom}_r)$ which gives the closed structure on $\text{Ho}A$ is the total derived adjunction of $(\otimes, \text{Hom}_l, \text{Hom}_r)$ described in proposition 1.7.14. The associativity and unit isomorphisms (and the commutativity isomorphism in case $A$ is symmetric) on $\text{Ho}A$ are derived from the corresponding isomorphisms of $A$.

**Proof.** We refer the reader to [10, theorem 4.3.2].

### 1.8 Localization of Model Categories

In this section we recall some of Hirschhorn’s constructions [7, sections 3.1, 3.2] restricted to the case where all the model categories are simplicial.
Definition 1.8.1. Let $\mathcal{A}$ be a model category and let $\mathcal{V}$ be a class of maps in $\mathcal{A}$. A left localization of $\mathcal{A}$ with respect to $\mathcal{V}$ is a model category $L_\mathcal{V}\mathcal{A}$ equipped with a left Quillen functor $\lambda: \mathcal{A} \to L_\mathcal{V}\mathcal{A}$ satisfying the following properties:

1. The total left derived functor $L\lambda : \text{Ho}\mathcal{A} \to \text{Ho}L_\mathcal{V}\mathcal{A}$ takes the images in $\text{Ho}\mathcal{A}$ of the elements in $\mathcal{V}$ into isomorphisms in $\text{Ho}L_\mathcal{V}\mathcal{A}$.

2. If $\mathcal{B}$ is a model category and $\tau: \mathcal{A} \to \mathcal{B}$ is a left Quillen functor such that $L\tau : \text{Ho}\mathcal{A} \to \text{Ho}\mathcal{B}$ takes the images in $\text{Ho}\mathcal{A}$ of the elements of $\mathcal{V}$ into isomorphisms in $\text{Ho}\mathcal{B}$, then there exists a unique left Quillen functor $\sigma: L_\mathcal{V}\mathcal{A} \to \mathcal{B}$ with $\sigma\lambda = \tau$.

Definition 1.8.2. Let $\mathcal{A}$ be a model category and let $\mathcal{V}$ be a class of maps in $\mathcal{A}$. A right localization of $\mathcal{A}$ with respect to $\mathcal{V}$ is a model category $R_\mathcal{V}\mathcal{A}$ equipped with a right Quillen functor $\rho: \mathcal{A} \to R_\mathcal{V}\mathcal{A}$ satisfying the following properties:

1. The total right derived functor $R\rho : \text{Ho}\mathcal{A} \to \text{Ho}R_\mathcal{V}\mathcal{A}$ takes the images in $\text{Ho}\mathcal{A}$ of the elements in $\mathcal{V}$ into isomorphisms in $\text{Ho}R_\mathcal{V}\mathcal{A}$.

2. If $\mathcal{B}$ is a model category and $\tau: \mathcal{A} \to \mathcal{B}$ is a right Quillen functor such that $R\tau : \text{Ho}\mathcal{A} \to \text{Ho}\mathcal{B}$ takes the images in $\text{Ho}\mathcal{A}$ of the elements of $\mathcal{V}$ into isomorphisms in $\text{Ho}\mathcal{B}$, then there exists a unique right Quillen functor $\sigma: R_\mathcal{V}\mathcal{A} \to \mathcal{B}$ with $\sigma\rho = \tau$.

From the universal property, we immediately get the following uniqueness statement.

Remark 1.8.3. Let $\mathcal{A}$ be a model category and $\mathcal{V}$ a class of maps in $\mathcal{A}$. If a left or right localization of $\mathcal{A}$ with respect to $\mathcal{V}$ exists, then it is unique up to a unique isomorphism.

Definition 1.8.4. Let $\mathcal{A}$ be a model category and $\mathcal{V}$ a class of maps in $\mathcal{A}$.

1. An object $A$ of $\mathcal{A}$ is $\mathcal{V}$-local if $A$ is fibrant and for every map $f : C \to D$ in $\mathcal{V}$, the induced map of simplicial sets $\text{Map}(QD, A) \to \text{Map}(QC, A)$ is a weak equivalence.

2. A map $f : C \to D$ in $\mathcal{A}$ is a $\mathcal{V}$-local equivalence if for every $\mathcal{V}$-local object $A$, the induced map of simplicial sets $\text{Map}(QD, A) \to \text{Map}(QC, A)$ is a weak equivalence.
Definition 1.8.5. Let $A$ be a model category and $V$ a class of maps in $A$.

1. An object $A$ of $A$ is $V$-colocal if $A$ is cofibrant and for every map $f : C \to D$ in $V$, the induced map of simplicial sets $\text{Map}(A, RC) \to \text{Map}(A, RD)$ is a weak equivalence.

2. A map $f : C \to D$ in $A$ is a $V$-colocal equivalence if for every $V$-colocal object $A$, the induced map of simplicial sets $\text{Map}(A, RC) \to \text{Map}(A, RD)$ is a weak equivalence.

The following definition will be necessary for the construction of right Bousfield localizations.

Definition 1.8.6. Let $A$ be a model category and let $K$ be a set of objects in $A$.

1. A map $g : X \to Y$ is a $K$-colocal equivalence if for every object $A$ in $K$ the induced map of simplicial sets $(Rg)_* : \text{Map}(QA, RX) \to \text{Map}(QA, RY)$ is a weak equivalence.

2. If $V$ is the class of $K$-colocal equivalences, then a $V$-colocal object will be called $K$-colocal.

Proposition 1.8.7 (Hirschhorn). Let $A$ be a model category and let $V$ be a class of maps in $A$.

1. The class of $V$-local equivalences satisfies the two out of three property (cf. MC2 in definition 1.1.1).

2. The class of $V$-colocal equivalences satisfies the two out of three property.

Proof. We refer the reader to [7, proposition 3.2.3].

1.9 Bousfield Localization

In this section we review Hirschhorn’s construction of Bousfield localizations [7, section 3.3] in the restricted situation where all the model categories are simplicial.

Definition 1.9.1. Let $A$ be a model category and let $V$ be a class of maps in $A$. The left Bousfield localization of $A$ with respect to $V$ (in case it exists) is a model category structure $L_V A$ on the underlying category of $A$ such that
1. the class of weak equivalences of $L_{\mathcal{V}}\mathcal{A}$ is defined as the class of $\mathcal{V}$-local equivalences of $\mathcal{A}$ (see definition 1.8.4).

2. the class of cofibrations of $L_{\mathcal{V}}\mathcal{A}$ is the same as the class of cofibrations of $\mathcal{A}$.

3. the class of fibrations of $L_{\mathcal{V}}\mathcal{A}$ is defined as the class of maps that have the right lifting property with respect to the maps which are cofibrations and $\mathcal{V}$-local equivalences.

We will also need the dual notion of right Bousfield localization.

**Definition 1.9.2.** Let $\mathcal{A}$ be a model category and let $\mathcal{V}$ be a class of maps in $\mathcal{A}$. The **right Bousfield localization** of $\mathcal{A}$ with respect to $\mathcal{V}$ (in case it exists) is a model category structure $R_{\mathcal{V}}\mathcal{A}$ on the underlying category of $\mathcal{A}$ such that

1. the class of weak equivalences of $R_{\mathcal{V}}\mathcal{A}$ is defined as the class of $\mathcal{V}$-colocal equivalences of $\mathcal{A}$ (see definition 1.8.5).

2. the class of fibrations of $R_{\mathcal{V}}\mathcal{A}$ is the same as the class of fibrations of $\mathcal{A}$.

3. the class of cofibrations of $R_{\mathcal{V}}\mathcal{A}$ is defined as the class of maps that have the left lifting property with respect to the maps which are fibrations and $\mathcal{V}$-colocal equivalences.

**Proposition 1.9.3** (Hirschhorn). Let $\mathcal{A}$ be a model category and $\mathcal{V}$ a class of maps in $\mathcal{A}$. Let $L_{\mathcal{V}}\mathcal{A}$ be the left Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$, then

1. every weak equivalence in $\mathcal{A}$ is a weak equivalence in $L_{\mathcal{V}}\mathcal{A}$.

2. the class of trivial fibrations of $L_{\mathcal{V}}\mathcal{A}$ equals the class of trivial fibrations of $\mathcal{A}$.

3. every fibration of $L_{\mathcal{V}}\mathcal{A}$ is a fibration of $\mathcal{A}$.

4. every trivial cofibration of $\mathcal{A}$ is a trivial cofibration of $L_{\mathcal{V}}\mathcal{A}$.

**Proof.** We refer the reader to proposition 3.3.3 in [7].

We then get the dual version for right Bousfield localizations.
Proposition 1.9.4 (Hirschhorn). Let $\mathcal{A}$ be a model category and $\mathcal{V}$ a class of maps in $\mathcal{A}$. Let $R_{\mathcal{V}}\mathcal{A}$ be the right Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$, then

1. every weak equivalence in $\mathcal{A}$ is a weak equivalence in $R_{\mathcal{V}}\mathcal{A}$.

2. the class of trivial cofibrations of $R_{\mathcal{V}}\mathcal{A}$ equals the class of trivial cofibrations of $\mathcal{A}$.

3. every cofibration of $R_{\mathcal{V}}\mathcal{A}$ is a cofibration of $\mathcal{A}$.

4. every trivial fibration of $\mathcal{A}$ is a trivial fibration of $R_{\mathcal{V}}\mathcal{A}$.

Proof. We refer the reader to proposition 3.3.3 in [7].

Proposition 1.9.5 (Hirschhorn). Let $\mathcal{A}$ be a model category and $\mathcal{V}$ a class of maps in $\mathcal{A}$.

1. If $L_{\mathcal{V}}\mathcal{A}$ is the left Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$, then the identity functor $id : \mathcal{A} \to L_{\mathcal{V}}\mathcal{A}$ is a left Quillen functor with right adjoint $id : L_{\mathcal{V}}\mathcal{A} \to \mathcal{A}$.

2. If $R_{\mathcal{V}}\mathcal{A}$ is the right Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$, then the identity functor $id : R_{\mathcal{V}}\mathcal{A} \to \mathcal{A}$ is a left Quillen functor with right adjoint $id : \mathcal{A} \to R_{\mathcal{V}}\mathcal{A}$.

Proof. Follows immediately from propositions 1.9.3 and 1.9.4.

Theorem 1.9.6 (Hirschhorn). Let $\mathcal{A}$ be a model category and let $\mathcal{V}$ be a class of maps in $\mathcal{A}$.

1. If $L_{\mathcal{V}}\mathcal{A}$ is the left Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$, then the identity functor $id : \mathcal{A} \to L_{\mathcal{V}}\mathcal{A}$ is a left localization of $\mathcal{A}$ with respect to $\mathcal{V}$ (see definition 1.8.1).

2. If $R_{\mathcal{V}}\mathcal{A}$ is the right Bousfield localization of $\mathcal{A}$ with respect to $\mathcal{V}$ then the identity functor $id : \mathcal{A} \to R_{\mathcal{V}}\mathcal{A}$ is a right localization of $\mathcal{A}$ with respect to $\mathcal{V}$.

Proof. We refer the reader to [7, theorem 3.3.19].
Chapter 2

Motivic Unstable and Stable Homotopy Theory

In this chapter we review the construction of the Morel-Voevodsky motivic stable model structure and the construction of Jardine's motivic symmetric stable model structure (see sections 2.4 and 2.6). We also show that these two model structures satisfy Hirschhorn's cellularity condition (see sections 2.5 and 2.7). Therefore, it is possible to apply Hirschhorn's localization techniques to get Bousfield localizations with respect to these two model structures.

2.1 The Injective Model Structure

Let $S$ be a Noetherian separated scheme of finite dimension, and consider the category $Sm|_S$ of smooth schemes of finite type over $S$. $(Sm|_S)_{Nis}$ will denote the site with underlying category $Sm|_S$ equipped with the Nisnevich topology. We are interested in the category $\Delta^{op} Pre(Sm|_S)_{Nis}$ of presheaves of simplicial sets on $Sm|_S$. The objects in $\Delta^{op} Pre(Sm|_S)_{Nis}$ can also be described as simplicial presheaves on $Sm|_S$. The work of Jardine (cf. [12]) shows in particular that $\Delta^{op} Pre(Sm|_S)_{Nis}$ has the structure of a proper simplicial cofibrantly generated model category.
2.1. The Injective Model Structure

We will denote by $\Delta^n_U$ the representable simplicial presheaf corresponding to the objects $U$ in $Sm|_S$ and $n$ in $\Delta$, i.e.

$$\Delta^n_U : (Sm|_S \times \Delta)^{op} \longrightarrow Sets$$

$$(V, m) \longrightarrow (\text{Hom}_{Sm|_S}(V, U)) \times (\Delta^n)_m$$

The following functor gives a fully faithful embedding of $Sm|_S$ into $\Delta^{op Pre(Sm|_S)_{Nis}}$:

$$Y : Sm|_S \longrightarrow \Delta^{op Pre(Sm|_S)_{Nis}}$$

$$U \longrightarrow \Delta^0_U$$

we will abuse notation and write $U$ instead of $\Delta^0_U$. Given any simplicial set $K$ we can consider the associated constant presheaf of simplicial sets which we also denote by $K$, i.e.

$$K : (Sm|_S \times \Delta)^{op} \longrightarrow Sets$$

$$(U, n) \longrightarrow K_n$$

The category of simplicial presheaves $\Delta^{op Pre(Sm|_S)_{Nis}}$ inherits a natural simplicial structure from the one on pointed simplicial sets.

Given a simplicial presheaf $X$, the tensor objects for the simplicial structure on $\Delta^{op Pre(Sm|_S)_{Nis}}$ are defined as follows:

$$X \otimes - : \text{SSets} \longrightarrow \Delta^{op Pre(Sm|_S)_{Nis}}$$

where $X \otimes K$ is the following simplicial presheaf:

$$X \otimes K : (Sm|_S \times \Delta)^{op} \longrightarrow Sets$$

$$(U, n) \longrightarrow X_n(U) \times K_n$$

The simplicial functor in two variables is:

$$\text{Map}(-, -) : (\Delta^{op Pre(Sm|_S)_{Nis}})^{op} \times \Delta^{op Pre(Sm|_S)_{Nis}} \longrightarrow \text{SSets}$$

where $\text{Map}(X, Y)$ is the simplicial set given by:

$$\text{Map}(X, Y) : \Delta^{op} \longrightarrow \text{Sets}$$

$$n \longrightarrow \text{Hom}_{\Delta^{op Pre(Sm|_S)_{Nis}}}(X \otimes \Delta^n, Y)$$
and finally for any simplicial presheaf $Y$ we have the following functor

$$Y^- : \textbf{SSets} \rightarrow (\Delta^{op} Pre (Sm|_S)_{Nis})^{op}$$

where $Y^K$ is the simplicial presheaf given as follows:

$$Y^K : (Sm|_S \times \Delta)^{op} \rightarrow Sets$$

$$(U, n) \rightarrow \text{Hom}_{\textbf{Sets}}(K \times \Delta^n, Y(U))$$

Let $t$ be a point in $(Sm|_S)_{Nis}$. Denote by $\theta_t$ the fibre functor which assigns to every simplicial presheaf its stalk at $t$:

$$\theta_t : \Delta^{op} Pre (Sm|_S)_{Nis} \rightarrow \textbf{SSets}$$

$$X \mapsto \theta_t(X) = X_t$$

Now we proceed to define the model structure on $\Delta^{op} Pre (Sm|_S)_{Nis}$ constructed by Jardine.

A map $f : X \rightarrow Y$ in $\Delta^{op} Pre (Sm|_S)_{Nis}$ is defined to be a weak equivalence, if $f$ induces a weak equivalence of simplicial sets in all the stalks on $(Sm|_S)_{Nis}$, i.e. if for every point $t$ in $(Sm|_S)_{Nis}$ the map

$$\theta_t(X) \rightarrow \theta_t(Y)$$

is a weak equivalence of simplicial sets.

The set $I$ of generating cofibrations is given by all the subobjects of $\Delta^n_U$ for $U$ in $Sm|_S$ and $n \geq 0$, i.e.

$$I = \{ Y \hookrightarrow \Delta^n_U | U \in (Sm|_S), n \geq 0 \}$$

it is easy to see that a map $i : X \rightarrow Y$ is in $I$-cell if and only if it is a monomorphism, i.e. $i_n(U) : X_n(U) \rightarrow Y_n(U)$ is an injective map of sets, for every $U$ in $Sm|_S$, $n \geq 0$.

Let $\lambda$ be a cardinal, and $X$ a simplicial presheaf on $Sm|_S$. We say that $X$ is $\lambda$-bounded if the cardinal of all the simplices of $X$ is bounded by $\lambda$, i.e. $|X_n(U)| < \lambda$ for every $U$ in $Sm|_S$, $n \geq 0$. The site $(Sm|_S)_{Nis}$ is essentially small, so we can find a cardinal $\kappa$ such that $\kappa$ is greater than $2^{\alpha}$, where $\alpha$ is the cardinality of the set $\text{Map}(Sm|_S)$ of maps in $Sm|_S$.

We say that a map $j : X \rightarrow Y$ of simplicial presheaves in $Sm|_S$ is a trivial cofibration, if it is both a cofibration and a weak equivalence. The set $J$ of generating trivial cofibrations
2.1. The Injective Model Structure

is given by all the trivial cofibrations where the codomain is bounded by the cardinal $\kappa$ described above, i.e.

$$J = \{ j : X \to Y \mid j \text{ is a trivial cofibration and } Y \text{ is } \kappa\text{-bounded}\}$$

**Theorem 2.1.1 (Jardine).** The category $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ of simplicial presheaves on the Nisnevich site $(Sm|_S)_{Nis}$, has the structure of a proper simplicial cofibrantly generated model category where the class $W$ of weak equivalences, and the sets $I, J$ of generating cofibrations and generating trivial cofibrations are defined as above.

**Proof.** We refer the reader to [12, theorem 2.3].

The model structure defined above will be called the **injective model structure** for $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$.

**Remark 2.1.2.** The cofibrations for the injective model structure on $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ have the following properties:

1. The class of cofibrations coincides with the class of relative $I$-cell complexes, therefore a map is a cofibration if and only if it is a monomorphism.
2. If a map $i : A \to B$ in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ is a cofibration then for every point $t$ in $(Sm|_S)_{Nis}$ the associated map $\theta_t(i) : \theta_t(A) \to \theta_t(B)$ is a cofibration of simplicial sets.
3. Every object $A$ in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ is an $I$-cell complex, therefore every object in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ is cofibrant.

The category $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ of simplicial presheaves on the smooth Nisnevich site $(Sm|_S)_{Nis}$ also has a closed symmetric monoidal structure which is compatible with the injective model structure, i.e. $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ equipped with the injective structure is a symmetric monoidal model category in the sense of Hovey (see definition 1.7.7).

The closed symmetric monoidal structure is defined as follows:

$$\begin{align*}
\Delta^{op}\text{Pre}(Sm|_S)_{Nis} \times \Delta^{op}\text{Pre}(Sm|_S)_{Nis} & \to \Delta^{op}\text{Pre}(Sm|_S)_{Nis} \\
(X,Y) & \to X \times Y
\end{align*}$$
where $X \times Y$ is the presheaf of simplicial sets defined as follows:

$$X \times Y : (Sm|_S \times \Delta)^{op} \to Sets$$

$$(U, n) \mapsto X_n(U) \times Y_n(U)$$

and the functor that gives the adjunction of two variables is the following:

$$\text{Hom}_{Pre}(-, -) : (\Delta^{op} Pre(Sm|_S)_{Nis})^{op} \times (\Delta^{op} Pre(Sm|_S)_{Nis}) \to \Delta^{op} Pre(Sm|_S)_{Nis}$$

where $\text{Hom}_{Pre}(X, Y)$ is the simplicial presheaf given by:

$$\text{Hom}_{Pre}(X, Y) : (Sm|_S \times \Delta)^{op} \to Sets$$

$$(U, n) \mapsto \text{Hom}_\Delta^{op} Pre(Sm|_S)_{Nis}(X \times \Delta^n_U, Y)$$

**Proposition 2.1.3.** Let $X, Y, Z$ be simplicial presheaves on $(Sm|_S)_{Nis}$.

1. There is a natural isomorphism of simplicial sets

$$\text{Map}(X \times Y, Z) \cong \text{Map}(X, \text{Hom}_{Pre}(Y, Z))$$

2. There is a natural isomorphism of simplicial presheaves on $(Sm|_S)_{Nis}$

$$\text{Hom}_{Pre}(X \times Y, Z) \cong \text{Hom}_{Pre}(X, \text{Hom}_{Pre}(Y, Z))$$

**Proof.**

(1). To any $n$-simplex $\alpha$ in $\text{Map}(X \times Y, Z)$

$$\text{id} \times \Delta^n \times Y \xrightarrow{\cong} (X \times Y) \times \Delta^n \xrightarrow{\alpha} Z$$

associate the $n$-simplex $\alpha_*$ in $\text{Map}(X, \text{Hom}_{Pre}(Y, Z))$

$$\alpha_* : X \times \Delta^n \to \text{Hom}_{Pre}(Y, Z)$$

coming from the adjunction between $- \times Y$ and $\text{Hom}_{Pre}(Y, -)$.

(2). To any $n$-simplex $\alpha$ in $\text{Hom}_{Pre}(X \times Y, Z)_n(U)$

$$\text{id} \times \Delta^n_U \times Y \xrightarrow{\cong} (X \times Y) \times \Delta^n_U \xrightarrow{\alpha} Z$$

associate the $n$-simplex $\alpha_*$ in $\text{Hom}_{Pre}(X, \text{Hom}_{Pre}(Y, Z))_n(U)$

$$\alpha_* : X \times \Delta^n_U \to \text{Hom}_{Pre}(Y, Z)$$

coming from the adjunction between $- \times Y$ and $\text{Hom}_{Pre}(Y, -)$.
Lemma 2.1.4 (cf. [13, lemma 1.5]). The category $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ of simplicial presheaves on the smooth Nisnevich site $(Sm|_S)_{Nis}$ equipped with the injective model structure is a symmetric monoidal model category (see definition 1.7.7).

Proof. We need to check that the conditions (1)-(2) in definition 1.7.7 are satisfied. Since every object is cofibrant in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$, condition (2) is trivially satisfied. To check condition (1), we need to show that if we take two cofibrations $i : A \to B$ and $j : C \to D$ for the injective model structure on $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$, then the induced map $i \Box j : A \times D \coprod_{A \times C} B \times C \to B \times D$ is also a cofibration, which is trivial if either $i$ or $j$ is a weak equivalence. To see that $i \Box j$ is a cofibration, it is enough to show that $i \Box j(U)$ is a cofibration of simplicial sets for every $U$ in $Sm|_S$, but this is true since the category of simplicial sets is a symmetric monoidal model category.

Now we show that $i \Box j$ is a trivial cofibration if either $i$ or $j$ is a weak equivalence. The definition of weak equivalences for the injective model structure implies that is enough to prove it at the level of the stalks, so let $t$ be any point in $(Sm|_S)_{Nis}$, and consider the induced map of simplicial sets

$$\theta_t(i \Box j) : \theta_t(A) \times \theta_t(D) \coprod_{\theta_t(A) \times \theta_t(C)} \theta_t(B) \times \theta_t(C) \to \theta_t(B) \times \theta_t(D)$$

Now since the category of simplicial sets is in particular a symmetric monoidal model category, we have that $\theta_t(i \Box j)$ is a trivial cofibration if either $i$ or $j$ is a weak equivalence. Since this holds for every point $t$ in $(Sm|_S)_{Nis}$, we have that $i \Box j$ is a cofibration in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$ which is trivial if either $i$ or $j$ is a weak equivalence, hence the result follows.

Lemma 2.1.5 (Morel, Voevodsky cf. [17, 2.1 lemma 1.10]). Let $X,Y$ be two fibrant simplicial presheaves in the injective model structure, and consider a map $f : X \to Y$. The following are equivalent:
1. \( f \) is a weak equivalence in the injective model structure for \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \).

2. For every \( U \) in \( Sm|_S \) the map

\[ f(U) : X(U) \to Y(U) \]

is a weak equivalence of simplicial sets.

**Proof.** Assume that \( f \) is a weak equivalence in \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \). Since \( X, Y \) are fibrant and weak equivalences of simplicial sets satisfy the two out of three property, by Ken Brown’s lemma (see lemma 1.1.4) we can assume that \( f \) is a trivial fibration in \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \).

Now consider \( U \) as an element of \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \). Since every object in \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \) is cofibrant, axiom \( \text{SM7} \) for simplicial model categories implies that: \( f_* : \text{Map}(U,X) \to \text{Map}(U,Y) \) is a trivial fibration of simplicial sets, but this is just equal to \( f(U) : X(U) \to Y(U) \).

Conversely, suppose now that for every \( U \) in \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \), \( f(U) : X(U) \to Y(U) \) is a weak equivalence of simplicial sets. Let \( t \) be an arbitrary point in \( (Sm|_S)_{\text{Nis}} \). We know that \( t \) is associated to a pro-object \( \{U_\alpha\} \) in \( (Sm|_S)_{\text{Nis}} \). Therefore \( \theta_t(f) : \theta_t(X) \to \theta_t(Y) \) is a filtered colimit of weak equivalences of simplicial sets, hence a weak equivalence of simplicial sets. But this implies that \( f \) is a weak equivalence in \( \Delta^\text{op} Pre(Sm|_S)_{\text{Nis}} \). \( \square \)

**Definition 2.1.6.** Let \( X \) be a simplicial presheaf on \( (Sm|_S)_{\text{Nis}} \). We say that \( X \) satisfies the **B.G. property** if any elementary Cartesian square

\[
\begin{array}{ccc}
U \times_W V & \longrightarrow & V \\
\downarrow & & \downarrow^p \\
U & \underset{i}{\longrightarrow} & W
\end{array}
\]

of smooth schemes over \( S \) with \( p \) étale, \( i \) an open immersion and \( p^{-1}(W - U) \cong W - U \) (both equipped with the reduced scheme structure) maps to a homotopy Cartesian diagram.
of simplicial sets after applying $X$

$$
\begin{array}{ccc}
X(W) & \longrightarrow & X(V) \\
\downarrow & & \downarrow \\
X(U) & \longrightarrow & X(U \times_W V)
\end{array}
$$

**Theorem 2.1.7** (Jardine). Let $X$ be a simplicial presheaf on $(Sm|_S)_{Nis}$. Then $X$ satisfies the B.G. property if and only if any fibrant replacement $X \rightarrow GX$ in the injective model structure for $\Delta^{op} Pre(Sm|_S)_{Nis}$ is a sectionwise weak equivalence of simplicial sets, i.e. for any $U$ in $Sm|_S$,

$$
\begin{array}{ccc}
X(U) & \xrightarrow{g_X(U)} & GX(U) \\
\uparrow & & \uparrow \\
X & \rightarrow & GX
\end{array}
$$

$g_X(U)$ is a weak equivalence of simplicial sets.

**Proof.** We refer the reader to [13, theorem 1.3].

**Definition 2.1.8.** Consider $U \in Sm|_S$ with structure map $\phi : U \rightarrow S$, i.e. $\phi$ is a smooth map of finite type. Then we have the following adjunction (see [1, proposition I.5.1]):

$$
(\phi^{-1}, \phi_*, \varphi) : \Delta^{op} Pre(Sm|_S)_{Nis} \longrightarrow \Delta^{op} Pre(Sm|_U)_{Nis}
$$

where $\phi^{-1}$ and $\phi_*$ are defined as follows:

$$
\phi^{-1} : \Delta^{op} Pre(Sm|_S)_{Nis} \longrightarrow \Delta^{op} Pre(Sm|_U)_{Nis}
\begin{array}{ccc}
X & \xrightarrow{\phi^{-1}X} & \phi^{-1}X
\end{array}
$$

with $\phi^{-1}X$ defined as the composition of $\phi$ and $X$:

$$
\begin{array}{ccc}
(Sm|_U \times \Delta)^{op} & \xrightarrow{\phi \times id} & (Sm|_S \times \Delta)^{op} \\
\downarrow & & \downarrow \\
\phi^{-1}X & \rightarrow & X
\end{array}
$$

and the right adjoint $\phi_*$ is given by:

$$
\phi_* : \Delta^{op} Pre(Sm|_U)_{Nis} \longrightarrow \Delta^{op} Pre(Sm|_S)_{Nis}
\begin{array}{ccc}
X & \xrightarrow{\phi_*X} & \phi_*X
\end{array}
$$
where $\phi_* X$ is the following simplicial presheaf:

$$
\phi_* X : (Sm|_S \times \Delta)^{op} \to \text{Sets}
$$

$$(V, n) \mapsto X_n(V \times_S U)
$$

**Remark 2.1.9.** Let $\phi : U \to S$ be a smooth map of finite type, and let $Y$ be an arbitrary simplicial presheaf on $(Sm|_U)_{Nis}$. It follows immediately from the description of the functors $\phi^{-1}$ and $\phi_*$ that the counit of the adjunction $(\phi^{-1}, \phi_*, \varphi)$

$$
\phi^{-1}\phi_* Y \cong Y
$$

is an isomorphism which can be naturally identified with the identity map on $Y$, in particular $\phi^{-1}\phi_* Y$ is canonically isomorphic to $Y$.

**Proposition 2.1.10.** Let $\phi : U \to S$ be a smooth map of finite type, and let $X$ be an arbitrary simplicial presheaf on $(Sm|_S)_{Nis}$. Then we have a canonical isomorphism:

$$
\phi_*\phi^{-1}X \cong \text{Hom}_{Pre}(U, X)
$$

**Proof.** To any $n$-simplex $\alpha$ in $(\phi_*\phi^{-1}X)_n(V) = X_n(V \times_S U)$

$$
\Delta^n_V \times U \cong \Delta^n_{V \times_S U} \xrightarrow{\alpha} X
$$

associate the $n$-simplex $\alpha_*$ in $\text{Hom}_{Pre}(U, X)_n(V)$

$$
\Delta^n_V \xrightarrow{\alpha_*} \text{Hom}_{Pre}(U, X)
$$

coming from the adjunction between $- \times U$ and $\text{Hom}_{Pre}(U, -)$.

**Proposition 2.1.11.** Let $\phi : U \to S$ be a smooth map of finite type, let $X$ be a simplicial presheaf on $(Sm|_S)_{Nis}$ and $Y$ a simplicial presheaf on $(Sm|_U)_{Nis}$. Then we have the following enriched adjunctions:

1. There is a natural isomorphism of simplicial sets

$$
\text{Map}(\phi^{-1}X, Y) \cong \text{Map}(X, \phi_* Y)
$$
2. There is a natural isomorphism of simplicial presheaves on \((Sm|S)_{Nis}\)

\[
\text{Hom}_{Pre}(X, \phi_* Y) \xrightarrow{\cong} \phi_*(\text{Hom}_{Pre}(\phi^{-1} X, Y))
\]

3. There is a natural isomorphism of simplicial presheaves on \((Sm|U)_{Nis}\)

\[
\phi^{-1}(\text{Hom}_{Pre}(X, \phi_* Y)) \xrightarrow{\cong} \text{Hom}_{Pre}(\phi^{-1} X, Y)
\]

**Proof.** (1): To any \(n\)-simplex \(\alpha\) in \(\text{Map}(\phi^{-1} X, Y)\)

\[
\phi^{-1}(X \otimes \Delta^n) \cong \phi^{-1} X \otimes \Delta^n \xrightarrow{\alpha} Y
\]

associate the \(n\)-simplex \(\alpha_*\) in \(\text{Map}(X, \phi_* Y)\)

\[
X \otimes \Delta^n \xrightarrow{\alpha_*} \phi_* Y
\]

coming from the adjunction between \(\phi^{-1}\) and \(\phi_*\).

(2): To any \(n\)-simplex \(\alpha\) in \(\text{Hom}_{Pre}(X, \phi_* Y)_n(V)\) (where \(V \in (Sm|S)\))

\[
X \times \Delta^n_V \xrightarrow{\alpha} \phi_* Y
\]

associate the \(n\)-simplex \(\alpha^*\) in \(\phi_*(\text{Hom}_{Pre}(\phi^{-1} X, Y))_n(V)\)

\[
\phi^{-1} X \times \Delta^n_{V \times S V} \cong \phi^{-1}(X \times \Delta^n_V) \xrightarrow{\alpha^*} Y
\]

coming from the adjunction between \(\phi^{-1}\) and \(\phi_*\).

(3): To any \(n\)-simplex \(\alpha\) in \(\phi^{-1}(\text{Hom}_{Pre}(X, \phi_* Y))_n(V)\) (where \(V \in (Sm|U)\))

\[
X \times \Delta^n_V \xrightarrow{\alpha} \phi_* Y
\]

associate the \(n\)-simplex \(\alpha^*\) in \(\text{Hom}_{Pre}(\phi^{-1} X, Y)_n(V)\)

\[
\phi^{-1} X \times \Delta^n_V \cong \phi^{-1}(X \times \Delta^n_V) \xrightarrow{\alpha^*} Y
\]

coming from the adjunction between \(\phi^{-1}\) and \(\phi_*\).

\[\square\]

**Definition 2.1.12** (cf. [13, section 1.4]). Let \(X\) be a simplicial presheaf on \((Sm|S)_{Nis}\). We say that \(X\) is **flasque** if:
2.2. Cellularity of the Injective Model Structure

1. $X$ is a presheaf of Kan complexes.

2. Every finite collection $V_i \rightarrow V$, $i = 1, \ldots, n$ of subschemes of a scheme $V$ induces a Kan fibration

\[ X(V) \cong \text{Map}(V, X) \xrightarrow{i^*} \text{Map}(\bigcup_{i=1}^{n} V_i, X) \]

**Remark 2.1.13.**

1. Let $X$ be a simplicial presheaf on $(Sm|_S)_{Nis}$ which is fibrant in the injective model structure for $\Delta^{op} Pre(Sm|_S)_{Nis}$. Then $X$ is flasque and satisfies the B.G. property.

2. The class of flasque simplicial presheaves is closed under filtered colimits.

3. The B.G. property is stable under filtered colimits.

4. The functors $\phi^{-1}$ and $\phi_*$ preserve flasque simplicial presheaves.

5. The functors $\phi^{-1}$ and $\phi_*$ preserve the B.G. property.

### 2.2 Cellularity of the Injective Model Structure

In this section we prove that the injective model structure on $\Delta^{op} Pre(Sm|_S)_{Nis}$ is cellular (see definition 1.3.12). This is an unpublished result due to Hirschhorn, which also appears in [8, theorem 1.4]. The author would like to thank Jens Hornbostel for the discussion related to Hirschhorn’s cellularity results.

**Lemma 2.2.1.** Let $A$ be a simplicial presheaf on the smooth Nisnevich site $(Sm|_S)_{Nis}$. Then $A$ is small (see definition 1.2.3).

**Proof.** Let $\mu$ be the cardinal of the set $S_A$ of simplices of $A$, i.e.

\[ S_A = \prod_{V \in (Sm|_S), n \geq 0} A_n(V) \]

and let $\kappa$ be the successor cardinal of $\mu$. Since $\kappa$ is a successor cardinal, we have that $\kappa$ is a regular cardinal (see [7, proposition 10.1.14]).
We claim that $A$ is $\kappa$ small with respect to the class of all maps in $\Delta^{op}\text{Pre}(Sm|S)_{Nis}$. In effect, consider an arbitrary $\lambda$-sequence where $\lambda$ is a regular cardinal greater than $\kappa$,

$$X_0 \to X_1 \to \cdots \to X_\beta \to \cdots \ (\beta < \lambda)$$

we need to show that the map $\operatorname{colim}_{\beta < \lambda} \operatorname{Hom}_{\Delta^{op}\text{Pre}(Sm|S)_{Nis}}(A, X_\beta) \to \operatorname{Hom}(A, X_\lambda)$ is a bijection. To check the injectivity, we just take sections on every $U \in (Sm|S)$, and use the fact that every simplicial set is small (see [10, lemma 3.1.1]). To check the surjectivity, consider an arbitrary map $f: A \to X_\lambda$, now the restriction of $f$ to every simplex of $A$ ($\Delta^n_U \to A$), factors through some $X_\beta$ with $\beta < \lambda$. Since $\lambda$ is a regular cardinal and there are fewer than $\kappa$ simplices in $A$ (where $\kappa < \lambda$), there exists $X_\alpha$ with $\alpha < \lambda$ such that the restriction of $f$ to every simplex of $A$ factors through $X_\alpha$. But this implies that $f$ factors through $X_\alpha$, and therefore we get the surjectivity.

**Lemma 2.2.2.** Consider the category $\Delta^{op}\text{Pre}(Sm|S)_{Nis}$ of simplicial presheaves on the smooth Nisnevich site $(Sm|S)_{Nis}$ equipped with the injective model structure. Then all the cofibrations in $\Delta^{op}\text{Pre}(Sm|S)_{Nis}$ are effective monomorphisms.

**Proof.** A map $i: A \to B$ is an effective monomorphism if and only if for every $U \in (Sm|S)$, $n \geq 0$ the induced map $i_n(U): A_n(U) \to B_n(U)$ is an effective monomorphism of sets, this is true since all small limits and colimits are computed termwise. Now in the injective model structure for $\Delta^{op}\text{Pre}(Sm|S)_{Nis}$ the class of cofibrations coincides with the class of monomorphisms. But this implies that all the cofibrations are effective monomorphisms in $\Delta^{op}\text{Pre}(Sm|S)_{Nis}$, since in the category of sets any injective map is an effective monomorphism (see remark 1.3.11).

The next proposition is an unpublished result due to Hirschhorn, which also appears in [8, lemma 1.5], nevertheless the proof given here is slightly different since it also handles the case of a relative $I$-cell complex, which is necessary according to Hirschhorn’s definition of compactness (see definition 1.3.12).
**Proposition 2.2.3.** Let $I$ be the set of generating cofibrations for the injective model structure in the category of simplicial presheaves $\Delta^{op} Pre(Sm|S)_{Nis}$ (see theorem 2.1.1). The domains and codomains of the maps in $I$ are compact relative to $I$.

**Proof.** Let $\mu$ be the cardinal of the set $S_I$ of simplices corresponding to all the domains and codomains of the maps in $I$, i.e.

$$S_I = \coprod_{(i: A \to B) \in I} \coprod_{U \in (Sm|S), n \geq 0} A_n(U) \cup B_n(U)$$

and let $\kappa$ be the successor cardinal of $\mu$. Since $\kappa$ is a successor cardinal, we have that it is a regular cardinal (see [7, proposition 10.1.14]).

If $X$ is a presented $I$-cell complex with presentation ordinal $\lambda$,

$$i : \emptyset \to X, \emptyset = X_0 \to X_1 \to \cdots \to X_\beta \to \cdots (\beta < \lambda), \{T^\beta, e^\beta, h^\beta\}_{\beta < \lambda}$$

we claim that every cell $e$ of $X$ is contained in a subcomplex $X_e$ of $X$ of size less than $\kappa$. This follows from a transfinite induction argument over the presentation ordinal of $e$ (see definition 1.3.2). If the presentation ordinal of $e$ is 0, then the cell $e$ defines a subcomplex of $X$ of size 1, this gets the induction started. Now assume that the result holds for every cell of presentation ordinal less than $\beta < \lambda$, and consider an arbitrary cell $e$ of presentation ordinal $\beta$. The attaching map $h_e$ of this cell has image contained in the union of fewer than $\kappa$ simplices $\{s^e\}$ of $X$ (since the domain of $h_e$ is also a domain for a map in $I$), now each such simplex $s^e$ is contained in a cell $e_s$ of presentation ordinal less than $\beta$ and the induction hypothesis implies that each such cell $e_s$ is contained in a subcomplex $X_s$ of size less than $\kappa$, thus taking the union of all these subcomplexes $X_s$ (which is possible by corollary 1.3.7 since all the $I$-cells are monomorphisms in this case) we get a subcomplex $X'_e$ of size less than $\kappa$ (since $\kappa$ is regular) which contains the image of the attaching map $h_e$. Therefore if we define $X_e$ as the subcomplex obtained from $X'_e$ after attaching the cell $e$ via $h_e$, we get a subcomplex of size less than $\kappa$ containing the given cell $e$. This proves the claim.

Now if $A$ is a simplicial presheaf on $(Sm|S)$ which is a domain or codomain of a map in $I$, we have that $A$ has less than $\kappa$ simplices. Consider a map $j : A \to X$ where $X$ is a
2.2. Cellularity of the Injective Model Structure

presented \( I \)-cell complex,

\[
i: \emptyset \to X, \emptyset = X_0 \to X_1 \to \cdots \to X_\beta \to \cdots (\beta < \lambda), \{T^\beta, e^\beta, h^\beta\}_{\beta < \lambda}
\]

then the image of \( j \) has less than \( \kappa \) simplices \( \{s_j\} \), each such simplex \( s_j \) is contained in some cell \( e_s \) of \( X \) which by the previous argument is contained in a subcomplex \( X_s \) of \( X \) of size less than \( \kappa \). We take now the union of all these subcomplexes \( X_s \) to get a subcomplex \( X_j \) of \( X \) of size less than \( \kappa \) (since \( \kappa \) is regular) which contains the image of \( j \). Therefore \( j \) factors through the subcomplex \( X_j \) which has size less than \( \kappa \).

Finally, we consider a relative cell complex \( f: X \to Y \),

\[
f: X \to Y, X = X_0 \to X_1 \to \cdots \to X_\beta \to \cdots (\beta < \lambda), \{T^\beta, e^\beta, h^\beta\}_{\beta < \lambda}
\]

Take any map \( j: A \to Y \) where \( A \) is a domain or codomain of a map in \( I \). Since all the inclusions are \( I \)-cells for the injective model structure, we have that \( X \) is a cell complex,

\[
i: \emptyset \to X, \emptyset = X_0 \to X_1 \to \cdots \to X_\beta \to \cdots (\beta < \nu), \{T^\beta, e^\beta, h^\beta\}_{\beta < \nu}
\]

Combining this presentation of \( X \) with the presentation of \( f \) we get a presentation for \( Y \) as a cell complex, where \( X \) is a subcomplex. The previous argument shows that the image of \( j \) is contained in a subcomplex \( W' \) of \( Y \) where the size of \( W' \) is less than \( \kappa \). Taking the union of \( W' \) and \( X \) we get a subcomplex \( X_f \) of \( f \) having the same size as \( W' \) (as a subcomplex of \( f \)) which contains the image of \( j \). Therefore \( j \) factors through \( X_f \) where \( X_f \) is a subcomplex of \( f \) of size less than \( \kappa \), and this shows that \( A \) is \( \kappa \)-compact relative to \( I \).

Finally we are ready to prove Hirschhorn’s cellularity theorem.

**Theorem 2.2.4.** The category \( \Delta^{op} Pre(\text{Sm}|_S)_{\text{Nis}} \) of simplicial presheaves on the smooth Nisnevich site \( (\text{Sm}|_S)_{\text{Nis}} \) is a cellular model category when it is equipped with the injective model structure, the sets of generating cofibrations and generating trivial cofibrations are the ones considered in theorem 2.1.1.

**Proof.** We have to check that the conditions (1)-(4) of definition 1.3.12 hold. (1) follows from theorem 2.1.1 which shows that the injective model structure is cofibrantly generated.
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(2) follows from proposition 2.2.3 and (3) follows from lemma 2.2.1 which says that every simplicial presheaf is small. Finally (4) follows from lemma 2.2.2.

Theorem 2.2.4 will be used to show that the category $\text{Spt}_T(Sm|_S)_{\text{Nis}}$ of $T$-spectra on $Sm|_S$ equipped with the motivic stable model structure is cellular (see theorem 2.5.4). This will allow us to apply all the localization technology of Hirschhorn [7] to construct new model structures for $\text{Spt}_T(Sm|_S)_{\text{Nis}}$.

2.3 The Motivic Model Structure

Let $A^1_S$ be the affine line over $S$. Consider the following set of maps

$V_M = \{ \pi_U : U \times A^1_S \to U \mid U \in (Sm|_S) \}$

In [17] Morel and Voevodsky show in particular that for simplicial sheaves on $(Sm|_S)_{\text{Nis}}$ the left Bousfield localization for the injective model structure with respect to $V_M$ exists, and furthermore they show it is a proper simplicial model structure. Their work was extended to the case of simplicial presheaves by Jardine in [13, section 1]. Following Jardine we call this localized model structure the \textbf{motivic model structure on } $\Delta^{op}\text{Pre}(Sm|_S)_{\text{Nis}}$.

\textbf{Theorem 2.3.1} (Morel-Voevodsky, Jardine). Consider the category of simplicial presheaves on the smooth Nisnevich site $(Sm|_S)_{\text{Nis}}$ equipped with the injective model structure. Then the left Bousfield localization (see section 1.9) with respect to the set of maps $V_M$ defined above exists. This model structure will be called \textbf{motivic}, and the category $\Delta^{op}\text{Pre}(Sm|_S)_{\text{Nis}}$ equipped with the motivic model structure will be denoted by $\mathcal{M}$. Furthermore $\mathcal{M}$ is a proper and simplicial model category.

\textbf{Proof.} We refer the reader to [13, theorem 1.1].

The following theorem gives explicit sets of generating cofibrations and trivial cofibrations for $\mathcal{M}$; and it also shows that with this choice of generators, $\mathcal{M}$ has the structure of a cellular model category. In [8, corollary 1.6] it is also proved that $\mathcal{M}$ is cellular.
2.3. The Motivic Model Structure

**Theorem 2.3.2.** \( \mathcal{M} \) is a cellular model category, where the set \( I_M \) of generating cofibrations and the set \( J_M \) of generating trivial cofibrations are defined as follows:

1. \( I_M = I \) where \( I \) is the set of generating cofibrations for the injective model structure on \( \Delta^{op}Pre(Sm|_S)^{Nis} \) (see theorem 2.1.1).

2. \( J_M = \{ j : A \to B \} \) such that:
   
   (a) \( j \) is a monomorphism.

   (b) \( j \) is a \( \mathcal{V}_M \)-local equivalence.

   (c) The size of \( B \) as an \( I \)-cell complex (see definition 1.3.2) is less than \( \kappa \), where \( \kappa \) is the cardinal defined by Hirschhorn in [7, definition 4.5.3].

**Proof.** By theorem 2.2.4 the injective model structure on \( \Delta^{op}Pre(Sm|_S)^{Nis} \) is cellular. Therefore we can use Hirschhorn’s techniques (see section 1.9) to construct the left Bousfield localization with respect to the set of maps \( \mathcal{V}_M \) defined above. This model structure is identical to the motivic model structure of theorem 2.3.1 since both are left Bousfield localizations with respect to the same set of maps. Now using [7, theorem 4.1.1] we have that the motivic model structure is cellular. So it only remains to show that the sets of generating cofibrations and trivial cofibrations are the ones described above. For the set of generating cofibrations it is clear. Theorem 4.1.1 in [7] implies that the generating trivial cofibrations are the maps \( j : A \to B \) where \( j \) is an inclusion of \( I \)-cell complexes and a \( \mathcal{V}_M \)-local equivalence, and the size of \( B \) is less than \( \kappa \). The result follows from the fact that in the injective model structure for \( \Delta^{op}Pre(Sm|_S)^{Nis} \), \( I \)-cell is just the class of monomorphisms and that every object in \( \Delta^{op}Pre(Sm|_S)^{Nis} \) is an \( I \)-cell complex (see remark 2.1.2). \( \Box \)

Following Jardine we say that a simplicial presheaf \( X \) is **motivic fibrant** if \( X \) is \( \mathcal{V}_M \)-local.

**Proposition 2.3.3.** The following conditions are equivalent:

1. \( X \) is motivic fibrant.
2. $X$ is fibrant in the injective structure and for every $U$ in $Sm|_S$ the map induced by
\[ U \times \mathbb{A}^1_S \to U \]
\[ \text{Map}(U, X) \to \text{Map}(U \times \mathbb{A}^1_S, X) \]
is a weak equivalence of simplicial sets.

3. $X$ is fibrant in the injective structure and for every $U$ in $Sm|_S$ the map induced by
\[ U \times * \to U \times \mathbb{A}^1_S \]
\[ \text{Map}(U \times \mathbb{A}^1_S, X) \to \text{Map}(U \times *, X) \]
is a weak equivalence of simplicial sets, where $* \to \mathbb{A}^1_S$ is any rational point for $\mathbb{A}^1_S$.

4. $X$ is fibrant in the injective structure and for every $U$ in $Sm|_S$ the map induced by
\[ U \times * \to U \times \mathbb{A}^1_S \]
\[ \text{Map}(U \times \mathbb{A}^1_S, X) \to \text{Map}(U \times *, X) \]
is a trivial fibration of Kan complexes, where $* \to \mathbb{A}^1_S$ is any rational point for $\mathbb{A}^1_S$.

5. $X$ is fibrant in the injective structure and for every $U$ in $Sm|_S$ the map induced by
\[ U \times * \to U \times \mathbb{A}^1_S \]
\[ \text{Hom}_{Pre}(U \times \mathbb{A}^1_S, X) \to \text{Hom}_{Pre}(U \times *, X) \]
is a trivial fibration between fibrant objects in the injective model structure for
\[ \Delta^{op} \text{Pre}(Sm|_S)_{Nis} \]
where $* \to \mathbb{A}^1_S$ is any rational point for $\mathbb{A}^1_S$.

**Proof.** The claim that (1) and (2) are equivalent follows from the definition of $\mathcal{V}_M$-local and the fact that every simplicial presheaf is cofibrant in the injective model structure. (2) and (3) are equivalent since the following diagram is commutative

\[ \begin{array}{c}
U \cong U \times * \to U \times \mathbb{A}^1_S \\
\downarrow id \ \\
U
\end{array} \]
and weak equivalences of simplicial sets satisfy the two out of three property. (3) and (4) are equivalent since the injective structure is in particular a simplicial model category.

(4) ⇒ (5): Since $\Delta^{op} Pre(Sm|S)_{Nis}$ equipped with the injective model structure is a symmetric monoidal model category we have that

$$\text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X) \xrightarrow{p} \text{Hom}_{\text{Pre}}(U \times *, X)$$

is a fibration between fibrant objects in the injective structure. It only remains to show that $p$ is a weak equivalence in the injective model structure. Lemma 2.1.5 implies that it is enough to show that

$$\text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X)(V) \xrightarrow{p(V)} \text{Hom}_{\text{Pre}}(U \times *, X)(V)$$

is a weak equivalence of simplicial sets for every $V$ in $(Sm|S)$. But for any simplicial presheaf $Z$ we have a natural isomorphism of simplicial sets $Z(V) \cong Map(V, Z)$, therefore $p(V)$ is just

$$\text{Map}(V, \text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X)) \xrightarrow{p(V)} \text{Map}(V, \text{Hom}_{\text{Pre}}(U \times *, X))$$

Now using the enriched adjunctions of 2.1.3, $p(V)$ becomes

$$\text{Map}(V \times U \times \mathbb{A}^1_S, X) \xrightarrow{p(V)} \text{Map}(V \times U \times *, X)$$

and by hypothesis we know that this map is a weak equivalence of simplicial sets.

(5) ⇒ (4): Since the injective model structure is simplicial, we have that

$$\text{Map}(U \times \mathbb{A}^1_S, X) \xrightarrow{f} \text{Map}(U \times *, X)$$

is a fibration between Kan complexes. So it only remains to show that $f$ is a weak equivalence of simplicial sets. By hypothesis we have that

$$\text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X) \xrightarrow{p} \text{Hom}_{\text{Pre}}(U \times *, X)$$

is a trivial fibration between fibrant objects in the injective model structure. Lemma 2.1.5 implies that if we take global sections at $S$:

$$\text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X)(S) \xrightarrow{p(S)} \text{Hom}_{\text{Pre}}(U \times *, X)(S)$$
we get a weak equivalence of simplicial sets. But $p(S)$ is natural isomorphic to

$$\text{Map}(U \times \mathbb{A}^1_S, X) \xrightarrow{f} \text{Map}(U \times *, X)$$

so this proves the result. \qed

**Proposition 2.3.4.** Let $X$ be a motivic fibrant simplicial presheaf on the smooth Nisnevich site $(Sm|_S)_{Nis}$. Then for any $Y$ in $\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$, the simplicial presheaf $\text{Hom}_{\text{Pre}}(Y, X)$ is also motivic fibrant.

**Proof.** Since the injective structure is a symmetric monoidal model category (see lemma 2.1.4) we have that $\text{Hom}_{\text{Pre}}(Y, X)$ is a fibrant object for the injective model structure. Proposition 2.3.3(5) implies that for every $U$ in $Sm|_S$, the map

$$\text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X) \xrightarrow{p_*} \text{Hom}_{\text{Pre}}(U \times *, X)$$

is a trivial fibration between fibrant objects in the injective model structure for

$$\Delta^{op}\text{Pre}(Sm|_S)_{Nis}$$

and since the injective model structure is simplicial we have that

$$\text{Map}(Y, \text{Hom}_{\text{Pre}}(U \times \mathbb{A}^1_S, X)) \xrightarrow{p_*} \text{Map}(Y, \text{Hom}_{\text{Pre}}(U \times *, X))$$

is a trivial fibration of Kan complexes. Now using the enriched adjunctions of proposition 2.1.3, $p_*$ becomes

$$\text{Map}(Y \times U \times \mathbb{A}^1_S, X) \xrightarrow{p_*} \text{Map}(Y \times U \times *, X)$$

and finally

$$\text{Map}(U \times \mathbb{A}^1_S, \text{Hom}_{\text{Pre}}(Y, X)) \xrightarrow{p_*} \text{Map}(U \times *, \text{Hom}_{\text{Pre}}(Y, X))$$

therefore proposition 2.3.3(4) implies that $\text{Hom}_{\text{Pre}}(Y, X)$ is motivic fibrant since $p_*$ is a trivial fibration of Kan complexes for every $U$ in $(Sm|_S)$. \qed
Since the motivic and the injective model structures have the same class of cofibrations and the same set of generating cofibrations, it follows that the cofibrations for the motivic model structure also have the properties described in remark 2.1.2.

**Corollary 2.3.5.** $M$ is a symmetric monoidal model category.

**Proof.** The cofibrations for the motivic and injective model structures coincide, therefore it only remains to show that if we have two cofibrations $i : A \to B$, $j : C \to D$ where $j$ is a motivic weak equivalence, the induced map

$$i \Box j : A \times D \coprod_{A \times C} B \times C \to B \times D$$

is a trivial cofibration in $M$. Since every simplicial presheaf is cofibrant in the motivic model structure, it is enough to prove the following claim: For any trivial cofibration $j : C \to D$ in $M$ and for any simplicial presheaf $A$, the induced map $j \times id : C \times A \to D \times A$ is a trivial cofibration in $M$. Since the injective model structure for $\Delta^{op} Pre(Sm|_S)_{Nis}$ is a symmetric monoidal model category (see lemma 2.1.4) we have that $j \times id$ is a cofibration, so it only remains to show that it is a weak equivalence in $M$. Let $X$ be any motivic fibrant simplicial presheaf, proposition 2.3.4 implies that $\text{Hom}_{Pre}(A, X)$ is also motivic fibrant, therefore since $j$ is a weak equivalence in $M$, the map

$$\text{Map}(D, \text{Hom}_{Pre}(A, X)) \xrightarrow{j^*} \text{Map}(C, \text{Hom}_{Pre}(A, X))$$

is a weak equivalence of simplicial sets. Now using the enriched adjunctions of proposition 2.1.3, $j^*$ becomes

$$\text{Map}(D \times A, X) \xrightarrow{j^*} \text{Map}(C \times A, X)$$

and this implies that $j \times id : C \times A \to D \times A$ is a weak equivalence in $M$, hence the result follows. 

**Remark 2.3.6.** Proposition 1.7.9 implies that the associated pointed category

$$\Delta^{op} Pre_a(Sm|_S)_{Nis}$$
of pointed simplicial presheaves is also closed symmetric monoidal, we denote by \( X \wedge Y \) the functor giving the monoidal structure, and by \( \text{Hom}_{\mathcal{M}}(X,Y) \) the adjunction of two variables.

**Proposition 2.3.7.** Let \( \mathcal{M}_* \) denote the pointed category associated to \( \mathcal{M} \) (see remark 1.1.2), i.e. the category with pointed simplicial presheaves as objects and base point preserving maps. The model structure on \( \mathcal{M}_* \) induced from the model structure on \( \mathcal{M} \) is cellular, proper, simplicial and symmetric monoidal. Furthermore, \( \mathcal{M}_* \) is a \( \text{SSets}_* \)-model category (see definition 1.7.12). The sets \( I_{\mathcal{M}_*} \), \( J_{\mathcal{M}_*} \) of generating cofibrations and trivial cofibrations respectively, are defined as follows:

1. \[
I_{\mathcal{M}_*} = \{i_+ : Y_+ \hookrightarrow (\Delta^n_+)_+\}
\]
   where \( i : Y \hookrightarrow \Delta^n_+ \) is a generating cofibration for \( \mathcal{M} \) (see theorem 2.3.2(1)).

2. \[
J_{\mathcal{M}_*} = \{j_+ : A_+ \rightarrow B_+\}
\]
   where \( j \) is a map in the set \( J \) defined in theorem 2.3.2(2), i.e. \( j \) is a generating trivial cofibration for \( \mathcal{M} \).

**Proof.** Theorems 2.3.1, 2.3.2 together with corollary 2.3.5 imply that \( \mathcal{M} \) is cellular, proper, simplicial and symmetric monoidal. Then theorem 1.3.13 and theorem 1.4.4 imply that the associated pointed category \( \mathcal{M}_* \) with the induced model structure is cellular (with the sets of generating cofibrations and trivial cofibrations as defined above) and proper. Now proposition 1.7.13 implies that \( \mathcal{M}_* \) is a \( \text{SSets}_* \)-model category, and this induces a simplicial model structure in \( \mathcal{M}_* \), since the natural functor \( \text{SSets} \rightarrow \text{SSets}_* \) which adds a disjoint base point is a left Quillen monoidal functor. Finally proposition 1.7.9 implies that \( \mathcal{M}_* \) is symmetric monoidal.

**Definition 2.3.8** (cf. [13, section 2.2]). Let \( X \in \mathcal{M} \) be a simplicial presheaf. We say that \( X \) is **motivic flasque** if:
1. $X$ is flasque (see definition 2.1.12).

2. For every $U \in S m|S$ the map

$$X(U) \cong Map(U, X) \xrightarrow{\sim} Map(U \times \mathbb{A}^1_S, X) \cong X(U \times \mathbb{A}^1_S)$$

induced by the projection $U \times \mathbb{A}^1_S \to U$ is a weak equivalence of simplicial sets.

**Remark 2.3.9.**

1. The class of motivic flasque simplicial presheaves is closed under filtered colimits.

2. The functors $\phi^{-1}$ and $\phi_*$ (see definition 2.1.8) preserve motivic flasque simplicial presheaves.

3. If $X$ is fibrant in the motivic model structure for $\Delta^{op}Pre_*(Sm|S)_{Nis}$ then $X$ is also motivic flasque.

**Definition 2.3.10** (cf. [13, section 2.2]). Let $X \in \mathcal{M}_s$ be a pointed simplicial presheaf. We say that $X$ is **compact** if:

1. All inductive systems $Z_1 \to Z_2 \to \cdots$ of pointed simplicial presheaves induce isomorphisms

$$\text{Hom}_{\mathcal{M}_s}(X, \lim \to Z_i) \cong \lim \to \text{Hom}_{\mathcal{M}_s}(X, Z_i)$$

2. If $Z$ is motivic flasque, then $\text{Hom}_{\mathcal{M}_s}(X, Z)$ is also motivic flasque.

3. The functor

$$\text{Hom}_{\mathcal{M}_s}(X, -) : \mathcal{M}_s \longrightarrow \mathcal{M}_s$$

 takes sectionwise weak equivalences of motivic flasque pointed simplicial presheaves to sectionwise weak equivalences.

**Proposition 2.3.11.** Let $X \in \mathcal{M}_s$ be a pointed simplicial presheaf, and let

$$Z_1 \longrightarrow Z_2 \longrightarrow \cdots$$
be an inductive system of pointed simplicial presheaves. If $X$ is compact in the sense of Jardine (see definition 2.3.10) then:

$$[X, \varinjlim Z_i] \cong \varinjlim [X, Z_i]$$

where $[-,-]$ denotes the set of maps in the homotopy category associated to $\mathcal{M}_e$.

**Proof.** Let $R$ denote a functorial fibrant replacement in $\mathcal{M}_e$, such that the natural map $R_Y : Y \to RY$ is always a trivial cofibration. Consider the following commutative diagram:

$$
\begin{array}{ccccccc}
Z_1 & \rightarrow & Z_2 & \rightarrow & \cdots & \rightarrow & \varinjlim Z_i & \rightarrow & R(\varinjlim Z_i) \\
\downarrow & & \downarrow & & \downarrow & & \downarrow i & & \downarrow i_R \\
RZ_1 & \rightarrow & RZ_2 & \rightarrow & \cdots & \rightarrow & \varinjlim RZ_i & \rightarrow & R(\varinjlim RZ_i)
\end{array}
$$

Since all the maps $Z_i \to RZ_i$ are trivial cofibrations, it follows that the induced map $i : \varinjlim Z_i \to \varinjlim RZ_i$ is also a trivial cofibration. Therefore:

$$[X, \varinjlim Z_i] \cong [X, \varinjlim RZ_i] \cong [X, R(\varinjlim RZ_i)]$$  \hspace{1cm} (2.1)

We have that the pointed simplicial presheaves $RZ_i$ are motivic fibrant, then remark 2.1.13(3) implies that $\varinjlim RZ_i$ satisfies the B.G. property. Therefore using theorem 2.1.7 we get that the map $j_R : \varinjlim RZ_i \to R(\varinjlim RZ_i)$ is a sectionwise weak equivalence. On the other hand $\varinjlim RZ_i$ and $R(\varinjlim RZ_i)$ are both motivic flasque (see remark 2.3.9(1)), and since $X$ is compact we have that

$$\varinjlim \text{Hom}_{\mathcal{M}_e}(X, RZ_i) \cong \text{Hom}_{\mathcal{M}_e}(X, \varinjlim RZ_i) \longrightarrow \text{Hom}_{\mathcal{M}_e}(X, R(\varinjlim RZ_i))$$

is a sectionwise weak equivalence of simplicial sets. Taking global sections at $S$ we get the following weak equivalence of simplicial sets:

$$\varinjlim \text{Map}(X, RZ_i) \rightarrow \text{Map}(X, R(\varinjlim RZ_i))$$

Therefore

$$[X, R(\varinjlim RZ_i)] \cong \pi_0 \text{Map}(X, R(\varinjlim RZ_i))$$

\hspace{1cm} (2.2)

$$\cong \pi_0 \varinjlim \text{Map}(X, RZ_i) \cong \varinjlim \pi_0 \text{Map}(X, RZ_i)$$
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On the other hand:

$$\lim_{\to} \pi_0 \text{Map}(X, RZ_i) \cong \lim_{\to} [X, RZ_i] \quad (2.3)$$

Hence equations (2.1), (2.2) and (2.3) imply that

$$[X, \lim Z_i] \cong [X, R(\lim RZ_i)] \cong \lim [X, RZ_i] \cong \lim [X, Z_i]$$

as we wanted. \qed

**Definition 2.3.12.** Let $A \in M_*$ be an arbitrary pointed simplicial presheaf. We define the functor of $A$-loops as follows:

$$\Omega_A : M_* \longrightarrow M_*$$

$$X \longmapsto \text{Hom}_{M_*}(A, X)$$

**Remark 2.3.13.**
1. The functor of $A$-loops $\Omega_A$ has a left adjoint given by smash product with $A$, i.e.

$$- \wedge A : M_* \longrightarrow M_*$$

$$X \longmapsto X \wedge A$$

2. The adjunction

$$(- \wedge A, \Omega_A, \varphi) : M_* \longrightarrow M_*$$

is a Quillen adjunction.

### 2.4 The Motivic Stable Model Structure

In [13] Jardine constructs a stable model structure for the category of $T$-spectra on $Sm|_S$. In order to define this stable model structure, he constructs two auxiliary model structures called projective and injective. In this section we recall Jardine’s definitions for these three model structures on the category of $T$-spectra.

Let $S^1$ denote the constant presheaf associated to the pointed simplicial set $\Delta^1/\partial \Delta^1$, let $S^n$ denote $S^1 \wedge \cdots \wedge S^1$ ($n$-factors) and let $\mathbb{G}_m$ denote the multiplicative group over the base scheme $S$, i.e. $\mathbb{G}_m = \mathbb{A}_S^1 - \{0\}$ pointed by the unit $e$ for the group operation. Let $T = S^1 \wedge \mathbb{G}_m$. 
Proposition 2.4.1. 1. $T = S^1 \wedge \mathbb{G}_m$ is compact in the sense of Jardine (see definition 2.3.10).

2. Consider $U \in Sm|_S$ and $r, s \geq 0$. Then the pointed simplicial presheaf $S^r \wedge \mathbb{G}_m^s \wedge U_+$ is compact in the sense of Jardine, where $\mathbb{G}_m^s$ denotes $\mathbb{G}_m \wedge \cdots \wedge \mathbb{G}_m$ ($s$-factors).

Proof. Follows immediately from [13, lemma 2.2].

Definition 2.4.2. 1. A $T$-spectrum $X$ is a collection of pointed simplicial presheaves $(X^n)_{n \geq 0}$ on the smooth Nisnevich site $Sm|_S$, together with bonding maps

$$T \wedge X^n \overset{\sigma^n}{\longrightarrow} X^{n+1}$$

2. A map $f : X \to Y$ of $T$-spectra is a collection of maps

$$X^n \overset{f^n}{\longrightarrow} Y^n$$

in $M_*$ which are compatible with the bonding maps, i.e. the following diagram:

$$\begin{array}{ccc}
T \wedge X^n & \overset{\text{id} \wedge f^n}{\longrightarrow} & T \wedge Y^n \\
\downarrow \sigma^n & & \downarrow \sigma^n \\
X^{n+1} & \overset{f^{n+1}}{\longrightarrow} & Y^{n+1}
\end{array}$$

commutes for all $n \geq 0$.

3. With the previous definitions we get a category called the category of $T$-spectra

which will be denoted by $\text{Spt}_T(Sm|_S)_{Nis}$.

The category of $T$-spectra has a natural simplicial structure induced from the one on pointed simplicial presheaves.

Given a $T$-spectrum $X$, the tensor objects are defined as follows:

$$X \wedge - : \text{SSets} \longrightarrow \text{Spt}_T(Sm|_S)_{Nis}$$

$$K \longrightarrow X \wedge K$$

where $(X \wedge K)^n = X^n \wedge K_+$ and the bonding maps are

$$T \wedge (X^n \wedge K_+) \overset{\cong}{\longrightarrow} (T \wedge X^n) \wedge K_+ \overset{\sigma^n \wedge \text{id}_{K_+}}{\longrightarrow} X^{n+1} \wedge K_+$$
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The simplicial functor in two variables is:

$$\text{Map}(-, -) : (\text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis}))^{\text{op}} \times \text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis}) \to \text{SSets}$$

$$(X, Y) \mapsto \text{Map}(X, Y)$$

where $\text{Map}(X, Y)_n = \text{Hom}_{\text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis})}(X \land \Delta^n, Y)$, and finally for any $T$-spectrum $Y$ we have the following functor

$$Y^* : \text{SSets} \to (\text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis}))^{\text{op}}$$

$$K \mapsto Y^K$$

where $(Y^K)^n = (Y^n)^{K+}$ with bonding maps

$$T \land (Y^n)^{K+} \xrightarrow{\alpha} (T \land Y^n)^{K+} \xrightarrow{(\sigma^n)_{K+}} (Y^{n+1})^{K+}$$

where for $U \in (\text{Sm}_{\mathcal{S}})$, $\alpha(U)$ is adjoint to

$$T(U) \land (Y^n(U))^{K+} \land K+ \xrightarrow{id_{T(U)} \land ev_{K+}} T(U) \land Y^n(U)$$

**Remark 2.4.3.**

1. In fact there exists an adjunction of two variables (see definition 1.7.2):

$$- \land - : \text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis}) \times \text{SSets}_* \to \text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis})$$

which induces the simplicial structure for $T$-spectra described above via the monoidal functor $\text{SSets} \to \text{SSets}_*$, which adds a disjoint base point.

2. For any two given spectra $X$, $Y$, the simplicial set $\text{Map}(X, Y)$ is just $\text{Map}_*(X, Y)$ (i.e. the pointed simplicial set coming from the adjunction of two variables described above) after forgetting its base point

$$\omega_0 : X \to * \to Y$$

We have the following family of shift functors between $T$-spectra defined for every $n \in \mathbb{Z}$

$$s_n : \text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis}) \to \text{Spt}_T(\text{Sm}_{\mathcal{S}}|\text{Nis})$$

$$X \mapsto X[n]$$
where $X[n]$ is defined as follows:

$$(X[n])^m = \begin{cases} 
* & \text{if } m + n < 0, \\
X^{m+n} & \text{if } m + n \geq 0.
\end{cases}$$

with the obvious bonding maps induced by $X$. It is clear that $s_0 = id$ and that for $n \geq 0$, $s_n$ is right adjoint to $s_{-n}$, i.e.

$$\text{Hom}_{\text{Spt}_T(Sm|S)_\text{Nis}}(X, Y[n]) \cong \text{Hom}_{\text{Spt}_T(Sm|S)_\text{Nis}}(X[-n], Y)$$

We define the projective model structure as follows.

**Definition 2.4.4.** Consider the following family of functors from the category of pointed simplicial presheaves to the category of $T$-spectra:

$$F_n : \mathcal{M}_* \longrightarrow \text{Spt}_T(Sm|S)_\text{Nis}$$

$$X \longmapsto (\Sigma^n_T X)[-n]$$

where $\Sigma^n_T X$ is defined as follows:

$$(\Sigma^n_T X)^k = T^k \wedge X$$

where the bonding maps are the canonical isomorphisms $T \wedge (T^k \wedge X) \cong T^{k+1} X$ and $T^0 \wedge X$ is just $X$.

We also have the following evaluation functors from the category of $T$-spectra to the category of pointed simplicial presheaves:

$$Ev_n : \text{Spt}_T(Sm|S)_\text{Nis} \longrightarrow \mathcal{M}_*$$

$$X \longmapsto X^n$$

where $n \geq 0$. It is clear that $F_0$ is left adjoint to $Ev_0$. This implies that for every $n > 0$, $F_n$ is left adjoint to $Ev_n$ and $F_{-n}$ is left adjoint to $\Omega^n_T \circ Ev_0$.

We say that a map of $T$-spectra $f : X \to Y$ is a **level equivalence** if for every $n \geq 0$, $f^n : X^n \to Y^n$ is a weak equivalence in $\mathcal{M}_*$.

Let $I_{\mathcal{M}_*}$ and $J_{\mathcal{M}_*}$ denote the sets of generating cofibrations and trivial cofibrations for $\mathcal{M}_*$ (see proposition 2.3.7).
**Theorem 2.4.5** (Jardine). There exists a cofibrantly generated model structure for the category $Spt_T(\text{Sm}|_S)_{\text{Nis}}$ of $T$-spectra with the following choices:

1. The weak equivalences are the level weak equivalences defined above.
2. The set $I$ of generating cofibrations is
   \[ I = \bigcup_{n \geq 0} F_n(I_{M_*}) \]
3. The set $J$ of generating trivial cofibrations is
   \[ J = \bigcup_{n \geq 0} F_n(J_{M_*}) \]

This model structure will be called the **projective model structure** for $T$-spectra. Furthermore, the projective model structure is proper and simplicial.

**Proof.** We refer the reader to [13, lemma 2.1].

**Remark 2.4.6.** Let $f : A \to B$ be a map of $T$-spectra.

1. $f$ is a cofibration in the projective model structure if and only if $f^0 : A^0 \to B^0$ and the induced maps
   \[ T \wedge B^n \coprod_{T \wedge A^n} A^{n+1} \rightarrow \rightarrow B^{n+1} \]
   are all cofibrations in $M_*$.
2. $f$ is a fibration in the projective model structure if and only if $f$ is a level motivic fibration, i.e. for every $n \geq 0$, $f^n : A^n \to B^n$ is a fibration in $M_*$. 

**Proposition 2.4.7.** Let $n \geq 0$. Consider $M_*$ and $Spt_T(\text{Sm}|_S)_{\text{Nis}}$ equipped with the projective model structure (see theorem 2.4.5). Then the adjunction

\[ (F_n, Ev_n, \varphi) : M_* \longrightarrow Spt_T(\text{Sm}|_S)_{\text{Nis}} \]

is a Quillen adjunction.
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**Proof.** It is enough to show that $Ev_n$ is a right Quillen functor. Let $p : X \to Y$ be a fibration in the projective model structure for $\text{Spt}_T(Sm|S)_{Nis}$, then $p$ is a level motivic fibration. In particular, $Ev_n(p) = p^n : X^n \to Y^n$ is a fibration in $\mathcal{M}_*$.

Now let $q : X \to Y$ be a trivial fibration in the projective model structure for $\text{Spt}_T(Sm|S)_{Nis}$. Then $q$ is a level motivic trivial fibration. In particular, $Ev_n(q) = q^n : X^n \to Y^n$ is a trivial fibration in $\mathcal{M}_*$. \hfill \Box

We now proceed to define the injective model structure for the category of $T$-spectra.

We say that a map of $T$-spectra $i : A \to B$ is a **level cofibration** (respectively **level trivial cofibration**) if for every $n \geq 0$, $i^n : A^n \to B^n$ is a cofibration (respectively trivial cofibration) in $\mathcal{M}_*$. Notice that a map $i : A \to B$ is a level cofibration if and only if it is a monomorphism in the category of $T$-spectra.

Let $A$ be an arbitrary $T$-spectrum. We say that $A$ is $\lambda$-bounded if for every $n \geq 0$, the presheaf of pointed simplicial sets $A^n$ is $\lambda$-bounded.

**Theorem 2.4.8 (Jardine).** Let $\kappa$ be a regular cardinal larger than $2^\alpha$ where $\alpha$ is the cardinality of the set $\text{Map}(Sm|S)$ of maps in $Sm|S$. There exists a cofibrantly generated model structure for the category $\text{Spt}_T(Sm|S)_{Nis}$ of $T$-spectra with the following choices:

1. The weak equivalences are the level weak equivalences.

2. The set $I$ of generating cofibrations is

   $$I = \{i : A \to B\}$$

   where $i$ satisfies the following conditions:

   (a) $i$ is a level cofibration.

   (b) The codomain $B$ of $i$ is $\kappa$-bounded.

3. The set $J$ of generating trivial cofibrations is

   $$J = \{j : A \to B\}$$

   where $j$ satisfies the following conditions:
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(a) \( j \) is a level trivial cofibration.

(b) The codomain \( B \) of \( j \) is \( \kappa \)-bounded.

This model structure will be called the **injective model structure** for \( T \)-spectra. Furthermore, the injective model structure is proper and simplicial.

**Proof.** We refer the reader [13, lemma 2.1].

**Remark 2.4.9.**

1. Let \( f : A \to B \) be a map of \( T \)-spectra. Then \( f \) is a cofibration in the injective model structure for \( \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \) if and only if \( f \) is a level cofibration.

2. The identity functor on \( \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \) induces a left Quillen functor from the projective model structure to the injective model structure.

Proposition 2.3.7 implies in particular that \( \mathcal{M}_* \) is a closed symmetric monoidal category. The category of \( T \)-spectra \( \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \) has the structure of a closed \( \mathcal{M}_* \)-module, which is obtained by extending the symmetric monoidal structure for \( \mathcal{M}_* \) levelwise.

The bifunctor giving the adjunction of two variables is defined as follows:

\[
- \wedge - : \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \times \mathcal{M}_* \to \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}}
\]

\[
(X, A) \mapsto X \wedge A
\]

with \( (X \wedge A)^n = X^n \wedge A \) and bonding maps given by

\[
T \wedge (X^n \wedge A) \xrightarrow{\sim} (T \wedge X^n) \wedge A \xrightarrow{\sigma^n \wedge \text{id}_A} X^{n+1} \wedge A
\]

The adjoints are given by:

\[
\Omega_- : \mathcal{M}_*^{\text{op}} \times \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \to \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}}
\]

\[
(A, X) \mapsto \Omega_A X
\]

\[
\text{hom}_r(-, -) : (\text{Spt}_T(\text{Sm}|_S)_{\text{Nis}})^{\text{op}} \times \text{Spt}_T(\text{Sm}|_S)_{\text{Nis}} \to \mathcal{M}_*
\]

\[
(X, Y) \mapsto \text{hom}_r(X, Y)
\]

where \( (\Omega_A X)^n = \Omega_A X^n \) and the bonding maps \( T \wedge (\Omega_A X^n) \to \Omega_A X^{n+1} \) are adjoint to

\[
T \wedge (\Omega_A X^n) \wedge A \xrightarrow{\text{id}_A \wedge \text{ev}_A} T \wedge X^n \xrightarrow{\sigma^n} X^{n+1}
\]
and \( \text{hom}_r(X, Y) \) is the following pointed simplicial presheaf on \( Sm|_S \):

\[
\text{hom}_r(X, Y) : (Sm|_S \times \Delta)^{op} \longrightarrow \text{Sets}
\]

\[
(U, n) \longmapsto \text{Hom}_{\text{Spt}_T(Sm|_S)_{Nis}}(X \wedge \Delta^n_U, Y)
\]

**Proposition 2.4.10.**

1. Let \( \text{Spt}_T(Sm|_S)_{Nis} \) denote the category of \( T \)-spectra equipped with the projective model structure. Then \( \text{Spt}_T(Sm|_S)_{Nis} \) is a \( \mathbb{M}_* \)-model category (see definition 1.7.12).

2. Let \( \text{Spt}_T(Sm|_S)_{Nis} \) denote the category of \( T \)-spectra equipped with the injective model structure. Then \( \text{Spt}_T(Sm|_S)_{Nis} \) is a \( \mathbb{M}_* \)-model category.

**Proof.** In both cases we need to check that conditions (1) and (2) in definition 1.7.12 are satisfied. Condition (2) is automatic since the unit \( * \coprod * \) is cofibrant in \( \mathbb{M}_* \).

(1): To check condition (1) in definition 1.7.12 we use lemma 1.7.5(3) which implies that it is enough to prove the following claim: Given a cofibration \( i : A \to B \) in \( \mathbb{M}_* \) and a fibration \( p : X \to Y \) in \( \text{Spt}_T(Sm|_S)_{Nis} \) then \( (i^*, p_*) : \Omega_B X \to \Omega_A X \times_{\Omega_A Y} \Omega_B Y \) is a fibration of \( T \)-spectra (in the projective model structure), which is trivial if either \( i \) or \( p \) is a weak equivalence. But fibrations in the projective model structure are level motivic fibrations, by proposition 2.3.7 we have that \( \mathbb{M}_* \) is a symmetric monoidal model category, so in particular \( (i^*, p_*) \) is a level motivic fibration which is trivial if either \( i \) or \( p \) is a weak equivalence. This proves the claim.

(2): We will prove directly that we have a Quillen bifunctor, i.e. given a cofibration \( i : A \to B \) in \( \mathbb{M}_* \) and a level cofibration \( j : C \to D \) of \( T \)-spectra, we will show that \( i \Box j : D \wedge A \coprod_{C \wedge A} C \wedge B \to D \wedge B \) is a level cofibration (i.e a cofibration in the injective model structure) which is trivial if either \( i \) or \( j \) is a weak equivalence. But cofibrations in the injective model structure are level cofibrations, and since \( \mathbb{M}_* \) is a symmetric monoidal model category, we have that \( i \Box j \) is a level cofibration which is trivial if either \( i \) or \( j \) is a weak equivalence. This finishes the proof.
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If we fix $A$ in $\mathcal{M}_*$, we get an adjunction

$$(- \land A, \Omega_A, \varphi_A) : \text{Spt}_T(Sm|_S)_{\text{Nis}} \longrightarrow \text{Spt}_T(Sm|_S)_{\text{Nis}}$$

**Proposition 2.4.11.** Let $A$ in $\mathcal{M}_*$ be an arbitrary presheaf of pointed simplicial sets on $Sm|_S$.

1. The adjunction $(- \land A, \Omega_A, \varphi_A)$ defined above is a Quillen adjunction for the projective model structure on $\text{Spt}_T(Sm|_S)_{\text{Nis}}$.

2. The adjunction $(- \land A, \Omega_A, \varphi_A)$ defined above is a Quillen adjunction for the injective model structure on $\text{Spt}_T(Sm|_S)_{\text{Nis}}$.

**Proof.** Since every object $A$ in $\mathcal{M}_*$ is cofibrant, the result follows immediately from proposition 2.4.10. □

**Proposition 2.4.12.** Let $X, Y$ be two arbitrary $T$-spectra and let $A$ in $\mathcal{M}_*$ be an arbitrary presheaf of pointed simplicial sets. Then we have the following enriched adjunctions:

$$\text{Map}(A, \text{hom}_r(X, Y)) \xrightarrow{\alpha_\approx} \text{Map}(X \land A, Y) \xrightarrow{\beta_\approx} \text{Map}(X, \Omega_A Y)$$

$$\text{Hom}_{\mathcal{M}_*}(A, \text{hom}_r(X, Y)) \xrightarrow{\delta_\approx} \text{hom}_r(X \land A, Y) \xrightarrow{\epsilon_\approx} \text{hom}_r(X, \Omega_A Y)$$

where the maps in the first row are isomorphisms of simplicial sets and the maps in the second row are isomorphisms in $\mathcal{M}_*$.

**Proof.** We consider first the simplicial adjunctions: To any $n$-simplex $t$ in $\text{Map}(A, \text{hom}_r(X, Y))$,

$$A \otimes \Delta^n \xrightarrow{t} \text{hom}_r(X, Y)$$

associate the following $n$-simplex in $\text{Map}(X \land A, Y)$:

$$X \land A \otimes \Delta^n \xrightarrow{\alpha(t)} Y$$

corresponding to the adjunction between $X \land -$ and $\text{hom}_r(X, -)$.
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To any \( n \)-simplex \( t \) in \( \text{Map}(X \land A, Y) \)

\[
\Delta^n \otimes X \land A \xrightarrow{\cong} X \land A \otimes \Delta^n \xrightarrow{t} Y
\]

associate the following \( n \)-simplex in \( \text{Map}(X, \Omega_A Y) \):

\[
X \otimes \Delta^n \xrightarrow{\cong} \Delta^n \otimes X \xrightarrow{\beta(t)} \Omega_A Y
\]

corresponding to the adjunction between \(- \land A\) and \( \Omega_A \).

We consider now the isomorphisms of simplicial presheaves:

To any simplex \( s \) in \( \text{Hom}_M(A, \text{hom}_r(X, Y)) \)

\[
A \land \Delta^n_U \xrightarrow{s} \text{hom}_r(X, Y)
\]

we associate the following simplex in \( \text{hom}_r(X \land A, Y) \)

\[
X \land A \land \Delta^n_U \xrightarrow{\delta(s)} Y
\]

corresponding to the adjunction between \( X \land - \) and \( \text{hom}_r(X, -) \).

To any simplex \( s \) in \( \text{hom}_r(X \land A, Y) \)

\[
X \land \Delta^n_U \land A \xrightarrow{\cong} X \land A \land \Delta^n_U \xrightarrow{s} Y
\]

we associate the following simplex in \( \text{hom}_r(X, \Omega_A Y) \)

\[
X \land \Delta^n_U \xrightarrow{\epsilon(s)} \Omega_A Y
\]

corresponding to the adjunction between \(- \land A\) and \( \Omega_A \).

We now proceed to define the stable model structure for the category of \( T \)-spectra. Consider the functor \( \Omega_T \) of \( T \)-loops in \( \text{Spt}_T(Sm|_S)_{Nis} \). There is another way to promote the \( T \)-loops functor from the category of pointed simplicial presheaves to the category of \( T \)-spectra.

**Definition 2.4.13.** We define the functor \( \Omega^f_T \) as follows:

\[
\Omega^f_T : \text{Spt}_T(Sm|_S)_{Nis} \longrightarrow \text{Spt}_T(Sm|_S)_{Nis}
\]

\[
X \longmapsto \Omega^f_T X
\]
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where \((\Omega^\ell_T X)^n = \Omega_T X^n\) and the bonding maps \(T \wedge \Omega_T X^n \to \Omega_T X^{n+1}\) are given by the adjoints to

\[
\Omega_T X^n \xrightarrow{\Omega_T (\sigma^n_*)} \Omega_T (\Omega_T X^{n+1})
\]

where \(\sigma^n_* : X^n \to \Omega_T X^{n+1}\) is adjoint to the bonding map

\[
X^n \wedge T \xrightarrow{\simeq} T \wedge X^n \xrightarrow{\sigma^n} X^{n+1}
\]

Following Jardine we call the functor \(\Omega^\ell_T\) the **fake \(T\) -loops functor**.

**Remark 2.4.14.** The fake \(T\)-loops functor \(\Omega^\ell_T\) has a left adjoint \(\Sigma^\ell_T\) called the **fake \(T\) -suspension functor** defined as follows:

\[
\Sigma^\ell_T : \text{Spt}_T(\text{Sm}|S)_{Nis} \longrightarrow \text{Spt}_T(\text{Sm}|S)_{Nis}
\]

\[
X \longrightarrow \Sigma^\ell_T X
\]

where \((\Sigma^\ell_T X)^n = T \wedge X^n\) and the bonding maps are

\[
id \wedge \sigma^n : T \wedge (T \wedge X^n) \to T \wedge X^{n+1}
\]

We will denote by \(\Sigma_T\) the left adjoint \((- \wedge T)\) to \(\Omega_T\).

For any \(T\)-spectrum \(X\), the adjoints \(\sigma^n_* : X^n \to \Omega_T X^{n+1}\) of the bonding maps are the levelwise components of a map \(\sigma_* : X \to \Omega^\ell_T X[1]\). Consider the following inductive system of \(T\)-spectra:

\[
X \xrightarrow{\sigma_*} \Omega^\ell_T X[1] \xrightarrow{\Omega^\ell_T \sigma_*[1]} (\Omega^\ell_T)^2 X[2] \xrightarrow{(\Omega^\ell_T)^2 \sigma_*[2]} \cdots
\]

and denote its colimit by \(Q_T X\). The functor \(Q_T\) is called the **stabilization functor**.

Following Jardine, \(J\) will denote a fibrant replacement functor for the projective model structure and \(I\) will denote the corresponding fibrant replacement functor for the injective model structure on \(\text{Spt}_T(\text{Sm}|S)_{Nis}\). The tranfinite composition \(X \to Q_T X\) will be denoted \(\eta_X\), and we define \(\tilde{\eta}_X\) as the composition

\[
X \xrightarrow{\eta_X} Q_T X \xrightarrow{Q_T(jX)} Q_T J X
\]
We say that a map \( f : X \to Y \) of \( T \)-spectra is a **stable equivalence** if it becomes a level equivalence after taking a fibrant replacement and applying the stabilization functor, i.e. if \( Q_TJ(f) : QTJX \to QTJY \) is a level equivalence of \( T \)-spectra.

**Remark 2.4.15.** Let \( f : X \to Y \) be a map of \( T \)-spectra.

1. \( f \) is a stable equivalence if and only if the map

\[ IQ_TJ(f) : IQ_TJX \to IQ_TJY \]

is a level equivalence of \( T \)-spectra.

2. If \( f \) is a level motivic equivalence then \( f \) is also a stable equivalence.

**Theorem 2.4.16** (Jardine). Let \( \text{Spt}_T(Sm|S)_{Nis} \) be the category of \( T \)-spectra equipped with the projective model structure (see theorem 2.4.5). Then the left Bousfield localization of \( \text{Spt}_T(Sm|S)_{Nis} \) with respect to the class of stable equivalences exists, and furthermore it is proper and simplicial. This model structure will be called **motivic stable**, and the category of \( T \)-spectra \( \text{Spt}_T(Sm|S)_{Nis} \), equipped with the motivic stable model structure will be denoted by \( \text{Spt}_T \mathcal{M}_\ast \).

**Proof.** We refer the reader to [13, theorem 2.9].

**Proposition 2.4.17.** Let \( n \geq 0 \). Consider the adjunction

\[ (F_n, Ev_n, \varphi) : \mathcal{M}_\ast \to \text{Spt}_T \mathcal{M}_\ast \]

described in proposition 2.4.7. Then \((F_n, Ev_n, \varphi)\) is a Quillen adjunction.

**Proof.** Follows immediately from proposition 2.4.7 and the following fact:

- The identity functor on \( \text{Spt}_T(Sm|S)_{Nis} \) is a left Quillen functor from the projective model structure to the motivic stable model structure.
Lemma 2.4.18 (Jardine). Let \( p : X \to Y \) be a map of \( T \)-spectra. Then \( p \) is a fibration in \( \text{Spt}_M^* \) (we then say that \( p \) is a **stable fibration**) if the following conditions are satisfied:

1. \( p \) is a fibration in the projective model structure for \( \text{Spt}_T(Sm|_S)_{\text{Nis}} \), i.e. \( p \) is a level motivic fibration.

2. The following diagram is level homotopy Cartesian:

\[
\begin{array}{ccc}
X & \xrightarrow{\eta_X} & Q_T J X \\
\downarrow p & & \downarrow Q_T J (p) \\
Y & \xrightarrow{\eta_Y} & Q_T J Y
\end{array}
\]

**Proof.** We refer the reader to [13, lemma 2.7].

Lemma 2.4.19 (Jardine). Let \( X \) be a \( T \)-spectrum. The following are equivalent:

1. \( X \) is a fibrant object in \( \text{Spt}_M^* \) (we then say that \( X \) is **stably fibrant**).

2. \( X \) is a fibrant object in the projective model structure for \( T \)-spectra (i.e. \( X \) is level motivic fibrant) and the adjoints to the bonding maps \( \sigma^n_* : X^n \to \Omega_T X^{n+1} \) are weak equivalences in \( M^* \).

3. \( X \) is a fibrant object in the projective model structure for \( T \)-spectra and the adjoints to the bonding maps are sectionwise weak equivalences of simplicial sets, i.e. for any \( U \in (Sm|_S) \) the induced map \( \sigma^n_* (U) : X^n(U) \to \Omega_T X^{n+1}(U) \) is a weak equivalence of simplicial sets.

**Proof.** We refer the reader to [13, lemma 2.8].

We say that a \( T \)-spectrum \( X \) is **stably fibrant injective**, if \( X \) is a fibrant object in both the motivic stable and the injective model structures for \( \text{Spt}_T(Sm|_S)_{\text{Nis}} \).

Corollary 2.4.20. Let \( X \) be a \( T \)-spectrum. Then \( IQ_T J X \) is a stably fibrant injective replacement for \( X \), i.e. the natural map

\[
X \xrightarrow{r_X} IQ_T J X
\]
is a level weak equivalence (in particular a stable weak equivalence) and $IQ_TJX$ is stably fibrant injective.

**Proof.** It is clear that $r_X$ is a level weak equivalence and that $IQ_TJX$ is fibrant in the injective model structure for $Spt_T(Sm|S)_{Nis}$, so we only need to show that $IQ_TJX$ is stably fibrant. Since the identity functor on $Spt_T(Sm|S)_{Nis}$ is a left Quillen functor from the projective to the injective model structure (see remark 2.4.9(2)), we have that $IQ_TJX$ is in particular a fibrant object in the projective model structure for $T$ spectra. Lemma 2.4.19(3) implies that it is enough to show that the adjoints to the bonding maps for $IQ_TJX$, $\sigma^*_n : (IQ_TJX)^n \to \Omega_T(IQ_TJX)^{n+1}$ are all sectionwise weak equivalences of simplicial sets. We will prove that using the following commutative diagram, and showing that the top row and the vertical maps are all sectionwise weak equivalences of simplicial sets:

$$
\begin{array}{c}
(Q_TJX)^n & \xrightarrow{\tau^n} & \Omega_T(Q_TJX)^{n+1} \\
\downarrow & & \downarrow \\
(IQ_TJX)^n & \xrightarrow{\sigma^n} & \Omega_T(IQ_TJX)^{n+1}
\end{array}
$$

A cofinal argument implies that the adjoints of the bonding maps for $Q_TJX$:

$$
(Q_TJX)^n \xrightarrow{\tau^n} \Omega_T(Q_TJX)^{n+1}
$$

are isomorphisms, so in particular these maps are sectionwise weak equivalences of simplicial sets.

Since the B.G. property (see definition 2.1.6) is preserved under filtered colimits and the fibrant objects for $\mathcal{M}_*$ in particular satisfy the B.G. property (see theorem 2.1.7), we have that the pointed simplicial presheaves $(Q_TJX)^n$ satisfy the B.G. property. Therefore theorem 2.1.7 implies that the maps $(Q_TJX)^n \to (IQ_TJX)^n$ are sectionwise weak equivalences of simplicial sets.

Remark 2.3.9(1) implies that the pointed simplicial presheaves $(Q_TJX)^n$ are all motivic flasque, and since the simplicial presheaves $(IQ_TJX)^n$ are fibrant in $\mathcal{M}_*$, we have that $(IQ_TJX)^n$ are also motivic flasque. Now since $T$ is compact in the sense of Jardine (see
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We have that the maps $\Omega_T(Q_T J X)^{n+1} \to \Omega_T(I Q_T J X)^{n+1}$ are section-wise weak equivalences of simplicial sets. This finishes the proof.

Corollary 2.4.21. Let $A$ in $M_*$ be an arbitrary pointed simplicial presheaf, and let $X$ be a stably fibrant $T$-spectrum. Then $\Omega_A X$ is also stably fibrant.

Proof. Using proposition 2.4.11 we have that $\Omega_A$ is a right Quillen functor for the projective model structure on $Spt_T(Sm|S)_{Nis}$, therefore in particular $\Omega_A X$ is level fibrant. Lemma 2.4.19(2) implies that $\sigma^n_* : X^n \to \Omega_T X^{n+1}$ are motivic weak equivalences between motivic fibrant objects. $M_*$ is a symmetric monoidal model category, then Ken Brown’s lemma 1.1.5 implies that $\Omega_A(\sigma^n_*) : \Omega_A X \to \Omega_A \Omega_T X^{n+1}$ is a motivic weak equivalence. Let $\theta^n : \Omega_A X^n \to \Omega_T \Omega_A X^{n+1}$ be the adjoint to the bonding map $T \land \Omega_A X^n \to \Omega_A X^{n+1}$ for the spectrum $\Omega_A X$, then we have the following commutative diagram:

$$
\begin{array}{ccc}
\Omega_A X^n & \xrightarrow{\theta^n} & \Omega_T \Omega_A X^{n+1} \\
\downarrow{\Omega_A(\sigma^*_n)} & \cong & \downarrow{t} \\
\Omega_A \Omega_T X^{n+1} & & 
\end{array}
$$

where $t$ is the isomorphism which flips loop factors. Then the two out of three property for weak equivalences in $M_*$ implies that the maps $\theta^n : \Omega_A X^n \to \Omega_T \Omega_A X^{n+1}$ are motivic weak equivalences. Finally, lemma 2.4.19(2) implies that $\Omega_A X$ is stably fibrant as we wanted.

Lemma 2.4.22 (Jardine). Let $f : A \to B$ be a map of $T$-spectra. The following are equivalent:

1. $f$ is a weak equivalence in $Spt_T M_*$.  

2. For every stably fibrant injective object $X$, $f$ induces a bijection

$$
\begin{array}{ccc}
[B, X]_{Spt} & \xrightarrow{f^*} & [A, X]_{Spt} \\
\end{array}
$$

in the homotopy category associated to $Spt_T M_*$.  

3. For every stably fibrant injective object $X$, $f$ induces a bijection

$$
\begin{array}{ccc}
[B, X] & \xrightarrow{f^*} & [A, X] \\
\end{array}
$$
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in the projective homotopy category for $\text{Spt}_T(Sm|S)_{\text{Nis}}$.

4. For every stably fibrant injective object $X$, $f$ induces a weak equivalence of simplicial sets

$$f^* : \text{Map}(B, X) \longrightarrow \text{Map}(A, X)$$

**Proof.** We refer the reader to [13, lemma 2.11 and corollary 2.12].

**Proposition 2.4.23.** Let $A$ in $\mathcal{M}_s$ be an arbitrary presheaf of pointed simplicial sets. Then the adjunction

$$(- \wedge A, \Omega_A, \varphi_A) : \text{Spt}_T \mathcal{M}_s \longrightarrow \text{Spt}_T \mathcal{M}_s$$

is a Quillen adjunction.

**Proof.** Since the cofibrations in the stable and projective model structures for $T$-spectra coincide, we have that $- \wedge A$ preserves stable cofibrations (since $- \wedge A$ is a left Quillen functor for the projective model structure). So it only remains to show that if $j : B \to C$ is a trivial cofibration in $\text{Spt}_T \mathcal{M}_s$, then $j \wedge id : B \wedge A \to C \wedge A$ is a weak equivalence in $\text{Spt}_T \mathcal{M}_s$. Let $X$ be an arbitrary stably fibrant injective $T$-spectrum, corollary 2.4.21 implies that $\Omega_A X$ is also stably fibrant, and since $\Omega_A$ is a right Quillen functor for the injective model structure on $\text{Spt}_T(Sm|S)_{\text{Nis}}$ (see proposition 2.4.11), we have that $\Omega_A X$ is also fibrant in the injective model structure. Thus $\Omega_A X$ is stably fibrant injective, then lemma 2.4.22 implies that $j^* : \text{Map}(C, \Omega_A X) \to \text{Map}(B, \Omega_A X)$ is a weak equivalence of simplicial sets. Using the enriched adjunction of proposition 2.4.12, $j^*$ becomes $(j \wedge id)^* : \text{Map}(C \wedge A, X) \to \text{Map}(B \wedge A, X)$. Finally since $(j \wedge id)^*$ is a weak equivalence for every stably fibrant injective spectrum $X$, we get that $j \wedge id : C \wedge A \to B \wedge A$ is a weak equivalence in $\text{Spt}_T \mathcal{M}_s$.

**Proposition 2.4.24.** $\text{Spt}_T \mathcal{M}_s$ is a $\mathcal{M}_s$-model category (see definition 1.7.12).

**Proof.** Condition (2) in definition 1.7.12 follows automatically since the unit in $\mathcal{M}_s$ is cofibrant. It only remains to prove that if $i : A \to B$ is a cofibration in $\mathcal{M}_s$ and $j : C \to D$ is
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a cofibration in \( \text{Spt}_T \mathcal{M}_* \) then \( i \Box j : D \land A \coprod_{C \land A} C \land B \to D \land B \) is a cofibration in \( \text{Spt}_T \mathcal{M}_* \) which is trivial if either \( i \) or \( j \) is a weak equivalence. Since the cofibrations in the projective and the motivic stable model structure for \( \text{Spt}_T(\text{Sm}_{|S})_{Nis} \) coincide, and proposition 2.4.10 implies in particular that the category of \( T \)-spectra equipped with the projective model structure is a \( \mathcal{M}_* \)-model category, we have that \( i \Box j \) is a cofibration in the motivic stable structure. It only remains to show that \( i \Box j \) is a stable weak equivalence when either \( i \) or \( j \) is a weak equivalence. If \( i \) is a weak equivalence (i.e. a trivial cofibration) then using proposition 2.4.10 again we have that \( i \Box j \) is a level weak equivalence, therefore \( i \Box j \) is also a stable equivalence (see remark 2.4.15). Finally if \( j \) is a stable equivalence (i.e. a trivial cofibration in the motivic stable structure) then we consider the following commutative diagram

\[
\begin{array}{ccc}
C \land A & \xrightarrow{id_{C \land i}} & C \land B \\
\downarrow j \land id_A & & \downarrow f \\
D \land A & \xrightarrow{i \Box j} & D \land B \\
\end{array}
\]

Proposition 2.4.23 implies that \( j \land id_A \) and \( j \land id_B \) are both trivial cofibrations in \( \text{Spt}_T \mathcal{M}_* \). Thus \( f \) is also a trivial cofibration (since it is the pushout of \( j \land id_A \) along \( id_C \land i \)), and therefore the two out of three property for stable weak equivalences implies that \( i \Box j \) is a stable equivalence. This finishes the proof. \( \Box \)

In order to prove that the motivic stable model structure on \( \text{Spt}_T(\text{Sm}_{|S})_{Nis} \) is in fact “stable”, i.e. that the \( T \)-suspension functor \( \Sigma_T \) is indeed a Quillen equivalence, Jardine introduces bigraded stable homotopy groups which allow to give another criterion to detect motivic stable weak equivalences.

**Definition 2.4.25.** Let \( X \) be an arbitrary \( T \)-spectrum. The **weighted stable homotopy groups** of \( X \) are presheaves of abelian groups \( \pi_{t,s} X \) (where \( t, s \in \mathbb{Z} \)) on \( \text{Sm}_{|S} \). For \( U \in (\text{Sm}_{|S}) \) the sections \( \pi_{t,s} X(U) \) are defined as the colimit of the inductive system:

\[
[S^{t+n} \land \mathbb{G}^{s+n}_m, X^n|U] \longrightarrow [S^{t+n+1} \land \mathbb{G}^{s+n+1}_m, X^{n+1}|U] \longrightarrow \ldots
\]
where \([-, X^i|_U]\) denotes the set of maps in the homotopy category associated to the motivic model structure on the category $\Delta^{op} Pre_*(Sm|_U)_{Nis}$ of pointed simplicial presheaves on the smooth Nisnevich site over the base scheme $U$, and the transition maps are given by taking suspension with $T$ and composing with the bonding maps of $X$. The index $t$ is called the **degree** and the index $s$ is called the **weight** of $\pi_{t,s}X$.

**Proposition 2.4.26.** Consider $t, s \in \mathbb{Z}$ and $U \in (Sm|_S)$. Then the following functor:

$$
\begin{array}{ccc}
\text{Spt}_T \mathcal{M}_* & \longrightarrow & \text{Abelian Groups} \\
X & \longmapsto & \pi_{t,s}X(U)
\end{array}
$$

is representable in the homotopy category associated to $\text{Spt}_T \mathcal{M}_*$. To represent it we can choose any spectrum of the form (see definition 2.4.4)

$$
F_n(S^p \wedge \mathbb{G}_m^q \wedge U_+)
$$

where $n, p, q \geq 0$, $p - n = t$ and $q - n = s$.

**Proof.** Since every pointed simplicial presheaf on $Sm|_S$ is cofibrant in $\mathcal{M}_*$, proposition 2.4.17 and corollary 2.4.20 imply that

$$
[F_n(S^p \wedge \mathbb{G}_m^q \wedge U_+), X]_{\text{Spt}} \cong [S^p \wedge \mathbb{G}_m^q \wedge U_+, (IQ_T JX)^n]
$$

where $[-, -]_{\text{Spt}}$ denotes the set of maps between two objects in the homotopy category associated to $\text{Spt}_T \mathcal{M}_*$, and $[-, -]$ denotes the set of maps in the homotopy category associated to $\mathcal{M}_*$. Since $Q_T JX \rightarrow IQ_T JX$ is in particular a level motivic trivial fibration we have the natural isomorphism

$$
[S^p \wedge \mathbb{G}_m^q \wedge U_+, (IQ_T JX)^n] \cong [S^p \wedge \mathbb{G}_m^q \wedge U_+, (Q_T JX)^n]
$$

Now since $S^p \wedge \mathbb{G}_m^q \wedge U_+$ is compact in the sense of Jardine (see proposition 2.4.1), using proposition 2.3.11 we have that

$$
[S^p \wedge \mathbb{G}_m^q \wedge U_+, (Q_T JX)^n] \cong \lim_{j \geq 0} [S^{p+j} \wedge \mathbb{G}_m^{q+j} \wedge U_+, (JX)^{n+j}]
$$
Since $\mathcal{M}_*$ is in particular a symmetric monoidal model category (see proposition 2.3.7) and $U_+ \in \Delta^{op} Pre_*(Sm|_S)_{Nis}$ is cofibrant, we have that

$$\lim_{j \geq 0}' [S^{p+j} \wedge G^{q+j}_m \wedge U_+, (JX)^{n+j}] \cong \lim_{j \geq 0}' [S^{p+j} \wedge G^{q+j}_m, \text{Hom}_{\mathcal{M}_*}(U_+, (JX)^{n+j})]$$

Proposition 2.1.10 implies that

$$\lim_{j \geq 0}' [S^{p+j} \wedge G^{q+j}_m, \text{Hom}_{\mathcal{M}_*}(U_+, (JX)^{n+j})] \cong \lim_{j \geq 0}' [S^{p+j} \wedge G^{q+j}_m, \phi_*\phi^{-1}(JX)^{n+j}]$$

where $\phi : U \to S$ is the structure map defining $U$ as an object in $Sm|_S$.

Now since $\mathcal{M}_*$ is in particular a simplicial model category, and

$$\phi_*\phi^{-1}(JX)^{n+j} \cong \text{Hom}_{\mathcal{M}_*}(U_+, (JX)^{n+j})$$

is a fibrant object, we have that

$$\pi_0(\text{Map}(S^{p+j} \wedge G^{q+j}_m, \phi_*\phi^{-1}(JX)^{n+j}))$$

computes $[S^{p+j} \wedge G^{q+j}_m, \phi_*\phi^{-1}(JX)^{n+j}]$. The enriched adjunctions of proposition 2.1.11 imply that

$$\text{Map}(S^{p+j} \wedge G^{q+j}_m, \phi_*\phi^{-1}(JX)^{n+j}) \cong \text{Map}(\phi^{-1}(S^{p+j} \wedge G^{q+j}_m), \phi^{-1}(JX)^{n+j})$$

$$= \text{Map}(S^{p+j} \wedge G^{q+j}_m, \phi^{-1}(JX)^{n+j})$$

Let $r_U : \phi^{-1}(JX)^{n+j} \to R_U\phi^{-1}(JX)^{n+j}$ be a functorial fibrant replacement for $\phi^{-1}(JX)^{n+j}$ in the category of pointed simplicial presheaves $\Delta^{op} Pre_*(Sm|_U)_{Nis}$ on the smooth Nisnevich site over $U$ equipped with the motivic model structure. It is clear that $(JX)^{n+j}$ is motivic flasque (see definition 2.3.8) and satisfies the B.G. property (see definition 2.1.6) on $\Delta^{op} Pre_*(Sm|_U)_{Nis}$, and since $\phi^{-1}$ preserves both properties we have that $\phi^{-1}(JX)^{n+j}$ is motivic flasque and satisfies the B.G. property on $\Delta^{op} Pre_*(Sm|_U)_{Nis}$. Thus $r_U$ is a sectionwise weak equivalence, and since $S^{p+j} \wedge G^{q+j}_m$ is compact in the sense of Jardine in
\[ \Delta^{op}Pre_*(Sm|U)_{Nis} \] (see proposition 2.4.1) we have that

\[
\text{Hom}_{\mathcal{M}}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}) \]

\[
\text{Hom}_{\mathcal{M}}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, R_{U}\phi^{-1}(JX)^{n+j})
\]

is also a sectionwise weak equivalence. Taking global sections at \( U \) we get a weak equivalence of simplicial sets:

\[
\text{Map}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}) \]

\[
\text{Map}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, R_{U}\phi^{-1}(JX)^{n+j})
\]

Thus \( \text{Map}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}) \) and \( \text{Map}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, R_{U}\phi^{-1}(JX)^{n+j}) \) are naturally weakly equivalent simplicial sets. Since \( \Delta^{op}Pre_*(Sm|U)_{Nis} \) is a simplicial model category we have that

\[
\pi_0\text{Map}(S^{p+j} \land \mathbb{G}_{m}^{q+j}, R_{U}\phi^{-1}(JX)^{n+j})
\]

computes \([S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}]_U = [S^{p+j} \land \mathbb{G}_{m}^{q+j}, (JX)^{n+j}|_U] \), where \([-,-]_U \) denotes the set of maps in the homotopy category associated to the motivic model structure on \( \Delta^{op}Pre_*(Sm|U)_{Nis} \). Thus \([S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}] \) is naturally isomorphic to \([S^{p+j} \land \mathbb{G}_{m}^{q+j}, (JX)^{n+j}|_U] \). This implies that

\[
[F_n(S^{p} \land \mathbb{G}_{m}^{q} \land U_+, X)]_{Spt} \cong \lim_{j \geq 0}[S^{p+j} \land \mathbb{G}_{m}^{q+j}, \phi^{-1}(JX)^{n+j}]
\]

\[
\cong \lim_{j \geq 0}[S^{p+j} \land \mathbb{G}_{m}^{q+j}, (JX)^{n+j}|_U]
\]

\[
\cong \lim_{j \geq 0}[S^{p+j} \land \mathbb{G}_{m}^{q+j}, X^{n+j}|_U]
\]

\[
\cong \pi_{p-n,q-n}X(U) = \pi_{t,s}X(U)
\]

Therefore the functors \([F_n(S^p \land \mathbb{G}_m^q \land U_+), -]_{Spt} \) and \( \pi_{t,s}(-)(U) \) have canonically isomorphic image for every \( T \)-spectrum \( X \). To finish the proof we will give an element \( \alpha \in \pi_{t,s}(F_n(S^p \land \mathbb{G}_m^q \land U_+))(U) \) which induces an isomorphism of functors

\[
[F_n(S^p \land \mathbb{G}_m^q \land U_+), -]_{Spt} \xrightarrow{\alpha^*} \pi_{t,s}(-)(U)
\]
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Consider the identity map $id : S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+ \rightarrow S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+$. Since $- \land U_+$ and $\text{Hom}_{M_*}(U_+,-)$ are adjoint functors, we have an associated adjoint $\beta^j$:

$$\beta^j: S^{t+j} \land \mathbb{G}^{s+j}_m \rightarrow \text{Hom}_{M_*}(U_+, S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+) \cong \phi_* \phi^{-1}(S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)$$

Now let $\gamma^j$ be the adjoint to $\beta^j$ corresponding to the adjunction between $\phi^{-1}$ and $\phi_*$:

$$\phi^{-1}(S^{t+j} \land \mathbb{G}^{s+j}_m) \cong \phi^{-1}(S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)$$

Let $[\gamma^j] \in [\phi^{-1}(S^{t+j} \land \mathbb{G}^{s+j}_m), \phi^{-1}(S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)]_U = [S^{t+j} \land \mathbb{G}^{s+j}_m, (S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)]_U$ denote the map induced by $\gamma^j$ in the homotopy category associated to

$$\Delta^{op}\text{Pre}_*(Sm|_U)_{Nis}$$

equipped with the motivic model structure. It is clear that the maps $[\gamma^j]$ define an element

$$\alpha \in \lim_{j \geq 0} [S^{t+j} \land \mathbb{G}^{s+j}_m, (S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)]_U$$

But

$$[S^{t+j} \land \mathbb{G}^{s+j}_m, (S^{t+j} \land \mathbb{G}^{s+j}_m \land U_+)]_U = [S^{t+j} \land \mathbb{G}^{s+j}_m, (S^{t+j} \land \mathbb{G}^{q+j-n}_m \land U_+)]_U$$

$$= [S^{t+j} \land \mathbb{G}^{s+j}_m, (F_n(S^p \land \mathbb{G}^q_m \land U_+))^j]_U$$

Thus

$$\alpha \in \lim_{j \geq 0} [S^{t+j} \land \mathbb{G}^{s+j}_m, (F_n(S^p \land \mathbb{G}^q_m \land U_+))^j]_U = \pi_{t,s}(F_n(S^p \land \mathbb{G}^q_m \land U_+))$$

Finally it is clear that $\alpha$ induces the required isomorphism of functors

$$[F_n(S^p \land \mathbb{G}^q_m \land U_+), -]_{\text{Sp}} \xrightarrow{\alpha_*} \pi_{t,s}(-)(U)$$

since by construction $\alpha$ is compatible with the isomorphisms in (2.7) which are induced by $r_U : \phi^{-1}(JX)^{n+j} \rightarrow R_U \phi^{-1}(JX)^{n+j}$ via the natural maps $r_U*$ in the diagrams (2.5) and (2.6), where $r_U$ denotes a functorial fibrant replacement in the category $\Delta^{op}\text{Pre}_*(Sm|_U)_{Nis}$ equipped with the motivic model structure. □
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**Proposition 2.4.27** (Jardine). Let \( f : X \to Y \) be a map of \( T \)-spectra. The following are equivalent:

1. \( f \) is a weak equivalence in \( \text{Spt}_T M_* \).

2. For every \( t, s \in \mathbb{Z} \), \( f \) induces an isomorphism

\[
\pi_{t,s}(f) : \pi_{t,s}X \longrightarrow \pi_{t,s}Y
\]

of presheaves of abelian groups on \( Sm|_S \).

**Proof.** We refer the reader to [13, lemma 3.7]. \( \square \)

**Corollary 2.4.28.** Let \( f : X \to Y \) be a map of \( T \)-spectra. The following are equivalent:

1. \( f \) is a weak equivalence in \( \text{Spt}_T M_* \).

2. For every \( n, p, q \geq 0 \) and every \( U \in Sm|_S \), \( f \) induces an isomorphism

\[
[F_n(S^p \wedge \mathbb{G}_m^q \wedge U_+), X]_{\text{Spt}} \xrightarrow{f_*} [F_n(S^p \wedge \mathbb{G}_m^q \wedge U_+), Y]_{\text{Spt}}
\]

in the homotopy category associated to \( \text{Spt}_T M_* \).

**Proof.** Follows immediately from propositions 2.4.27 and 2.4.26. \( \square \)

**Theorem 2.4.29** (Jardine). The Quillen adjunction:

\[
(\Sigma_T, \Omega_T, \varphi) : \text{Spt}_T M_* \longrightarrow \text{Spt}_T M_*
\]

is a Quillen equivalence.

**Proof.** We refer the reader to [13, theorem 3.11 and corollary 3.17]. \( \square \)

**Proposition 2.4.30** (Jardine). The natural map \( \Sigma_T^\ell X \to X[1] \) from the fake suspension functor to the shift functor is a weak equivalence in \( \text{Spt}_T M_* \). Therefore the fake suspension functor and the shift functor are naturally equivalent in the homotopy category associated to \( \text{Spt}_T M_* \).
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Proof. We refer the reader to [13, lemma 3.19].

**Proposition 2.4.31** (Jardine). The fake suspension functor $\Sigma^f_T$ and the suspension functor $\Sigma_T$ are naturally equivalent in the homotopy category associated to $\text{Spt}_T\mathcal{M}_*$. 

Proof. We refer the reader to [13, lemma 3.20].

**Corollary 2.4.32** (Jardine). The $T$-loops functor $\Omega_T$, fake $T$-loops functor $\Omega^f_T$, and shift functor $s_{-1}$ ($s_{-1}X = X[-1]$) are all naturally equivalent in the homotopy category associated to $\text{Spt}_T\mathcal{M}_*$. 

Proof. Follows immediately from propositions 2.4.30 and 2.4.31.

**Proposition 2.4.33.** Let $X \in \Delta^{op}\text{Pre}_*(Sm|_S)_{\text{Nis}}$ be a pointed simplicial presheaf which is compact in the sense of Jardine (see definition 2.3.10), and let $F_n(X)$ be the $T$-spectrum constructed in definition 2.4.4. Consider an inductive system of $T$-spectra:

$$Z_0 \rightarrow Z_1 \rightarrow Z_2 \rightarrow \cdots$$

Then

$$[F_n(X), \lim_{\rightarrow} Z_i]_{\text{Spt}} \cong \lim_{\leftarrow} [F_n(X), Z_i]_{\text{Spt}}$$

where $[-,-]_{\text{Spt}}$ denotes the set of maps in the homotopy category associated to $\text{Spt}_T\mathcal{M}_*$. 

Proof. Since $X$ is cofibrant in $\mathcal{M}_*$, proposition 2.4.17 and corollary 2.4.20 imply that

$$[F_n(X), \lim_{\rightarrow} Z_i]_{\text{Spt}} \cong [X, (IQ_TJ \lim_{\rightarrow} Z_i)^n]$$

$$\cong [X, (Q_TJ \lim_{\rightarrow} Z_i)^n]$$

where $[-,-]$ denotes the set of maps in the homotopy category associated to $\mathcal{M}_*$. Since $X$ is compact in the sense of Jardine, we have that proposition 2.3.11 implies the following:

$$[X, (Q_TJ \lim_{\rightarrow} Z_i)^n] \cong \lim_{\leftarrow} [S^j \wedge G^j_m \wedge X, (J \lim_{\leftarrow} Z_i)^{n+j}]$$

$$\cong \lim_{\leftarrow} [S^j \wedge G^j_m \wedge X, (\lim_{\leftarrow} Z_i)^{n+j}]$$
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Now lemma 2.2(4) in [13] implies that $S^j \wedge \mathbb{G}_m^j \wedge X$ are all compact in the sense of Jardine, therefore using proposition 2.3.11 again, we have:

$$
\lim_{j \geq 0} [S^j \wedge \mathbb{G}_m^j \wedge X, (\lim_{i \geq 0} Z_i)^{n+j}] \cong \lim_{j \geq 0} \lim_{i \geq 0} [S^j \wedge \mathbb{G}_m^j \wedge X, (Z_i)^{n+j}]
$$

$$
\cong \lim_{i \geq 0} \lim_{j \geq 0} [S^j \wedge \mathbb{G}_m^j \wedge X, (Z_i)^{n+j}]
$$

$$
\cong \lim_{i \geq 0} [X, (Q_T J Z_i)^n]
$$

$$
\cong \lim_{i \geq 0} [F_n(X), Z_i]_{Spt}
$$

and this finishes the proof.

2.5 Cellularity of the Motivic Stable Model Structure

In this section we will show that Spt$_T$-M$_*$ is a cellular model category. For this we will use the cellularity of M$_*$ (see proposition 2.3.7) together with some results of Hovey [11].

The cellularity for the motivic stable model structure is also proved in [8, corollary 1.6]. However, our proof is different since we use the characterization for weak equivalences given in corollary 1.6.11(2) (which holds in any simplicial model category) whereas the argument given in [8, corollary 1.6] relies on [11, theorem 4.12] which does not apply to the model category M$_*$ described in proposition 2.3.7 (see [11, p. 83]).

**Theorem 2.5.1** (Hovey). Let Spt$_T$(Sm$_{|S}_Nis$) be the category of T-spectra equipped with the projective model structure (see theorem 2.4.5). Then the category Spt$_T$(Sm$_{|S}_Nis$) is a cellular model category where the sets of generating cofibrations and trivial cofibrations are the ones described in theorem 2.4.5.

**Proof.** Proposition 2.3.7 implies that the model category M$_*$ is in particular cellular and left proper. Therefore we can apply theorem A.9 in [11], which says that the category of T-spectra equipped with the projective model structure is also cellular under our conditions. □
Theorem 2.4.5 together with theorem 2.5.1 imply that the projective model structure on $\text{Spt}_T(\text{Sm}|_S)_{Nis}$ is cellular, proper and simplicial. Therefore we can apply Hirschhorn’s localization technology to it. If we are able to find a suitable set of maps such that the left Bousfield localization with respect to this set recovers the motivic stable model structure, then an immediate corollary of this will be the cellularity of the motivic stable model structure for $\text{Spt}_T(\text{Sm}|_S)_{Nis}$.

**Definition 2.5.2** (Hovey, cf. [11, definition 3.3]). Let $I_{M_*} = \{Y_+ \hookrightarrow (\Delta^n_U)_+\}$ be the set of generating cofibrations for $M_*$ (see proposition 2.3.7). Notice that $Y_+$ may be equal to $(\Delta^n_U)_+$. We consider the following set of maps of $T$-spectra

$$S = \{F_{n+1}(T \wedge Y_+) \xrightarrow{\zeta_n^Y} F_n Y_+\}$$

where $\zeta_n^Y$ is the adjoint to the identity map (in $\Delta^{op} Pre_*(\text{Sm}|_S)_{Nis}$)

$$id : T \wedge Y_+ \to Ev_{n+1}(F_n Y_+) = T \wedge Y_+$$

coming from the adjunction between $F_{n+1}$ and $Ev_{n+1}$ (see definition 2.4.4)

**Proposition 2.5.3** (Hovey). Let $X$ be a $T$-spectrum. The following conditions are equivalent:

1. $X$ is stably fibrant, i.e. $X$ is a fibrant object in $\text{Spt}_T M_*$.

2. $X$ is $S$-local.

**Proof.** Follows from [11, theorem 3.4] and lemma 2.4.19.

Now it is very easy to show that the motivic stable model structure for $T$-spectra is in fact cellular.

**Theorem 2.5.4.** $\text{Spt}_T M_*$ is a cellular model category with the following sets $I^T_{M_*}, J^T_{M_*}$ of generating cofibrations and trivial cofibrations respectively:

$$I^T_{M_*} = \bigcup_{n \geq 0} \{F_n(Y_+ \hookrightarrow (\Delta^n_U)_+)\}$$

$$J^T_{M_*} = \{j : A \to B\}$$
where \( j \) satisfies the following conditions:

1. \( j \) is an inclusion of \( I^T_{M_*} \)-complexes.

2. \( j \) is a stable weak equivalence.

3. the size of \( B \) as an \( I^T_{M_*} \)-complex is less than \( \kappa \), where \( \kappa \) is the regular cardinal described by Hirschhorn in [7, definition 4.5.3].

**Proof.** By theorem 2.5.1 we know that \( \text{Spt}_T(Sm|_S)_{Nis} \) is cellular when it is equipped with the projective model structure. Therefore we can apply Hirschhorn’s localization techniques to construct the left Bousfield localization with respect to the set \( S \) of definition 2.5.2. We claim that this localization coincides with \( \text{Spt}_T\mathcal{M}_* \). In effect, using proposition 2.5.3, we have that the fibrant objects in the left Bousfield localization with respect to \( S \) coincide with the fibrant objects in \( \text{Spt}_T\mathcal{M}_* \). Therefore a map \( f : X \to Y \) of \( T \)-spectra is a weak equivalence in the left Bousfield localization with respect to \( S \) if and only if \( Qf^* : Map(QY, Z) \to Map(QX, Z) \) is a weak equivalence of simplicial sets for every stably fibrant object \( Z \) (here \( Q \) denotes the cofibrant replacement functor in \( \text{Spt}_T(Sm|_S)_{Nis} \) equipped with the projective model structure). But since \( \text{Spt}_T\mathcal{M}_* \) is a simplicial model category and the cofibrations coincide with the projective cofibrations, using corollary 1.6.11(2) we get exactly the same characterization for the stable equivalences. Hence the weak equivalences in both the motivic stable structure and the left Bousfield localization with respect to \( S \) coincide. This implies that the motivic stable model structure and the left Bousfield localization with respect to \( S \) are identical, since the cofibrations in both cases are just the cofibrations for the projective model structure on \( \text{Spt}_T(Sm|_S)_{Nis} \).

Therefore using theorem 4.1.1 in [7] we have that \( \text{Spt}_T\mathcal{M}_* \) is cellular, since it is constructed applying Hirschhorn technology with respect to the set \( S \).

The claim with respect to the sets of generating cofibrations and trivial cofibrations also follows from [7, theorem 4.1.1] and the fact that \( I^T_{M_*} \) is just the set of generating cofibrations for the projective model structure on \( \text{Spt}_T(Sm|_S)_{Nis} \). \( \Box \)
Theorem 2.5.4 will be one of the main technical ingredients for the construction of new model structures on $\text{Spt}_T(Sm|_S)_{Nis}$ which lift Voevodsky’s slice filtration to the model category level.

2.6 The Motivic Symmetric Stable Model Structure

One of the technical disadvantages of the category of $T$-spectra $\text{Spt}_T(Sm|_S)_{Nis}$ (see definition 2.4.2) is that it does not inherit a closed symmetric monoidal structure from the category of pointed simplicial presheaves $\mathcal{M}_*$. Symmetric spectra were introduced by Hovey, Shipley and Smith in [9] to solve this problem in the context of simplicial sets.

Their construction was lifted to the motivic setting by Jardine in [13], where he constructs a closed symmetric monoidal category of $T$-spectra together with a suitable model structure which is Quillen equivalent to the category $\text{Spt}_T\mathcal{M}_*$ (see theorem 2.4.16). In this section we describe some of his constructions and results that will be necessary for our study of the multiplicative properties of the slice filtration.

**Definition 2.6.1.** For $n \geq 0$, let $\Sigma_n$ denote the symmetric group on $n$ letters where $\Sigma_0$ is by definition the group with only one element.

The $(q, p)$-shuffle $c_{q,p} \in \Sigma_{p+q}$ is given by the following formula:

$$c_{q,p}(i) = \begin{cases} i + p & \text{if } 1 \leq i \leq q, \\ i - q & \text{if } q + 1 \leq i \leq p + q. \end{cases}$$

**Definition 2.6.2** (Jardine cf. [13, p. 504]). 1. A **symmetric $T$-spectrum** $X$ is a collection of pointed simplicial presheaves $(X^n)_{n \geq 0}$ on the smooth Nisnevich site $Sm|_S$, together with:

(a) Left actions

$$\Sigma_n \times X^n \longrightarrow X^n$$

(b) Bonding maps

$$T \wedge X^n \overset{\sigma^n}{\longrightarrow} X^{n+1}$$
such that the iterated composition

\[ T^r \wedge X^n \longrightarrow X^{n+r} \]

is $\Sigma_r \times \Sigma_n$-equivariant for $r \geq 1$ and $n \geq 0$.

2. A map $f : X \to Y$ of symmetric $T$-spectra is a collection of maps

\[ X^n \xrightarrow{f^n} Y^n \]

in $\mathcal{M}_*$ satisfying the following conditions:

(a) Compatibility with the bonding maps, i.e. the following diagram:

\[
\begin{array}{ccc}
T \wedge X^n & \xrightarrow{id \wedge f^n} & T \wedge Y^n \\
\sigma^n \downarrow & & \downarrow \sigma^n \\
X^{n+1} & \xrightarrow{f^{n+1}} & Y^{n+1}
\end{array}
\]

commutes for all $n \geq 0$

(b) $f^n$ is $\Sigma_n$-equivariant.

3. With the previous definitions we get a category, called the category of **symmetric $T$-spectra** which will be denoted by $\text{Spt}_T^\Sigma(\text{Sm}|_S)_{\text{Nis}}$.

**Example 2.6.3.** Given any pointed simplicial presheaf $X$ in $\mathcal{M}_*$, the $T$-spectrum $F_0(X)$ has the structure of a symmetric $T$-spectrum; where the left action of $\Sigma_n$ on $F_0(X)^n = T^n \wedge X$ is given by the permutation of the $T$ factors.

In particular if we take $X = S^0$, we get the **sphere $T$-spectrum**; which will be denoted by $\mathbf{1}$.

The category of symmetric $T$-spectra has a simplicial structure similar to the one that exists for $T$-spectra, which is induced from the one on pointed simplicial presheaves.

Given a symmetric $T$-spectrum $X$, the tensor objects are defined as follows:

\[
\begin{array}{ccc}
X \wedge - : \text{SSets} & \longrightarrow & \text{Spt}_T^\Sigma(\text{Sm}|_S)_{\text{Nis}} \\
K & \longmapsto & X \wedge K
\end{array}
\]
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where \((X \wedge K)^n = X^n \wedge K^+\) which has an action of \(\Sigma_n\) induced by the one in \(X^n\) and the functor \(- \wedge K^+_n\), and with bonding maps

\[
T \wedge (X^n \wedge K^+) \overset{\cong}{\longrightarrow} (T \wedge X^n) \wedge K^+ \overset{\sigma^n \wedge id_{K^+}}{\longrightarrow} X^{n+1} \wedge K^+
\]

The simplicial functor in two variables is:

\[
\text{Map}_\Sigma (-, -) : (\text{Spt}_\Sigma T(\text{Sm} \mid S)_{Nis})^{op} \times \text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis} \longrightarrow \text{SSets}
\]

\[
(X, Y) \quad \longrightarrow \quad \text{Map}_\Sigma (X, Y)
\]

where \(\text{Map}_\Sigma (X, Y)_n = \text{Hom}_{\text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis}} (X \wedge \Delta^n, Y)\), and finally for any symmetric \(T\)-spectrum \(Y\) we have the following functor

\[
Y^- : \text{SSets} \longrightarrow (\text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis})^{op}
\]

\[
K \quad \longrightarrow \quad Y^K
\]

where \((Y^K)^n = (Y^n)^{K^+}\) which has an action of \(\Sigma_n\) induced by the one in \(Y^n\) and the \(K^+_n\)-loops functor, and with bonding maps

\[
T \wedge (Y^n)^{K^+} \overset{\alpha}{\longrightarrow} (T \wedge Y^n)^{K^+} \overset{(\sigma^n)_*}{\longrightarrow} (Y^{n+1})^{K^+}
\]

where for \(U \in (\text{Sm} \mid S)\), \(\alpha(U)\) is adjoint to

\[
T(U) \wedge (Y^n(U))^{K^+} \wedge K^+_n \overset{id_{T(U)} \wedge ev_{K^+_n}}{\longrightarrow} T(U) \wedge Y^n(U)
\]

In a similar way, it is possible to promote the action of \(\mathcal{M}_*\) on the category of \(T\)-spectra to the category of symmetric \(T\)-spectra, i.e. the category of symmetric \(T\)-spectra \(\text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis}\) has the structure of a closed \(\mathcal{M}_*\)-module, which is obtained by extending the symmetric monoidal structure for \(\mathcal{M}_*\) levelwise.

The bifunctor giving the adjunction of two variables is defined as follows:

\[
- \wedge - : \text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis} \times \mathcal{M}_* \longrightarrow \text{Spt}_\Sigma (\text{Sm} \mid S)_{Nis}
\]

\[
(X, A) \quad \longrightarrow \quad X \wedge A
\]

with \((X \wedge A)^n = X^n \wedge A\) which has an action of \(\Sigma_n\) induced by the one in \(X^n\) and the functor \(- \wedge A\), and with bonding maps

\[
T \wedge (X^n \wedge A) \overset{\cong}{\longrightarrow} (T \wedge X^n) \wedge A \overset{\sigma^n \wedge id_A}{\longrightarrow} X^{n+1} \wedge A
\]
The adjoints are given by:

$$
\Omega: \mathcal{M}_o^\times \times \text{Spt}_T(Sm|_S)_{Nis} \rightarrow \text{Spt}_T(Sm|_S)_{Nis} \\
(A, X) \mapsto \Omega_AX$$

$$
\text{hom}_\Sigma(-, -): (\text{Spt}_T(Sm|_S)_{Nis})^\times \times \text{Spt}_T(Sm|_S)_{Nis} \rightarrow \mathcal{M}_s, \\
(X, Y) \mapsto \text{hom}_\Sigma(X, Y)
$$

where $(\Omega_AX)^n = \Omega_AX^n$ which has an action of $\Sigma_n$ induced by the one in $X^n$ and the $A$-loops functor, with bonding maps $T \wedge (\Omega_AX^n) \rightarrow \Omega_AX^{n+1}$ adjoint to

$$
T \wedge (\Omega_AX^n) \wedge A \xrightarrow{id \wedge ev_A} T \wedge X^n \xrightarrow{\sigma^n} X^{n+1}
$$

and $\text{hom}_\Sigma(X, Y)$ is the following pointed simplicial presheaf on $Sm|_S$:

$$
\text{hom}_\Sigma(X, Y): (Sm|_S \times \Delta)^\times \rightarrow \text{Sets} \\
(U, n) \mapsto \text{Hom}_{\text{Spt}_T(Sm|_S)_{Nis}}(X \wedge \Delta^n_U, Y)
$$

The main difference between the categories of $T$-spectra and symmetric $T$-spectra is that the latter has a closed symmetric monoidal structure, i.e. it is possible to construct the smash product of two symmetric $T$-spectra.

**Definition 2.6.4** (cf. [13, p. 506]).

1. A **symmetric sequence** $X$ is a collection of pointed simplicial presheaves $(X^n)_{n \geq 0}$ on the smooth Nisnevich site $Sm|_S$, together with left actions

$$
\Sigma_n \times X^n \rightarrow X^n
$$

2. A map $f: X \rightarrow Y$ of symmetric sequences consists of a collection of $\Sigma_n$-equivariant maps

$$
f^n: X^n \rightarrow Y^n
$$

in $\mathcal{M}_s$.

3. With these definitions we get a category, called the category of symmetric sequences which will be denoted by $(\mathcal{M}_s)^\Sigma$.  

Definition 2.6.5. Let $X$ and $Y$ be two symmetric sequences. Then the product $X \otimes Y$ is given by the following symmetric sequence:

$$(X \otimes Y)^n = \bigvee_{p+q=n} \Sigma_p \otimes \Sigma_q \times \Sigma_q X^p \wedge Y^q$$

Remark 2.6.6. A symmetric $T$-spectrum $X$ can be identified with a symmetric sequence $X$ equipped with a module structure over the sphere spectrum, i.e. with a map of symmetric sequences:

$$1 \otimes X \xrightarrow{\sigma_X} X$$

satisfying the usual associativity conditions.

Definition 2.6.7 (cf. [9, definition 2.1.7]). For every $n \geq 0$, we have the following adjunction:

$$(G_n, Ev_n, \varphi) : M_* \longrightarrow (M_*)^\Sigma$$

where $Ev_n$ is the $n$-evaluation functor

$$Ev_n : (M_*)^\Sigma \longrightarrow M_*$$

$$X \xrightarrow{\sigma} X^n$$

and $G_n$ is the $n$-free symmetric sequence functor:

$$G_n : M_* \longrightarrow (M_*)^\Sigma$$

$$X \xleftarrow{\sigma} G_n(X)$$

where

$$G_n(X)^m = \begin{cases} * & \text{if } m \neq n, \\ \bigvee_{\sigma \in \Sigma_n} X & \text{if } m = n. \end{cases}$$

Definition 2.6.8 (cf. [13, p. 506]). For every $n \geq 0$, we have the following adjunction:

$$(F_n^\Sigma, Ev_n, \varphi) : M_* \longrightarrow \text{Spt}_T^\Sigma(Sm|_S)_{Nis}$$

where $Ev_n$ is the $n$-evaluation functor

$$Ev_n : \text{Spt}_T^\Sigma(Sm|_S)_{Nis} \longrightarrow M_*$$

$$X \xleftarrow{\sigma} X^n$$
and $F_n^\Sigma$ is the $n$-free symmetric $T$-spectrum functor:

$$F_n^\Sigma : M_s \longrightarrow \text{Spt}_T^\Sigma(Sm|_S)_{Nis}$$

$$X \longleftarrow 1 \otimes G_n(X)$$

**Definition 2.6.9** (cf. [13, section 4.3]). Let $X$ and $Y$ be two symmetric $T$-spectra. Then the smash product $X \wedge Y$ is given by the colimit of the following diagram

$$1 \otimes X \otimes Y \xrightarrow{\sigma_Y \otimes \text{id}} X \otimes Y$$

where the bottom row is the following composition

$$1 \otimes X \otimes Y \xrightarrow{t} X \otimes 1 \otimes Y \xrightarrow{\text{id} \otimes \sigma_X} X \otimes Y$$

**Proposition 2.6.10** (Jardine). The category of symmetric $T$-spectra $\text{Spt}_T^\Sigma(Sm|_S)_{Nis}$ has a closed symmetric monoidal structure where the product is given by the smash product described in definition 2.6.9, and the functor that gives the adjunction of two variables is the following:

$$\Hom_{\text{Spt}_T^\Sigma}(-,-) : (\text{Spt}_T^\Sigma(Sm|_S)_{Nis})^{op} \times \text{Spt}_T^\Sigma(Sm|_S)_{Nis} \longrightarrow \text{Spt}_T^\Sigma(Sm|_S)_{Nis}$$

$$(X,Y) \longleftarrow \Hom_{\text{Spt}_T^\Sigma}(X,Y)$$

where $\Hom_{\text{Spt}_T^\Sigma}(X,Y)^n = \text{hom}^\Sigma_n(F_n^\Sigma(S^0) \wedge X,Y)$, and the adjoints $\sigma_X^n$ to the bonding maps are given as follows: Let $\zeta : F_{n+1}^\Sigma(T) \cong F_{n+1}^\Sigma(S^0) \wedge T \longrightarrow F_n^\Sigma(S^0)$ be the adjoint corresponding to the inclusion determined by the identity in $\Sigma_{n+1}$:

$$i_e : T \hookrightarrow E_{n+1}(F_n^\Sigma(S^0)) = \Sigma_{n+1} \otimes_{\Sigma_1 \times \Sigma_n} (T \wedge \bigvee_{\sigma \in \Sigma_n} S^0) = \bigvee_{\sigma \in \Sigma_{n+1}} T$$

then $\sigma_X^n$ is the following map induced by $\zeta \wedge \text{id}$:

$$\text{hom}_\Sigma^T(F_n^\Sigma(S^0) \wedge X,Y) \xrightarrow{(\zeta \wedge \text{id})^*} \text{hom}_\Sigma^T(F_{n+1}^\Sigma(S^0) \wedge T \wedge X,Y)$$

The twist isomorphism $\tau : X \wedge Y \rightarrow Y \wedge X$ is induced levelwise by:

$$X^p \wedge Y^q \xrightarrow{t} Y^q \wedge X^p$$

$$\alpha \bigg| \bigg| \alpha_{q,p}$$

$$(X \otimes Y)^{p+q} \xrightarrow{\tau} (Y \otimes X)^{p+q}$$

Finally, the unit is given by the sphere $T$-spectrum $F_0^\Sigma(S^0) = 1$. 
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\textbf{Proof.} We refer the reader to [13, section 4.3].

\textbf{Proposition 2.6.11.} Let $X, Y$ be two arbitrary symmetric $T$-spectra and let $A$ in $\mathcal{M}_*$ be an arbitrary pointed simplicial presheaf. Then we have the following enriched adjunctions:

$$\text{Map}(A, \text{hom}_T^\Sigma(X, Y)) \xrightarrow{\alpha} \text{Map}_\Sigma(X \wedge A, Y) \xrightarrow{\beta} \text{Map}_\Sigma(X, \Omega_A Y)$$

(2.8)

$$\text{Hom}_{\mathcal{M}_*}(A, \text{hom}_T^\Sigma(X, Y)) \xrightarrow{\delta} \text{hom}_T^\Sigma(X \wedge A, Y) \xrightarrow{\epsilon} \text{hom}_T^\Sigma(X, \Omega_A Y)$$

(2.9)

$$\text{Hom}_{\text{Spt}_T}(X \wedge A, Y) \xrightarrow{\gamma} \text{Hom}_{\text{Spt}_T}(X, \Omega_A Y)$$

(2.10)

where the maps in (2.8) are isomorphisms of simplicial sets, the maps in (2.9) are isomorphisms of simplicial presheaves, and the map in (2.10) is an isomorphism of symmetric $T$-spectra.

\textbf{Proof.} We consider first the simplicial adjunctions: To any $n$-simplex $t$ in $\text{Map}(A, \text{hom}_T^\Sigma(X, Y))$,

$$A \wedge \Delta^n \xrightarrow{t} \text{hom}_T^\Sigma(X, Y)$$

associate the following $n$-simplex in $\text{Map}_\Sigma(X \wedge A, Y)$:

$$X \wedge A \wedge \Delta^n \xrightarrow{\alpha(t)} Y$$

corresponding to the adjunction between $X \wedge -$ and $\text{hom}_T^\Sigma(X, -)$.

To any $n$-simplex $t$ in $\text{Map}_\Sigma(X \wedge A, Y)$

$$\Delta^n \wedge X \wedge A \xrightarrow{\gamma} X \wedge A \wedge \Delta^n \xrightarrow{t} Y$$

associate the following $n$-simplex in $\text{Map}_\Sigma(X, \Omega_A Y)$:

$$X \wedge \Delta^n \xrightarrow{\alpha} \Delta^n \wedge X \xrightarrow{\beta(t)} \Omega_A Y$$

corresponding to the adjunction between $- \wedge A$ and $\Omega_A$.

We consider now the isomorphisms of simplicial presheaves:
To any simplex $s$ in $\text{Hom}_{M_r}(A, \text{hom}^\Sigma r(X, Y))$ 

$$A \land \Delta^n_U \xrightarrow{s} \text{hom}^\Sigma r(X, Y)$$

we associate the following simplex in $\text{hom}^\Sigma r(X \land A, Y)$ 

$$X \land A \land \Delta^n_U \xrightarrow{\delta(s)} Y$$

corresponding to the adjunction between $X \land -$ and $\text{hom}^\Sigma r(X, -)$.

To any simplex $s$ in $\text{hom}^\Sigma r(X \land A, Y)$ 

$$X \land \Delta^n_U \land A \xrightarrow{\cong} X \land A \land \Delta^n_U \xrightarrow{s} Y$$

we associate the following simplex in $\text{hom}^\Sigma r(X, \Omega A Y)$ 

$$X \land \Delta^n_U \xrightarrow{\epsilon(s)} \Omega A Y$$

corresponding to the adjunction between $- \land A$ and $\Omega A$.

Finally, we consider the isomorphism of symmetric $T$-spectra: Using the adjunction given by $\epsilon$ in (2.9), we get for every $n \geq 0$ the following commutative diagram, where the vertical maps are isomorphisms of simplicial presheaves:

$$\xymatrix{ \text{hom}^\Sigma r(F_n^\Sigma(S^0) \land X \land A, Y) \ar[r]^{(\alpha \land \text{id}_{X \land A})^*} \ar[d]_{\cong}^{\epsilon} & \text{hom}^\Sigma r(F_{n+1}^\Sigma(T) \land X \land A, Y) \ar[d]_{\cong}^{\epsilon} \\
\text{hom}^\Sigma r(F_n^\Sigma(S^0) \land X, \Omega A Y) \ar[r]^{(\alpha \land \text{id}_X)^*} & \text{hom}^\Sigma r(F_{n+1}^\Sigma(T) \land X, \Omega A Y) }$$

By definition (see proposition 2.6.10) the diagram above is equal to:

$$\xymatrix{ \text{Hom}_{\text{Spt}}^\Sigma(X \land A, Y)^n \ar[r]^{\sigma^n} \ar[d]_{\cong}^{\epsilon} & \Omega T \text{Hom}_{\text{Spt}}^\Sigma(X \land A, Y)^{n+1} \ar[d]_{\cong}^{\epsilon} \\
\text{Hom}_{\text{Spt}}^\Sigma(X, \Omega A Y)^n \ar[r]_{\sigma^n} & \Omega T \text{Hom}_{\text{Spt}}^\Sigma(X, \Omega A Y)^{n+1} }$$

This induces the isomorphism $\gamma$. \qed
Proposition 2.6.12. Let $X, Y, Z$ be three arbitrary symmetric $T$-spectra. Then we have the following enriched adjunctions:

\[
\begin{align*}
\text{Map}_\Sigma(X \wedge Y, Z) & \xrightarrow{\lambda} \text{Map}_\Sigma(X, \text{Hom}_{\text{Sp}_T}(Y, X)) \\
\text{hom}^\Sigma_r(X \wedge Y, Z) & \xrightarrow{\kappa} \text{hom}^\Sigma_r(X, \text{Hom}_{\text{Sp}_T}(Y, Z)) \\
\text{Hom}_{\text{Sp}_T}(X \wedge Y, Z) & \xrightarrow{\mu} \text{Hom}_{\text{Sp}_T}(X, \text{Hom}_{\text{Sp}_T}(Y, Z))
\end{align*}
\]  

(2.11)

(2.12)

(2.13)

where the map in (2.11) is an isomorphism of simplicial sets, the map in (2.12) is an isomorphism of simplicial presheaves, and the map in (2.13) is an isomorphism of symmetric $T$-spectra.

Proof. We consider first the simplicial adjunctions: To any $n$-simplex $t$ in $\text{Map}_\Sigma(X \wedge Y, Z)$

\[
\Delta^n \wedge X \wedge Y \xrightarrow{\simeq} X \wedge Y \wedge \Delta^n \xrightarrow{t} Z
\]

associate the following $n$-simplex in $\text{Map}_\Sigma(X, \text{Hom}_{\text{Sp}_T}(Y, Z))$:

\[
X \wedge \Delta^n \xrightarrow{\simeq} \Delta^n \wedge X \xrightarrow{\lambda(t)} \text{Hom}_{\text{Sp}_T}(Y, Z)
\]

corresponding to the adjunction between $- \wedge Y$ and $\text{Hom}_{\text{Sp}_T}(Y, -)$.

We consider now the isomorphisms of simplicial presheaves: To any simplex $s$ in $\text{hom}^\Sigma_r(X \wedge Y, Z)$

\[
\Delta^n_U \wedge X \wedge Y \xrightarrow{\simeq} X \wedge Y \wedge \Delta^n_U \xrightarrow{\kappa(s)} Z
\]

we associate the following simplex in $\text{hom}^\Sigma_r(X, \text{Hom}_{\text{Sp}_T}(Y, Z))$

\[
X \wedge \Delta^n_U \xrightarrow{\simeq} \Delta^n_U \wedge X \xrightarrow{\kappa(s)} \text{Hom}_{\text{Sp}_T}(Y, Z)
\]

corresponding to the adjunction between $- \wedge Y$ and $\text{Hom}_{\text{Sp}_T}(Y, -)$. 

Finally, we consider the isomorphism of symmetric $T$-spectra: Using the adjunction given by $\kappa$ in (2.12), we get for every $n \geq 0$ the following commutative diagram, where the vertical maps are isomorphisms of simplicial presheaves:

\[
\begin{array}{ccc}
\text{hom}_r^\Sigma(F_n^\Sigma(S^0) \wedge X \wedge Y, Z) & \xrightarrow{\sim} & \text{hom}_r^\Sigma(F_{n+1}^\Sigma(T) \wedge X \wedge Y, Z) \\
\kappa & & \kappa \\
\text{hom}_r^\Sigma(F_n^\Sigma(S^0) \wedge X, \text{Hom}_{\Sigma T}(Y, Z)) & \xrightarrow{\sim} & \text{hom}_r^\Sigma(F_{n+1}^\Sigma(T) \wedge X, \text{Hom}_{\Sigma T}(Y, Z))
\end{array}
\]

By definition (see proposition 2.6.10) the diagram above is equal to:

\[
\begin{array}{ccc}
\text{Hom}_{\Sigma T}(X \wedge Y, Z)^n & \xrightarrow{\sigma_n^\Sigma} & \Omega_T \text{Hom}_{\Sigma T}(X \wedge Y, Z)^{n+1} \\
\kappa & & \kappa \\
\text{Hom}_{\Sigma T}(X, \text{Hom}_{\Sigma T}(Y, Z))^n & \xrightarrow{\sigma_n^\Sigma} & \Omega_T \text{Hom}_{\Sigma T}(X, \text{Hom}_{\Sigma T}(Y, Z))^{n+1}
\end{array}
\]

This induces the isomorphism $\mu$. \qed

The following proposition will have remarkable consequences in our study of the multiplicative properties for Voevodsky’s slice filtration.

**Proposition 2.6.13** (Jardine). Let $A, B$ be two arbitrary pointed simplicial presheaves in $\mathcal{M}_\ast$. Then we have an isomorphism:

\[
F_n^\Sigma(A) \wedge F_m^\Sigma(B) \xrightarrow{\sim} F_{m+n}^\Sigma(A \wedge B)
\]

which is natural in $A$ and $B$.

**Proof.** We refer the reader to [13, corollary 4.18]. \qed

For the construction of the motivic stable model structure on the category of $T$-spectra, it was necessary to introduce the projective and injective model structures (see theorem
2.6. The Motivic Symmetric Stable Model Structure

2.4.16). In [13], Jardine considers an injective model structure for symmetric \( T \)-spectra as a preliminary step in the construction of a model structure which turns out to be Quillen equivalent to \( \text{Spt}_T \mathcal{M}_* \). We will also need to consider a projective model structure for symmetric \( T \)-spectra, in order to show that this stable model structure for symmetric \( T \)-spectra is cellular.

**Definition 2.6.14.** Let \( f : X \to Y \) be a map of symmetric \( T \)-spectra. We say that \( f \) is a level cofibration (respectively level fibration, level weak equivalence), if for every \( n \geq 0 \), the map \( f^n : X^n \to Y^n \) is a cofibration (respectively a fibration, a weak equivalence) in \( \mathcal{M}_* \).

In proposition 2.3.7 we used \( I_{\mathcal{M}_*} \) and \( J_{\mathcal{M}_*} \) to denote the sets of generating cofibrations and trivial cofibrations for \( \mathcal{M}_* \).

**Theorem 2.6.15** (Hovey). There exists a cofibrantly generated model structure for the category \( \text{Spt}_T^\Sigma(Sm|_S)_{\text{Nis}} \) of symmetric \( T \)-spectra with the following choices:

1. The weak equivalences are the level weak equivalences.
2. The set \( I \) of generating cofibrations is
   \[
   I = \bigcup_{n \geq 0} F_\Sigma^n(I_{\mathcal{M}_*})
   \]
3. The set \( J \) of generating trivial cofibrations is
   \[
   J = \bigcup_{n \geq 0} F_\Sigma^n(J_{\mathcal{M}_*})
   \]

This model structure will be called the **projective model structure** for symmetric \( T \)-spectra. Furthermore, the projective model structure is left proper and simplicial.

**Proof.** Proposition 2.3.7 implies that the model category \( \mathcal{M}_* \) is in particular pointed, proper, simplicial and symmetric monoidal. We also have that every pointed simplicial presheaf in \( \mathcal{M}_* \) is cofibrant. Then the result follows immediately from theorems 8.2 and 8.3 in [11]. \( \square \)
Remark 2.6.16. Let $f : X \to Y$ be a map of symmetric $T$-spectra.

1. $f$ is a fibration in $\text{Spt}^\Sigma_T(Sm|_S)_{Nis}$ equipped with the projective model structure if and only if $f$ is a level fibration.

2. $f$ is a trivial fibration in $\text{Spt}^\Sigma_T(Sm|_S)_{Nis}$ equipped with the projective model structure if and only if $f$ is both a level fibration and a level weak equivalence.

We say that a map $f : X \to Y$ of symmetric $T$-spectra is an injective fibration if it has the right lifting property with respect to the class of maps which are both level cofibrations and level weak equivalences.

Theorem 2.6.17 (Jardine). There exists a model structure for the category $\text{Spt}^\Sigma_T(Sm|_S)_{Nis}$ of symmetric $T$-spectra with the following choices:

1. The weak equivalences are the level weak equivalences.

2. The cofibrations are the level cofibrations.

3. The fibrations are the injective fibrations.

This model structure will be called the injective model structure for symmetric $T$-spectra. Furthermore, the injective model structure is proper and simplicial.

Proof. We refer the reader to [13, theorem 4.2].

It follows directly from the definition that every symmetric $T$-spectrum after forgetting the $\Sigma_n$-actions becomes a $T$-spectrum in $\text{Spt}_T(Sm|_S)_{Nis}$. Therefore we get a functor:

$$U : \text{Spt}^\Sigma_T(Sm|_S)_{Nis} \longrightarrow \text{Spt}_T(Sm|_S)_{Nis}$$

It turns out that this forgetful functor has a left adjoint.
**Definition 2.6.18** (Jardine, cf. [13, section 3.4]). Let $X$ be an arbitrary $T$-spectrum in $\text{Spt}_T(Sm|_S)_{Nis}$. Then $X$ has a natural filtration $\{L_nX\}_{n \geq 0}$ called the layer filtration, where $L_nX$ is defined as

$$X^0, X^1, \ldots, X^n, T \wedge X^n, T^2 \wedge X^n, \ldots$$

and furthermore

$$X \cong \lim_{\rightarrow} L_nX$$

It is also possible to give an inductive definition for the layers $L_nX$ using the following pushout diagrams (see definition 2.6.18):

$$
\begin{array}{ccc}
F_{n+1}(T \wedge X^n) & \rightarrow & L_nX \\
\downarrow & & \downarrow \\
F_{n+1}(X^{n+1}) & \rightarrow & L_{n+1}X
\end{array}
$$

**Proposition 2.6.19** (Jardine). We have the following adjunction

$$(V, U, \varphi) : \text{Spt}_T(Sm|_S)_{Nis} \longrightarrow \text{Spt}^\Sigma_T(Sm|_S)_{Nis}$$

The functor $V$ is called the symmetrization functor and is defined as follows:

1. For every pointed simplicial presheaf $X$ on the smooth Nisnevich site $(Sm|_S)_{Nis}$ we have

$$V(F_n(X)) = F^\Sigma_n(X)$$

2. $V$ is constructed inductively using the layer filtration (see definition 2.6.18) together with the following pushout diagrams (see definition 2.6.8):

$$
\begin{array}{ccc}
F^\Sigma_{n+1}(T \wedge X^n) & \rightarrow & V(L_nX) \\
\downarrow & & \downarrow \\
F^\Sigma_{n+1}(X^{n+1}) & \rightarrow & V(L_{n+1}X)
\end{array}
$$

3. Finally, $V(X) = \lim_{\rightarrow} V(L_nX)$

**Proof.** We refer the reader to [13, p. 507]
Proposition 2.6.20. The adjunction

\[(V, U, \varphi) : \text{Spt}_T(Sm|S)_{Nis} \longrightarrow \text{Spt}_{T}^{\Sigma}(Sm|S)_{Nis}\]

is enriched in the categories of simplicial sets and pointed simplicial presheaves on \((Sm|S)_{Nis}\), i.e. for every \(T\)-spectrum \(X\) and for every symmetric \(T\)-spectrum \(Y\) we have the following natural isomorphisms:

\[\text{Map}_{\Sigma}(V X, Y) \xrightarrow{\sim} \text{Map}(X, U Y)\]

\[\text{hom}_{\Sigma}^r(V X, Y) \xrightarrow{\sim} \text{hom}_r(X, U Y)\]

Proof. We consider first the simplicial isomorphism: Given any \(n\)-simplex \(t\) in \(\text{Map}_{\Sigma}(V X, Y)\),

\[V X \wedge \Delta^n \xrightarrow{t} Y\]

consider the map corresponding to the adjunction between \(- \wedge \Delta^n\) and \(- \Delta^n\) in \(\text{Spt}_{T}^{\Sigma}(Sm|S)_{Nis}\),

\[V X \xrightarrow{t'} Y \Delta^n\]

Now use the adjunction between \(V\) and \(U\) to get the map:

\[X \xrightarrow{t''} U(Y \Delta^n) = (U Y)^{\Delta^n}\]

and finally use the adjunction between \(- \wedge \Delta^n\) and \(- \Delta^n\) in \(\text{Spt}_T(Sm|S)_{Nis}\) to get the associated \(n\)-simplex \(\epsilon(t)\) in \(\text{Map}(X, U Y)\):

\[X \wedge \Delta^n \xrightarrow{\epsilon(t)} U Y\]

We consider now the isomorphism of simplicial presheaves:

Given any simplex \(s\) in \(\text{hom}_{\Sigma}^r(V X, Y)\)

\[V X \wedge \Delta^n_W \xrightarrow{s} Y\]

consider the map corresponding to the adjunction between

\[- \wedge \Delta^n_W \text{ and } \Omega \Delta^n_W -\]
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in $\operatorname{Spt}_T^\Sigma (Sm|_S)_{Nis}$

$$V X \xrightarrow{s'} \Omega \Delta^n W Y$$

Now use the adjunction between $V$ and $U$ to get the map:

$$X \xrightarrow{s''} U(\Omega \Delta^n W Y) = \Omega \Delta^n W Y$$

and finally use the adjunction between $- \wedge \Delta^n W$ and $\Omega \Delta^n W$ in $\operatorname{Spt}_T(Sm|_S)_{Nis}$ to get the associated simplex $\eta(s)$ in $\operatorname{hom}_r(X, UY)$:

$$X \wedge \Delta^n W \xrightarrow{\eta(s)} UY$$

\[\square\]

**Definition 2.6.21.** 1. Let $Z$ be a symmetric $T$-spectrum. We say that $Z$ is **injective stably fibrant** if $Z$ satisfies the following conditions:

(a) $Z$ is fibrant in $\operatorname{Spt}_T^\Sigma (Sm|_S)_{Nis}$ equipped with the injective model structure.

(b) $UZ$ is fibrant in $\operatorname{Spt}_T M_\ast$.

2. Let $f : X \to Y$ be a map of symmetric $T$-spectra. We say that $f$ is a **stable weak equivalence** if for every injective stably fibrant symmetric $T$-spectrum $Z$, the induced map

$$\operatorname{Map}_\Sigma (Y, Z) \xrightarrow{f^*} \operatorname{Map}_\Sigma (X, Z)$$

is a weak equivalence of simplicial sets.

3. Let $f : X \to Y$ be a map of symmetric $T$-spectra. We say that $f$ is a **stable fibration** if $Uf$ is a fibration in $\operatorname{Spt}_T M_\ast$ (see theorem 2.4.16).

In theorem 2.5.4 we used $I^T_{M_\ast}$ and $J^T_{M_\ast}$ to denote the sets of generating cofibrations and trivial cofibrations for $\operatorname{Spt}_T M_\ast$.

**Theorem 2.6.22** (Jardine). There exists a model structure for the category

$$\operatorname{Spt}_T^\Sigma (Sm|_S)_{Nis}$$

of symmetric $T$-spectra with the following choices:
2.6. The Motivic Symmetric Stable Model Structure

1. The weak equivalences are the stable weak equivalences.

2. The cofibrations are the projective cofibrations (see theorem 2.6.15), i.e. they are generated by the set

\[ \bigcup_{n \geq 0} F_n^\Sigma(I_{M*}) = V(I_{M*}) \]

3. The fibrations are the stable fibrations.

This model structure will be called **motivic symmetric stable**, and the category of symmetric $T$-spectra equipped with the motivic symmetric stable model structure will be denoted by $\text{Spt}^\Sigma_T M_*$. Furthermore, $\text{Spt}^\Sigma_T M_*$ is a proper and simplicial model category.

**Proof.** We refer the reader to [13, proposition 4.4 and theorem 4.15].

**Remark 2.6.23.** Let $p : X \to Y$ be a map of symmetric $T$-spectra. Then $p$ is a trivial fibration in $\text{Spt}^\Sigma_T M_*$ if and only if $Up$ is a trivial fibration in $\text{Spt}_T M_*$. 

**Proposition 2.6.24.** $\text{Spt}^\Sigma_T M_*$ is a $M_*$-model category (see definition 1.7.12).

**Proof.** Condition (2) in definition 1.7.12 follows automatically since the unit in $M_*$ is cofibrant. It remains to show that

\[ - \smash{\land} - : \text{Spt}^\Sigma_T (Sm|_S)_{Nis} \times M_* \to \text{Spt}^\Sigma_T (Sm|_S)_{Nis} \]

is a Quillen bifunctor. By lemma 1.7.5 it is enough to prove the following claim:

Given a cofibration $i : A \to B$ in $M_*$ and a fibration $p : X \to Y$ in $\text{Spt}^\Sigma_T M_*$, then the map

\[ \Omega_B X \xrightarrow{(i^*_p \smash{\land} p_*)} \Omega_B Y \times_{\Omega_A Y} \Omega_A X \]

is a fibration in $\text{Spt}^\Sigma_T M_*$ which is trivial if either $i$ or $p$ is a weak equivalence.

But this follows immediately from the following facts:

1. A map of symmetric $T$-spectra $f : X \to Y$ is a fibration (respectively a trivial fibration) in $\text{Spt}^\Sigma_T M_*$ if and only if $Uf : UX \to UY$ is a fibration (respectively a trivial fibration) in $Spt_T M_*$. 

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2. For every symmetric $T$-spectrum $X$ and for any pointed simplicial presheaf $A$ in $\mathcal{M}_*$, we have that $U(\Omega_A X) = \Omega_A U_X$, where the right hand side denotes the action of $\mathcal{M}_*$ in $\text{Spt}_T \mathcal{M}_*$.

3. $\text{Spt}_T \mathcal{M}_*$ is a $\mathcal{M}_*$-model category (see proposition 2.4.24).

\begin{proof}
We have that every pointed simplicial presheaf is cofibrant in $\mathcal{M}_*$. Then the result follows from proposition 2.6.24.
\end{proof}

Corollary 2.6.25. For every pointed simplicial presheaf $A \in \mathcal{M}_*$, the adjunction

$$(- \wedge A, \Omega_A -, \varphi) : \text{Spt}_T^\Sigma \mathcal{M}_* \longrightarrow \text{Spt}_T^\Sigma \mathcal{M}_*$$

is a Quillen adjunction.

\begin{proof}
We have that every pointed simplicial presheaf is cofibrant in $\mathcal{M}_*$. Then the result follows from proposition 2.6.24.
\end{proof}

Theorem 2.6.26 (Jardine). Let $T = S^1 \wedge G_m \in \mathcal{M}_*$. Then the Quillen adjunction:

$$(- \wedge T, \Omega_T, \varphi) : \text{Spt}_T^\Sigma \mathcal{M}_* \longrightarrow \text{Spt}_T^\Sigma \mathcal{M}_*$$

is a Quillen equivalence.

\begin{proof}
Let $\eta, \epsilon$ denote the unit and counit of the adjunction $(- \wedge T, \Omega_T, \varphi)$. By proposition 1.3.13 in [10], it suffices to check that the following conditions hold:

1. For every cofibrant symmetric $T$-spectrum $A$ in $\text{Spt}_T^\Sigma \mathcal{M}_*$, the following composition

$$A \xrightarrow{\eta_A} \Omega_T (T \wedge A) \xrightarrow{\Omega_T (R^{T \wedge A})} \Omega_T R (T \wedge A)$$

is a weak equivalence in $\text{Spt}_T^\Sigma \mathcal{M}_*$, where $R$ denotes a fibrant replacement functor in $\text{Spt}_T^\Sigma \mathcal{M}_*$.

2. For every fibrant symmetric $T$-spectrum $X$ in $\text{Spt}_T^\Sigma \mathcal{M}_*$, the following composition

$$T \wedge Q(\Omega_T X) \xrightarrow{id \wedge Q^{\Omega T X}} T \wedge (\Omega_T X) \xrightarrow{\epsilon_X} X$$

is a weak equivalence in $\text{Spt}_T^\Sigma \mathcal{M}_*$, where $Q$ denotes a cofibrant replacement functor in $\text{Spt}_T^\Sigma \mathcal{M}_*$.
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(1): Follows directly from corollary 4.26 in [13].

(2): By construction the map $Q^{\Omega_T X} : Q(\Omega_T X) \to \Omega_T X$ is a weak equivalence in $\text{Spt}_T^SM_*$. Therefore by lemma 4.25 in [13], we have that $id \wedge Q^{\Omega_T X}$ is also a weak equivalence in $\text{Spt}_T^SM_*$. Then by the two out of three property for weak equivalences, it suffices to show that $\epsilon_X$ is a weak equivalence in $\text{Spt}_T^SM_*$.

Since $X$ is fibrant in $\text{Spt}_T^SM_*$, it follows that $UX$ is fibrant in $\text{Spt}_T^SM_*$. Therefore by lemma 2.4.19(2) we have that $UX$ is in particular level fibrant. Then by corollary 3.16 in [13] it follows that the map:

$$\epsilon_{UX} : T \wedge (\Omega_T UX) \longrightarrow UX$$

is a weak equivalence in $\text{Spt}_T^SM_*$, but this is just $U(\epsilon_X)$. Hence by proposition 4.8 in [13], we have that $\epsilon_X$ is a weak equivalence in $\text{Spt}_T^SM_*$, as we wanted. □

**Proposition 2.6.27** (Jardine). $\text{Spt}_T^SM_*$ is a symmetric monoidal model category (with respect to the smash product of symmetric $T$-spectra) in the sense of Hovey (see definition 1.7.7).

**Proof.** We refer the reader to [13, proposition 4.19]. □

**Corollary 2.6.28.** Let $A$ be a cofibrant symmetric $T$-spectrum in $\text{Spt}_T^SM_*$. Then the adjunction:

$$(- \wedge A, \text{Hom}_{\text{Spt}_T^SM_*}(A, -), \varphi) : \text{Spt}_T^SM_* \longrightarrow \text{Spt}_T^SM_*$$

is a Quillen adjunction.

**Proof.** Follows directly from proposition 2.6.27. □

**Theorem 2.6.29** (Jardine). The adjunction:

$$(V, U, \varphi) : \text{Spt}_T^SM_* \longrightarrow \text{Spt}_T^SM_*$$

given by the symmetrization and the forgetful functor is a Quillen equivalence.

**Proof.** We refer the reader to [13, theorem 4.31]. □
2.7 Cellularity of the Motivic Symmetric Stable Model Structure

In this section we will show that the model category $\text{Spt}_T^\Sigma \mathcal{M}_*$ is cellular. For this we will use the cellularity of $\mathcal{M}_*$ (see proposition 2.3.7) together with some results of Hovey [11].

**Theorem 2.7.1** (Hovey). Consider the category of symmetric $T$-spectra $\text{Spt}_T^\Sigma (\text{Sm}_S|_S)_{\text{Nis}}$ equipped with the projective model structure (see theorem 2.6.15). Then $\text{Spt}_T^\Sigma (\text{Sm}_S|_S)_{\text{Nis}}$ is a cellular model category where the sets of generating cofibrations and trivial cofibrations are the ones described in theorem 2.6.15.

**Proof.** Proposition 2.3.7 implies that $M_*$ is in particular a cellular, left proper and symmetric monoidal model category. We also have that $T = S^1 \wedge G_m$ is cofibrant in $M_*$. Therefore we can apply theorem A.9 in [11], which says that the category of symmetric $T$-spectra equipped with the projective model structure is also cellular under our conditions. $\square$

Theorem 2.6.15 together with theorem 2.7.1 imply that the projective model structure on $\text{Spt}_T^\Sigma (\text{Sm}_S|_S)_{\text{Nis}}$ is cellular, left proper and simplicial. Therefore we can apply Hirschhorn’s localization technology to construct left Bousfield localizations. If we are able to find a suitable set of maps such that the left Bousfield localization with respect to this set recovers the motivic stable model structure on $\text{Spt}_T^\Sigma (\text{Sm}_S|_S)_{\text{Nis}}$, then an immediate corollary of this will be the cellularity of the motivic stable model structure for symmetric $T$-spectra.

**Definition 2.7.2** (Hovey, cf. [11, definition 8.7]). Let $I_{M_*} = \{ Y_+ \hookrightarrow (\Delta^n_U)_+ \}$ be the set of generating cofibrations for $M_*$ (see proposition 2.3.7). Notice that $Y_+$ may be equal to $(\Delta^n_U)_+$. We consider the following set of maps of symmetric $T$-spectra

$$S_\Sigma = \{ F_{n+1}^\Sigma (T \wedge Y_+) \xrightarrow{\zeta_{\Sigma,n}^Y} F_n^\Sigma (Y_+) \}$$

where $\zeta_{\Sigma,n}^Y$ is the adjoint corresponding to the inclusion determined by the identity in $\Sigma_{n+1}$

$$\iota_e : T \wedge Y_+ \hookrightarrow E v_{n+1}(F_n^\Sigma (Y_+)) = \Sigma_{n+1} \otimes_{\Sigma_1 \times \Sigma_n} (T \wedge \bigvee_{\sigma \in \Sigma_n} Y_+) = \bigvee_{\sigma \in \Sigma_{n+1}} T \wedge Y_+$$
Proposition 2.7.3 (Hovey). Let $X$ be a symmetric $T$-spectrum. The following conditions are equivalent:

1. $X$ is stably fibrant, i.e. $X$ is a fibrant object in $\text{Spt}_{\Sigma}^T \mathcal{M}_\ast$.

2. $X$ is $S_{\Sigma}$-local.

Proof. Follows from definition 8.6 and theorem 8.8 in [11], together with definition 2.6.21(3) and lemma 2.4.19.

Now it is very easy to show that the motivic symmetric stable model structure for symmetric $T$-spectra is in fact cellular.

Theorem 2.7.4. $\text{Spt}_{\Sigma}^T \mathcal{M}_\ast$ is a cellular model category with the following sets $I^T_{\Sigma}, J^T_{\Sigma}$ of generating cofibrations and trivial cofibrations respectively:

$$I^T_{\Sigma} = \bigcup_{n \geq 0} F_n^\Sigma (I^{\mathcal{M}_\ast}) = V(I^{\mathcal{M}_\ast})$$

$$J^T_{\Sigma} = \{ j : A \to B \}$$

where $j$ satisfies the following conditions:

1. $j$ is an inclusion of $I^T_{\Sigma}$-complexes.

2. $j$ is a stable weak equivalence of symmetric $T$-spectra.

3. the size of $B$ as an $I^T_{\Sigma}$-complex is less than $\kappa$, where $\kappa$ is the regular cardinal described by Hirschhorn in [7, definition 4.5.3].

Proof. By theorem 2.7.1 we know that $\text{Spt}_{\Sigma}^T (\text{Sm}_{\text{Nis}})$ is cellular when it is equipped with the projective model structure. Therefore we can apply Hirschhorn’s localization techniques to construct the left Bousfield localization with respect to the set $S_{\Sigma}$ of definition 2.7.2. We claim that this localization coincides with $\text{Spt}_{\Sigma}^T \mathcal{M}_\ast$. In effect, using proposition 2.7.3, we
2.7. Cellularity of the Motivic Symmetric Stable Model Structure

have that the fibrant objects in the left Bousfield localization with respect to $S_{\Sigma}$ coincide with the fibrant objects in $\text{Spt}^{S_{\Sigma}}_T M_*$. Therefore a map $f : X \to Y$ of symmetric $T$-spectra is a weak equivalence in the left Bousfield localization with respect to $S_{\Sigma}$ if and only if $Qf^* : \text{Map}(QY, Z) \to \text{Map}(QX, Z)$ is a weak equivalence of simplicial sets for every stably fibrant object $Z$ (here $Q$ denotes the cofibrant replacement functor in $\text{Spt}^{S_{\Sigma}}_T (Sm|_S)_{Nis}$ equipped with the projective model structure). But since $\text{Spt}^{S_{\Sigma}}_T M_*$ is a simplicial model category and the cofibrations coincide with the projective cofibrations, using corollary 1.6.11(2) we get exactly the same characterization for the stable equivalences. Hence the weak equivalences in both the motivic symmetric stable structure and the left Bousfield localization with respect to $S_{\Sigma}$ coincide. This implies that the motivic symmetric stable model structure and the left Bousfield localization with respect to $S_{\Sigma}$ are identical, since the cofibrations in both cases are just the cofibrations for the projective model structure on $\text{Spt}_T (Sm|_S)_{Nis}$.

Therefore using [7, theorem 4.1.1] we have that the motivic symmetric stable model structure on $\text{Spt}^{S_{\Sigma}}_T (Sm|_S)_{Nis}$ is cellular, since it is constructed applying Hirschhorn technology with respect to the set $S_{\Sigma}$.

The claim with respect to the sets of generating cofibrations and trivial cofibrations also follows from [7, theorem 4.1.1].

Theorem 2.7.4 will be used for the construction of new model structures on

$$\text{Spt}^{S_{\Sigma}}_T (Sm|_S)_{Nis}$$

which are adequate to study the multiplicative properties of Voevodsky’s slice filtration.
Chapter 3

Model Structures for the Slice Filtration

This chapter contains our main results. In section 3.1, we recall Voevodsky’s construction of the slice filtration in the context of simplicial presheaves. In section 3.2, we apply Hirschhorn’s localization techniques to the Morel-Voevodsky stable model structure $\text{Spt}_T^\ast M_\ast$, in order to construct three new families of model structures, namely $R^{c_{eff}}_{e_{eff}} \text{Spt}_T^\Sigma M_\ast$, $L_{<q} \text{Spt}_T^\Sigma M_\ast$ and $S^g \text{Spt}_T^\Sigma M_\ast$. These model structures will provide a lifting of Voevodsky’s slice filtration to the model category setting. Furthermore, we will also get a simple description for the exact functors $f_q$ ($q$-connective cover) and $s_q$ ($q$-slice) defined in section 3.1, in terms of a suitable composition of cofibrant and fibrant replacement functors.

In section 3.3, we promote the model structures introduced in section 3.2 to the setting of symmetric $T$-spectra. These new model structures will be denoted by $R^{c_{eff}}_{e_{eff}} \text{Spt}_T^\Sigma M_\ast$, $L_{<q} \text{Spt}_T^\Sigma M_\ast$ and $S^g \text{Spt}_T^\Sigma M_\ast$. We will prove that the Quillen adjunction given by the symmetrization and the forgetful functors descends to a Quillen equivalence for these three new model structures. As a consequence we will see that the model categories $R^{c_{eff}}_{e_{eff}} \text{Spt}_T^\Sigma M_\ast$, $L_{<q} \text{Spt}_T^\Sigma M_\ast$ and $S^g \text{Spt}_T^\Sigma M_\ast$ provide a lifting for Voevodsky’s slice filtration and give an alternative description for the functors $f_q$ and $s_q$. The great technical advantage of these
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model structures relies on the fact that the underlying category is symmetric monoidal. Hence, we have a natural framework to describe the multiplicative properties of the slice filtration.

In section 3.4, we will show that the slice filtration is compatible with the smash product of symmetric $T$-spectra.

Finally, in section 3.5 we will use all our previous results to show that the smash product of symmetric $T$-spectra induces natural pairings for the functors $f_q$ and $s_q$. Then we will show that for every symmetric $T$-spectrum $X$, and for every $q \in \mathbb{Z}$:

1. $f_q^\Sigma X$ is a module over the zero connective cover of the sphere spectrum $f_0^\Sigma 1$.

2. $s_q^\Sigma X$ is a module over the zero slice of the sphere spectrum $s_0^\Sigma 1$.

If the base scheme $S$ is a field of characteristic zero, then as a consequence we will prove that all the slices $s_n^\Sigma X$ are big motives in the sense of Voevodsky.

3.1 The Slice Filtration

Let $\mathcal{H}(S)$ denote the homotopy category associated to $\text{Spt}_T M_*$. We call $\mathcal{H}(S)$ the **motivic stable homotopy category**. We will denote by $[-,-]_{\text{Spt}}$ the set of maps between two objects in $\mathcal{H}(S)$. In [24] Voevodsky constructs the **slice filtration** on motivic stable homotopy theory, using sheaves on the Nisnevich site $(Sm|_S)_{\text{Nis}}$ instead of simplicial presheaves as the underlying category. In this section we recall his construction in the context of simplicial presheaves.

**Definition 3.1.1.** Let $Q_s$ denote a cofibrant replacement functor on $\text{Spt}_T M_*$; such that for every $T$-spectrum $X$, the natural map:

$$Q_s X \xrightarrow{Q_s^X} X$$

is a trivial fibration in $\text{Spt}_T M_*$. 
Proposition 3.1.2. The motivic stable homotopy category $\mathcal{SH}(S)$ has a structure of triangulated category defined as follows:

1. The suspension functor $\Sigma_T^{1,0}$ is given by
   \[
   - \wedge S^1 : \mathcal{SH}(S) \longrightarrow \mathcal{SH}(S)
   \]
   \[
   X \longleftarrow Q_s X \wedge S^1
   \]

2. The distinguished triangles are isomorphic to triangles of the form
   \[
   A \xrightarrow{i} B \xrightarrow{j} C \xrightarrow{k} \Sigma_T^{1,0} A
   \]
   where $i$ is a cofibration in $\text{Spt}_T M_*$, and $C$ is the homotopy cofibre of $i$.

Proof. Theorem 2.4.16 implies in particular that $\text{Spt}_T M_*$ is a pointed simplicial model category, and theorem 2.4.29 implies that the adjunction:

\[
(- \wedge S^1, \Omega S^1, \varphi) : \text{Spt}_T M_* \longrightarrow \text{Spt}_T M_*
\]

is a Quillen equivalence. The result now follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII] (see [10, proposition 7.1.6]).

Note 3.1.3. For $n \in \mathbb{Z}$, $\Sigma_T^{n,0}$ will denote the $n^{th}$ iteration of the suspension functor if $n \geq 0$ ($\Sigma_T^{0,0} = \text{id}$) or the $(-n)^{th}$ iteration of the desuspension functor for $n < 0$.

Lemma 3.1.4. Let $X \in M_*$ be a pointed simplicial presheaf which is compact in the sense of Jardine (see definition 2.3.10), and let $F_n(X)$ be the $T$-spectrum constructed in definition 2.4.4. Consider an arbitrary collection of $T$-spectra $\{Z_i\}_{i \in I}$ indexed by a set $I$. Then

\[
[F_n(X), \coprod_{i \in I} Z_i]_{Spt} \cong \coprod_{i \in I} [F_n(X), Z_i]_{Spt}
\]

Proof. If the indexing set $I$ is finite then the claim holds trivially since $\mathcal{SH}(S)$ is a triangulated category and therefore finite coproducts and finite products are canonically isomorphic. Thus we can assume that the indexing set $I$ is infinite.
Choosing a well ordering for the set $I$ there exists a unique ordinal $\mu$ which is isomorphic to the ordered set $I$ (see [7, proposition 10.2.7]). We will prove the lemma by transfinite induction, so assume that for every ordinal $\lambda < \mu$, $F_n(X)$ commutes in $\mathcal{SH}(S)$ with coproducts indexed by $\lambda$. If $\mu = \lambda + 1$, i.e. if $\mu$ is the successor of $\lambda$, then

$$\prod_{\alpha < \lambda + 1} Z_\alpha \cong \left( \prod_{\alpha < \lambda} Z_\alpha \right) \prod Z_\lambda$$

Therefore

$$[F_n(X), \prod_{\alpha < \lambda + 1} Z_\alpha]_{Spt} \cong ([F_n(X), \prod_{\alpha < \lambda} Z_\alpha]_{Spt}) \prod ([F_n(X), Z_\lambda]_{Spt})$$

but by the induction hypothesis

$$[F_n(X), \prod_{\alpha < \lambda} Z_\alpha]_{Spt} \cong \prod_{\alpha < \lambda} [F_n(X), Z_\alpha]_{Spt}$$

thus

$$[F_n(X), \prod_{\alpha < \lambda + 1} Z_\alpha]_{Spt} \cong \prod_{\alpha < \lambda + 1} [F_n(X), Z_\alpha]_{Spt}$$

as we wanted.

It remains to consider the case when $\mu$ is a limit ordinal. In this case proposition 10.2.7 in [7] implies that we can recover the map $* \to \prod_{\alpha < \mu} Z_\alpha$ as the transfinite composition of a $\mu$-sequence:

$$A_0 \to A_1 \to \cdots \to A_\beta \to \cdots \quad (\beta < \mu)$$

where $A_0 = *$, $A_\beta = \prod_{\alpha < \beta} Z_\alpha$, and the maps in the sequence are the obvious ones. In particular we have that $\prod_{\alpha < \mu} Z_\alpha \cong \varinjlim_{\beta < \mu} A_\beta$.

Since $X$ is compact, proposition 2.4.33 implies that:

$$[F_n(X), \varinjlim_{\beta < \mu} A_\beta]_{Spt} \cong \varinjlim_{\beta < \mu} [F_n(X), A_\beta]_{Spt}$$

Now using the induction hypothesis we have:

$$[F_n(X), A_\beta]_{Spt} \cong \prod_{\alpha < \beta} [F_n(X), Z_\alpha]_{Spt}$$
and using proposition 10.2.7 in [7] again, we get:

$$\lim_{\beta<\mu, \alpha<\beta} \prod [F_n(X), Z_\alpha]_{Spt} \cong \prod_{\alpha<\mu} [F_n(X), Z_\alpha]_{Spt}$$

thus

$$[F_n(X), \prod_{\alpha<\mu} Z_\alpha]_{Spt} \cong \prod_{\alpha<\mu} [F_n(X), Z_\alpha]_{Spt}$$

as we wanted.

**Proposition 3.1.5.** The motivic stable homotopy category $\mathcal{SH}(S)$ is a **compactly generated** triangulated category in the sense of Neeman (see [18, definition 1.7]). The set of compact generators is given by (see definition 2.4.4):

$$C = \bigcup_{n,r,s \geq 0} \bigcup_{U \in (\text{Sm} | S)} F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+)$$

i.e. the smallest triangulated subcategory of $\mathcal{SH}(S)$ closed under small coproducts and containing all the objects in $C$ coincides with $\mathcal{SH}(S)$.

**Proof.** Since $\mathcal{SH}(S)$ is closed under small coproducts, we just need to prove the following two claims:

1. For every $F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+) \in C$; $F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+)$ commutes with coproducts in $\mathcal{SH}(S)$, i.e. given a family of $T$-spectra $\{X_i\}_{i \in I}$ indexed by a set $I$ we have:

$$[F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+), \prod_{i \in I} X_i]_{Spt} \cong \prod_{i \in I} [F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+), X_i]_{Spt}$$

2. If a $T$ spectrum $X$ has the following property: $[F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+), X]_{Spt} = 0$ for every $F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+) \in C$, then $X \equiv *$ in $\mathcal{SH}(S)$.

(1): Follows immediately from lemma 3.1.4 since we know by proposition 2.4.1 that the pointed simplicial presheaves $S^r \wedge \mathbb{G}^s_m \wedge U_+$ are all compact in the sense of Jardine.

(2): Consider the canonical map $X \to *$ in $\text{Spt}_T\text{M}_s$. Corollary 2.4.28 together with our hypotheses implies that $X \to *$ is a weak equivalence in $\text{Spt}_T\text{M}_s$, therefore $X \equiv *$ in $\mathcal{SH}(S)$ as we wanted. □
Corollary 3.1.6. Let \( f : X \to Y \) be a map in \( \mathbb{H}(S) \). Then \( f \) is an isomorphism if and only if \( f \) induces an isomorphism of abelian groups:

\[
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), X]_{Spt} \xrightarrow{f_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Y]_{Spt}
\]

for every \( F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C \).

**Proof.** (\( \Rightarrow \)): If \( f \) is an isomorphism in \( \mathbb{H}(S) \) it is clear that the induced maps \( f_* \) are isomorphisms of abelian groups for every \( F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C \).

(\( \Leftarrow \)): Complete \( f \) to a distinguished triangle in \( \mathbb{H}(S) \):

\[
X \xrightarrow{f} Y \xrightarrow{g} Z \xrightarrow{h} \Sigma^1 T X
\]

Then \( f \) is an isomorphism if and only if \( Z \cong * \) in \( \mathbb{H}(S) \).

Now since the functor \( [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), -]_{Spt} \) is homological, we get the following long exact sequence of abelian groups:

\[
\cdots \xrightarrow{} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), X]_{Spt} \xrightarrow{f_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Y]_{Spt} \xrightarrow{g_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z]_{Spt} \xrightarrow{h_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Sigma^1 T X]_{Spt} \xrightarrow{\Sigma^1 T f_*} [F_{n+1}(S^r \wedge \mathbb{G}_m^{s+1} \wedge U_+), X]_{Spt} \xrightarrow{f_*} [F_{n+1}(S^r \wedge \mathbb{G}_m^{s+1} \wedge U_+), Y]_{Spt} \xrightarrow{g_*} \cdots
\]

But by hypothesis all the maps \( f_* \) are isomorphisms, therefore \( [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z]_{Spt} = 0 \) for every \( F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C \). Since \( \mathbb{H}(S) \) is a compactly generated triangulated
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category (see proposition 3.1.5) with set of compact generators $C$, we have that $Z \cong \ast$. This implies that $f$ is an isomorphism, as we wanted. \hfill \Box

**Definition 3.1.7** (Voevodsky, cf. [24]). We define the effective motivic stable homotopy category $\mathcal{SH}^{\text{eff}}(S) \subseteq \mathcal{SH}(S)$ as the smallest triangulated full subcategory of $\mathcal{SH}(S)$ that is closed under small coproducts and contains

$$C_{\text{eff}} = \bigcup_{n,r,s \geq 0; s-n \geq 0} \bigcup_{U \in (\text{Sm}|_S)} F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$$

**Definition 3.1.8** (Voevodsky, cf. [24]). Let $q \in \mathbb{Z}$. We define $\Sigma^q T \mathcal{SH}^{\text{eff}}(S) \subseteq \mathcal{SH}(S)$ as follows:

1. If $q = 0$, we just take $\mathcal{SH}^{\text{eff}}(S)$.

2. If $q \neq 0$, then $\Sigma^q T \mathcal{SH}^{\text{eff}}(S)$ is the smallest triangulated full subcategory of $\mathcal{SH}(S)$ that is closed under small coproducts and contains

$$C^q_{\text{eff}} = \bigcup_{n,r,s \geq 0; s-n \geq q} \bigcup_{U \in (\text{Sm}|_S)} F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$$

**Definition 3.1.9** (Voevodsky, cf. [24]). The collection of triangulated subcategories

$$\Sigma^q T \mathcal{SH}^{\text{eff}}(S)$$

for $q \in \mathbb{Z}$ give a filtration on $\mathcal{SH}(S)$ which is called the slice filtration, i.e. we have an inductive system of full embeddings

$$\ldots \subseteq \Sigma^{q+1} T \mathcal{SH}^{\text{eff}}(S) \subseteq \Sigma^q T \mathcal{SH}^{\text{eff}}(S) \subseteq \Sigma^{q-1} T \mathcal{SH}^{\text{eff}}(S) \subseteq \ldots$$

and proposition 3.1.5 implies that the smallest triangulated subcategory of $\mathcal{SH}(S)$ containing $\Sigma^q T \mathcal{SH}^{\text{eff}}(S)$ for all $q \in \mathbb{Z}$ and closed under small coproducts coincides with $\mathcal{SH}(S)$.

**Proposition 3.1.10.** For every $q \in \mathbb{Z}$, $\Sigma^q T \mathcal{SH}^{\text{eff}}(S)$ is a compactly generated triangulated category in the sense of Neeman, where the set of compact generators is

$$C^q_{\text{eff}} = \bigcup_{n,r,s \geq 0; s-n \geq q} \bigcup_{U \in (\text{Sm}|_S)} F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$$
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Proof. By construction $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ is closed under small coproducts. Therefore we just need to check the following two properties:

1. For every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{e f f}$; $F_n(S^r \wedge G^s_m \wedge U_+)$ commutes with coproducts in $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$, i.e. given a family of $T$-spectra $\{X_i \in \Sigma^q_T S^T \mathcal{S}^{e f f}(S)\}_{i \in I}$ indexed by a set $I$ we have:

$$\text{Hom}_{\Sigma^q_T S^T \mathcal{S}^{e f f}(S)}(F_n(S^r \wedge G^s_m \wedge U_+), \prod_{i \in I} X_i) \cong \prod_{i \in I} \text{Hom}_{\Sigma^q_T S^T \mathcal{S}^{e f f}(S)}(F_n(S^r \wedge G^s_m \wedge U_+), X_i)$$

2. If a $T$-spectrum $X \in \Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ has the following property:

$$\text{Hom}_{\Sigma^q_T S^T \mathcal{S}^{e f f}(S)}(F_n(S^r \wedge G^s_m \wedge U_+), X) = 0$$

for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{e f f}$, then $X \cong *$ in $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$.

(1): Follows immediately from proposition 3.1.5 since $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ is in particular a full subcategory of $\mathcal{S}(S)$.

(2): The natural map $X \to *$ is an isomorphism in $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ if and only if for every $Z \in \Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ we get an induced isomorphism of abelian groups

$$\text{Hom}_{\Sigma^q_T S^T \mathcal{S}^{e f f}(S)}(Z, X) \xrightarrow{\cong} \text{Hom}_{\Sigma^q_T S^T \mathcal{S}^{e f f}(S)}(Z, *) = 0$$

and since $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ is a full subcategory of $\mathcal{S}(S)$, this last condition is equivalent to:

For every $Z \in \Sigma^q_T S^T \mathcal{S}^{e f f}(S)$ we have an induced isomorphism of abelian groups

$$[Z, X]_{S pt} \xrightarrow{\cong} [Z, *]_{S pt} = 0$$

Let $A_X$ be the full subcategory of $\mathcal{S}(S)$ generated by the $T$-spectra $Y$ satisfying the following property

$$[\Sigma^n T Y, X]_{S pt} \xrightarrow{\cong} [\Sigma^n T Y, *]_{S pt} = 0$$

for all $n \in \mathbb{Z}$. To finish the proof it is enough to show that $\Sigma^q_T S^T \mathcal{S}^{e f f}(S) \subseteq A_X$, and by construction of $\Sigma^q_T S^T \mathcal{S}^{e f f}(S)$, it suffices to prove that $A_X$ is a triangulated subcategory of
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\text{SH}(S)$ which is closed under small coproducts and contains the objects $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in \mathcal{C}_{\text{eff}}^q$. The claim that $\mathcal{A}_X$ is triangulated follows immediately from the fact that the functor $[-, X]_{\text{Spt}}$ is cohomological. The claim that $\mathcal{A}_X$ is closed under small coproducts follows from the universal property of the coproduct. Finally by hypothesis $\mathcal{A}_X$ contains the generators $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in \mathcal{C}_{\text{eff}}^q$. This finishes the proof.

\textbf{Corollary 3.1.11.} Let $f : X \to Y$ be a map in $\Sigma_T^q \text{SH}^{\text{eff}}(S)$. Then $f$ is an isomorphism if and only if one of the following equivalent conditions holds:

1. For every $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in \mathcal{C}_{\text{eff}}^q$, $f$ induces an isomorphism of abelian groups:

$$\text{Hom}_{\Sigma_T^q \text{SH}^{\text{eff}}(S)}(F_n(S^r \land \mathbb{G}_m^s \land U_+), X) \xrightarrow{f_*} \text{Hom}_{\Sigma_T^q \text{SH}^{\text{eff}}(S)}(F_n(S^r \land \mathbb{G}_m^s \land U_+), Y)$$

2. For every $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in \mathcal{C}_{\text{eff}}^q$, $f$ induces an isomorphism of abelian groups:

$$[F_n(S^r \land \mathbb{G}_m^s \land U_+), X]_{\text{Spt}} \xrightarrow{\text{iso}(f)_*} [F_n(S^r \land \mathbb{G}_m^s \land U_+), Y]_{\text{Spt}}$$

\textbf{Proof.} Since by construction $\Sigma_T^q \text{SH}^{\text{eff}}(S)$ contains $\mathcal{C}_{\text{eff}}^q$ and it is a full subcategory of $\text{SH}(S)$, we get immediately that (1) and (2) are equivalent.

We will prove (1). It is clear that if $f$ is an isomorphism then the induced maps $f_*$ considered above are all isomorphisms of abelian groups. Conversely, assume that all the induced maps:

$$\text{Hom}_{\Sigma_T^q \text{SH}^{\text{eff}}(S)}(F_n(S^r \land \mathbb{G}_m^s \land U_+), X) \xrightarrow{f_*} \text{Hom}_{\Sigma_T^q \text{SH}^{\text{eff}}(S)}(F_n(S^r \land \mathbb{G}_m^s \land U_+), Y)$$

are isomorphisms for $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in \mathcal{C}_{\text{eff}}^q$. Complete the map $f : X \to Y$ to a distinguished triangle in $\Sigma_T^q \text{SH}^{\text{eff}}(S)$:

$$X \xrightarrow{f} Y \xrightarrow{g} Z \xrightarrow{h} \Sigma_T^{1,0} X$$
then \( f \) is an isomorphism if and only if \( Z \cong * \) in \( \Sigma^q_T \mathcal{S}^{eff} \). Now since the functor
\[
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_n(S^r \wedge G_m^s \wedge U_+), -)
\]
is homological, we get the following long exact sequence of abelian groups:

\[
\begin{align*}
\ldots & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_n(S^r \wedge G_m^s \wedge U_+), X) & \to \\
f_* & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_n(S^r \wedge G_m^s \wedge U_+), Y) & \to \\
g_* & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_n(S^r \wedge G_m^s \wedge U_+), Z) & \to \\
h_* & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), X) & \to \\
sigma_T^{1,0} f_* & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), Y) & \to \\
sigma_T^{1,0} g_* & \to \\
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), Z) & \to \\
\ldots & \to
\end{align*}
\]

But by hypothesis all the maps \( f_* \) are isomorphisms, therefore

\[
\text{Hom}_{\Sigma^q_T \mathcal{S}^{eff}}(F_n(S^r \wedge G_m^s \wedge U_+), Z) = 0
\]

for every \( F_n(S^r \wedge G_m^s \wedge U_+) \in C^q_{eff} \). Since \( \Sigma^q_T \mathcal{S}^{eff} \) is a compactly generated triangulated category (see proposition 3.1.10) with set of compact generators \( C^q_{eff} \), we have that \( Z \cong * \).

This implies that \( f \) is an isomorphism, as we wanted. \( \square \)
Proposition 3.1.12. For every \( q \in \mathbb{Z} \) the inclusion

\[ i_q : \Sigma_q \mathcal{S}^e(S) \to \mathcal{S}(S) \]

has a right adjoint

\[ r_q : \mathcal{S}(S) \to \Sigma_q \mathcal{S}^e(S) \]

which is also an exact functor.

Proof. We have that \( \Sigma_q \mathcal{S}^e(S) \) is a compactly generated triangulated category (see proposition 3.1.10), and it is clear that the inclusion \( i_q \) is an exact functor which preserves coproducts. Then the existence of the exact right adjoint \( r_q \) follows from theorem 4.1 in [18].

Remark 3.1.13. 1. Since the inclusion \( i_q : \Sigma_q \mathcal{S}^e(S) \to \mathcal{S}(S) \) is a full embedding, we have that the unit of the adjunction \( id \xrightarrow{\tau} r_q i_q \) is an isomorphism of functors.

2. We define \( f_q = i_q r_q \). Then clearly \( f_{q+1} f_q = f_{q+1} \) and there exists a canonical natural transformation \( f_{q+1} \to f_q \).

Proposition 3.1.14. Fix \( q \in \mathbb{Z} \), and let \( g : X \to Y \) be a map in \( \mathcal{S}(S) \). Then \( f_q(g) : f_q X \to f_q Y \) is an isomorphism in \( \mathcal{S}(S) \) if and only if for every \( F_n(S^r \wedge G_m \wedge U_+) \in C^q_{eff} \) the induced map:

\[ [F_n(S^r \wedge G_m \wedge U_+), X]_{Spt} \xrightarrow{g_*} [F_n(S^r \wedge G_m \wedge U_+), Y]_{Spt} \]

is an isomorphism of abelian groups.

Proof. We have that \( f_q = i_q r_q \), where \( i_q : \Sigma_q \mathcal{S}^e(S) \to \mathcal{S}(S) \) is a full embedding. Therefore, \( f_q(g) \) is an isomorphism in \( \mathcal{S}(S) \) if and only if \( r_q(g) \) is an isomorphism in \( \Sigma_q \mathcal{S}^e(S) \).

Hence, corollary 3.1.11 implies that \( f_q(g) \) is an isomorphism if and only if for every \( F_n(S^r \wedge
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\[ G_n^a \in C_{eff}^a \] the induced map:

\[
\text{Hom}_{\Sigma^q \mathcal{S}^-eff(S)}(F_n(S^r \wedge G_m^s \wedge U_+), X) \\
\xrightarrow{r_q(g)*} \\
\text{Hom}_{\Sigma^q \mathcal{S}^-eff(S)}(F_n(S^r \wedge G_m^s \wedge U_+), Y)
\]

is an isomorphism. Fix \( F_n(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^a \). Finally since \( i_q, r_q \) are adjoint functors and \( C_{eff}^a \subseteq \Sigma^q \mathcal{S}^-eff(S) \), we have the following commutative diagram, where the vertical arrows are all isomorphisms:

\[
\text{Hom}_{\Sigma^q \mathcal{S}^-eff(S)}(F_n(S^r \wedge G_m^s \wedge U_+), r_qX) \\
\xrightarrow{\cong} \\
\text{Hom}_{\Sigma^q \mathcal{S}^-eff(S)}(F_n(S^r \wedge G_m^s \wedge U_+), r_qY) \\
\xrightarrow{\cong} \\
[F_n(S^r \wedge G_m^s \wedge U_+), X]_{Spt} \\
\xrightarrow{g*} \\
[F_n(S^r \wedge G_m^s \wedge U_+), Y]_{Spt}
\]

Therefore, \( f_q(g) \) is an isomorphism if and only if for every \( F_n(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^a \) the induced map:

\[
[F_n(S^r \wedge G_m^s \wedge U_+), X]_{Spt} \xrightarrow{g*} [F_n(S^r \wedge G_m^s \wedge U_+), Y]_{Spt}
\]

is an isomorphism, as we wanted. \( \square \)

**Proposition 3.1.15.** For every \( q \in \mathbb{Z} \) the counit of the adjunction constructed in proposition 3.1.12, \( f_q = i_q r_q \xrightarrow{\theta} id \), has the following property:

For any \( T \)-spectrum \( X \), and for any compact generator \( F_n(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^a \), the map \( f_q X \xrightarrow{\theta_X} X \) in \( \mathcal{S}^-H(S) \) induces an isomorphism of abelian groups:

\[
[F_n(S^r \wedge G_m^s \wedge U_+), X]_{Spt} \xrightarrow{\theta_X*} [F_n(S^r \wedge G_m^s \wedge U_+), X]_{Spt}
\]

**Proof.** Let \( F_n(S^r \wedge G_m^s \wedge U_+) \) be an arbitrary element in \( C_{eff}^a \). Since \( F_n(S^r \wedge G_m^s \wedge U_+) \in \)
σ_n^q \mathcal{S}eff(S) for n, r, s ≥ 0 with s − n ≥ q, we get the following commutative diagram:

\[
\begin{array}{c}
\left[ F_n(S^r \wedge G^s_m \wedge U_+), f_q X \right]_{SpT} \\
\downarrow \\
\left[ i_q(F_n(S^r \wedge G^s_m \wedge U_+)), i_q r_q X \right]_{SpT}
\end{array}
\xrightarrow{\theta_{X*}}
\begin{array}{c}
\left[ F_n(S^r \wedge G^s_m \wedge U_+), X \right]_{SpT} \\
\downarrow \\
\left[ i_q(F_n(S^r \wedge G^s_m \wedge U_+)), X \right]_{SpT}
\end{array}
\]

Now using the adjunction between \( i_q \) and \( r_q \) we have the following commutative diagram:

\[
\begin{array}{c}
\left[ i_q(F_n(S^r \wedge G^s_m \wedge U_+)), i_q r_q X \right]_{SpT} \\
\downarrow \cong \\
\left[ i_q(F_n(S^r \wedge G^s_m \wedge U_+)), X \right]_{SpT}
\end{array}
\xrightarrow{\theta_{X*}}
\begin{array}{c}
\text{Hom}_{\Sigma^q_+ \mathcal{S}eff(S)}(F_n(S^r \wedge G^s_m \wedge U_+), r_q i_q r_q X) \\
\downarrow \cong \\
\text{Hom}_{\Sigma^q_+ \mathcal{S}eff(S)}(F_n(S^r \wedge G^s_m \wedge U_+), r_q X)
\end{array}
\]

where \( \tau \) is the unit of the adjunction between \( i_q \) and \( r_q \). This shows that \( \theta_{X*} \) is an isomorphism, as we wanted.

\[\square\]

**Theorem 3.1.16** (Voevodsky, cf. [24, theorem 2.2]). For every \( q \in \mathbb{Z} \) there exist exact functors

\[ s_q : \mathcal{SH}(S) \longrightarrow \mathcal{SH}(S) \]

together with natural transformations

\[ \pi_q : f_q \longrightarrow s_q \]
\[ \sigma_q : s_q \longrightarrow \Sigma^1_T f_{q+1} \]

such that the following conditions hold:
1. Given any $T$-spectrum $X$, we get the following distinguished triangle in $\mathcal{SH}(S)$

$$f_{q+1}X \rightarrow f_qX \xrightarrow{\pi_q} s_qX \xrightarrow{\sigma_q} \Sigma_T^{1,0} f_{q+1}X$$  \hspace{1cm} (3.1)

2. For any $T$-spectrum $X$, $s_qX$ is in $\Sigma_T^q \mathcal{SH}^e(S)$.

3. For any $T$-spectrum $X$, and for any $T$-spectrum $Y$ in $\Sigma_T^{q+1} \mathcal{SH}^e(S)$, $[Y, s_qX]_{Spt} = 0$.

**Proof.** Since the triangulated categories $\Sigma_T^{q+1} \mathcal{SH}^e(S)$ and $\Sigma_T^q \mathcal{SH}^e(S)$ are both compactly generated (see proposition 3.1.10), the result follows from propositions 9.1.19 and 9.1.8 in [19].

**Definition 3.1.17** (Voevodsky). Given an arbitrary $T$-spectrum $X$, the sequence of distinguished triangles (3.1) is called the **slice tower** of $X$. The $T$-spectrum $s_qX$ is called the **$q$-slice** of $X$, and the $T$-spectrum $f_qX$ is called the **$q$-connective cover** of $X$.

**Theorem 3.1.18.** For every $q \in \mathbb{Z}$ there exist exact functors

$$s_{<q} : \mathcal{SH}(S) \longrightarrow \mathcal{SH}(S)$$

together with natural transformations

$$\pi_{<q} : id \longrightarrow s_{<q}$$

$$\sigma_{<q} : s_{<q} \longrightarrow \Sigma_T^{1,0} f_q$$

such that the following conditions hold:

1. Given any $T$-spectrum $X$, we get the following distinguished triangle in $\mathcal{SH}(S)$

$$f_qX \longrightarrow X \xrightarrow{\pi_{<q}} s_{<q}X \xrightarrow{\sigma_{<q}} \Sigma_T^{1,0} f_qX$$  \hspace{1cm} (3.2)

2. For any $T$-spectrum $X$, and for any $T$-spectrum $Y$ in $\Sigma_T^q \mathcal{SH}^e(S)$, $[Y, s_{<q}X]_{Spt} = 0$.

**Proof.** The result follows from propositions 9.1.19 and 9.1.8 in [19], using the fact that the triangulated categories $\Sigma_T^q \mathcal{SH}^e(S)$ and $\mathcal{SH}(S)$ are both compactly generated (see propositions 3.1.5 and 3.1.10).
**Proposition 3.1.19.** Let $X$ be an arbitrary $T$-spectrum. Then for every $q \in \mathbb{Z}$, we have the following commutative diagram, where all the rows and columns are distinguished triangles in $\mathcal{SH}(S)$:

\[
\begin{array}{cccccccc}
  f_{q+1}X & \rightarrow & f_qX & \xrightarrow{\pi_q} & s_qX & \xrightarrow{\sigma_q} & \Sigma^1_1 f_{q+1}X \\
  \downarrow & & \downarrow & \sigma_{<q+1} & & \downarrow & \sigma_{q+1} \\
  f_{q+1}X & \rightarrow & X & \xrightarrow{\pi_{<q+1}} & s_{<q+1}X & \xrightarrow{\sigma_{<q+1}} & \Sigma^1_1 f_{q+1}X \\
  \downarrow & & \downarrow & \sigma_{<q+1} & & \downarrow & \sigma_{<q} \\
  * & \rightarrow & s_{<q}X & \xrightarrow{\pi_{<q}} & s_{<q}X & \xrightarrow{\sigma_{<q}} & * \\
  \downarrow & & \downarrow & \sigma_{<q} & & \downarrow & \sigma_{<q} \\
  \Sigma^1_1 f_{q+1}X & \xrightarrow{\Sigma^1_1 \sigma_{<q}} & \Sigma^1_1 f_qX & \xrightarrow{\Sigma^1_1 \pi_q} & \Sigma^1_1 s_qX & \xrightarrow{\Sigma^1_1 \sigma_q} & \Sigma^2_1 f_{q+1}X
\end{array}
\]

**Proof.** It follows from theorems 3.1.16 and 3.1.18, together with the octahedral axiom applied to the following commutative diagram:

\[
\begin{array}{ccc}
  f_{q+1}X & \rightarrow & f_qX \\
  \downarrow & \searrow & \downarrow \\
  X & \rightarrow & X
\end{array}
\]

\[
\]

**Proposition 3.1.20.** Fix $q \in \mathbb{Z}$ and let $f : X \rightarrow Y$ be a map in $\mathcal{SH}(S)$. Then

\[s_{<q}f : s_{<q}X \rightarrow s_{<q}Y\]

is an isomorphism in $\mathcal{SH}(S)$ if and only if $f$ induces the following isomorphisms of abelian groups:

\[
[F_n(S^r \land \mathbb{G}_m^a \land U_+), s_{<q}X]_{S_{pt}} \cong [F_n(S^r \land \mathbb{G}_m^a \land U_+), s_{<q}Y]_{S_{pt}}
\]

for every $F_n(S^r \land \mathbb{G}_m^a \land U_+ \notin C^q_{eff}$.

**Proof.** ($\Rightarrow$): Assume that $s_{<q}f$ is an isomorphism. Then it is clear that $(s_{<q}f)_*$ is also an isomorphism for every $F_n(S^r \land \mathbb{G}_m^a \land U_+ \notin C^q_{eff}$. 

\[
\]

\[
\]
3.1. The Slice Filtration

(⇐): Corollary 3.1.6 implies that \( s_{<q}f \) is an isomorphism in \( \mathcal{SH}(S) \) if and only if for every \( F_n(S^r \wedge G_{m}^s \wedge U_+) \in C \), the induced maps:

\[
[F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}X]_{Spt} \xrightarrow{(s_{<q}f)_*} [F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}Y]_{Spt}
\]

are isomorphisms of abelian groups.

But theorem 3.1.18(2) implies that for every \( F_n(S^r \wedge G_{m}^s \wedge U_+) \in C^q_{eff} \), we have:

\[0 \cong [F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}X]_{Spt} \xrightarrow{(s_{<q}f)_*} [F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}Y]_{Spt} \cong 0\]

thus \( (s_{<q}f)_* \) is an isomorphism in this case.

Thus in order to show that \( s_{<q}f \) is an isomorphism, we only need to check that for every \( F_n(S^r \wedge G_{m}^s \wedge U_+) \notin C^q_{eff} \), the induced maps:

\[
[F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}X]_{Spt} \xrightarrow{(s_{<q}f)_*} [F_n(S^r \wedge G_{m}^s \wedge U_+), s_{<q}Y]_{Spt}
\]

are all isomorphisms of abelian groups; but this holds by hypothesis. This finishes the proof.

**Proposition 3.1.21.** Fix \( q \in \mathbb{Z} \) and let \( f : X \to Y \) be a map in \( \mathcal{SH}(S) \). Then

\[s_qf : s_qX \to s_qY\]

is an isomorphism in \( \mathcal{SH}(S) \) if and only if \( f \) induces the following isomorphisms of abelian groups:

\[
[F_n(S^r \wedge G_{m}^s \wedge U_+), s_qX]_{Spt} \xrightarrow{(s_qf)_*} [F_n(S^r \wedge G_{m}^s \wedge U_+), s_qY]_{Spt}
\]

for every \( F_n(S^r \wedge G_{m}^s \wedge U_+) \in C^q_{eff} \) where \( s - n = q \).

**Proof.** (⇒): Assume that \( s_qf \) is an isomorphism. Then it is clear that \( (s_qf)_* \) is also an isomorphism for every \( F_n(S^r \wedge G_{m}^s \wedge U_+) \in C^q_{eff} \) with \( s - n = q \).

(⇐): Theorem 3.1.16(2) implies that \( s_qX \) and \( s_qY \) are both in \( \Sigma^q_T\mathcal{SH}^{eff}(S) \). Therefore using corollary 3.1.11 and the fact that \( \Sigma^q_T\mathcal{SH}^{eff}(S) \) is a full subcategory of \( \mathcal{SH}(S) \), we have that \( s_qf \) is an isomorphism if and only if the maps:

\[
[F_n(S^r \wedge G_{m}^s \wedge U_+), s_qX]_{Spt} \xrightarrow{(s_qf)_*} [F_n(S^r \wedge G_{m}^s \wedge U_+), s_qY]_{Spt}
\]
are all isomorphisms of abelian groups for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{\text{eff}}^q$.

But if $s - n \geq q + 1$, we have that $F_n(S^r \wedge G^s_m \wedge U_+)$ is in fact in $\Sigma_T^{q+1} \mathcal{H}_{\text{eff}}(S)$; and using theorem 3.1.16(3) again, we have that in this case:

$$0 \cong [F_n(S^r \wedge G^s_m \wedge U_+), s_qX]_{Spt} \xrightarrow{(s_qf)_*} [F_n(S^r \wedge G^s_m \wedge U_+), s_qY]_{Spt} \cong 0$$

Thus in order to show that $s_qf$ is an isomorphism, we only need to check that the maps:

$$[F_n(S^r \wedge G^s_m \wedge U_+), s_qX]_{Spt} \xrightarrow{(s_qf)_*} [F_n(S^r \wedge G^s_m \wedge U_+), s_qY]_{Spt}$$

are all isomorphisms of abelian groups, for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{\text{eff}}^q$ with $s - n = q$.

This finishes the proof.

\[\square\]

### 3.2 Model Structures for the Slice Filtration

Our goal in this section is to use the cellularity of $Spt_{T}M_{+}$ (see theorem 2.5.4), to construct using Hirschhorn’s localization techniques, several families of model structures on $Spt_{T}(Sm|S)_{Nis}$ via left and right Bousfield localization. This new model structures will provide liftings in a suitable sense for the functors

$$f_q, s < q, s_q : \mathcal{H}(S) \to \mathcal{H}(S)$$

described in section 3.1.

The first family of model structures on $Spt_{T}(Sm|S)_{Nis}$ will be constructed via right Bousfield localization. These model structures will have the property that the cofibrant replacement functor coincides in a suitable sense with the functor $f_q$ defined in remark 3.1.13. This will provide a natural lifting of Voevodsky’s slice filtration to the level of model categories.

**Theorem 3.2.1.** Fix $q \in \mathbb{Z}$. Consider the following set of objects in $Spt_{T}M_{+}$

$$C_{\text{eff}}^q = \bigcup_{n,r,s \geq 0; s - n \geq q} \bigcup_{U \in (Sm|S)} F_n(S^r \wedge G^s_m \wedge U_+)$$
Then the right Bousfield localization of $\text{Spt}_T \text{M}_*$ with respect to the class of $C_{eff}^q$-colocal equivalences exists (see definitions 1.8.6 and 1.9.2). This model structure will be called $q$-\textbf{connected motivic stable}, and the category of $T$-spectra equipped with the $q$-connected motivic stable model structure will be denoted by $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$. Furthermore $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$ is a right proper and simplicial model category. The homotopy category associated to $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$ will be denoted by $R_{C_{eff}^q} \text{SH}(S)$.

\textbf{Proof.} Theorems 2.4.16 and 2.5.4 imply that $\text{Spt}_T \text{M}_*$ is cellular, proper and simplicial. Therefore we can apply theorem 5.1.1 in [7] to construct the right Bousfield localization of $\text{Spt}_T \text{M}_*$ with respect to the class of $C_{eff}^q$-colocal equivalences. Using theorem 5.1.1 in [7] again, we have that this new model structure is right proper and simplicial. \hfill $\Box$

\textbf{Definition 3.2.2.} Fix $q \in \mathbb{Z}$. Let $C_q$ denote a cofibrant replacement functor on

$$R_{C_{eff}^q} \text{Spt}_T \text{M}_*$$

such that for every $T$-spectrum $X$, the natural map

$$C_q X \xrightarrow{C_q X} X$$

is a trivial fibration in $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$, and $C_q X$ is always a $C_{eff}^q$-colocal $T$-spectrum.

\textbf{Proposition 3.2.3.} Fix $q \in \mathbb{Z}$. Then $IQ_T J$ is also a fibrant replacement functor on $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$ (see corollary 2.4.20).

\textbf{Proof.} Since $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$ is the right Bousfield localization of $\text{Spt}_T \text{M}_*$ with respect to the $C_{eff}^q$-colocal equivalences, by construction we have that the fibrations and the trivial cofibrations are indentical in $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$ and $\text{Spt}_T \text{M}_*$ respectively. This implies that for every $T$-spectrum $X$, $IQ_T J X$ is fibrant in $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$, and using [7, proposition 3.1.5] we have that the natural map:

$$X \xrightarrow{IQ_T J X} IQ_T J X$$

is a weak equivalence in $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$. Hence $IQ_T J$ is also a fibrant replacement functor for $R_{C_{eff}^q} \text{Spt}_T \text{M}_*$. \hfill $\Box$
Proposition 3.2.4. Fix \( q \in \mathbb{Z} \) and let \( f : X \to Y \) be a map in \( \text{Spt}_T \mathcal{M}_s \). Then \( f \) is a \( C_{q_{eff}} \)-colocal equivalence if and only if for every \( F_n(S^r \land G^s_m \land U_+) \in C_{q_{eff}} \), \( f \) induces the following isomorphisms of abelian groups:

\[
[F_n(S^r \land G^s_m \land U_+), X]_{\text{Spt}} \xrightarrow{f_*} [F_n(S^r \land G^s_m \land U_+), Y]_{\text{Spt}}
\]

Proof. (\( \Rightarrow \)): Assume that \( f \) is a \( C_{q_{eff}} \)-colocal equivalence. Since all the compact generators \( F_n(S^r \land G^s_m \land U_+) \) are cofibrant in \( \text{Spt}_T \mathcal{M}_s \), we have that \( f \) is a \( C_{q_{eff}} \)-colocal equivalence if and only if the following maps are weak equivalences of simplicial sets:

\[
\text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JX) \xrightarrow{(IQ_T f)_*} \text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JY)
\]

for every \( F_n(S^r \land G^s_m \land U_+) \in C_{q_{eff}} \). Since \( \text{Spt}_T \mathcal{M}_s \) is a simplicial model category and \( F_n(S^r \land G^s_m \land U_+) \) is cofibrant, we have that \( \text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JX) \) and \( \text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JY) \) are both Kan complexes, thus we get the following commutative diagram where the top row and the vertical maps are all isomorphisms of abelian groups:

\[
\begin{array}{ccc}
\pi_0 \text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JX) & \xrightarrow{(IQ_T f)_*} & \pi_0 \text{Map}(F_n(S^r \land G^s_m \land U_+), IQ_T JY) \\
\cong & & \cong \\
[F_n(S^r \land G^s_m \land U_+), X]_{\text{Spt}} & \xrightarrow{f_*} & [F_n(S^r \land G^s_m \land U_+), Y]_{\text{Spt}}
\end{array}
\]

Therefore

\[
[F_n(S^r \land G^s_m \land U_+), X]_{\text{Spt}} \xrightarrow{f_*} [F_n(S^r \land G^s_m \land U_+), Y]_{\text{Spt}}
\]

is an isomorphism of abelian groups for every \( F_n(S^r \land G^s_m \land U_+) \in C_{q_{eff}} \), as we wanted.

(\( \Leftarrow \)): Fix \( F_n(S^r \land G^s_m \land U_+) \in C_{q_{eff}} \). Let \( \omega_0, \eta_0 \) denote the base points corresponding to \( \text{Map}_*(F_n(S^r \land G^s_m \land U_+), IQ_T JX) \) and \( \text{Map}_*(F_n(S^r \land G^s_m \land U_+), IQ_T JY) \) respectively. We
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need to show that the map:

\[
\begin{align*}
\text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T JX) & \to \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T JY) \\
\downarrow{(IQ_T Jf)_*} & \downarrow{(IQ_T Jf)_*} \\
\text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JX) & \to \text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JY)
\end{align*}
\]

is a weak equivalence of simplicial sets.

We know that the map

\[ j : F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+) \to F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \]

which is adjoint to the identity map

\[ id : S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+ \to Ev_{n+1}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)) = S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+ \]

is a weak equivalence in Spt_\tau M_*. Now since \( F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ \) and \( F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+) \)

are both cofibrant and Spt_\tau M_* is a simplicial model category, we can apply Ken Brown’s lemma (see lemma 1.1.4) to conclude that the horizontal maps in the following commutative diagram are weak equivalences of simplicial sets:

\[
\begin{align*}
\text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T JX) & \to \text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JX) \\
\downarrow{(IQ_T Jf)_*} & \downarrow{(IQ_T Jf)_*} \\
\text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T JY) & \to \text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JY)
\end{align*}
\]

Hence by the two out of three property for weak equivalences, it is enough to show that the following induced map

\[
\begin{align*}
\text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JX) & \to \text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JY) \\
\downarrow{(IQ_T Jf)_*} & \downarrow{(IQ_T Jf)_*} \\
\text{Map}(F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T JY)
\end{align*}
\]
is a weak equivalence of simplicial sets.

On the other hand, since $\text{Spt}_T M_*$ is a pointed simplicial model category, we have that lemma 6.1.2 in [10] together with remark 2.4.3(2) imply that the following diagram is commutative for $k \geq 0$:

\[
\begin{array}{ccc}
\pi_{k,\omega_0} \text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J X) & \xrightarrow{(IQ_T J f)_*} & \pi_{k,\eta_0} \text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J Y) \\
\pi_{k,\omega_0} \text{Map}_*(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J X) & \xrightarrow{(IQ_T J f)_*} & \pi_{k,\eta_0} \text{Map}_*(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J Y) \\
\cong & & \cong \\
[F_n(S^r \wedge G^s_m \wedge U_+) \wedge S^k, IQ_T J X]_{\text{Spt}} & \xrightarrow{(IQ_T J f)_*} & [F_n(S^r \wedge G^s_m \wedge U_+) \wedge S^k, IQ_T J Y]_{\text{Spt}} \\
\cong & & \cong \\
[F_n(S^r \wedge G^s_m \wedge U_+) \wedge S^k, X]_{\text{Spt}} & \xrightarrow{f_*} & [F_n(S^r \wedge G^s_m \wedge U_+) \wedge S^k, Y]_{\text{Spt}} \\
\cong & & \cong \\
[F_n(S^{k+r} \wedge G^s_m \wedge U_+), X]_{\text{Spt}} & \xrightarrow{f_*} & [F_n(S^{k+r} \wedge G^s_m \wedge U_+), Y]_{\text{Spt}} \\
\end{array}
\]

but by hypothesis we have that the bottom row is an isomorphism of abelian groups. Therefore all the maps in the top row are also isomorphisms. Then for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^d_{\text{eff}}$, the induced map

\[
\text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J X) \xrightarrow{(IQ_T J f)_*} \text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J Y)
\]

is a weak equivalence when it is restricted to the path component of $\text{Map}(F_n(S^r \wedge G^s_m \wedge U_+) \wedge S^k, \text{Spt})$. 

\[
\text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J X) \xrightarrow{(IQ_T J f)_*} \text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T J Y)
\]
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$U_+, IQ_T JX)$ containing $\omega_0$. But $F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+)$ is also in $C^q_{eff}$, therefore the following induced map

$$Map_*(S^1, Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JX))$$

$$\xrightarrow{(IQ_T Jf)_*}$$

$$Map_*(S^1, Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JY))$$

is a weak equivalence of simplicial sets, since taking $S^1$-loops kills the path components that do not contain the base point.

Finally, since $Spt_T M_*$ is a simplicial model category we have that the rows in the following commutative diagram are isomorphisms:

$$Map_*(S^1, Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JX))$$

$$\xrightarrow{\cong}$$

$$Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land S^1, IQ_T JX))$$

$$\xrightarrow{(IQ_T Jf)_*}$$

$$Map_*(S^1, Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JY))$$

$$\xrightarrow{\cong}$$

$$Map_*(F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+ \land S^1, IQ_T JY))$$

Hence the two out of three property for weak equivalences implies that the right vertical map is a weak equivalence of simplicial sets. But $F_{n+1}(S^r \land \mathbb{G}_{m}^{s+1} \land U_+ \land S^1)$ is clearly isomorphic to $F_{n+1}(S^{r+1} \land \mathbb{G}_{m}^{s+1} \land U_+) \land S^1$, therefore the induced map

$$Map(F_{n+1}(S^{r+1} \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JX)$$

$$\xrightarrow{(IQ_T Jf)_*}$$

$$Map(F_{n+1}(S^{r+1} \land \mathbb{G}_{m}^{s+1} \land U_+), IQ_T JY)$$

is a weak equivalence, as we wanted.

\[ \square \]

**Corollary 3.2.5.** Fix $q \in \mathbb{Z}$ and let $f : X \rightarrow Y$ be a map in $Spt_T M_*$. Then $f$ is a $C^q_{eff}$-colocal equivalence if and only if the following map

$$r_q X \xrightarrow{r_q(f)} r_q Y$$

is an isomorphism in $\Sigma_T^q g \mathcal{H}^{eff}(S)$. 

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**Proof.** The result follows immediately from proposition 3.2.4 and corollary 3.1.11(2).

**Corollary 3.2.6.** Fix $q \in \mathbb{Z}$ and let $X$ be an arbitrary $T$-spectrum $X$. Then $X \cong \ast$ in $R_{C_{eff}^q} \mathcal{S}\mathcal{T}(S)$ if and only if the following condition holds:

For every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$:

$$[F_n(S^r \wedge G^s_m \wedge U_+), X]_{Spt} \cong 0$$

**Proof.** We have that $X$ is isomorphic to $\ast$ in $R_{C_{eff}^q} \mathcal{S}\mathcal{T}(S)$ if and only if the map $\ast \to X$ is a $C_{eff}^q$-colocal equivalence. But corollary 3.2.5 implies that $\ast \to X$ is a $C_{eff}^q$-colocal equivalence if and only if

$$\ast \cong r_q(\ast) \xrightarrow{\cong} r_q X$$

becomes an isomorphism in $\Sigma_T^q \mathcal{S}\mathcal{T}_{eff}(S)$.

Finally by corollary 3.1.11(2) we have that $\ast \to r_q X$ is an isomorphism in $\Sigma_T^q \mathcal{S}\mathcal{T}_{eff}(S)$ if and only if for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$ the following induced maps are isomorphisms of abelian groups:

$$0 \cong [F_n(S^r \wedge G^s_m \wedge U_+), \ast]_{Spt} \xrightarrow{\cong} [F_n(S^r \wedge G^s_m \wedge U_+), X]_{Spt}$$

as we wanted.

**Lemma 3.2.7.** Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map in $\text{Spt}_T \mathcal{M}_*$, then $f$ is a $C_{eff}^q$-colocal equivalence if and only if $\Omega_{S^1} IQ_T J(f)$ is a $C_{eff}^q$-colocal equivalence.

**Proof.** Assume that $f$ is a $C_{eff}^q$-colocal equivalence. We need to show that $\Omega_{S^1} IQ_T J(f)$ is a $C_{eff}^q$-colocal equivalence. Fix $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$. Since $\text{Spt}_T \mathcal{M}_*$ is a simplicial model category and all the compact generators $F_n(S^r \wedge G^s_m \wedge U_+)$ are cofibrant, we have
the following commutative diagram:

\[
\begin{align*}
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega_{S^1}IQ_TJX]_{Spt} & \xrightarrow{(IQ_TJf)_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega_{S^1}IQ_TJY]_{Spt} \\
\cong \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \qa
an isomorphism:

\[
[F_{n+1}(S^r \wedge \mathbb{G}^{s+1}_m \wedge U_+), \Omega S_1 IQ_T J X]_{spt} 
\xrightarrow{\sim} [F_{n+1}(S^r \wedge \mathbb{G}^{s+1}_m \wedge U_+), \Omega S_1 IQ_T J Y]_{spt}
\]

\[
[F_{n+1}(S^r \wedge \mathbb{G}^{s+1}_m \wedge U_+) \wedge S_1, X]_{spt} 
\xrightarrow{f_*} [F_{n+1}(S^r \wedge \mathbb{G}^{s+1}_m \wedge U_+) \wedge S_1, Y]_{spt}
\]

\[
[F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+), X]_{spt} 
\xrightarrow{f_*} [F_n(S^r \wedge \mathbb{G}^s_m \wedge U_+), Y]_{spt}
\]

therefore the bottom row is also an isomorphism. Finally using Proposition 3.2.4 again, we have that \(f\) is a \(C_{q eff}\)-colocal equivalence. This finishes the proof. \(\square\)

**Corollary 3.2.8.** For every \(q \in \mathbb{Z}\), the adjunction

\[
(- \wedge S^1, \Omega S_1, \varphi) : R_{C_{q eff}}^{\mathbb{Z}} Spt_T M_* \rightarrow R_{C_{q eff}}^{\mathbb{Z}} Spt_T M_*
\]

is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.2.3 we have that it suffices to verify the following two conditions:

1. For every cofibrant object \(X\) in \(R_{C_{q eff}}^{\mathbb{Z}} Spt_T M_*\), the following composition

\[
X \xrightarrow{\eta_X} \Omega S_1 (X \wedge S^1) \xrightarrow{\Omega S_1 IQ_T J X \wedge S^1} \Omega S_1 IQ_T J (X \wedge S^1)
\]

is a \(C_{q eff}\)-colocal equivalence.

2. \(\Omega S_1\) reflects \(C_{q eff}\)-colocal equivalences between fibrant objects in \(R_{C_{q eff}}^{\mathbb{Z}} Spt_T M_*\).
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(1): By construction $R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_*$ is a right Bousfield localization of $\text{Spt}_T M_*$, therefore the identity functor

$$id : R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_* \rightarrow \text{Spt}_T M_*$$

is a left Quillen functor. Thus $X$ is also cofibrant in $\text{Spt}_T M_*$. Since the adjunction $(- \land S^1, \Omega S^1, \varphi)$ is a Quillen equivalence on $\text{Spt}_T M_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $\text{Spt}_T M_*$:

$$X \xrightarrow{\eta_X} \Omega S^1(X \land S^1) \xrightarrow{\Omega S^1 IQ_T J X \land S^1} \Omega S^1 IQ_T J (X \land S^1)$$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $C_{q \text{eff}}$-colocal equivalence.

(2): This follows immediately from proposition 3.2.3 and lemma 3.2.7.

Remark 3.2.9. The adjunction $(\Sigma_T, \Omega_T, \varphi)$ is a Quillen equivalence on $\text{Spt}_T M_*$. However it does not descend even to a Quillen adjunction on the $q$-connected motivic stable model category $R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_*$.

Corollary 3.2.10. For every $q \in \mathbb{Z}$, $R_{C_{q \text{eff}}}^{q} \mathcal{H}(S)$ has the structure of a triangulated category.

Proof. Theorem 3.2.1 implies in particular that $R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_*$ is a pointed simplicial model category, and corollary 3.2.8 implies that the adjunction

$$(- \land S^1, \Omega S^1, \varphi) : R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_* \rightarrow R_{C_{q \text{eff}}}^{q} \text{Spt}_T M_*$$

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII].

Proposition 3.2.11. We have the following adjunction

$$(C_q, IQ_T J, \varphi) : R_{C_{q \text{eff}}}^{q} \mathcal{H}(S) \rightarrow \mathcal{H}(S)$$

between exact functors of triangulated categories.
3.2. Model Structures for the Slice Filtration

**Proof.** Since $R_{C_{eff}^q}$ Spt₇Mₘₙ is the right Bousfield localization of Spt₇Mₘₙ with respect to the $C_{eff}^q$-colocal equivalences, we have that the identity functor $id : R_{C_{eff}^q}$ Spt₇Mₘₙ → Spt₇Mₘₙ is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(C_q, IQ_TJ, \varphi) : R_{C_{eff}^q} \mathcal{H}(S) \longrightarrow \mathcal{H}(S)$$

Now proposition 6.4.1 in [10] implies that $C_q$ maps cofibre sequences in $R_{C_{eff}^q} \mathcal{H}(S)$ to cofibre sequences in $\mathcal{H}(S)$. Therefore using proposition 7.1.12 in [10] we have that $C_q$ and $IQ_TJ$ are both exact functors between triangulated categories. □

**Proposition 3.2.12.** Fix $q \in \mathbb{Z}$. Then the unit of the adjunction

$$(C_q, IQ_TJ, \varphi) : R_{C_{eff}^q} \mathcal{H}(S) \longrightarrow \mathcal{H}(S)$$

$\sigma_X : X \rightarrow IQ_TJC_qX$ is an isomorphism in $R_{C_{eff}^q} \mathcal{H}(S)$ for every $T$-spectrum $X$, and the functor:

$$C_q : R_{C_{eff}^q} \mathcal{H}(S) \rightarrow \mathcal{H}(S)$$

is a full embedding.

**Proof.** For any $T$-spectrum $X$, we have the following commutative diagram in $R_{C_{eff}^q}$ Spt₇Mₘₙ:

$$\begin{array}{ccc}
C_qX & \xrightarrow{C_qX} & X \\
IQ_TJC_qX \downarrow & & \downarrow IQ_TX \\
IQ_TJC_qX & \xrightarrow{IQ_TJ(C_qX)} & IQ_TX
\end{array}$$

where $IQ_TJC_qX$ is in particular a weak equivalence in Spt₇Mₘₙ. But since $R_{C_{eff}^q}$ Spt₇Mₘₙ is the right Bousfield localization of Spt₇Mₘₙ with respect to the $C_{eff}^q$-colocal equivalences, proposition 3.1.5 in [7] implies that $IQ_TJC_qX$ is also a $C_{eff}^q$-colocal equivalence.

On the other hand, by construction we have that $C_qX$ is a $C_{eff}^q$-colocal equivalence. Therefore $IQ_TJC_qX$ and $C_qX$ both become isomorphisms in $R_{C_{eff}^q} \mathcal{H}(S)$. 

Finally, since $\sigma_X$ is the following composition in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$:

$$X \xrightarrow{(C_X)^{-1}} C_q X \xrightarrow{I_{\mathcal{T}} J C_q X} I_{\mathcal{T}} J C_q X$$

it follows that $\sigma_X$ is an isomorphism in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$ as we wanted. This also implies that the functor

$$C_q : R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S) \to \mathcal{M}(S)$$

is a full embedding.

\begin{proof}
Complete the map $f$ to a distinguished triangle in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$:

$$X \xrightarrow{f} Y \xrightarrow{} Z \xrightarrow{} \Sigma^1_{\mathcal{T}} X$$

We have that

$$C_q X \xrightarrow{C_q f} C_q Y \xrightarrow{} C_q Z \xrightarrow{} \Sigma^1_{\mathcal{T}} C_q X$$

is also a distinguished triangle in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$, therefore $C_q f$ is an isomorphism in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$ if and only if $C_q Z \cong *$ in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$; and since $C_q$ is a cofibrant replacement functor in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \text{Spt}_{\mathcal{T}} \mathcal{M}_*$ we have that $f$ is an isomorphism in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$ if and only if $C_q f$ is an isomorphism in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$.

Hence, $f$ is an isomorphism in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$ if and only if $C_q Z \cong *$ in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$. Now corollary 3.2.6 implies that $C_q Z \cong *$ in $R_{\mathcal{C}^q_{e_{\text{eff}}}} \mathcal{M}(S)$ if and only if for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U) \in \mathcal{C}^q_{e_{\text{eff}}}$:

$$[F_n(S^r \wedge \mathbb{G}_m^s \wedge U), C_q Z]_{\text{Spt}} \cong 0$$
But proposition 3.2.11 implies that the diagram (3.3) is a distinguished triangle in \( \mathcal{SH}(S) \); and since for every \( F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{eff} \), the functor \( [F_n(S^r \wedge G^s_m \wedge U_+), -]_{Spt} \) is homological, we get the following long exact sequence of abelian groups

\[
\begin{align*}
\vdots \\
[F_n(S^r \wedge G^s_m \wedge U_+), C_q X]_{Spt} \\
\downarrow (C_q f)_* \\
[F_n(S^r \wedge G^s_m \wedge U_+), C_q Y]_{Spt} \\
\downarrow \\
[F_n(S^r \wedge G^s_m \wedge U_+), C_q Z]_{Spt} \\
\downarrow \\
[F_n(S^r \wedge G^s_m \wedge U_+), \Sigma^1_\mathcal{T} C_q X]_{Spt} \xrightarrow{\cong} [F_n(S^r \wedge G^{s+1}_m \wedge U_+), C_q X]_{Spt} \\
\downarrow (\Sigma^1_\mathcal{T} C_q f)_* \\
[F_n(S^r \wedge G^s_m \wedge U_+), \Sigma^1_\mathcal{T} C_q Y]_{Spt} \xrightarrow{\cong} [F_n(S^r \wedge G^{s+1}_m \wedge U_+), C_q Y]_{Spt} \\
\downarrow \\
\vdots
\end{align*}
\]

Therefore \( [F_n(S^r \wedge G^s_m \wedge U_+), C_q Z]_{Spt} \cong 0 \) for every \( F_n(S^r \wedge G^s_m \wedge U_+) \in \mathcal{C}^q_{eff} \) if and only if the induced map

\[
[F_n(S^r \wedge G^s_m \wedge U_+), C_q X]_{Spt} \xrightarrow{(C_q f)_*} [F_n(S^r \wedge G^s_m \wedge U_+), C_q Y]_{Spt}
\]

is an isomorphism of abelian groups for every \( F_n(S^r \wedge G^s_m \wedge U_+) \in \mathcal{C}^q_{eff} \). This finishes the proof. \( \square \)

**Proposition 3.2.14.** Fix \( q \in \mathbb{Z} \), and let \( A \) be an arbitrary \( T \)-spectrum in \( \Sigma^q_\mathcal{T} \mathcal{SH^{eff}}(S) \). Then \( (Q_s A) \wedge S^1 \) is a \( C^q_{eff} \)-colocal \( T \)-spectrum in \( \text{Spt}_T M_* \).

**Proof.** Let \( \omega_0, \eta_0 \) denote the base points corresponding to

\[
\text{Map}_*(Q_s A, IQ_T JX) \quad \text{and} \quad \text{Map}_*(Q_s A, IQ_T JY)
\]

respectively.
It is clear that $Q_s A \cong A$ in $\mathcal{SH}(S)$; then $Q_s A$ is in $\Sigma^{q}_{T} \mathcal{SH}^{eff}(S)$, since $A$ is in $\Sigma^{q}_{T} \mathcal{SH}^{eff}(S)$ and $\Sigma^{q}_{T} \mathcal{SH}^{eff}(S)$ is a triangulated subcategory of $\mathcal{SH}(S)$.

Since $\text{Spt}_{T} M^*$ is a simplicial model category, we have that $Q_s A \wedge S^1$ is cofibrant in $\text{Spt}_{T} M^*$, hence it suffices to check that for every $C_{eff}^{q}$-colocal equivalence $f : X \to Y$, the induced map

$$\text{Map}(Q_s A \wedge S^1, I_{Q T} J X) \xrightarrow{(I_{Q T} J f)_*} \text{Map}(Q_s A \wedge S^1, I_{Q T} J Y)$$

is a weak equivalence of simplicial sets.

Now corollary 3.2.8 together with proposition 3.2.3 imply that for every $n \geq 0$,

$$\Omega_{S^n} I_{Q T} J (f)$$

is also a $C_{eff}^{q}$-colocal equivalence. Hence corollary 3.2.5 implies that $r_q \Omega_{S^n} I_{Q T} J (f)$ is an isomorphism in $\Sigma^{q}_{T} \mathcal{SH}^{eff}(S)$. Since $Q_s A \in \Sigma^{q}_{T} \mathcal{SH}^{eff}(S)$, we have that $i_q Q_s A = Q_s A$, then by proposition 3.1.12 we get the following commutative diagram where both rows and the left vertical map are isomorphisms of abelian groups:

Therefore the right vertical map is also an isomorphism of abelian groups.

Now since $\text{Spt}_{T} M^*$ is a pointed simplicial model category, we have that lemma 6.1.2 in [10] together with remark 2.4.3(2) imply that the following diagram is commutative for $n \geq 0$, where all the vertical maps together with the bottom row are isomorphisms of abelian groups:

$$\begin{align*}
\pi_{n,\omega_0} \text{Map}(Q_s A, I_{Q T} J X) & \xrightarrow{(I_{Q T} J f)_*} \pi_{n,\omega_0} \text{Map}(Q_s A, I_{Q T} J Y) \\
\pi_{n,\omega_0} \text{Map}_{s}(Q_s A, I_{Q T} J X) & \xrightarrow{(I_{Q T} J f)_*} \pi_{n,\omega_0} \text{Map}_{s}(Q_s A, I_{Q T} J Y)
\end{align*}$$

$$\begin{align*}
\Omega_{S^n} I_{Q T} J (f)
\end{align*}$$

$$\begin{align*}
\pi_{n,\omega_0} \text{Map}(Q_s A, I_{Q T} J X) & \xrightarrow{(I_{Q T} J f)_*} \pi_{n,\omega_0} \text{Map}(Q_s A, I_{Q T} J Y) \\
\pi_{n,\omega_0} \text{Map}_{s}(Q_s A, I_{Q T} J X) & \xrightarrow{(I_{Q T} J f)_*} \pi_{n,\omega_0} \text{Map}_{s}(Q_s A, I_{Q T} J Y)
\end{align*}$$

$$\begin{align*}
\Omega_{S^n} I_{Q T} J (f)
\end{align*}$$
Therefore all the maps in the top row are also isomorphisms. Thus, the induced map

$$\text{Map}(Q_s A, IQ_T JX) \xrightarrow{(IQ_T Jf)_*} \text{Map}(Q_s A, IQ_T JY)$$

is a weak equivalence when it is restricted to the path component of $\text{Map}(Q_s A, IQ_T JX)$ containing $\omega_0$. This implies that the following induced map

$$\text{Map}_*(S^1, \text{Map}_*(Q_s A, IQ_T JX)) \xrightarrow{(IQ_T Jf)_*} \text{Map}_*(S^1, \text{Map}_*(Q_s A, IQ_T JY))$$

is a weak equivalence since taking $S^1$-loops kills the path components that do not contain the base point.

Finally, since $\text{Spt}_T M$ is a simplicial model category we have that the rows in the following commutative diagram are isomorphisms:

$$\text{Map}_*(S^1, \text{Map}_*(Q_s A, IQ_T JX)) \xrightarrow{\cong} \text{Map}_*(Q_s A \wedge S^1, IQ_T JX) \xrightarrow{(IQ_T Jf)_*} \text{Map}_*(Q_s A \wedge S^1, IQ_T JY) \xrightarrow{\cong} \text{Map}_*(S^1, \text{Map}_*(Q_s A, IQ_T JY))$$

Hence the two out of three property for weak equivalences implies that the right vertical map is a weak equivalence of simplicial sets, as we wanted.

**Corollary 3.2.15.** Fix $q \in \mathbb{Z}$ and let $X$ be an arbitrary $T$-spectrum in $\Sigma_T^{q, \text{eff}} \text{SH}^e(S)$. Then $Q_s X$ is a $C_{\text{eff}}^q$-colocal $T$-spectrum in $\text{Spt}_T M$.

**Proof.** Let $R$ denote a fibrant replacement functor on $\text{Spt}_T M$ such that for every $T$-spectrum $Y$, the natural map

$$Y \xrightarrow{R_Y} RY$$

is a trivial cofibration in $\text{Spt}_T M$. Then $RQ_s X$ is cofibrant in $\text{Spt}_T M$. Now the map

$$Q_s X \xrightarrow{RQ_s X} RQ_s X$$
is in particular a weak equivalence in $\text{Spt}_T M_*$, therefore using \cite[lemma 3.2.1(2)]{7} we get that $Q_s X$ is $C_{eff}^q$-colocal if and only if $RQ_s X$ is $C_{eff}^q$-colocal. We will show that $RQ_s X$ is $C_{eff}^q$-colocal.

By hypothesis $X$ is in $\Sigma^q_T \mathcal{H}^{eff}(S)$ and it is clear that $Q_s X \cong X$ in $S\mathcal{H}(S)$. Hence $Q_s X$ is also in $\Sigma^q_T \mathcal{H}^{eff}(S)$ since it is a triangulated subcategory of $S\mathcal{H}(S)$. Therefore $\Omega_{S^1} RQ_s X$ is also in $\Sigma^q_T \mathcal{H}^{eff}(S)$ since $\Omega_{S^1} RQ_s X$ computes the desuspension $\Sigma^{-1,0}_T Q_s X$ of $Q_s X$.

Using proposition 3.2.14 we have that $(Q_s \Omega_{S^1} RQ_s X) \wedge S^1$ is $C_{eff}^q$-colocal. But since the adjunction

$(- \wedge S^1, \Omega_{S^1}, \varphi) : \text{Spt}_T M_* \to \text{Spt}_T M_*$

is a Quillen equivalence, we have the following weak equivalence in $\text{Spt}_T M_*$:

$$(Q_s \Omega_{S^1} RQ_s X) \wedge S^1 \xrightarrow{\epsilon_{RQ_s X \wedge (Q_s \Omega_{S^1} RQ_s X) \wedge \text{id}}} RQ_s X$$

where $\epsilon$ denotes the counit of the adjunction considered above.

Finally using \cite[lemma 3.2.1(2)]{7} again, we get that $RQ_s X$ is $C_{eff}^q$-colocal. This finishes the proof.

**Proposition 3.2.16.** Fix $q \in \mathbb{Z}$ and let $\rho$ be the counit of the adjunction:

$$(C_q, IQ_T J, \varphi) : R_{C_{eff}^q} S\mathcal{H}(S) \to S\mathcal{H}(S)$$

Then for every $T$-spectrum $X$, the map

$$r_q(\rho_X) : r_q C_q IQ_T J X \to r_q X$$

is an isomorphism in $\Sigma^q_T \mathcal{H}^{eff}(S)$; and this map induces a natural isomorphism between the following exact functors

$$S\mathcal{H}(S) \xrightarrow{r_q C_q IQ_T J} \Sigma^q_T \mathcal{H}^{eff}(S)$$

**Proof.** The naturality of the counit $\rho$, implies that $r_q(\rho_\ast) : r_q C_q IQ_T J \to r_q$ is a natural transformation. Hence, it is enough to show that for every $T$-spectrum $X$, $r_q(\rho_X)$ is an isomorphism in $\Sigma^q_T \mathcal{H}^{eff}(S)$.
Consider the following diagram of $T$-spectra:

$$
\begin{array}{c}
C_q IQ_T JX \xrightarrow{C_q^{IQ_T JX}} IQ_T JX \xleftarrow{IQ_T JX} X \\
\end{array}
$$

where $IQ_T JX$ is a weak equivalence in $\text{Spt}_T \mathcal{M}_*$ and $C_q^{IQ_T JX}$ is a $C_q$-colocal equivalence.

Then it is clear that $r_q(IQ_T JX)$ is an isomorphism in $\Sigma^q_T \text{SH}^{eff}(S)$. On the other hand, corollary 3.2.5 implies that $r_q(C_q^{IQ_T JX})$ is also an isomorphism in $\Sigma^q_T \text{SH}^{eff}(S)$.

And this proves the result, since $\rho_X$ is just the following composition in $\text{SH}(S)$:

$$
\begin{array}{c}
C_q IQ_T JX \xrightarrow{C_q^{IQ_T JX}} IQ_T JX \xrightarrow{(IQ_T JX)^{-1}} X \\
\end{array}
$$

\[ \square \]

**Proposition 3.2.17.** Fix $q \in \mathbb{Z}$ and let $\theta$ be the counit of the adjunction

$$(i_q, r_q, \varphi) : \Sigma^q_T \text{SH}^{eff}(S) \longrightarrow \text{SH}^{eff}(S)$$

Then for any $T$-spectrum $X$ in $\text{Spt}_T \mathcal{M}_*$, the map

$$IQ_T J(\theta_X) : IQ_T J(i_q r_q)X \longrightarrow IQ_T JX$$

is an isomorphism in $R_{C_q^{eff}} \text{SH}(S)$; and this map induces a natural isomorphism between the following exact functors

$$
\begin{array}{c}
\text{SH}(S) \xrightarrow{IQ_T J(\theta_X)} R_{C_q^{eff}} \text{SH}(S) \\
\end{array}
$$

**Proof.** The naturality of the counit $\theta$, implies that $IQ_T J(\theta_\cdot) : IQ_T J(i_q r_q) \longrightarrow IQ_T J$ is a natural transformation. Hence, it is enough to show that for every $T$-spectrum $X$, $IQ_T J(\theta_X)$ is an isomorphism in $R_{C_q^{eff}} \text{SH}(S)$.

By proposition 3.2.13 it is enough to show that for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_q$ the induced maps

$$
\begin{array}{c}
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), C_q IQ_T J(i_q r_q)X]_{\text{Spt}} \xrightarrow{C_q IQ_T J(\theta_X)_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), C_q IQ_T JX]_{\text{Spt}} \\
\end{array}
$$


are all isomorphisms of abelian groups.

Consider the following commutative diagram in $\mathcal{SH}(S)$:

$$
\begin{array}{ccc}
C_qIQ_TJ(i_qr_q)X & \xrightarrow{C_qIQ_TJ(\theta_X)} & C_qIQ_TJX \\
\downarrow & & \downarrow \\
IQ_TJ(i_qr_q)X & \xrightarrow{IQ_TJ(\theta_X)} & IQ_TJX \\
\end{array}
$$

where $C_qIQ_TJi_qr_qX$ and $C_qIQ_TJX$ are by construction maps of $T$-spectra and $C^q_{eff}$-colocal equivalences. Therefore proposition 3.2.4 implies that for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{eff}$ the induced maps

$$
[F_n(S^r \wedge G^s_m \wedge U_+), C_qIQ_TJ(i_qr_q)X]_{Spt} \quad [F_n(S^r \wedge G^s_m \wedge U_+), C_qIQ_TJX]_{Spt}
$$

are both isomorphisms of abelian groups.

On the other hand, proposition 3.1.15 implies that we have an induced isomorphism of abelian groups:

$$
[F_n(S^r \wedge G^s_m \wedge U_+), IQ_TJ(i_qr_q)X]_{Spt} \quad [F_n(S^r \wedge G^s_m \wedge U_+), IQ_TJX]_{Spt}
$$

for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{eff}$.

Finally, this implies that for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{eff}$, we get the following induced isomorphisms of abelian groups

$$
[F_n(S^r \wedge G^s_m \wedge U_+), C_qIQ_TJ(i_qr_q)X]_{Spt} \quad [F_n(S^r \wedge G^s_m \wedge U_+), C_qIQ_TJX]_{Spt}
$$

as we wanted.

\[\square\]

**Proposition 3.2.18.** Fix $q \in \mathbb{Z}$, and let $\theta$ be the counit of the adjunction

$$(i_q, r_q, \varphi) : \Sigma^q_T \mathcal{SH}^{eff}(S) \longrightarrow \mathcal{SH}^{eff}(S)$$
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Then for any $T$-spectrum $X$, the map

$$C_q IQ_T J(\theta_X) : C_q IQ_T J(i_q r_q) X \longrightarrow C_q IQ_T J X$$

is an isomorphism in $\mathcal{SH}(S)$; and this map induces a natural isomorphism between the following exact functors

$$\mathcal{SH}(S) \xrightarrow{C_q IQ_T J(i_q r_q)} \mathcal{SH}(S)$$

**Proof.** The naturality of the counit $\theta$, implies that $C_q IQ_T J(\theta_-) : C_q IQ_T J(i_q r_q) \rightarrow C_q IQ_T J$ is a natural transformation. Hence, it is enough to show that for every $T$-spectrum $X$, $C_q IQ_T J(\theta_X)$ is an isomorphism in $\mathcal{SH}(S)$.

But this follows immediately from proposition 3.2.17 together with proposition 3.2.11. □

**Proposition 3.2.19.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, the natural map

$$C_q IQ_T J(i_q r_q) X \xrightarrow{C_q IQ_T J(i_q r_q) X} IQ_T J(i_q r_q) X$$

is a weak equivalence in $\text{Spt}_T \mathcal{M}_*$. Therefore we have a natural isomorphism between the following exact functors

$$\mathcal{SH}(S) \xrightarrow{C_q IQ_T J(i_q r_q)} \mathcal{SH}(S)$$

**Proof.** The naturality of the maps $C_q^X : C_q X \rightarrow X$ implies that we have an induced natural transformation of functors $C_q IQ_T J(i_q r_q) \rightarrow IQ_T J(i_q r_q)$. Hence, it is enough to show that for every $T$-spectrum $X$, $C_q^X IQ_T J(i_q r_q) X$ is a weak equivalence in $\text{Spt}_T \mathcal{M}_*$.

Consider the following commutative diagram in $\text{Spt}_T \mathcal{M}_*$:

$$
\begin{array}{ccc}
Q_s C_q IQ_T J(i_q r_q) X & \xrightarrow{Q_s(C_q^X IQ_T J(i_q r_q) X)} & Q_s IQ_T J(i_q r_q) X \\
Q_s C_q IQ_T J(i_q r_q) X & \xrightarrow{Q_s C_q^X IQ_T J(i_q r_q) X} & Q_s IQ_T J(i_q r_q) X \\
C_q IQ_T J(i_q r_q) X & \xrightarrow{C_q^X IQ_T J(i_q r_q) X} & IQ_T J(i_q r_q) X \\
\end{array}
$$

Since $Q_s$ is a cofibrant replacement functor in $\text{Spt}_T \mathcal{M}_*$, it follows that the vertical maps are weak equivalences in $\text{Spt}_T \mathcal{M}_*$. Hence by the two out of three property for weak equivalences it suffices to show that $Q_s(C_q^X IQ_T J(i_q r_q) X)$ is a weak equivalence in $\text{Spt}_T \mathcal{M}_*$. 

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On the other hand we have that by construction $C_q^{IQ_TJ(i_q r_q)X}$ is a $C_{eff}^q$-colocal equivalence, and [7, proposition 3.1.5] implies that the vertical maps in the diagram above are also $C_{eff}^q$-colocal equivalences. Then by the two out of three property for $C_{eff}^q$-colocal equivalences we have that $Q_s(C_q^{IQ_TJ(i_q r_q)X})$ is a $C_{eff}^q$-colocal equivalence.

Now by construction we have that $C_q^{IQ_TJ(i_q r_q)X}$ is a $C_{eff}^q$-colocal $T$-spectrum, and that $Q_sC_q^{IQ_TJ(i_q r_q)X}$ is cofibrant in $Spt_{T\mathcal{M}}$. Since $Q_sC_q^{IQ_TJ(i_q r_q)X}$ is in particular a weak equivalence in $Spt_{T\mathcal{M}}$, using [7, lemma 3.2.1(2)] we have that $Q_sC_q^{IQ_TJ(i_q r_q)X}$ is also a $C_{eff}^q$-colocal $T$-spectrum.

Finally we have that $Q_s(C_q^{IQ_TJ(i_q r_q)X})$ is a $C_{eff}^q$-colocal equivalence, and that $Q_sC_q^{IQ_TJ(i_q r_q)X}$ and $Q_s^{IQ_TJ(i_q r_q)X}$ are both $C_{eff}^q$-colocal $T$-spectra. Then [7, theorem 3.2.13(2)] implies that $Q_s(C_q^{IQ_TJ(i_q r_q)X})$ is a weak equivalence in $Spt_{T\mathcal{M}}$, as we wanted.

**Theorem 3.2.20.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, we have the following diagram in $\mathcal{H}(S)$:

\[
\begin{array}{c}
\overset{\cong}{\cong}
\end{array}
\]

where all the maps are isomorphisms in $\mathcal{H}(S)$. This diagram induces a natural isomorphism between the following exact functors:

\[
\begin{array}{c}
\overset{\cong}{\cong}
\end{array}
\]
Proof. Since $IQ_T J$ is a fibrant replacement functor in $Spt_T M_*$, it is clear that $IQ_T J f_q X$ becomes an isomorphism in the associated homotopy category $SH(S)$. The fact that $C_q IQ_T J f_q X$ is an isomorphism in $SH(S)$ follows from proposition 3.2.19. Finally, proposition 3.2.18 implies that $C_q IQ_T J (\theta_X)$ is also an isomorphism in $SH(S)$. This shows that all the maps in the diagram (3.4) are isomorphisms in $SH(S)$, therefore for every $T$-spectrum $X$ we can define the following composition in $SH(S)$

$$f_q X \xrightarrow{IQ_T J f_q X} IQ_T J f_q X \xrightarrow{\cong} C_q IQ_T J f_q X \xrightarrow{\cong} C_q IQ_T J X$$

which is an isomorphism. The fact that $IQ_T J$ is a functorial fibrant replacement in $Spt_T M_*$, propositions 3.2.19 and 3.2.18, imply all together that the isomorphisms defined in diagram (3.5) induce a natural isomorphism of functors $f_q \cong C_q IQ_T J$. This finishes the proof.

Theorem 3.2.20 gives the desired lifting to the model category level for the functor $f_q$. Now we proceed to show that the homotopy categories $RC_q eff SH(S)$ are in fact equivalent to the categories $\Sigma^q_T SH eff(S)$ defined in section 3.1.

Using propositions 3.1.12 and 3.2.11, we get the following diagram of adjunctions:

$$RC_q eff SH(S) \xrightarrow{(C_q, IQ_T J, \varphi)} SH(S) \xrightarrow{(i_q, r_q, \varphi)} \Sigma^q_T SH eff(S)$$

$$RC_q eff SH(S) \xleftarrow{C_q} SH(S) \xleftarrow{r_q} \Sigma^q_T SH eff(S)$$

(3.6)

where all the functors are exact.
Proposition 3.2.21. For every $q \in \mathbb{Z}$ the adjunctions of diagram (3.6) induce an equivalence of categories:

$$
\begin{array}{ccc}
R_{C_q^{eff}} \mathcal{S}H(S) & \xrightarrow{r_q C_q} & \Sigma^q \mathcal{S}H^{eff}(S) \\
\downarrow_{iQ_T J_iq} & & \downarrow_{\sigma^q} \\
\Sigma^q \mathcal{S}H^{eff}(S) & \xleftarrow{\Sigma_T C_q} & R_{C_q^{eff}} \mathcal{S}H(S)
\end{array}
$$

between $R_{C_q^{eff}} \mathcal{S}H(S)$ and $\Sigma^q \mathcal{S}H^{eff}(S)$.

Proof. It is enough to show the existence of the following natural isomorphisms between functors:

$$
id \xrightarrow{\epsilon} (IQT \ J_iq)(r_q C_q)
$$

(3.8)

We construct first the natural equivalence $\epsilon$. Let $f : X \rightarrow Y$ be a map in $R_{C_q^{eff}} \mathcal{S}H(S)$. Applying the functor $i_q r_q C_q$, we get the following commutative diagram in $\mathcal{S}H(S)$:

$$
\begin{array}{ccc}
i_q r_q C_q X & \xrightarrow{\theta_{C_q X}} & C_q X \\
\downarrow i_q r_q C_q f & & \downarrow C_q f \\
i_q r_q C_q Y & \xrightarrow{\theta_{C_q Y}} & C_q Y
\end{array}
$$

where $\theta$ denotes the counit of the adjunction between $i_q$ and $r_q$. Now if we apply the functor $IQT \ J$, we have the following commutative diagram in $R_{C_q^{eff}} \mathcal{S}H(S)$:

$$
\begin{array}{ccc}
IQT \ J i_q r_q C_q X & \xrightarrow{IQT \ J(\theta_{C_q X})} & IQT \ J C_q X \\
\downarrow_{IQT \ J i_q r_q C_q f} & & \downarrow_{IQT \ J C_q f} \\
IQT \ J i_q r_q C_q Y & \xrightarrow{\cong} & IQT \ J C_q Y
\end{array}
$$

where $\sigma$ denotes the unit of the adjunction between $C_q$ and $IQT \ J$. But propositions 3.2.17 and 3.2.12 imply that all the horizontal maps are isomorphisms in $R_{C_q^{eff}} \mathcal{S}H(S)$. Now if we define

$$
\epsilon_X = (IQT \ J(\theta_{C_q X}))^{-1} \circ (\sigma_X)
$$

we get the natural isomorphism of functors $\epsilon : id \rightarrow (IQT \ J_iq)(r_q C_q)$.

To finish the proof, we proceed to construct the natural equivalence $\eta$. Let $f : X \rightarrow Y$ be a map in $\Sigma^q \mathcal{S}H^{eff}(S)$. Applying the functor $C_q IQT \ J_iq$, we get the following commutative
diagram in $\mathcal{SH}(S)$:

\[
\begin{array}{ccc}
C_qIQ_T Ji_q X & \xrightarrow{\rho_{iq} X} & i_q X \\
C_qIQ_T Ji_q f & \downarrow & \downarrow i_q f \\
C_qIQ_T Ji_q Y & \xrightarrow{\rho_{iq} Y} & i_q Y
\end{array}
\]

where $\rho$ denotes the counit of the adjunction between $C_q$ and $IQ_T$. Now if we apply the functor $r_q$, we have the following commutative diagram in $\Sigma^q_T \mathcal{SH}_{eff}(S)$:

\[
\begin{array}{ccc}
r_q C_q IQ_T Ji_q X & \xrightarrow{\approx} & r_q i_q X \\
r_q C_q IQ_T Ji_q f & \xrightarrow{\approx} & r_q i_q f \\
r_q C_q IQ_T Ji_q Y & \xrightarrow{\approx} & r_q i_q Y
\end{array}
\]

where $\tau$ denotes the unit of the adjunction between $i_q$ and $r_q$. But proposition 3.2.16 and remark 3.1.13 imply that all the horizontal maps are isomorphisms in $\Sigma^q_T \mathcal{SH}_{eff}(S)$. Now if we define

\[
\eta_X = (\tau_X)^{-1} \circ r_q(\rho_{iq} X)
\]

we get the natural isomorphism of functors $\eta : (r_q C_q)(IQ_T Ji_q) \to id$. This finishes the proof.

\[
\text{Proposition 3.2.22.} \text{ Fix } q \in \mathbb{Z}.
\]

1. We have the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
R_{C^{q+1}_{eff}} Spt_T M_* & \xrightarrow{id} & R_{C^q_{eff}} Spt_T M_* \\
\downarrow{id} & & \downarrow{id} \\
Spt_T M_* & \xrightarrow{id} & Spt_T M_*
\end{array}
\]

(3.9)

2. For every $T$-spectrum $X$, the natural map:

\[
C_q C_{q+1} X \xrightarrow{C^{q+1}_{eff} X} C_{q+1} X
\]

is a weak equivalence in $\mathcal{SH}(S)$, and it induces a natural equivalence $C_{q+1} : C_q \circ$
$C_{q+1} \to C_q$ between the following functors:

\[
\begin{array}{cccc}
\mathcal{R}_{C_{q+1}}^{\text{eff}} \mathcal{SH}(S) & \xrightarrow{C_{q+1}} & \mathcal{R}_{C_q}^{\text{eff}} \mathcal{SH}(S) \\
\downarrow & & \downarrow & \\
\mathcal{SH}(S) & \xrightarrow{C_q} & \mathcal{SH}(S)
\end{array}
\]

3. The natural transformation $f_{q+1}X \to f_qX$ (see theorem 3.1.16(1)) gets canonically identified, through the equivalence of categories $r_qC_q$, $IQ_T J_i q$ constructed in proposition 3.2.21; with the following composition in $SH(S)$

\[
\begin{array}{ccc}
C_qC_{q+1}IQ_T JX & \xrightarrow{(C_qC_{q+1}IQ_T JX)} & C_qIQ_T JX \\
\downarrow & & \downarrow & \\
C_{q+1}IQ_T JX & \xrightarrow{C_{q+1}IQ_T JX} & C_qIQ_T JX
\end{array}
\]

which is induced by the following commutative diagram in $Spt_T M_*$

\[
\begin{array}{ccc}
C_qC_{q+1}IQ_T JX & \xrightarrow{C_q(C_{q+1}IQ_T JX)} & C_qIQ_T JX \\
\downarrow & & \downarrow & \\
C_{q+1}IQ_T JX & \xrightarrow{C_{q+1}IQ_T JX} & IQ_T JX
\end{array}
\]

(3.10)

**Proof.** (1): Since $R_{C_{q+1}}^{\text{eff}} Spt_T M_*$ and $R_{C_q}^{\text{eff}} Spt_T M_*$ are both right Bousfield localizations of $Spt_T M_*$, by construction the identity functor

\[
\begin{array}{ccc}
R_{C_{q+1}}^{\text{eff}} Spt_T M_* & \xrightarrow{id} & Spt_T M_* \\
R_{C_q}^{\text{eff}} Spt_T M_* & \xrightarrow{id} & Spt_T M_*
\end{array}
\]

is in both cases a left Quillen functor. To finish the proof, it suffices to show that the identity functor

\[
id : R_{C_q}^{\text{eff}} Spt_T M_* \to R_{C_{q+1}}^{\text{eff}} Spt_T M_*
\]

is a right Quillen functor. Using the universal property of right Bousfield localizations (see definition 1.8.2), it is enough to check that if $f : X \to Y$ is a $C_{q+1}^{\text{eff}}$-colocal equivalence in $Spt_T M_*$ then $IQ_T J(f)$ is a $C_q^{\text{eff}}$-colocal equivalence. But since $IQ_T JX$ and $IQ_T JY$ are
already fibrant in $\text{Spt}_T M_*$, we have that $IQ_T J(f)$ is a $C^{q+1}_\text{eff}$-colocal equivalence if and only if for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^{q+1}_\text{eff}$, the induced map:

$$
\begin{align*}
\text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T JX) \\
\downarrow^{IQ_T J(f)_*} \\
\text{Map}(F_n(S^r \wedge G^s_m \wedge U_+), IQ_T JY)
\end{align*}
$$

is a weak equivalence of simplicial sets. But since $C^{q+1}_\text{eff} \subseteq C^q_{\text{eff}}$, and by hypothesis $f$ is a $C^q_{\text{eff}}$-colocal equivalence; we have that all the induced maps $IQ_T J(f)_*$ are weak equivalences of simplicial sets. Thus $IQ_T J(f)$ is a $C^{q+1}_\text{eff}$-colocal equivalence, as we wanted.

Finally (2) and (3) follow directly from proposition 3.2.21, theorem 3.2.20 together with the commutative diagram (3.9) of left Quillen functors constructed above and [10, theorem 1.3.7].

\[\text{Theorem 3.2.23.} \text{ We have the following commutative diagram of left Quillen functors:}\]

\[
\begin{array}{ccc}
\vdots & \downarrow{id} & \\
& R_{C^{q+1}_{\text{eff}}} \text{Spt}_T M_* & \\
& \downarrow{id} & \downarrow{id} \\
& R_{C^q_{\text{eff}}} \text{Spt}_T M_* & \Rightarrow \text{Spt}_T M_* \\
& \downarrow{id} & \downarrow{id} \\
& R_{C^{q-1}_{\text{eff}}} \text{Spt}_T M_* & \\
& \downarrow{id} & \\
& \vdots & \\
\end{array}
\]
and the associated diagram of homotopy categories:

\[
\begin{array}{c}
\vdots \\
R_{C_{\text{eff}}^{q+1}} \mathcal{SH}(S) \\
C_{q+1} \\
R_{C_{\text{eff}}^q} \mathcal{SH}(S) \\
C_q \\
R_{C_{\text{eff}}^{q-1}} \mathcal{SH}(S) \\
\vdots
\end{array}
\]

gets canonically identified, through the equivalences of categories \(r_q C_q, IQ_T J i_q\) constructed in proposition 3.2.21; with Voevodsky’s slice filtration:

\[
\begin{array}{c}
\vdots \\
\Sigma_{T}^{q+1} \mathcal{SH}(S) \\
r_{q+1} \\
\Sigma_{T}^{q} \mathcal{SH}_{\text{eff}}(S) \\
r_q \\
\Sigma_{T}^{q-1} \mathcal{SH}(S) \\
\vdots
\end{array}
\]

\[(3.12)\]

**Proof.** Follows immediately from propositions 3.2.22 and 3.2.21.

**Remark 3.2.24.** The drawback of the model structures on \(R_{C_{\text{eff}}^q} \text{Spt}_T \mathcal{M}_*\) is that it is not clear if they are cellular again. Therefore in order to recover a lifting for the slice functors \(s_q\), we are forced to take an indirect approach.

The first step in this new approach will be to construct another family of model structures
on $\text{Spt}_T(\text{Sm}|_S)_{\text{Nis}}$, via left Bousfield localization; such that the fibrant replacement functor provides an alternative description of the functors $s_{<q}$ defined in theorem 3.1.18.

**Definition 3.2.25.** For $r \geq 1$, we define $D^r$ using the following pushout diagram of simplicial sets:

$$
\begin{array}{ccc}
S^{r-1} & \xrightarrow{j_0} & S^{r-1} \times \Delta^1 \\
\downarrow & & \downarrow p \\
* & \xrightarrow{\iota_1} & D^r
\end{array}
$$

where $j_0$ is the following composition:

$$
S^{r-1} \cong S^{r-1} \times \Delta^0 \xrightarrow{id \times d_1} S^{r-1} \times \Delta^1
$$

and let $\iota_1 : S^{r-1} \to D^r$ be the following composition:

$$
S^{r-1} \cong S^{r-1} \times \Delta^0 \xrightarrow{id \times d_0} S^{r-1} \times \Delta^1 \xrightarrow{p} D^r
$$

**Remark 3.2.26.** It is clear that the canonical map $* \to D^r$ is a trivial cofibration in the category of pointed simplicial sets.

**Proposition 3.2.27.** For every $r \geq 1$, $s \geq 0$, and for every scheme $U \in \text{Sm}|_S$; the pointed simplicial presheaf on the smooth Nisnevich site over $S$

$$
D^r \land G^s_\mathbb{m} \land U_+
$$

has the following properties:

1. it is compact in the sense of Jardine (see definition 2.3.10).

2. the canonical map $* \to F_n(D^r \land G^s_\mathbb{m} \land U_+)$ is a trivial cofibration in $\text{Spt}_T\mathcal{M}_*$.  

3. the canonical map $F_n(D^r \land G^s_\mathbb{m} \land U_+) \to *$ is a weak equivalence in $\text{Spt}_T\mathcal{M}_*$.

**Proof.** (1): It is clear from the construction that $D^r$ has only finitely many non-degenerate simplices. Therefore the result follows from [13, lemma 2.2].
3.2. Model Structures for the Slice Filtration

(2): Proposition 2.3.7 implies that $M_*$ is a $\text{SSets}_*$-model category; and since $G^s_m \wedge U_+$ is cofibrant, we have the following Quillen adjunction:

$$
\begin{array}{ccc}
\text{SSets}_* & \xrightarrow{- \wedge G^s_m \wedge U_+} & M_* \\
\downarrow & & \downarrow \\
\text{Map}_* (G^s_m \wedge U_+, -) & \rightarrow & 
\end{array}
$$

But $* \rightarrow D^r$ is a trivial cofibration of pointed simplicial sets, therefore the induced map

$$
* \cong * \wedge G^s_m \wedge U_+ \rightarrow D^r \wedge G^s_m \wedge U_+
$$

is a trivial cofibration in $M_*$. Finally using proposition 2.4.17 we have that

$$(F_n, Ev_n, \varphi) : M_* \longrightarrow \text{Spt}_T M_*
$$

is a Quillen adjunction. Hence the canonical map

$$
* \cong F_n(*) \rightarrow F_n(D^r \wedge G^s_m \wedge U_+)
$$

is a trivial cofibration in $\text{Spt}_T M_*$, as we wanted.

(3): Follows immediately from (2) and the two out of three property for weak equivalences.

$\square$

**Proposition 3.2.28.** For every compact generator $F_n(S^r \wedge G^s_m \wedge U_+) \in C$ (see proposition 3.1.5), there exists a natural cofibration:

$$
F_n(S^r \wedge G^s_m \wedge U_+) \xrightarrow{\iota^U_{n,r,s}} F_n(D^{r+1} \wedge G^s_m \wedge U_+)
$$

in $\text{Spt}_T M_*$.

**Proof.** We define $\iota^U_{n,r,s}$ as $F_n(\iota_1 \wedge G^s_m \wedge U_+)$, where $\iota_1 : S^r \rightarrow D^{r+1}$ is the map constructed in definition 3.2.25.

It is clear that $\iota_1$ is a cofibration of pointed simplicial sets, therefore the result follows from propositions 2.4.17 and 2.3.7 which imply that $F_n$ and $- \wedge G^s_m \wedge U_+$ are both left Quillen functors.

$\square$
Theorem 3.2.29. Fix $q \in \mathbb{Z}$, and consider the following set of maps in $\text{Spt}_T^{\mathcal{M}_*}$:

$$L(<q) = \{ i_{n,r,s}^U : F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \to F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+) |$$

$$F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C^q_{eff} \}$$

Then the left Bousfield localization of $\text{Spt}_T^{\mathcal{M}_*}$ with respect to the $L(<q)$-local equivalences exist. This new model structure will be called \textbf{weight}$_{<q}$ \textbf{motivic stable}. $L_{<q}\text{Spt}_T^{\mathcal{M}_*}$ will denote the category of $T$-spectra equipped with the weight$^{<q}$ motivic stable model structure, and $L_{<q}\mathcal{H}(S)$ will denote its associated homotopy category. Furthermore the weight$^{<q}$ motivic stable model structure is cellular, left proper and simplicial; with the following sets of generating cofibrations and trivial cofibrations respectively:

$$I_{L(<q)} = I_{M_*}^T = \bigcup_{n \geq 0} \{ F_n(Y_+ \hookrightarrow (\Delta^n_U)_+) \}$$

$$J_{L(<q)} = \{ j : A \to B \}$$

where $j$ satisfies the following conditions:

1. $j$ is an inclusion of $I_{M_*}^T$-complexes.

2. $j$ is a $L(<q)$-local equivalence.

3. the size of $B$ as an $I_{M_*}^T$-complex is less than $\kappa$, where $\kappa$ is the regular cardinal defined by Hirschhorn in [7, definition 4.5.3].

\textbf{Proof}. Theorems 2.5.4 and 2.4.16 imply that $\text{Spt}_T^{\mathcal{M}_*}$ is a cellular, proper and simplicial model category. Therefore the existence of the left Bousfield localization follows from [7, theorem 4.1.1]. Using [7, theorem 4.1.1] again, we have that $L_{<q}\text{Spt}_T^{\mathcal{M}_*}$ is cellular, left proper and simplicial; where the sets of generating cofibrations and trivial cofibrations are the ones described above.

\textbf{Definition 3.2.30}. Fix $q \in \mathbb{Z}$ and let $W_q$ denote a fibrant replacement functor in $L_{<q}\text{Spt}_T^{\mathcal{M}_*}$.
such that the for every $T$-spectrum $X$, the natural map:

$$X \xrightarrow{W^X_q} W_qX$$

is a trivial cofibration in $L_{<q}\text{Spt}_T\mathbb{M}_*$, and $W_qX$ is $L(<q)$-local in $\text{Spt}_T\mathbb{M}_*$.

**Proposition 3.2.31.** Fix $q \in \mathbb{Z}$. Then $Q_s$ is also a cofibrant replacement functor on $L_{<q}\text{Spt}_T\mathbb{M}_*$, and for every $T$-spectrum $X$ the natural map

$$Q_sX \xrightarrow{Q^X_s} X$$

is a trivial fibration in $L_{<q}\text{Spt}_T\mathbb{M}_*$.

**Proof.** Since $L_{<q}\text{Spt}_T\mathbb{M}_*$ is the left Bousfield localization of $\text{Spt}_T\mathbb{M}_*$ with respect to the $L(<q)$-local equivalences, by construction we have that the cofibrations and the trivial fibrations are identical in $L_{<q}\text{Spt}_T\mathbb{M}_*$ and $\text{Spt}_T\mathbb{M}_*$ respectively. This implies that for every $T$-spectrum $X$, $Q_sX$ is cofibrant in $L_{<q}\text{Spt}_T\mathbb{M}_*$, and we also have that the natural map

$$Q_sX \xrightarrow{Q^X_s} X$$

is a trivial fibration in $L_{<q}\text{Spt}_T\mathbb{M}_*$. Hence $Q_s$ is also a cofibrant replacement functor for $L_{<q}\text{Spt}_T\mathbb{M}_*$. \qed

**Proposition 3.2.32.** Fix $q \in \mathbb{Z}$ and let $Z$ be an arbitrary $T$-spectrum. Then $Z$ is $L(<q)$-local in $\text{Spt}_T\mathbb{M}_*$ if and only if the following conditions hold:

1. $Z$ is fibrant in $\text{Spt}_T\mathbb{M}_*$.
2. For every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{\text{eff}}^q$, $[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z]_{\text{Spt}} \cong 0$

**Proof.** ($\Rightarrow$): Assume that $Z$ is $L(<q)$-local. Then by definition we have that $Z$ must be fibrant in $\text{Spt}_T\mathbb{M}_*$. Since all the $T$-spectra $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$ and $F_n(D^r \wedge \mathbb{G}_m^s \wedge U_+)$ are cofibrant, and $Z$ is $L(<q)$-local; for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{\text{eff}}^q$ we get the following weak equivalence of simplicial sets:

$$\text{Map}(F_n(D^r+1 \wedge \mathbb{G}_m^s \wedge U_+), Z) \xrightarrow{(\iota_{u,r,s})^*} \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z)$$
Finally proposition 3.2.27(2) implies that the vertical arrows and the top row are isomorphisms. Therefore we get the following isomorphism:

\[ \pi_0 \text{Map}(F_n(D^{r+1} \land G^s_m \land U_+), Z) \xrightarrow{\cong} \pi_0 \text{Map}(F_n(S^r \land G^s_m \land U_+), Z) \]

where the vertical arrows and the top row are isomorphisms. Therefore we get the following isomorphism:

\[ [F_n(D^{r+1} \land G^s_m \land U_+), Z]_{\text{Spt}} \xrightarrow{\cong} [F_n(S^r \land G^s_m \land U_+), Z]_{\text{Spt}} \]

Finally proposition 3.2.27(2) implies that \([F_n(D^{r+1} \land G^s_m \land U_+), Z]_{\text{Spt}} \cong 0\). Thus, for every \(F_n(S^r \land G^s_m \land U_+) \in C^{q}_{\text{eff}}\) we have that \([F_n(S^r \land G^s_m \land U_+), Z]_{\text{Spt}} \cong 0\), as we wanted.

\((\Leftarrow)\): Assume that \(Z\) satisfies (1) and (2). Let \(\omega_0, \eta_0\) denote the base points corresponding to the pointed simplicial sets \(\text{Map}_*(F_n(D^{r+1} \land G^s_m \land U_+), Z)\) and \(\text{Map}_*(F_n(S^r \land G^s_m \land U_+), Z)\) respectively. Since \(F_n(S^r \land G^s_m \land U_+)\) and \(F_n(D^{r+1} \land G^s_m \land U_+)\) are always cofibrant, it is enough to show that the induced map:

\[ \text{Map}(F_n(D^{r+1} \land G^s_m \land U_+), Z) \xrightarrow{(i^U_{n,r,s})^*} \text{Map}(F_n(S^r \land G^s_m \land U_+), Z) \]

is a weak equivalence of simplicial sets for every map \(i^U_{n,r,s} \in L(< q)\).

Fix \(i^U_{n,r,s} \in L(< q)\). By proposition 3.2.27(3) we know that the map \(F_n(D^{r+1} \land G^s_m \land U_+) \to *\) is a weak equivalence in \(\text{Spt}_T M_*\). Then Ken Brown’s lemma (see lemma 1.1.4) together with the fact that \(\text{Spt}_T M_*\) is a simplicial model category, imply that the following map is a weak equivalence of simplicial sets:

\[ * \cong \text{Map}(*, Z) \longrightarrow \text{Map}(F_n(D^{r+1} \land G^s_m \land U_+), Z) \]

In particular \(\text{Map}(F_n(D^{r+1} \land G^s_m \land U_+), Z)\) has only one path connected component.

Since \(\text{Spt}_T M_*\) is a simplicial model category, we have the following isomorphism of abelian groups

\[ \pi_0 \text{Map}(F_n(S^r \land G^s_m \land U_+), Z) \xrightarrow{\cong} [F_n(S^r \land G^s_m \land U_+), Z]_{\text{Spt}} \]
but our hypothesis implies that $[F_n(S^r \land G^s_m \land U_+), Z]_{Spt} \cong 0$, hence $\pi_0 \text{Map}(F_n(S^r \land G^s_m \land U_+), Z) \cong 0$, i.e. $\text{Map}(F_n(S^r \land G^s_m \land U_+), Z)$ has only one path connected component.

Now proposition 3.2.27(2) implies that $* \to F_n(D^{r+1} \land G^s_m \land U_+)$ is a trivial cofibration in $Spt_{T^*M}$, and since $-* \land S^1$ is a left Quillen functor, it follows that

$$* \cong * \land S^k \xrightarrow{\text{cofib}} F_n(D^{r+1} \land G^s_m \land U_+) \land S^k$$

is also a trivial cofibration for $k \geq 0$. Therefore $[F_n(D^{r+1} \land G^s_m \land U_+) \land S^k, Z]_{Spt} \cong 0$, and this implies that the induced map $(\iota_{n,r,s}^U)^*$ is an isomorphism of abelian groups:

$$0 \cong [F_n(D^{r+1} \land G^s_m \land U_+) \land S^k, Z]_{Spt}$$

$$\downarrow (\iota_{n,r,s}^U)^*$$

$$[F_n(S^r \land G^s_m \land U_+) \land S^k, Z]_{Spt} \cong [F_n(S^{r+k} \land G^s_m \land U_+), Z]_{Spt} \cong 0.$$ 

since by hypothesis $[F_n(S^{k+r} \land G^s_m \land U_+), Z]_{Spt} \cong 0$.

On the other hand, since $Spt_{T^*M}$ is a pointed simplicial model category, we have that lemma 6.1.2 in [10] together with remark 2.4.3(2) imply that the following diagram is commutative
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for \( k \geq 0 \) and all the vertical arrows are isomorphisms:

\[
\begin{array}{c}
\pi_{k,\omega_0} \text{Map}(F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), Z) \\
\quad \xrightarrow{(\iota_{U_{n,r,s}}^*)^*} \pi_{k,\eta_0} \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z) \\
\pi_{k,\omega_0} \text{Map}_*(F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), Z) \\
\quad \xrightarrow{(\iota_{U_{n,r,s}}^*)^*} \pi_{k,\eta_0} \text{Map}_*(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z) \\
\cong \\
[F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+) \wedge S^k, Z]_{\text{Spt}} \\
\quad \xrightarrow{(\iota_{U_{n,r,s}}^*)^*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \wedge S^k, Z]_{\text{Spt}} \\
\cong \\
[F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+) \wedge S^k, Z]_{\text{Spt}} \\
\quad \xrightarrow{(\iota_{U_{n,r,s}}^*)^*} [F_n(S^{k+r} \wedge \mathbb{G}_m^s \wedge U_+), Z]_{\text{Spt}}
\end{array}
\]

but we know that the bottom row is always an isomorphism of abelian groups, hence the top row is also an isomorphism. This implies that the map

\[
\text{Map}(F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), Z) \xrightarrow{(\iota_{U_{n,r,s}}^*)^*} \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z)
\]

is a weak equivalence when it is restricted to the path component of \( \text{Map}(F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), Z) \) containing \( \omega_0 \). However we already know that \( \text{Map}(F_n(D^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), Z) \) and \( \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z) \) have only one path connected component. This implies that the map defined above is a weak equivalence of simplicial sets, as we wanted.

\[
\text{Corollary 3.2.33.} \text{ Let } m, n \in \mathbb{Z} \text{ with } m > n. \text{ If } Z \text{ is a } L(< n)\text{-local } T\text{-spectrum in } \text{Spt}_{T\text{-M}_*} \text{ then } Z \text{ is also } L(< m)\text{-local in } \text{Spt}_{T\text{-M}_*}.
\]

\[
\text{Proof.} \text{ We have that } C_{m}^{\text{eff}} \subseteq C_{n}^{\text{eff}}, \text{ since } m > n. \text{ The result now follows immediately from the characterization of } L(< q)\text{-local objects given in proposition 3.2.32.}
\]

\[
\square
\]
Corollary 3.2.34. Fix $q \in \mathbb{Z}$ and let $Z$ be a fibrant $T$-spectrum in $\text{Spt}_T \mathcal{M}_*$. Then $Z$ is $L(<q)$-local if and only if $\Omega_{S^1} Z$ is $L(<q)$-local.

**Proof.** ($\Rightarrow$): Assume that $Z$ is $L(<q)$-local. We have that $Z$ is fibrant in $\text{Spt}_T \mathcal{M}_*$; and since $\text{Spt}_T \mathcal{M}_*$ is a simplicial model category, it follows that $\Omega_{S^1} Z$ is also fibrant.

Fix $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{\text{eff}}$. Since $\text{Spt}_T \mathcal{M}_*$ is a simplicial model category, we have the following natural isomorphisms:

$$[F_n(S^r \wedge G^s_m \wedge U_+), \Omega_{S^1} Z]_{\text{Spt}} \cong [F_n(S^r \wedge G^s_m \wedge U_+ \wedge S^1, Z]_{\text{Spt}}$$

$$\cong [F_n(S^{r+1} \wedge G^s_m \wedge U_+), Z]_{\text{Spt}}$$

but proposition 3.2.32 implies that $[F_n(S^{r+1} \wedge G^s_m \wedge U_+), Z]_{\text{Spt}} \cong 0$, hence $[F_n(S^r \wedge G^s_m \wedge U_+), \Omega_{S^1} Z]_{\text{Spt}} \cong 0$ for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{\text{eff}}$. Finally, using proposition 3.2.32 again, we have that $\Omega_{S^1} Z$ is $L(<q)$-local, as we wanted.

($\Leftarrow$): Assume that $\Omega_{S^1} Z$ is $L(<q)$-local. Since by hypothesis $Z$ is fibrant in $\text{Spt}_T \mathcal{M}_*$, proposition 3.2.32 implies that it is enough to show that for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{\text{eff}}$:

$$[F_n(S^r \wedge G^s_m \wedge U_+), Z]_{\text{Spt}} \cong 0$$

Fix $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{\text{eff}}$. Since $\text{Spt}_T \mathcal{M}_*$ is a simplicial model category, and $Z$ is fibrant by hypothesis; we have the following natural isomorphisms of abelian groups:

$$[F_{n+1}(S^r \wedge G^{s+1}_m \wedge U_+), \Omega_{S^1} Z]_{\text{Spt}} \cong [F_{n+1}(S^{r+1} \wedge G^{s+1}_m \wedge U_+), Z]_{\text{Spt}}$$

$$\cong [F_n(S^r \wedge G^s_m \wedge U_+), Z]_{\text{Spt}}$$

Now using proposition 3.2.32 and the fact that $\Omega_{S^1} Z$ is $L(<q)$-local, it follows that $[F_{n+1}(S^r \wedge G^{s+1}_m \wedge U_+), \Omega_{S^1} Z]_{\text{Spt}} \cong 0$. Therefore, $[F_n(S^r \wedge G^s_m \wedge U_+), Z]_{\text{Spt}} \cong 0$ for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C^q_{\text{eff}}$, as we wanted.

**Corollary 3.2.35.** Fix $q \in \mathbb{Z}$, and let $Z$ be a fibrant $T$-spectrum in $\text{Spt}_T \mathcal{M}_*$. Then $Z$ is $L(<q)$-local if and only if $IQ_T J(Q_s Z \wedge S^1)$ is $L(<q)$-local.
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Proof. \((\Rightarrow)\): Assume that \(Z\) is \(L(<q)\)-local. Since \(IQ_T J(Q_sZ \wedge S^1)\) is fibrant, using proposition 3.2.32 we have that it is enough to show that for every \(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{eff}^q\), 
\[ [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T J(Q_sZ \wedge S^1)]_{Spt} \cong 0. \] 
But since \(- \wedge S^1\) is a Quillen equivalence, we get the following diagram:

\[
\begin{array}{ccc}
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T J(Q_sZ \wedge S^1)]_{Spt} & \cong & [F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), IQ_T J(Q_sZ \wedge S^1)]_{Spt} \\
\downarrow \cong & & \uparrow \cong \\
[F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), Z]_{Spt} & \cong & [F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), Q_sZ \wedge S^1]_{Spt} \\
\downarrow \Sigma_T^{1,0} & & \uparrow \cong \\
[F_{n+1}(S^{r+1} \wedge \mathbb{G}_m^{s+1} \wedge U_+), Q_sZ \wedge S^1]_{Spt}
\end{array}
\]

where all the maps are isomorphisms of abelian groups. Since \(Z\) is \(L(<q)\)-local, proposition 3.2.32 implies that \([F_{n+1}(S^r \wedge \mathbb{G}_m^{s+1} \wedge U_+), Z]_{Spt} \cong 0.\) Therefore

\[ [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), IQ_T J(Q_sZ \wedge S^1)]_{Spt} \cong 0 \]

for every \(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ) \in C_{eff}^q\), as we wanted.

\((\Leftarrow)\): Assume that \(IQ_T J(Q_sZ \wedge S^1)\) is \(L(<q)\)-local. By hypothesis, \(Z\) is fibrant; therefore proposition 3.2.32 implies that it is enough to show that for every \(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{eff}^q\), 
\[ [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ), Z]_{Spt} \cong 0. \] 
Since \(\text{Spt}_T \mathcal{M}_s\) is a simplicial model category and \(- \wedge S^1\) is a Quillen equivalence; we have the following diagram:

\[
\begin{array}{ccc}
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ), \Omega_{S^1}IQ_T J(Q_sZ \wedge S^1)]_{Spt} & \cong & [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ) \wedge S^1, Q_sZ \wedge S^1]_{Spt} \\
\downarrow \cong & & \downarrow \cong \\
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ) \wedge S^1, Q_sZ \wedge S^1]_{Spt} & \cong & [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ), Z]_{Spt}
\end{array}
\]

where all the maps are isomorphisms of abelian groups. On the other hand, using corollary 3.2.34 we have that \(\Omega_{S^1}IQ_T J(Q_sZ \wedge S^1)\) is \(L(<q)\)-local. Therefore using proposition 3.2.32 again, we have that for every \(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{eff}^q\):

\[ [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ), Z]_{Spt} \cong [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+ ), \Omega_{S^1}IQ_T J(Q_sZ \wedge S^1)]_{Spt} \cong 0 \]
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and this finishes the proof. □

Corollary 3.2.36. Fix \( q \in \mathbb{Z} \) and let \( f : X \to Y \) be a map in \( \text{Spt}_T M_* \). Then \( f \) is a \( L(< q) \)-local equivalence if and only if for every \( L(< q) \)-local \( T \)-spectrum \( Z \), \( f \) induces the following isomorphism of abelian groups:

\[
[Y, Z]_{\text{Spt}} \xrightarrow{f^*} [X, Z]_{\text{Spt}}
\]

Proof. Suppose that \( f \) is a \( L(< q) \)-local equivalence, then by definition the induced map:

\[
\text{Map}(Q_s Y, Z) \xrightarrow{(Q_s f)^*} \text{Map}(Q_s X, Z)
\]

is a weak equivalence of simplicial sets for every \( L(< q) \)-local \( T \)-spectrum \( Z \). Proposition 3.2.32(1) implies that \( Z \) is fibrant in \( \text{Spt}_T M_* \), and since \( \text{Spt}_T M_* \) is in particular a simplicial model category; we get the following commutative diagram, where the top row and all the vertical maps are isomorphisms of abelian groups:

\[
\pi_0 \text{Map}(Q_s Y, Z) \xrightarrow{(Q_s f)^*} \pi_0 \text{Map}(Q_s X, Z)
\]

\[
\cong
\]

\[
[Y, Z]_{\text{Spt}} \xrightarrow{f^*} [X, Z]_{\text{Spt}}
\]

hence \( f^* \) is an isomorphism for every \( L(< q) \)-local \( T \)-spectrum \( Z \), as we wanted.

Conversely, assume that for every \( L(< q) \)-local \( T \)-spectrum \( Z \), the induced map

\[
[Y, Z]_{\text{Spt}} \xrightarrow{f^*} [X, Z]_{\text{Spt}}
\]

is an isomorphism of abelian groups.

Since \( L<q \text{Spt}_T M_* \) is the left Bousfield localization of \( \text{Spt}_T M_* \) with respect to the \( L(< q) \)-local equivalences, we have that the identity functor \( \text{id} : \text{Spt}_T (Sm|S)_{Nis} \to L<q \text{Spt}_T M_* \) is a left Quillen functor. Therefore for every \( T \)-spectrum \( Z \), we get the following commutative diagram where all the vertical arrows are isomorphisms:

\[
\text{Hom}_{L<q \text{Spt}(S)}(Q_s Y, Z) \xrightarrow{(Q_s f)^*} \text{Hom}_{L<q \text{Spt}(S)}(Q_s X, Z)
\]

\[
\cong
\]

\[
[Y, W_q Z]_{\text{Spt}} \xrightarrow{f^*} [X, W_q Z]_{\text{Spt}}
\]

\[
\cong
\]

\[
[X, W_q Z]_{\text{Spt}}
\]
but $W_q Z$ is by construction $L(< q)$-local, then by hypothesis the bottom row is an isomorphism of abelian groups. Hence it follows that the induced map:

$$\text{Hom}_{L_{<q} S\mathcal{M}}(Q_s Y, Z) \xrightarrow{(Q_s f)^*} \text{Hom}_{L_{<q} S\mathcal{M}}(Q_s X, Z)$$

is an isomorphism for every $T$-spectrum $Z$. This implies that $Q_s f$ is a weak equivalence in $L_{<q} \text{Spt}_T \mathcal{M}$, and since $Q_s$ is also a cofibrant replacement functor on $L_{<q} \text{Spt}_T \mathcal{M}$, it follows that $f$ is a weak equivalence in $L_{<q} \text{Spt}_T \mathcal{M}$. Therefore we have that $f$ is a $L(< q)$-local equivalence, as we wanted.

\[ \square \]

**Lemma 3.2.37.** Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map in $\text{Spt}_T \mathcal{M}$, then $f$ is a $L(< q)$-local equivalence if and only if

$$Q_s f \wedge id : Q_s X \wedge S^1 \to Q_s Y \wedge S^1$$

is a $L(< q)$-local equivalence.

**Proof.** Assume that $f$ is a $L(< q)$-local equivalence, and let $Z$ be an arbitrary $L(< q)$-local $T$-spectrum. Then corollary 3.2.34 implies that $\Omega_{S^1} Z$ is also $L(< q)$-local. Therefore the induced map

$$\text{Map}(Q_s Y, \Omega_{S^1} Z) \xrightarrow{(Q_s f)^*} \text{Map}(Q_s X, \Omega_{S^1} Z)$$

is a weak equivalence of simplicial sets. Now since $\text{Spt}_T \mathcal{M}$ is a simplicial model category, we have the following commutative diagram:

$$\begin{array}{ccc}
\text{Map}(Q_s Y, \Omega_{S^1} Z) & \xrightarrow{(Q_s f)^*} & \text{Map}(Q_s X, \Omega_{S^1} Z) \\
\cong & & \cong \\
\text{Map}(Q_s Y \wedge S^1, Z) & \xrightarrow{(Q_s f \wedge id)^*} & \text{Map}(Q_s X \wedge S^1, Z)
\end{array}$$

and using the two out of three property for weak equivalences of simplicial sets, we have that

$$\text{Map}(Q_s Y \wedge S^1, Z) \xrightarrow{(Q_s f \wedge id)^*} \text{Map}(Q_s X \wedge S^1, Z)$$

is a weak equivalence. Since this holds for every $L(< q)$-local $T$-spectrum $Z$, it follows that

$$Q_s f \wedge id : Q_s X \wedge S^1 \to Q_s Y \wedge S^1$$
is a $L(< q)$-local equivalence, as we wanted.

Conversely, suppose that

$$Q_s f \wedge \text{id} : Q_s X \wedge S^1 \to Q_s Y \wedge S^1$$

is a $L(< q)$-local equivalence. Let $Z$ be an arbitrary $L(< q)$-local $T$-spectrum. Since \(\text{Spt}_T \text{M}_\ast\) is a simplicial model category and $- \wedge S^1$ is a Quillen equivalence, we get the following commutative diagram:

\[
\begin{array}{ccc}
[Q_s Y \wedge S^1, \text{IQ}_T J(Q_s Z \wedge S^1)]_{\text{Spt}} & \xrightarrow{(Q_s f \wedge \text{id})^*} & [Q_s X \wedge S^1, \text{IQ}_T J(Q_s Z \wedge S^1)]_{\text{Spt}} \\
\cong [Q_s Y \wedge S^1, Q_s Z \wedge S^1]_{\text{Spt}} & \xrightarrow{(Q_s f \wedge \text{id})^*} & [Q_s X \wedge S^1, Q_s Z \wedge S^1]_{\text{Spt}} \\
\cong [Q_s Y \wedge S^1, Q_s Z \wedge S^1]_{\text{Spt}} & \xrightarrow{\Sigma^1_T} & [Q_s Y \wedge S^1, Q_s Z \wedge S^1]_{\text{Spt}} \\
[\text{Spt}]_{\text{Spt}} & \xrightarrow{f^*} & [\text{Spt}]_{\text{Spt}} \\
& \cong & \Sigma^1_T \cong
\end{array}
\]

Now, corollary 3.2.35 implies that $\text{IQ}_T J(QZ \wedge S^1)$ is also $L(< q)$-local. Therefore using corollary 3.2.36 we have that the top row in the diagram above is an isomorphism of abelian groups. This implies that the induced map:

$$[Y, Z]_{\text{Spt}} \xrightarrow{f^*} [X, Z]_{\text{Spt}}$$

is an isomorphism of abelian groups for every $L(< q)$-local spectrum $Z$. Finally using corollary 3.2.36 again, we have that $f : X \to Y$ is a $L(< q)$-local equivalence, as we wanted.

**Corollary 3.2.38.** For every $q \in \mathbb{Z}$, the following adjunction:

$$(- \wedge S^1, \Omega_{S^1}, \varphi) : L_{<q} \text{Spt}_T \text{M}_\ast \xrightarrow{\cong} L_{<q} \text{Spt}_T \text{M}_\ast$$

is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.2.31 we have that it suffices to verify the following two conditions:
1. For every fibrant object $X$ in $L_{<q}\text{Spt}_T\text{M}_*$, the following composition

$$
(Q_s\Omega S^1 X) \wedge S^1 \xrightarrow{Q_s^{S^1} X \wedge \text{id}} (\Omega S^1 X) \wedge S^1 \xrightarrow{\epsilon_X} X
$$

is a $L(<q)$-local equivalence.

2. $\wedge S^1$ reflects $L(<q)$-local equivalences between cofibrant objects in $L_{<q}\text{Spt}_T\text{M}_*$.

(1): By construction $L_{<q}\text{Spt}_T\text{M}_*$ is a left Bousfield localization of $\text{Spt}_T\text{M}_*$, therefore the identity functor

$$id : L_{<q}\text{Spt}_T\text{M}_* \rightarrow \text{Spt}_T\text{M}_*$$

is a right Quillen functor. Thus $X$ is also fibrant in $\text{Spt}_T\text{M}_*$. Since the adjunction $(- \wedge S^1, \Omega S^1, \varphi)$ is a Quillen equivalence on $\text{Spt}_T\text{M}_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $\text{Spt}_T\text{M}_*$:

$$
(Q_s\Omega S^1 X) \wedge S^1 \xrightarrow{Q_s^{S^1} X \wedge \text{id}} (\Omega S^1 X) \wedge S^1 \xrightarrow{\epsilon_X} X
$$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $L(<q)$-local equivalence.

(2): This follows immediately from proposition 3.2.31 and lemma 3.2.37.

**Remark 3.2.39.** We have a situation similar to the one described in remark 3.2.9 for the model categories $R_{C_{eff}}\text{Spt}_T\text{M}_*$; i.e. although the adjunction $(\Sigma_T, \Omega_T, \varphi)$ is a Quillen equivalence on $\text{Spt}_T\text{M}_*$, it does not descend even to a Quillen adjunction on the weight $<q$ motivic stable model category $L_{<q}\text{Spt}_T\text{M}_*$.

**Corollary 3.2.40.** For every $q \in \mathbb{Z}$, the homotopy category $L_{<q}\text{SH}(S)$ associated to $L_{<q}\text{Spt}_T\text{M}_*$ has the structure of a triangulated category.

**Proof.** Theorem 3.2.29 implies in particular that $L_{<q}\text{Spt}_T\text{M}_*$ is a pointed simplicial model category, and corollary 3.2.38 implies that the adjunction

$$(- \wedge S^1, \Omega S^1, \varphi) : L_{<q}\text{Spt}_T\text{M}_* \rightarrow L_{<q}\text{Spt}_T\text{M}_*$$

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII].

**Corollary 3.2.41.** For every $q \in \mathbb{Z}$, $L_{<q}\text{Spt}_T\mathcal{M}_s$ is a right proper model category.

**Proof.** We need to show that the $L(<q)$-local equivalences are stable under pullback along fibrations in $L_{<q}\text{Spt}_T\mathcal{M}_s$. Consider the following pullback diagram:

\[
\begin{array}{ccc}
Z & \xrightarrow{w^*} & X \\
P & \downarrow & \downarrow \\
W & \xrightarrow{w} & Y \\
\end{array}
\]

where $p$ is a fibration in $L_{<q}\text{Spt}_T\mathcal{M}_s$, and $w$ is a $L(<q)$-local equivalence. Let $F$ be the homotopy fibre of $p$. Then we get the following commutative diagram in $L_{<q}\text{SH}(S)$:

\[
\begin{array}{ccc}
\Omega S_1 Y & \xrightarrow{q} & F & \xrightarrow{i} & X & \xrightarrow{p} & Y \\
\Omega S_1 w & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow & \downarrow \\
\Omega S_1 W & \xrightarrow{p^*} & F & \xrightarrow{j} & Z & \xrightarrow{w^*} & W \\
\end{array}
\]

Since the rows in the diagram above are both fibre sequences in $L_{<q}\text{Spt}_T\mathcal{M}_s$, it follows that both rows are distinguished triangles in $L_{<q}\text{SH}(S)$ (which has the structure of a triangulated category given by corollary 3.2.40). Now $w, id_F$ are both isomorphisms in $L_{<q}\text{SH}(S)$, hence it follows that $w^*$ is also an isomorphism in $L_{<q}\text{SH}(S)$. Therefore $w^*$ is a $L(<q)$-local equivalence, as we wanted.

**Proposition 3.2.42.** For every $q \in \mathbb{Z}$ we have the following adjunction

\[
(Q_s, W_q, \varphi) : \text{SH}(S) \longrightarrow L_{<q}\text{SH}(S)
\]
of exact functors between triangulated categories.

**Proof.** Since $L_{<q}\text{Spt}_T\mathcal{M}_s$ is the left Bousfield localization of $\text{Spt}_T\mathcal{M}_s$ with respect to the $L(<q)$-local equivalences, we have that the identity functor $id : \text{Spt}_T\mathcal{M}_s \rightarrow L_{<q}\text{Spt}_T\mathcal{M}_s$ is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

\[
(Q_s, W_q, \varphi) : \text{SH}(S) \longrightarrow L_{<q}\text{SH}(S)
\]
Now proposition 6.4.1 in [10] implies that $Q_s$ maps cofibre sequences in $\mathcal{SH}(S)$ to cofibre sequences in $L_{<q}\mathcal{SH}(S)$. Therefore using proposition 7.1.12 in [10] we have that $Q_s$ and $W_q$ are both exact functors between triangulated categories.

**Proposition 3.2.43.** Fix $q \in \mathbb{Z}$ and let $\eta_X : Q_sW_qX \to X$ denote the counit of the adjunction

$$(Q_s, W_q, \varphi) : \mathcal{SH}(S) \longrightarrow L_{<q}\mathcal{SH}(S)$$

Then the following conditions hold:

1. For every $T$-spectrum $X$, we have that $\eta_X$ is an isomorphism in $L_{<q}\mathcal{SH}(S)$.

2. The exact functor

$$W_q : L_{<q}\mathcal{SH}(S) \longrightarrow \mathcal{SH}(S)$$

is a full embedding of triangulated categories.

**Proof.** (1): We have that $\eta_X$ is the following composition in $L_{<q}\mathcal{SH}(S)$:

$$Q_sW_qX \xrightarrow{Q_sW_qX} W_qX \xrightarrow{(W_qX)^{-1}} X$$

where $Q_sW_qX$ is a weak equivalence in $\text{Spt}_T\mathbb{M}_+$. Now [7, proposition 3.1.5] implies that $Q_sW_qX$ is a $L(<q)$-local equivalence, i.e. a weak equivalence in $L_{<q}\text{Spt}_T\mathbb{M}_+$. Therefore $Q_sW_qX$ becomes an isomorphism in $L_{<q}\mathcal{SH}(S)$, and this implies that $\eta_X$ is an isomorphism in $L_{<q}\mathcal{SH}(S)$, as we wanted.

(2): Follows immediately from (1). \qed

**Proposition 3.2.44.** Fix $q \in \mathbb{Z}$. Then for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$, the map $\ast \to F_n(S^r \wedge G^s_m \wedge U_+)$ is a $L(<q)$-local equivalence in $\text{Spt}_T\mathbb{M}_+$.

**Proof.** Let $Z$ be an arbitrary $L(<q)$-local $T$-spectrum. Then proposition 3.2.32(2) implies that the following induced map

$$0 \cong [F_n(S^r \wedge G^s_m \wedge U_+), Z]_{\text{Spt}} \longrightarrow [* , Z]_{\text{Spt}} \cong 0$$
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is an isomorphism of abelian groups. Therefore using corollary 3.2.36, it follows that \( * \to F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ) \) is a \( L(< q) \)-local equivalence.

\[ \text{Proof.} \] Proposition 3.2.43 implies that \( f \) is an isomorphism in \( L_{<q} \mathcal{SH}(S) \) if and only if \( W_q f \) becomes an isomorphism in \( \mathcal{SH}(S) \). Thus it only remains to show that (1), (2) and (3) are all equivalent.

(1) \( \iff \) (2) Corollary 3.1.6 implies that \( W_q f \) is an isomorphism in \( \mathcal{SH}(S) \) if and only if for every \( F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ) \in C_{q}^{d} \) the following induced map

\[
[W_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ), W_q X]_{Spt} \xrightarrow{(W_q f)_*} [F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ), W_q Y]_{Spt}
\]

is an isomorphism of abelian groups. But using proposition 3.2.32(2) we have that for every \( F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+) \in C_{q}^{d}, \)

\[
0 \cong [F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ), W_q X]_{Spt} \cong [F_n(S^\tau \wedge \mathbb{G}_m^s \wedge U_+ ), W_q Y]_{Spt}
\]
since by construction $W_q X$ and $W_q Y$ are both $L(<q)$-local $T$-spectra. Hence $W_q f$ is an isomorphism in $\mathcal{SH}(S)$ if and only if for every $F_n(\mathcal{G}_m^s \wedge U_+) \notin C^q_{eff}$ the following induced map

$$\left[ F_n(\mathcal{G}_m^s \wedge U_+), W_q X \right]_{Spt} \xrightarrow{(W_q f)_*} \left[ F_n(\mathcal{G}_m^s \wedge U_+), W_q Y \right]_{Spt}$$

is an isomorphism of abelian groups.

(2) $\Leftrightarrow$ (3) By proposition 3.2.42 we have the following adjunction between exact functors of triangulated categories:

$$(Q_s, W_q, \varphi) : \mathcal{SH}(S) \xrightarrow{L \leq q} \mathcal{SH}(S)$$

In particular for every $F_n(\mathcal{G}_m^s \wedge U_+) \notin C^q_{eff}$, we get the following commutative diagram, where all the vertical arrows are isomorphisms of abelian groups:

$$\begin{CD}
\left[ F_n(\mathcal{G}_m^s \wedge U_+), W_q X \right]_{Spt} @> (W_q f)_* >> \left[ F_n(\mathcal{G}_m^s \wedge U_+), W_q Y \right]_{Spt} \\
\cong @. \cong \\
\text{Hom}_{L \leq q \mathcal{SH}(S)}(Q_s F_n(\mathcal{G}_m^s \wedge U_+), X) @> f^* >> \text{Hom}_{L \leq q \mathcal{SH}(S)}(Q_s F_n(\mathcal{G}_m^s \wedge U_+), Y)
\end{CD}$$

therefore the top row is an isomorphism if and only if the bottom row is an isomorphism of abelian groups, as we wanted.

\begin{proof}
Let $j : * \to Z$ denote the canonical map. Proposition 3.1.14 implies that $f_q(j) : * \cong f_q(*) \to f_q X$ is an isomorphism in $\mathcal{SH}(S)$ if and only if for every $F_n(\mathcal{G}_m^s \wedge U_+) \in C^q_{eff}$ the induced map

$$0 \cong [F_n(\mathcal{G}_m^s \wedge U_+), \ast]_{Spt} \xrightarrow{f_q(j)^*} [F_n(\mathcal{G}_m^s \wedge U_+), Z]_{Spt}$$

\end{proof}

\textbf{Lemma 3.2.46.} Fix $q \in \mathbb{Z}$ and let $Z$ be a $L(<q)$-local $T$-spectrum. Then $f_q Z \cong *$ in $\mathcal{SH}(S)$ (see remark 3.1.13).

\textbf{Proof.} Let $j : * \to Z$ denote the canonical map. Proposition 3.1.14 implies that $f_q(j) : * \cong f_q(*) \to f_q X$ is an isomorphism in $\mathcal{SH}(S)$ if and only if for every $F_n(\mathcal{G}_m^s \wedge U_+) \in C^q_{eff}$ the induced map

$$0 \cong [F_n(\mathcal{G}_m^s \wedge U_+), \ast]_{Spt} \xrightarrow{f_q(j)^*} [F_n(\mathcal{G}_m^s \wedge U_+), Z]_{Spt}$$
is an isomorphism of abelian groups. Therefore it is enough to show that for every \( F_n(S^r \wedge G_m \wedge U_+) \in C^q_{\text{eff}}, \) we have \([F_n(S^r \wedge G_m \wedge U_+), Z]_{\text{Spt}} \cong 0. \) But this follows from proposition 3.2.32(2), since \( Z \) is \( L(<q) \)-local by hypothesis.

**Corollary 3.2.47.** For every \( q \in \mathbb{Z}, \) and for every \( T \)-spectrum \( X, Q_s f_q X \cong \ast \) in \( L_{<q} \mathcal{H}(S) \).

**Proof.** We will show that the map \( \ast \rightarrow Q_s f_q X \) is an isomorphism in \( L_{<q} \mathcal{H}(S) \). By Yoneda’s lemma it suffices to check that for every \( T \)-spectrum \( Z \), the induced map

\[
\text{Hom}_{L_{<q} \mathcal{H}(S)}(Q_s f_q X, Z) \rightarrow \text{Hom}_{L_{<q} \mathcal{H}(S)}(\ast, Z) \cong 0
\]

is an isomorphism of abelian groups. Now propositions 3.2.42 and 3.1.12 imply that we have the following isomorphisms:

\[
\text{Hom}_{L_{<q} \mathcal{H}(S)}(Q_s f_q X, Z) \cong [f_q X, W_q Z]_{\text{Spt}} = [i_q r_q X, W_q Z]_{\text{Spt}}
\]

\[
\cong \text{Hom}_{\Sigma_{<q} \mathcal{H}_{\text{eff}}(S)}(r_q X, r_q W_q Z)
\]

Finally since \( i_q \) is a full embedding, we have

\[
\text{Hom}_{\Sigma_{<q} \mathcal{H}_{\text{eff}}(S)}(r_q X, r_q W_q Z) \cong [i_q r_q X, i_q r_q W_q Z]_{\text{Spt}} = [f_q X, f_q W_q Z]_{\text{Spt}}
\]

and lemma 3.2.46 implies that \( f_q W_q Z \cong \ast \) in \( \mathcal{H}(S) \). Hence

\[
\text{Hom}_{L_{<q} \mathcal{H}(S)}(Q_s f_q X, Z) \cong [f_q X, f_q W_q Z]_{\text{Spt}} \cong [f_q X, \ast]_{\text{Spt}} \cong 0
\]

as we wanted. \( \square \)

**Proposition 3.2.48.** For every \( q \in \mathbb{Z} \) and for every \( T \)-spectrum \( X \), the natural map in \( L_{<q} \mathcal{H}(S) \)

\[
Q_s X \xrightarrow{Q_s (\pi_{<q} X)} Q_s s_{<q} X
\]

is an isomorphism, where \( \pi_{<q} \) is the natural transformation defined in theorem 3.1.18. Furthermore, these maps induce a natural isomorphism between the following exact functors

\[
\mathcal{H}(S) \xrightarrow{Q_s} L_{<q} \mathcal{H}(S)
\]
Proof. The naturality of $\pi_{<q}$ and the fact that $Q_s$ is a functor imply that the maps $Q_s(\pi_{<q}X)$ induce a natural transformation $Q_s \to Q_s s_{<q}$. Hence it suffices to show that for every $T$-spectrum $X$, the map $Q_s(\pi_{<q}X)$ is an isomorphism in $L_{<q}\mathcal{SH}(S)$.

Theorem 3.1.18 implies that we have the following distinguished triangle in $\mathcal{SH}(S)$:

\[
\begin{array}{c}
  f_qX \\
  \pi_{<q}X \\
  s_{<q}X \\
  \sigma_{<q}X \\
  \Sigma^1_T f_qX
  \end{array}
\]

and using proposition 3.2.42, we get the following distinguished triangle in $L_{<q}\mathcal{SH}(S)$:

\[
\begin{array}{c}
  Q_sf_qX \\
  Q_sX \\
  Q_s s_{<q}X \\
  Q_s(\sigma_{<q}X) \\
  \Sigma^1_T Q_sf_qX
  \end{array}
\]

But corollary 3.2.47 implies that $Q sf_qX \cong *$ in $L_{<q}\mathcal{SH}(S)$, therefore $Q_s(\pi_{<q}X)$ is an isomorphism in $L_{<q}\mathcal{SH}(S)$, as we wanted.

**Corollary 3.2.49.** For every $q \in \mathbb{Z}$ and for every $T$-spectrum $X$, the natural map in $\mathcal{SH}(S)$

\[
W_qQ_sX \xrightarrow{W_qQ_s(\pi_{<q}X)} W_qQ_s s_{<q}X
\]

is an isomorphism. Furthermore, these maps induce a natural isomorphism between the following exact functors

\[
\mathcal{SH}(S) \xrightarrow{W_qQ_s} \mathcal{SH}(S) \xrightarrow{W_qQ_s s_{<q}} \mathcal{SH}(S)
\]

Proof. Since $Q_s$, $W_q$ are both functors and $\pi_{<q} : id \to s_{<q}$ is a natural transformation (see theorem 3.1.18); we have that the maps $W_qQ_s(\pi_{<q}X)$ induce a natural transformation $W_qQ_s \to W_qQ_s s_{<q}$. Therefore it suffices to see that for every $T$-spectrum $X$, the map $W_qQ_s(\pi_{<q}X)$ is an isomorphism in $\mathcal{SH}(S)$.

But proposition 3.2.48 implies that the map $Q_s(\pi_{<q}X)$ is an isomorphism in $L_{<q}\mathcal{SH}(S)$. Therefore using proposition 3.2.42, we have that $W_qQ_s(\pi_{<q}X)$ is also an isomorphism in $\mathcal{SH}(S)$.

**Lemma 3.2.50.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, $IQ_T J(Q_s s_{<q}X)$ is $L(<q)$-local in $\text{Spt}_T M_*$. 
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Proof. Proposition 3.2.32 implies that it is enough to show that $IQ_TJ(Q_{s<s} X)$ satisfies the following properties:

1. $IQ_TJ(Q_{s<s} X)$ is fibrant in $Spt_T M_*$.

2. For every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$

$$[F_n(S^r \wedge G^s_m \wedge U_+), IQ_TJ(Q_{s<s} X)]_{Spt} \cong 0$$

The first condition is obvious since $IQ_TJ$ is a fibrant replacement functor on $Spt_T M_*$. Fix $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$. Using theorem 3.1.18(2) and the fact that $C_{eff}^q \subseteq \Sigma^q T \mathcal{H}^{eff}(S)$, we have that

$$[F_n(S^r \wedge G^s_m \wedge U_+, s_{<q} X)]_{Spt} \cong 0$$

Therefore

$$[F_n(S^r \wedge G^s_m \wedge U_+), IQ_TJ(Q_{s<s} X)]_{Spt} \cong [F_n(S^r \wedge G^s_m \wedge U_+, s_{<q} X)]_{Spt} \cong 0$$

for every $F_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^q$. This takes care of the second condition and finishes the proof.

Proposition 3.2.51. Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$ the natural map

$$Q_{s<s} X \xrightarrow{W_q Q_{s<s} X} W_q Q_{s<s} X$$

is a weak equivalence in $Spt_T M_*$. Therefore, we have a natural isomorphism between the following exact functors

$$\mathcal{H}(S) \xrightarrow{Q_{s<s}} \mathcal{H}(S) \xrightarrow{W_q Q_{s<s}} \mathcal{H}(S)$$

Proof. The naturality of the maps $W_q^X : X \to W_q X$ implies that we have an induced natural transformation of functors $Q_{s<s} \to W_q Q_{s<s}$. Hence, it is enough to show that for every $T$-spectrum $X$, $W_q Q_{s<s} X$ is a weak equivalence in $Spt_T M_*$. 

Consider the following commutative diagram in $\text{Spt}_T$:

\[
\begin{array}{ccc}
Q_{s} s_{<q} X & \longrightarrow & IQ_T J(Q_{s} s_{<q} X) \\
W_q Q_{s} s_{<q} X & \downarrow & IQ_T J(W_q Q_{s} s_{<q} X) \\
W_q Q_{s} s_{<q} X & \longrightarrow & IQ_T J(W_q Q_{s} s_{<q} X)
\end{array}
\]

(3.15)

where the horizontal maps are weak equivalences in $\text{Spt}_T$. Hence, the two out of three property for weak equivalences implies that it is enough to show that $IQ_T J(W_q Q_{s} s_{<q} X)$ is a weak equivalence in $\text{Spt}_T$.

By construction the map $W_q Q_{s} s_{<q} X$ is a $L(<q)$-local equivalence, and since the horizontal maps in diagram (3.15) are weak equivalences in $\text{Spt}_T$, it follows from [7, proposition 3.1.5] that these horizontal maps are also $L(<q)$-local equivalences. Therefore, the two out of three property for $L(<q)$-local equivalences implies that $IQ_T J(W_q Q_{s} s_{<q} X)$ is a $L(<q)$-local equivalence.

Now lemma 3.2.50 implies that $IQ_T J(Q_{s} s_{<q} X)$ is $L(<q)$-local. On the other hand, since the map

\[
W_q Q_{s} s_{<q} X \longrightarrow IQ_T J(W_q Q_{s} s_{<q} X)
\]

is a weak equivalence in $\text{Spt}_T$, $W_q Q_{s} s_{<q} X$ is by construction $L(<q)$-local, and

\[
IQ_T J(W_q Q_{s} s_{<q} X), \quad W_q Q_{s} s_{<q} X
\]

are both fibrant in $\text{Spt}_T$; it follows from [7, lemma 3.2.1] that $IQ_T J(W_q Q_{s} s_{<q} X)$ is also $L(<q)$-local.

Finally we have a $L(<q)$-local equivalence

\[
IQ_T J(Q_{s} s_{<q} X) \xrightarrow{IQ_T J(W_q Q_{s} s_{<q} X)} IQ_T J(W_q Q_{s} s_{<q} X)
\]

where the domain and the codomain are both $L(<q)$-local. Then theorem 3.2.13 in [7] implies that $IQ_T J(W_q Q_{s} s_{<q} X)$ is a weak equivalence in $\text{Spt}_T$. This finishes the proof.

**Theorem 3.2.52.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, we have the following diagram


in $\mathcal{SH}(S)$:

$$
\begin{array}{ccc}
\text{s}_{<q}X & \xleftarrow{Q^s_{<q}X} & Q_s\text{s}_{<q}X \\
\cong & & \cong \\
W_q\text{s}_{<q}X & \xrightarrow{W_qQ_s(\pi_{<q})} & W_qQ_sX
\end{array}
$$

where all the maps are isomorphisms in $\mathcal{SH}(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$
\begin{array}{ccc}
\mathcal{SH}(S) & \xrightarrow{s_{<q}} & \mathcal{SH}(S) \\
W_qQ_s & \xrightarrow{W_qQ_s} & W_qQ_s
\end{array}
$$

**Proof.** Since $Q_s$ is a cofibrant replacement functor on $\text{Spt}_T^*M_*$, it is clear that $Q^s_{<q}X$ becomes an isomorphism in the associated homotopy category $\mathcal{SH}(S)$.

The fact that $W_qQ_s s_{<q}X$ is an isomorphism in $\mathcal{SH}(S)$ follows from proposition 3.2.51. Finally, corollary 3.2.49 implies that $W_qQ_s(\pi_{<q})$ is also an isomorphism in $\mathcal{SH}(S)$. This shows that all the maps in the diagram (3.16) are isomorphisms in $\mathcal{SH}(S)$, therefore for every $T$-spectrum $X$ we can define the following composition in $\mathcal{SH}(S)$

$$
\begin{array}{ccc}
\text{s}_{<q}X & \xrightarrow{(Q^s_{<q}X)^{-1}} & Q_s\text{s}_{<q}X \\
\cong & & \cong \\
W_q\text{s}_{<q}X & \xrightarrow{(W_qQ_s(\pi_{<q}))^{-1}} & W_qQ_sX
\end{array}
$$

which is an isomorphism. The fact that $Q_s$ is a functorial cofibrant replacement in $\text{Spt}_T^*M_*$, proposition 3.2.51 and corollary 3.2.49, imply all together that the isomorphisms defined in diagram (3.17) induce a natural isomorphism of functors $s_{<q} \cong W_qQ_s$. This finishes the proof.

**Remark 3.2.53.** Theorem 3.2.52 gives the desired lifting to the model category level for the functors $s_{<q}$ defined in theorem 3.1.18.
Proposition 3.2.54. For every \( q \in \mathbb{Z} \), we have the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
\text{Spt}_{T}\mathcal{M}_{\ast} & \xrightarrow{id} & \text{Spt}_{T}\mathcal{M}_{\ast} \\
\downarrow{\text{id}} & & \downarrow{\text{id}} \\
L_{<q+1}\text{Spt}_{T}\mathcal{M}_{\ast} & \xrightarrow{id} & L_{<q}\text{Spt}_{T}\mathcal{M}_{\ast}
\end{array}
\]

Proof. Since \( L_{<q}\text{Spt}_{T}\mathcal{M}_{\ast} \) and \( L_{<q+1}\text{Spt}_{T}\mathcal{M}_{\ast} \) are both left Bousfield localizations for \( \text{Spt}_{T}\mathcal{M}_{\ast} \), we have that the identity functors:

\[
\begin{array}{ccc}
id : \text{Spt}_{T}\mathcal{M}_{\ast} & \longrightarrow & L_{<q}\text{Spt}_{T}\mathcal{M}_{\ast} \\
id : \text{Spt}_{T}\mathcal{M}_{\ast} & \longrightarrow & L_{<q+1}\text{Spt}_{T}\mathcal{M}_{\ast}
\end{array}
\]

are both left Quillen functors. Hence, it suffices to show that

\[
id : L_{<q+1}\text{Spt}_{T}\mathcal{M}_{\ast} \longrightarrow L_{<q}\text{Spt}_{T}\mathcal{M}_{\ast}
\]

is a left Quillen functor. Using the universal property for left Bousfield localizations (see definition 1.8.1), we have that it is enough to check that if \( f : X \rightarrow Y \) is a \( L(<q+1) \)-local equivalence then \( Q_{\ast}(f) : Q_{\ast}X \rightarrow Q_{\ast}Y \) is a \( L(<q) \)-local equivalence.

But theorem 3.1.6(c) in [7] implies that this last condition is equivalent to the following one: Let \( Z \) be an arbitrary \( L(<q) \)-local \( T \)-spectrum, then \( Z \) is also \( L(<q+1) \)-local. Finally, this last condition follows immediately from corollary 3.2.33.

Corollary 3.2.55. For every \( q \in \mathbb{Z} \), we have the following adjunction

\[
(Q_{\ast}, W_{q}, \varphi) : L_{<q+1}\mathcal{H}(S) \longrightarrow L_{<q}\mathcal{H}(S)
\]

of exact functors between triangulated categories.

Proof. Proposition 3.2.54 implies that \( id : L_{<q+1}\text{Spt}_{T}\mathcal{M}_{\ast} \rightarrow L_{<q}\text{Spt}_{T}\mathcal{M}_{\ast} \) is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories

\[
(Q_{\ast}, W_{q}, \varphi) : L_{<q+1}\mathcal{H}(S) \longrightarrow L_{<q}\mathcal{H}(S)
\]
Now proposition 6.4.1 in [10] implies that $Q_s$ maps cofibre sequences in $L_{<q+1} \mathcal{SH}(S)$ to cofibre sequences in $L_{<q} \mathcal{SH}(S)$. Therefore using proposition 7.1.12 in [10] we have that $Q_s$ and $W_q$ are both exact functors between triangulated categories.

**Theorem 3.2.56.** We have the following tower of left Quillen functors:

\[
\begin{array}{ccc}
L_{<q+1} \text{Spt}_T \mathcal{M}_* & \xrightarrow{id} & L_{<q} \text{Spt}_T \mathcal{M}_* \\
\downarrow{id} & & \downarrow{id} \\
L_{<q-1} \text{Spt}_T \mathcal{M}_* & \xrightarrow{id} & L_{<q-2} \text{Spt}_T \mathcal{M}_* \\
\downarrow{id} & & \downarrow{id} \\
\vdots & & \vdots
\end{array}
\]  

(3.18)

together with the corresponding tower of associated homotopy categories:

\[
\begin{array}{ccc}
L_{<q+1} \mathcal{SH}(S) & \xrightarrow{Q_s} & W_{q+1} \\
\downarrow{Q_s} & & \downarrow{W_{q+1}} \\
L_{<q} \mathcal{SH}(S) & \xrightarrow{Q_s} & W_q \\
\downarrow{Q_s} & & \downarrow{W_q} \\
S\mathcal{H}(S) & \xrightarrow{Q_s} & L_{<q-1} \mathcal{SH}(S) \\
\downarrow{Q_s} & & \downarrow{W_{q-1}} \\
L_{<q-2} \mathcal{SH}(S) & \xrightarrow{Q_s} & W_{q-2} \\
\downarrow{Q_s} & & \downarrow{W_{q-2}} \\
\vdots & & \vdots
\end{array}
\]  

(3.19)

Furthermore, the tower (3.19) satisfies the following properties:

1. All the categories are triangulated.
2. All the functors are exact.
3. $Q_s$ is a left adjoint for all the functors $W_q$. 
3.2. Model Structures for the Slice Filtration

**Proof.** Follows immediately from propositions 3.2.42, 3.2.54 and corollary 3.2.55.

**Remark 3.2.57.** The great technical advantage of the categories $L_{<q} \text{Spt}_T M_*$ over the categories $R_{C_{eff}^q} \text{Spt}_T M_*$ is the fact that $L_{<q} \text{Spt}_T M_*$ are always cellular, whereas it is not clear if $R_{C_{eff}^q} \text{Spt}_T M_*$ satisfy the cellularity property. Therefore we still can apply Hirschhorn’s localization technology to the categories $L_{<q} \text{Spt}_T M_*$. This will be the final step in our approach to get the desired lifting for the functors $s_q$ (see theorem 3.1.16) to the model category level.

**Definition 3.2.58.** For every $q \in \mathbb{Z}$, we consider the following set of $T$-spectra

$$S(q) = \{ F_n(S^r \wedge G^s_m \wedge U_+) \in C | s - n = q \} \subseteq C_{eff}^q$$

(see proposition 3.1.5 and definition 3.1.8).

**Theorem 3.2.59.** Fix $q \in \mathbb{Z}$. Then the right Bousfield localization of the model category $L_{<q+1} \text{Spt}_T M_*$ with respect to the $S(q)$-colocal equivalences exists. This new model structure will be called $q$-slice motivic stable. $S^q \text{Spt}_T M_*$ will denote the category of $T$-spectra equipped with the $q$-slice motivic stable model structure, and $S^q \text{SH}(S)$ will denote its associated homotopy category. Furthermore the $q$-slice motivic stable model structure is right proper and simplicial.

**Proof.** Theorem 3.2.29 implies that $L_{<q+1} \text{Spt}_T M_*$ is a cellular and simplicial model category. On the other hand, corollary 3.2.41 implies that $L_{<q+1} \text{Spt}_T M_*$ is right proper. Therefore we can apply theorem 5.1.1 in [7] to construct the right Bousfield localization of $L_{<q+1} \text{Spt}_T M_*$ with respect to the $S(q)$-colocal equivalences. Using [7, theorem 5.1.1] again, we have that $S^q \text{Spt}_T M_*$ is a right proper and simplicial model category.

**Definition 3.2.60.** Fix $q \in \mathbb{Z}$. Let $P_q$ denote a functorial cofibrant replacement functor on $S^q \text{Spt}_T M_*$ such that for every $T$-spectrum $X$, the natural map

$$P_q X \overset{P_q X_{(q)}}{\longrightarrow} X$$

is a trivial fibration in $S^q \text{Spt}_T M_*$, and $P_q X$ is a $S(q)$-colocal $T$-spectrum in $L_{<q+1} \text{Spt}_T M_*$. 
3.2. Model Structures for the Slice Filtration

Proposition 3.2.61. Fix $q \in \mathbb{Z}$. Then $W_{q+1}$ is also a fibrant replacement functor on $S^q \text{Spt}_T M_*$ (see definition 3.2.30), and for every $T$-spectrum $X$ the natural map

$$X \xrightarrow{W^X_{q+1}} W_{q+1}X$$

is a trivial cofibration in $S^q \text{Spt}_T M_*$. 

**Proof.** Since $S^q \text{Spt}_T M_*$ is the right Bousfield localization of $L_{<q+1} \text{Spt}_T M_*$ with respect to the $S(q)$-colocal equivalences, by construction we have that the fibrations and the trivial cofibrations are identical in $S^q \text{Spt}_T M_*$ and $L_{<q+1} \text{Spt}_T M_*$ respectively. This implies that for every $T$-spectrum $X$, $W_{q+1}X$ is fibrant in $S^q \text{Spt}_T M_*$, and we also have that the natural map:

$$X \xrightarrow{W^X_{q+1}} W_{q+1}X$$

is a trivial cofibration in $S^q \text{Spt}_T M_*$. Hence $W_{q+1}$ is also a fibrant replacement functor for $S^q \text{Spt}_T M_*$. \qed

Proposition 3.2.62. Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map of $T$-spectra. Then $f$ is a $S(q)$-colocal equivalence in $L_{<q+1} \text{Spt}_T M_*$ if and only if for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q)$ the induced map

$$[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1}X]_{\text{Spt}} \xrightarrow{(W_{q+1}f)_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1}Y]_{\text{Spt}}$$

is an isomorphism of abelian groups.

**Proof.** ($\Rightarrow$): Assume that $f$ is a $S(q)$-colocal equivalence. All the compact generators $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$ are cofibrant in $L_{<q+1} \text{Spt}_T M_*$, since they are cofibrant in $\text{Spt}_T M_*$, and the cofibrations are exactly the same in both model structures.

Therefore we have that $f$ is a $S(q)$-colocal equivalence if and only if for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q)$ the following maps are weak equivalences of simplicial sets:

$$\text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1}X) \xrightarrow{(W_{q+1}f)_*} \text{Map}(F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1}Y)$$
Therefore 

$L_{<q+1}\text{Spt}_\tau\mathcal{M}_*$ is a simplicial model category, we have that $\text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}X)$ and $\text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}Y)$ are both Kan complexes. Now proposition 3.2.32(1) implies that $W_{q+1}X, W_{q+1}Y$ are both fibrant in $\text{Spt}_\tau\mathcal{M}_*$, therefore since $\text{Spt}_\tau\mathcal{M}_*$ is a simplicial model category we get the following commutative diagram where the top row and all the vertical maps are isomorphisms of abelian groups:

\[
\begin{array}{cccc}
\pi_0\text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}X) & \cong & \pi_0\text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}Y) \\
\end{array}
\]

\[
\begin{array}{cccc}
[F_n(S^r \land G_m^s \land U_+), W_{q+1}X]_{\text{Spt}} & \overset{(W_{q+1}f)_*}{\longrightarrow} & [F_n(S^r \land G_m^s \land U_+), W_{q+1}Y]_{\text{Spt}} \\
\end{array}
\]

Therefore

\[
[F_n(S^r \land G_m^s \land U_+), W_{q+1}X]_{\text{Spt}} \overset{(W_{q+1}f)_*}{\cong} [F_n(S^r \land G_m^s \land U_+), W_{q+1}Y]_{\text{Spt}}
\]

is an isomorphism of abelian groups for every $F_n(S^r \land G_m^s \land U_+) \in S(q)$, as we wanted.

$(\Leftarrow)$: Fix $F_n(S^r \land G_m^s \land U_+) \in S(q)$. Let $\omega_0, \eta_0$ be the base points corresponding to $\text{Map}_*(F_{n+1}(S^r \land G_m^{s+1} \land U_+), W_{q+1}X)$ and $\text{Map}_*(F_{n+1}(S^r \land G_m^{s+1} \land U_+), W_{q+1}Y)$ respectively. We need to show that the map:

\[
\text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}X) \overset{(W_{q+1}f)_*}{\longrightarrow} \text{Map}(F_n(S^r \land G_m^s \land U_+), W_{q+1}Y)
\]

is a weak equivalence of simplicial sets. Let

\[
j : F_{n+1}(S^{r+1} \land G_m^{s+1} \land U_+) \rightarrow F_n(S^r \land G_m^s \land U_+)
\]

be the adjoint to the identity map

\[
id : S^{r+1} \land G_m^{s+1} \land U_+ \rightarrow E\nu_{n+1}F_n(S^r \land G_m^s \land U_+) = S^{r+1} \land G_m^{s+1} \land U_+
\]

We know that $j$ is a weak equivalence in $\text{Spt}_\tau\mathcal{M}_*$, therefore [7, proposition 3.1.5] implies that $j$ is a $L(< q + 1)$-local equivalence, i.e. a weak equivalence in $L_{<q+1}\text{Spt}_\tau\mathcal{M}_*$. Now
since $F_n(S^r \land G^s_m \land U_+)$ and $F_{n+1}(S^{r+1} \land G^{s+1}_m \land U_+)$ are both cofibrant in $L_{<q+1}\text{Spt}_T\mathcal{M}_*$, and $L_{<q+1}\text{Spt}_T\mathcal{M}_*$ is a simplicial model category, we can apply Ken Brown's lemma (see lemma 1.1.4) to conclude that the horizontal maps in the following commutative diagram are weak equivalences of simplicial sets:

\[
\begin{array}{ccc}
\text{Map}(F_n(S^r \land G^s_m \land U_+), W_{q+1}X) & \xrightarrow{j^*} & \text{Map}(F_{n+1}(S^{r+1} \land G^{s+1}_m \land U_+), W_{q+1}X) \\
(W_{q+1}f)_* & \downarrow & (W_{q+1}f)_* \\
\text{Map}(F_n(S^r \land G^s_m \land U_+), W_{q+1}Y) & \xrightarrow{j^*} & \text{Map}(F_{n+1}(S^{r+1} \land G^{s+1}_m \land U_+), W_{q+1}Y)
\end{array}
\]

Hence by the two out of three property for weak equivalences, it is enough to show that the following induced map

\[
\text{Map}(F_{n+1}(S^{r+1} \land G^{s+1}_m \land U_+), W_{q+1}X) \\
(W_{q+1}f)_* \\
\text{Map}(F_{n+1}(S^{r+1} \land G^{s+1}_m \land U_+), W_{q+1}Y)
\]

is a weak equivalence of simplicial sets.

On the other hand, since $\text{Spt}_T\mathcal{M}_*$ is a pointed simplicial model category and $W_{q+1}X$, $W_{q+1}Y$ are both fibrant in $\text{Spt}_T\mathcal{M}_*$ by proposition 3.2.32(1); we have that lemma 6.1.2 in [10] together with remark 2.4.3(2) imply that the following diagram is commutative for
k \geq 0:

\[ \pi_{k, \omega} \text{Map}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}X) \xrightarrow{(W_{q+1}f)_*} \pi_{k, \eta} \text{Map}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}Y) \]

\[ \pi_{k, \omega} \text{Map}_*(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}X) \xrightarrow{(W_{q+1}f)_*} \pi_{k, \eta} \text{Map}_*(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}Y) \cong \]

\[ [F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+) \wedge S^k, W_{q+1}X]_{\text{spt}} \xrightarrow{(W_{q+1}f)_*} [F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+) \wedge S^k, W_{q+1}Y]_{\text{spt}} \cong \]

\[ [F_{n+1}(S^{k+r} \wedge G_m^{s+1} \wedge U_+), W_{q+1}X]_{\text{spt}} \xrightarrow{(W_{q+1}f)_*} [F_{n+1}(S^{k+r} \wedge G_m^{s+1} \wedge U_+), W_{q+1}Y]_{\text{spt}} \]

but by hypothesis we have that the bottom row is an isomorphism of abelian groups, since \( F_{n+1}(S^{k+r} \wedge G_m^{s+1} \wedge U_+) \) is also in \( S(q) \). Therefore all the maps in the top row are also isomorphisms. Hence, the induced map

\[ \text{Map}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}X) \xrightarrow{(W_{q+1}f)_*} \text{Map}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}Y) \]

is a weak equivalence when it is restricted to the path component of \( \text{Map}(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}X) \) containing \( \omega_0 \). This implies that the following induced map

\[ \text{Map}_*(S^1, \text{Map}_*(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}X)) \xrightarrow{(W_{q+1}f)_*} \text{Map}_*(S^1, \text{Map}_*(F_{n+1}(S^r \wedge G_m^{s+1} \wedge U_+), W_{q+1}Y)) \]
is a weak equivalence since taking $S^1$-loops kills the path components that do not contain the base point.

Finally, since $\text{Spt}_T M_*$ is a simplicial model category we have that the rows in the following commutative diagram are isomorphisms:

\[
\begin{array}{ccc}
\text{Map}_*(S^1, \text{Map}_*(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+), W_{q+1}X)) & \cong & \text{Map}_*(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+ \land S^1, W_{q+1}X)) \\
(W_{q+1}f)_* & & (W_{q+1}f)_* \\
\text{Map}_*(S^1, \text{Map}_*(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+), W_{q+1}Y)) & \cong & \text{Map}_*(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+ \land S^1, W_{q+1}Y))
\end{array}
\]

Hence the two out of three property for weak equivalences implies that the right vertical map is a weak equivalence of simplicial sets. But $F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+ \land S^1)$ is clearly isomorphic to $F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+)$, therefore the induced map

\[
\begin{array}{c}
\text{Map}(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+), W_{q+1}X) \\
\downarrow (W_{q+1}f)_* \\
\text{Map}(F_{n+1}(S^r \land \mathbb{G}_m^{s+1} \land U_+), W_{q+1}Y)
\end{array}
\]

is a weak equivalence, as we wanted. \(\square\)

**Corollary 3.2.63.** Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map of $T$-spectra. Then $f$ is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T M_*$ if and only if

\[
W_{q+1}X \xrightarrow{W_{q+1}f} W_{q+1}Y
\]

is a $C^q_{\text{eff}}$-colocal equivalence in $\text{Spt}_T M_*$. \hfill \(\blacksquare\)

**Proof.** ($\Rightarrow$): Assume that $f$ is a $S(q)$-colocal equivalence, and fix $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in C^q_{\text{eff}}$. By proposition 3.2.4 it suffices to show that the induced map

\[
\begin{equation}(3.20)\end{equation}
\[
[\text{Map}_n(S^r \land \mathbb{G}_m^s \land U_+, W_{q+1}X)]_{\text{Spt}} \\
(W_{q+1}f)_* \\
[\text{Map}_n(S^r \land \mathbb{G}_m^s \land U_+, W_{q+1}Y)]_{\text{Spt}}
\]

is an isomorphism of abelian groups.

Since $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C_{\text{eff}}^q$, we have two possibilities:

1. $s - n = q$, i.e. $F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \in S(q)$.

2. $s - n \geq q + 1$, i.e. $F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \in C_{\text{eff}}^{q+1}$

In case (1), proposition 3.2.62 implies that the induced map in diagram (3.20) is an isomorphism of abelian groups.

On the other hand, in case (2), we have by proposition 3.2.32(2) that

$$[F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \wedge W_{q+1}X, W_{q+1}Y]_{\text{Spt}} \cong 0 \cong [F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \wedge W_{q+1}Y, W_{q+1}Y]_{\text{Spt}}$$

since by construction $W_{q+1}X$ and $W_{q+1}Y$ are both $L(< q + 1)$-local $T$-spectra. Hence the induced map in diagram (3.20) is also an isomorphism of abelian groups in this case, as we wanted.

$(\Leftarrow)$: Assume that $W_{q+1}f$ is a $C_{\text{eff}}^q$-colocal equivalence in $\text{Spt}_T\mathcal{M}_s$, and fix $F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \in S(q)$.

Since $S(q) \subseteq C_{\text{eff}}^q$, it follows from proposition 3.2.4 that the induced map

$$[F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \wedge W_{q+1}X, W_{q+1}Y]_{\text{Spt}} \xrightarrow{(W_{q+1}f)^*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U+) \wedge W_{q+1}Y]_{\text{Spt}}$$

is an isomorphism of abelian groups. Therefore, proposition 3.2.62 implies that $f$ is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T\mathcal{M}_s$. This finishes the proof.

**Lemma 3.2.64.** Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map of $T$-spectra, then $f$ is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T\mathcal{M}_s$ if and only if

$$\Omega_{S^1}W_{q+1}(f) : \Omega_{S^1}W_{q+1}X \to \Omega_{S^1}W_{q+1}Y$$

is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T\mathcal{M}_s$.

**Proof.** Assume that $f$ is a $S(q)$-colocal equivalence. We need to show that $\Omega_{S^1}W_{q+1}(f)$ is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T\mathcal{M}_s$. 

Fix $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q)$. Corollary 3.2.34 implies that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$ are both $L(< q + 1)$-local; and proposition 3.2.32(1) implies that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$ are both fibrant in $\text{Spt}_T \mathcal{M}_s$. Therefore using the fact that $\text{Spt}_T \mathcal{M}_s$ is a simplicial model category, we get the following commutative diagram:

\[
\begin{array}{ccc}
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega S^1 W_{q+1} X]_{\text{Spt}} & \xrightarrow{(\Omega S^1 W_{q+1} f)_*} & [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega S^1 W_{q+1} Y]_{\text{Spt}} \\
\cong & & \cong \\
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), S^1, W_{q+1} X]_{\text{Spt}} & \xrightarrow{(W_{q+1} f)_*} & [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), S^1, W_{q+1} Y]_{\text{Spt}} \\
\cong & & \cong \\
[F_n(S^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1} X]_{\text{Spt}} & \xrightarrow{(W_{q+1} f)_*} & [F_n(S^{r+1} \wedge \mathbb{G}_m^s \wedge U_+), W_{q+1} Y]_{\text{Spt}}
\end{array}
\]

but using proposition 3.2.62 and the fact that $f$ is a $S(q)$-colocal equivalence, we have that the bottom row is an isomorphism, therefore the top row is also an isomorphism. Hence, the induced map:

\[
[F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega S^1 W_{q+1} X]_{\text{Spt}} \xrightarrow{(\Omega S^1 W_{q+1} f)_*} [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), \Omega S^1 W_{q+1} Y]_{\text{Spt}}
\]

is an isomorphism of abelian groups for every $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q)$. Finally, using proposition 3.2.62 again, together with the fact that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$ are both $L(< q + 1)$-local $T$-spectra; we have that $\Omega S^1 W_{q+1}(f)$ is a $S(q)$-colocal equivalence in $L_{< q+1} \text{Spt}_T \mathcal{M}_s$, as we wanted.

Conversely, assume that $\Omega S^1 W_{q+1}(f)$ is a $S(q)$-colocal equivalence in $L_{< q+1} \text{Spt}_T \mathcal{M}_s$, and fix $F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q)$. Corollary 3.2.34 implies that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$ are both $L(< q + 1)$-local; and proposition 3.2.32(1) implies that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$
are both fibrant in $\text{Spt}_T$. Therefore using the fact that $\text{Spt}_T$ is a simplicial model category, we get the following commutative diagram:

Since $\Omega S^1 W_{q+1} f$ is a $S(q)$-colocal equivalence, we have that proposition 3.2.62 together with the fact that $\Omega S^1 W_{q+1} X$ and $\Omega S^1 W_{q+1} Y$ are both $L(< q + 1)$-local imply that the top row in the diagram above is an isomorphism; therefore the bottom row is also an isomorphism. Thus, the induced map:

$$[F_n(S^r \wedge G^s_m \wedge U_+), W_{q+1} X]_{\text{Spt}} \xrightarrow{(W_{q+1} f)^*} [F_n(S^r \wedge G^s_m \wedge U_+), W_{q+1} Y]_{\text{Spt}}$$

is an isomorphism of abelian groups for every $F_n(S^r \wedge G^s_m \wedge U_+) \in S(q)$. Now using proposition 3.2.62 again, we have that $f$ is a $S(q)$-colocal equivalence. This finishes the proof.

**Corollary 3.2.65.** For every $q \in \mathbb{Z}$, the adjunction

$$(- \wedge S^1, \Omega S^1, \varphi) : S^q \text{Spt}_T \mathcal{M}_* \longrightarrow S^q \text{Spt}_T \mathcal{M}_*$$
is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.2.61 we have that it suffices to verify the following two conditions:

1. For every cofibrant object $X$ in $S^q\text{Spt}_T\mathcal{M}_*$, the following composition

   $X \xrightarrow{\eta_X} \Omega_{S^1}(X \wedge S^1) \xrightarrow{\Omega_{S^1} W_{q+1}^X} \Omega_{S^1} W_{q+1}(X \wedge S^1)$

   is a $S(q)$-colocal equivalence.

2. $\Omega_{S^1}$ reflects $S(q)$-colocal equivalences between fibrant objects in $S^q\text{Spt}_T\mathcal{M}_*$.

(1): By construction $S^q\text{Spt}_T\mathcal{M}_*$ is a right Bousfield localization of $L_{<q+1}\text{Spt}_T\mathcal{M}_*$, therefore the identity functor

   $id : S^q\text{Spt}_T\mathcal{M}_* \longrightarrow L_{<q+1}\text{Spt}_T\mathcal{M}_*$

   is a left Quillen functor. Thus $X$ is also cofibrant in $L_{<q+1}\text{Spt}_T\mathcal{M}_*$. Since the adjunction $(-\wedge S^1, \Omega_{S^1}, \varphi)$ is a Quillen equivalence on $L_{<q+1}\text{Spt}_T\mathcal{M}_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $L_{<q+1}\text{Spt}_T\mathcal{M}_*$:

   $X \xrightarrow{\eta_X} \Omega_{S^1}(X \wedge S^1) \xrightarrow{\Omega_{S^1} W_{q+1}^X} \Omega_{S^1} W_{q+1}(X \wedge S^1)$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $S(q)$-colocal equivalence.

(2): This follows immediately from proposition 3.2.61 and lemma 3.2.64.

**Remark 3.2.66.** We have a situation similar to the one described in remarks 3.2.9 and 3.2.39 for the model categories $R_{C_{eff}}\mathcal{Spt}_T\mathcal{M}_*$ and $L_{<q}\text{Spt}_T\mathcal{M}_*$; i.e. although the adjunction $(\Sigma_T, \Omega_T, \varphi)$ is a Quillen equivalence on $\text{Spt}_T\mathcal{M}_*$, it does not descend even to a Quillen adjunction on the $q$-slice motivic stable model category $S^q\text{Spt}_T\mathcal{M}_*$.

**Corollary 3.2.67.** For every $q \in \mathbb{Z}$, $S^q\mathcal{Sht}(S)$ has the structure of a triangulated category.
3.2. Model Structures for the Slice Filtration

**Proof.** Theorem 3.2.59 implies in particular that $S^q \text{Spt}_T M_*$ is a pointed simplicial model category, and corollary 3.2.65 implies that the adjunction

$$(- \wedge S^1, \Omega_S, \varphi) : S^q \text{Spt}_T M_* \to S^q \text{Spt}_T M_*$$

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII].

**Proposition 3.2.68.** For every $q \in \mathbb{Z}$ we have the following adjunction

$$(P_q, W_{q+1}, \varphi) : S^q \mathcal{H}(S) \to L_{<q+1} \mathcal{H}(S)$$

of exact functors between triangulated categories.

**Proof.** Since $S^q \text{Spt}_T M_*$ is the right Bousfield localization of $L_{<q+1} \text{Spt}_T M_*$ with respect to the $S(q)$-colocal equivalences, we have that the identity functor $id : S^q \text{Spt}_T M_* \to L_{<q+1} \text{Spt}_T M_*$ is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(P_q, W_{q+1}, \varphi) : S^q \mathcal{H}(S) \to L_{<q+1} \mathcal{H}(S)$$

Now proposition 6.4.1 in [10] implies that $P_q$ maps cofibre sequences in $S^q \mathcal{H}(S)$ to cofibre sequences in $L_{<q+1} \mathcal{H}(S)$. Therefore using proposition 7.1.12 in [10] we have that $P_q$ and $W_{q+1}$ are both exact functors between triangulated categories.

**Proposition 3.2.69.** Fix $q \in \mathbb{Z}$. Then the identity functor

$$id : S^q \text{Spt}_T M_* \to R_{C^q_{eff}} \text{Spt}_T M_*$$

is a right Quillen functor.

**Proof.** Consider the following diagram of right Quillen functors

$$\begin{array}{ccc}
L_{<q+1} \text{Spt}_T M_* & \xrightarrow{id} & \text{Spt}_T M_* & \xrightarrow{id} & R_{C^q_{eff}} \text{Spt}_T M_* \\
\downarrow{id} & & & & \xrightarrow{id} \\
S^q \text{Spt}_T M_* & & & &
\end{array}$$
By the universal property of right Bousfield localizations (see definition 1.8.2) it suffices to check that if \( f : X \to Y \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_T\mathcal{M}_* \), then \( W_{q+1}f : W_{q+1}X \to W_{q+1}Y \) is a \( C^q_{eff} \)-colocal equivalence in \( \text{Spt}_T\mathcal{M}_* \). But this follows immediately from corollary 3.2.63.

**Corollary 3.2.70.** For every \( q \in \mathbb{Z} \) we have the following adjunction

\[
(C_q, W_{q+1}, \varphi) : R_{C^q_{eff}} \mathcal{SH}(S) \longrightarrow \mathcal{SH}(S)
\]

of exact functors between triangulated categories.

**Proof.** By proposition 3.2.69 the identity functor \( id : R_{C^q_{eff}} \text{Spt}_T\mathcal{M}_* \to S^q\text{Spt}_T\mathcal{M}_* \) is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

\[
(C_q, W_{q+1}, \varphi) : R_{C^q_{eff}} \mathcal{SH}(S) \longrightarrow \mathcal{SH}(S)
\]

Now proposition 6.4.1 in [10] implies that \( C_q \) maps cofibre sequences in \( R_{C^q_{eff}} \mathcal{SH}(S) \) to cofibre sequences in \( S^q\mathcal{SH}(S) \). Therefore using proposition 7.1.12 in [10] we have that \( C_q \) and \( W_{q+1} \) are both exact functors between triangulated categories. \( \square \)

**Lemma 3.2.71.** Fix \( q \in \mathbb{Z} \), and let \( A \) be a cofibrant \( T \)-spectrum in \( S^q\text{Spt}_T\mathcal{M}_* \). Then the map \( * \to A \) is a trivial cofibration in \( L_{<q}\text{Spt}_T\mathcal{M}_* \).

**Proof.** Let \( Z \) be an arbitrary \( L(<q) \)-local \( T \)-spectrum in \( \text{Spt}_T\mathcal{M}_* \). We claim that the map \( Z \to * \) is a trivial fibration in \( S^q\text{Spt}_T\mathcal{M}_* \). In effect, using corollary 3.2.33 we have that \( Z \) is \( L(<q+1) \)-local in \( \text{Spt}_T\mathcal{M}_* \), i.e. a fibrant object in \( L_{<q+1}\text{Spt}_T\mathcal{M}_* \). By construction \( S^q\text{Spt}_T\mathcal{M}_* \) is a right Bousfield localization of \( L_{<q+1}\text{Spt}_T\mathcal{M}_* \), hence \( Z \) is also fibrant in \( S^q\text{Spt}_T\mathcal{M}_* \). Then by proposition 3.2.62 it suffices to show that for every \( F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S(q) \) (i.e. \( s - n = q \)):

\[
0 \simeq [F_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), Z]_{\text{Spt}}
\]

But this follows immediately from proposition 3.2.32, since \( Z \) is \( L(<q) \)-local.
Now since $S^q\text{Spt}_TM_*$ is a simplicial model category and $A$ is cofibrant in $S^q\text{Spt}_TM_*$, we have that the following map is a trivial fibration of simplicial sets:

$$\text{Map}(A, Z) \rightarrow \text{Map}(A, \ast) = \ast$$

The identity functor

$$id : S^q\text{Spt}_TM_* \rightarrow L_{<q+1}\text{Spt}_TM_*$$

is a left Quillen functor, since $S^q\text{Spt}_TM_*$ is a right Bousfield localization of $L_{<q+1}\text{Spt}_TM_*$. Therefore $A$ is also cofibrant in $L_{<q+1}\text{Spt}_TM_*$, and since $L_{<q+1}\text{Spt}_TM_*$ is a left Bousfield localization of $\text{Spt}_TM_*$, it follows that $A$ is also cofibrant in $\text{Spt}_TM_*$. On the other hand, we have that $Z$ is in particular fibrant in $\text{Spt}_TM_*$. Hence $\pi_0\text{Map}(A, Z)$ computes $[A, Z]_{\text{Spt}}$, since $\text{Spt}_TM_*$ is a simplicial model category. But $\text{Map}(A, Z) \rightarrow \ast$ is in particular a weak equivalence of simplicial sets, then

$$[A, Z]_{\text{Spt}} \cong 0$$

for every $L(< q)$-local $T$-spectrum $Z$. Finally, corollary 3.2.36 implies that $\ast \rightarrow A$ is a weak equivalence in $L_{<q}\text{Spt}_TM_*$. This finishes the proof, since we already know that $A$ is cofibrant in $L_{<q}\text{Spt}_TM_*$. \hfill \Box

**Lemma 3.2.72.** Fix $q \in \mathbb{Z}$. Then the natural map

$$C_q^qX \xrightarrow{C_q^qX} s_qX$$

is a weak equivalence in $\text{Spt}_TM_*$. 

**Proof.** Consider the following commutative diagram in $\text{Spt}_TM_*$:

$$
\begin{array}{ccc}
C_q^qX & \xrightarrow{C_q^qX} & s_qX \\
\downarrow & & \downarrow \\
C_q^qX & \xrightarrow{C_q^qX} & C_qQ^qX \\
\end{array}
\quad
\begin{array}{ccc}
C_q^qX & \xrightarrow{C_q^qX} & C_qQ^qX \\
\downarrow & & \downarrow \\
C_q^qX & \xrightarrow{C_q^qX} & C_qQ^qX \\
\end{array}
$$
By construction $C^q s_q X$, $C^q Q_s s_q X$ are both weak equivalences in $R_{C^q_{eff}} Spt_T M_+$; and [7, proposition 3.1.5] implies that $Q^q s_q X$ is a $C^q_{eff}$-colocal equivalence in $Spt_T M_+$, i.e. a weak equivalence in $R_{C^q_{eff}} Spt_T M_+$. Then the two out of three property for weak equivalences implies that $C^q(Q^q s_q X)$ is a weak equivalence in $R_{C^q_{eff}} Spt_T M_+$.

Now [7, theorem 3.2.13(2)] implies that $C^q(Q^q s_q X)$ is a weak equivalence in $Spt_T M_+$, since $C^q s_q X$ and $C^q Q_s s_q X$ are by construction $C^q_{eff}$-colocal $T$-spectra in $Spt_T M_+$. It is clear that $Q^q s_q X$ is a weak equivalence in $Spt_T M_+$, then by the two out of three property for weak equivalences, it suffices to show that $C^q Q^q s_q X$ is a weak equivalence in $Spt_T M_+$. By theorem 3.1.16(2) we have that $s_q X$ is in $\Sigma^q_{T} SH^{eff}(S)$, then corollary 3.2.15 implies that $Q^q s_q X$ is $C^q_{eff}$-colocal in $Spt_T M_+$. We already know that $C^q Q^q s_q X$ is a $C^q_{eff}$-colocal equivalence in $Spt_T M_+$; then [7, theorem 3.2.13(2)] implies that $C^q Q^q s_q X$ is also a weak equivalence in $Spt_T M_+$, since by construction $C^q Q_s s_q X$ is a $C^q_{eff}$-colocal $T$-spectrum. This finishes the proof.

**Lemma 3.2.73.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, we have that $IQ_T J s_q X$ (see theorem 3.1.16) is $L(< q + 1)$-local.

**Proof.** Proposition 3.2.32 implies that it suffices to check that $IQ_T J s_q X$ satisfies the following conditions:

1. $IQ_T J s_q X$ is fibrant in $Spt_T M_+$.
2. For every $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in C^{q+1}_{eff}$,

$$\left[ F_n(S^r \land \mathbb{G}_m^s \land U_+), IQ_T J s_q X \right]_{Spt} \cong 0$$

Condition (1) holds trivially, since $IQ_T J$ is a fibrant replacement functor in $Spt_T M_+$.

Fix $F_n(S^r \land \mathbb{G}_m^s \land U_+) \in C^{q+1}_{eff}$. Since $C^{q+1}_{eff} \subseteq \Sigma^q_{T} SH^{eff}(S)$, it follows from theorem 3.1.16(3) that:

$$\left[ F_n(S^r \land \mathbb{G}_m^s \land U_+), IQ_T J s_q X \right]_{Spt} \cong \left[ F_n(S^r \land \mathbb{G}_m^s \land U_+), s_q X \right]_{Spt} \cong 0$$

and this takes care of condition (2).
Lemma 3.2.74. Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, $C_qIQ_TJf_{q+1}X \cong *$ in $S^q \mathcal{H}(S)$.

Proof. Consider the following commutative diagram in $S^T_\mathcal{M}_*$:

\[
\begin{array}{c}
Qsf_{q+1}X & \xrightarrow{Qs^{f_{q+1}X}} & f_{q+1}X & \xrightarrow{IQ_TJf_{q+1}X} & IQ_TJf_{q+1}X \\
C_qQsf_{q+1}X & \xrightarrow{C_qQs^{f_{q+1}X}} & C_qf_{q+1}X & \xrightarrow{C_qIQ_TJf_{q+1}X} & C_qIQ_TJf_{q+1}X \\
\end{array}
\]

(3.21)

We claim that all the maps in the diagram (3.21) above are weak equivalences in $S^T_\mathcal{M}_*$. In effect, it is clear that all the maps in the top row are weak equivalences in $S^T_\mathcal{M}_*$. Hence, by the two out of three property for weak equivalences it suffices to show that $C_qQs^{f_{q+1}X}$, $C_q(Qs^{f_{q+1}X})$ and $C_q(IQ_TJf_{q+1}X)$ are all weak equivalences in $S^T_\mathcal{M}_*$.

On the other hand, [7, proposition 3.1.5] implies that all the maps in the top row are weak equivalences in $R^{q}_{C^{\text{eff}}e_{eff}}S^T_\mathcal{M}_*$, and it is clear that all the vertical maps are also weak equivalences in $R^{q}_{C^{\text{eff}}e_{eff}}S^T_\mathcal{M}_*$. Thus, by the two out of three property for weak equivalences we have that all the maps in the diagram (3.21) above are weak equivalences in $R^{q}_{C^{\text{eff}}e_{eff}}S^T_\mathcal{M}_*$.

By construction we have that $C_qQsf_{q+1}X$, $C_qf_{q+1}X$ and $C_qIQ_TJf_{q+1}X$ are all $C^{\text{eff}}e_{eff}$-colocal $T$-spectra in $S^T_\mathcal{M}_*$. Then [7, theorem 3.2.13(2)] implies that $C_q(Qs^{f_{q+1}X})$ and $C_q(IQ_TJf_{q+1}X)$ are both weak equivalences in $S^T_\mathcal{M}_*$.

Now, by proposition 3.1.12 we have that $f_{q+1}X \in \Sigma^{q+1} \mathcal{H}^{\text{eff}}(S) \subseteq \Sigma^{q} \mathcal{H}^{\text{eff}}(S)$. Thus, corollary 3.2.15 implies that $Qsf_{q+1}X$ is a $C^{\text{eff}}e_{eff}$-colocal $T$-spectrum in $S^T_\mathcal{M}_*$. Then using [7, theorem 3.2.13(2)] again, we have that $C_qQsf_{q+1}X$ is a weak equivalence in $S^T_\mathcal{M}_*$ since by construction $C_qQsf_{q+1}X$ is a $C^{\text{eff}}e_{eff}$-colocal $T$-spectrum and $C_qQsf_{q+1}X$ is a $C^{\text{eff}}e_{eff}$-colocal equivalence in $S^T_\mathcal{M}_*$.

This proves the claim, i.e. all the maps in the diagram (3.21) above are weak equivalences in $S^T_\mathcal{M}_*$. Then using [7, proposition 3.1.5] again, we have that all the maps in the diagram (3.21) above are also weak equivalences in $S^qS^T_\mathcal{M}_*$. Therefore, to finish the proof it is enough to check that $* \rightarrow Qsf_{q+1}X$ is a weak equivalence in $S^qS^T_\mathcal{M}_*$.

But corollary 3.2.47 implies that $* \rightarrow Qsf_{q+1}X$ is a weak equivalence in $L_{<q+1}S^T_\mathcal{M}_*$. 


Therefore, using [7, proposition 3.1.5], we have that \( * \to Q_s f_{q+1} X \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T M_\ast \), i.e. a weak equivalence in \( S^q \text{Spt}_T M_\ast \). This finishes the proof. \( \square \)

**Proposition 3.2.75.** Fix \( q \in \mathbb{Z} \). Then for every \( T \)-spectrum \( X \), the following maps of \( T \)-spectra:

\[
\begin{align*}
    s_q X & \xrightarrow{IQ_T J^s q X} IQ_T J s_q X \xleftarrow{C_q IQ_T J s_q X} C_q IQ_T J s_q X \\
\end{align*}
\]  

(3.22)

are both weak equivalences in \( \text{Spt}_T \mathcal{M}_\ast \).

Furthermore, these weak equivalences induce natural isomorphisms between the following exact functors

\[
\begin{align*}
    \mathcal{SH}(S) & \xrightarrow{s_q} \mathcal{SH}(S) \\
\end{align*}
\]

\[
\begin{align*}
    \mathcal{SH}(S) & \xrightarrow{IQ_T J s_q} \mathcal{SH}(S) \\
\end{align*}
\]

**Proof.** The naturality of the maps \( IQ_T J^X : X \to IQ_T J X \) and \( C_q^X : C_q X \to X \) implies that we have induced natural transformations of functors \( s_q \to IQ_T J s_q \) and \( C_q IQ_T J s_q \to IQ_T J s_q \). Hence, it is enough to show that for every \( T \)-spectrum \( X \), \( IQ_T J^s q X \) and \( C_q^IQ_T J s_q X \) are weak equivalences in \( \text{Spt}_T \mathcal{M}_\ast \).

It is clear that \( IQ_T J^s q X \) is a weak equivalence in \( \text{Spt}_T \mathcal{M}_\ast \), since \( IQ_T J \) is a fibrant replacement functor for \( \text{Spt}_T \mathcal{M}_\ast \).

We now proceed to show that \( C_q^IQ_T J s_q X \) is a weak equivalence in \( \text{Spt}_T \mathcal{M}_\ast \). Consider the following commutative diagram in \( \text{Spt}_T \mathcal{M}_\ast \):

\[
\begin{align*}
    s_q X & \xleftarrow{C_q^s q X} C_q s_q X \\
    IQ_T J^s q X & \xrightarrow{C_q^s q X} C_q IQ_T J s_q X \\
\end{align*}
\]

Lemma 3.2.72 implies that \( C_q^s q X \) is a weak equivalence in \( \text{Spt}_T \mathcal{M}_\ast \). Since we know that \( IQ_T J^s q X \) is always a weak equivalence in \( \text{Spt}_T \mathcal{M}_\ast \), the two out of three property for weak equivalences implies that it suffices to check that \( C_q^IQ_T J^s q X \) is also a weak equivalence in \( \text{Spt}_T \mathcal{M}_\ast \).
Using [7, proposition 3.1.5], we have that $IQ_T J^s_q X$ is a $C^q_{eff}$-colocal equivalence. Then the two out of three property for $C^q_{eff}$-colocal equivalences implies that $C_q (IQ_T J^s_q X)$ is a $C^q_{eff}$-colocal equivalence, since by construction $C^q_{q} X$ and $C^I Q_T J^s_q X$ are both $C^q_{eff}$-colocal equivalences.

Finally, by construction $C^q_{q} X$ and $C^I Q_T J^s_q X$ are both $C^q_{eff}$-colocal, therefore [7, theorem 3.2.13(2)] implies that $C_q (IQ_T J^s_q X)$ is a weak equivalence in $Spt_T M_*$, as we wanted.

\[ \square \]

**Proposition 3.2.76.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, the natural map:

$$C_q IQ_T J^s_q X \xrightarrow{W_{q+1} C_q IQ_T J^s_q X} W_{q+1} C_q IQ_T J^s_q X$$

is a weak equivalence in $Spt_T M_*$.

Furthermore, this weak equivalence induces a natural isomorphism between the following exact functors

$$\mathcal{S}H(S) \xrightarrow{C_q IQ_T J^s_q X} \mathcal{S}H(S)$$

**Proof.** The naturality of the maps $W^X_{q+1} : X \rightarrow W_{q+1} X$ implies that we have an induced natural transformation of functors $C_q IQ_T J^s_q \rightarrow W_{q+1} C_q IQ_T J^s_q$. Hence, it is enough to show that for every $T$-spectrum $X$, $W_{q+1} C_q IQ_T J^s_q$ is a weak equivalence in $Spt_T M_*$. Consider the following commutative diagram in $Spt_T M_*$:

$$
\begin{array}{ccc}
IQ_T J^s_q X & \xrightarrow{W_{q+1} C_q I Q_T J^s_q X} & W_{q+1} IQ_T J^s_q X \\
C^I Q_T J^s_q X & \xrightarrow{W_{q+1} C_q I Q_T J^s_q X} & W_{q+1} C_q I Q_T J^s_q X \\
\end{array}
$$

By construction, $W_{q+1} I Q_T J^s_q X$ is a $L(< q + 1)$-local equivalence, and $W_{q+1} IQ_T J^s_q X$ is $L(< q + 1)$-local in $Spt_T M_*$. By lemma 3.2.73 we have that $IQ_T J^s_q X$ is also $L(< q + 1)$-local. Therefore, [7, theorem 3.2.13(1)] implies that $W_{q+1} I Q_T J^s_q X$ is a weak equivalence in $Spt_T M_*$. Now, it follows directly from proposition 3.2.75 that $C_q I Q_T J^s_q X$ is a weak equivalence in $Spt_T M_*$. Hence by the two out of three property for weak equivalences, it suffices to show
that $W_{q+1}(C_q^{IQTJ.s_q}X)$ is a weak equivalence in $S_{pt}T_{s_q}$. 

We already know that $C_q^{IQTJ.s_q}X$ is a weak equivalence in $S_{pt}T_{s_q}$, then using [7, proposition 3.1.5] we have that $C_q^{IQTJ.s_q}X$ is a $L(< q + 1)$-local equivalence. Then the two out of three property for $L(< q + 1)$-local equivalences implies that $W_{q+1}(C_q^{IQTJ.s_q}X)$ is also a $L(< q + 1)$-local equivalence, since by construction $W_{q+1}^{IQTJ.s_q}X$ and $W_{q+1}^{C_q^{IQTJ.s_q}X}$ are both $L(< q + 1)$-local equivalences.

Finally, by construction $W_{q+1}^{IQTJ.s_q}X$ and $W_{q+1}^{C_q^{IQTJ.s_q}X}$ are $L(< q + 1)$-local in $S_{pt}T_{s_q}$, then [7, theorem 3.2.13(1)] implies that $W_{q+1}(C_q^{IQTJ.s_q}X)$ is a weak equivalence in $S_{pt}T_{s_q}$, as we wanted. 

\[\text{Proposition 3.2.77.} \text{ Fix } q \in \mathbb{Z}. \text{ Then for every } T\text{-spectrum } X, \text{ the natural map:} \]

\[\begin{array}{c}
W_{q+1}C_q^{IQTJ.s_q}X \\
\end{array} \xleftarrow{C_q^{W_{q+1}C_q^{IQTJ.s_q}X}} \xrightarrow{C_qC_{q+1}^{IQTJ.s_q}X} \]

\[\begin{array}{c}
C_qW_{q+1}C_q^{IQTJ.s_q}X \\
\end{array} \]

is a weak equivalence in $S_{pt}T_{s_q}$.

Furthermore, this weak equivalence induces a natural isomorphism between the following exact functors

\[\mathcal{H}(S) \xrightarrow{W_{q+1}C_q^{IQTJ.s_q}} \mathcal{H}(S) \xleftarrow{C_qW_{q+1}C_q^{IQTJ.s_q}} \]

\[\text{Proof.} \text{ The naturality of the maps } C_q^X : C_qX \to X \text{ implies that we have an induced natural transformation of functors } C_qW_{q+1}C_q^{IQTJ.s_q}X \to W_{q+1}C_q^{IQTJ.s_q}X. \text{ Hence, it is enough to show that for every } T\text{-spectrum } X, C_q^{W_{q+1}C_q^{IQTJ.s_q}X} \text{ is a weak equivalence in } S_{pt}T_{s_q}. \]

Consider the following commutative diagram in $S_{pt}T_{s_q}$:

\[\begin{array}{c}
C_q^{IQTJ.s_q}X \\
W_{q+1}^{C_q^{IQTJ.s_q}X} \xrightarrow{C_q^{W_{q+1}C_q^{IQTJ.s_q}X}} \xleftarrow{C_q^{C_q^{IQTJ.s_q}X}} \xrightarrow{C_q(W_{q+1}^{C_q^{IQTJ.s_q}X})} \xleftarrow{C_qW_{q+1}C_q^{IQTJ.s_q}X} \]

By construction $C_q^{C_q^{IQTJ.s_q}X}$ is a $C_q^{eff}$-colocal equivalence, and

\[C_q^{IQTJ.s_q}X, \ C_qC_q^{IQTJ.s_q}X\]
are both $C^q_{eff}$-colocal in $\text{Spt}_{T\mathbb{M}}$. Therefore, [7, theorem 3.2.13(2)] implies that
\[
C_q IQ_T J s_q X
\]
is a weak equivalence in $\text{Spt}_{T\mathbb{M}}$.

Now, it follows directly from proposition 3.2.76 that $W_{q+1} C_q IQ_T J s_q X$ is a weak equivalence in $\text{Spt}_{T\mathbb{M}}$. Hence by the two out of three property for weak equivalences, it suffices to show that $C_q(W_{q+1} C_q IQ_T J s_q X)$ is a weak equivalence in $\text{Spt}_{T\mathbb{M}}$.

We already know that $W_{q+1} C_q IQ_T J s_q X$ is a weak equivalence in $\text{Spt}_{T\mathbb{M}}$, then using [7, proposition 3.1.5] we have that $W_{q+1} C_q IQ_T J s_q X$ is a $C^q_{eff}$-colocal equivalence. Then the two out of three property for $C^q_{eff}$-colocal equivalences implies that $C_q(W_{q+1} C_q IQ_T J s_q X)$ is also a $C^q_{eff}$-colocal equivalence, since by construction $C_q W_{q+1} C_q IQ_T J s_q X$ and $C_q W_{q+1} C_q IQ_T J s_q X$ are both $C^q_{eff}$-colocal equivalences.

Finally, by construction $C_q C_q IQ_T J s_q X$ and $C_q W_{q+1} C_q IQ_T J s_q X$ are $C^q_{eff}$-colocal in $\text{Spt}_{T\mathbb{M}}$ then [7, theorem 3.2.13(2)] implies that $C_q(W_{q+1} C_q IQ_T J s_q X)$ is a weak equivalence in $\text{Spt}_{T\mathbb{M}}$, as we wanted.

\[\square\]

**Proposition 3.2.78.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, the following natural maps in $R_{C^q_{eff}} \mathcal{SH}(S)$ (see proposition 3.1.15 and theorem 3.1.16):
\[
\begin{array}{ccc}
IQ_T J X & \overset{IQ_T J(\theta_{X})}{\longrightarrow} & IQ_T J f_q X \\
\overset{IQ_T J(\pi_{q}^{X})}{\longrightarrow} & IQ_T J s_q X
\end{array}
\]
become isomorphisms in $S^q \mathcal{SH}(S)$ after applying the functor $C_q$:
\[
\begin{array}{ccc}
C_q IQ_T J X & \overset{C_q IQ_T J(\theta_{X})}{\longrightarrow} & C_q IQ_T J f_q X \\
\overset{C_q IQ_T J(\pi_{q}^{X})}{\longrightarrow} & C_q IQ_T J s_q X
\end{array}
\]

**Proof.** Proposition 3.2.17 implies that the map
\[
IQ_T J f_q X \overset{IQ_T J(\theta_{X})}{\longrightarrow} IQ_T J X
\]
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is an isomorphism in $R_{C^q_{eff}} S\mathcal{H}(S)$. Hence using corollary 3.2.70 we have that

$$C_q IQ_T J f_q X \xrightarrow{C_q IQ_T J(\theta_X)} C_q IQ_T J X$$

is an isomorphism in $S^q S\mathcal{H}(S)$.

On the other hand, theorem 3.1.16(1) implies that we have the following distinguished triangle in $S\mathcal{H}(S)$:

$$f_{q+1} X \rightarrow f_q X \xrightarrow{\pi^X_q} s_q X \rightarrow \Sigma_T^{1,0} f_{q+1} X$$

Proposition 3.2.11 implies that after applying $IQ_T J$ we get the following distinguished triangle in $R_{C^q_{eff}} S\mathcal{H}(S)$

$$IQ_T J f_{q+1} X \rightarrow IQ_T J f_q X \xrightarrow{IQ_T J(\pi^X_q)} IQ_T J s_q X \rightarrow \Sigma_T^{1,0} IQ_T J f_{q+1} X$$

Now corollary 3.2.70 implies that after applying $C_q$ we get the following distinguished triangle in $S^q S\mathcal{H}(S)$

$$C_q IQ_T J f_{q+1} X \rightarrow C_q IQ_T J f_q X \xrightarrow{C_q IQ_T J(\pi^X_q)} C_q IQ_T J s_q X \rightarrow \Sigma_T^{1,0} C_q IQ_T J f_{q+1} X$$

Therefore it is enough to check that $C_q IQ_T J f_{q+1} X \cong *$ in $S^q S\mathcal{H}(S)$. But this follows directly from lemma 3.2.74.

\[ \square \]

**Corollary 3.2.79.** Fix $q \in \mathbb{Z}$. Then for every $T$-spectrum $X$, the following natural maps in $S\mathcal{H}(S)$ (see proposition 3.1.15 and theorem 3.1.16):

$$X \xleftarrow{\theta_X} f_q X \xrightarrow{\pi^X_q} s_q X$$

become isomorphisms in $S\mathcal{H}(S)$ after applying the functor $C_q W_{q+1} C_q IQ_T J$:

$$C_q W_{q+1} C_q IQ_T J X \xleftarrow{C_q W_{q+1} C_q IQ_T J(\theta_X)} C_q W_{q+1} C_q IQ_T J f_q X \xrightarrow{\cong} C_q W_{q+1} C_q IQ_T J s_q X$$

$$\cong C_q W_{q+1} C_q IQ_T J(\pi^X_q)$$
Furthermore, these maps induce natural isomorphisms between the following exact functors

\[ \mathcal{H}(S) \xrightarrow{C_q W_{q+1} C_q I Q_T J s_q X} \mathcal{H}(S) \]

\[ \mathcal{H}(S) \xrightarrow{C_q W_{q+1} C_q I Q_T J f_q X} \mathcal{H}(S) \]

**Proof.** The naturality of the maps \( \pi^X_q : f_q X \to s_q X \) and \( \theta^X_q : f_q X \to X \) implies that we have induced natural transformations of functors

\[ C_q W_{q+1} C_q I Q_T J f_q \to C_q W_{q+1} C_q I Q_T J s_q \]

and \( C_q W_{q+1} C_q I Q_T J f_q \to C_q W_{q+1} C_q I Q_T J. \) Hence, it is enough to show that for every \( T \)-spectrum \( X \), \( C_q W_{q+1} C_q I Q_T J(\pi^X_q) \) and \( C_q W_{q+1} C_q I Q_T J(\theta^X_q) \) are weak equivalences in \( \text{Spt}_T M_* \).

Proposition 3.2.78 implies that the following natural maps

\[ C_q I Q_T J X \xrightarrow{C_q I Q_T J(\pi^X_q)} C_q I Q_T J f_q X \xrightarrow{C_q I Q_T J(\theta^X_q)} C_q I Q_T J s_q X \]

are isomorphisms in \( S^q \mathcal{H}(S) \). Then the result follows immediately from corollary 3.2.70 and proposition 3.2.11.

**Theorem 3.2.80.** Fix \( q \in \mathbb{Z} \). Then for every \( T \)-spectrum \( X \), we have the following diagram in \( \mathcal{H}(S) \):

\[ \begin{array}{ccc}
C_q I Q_T J s_q X & \xrightarrow{W_{q+1} C_q I Q_T J s_q X} & C_q W_{q+1} C_q I Q_T J s_q X \\
\downarrow_{C_q I Q_T J s_q X} & \cong & \downarrow_{C_q W_{q+1} C_q I Q_T J s_q X} \\
I Q_T J s_q X & \xrightarrow{W_{q+1} C_q I Q_T J s_q X} & C_q W_{q+1} C_q I Q_T J s_q X \\
\downarrow_{I Q_T J s_q X} & \cong & \downarrow_{C_q W_{q+1} C_q I Q_T J s_q X} \\
s_q X & \xrightarrow{W_{q+1} C_q I Q_T J s_q X} & C_q W_{q+1} C_q I Q_T J s_q X \\
\downarrow_{s_q X} & \cong & \downarrow_{C_q W_{q+1} C_q I Q_T J X} \\
\end{array} \]

(3.23)
where all the maps are isomorphisms in $\mathcal{H}(S)$. Furthermore, this diagram induces a natural isomorphism between the following exact functors:

$$\mathcal{H}(S) \xrightarrow{\sim} \mathcal{H}(S)$$

**Proof.** The fact that $IQ_T^J s_q X$ and $C_q IQ_T^J s_q X$ are isomorphisms in $\mathcal{H}(S)$ follows from proposition 3.2.75. Now proposition 3.2.76 implies that $W_{q+1}^q C_q IQ_T^J s_q X$ is an isomorphism in $\mathcal{H}(S)$, and proposition 3.2.77 implies that $C_{q+1} W_{q+1}^q C_q IQ_T^J s_q X$ is also an isomorphism in $\mathcal{H}(S)$. Finally, corollary 3.2.79 implies that $C_q W_{q+1}^q C_q IQ_T^J (\pi_q^X)$ and $C_q W_{q+1}^q C_q IQ_T^J (\theta_X)$ are both isomorphisms in $\mathcal{H}(S)$.

This shows that all the maps in the diagram (3.23) are isomorphisms in $\mathcal{H}(S)$, therefore for every $T$-spectrum $X$ we can define the following composition in $\mathcal{H}(S)$

\[
\begin{array}{c}
W_{q+1}^q C_q IQ_T^J s_q X \\
\cong \\
C_q IQ_T^J s_q X \\
\cong \\
s_q X
\end{array}
\]

\[
\begin{array}{c}
C_q W_{q+1}^q C_q IQ_T^J f_q X \\
\cong \\
C_q W_{q+1}^q C_q IQ_T^J (\theta_X) \\
\cong \\
C_q W_{q+1}^q C_q IQ_T^J X
\end{array}
\]

which is an isomorphism.

On the other hand, propositions 3.2.75, 3.2.76 and 3.2.77, and corollary 3.2.79 imply all together that the isomorphisms defined in diagram (3.24) induce a natural isomorphism of functors $s_q \cong C_q W_{q+1}^q C_q IQ_T^J$. This finishes the proof.

**Proposition 3.2.81.** Fix $q \in \mathbb{Z}$. Let $\eta$ denote the unit of the adjunction $(C_q, W_{q+1}, \varphi) : R_{C_{q+1}}^q \mathcal{H}(S) \to S^q \mathcal{H}(S)$ constructed in corollary 3.2.70. Then the natural transformation $\pi_q : f_q \to s_q$ (see theorem 3.1.16) gets canonically identified, through the equivalence of categories $r_q C_q, IQ_T^J i_q$ constructed in proposition 3.2.21 with the following map in $\mathcal{H}(S)$:

$$C_q IQ_T^J X \xrightarrow{C_q(\eta IQ_T^J X)} C_q W_{q+1}^q C_q IQ_T^J X$$
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**Proof.** It follows directly from theorem 3.1.16, corollary 3.2.63 together with [19, proposition 9.1.8].

**Remark 3.2.82.** Theorem 3.2.80 gives the desired lifting to the model category level for the functors $s_q$ defined in theorem 3.1.16; and it completes the program that we started at the beginning of this section, where the goal was to get a lifting for the slice functors $s_q$.

3.3 The Symmetric Model Structure for the Slice Filtration

Our goal now is to lift the model structures constructed in section 3.2 to the category of symmetric $T$-spectra, in order to have a natural framework for the study of the multiplicative properties of Voevodsky’s slice filtration.

Let $\mathcal{H}^\Sigma(S)$ denote the homotopy category associated to $\text{Spt}_T^{\Sigma}$M. We call $\mathcal{H}^\Sigma(S)$ the **motivic symmetric stable homotopy category**. We will denote by $[-,-]^{\Sigma}_{Spt}$ the set of maps between two objects in $\mathcal{H}^\Sigma(S)$.

**Definition 3.3.1.** Let $Q_{\Sigma}$ denote a cofibrant replacement functor on $\text{Spt}_T^{\Sigma}$M; such that for every symmetric $T$-spectrum $X$, the natural map

$$Q_{\Sigma}X \xrightarrow{Q_X} X$$

is a trivial fibration in $\text{Spt}_T^{\Sigma}$M.

**Definition 3.3.2.** Let $R_{\Sigma}$ denote a fibrant replacement functor on $\text{Spt}_T^{\Sigma}$M; such that for every symmetric $T$-spectrum $X$, the natural map

$$X \xrightarrow{R_X} R_{\Sigma}X$$

is a trivial cofibration in $\text{Spt}_T^{\Sigma}$M.

**Proposition 3.3.3.** The motivic symmetric stable homotopy category $\mathcal{H}^\Sigma(S)$ has a structure of triangulated category defined as follows:
1. The suspension $\Sigma^{1,0}_T$ functor is given by

$$- \wedge S^1 : \mathfrak{H}^\Sigma(S) \longrightarrow \mathfrak{H}^\Sigma(S)$$

$$X \longrightarrow Q_\Sigma X \wedge S^1$$

2. The distinguished triangles are isomorphic to triangles of the form

$$A \xrightarrow{i} B \xrightarrow{j} C \xrightarrow{k} \Sigma^{1,0}_T A$$

where $i$ is a cofibration in $\text{Spt}_T^{\Sigma} M_*$, and $C$ is the homotopy cofibre of $i$.

**Proof.** Theorem 2.6.22 implies in particular that $\text{Spt}_T^{\Sigma} M_*$ is a pointed simplicial model category, and theorem 2.6.26 implies that the adjunction:

$$(-, \wedge S^1, \Omega S^1, \varphi) : \text{Spt}_T^{\Sigma} M_* \longrightarrow \text{Spt}_T^{\Sigma} M_*$$

is a Quillen equivalence. The result now follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII] (see [10, proposition 7.1.6]).

**Theorem 3.3.4.** The adjunction

$$(V, U, \varphi) : \text{Spt}_T M_* \longrightarrow \text{Spt}_T^{\Sigma} M_*$$

given by the symmetrization and the forgetful functors, induces an adjunction

$$(VQ_\Sigma, UR_\Sigma, \varphi) : \mathfrak{H}(S) \longrightarrow \mathfrak{H}^\Sigma(S)$$

of exact functors between triangulated categories. Furthermore, $VQ_\Sigma$ and $UR_\Sigma$ are both equivalences of categories.

**Proof.** Theorem 2.6.29 implies that the adjunction $(V, U, \varphi)$ is a Quillen equivalence. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(VQ_\Sigma, UR_\Sigma, \varphi) : \mathfrak{H}(S) \longrightarrow \mathfrak{H}^\Sigma(S)$$

Now [10, proposition 1.3.13] implies that $VQ_\Sigma, UR_\Sigma$ are both equivalences of categories. Finally, proposition 2.6.20 together with [10, proposition 6.4.1] imply that $VQ_\Sigma$ maps cofibre
sequences in $\mathcal{SH}(S)$ to cofibre sequences in $\mathcal{SH}^\Sigma(S)$. Therefore using proposition 7.1.12 in [10] we have that $VQ_s$ and $UR_\Sigma$ are both exact functors between triangulated categories. \hfill \Box

**Corollary 3.3.5.** Fix $q \in \mathbb{Z}$.

1. The exact functor (see remark 3.1.13)
   \[
   f_q : \mathcal{SH}(S) \rightarrow \mathcal{SH}(S)
   \]
   gets canonically identified with the following exact functor:
   \[
   \tilde{f}_q : \mathcal{SH}^\Sigma(S) \rightarrow \mathcal{SH}^\Sigma(S)
   X \rightarrow VQ_s(f_q(UR_\Sigma X))
   \]
   i.e. $\tilde{f}_q = VQ_s \circ f_q \circ UR_\Sigma$.

2. The exact functor (see theorem 3.1.18)
   \[
   s_{<q} : \mathcal{SH}(S) \rightarrow \mathcal{SH}(S)
   \]
   gets canonically identified with the following exact functor:
   \[
   \tilde{s}_{<q} : \mathcal{SH}^\Sigma(S) \rightarrow \mathcal{SH}^\Sigma(S)
   X \rightarrow VQ_s(s_{<q}(UR_\Sigma X))
   \]
   i.e. $\tilde{s}_{<q} = VQ_s \circ s_{<q} \circ UR_\Sigma$.

3. The exact functor (see theorem 3.1.16)
   \[
   s_q : \mathcal{SH}(S) \rightarrow \mathcal{SH}(S)
   \]
   gets canonically identified with the following exact functor:
   \[
   \tilde{s}_q : \mathcal{SH}^\Sigma(S) \rightarrow \mathcal{SH}^\Sigma(S)
   X \rightarrow VQ_s(s_q(UR_\Sigma X))
   \]
   i.e. $\tilde{s}_q = VQ_s \circ s_q \circ UR_\Sigma$.

**Proof.** Follows immediately from theorem 3.3.4. \hfill \Box
Lemma 3.3.6. Let $X \in \mathcal{M}_*$ be a pointed simplicial presheaf which is compact in the sense of Jardine (see definition 2.3.10), and let $F_n^\Sigma(X)$ be the symmetric $T$-spectrum constructed in definition 2.6.8. Consider an arbitrary collection of symmetric $T$-spectra $\{Z_i\}_{i \in I}$ indexed by a set $I$. Then

$$[F_n^\Sigma(X), \prod_{i \in I} Z_i]^\Sigma_{Spt} \cong \prod_{i \in I} [F_n^\Sigma(X), Z_i]^\Sigma_{Spt}$$

Proof. Using proposition 2.6.19 and theorem 2.6.29 we have:

$$[F_n^\Sigma(X), \prod_{i \in I} Z_i]^\Sigma_{Spt} = [V(F_n(X)), \prod_{i \in I} Z_i]^\Sigma_{Spt}$$

$$\cong [F_n(X), U(\prod_{i \in I} Z_i)]_{Spt} = [F_n(X), \prod_{i \in I} UZ_i]_{Spt}$$

Now since $X \in \mathcal{M}_*$ is compact in the sense of Jardine, lemma 3.1.4 implies that:

$$[F_n(X), \prod_{i \in I} UZ_i]_{Spt} \cong \prod_{i \in I} [F_n(X), UZ_i]_{Spt}$$

Finally using proposition 2.6.19 and theorem 2.6.29 again, we get:

$$[F_n^\Sigma(X), \prod_{i \in I} Z_i]^\Sigma_{Spt} \cong \prod_{i \in I} [F_n^\Sigma(X), UZ_i]^\Sigma_{Spt}$$

$$\cong \prod_{i \in I} [V(F_n(X)), Z_i]^\Sigma_{Spt}$$

$$= \prod_{i \in I} [F_n^\Sigma(X), Z_i]^\Sigma_{Spt}$$

as we wanted. \qed

Proposition 3.3.7. The motivic symmetric stable homotopy category $SH^\Sigma(S)$ is a compactly generated triangulated category in the sense of Neeman (see [18, definition 1.7]). The set of compact generators is given by (see definition 2.6.8):

$$C^\Sigma = \bigcup_{n,r,s \geq 0} \bigcup_{U \in (Sm|_S)} F_n^\Sigma(S^r \wedge \mathbb{G}_{m}^s \wedge U_+)$$

i.e. the smallest triangulated subcategory of $SH^\Sigma(S)$ closed under small coproducts and containing all the objects in $C^\Sigma$ coincides with $SH^\Sigma(S)$. 
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**Proof.** Since $\mathcal{S}^\Sigma(S)$ is closed under small coproducts, we just need to prove the following two claims:

1. For every $F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C^\Sigma$; $F^\Sigma_n(S^r \wedge G^s_m \wedge U_+)$ commutes with coproducts in $\mathcal{S}^\Sigma(S)$, i.e. given a family of symmetric $T$-spectra $\{X_i\}_{i \in I}$ indexed by a set $I$ we have:

$$[F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), \prod_{i \in I} X_i]_{Spt} \cong \prod_{i \in I} [F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), X_i]_{Spt}$$

2. If a symmetric $T$-spectrum $X$ has the following property: $[F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), X]_{Spt} = 0$ for every $F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C^\Sigma$, then $X \cong *$ in $\mathcal{S}^\Sigma(S)$.

(1): Follows immediately from lemma 3.3.6 since we know by proposition 2.4.1 that the pointed simplicial presheaves $S^r \wedge G^s_m \wedge U_+$ are all compact in the sense of Jardine.

(2): Fix $F_n(S^r \wedge G^s_m \wedge U_+) \in C \subseteq \text{Spt}_T M_*$. Using theorem 2.6.29 we have that:

$$[F_n(S^r \wedge G^s_m \wedge U_+), UX]_{Spt} \cong [F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), X]_{Spt} = 0$$

Therefore, proposition 3.1.5 implies that the map $UX \to U(*) = *$ is a weak equivalence in $\text{Spt}_T M_*$. Hence, [13, proposition 4.8] implies that $X \to *$ is also a weak equivalence in $\text{Spt}_T M_*$, i.e. $X \cong *$ in $\mathcal{S}^\Sigma(S)$. This finishes the proof. \qed

**Corollary 3.3.8.** Let $f : X \to Y$ be a map in $\mathcal{S}^\Sigma(S)$. Then $f$ is an isomorphism if and only if $f$ induces an isomorphism of abelian groups:

$$[F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), X]_{Spt}^\Sigma \xrightarrow{f_*} [F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), Y]_{Spt}^\Sigma$$

for every $F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C^\Sigma$.

**Proof.** ($\Rightarrow$): If $f$ is an isomorphism in $\mathcal{S}^\Sigma(S)$ it is clear that the induced maps $f_*$ are isomorphisms of abelian groups for every $F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C^\Sigma$.

($\Leftarrow$): Complete $f$ to a distinguished triangle in $\mathcal{S}^\Sigma(S)$:

$$X \xrightarrow{f} Y \xrightarrow{g} Z \xrightarrow{h} \Sigma^1_{T} X$$
Then $f$ is an isomorphism if and only if $Z \cong \ast$ in $\mathcal{S}H^\Sigma(S)$.

Now since the functor $[F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+), -, \Sigma]_{\text{Spt}}$ is homological, we get the following long exact sequence of abelian groups:

$$
\cdots \to F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, X)^\Sigma_{\text{Spt}} \xrightarrow{f_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, Y)^\Sigma_{\text{Spt}} \xrightarrow{g_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, Z)^\Sigma_{\text{Spt}} \xrightarrow{h_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, \Sigma_1^1 X)^\Sigma_{\text{Spt}} \xrightarrow{\Sigma_1^1 f_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, \Sigma_1^1 Y)^\Sigma_{\text{Spt}} \xrightarrow{g_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, \Sigma_1^1 Z)^\Sigma_{\text{Spt}} \xrightarrow{h_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+ + 1, X)^\Sigma_{\text{Spt}} \xrightarrow{\Sigma_1^1 f_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+ + 1, Y)^\Sigma_{\text{Spt}} \xrightarrow{\Sigma_1^1 f_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+ + 1, Z)^\Sigma_{\text{Spt}} \xrightarrow{h_*} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+ + 1, \Sigma_1^1 X)^\Sigma_{\text{Spt}} \xrightarrow{\Sigma_1^1 f_*} \cdots
$$

But by hypothesis all the maps $f_*$ are isomorphisms, therefore $F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+, Z)^\Sigma_{\text{Spt}} = 0$ for every $F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in C^\Sigma$. Since $\mathcal{S}H^\Sigma(S)$ is a compactly generated triangulated category (see proposition 3.3.7) with set of compact generators $C^\Sigma$, we have that $Z \cong \ast$. This implies that $f$ is an isomorphism, as we wanted.

**Theorem 3.3.9.** Fix $q \in \mathbb{Z}$. Consider the following set of objects in $\text{Spt}^T_{\Sigma^*}$ (see theorem 3.2.1):

$$
C^q_{\text{eff}} = \bigcup_{n,r,s \geq 0, s-n \geq q} \bigcup_{U \in (\mathbb{G}_m)_S} F_n^\Sigma(S^r \wedge \mathbb{G}_m^s \wedge U_+)
$$

Then the right Bousfield localization of $\text{Spt}^T_{\Sigma^*}$ with respect to the class of $C^q_{\text{eff}}$-colocal equivalences exists (see definitions 1.8.6 and 1.9.2). This model structure will be called $q$-connected motivic symmetric stable, and the category of symmetric $T$-spectra equipped
with the $q$-connected motivic symmetric stable model structure will be denoted by $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$. Furthermore $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ is a right proper and simplicial model category. The homotopy category associated to $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ will be denoted by $R_{\text{eff}}^q \text{Spt}^\Sigma(S)$.

**Proof.** Theorems 2.6.22 and 2.7.4 imply that $\text{Spt}^\Sigma M_*$ is a cellular, proper and simplicial model category. Therefore we can apply theorem 5.1.1 in [7] to construct the right Bousfield localization of $\text{Spt}^\Sigma M_*$ with respect to the class of $C_{\text{eff}}^q \Sigma$-colocal equivalences. Using theorem 5.1.1 in [7] again, we have that this new model structure is right proper and simplicial.

**Definition 3.3.10.** Fix $q \in \mathbb{Z}$. Let $C^\Sigma_q$ denote a cofibrant replacement functor on $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ such that for every symmetric $T$-spectrum $X$, the natural map

$$C^\Sigma_q X \xrightarrow{C^\Sigma_q X} X$$

is a trivial fibration in $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$, and $C^\Sigma_q X$ is always $C_{\text{eff}}^q \Sigma$-colocal in $\text{Spt}^\Sigma M_*$. 

**Proposition 3.3.11.** Fix $q \in \mathbb{Z}$. Then $R^\Sigma_q$ is also a fibrant replacement functor on $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ (see definition 3.3.2), and for every symmetric $T$-spectrum $X$ the natural map

$$X \xrightarrow{R^\Sigma_q X} R^\Sigma X$$

is a trivial cofibration in $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$. 

**Proof.** Since $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ is the right Bousfield localization of $\text{Spt}^\Sigma M_*$ with respect to the $C_{\text{eff}}^q \Sigma$-colocal equivalences, by construction we have that the fibrations and the trivial cofibrations are identical in $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$ and $\text{Spt}^\Sigma M_*$ respectively. This implies that for every symmetric $T$-spectrum $X$, $R^\Sigma X$ is fibrant in $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$, and we also have that the natural map

$$X \xrightarrow{R^\Sigma X} R^\Sigma X$$

is a trivial cofibration in $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$. Hence $R^\Sigma$ is also a fibrant replacement functor for $R_{\text{eff}}^q \text{Spt}^\Sigma M_*$. 

$\square$
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Proposition 3.3.12. Fix \( q \in \mathbb{Z} \). Then a map of symmetric \( T \)-spectra \( f : X \to Y \) is a \( C_{eff}^{q,\Sigma} \)-colocal equivalence in \( Spt_\Sigma^T_M_* \) if and only if the underlying map \( UR_\Sigma(f) : UR_\Sigma X \to UR_\Sigma Y \) is a \( C_{eff}^q \)-colocal equivalence in \( Spt_T M_* \).

Proof. Consider \( F_n^\Sigma(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^{q,\Sigma} \). Using the enriched adjunctions of proposition 2.6.20, we get the following commutative diagram where all the vertical arrows are isomorphisms:

\[
\begin{array}{ccc}
Map_\Sigma(F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), R_\Sigma X) & \xrightarrow{R_\Sigma f_*} & Map_\Sigma(F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), R_\Sigma Y) \\
\| & & \| \\
Map_\Sigma(V(F_n(S^r \wedge G_m^s \wedge U_+)), R_\Sigma X) & \xrightarrow{R_\Sigma f_*} & Map_\Sigma(V(F_n(S^r \wedge G_m^s \wedge U_+)), R_\Sigma Y) \\
\cong & & \cong \\
Map(F_n(S^r \wedge G_m^s \wedge U_+), UR_\Sigma X) & \xrightarrow{UR_\Sigma f_*} & Map(F_n(S^r \wedge G_m^s \wedge U_+), UR_\Sigma Y)
\end{array}
\]

Since \( UR_\Sigma X \) and \( UR_\Sigma Y \) are both fibrant in \( Spt_T M_* \), we have that \( UR_\Sigma(f) \) is a \( C_{eff}^q \)-colocal equivalence in \( Spt_T M_* \) if and only if the bottom row in the diagram above is a weak equivalence of simplicial sets for every \( F_n(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^q \). By the two out of three property for weak equivalences we have that this happens if and only if the top row in the diagram above is a weak equivalence for every \( F_n^\Sigma(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^{q,\Sigma} \). But this last condition holds if and only if \( f \) is a \( C_{eff}^{q,\Sigma} \)-colocal equivalence in \( Spt_\Sigma^T M_* \). This finishes the proof.

\( \Box \)

Proposition 3.3.13. Fix \( q \in \mathbb{Z} \), and let \( f : X \to Y \) be a map of symmetric \( T \)-spectra. Then \( f \) is a \( C_{eff}^{q,\Sigma} \)-colocal equivalence in \( Spt_\Sigma^T M_* \) if and only if for every \( F_n^\Sigma(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^{q,\Sigma} \), the induced map:

\[
[F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), X]_{Spt}^\Sigma \xrightarrow{f_*} [F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), Y]_{Spt}^\Sigma
\]

is an isomorphism of abelian groups.

Proof. By proposition 3.3.12, \( f \) is a \( C_{eff}^{q,\Sigma} \)-colocal equivalence in \( Spt_\Sigma^T M_* \) if and only if \( UR_\Sigma(f) \) is a \( C_{eff}^q \)-colocal equivalence in \( Spt_T M_* \). Using proposition 3.2.4 we have that
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$UR\Sigma(f)$ is a $C^q_{eff}$-colocal equivalence if and only if for every $F_n(S^r \wedge G^*_m \wedge U_+) \in C^q_{eff}$, the induced map

$$[F_n(S^r \wedge G^*_m \wedge U_+), UR\Sigma X]_{Spt} \xrightarrow{UR\Sigma(f)_*} [F_n(S^r \wedge G^*_m \wedge U_+), UR\Sigma Y]_{Spt}$$

is an isomorphism of abelian groups.

Now theorem 2.6.29 implies that we have the following commutative diagram, where all the vertical arrows are isomorphisms:

$$
\begin{array}{ccc}
[F_n(S^r \wedge G^*_m \wedge U_+), UR\Sigma X]_{Spt} & \xrightarrow{UR\Sigma(f)_*} & [F_n(S^r \wedge G^*_m \wedge U_+), UR\Sigma Y]_{Spt} \\
\cong & & \cong \\
[V(F_n(S^r \wedge G^*_m \wedge U_+)), X]_{Spt} & \xrightarrow{f_*} & [V(F_n(S^r \wedge G^*_m \wedge U_+)), Y]_{Spt} \\
\cong & & \cong \\
[F^\Sigma_n(S^r \wedge G^*_m \wedge U_+), X]_{Spt} & \xrightarrow{f_*} & [F^\Sigma_n(S^r \wedge G^*_m \wedge U_+), Y]_{Spt}
\end{array}
$$

Therefore $f$ is a $C^q_{eff}$-colocal equivalence if and only if for every $F^\Sigma_n(S^r \wedge G^*_m \wedge U_+) \in C^q_{eff}$, the bottom row is an isomorphism of abelian groups. This finishes the proof.

**Lemma 3.3.14.** Fix $q \in \mathbb{Z}$, and let $f : X \to Y$ be a map of symmetric $T$-spectra. Then $f$ is a $C^q_{eff}$-colocal equivalence in $Spt^\Sigma_T M_*$ if and only if $\Omega S^1 R\Sigma f$ is a $C^q_{eff}$-colocal equivalence in $Spt^\Sigma_T M_*$.

**Proof.** It follows from proposition 3.3.12 that $f$ is a $C^q_{eff}$-colocal equivalence in $Spt^\Sigma_T M_*$ if and only if $UR\Sigma f$ is a $C^q_{eff}$-colocal equivalence in $Spt_T M_*$. Since $UR\Sigma X, UR\Sigma Y$ are both fibrant in $Spt_T M_*$, using lemma 3.2.7 we have that $UR\Sigma f$ is a $C^q_{eff}$-colocal equivalence if and only if $\Omega S^1 UR\Sigma f = U(\Omega S^1 R\Sigma f)$ is a $C^q_{eff}$-colocal equivalence in $Spt_T M_*$. Finally, since $\Omega S^1 R\Sigma X, \Omega S^1 R\Sigma Y$ are both fibrant in $Spt^\Sigma_T M_*$, we have by proposition 3.3.12 that $U(\Omega S^1 R\Sigma f)$ is a $C^q_{eff}$-colocal equivalence if and only if $\Omega S^1 R\Sigma f$ is a $C^q_{eff}$-colocal equivalence. This finishes the proof.

**Corollary 3.3.15.** Fix $q \in \mathbb{Z}$. Then the adjunction

$$(- \land S^1, \Omega S^1, \varphi) : R_{C^q_{eff}} Spt^\Sigma_T M_* \xrightarrow{\sim} R_{C^q_{eff}} Spt^\Sigma_T M_*$$
is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.3.11 we have that it suffices to verify the following two conditions:

1. For every cofibrant object \( X \) in \( R_{C_{q_{eff}}^q}^{\Sigma} \text{Spt}_T \Sigma M_* \), the following composition

\[
X \xrightarrow{\eta_X} \Omega_{S^1}(X \wedge S^1) \xrightarrow{\Omega_{S^1} R_{\Sigma}^{X \wedge S^1}} \Omega_{S^1} R_{\Sigma}(X \wedge S^1)
\]

is a \( C_{q_{eff}}^{\Sigma} \)-colocal equivalence.

2. \( \Omega_{S^1} \) reflects \( C_{q_{eff}}^{\Sigma} \)-colocal equivalences between fibrant objects in \( R_{C_{q_{eff}}^q}^{\Sigma} \text{Spt}_T \Sigma M_* \).

(1): By construction \( R_{C_{q_{eff}}^q}^{\Sigma} \text{Spt}_T \Sigma M_* \) is a right Bousfield localization of \( \text{Spt}_T \Sigma M_* \), therefore the identity functor

\[
id : R_{C_{q_{eff}}^q}^{\Sigma} \text{Spt}_T \Sigma M_* \longrightarrow \text{Spt}_T \Sigma M_*
\]

is a left Quillen functor. Thus \( X \) is also cofibrant in \( \text{Spt}_T \Sigma M_* \). Since the adjunction \( (\Sigma_T, \Omega_T, \varphi) \) is a Quillen equivalence on \( \text{Spt}_T \Sigma M_* \), [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in \( \text{Spt}_T \Sigma M_* \):

\[
X \xrightarrow{\eta_X} \Omega_{S^1}(X \wedge S^1) \xrightarrow{\Omega_{S^1} R_{\Sigma}^{X \wedge S^1}} \Omega_{S^1} R_{\Sigma}(X \wedge S^1)
\]

Hence using [7, proposition 3.1.5] it follows that the composition above is a \( C_{q_{eff}}^{\Sigma} \)-colocal equivalence.

(2): This follows immediately from proposition 3.3.11 and lemma 3.3.14. \( \square \)

**Remark 3.3.16.** The adjunction \( (\Sigma_T, \Omega_T, \varphi) \) is a Quillen equivalence on \( \text{Spt}_T \Sigma M_* \). However it does not descend even to a Quillen adjunction on the \( q \)-connected motivic symmetric stable model category \( R_{C_{q_{eff}}^q}^{\Sigma} \text{Spt}_T \Sigma M_* \).

**Corollary 3.3.17.** Fix \( q \in \mathbb{Z} \). Then \( R_{C_{q_{eff}}^q}^{\Sigma} \mathbb{SH}\Sigma(S) \) has the structure of a triangulated category.
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Proof. Theorem 3.3.9 implies in particular that \( R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_* \) is a pointed simplicial model category, and corollary 3.3.15 implies that the adjunction

\[
( - \wedge S^1, \Omega S^1, \varphi ) : R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_* \to R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_*
\]

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII].

Proposition 3.3.18. For every \( q \in \mathbb{Z} \), we have the following adjunction

\[
(C_q^{\Sigma}, R_{\Sigma}, \varphi) : R_{C_{\text{eff}}}^{\Sigma} \mathcal{H}^{\Sigma}(S) \longrightarrow \mathcal{H}^{\Sigma}(S)
\]

between exact functors of triangulated categories.

Proof. Since \( R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_* \) is the right Bousfield localization of \( \text{Spt}_T^{\Sigma}M_* \) with respect to the \( C^q_{\text{eff}} \)-colocal equivalences, we have that the identity functor \( \text{id} : R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_* \to \text{Spt}_T^{\Sigma}M_* \) is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

\[
(C_q^{\Sigma}, R_{\Sigma}, \varphi) : R_{C_{\text{eff}}}^{\Sigma} \mathcal{H}^{\Sigma}(S) \longrightarrow \mathcal{H}^{\Sigma}(S)
\]

Now proposition 6.4.1 in [10] implies that \( C_q^{\Sigma} \) maps cofibre sequences in \( R_{C_{\text{eff}}}^{\Sigma} \mathcal{H}^{\Sigma}(S) \) to cofibre sequences in \( \mathcal{H}^{\Sigma}(S) \). Therefore using proposition 7.1.12 in [10] we have that \( C_q^{\Sigma} \) and \( R_{\Sigma} \) are both exact functors between triangulated categories.

Theorem 3.3.19. Fix \( q \in \mathbb{Z} \). Then the adjunction

\[
(V, U, \varphi) : R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T M_* \longrightarrow R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_*
\]

given by the symmetrization and the forgetful functors is a Quillen equivalence.

Proof. Proposition 3.3.12 together with the universal property for right Bousfield localizations (see definition 1.8.2) imply that

\[
U : R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T^{\Sigma}M_* \longrightarrow R_{C_{\text{eff}}}^{\Sigma} \text{Spt}_T M_*
\]

is a right Quillen functor. Using corollary 1.3.16 in [10] and proposition 3.3.11 we have that it suffices to verify the following two conditions:
1. For every cofibrant object $X$ in $R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_*$, the following composition

$$X \xrightarrow{\eta_X} UV(X) \xrightarrow{UR_{\Sigma}^X} UR_{\Sigma} V(X)$$

is a weak equivalence in $R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_*$.

2. $U$ reflects weak equivalences between fibrant objects in $R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_*$.

(1): By construction $R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_*$ is a right Bousfield localization of $\text{Spt}_T \mathcal{M}_*$, therefore the identity functor

$$id : R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_* \rightarrow \text{Spt}_T \mathcal{M}_*$$

is a left Quillen functor. Thus $X$ is also cofibrant in $\text{Spt}_T \mathcal{M}_*$. Since the adjunction $(V, U, \varphi)$ is a Quillen equivalence between $\text{Spt}_T \mathcal{M}_*$ and $\text{Spt}_T \Sigma \mathcal{M}_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $\text{Spt}_T \mathcal{M}_*$:

$$X \xrightarrow{\eta_X} UV(X) \xrightarrow{UR_{\Sigma}^X} UR_{\Sigma} V(X)$$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $C^q_{\text{eff}}$-colocal equivalence in $\text{Spt}_T \mathcal{M}_*$, i.e. a weak equivalence in $R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_*$.

(2): This follows immediately from propositions 3.3.11 and 3.3.12.

**Corollary 3.3.20.** Fix $q \in \mathbb{Z}$. Then the adjunction

$$(V, U, \varphi) : R_{\text{eff}}^q \text{Spt}_T \mathcal{M}_* \rightarrow R_{\text{eff}}^q \text{Spt}_T \Sigma \mathcal{M}_*$$

given by the symmetrization and the forgetful functors, induces an adjunction

$$(VC_q, U R_{\Sigma}, \varphi) : R_{\text{eff}}^q \mathcal{H}(S) \rightarrow R_{\text{eff}}^q \mathcal{H}^\Sigma(S)$$

of exact functors between triangulated categories. Furthermore, $VC_q$ and $UR_{\Sigma}$ are both equivalences of categories.

**Proof.** Theorem 3.3.19 implies that the adjunction $(V, U, \varphi)$ is a Quillen equivalence. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(VC_q, U R_{\Sigma}, \varphi) : R_{\text{eff}}^q \mathcal{H}(S) \rightarrow R_{\text{eff}}^q \mathcal{H}^\Sigma(S)$$
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Now [10, proposition 1.3.13] implies that $VC_q, UR_\Sigma$ are both equivalences of categories. Finally, proposition 2.6.20 together with [10, proposition 6.4.1] imply that $VC_q$ maps cofibre sequences in $R_{C_{eff}^q} \mathcal{H}(S)$ to cofibre sequences in $R_{C_{eff}^q} \mathcal{H}^\Sigma(S)$. Therefore using proposition 7.1.12 in [10] we have that $VC_q$ and $UR_\Sigma$ are both exact functors between triangulated categories.

Now it is very easy to find the desired lifting for the functor $\tilde{f}_q : \mathcal{H}^\Sigma(S) \rightarrow \mathcal{H}^\Sigma(S)$ (see corollary 3.3.5(1)) to the model category level.

**Lemma 3.3.21.** Fix $q \in \mathbb{Z}$.

1. Let $X$ be an arbitrary $T$-spectrum in $R_{C_{eff}^q} \text{Spt}_T M_s$. Then the following maps in $\text{Spt}_T M_s$

$$VQ_s(C_q X) \xrightarrow{V(Q_s C_q X)} VC_q X \xrightarrow{C_q^{\Sigma, VC_q X}} C_q^{\Sigma}(VC_q X)$$

induce natural isomorphisms between the functors:

$$C_q^{\Sigma} \circ VC_q, VC_q, VQ_s \circ C_q : R_{C_{eff}^q} \mathcal{H}(S) \rightarrow \mathcal{H}^\Sigma(S)$$

Given a $T$-spectrum $X$

$$\alpha_X : VQ_s(C_q X) \xrightarrow{\cong} C_q^{\Sigma}(VC_q X)$$

will denote the isomorphism in $\mathcal{H}^\Sigma(S)$ corresponding to the natural isomorphism between $VQ_s \circ C_q$ and $C_q^{\Sigma} \circ VC_q$. 

2. Let $X$ be an arbitrary symmetric $T$-spectrum. Then the following maps in $R_{C_{e f f}^q}^{\ast} \text{Spt}_T M_*,$

\[ IQ_T J (UR_{\Sigma} X) \xrightarrow{IQ_T J UR_{\Sigma} X} UR_{\Sigma} X \xrightarrow{U (R_{\Sigma} X)} UR_{\Sigma} (R_{\Sigma} X) \]

induce natural isomorphisms between the functors:

\[ IQ_T J \circ UR_{\Sigma}, UR_{\Sigma} \circ R_{\Sigma} : \mathcal{SH}^\Sigma (S) \rightarrow R_{C_{e f f}^q}^{\ast} \mathcal{SH} (S) \]

Given a symmetric $T$-spectrum $X$

\[ \beta_X : IQ_T J (UR_{\Sigma} X) \xrightarrow{\cong} UR_{\Sigma} (R_{\Sigma} X) \]

will denote the isomorphism in $R_{C_{e f f}^q}^{\ast} \mathcal{SH} (S)$ corresponding to the natural isomorphism between $IQ_T J \circ UR_{\Sigma}$ and $UR_{\Sigma} \circ R_{\Sigma}.$

**Proof.** (1): Follows immediately from theorem 1.3.7 in [10] and the following commutative diagram of left Quillen functors:

\[ R_{C_{e f f}^q}^{\ast} \text{Spt}_T M_* \xrightarrow{V} R_{C_{e f f}^q}^{\ast} \text{Spt}_T M_* \]

\[ \text{id} \downarrow \quad \quad \text{id} \downarrow \]

\[ \text{Spt}_T M_* \xrightarrow{V} \text{Spt}_T^\Sigma M_* \]

(2): Follows immediately from the dual of theorem 1.3.7 in [10] and the following commutative diagram of right Quillen functors:

\[ R_{C_{e f f}^q}^{\ast} \text{Spt}_T M_* \xleftarrow{U} R_{C_{e f f}^q}^{\ast} \text{Spt}_T^\Sigma M_* \]

\[ \text{id} \uparrow \quad \quad \text{id} \uparrow \]

\[ \text{Spt}_T M_* \xleftarrow{U} \text{Spt}_T^\Sigma M_* \]
Theorem 3.3.22. Fix $q \in \mathbb{Z}$, and let $X$ be an arbitrary symmetric $T$-spectrum.

1. The diagram (3.4) in theorem 3.2.20 induces the following diagram in $\mathcal{SH}_\Sigma(S)$:

$$
\begin{align*}
VQ_s(IQTJ f_q(UR_\Sigma X)) &\xrightarrow{\cong} VQ_s(C_q IQTJ f_q(UR_\Sigma X)) \\
\cong &\xrightarrow{\cong} VQ_s(IQTJ f_q(UR_\Sigma X)) \\
\cong &\xrightarrow{\cong} VQ_s(C_q IQTJ f_q(UR_\Sigma X)) \\
\cong &\xrightarrow{\cong} VQ_s(IQT J f_q(UR_\Sigma X))
\end{align*}
$$

where all the maps are isomorphisms in $\mathcal{SH}_\Sigma(S)$. Furthermore, this diagram induces a natural isomorphism between the following exact functors:

$$
\begin{align*}
\mathcal{SH}_\Sigma(S) &\xrightarrow{\tilde{f}_q} \mathcal{SH}_\Sigma(S) \\
\xrightarrow{VQ_s C_q IQT J f_q(UR_\Sigma X)} &\xrightarrow{\cong} \mathcal{SH}_\Sigma(S)
\end{align*}
$$

2. Let $\epsilon$ be the counit of the adjunction (see corollary 3.3.20):

$$
(V C_q, UR_\Sigma, \varphi) : R_{C_q^{eff}} \mathcal{SH}(S) \xrightarrow{R_{C_q^{eff}}} R_{C_q^{eff}} \mathcal{SH}_\Sigma(S)
$$

Then we have the following diagram in $\mathcal{SH}_\Sigma(S)$ (see lemma 3.3.21):

$$
\begin{align*}
C_q^\Sigma(V C_q(IQTJ(UR_\Sigma X))) &\xrightarrow{C_q^\Sigma(VC_q(\beta_X))} C_q^\Sigma(V C_q(UR_\Sigma(R_\Sigma X))) \\
\cong &\xrightarrow{\alpha_{IQTJ(UR_\Sigma X)}} C_q^\Sigma(V C_q(UR_\Sigma(R_\Sigma X))) \\
\cong &\xrightarrow{C_q^\Sigma(\epsilon_{R_\Sigma X})} C_q^\Sigma R_\Sigma X = f_q^\Sigma X
\end{align*}
$$

where all the maps are isomorphisms in $\mathcal{SH}_\Sigma(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$
\begin{align*}
\mathcal{SH}_\Sigma(S) &\xrightarrow{VQ_s C_q IQT J f_q(UR_\Sigma X)} \mathcal{SH}_\Sigma(S) \\
\xrightarrow{C_q^\Sigma R_\Sigma = f_q^\Sigma} &\xrightarrow{\cong} \mathcal{SH}_\Sigma(S)
\end{align*}
$$
3. Combining the diagrams (3.25) and (3.26) above we get a natural isomorphism between the following exact functors:

\[ \mathcal{S}t^\Sigma(S) \xrightarrow{\sim} \mathcal{S}t^\Sigma(S) \]

**Proof.** It is clear that it suffices to prove only the first two claims.

(1): Follows immediately from theorems 3.2.20 and 3.3.4.

(2): Follows immediately from lemma 3.3.21 and corollary 3.3.20.

The functor \( f_q^\Sigma \) gives the desired lifting for the functor \( \tilde{f}_q \) to the model category level, and it will be used in the study of the multiplicative properties of Voevodsky’s slice filtration.

**Proposition 3.3.23.** Fix \( q \in \mathbb{Z} \).

1. We have the following commutative diagram of left Quillen functors:

\[ R_{C_{eff}^q}^{q+1} \text{Spt}_{T}^\Sigma \text{M}_* \xrightarrow{id} R_{C_{eff}^q}^{q+1} \text{Spt}_{T}^\Sigma \text{M}_* \]

\[ \xrightarrow{id} \text{Spt}_{T}^\Sigma \text{M}_* \xrightarrow{id} \]

\[ (3.27) \]

2. For every symmetric \( T \)-spectrum \( X \), the natural map:

\[ C_q^\Sigma C_{q+1}^\Sigma X \xrightarrow{C_q^\Sigma C_{q+1}^\Sigma X} C_{q+1}^\Sigma X \]

is a weak equivalence in \( \mathcal{S}t^\Sigma(S) \), and it induces a natural equivalence \( C_q^\Sigma C_{q+1}^\Sigma : C_q^\Sigma \circ C_q^\Sigma_{q+1} \rightarrow C_{q+1}^\Sigma \) between the following functors:

\[ R_{C_{eff}^q}^{q+1} \mathcal{S}t^\Sigma(S) \xrightarrow{C_{q+1}^\Sigma} R_{C_{eff}^q}^{q+1} \mathcal{S}t^\Sigma(S) \]

\[ \xrightarrow{C_q^\Sigma} \mathcal{S}t^\Sigma(S) \]

3. The natural transformation \( f_{q+1}^1 X \rightarrow f_q^1 X \) (see theorem 3.1.16(1)) gets canonically identified, through the equivalence of categories \( r_q C_q \), \( IQ_T J_{iq} \), \( VC_q \) and \( UR^\Sigma \) constructed in proposition 3.2.21 and corollary 3.3.20; with the following composition
$\rho_q^X : f_{q+1}^X \to f_q^X$ in $\mathcal{SH}(S)$

which is induced by the following commutative diagram in $\text{Spt}_{\Sigma}^T M_*$

$$
\begin{array}{ccc}
C_{q+1}^\Sigma R\Sigma X & \xrightarrow{id_{C_{q+1}^\Sigma R\Sigma X}} & C_q^\Sigma R\Sigma X \\
\downarrow & & \downarrow \\
C_{q+1}^\Sigma C_{q+1}^\Sigma R\Sigma X & \xrightarrow{id_{C_{q+1}^\Sigma C_{q+1}^\Sigma R\Sigma X}} & C_{q+1}^\Sigma C_q^\Sigma R\Sigma X \\
\end{array}
$$

(3.28)

**Proof.** (1): Since $R_{C_{eff}}^{q+1} \text{Spt}_{\Sigma}^T M_*$ and $R_{C_{eff}}^q \text{Spt}_{\Sigma}^T M_*$ are both right Bousfield localizations of $\text{Spt}_{\Sigma}^T M_*$, by construction the identity functor

$$
id : R_{C_{eff}}^{q+1} \text{Spt}_{\Sigma}^T M_* \to \text{Spt}_{\Sigma}^T M_*
$$

$$
id : R_{C_{eff}}^q \text{Spt}_{\Sigma}^T M_* \to \text{Spt}_{\Sigma}^T M_*
$$

is in both cases a left Quillen functor. To finish the proof, it suffices to show that the identity functor

$$
id : R_{C_{eff}}^q \text{Spt}_{\Sigma}^T M_* \to R_{C_{eff}}^{q+1} \text{Spt}_{\Sigma}^T M_*
$$

is a right Quillen functor. Using the universal property of right Bousfield localizations (see definition 1.8.2), it is enough to check that if $f : X \to Y$ is a $C_{eff}^q$-colocal equivalence in $\text{Spt}_{\Sigma}^T M_*$ then $R_{\Sigma} f$ is a $C_{eff}^{q+1,\Sigma}$-colocal equivalence. But since $R_{\Sigma} X$ and $R_{\Sigma} Y$ are already fibrant in $\text{Spt}_{\Sigma}^T M_*$, we have that $R_{\Sigma}(f)$ is a $C_{eff}^{q+1,\Sigma}$-colocal equivalence if and only if for every $F_n^\Sigma(S^r \wedge G_m^s \wedge U_+) \in C_{eff}^{q+1,\Sigma}$, the induced map:

$$\text{Map}^\Sigma(F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), R_{\Sigma} X)$$

$$\xrightarrow{(R_{\Sigma} f)_*}$$

$$\text{Map}^\Sigma(F_n^\Sigma(S^r \wedge G_m^s \wedge U_+), R_{\Sigma} Y)$$

is a weak equivalence of simplicial sets. But since $C_{eff}^{q+1,\Sigma} \subseteq C_{eff}^q$, and by hypothesis $f$ is a $C_{eff}^q$-colocal equivalence; we have that all the induced maps $(R_{\Sigma} f)_*$ are weak equivalences of simplicial sets. Thus $R_{\Sigma} f$ is a $C_{eff}^{q+1,\Sigma}$-colocal equivalence, as we wanted.
Finally (2) and (3) follow directly from proposition 3.2.21, corollary 3.3.20, theorems 3.2.20, 3.3.22 together with the commutative diagram (3.27) of left Quillen functors constructed above and [10, theorem 1.3.7].

**Theorem 3.3.24.** We have the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
\vdots & & \\
\downarrow{id} & & \\
R_{C_q^{+1}}\text{Spt}_M^{\Sigma} & \rightarrow & \text{Spt}_M^{\Sigma} \\
\downarrow{id} & & \\
R_{C_q^{\ell}}\text{Spt}_M^{\Sigma} & \rightarrow & \text{Spt}_M^{\Sigma} \\
\downarrow{id} & & \\
R_{C_q^{\ell+1}}\text{Spt}_M^{\Sigma} & \rightarrow & \text{Spt}_M^{\Sigma} \\
\vdots & & \\
\end{array}
\]  

(3.29)

and the associated diagram of homotopy categories:

\[
\begin{array}{ccc}
\vdots & & \\
\downarrow{\text{id}} & & \\
R_{C_q^{+1}}\text{S} & \rightarrow & \text{S} \\
\downarrow{C_{q+1}} & \rightarrow & \\
R_{C_q^{\ell}}\text{S} & \rightarrow & \text{S} \\
\downarrow{C_q} & \rightarrow & \\
R_{C_q^{\ell+1}}\text{S} & \rightarrow & \text{S} \\
\vdots & & \\
\end{array}
\]  

(3.30)

gets canonically identified, through the equivalences of categories \(r_qC_q, IQ_Tj_q, VC_q\) and
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$UR_\Sigma$ constructed in proposition 3.2.21 and corollary 3.3.20; with Voevodsky’s slice filtration:

\[
\begin{array}{c}
\Sigma^q \mathcal{SH}(S) \\
\downarrow i_q \\
\Sigma^q \mathcal{SH}^{eff}(S) \\
\downarrow i_q \\
\Sigma^q \mathcal{SH}(S) \\
\downarrow \\
\vdots
\end{array}
\]

\[
\begin{array}{c}
\Sigma^{q+1} \mathcal{SH}(S) \\
\downarrow r_q \\
\Sigma^{q+1} \mathcal{SH}^{eff}(S) \\
\downarrow r_q \\
\Sigma^{q+1} \mathcal{SH}(S) \\
\downarrow \\
\vdots
\end{array}
\]

\[
\Sigma^{q-1} \mathcal{SH}(S) \\
\downarrow r_{q-1} \\
\Sigma^{q-1} \mathcal{SH}^{eff}(S) \\
\downarrow r_{q-1} \\
\Sigma^{q-1} \mathcal{SH}(S) \\
\downarrow \\
\vdots
\]

(3.31)

**Proof.** Follows immediately from proposition 3.3.23, corollary 3.3.20 and theorem 3.2.23.

\[\square\]

**Theorem 3.3.25.** Fix $q \in \mathbb{Z}$. Consider the following set of maps in $\text{Spt}^T_\Sigma^* M_*$ (see theorem 3.2.29):

\[L^\Sigma(<q) = \{ V_{n,r,s} : F_n^\Sigma(S^r \land \mathbb{G}_m^s \land U_+) \to F_n^\Sigma(D^{r+1} \land \mathbb{G}_m^s \land U_+) \mid F_n^\Sigma(S^r \land \mathbb{G}_m^s \land U_+) \in C_q^{\Sigma \text{eff}} \}\]  

(3.32)

Then the left Bousfield localization of $\text{Spt}^T_\Sigma^* M_*$ with respect to the $L^\Sigma(<q)$-local equivalences exists. This new model structure will be called **weight**$<q$ **motivic symmetric stable**. $L_{<q} \text{Spt}^T_\Sigma^* M_*$ will denote the category of symmetric $T$-spectra equipped with the weight$<q$ motivic symmetric stable model structure, and $L_{<q} \mathcal{SH}^\Sigma(S)$ will denote its associated homotopy category. Furthermore the weight$<q$ motivic symmetric stable model structure is cellular, left proper and simplicial; with the following sets of generating cofibrations and trivial cofibrations respectively:

\[I_{L^\Sigma(<q)} = I^T_\Sigma = \bigcup_{n \geq 0} \{ F_n^\Sigma(Y_+ \hookrightarrow (\Delta^n_U)_+) \} \]

\[J_{L^\Sigma(<q)} = \{ j : A \to B \} \]

where $j$ satisfies the following conditions:
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1. $j$ is an inclusion of $I_T^\Sigma$-complexes.

2. $j$ is a $L^\Sigma(<q)$-local equivalence.

3. the size of $B$ as an $I_T^\Sigma$-complex is less than $\kappa$, where $\kappa$ is the regular cardinal defined by Hirschhorn in [7, definition 4.5.3].

**Proof.** Theorems 2.7.4 and 2.6.22 imply that $\Spt_*^\Sigma T$ is a cellular, proper and simplicial model category. Therefore the existence of the left Bousfield localization follows from [7, theorem 4.1.1]. Using [7, theorem 4.1.1] again, we have that $L_{<q}\Spt_*^\Sigma T$ is cellular, left proper and simplicial; where the sets of generating cofibrations and trivial cofibrations are the ones described above.

**Definition 3.3.26.** Fix $q \in \mathbb{Z}$. Let $W_q^\Sigma$ denote a fibrant replacement functor on $L_{<q}\Spt_*^\Sigma T$, such that for every symmetric $T$-spectrum $X$, the natural map:

$$X \xrightarrow{W_q^\Sigma X} W_q^\Sigma X$$

is a trivial cofibration in $L_{<q}\Spt_*^\Sigma T$, and $W_q^\Sigma X$ is $L^\Sigma(<q)$-local in $\Spt_*^\Sigma T$.

**Proposition 3.3.27.** Fix $q \in \mathbb{Z}$. Then $Q_\Sigma$ is also a cofibrant replacement functor on $L_{<q}\Spt_*^\Sigma T$, and for every symmetric $T$-spectrum $X$ the natural map

$$Q_\Sigma X \xrightarrow{Q_\Sigma X} X$$

is a trivial fibration in $L_{<q}\Spt_*^\Sigma T$.

**Proof.** Since $L_{<q}\Spt_*^\Sigma T$ is the left Bousfield localization of $\Spt_*^\Sigma T$ with respect to the $L^\Sigma(<q)$-local equivalences, by construction we have that the cofibrations and the trivial fibrations are identical in $L_{<q}\Spt_*^\Sigma T$ and $\Spt_*^\Sigma T$ respectively. This implies that for every symmetric $T$-spectrum $X$, $Q_\Sigma X$ is cofibrant in $L_{<q}\Spt_*^\Sigma T$, and we also have that the natural map

$$Q_\Sigma X \xrightarrow{Q_\Sigma X} X$$

is a trivial fibration in $L_{<q}\Spt_*^\Sigma T$. Hence $Q_\Sigma$ is also a cofibrant replacement functor for $L_{<q}\Spt_*^\Sigma T$. 

\[\square\]
Proposition 3.3.28. Fix $q \in \mathbb{Z}$. Then a symmetric $T$-spectrum $Z$ is $L^\Sigma(<q)$-local in Spt$^\Sigma_T M_*$ if and only if $UZ$ is $L(<q)$-local in Spt$_T M_*$. 

Proof. We have that $Z$ is $L^\Sigma(<q)$-local if and only if $Z$ is fibrant in Spt$^\Sigma_T M_*$ and for every $i^U_{n,r,s} : F_n(S^r \land \mathbb{G}_m^s \land U_+) \to F_n(D^{r+1} \land \mathbb{G}_m^s \land U_+) \in L(<q)$, the induced map
\[
\text{Map}_\Sigma(V(F_n(D^{r+1} \land \mathbb{G}_m^s \land U_+)), Z) \xrightarrow{V(i^U_{n,r,s})^*} \text{Map}_\Sigma(V(F_n(S^r \land \mathbb{G}_m^s \land U_+)), Z)
\]
is a weak equivalence of simplicial sets.

On the other hand, we have that $UZ$ is $L(<q)$-local in Spt$_T M_*$ if and only if $UZ$ is fibrant in Spt$_T M_*$ and for every $i^U_{n,r,s} : F_n(S^r \land \mathbb{G}_m^s \land U_+) \to F_n(D^{r+1} \land \mathbb{G}_m^s \land U_+) \in L(<q)$, the induced map
\[
\text{Map}(F_n(D^{r+1} \land \mathbb{G}_m^s \land U_+), UZ) \xrightarrow{(i^U_{n,r,s})^*} \text{Map}(F_n(S^r \land \mathbb{G}_m^s \land U_+), UZ)
\]
is a weak equivalence of simplicial sets.

Then the result follows from the following facts:

1. By definition, $Z$ is fibrant in Spt$^\Sigma_T M_*$ if $UZ$ is fibrant in Spt$_T M_*$. 

2. Proposition 2.6.20, which implies that the adjunction
\[
(V, U, \varphi) : \text{Spt}_T M_* \rightarrow \text{Spt}^\Sigma_T M_*
\]
is enriched in the category of simplicial sets.

Proposition 3.3.29. Fix $q \in \mathbb{Z}$, and let $Z$ be a symmetric $T$-spectrum. Then $Z$ is $L^\Sigma(<q)$-local in Spt$^\Sigma_T M_*$ if and only if the following conditions hold:

1. $Z$ is fibrant in Spt$^\Sigma_T M_*$. 

2. For every \( F^\Sigma_n(S^r \wedge G^*_m \wedge U_+) \in C^q_{eff} \), \( [F^\Sigma_n(S^r \wedge G^*_m \wedge U_+), Z]^\Sigma_{Spt} \cong 0 \)

**Proof.** Follows directly from propositions 3.3.28 and 3.2.32, together with the fact that \((V, U, \varphi) : \text{Spt}_T M_s \to \text{Spt}_T^\Sigma M_s\) is a Quillen adjunction.

**Corollary 3.3.30.** Fix \( q \in \mathbb{Z} \), and let \( Z \) be a fibrant symmetric \( T \)-spectrum in \( \text{Spt}_T^\Sigma M_s \).

Then \( Z \) is \( L^\Sigma( < q ) \)-local in \( \text{Spt}_T^\Sigma M_s \) if and only if \( \Omega S_1 Z \) is \( L^\Sigma( < q ) \)-local in \( \text{Spt}_T^\Sigma M_s \).

**Proof.** By proposition 3.3.28 we have that \( Z \) is \( L^\Sigma( < q ) \)-local if and only if \( UZ \) is \( L( < q ) \)-local in \( \text{Spt}_T^\Sigma M_s \). Now corollary 3.2.34 implies that \( UZ \) is \( L( < q ) \)-local if and only if \( \Omega S_1 UZ = U(\Omega S_1 Z) \) is \( L( < q ) \)-local.

Therefore using proposition 3.3.28 again, we get that \( Z \) is \( L^\Sigma( < q ) \)-local if and only if \( \Omega S_1 Z \) is \( L^\Sigma( < q ) \)-local.

**Corollary 3.3.31.** Fix \( q \in \mathbb{Z} \), and let \( Z \) be a fibrant symmetric \( T \)-spectrum in \( \text{Spt}_T^\Sigma M_s \).

Then \( Z \) is \( L^\Sigma( < q ) \)-local in \( \text{Spt}_T^\Sigma M_s \) if and only if \( R\Sigma(Q\Sigma Z \wedge S^1) \) is \( L^\Sigma( < q ) \)-local in \( \text{Spt}_T^\Sigma M_s \).

**Proof.** (\( \Rightarrow \)): Assume that \( Z \) is \( L^\Sigma( < q ) \)-local. Since \( R\Sigma(Q\Sigma Z \wedge S^1) \) is fibrant, using proposition 3.3.29 we have that it is enough to check that for every \( F^\Sigma_n(S^r \wedge G^*_m \wedge U_+) \in C^q_{eff} \),

\[ [F^\Sigma_n(S^r \wedge G^*_m \wedge U_+), R\Sigma(Q\Sigma Z \wedge S^1)]^\Sigma_{Spt} \cong 0. \]

But since \(- \wedge S^1\) is a Quillen equivalence, we get the following diagram:

\[ [F^\Sigma_n(S^r \wedge G^*_m \wedge U_+), R\Sigma(Q\Sigma Z \wedge S^1)]^\Sigma_{Spt} \cong [F^\Sigma_{n+1}(S^{r+1} \wedge G^*_{m+1} \wedge U_+), R\Sigma(Q\Sigma Z \wedge S^1)]^\Sigma_{Spt} \]

\[ [F^\Sigma_{n+1}(S^{r+1} \wedge G^*_{m+1} \wedge U_+), Z]^\Sigma_{Spt} \cong [F^\Sigma_{n+1}(S^{r+1} \wedge G^*_{m+1} \wedge U_+), Q\Sigma Z \wedge S^1]^\Sigma_{Spt} \]
where all the maps are isomorphisms of abelian groups. Since $Z$ is $L^\Sigma(<q)$-local, proposition 3.3.29 implies that $[F_n^\Sigma(S^r \land G_m^s \land U_+), Z]_{S_{pt}}^\Sigma \cong 0$. Therefore

$$[F_n^\Sigma(S^r \land G_m^s \land U_+), R_{\Sigma}(Q_{\Sigma}Z \land S^1)]_{S_{pt}}^\Sigma \cong 0$$

for every $F_n^\Sigma(S^r \land G_m^s \land U_+) \in C^q_{eff}$, as we wanted.

(⇐): Assume that $R_{\Sigma}(Q_{\Sigma}Z \land S^1)$ is $L^\Sigma(<q)$-local. By hypothesis, $Z$ is fibrant; therefore proposition 3.3.29 implies that it is enough to show that for every $F_n^\Sigma(S^r \land G_m^s \land U_+) \in C^q_{eff}$, $[F_n^\Sigma(S^r \land G_m^s \land U_+), Z]_{S_{pt}}^\Sigma \cong 0$. Since $S_{pt}^\Sigma M_*$ is a simplicial model category and $- \land S^1$ is a Quillen equivalence; we have the following diagram:

$$[F_n^\Sigma(S^r \land G_m^s \land U_+), \Omega_{S^1}R_{\Sigma}(Q_{\Sigma}Z \land S^1)]_{S_{pt}}^\Sigma$$

$$\cong$$

$$[F_n^\Sigma(S^r \land G_m^s \land U_+) \land S^1, Q_{\Sigma}Z \land S^1]_{S_{pt}}^\Sigma \xrightarrow{\Sigma_1^1_0} [F_n^\Sigma(S^r \land G_m^s \land U_+), Z]_{S_{pt}}^\Sigma$$

where all the maps are isomorphisms of abelian groups. On the other hand, using corollary 3.3.30 we have that $\Omega_{S^1}R_{\Sigma}(Q_{\Sigma}Z \land S^1)$ is $L^\Sigma(<q)$-local. Therefore using proposition 3.3.29 again, we have that for every $F_n^\Sigma(S^r \land G_m^s \land U_+) \in C^q_{eff}$:

$$[F_n^\Sigma(S^r \land G_m^s \land U_+), Z]_{S_{pt}}^\Sigma \cong [F_n^\Sigma(S^r \land G_m^s \land U_+), \Omega_{S^1}R_{\Sigma}(Q_{\Sigma}Z \land S^1)]_{S_{pt}}^\Sigma \cong 0$$

and this finishes the proof.

**Corollary 3.3.32.** Fix $q \in \mathbb{Z}$, and let $f : X \rightarrow Y$ be a map of symmetric $T$-spectra. Then $f$ is a $L^\Sigma(<q)$-local equivalence in $Spt_{T}M_*$ if and only if for every $L^\Sigma(<q)$-local symmetric $T$-spectrum $Z$, $f$ induces the following isomorphism of abelian groups:

$$[Y, Z]_{S_{pt}}^\Sigma \xrightarrow{f^*} [X, Z]_{S_{pt}}^\Sigma$$

**Proof.** Suppose that $f$ is a $L^\Sigma(<q)$-local equivalence, then by definition the induced map:

$$Map_{\Sigma}(Q_{\Sigma}Y, Z) \xrightarrow{(Q_{\Sigma}f)^*} Map_{\Sigma}(Q_{\Sigma}X, Z)$$

is a weak equivalence of simplicial sets for every $L^\Sigma(<q)$-local symmetric $T$-spectrum $Z$. Proposition 3.3.29(1) implies that $Z$ is fibrant in $Spt_{T}^\Sigma M_*$, and since $Spt_{T}^\Sigma M_*$ is in particular
a simplicial model category; we get the following commutative diagram, where the top row and all the vertical maps are isomorphisms of abelian groups:

\[
\begin{array}{c}
\pi_0 \text{Map}_\Sigma(Q_\Sigma Y, Z) \xrightarrow{(Q_\Sigma f)^*} \pi_0 \text{Map}_\Sigma(Q_\Sigma X, Z)
\
\cong
\
[Y, Z]_\text{Spt}^\Sigma \xrightarrow{f^*} [X, Z]_\text{Spt}^\Sigma
\end{array}
\]

hence \(f^*\) is an isomorphism for every \(L^\Sigma(\leq q)\)-local symmetric \(T\)-spectrum \(Z\), as we wanted. Conversely, assume that for every \(L^\Sigma(\leq q)\)-local symmetric \(T\)-spectrum \(Z\), the induced map

\[
[Y, Z]_\text{Spt}^\Sigma \xrightarrow{f^*} [X, Z]_\text{Spt}^\Sigma
\]

is an isomorphism of abelian groups.

Since \(L_{\leq q}\text{Spt}_T^\Sigma M_*\) is the left Bousfield localization of \(\text{Spt}_T^\Sigma M_*\) with respect to the \(L^\Sigma(\leq q)\)-local equivalences, we have that the identity functor \(id : \text{Spt}_T^\Sigma M_* \to L_{\leq q}\text{Spt}_T^\Sigma M_*\) is a left Quillen functor. Therefore for every symmetric \(T\)-spectrum \(Z\), we get the following commutative diagram where all the vertical arrows are isomorphisms:

\[
\begin{array}{c}
\text{Hom}_{L_{\leq q}\text{Spt}_T^\Sigma(\Sigma)}(Q_\Sigma Y, Z) \xrightarrow{(Q_\Sigma f)^*} \text{Hom}_{L_{\leq q}\text{Spt}_T^\Sigma(\Sigma)}(Q_\Sigma X, Z)
\
\cong
\
[Y, W_q^\Sigma Z]_\text{Spt} \xrightarrow{f^*} [X, W_q^\Sigma Z]_\text{Spt}
\end{array}
\]

but \(W_q^\Sigma Z\) is by construction \(L^\Sigma(\leq q)\)-local, then by hypothesis the bottom row is an isomorphism of abelian groups. Hence it follows that the induced map:

\[
\text{Hom}_{L_{\leq q}\text{Spt}_T^\Sigma(\Sigma)}(Q_\Sigma Y, Z) \xrightarrow{(Q_\Sigma f)^*} \text{Hom}_{L_{\leq q}\text{Spt}_T^\Sigma(\Sigma)}(Q_\Sigma X, Z)
\]

is an isomorphism for every symmetric \(T\)-spectrum \(Z\). This implies that \(Q_\Sigma f\) is a weak equivalence in \(L_{\leq q}\text{Spt}_T^\Sigma M_*\), and since \(Q_\Sigma\) is also a cofibrant replacement functor on

\[
L_{\leq q}\text{Spt}_T^\Sigma M_*
\]

it follows that \(f\) is a weak equivalence in \(L_{\leq q}\text{Spt}_T^\Sigma M_*\). Therefore we have that \(f\) is a \(L^\Sigma(\leq q)\)-local equivalence, as we wanted. \(\square\)
Lemma 3.3.33. Fix $q \in \mathbb{Z}$, and let $f : X \to Y$ be a map of symmetric $T$-spectra. Then $f$ is a $L_{T}^{\Sigma}(< q)$-local equivalence in $\text{Spt}_{T}^{\Sigma}M_{*}$ if and only if

$$Q_{\Sigma}f \wedge id : Q_{\Sigma}X \wedge S^{1} \to Q_{\Sigma}Y \wedge S^{1}$$

is a $L_{T}^{\Sigma}(< q)$-local equivalence in $\text{Spt}_{T}^{\Sigma}M_{*}$.

Proof. Assume that $f$ is a $L_{T}^{\Sigma}(< q)$-local equivalence, and let $Z$ be an arbitrary $L_{T}^{\Sigma}(< q)$-local symmetric $T$-spectrum. Then corollary 3.3.30 implies that $\Omega_{S^{1}}Z$ is also $L_{T}^{\Sigma}(< q)$-local. Therefore the induced map

$$\text{Map}_{\Sigma}(Q_{\Sigma}Y, \Omega_{S^{1}}Z) \xrightarrow{(Q_{\Sigma}f)^{*}} \text{Map}_{\Sigma}(Q_{\Sigma}X, \Omega_{S^{1}}Z)$$

is a weak equivalence of simplicial sets. Now since $\text{Spt}_{T}^{\Sigma}M_{*}$ is a simplicial model category, we have the following commutative diagram:

$$\begin{array}{ccc}
\text{Map}_{\Sigma}(Q_{\Sigma}Y, \Omega_{S^{1}}Z) & \xrightarrow{(Q_{\Sigma}f)^{*}} & \text{Map}_{\Sigma}(Q_{\Sigma}X, \Omega_{S^{1}}Z) \\
\cong & & \cong \\
\text{Map}_{\Sigma}(Q_{\Sigma}Y \wedge S^{1}, Z) & \xrightarrow{(Q_{\Sigma}f \wedge id)^{*}} & \text{Map}_{\Sigma}(Q_{\Sigma}X \wedge S^{1}, Z)
\end{array}$$

and using the two out of three property for weak equivalences of simplicial sets, we have that

$$\text{Map}_{\Sigma}(Q_{\Sigma}Y \wedge S^{1}, Z) \xrightarrow{(Q_{\Sigma}f \wedge id)^{*}} \text{Map}_{\Sigma}(Q_{\Sigma}X \wedge S^{1}, Z)$$

is a weak equivalence. Since this holds for every $L_{T}^{\Sigma}(< q)$-local symmetric $T$-spectrum $Z$, it follows that

$$Q_{\Sigma}f \wedge id : Q_{\Sigma}X \wedge S^{1} \to Q_{\Sigma}Y \wedge S^{1}$$

is a $L_{T}^{\Sigma}(< q)$-local equivalence, as we wanted.

Conversely, suppose that

$$Q_{\Sigma}f \wedge id : Q_{\Sigma}X \wedge S^{1} \to Q_{\Sigma}Y \wedge S^{1}$$

is a $L_{T}^{\Sigma}(< q)$-local equivalence. Let $Z$ be an arbitrary $L_{T}^{\Sigma}(< q)$-local symmetric $T$-spectrum. Since $\text{Spt}_{T}^{\Sigma}M_{*}$ is a simplicial model category and $\wedge S^{1}$ is a Quillen equivalence, we get
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the following commutative diagram:

\[
\begin{array}{ccc}
[Q \Sigma Y \wedge S^1, R \Sigma (Q \Sigma Z \wedge S^1)]_{Spt} & \xrightarrow{(Q \Sigma f \wedge id)^*} & [Q \Sigma X \wedge S^1, R \Sigma (Q \Sigma Z \wedge S^1)]_{Spt} \\
\cong & & \cong \\
[Q \Sigma Y \wedge S^1, Q \Sigma Z \wedge S^1]_{Spt} & \xrightarrow{(Q \Sigma f \wedge id)^*} & [Q \Sigma X \wedge S^1, Q \Sigma Z \wedge S^1]_{Spt} \\
\cong & & \cong \\
[Y, Z]_{Spt} & \xrightarrow{f^*} & [X, Z]_{Spt}
\end{array}
\]

Now, corollary 3.3.31 implies that \( R \Sigma (Q \Sigma Z \wedge S^1) \) is also \( L^\Sigma(\leq q) \)-local. Therefore using corollary 3.3.32 we have that the top row in the diagram above is an isomorphism of abelian groups. This implies that the induced map:

\[
[Y, Z]_{Spt} \xrightarrow{f^*} [X, Z]_{Spt}
\]

is an isomorphism of abelian groups for every \( L^\Sigma(\leq q) \)-local symmetric spectrum \( Z \). Finally using corollary 3.3.32 again, we have that \( f : X \to Y \) is a \( L^\Sigma(\leq q) \)-local equivalence, as we wanted.

**Corollary 3.3.34.** For every \( q \in \mathbb{Z} \), the following adjunction:

\[
(- \wedge S^1, \Omega S^1, \varphi) : L_{\leq q} Spt_{T}^{\Sigma} M_* \xrightarrow{\sim} L_{\leq q} Spt_{T}^{\Sigma} M_*
\]

is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.3.27 we have that it suffices to verify the following two conditions:

1. For every fibrant object \( X \) in \( L_{\leq q} Spt_{T}^{\Sigma} M_* \), the following composition

\[
(Q \Sigma \Omega S^1 X) \wedge S^1 \xrightarrow{Q \Sigma \Omega S^1 \wedge id} (\Omega S^1 X) \wedge S^1 \xrightarrow{\iota_X} X
\]

is a \( L^\Sigma(\leq q) \)-local equivalence.

2. \(- \wedge S^1 \) reflects \( L^\Sigma(\leq q) \)-local equivalences between cofibrant objects in \( L_{\leq q} Spt_{T}^{\Sigma} M_* \).
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(1): By construction $L_{<q}\text{Spt}_T^{\Sigma}M_*$ is a left Bousfield localization of $\text{Spt}_T^{\Sigma}M_*$, therefore the identity functor

$$id : L_{<q}\text{Spt}_T^{\Sigma}M_* \to \text{Spt}_T^{\Sigma}M_*$$

is a right Quillen functor. Thus $X$ is also fibrant in $\text{Spt}_T^{\Sigma}M_*$. Since the adjunction $(- \wedge S^1, \Omega S^1, \varphi)$ is a Quillen equivalence on $\text{Spt}_T^{\Sigma}M_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $\text{Spt}_T^{\Sigma}M_*$:

$$(Q\Sigma \Omega S^1 X) \wedge S^1 \xrightarrow{Q\Sigma \Omega S^1 X \wedge id} (\Omega S^1 X) \wedge S^1 \xrightarrow{\epsilon_X} X$$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $L^{\Sigma}(< q)$-local equivalence.

(2): This follows immediately from proposition 3.3.27 and lemma 3.3.33.

**Remark 3.3.35.** We have a situation similar to the one described in remark 3.3.16 for the model categories $R_{\text{eff}}^{<q}\text{Spt}_T^{\Sigma}M_*$; i.e. although the adjunction $(\Sigma_T, \Omega_T, \varphi)$ is a Quillen equivalence on $\text{Spt}_T^{\Sigma}M_*$, it does not descend even to a Quillen adjunction on the weight $<q$ motivic symmetric stable model category $L_{<q}\text{Spt}_T^{\Sigma}M_*$.

**Corollary 3.3.36.** For every $q \in \mathbb{Z}$, the homotopy category $L_{<q}\mathcal{H}^{\Sigma}(S)$ associated to $L_{<q}\text{Spt}_T^{\Sigma}M_*$ has the structure of a triangulated category.

**Proof.** Theorem 3.3.25 implies in particular that $L_{<q}\text{Spt}_T^{\Sigma}M_*$ is a pointed simplicial model category, and corollary 3.3.34 implies that the adjunction

$$( - \wedge S^1, \Omega S^1, \varphi) : L_{<q}\text{Spt}_T^{\Sigma}M_* \to L_{<q}\text{Spt}_T^{\Sigma}M_*$$

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII].

**Corollary 3.3.37.** For every $q \in \mathbb{Z}$, $L_{<q}\text{Spt}_T^{\Sigma}M_*$ is a right proper model category.
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**Proof.** We need to show that the \( L^\Sigma(< q) \)-local equivalences are stable under pullback along fibrations in \( L_{<q}Spt^\Sigma T \). Consider the following pullback diagram:

\[
\begin{array}{ccc}
Z & \xrightarrow{w^*} & X \\
p^* & & \downarrow p \\
W & \xrightarrow{w} & Y
\end{array}
\]

where \( p \) is a fibration in \( L_{<q}Spt^\Sigma T \), and \( w \) is a \( L^\Sigma(< q) \)-local equivalence. Let \( F \) be the homotopy fibre of \( p \). Then we get the following commutative diagram in \( L_{<q}SH^\Sigma(S) \):

\[
\begin{array}{cccc}
\Omega S^1 Y & \xrightarrow{q} & F & \xrightarrow{i} X \\
\Omega S^1 w & & \downarrow w^* & \downarrow w \\
\Omega S^1 W & \xrightarrow{r} F & \xrightarrow{j} Z & \xrightarrow{p^*} W
\end{array}
\]

Since the rows in the diagram above are both fibre sequences in \( L_{<q}Spt^\Sigma T \), it follows that both rows are distinguished triangles in \( L_{<q}SH^\Sigma(S) \) (which has the structure of a triangulated category given by corollary 3.3.36). Now \( w, id_F \) are both isomorphisms in \( L_{<q}SH^\Sigma(S) \), hence it follows that \( w^* \) is also an isomorphism in \( L_{<q}SH^\Sigma(S) \). Therefore \( w^* \) is a \( L^\Sigma(< q) \)-local equivalence, as we wanted.

**Proposition 3.3.38.** For every \( q \in \mathbb{Z} \) we have the following adjunction

\[
(Q_\Sigma, W^\Sigma_q, \varphi) : SH^\Sigma(S) \longrightarrow L_{<q}SH^\Sigma(S)
\]

of exact functors between triangulated categories.

**Proof.** Since \( L_{<q}Spt^\Sigma T \) is the left Bousfield localization of \( Spt^\Sigma T \) with respect to the \( L^\Sigma(< q) \)-local equivalences, we have that the identity functor \( id : Spt^\Sigma T \to L_{<q}Spt^\Sigma T \) is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

\[
(Q_\Sigma, W^\Sigma_q, \varphi) : SH^\Sigma(S) \longrightarrow L_{<q}SH^\Sigma(S)
\]

Now proposition 6.4.1 in [10] implies that \( Q_\Sigma \) maps cofibre sequences in \( SH^\Sigma(S) \) to cofibre sequences in \( L_{<q}SH^\Sigma(S) \). Therefore using proposition 7.1.12 in [10] we have that \( Q_\Sigma \) and \( W^\Sigma_q \) are both exact functors between triangulated categories.

\[\square\]
Lemma 3.3.39. Fix $q \in \mathbb{Z}$, and let $X$ be a $L(<q)$-local spectrum in $\text{Spt}_T\mathcal{M}_s$. Then $Q_sX$ and $UR_\Sigma VQ_sX$ are also $L(<q)$-local in $\text{Spt}_T\mathcal{M}_s$.

Proof. Since $X$ is $L(<q)$-local, it follows that $X$ is fibrant in $\text{Spt}_T\mathcal{M}_s$. By definition we have that the natural map

$$Q_sX \xrightarrow{Q_sX} X$$

is a trivial fibration in $\text{Spt}_T\mathcal{M}_s$, therefore $Q_sX$ is also fibrant in $\text{Spt}_T\mathcal{M}_s$. Hence [7, lemma 3.2.1(a)] implies that $Q_sX$ is $L(<q)$-local.

Since the adjunction $(V, U, \varphi)$ is a Quillen equivalence between $\text{Spt}_T\mathcal{M}_s$ and $\text{Spt}_\Sigma^\mathcal{T}\mathcal{M}_s$, we have that $UR_\Sigma VQ_sX$ is fibrant in $\text{Spt}_T\mathcal{M}_s$, and [10, proposition 1.3.13(b)] implies that the composition

$$Q_sX \xrightarrow{\eta Q_sX} UV(Q_sX) \xrightarrow{U(R_\Sigma VQ_sX)} UR_\Sigma VQ_sX$$

is a weak equivalence in $\text{Spt}_T\mathcal{M}_s$. Since we already know that $Q_sX$ is $L(<q)$-local, using [7, lemma 3.2.1(a)] again we get that $UR_\Sigma VQ_sX$ is also $L(<q)$-local in $\text{Spt}_T\mathcal{M}_s$. This finishes the proof. 

Proposition 3.3.40. Fix $q \in \mathbb{Z}$, and let $f : X \rightarrow Y$ be a map in $\text{Spt}_T\mathcal{M}_s$. Then $f$ is a $L(<q)$-local equivalence in $\text{Spt}_T\mathcal{M}_s$ if and only if $VQ_s f$ is a $L^\Sigma(<q)$-local equivalence in $\text{Spt}_T^\Sigma\mathcal{M}_s$.

Proof. ($\Rightarrow$): Assume that $f$ is a $L(<q)$-local equivalence, and let $Z$ be an arbitrary $L^\Sigma(<q)$-local symmetric $T$-spectrum. Then $Z$ is fibrant in $\text{Spt}_T^\Sigma\mathcal{M}_s$, and using theorem 2.6.29 we get the following commutative diagram where all the vertical arrows are isomorphisms:

$$
\begin{array}{c}
\left[ VQ_sY, Z \right]_{\text{Spt}}^\Sigma \\
\downarrow \cong \\
\left[ Y, UZ \right]_{\text{Spt}} \\
\end{array}
\xrightarrow{(VQsf)^*} 
\begin{array}{c}
\left[ VQ_sX, Z \right]_{\text{Spt}}^\Sigma \\
\downarrow \cong \\
\left[ X, UZ \right]_{\text{Spt}} \\
\end{array}
$$

By proposition 3.3.28 we have that $UZ$ is $L(<q)$-local in $\text{Spt}_T\mathcal{M}_s$, hence corollary 3.2.36 implies that the bottom row in the diagram above is always an isomorphism. Therefore the top row in the diagram above is an isomorphism for every $L^\Sigma(<q)$-local symmetric
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$T$-spectrum $Z$, then by corollary 3.3.32 it follows that $VQ_s f$ is a $L^\Sigma(< q)$-local equivalence in $\text{Spt}^\Sigma_T$. 

$(\Leftarrow)$: Assume that $VQ_s f$ is a $L^\Sigma(< q)$-local equivalence in $\text{Spt}^\Sigma_T$, and let $Z$ be an arbitrary $L(< q)$-local $T$-spectrum in $\text{Spt}_T$. We need to show that the induced map:

$$\text{Map}(Q_s Y, Z) \xrightarrow{(Q_s f)^*} \text{Map}(Q_s X, Z)$$

is a weak equivalence of simplicial sets.

But theorem 2.6.29 implies that the adjunction $(V, U, \varphi)$ is a Quillen equivalence between $\text{Spt}_T$ and $\text{Spt}^\Sigma_T$, therefore using [10, proposition 1.3.13(b)] we have that all the maps in the following diagram are weak equivalences in $\text{Spt}_T$:

$$Z \xleftarrow{Q_s^2} Q_s Z \xrightarrow{U(R^\Sigma V Q_s Z) \circ \eta_{Q_s Z}} UR^\Sigma V Q_s Z$$

Lemma 3.3.39 implies in particular that $Z, Q_s Z, UR^\Sigma V Q_s Z$ are all fibrant in $\text{Spt}_T$. Now using the fact that $\text{Spt}_T$ is a simplicial model category together with Ken Brown’s lemma (see lemma 1.1.5) and the two out of three property for weak equivalences, we have that it suffices to prove that the induced map:

$$\text{Map}(Q_s Y, UR^\Sigma V Q_s Z) \xrightarrow{(Q_s f)^*} \text{Map}(Q_s X, UR^\Sigma V Q_s Z)$$

is a weak equivalence of simplicial sets. Using the enriched adjunctions of proposition 2.6.20, we get the following commutative diagram where all the vertical arrows are isomorphisms:

$$\text{Map}(Q_s Y, UR^\Sigma V Q_s Z) \xrightarrow{(Q_s f)^*} \text{Map}(Q_s X, UR^\Sigma V Q_s Z)$$

$$\cong$$

$$\text{Map} \Sigma(V Q_s Y, R^\Sigma V Q_s Z) \xrightarrow{(V Q_s f)^*} \text{Map} \Sigma(V Q_s X, R^\Sigma V Q_s Z)$$

Finally, lemma 3.3.39 implies that $UR^\Sigma V Q_s Z$ is $L(< q)$-local in $\text{Spt}_T$, therefore by proposition 3.3.28 we have that $R^\Sigma V Q_s Z$ is $L^\Sigma(< q)$-local in $\text{Spt}^\Sigma_T$. Since $V Q_s f$ is a $L^\Sigma(< q)$-local equivalence and $V Q_s X, V Q_s Y$ are both cofibrant in $\text{Spt}^\Sigma_T$, it follows that the bottom row in the diagram above is a weak equivalence of simplicial sets. This implies that the top row is also a weak equivalence of simplicial sets, as we wanted. $\square$
Theorem 3.3.41. For every \( q \in \mathbb{Z} \), the adjunction
\[
(V, U, \varphi) : L_{<q} \mathbf{Spt}_T \mathbb{M}_* \longrightarrow L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_*
\]
given by the symmetrization and the forgetful functor is a Quillen equivalence.

Proof. Proposition 3.3.40 together with the universal property for left Bousfield localizations (see definition 1.8.1) imply that
\[
V : L_{<q} \mathbf{Spt}_T \mathbb{M}_* \longrightarrow L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_*
\]
is a left Quillen functor. Using corollary 1.3.16 in [10] and proposition 3.2.31 we have that it suffices to verify the following two conditions:

1. For every fibrant object \( X \) in \( L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_* \), the following composition
\[
V Q_s U (X) \xymatrix{ \ar[r]^{V(Q_s U X)} & VU(X) \ar[r]^{\epsilon X} & X}
\]
is a weak equivalence in \( L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_* \).

2. \( V \) reflects weak equivalences between cofibrant objects in \( L_{<q} \mathbf{Spt}_T \mathbb{M}_* \).

(1): By construction \( L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_* \) is a left Bousfield localization of \( \mathbf{Spt}_T \Sigma \mathbb{M}_* \), therefore the identity functor
\[
\text{id} : L_{<q} \mathbf{Spt}_T \Sigma \mathbb{M}_* \longrightarrow \mathbf{Spt}_T \Sigma \mathbb{M}_*
\]
is a right Quillen functor. Thus \( X \) is also fibrant in \( \mathbf{Spt}_T \Sigma \mathbb{M}_* \). Since the adjunction \( (V, U, \varphi) \) is a Quillen equivalence between \( \mathbf{Spt}_T \mathbb{M}_* \) and \( \mathbf{Spt}_T \Sigma \mathbb{M}_* \), [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in \( \mathbf{Spt}_T \Sigma \mathbb{M}_* \):
\[
V Q_s U (X) \xymatrix{ \ar[r]^{V(Q_s U X)} & VU(X) \ar[r]^{\epsilon X} & X}
\]
Hence using [7, proposition 3.1.5] it follows that the composition above is a \( \Sigma (< q) \)-local equivalence.

(2): This follows immediately from propositions 3.2.31 and 3.3.40.
Corollary 3.3.42. Fix $q \in \mathbb{Z}$. Then the adjunction

$$(V, U, \varphi) : L_{<q}\text{Spt}_T M_* \longrightarrow L_{<q}\text{Spt}_T^\Sigma M_*$$

given by the symmetrization and the forgetful functors, induces an adjunction

$$(VQ_s, UW_q^\Sigma, \varphi) : L_{<q}\mathcal{H}(S) \longrightarrow L_{<q}\mathcal{H}^\Sigma(S)$$

of exact functors between triangulated categories. Furthermore, $VQ_s$ and $UW_q^\Sigma$ are both equivalences of categories.

Proof. Theorem 3.3.41 implies that the adjunction $(V, U, \varphi)$ is a Quillen equivalence. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(VQ_s, UW_q^\Sigma, \varphi) : L_{<q}\mathcal{H}(S) \longrightarrow L_{<q}\mathcal{H}^\Sigma(S)$$

Now [10, proposition 1.3.13] implies that $VQ_s, UW_q^\Sigma$ are both equivalences of categories. Finally, proposition 2.6.20 together with [10, proposition 6.4.1] imply that $VQ_s$ maps cofibre sequences in $L_{<q}\mathcal{H}(S)$ to cofibre sequences in $L_{<q}\mathcal{H}^\Sigma(S)$. Therefore using proposition 7.1.12 in [10] we have that $VQ_s$ and $UW_q^\Sigma$ are both exact functors between triangulated categories.

Now it is very easy to find the desired lifting for the functor $\tilde{s}_{<q} : \mathcal{H}^\Sigma(S) \to \mathcal{H}^\Sigma(S)$ (see corollary 3.3.5(2)) to the model category level.

Lemma 3.3.43. Fix $q \in \mathbb{Z}$, and let $X$ be an arbitrary symmetric $T$-spectrum.

1. The following maps in $L_{<q}\text{Spt}_T^\Sigma M_*$

$$Q^\Sigma(VQ_s X) \xrightarrow{Q^\Sigma(VQ_s X)} VQ_s X \xrightarrow{V(Q^S_s X)} VQ_s(Q^S_s X)$$

induce natural isomorphisms between the functors:

$$Q^\Sigma \circ VQ_s, VQ_s, VQ_s \circ Q^S_s : \mathcal{H}(S) \to L_{<q}\mathcal{H}^\Sigma(S)$$
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Given a $T$-spectrum $X$

$$
\kappa_X : Q_\Sigma(VQ_s X) \xrightarrow{\cong} VQ_s(Q_s X)
$$

will denote the isomorphism in $L_{<q} S\mathcal{H}^\Sigma(S)$ corresponding to the natural isomorphism between $Q_\Sigma \circ VQ_s$ and $VQ_s \circ Q_s$.

2. The following maps in $\text{Spt}_T \mathcal{M}_s$

$$
UR_\Sigma(W_q^{\Sigma} X) \xleftarrow{UR_\Sigma(W_q^{\Sigma} X)} UW_q^{\Sigma} X \xrightarrow{W_q^{UW_q^{\Sigma} X}} W_q(UW_q^{\Sigma} X)
$$

induce natural isomorphisms between the functors:

$$
UR_\Sigma \circ W_q^{\Sigma}, UW_q^{\Sigma}, W_q \circ UW_q^{\Sigma} : L_{<q} S\mathcal{H}^\Sigma(S) \to S\mathcal{H}(S)
$$

Given a symmetric $T$-spectrum $X$

$$
\mu_X : UR_\Sigma(W_q^{\Sigma} X) \xrightarrow{\cong} W_q(UW_q^{\Sigma} X)
$$

will denote the isomorphism in $S\mathcal{H}(S)$ corresponding to the natural isomorphism between $UR_\Sigma \circ W_q^{\Sigma}$ and $W_q \circ UW_q^{\Sigma}$. 
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**Proof.** (1): Follows immediately from theorem 1.3.7 in [10] and the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
\text{Spt}_T M_* & \xrightarrow{V} & \text{Spt}_T^\Sigma M_* \\
\text{id} & & \text{id} \\
L_{<q}\text{Spt}_T M_* & \xrightarrow{V} & L_{<q}\text{Spt}_T^\Sigma M_*
\end{array}
\]

(2): Follows immediately from the dual of theorem 1.3.7 in [10] and the following commutative diagram of right Quillen functors:

\[
\begin{array}{ccc}
\text{Spt}_T M_* & \xleftarrow{U} & \text{Spt}_T^\Sigma M_* \\
\text{id} & & \text{id} \\
L_{<q}\text{Spt}_T M_* & \xleftarrow{U} & L_{<q}\text{Spt}_T^\Sigma M_*
\end{array}
\]

\[\square\]

**Theorem 3.3.44.** Fix \( q \in \mathbb{Z} \), and let \( X \) be an arbitrary symmetric \( T \)-spectrum.

1. The diagram (3.16) in theorem 3.2.52 induces the following diagram in \( \mathcal{SH}^\Sigma(S) \):

\[
\begin{array}{ccc}
VQ_s(Q_s s_{<q}(UR_S X)) & \xrightarrow{\cong} & VQ_s(W_q Q_s s_{<q}(UR_S X)) \\
VQ_s(Q_s s_{<q}^{UR_S X}) & & \cong & VQ_s(W_q Q_s s_{<q}(UR_S X)) \\
\hat{s}_{<q} X = VQ_s(s_{<q}(UR_S X)) & \cong & VQ_s(W_q Q_s(\pi_{<q}^{UR_S X}))
\end{array}
\]

(3.33)

where all the maps are isomorphisms in \( \mathcal{SH}^\Sigma(S) \). Furthermore, this diagram induces a natural isomorphism between the following exact functors:

\[
\begin{array}{ccc}
\mathcal{SH}^\Sigma(S) & \xrightarrow{\hat{s}_{<q}} & \mathcal{SH}^\Sigma(S) \\
VQ_s W_q Q_s UR_S & & VQ_s W_q Q_s UR_S
\end{array}
\]

2. Let \( \eta \) be the unit of the adjunction (see corollary 3.3.42):

\[
(VQ_s, UW_q^\Sigma, \varphi) : L_{<q} \mathcal{H}(S) \xrightarrow{\cong} L_{<q} \mathcal{H}^\Sigma(S)
\]
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Then we have the following diagram in $\mathcal{SH}(S)$ (see lemma 3.3.43):

$$
\begin{array}{ccc}
W_q(UW_q^\Sigma (Q_\Sigma (VQ_\Sigma X))) & \xrightarrow{W_q(UW_q^\Sigma (\epsilon_X))} & W_q(UW_q^\Sigma (VQ_\Sigma (Q_\Sigma X))) \\
\mu_{Q_\Sigma (VQ_\Sigma X)} \cong & & \cong \mu_{\nu_{Q_\Sigma (VQ_\Sigma X)}} \\
UR_\Sigma (W_q^\Sigma Q_\Sigma (VQ_\Sigma X)) & \xrightarrow{W_q\nu_{Q_\Sigma (VQ_\Sigma X)}} & W_q Q_\Sigma X \\
\end{array}
$$

(3.34)

where all the maps are isomorphisms in $\mathcal{SH}(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$
\begin{array}{ccc}
\mathcal{SH}(S) & \xrightarrow{UR_\Sigma \circ W_q^\Sigma \circ VQ_\Sigma} & \mathcal{SH}(S) \\
W_q Q_\Sigma & \cong & W_q Q_\Sigma \\
\end{array}
$$

3. Let $\epsilon$ denote the counit of the adjunction (see theorem 3.3.4):

$$
(VQ_\Sigma, UR_\Sigma, \varphi) : \mathcal{SH}(S) \longrightarrow \mathcal{SH}^\Sigma(S)
$$

and let $\gamma$ denote the natural isomorphism constructed above in (2). Then we have the following diagram in $\mathcal{SH}^\Sigma(S)$:

$$
\begin{array}{ccc}
VQ_\Sigma (UR_\Sigma W_q^\Sigma Q_\Sigma VQ_\Sigma (UR_\Sigma X)) & \xrightarrow{W_q^\Sigma Q_\Sigma VQ_\Sigma (UR_\Sigma X)} & W_q^\Sigma Q_\Sigma VQ_\Sigma (UR_\Sigma X) \\
VQ_\Sigma (\gamma_{UR_\Sigma X})^{-1} \cong & & \cong W_q^\Sigma Q_\Sigma VQ_\Sigma (UR_\Sigma X) \\
VQ_\Sigma (W_q Q_\Sigma (UR_\Sigma X)) & \xrightarrow{W_q^\Sigma Q_\Sigma (\epsilon_X)} & W_q^\Sigma Q_\Sigma X = s^\Sigma_{\leq q} X \\
\end{array}
$$

(3.35)

where all the maps are isomorphisms in $\mathcal{SH}^\Sigma(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$
\begin{array}{ccc}
\mathcal{SH}^\Sigma(S) & \xrightarrow{VQ_\Sigma \circ W_q Q_\Sigma \circ UR_\Sigma} & \mathcal{SH}^\Sigma(S) \\
W_q^\Sigma Q_\Sigma = s^\Sigma_{\leq q} & \cong & W_q^\Sigma Q_\Sigma = s^\Sigma_{\leq q} \\
\end{array}
$$
4. Combining the diagrams (3.33) and (3.35) above we get a natural isomorphism between the following exact functors:

\[
\begin{align*}
\mathcal{SH} &\xrightarrow{s_{\leq q}} \mathcal{SH} \\
\Sigma(S) &\xrightarrow{\tilde{s}_{\leq q}} \Sigma(S)
\end{align*}
\]

**Proof.** It is clear that it suffices to prove only the first three claims.

(1): Follows immediately from theorems 3.2.52 and 3.3.4.

(2): Follows immediately from lemma 3.3.43 and corollary 3.3.42.

(3): Follows immediately from (2) above, and theorem 3.3.4. 

The functor \(s_{\leq q}^\Sigma\) gives the desired lifting for the functor \(\tilde{s}_{\leq q}\) to the model category level.

**Proposition 3.3.45.** For every \(q \in \mathbb{Z}\), we have the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
\operatorname{Spt}_T^\Sigma M_* & \xrightarrow{id} & \operatorname{Spt}_T^\Sigma M_* \\
\downarrow & & \downarrow \\
L_{<q+1}\operatorname{Spt}_T^\Sigma M_* & \xrightarrow{id} & L_{<q}\operatorname{Spt}_T^\Sigma M_*
\end{array}
\]

**Proof.** Since \(L_{<q}\operatorname{Spt}_T^\Sigma M_*\) and \(L_{<q+1}\operatorname{Spt}_T^\Sigma M_*\) are both left Bousfield localizations for \(\operatorname{Spt}_T^\Sigma M_*\), we have that the identity functors:

\[
\begin{align*}
\operatorname{id} : \operatorname{Spt}_T^\Sigma M_* &\longrightarrow L_{<q}\operatorname{Spt}_T^\Sigma M_* \\
\operatorname{id} : \operatorname{Spt}_T^\Sigma M_* &\longrightarrow L_{<q+1}\operatorname{Spt}_T^\Sigma M_*
\end{align*}
\]

are both left Quillen functors. Hence, it suffices to show that

\[
\operatorname{id} : L_{<q+1}\operatorname{Spt}_T^\Sigma M_* \longrightarrow L_{<q}\operatorname{Spt}_T^\Sigma M_*
\]

is a left Quillen functor. Using the universal property for left Bousfield localizations (see definition 1.8.1), we have that it is enough to check that if \(f : X \rightarrow Y\) is a \(L^\Sigma(<q+1)\)-local equivalence then \(Q_\Sigma f : Q_\Sigma X \rightarrow Q_\Sigma Y\) is a \(L^\Sigma(<q)\)-local equivalence.
But theorem 3.1.6(c) in [7] implies that this last condition is equivalent to the following one:
Let \( Z \) be an arbitrary \( L^\Sigma(<q) \)-local symmetric \( T \)-spectrum, then \( Z \) is also \( L^\Sigma(<q+1) \)-local. Finally, this last condition follows immediately from proposition 3.3.28 and corollary 3.2.33.

**Corollary 3.3.46.** For every \( q \in \mathbb{Z} \), we have the following adjunction

\[
(Q_\Sigma, W^\Sigma_q, \varphi) : L_{<q+1}^\Sigma \mathfrak{H}(S) \xrightarrow{\sim} L_{<q}^\Sigma \mathfrak{H}(S)
\]

of exact functors between triangulated categories.

**Proof.** Proposition 3.3.45 implies that \( \text{id} : L_{<q+1}^\Sigma \text{Spt}_T^\Sigma M_* \rightarrow L_{<q}^\Sigma \text{Spt}_T^\Sigma M_* \) is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories

\[
(Q_\Sigma, W^\Sigma_q, \varphi) : L_{<q+1}^\Sigma \mathfrak{H}(S) \xrightarrow{\sim} L_{<q}^\Sigma \mathfrak{H}(S)
\]

Now proposition 6.4.1 in [10] implies that \( Q_\Sigma \) maps cofibre sequences in \( L_{<q+1}^\Sigma \mathfrak{H}(S) \) to cofibre sequences in \( L_{<q}^\Sigma \mathfrak{H}(S) \). Therefore using proposition 7.1.12 in [10] we have that \( Q_\Sigma \) and \( W^\Sigma_q \) are both exact functors between triangulated categories.

**Theorem 3.3.47.** We have the following tower of left Quillen functors:

\[
\begin{array}{ccc}
\vdots & \downarrow \text{id} & \\
& L_{<q+1}^\Sigma \text{Spt}_T^\Sigma M_* & \\
& \downarrow \text{id} & \\
\vdots & \downarrow \text{id} & \\
\end{array}
\]

\[
\begin{array}{ccc}
Spt_T^\Sigma M_* & \xrightarrow{\text{id}} & L_{<q}^\Sigma \text{Spt}_T^\Sigma M_* \\
\downarrow \text{id} & & \downarrow \text{id} \\
L_{<q-1}^\Sigma \text{Spt}_T^\Sigma M_* & \xrightarrow{\text{id}} & \vdots
\end{array}
\]
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together with the corresponding tower of associated homotopy categories:

\[
\begin{array}{c}
\vdots \\
Q_\Sigma \downarrow \quad W_{q+1}^{\Sigma} \\
L_{<q+1} S^\Sigma T^\Sigma(M) \\
Q_\Sigma \downarrow \quad W_q^{\Sigma} \\
S^\Sigma T^\Sigma(M) \\
Q_\Sigma \downarrow \quad W_{q-1}^{\Sigma} \\
L_{<q-1} S^\Sigma T^\Sigma(M) \\
Q_\Sigma \downarrow \quad W_{q-2}^{\Sigma} \\
\vdots
\end{array}
\]

(3.37)

The tower (3.37) gets canonically identified, through the equivalences of categories \(VQ_s, UR_\Sigma \) and \(UW_\Sigma \) constructed in theorem 3.3.4 and corollary 3.3.42; with the tower (3.19) defined in theorem 3.2.56. Moreover, this tower also satisfies the following properties:

1. All the categories are triangulated.

2. All the functors are exact.

3. \(Q_\Sigma \) is a left adjoint for all the functors \(W_q^{\Sigma} \).

\textbf{Proof.} Follows immediately from propositions 3.3.38, 3.3.45, corollary 3.3.46 together with theorem 3.3.4 and corollary 3.3.42.

\textbf{Definition 3.3.48.} For every \(q \in \mathbb{Z} \), we consider the following set of symmetric \(T\)-spectra

\[
S^\Sigma(q) = \{F_n^\Sigma(S^r \wedge G_m^s \wedge U_+) \in C^\Sigma | s - n = q \} \subseteq C^\Sigma_{eff}
\]

(see proposition 3.1.5 and definition 3.1.8).

\textbf{Theorem 3.3.49.} Fix \(q \in \mathbb{Z} \). Then the right Bousfield localization of the model category \(L_{<q+1} \text{Spt}_T^\Sigma M_* \) with respect to the \(S^\Sigma(q)\)-colocal equivalences exists. This new model structure will be called \(q\)-slice motivic symmetric stable. \(S^q \text{Spt}_T^\Sigma M_* \) will denote the
category of symmetric $T$-spectra equipped with the $q$-slice motivic symmetric stable model structure, and $S^qSH^\Sigma(S)$ will denote its associated homotopy category. Furthermore, the $q$-slice motivic symmetric stable model structure is right proper and simplicial.

**Proof.** Theorem 3.3.25 implies that $L_{<q+1}\text{Spt}^\Sigma_T M_*$ is a cellular and simplicial model category. On the other hand, corollary 3.3.37 implies that $L_{<q+1}\text{Spt}^\Sigma_T M_*$ is right proper. Therefore we can apply theorem 5.1.1 in [7] to construct the right Bousfield localization of $L_{<q+1}\text{Spt}^\Sigma_T M_*$ with respect to the $S^\Sigma(q)$-colocal equivalences. Using [7, theorem 5.1.1] again, we have that $S^q\text{Spt}^\Sigma_T M_*$ is a right proper and simplicial model category. \(\square\)

**Definition 3.3.50.** Fix $q \in \mathbb{Z}$. Let $P^\Sigma_q$ denote a cofibrant replacement functor on $S^q\text{Spt}^\Sigma_T M_*$; such that for every symmetric $T$-spectrum $X$, the natural map

$$P^\Sigma_q X \xrightarrow{P^\Sigma_{q,X}} X$$

is a trivial fibration in $S^q\text{Spt}^\Sigma_T M_*$, and $P^\Sigma_q X$ is always a $S^\Sigma(q)$-colocal symmetric $T$-spectrum in $L_{<q+1}\text{Spt}^\Sigma_T M_*$.

**Proposition 3.3.51.** Fix $q \in \mathbb{Z}$. Then $W^\Sigma_{q+1}$ is also a fibrant replacement functor on $S^q\text{Spt}^\Sigma_T M_*$ (see definition 3.3.26), and for every symmetric $T$-spectrum $X$ the natural map

$$X \xrightarrow{W^\Sigma_{q+1,X}} W^\Sigma_{q+1} X$$

is a trivial cofibration in $S^q\text{Spt}^\Sigma_T M_*$. \(\square\)

**Proof.** Since $S^q\text{Spt}^\Sigma_T M_*$ is the right Bousfield localization of $L_{<q+1}\text{Spt}^\Sigma_T M_*$ with respect to the $S^\Sigma(q)$-colocal equivalences, by construction we have that the fibrations and the trivial cofibrations are identical in $S^q\text{Spt}^\Sigma_T M_*$ and $L_{<q+1}\text{Spt}^\Sigma_T M_*$ respectively. This implies that for every symmetric $T$-spectrum $X$, $W^\Sigma_{q+1} X$ is fibrant in $S^q\text{Spt}^\Sigma_T M_*$, and we also have that the natural map

$$X \xrightarrow{W^\Sigma_{q+1,X}} W^\Sigma_{q+1} X$$

is a trivial cofibration in $S^q\text{Spt}^\Sigma_T M_*$. Hence $W^\Sigma_{q+1}$ is also a fibrant replacement functor for $S^q\text{Spt}^\Sigma_T M_*$. \(\square\)
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**Proposition 3.3.52.** Fix \( q \in \mathbb{Z} \), and let \( f : X \to Y \) be a map in \( L_{<q+1}\text{Spt}_{T}^{\Sigma}M_{*} \). Then \( f \) is a \( S^{\Sigma}(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_{T}^{\Sigma}M_{*} \) if and only if the underlying map \( UW_{q+1}^{\Sigma}(f) : UW_{q+1}^{\Sigma}X \to UW_{q+1}^{\Sigma}Y \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_{T}M_{*} \).

**Proof.** Consider \( F_{n}^{\Sigma}(S^{r} \land G_{m}^{s} \land U_{+}) \in S^{\Sigma}(q) \). Using the enriched adjunctions of proposition 2.6.20, we get the following commutative diagram where the vertical arrows are all isomorphisms:

\[
\begin{array}{ccc}
\text{Map}_{\Sigma}(F_{n}^{\Sigma}(S^{r} \land G_{m}^{s} \land U_{+}), W_{q+1}^{\Sigma}X) & \xrightarrow{W_{q+1}^{\Sigma}f_{*}} & \text{Map}_{\Sigma}(F_{n}^{\Sigma}(S^{r} \land G_{m}^{s} \land U_{+}), W_{q+1}^{\Sigma}Y) \\
\text{Map}_{\Sigma}(V(F_{n}(S^{r} \land G_{m}^{s} \land U_{+})), W_{q+1}^{\Sigma}X) & \cong & \text{Map}_{\Sigma}(V(F_{n}(S^{r} \land G_{m}^{s} \land U_{+})), W_{q+1}^{\Sigma}Y) \\
\text{Map}(F_{n}(S^{r} \land G_{m}^{s} \land U_{+}), UW_{q+1}^{\Sigma}X) & \xrightarrow{UW_{q+1}^{\Sigma}f_{*}} & \text{Map}(F_{n}(S^{r} \land G_{m}^{s} \land U_{+}), UW_{q+1}^{\Sigma}Y)
\end{array}
\]

Since \( UW_{q+1}^{\Sigma}X \) and \( UW_{q+1}^{\Sigma}Y \) are both fibrant in \( L_{<q+1}\text{Spt}_{T}M_{*} \), we have that \( UW_{q+1}^{\Sigma}(f) \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_{T}M_{*} \) if and only if the bottom row in the diagram above is a weak equivalence of simplicial sets for every \( F_{n}(S^{r} \land G_{m}^{s} \land U_{+}) \in S(q) \). By the two out of three property for weak equivalences we have that this happens if and only if the top row in the diagram above is a weak equivalence for every \( F_{n}^{\Sigma}(S^{r} \land G_{m}^{s} \land U_{+}) \in S^{\Sigma}(q) \). But this last condition holds if and only if \( f \) is a \( S^{\Sigma}(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_{T}^{\Sigma}M_{*} \). This finishes the proof. \( \square \)

**Proposition 3.3.53.** Fix \( q \in \mathbb{Z} \), and let \( f : X \to Y \) be a map in \( L_{<q+1}\text{Spt}_{T}^{\Sigma}M_{*} \). Then \( f \) is a \( S^{\Sigma}(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}_{T}^{\Sigma}M_{*} \) if and only if for every \( F_{n}^{\Sigma}(S^{r} \land G_{m}^{s} \land U_{+}) \in \)
3.3. The Symmetric Model Structure for the Slice Filtration

\( S^\Sigma(q) \), the induced map:

\[
[F_n(S^r \wedge G^s_m \wedge U_+), W^\Sigma_{q+1} X]_{\text{Spt}} \xrightarrow{(W^\Sigma_{q+1} f)_*} [F_n(S^r \wedge G^s_m \wedge U_+), W^\Sigma_{q+1} Y]_{\text{Spt}}
\]

is an isomorphism of abelian groups.

**Proof.** By proposition 3.3.52, \( f \) is a \( S^\Sigma(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}^\Sigma T\mathcal{M}_+ \) if and only if \( UW^\Sigma_{q+1}(f) \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1}\text{Spt}^\Sigma T\mathcal{M}_+ \). Since \( UW^\Sigma_{q+1}X, UW^\Sigma_{q+1}Y \) are both fibrant in \( L_{<q+1}\text{Spt}^\Sigma T\mathcal{M}_+ \), using proposition 3.2.62 we have that \( UW^\Sigma_{q+1}(f) \) is a \( S(q) \)-colocal equivalence if and only if for every \( F_n(S^r \wedge G^s_m \wedge U_+ \in S(q) \), the induced map

\[
[F_n(S^r \wedge G^s_m \wedge U_+), UW^\Sigma_{q+1} X]_{\text{Spt}} \xrightarrow{(UW^\Sigma_{q+1} f)_*} [F_n(S^r \wedge G^s_m \wedge U_+), UW^\Sigma_{q+1} Y]_{\text{Spt}}
\]

is an isomorphism of abelian groups.

Now since \( W^\Sigma_{q+1}X, W^\Sigma_{q+1}Y \) are also fibrant in \( \text{Spt}^\Sigma T\mathcal{M}_+ \), theorem 2.6.29 implies that we have the following commutative diagram, where all the vertical arrows are isomorphisms:

\[
\begin{array}{c}
[F_n(S^r \wedge G^s_m \wedge U_+), UW^\Sigma_{q+1} X]_{\text{Spt}} \\
\downarrow \cong \\
[F_n(S^r \wedge G^s_m \wedge U_+), UW^\Sigma_{q+1} Y]_{\text{Spt}} \\
\downarrow \cong \\
[V(F_n(S^r \wedge G^s_m \wedge U_+)), W^\Sigma_{q+1} X]_{\text{Spt}} \\
\downarrow (W^\Sigma_{q+1} f)_* \\
\downarrow \cong \\
[V(F_n(S^r \wedge G^s_m \wedge U_+)), W^\Sigma_{q+1} Y]_{\text{Spt}} \\
\downarrow (W^\Sigma_{q+1} f)_* \\
\downarrow \cong \\
[F_n(S^r \wedge G^s_m \wedge U_+), W^\Sigma_{q+1} X]_{\text{Spt}} \\
\downarrow (W^\Sigma_{q+1} f)_* \\
\downarrow \cong \\
[F_n(S^r \wedge G^s_m \wedge U_+), W^\Sigma_{q+1} Y]_{\text{Spt}}
\end{array}
\]

Therefore \( f \) is a \( S^\Sigma(q) \)-colocal equivalence if and only if for every \( F_n(S^r \wedge G^s_m \wedge U_+ \in S^\Sigma(q) \), the bottom row is an isomorphism of abelian groups. This finishes the proof. \( \square \)
Corollary 3.3.54. Fix $q \in \mathbb{Z}$ and let $f : X \to Y$ be a map of symmetric $T$-spectra. Then $f$ is a $S^\Sigma(q)$-colocal equivalence in $L_{< q+1}\text{Spt}_T^\Sigma \mathcal{M}_*$ if and only if

$$W^\Sigma_{q+1}X \xrightarrow{W^\Sigma_{q+1}f} W^\Sigma_{q+1}Y$$

is a $C^q_{\Sigma \text{eff}}$-colocal equivalence in $\text{Spt}_T^\Sigma \mathcal{M}_*$.

Proof. $(\Rightarrow)$: Assume that $f$ is a $S^\Sigma(q)$-colocal equivalence, and fix $F^\Sigma_n(S^r \wedge G_m^s \wedge U_+) \in C^q_{\Sigma \text{eff}}$. By proposition 3.3.13 it suffices to show that the induced map

$$\left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}X \right]_{\text{Spt}}^{S^\Sigma} \xrightarrow{(W^\Sigma_{q+1}f)^*} \left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}Y \right]_{\text{Spt}}^{S^\Sigma}$$

is an isomorphism of abelian groups.

Since $F^\Sigma_n(S^r \wedge G_m^s \wedge U_+) \in C^q_{\Sigma \text{eff}}$, we have two possibilities:

1. $s - n = q$, i.e. $F^\Sigma_n(S^r \wedge G_m^s \wedge U_+) \in S^\Sigma(q)$.

2. $s - n \geq q + 1$, i.e. $F^\Sigma_n(S^r \wedge G_m^s \wedge U_+) \in C^{q+1}_{\Sigma \text{eff}}$.

In case (1), proposition 3.3.53 implies that the induced map in diagram (3.38) is an isomorphism of abelian groups.

On the other hand, in case (2), we have by proposition 3.3.29(2) that

$$\left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}X \right]_{\text{Spt}}^{S^\Sigma} \cong 0 \cong \left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}Y \right]_{\text{Spt}}^{S^\Sigma}$$

since by construction $W^\Sigma_{q+1}X$ and $W^\Sigma_{q+1}Y$ are both $L^\Sigma(< q+1)$-local symmetric $T$-spectra. Hence the induced map in diagram (3.38) is also an isomorphism of abelian groups in this case, as we wanted.

$(\Leftarrow)$: Assume that $W^\Sigma_{q+1}f$ is a $C^q_{\Sigma \text{eff}}$-colocal equivalence in $\text{Spt}_T^\Sigma \mathcal{M}_*$, and fix $F^\Sigma_n(S^r \wedge G_m^s \wedge U_+) \in S^\Sigma(q)$.

Since $S^\Sigma(q) \subseteq C^q_{\Sigma \text{eff}}$, it follows from proposition 3.3.13 that the induced map

$$\left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}X \right]_{\text{Spt}}^{S^\Sigma} \xrightarrow{(W^\Sigma_{q+1}f)^*} \left[ F^\Sigma_n(S^r \wedge G_m^s \wedge U_+), W^\Sigma_{q+1}Y \right]_{\text{Spt}}^{S^\Sigma}$$
is an isomorphism of abelian groups. Therefore, proposition 3.3.53 implies that \( f \) is a \( S^\Sigma(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma \). This finishes the proof. \( \square \)

**Lemma 3.3.55.** Fix \( q \in \mathbb{Z} \), and let \( f : X \to Y \) be a map in \( L_{<q+1} \text{Spt}_T^\Sigma \). Then \( f \) is a \( S^\Sigma(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma \) if and only if \( \Omega_{S^1} W^\Sigma_{q+1} f \) is a \( S^\Sigma(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma \).

**Proof.** It follows from proposition 3.3.52 that \( f \) is a \( S^\Sigma(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma \) if and only if \( UW^\Sigma_{q+1} f \) is a \( S(q) \)-colocal equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma \). Since

\[
UW^\Sigma_{q+1} X, \quad UW^\Sigma_{q+1} Y
\]

are both fibrant in \( L_{<q+1} \text{Spt}_T^\Sigma \), using lemma 3.2.64 we have that \( UW^\Sigma_{q+1} f \) is a \( S(q) \)-colocal equivalence if and only if \( \Omega_{S^1} UW^\Sigma_{q+1} f = U(\Omega_{S^1} W^\Sigma_{q+1} f) \) is a \( S(q) \)-colocal equivalence.

Finally, since \( \Omega_{S^1} W^\Sigma_{q+1} X, \Omega_{S^1} W^\Sigma_{q+1} Y \) are both fibrant in \( L_{<q+1} \text{Spt}_T^\Sigma \), we have by proposition 3.3.52 that \( U(\Omega_{S^1} W^\Sigma_{q+1} f) \) is a \( S^\Sigma(q) \)-colocal equivalence if and only if \( \Omega_{S^1} W^\Sigma_{q+1} f \) is a \( S^\Sigma(q) \)-colocal equivalence. This finishes the proof. \( \square \)

**Corollary 3.3.56.** Fix \( q \in \mathbb{Z} \). Then the adjunction

\[
(- \wedge S^1, \Omega_{S^1}, \varphi) : S^q \text{Spt}_T^\Sigma \to S^q \text{Spt}_T^\Sigma
\]

is a Quillen equivalence.

**Proof.** Using corollary 1.3.16 in [10] and proposition 3.3.51 we have that it suffices to verify the following two conditions:

1. For every cofibrant object \( X \) in \( S^q \text{Spt}_T^\Sigma \), the following composition

\[
X \xrightarrow{\eta_X} \Omega_{S^1} (X \wedge S^1) \xrightarrow{\Omega_{S^1} W^\Sigma_{q+1}} \Omega_{S^1} W^\Sigma_{q+1} (X \wedge S^1)
\]

is a \( S^\Sigma(q) \)-colocal equivalence.
2. \( \Omega S^1 \) reflects \( S^\Sigma (q) \)-colocal equivalences between fibrant objects in \( S^q \text{Spt}_T^\Sigma M_* \).

(1): By construction \( S^q \text{Spt}_T^\Sigma M_* \) is a right Bousfield localization of \( L_{<q+1} \text{Spt}_T^\Sigma M_* \), therefore the identity functor

\[
\text{id} : S^q \text{Spt}_T^\Sigma M_* \longrightarrow L_{<q+1} \text{Spt}_T^\Sigma M_*
\]

is a left Quillen functor. Thus \( X \) is also cofibrant in \( L_{<q+1} \text{Spt}_T^\Sigma M_* \). Since the adjunction \((- \wedge S^1, \Omega S^1, \varphi)\) is a Quillen equivalence on \( L_{<q+1} \text{Spt}_T^\Sigma M_* \), [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in \( L_{<q+1} \text{Spt}_T^\Sigma M_* \):

\[
X \xrightarrow{\eta_X} \Omega S^1 (X \wedge S^1) \xrightarrow{\Omega S^1 W^\Sigma_{<q+1} (X \wedge S^1)} \Omega S^1 W^\Sigma_{<q+1} (X \wedge S^1)
\]

Hence using [7, proposition 3.1.5] it follows that the composition above is a \( S^\Sigma (q) \)-colocal equivalence.

(2): This follows immediately from proposition 3.3.51 and lemma 3.3.55. \( \square \)

**Remark 3.3.57.** The adjunction \((\Sigma_T, \Omega_T, \varphi)\) is a Quillen equivalence on \( \text{Spt}_T^\Sigma M_* \). However it does not descend even to a Quillen adjunction on the \( q \)-slice motivic symmetric stable model category \( S^q \text{Spt}_T^\Sigma M_* \).

**Corollary 3.3.58.** For every \( q \in \mathbb{Z} \), \( S^q \mathcal{H}^\Sigma (S) \) has the structure of a triangulated category.

**Proof.** Theorem 3.3.49 implies in particular that \( S^q \text{Spt}_T^\Sigma M_* \) is a pointed simplicial model category, and corollary 3.3.56 implies that the adjunction

\[
(- \wedge S^1, \Omega S^1, \varphi) : S^q \text{Spt}_T^\Sigma M_* \longrightarrow S^q \text{Spt}_T^\Sigma M_*
\]

is a Quillen equivalence. Therefore the result follows from the work of Quillen in [20, sections I.2 and I.3] and the work of Hovey in [10, chapters VI and VII]. \( \square \)

**Proposition 3.3.59.** Fix \( q \in \mathbb{Z} \). Then we have the following adjunction

\[
(P^\Sigma_q, W^\Sigma_{<q+1}, \varphi) : S^q \mathcal{H}^\Sigma (S) \longrightarrow L_{<q+1} S^q \mathcal{H}^\Sigma (S)
\]

between exact functors of triangulated categories.
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**Proof.** Since $S^q \text{Spt}^\Sigma T_\ast$ is the right Bousfield localization of $L_{<q+1} \text{Spt}^\Sigma T_\ast$ with respect to the $S^\Sigma(q)$-colocal equivalences, we have that the identity functor $id : S^q \text{Spt}^\Sigma T_\ast \to L_{<q+1} \text{Spt}^\Sigma T_\ast$ is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(P^\Sigma_q, W^\Sigma_{q+1}; \varphi) : S^q \mathcal{H}^\Sigma(S) \xrightarrow{\sim} L_{<q+1} \mathcal{H}^\Sigma(S)$$

Now proposition 6.4.1 in [10] implies that $P^\Sigma_q$ maps cofibre sequences in $S^q \mathcal{H}^\Sigma(S)$ to cofibre sequences in $L_{<q+1} \mathcal{H}^\Sigma(S)$. Therefore using proposition 7.1.12 in [10] we have that $P^\Sigma_q$ and $W^\Sigma_{q+1}$ are both exact functors between triangulated categories. □

**Proposition 3.3.60.** Fix $q \in \mathbb{Z}$. Then the identity functor

$$id : S^q \text{Spt}^\Sigma T_\ast \xrightarrow{\sim} R_{c_{eff}^q} \text{Spt}^\Sigma T_\ast$$

is a right Quillen functor.

**Proof.** Consider the following diagram of right Quillen functors

$$
\begin{array}{ccc}
L_{<q+1} \text{Spt}^\Sigma T_\ast & \xrightarrow{id} & \text{Spt}^\Sigma T_\ast \\
\downarrow{id} & & \downarrow{id} \\
S^q \text{Spt}^\Sigma T_\ast & \xrightarrow{id} & S^q \text{Spt}^\Sigma T_\ast
\end{array}
\xrightarrow{id}
L_{<q+1} \text{Spt}^\Sigma T_\ast \\
\xrightarrow{id}
S^q \text{Spt}^\Sigma T_\ast
R_{c_{eff}^q} \text{Spt}^\Sigma T_\ast

By the universal property of right Bousfield localizations (see definition 1.8.2) it suffices to check that if $f : X \to Y$ is a $S^\Sigma(q)$-colocal equivalence in $L_{<q+1} \text{Spt}^\Sigma T_\ast$, then $W^\Sigma_{q+1} f : W^\Sigma_{q+1} X \to W^\Sigma_{q+1} Y$ is a $C^q_{eff}$-colocal equivalence in $\text{Spt}^\Sigma T_\ast$. But this follows immediately from corollary 3.3.54. □

**Corollary 3.3.61.** For every $q \in \mathbb{Z}$ we have the following adjunction

$$(C^\Sigma_q, W^\Sigma_{q+1}; \varphi) : R_{c_{eff}^q} \mathcal{H}^\Sigma(S) \xrightarrow{\sim} S^q \mathcal{H}^\Sigma(S)$$

of exact functors between triangulated categories.
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Proof. By proposition 3.3.60 the identity functor $\text{id} : R_{C_{q}}^{\Sigma} \text{Spt}_{T}^{\Sigma}M_{\ast} \to S^{q}\text{Spt}_{T}^{\Sigma}M_{\ast}$ is a left Quillen functor. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(C_{q}^{\Sigma}, W_{q+1}^{\Sigma}; \varphi) : R_{C_{q}}^{\Sigma} \mathcal{H}_{q}^{\Sigma}(S) \longrightarrow S^{q} \mathcal{H}_{q}^{\Sigma}(S)$$

Now proposition 6.4.1 in [10] implies that $C_{q}^{\Sigma}$ maps cofibre sequences in $R_{C_{q}}^{\Sigma} \mathcal{H}_{q}^{\Sigma}(S)$ to cofibre sequences in $S^{q} \mathcal{H}_{q}^{\Sigma}(S)$. Therefore using proposition 7.1.12 in [10] we have that $C_{q}^{\Sigma}$ and $W_{q+1}^{\Sigma}$ are both exact functors between triangulated categories. □

Lemma 3.3.62. Fix $q \in \mathbb{Z}$, and let $A$ be a cofibrant symmetric $T$-spectrum in $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$. Then the map $\ast \to A$ is a trivial cofibration in $L_{<q} \text{Spt}_{T}^{\Sigma}M_{\ast}$.

Proof. Let $Z$ be an arbitrary $L^{\Sigma}(<q)$-local symmetric $T$-spectrum in $\text{Spt}_{T}^{\Sigma}M_{\ast}$. We claim that the map $Z \to \ast$ is a trivial fibration in $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$. In effect, using proposition 3.3.28 and corollary 3.2.33 we have that $Z$ is $L^{\Sigma}(<q+1)$-local in $\text{Spt}_{T}^{\Sigma}M_{\ast}$, i.e. a fibrant object in $L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$. By construction $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$ is a right Bousfield localization of $L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$, hence $Z$ is also fibrant in $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$. Then by proposition 3.3.53 it suffices to show that for every $F_{n}^{\Sigma}(S^{r} \wedge \mathbb{G}_{m}^{s} \wedge U_{+}) \in S^{\Sigma}(q)$ (i.e. $s - n = q$):

$$0 \cong [F_{n}(S^{r} \wedge \mathbb{G}_{m}^{s} \wedge U_{+}), Z]_{S^{\Sigma}}$$

But this follows immediately from proposition 3.3.29, since $Z$ is $L^{\Sigma}(<q)$-local.

Now since $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$ is a simplicial model category and $A$ is cofibrant in $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$, we have that the following map is a trivial fibration of simplicial sets:

$$\text{Map}_{\Sigma}(A, Z) \longrightarrow \text{Map}_{\Sigma}(A, \ast) = \ast$$

The identity functor

$$id : S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast} \longrightarrow L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$$

is a left Quillen functor, since $S^{q} \text{Spt}_{T}^{\Sigma}M_{\ast}$ is a right Bousfield localization of $L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$. Therefore $A$ is also cofibrant in $L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$, and since $L_{<q+1} \text{Spt}_{T}^{\Sigma}M_{\ast}$ is a left Bousfield
localization of $\text{Spt}_T^{\Sigma}M_*$; it follows that $A$ is also cofibrant in $\text{Spt}_T^{\Sigma}M_*$. On the other hand, we have that $Z$ is in particular fibrant in $\text{Spt}_T^{\Sigma}M_*$. Hence $\pi_0\text{Map}_\Sigma(A, Z)$ computes $[A, Z]_S^{\Sigma}_{\text{Spt}}$, since $\text{Spt}_T^{\Sigma}M_*$ is a simplicial model category. But $\text{Map}_\Sigma(A, Z) \to *$ is in particular a weak equivalence of simplicial sets, then

$$[A, Z]_S^{\Sigma}_{\text{Spt}} \cong 0$$

for every $L^{\Sigma}(\prec q)$-local symmetric $T$-spectrum $Z$. Finally, corollary 3.3.32 implies that $* \to A$ is a weak equivalence in $L_{\prec q}\text{Spt}_T^{\Sigma}M_*$. This finishes the proof, since we already know that $A$ is cofibrant in $L_{\prec q}\text{Spt}_T^{\Sigma}M_*$. \hfill \Box

**Theorem 3.3.63.** Fix $q \in \mathbb{Z}$. Then the adjunction

$$(V, U, \varphi) : S^q\text{Spt}_T M_* \xrightarrow{\sim} S^q\text{Spt}_T^{\Sigma}M_*$$

given by the symmetrization and the forgetful functors is a Quillen equivalence.

**Proof.** Proposition 3.3.52 together with the universal property for right Bousfield localizations (see definition 1.8.2) imply that $U : S^q\text{Spt}_T^{\Sigma}M_* \xrightarrow{\sim} S^q\text{Spt}_T M_*$ is a right Quillen functor. Using corollary 1.3.16 in [10] and proposition 3.3.51 we have that it suffices to verify the following two conditions:

1. For every cofibrant object $X$ in $S^q\text{Spt}_T M_*$, the following composition

$$X \xrightarrow{\eta_X} UV(X) \xrightarrow{UW_{q+1}^{\Sigma \Sigma}} UW_{q+1}^{\Sigma}V(X)$$

is a weak equivalence in $S^q\text{Spt}_T M_*$. 

2. $U$ reflects weak equivalences between fibrant objects in $S^q\text{Spt}_T^{\Sigma}M_*$. 

(1): By construction $S^q\text{Spt}_T M_*$ is a right Bousfield localization of $L_{\prec q+1}\text{Spt}_T M_*$, therefore the identity functor

$$id : S^q\text{Spt}_T M_* \xrightarrow{\sim} L_{\prec q+1}\text{Spt}_T M_*$$

is a weak equivalence. 

(2): Theorem 3.3.63 together with Proposition 3.3.52 imply that $U : S^q\text{Spt}_T^{\Sigma}M_* \xrightarrow{\sim} S^q\text{Spt}_T M_*$ is a right Quillen functor. Using corollary 1.3.16 in [10] and Proposition 3.3.51 we have that it suffices to verify the following two conditions:

1. For every cofibrant object $X$ in $S^q\text{Spt}_T M_*$, the following composition

$$X \xrightarrow{\eta_X} UV(X) \xrightarrow{UW_{q+1}^{\Sigma \Sigma}} UW_{q+1}^{\Sigma}V(X)$$

is a weak equivalence in $S^q\text{Spt}_T M_*$. 

2. $U$ reflects weak equivalences between fibrant objects in $S^q\text{Spt}_T^{\Sigma}M_*$. 

(1): By construction $S^q\text{Spt}_T M_*$ is a right Bousfield localization of $L_{\prec q+1}\text{Spt}_T M_*$, therefore the identity functor

$$id : S^q\text{Spt}_T M_* \xrightarrow{\sim} L_{\prec q+1}\text{Spt}_T M_*$$

is a weak equivalence.

(2): Theorem 3.3.63 together with Proposition 3.3.52 imply that $U : S^q\text{Spt}_T^{\Sigma}M_* \xrightarrow{\sim} S^q\text{Spt}_T M_*$ is a right Quillen functor. Using corollary 1.3.16 in [10] and Proposition 3.3.51 we have that it suffices to verify the following two conditions:

1. For every cofibrant object $X$ in $S^q\text{Spt}_T M_*$, the following composition

$$X \xrightarrow{\eta_X} UV(X) \xrightarrow{UW_{q+1}^{\Sigma \Sigma}} UW_{q+1}^{\Sigma}V(X)$$

is a weak equivalence in $S^q\text{Spt}_T M_*$. 

2. $U$ reflects weak equivalences between fibrant objects in $S^q\text{Spt}_T^{\Sigma}M_*$. 

(1): By construction $S^q\text{Spt}_T M_*$ is a right Bousfield localization of $L_{\prec q+1}\text{Spt}_T M_*$, therefore the identity functor

$$id : S^q\text{Spt}_T M_* \xrightarrow{\sim} L_{\prec q+1}\text{Spt}_T M_*$$

is a weak equivalence.
is a left Quillen functor. Thus $X$ is also cofibrant in $L_{<q+1}\text{Spt}_T M_*$. Since the adjunction $(V, U, \varphi)$ is a Quillen equivalence between $L_{<q+1}\text{Spt}_T M_*$ and $L_{<q+1}\text{Spt}_T^\Sigma M_*$, [10, proposition 1.3.13(b)] implies that the following composition is a weak equivalence in $L_{<q+1}\text{Spt}_T M_*$:

$$
X \xrightarrow{\eta_X} U(V(X)) \xrightarrow{UW_{q+1}^\Sigma V} UW_{q+1}^\Sigma V(X)
$$

Hence using [7, proposition 3.1.5] it follows that the composition above is a $S(q)$-colocal equivalence in $L_{<q+1}\text{Spt}_T M_*$, i.e. a weak equivalence in $S^q\text{Spt}_T M_*$. (2): This follows immediately from propositions 3.3.51 and 3.3.52.

**Corollary 3.3.64.** Fix $q \in \mathbb{Z}$. Then the adjunction

$$(V, U, \varphi) : S^q\text{Spt}_T M_* \longrightarrow S^q\text{Spt}_T^\Sigma M_*$$

given by the symmetrization and the forgetful functors, induces an adjunction

$$(VP_q, UW_{q+1}^\Sigma, \varphi) : S^q\mathcal{H}(S) \longrightarrow S^q\mathcal{H}^\Sigma(S)$$

of exact funtors between triangulated categories. Furthermore, $VP_q$ and $UW_{q+1}^\Sigma$ are both equivalences of categories.

**Proof.** Theorem 3.3.63 implies that the adjunction $(V, U, \varphi)$ is a Quillen equivalence. Therefore we get the following adjunction at the level of the associated homotopy categories:

$$(VP_q, UW_{q+1}^\Sigma, \varphi) : S^q\mathcal{H}(S) \longrightarrow S^q\mathcal{H}^\Sigma(S)$$

Now [10, proposition 1.3.13] implies that $VP_q, UW_{q+1}^\Sigma$ are both equivalences of categories. Finally, proposition 2.6.20 together with [10, proposition 6.4.1] imply that $VP_q$ maps cofibre sequences in $S^q\mathcal{H}(S)$ to cofibre sequences in $S^q\mathcal{H}^\Sigma(S)$. Therefore using proposition 7.1.12 in [10] we have that $VP_q$ and $UW_{q+1}^\Sigma$ are both exact functors between triangulated categories.

Now it is very easy to find the desired lifting for the functor $s_q^\Sigma : \mathcal{H}^\Sigma(S) \rightarrow \mathcal{H}^\Sigma(S)$ (see corollary 3.3.5(3)) to the model category level.
Lemma 3.3.65. Fix $q \in \mathbb{Z}$.

1. Let $X$ be an arbitrary $T$-spectrum in $R_{C_{eff}}^q Spt_T M_*$. Then the following maps in $S^q Spt_T^\Sigma M_*$

\[ VP_q(C_q X) \xrightarrow{V(P_q X)} VC_q X \xleftarrow{C_q^\Sigma V C_q X} C_q^\Sigma (VC_q X) \]

induce natural isomorphisms between the functors:

\[ C_q^\Sigma \circ VC_q, VC_q \circ VP_q, C_q : R_{C_{eff}}^q \mathcal{H}(S) \to S^q \mathcal{H}^\Sigma(S) \]

Given a $T$-spectrum $X$

\[ \sigma_X : VP_q(C_q X) \xrightarrow{\cong} C_q^\Sigma (VC_q X) \]

will denote the isomorphism in $S^q \mathcal{H}^\Sigma(S)$ corresponding to the natural isomorphism between $VP_q \circ C_q$ and $C_q^\Sigma \circ VC_q$.

2. Let $X$ be an arbitrary symmetric $T$-spectrum in $S^q Spt_T^\Sigma M_*$. Then the following maps in $R_{C_{eff}}^q Spt_T M_*$

\[ W_{q+1}(UW_{q+1}^\Sigma X) \xleftarrow{U W_{q+1}^{\Sigma, x}} UW_{q+1}^\Sigma X \xrightarrow{U(R_{\Sigma, q+1}^x)} UR_{\Sigma}(W_{q+1}^\Sigma X) \]

induce natural isomorphisms between the functors:

\[ W_{q+1} \circ UW_{q+1}^\Sigma, UW_{q+1}^\Sigma, UR_{\Sigma} \circ W_{q+1}^\Sigma : S^q \mathcal{H}^\Sigma(S) \to R_{C_{eff}}^q \mathcal{H}(S) \]
Given a symmetric \( T \)-spectrum \( X \)

\[ \tau_X : W_{q+1}(UW^\Sigma_{q+1}X) \xrightarrow{\cong} UR_\Sigma(W^\Sigma_{q+1}X) \]

will denote the isomorphism in \( R_{C_q}^\Sigma SH(S) \) corresponding to the natural isomorphism between \( W_{q+1} \circ UW^\Sigma_{q+1} \) and \( UR_\Sigma \circ W^\Sigma_{q+1} \).

**Proof.** (1): Follows immediately from theorem 1.3.7 in [10] and the following commutative diagram of left Quillen functors:

\[
\begin{array}{ccc}
R_{C_q}^\Sigma \mathbf{Spt}_T M_* & \xrightarrow{V} & R_{C_q}^\Sigma \mathbf{Spt}_T^\Sigma M_* \\
\downarrow{id} & & \downarrow{id} \\
S^q \mathbf{Spt}_T M_* & \xrightarrow{V} & S^q \mathbf{Spt}_T^\Sigma M_*
\end{array}
\]

(2): Follows immediately from the dual of theorem 1.3.7 in [10] and the following commutative diagram of right Quillen functors:

\[
\begin{array}{ccc}
R_{C_q}^\Sigma \mathbf{Spt}_T M_* & \xleftarrow{U} & R_{C_q}^\Sigma \mathbf{Spt}_T^\Sigma M_* \\
\downarrow{id} & & \downarrow{id} \\
S^q \mathbf{Spt}_T M_* & \xleftarrow{U} & S^q \mathbf{Spt}_T^\Sigma M_*
\end{array}
\]

\[ \square \]

**Lemma 3.3.66.** Fix \( q \in \mathbb{Z} \). Let \( X \) be an arbitrary \( T \)-spectrum, and let \( \eta \) be the unit of the adjunction (see corollary 3.3.64):

\[ (VP_q, UW_{q+1}^\Sigma, \varphi) : S^qSH(S) \longrightarrow S^qSH^\Sigma(S) \]
Then we have the following diagram in $R_{eff}^{\sigmaq} \mathcal{SH}(S)$ (see lemma 3.3.65):

\[
\begin{array}{ccc}
W_{q+1}UW^{\Sigma}_{q+1}VP_qC_qX & \xrightarrow{W_{q+1}UW^{\Sigma}_{q+1}(\sigma X)} & W_{q+1}UW^{\Sigma}_{q+1}C_q^{\Sigma}VC_qX \\
W_{q+1}(\eta_{C_qX}) \cong & & \cong \tau_{C_q^{\Sigma}VC_qX} \\
W_{q+1}C_qX & \cong & UR^{\Sigma}W^{\Sigma}_{q+1}C_q^{\Sigma}VC_qX \\
\end{array}
\]

where all the maps are isomorphisms in $R_{eff}^{\sigmaq} \mathcal{SH}(S)$. This diagram induces a natural isomorphism between the following exact functors:

\[
\begin{array}{ccc}
R_{eff}^{\sigmaq} \mathcal{SH}(S) & \xrightarrow{W_{q+1}C_q} & R_{eff}^{\sigmaq} \mathcal{SH}(S) \\
UR^{\Sigma}W^{\Sigma}_{q+1}C_q^{\Sigma}VC_q & \cong & \cong \\
\end{array}
\]

**Proof.** Follows immediately from lemma 3.3.65 and corollary 3.3.64. \qed

**Theorem 3.3.67.** Fix $q \in \mathbb{Z}$, and let $X$ be an arbitrary symmetric $T$-spectrum.

1. The diagram (3.23) in theorem 3.2.80 induces the following diagram in $\mathcal{SH}^{\Sigma}(S)$:

\[
\begin{array}{ccc}
\tilde{s}_qX = VQ_s(s_qUR^{\Sigma}X) & \cong & VQ_s(IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(C_q IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) & \cong & VQ_s(C_q W^{\Sigma}_{q+1}C_q IQ_T J_{s_q}UR^{\Sigma}X) \\
\end{array}
\]  

(3.39)
where all the maps are isomorphisms in $\mathcal{SH}^\Sigma(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$\begin{align*}
\mathcal{SH}^\Sigma(S) & \xrightarrow{\tilde{s}_q} \mathcal{SH}^\Sigma(S) \\
\xrightarrow{VQ\circ C_q W_{q+1} C_q I Q T J \circ U R \Sigma} & \\
\end{align*}$$

2. Let $\epsilon$ denote the counit of the adjunction (see corollary 3.3.20):

$$(V C_q, U R \Sigma, \varphi) : R_{C_{eff}} \mathcal{SH}(S) \xrightarrow{\epsilon} R_{C_{eff}} \mathcal{SH}^\Sigma(S)$$

and let $\delta$ denote the natural isomorphism constructed in lemma 3.3.66. Then we have the following diagram in $\mathcal{SH}^\Sigma(S)$ (see lemmas 3.3.66 and 3.3.21):

$$\begin{align*}
C_q^\Sigma & W_{q+1}^\Sigma C_q^\Sigma R \Sigma X = s_q^\Sigma X \\
C_q^\Sigma \epsilon_{q+1}^\Sigma C_q^\Sigma R \Sigma X & \cong \\
C_q^\Sigma & (V C_q U R \Sigma W_{q+1}^\Sigma C_q^\Sigma R \Sigma X) \\
C_q^\Sigma V C_q U R \Sigma W_{q+1}^\Sigma C_q^\Sigma \epsilon_{q+1}^\Sigma R \Sigma X & \cong \\
C_q^\Sigma & V C_q U R \Sigma W_{q+1}^\Sigma C_q^\Sigma (V C_q U R \Sigma R \Sigma X) \\
C_q^\Sigma V C_q & (W_{q+1}^\Sigma + C_q) U R \Sigma R \Sigma X \\
C_q^\Sigma V C_q W_{q+1}^\Sigma C_q \beta_X & \cong \\
C_q^\Sigma V C_q W_{q+1}^\Sigma C_q (I Q T J U R \Sigma X) \\
\alpha W_{q+1}^\Sigma C_q I Q T \Sigma & \cong \\
V Q s C_q (W_{q+1}^\Sigma + C_q I Q T J U R \Sigma X) & \cong \\
\end{align*}$$

where all the maps are isomorphisms in $\mathcal{SH}^\Sigma(S)$. This diagram induces a natural isomorphism between the following exact functors:

$$\begin{align*}
\mathcal{SH}^\Sigma(S) & \xrightarrow{VQ\circ C_q W_{q+1} C_q I Q T J \circ U R \Sigma} \mathcal{SH}^\Sigma(S) \\
\xrightarrow{C_q^\Sigma W_{q+1}^\Sigma C_q^\Sigma R \Sigma = s_q^\Sigma} & \\
\end{align*}$$

3. Combining the diagrams (3.39) and (3.40) above we get a natural isomorphism between the following exact functors:

$$\begin{align*}
\mathcal{SH}^\Sigma(S) & \xrightarrow{\tilde{s}_q} \mathcal{SH}^\Sigma(S) \\
\xrightarrow{s_q^\Sigma} & \\
\end{align*}$$
Proof. It is clear that it suffices to prove only the first two claims.

(1): Follows immediately from theorems 3.2.80 and 3.3.4.

(2): Follows immediately from lemmas 3.3.21 and 3.3.66 together with corollary 3.3.20.

Proposition 3.3.68. Fix \( q \in \mathbb{Z} \). Let \( \eta \) denote the unit of the adjunction \((C^\Sigma_q, W^\Sigma_{q+1}, \varphi) : R_{C_{eff}} \mathcal{H}^\Sigma(S) \to S^q \mathcal{H}^\Sigma(S)\) constructed in corollary 3.3.61. Then the natural transformation \( \pi_q : f_q \to s_q \) (see theorem 3.1.16) gets canonically identified, through the equivalence of categories \( r_q C_q, IQ_T J_i q, VC_q \) and \( UR_\Sigma \) constructed in proposition 3.2.21 and corollary 3.3.20; with the following map \( \pi^\Sigma_q : f^\Sigma_q \to s^\Sigma_q \) in \( \mathcal{H}^\Sigma(S) \):

\[
C^\Sigma_q R_\Sigma X \xrightarrow{C^\Sigma_q(\eta_{R_\Sigma X})} C^\Sigma_q W^\Sigma_{q+1} C^\Sigma_q R_\Sigma X
\]

Proof. The result follows easily from proposition 3.2.81, corollaries 3.3.20, 3.3.64 and theorem 3.3.67.

The functor \( s^\Sigma_q \) gives the desired lifting for the functor \( \tilde{s}_q \) to the model category level, and it will be the main ingredient for the study of the multiplicative properties of Voevodsky’s slice filtration. This completes the program that we started at the beginning of this section.

3.4 Multiplicative Properties of the Slice Filtration

Our goal in this section is to show that the smash product of spectra is compatible in a suitable sense with the slice filtration. To establish this compatibility in a formal way, we will use the model structures constructed in section 3.3.

Lemma 3.4.1. Fix \( p, q \in \mathbb{Z} \), and let \( A \) be a symmetric \( T \)-spectrum.

1. If \( A \) is cofibrant in \( R_{C_{eff}} \operatorname{Spt}^\Sigma_T M_* \), then the functor \( \operatorname{Hom}_{\operatorname{Spt}^\Sigma_T}(A, -) \) maps fibrations in \( R_{C_{eff}} \operatorname{Spt}^\Sigma_T M_* \) to fibrations in \( R_{C_{eff}} \operatorname{Spt}^\Sigma_T M_* \).

2. If \( A \) is cofibrant in \( \operatorname{Spt}^\Sigma_T M_* \), then the functor \( \operatorname{Hom}_{\operatorname{Spt}^\Sigma_T}(A, -) \) maps fibrations in \( R_{C_{eff}} \operatorname{Spt}^\Sigma_T M_* \) to fibrations in \( R_{C_{eff}} \operatorname{Spt}^\Sigma_T M_* \).
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**Proof.** Since $R_{C_{eff}^p} \text{Spt}^\Sigma_{T_*} M_*$, $R_{C_{eff}^q} \text{Spt}^\Sigma_{T_*} M_*$ and $R_{C_{eff}^p+q} \text{Spt}^\Sigma_{T_*} M_*$ are all right Bousfield localizations of $\text{Spt}^\Sigma_{T_*} M_*$, we have that the fibrations in all these model structures coincide and also the identity functor

$$id : R_{C_{eff}^p} \text{Spt}^\Sigma_{T_*} M_* \longrightarrow \text{Spt}^\Sigma_{T_*} M_*$$

is a left Quillen functor. Therefore if $A$ is cofibrant in $R_{C_{eff}^p} \text{Spt}^\Sigma_{T_*} M_*$, then $A$ is also cofibrant in $\text{Spt}^\Sigma_{T_*} M_*$. Hence it suffices to prove (2).

So assume that $A$ is cofibrant in $\text{Spt}^\Sigma_{T_*} M_*$, and let $f : X \longrightarrow Y$ be an arbitrary fibration in $R_{C_{eff}^p+q} \text{Spt}^\Sigma_{T_*} M_*$. Then using corollary 2.6.28 together with the fact that $A$ is cofibrant in $\text{Spt}^\Sigma_{T_*} M_*$, we get that

$$\text{Hom}_{\text{Spt}^\Sigma_{T_*}}(A, X) \longrightarrow \text{Hom}_{\text{Spt}^\Sigma_{T_*}}(A, Y)$$

is a fibration in $\text{Spt}^\Sigma_{T_*} M_*$, or equivalently a fibration in $R_{C_{eff}^q} \text{Spt}^\Sigma_{T_*} M_*$.

**Lemma 3.4.2.** Fix $p, q \in \mathbb{Z}$, and let $A = \Sigma^j_n (S^r \wedge G^l_m \wedge U_+)$ be an arbitrary element in $S^\Sigma(p)$, i.e. $s - n = p$. Assume that $F$ is a symmetric $T$-spectrum such that the map $F \rightarrow *$ is a trivial fibration in $R_{C_{eff}^p+q} \text{Spt}^\Sigma_{T_*} M_*$. Then $\pi : \text{Hom}_{\text{Spt}^\Sigma_{T_*}}(A, F) \rightarrow *$ is a trivial fibration in $R_{C_{eff}^q} \text{Spt}^\Sigma_{T_*} M_*$.

**Proof.** Since $A$ is cofibrant in $\text{Spt}^\Sigma_{T_*} M_*$, it follows directly from lemma 3.4.1 that $\pi$ is a fibration in $R_{C_{eff}^q} \text{Spt}^\Sigma_{T_*} M_*$. Thus, it only remains to show that $\pi$ is a weak equivalence in $R_{C_{eff}^q} \text{Spt}^\Sigma_{T_*} M_*$.

Fix $F^\Sigma_j (S^k \wedge G^l_m \wedge V_+) \in C^\Sigma_{eff}$. By construction $R_{C_{eff}^p+q} \text{Spt}^\Sigma_{T_*} M_*$ is a right Bousfield localization of $\text{Spt}^\Sigma_{T_*} M_*$, therefore $F$ is also fibrant in $\text{Spt}^\Sigma_{T_*} M_*$. Since $A$ is cofibrant and $F$ is fibrant in $\text{Spt}^\Sigma_{T_*} M_*$, corollary 2.6.28 implies that we have the following natural isomorphism of abelian groups:

$$[F^\Sigma_j (S^k \wedge G^l_m \wedge V_+), \text{Hom}_{\text{Spt}^\Sigma_{T_*}}(A, F)]^\Sigma \cong [F^\Sigma_j (S^k \wedge G^l_m \wedge V_+) \wedge A, F]_\text{Spt}^\Sigma$$

and proposition 2.6.13 implies that:

$$F^\Sigma_j (S^k \wedge G^l_m \wedge V_+) \wedge A = F^\Sigma_j (S^k \wedge G^l_m \wedge V_+) \wedge F^\Sigma_n (S^r \wedge G^s_m \wedge U_+)$$

$$\cong F^\Sigma_{j+n} (S^{k+r} \wedge G^{l+s}_m \wedge U \times V_+)$$
But clearly $F^{\Sigma}_{j+n}(S^{k+r} \land G_{m}^{l+s} \land U \times S V_+) \in C_{eff}^{q, \Sigma}$, and since $F \to \ast$ is a weak equivalence in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$, we have by proposition 3.3.13:

$0 \cong [F^{\Sigma}_{j+n}(S^{k+r} \land G_{m}^{l+s} \land U \times S V_+), F]_{Spt}^{\Sigma}$

$\cong [F^{\Sigma}(S^{k} \land G_{m}^{l} \land V_+), Hom_{Spt_{T}^{\Sigma}}(A, F)]_{Spt}^{\Sigma}$

Finally, using proposition 3.3.13 again, we get that $\pi$ is a weak equivalence in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$ as we wanted.

\[\square\]

**Lemma 3.4.3.** Fix $p, q \in \mathbb{Z}$, and let $A$ be cofibrant symmetric $T$-spectrum in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$.

Assume that $F$ is a symmetric $T$-spectrum such that the map $F \to \ast$ is a trivial fibration in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$. Then $\pi : Hom_{Spt_{T}^{\Sigma}}(A, F) \to \ast$ is a trivial fibration in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$.

**Proof.** Since $A$ is cofibrant in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$, it follows from lemma 3.4.1(1) that $\pi$ is a fibration in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$. Thus, it only remains to show that $\pi$ is a weak equivalence in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$.

Fix $F^{\Sigma}_{n}(S^{r} \land G_{m}^{s} \land U_+) \in C_{eff}^{q, \Sigma}$. Then lemma 3.4.2 implies that

$$\text{Hom}_{Spt_{T}^{\Sigma}}(F^{\Sigma}_{n}(S^{r} \land G_{m}^{s} \land U_+), F) \to \ast$$

is a trivial fibration in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$. Now, since $A$ is cofibrant in $R_{C_{eff}^{q, \Sigma}} Spt_{T} \Sigma_{*}$ which is in particular a simplicial model category, we have that the induced map:

$$Map_{\Sigma}(A, Hom_{Spt_{T}^{\Sigma}}(F^{\Sigma}_{n}(S^{r} \land G_{m}^{s} \land U_+), F)) \to Map_{\Sigma}(A, \ast) = \ast$$

is a trivial fibration of simplicial sets. Finally using the enriched adjunctions of proposition 2.6.12, this last map gets canonically identified with

$$Map_{\Sigma}(F^{\Sigma}_{n}(S^{r} \land G_{m}^{s} \land U_+), Hom_{Spt_{T}^{\Sigma}}(A, F))$$

$$\downarrow$$

$$Map_{\Sigma}(F^{\Sigma}_{n}(S^{r} \land G_{m}^{s} \land U_+, \ast) = \ast$$
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Since $\text{Hom}_{\text{Spt}^T} \Sigma^T_*(A, F)$ is in particular fibrant in $\text{Spt}^T_\Sigma M_*$, by definition we have that $\pi$ is a $C^T_{eff}$-colocal equivalence in $\text{Spt}^T_\Sigma M_*$, i.e. a weak equivalence in $R^T_{eff} \text{Spt}^T_\Sigma M_*$. This finishes the proof.

Theorem 3.4.4. Fix $p, q \in \mathbb{Z}$. Then the smash product of symmetric $T$-spectra

$$- \wedge -: R^p_{eff} \text{Spt}^T_\Sigma M_* \times R^q_{eff} \text{Spt}^T_\Sigma M_* \longrightarrow R^{p+q}_{eff} \text{Spt}^T_\Sigma M_*$$

is a Quillen bifunctor in the sense of Hovey (see definition 1.7.4).

Proof. By lemma 1.7.5, it is enough to prove the following claim:

Given a cofibration $i: A \rightarrow B$ in $R^p_{eff} \text{Spt}^T_\Sigma M_*$ and a fibration $f: X \rightarrow Y$ in $R^{p+q}_{eff} \text{Spt}^T_\Sigma M_*$, the induced map

$$(i^*, f_*) : \text{Hom}_{\text{Spt}^T_\Sigma}(B, X) \longrightarrow \text{Hom}_{\text{Spt}^T_\Sigma}(A, X) \times \text{Hom}_{\text{Spt}^T_\Sigma}(A, Y) \times \text{Hom}_{\text{Spt}^T_\Sigma}(B, Y)$$

is a fibration in $R^q_{eff} \text{Spt}^T_\Sigma M_*$ which is trivial if either $i$ or $f$ is a weak equivalence.

Since $R^p_{eff} \text{Spt}^T_\Sigma M_*$, $R^q_{eff} \text{Spt}^T_\Sigma M_*$ and $R^{p+q}_{eff} \text{Spt}^T_\Sigma M_*$ are all right Bousfield localizations of $\text{Spt}^T_\Sigma M_*$, we have that the fibrations in all these model structures coincide and also the identity functor

$$id : R^p_{eff} \text{Spt}^T_\Sigma M_* \longrightarrow \text{Spt}^T_\Sigma M_* \quad (3.41)$$

is a left Quillen functor. Hence it follows that $i$ is cofibration in $\text{Spt}^T_\Sigma M_*$ and $f$ is fibration in $\text{Spt}^T_\Sigma M_*$. Then proposition 2.6.27 implies that $(i^*, f_*)$ is a fibration in $\text{Spt}^T_\Sigma M_*$, or equivalently a fibration in $R^q_{eff} \text{Spt}^T_\Sigma M_*$.

Now assume that $i$ is a trivial cofibration in $R^p_{eff} \text{Spt}^T_\Sigma M_*$. Since the identity functor considered in (3.41) above is a left Quillen functor, we have that $i$ is also a trivial cofibration in $\text{Spt}^T_\Sigma M_*$. Hence using proposition 2.6.27 again, we have that $(i^*, f_*)$ is in particular a weak equivalence in $\text{Spt}^T_\Sigma M_*$. Then [7, proposition 3.1.5] implies that $(i^*, f_*)$ is also a weak equivalence in $R^q_{eff} \text{Spt}^T_\Sigma M_*$. 

Finally, assume that \( f \) is a trivial fibration in \( R_{C_{eff}^p}^{\Sigma} \text{Spt}_T \mathcal{M}_* \). Consider the following commutative diagrams

\[
\begin{array}{ccc}
F & \xrightarrow{\kappa} & * \\
\downarrow & & \downarrow \\
X & \xrightarrow{f} & Y \\
\end{array}
\quad
\begin{array}{ccc}
A & \xrightarrow{i} & B \\
\downarrow & & \downarrow \\
* & \xrightarrow{\iota} & B/A \\
\end{array}
\]

where the diagram on the left is a pullback in \( R_{C_{eff}^p}^{\Sigma} \text{Spt}_T \mathcal{M}_* \) and the diagram on the right is a pushout in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \). We already know that the map \((i^*, f_*)\) is a fibration in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \), therefore it is clear that \( \text{Hom}_{\text{Spt}_T^\Sigma}(B/A, F) \) is the homotopy fibre of \((i^*, f_*)\) in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \). On the other hand, it is clear that \( \kappa \) is a trivial fibration in \( R_{C_{eff}^p}^{\Sigma} \text{Spt}_T \mathcal{M}_* \) and \( \iota \) is a cofibration in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \).

By corollary 3.3.17 we have that the homotopy category associated to \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \) is triangulated, hence to check that \((i^*, f_*)\) is a weak equivalence in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \) it is enough to show that the map

\[
\pi : \text{Hom}_{\text{Spt}_T^\Sigma}(B/A, F) \to *
\]

is a weak equivalence in \( R_{C_{eff}^q}^{\Sigma} \text{Spt}_T \mathcal{M}_* \). But this follows immediately from lemma 3.4.3.

**Lemma 3.4.5.** Fix \( p, q, r \in \mathbb{Z} \). Let \( i : A \to B \) be a cofibration in \( L_{<p} \text{Spt}_T^\Sigma \mathcal{M}_* \), and let \( j : C \to D \) be a cofibration in \( L_{<q} \text{Spt}_T^\Sigma \mathcal{M}_* \). Then

\[
B \wedge C \coprod_{A \wedge C} A \wedge D \xrightarrow{i \Box j} B \wedge D
\]

is a cofibration in \( L_{<r} \text{Spt}_T^\Sigma \mathcal{M}_* \).

**Proof.** Since \( L_{<p} \text{Spt}_T^\Sigma \mathcal{M}_* \), \( L_{<q} \text{Spt}_T^\Sigma \mathcal{M}_* \), and \( L_{<r} \text{Spt}_T^\Sigma \mathcal{M}_* \) are all left Bousfield localizations of \( \text{Spt}_T^\Sigma \mathcal{M}_* \), we have that the cofibrations in these four model categories coincide.

Then the result follows immediately from proposition 2.6.27.

**Lemma 3.4.6.** Fix \( p, q \in \mathbb{Z} \). Let \( A = F_0^\Sigma(S^r \wedge G_m^s \wedge U_+) \) be an arbitrary element in \( S^\Sigma(p) \), i.e. \( s - n = p \), and let \( Z \) be an arbitrary \( L^\Sigma(<p+q)\)-local symmetric \( T \)-spectrum in \( \text{Spt}_T^\Sigma \mathcal{M}_* \). Then \( \text{Hom}_{\text{Spt}_T^\Sigma}(A, Z) \) is a \( L^\Sigma(<q)\)-local symmetric \( T \)-spectrum in \( \text{Spt}_T^\Sigma \mathcal{M}_* \).
3.4. Multiplicative Properties of the Slice Filtration

Proof. By proposition 3.3.29 it is enough to check that the following two conditions hold:

1. $\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)$ is fibrant in $\text{Spt}^\Sigma_T M_*$.

2. For every $F^\Sigma_j(S^k \wedge G^l_m \wedge V_+) \in C_{eff}^{q,\Sigma}$

$$[F^\Sigma_j(S^k \wedge G^l_m \wedge V_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]_{Spt}^\Sigma \cong 0$$

Since $Z$ is $L^\Sigma(< p + q)$-local in $\text{Spt}^\Sigma_T M_*$, we have that $Z$ is in particular fibrant in $\text{Spt}^\Sigma_T M_*$. Now corollary 2.6.28 together with the fact that $A$ is cofibrant in $\text{Spt}^\Sigma_T M_*$ imply that $\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)$ is fibrant in $\text{Spt}^\Sigma_T M_*$. This takes care of the first condition.

Fix $F^\Sigma_j(S^k \wedge G^l_m \wedge V_+) \in C_{eff}^{q,\Sigma}$. Since $A$ is cofibrant and $Z$ is fibrant in $\text{Spt}^\Sigma_T M_*$, it follows from corollary 2.6.28 that we have the following natural isomorphism of abelian groups:

$$[F^\Sigma_j(S^k \wedge G^l_m \wedge V_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]_{Spt}^\Sigma \cong [F^\Sigma_j(S^k \wedge G^l_m \wedge V_+) \wedge A, Z]_{Spt}^\Sigma$$

Using proposition 2.6.13 we have the following isomorphisms of symmetric $T$-spectra:

$$F^\Sigma_j(S^k \wedge G^l_m \wedge V_) \wedge A = F^\Sigma_j(S^k \wedge G^l_m \wedge V_+) \wedge F^\Sigma_n(S^r \wedge G^s_m \wedge U_+)$$

$$= F^\Sigma_{j+n}(S^{k+r} \wedge G^{l+s}_m \wedge U \wedge V_+)$$

But clearly $F^\Sigma_{j+n}(S^{k+r} \wedge G^{l+s}_m \wedge U \wedge V_+) \in C_{eff}^{p+q,\Sigma}$. Since $Z$ is a $L^\Sigma(< p + q)$-local in $\text{Spt}^\Sigma_T M_*$, proposition 3.3.29 implies:

$$0 \cong [F^\Sigma_{j+n}(S^{k+r} \wedge G^{l+s}_m \wedge U \wedge V_+), Z]_{Spt}^\Sigma$$

$$\cong [F^\Sigma_j(S^k \wedge G^l_m \wedge V_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]_{Spt}^\Sigma$$

This finishes the proof. 

Lemma 3.4.7. Fix $p, q \in \mathbb{Z}$. Let $A$ be a symmetric $T$-spectrum such that the map $* \to A$ is a trivial cofibration in $L_{< p} \text{Spt}^\Sigma_T M_*$, and let $Z$ be an arbitrary $L^\Sigma(< p + q)$-local symmetric $T$-spectrum in $\text{Spt}^\Sigma_T M_*$. Then $\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)$ is a $L^\Sigma(< q)$-local symmetric $T$-spectrum in $\text{Spt}^\Sigma_T M_*$. 

Proof. By proposition 3.3.29 it is enough to check that the following two conditions hold:
1. \( \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z) \) is fibrant in \( \text{Spt}^\Sigma_T M_* \).

2. For every \( F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^{q, \Sigma} \)

\[
[F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}} \cong 0
\]

Since \( Z \) is \( L^{(p+q)} \)-local in \( \text{Spt}^\Sigma_T M_* \), we have that \( Z \) is in particular fibrant in \( \text{Spt}^\Sigma_T M_* \).

By construction \( L^{<p} \text{Spt}^\Sigma_T M_* \) is a left Bousfield localization of \( \text{Spt}^\Sigma_T M_* \), then it follows that \( A \) is cofibrant in \( \text{Spt}^\Sigma_T M_* \). Therefore, corollary 2.6.28 implies that \( \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z) \) is fibrant in \( \text{Spt}^\Sigma_T M_* \). This takes care of the first condition.

Fix \( F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^{q, \Sigma} \). By lemma 3.4.6 we have that the induced map

\[
\text{Hom}_{\text{Spt}^\Sigma_T}(F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), Z) \longrightarrow *
\]

is a fibration in \( L^{<p} \text{Spt}^\Sigma_T M_* \). Since \( L^{<p} \text{Spt}^\Sigma_T M_* \) is a simplicial model category and \( * \to A \) is a trivial cofibration in \( L^{<p} \text{Spt}^\Sigma_T M_* \), it follows that the following map is a trivial fibration of simplicial sets:

\[
\text{Map}_\Sigma(A, \text{Hom}_{\text{Spt}^\Sigma_T}(F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), Z)) \longrightarrow \text{Map}_\Sigma(A, *) = *
\]

Finally using the enriched adjunctions of proposition 2.6.12, the map above becomes:

\[
\text{Map}_\Sigma(F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z))
\]

\[
\downarrow
\]

\[
\text{Map}_\Sigma(F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), *) = *
\]

which is in particular a weak equivalence of simplicial sets. We already know that

\[
\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)
\]

is fibrant in \( \text{Spt}^\Sigma_T M_* \), and we have that \( F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \) is cofibrant in \( \text{Spt}^\Sigma_T M_* \). Since \( \text{Spt}^\Sigma_T M_* \) is a simplicial model category, we have that

\[
0 \cong \pi_0 \text{Map}_\Sigma(F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z))
\]

\[
\cong [F^\Sigma_n(S^r \wedge G^s_m \wedge U_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}}
\]

for every \( F^\Sigma_n(S^r \wedge G^s_m \wedge U_+) \in C_{eff}^{q, \Sigma} \). This finishes the proof. \( \square \)
Lemma 3.4.8. Fix $p, q \in \mathbb{Z}$, and let $A = F^\Sigma_n (S^r \wedge G^m \wedge U_+)$ be an arbitrary element in $S^\Sigma(p)$, i.e. $s - n = p$. Assume that $C$ is a symmetric $T$-spectrum such that the map $\ast \to C$ is a trivial cofibration in $L_{<q} \text{Spt}^\Sigma_T M_\ast$. Then $\iota : \ast \to C \wedge A$ is a trivial cofibration in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$.

Proof. Since $A$ is cofibrant in $\text{Spt}^\Sigma_T M_\ast$ and $L_{<p} \text{Spt}^\Sigma_T M_\ast$ is a left Bousfield localization of $\text{Spt}^\Sigma_T M_\ast$, we have that $A$ is also cofibrant in $L_{<p} \text{Spt}^\Sigma_T M_\ast$. Then it follows directly from lemma 3.4.5 that $\iota$ is a cofibration in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$. Thus, it only remains to show that $\iota$ is a weak equivalence in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$.

Let $Z$ be an arbitrary $L^\Sigma(< p + q)$-local $T$-spectrum in $\text{Spt}^\Sigma_T M_\ast$. Then by lemma 3.4.6, we have that $\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)$ is $L^\Sigma(< q)$-local in $\text{Spt}^\Sigma_T M_\ast$. Now corollary 3.3.32 implies that

$$[C, \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}} \cong 0$$

But $A, C$ are cofibrant in $\text{Spt}^\Sigma_T M_\ast$ and $Z$ is in particular fibrant in $\text{Spt}^\Sigma_T M_\ast$, then using corollary 2.6.28 we get the following isomorphism:

$$[C \wedge A, Z]^\Sigma_{\text{Spt}} \cong [C, \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}} \cong 0$$

Hence the induced map

$$0 \cong [C \wedge A, Z]^\Sigma_{\text{Spt}} \xrightarrow{\iota^\ast} [\ast, Z]^\Sigma_{\text{Spt}} \cong 0$$

is an isomorphism for every $L^\Sigma(< p + q)$-local $T$-spectrum $Z$. Thus, using corollary 3.3.32 again, we have that $\iota$ is a $L^\Sigma(< p + q)$-local equivalence. This finishes the proof. \qed

Lemma 3.4.9. Fix $p, q \in \mathbb{Z}$. Assume that $A, C$ are symmetric $T$-spectra such that $\ast \to A$ is a trivial cofibration in $L_{<p} \text{Spt}^\Sigma_T M_\ast$, and $\ast \to C$ is a trivial cofibration in $L_{<q} \text{Spt}^\Sigma_T M_\ast$. Then $\iota : \ast \to C \wedge A$ is a trivial cofibration in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$.

Proof. Since $A$ is in particular cofibrant in $L_{<p} \text{Spt}^\Sigma_T M_\ast$, it follows directly from lemma 3.4.5 that $\iota$ is a cofibration in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$. Thus, it only remains to show that $\iota$ is a weak equivalence in $L_{<p+q} \text{Spt}^\Sigma_T M_\ast$. 


Let $Z$ be an arbitrary $L^\Sigma(< p + q)$-local $T$-spectrum in $\text{Spt}^\Sigma_T \mathbb{M}_*$. Then by lemma 3.4.7, we have that $\text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)$ is $L^\Sigma(< q)$-local in $\text{Spt}^\Sigma_T \mathbb{M}_*$. Now corollary 3.3.32 implies that

$$[C, \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}} \cong 0$$

But $A, C$ are in particular cofibrant in $\text{Spt}^\Sigma_T \mathbb{M}_*$, and $Z$ is in particular fibrant in $\text{Spt}^\Sigma_T \mathbb{M}_*$, then using corollary 2.6.28 we get the following isomorphism:

$$[C \land A, Z]_{\text{Spt}}^\Sigma \cong [C, \text{Hom}_{\text{Spt}^\Sigma_T}(A, Z)]^\Sigma_{\text{Spt}} \cong 0$$

Hence the induced map

$$0 \cong [C \land A, Z]_{\text{Spt}}^\Sigma \xrightarrow{\iota^*} [*]_{\text{Spt}}^\Sigma$$

is an isomorphism for every $L^\Sigma(< p + q)$-local $T$-spectrum $Z$. Thus, using corollary 3.3.32 again, we have that $\iota$ is a $L^\Sigma(< p + q)$-local equivalence. This finishes the proof.

**Lemma 3.4.10.** Fix $p, q \in \mathbb{Z}$, and let $A = F^\Sigma_n(S^r \land \mathbb{G}_m^s \land U_+)$ be an arbitrary element in $S^\Sigma(p)$, i.e. $s - n = p$. Assume that $F$ is a symmetric $T$-spectrum such that the map $F \to *$ is a trivial fibration in $S^{p + q}\text{Spt}^\Sigma_T \mathbb{M}_*$. Then $\pi : \text{Hom}_{\text{Spt}^\Sigma_T}(A, F) \to *$ is a trivial fibration in $\text{Spt}^\Sigma_T \mathbb{M}_*$.

**Proof.** $F$ is fibrant in $L^{<p+q+1}\text{Spt}^\Sigma_T \mathbb{M}_*$, since by construction $S^{p+q}\text{Spt}^\Sigma_T \mathbb{M}_*$ is a right Bousfield localization of $L^{<p+q+1}\text{Spt}^\Sigma_T \mathbb{M}_*$. Applying lemma 3.4.6, we get that

$$\text{Hom}_{\text{Spt}^\Sigma_T}(A, F)$$

is fibrant in $L^{<q+1}\text{Spt}^\Sigma_T \mathbb{M}_*$; and since $S^q\text{Spt}^\Sigma_T \mathbb{M}_*$ is a right Bousfield localization of

$$L^{<q+1}\text{Spt}^\Sigma_T \mathbb{M}_*$$

it follows that $\text{Hom}_{\text{Spt}^\Sigma_T}(A, F)$ is fibrant in $S^q\text{Spt}^\Sigma_T \mathbb{M}_*$.

By proposition 3.3.53 it only remains to check that for every $F^\Sigma_j(S^k \land \mathbb{G}_m^l \land V_+) \in S^\Sigma(q)$, i.e. $l - j = q$,

$$[F^\Sigma_j(S^k \land \mathbb{G}_m^l \land V_+), \text{Hom}_{\text{Spt}^\Sigma_T}(A, F)]_{\text{Spt}}^\Sigma \cong 0$$
3.4. Multiplicative Properties of the Slice Filtration

Since $A$ is cofibrant in $\text{Spt}^\Sigma T M_*$ and $F$ is in particular fibrant in $\text{Spt}^\Sigma T M_*$, corollary 2.6.28 implies that we have the following natural isomorphism of abelian groups:

$$[F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+), \text{Hom}_{\text{Spt}}(A, F)]_{\text{Spt}}^\Sigma \cong [F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+ \wedge A, F)]_{\text{Spt}}^\Sigma$$

But using proposition 2.6.13 we get:

$$F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+ \wedge A) = F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+) \wedge F^\Sigma_n(S^r \wedge \mathbb{G}_m^s \wedge U_+)$$

$$\cong F^\Sigma_{j+n}(S^{k+r} \wedge \mathbb{G}_m^{l+s} \wedge U \times_S V_+)$$

and it is clear that $F^\Sigma_{j+n}(S^{k+r} \wedge \mathbb{G}_m^{l+s} \wedge U \times_S V_+) \in S^\Sigma(p + q)$.

Finally, since $F \rightarrow \ast$ is a trivial fibration in $S^{p+q} \text{Spt}^\Sigma T M_*$, using proposition 3.3.53 we get that for every $F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+) \in S^\Sigma(q)$:

$$0 \cong [F^\Sigma_{j+n}(S^{k+r} \wedge \mathbb{G}_m^{l+s} \wedge U \times_S V_+), F]_{\text{Spt}}^\Sigma$$

$$\cong [F^\Sigma_j(S^k \wedge \mathbb{G}_m^l \wedge V_+), \text{Hom}_{\text{Spt}}(A, F)]_{\text{Spt}}^\Sigma$$

as we wanted.

\[\square\]

**Lemma 3.4.11.** Fix $p, q \in \mathbb{Z}$. Assume that $A$ is a cofibrant symmetric $T$-spectrum in $S^{p+q} \text{Spt}^\Sigma T M_*$, and $F$ is a symmetric $T$-spectrum such that the map $F \rightarrow \ast$ is a trivial fibration in $S^{p+q} \text{Spt}^\Sigma T M_*$. Then $\pi : \text{Hom}_{\text{Spt}}(A, F) \rightarrow \ast$ is a trivial fibration in $S^q \text{Spt}^\Sigma T M_*$.

**Proof.** $F$ is fibrant in $L_{<p+q+1} \text{Spt}^\Sigma T M_*$, since by construction $S^{p+q} \text{Spt}^\Sigma T M_*$ is a right Bousfield localization of $L_{<p+q+1} \text{Spt}^\Sigma T M_*$. Now, lemma 3.3.62 implies that $\ast \rightarrow A$ is a trivial cofibration in $L_{<p} \text{Spt}^\Sigma T M_*$. Applying lemma 3.4.7, we get that $\text{Hom}_{\text{Spt}}(A, F)$ is fibrant in $L_{<q+1} \text{Spt}^\Sigma T M_*$; and since $S^q \text{Spt}^\Sigma T M_*$ is a right Bousfield localization of $L_{<q+1} \text{Spt}^\Sigma T M_*$, it follows that $\text{Hom}_{\text{Spt}}(A, F)$ is fibrant in $S^q \text{Spt}^\Sigma T M_*$. Fix $F^\Sigma_n(S^r \wedge \mathbb{G}_m^s \wedge U_+) \in S^\Sigma(q)$, i.e $s - n = q$. Applying lemma 3.4.10 we have that

$$\text{Hom}_{\text{Spt}}(F^\Sigma_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), F) \longrightarrow \ast$$

is a trivial fibration in $S^q \text{Spt}^\Sigma T M_*$ which is in particular a simplicial model category. Therefore the induced map

$$\text{Map}_\Sigma(A, \text{Hom}_{\text{Spt}}(F^\Sigma_n(S^r \wedge \mathbb{G}_m^s \wedge U_+), F)) \longrightarrow \text{Map}_\Sigma(A, \ast) = \ast$$
is a trivial fibration of simplicial sets. Finally using the enriched adjunctions of proposition 2.6.12, the map above becomes:

\[
\text{Map}_{\Sigma}(F_n^\Sigma(S^r \wedge G_m \wedge U_+), \text{Hom}_{\text{SpT}}^T(A, F)) \\
\text{Map}_{\Sigma}(F_n^\Sigma(S^r \wedge G_m \wedge U_+), *) = *
\]

which is in particular a weak equivalence of simplicial sets. We already know that \(\text{Hom}_{\text{SpT}}^T(A, F)\) is fibrant in \(L_{<q+1}\text{SpT}_*\), then by definition it follows that \(\pi\) is a \(S^\Sigma(q)\)-colocal equivalence in \(L_{<q+1}\text{SpT}_*\), i.e. a weak equivalence in \(S^q\text{SpT}_*\). This finishes the proof.

**Theorem 3.4.12.** Fix \(p, q \in \mathbb{Z}\). Then the smash product of symmetric \(T\)-spectra

\[- \wedge - : Sp^pT_* \times Sp^qT_* \to Sp^{p+q}T_*\]

is a Quillen bifunctor in the sense of Hovey (see definition 1.7.4).

**Proof.** Since

\[- \wedge - : Sp^pT_* \times Sp^qT_* \to Sp^{p+q}T_*\]

is an adjunction of two variables (see lemma 1.7.5), it follows that it is enough to prove the following two claims:

1. Let \(i : A \to B\) be a cofibration in \(Sp^pT_*\), and let \(j : C \to D\) be a cofibration in \(Sp^qT_*\). Assume that either \(i\) or \(j\) is trivial. Then

\[
B \wedge C \coprod_{A \wedge D} A \wedge D \xrightarrow{i \coprod j} B \wedge D
\]

is a trivial cofibration in \(Sp^{p+q}T_*\).

2. Let \(i : A \to B\) be a cofibration in \(Sp^pT_*\), and let \(p : X \to Y\) be a trivial fibration in \(Sp^{p+q}T_*\). Then

\[
\text{Hom}_{Sp^pT_*}(B, X) \cong (i^* \cdot p^*) \text{Hom}_{Sp^qT_*}(B, Y) \times \text{Hom}_{Sp^{p+q}T_*}(A, Y) \text{Hom}_{Sp^pT_*}(A, X)
\]

is a trivial fibration in \(Sp^qT_*\).
(1): By symmetry, it is enough to consider the case where \( i \) is a cofibration in \( S^p \text{Spt}_T^\Sigma \mathcal{M}_* \), and \( j \) is a trivial cofibration in \( S^q \text{Spt}_T^\Sigma \mathcal{M}_* \). Since \( S^p \text{Spt}_T^\Sigma \mathcal{M}_* \) and \( S^q \text{Spt}_T^\Sigma \mathcal{M}_* \) are right Bousfield localizations of \( L_{<q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \) and \( L_{<p+1} \text{Spt}_T^\Sigma \mathcal{M}_* \) respectively, we have that the identity functor

\[
\begin{array}{c}
id : S^q \text{Spt}_T^\Sigma \mathcal{M}_* \\
\downarrow \\
L_{<q+1} \text{Spt}_T^\Sigma \mathcal{M}_*
\end{array}
\quad \text{and} \quad \begin{array}{c}
id : S^p \text{Spt}_T^\Sigma \mathcal{M}_* \\
\downarrow \\
L_{<p+1} \text{Spt}_T^\Sigma \mathcal{M}_*
\end{array}
\]

is in both cases a left Quillen functor. This implies in particular that \( i \) is a cofibration in \( L_{<p+1} \text{Spt}_T^\Sigma \mathcal{M}_* \) and \( j \) is a cofibration in \( L_{<q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \). Then by lemma 3.4.5 we have that \( i \square j \) is a cofibration in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \).

By construction \( S^{p+q} \text{Spt}_T^\Sigma \mathcal{M}_* \) is a right Bousfield localization of \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \), hence the trivial cofibrations in both model structures are exactly the same. Thus, it only remains to show that \( i \square j \) is a weak equivalence in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \).

Consider the following pushout diagrams in \( \text{Spt}_T \mathcal{M}_* \):

\[
\begin{array}{ccc}
A & \xrightarrow{i} & B \\
\downarrow & & \downarrow \\
\ast & \xrightarrow{\iota} & B/A
\end{array}
\quad \begin{array}{ccc}
C & \xrightarrow{j} & D \\
\downarrow & & \downarrow \\
\ast & \xrightarrow{\kappa} & D/C
\end{array}
\]

By construction \( S^q \text{Spt}_T^\Sigma \mathcal{M}_* \) is a right Bousfield localization of \( L_{<q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \); therefore the trivial cofibrations coincide in both model structures. This implies that \( j \) and \( \kappa \) are both trivial cofibrations in \( L_{<q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \). On the other hand, it is clear that \( \iota \) is a cofibration in \( S^p \text{Spt}_T^\Sigma \mathcal{M}_* \). Then lemma 3.3.62 implies that \( \iota \) is a trivial cofibration in \( L_{<p} \text{Spt}_T^\Sigma \mathcal{M}_* \).

Using lemma 3.4.9, we get that the map \( \ast \to (B/A) \wedge (D/C) \) is a trivial cofibration in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \).

Finally, since \( i \square j \) is a cofibration in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \), it follows that \( (B/A) \wedge (D/C) \) is the homotopy cofibre of \( i \square j \) in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \). But corollary 3.3.36 implies that the homotopy category associated to \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \) is triangulated. Therefore \( i \square j \) is a trivial cofibration in \( L_{<p+q+1} \text{Spt}_T^\Sigma \mathcal{M}_* \), since its homotopy cofibre is contractible.

(2): Using (1) above together with the fact that

\[
- \wedge - : S^p \text{Spt}_T^\Sigma \mathcal{M}_* \times S^q \text{Spt}_T^\Sigma \mathcal{M}_* \longrightarrow S^{p+q} \text{Spt}_T^\Sigma \mathcal{M}_*
\]
is an adjunction of two variables, we have that \((i^*, p_*)\) is a fibration in \(S^q\text{Spt}_T^\Sigma M_*\). Thus, it only remains to show that \((i^*, p_*)\) is a weak equivalence in \(S^q\text{Spt}_T^\Sigma M_*\).

Consider the following diagrams in \(\text{Spt}_T M_*\):

\[
\begin{array}{ccc}
A & \xrightarrow{i} & B \\
\downarrow & & \downarrow \\
* & \xrightarrow{\iota} & B/A \\
\end{array} \\
\begin{array}{ccc}
F & \xrightarrow{\kappa} & * \\
\downarrow & & \downarrow \\
X & \xrightarrow{p} & Y \\
\end{array}
\]

where the diagram on the left is a pushout square and the diagram on the right is a pullback square. It is clear that \(\iota\) is a cofibration in \(S^q\text{Spt}_T^\Sigma M_*\) and that \(\kappa\) is a trivial fibration in \(S^{p+q}\text{Spt}_T^\Sigma M_*\). Then lemma 3.4.11 implies that \(\text{Hom}_{\text{Spt}_T^\Sigma}(B/A, F) \rightarrow *\) is a trivial fibration in \(S^q\text{Spt}_T^\Sigma M_*\).

We already know that \((i^*, p_*)\) is a fibration in \(S^q\text{Spt}_T^\Sigma M_*\), therefore \(\text{Hom}_{\text{Spt}_T^\Sigma}(B/A, F)\) is the homotopy fibre of \((i^*, p_*)\) in \(S^q\text{Spt}_T^\Sigma M_*\). Finally, by corollary 3.3.58 we have that the homotopy category associated to \(S^q\text{Spt}_T^\Sigma M_*\) is triangulated. Therefore it follows that \((i^*, p_*)\) is a trivial fibration in \(S^q\text{Spt}_T^\Sigma M_*\), since its homotopy fibre is contractible.

3.5 Applications

In this section we will describe some of the consequences that follow from the compatibility of the slice filtration with the smash product of symmetric \(T\)-spectra in the sense of theorems 3.4.4 and 3.4.12.

**Lemma 3.5.1.** The sphere spectrum \(1\) is a cofibrant object in \(\text{RC}_{\text{eff}}^0 \text{Spt}_T^\Sigma M_*\) and \(S^0\text{Spt}_T^\Sigma M_*\).

**Proof.** By proposition 3.3.60 we have that it is enough to show that \(1\) is cofibrant in \(\text{RC}_{\text{eff}}^0 \text{Spt}_T^\Sigma M_*\).

Now, corollary 3.2.15 implies that \(F_0(S^0)\) is a \(C_{\text{eff}}\)-colocal \(T\)-spectrum in \(\text{Spt}_T M_*\), since \(F_0(S^0) \in \text{Spt}_{\text{eff}}(S)\). Then using [7, theorem 5.1.1(2)] we have that \(F_0(S^0)\) is a cofibrant object in \(\text{RC}_{\text{eff}}^0 \text{Spt}_T M_*\), and this implies that \(1 = V(F_0(S^0))\) is also cofibrant in \(\text{RC}_{\text{eff}}^0 \text{Spt}_T^\Sigma M_*\),
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since the symmetrization functor

\[ V : R_{C_{eff}}^0 \text{Spt}_T M_\ast \rightarrow R_{C_{eff}}^0 \text{Spt}_T^\Sigma M_\ast \]

is a left Quillen functor.

Proposition 3.5.2. The model categories \(R_{C_{eff}}^0 \text{Spt}_T M_\ast\) and \(S^0 \text{Spt}_T M_\ast\) are both symmetric monoidal (with respect to the smash product of symmetric \(T\)-spectra) model categories in the sense of Hovey (see definition 1.7.7).

Proof. Follows directly from lemma 3.5.1, together with theorems 3.4.4 and 3.4.12.

Theorem 3.5.3. The triangulated categories \(\mathcal{SH}^\Sigma(S), R_{C_{eff}} \mathcal{H}^\Sigma(S)\) and \(S^0 \mathcal{H}^\Sigma(S)\) inherit a natural symmetric monoidal structure from the smash product of symmetric \(T\)-spectra. The symmetric monoidal structure is defined as follows:

1. \[ - \wedge^L : \mathcal{SH}^\Sigma(S) \times \mathcal{H}^\Sigma(S) \rightarrow \mathcal{SH}^\Sigma(S) \]
   \[ (X,Y) \mapsto Q_\Sigma X \wedge Q_\Sigma Y \]

2. \[ - \wedge^L : R_{C_{eff}}^0 \mathcal{SH}^\Sigma(S) \times R_{C_{eff}}^0 \mathcal{H}^\Sigma(S) \rightarrow R_{C_{eff}}^0 \mathcal{SH}^\Sigma(S) \]
   \[ (X,Y) \mapsto C_0^\Sigma X \wedge C_0^\Sigma Y \]

3. \[ - \wedge^L : S^0 \mathcal{SH}^\Sigma(S) \times S^0 \mathcal{H}^\Sigma(S) \rightarrow S^0 \mathcal{SH}^\Sigma(S) \]
   \[ (X,Y) \mapsto P_0^\Sigma X \wedge P_0^\Sigma Y \]

Proof. Follows directly from propositions 2.6.27 and 3.5.2, together with theorem 1.7.15.

Proposition 3.5.4. The following exact functors between triangulated categories are both strong symmetric monoidal:

\[ C_{0}^\Sigma : R_{C_{eff}}^0 \mathcal{H}^\Sigma(S) \rightarrow S^0 \mathcal{H}^\Sigma(S) \]
\[ C_{0}^\Sigma : R_{C_{eff}}^0 \mathcal{H}^\Sigma(S) \rightarrow \mathcal{H}^\Sigma(S) \]
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**Proof.** Propositions 2.6.27 and 3.5.2 imply that

\[ \text{Spt}_T^\Sigma (Sm|_S)_{Nis}, \quad R_{C_{eff}^0} \text{Spt}_T^\Sigma \mathcal{M}_* \quad \text{and} \quad S^0 \text{Spt}_T^\Sigma \mathcal{M}_* \]

are all symmetric monoidal model categories in the sense of Hovey. Now, using proposition 3.3.60 and theorem 3.3.9 we have that the following adjunctions

\[
(id, id, \varphi) : R_{C_{eff}^0} \text{Spt}_T^\Sigma \mathcal{M}_* \rightarrow S^0 \text{Spt}_T^\Sigma \mathcal{M}_*
\]

\[
(id, id, \varphi) : R_{C_{eff}^0} \text{Spt}_T^\Sigma \mathcal{M}_* \rightarrow \text{Spt}_T^\Sigma (Sm|_S)_{Nis}
\]

are both symmetric monoidal Quillen adunctions (see definition 1.7.11). The result then follows immediately from theorem 4.3.3 in [10].

**Corollary 3.5.5.** The following exact functors between triangulated categories are both lax symmetric monoidal:

\[
R_\Sigma : \mathcal{H}^\Sigma (S) \rightarrow R_{C_{eff}^0} \mathcal{H}^\Sigma (S)
\]

\[
W_1^\Sigma : S^0 \mathcal{H}^\Sigma (S) \rightarrow R_{C_{eff}^0} \mathcal{H}^\Sigma (S)
\]

**Proof.** By proposition 3.3.18 and corollary 3.3.61 we have the following adjunctions

\[
(C_0^\Sigma, R_\Sigma, \varphi) : R_{C_{eff}^0} \mathcal{H}^\Sigma (S) \rightarrow \mathcal{H}^\Sigma (S)
\]

\[
(C_0^\Sigma, W_1^\Sigma, \varphi) : R_{C_{eff}^0} \mathcal{H}^\Sigma (S) \rightarrow S^0 \mathcal{H}^\Sigma (S)
\]

Using proposition 3.5.4 we have that the left adjoints for \( R_\Sigma \) and \( W_1^\Sigma \) are both strong symmetric monoidal. Finally by standard results in category theory we get that the right adjoints \( R_\Sigma \) and \( W_1^\Sigma \) are both lax symmetric monoidal (see [14, theorem 1.5]).

**Proposition 3.5.6.** Fix \( q \in \mathbb{Z} \). Then the smash product of symmetric \( T \)-spectra induces the following Quillen adjunctions of two variables:

1. \( R_{C_{eff}^q} \text{Spt}_T^\Sigma \mathcal{M}_* \) is a \( R_{C_{eff}^0} \text{Spt}_T^\Sigma \mathcal{M}_* \)-model category in the sense of Hovey (see definition 1.7.12).

2. \( S^q \text{Spt}_T^\Sigma \mathcal{M}_* \) is a \( S^0 \text{Spt}_T^\Sigma \mathcal{M}_* \)-model category in the sense of Hovey.
3. $\Sigma T M$ is a $R_{C_{eff}}^\Sigma S_{eff} M$-model category in the sense of Hovey.

4. $S^q \Sigma T M$ is a $R_{C_{eff}}^\Sigma S_{eff} M$-model category in the sense of Hovey.

**Proof.** (1): Follows immediately from lemma 3.5.1 and theorem 3.4.4.

(2): Follows immediately from lemma 3.5.1 and theorem 3.4.12.

(3): Follows from proposition 2.6.27 and theorem 3.3.9 which imply that the following composition is a Quillen adjunction of two variables:

\[
R_{C_{eff}}^\Sigma S_{eff} M \times S^q \Sigma T M \xrightarrow{(id, id)} S^q \Sigma T M \times S^q \Sigma T M \\
\downarrow \land \downarrow \\
S^q \Sigma T M
\]

(4): Follows from proposition 3.3.60 and theorem 3.4.12 which imply that the following composition is a Quillen adjunction of two variables:

\[
R_{C_{eff}}^\Sigma S_{eff} M \times S^q S_{eff} M \xrightarrow{(id, id)} S^0 S_{eff} M \times S^q S_{eff} M \\
\downarrow \land \downarrow \\
S^0 S_{eff} M
\]

\[
\square
\]

**Theorem 3.5.7.** Fix $q \in \mathbb{Z}$. Then the smash product of symmetric $T$-spectra induces the following natural module structures (see definition 1.7.1):

1. The triangulated category $R_{C_{eff}}^\Sigma S^q \mathcal{E}(S)$ has a natural structure of $R_{C_{eff}}^\Sigma S^q \mathcal{E}(S)$-module, defined as follows:

\[
- \land - : R_{C_{eff}}^\Sigma S^q \mathcal{E}(S) \times R_{C_{eff}}^\Sigma S^q \mathcal{E}(S) \longrightarrow R_{C_{eff}}^\Sigma S^q \mathcal{E}(S) \\
(X, Y) \longmapsto C_0^q X \land C_0^q Y
\]

2. The triangulated category $S^q S^q \mathcal{E}(S)$ has a natural structure of $S^0 S^q \mathcal{E}(S)$-module, defined as follows:

\[
- \land - : S^0 S^q \mathcal{E}(S) \times S^0 S^q \mathcal{E}(S) \longrightarrow S^0 S^q \mathcal{E}(S) \\
(X, Y) \longmapsto P_0^q X \land P_0^q Y
\]
3. The triangulated category $\mathcal{SH}^\Sigma(S)$ has a natural structure of $R_{c_{eff}} \mathcal{SH}^\Sigma(S)$-module, defined as follows:

$$- \land - : R_{c_{eff}} \mathcal{SH}^\Sigma(S) \times \mathcal{SH}^\Sigma(S) \to \mathcal{SH}^\Sigma(S)$$

$$(X, Y) \mapsto C^\Sigma_0 X \land Q_\Sigma Y$$

4. The triangulated category $S^q \mathcal{SH}^\Sigma(S)$ has a natural structure of $R_{c_{eff}} \mathcal{SH}^\Sigma(S)$-module, defined as follows:

$$- \land - : R_{c_{eff}} S^q \mathcal{SH}^\Sigma(S) \times S^q \mathcal{SH}^\Sigma(S) \to S^q \mathcal{SH}^\Sigma(S)$$

$$(X, Y) \mapsto C^\Sigma_0 X \land P^\Sigma Y$$

**Proof.** Follows directly from lemma 3.5.1, proposition 3.5.6 and [10, theorem 4.3.4].

**Theorem 3.5.8.** Fix $p, q \in \mathbb{Z}$. Then the smash product of symmetric $T$-spectra induces the following adjunctions of two variables (see definition 1.7.2):

1. We have the following adjunction of two variables, which is also a bilinear pairing:

$$- \land - : R_{c_{eff}} \mathcal{SH}^\Sigma(S) \times R_{c_{eff}} \mathcal{SH}^\Sigma(S) \to R_{c_{eff}} \mathcal{SH}^\Sigma(S)$$

$$(X, Y) \mapsto C^\Sigma_0 X \land C^\Sigma_0 Y$$

2. We have the following adjunction of two variables, which is also a bilinear pairing:

$$- \land - : S^p \mathcal{SH}^\Sigma(S) \times S^q \mathcal{SH}^\Sigma(S) \to S^{p+q} \mathcal{SH}^\Sigma(S)$$

$$(X, Y) \mapsto P^\Sigma_p X \land P^\Sigma_q Y$$

**Proof.** (1): By theorem 3.4.4 we have that

$$- \land - : R_{c_{eff}} \text{Sp}^\Sigma T M_\ast \times R_{c_{eff}} \text{Sp}^\Sigma T M_\ast \to R_{c_{eff}} \text{Sp}^\Sigma T M_\ast$$

is a Quillen bifunctor. Then proposition 1.7.14 implies that

$$- \land - : R_{c_{eff}} \mathcal{SH}^\Sigma(S) \times R_{c_{eff}} \mathcal{SH}^\Sigma(S) \to R_{c_{eff}} \mathcal{SH}^\Sigma(S)$$

$$(X, Y) \mapsto C^\Sigma_0 X \land C^\Sigma_0 Y$$
is an adjunction of two variables. Finally, since the coproduct of two cofibrant objects is always cofibrant, and \(X \land (Y \coprod Z)\) is canonically isomorphic in \(\text{Spt}_T^\Sigma(Sm|_S)_{Nis}\) to \((X \land Y) \coprod (X \land Z)\), we get that the pairing \(- \land -\) is bilinear.

(2): By theorem 3.4.12 we have that

\[
- \land - : \text{Spt}_T^{\Sigma}(S) \times \text{Spt}_T^{\Sigma}(S) \longrightarrow \text{Spt}_T^{\Sigma}(S)
\]

is a Quillen bifunctor. Then proposition 1.7.14 implies that

\[
- \land^L - : \text{SH}(S) \times \text{SH}(S) \longrightarrow \text{SH}(S)
\]

is an adjunction of two variables. Finally, since the coproduct of two cofibrant objects is always cofibrant and \((X \land Y) \coprod (X \land Z)\) is canonically isomorphic in \(\text{Spt}_T^\Sigma(Sm|_S)_{Nis}\) to \((X \land Y) \coprod (X \land Z)\), we get that the pairing \(- \land^L -\) is bilinear.

\[ \square \]

**Proposition 3.5.9.** Fix \(p, q \in \mathbb{Z}\), and let \(X, Y\) be two arbitrary symmetric \(T\)-spectra.

1. There exists a natural bilinear isomorphism in \(\text{SH}(S)\):

\[
C_p^\Sigma X \land C_q^\Sigma Y \xrightarrow{m_{1,x,y}^{X,Y}} C_{p+q}^\Sigma (C_p^\Sigma X \land C_q^\Sigma Y)
\]

2. There exists a natural bilinear map in \(R_{C_{eff}^{p+q}\text{SH}(S)}\):

\[
C_p^\Sigma R_{\Sigma}X \land C_q^\Sigma R_{\Sigma}Y \xrightarrow{m_{2,x,y}^{X,Y}} R_{\Sigma}(X \land Y)
\]

3. There exists a natural bilinear isomorphism in \(S^{p+q}\text{SH}(S)\):

\[
C_p^\Sigma X \land C_q^\Sigma Y \xrightarrow{m_{3,x,y}^{X,Y}} C_{p+q}^\Sigma (C_p^\Sigma X \land C_q^\Sigma Y)
\]

4. There exists a natural bilinear map in \(R_{C_{eff}^{p+q}\text{SH}(S)}\):

\[
C_p^\Sigma W_{p+1}^\Sigma X \land C_q^\Sigma W_{q+1}^\Sigma Y \xrightarrow{m_{4,x,y}^{X,Y}} W_{p+q+1}^\Sigma (X \land Y)
\]
Proof. (1): Theorems 3.4.4 and 3.3.9 imply that we have the following commutative diagram of Quillen bifunctors:

\[
\begin{array}{ccc}
R_{C_{\Sigma}^{+}} \times R_{C_{\Sigma}^{-}} & \rightarrow & \text{Sp} \Sigma \text{TM} \\
\downarrow & & \downarrow \\
R_{C_{\Sigma}^{+,q}} \text{Sp} \Sigma \text{TM} & \rightarrow & \text{Sp} \Sigma \text{TM}
\end{array}
\]

Using [10, theorem 1.3.7] we get the natural isomorphism \( m_1 \), which is bilinear since the functors \( C_{\Sigma}^{+}, C_{\Sigma}^{-}, C_{\Sigma}^{+,q} \) are all exact and the smash product is bilinear.

(2): By proposition 3.3.18 we have the following adjunctions:

\[
(C_{\Sigma}^{+}, R_{\Sigma}, \varphi) : R_{C_{\Sigma}^{+}} \text{Sp} \Sigma \text{(S)} \rightarrow \text{Sp} \Sigma \text{(S)}
\]

\[
(C_{\Sigma}^{-}, R_{\Sigma}, \varphi) : R_{C_{\Sigma}^{-}} \text{Sp} \Sigma \text{(S)} \rightarrow \text{Sp} \Sigma \text{(S)}
\]

Let \( \epsilon_p, \epsilon_q \) denote the respective counits, and let \( \tilde{m}_{2}^{X,Y} \) be the following composition in \( \text{Sp} \Sigma \text{(S)} \):

\[
\xymatrix{ C_{\Sigma}^{p+q} (C_{\Sigma}^{p} R_{\Sigma} X \land C_{\Sigma}^{q} R_{\Sigma} Y) \ar[r]^{(m_1 R_{\Sigma} X, R_{\Sigma} Y)^{-1}} \ar[dr]_{\tilde{m}_{2}^{X,Y}} & C_{\Sigma}^{p} R_{\Sigma} X \land C_{\Sigma}^{q} R_{\Sigma} Y \\
& \epsilon_{p}^{X} \land \epsilon_{q}^{Y} \\
X \land Y \ar[u]_{\epsilon_{p}^{Y} \land \epsilon_{q}^{Y}} }
\]

Then using the adjunction between \( C_{\Sigma}^{p+q} \) and \( R_{\Sigma} \) considered above, we define \( m_{2}^{X,Y} \) as the adjoint of \( \tilde{m}_{2}^{X,Y} \). The naturality of \( m_{2}^{X,Y} \) follows from:

1. the naturality of \( m_1 \)
2. the naturality of the fibrant replacement functor, and
3. the naturality of the counits \( \epsilon_p \) and \( \epsilon_q \).

Finally we have that \( m_{2}^{X,Y} \) is bilinear since:

1. \( m_1 \) is bilinear
2. the functors \( C_{\Sigma}^{p}, C_{\Sigma}^{q}, C_{\Sigma}^{p+q} \) and \( R_{\Sigma} \) are all exact, and
3. the smash product is bilinear.

(3): Theorem 3.4.4 and proposition 3.3.60 imply that we have the following commutative diagram of Quillen bifunctors:

\[
R_{C^p_{eff}} \text{Spt}^\Sigma M_* \times R_{C^q_{eff}} \text{Spt}^\Sigma M_* \xrightarrow{-\wedge-} R_{C^{p+q}_{eff}} \text{Spt}^\Sigma M_* \xrightarrow{id} S^{p+q} \text{Spt}^\Sigma M_*
\]

Using [10, theorem 1.3.7] we get the natural isomorphism \(m_3\), which is bilinear since the functors \(C^\Sigma_p\), \(C^\Sigma_q\), \(C^{\Sigma}_{p+q}\) are all exact and the smash product is bilinear.

(4): By corollary 3.3.61 we have the following adjunctions:

\[
(C_p^\Sigma, W_p^{\Sigma+1}, \varphi) : R_{C^p_{eff}} \mathcal{S}^\Sigma(S) \rightarrow S^q \mathcal{S}^\Sigma(S)
\]

\[
(C_q^\Sigma, W_q^{\Sigma+1}, \varphi) : R_{C^q_{eff}} \mathcal{S}^\Sigma(S) \rightarrow S^q \mathcal{S}^\Sigma(S)
\]

Let \(\epsilon_p\), \(\epsilon_q\) denote the respective counits, and let \(\tilde{m}_4^{X,Y}\) be the following composition in \(S^q \mathcal{S}^\Sigma(S)\):

\[
\begin{array}{c}
C^{\Sigma}_{p+q}(C_p^\Sigma W_p^{\Sigma+1} X \wedge C_q^\Sigma W_q^{\Sigma+1} Y) \\
\tilde{m}_4^{X,Y}
\end{array} \xrightarrow{(m_{p+q}^{\Sigma+1,X,Y})^{-1}} C_p^\Sigma W_p^{\Sigma+1} X \wedge C_q^\Sigma W_q^{\Sigma+1} Y
\]

Then using the adjunction between \(C^{\Sigma}_{p+q}\) and \(W_{p+q+1}^{\Sigma}\) considered above, we define \(m_4^{X,Y}\) as the adjoint of \(\tilde{m}_4^{X,Y}\). The naturality of \(m_4\) follows from:

1. the naturality of \(m_3\)
2. the naturality of the fibrant replacement functors, and
3. the naturality of the counits \(\epsilon_p\) and \(\epsilon_q\).

Finally we have that \(m_4\) is bilinear since:

1. \(m_3\) is bilinear
2. the functors $C^E_p, C^E_q, C^E_{p+q}, W^E_{p+1}, W^E_{q+1}$ and $W^E_{p+q+1}$ are all exact, and

3. the smash product is bilinear.

\[\square\]

**Theorem 3.5.10.** Fix $p, q \in \mathbb{Z}$. Then the smash product of symmetric $T$-spectra induces the following natural pairings (external products):

1. For every couple of symmetric $T$-spectra $X, Y$ we have the following natural map in $\mathcal{H}^E(S)$:

\[
\begin{align*}
\mathcal{H}^E(X) \times \mathcal{H}^E(Y) & \longrightarrow \mathcal{H}^E(X \wedge Y) \\
(C_p \wedge C_q) & \longrightarrow (C_{p+q})
\end{align*}
\]

(see proposition 3.5.9) which induces a bilinear natural transformation between the functors:

\[
\begin{align*}
\mathcal{H}^E(S) \times \mathcal{H}^E(S) & \longrightarrow \mathcal{H}^E(S) \\
(X, Y) & \longrightarrow f^E_p(X \wedge Y)
\end{align*}
\]

2. For every couple of symmetric $T$-spectra $X, Y$ we have the following natural map in
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$\mathcal{H}^\Sigma(S)$:

\[
\begin{align*}
\mathcal{H}^\Sigma(S) \times \mathcal{H}^\Sigma(S) & \longrightarrow \mathcal{H}^\Sigma(S) \\
(X, Y) & \longmapsto s_p^\Sigma X \land s_q^\Sigma Y \\
\end{align*}
\]

(see proposition 3.5.9) which induces a bilinear natural transformation between the following functors:

\[
\begin{align*}
\mathcal{H}^\Sigma(S) \times \mathcal{H}^\Sigma(S) & \longrightarrow \mathcal{H}^\Sigma(S) \\
(X, Y) & \longmapsto s_p^\Sigma X \land s_q^\Sigma Y \\
\end{align*}
\]

**Proof.** (1): Follows immediately from (1) and (2) in proposition 3.5.9.

(2): Follows immediately from (1), (4), (3) and (2) in proposition 3.5.9.

**Theorem 3.5.11.** Fix $p, q \in \mathbb{Z}$. Then the pairings $\cup_{p,q}^\Sigma$ and $\cup_{p,q}^\bullet$ constructed in theorem 3.5.10 are compatible with the natural transformations $\rho$ and $\pi^\Sigma$ (see propositions 3.3.23(3) and 3.3.68) in the following sense:
1. For every couple of symmetric $T$-spectra $X$, $Y$; the following diagram is commutative in $\mathcal{SH}_S^\Sigma(S)$:

$$
\begin{array}{cccc}
\Sigma^{p+1} X \land \Sigma^q Y & \xrightarrow{\rho_p \land \text{id}_p} & \Sigma^p X \land \Sigma^q Y \\
\cup_{p+1,q} & & & \downarrow_{\cup_{p,q}} \\
\Sigma^{p+q+1}(X \land Y) & \xrightarrow{\rho_{p+q+1}^{X \land Y}} & \Sigma^{p+q}(X \land Y)
\end{array}
$$

2. For every couple of symmetric $T$-spectra $X$, $Y$; the following diagram is commutative in $\mathcal{SH}_S^\Sigma(S)$:

$$
\begin{array}{cccc}
\Sigma^{p} X \land \Sigma^{q+1} Y & \xrightarrow{\text{id} \land \rho_q^Y} & \Sigma^{p} X \land \Sigma^{q+1} Y \\
\cup_{p,q+1} & & & \downarrow_{\cup_{p,q}} \\
\Sigma^{p+q+1}(X \land Y) & \xrightarrow{\rho_{p+q+1}^{X \land Y}} & \Sigma^{p+q}(X \land Y)
\end{array}
$$

3. For every couple of symmetric $T$-spectra $X$, $Y$; the following diagram is commutative in $\mathcal{SH}_S^\Sigma(S)$:

$$
\begin{array}{cccc}
\Sigma^p X \land \Sigma^q Y & \xrightarrow{s_p \land s_q^{X \land Y}} & \Sigma^p X \land \Sigma^q Y \\
\cup_{p,q} & & & \downarrow_{\cup_{p,q}} \\
\Sigma^{p+q}(X \land Y) & \xrightarrow{s_{p+q}^{X \land Y}} & \Sigma^{p+q}(X \land Y)
\end{array}
$$

**Proof.** (1): This follows from the following commutative diagram of left Quillen (bi)functors, together with the construction of the external pairing $\cup^c$ given in theorem 3.5.10(1) and the construction of the natural transformation $\rho$ given in proposition 3.3.23(3):

$$
\begin{array}{cccc}
R_{C_{eff}^{p+1}}\text{Spt}^\Sigma T M_* \times R_{C_{eff}^q} \text{Spt}^\Sigma T M_* & \xrightarrow{\text{id} \times \text{id}} & R_{C_{eff}^{p}} \text{Spt}^\Sigma T M_* \times R_{C_{eff}^q} \text{Spt}^\Sigma T M_* \\
\downarrow{\wr} & & & \downarrow{\wr} \\
R_{C_{eff}^{p+q+1}}\text{Spt}^\Sigma T M_* & & & R_{C_{eff}^{p+q}} \text{Spt}^\Sigma T M_*
\end{array}
$$

(2): This follows from the following commutative diagram of left Quillen (bi)functors, together with the construction of the external pairing $\cup^c$ given in theorem 3.5.10(1) and the
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construction of the natural transformation $\rho$ given in proposition 3.3.23(3):

\[
\begin{array}{ccc}
R^{C_p}_{eff} \text{Spt}_T^\Sigma M_* \times R^{C_q+1}_{eff} \text{Spt}_T^\Sigma M_* & \xrightarrow{id \times id} & R^{C_p}_{eff} \text{Spt}_T^\Sigma M_* \times R^{C_q-1}_{eff} \text{Spt}_T^\Sigma M_* \\
\text{Spt}_T^\Sigma M_* & \xrightarrow{-\wedge -} & \text{Spt}_T^\Sigma M_* \\
R^{C_{p+q+1}}_{eff} \text{Spt}_T^\Sigma M_* & \xrightarrow{id} & R^{C_{p+q}}_{eff} \text{Spt}_T^\Sigma M_*
\end{array}
\]

(3): This follows from the following commutative diagram of left Quillen (bi)functors, together with the construction of the external pairings $\cup^c, \cup^s$ given in theorem 3.5.10(1)-(2) and the construction of the natural transformation $\pi^\Sigma$ given in proposition 3.3.68:

\[
\begin{array}{ccc}
\text{Spt}_T^\Sigma M_* \times \text{Spt}_T^\Sigma M_* & \xrightarrow{-\wedge -} & \text{Spt}_T^\Sigma M_* \\
id \times id & \downarrow & id \\
R^{C_p}_{eff} \text{Spt}_T^\Sigma M_* \times R^{C_q}_{eff} \text{Spt}_T^\Sigma M_* & \xrightarrow{-\wedge -} & R^{C_{p+q}}_{eff} \text{Spt}_T^\Sigma M_* \\
id \times id & \downarrow & id \\
S^p \text{Spt}_T^\Sigma M_* \times S^q \text{Spt}_T^\Sigma M_* & \xrightarrow{-\wedge -} & S^{p+q} \text{Spt}_T^\Sigma M_*
\end{array}
\]

\[\square\]

**Definition 3.5.12.** Consider the following functors:

\[
f^\Sigma : \mathcal{SH}_T^\Sigma (S) \longrightarrow \mathcal{SH}_T^\Sigma (S) \\
X \longmapsto \bigoplus_{q \in \mathbb{Z}} f_q^\Sigma X
\]

\[
s^\Sigma : \mathcal{SH}_T^\Sigma (S) \longrightarrow \mathcal{SH}_T^\Sigma (S) \\
X \longmapsto \bigoplus_{q \in \mathbb{Z}} s_q^\Sigma X
\]

**Proposition 3.5.13.** 1. The functor $f^\Sigma : \mathcal{SH}_T^\Sigma (S) \to \mathcal{SH}_T^\Sigma (S)$ is an exact functor.

2. The functor $s^\Sigma : \mathcal{SH}_T^\Sigma (S) \to \mathcal{SH}_T^\Sigma (S)$ is an exact functor.

**Proof.** (1): Theorem 3.3.22(3) implies that all the functors $f_q^\Sigma$ are exact. Therefore $f^\Sigma = \bigoplus_{q \in \mathbb{Z}} f_q^\Sigma$ is also an exact functor, since the coproduct of a collection of distinguished triangles is a distinguished triangle.
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(2): Theorem 3.3.67(3) implies that all the functors $s^\Sigma_q$ are exact. Therefore $s^\Sigma = \oplus_{q \in \mathbb{Z}} s^\Sigma_q$ is also an exact functor, since the coproduct of a collection of distinguished triangles is a distinguished triangle. ∎

**Theorem 3.5.14.** Fix $q \in \mathbb{Z}$. Let $X$ be a ring spectrum in $\mathcal{S}\mathcal{H}^\Sigma(S)$ and let $M$ be an $X$-module.

1. The zero connective cover of $X$, $f_0^\Sigma X$ (see theorem 3.3.22(3)) also has the structure of a ring spectrum in $\mathcal{S}\mathcal{H}^\Sigma(S)$.

2. The $q$-connective cover of $M$, $f_q^\Sigma M$ is a module in $\mathcal{S}\mathcal{H}^\Sigma(S)$ over the zero connective cover of $X$, $f_0^\Sigma X$.

3. The coproduct of all the connective covers of $X$, $f^\Sigma X$ has the structure of a graded ring spectrum in $\mathcal{S}\mathcal{H}^\Sigma(S)$.

4. The coproduct of all the connective covers of $M$, $f^\Sigma M$ is a graded module in $\mathcal{S}\mathcal{H}^\Sigma(S)$ over the graded ring $f^\Sigma X$.

5. The zero slice of $X$, $s_0^\Sigma X$ (see theorem 3.3.67(3)) also has the structure of a ring spectrum in $\mathcal{S}\mathcal{H}^\Sigma(S)$.

6. The $q$-slice of $M$, $s_q^\Sigma M$ is a module in $\mathcal{S}\mathcal{H}^\Sigma(S)$ over the zero slice of $X$, $s_0^\Sigma X$.

7. The coproduct of all the slices of $X$, $s^\Sigma X$ has the structure of a graded ring spectrum in $\mathcal{S}\mathcal{H}^\Sigma(S)$.

8. The coproduct of all the slices of $M$, $s^\Sigma M$ is a graded module in $\mathcal{S}\mathcal{H}^\Sigma(S)$ over the graded ring $s^\Sigma X$.

**Proof.** We have that (1) and (5) follow immediately from proposition 3.5.4 and corollary 3.5.5. On the other hand, (2), (3) and (4) follow directly from theorem 3.5.10(1). Finally, (6), (7) and (8) follow directly from theorem 3.5.10(2). ∎

**Theorem 3.5.15.** Fix $q \in \mathbb{Z}$, and let $X$ be an arbitrary symmetric $T$-spectrum.
1. The zero connective cover of the sphere spectrum, \( f_0^\Sigma 1 \) has the structure of a ring spectrum in \( \mathcal{SH}^\Sigma(S) \).

2. The \( q \)-connective cover of \( X \), \( f_q^\Sigma X \) is a module in \( \mathcal{SH}^\Sigma(S) \) over the zero connective cover of the sphere spectrum, \( f_0^\Sigma 1 \).

3. The coproduct of all the connective covers of the sphere spectrum, \( f^\Sigma 1 \) has the structure of a graded ring spectrum in \( \mathcal{SH}^\Sigma(S) \).

4. The coproduct of all the connective covers of \( X \), \( f^\Sigma X \) is a graded module in \( \mathcal{SH}^\Sigma(S) \) over the graded ring \( f^\Sigma 1 \).

5. The zero slice of the sphere spectrum, \( s_0^\Sigma 1 \) has the structure of a ring spectrum in \( \mathcal{SH}^\Sigma(S) \).

6. The \( q \)-slice of \( X \), \( s_q^\Sigma X \) is a module in \( \mathcal{SH}^\Sigma(S) \) over the zero slice of the sphere spectrum, \( s_0^\Sigma 1 \).

7. The coproduct of all the slices of the sphere spectrum, \( s^\Sigma 1 \) has the structure of a graded ring spectrum in \( \mathcal{SH}^\Sigma(S) \).

8. The coproduct of all the slices of \( X \), \( s^\Sigma X \) is a graded module in \( \mathcal{SH}^\Sigma(S) \) over the graded ring \( s^\Sigma 1 \).

**Proof.** It is clear that the sphere spectrum \( 1 \) is a ring spectrum in \( \mathcal{SH}^\Sigma(S) \), and by construction we have that every symmetric \( T \)-spectrum \( X \) is a module in \( \mathcal{SH}^\Sigma(S) \) over the sphere spectrum.

The result then follows immediately from theorem 3.5.14.

**Theorem 3.5.16.** Let \( k \) be a field of characteristic zero. Then for every \( q \in \mathbb{Z} \) and for every symmetric \( T \)-spectrum \( X \) in \( \mathcal{SH}^\Sigma(k) \):

- The \( q \)-slice of \( X \), \( s_q^\Sigma X \) is a big motive (see [23], [21, section 2.3]) in the sense of Voevodsky.
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**Proof.** Independently, Levine [15, theorem 10.5.1] and Voevodsky [22, theorem 6.6] show that over a field of characteristic zero, the zero slice of the sphere spectrum is given by the motivic Eilenberg-MacLane spectrum $H\mathbb{Z}$.

Then, theorem 3.5.15(6) implies that for every $q \in \mathbb{Z}$ and for every symmetric $T$-spectrum $X$, the $q$-slice of $X$, $s_q^X$ has the structure of a module in $\mathcal{S}\text{pt}^{\Sigma}(k)$ over the motivic Eilenberg-MacLane spectrum $H\mathbb{Z}$.

Finally, the result follows from the work of Röndigs and Østvær in [21], which shows in particular that over a field of characteristic zero, the stable homotopy category of modules over the motivic Eilenberg-MacLane spectrum $H\mathbb{Z}$ is equivalent to Voevodsky’s big category of motives $DM_k$, where the equivalence preserves the monoidal and triangulated structures (see [21, theorem 1.1]).

Using the slice filtration, it is possible to construct a spectral sequence which is an analogue of the classical Atiyah-Hirzebruch spectral sequence in algebraic topology.

**Definition 3.5.17 (Motivic Atiyah-Hirzebruch Spectral Sequence).** Let $X, Y$ be a pair of symmetric $T$-spectra. Then the collection of distinguished triangles in $\mathcal{S}\text{pt}^{\Sigma}(S)$ (see theorem 3.1.16 and propositions 3.3.23(3), 3.3.68):

\[ f_{q+1}^{\Sigma}X \xrightarrow{\rho_q^{X}} f_q^{\Sigma}X \xrightarrow{s_q^{X}} s_q^{\Sigma}X \xrightarrow{\sigma_q^{X}} \Sigma_1^0 f_{q+1}^{\Sigma}X \]

generates an exact couple $(D_1^{p,q}(Y; X), E_1^{p,q}(Y; X))$, where:

1. $D_1^{p,q} = [Y, \Sigma_T^{p+q,0} f_p^{\Sigma}X]_{\text{Spt}}$, and
2. $E_1^{p,q}(Y; X) = [Y, \Sigma_T^{p+q,0} s_p^{\Sigma}X]_{\text{Spt}}$.

The compatibility of the slice filtration with the smash product of symmetric $T$-spectra implies that the smash product of symmetric $T$-spectra induces a pairing of spectral sequences:

**Theorem 3.5.18.** Let $X, X', Y, Y'$ be symmetric $T$-spectra. Then the smash product of symmetric $T$-spectra induces the following natural external pairings in the motivic Atiyah-
Hirzebruch spectral sequence:

\[ E_p^r(Y; X) \otimes E_p^{r'}(Y'; X') \longrightarrow E_p^{p'+q'+q}(Y \wedge Y'; X \wedge X') \]

\[ (\alpha, \beta) \longrightarrow \alpha \circ \beta \]

where \( \alpha : Y \to \Sigma^{p+q,0}_p X, \beta : Y' \to \Sigma^{p'+q',0}_{p'} X' \) and \( \alpha \circ \beta \) is the following composition (see theorem 3.5.10(2)):

\[
Y \wedge Y' \xrightarrow{\alpha \wedge \beta} \Sigma^{p+q,0}_p X \wedge \Sigma^{p'+q',0}_{p'} X' \\
\downarrow \cong \\
\Sigma^{p+p'+q+q',0}_{p+p'} X \wedge s_p^0 \Sigma X \wedge s_{p'}^0 \Sigma X' \xrightarrow{\Sigma^{p+p'+q+q',0}_{p+p'} \cup^p \cup_{p'}^{s_p^0}} \\
\Sigma^{p+p'+q+q',0}_{p+p'} X \wedge X' \]

**Proof.** Using the naturality of the external pairings \( \cup^p_{p, q} \), \( \cup^p_{p, q} \) (see theorem 3.5.10) and theorem 3.5.11, the result follows immediately from the work of Massey [16] together with [3, proposition 14.3].
Bibliography


