THE STANDARD MODEL OF PARTICLE COSMOLOGY AND ITS UNSOLVED PROBLEMS

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Abstract: Modern cosmology is based on the synthesis of general relativity (GR) and the Standard Model (SM) of particle physics, known as the ΛCDM model. Despite successes in describing the evolution of the Universe, fundamental questions remain: the nature of dark matter and dark energy, the mechanism of cosmic inflation, and the unification of quantum theory with gravity. This work analyzes key aspects of the ΛCDM model, its connection to particle physics, and prospects for addressing unresolved issues.

1. Introduction. Particle cosmology is an interdisciplinary field that studies the evolution of the Universe through the lens of elementary particle physics. The foundation is the ΛCDM model, which includes [1-2]:

▪ Dark matter (26.7% energy density), explaining anomalies in galactic rotation curves;

▪ Dark energy (68.5%), responsible for accelerated expansion;

▪ Baryonic matter (4.8%) and cosmic inflation—rapid expansion in the early stages.

However, the model faces challenges: the absence of direct dark matter detections, uncertainty in the inflation mechanism, and the incompatibility of GR with quantum mechanics [3].

2. Methodology and Key Results [4-5].

2.1. From Newtonian Cosmology to ΛCDM.

Classical Newtonian cosmology, relying on a static Universe model, failed to explain Hubble's observations (1929) of expansion. The solution emerged from Friedmann's equations derived from the Friedmann–Robertson–Walker (FRW) metric:

$$\left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2} + \frac{\Lambda}{3}.$$

where $a(t)$ is the scale factor, ρ is energy density, and Λ is the cosmological constant.

2.2. The Standard Model of Particles and Its Limitations.

The SM describes three of the four fundamental interactions (excluding gravity) via the gauge group, $SU(3) \times SU(2) \times U(1)$. Despite the Higgs boson discovery (2012), the SM fails to explain:

▪ Dark matter: Hypotheses include WIMPs (weakly interacting massive particles) and actions:

▪ Baryon asymmetry: CP-violation in the SM is insufficient to explain matter-antimatter dominance.

2.3. Inflation and Its Problems [6-7].

Inflation solves the horizon and flatness problems by postulating exponential expansion within the first 10^{-32} s. Remaining questions include:

▪ Inflation nature: The scalar field driving inflation remains undetected;

▪ Initial conditions: The trigger mechanism for inflation is unknown.

2.4. Beyond the Standard Model.

▪ Supersymmetry (SUSY): Predicts SM particle partners but lacks confirmation at the LHC;

▪ Grand Unified Theories (GUTs): Unify interactions at 10^{16} GeV energies but predict unobserved proton decay.

3. Unsolved Problems and Prospects [8-11].

▪ Dark matter: Ongoing searches in XENONnT and LZ experiments.

▪ Quantum gravity: String theory and loop quantum gravity are leading candidates.

▪ Inflation: Data from the JWST telescope and LISA mission may clarify early expansion [12].

4. Conclusion. The ΛCDM model successfully describes the Universe's large-scale structure but requires extensions to resolve fundamental issues. Integrating new theories (SUSY, GUTs) with next-generation observatories (JWST, LISA) will advance the quest for a complete quantum gravity theory.

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