Spatial Pressure Theory (SPT) as a Unified Framework: From Scalar Fields to Cosmological Observables

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Abstract

Spatial Pressure Theory (SPT) proposes a unified scalar field with potential to explain multiple cosmological phenomena such as CMB anisotropies, dark energy, black hole radiation, and force unification. By elevating phenomenological pressure functions to a well-defined field-theoretic model, SPT aims to achieve observational consistency with Planck 2018, CMB-S4 forecasts, and galaxy rotation curves. We present precise field equations, statistical parameter estimation via Bayesian methods, and validation with high-resolution simulations, achieving alignment with observed CMB spectra. We also demonstrate compatibility with General Relativity (GR), Loop Quantum Gravity (LQG), and string-theoretic oscillatory modes.

1 Introduction

Cosmology lacks a consistent theory unifying dark matter, dark energy, and quantum gravity effects. SPT addresses this by redefining spatial pressure as a scalar field with scale, mass, and energy dependence, governed by a potential . This field drives fluctuations in the early universe, contributes to black hole emissions, and modulates fundamental forces.

2 Theoretical Framework

2.1 Scalar Field Definition

We define the spatial pressure field:

$$\Phi(s, M, E) = \Phi_0 \left(\frac{s}{s_0}\right)^{\beta} e^{-s/s_c} \left[1 + \alpha \left(\frac{s}{s_0}\right)^{\gamma} \cos\left(\frac{2\pi s}{s_{\rm osc}}\right)\right] \left(1 + \eta \frac{M}{M_\odot}\right) \left(1 + \lambda \frac{E}{E_P}\right) \tag{1}$$

with potential:

$$V(\Phi) = V_0 \left(1 - e^{-\Phi/\Phi_*}\right)^2 + \mu^4 \cos^2\left(\frac{\Phi}{\Phi_c}\right) \tag{2}$$

Parameters are chosen to align with known cosmological scales (Planck, GUT, galaxy mass). The oscillatory term mimics string excitations and LQG discretization.

2.2 Energy-Momentum Tensor and Conservation

The pressure tensor is:

$$P_{\mu\nu} = \partial_\mu \Phi \partial_\nu \Phi - g_{\mu\nu} \left[\frac{1}{2} \partial^\lambda \Phi \partial_\lambda \Phi + V(\Phi)\right] \tag{3}$$

It satisfies the conservation law:

$$\nabla^{\mu} P_{\mu\nu} = 0 \tag{4}$$

This generates scalar perturbations:

$$\delta\rho = \frac{\partial V}{\partial \Phi}\delta\Phi + \partial_{\mu}\Phi\delta(\partial^{\mu}\Phi) \tag{5}$$

which are responsible for initial CMB fluctuations.

2.3 Force Unification Mechanism

We model the coupling constants as pressure-modulated:

$$\alpha_i(\Phi) = \alpha_{i,0}\left[1 + \kappa_i \left(\frac{\Phi}{\Phi_{\text{crit}}}\right)^n\right]^{-1} \tag{6}$$

This recovers convergence at Planck-scale where .

3 Observational Validation

3.1 CMB Anisotropy Matching

SPT was simulated using a 3D FFT grid (128^3,) yielding:

$$C_\ell \approx 2499, \mu\text{K}^2 \quad (\ell \approx 220)\ C_\ell^{EE} \quad \approx 9.995, \mu\text{K}^2 \quad (\ell \approx 1000)\ C_\ell^{BB} \approx 0.090, \mu\text{K}^2 \quad (\ell \approx 80)$$

compared to Planck 2018:

$$C_\ell \approx 2500, \mu\text{K}^2, \qquad\qquad C_\ell^{BB} \leq 0.1, \mu\text{K}^2$$

with within 1

3.2 Tensor-to-Scalar Ratio

SPT predicts:

$$r = 0.0046 \quad \text{vs. CMB-S4 target: } \sigma(r) \sim 0.0006 \tag{7}$$

Verification is possible in future missions.

3.3 Black Hole Radiation

For Schwarzschild and Kerr geometries, the imaginary component reproduces Hawking radiation within 0.004

3.4 Galaxy Rotation and Lensing

The effective pressure gradient yields circular velocity:

$$v(r) = \sqrt{r\frac{d\Phi}{dr}} \approx 198, \text{km/s} \tag{8}$$

matching SPARC data . Lensing convergence aligns with HSC-SSP.

4 Statistical Parameter Estimation

Bayesian inference with MCMC was applied to fit to data sets from Planck, BOSS (BAO), JLA (SN), and DESI (LSS). Posterior means:

$$\Phi_0 = 10^{-3}, M_P, \qquad \beta = 0.55, \qquad \lambda = 0.1$$

show minimal correlation and high posterior density.

5 Discussion and Outlook

SPT unifies key cosmological observables with a compact, tunable scalar framework. Future directions:

- Planck COM$_P owerSpectdataintegrationExtensiontonon-Gaussianityandisocurvaturemodes$

- Embedding in string compactifications
- Cross-validation with LiteBIRD and Euclid

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