GAMMAS AND NEUTRINOS FROM TXS 0506+056

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ICECUBE 170922A

On **September 22, 2017** IceCube detected a very-high-energy neutrino, with high probability of being of astrophysical origin [1].

Prompt follow-up observations in the electromagnetic band revealed the presence of a blazar within the IceCube error region: **TXS 0506+056**

Fermi-LAT observations showed TXS 0506+056 to be in a high-state since April 2017 [2];
MAGIC detected very-high-energy (E > 100 GeV) gamma-rays [3];
Swift and NuSTAR triggered ToO observations in X-rays;
Spectroscopic redshift is 0.337 [4]

→ TXS 0506+056 is a typical BL Lacertae object, with synchrotron-peak frequency ν_{syn} located at around 10^{15} Hz, classifying the source as intermediate / high-frequency peaked BL Lac (IBL / HBL)

Chance probability of the ν-γ coincidence is estimated at 3σ

BLAZAR HADRONIC MODELS

Blazar spectral energy distribution (SED): characterized by **two non-thermal emission bumps**

Low energy bump: synchrotron emission by $e^{\pm}$ in the emitting region;
High energy bump, in hadronic models: **proton synchrotron** emission or synchrotron emission by **secondary leptons** from p-γ interactions

Stationary lepto-hadronic code as described in [5]:
- leptonic processes computed analytically
- p-γ interactions computed using SOPHIA [6]
- synchrotron-supported pair cascades computed iteratively
- Bethe-Heitler pair production computed analytically

Constraints on the parameter space (see [5]):
- co-acceleration of leptons and hadrons : same injection index
- self-consistent cooling of primary particles
- size of the emitting region limited by the observed variability

Neutrinos are produced in p-γ interactions: the goal of this study is to **investigate the γ-ν connection for TXS 0506+056,** taking advantage of the first 3σ evidence of multi-messenger emission from a blazar

PROTON SYNCHROTRON SOLUTIONS

Gamma-ray emission dominated by **proton-synchrotron** radiation

Emission by secondaries from p-γ interactions emerges at VHE

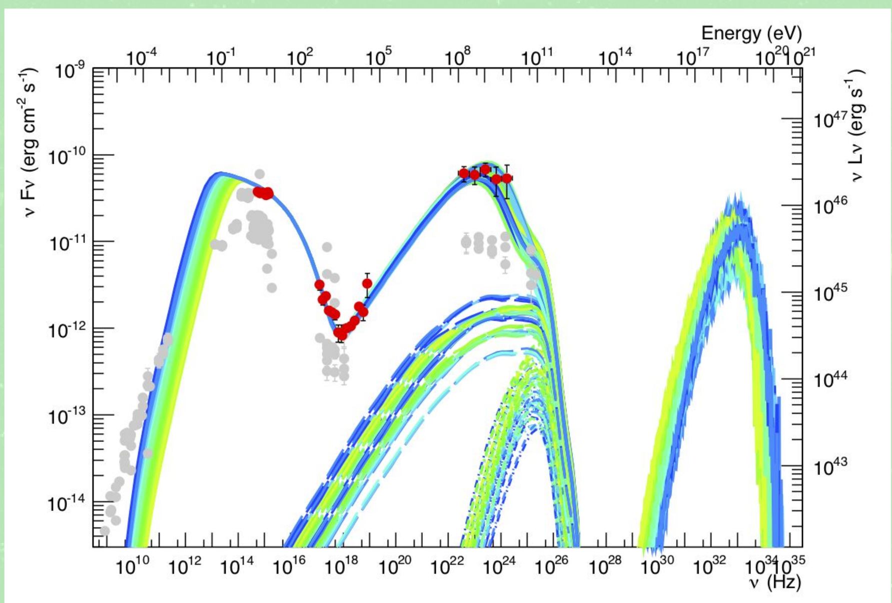
Systematic scan of the parameter space :
- Index of particle distribution : $\alpha = 2.0$
- Doppler factor of emitting region : $\delta = 35\text{-}50$
- Magnetic field : B = 0.2 G – 7.1 G
- Size of emitting region : $R = (0.3 - 9.7)e^{16}$ cm
- Maximum proton Lorentz factor : $\gamma_{p,max} = (0.2 - 1.7)e^{9}$
- Luminosity of emitting region : $L = 4e^{46} - 1.7e^{48}$ erg s^{-1}

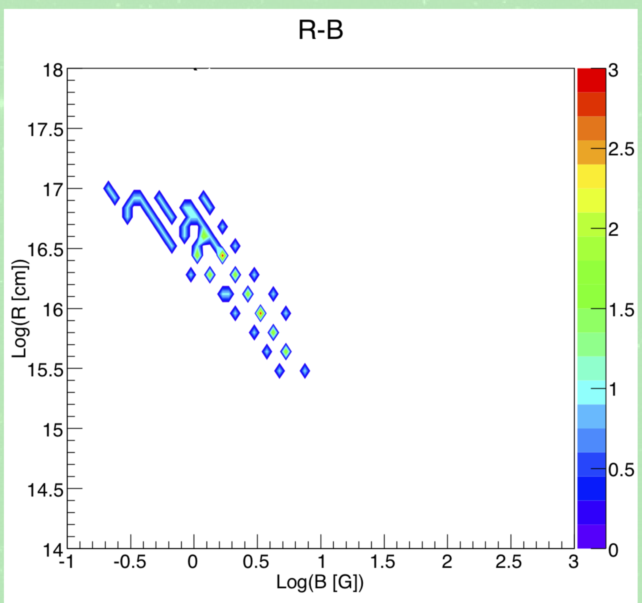
Neutrino emission :

All proton-synchrotron solutions predict ν emission peaking at EeV energies, much higher than IceCube sensitivity (100 TeV → 100 PeV)

Convolution with IceCube effective area results in expected ν rates of 0.006-0.16 $year^{-1}$, or 0.003-0.08 events during the six months of γ-ray high-state.

PROTON SYNCHROTRON SOLUTIONS ARE NOT FAVORABLE FOR γ-ν CONNECTION





Left: SED of TXS 0506+056, including data around the IceCube 170922A neutrino (red) and archival data (gray). The SED models show the total emission (bold lines), together with emission from secondary pairs (dashed) and muons (dotted). Color indicates different values of B. The rightmost component represents the neutrino emission. Right: parameter space (R-B plane) for all the solutions showed in the SED plot.

LEPTO-HADRONIC SOLUTIONS

Gamma-ray emission dominated by **synchrotron-self-Compton (SSC)** radiation as well as radiation from **secondary cascades** from p-γ interactions

Emission by secondaries from p-γ interactions emerges in X-rays and VHE

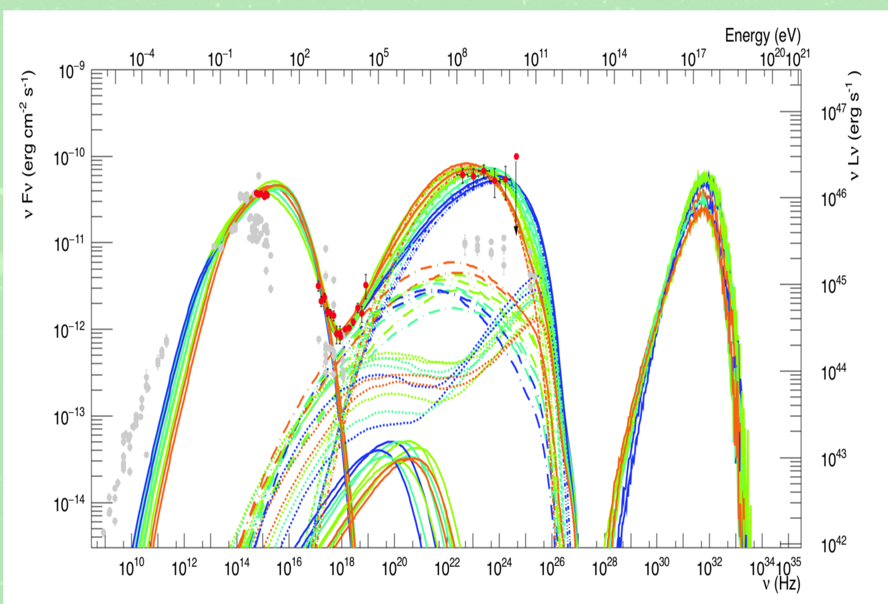
Systematic scan of the parameter space :
- Index of particle distribution : $\alpha = 2.0$
- Doppler factor of emitting region : $\delta = 20\text{-}40$
- Magnetic field : B = 0.1 G – 1.0 G
- Size of emitting region : $R = (0.15 - 2.8)e^{16}$ cm
- Maximum proton Lorentz factor : $\gamma_{p,max} = (0.08 - 0.3)e^{9}$
- Luminosity of emitting region : $L = 2e^{47} - 3.9e^{48}$ erg s^{-1}

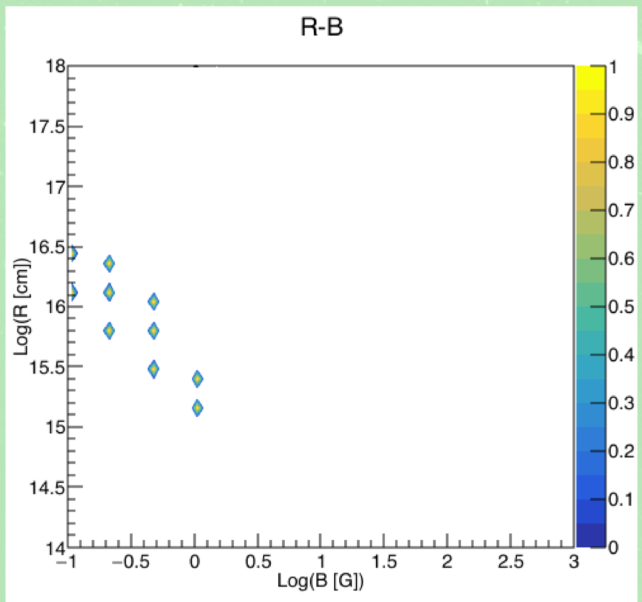
Neutrino emission :

Proton maximum energies are lower compared to the proton synchrotron scenario, allowing for ν spectra peaking at ~100 PeV

Predicted ν rates are consequently much higher: 0.2-1.2 $year^{-1}$, or 0.1-0.6 events during the six months of γ-ray high-state.

LEPTO-HADRONIC SOLUTIONS CAN FIT THE γ-RAY SED AND PROVIDE ν RATES CONSISTENT WITH THE ICECUBE DETECTION





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