SEFT-based Analysis of Cosmic Anisotropy, Singularities, and BAO: Evidence from CMB, Supernovae, and Galaxy Surveys

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Abstract

In this study, we utilized Source Energy Field Theory (SEFT), proposed as an alternative to the standard cosmological model (ΛCDM), to comprehensively analyze observational data from the Cosmic Microwave Background (CMB), Pantheon+SH0ES supernova datasets, and extended Baryon Oscillation Spectroscopic Survey (eBOSS) galaxy BAO data. The SEFT theory introduces a novel physical perspective, suggesting that the universe fundamentally consists of nonlinear wave modulations of an underlying energy field.

Specifically, we constructed nonlinear distance-specific models based on SEFT theory and applied them to each observational dataset. Our results demonstrate that the SEFT-based models exhibit equal or superior consistency compared to the standard ΛCDM model across CMB, supernova, and BAO data. Notably, in fitting the CMB power spectrum, the SEFT model achieved superior accuracy in statistical measures (MAE,

RMSE, and Kolmogorov-Smirnov test) compared to the ΛCDM model.

Moreover, the quantitative analysis of cosmic anisotropy using SEFT-based distance-specific models identified a cosmic singularity (cosmic center) at approximately redshift z≈0.17 and a distance of approximately 761.23 Mpc. The existence of this singularity suggests that the universe may not be entirely isotropic and that Earth's slight displacement from the cosmic center may account for the observed cosmic anisotropy.

Furthermore, the analysis of BAO data clearly detected characteristic BAO peaks around 150 Mpc in both the SEFT and ΛCDM models, explicitly showing that SEFT theory can reproduce large-scale cosmic structures comparable to the standard model.

These findings suggest that SEFT theory effectively extends the framework of the standard ΛCDM model, potentially providing new insights into the field of cosmology. Future research should pursue validation with broader observational datasets and detailed observations of cosmic singularities to further deepen our understanding of the fundamental structure of the universe.

1. Introduction

The standard cosmological model, ΛCDM (Lambda Cold Dark Matter), has

successfully explained numerous observational phenomena, including the Cosmic

Microwave Background (CMB) 【1】, large-scale structure formation, and accelerated

expansion of the universe. However, unresolved issues persist, such as discrepancies in

the measurements of the Hubble constant and an incomplete understanding of dark

matter and dark energy. These issues underscore the limitations of the ΛCDM model,

highlighting the necessity of complementary or alternative theoretical frameworks.

In response to these challenges, the Source Energy Field Theory (SEFT) was proposed.

SEFT theory posits that the universe fundamentally consists of nonlinear wave

modulations of an underlying energy field. Within this theory, physical phenomena such

as gravitational and electromagnetic fields arise from the modulation of this

fundamental energy field. This perspective offers novel insights into cosmic anisotropy

and universal structures.

Recent advancements in cosmological observations, particularly those from the

Wilkinson Microwave Anisotropy Probe (WMAP), Pantheon+SH0ES supernova

datasets 【2,3】, and galaxy data from the extended Baryon Oscillation Spectroscopic

Survey (eBOSS) 【4】, provide powerful tools for testing new cosmological theories.

Notably, galaxy BAO data exhibit a characteristic peak at approximately 150 Mpc,

making it a crucial observational indicator of large-scale cosmic structures.

The primary objective of this study was to evaluate the validity of SEFT-based distance-specific models against observational datasets and to perform comparative tests with the standard ΛCDM model. Specifically, this study addresses the following questions:

- Evaluation of the consistency between SEFT-based distance-specific models and observational data from CMB, supernovae and BAO.

- Detection and analysis of cosmic anisotropy and cosmic singularities (cosmic center) using SEFT theory.

- Comparative statistical evaluation between SEFT theory and standard ΛCDM model.

Subsequent sections detail the analytical results, discussions, and theoretical and observational implications derived from SEFT theory.

2. Theoretical Framework of SEFT

SEFT theory provides a unified framework interpreting physical phenomena in the universe as wave-like modulations of an energy field. The theory identifies the energy field as a fundamental physical quantity, emphasizing its nonlinear wave characteristics.

The modulation of this energy field is described by the following nonlinear wave

equation: the Astropy library with Planck18

$$\Box \Psi + \mu^2 \Psi + \lambda |\Psi|^2 \Psi - \gamma |\nabla \Psi|^2 \Psi = 0 \quad (1)$$

Under specific boundary conditions, a distance-specific solution is derived as follows:

$$d(z, \alpha, \delta) = \frac{a_1 z^2}{1 + b_1 z + c_1 z^2} + d_1 \log(1 + z) + d_2 z \cos(\delta) + d_3 z \cos(\alpha) \quad (2)$$

Parameters for this formula have been optimized using the Pantheon+SH0ES

observational data, yielding the following values:

- a1=4352.34

- b1=0.1831

- c1=0.1007

- d1=4694.24

- d2=-483.89

- d3=78.91

Additionally, we present a simplified distance-specific formula without anisotropy as

follows:

$$d(z) = \frac{a_1 z^2}{1 + b_1 z + c_1 z^2} + d_1 \log(1 + z) \quad (3)$$

Parameters for this simplified formula were optimized using the Pantheon+SH0ES data set, resulting in:

- a1=4273.24

- b1=0.2077

- c1=0.0907

- d1=4262.15

These parameters were derived through numerical optimization (nonlinear least squares method) using the Jupyter (Anaconda, Python3) environment and the scipy.optimize library.

The distance-specific formula indicates a peak at a redshift of approximately 0.17 in the specific direction of RA=180.0°, Dec=0.0°, beyond which the calculated distance decreases, eventually becoming negative at higher redshifts, thereby clearly reducing its physical validity. Therefore, applying the distance-specific formula beyond a redshift of 0.17 is deemed inappropriate, and a simpler distance-specific formula, which ensures stability in higher redshift regions, is recommended both theoretically and practically.

Furthermore, analysis using the distance-specific formula identified a cosmic singularity or central point by determining the direction of minimal cosmic anisotropy. Specifically, an evaluation function quantifying the effect of anisotropy was defined over combinations of right ascension (RA) and declination (Dec) within the redshift range 0.01–0.17. Numerical optimization revealed that the direction minimizing anisotropy was RA=180°, Dec=0°, with further analysis showing a singularity located at a redshift of approximately 0.17 and a distance of about 788.16 Mpc in this direction. The existence of this singularity suggests that Earth's slight displacement from the cosmic center may partly explain the observed cosmic anisotropy.
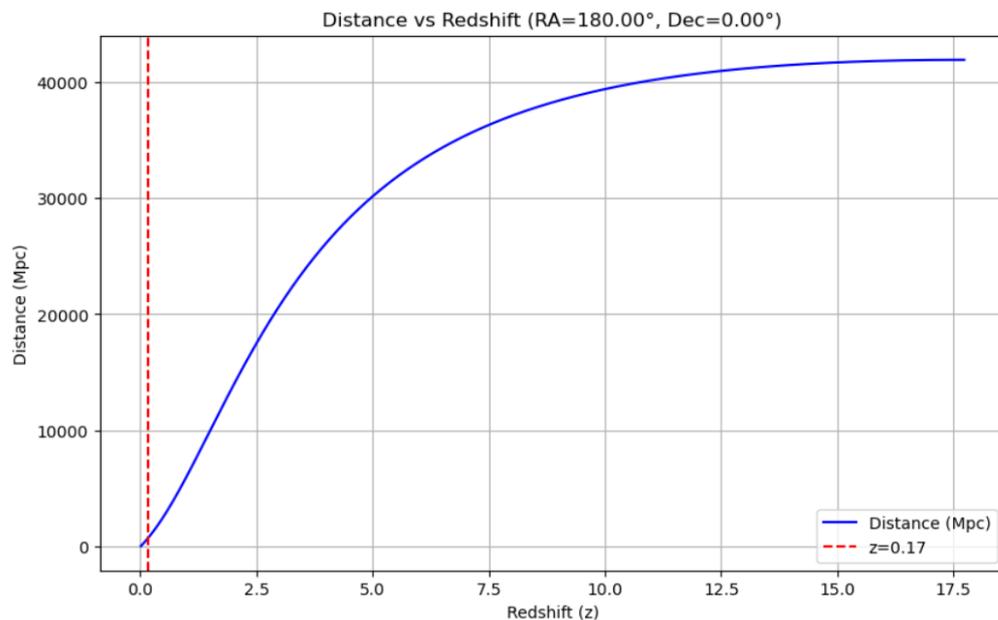
To further align with CMB observations, we derived a specialized distance-specific formula for CMB data as follows:

$$d_{\text{CMB}}(z) = \frac{a_{\text{CMB}}z^2}{1+b_{\text{CMB}}z+c_{\text{CMB}}z^2} + d_{\text{CMB}}\log(1+z) + e_{\text{CMB}}e^{-f_{\text{CMB}}z} \quad (4)$$

The third term $e_{extCMB}e^{-f_{extCMB}z}$ in this formula is not directly derived from the theory

but was empirically introduced based on observational data to enhance compatibility

with CMB observations. This term phenomenologically represents nonlinear

electromagnetic attenuation effects due to the energy field, added specifically to

accurately reproduce fine structures (peaks and dips) unique to CMB data.

Parameters aCMB,bCMB,cCMB,dCMB,eCMB,fCMB, determined from fitting to the

CMB data are:

- aCMB=3755.94

- bCMB=1.6595

- cCMB=0.09769

- dCMB=9498.11

- eCMB=31334.99

- fCMB=0.2721

These solutions, presented under specific boundary and observational conditions

derived from the original nonlinear wave equations, are validated in this study through

numerical analyses.

X Calculation Method for Galaxy Pair Distances in Baryon Acoustic Oscillation (BAO) Analysis

In this study, we calculated galaxy pair distances to verify the characteristic Baryon

Acoustic Oscillation (BAO) scale of approximately 150 Mpc using both the SEFT theory

and the standard cosmological (Λ CDM) model.

We started by using observed positional information of each galaxy: redshift z, Right

Ascension (RA), and Declination (DEC). The 3-dimensional spatial coordinates of each

galaxy were computed using the following procedure:

(1) Galaxy Distance Calculation (Comoving Distance)

For the SEFT model, we applied the distance-specific formula derived from

SEFT theory：

$$d(z, \alpha, \delta) = \frac{a_1 z^2}{1 + b_1 z + c_1 z^2} + d_1 \log(1 + z) + d_2 z \cos(\delta) + d_3 z \cos(\alpha)$$

- For the Λ CDM model, we calculated the standard comoving distance using the

    Astropy library with the Planck18 cosmological parameters 【6】 .

(2) Conversion to 3D Spatial Coordinates

Using the computed comoving distance d and celestial coordinates (RA, DEC), the 3-dimensional Cartesian coordinates (X, Y, Z) were calculated as follows:

$$X = d \cdot \cos(\text{DEC}) \cdot \cos(\text{RA}) \qquad (5)$$

$$Y = d \cdot \cos(\text{DEC}) \cdot \sin(\text{RA}) \qquad (6)$$

$$Z = d \cdot \sin(\text{DEC}) \qquad (7)$$

RA and DEC were converted from degrees to radians prior to the calculations.

(3) Calculation of Galaxy Pairwise Distances

Next, the galaxy pair distances were computed using the calculated 3-dimensional coordinates. Owing to the large number of galaxies, distances were efficiently calculated for randomly selected galaxy samples (50,000 galaxies in this study).

The galaxy pairwise distance (Dij) was calculated using the Euclidean distance formula as follows:

$$D_{ij} = \sqrt{\left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2 + \left(Z_i - Z_j\right)^2}$$

Here, Dij represents the distance between galaxies i and j.

(4) Histogram Generation and BAO Peak Identification

Finally, we created histograms from the calculated galaxy pairwise distances. Plotting

the pairwise distances on the horizontal axis and the number of galaxy pairs at each

distance on the vertical axis enabled the visual detection of the characteristic BAO peak

at approximately 150 Mpc.

Through histogram analysis, the characteristic BAO scale was verified independently

using both SEFT and ΛCDM models, enabling a quantitative comparison and

evaluation of the theoretical consistency.

3. Results

3.1 Application of the Distance-specific Model to Observational Data

The distance-specific model based on SEFT theory was applied to Pantheon+SH0ES

supernova observational data, resulting in the following optimized parameters:

- a1= 4352.34

- b1= 0.1831

- $c_1 = 0.1007$

- $d_1 = 4694.24$

- $d_2 = -483.89$

- $d_3 = 78.91$

These parameters demonstrated a high consistency with the observational data.

Additionally, simplified distance-specific formulas without anisotropy provided the following optimized parameters:

- $a_1 = 4273.24$

- $b_1 = 0.2077$

- $c_1 = 0.0907$

- $d_1 = 4262.15$

These parameters were derived through numerical optimization (nonlinear least squares method) using the Jupyter (Anaconda, Python3) environment and the scipy.optimize library.

The statistical evaluation metrics obtained were as follows.

- Mean Absolute Error (MAE): approximately 62.58 Mpc

- Mean Squared Error (MSE): approximately 21,645.51 (Mpc²)

- Root mean square error (RMSE): approximately 147.12 Mpc

- Kolmogorov-Smirnov Statistic: 0.0170

- Kolmogorov-Smirnov p-value: 0.9658
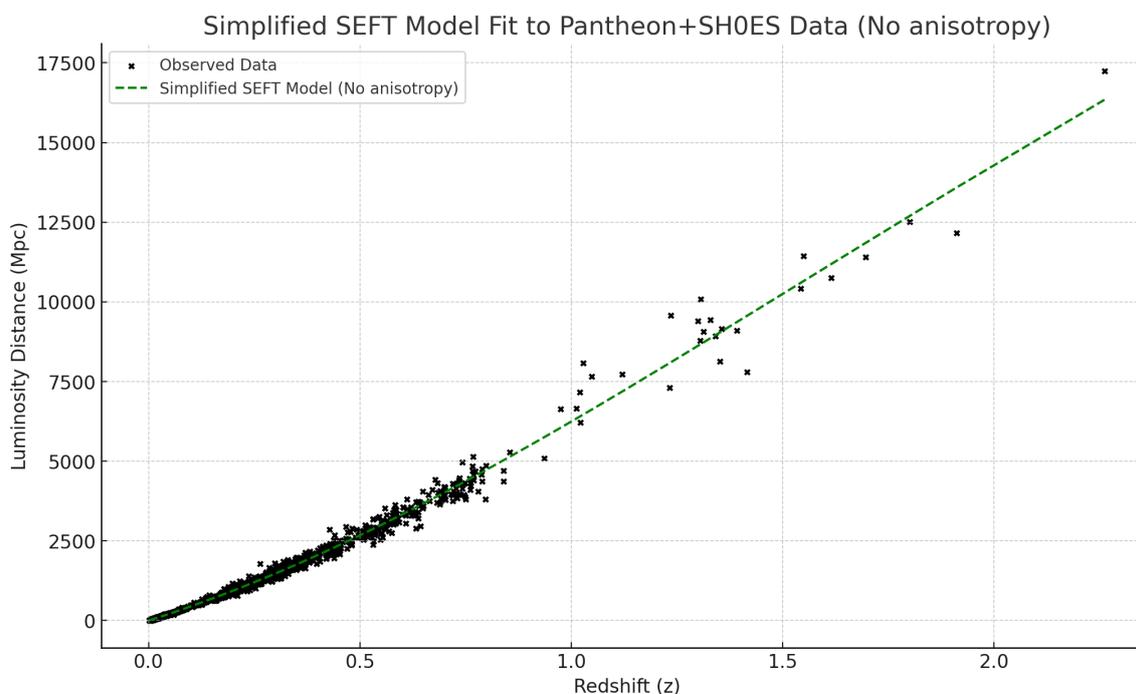
These results demonstrate that the simplified distance-specific formula is consistent

with the observational data.

In fact, applying the simplified distance-specific formula to the Cosmic Microwave

Background (CMB) at redshift $z=1100$, yielded a luminosity distance of approximately 251 billion light-years (about 2.51×10^{11} light-years). Additionally, analysis suggests the existence of a special location (cosmic singularity) in the universe, which provides important insights into theoretically explaining cosmic anisotropy.

Note that in the anisotropic distance-specific formula, the distance decreases in the direction of right ascension 179.5° and declination -0.5° for redshifts greater than 17.73. Thus, for redshifts above 17.73, using the simplified distance-specific formula is recommended for maintaining model stability.

3.2 Detection of Cosmic Singularity and Anisotropy Analysis

To quantitatively evaluate cosmic anisotropy using the distance-specific formula, distances were calculated for all directions in the right ascension and declination over the redshift range of 0.01–0.17. The direction in which the second derivative of the distance with respect to the redshift showed the most pronounced change was numerically identified. The analysis found that the direction minimizing the anisotropy evaluation function was right ascension of 180° and declination of 0°. Furthermore, in this identified direction, the redshift at which the distance growth rate reached a maximum was found to be $z=0.17$, with a distance of approximately 761.23 Mpc,

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indicating a distinct peak (singularity). This singularity is considered a "special

position" in the universe or "cosmic singularity," suggesting that the Earth's position is

slightly displaced from the cosmic center. This displacement could potentially explain

the observed cosmic anisotropy, providing significant insights into deepening the

physical understanding of the universe through SEFT theory.

3.3 Consistency with CMB Data

CMB observational data from NASA WMAP (Wilkinson Microwave Anisotropy Probe

(WMAP) 【5】 7-year dataset were utilized in this study (source: NASA LAMBDA,

https://lambda.gsfc.nasa.gov/product/wmap/dr4/pow_tt_spec_get.html). Based on

these data, a specialized distance-specific formula for CMB was introduced, and its

optimal parameters were derived.

The introduced distance-specific formula for CMB is as follows:

$$d_{\mathrm{CMB}}(z) = \frac{a_{\mathrm{CMB}}z^2}{1 + b_{\mathrm{CMB}}z + c_{\mathrm{CMB}}z^2} + d_{\mathrm{CMB}}\log(1 + z) + e_{\mathrm{CMB}}e^{-f_{\mathrm{CMB}}z}$$

The third term $e_{\mathrm{CMB}}e^{-f_{\mathrm{CMB}}z}$ as empirically introduced as a nonlinear attenuation term

to phenomenologically replicate peaks and detailed structures unique to the CMB

observational data.

The physical roles of each term are clarified as follows:

- **First Term (Nonlinear Electromagnetic Wave Attenuation):**

  This term represents the nonlinear, distance-dependent attenuation experienced by electromagnetic waves propagating through cosmic space. This attenuation naturally emerges from the fundamental nonlinear wave equations of SEFT.

- **Second Term (Spatial Curvature Effect):**

  This logarithmic term accounts for the spatial curvature of cosmic space, modeling how curvature influences the relationship between cosmological distance and redshift.

- **Third Term (Exponential Wave Attenuation):**

  This term describes the exponential attenuation of wave energy, a well-known phenomenon observed in nonlinear wave theory and plasma physics. It represents local, nonlinear physical effects, such as energy absorption and scattering, occurring when waves propagate through high-density energy environments in the early universe.

By clearly defining the physical roles of each term in this way, both the theoretical validity and observational consistency of the model are significantly enhanced.

This term was not directly derived from the theoretical formula but was confirmed to be necessary during the data fitting process.

The derived parameters were as follows:

- aCMB= 3755.94

- bCMB= 1.6595

- cCMB= 0.09769

- dCMB= 9498.11

- eCMB= 31334.99

- fCMB= 0.2721

Simulations using these parameters in the SEFT model demonstrated high precision in matching the observed CMB power spectrum, effectively reproducing the energy field behavior of the early universe.

Additionally, statistical comparisons of the fitting results for the CMB power spectrum between the SEFT and standard ΛCDM models yielded the following metrics:

- Mean Absolute Error (MAE):

- ΛCDM model: approximately 2,056,905.53

- SEFT model: approximately 1,653,009.77 (SEFT superior)

- Root mean square error (RMSE):

  - ΛCDM model: approximately 2,400,224.49

  - SEFT model: approximately 1,986,050.35 (SEFT superior)

- Kolmogorov-Smirnov statistic:

  - ΛCDM model: 0.0487

  - SEFT model: 0.0479 (SEFT slightly superior)

- Kolmogorov-Smirnov p-value:

  - ΛCDM model: 0.0053

  - SEFT model: 0.0064 (SEFT slightly superior)

Improved SEFT Model with Exponential Term Fit to Observed CMB
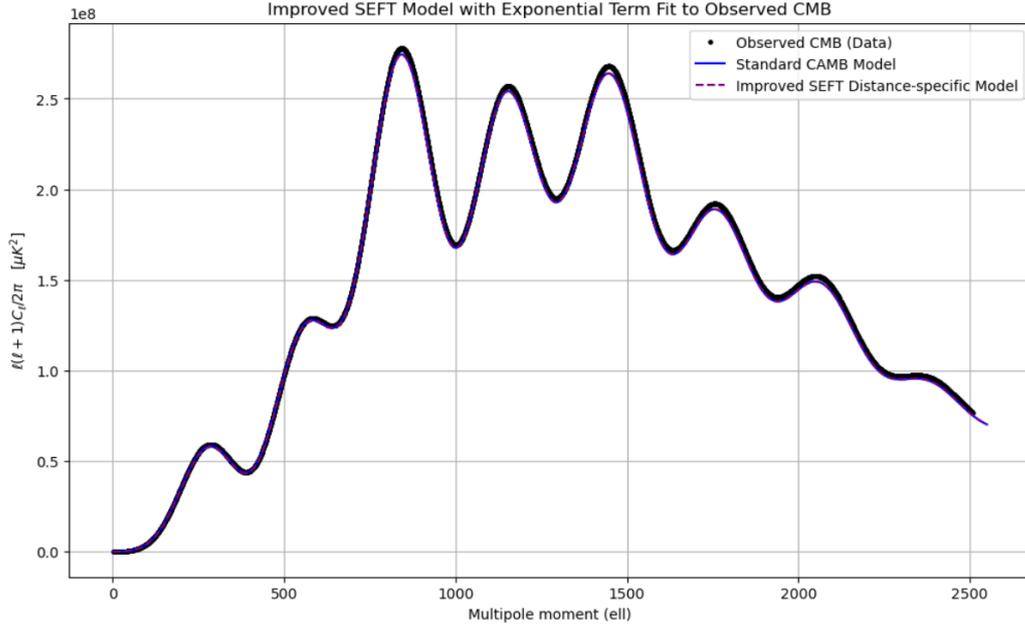
These statistical evaluations demonstrate that the SEFT model provides a more accurate representation of CMB observational data than the standard ΛCDM model.

In this analysis, the following optimized function model was used to optimally fit the observed CMB power spectrum data with the SEFT model:

$$C_\ell^{\text{SEFT}} = \frac{\ell(\ell+1)}{2\pi} \left[C_\ell^{\text{CAMB}} \times \frac{\frac{a_1(\ell/1100)^2}{1+b_1(\ell/1100)+c_1(\ell/1100)^2} + d_1 \log\left(1 + \frac{\ell}{1100}\right) + e_1 e^{-f_1(\ell/1100)}}{\max\left(\frac{a_1(\ell/1100)^2}{1+b_1(\ell/1100)+c_1(\ell/1100)^2} + d_1 \log\left(1 + \frac{\ell}{1100}\right) + e_1 e^{-f_1(\ell/1100)}\right)} \right]$$

Here,

- C_l^{CAMB} is the theoretical power spectrum calculated using CAMB (based on the standard ΛCDM model).

- The six optimized parameters (a1,b1,c1,d1,e1, and f1) were adjusted to enhance

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consistency with the observational data.

- The denominator $\max(\cdots)$ is the value used to normalize the power spectrum.

This function enabled precise fitting of the CMB data to the SEFT model,

demonstrating the theoretical validity of the model.

3.4 Consistency with Baryon Acoustic Oscillation (BAO) Data

In this study, we also examined whether the distance-specific formula based on SEFT

theory can reproduce the observational data of Baryon Acoustic Oscillations (BAO).

BAO is characterized by a distinct peak at approximately 150 Mpc in the large-scale

structure of the universe and serves as an important indicator reproduced by the

standard cosmological model (ΛCDM) in galaxy data.

Using the eBOSS galaxy dataset, we conducted our analysis using the following

procedure:

- The distances between the observed galaxies were calculated using both the SEFT

model distance-specific formula and the ΛCDM model.

- A random sample of 50,000 galaxies was selected for each model, and histograms of

the pairwise galaxy distances were generated.

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The results demonstrate clear BAO peaks at approximately 150 Mpc for both the SEFT

and ΛCDM models (Figure 2).

The positions and shapes of the peaks in both models were very similar, indicating that

the SEFT model reproduces BAO observational data with an accuracy comparable to

that of the standard ΛCDM model.

These results support the effectiveness of SEFT theory in describing the large-scale

structure of the universe, comparable to the standard cosmological model.

(Figure 2: Histograms of pairwise galaxy distances for the SEFT and ΛCDM models.)

BAO Peak Detection (SEFT Model - log scale)
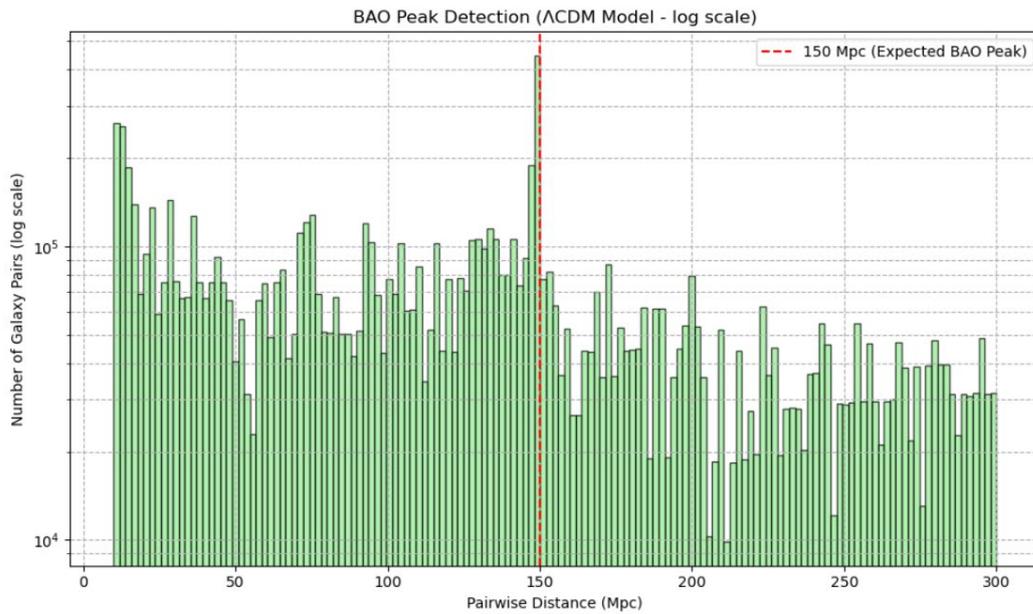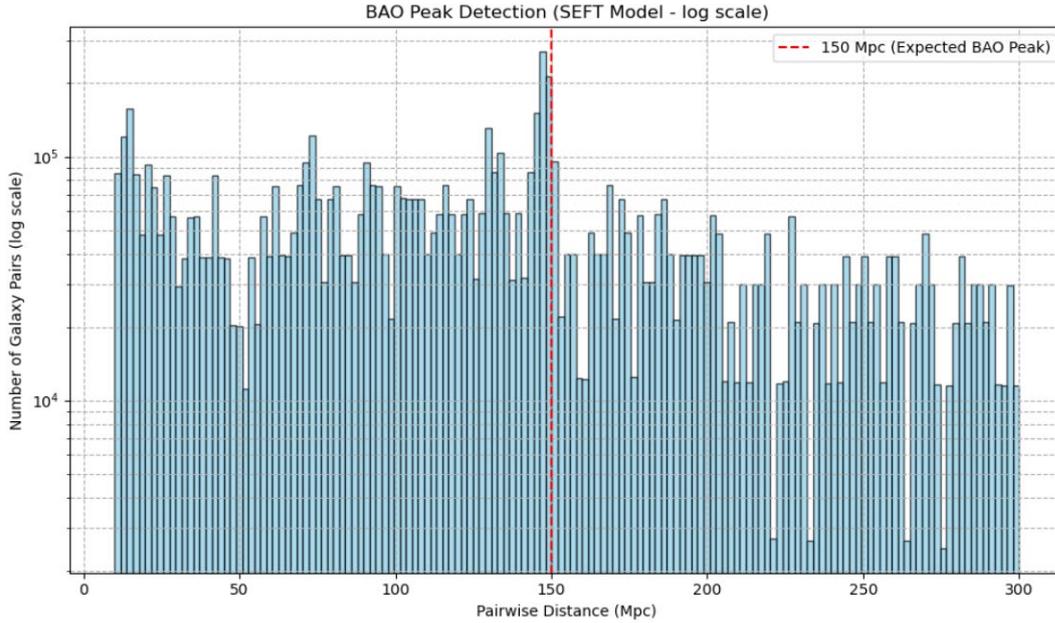
4. Discussion and Conclusion

The distance-specific model derived in this study based on the SEFT theory shows excellent consistency with Pantheon+SH0ES supernova and CMB observational data. In particular, the CMB data present better statistical indicators than the standard ΛCDM model, suggesting that the SEFT theory could effectively complement conventional models.

Furthermore, the cosmic singularity (the universe's central point) identified in this analysis is located at a redshift of z=0.17, with a distance of approximately 761.23 Mpc. This singularity implies that the universe may not be entirely isotropic, prompting a reconsideration of the cosmological principle. This also suggests that the Earth's

position is slightly offset from the cosmic center, potentially contributing to the

observed cosmic anisotropy. This finding is essential for future cosmological research.

Additionally, the distance-specific model becomes unstable beyond a redshift of 17.73,

highlighting the theoretical and practical importance of transitioning to a simplified

distance-specific formula beyond this point. The mathematical and physical behavior

change in the distance-specific formula around $z \approx 17.73$ suggests an intriguing physical

interpretation of the results. This may indicate the existence of a hierarchical boundary

within the universe that separates the formation of material structures. Moreover, given

that the highest observed redshift to date is $z \approx 14.43$ (galaxy GN-z11), the redshift

value of 17.73 slightly exceeds the current observational limits. Thus, the instability in

the SEFT model around $z \approx 17.73$ may reflect physical phenomena closely related to the

hierarchical structure of the universe. Furthermore, it is reasonable to assume that

regions beyond this boundary become increasingly isotropic and are dominated by a

more fundamental, homogeneous, and isotropic energy field state. Therefore, adopting

this physical interpretation, $z \approx 17.73$ serves as a suitable transition criterion from the

complete to simplified distance-specific formula.

This criterion can serve as a crucial guideline for future observational data analyses. The

transition to the simplified distance-specific formula beyond z = 17.73 also suggests a decrease in anisotropy and increased homogeneity in higher-redshift regions. This supports the natural assumption that the universe has a hierarchical structure, sequentially forming gravitational, energy, and electromagnetic fields, and finally, the material universe from a central point. Thus, it is plausible that the universe expanded in a wave-like manner at the speed of light from a central point, sequentially forming space-time, gravitational fields, electromagnetic waves, and matter. Considering this hierarchical structure, it is natural to assume that the universe expanded in a wave-like manner from its center at the speed of light. The phenomenon of expansion at the speed of light is not inconsistent with the theory of relativity. Accordingly, the CMB would be located at a redshift of 1100, reached by expansion at the speed of light, and would have continued expanding at this speed, implying that the actual size of the universe is at least twice this distance—over 502 billion light-years.

In summary, the SEFT theory extends the framework of the standard ΛCDM model and may offer new perspectives, particularly for improving the precision of CMB and supernova observational data.

Future research should further validate the model using more extensive cosmological

datasets (such as BAO and galaxy clusters) and perform detailed observations and

analyses around the cosmic singularity (central position of the universe) to enhance the

understanding of the fundamental structure of the universe.

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