Diffuse neutrinos from γ-ray blazars via UHECR propagation

Saikat Das[1], Nayantara Gupta[1] and Soebur Razzaque[2]

[1]Astronomy & Astrophysics Group, Raman Research Institute, Bengaluru 560080, India

[2]Centre for Astro-Particle Physics, University of Johannesburg, Auckland Park 2006, South Africa

ONLINE ICRC 2021
THE ASTROPARTICLE PHYSICS CONFERENCE
Berlin | Germany
37th International Cosmic Ray Conference
12–23 July 2021

Objectives

The sources of the cosmic neutrino signal measured by IceCube neutrino observatory in Antarctica is still unresolved.

- We study the plausibility of their origin from blazars, that dominate the high-energy γ-ray sky [1]
- Cosmic rays from blazars ($E \gtrsim 10^{16}$ PeV) interact with the EBL (IR/UV/optical) and CMB photons to produce diffuse neutrinos
- The cumulative contribution from resolved + unresolved blazars is calculated by using a luminosity function (LF) [2, 3]
- The proton energy threshold for pion production on EBL is $E_{\rm th}^{p,\pi} \approx 10^{17}$ eV. The latter can yield PeV neutrinos

Methods

1. Denoting primed quantities for comoving frame, $L_{100} = (\delta_e^6/\Gamma_e^2)L'_{100}$ for FSRQs, and $L_{100} = \delta_e^4 L'_{100}$ for BL Lacs. $L'_p = \eta L'_{100}$
2. Protons with $E > 10$ PeV are injected as cosmic rays. The cosmic-ray luminosity outside the jet (AGN frame) $L_p = \Gamma_e^2 L'_p$
3. In the observer frame, $L_p = \Gamma_e^2 L'_p = \Gamma_e^2 \eta L'_{100} = \eta_{\rm eff} L_{100}$, where we assume $\delta_e \simeq \Gamma_e$, for jet opening angles $\theta_j \sim 1/\Gamma_e$ and $\eta_{\rm eff} = \eta/\Gamma_e^2$
4. $p\gamma$ interactions on CMB and EBL produces secondary e$^\pm$, γ-rays, and neutrinos. EM cascade results in γ-ray spectrum contributing to IGRB
5. Diffuse neutrino luminosity from a single source is $L_\nu^{\rm obs} = f_\nu L_p = f_\nu \eta_{\rm eff} L_{100}$, where $f\nu$ is the fraction of CR energy in neutrinos
6. The luminsoity function is a double power-law $\Phi(L_{100}, z = 0, \Gamma) =$
$$\frac{dN}{dL_{100}dV_c d\Gamma} = \frac{A}{\ln(10)L_{100}} \times \left[\left(\frac{L_{100}}{L_*}\right)^{\gamma_1} + \left(\frac{L_{100}}{L_*}\right)^{\gamma_2}\right]^{-1} g(\Gamma, L_{100})$$
7. Multiplying by the photon index evolution we get the LDDE given as $\Phi(L_{100}, z, \Gamma) = \Phi(L_{100}, z = 0, \Gamma) \times e(z, L_{100})$

Results

1. Total 9172 blazars are obtained by integrating $\Phi(L_{100}, z, \Gamma)$ over the parameter range of luminosity, spectral index, and redshift (cf. Fig 1)
2. The dashed line separates the region into resolved and unresolved sources above and below, in accordance with ~2800 blazars in 4LAC

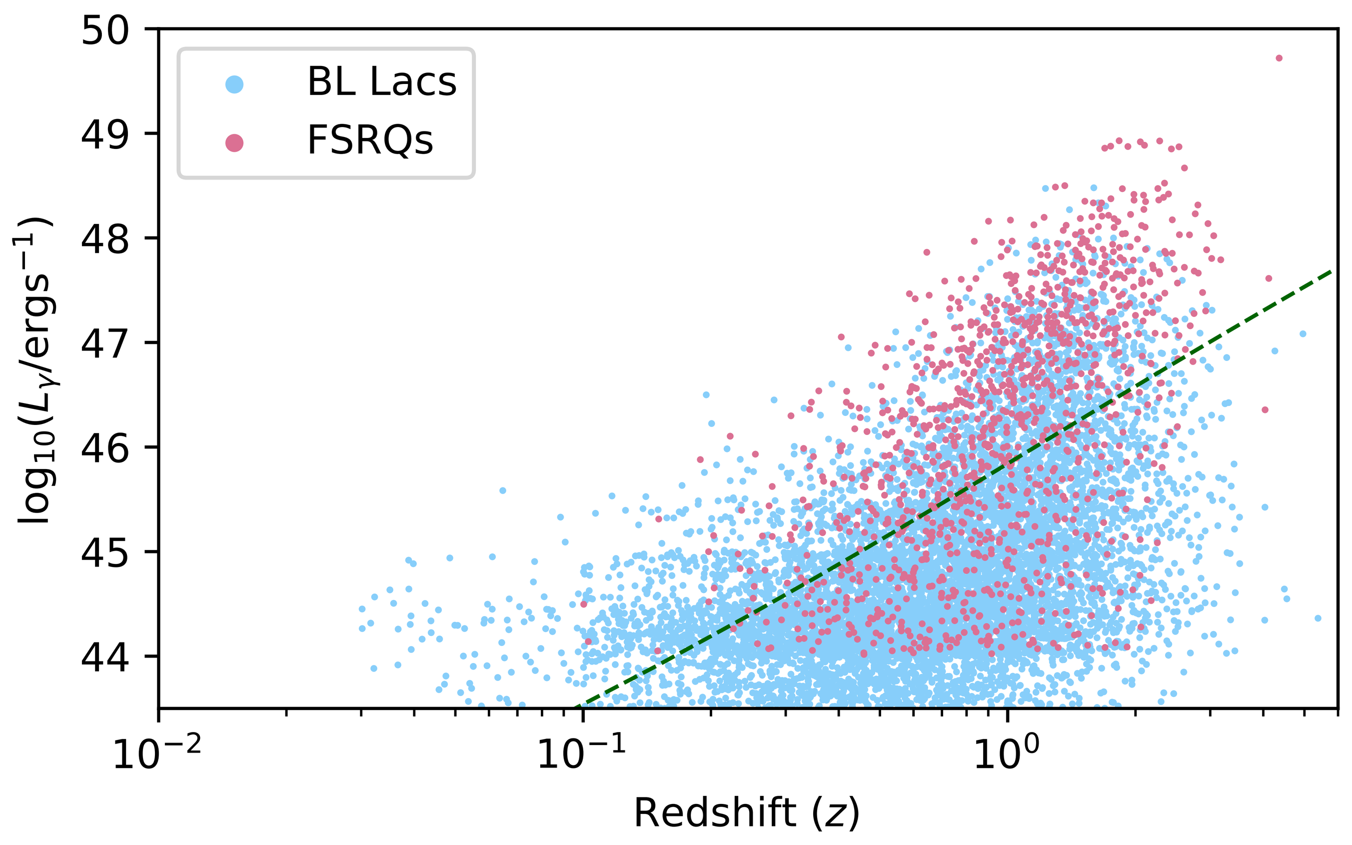

Figure 1: Blazar distribution in redshift luminosity space. The dashed line separates the region into resolved and unresolved sources in *Fermi*-LAT survey.

1. The secondary fluxes obtained from the LDDE are shown in Fig. 2. The neutrino flux peaks at ~ 6 PeV.
2. The sources are binned in a two-dimensional (ℓ, z) grid, where $\ell = \log_{10}(L_{100}/\text{erg s}^{-1})$. Number of blazars w in each grid is calculated
3. We see that cosmic ray interactions can explain a little more than 10% of the IceCube flux upper limit at ~6 PeV.
4. UHECR flux measured by Auger puts an upper bound of $\eta_{\rm eff} = 11.1$, 5.8, and 4.4, for $E_{p,\max} = 1$, 10, and 100 EeV respectively
5. An increase in the value of $E_{p,\max}$ to 10 EeV increases the cascade photon flux and saturates the IGRB background at TeV energies

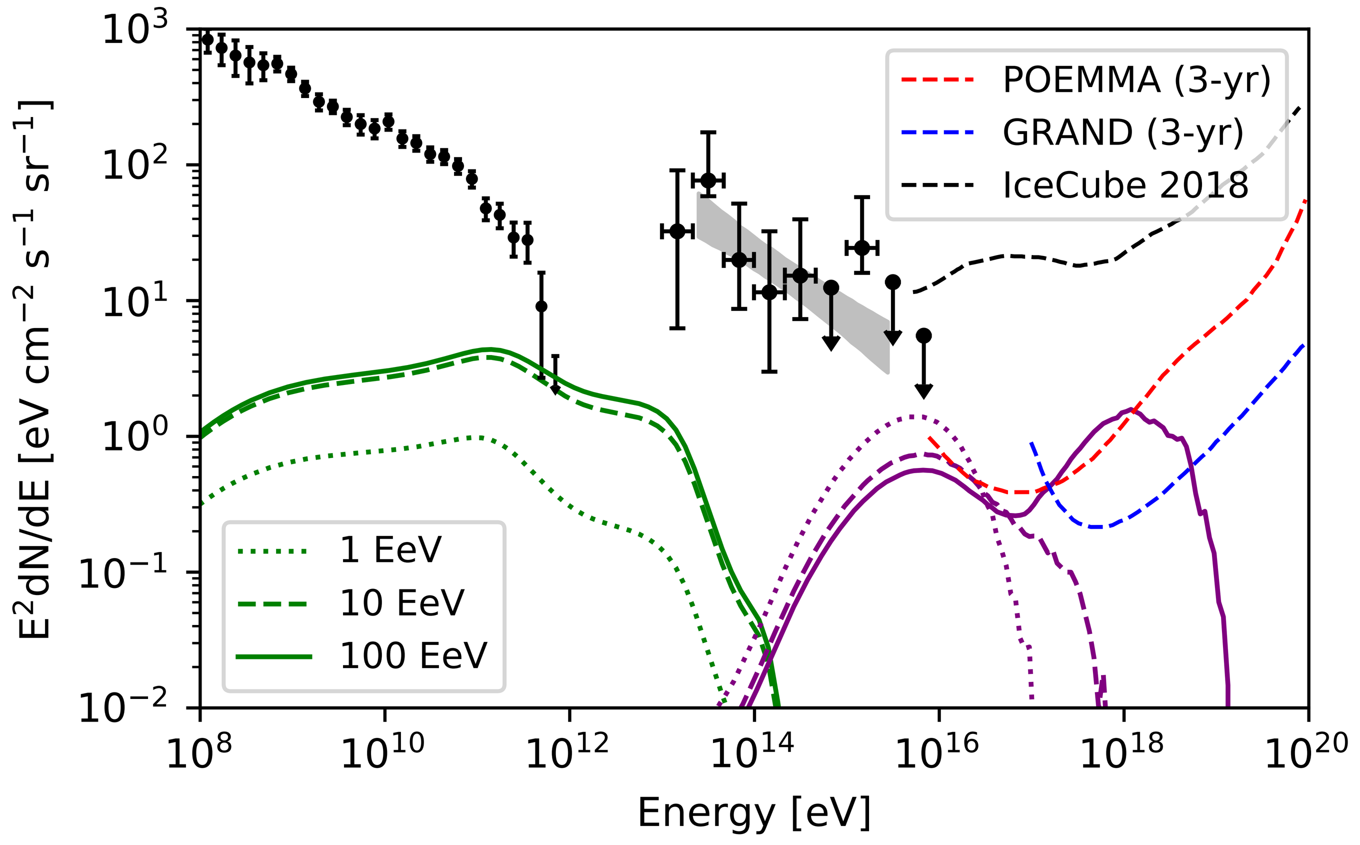

Figure 2: The neutrino and IGRB flux, including the unresolved blazars, for the maximum values of $\eta_{\rm eff}$ corresponding to $E_{p,\max} = 1$, 10, and 100 EeV

Conclusions

1. CR interactions on EBL produce diffuse flux of PeV neutrinos. More luminous sources contribute more to neutrino and IGRB
2. To maintain the constraints put by IGRB measurements, the baryonic loading η must be decreased for $E_{p,\max} \gtrsim 10^{19}$ eV.
3. Neutrino flux obtained from an individual source, $F_\nu \propto \eta_{\rm eff} \propto \eta/\delta_e^2$, for a given value of L_{100} and $E_{p,\max}$
4. Including the unresolved sources increases the flux by a factor of two at a few PeV. A strict L_p/L_{100} correlation may not hold invariably

References

[1] S. Das, N. Gupta and S. Razzaque, *Astrophys. J.* **910** (2021), 100

[2] M. Ajello *et al.* *Astrophys. J.* **751** (2012), 108

[3] M. Ajello *et al.* *Astrophys. J.* **780** (2014), 73