Cosmogenic Origin of KM3-230213A

Delayed Gamma Ray Emission from a Cosmic Transient

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The 230213A Event

Detection

A historic 220 PeV νμ track event (KM3-230213A) was recorded by the ARCA detector of the KM3NeT collaboration.

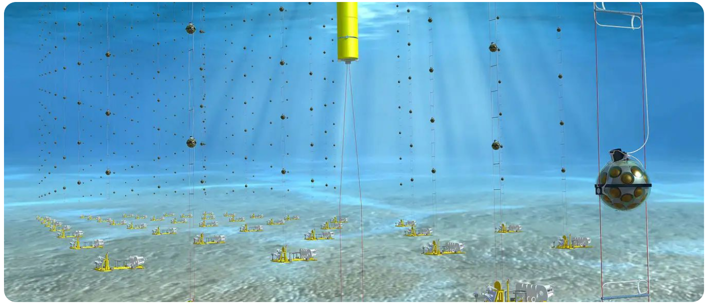


Image: Edward Berbee, Nikhef.

Astrophysical Candidates

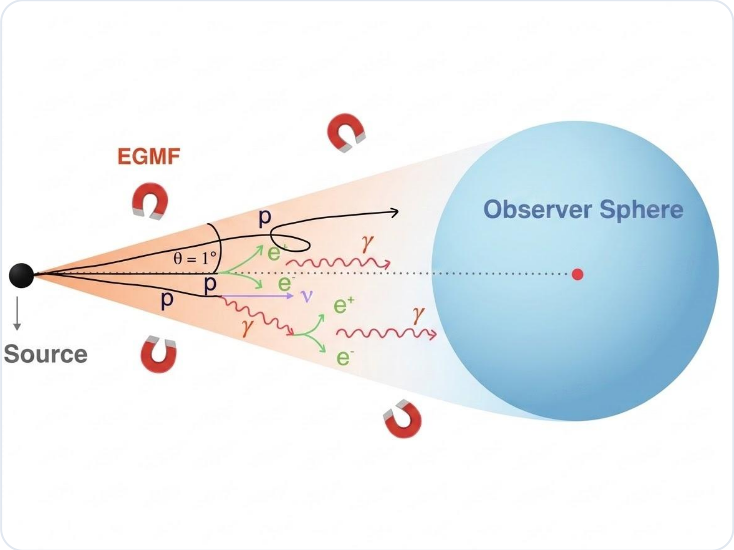
Several astrophysical candidate sources have been proposed, no compelling association established yet.

Cosmogenic Hypothesis

A diffused cosmogenic hypothesis has been proposed: Ref. Castellina’s talk

In this work, we are proposing cosmogenic flux from a transient point source of subdominant unresolved population.

3D Monte Carlo Transport & EGMF Deflection



Time delay: $\Delta t = (d_{traj} - d_{eff})/c$

Numerical Setup (CRPropa3)

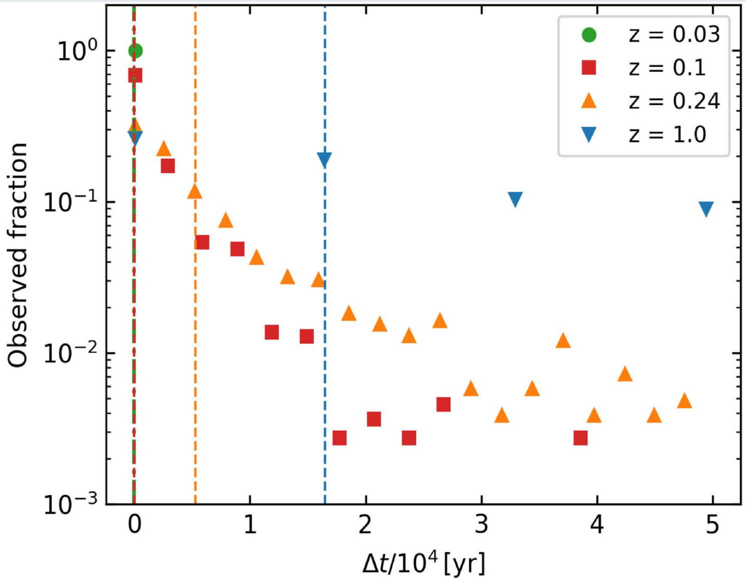
3D Particle Transport: Full 3D Monte Carlo simulations using CRPropa3 to track primary protons and secondaries.

Injection: Power Law proton injection $dN/dE \propto E^{-2}$.

Turbulent Magnetic field: Simulated random turbulent EGMF following a Kolmogorov power spectrum with strength $B_{rms} \approx 10^{-5}$ nG

Energy losses: Photopion-production, Bethe-Heitler Pair Production, adiabatic loss, and secondary EM processes.

Time Delay Distribution of Neutrinos



Time Delays distribution

$\Delta t = (d_{traj} - d_{eff})/c$

Proton Deflections

EeV protons experience deflections within the EGMF.

Neutrino delay

Neutrinos inherit a geometric delay relative to light because their parent proton

EM Cascade

Secondary e± cycles through IC scattering and pair production, delaying multi-TeV photons by $\Delta t \gtrsim 10^4$ years.

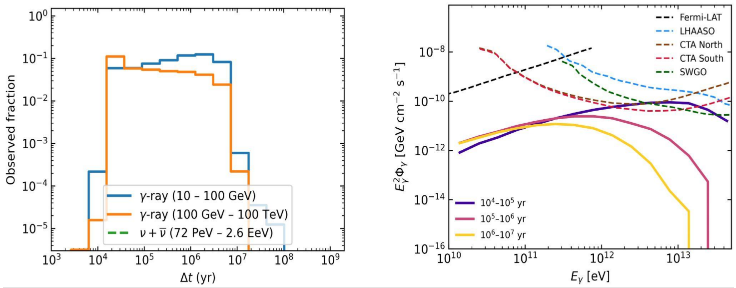
Key Takeaways

Neutrino Arrival: For nearest case z=0.03 entire population arrives without delay; higher redshifts show prompt component and low fractional tail.

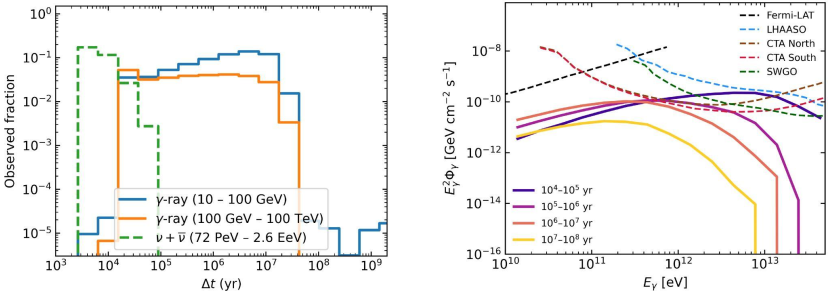
Photon Arrival: Simultaneous with neutrinos at low redshift; high redshift leads to clear temporal separation via EM cascade development.

Cosmogenic Neutrinos & γ-rays: Delay & Spectrum

EM Cascade: Nearby Transient (z~0.03)



EM Cascade: Nearby Transient (z~0.1)

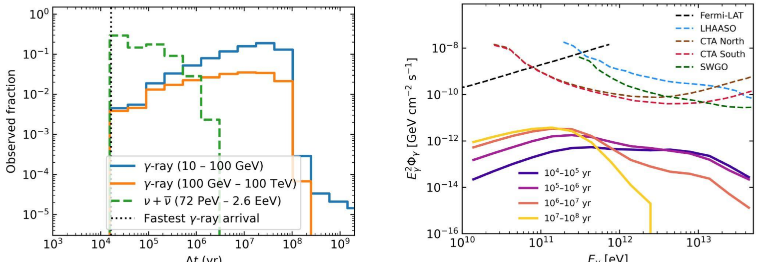


UHECR interaction dominant with EBL, secondary gamma rays initiate cascade in CMB & EBL

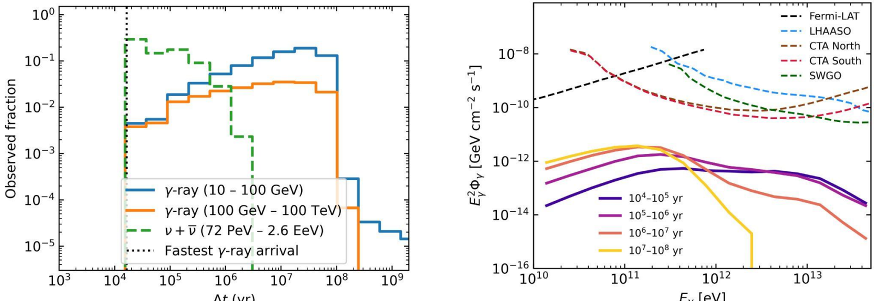
EM Cascade not fully developed, multi-TeV gamma-ray cascade matches telescopecurrent+upcoming detectors sensitivity.

Cosmogenic Neutrinos & γ-ray: Delay & Spectrum

EM Cascade: Distant Transient (z~0.24)



EM Cascade: Distant Transient (z~1.0)



Cascade developed, downshifting spectrum peak.

Summary

Cascade Delay

The missing GeV-TeV gamma-ray counterpart is a direct consequence of cascade delay.

Future Detection Prospects

- Sensitivities of current and next-gen facilities are essential.
- Multi-TeV orphan echoes of gamma rays from past transients constrain the source distance to ~500 Mpc.
- Nondetection by CTAO would imply transient distance ≳500 Mpc.

B-Field Sensitivity

- ❑ A weaker magnetic field → γ-ray flux comparable to detector sensitivities at multi-TeV energies → degeneracy
- ❑ multi-TeV detection favors a weaker EGMF or shorter distance.

Sensitivity of our result to B field (z~0.24)