The Neutrino Contribution of Gamma-Ray Flares from Fermi Bright Blazars

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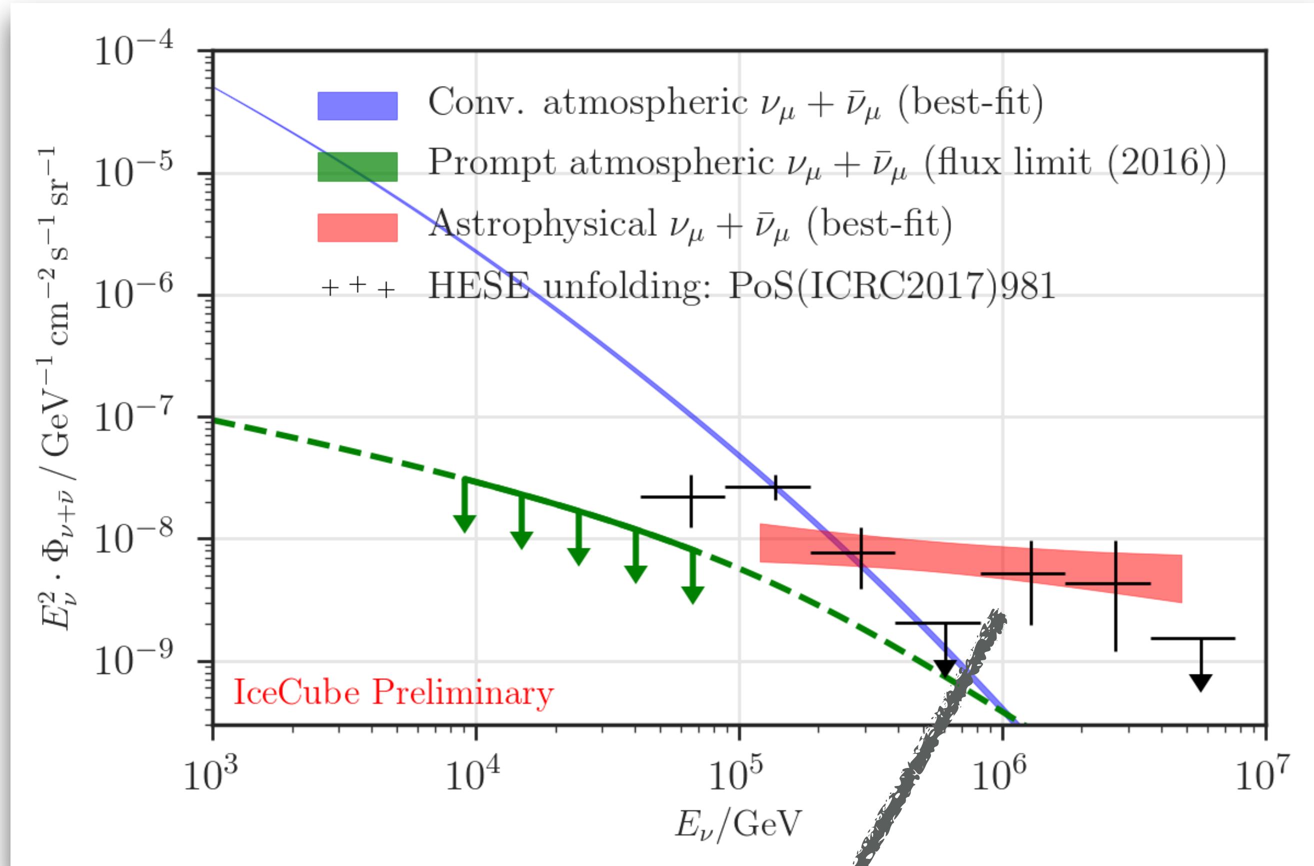
37th ICRC (Online - Berlin, Germany, July 12th, 2021)

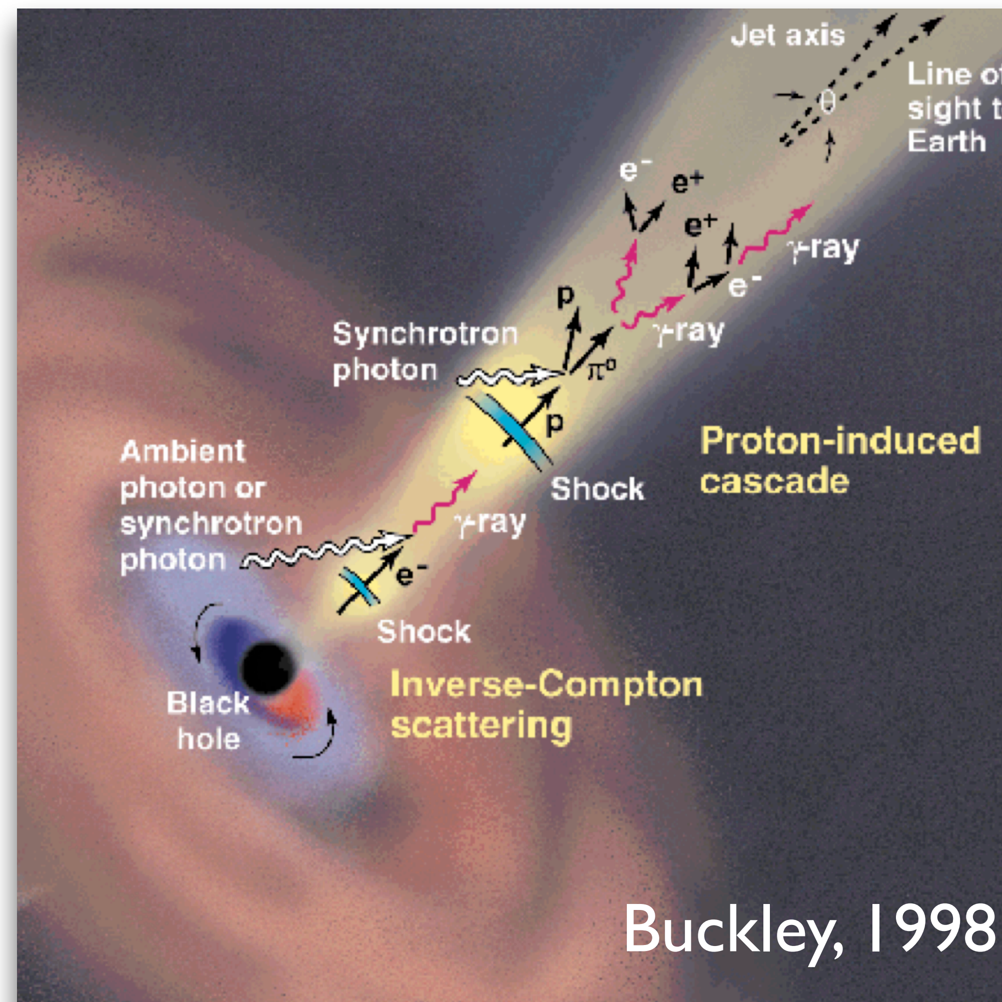
Isotropic Diffuse Neutrinos and Blazars



IceCube Collaboration, ICRC 2017

The isotropic diffuse neutrinos:
=> produced by a large number of extragalactic sources

"Blazar"



A candidate of the origin of Ultra High Energy Cosmic rays and High Energy Neutrinos

In This Work

- Analysis of flares of 145 gamma-ray blazars of Fermi-LAT Monitored Source List and TXS 0506+056
  - 0.1-316GeV gamma-ray light curves with one week time bin through 2008-2019
  - 105 FSRQs, 31 BL Lacs, and 9 blazar candidates of uncertain type
- Estimation of high-energy neutrino fluxes of blazars from the gamma-ray flare fluxes
- Constrain of the contribution of bright gamma-ray blazar flares to the isotropic diffuse neutrino flux

Extraction of Gamma-ray Flares

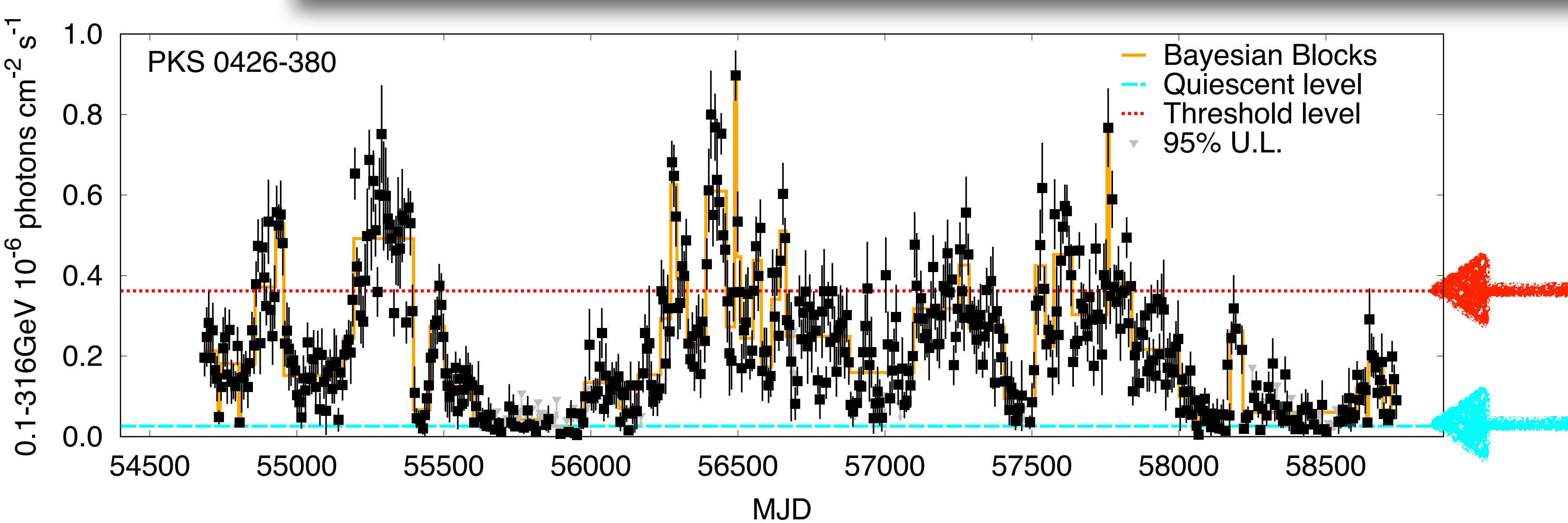
Application of a Bayesian Blocks algorithm for gamma-ray light curves
=> Gamma-ray quiescent flux level

Flaring threshold level => gamma-ray flare flux

$$F_\gamma^{th} = F_\gamma^{q} + s\langle F_\gamma^{err} \rangle$$

Unless otherwise noted, s =6

F_γ^{q}: the gamma-ray quiescent level
$\langle F_\gamma^{err} \rangle$: an average error of the gamma-ray light curve
s: the significance above the quiescent level in units of σ



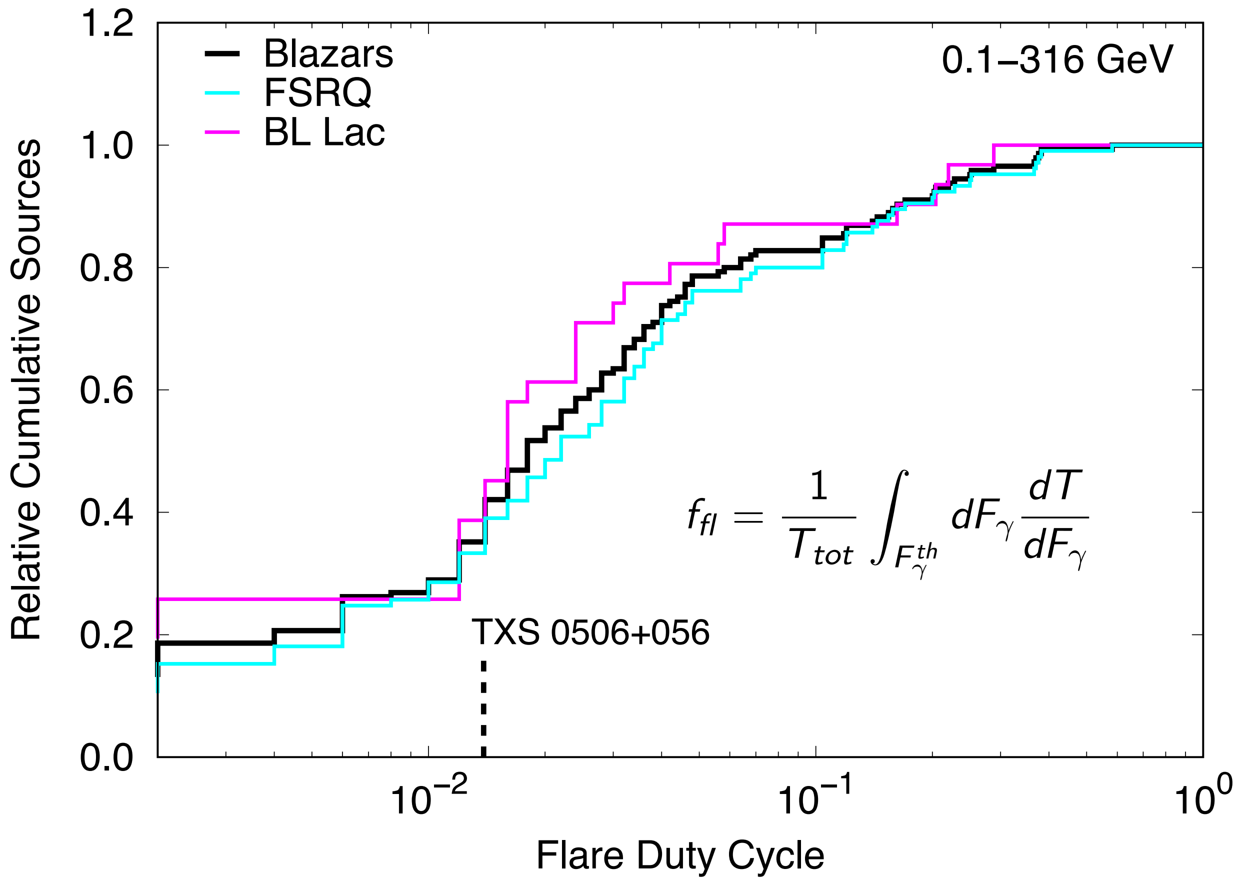
Flaring Threshold Level (s=6)

Quiescent Flux Level

Gamma-ray Flare Duty Cycle and Flare Energy Fraction

Cumulative distribution

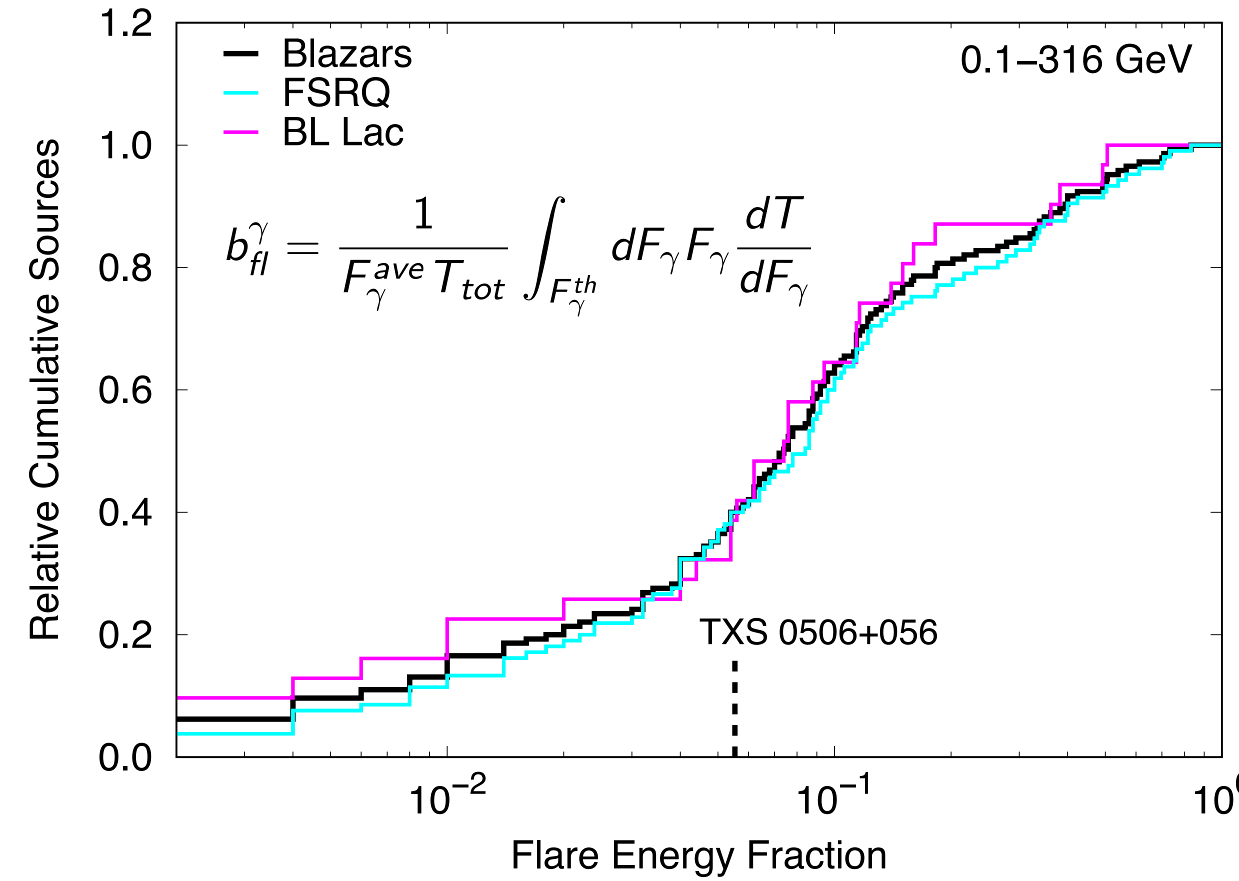
Flare Duty Cycle
= (Flaring Time)/(Total Observation Time)



Median of Flare Duty Cycles = 1.9%

Cumulative distribution

Flare Energy Fraction
= Fraction of Energy Emitted
in the Flaring State



Median of Flare Energy Fraction = 7.5%

K-S test => No significant difference between FSRQs and BL Lacs for Flare Duty Cycles and Flare Energy Fractions

A Simple Scaling Relation between the Gamma-ray and Neutrino Fluxes

Leptonic models of blazar gamma-ray emission
=> A relation between the gamma-ray and neutrino flux:

$$F_\nu \propto F_\gamma^\gamma \qquad \gamma = 1.0 - 2.0$$

e.g. Murase, Oikonomou, Petropoulou (2018)

A simple scaling relation between the gamma-ray and neutrino fluxes, independent of the details of neutrino production

$$\epsilon_\nu F_\nu^{fl} = \epsilon_\nu F_\nu^{q} \left(\frac{F_\gamma^{fl}}{F_\gamma^{q}} \right)^\gamma$$

$\epsilon_\nu F_\nu^{fl}$: Flaring neutrino flux
$\epsilon_\nu F_\nu^{q}$: Quiescent neutrino flux
F_γ^{fl}: Flaring gamma-ray flux
F_γ^{q}: Quiescent gamma-ray flux

Quiescent Neutrino Flux

- **Scenario 1** Quiescent X-ray flux = Upper limit to the quiescent neutrino flux

e.g. Murase, Oikonomou, Petropoulou (2018), Padovani et al. (2019)

Blazar X-ray light curves in 0.3–10 keV based on 14 years of Swift-XRT data (P. Giommi et al. 2019)

$$\epsilon_\nu F_\nu^{fl} = A \cdot \epsilon_X F_X^q \left(\frac{F_\gamma^{fl}}{F_\gamma^q} \right)^\gamma$$

$\epsilon_X F_X^q$: Quiescent X-ray flux
A: Normalization parameter

- **Scenario 2** Quiescent gamma-ray flux = Upper limit to the quiescent neutrino flux

$$\epsilon_\nu F_\nu^{fl} = A \cdot \epsilon_\gamma F_\gamma^q \left(\frac{F_\gamma^{fl}}{F_\gamma^q} \right)^\gamma$$

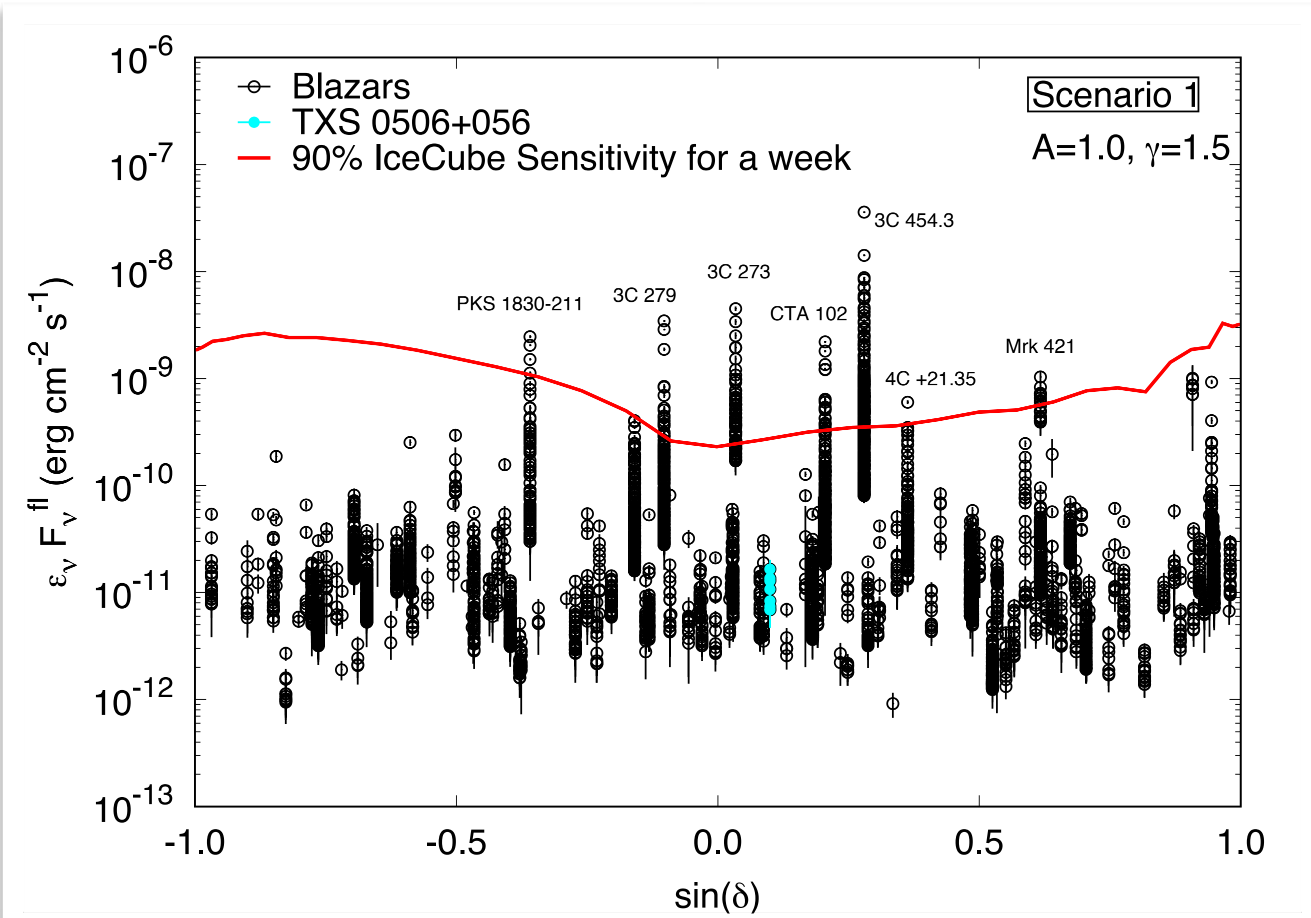
$\epsilon_\gamma F_\gamma^q$: Quiescent gamma-ray flux
A: Normalization parameter

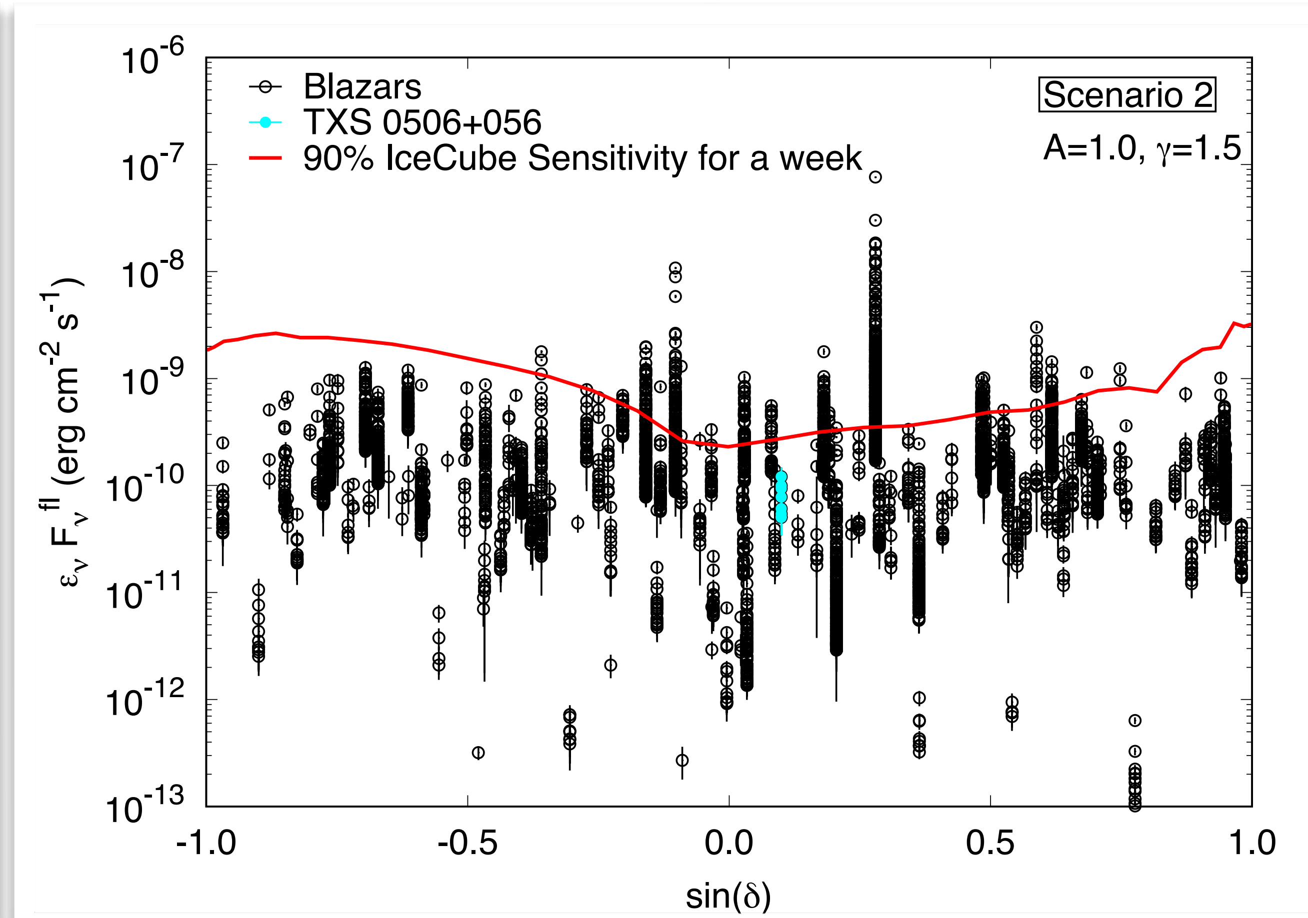
Estimated Neutrino Flare Fluxes from Gamma-ray Blazars

Estimated muon neutrino flare fluxes with A=1.0 and γ=1.5 as a function of sinδ (δ= declination), compared to IceCube 90% sensitivity for a week

Scenario1: $\epsilon_\nu F_\nu^q = A \cdot \epsilon_X F_X^q$

Scenario 2: $\epsilon_\nu F_\nu^q = A \cdot \epsilon_\gamma F_\gamma^q$





- A = 1.0 for the sources whose all flares are less than the sensitivity
- If not, A is reduced for the maximum flare of the source to be the sensitivity.

Contribution of Blazar Flares to the Isotropic Diffuse Neutrino Flux in Accordance with Stacking/Clustering Constraints

$$E_\nu^2 \Phi_\nu \lesssim 3.8\times10^{-10}\mathrm{GeV\,cm^{-2}s^{-1}sr^{-1}} \left(\frac{\xi_z}{0.7}\right) \left(\frac{0.02}{f_{fl}}\right)^{1/2} \left(\frac{b_{fl}^\nu}{0.4}\right)^{1/2} \left(\frac{10^{46}\mathrm{erg\,s^{-1}}}{\epsilon_\nu L^{fl}_{\epsilon_{\nu_\mu}}}\right)^{1/2}$$

A dimensionless parameter depending on the z evolution of blazars

$\xi_z = 0.68$ for BL Lacs

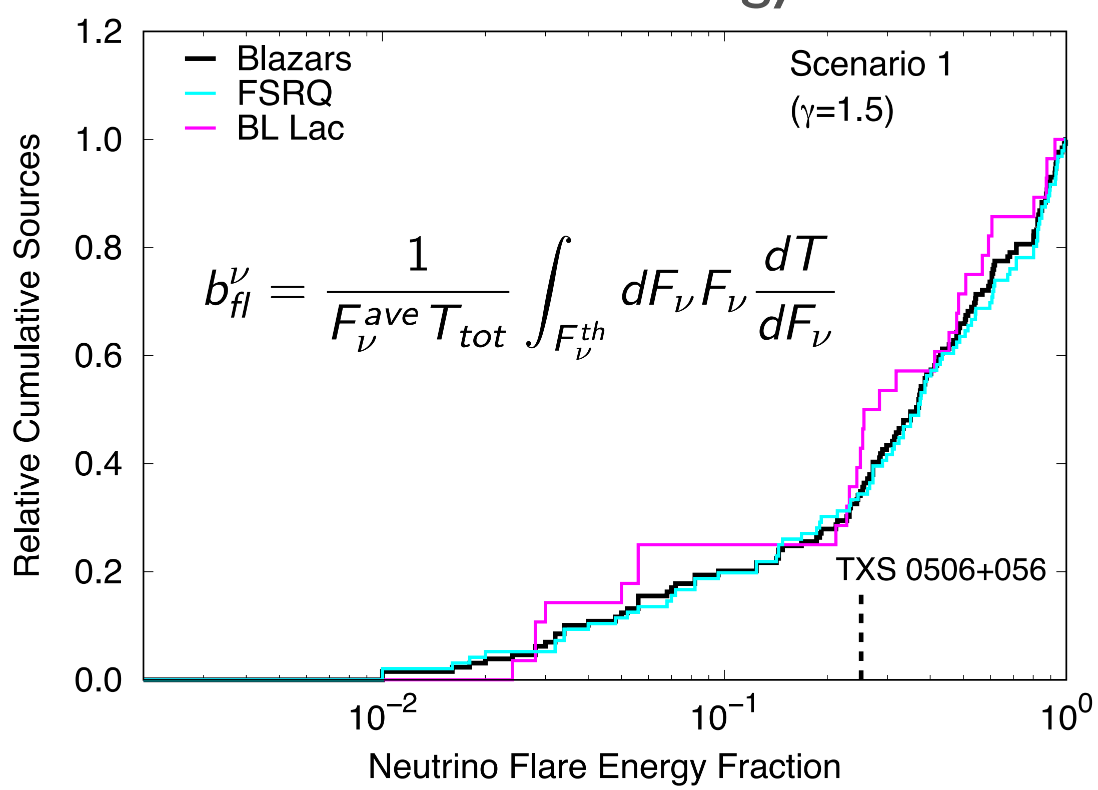
$\xi_z = 8.4$ for FSRQs

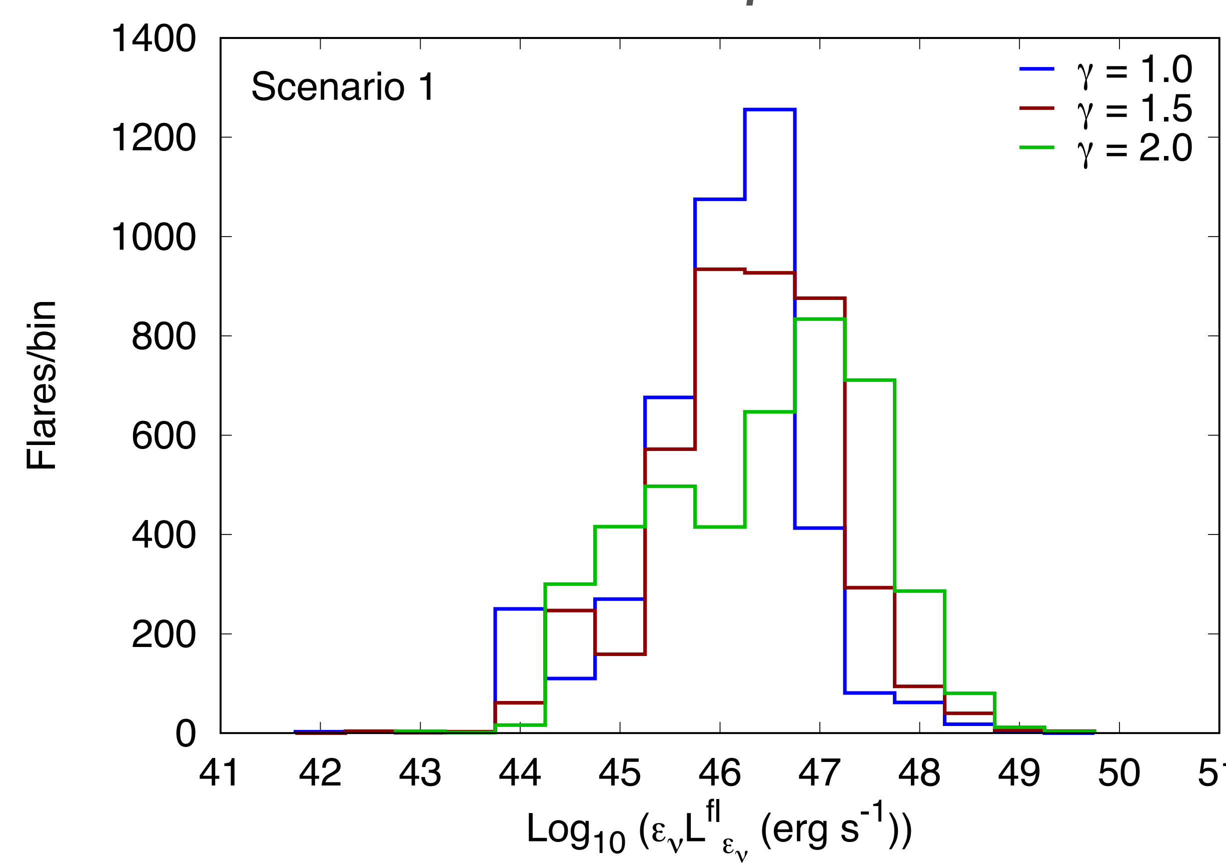
Flare Duty Cycle

Murase, Oikonomou, Petropoulou (2018)

Estimated neutrino flare luminosities

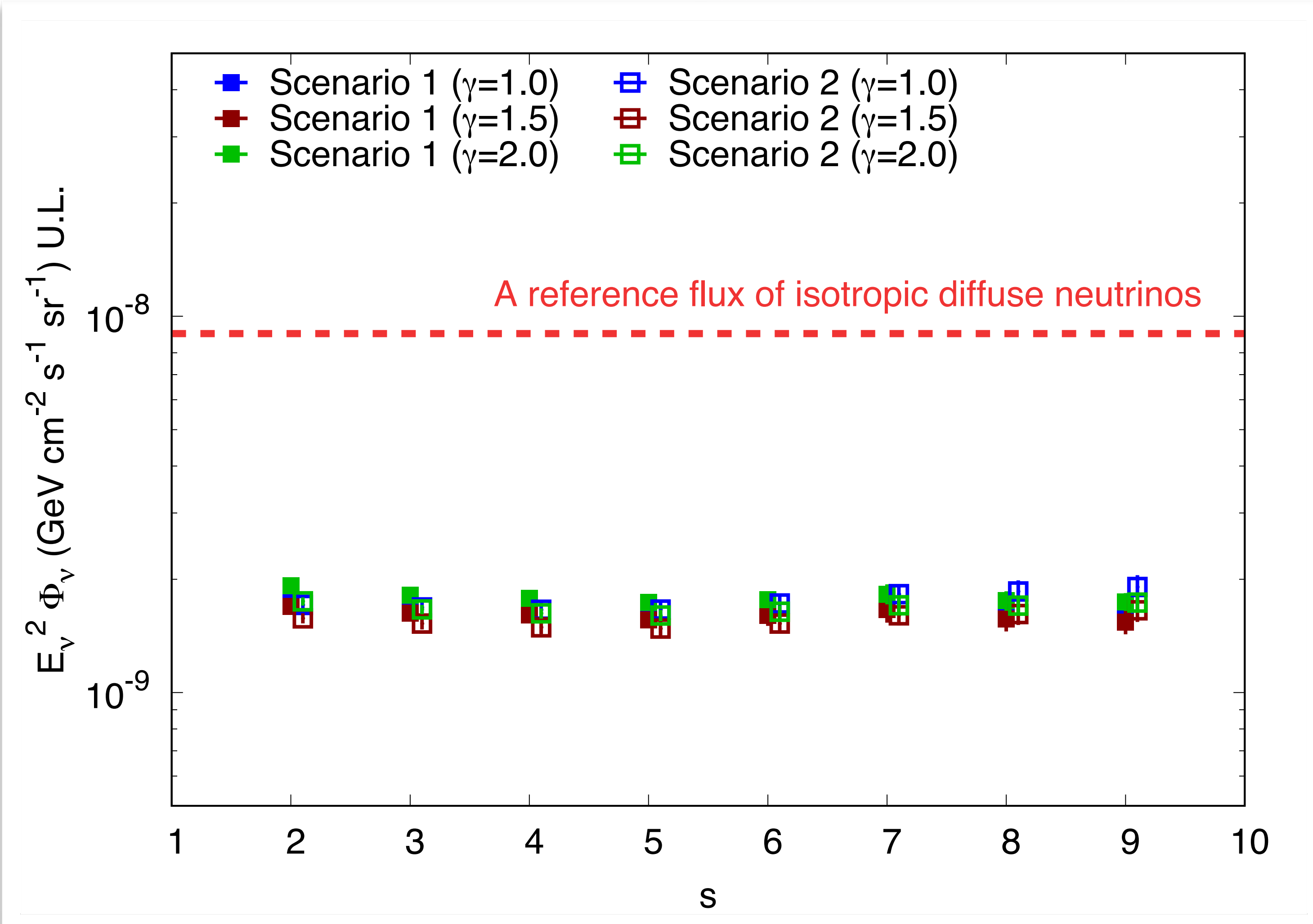
Neutrino Flare Energy Fraction





Contribution of Bright Blazars to the Isotropic Diffuse Neutrino Flux

U.L.s of the contribution of bright gamma-ray/neutrino blazars to the isotropic diffuse neutrino flux ($E_\nu{}^2\Phi_\nu$) as a function of the flare significance s



Almost independent of the flare significance s, the power index γ, and the two scenarios

The U.L.s of this sample, i.e. the bright gamma-ray and neutrino blazars: ~20 % of the isotropic diffuse neutrino flux

=> Dimmer neutrino blazars could make a larger contribution.

Summary

- For flare duty cycles and flare energy fractions, no significant differences between FSRQs and BL Lacs
- By using the simple scaling relation $L_\nu \propto (L_\gamma)^\gamma$ (γ=1.0-2.0), we estimated the neutrino fluxes of gamma-ray blazars.
- Comparison of the neutrino fluxes with IceCube sensitivity suggests:
    - The quiescent neutrino flux tends to be smaller than the quiescent X-ray and gamma-ray flux.
    - The power index γ tends to be closer to 1.0 rather than 2.0.
- The upper limits of the contribution of bright gamma-ray and neutrino blazars to the isotropic diffuse neutrinos are ~20 %.
  - Dimmer neutrino blazars could make a larger contribution to the isotropic diffuse neutrino flux.