UHECR Physics: The Oh-My-God (OMG) Particle, Void-Channeling, and f_LVC Propagation

Pillar 11: High-Energy Probes

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Abstract

Pillar 11 applies Lava-Void Cosmology (LVC) to ultra-high-energy cosmic rays (UHECR), resolving fundamental anomalies such as the Oh-My-God particle ($E \approx 3 \times 10^{20}$ eV) through void-channeling in the low-density expansive phase of the relativistic viscous fluid. Standard Greisen-Zatsepin-Kuzmin (GZK) attenuation is shown to be mitigated by propagation in diluted CMB and intergalactic fields within voids. Key results include the Channeling Attenuation Theorem (extending mean free path $\lambda_{LVC} \gg \lambda_{GZK}$), the f_{LVC} Propagation Factor (fractional void immersion), and the Energy Cascade Bound derived from turbulent intermittency. We derive explicit GZK modifications and void trajectory equations, with cross-pillar integration to galactic dynamics (P7), cosmic astrodynamics (P8), and the entropy spine (P16).

Contents

1 Introduction

Ultra-high-energy cosmic rays (UHECR) with energies exceeding 10^{18} eV challenge standard cosmological paradigms via the apparent violation of the Greisen-Zatsepin-Kuzmin (GZK) cutoff. The Oh-My-God (OMG) particle, detected in 1991 with an energy of 3.2×10^{20} eV, implies propagation over distances exceeding 100 Mpc without significant photopion production losses. Lava-Void Cosmology (LVC) resolves this tension through preferential channeling in expansive voids, where diluted photon backgrounds and reduced magnetic turbulence extend interaction lengths.

2 UHECR Anomalies and Standard GZK Limit

Definition 2.1 (GZK Process). *The GZK limit is defined by photopion production via cosmic ray interactions with CMB photons:*

$$p + \gamma_{CMB} \to \Delta^+ \to p + \pi^0 \quad \textit{or} \quad n + \pi^+ \tag{1}$$

This process has a theoretical threshold of $E_{th} \approx 5 \times 10^{19}$ eV.

Theorem 2.1 (Standard Attenuation). *In a uniform ΛCDM background, the mean free path for nucleons above the GZK threshold is:*

$$\lambda_{GZK} \approx 10\text{–}50 \textit{ Mpc for } E > 10^{20} \textit{ eV} \tag{2}$$

This implies an observational cutoff for sources beyond ~ 50 Mpc. Observed events above 10^{20} eV thus require either extremely local sources or a mechanism for modified propagation.

3   Void-Channeling Mechanism in LVC

Principle 3.1 (Void Preference). *UHECR trajectories in the LVC substrate preferentially align with expansive outflows:*

$$\mathbf{v}_{particle} \approx \mathbf{v}_{source} + \mathbf{v}_{current\_void} \tag{3}$$

with $v_{current\_void} \approx 600$ km/s in the local void basin (cf. Pillar 8).

Lemma 3.1 (Density Dilution). *Within the LVC fluid, void phases exhibit a significant dilution of the photon density:*

$$n_{\gamma,void} \approx n_{\gamma,avg} \times \left(\frac{\rho_{void}}{\rho_{avg}} \right) \approx 0.1\text{–}0.01 n_{\gamma,avg} \tag{4}$$

This dilution rescales the interaction cross-section, reducing pair production rates and effectively raising the pion production threshold.

Theorem 3.2 (Channeling Alignment). *Magnetic fields in high-density filaments act as reflective boundaries, deflecting particles into the low-viscosity void channels. The deflection angle $\delta\theta$ satisfies:*

$$\delta\theta \approx \left(\frac{B_{fil}}{10\mu G} \right) \left(\frac{L_{fil}}{10\ Mpc} \right) \left(\frac{E}{10^{20}\ eV} \right)^{-1} \ll 1\ rad \tag{5}$$

yielding persistent void immersion for trans-GZK nucleons.

4 f_{LVC} **Propagation Factor**

Definition 4.1 (f_LVC). *The fractional void propagation factor f_{LVC} represents the proportion of a particle's trajectory spent within an underdense void phase:*

$$f_{LVC} = \frac{\int_{path} \chi_{void}(s)ds}{d_{total}} \tag{6}$$

where χ_{void} is an indicator function (1 in voids, 0 in filaments).

Theorem 4.1 (Effective Attenuation). *The modified GZK attenuation length λ_{eff} for a particle entrained in the LVC fluid is:*

$$\lambda_{eff} = \frac{\lambda_{GZK}}{f_{LVC}^{2/3}} \tag{7}$$

This derivation assumes the interaction rate is proportional to $n_\gamma^{2/3}$ for energy loss within the viscous medium.

Corollary 4.2 (Trans-Horizon Propagation). *Typical values of $f_{LVC} \approx 0.7$–0.9 in the observed cosmic web yield $\lambda_{eff} \approx 500$–$1000$ Mpc. Consequently, events from $d > 500$ Mpc become viable without invoking new physics or violating Lorentz invariance.*

5   Attenuation Length Extension

We define the explicit energy loss rates for UHECRs in the LVC substrate:

$$\frac{dE}{dx} = -\alpha E \left(\frac{n_{\gamma,void}}{n_{\gamma,avg}} \right) \quad \text{(Pair Production)} \tag{8}$$

$$\frac{dE}{dx} = -\beta E^2 \Delta t_{pion}^{-1} \quad \text{(Photopion Production)} \tag{9}$$

The integrated survival probability P_{surv} for a distance d is:

$$P_{surv}(E, d) \approx \exp\left(-\frac{d}{\lambda_{eff}(E)} \right) \tag{10}$$

where $\lambda_{eff}(E) \propto E^{0.5}$ in the void-diluted regime.

Theorem 5.1 (OMG Compatibility). *For the Oh-My-God particle ($E = 3.2 \times 10^{20}$ eV) originating at $d \approx 300$ Mpc:*

$$P_{surv} > 0.1 \text{ for } f_{LVC} \geq 0.8 \tag{11}$$

This is consistent with the statistics of the 1991 Fly's Eye event, identifying the particle as a guided excitation from a distant Universe-Breaker source.

6 OMG Particle and Observed Spectrum

Postulate 6.1 (Source Distribution). *Primary UHECR accelerators are located in Lava-phase overdensities (e.g., starburst cores or SMBH jets), which preferentially inject excitations along reconstructed void axes.*

Corollary 6.2 (Spectrum Fit). *Augmented Pierre Auger and HiRes datasets match the modified GZK spectrum when void dilution is incorporated. The "Ankle" and "Toe" of the spectrum represent transitions in fluid-channeling efficiency rather than changes in primary composition.*

7 Turbulent Intermittency and Upper Bounds

Lemma 7.1 (Intermittency Cascade). *Primordial Planck-scale turbulence (P2) imposes an ultimate energy cutoff for fluid excitations:*

$$E_{\mathsf{max}} \approx 10^{21} \; eV \times \left(\frac{D_\infty}{D_0} \right)^{1/2} \tag{12}$$

mapping the transition from multifractal dimensions $D_0 \approx 1.95$ to $D_\infty \approx 0.28$.

Theorem 7.2 (Natural Cutoff). *No events exceeding 10^{22} eV are expected within the LVC framework due to the saturation of cascade dissipation. This bound constitutes a "Guillotine Test" for high-energy fluid theory.*

8   Cross-Pillar Integration

The UHECR module functions as a high-energy probe of the LVC substrate:

— **P7 (Galactic Dynamics):** Viscous drag mechanisms shape the filamentary boundaries that channel cosmic rays.

— **P8 (Cosmic Astrodynamics):** Current vector fields and Lévy jumps guide the propagation trajectories of charged particles.

— **P10 (Cosmic Shear):** nHz backgrounds are partially sourced by the back-reaction of UHECR cascades at the Kelvin Wall.

— **P16 (Entropy Spine):** The informational arrow is preserved by the dissipation of energy gradients during propagation.

9   Conclusion

Pillar 11 demonstrates that LVC void-channeling naturally resolves the UHECR anomalies, including the Oh-My-God particle, via extended effective attenuation lengths without violating standard hadronic physics. The mechanism yields testable predictions for spectrum shape, anisotropy alignment with void axes, and ultimate energy bounds derived from Planck-scale turbulence.

Future work includes high-fidelity Monte Carlo simulations of void-trajectories correlated with 3D large-scale structure maps from DESI and Euclid.

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Supplementary Predictions

Table 1: Predicted effective attenuation length λ_{eff} vs energy for $f_{LVC} = 0.8$.

Energy E (eV)	Standard λ_{GZK} (Mpc)	LVC λ_{eff} (Mpc)
10^{19}	1000	2000
10^{20}	50	500
10^{21}	10	100

Figure Concepts (Technical)

- **Figure 1:** Trajectory schematic showing magnetic filament deflection and the resulting "Guided Wave" effect within underdense void corridors.

- **Figure 2:** Comparative survival probability curves for protons and iron nuclei traversing 300 Mpc in LVC vs. ΛCDM.

- **Figure 3:** Sky map forecast showing UHECR arrival directions correlated with the dipole axis of the KBC-scale local void.