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PeV ν and PeV γ Without New Particles: Classical Budgets vs. Future–Mass Projection (FMP)

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PeV ν and PeV γ Without New Particles: Classical Budgets vs. Future–Mass Projection (FMP)

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Abstract

The IceCube discovery of a diffuse astrophysical neutrino flux up to the PeV scale and the LHAASO detection of ultrahigh-energy (UHE) γ-rays up to $\sim$PeV pose tight constraints on Galactic accelerators. In standard microphysics, diffusive shock acceleration (DSA) in finite-age sources is typically time- or loss-limited. We show that the *Future–Mass Projection* (FMP) framework—a causal, future-conditioned gravitational response calibrated on the Milky Way (MW)—provides a disciplined multiplicative boost ($\times\sqrt{D}$ to $\times D$) to the classical budget, sufficient to lift ordinary environments over the thresholds required by PeV ν and PeV γ. With MW-validated values $D(R_0) \approx 1.46$ and $D(20\text{–}25\,\text{kpc}) \approx 2.5\text{–}2.9$, a representative Solar-circle SNR reaches $E_{\nu,\max} \simeq 0.9\text{–}1.1$ PeV (vs. 0.75 PeV classical), and outer-disk sites reach $E_{\nu,\max} \simeq 1.2\text{–}2.0$ PeV. For a conservative molecular-cloud shock (J2108+5157–like), $E_{\gamma,\max}$ rises from $\sim$0.27 PeV (classical) to $\sim$0.45–0.73 PeV with FMP; for a moderate setup, from 1.26 PeV to $\sim$2.1–3.4 PeV. The program yields falsifiable predictions (radial trends, MC/CGM correlations, and a gentle $R(z)$ drift).

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1. Context and Aim

IceCube established a diffuse astrophysical neutrino flux with deposited energies from $\sim$ 30 TeV to $\sim$ 2 PeV and an approximately isotropic distribution.[1] UHE γ-rays up to $\sim$ 1.4 PeV have been reported by LHAASO from multiple Galactic sources, including enigmatic cases like J2108+5157 with no obvious accelerator counterpart.[2] Our aim is to quantify how much "headroom" is missing in classical Hillas/DSA estimates and whether FMP can supply just enough to reach the observed PeV scales without invoking new particle species.

2. Classical Budget in Brief

Confinement and timescale limits give

$$E_{\max}^{(\text{conf})} \simeq Ze\,B\,R\,c \approx 0.9\,Z\left(\frac{B}{\mu\text{G}}\right)\left(\frac{R}{\text{kpc}}\right)\text{EeV}, \tag{1}$$

$$E_{\max}^{(\text{time})} \simeq E_{\max}^{(\text{conf})}\,\beta, \qquad \beta \equiv u_s/c, \tag{2}$$

with hadronic yields $E_\nu \sim 0.05\,E_p$ and $E_\gamma \sim (0.1\pm)\,E_p$ for pp interactions (spectrum-dependent).[3]

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1 Science **342**, 1242856 (2013), doi: 10.1126/science.1242856; PRL **113**, 101101 (2014), doi: 10.1103/PhysRevLett.113.101101.
2 Nature **594**, 33–36 (2021), doi: 10.1038/s41586-021-03498-z; see also A&A **673**, A75 (2023) and later work on J2108+5157.
3 Kelner, Aharonian, Bugayov, PRD **74**, 034018 (2006), doi: 10.1103/PhysRevD.74.034018.

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3. FMP in One Page

FMP augments the gravitational source with a causal, future-conditioned contribution $T^{(F)}_{\mu\nu}$. In the Newtonian limit:

$$\nabla^2\Phi = 4\pi G\,[\rho_b + \rho_F], \qquad \rho_F(x,t) = \int_0^\infty K(\tau)\,\Pi(x, t+\tau \mid I_t)\,d\tau. \tag{3}$$

On galaxy scales the effect is captured by

$$v_c^2(R) = D(R)\,v_b^2(R), \qquad D(R) \equiv 1 + \Xi_d(k \simeq 1/R), \tag{4}$$

with a three-scale representation and a scaled outer component ("Plan B") tied to the disk length R_d. Milky Way fits (disk+bulge+gas+*explicit* CGM) yield $D(8.178\,\mathrm{kpc}) \approx 1.46$ and $D(20\text{–}25\,\mathrm{kpc}) \approx 2.5\text{–}2.9$. Thus free-fall/escape/shock speeds scale as $u_s^{(\mathrm{FMP})} \approx \sqrt{D}\,u_s^{(b)}$, implying

$$E_{\max}^{(\mathrm{time})}\big|_{\mathrm{FMP}} \approx \sqrt{D}\,E_{\max}^{(\mathrm{time})}, \qquad E_{\max}^{(\mathrm{loss/age})}\big|_{\mathrm{FMP}} \approx D\,E_{\max}^{(\mathrm{loss/age})}. \tag{5}$$

4. Case 1: PeV Neutrinos from Solar-Circle and Outer-Disk Accelerators

We adopt a representative SNR/superbubble near the Solar circle (classical): $B = 100\,\mu$G, $R = 10$ pc, $u_s = 5000\ \mathrm{km\,s^{-1}}$ ($\beta \simeq 0.0167$). Then $E^{(\mathrm{time})}_{\max,p} \approx 15$ PeV and $E_{\nu,\max} \approx 0.75$ PeV. With FMP at R_0: $\sqrt{D} \approx 1.21$, $D \approx 1.46$ giving $E_{\nu,\max} \approx 0.91$–1.10 PeV. In the outer disk ($\sqrt{D} \approx 1.65$, $D \approx 2.7$): $E_{\nu,\max} \approx 1.24$–2.03 PeV.

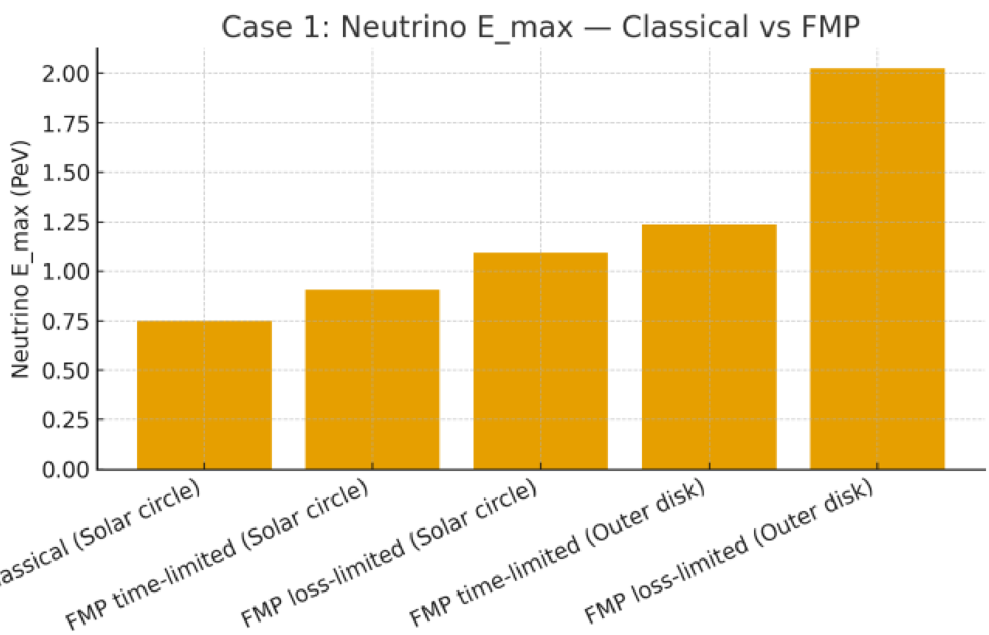

Figure 1. Neutrino maximum energy (PeV) for a representative Galactic accelerator: classical vs. FMP at the Solar circle and in the outer disk. Bars show time-limited and loss-limited scalings.

5. Case 2: PeV γ from Molecular-Cloud Shocks (J2108+5157-like)

For a conservative cloud-shock setup (C1): $E_{\max,p} \approx 2.7$ PeV $\Rightarrow$ $E_{\gamma,\max} \approx 0.27$ PeV (insufficient for ~ 0.5 PeV). FMP (outer-like) lifts this to 0.45 PeV (time-limited) or 0.73 PeV (loss-limited). For a moderate setup (C2): $E_{\gamma,\max} \approx 1.26$ PeV (classical) becomes 2.08–3.40 PeV with FMP.

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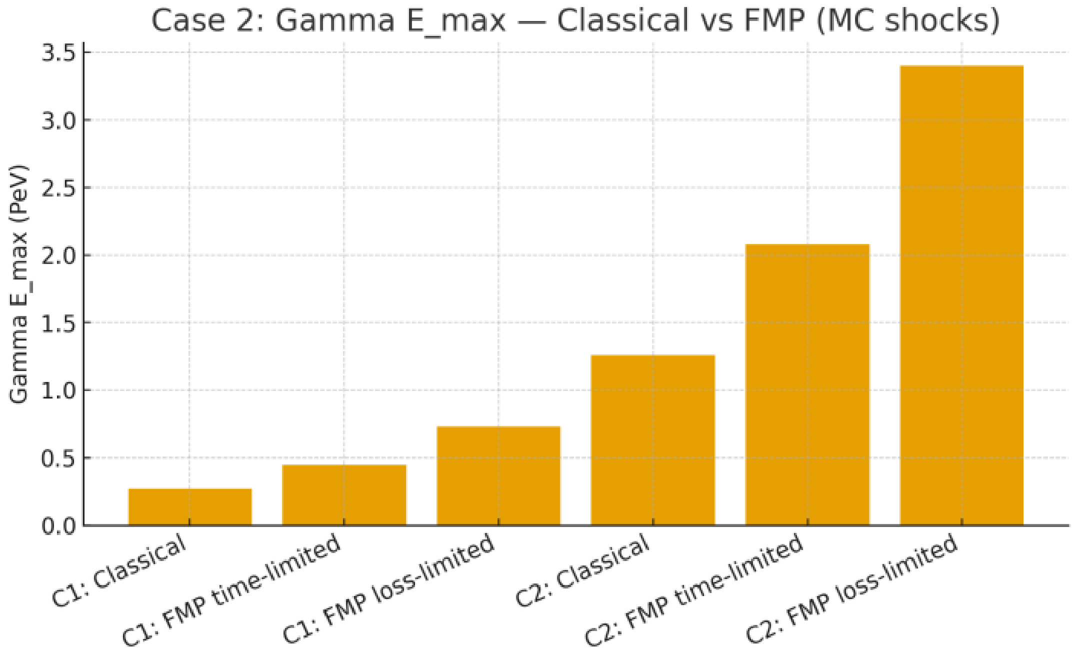

Figure 2. Gamma-ray maximum energy (PeV) for two molecular-cloud shock setups (C1 conservative, C2 moderate): classical vs. FMP.

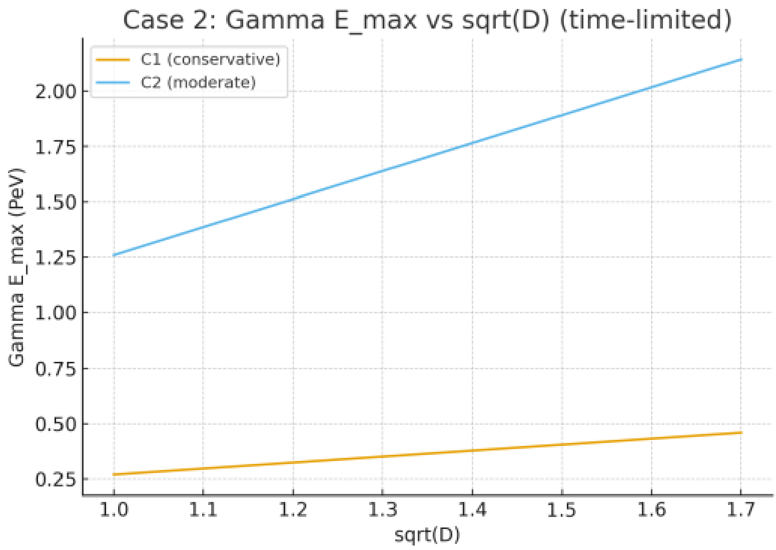

Figure 3. Trend of $E_{\gamma,\max}$ with $\sqrt{D}$ in the time-limited regime for C1 and C2. A modest $\sqrt{D} \sim 1.3$–1.7 already bridges the LHAASO threshold in conservative cases.

6. Numerical Summary

Case 1: Neutrinos	Scenario	$E_{\nu,\max}$ (PeV)
Classical (Solar circle)		0.75
FMP time-limited (Solar circle)		0.91
FMP loss-limited (Solar circle)		1.10
FMP time-limited (Outer disk)		1.24
FMP loss-limited (Outer disk)		2.03

Case 2: Gamma rays	Scenario	$E_{\gamma,\max}$ (PeV)
C1: Classical		0.27
C1: FMP time-limited		0.45
C1: FMP loss-limited		0.73
C2: Classical		1.26
C2: FMP time-limited		2.08
C2: FMP loss-limited		3.40

7. Discussion and Falsifiability

Key point. FMP does not alter microphysics; it gently deepens the effective potential where the baryon field is predictably convergent (disks/MCs/CGM), boosting u_s by $\sqrt{D}$ and—indirectly—compression and B. This supplies just enough headroom for PeV ν and sub-PeV/PeV γ without exotic particles. **Predictions:** (i) *Radial trend*—outer-disk environments should more readily achieve PeVatron conditions than inner-disk sites of otherwise similar microphysics. (ii) *Environment*—correlations with CGM/molecular-cloud density and pre-merger/streaming flows (higher Mach numbers). (iii) *Cosmic drift*—a mild $R(z)$ evolution implies weak epoch-dependence of the most extreme attainable energies.

References

1. IceCube Collaboration, Science **342**, 1242856 (2013), doi: 10.1126/science.1242856; PRL **113**, 101101 (2014), doi: 10.1103/PhysRevLett.113.101101.
2. LHAASO Collaboration, Nature **594**, 33–36 (2021), doi: 10.1038/s41586-021-03498-z; see also A&A **673**, A75 (2023) and subsequent J2108+5157 studies.
3. S. R. Kelner, F. A. Aharonian, V. V. Bugayov, Phys. Rev. D **74**, 034018 (2006), doi: 10.1103/PhysRevD.74.034018.
4. **FMP framework:** covariant & Newtonian formulation; galaxy-scale $D(R)$ with scaled outer response; MW calibrations; $R(z)$ drift (project preprints).