The Ultimate Evolution of the Universe: Based on ABC Theory of Dark Energy Decay, Proton Decay, and a New Balance Beneath Heat Death

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Abstract:  
Based on Li Zhijun’s ABC theory, this paper proposes a complete dynamical model of the ultimate fate of the universe. The core thesis is that the current accelerated expansion driven jointly by dark energy (DE) and negative mass dark matter (NMDM) is not eternal. The dark energy density is not a true constant but decays slowly due to the quantum tunneling effect of the Higgs field vacuum. Simultaneously, positive mass matter (especially protons) will ultimately decay through a new baryon number violation process. We construct a dynamical model for the dark energy equation of state and a relationship between the proton decay rate and cosmic age . By solving the Friedmann equations with source terms and the matter density evolution equations, we precisely calculate that the universe will enter a “low-temperature equilibrium state” with nearly stagnant expansion and extremely rarefied matter around years from now, with a temperature just above absolute zero (). This state is not a traditional heat death but an eternal and dynamic quantum vacuum dominated by quantum fluctuations and residual dark matter topological defects. The model predicts the frequency redshift of the cosmic microwave background (CMB), the decay of its anisotropies, and the blackbody spectrum form in this final state, providing a conceivable “observational” window to test our theory in the extremely distant future.

Keywords: ABC theory; Ultimate fate of the universe; Dark energy decay; Proton decay; Quantum vacuum; Heat death; CMB evolution

1. Introduction: A Cosmic Vista Beyond Heat Death

The “heat death” outcome under the standard cosmological model is an inert state of eternal expansion, infinite cold, and the dissolution of all ordered structures. However, within the framework of Li Zhijun’s ABC theory, dark energy and matter themselves are dynamic field combinations whose properties may change extremely slowly with the age of the universe. This offers a new possibility for the ultimate fate of the universe: a dynamic, rather than completely static, final state.

1. Theoretical Framework: Dynamic Dark Energy and Unstable Matter

2.1 Dynamical Model of Dark Energy

We propose that dark energy is not a true cosmological constant but is associated with the potential energy of the Higgs field vacuum. This potential energy features a metastable false vacuum, which can transition to the true vacuum via quantum tunneling.

Parameterization of the dark energy equation of state:

where is the scale factor (presently ), and is a small positive parameter (e.g., ), indicating that dark energy very slowly becomes “less like” a cosmological constant ().

The evolution equation for its energy density with the scale factor is:

When , , and decays slightly faster than in the constant case.

2.2 New Mechanism for Proton Decay

In the ABC theory, baryon number conservation may not be absolute. We propose a baryon number violation term induced by quantum gravity effects or interactions with the dark matter sector:

where is the quark field and is the dark matter field. This effective term can lead to proton decay, such as (where is some dark matter particle).

The proton lifetime can be estimated as:

By adjusting the coupling constant , the proton lifetime can be matched to the timescale of cosmic evolution ( years).

1. Revision and Solution of the Cosmological Evolution Equations

3.1 Revised Friedmann Equations

The Friedmann equations incorporating dynamic dark energy and matter decay become:

where is the decay rate of (baryonic) matter,

3.2 Numerical Solution for Long-Term Evolution

We obtained the evolution of the cosmic scale factor over extreme timescales through numerical integration of the above equations.

Results:

1. Slowing of Accelerated Expansion ( yr): The acceleration of expansion gradually decreases due to the slow decay of dark energy density.
2. Stagnation of Expansion ( yr): The Hubble parameter drops to a very low value, and the universe enters a quasi-static state of exponentially slow expansion, , where yr.
3. Exponential Decay of Matter Density ( yr): Proton decay dominates, and the matter density nearly vanishes.
4. The Ultimate Fate of the Cosmic Microwave Background Radiation

CMB photons will faithfully record the entire evolutionary history of the universe until the final state.

4.1 Frequency Redshift and Cooling

The CMB temperature redshifts with cosmic expansion:

where As the cosmic scale factor tends to infinity, However, since the cosmic expansion nearly stagnates after years (), the CMB temperature will approach a non-zero minimum:

This means the universe will not reach absolute “heat” death () but will stabilize at an extremely low temperature.

4.2 Decay of Anisotropies and Homogenization

The CMB anisotropy originates from density perturbations in the early universe. After the expansion nearly stagnates, photons no longer experience significant redshift, and the CMB pattern becomes “frozen.” However, due to processes like proton decay, scattering sources will eventually disappear. The last CMB photons will free-stream eternally, their anisotropic pattern becoming an eternal fossil of the early universe’s state.

4.3 Final Form of the Spectrum

Even at years, the residual CMB photons will maintain their perfect blackbody spectrum shape, as the universe will have reached global thermal equilibrium. Their peak wavelength will be located at:

This extremely long-wavelength, ultra-low-temperature blackbody radiation will be the final relic of the observable universe.

1. The Final State of the Universe: Quantum Vacuum and Topological Fluctuations

When matter has almost entirely decayed and expansion has nearly ceased, the universe is not empty.

1. Residual Dark Matter Topological Structures: Negative mass dark matter may form stable topological defects (e.g., dark strings, dark domain walls), which can exist almost eternally due to topological protection.
2. Quantum Vacuum Fluctuations: The vacuum itself is not absolutely empty. Quantum fluctuations (e.g., the creation and annihilation of virtual particle pairs) will persist, becoming the last “activity” in the universe.
3. Ultra-Low-Energy Cosmological Phenomena: At a temperature of the thermal de Broglie wavelength of any residual particles (e.g., electrons, photons) will reach astronomical scales (), and quantum effects will dominate the largest scales of the universe.

Therefore, the final state of the universe is a “quantum vacuum sea,” dotted with some eternal dark matter topological defects and permeated by an ultra-low-temperature, extremely long-wavelength fossil blackbody radiation. This is a dynamic, quantized final state that transcends the classical concept of heat death.

1. Conclusion and Outlook

Based on the ABC theory, this paper depicts a detailed picture of the ultimate fate of the universe:

1. Dark Energy Decay: Leads to the eventual cessation of the accelerated expansion.
2. Proton Decay: Leads to the dissolution of all material structures on extreme timescales.
3. Low-Temperature Equilibrium: The universe stabilizes at a temperature extremely low but not absolute zero.
4. Quantum Vacuum: The final state of the universe is dominated by quantum fluctuations and topological defects.

Future Work (Theoretical):

1. More precise calculation of the tunneling rate for the dark energy potential .
2. Derivation of the specific form of the baryon number violation operator from more fundamental theories.
3. Investigation of the stability and evolution of residual dark matter topological structures.

Although all this occurs in an unimaginably distant future, constructing such a self-consistent mathematical model allows us to rationally deduce the complete life cycle of the universe from physical principles, thereby deepening our understanding of our place and time in the cosmos.

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