A Cosmological Study Based on Variable Fundamental Natural Constants

Bekithemba Sibanda
National University of Science and Technology (NUST), Zimbabwe
Department of Applied Physics

Research Question: Do fundamental natural constants change over cosmic time? If so, what observational consequences does this have for the existing cosmological models?

Introduction: The Crisis in Modern Cosmology

- The ΛCDM model faces significant challenges, most notably the **Hubble Tension**: a 5σ discrepancy between early and late universe measurements of H_0
- **Early Universe (Planck CMB)**: 67.4 ± 0.5 km/s/Mpc
- **Late Universe (SH0ES)**: 73.04 ± 1.04 km/s/Mpc
- Additional anomalies: Lithium problem, α-dipole, planetary orbit anomalies
- **Core hypothesis**: Fundamental constants (α, G, c) may vary over cosmic time and space

The Hubble Tension

Source	H_0 (km/s/Mpc)
Planck CMB (Early Universe)	67.4 ± 0.5
SH0ES (Late Universe)	73.04 ± 1.04

Difference: 5.6 **km/s/Mpc**
Statistical Significance: $> 5\sigma$
(Probability of random chance: $<$ 1 in 3.5 million)

- **Early Universe measurements** (CMB, ACT, DES, WMAP9) prefer lower H_0
- **Late Universe measurements** (SH0ES, H0LiCOW) prefer higher H_0
- This $> 5\sigma$ discrepancy cannot be explained by known systematics

Theoretical Innovation

Generalized FLRW Metric:

$$ds^2 = a_t^2(r)c^2dt^2 - a_s^2(t)\left[\frac{dr^2}{1-k(r/d_H)^2} + r^2 d\Omega^2\right]$$

- $a_s(t)$: Standard spatial scale factor (cosmic expansion)
- $a_t(r)$: Temporal scale factor introducing **Spatial Time-Flow Anisotropy**
- *Key departure:* Cosmic time flow depends on spatial position
- Provides geometric mechanism for apparent variation of constants

Fundamental Constants as Dynamical Fields:

- Treat α, G, c, $\hbar$ as dynamical fields
- $G = G(t,r)$, $c = c(t,r)$, $\alpha = \alpha(t,r)$, $\hbar = \hbar(t,r)$

Invariant Planck Scale Hypothesis:

$$\ell_P = \sqrt{\frac{G\hbar}{c^3}} = \text{constant}$$

Leads to coupling equation:

$$\frac{\Delta G}{G} + \frac{\Delta\hbar}{\hbar} - 3\frac{\Delta c}{c} = 0$$

Constants cannot vary independently—they must vary in a coordinated manner.

Methodology

Research Workflow:

1. **Theory:** Develop model from modified FLRW metric
2. **Equations:** Derive modified Friedmann equations
3. **Simulation:** Implement in Python/Mathematica
4. **Data:** Compare with Planck, SH0ES, quasar spectra
5. **Validation:** Statistical analysis (χ^2, likelihood)
6. **Predictions:** Generate testable forecasts

Modified Friedmann Equation:

$$\left(\frac{\dot{a}_s}{a_s}\right)^2 = \frac{8\pi G(t)}{3c(t)^2}\rho + (\text{terms from varying constants})$$

Parameterization of Variation:

- **Temporal:** $G(t) = G_0\left(\frac{a_s(t)}{a_s(t_0)}\right)^{\beta_G}$ (β_G to be constrained)
- **Spatial:** $G(r) = G_0\left(1 + \gamma_G \frac{r}{d_H}\right)$ (γ_G to be constrained)
- Similar parameterizations for $\alpha(t,r)$ and $c(t,r)$

Expected Results & Predictions

Prediction	ΛCDM	Our Model
H_0 (km/s/Mpc)	Discrepancy	Consistent
Primordial ^{7}Li	Overpredicted	Resolved
α-dipole	Anomaly	Explained
Modified CMB spectrum	—	Predicted
Spatial variation in constants	—	Predicted