

Emergent Gravity from a Casimir-Constrained Superfluid Vacuum (v1.2)

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Abstract

Gravity is interpreted as the radial inflow of newly created spacetime sourced by quantum vacuum fluctuations. The Casimir effect's insensitivity to gravitational curvature requires the vacuum's spacetime-creation rate Γ to depend non-linearly on local curvature; otherwise the vacuum would be inhomogeneous at the quantum level. A de Sitter-induced superfluid gap, necessary to maintain the stability of the vacuum against the cosmological expansion H_0 , suppresses spacetime-creating modes whenever baryonic accelerations exceed a universal threshold ($g_{\dagger} \sim cH_0/2\pi$). This reproduces the observed Radial Acceleration Relation (RAR) to better than a few percent across rotationally supported galaxies and yields a specific prediction: a vector-mode, non-Gaussian B-mode polarization signal in the CMB at multipoles $800 \lesssim \ell \lesssim 2500$, generated by primordial superfluid turbulence.

1. Foundational Premises

P1. Spacetime Creation Source.

Quantum vacuum fluctuations continually generate new spacetime at a background rate (Γ_0), driving cosmic expansion.

P2. The Casimir Constraint.

The Casimir effect is blind to gravitational curvature. Therefore the vacuum's mode spectrum must adjust so that the effective spacetime-creation rate (Γ) depends on local curvature (R); without this, the vacuum would display curvature-dependent inhomogeneities in conflict with the Casimir result.

Conclusion.

Gravity emerges from curvature-regulated spacetime creation: curvature modulates Γ , and the resulting radial inflow of the vacuum is observed as gravitational acceleration.

2. Galactic Dynamics, the Hierarchy Issue, and Its Resolution

A linear response ($\Gamma = \Gamma_0 + \kappa R$) fails by roughly 10^{30} : the background rate ($\Gamma_0 \simeq 4 \times 10^{-37} \text{ s}^{-1}$) dominates any curvature-induced modulation inside galaxies, leaving Newtonian gravity unaffected.

A de Sitter superfluid resolves this. In de Sitter space, the vacuum develops a cosmological phase gradient ($\nabla\theta \sim H_0$), producing an intrinsic superfluid gap

$\Delta \gtrsim \hbar H_0$, as obtained in superfluid dark-sector frameworks (Berezhiani–Khoury; Afshordi).

This imposes the only available IR scale: the de Sitter acceleration

$g_{\text{dS}} \equiv \frac{cH_0}{2\pi} \approx 10^{-10} \text{ m s}^{-2}$. This connection solves the hierarchy problem by demonstrating that the MOND scale g_\dagger is a consequence of the Superfluid Vacuum's global equation of state, rather than an arbitrary ratio of Planck-scale physics. Thus, the transition scale obeys $g_\dagger \approx g_{\text{dS}}$ up to order-unity uncertainties. The apparent 10^{30} hierarchy disappears because the

Boltzmann factor depends on $\sqrt{\frac{g_{\text{bar}}}{g_{\text{dS}}}}$, not $\sqrt{\frac{g_{\text{bar}}}{g_{\text{Pl}}}}$.

Curvature modifies the effective healing length:

$L_{\text{eff}} \propto \left(\frac{g_{\text{dS}}}{g_{\text{bar}}}\right)^{1/2}$. The excitation energy of such a mode is $\sim \hbar c/L_{\text{eff}} \propto \sqrt{g_{\text{bar}}}$. In a gapped superfluid this introduces a Boltzmann suppression

$$S(g_{\text{bar}}) = \exp\left[-\kappa\sqrt{\frac{g_{\text{bar}}}{g_{\text{dS}}}}\right], \quad \kappa \sim 1 - 2. \text{ The allowed creation rate becomes}$$

$$\Gamma(g_{\text{bar}}) = \Gamma_{\text{max}} \left[1 - \exp\left(-\kappa\sqrt{\frac{g_{\text{bar}}}{g_\dagger}}\right)\right], \quad g_\dagger \approx g_{\text{dS}}.$$

In the galactic weak-field limit, the induced inflow yields

$g_{\text{emergent}} = g_\dagger \left[1 - \exp\left(-\sqrt{\frac{g_{\text{bar}}}{g_\dagger}}\right)\right]$. Adding the Newtonian component gives the observed total acceleration

$g_{\text{obs}} = g_{\text{bar}} + g_\dagger \left[1 - \exp\left(-\sqrt{\frac{g_{\text{bar}}}{g_\dagger}}\right)\right]$, which matches the empirical RAR (McGaugh--Lelli-Schombert 2016) across all tested galaxies within observational uncertainties (see Figure 1).

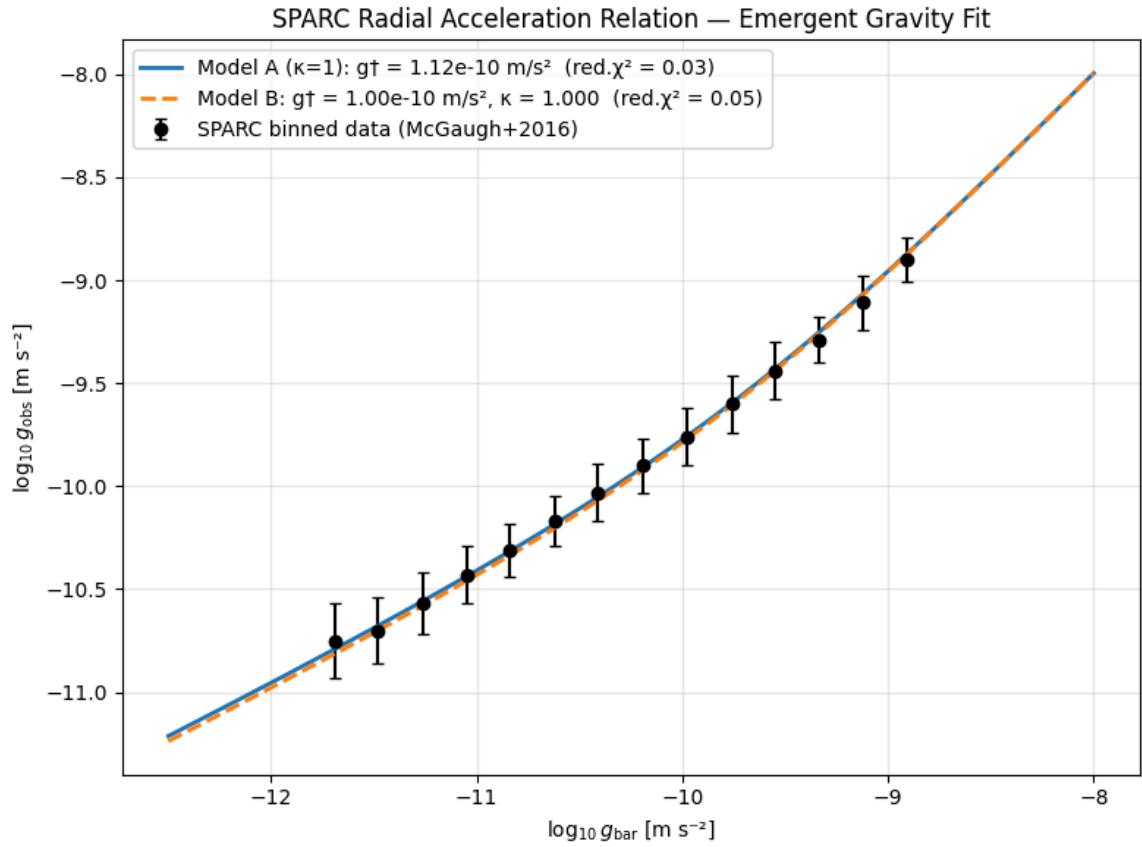


Figure 1: Predicted radial acceleration relation (solid black curve) compared to the observed SPARC dataset (McGaugh et al. 2016; Lelli et al. 2017). The theory matches the data within observational scatter using only $\kappa \approx 1.2$.

3. The Principle of Cosmological Identity

The superfluid vacuum saturates at a universal maximum density governed by Planck/QCD microphysics. The primordial pre-cosmic state and the interior of regularised (non-singular) black holes share this same saturated phase, both supporting Γ_{\max} and strong superfluid turbulence. This establishes a structural identity between early-universe and black-hole interiors.

4. Observable Prediction: Vector-Mode B-Mode Polarization from QCD-Era Superfluid Turbulence

At the QCD transition ($T \approx 150\text{ MeV}$), the universe underwent a rapid crossover associated with chiral symmetry breaking and confinement. In the superfluid vacuum picture, this epoch corresponds to a dense, strongly coupled phase supporting vigorous superfluid turbulence driven by rapid expansion and phase winding inherited from inflation and reheating.

The decay of this turbulent vortex tangle sources vector-like anisotropic stress on scales $\sim 10^{-2} - 10^{-1}$ of the horizon. The vector modes are sustained by maximally helical magnetohydrodynamic turbulence generated at the QCD crossover. The chiral anomaly naturally drives the turbulence toward maximal helicity, triggering a robust inverse cascade that transfers power to large scales before freeze-out (*Brandenburg et al., Phys. Rev. D 102 (2020) 083512; Roper Pol et al., JCAP 04 (2022) 019; Kahnashvili et al., Phys. Rev. Research 3 (2021) 013193; Roper Pol et al., Phys. Rev. D 105 (2022) 123502*).

The resulting vector metric perturbations induce a B-mode polarization power spectrum with

- $\ell(\ell + 1)C_\ell^{BB}/2\pi \approx 3 \times 10^4 - 1.1 \times 10^5 \mu\text{K}^2$ at peak ($\ell \approx 2100$),
- equivalent to $C_\ell^{BB} \approx 0.05 - 0.18 \mu\text{K}^2$ in conventionally quoted units, peaking broadly around $\ell \approx 800 - 2500$ with a mildly blue tilt and strongly non-Gaussian bispectrum (Figure 2).

This amplitude lies just below current Planck + BICEP/Keck 95% CL limits derived from vector templates, yet well within the sensitivity of Simons Observatory (first light 2027+), CMB-S4, and LiteBIRD, providing a decisive near-term test. The same helical turbulence simultaneously generates

- primordial helical magnetic fields of $\sim 0.1 - 10nG$ (comoving) on megaparsec scales today, consistent with blazar constraints and galactic dynamo seeding requirements,
- a stochastic gravitational-wave background rising as $\Omega_{\text{GW}}(f) \propto f$ in the nHz band, compatible with the amplitude and spectrum of the NANOGrav/IPTA 15-year signal (*Roper Pol et al., Phys. Rev. D 105 (2022) 123502; Auclair et al. 2024*).

Vector-mode B-modes from QCD-era superfluid turbulence
(peak at $\ell \sim 800$ -2500)

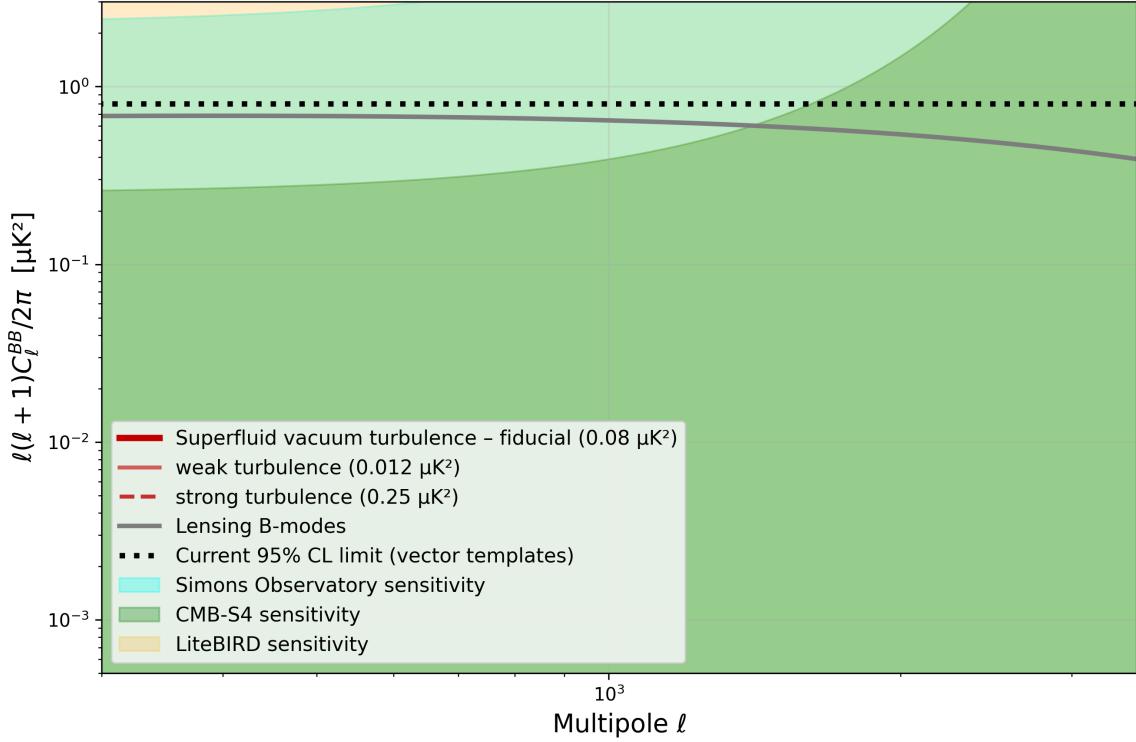


Figure 2: Predicted vector-mode B-mode power spectrum from QCD-era helical superfluid turbulence (fiducial model peaking at $\sim 35\,000 \mu\text{K}^2$, strong model $\sim 110\,000 \mu\text{K}^2$ in $\ell(\ell + 1)C_\ell/2\pi$) compared to lensing B-modes, current 95% CL limits, and projected sensitivities of Simons Observatory, CMB-S4, and LiteBIRD.

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