The Inner-Outer Blob Model for "Orphan" Neutrino Flares

Rui Xue
Zhejiang Normal University

Collaborators： Ruo-Yu Liu (NJU), Ze-Rui Wang (NJU), Nan Ding (KMU), Xiang-Yu Wang (NJU)

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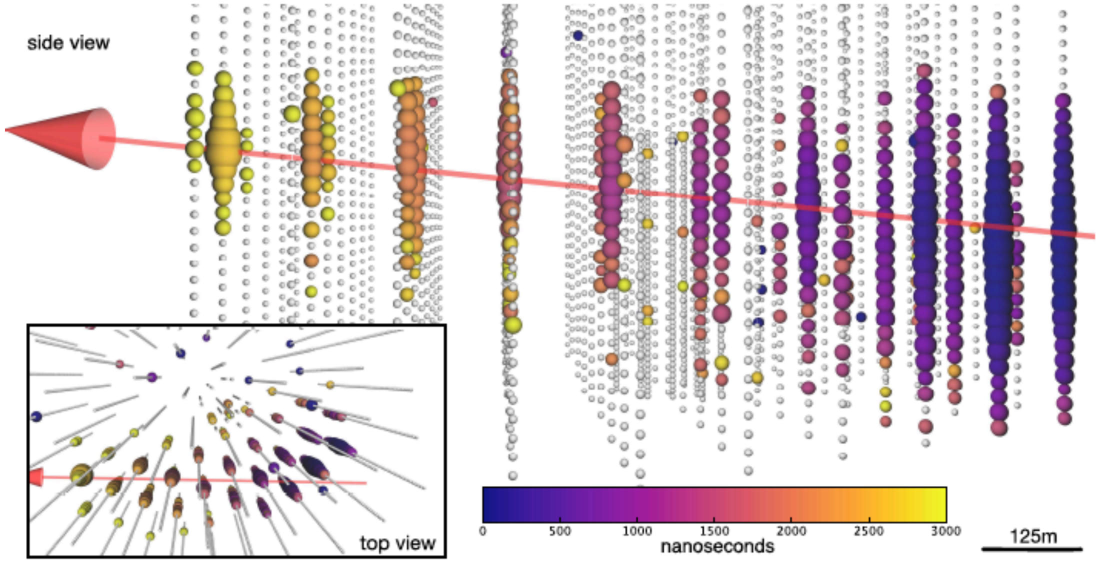
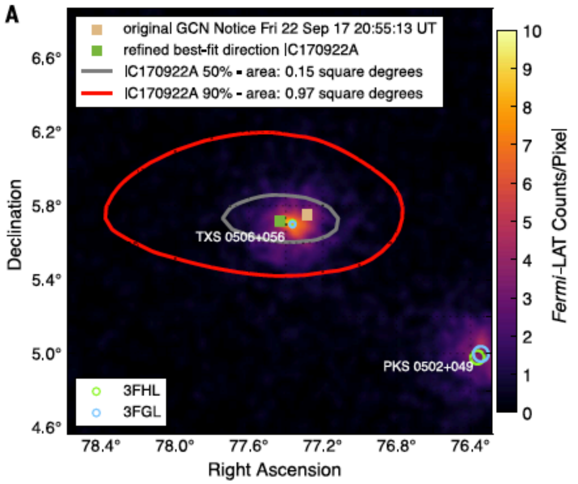
TXS 0506+056 — IC-170922A

~300 TeV

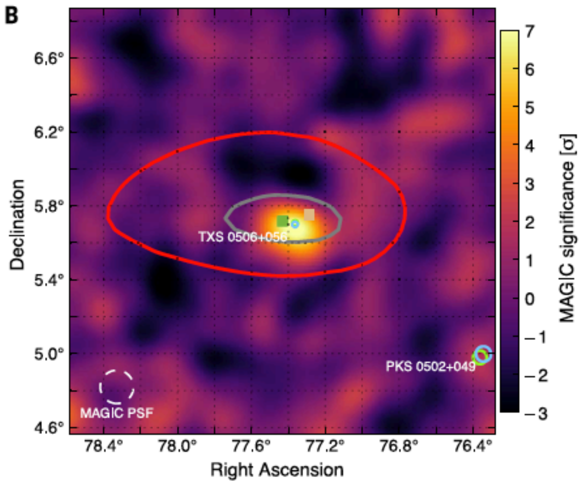


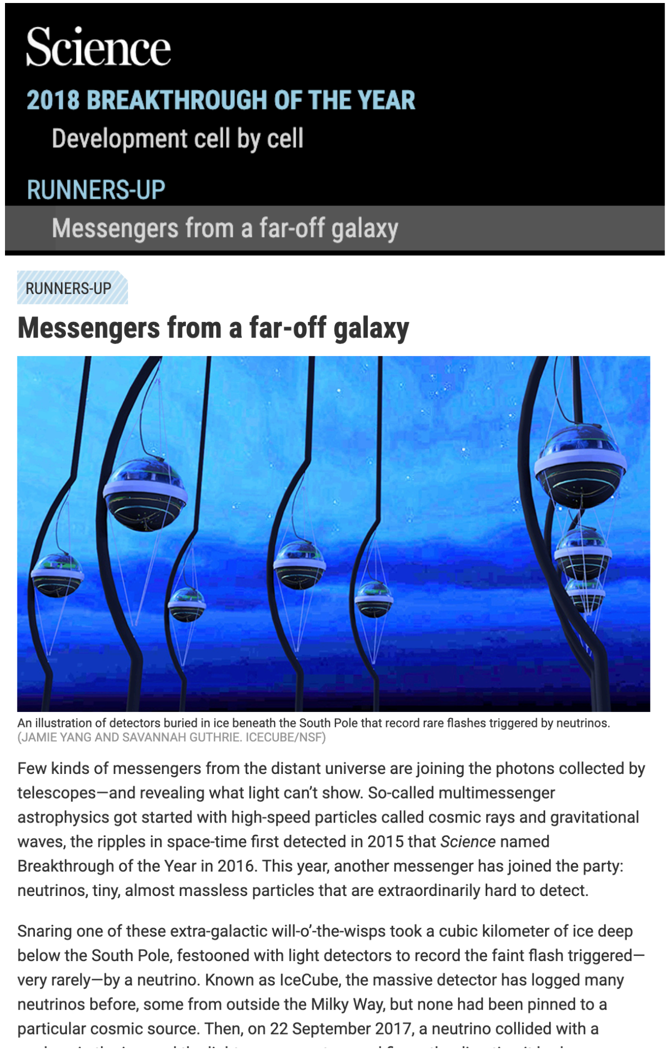
~3σ

Fermi-LAT



MAGIC





Science

2018 BREAKTHROUGH OF THE YEAR

Development cell by cell

RUNNERS-UP

Messengers from a far-off galaxy

RUNNERS-UP

Messengers from a far-off galaxy

An illustration of detectors buried in ice beneath the South Pole that record rare flashes triggered by neutrinos. (JAMIE YANG AND SAVANNAH GUTHRIE. ICECUBE/NSF)

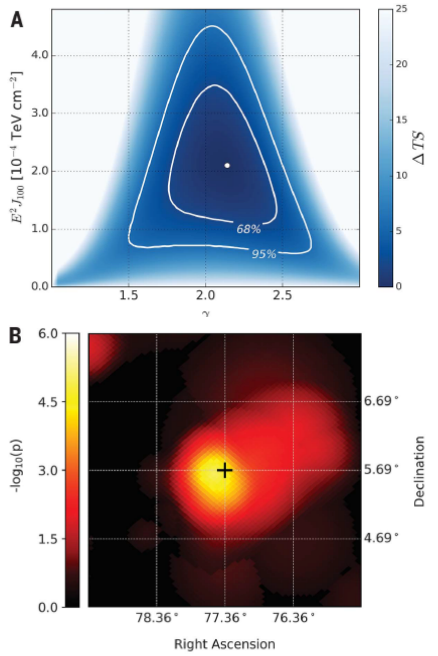
Few kinds of messengers from the distant universe are joining the photons collected by telescopes—and revealing what light can't show. So-called multimessenger astrophysics got started with high-speed particles called cosmic rays and gravitational waves, the ripples in space-time first detected in 2015 that *Science* named Breakthrough of the Year in 2016. This year, another messenger has joined the party: neutrinos, tiny, almost massless particles that are extraordinarily hard to detect.

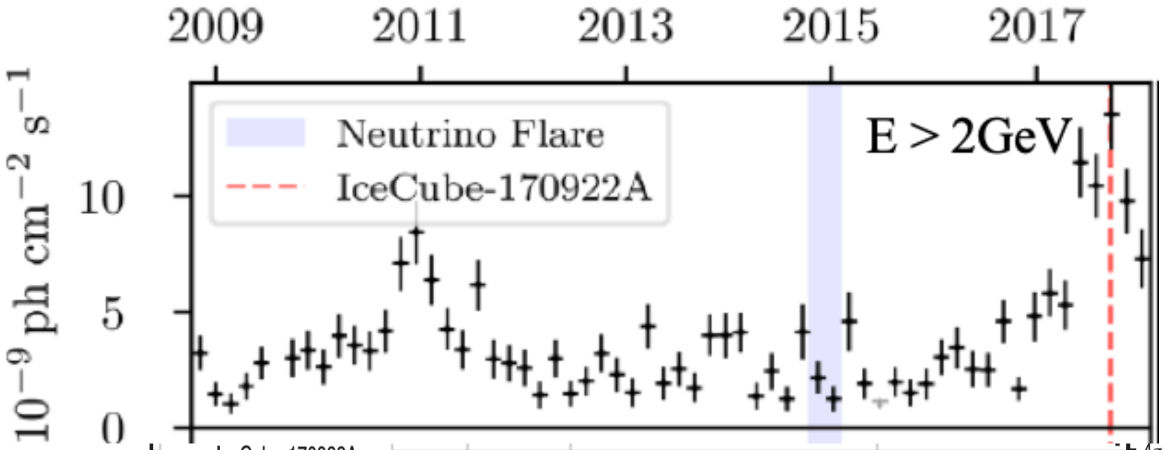
Snaring one of these extra-galactic will-o'-the-wisps took a cubic kilometer of ice deep below the South Pole, festooned with light detectors to record the faint flash triggered—very rarely—by a neutrino. Known as IceCube, the massive detector has logged many neutrinos before, some from outside the Milky Way, but none had been pinned to a particular cosmic source. Then, on 22 September 2017, a neutrino collided with a

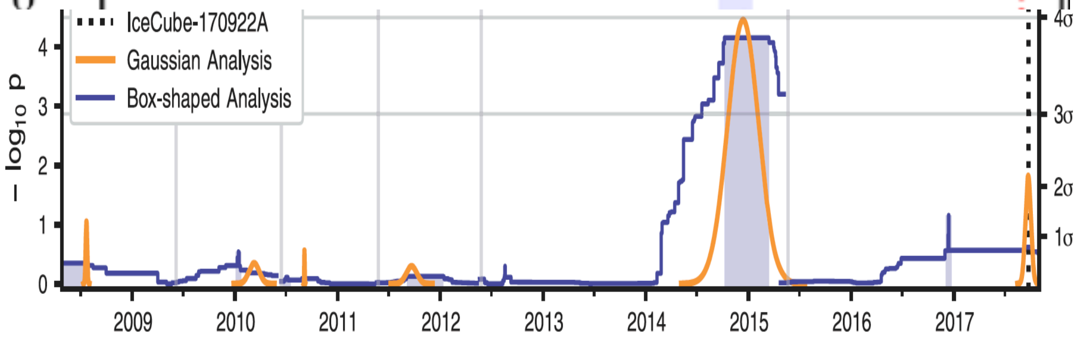
IceCube Collaboation et al. 2018, Science, 361, eaat1378

Top 10 Development in Science of 2018

TXS 0506+056 — 14-15 neutrino flare







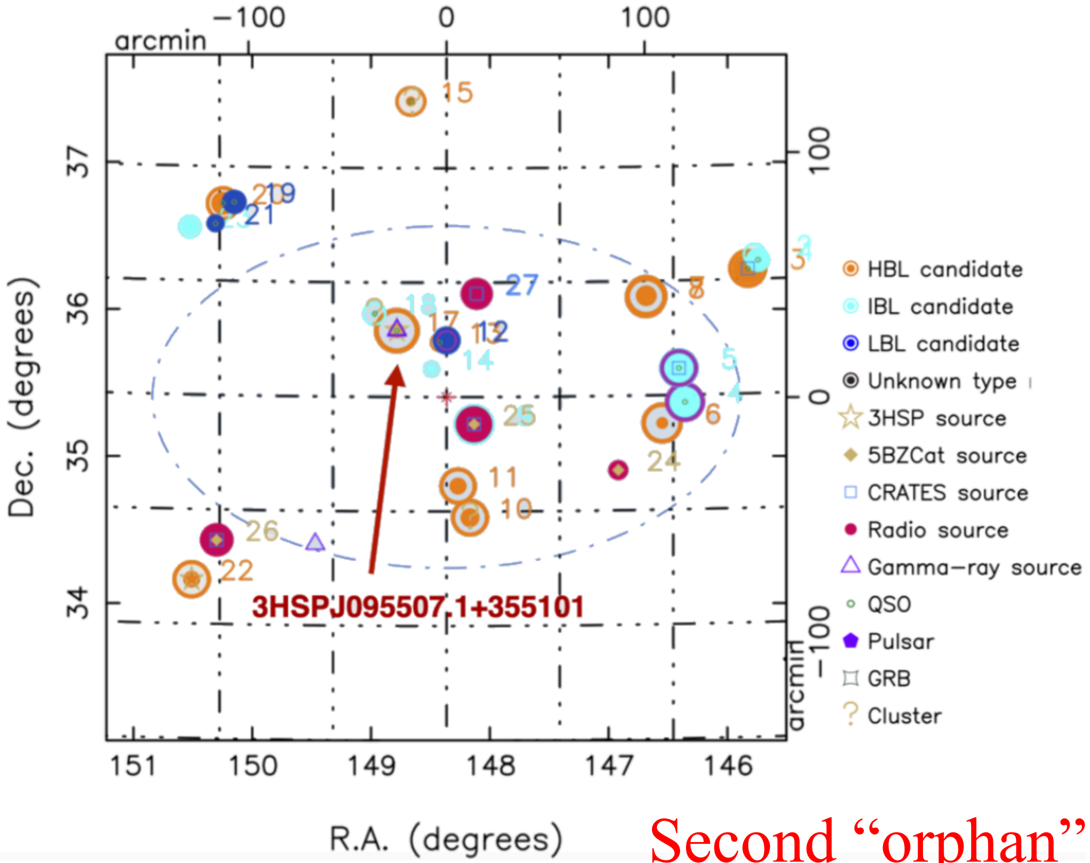
Padovani et al. 2018, MNRAS, 480, 192

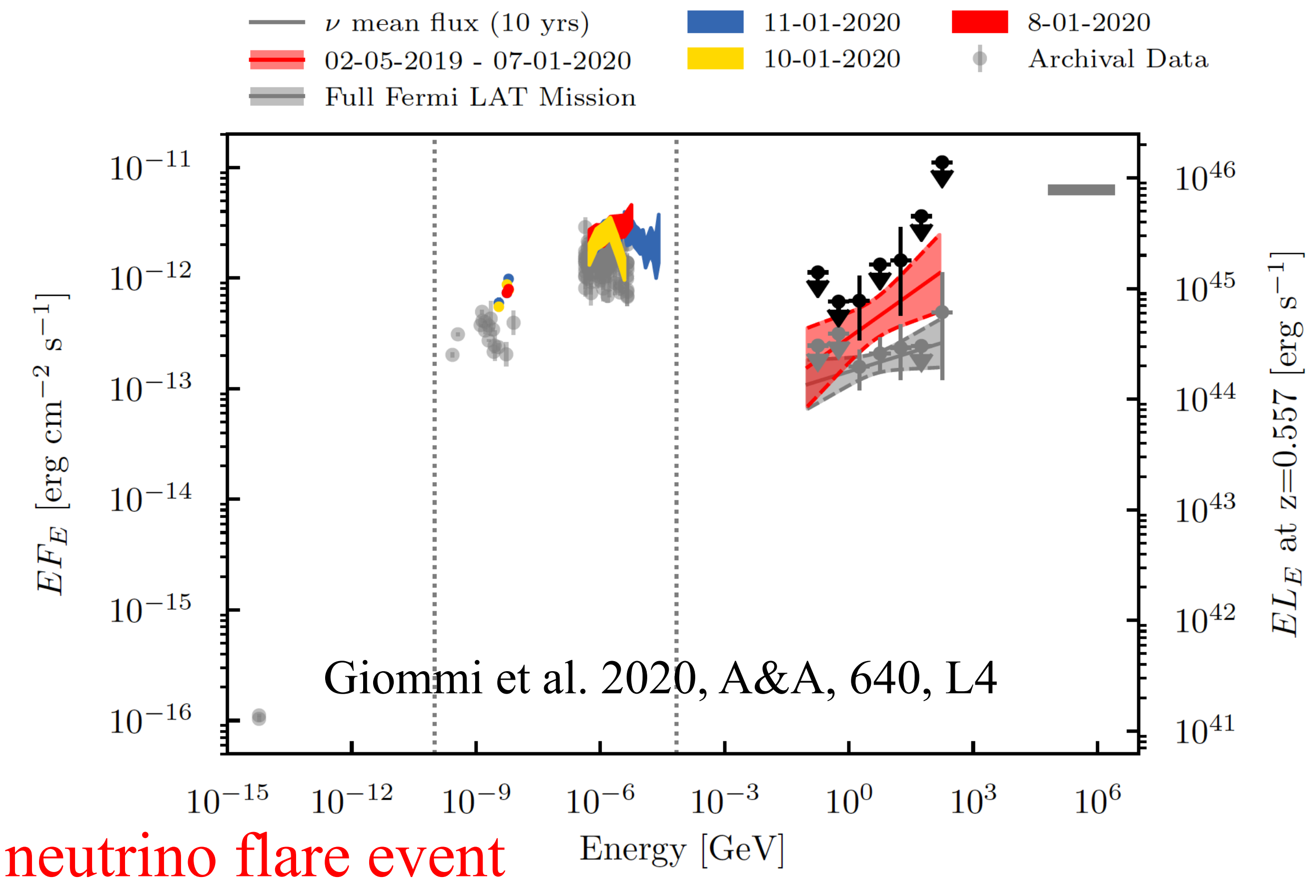
IceCube Collaboration et al. 2018, Sci, 361, 147

- A 3.5 σ excess of 13±5 high-energy neutrinos was discovered in 6 months.
- The neutrino flux is about 5 times higher than the average γ-ray flux.
- No evidence of multiwavelength activity was found.

"orphan" neutrino flare

4FGL J0955.1+3551 — IC-200107A

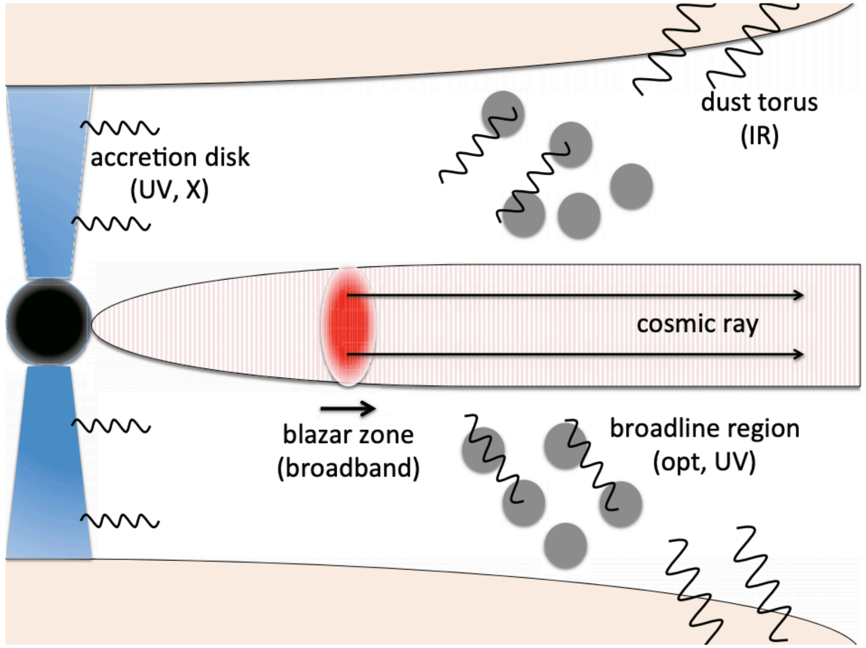




Second "orphan" neutrino flare event

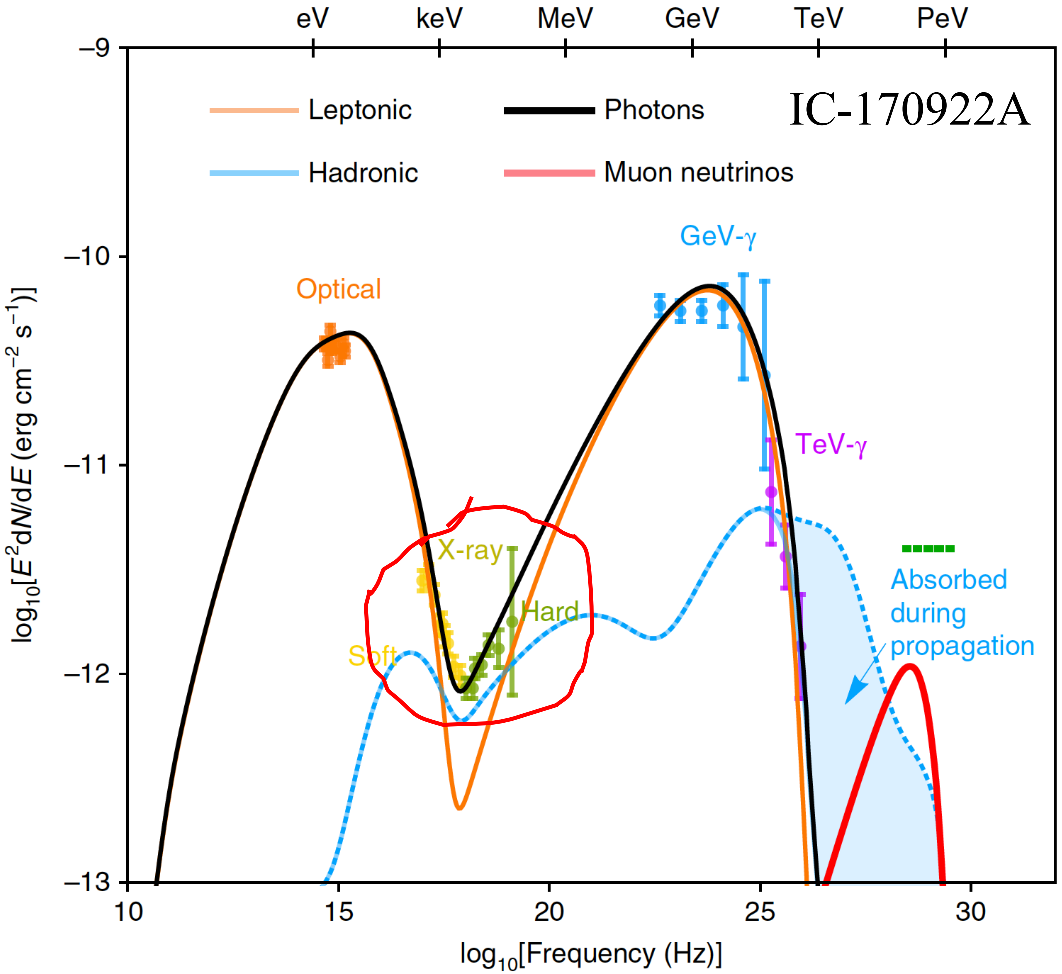
- Only X-ray flux was found in a high state with a factor of 2.5 larger than the average flux in 2012–2013.
- Assuming a 10 yr emission period, the neutrino flux is about 10 times higher than the average γ-ray flux.

The conventional one-zone pγ model



Murase et al. 2014, PRD, 90, 023007

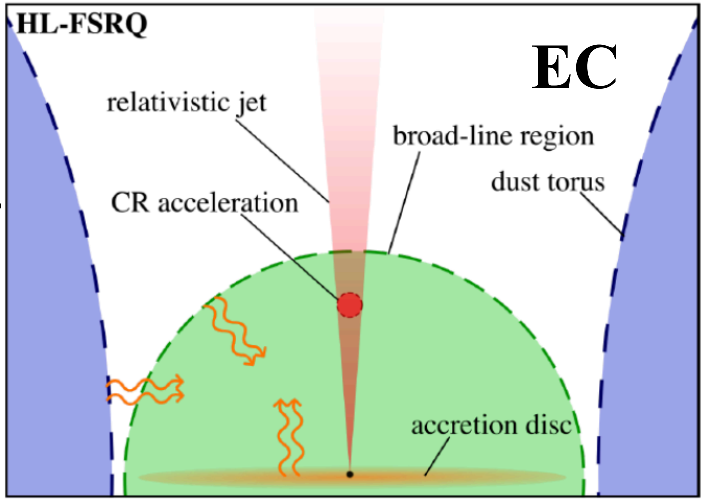
yielding a detection rate < 0.03 yr^{-1}



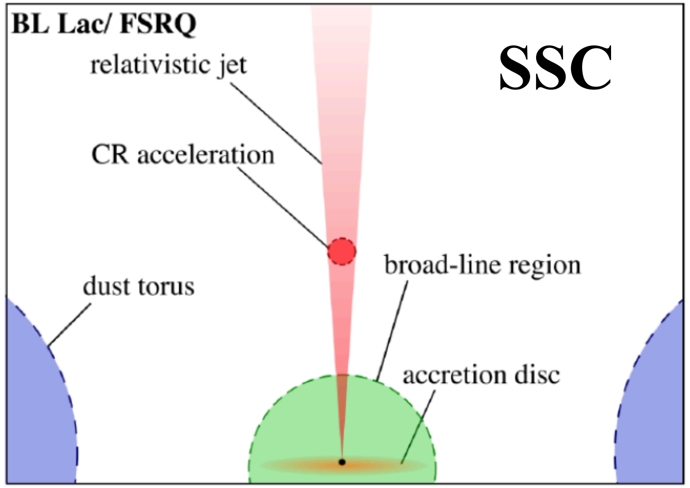
Gao et al. 2019, NatAs, 3, 88

The conventional one-zone pγ model

Rodrigues et al. 2018, ApJ, 854, 54

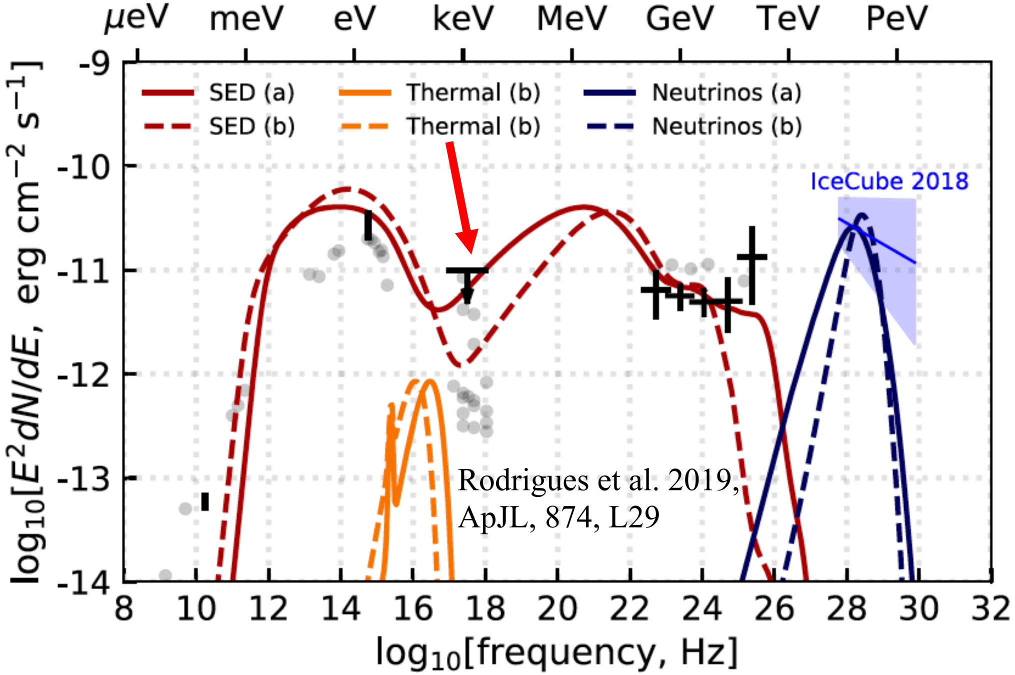


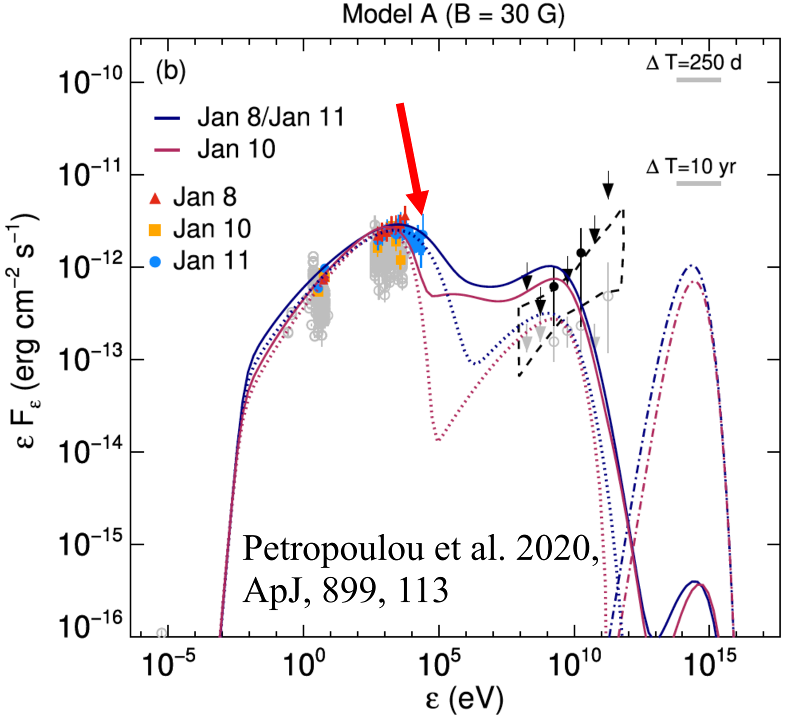
< 4.9 events



Detection rate < 5×10^{-3} yr^{-1}

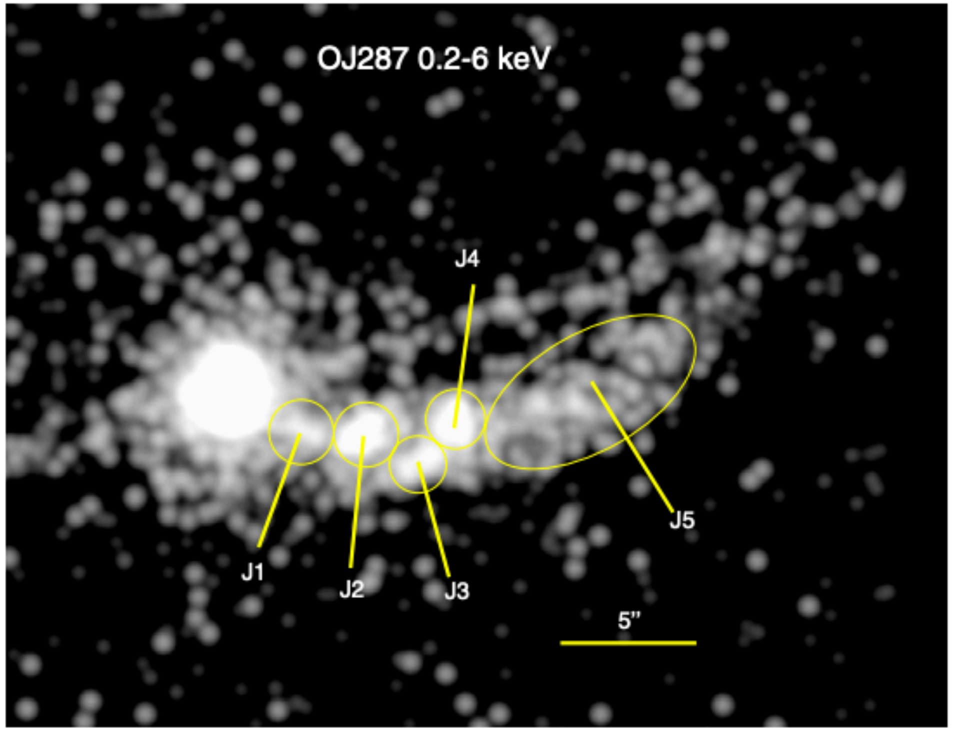
14-15 neutrino flare



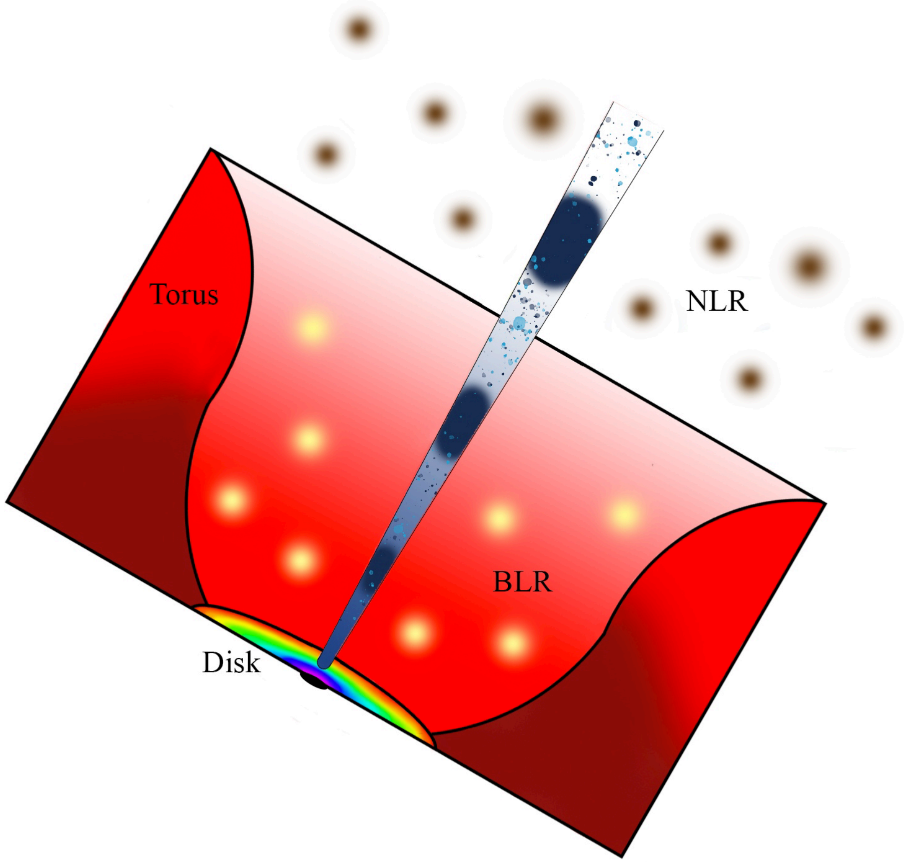


4FGL J0955.1+3551
IC-200107A

Multiple emission zones in blazar jets



Marscher & Jorstad, 2011, ApJ, 729, 26



Cerruti, 2020, Galaxies, 8, 72

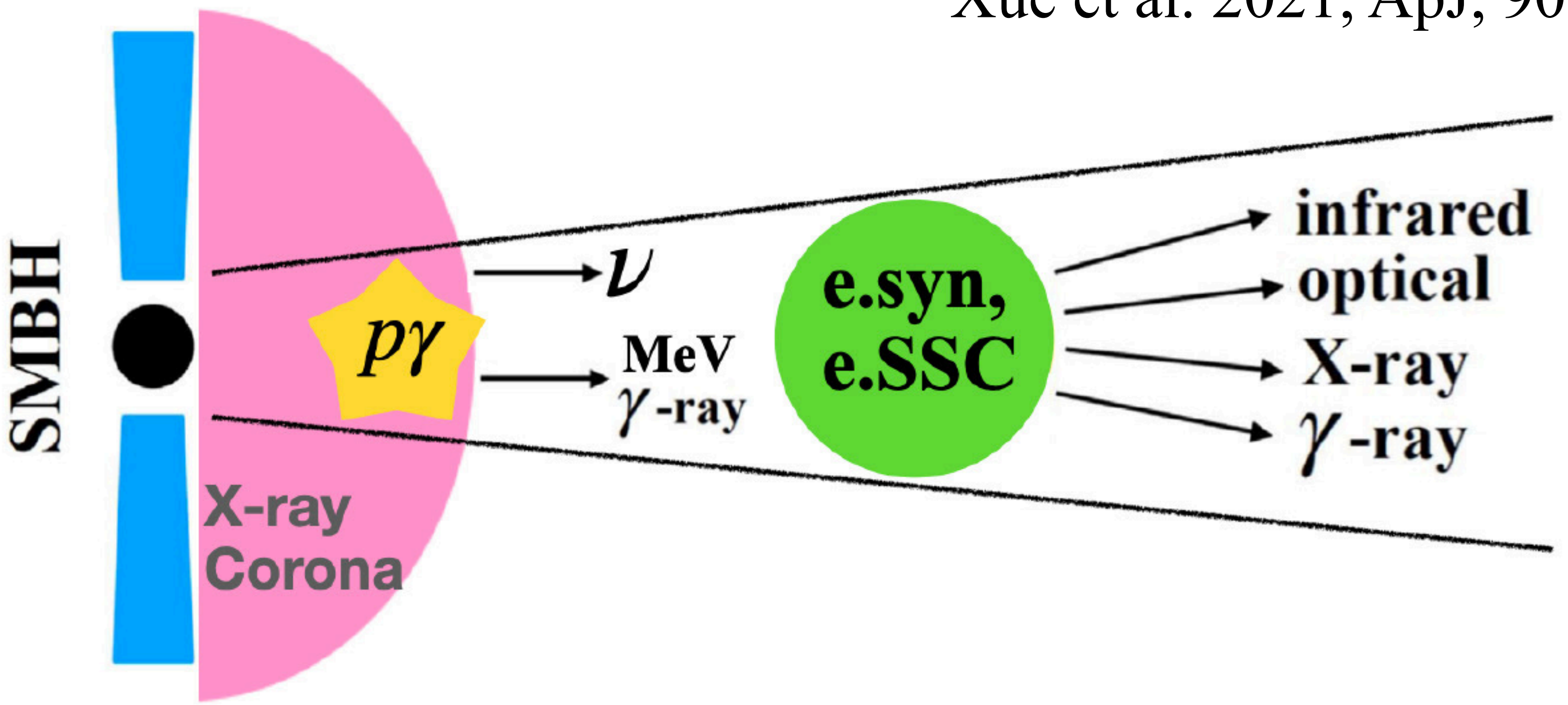
What the two "orphan" neutrino flares have in common

- No gamma-ray activity is found.
- Gamma-ray generated in the neutrino production region is absorbed.

- The neutrino flux is higher than the average γ-ray flux.
- There are multiple emitting region.

The inner-outer blob model for "orphan" neutrino flare

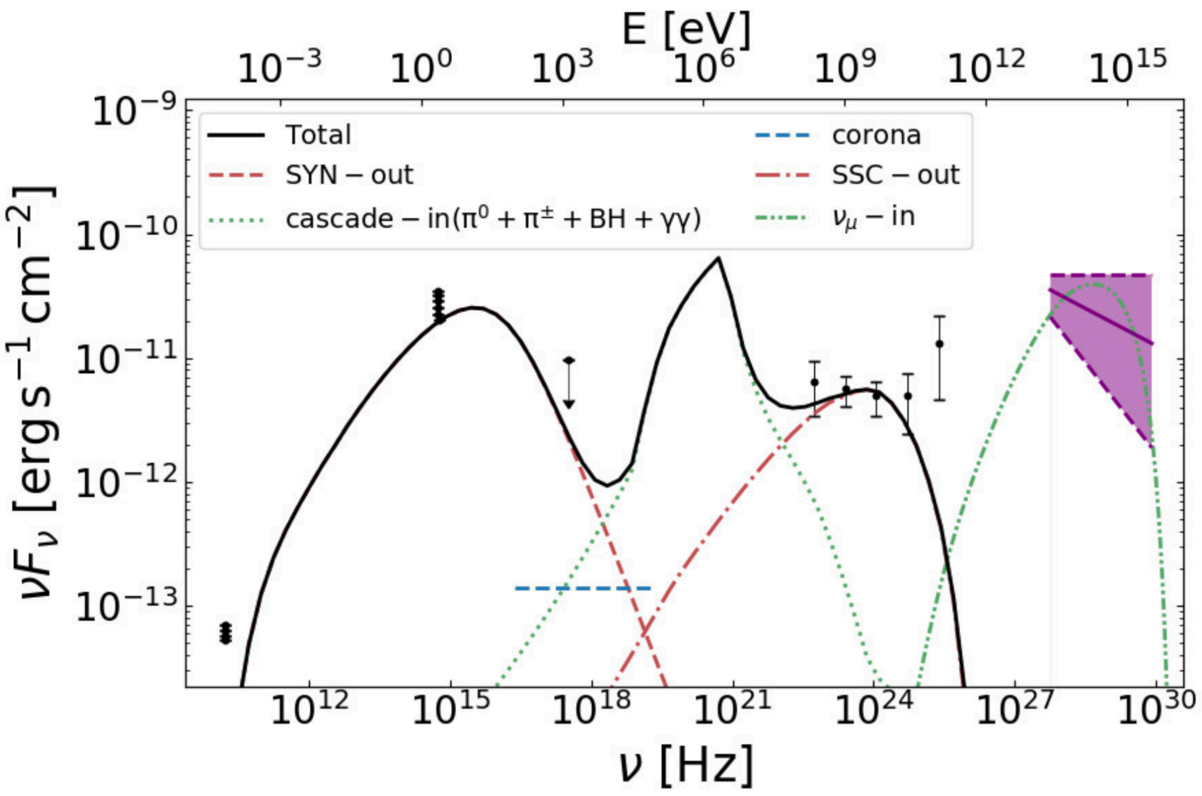
Xue et al. 2021, ApJ, 906, 51



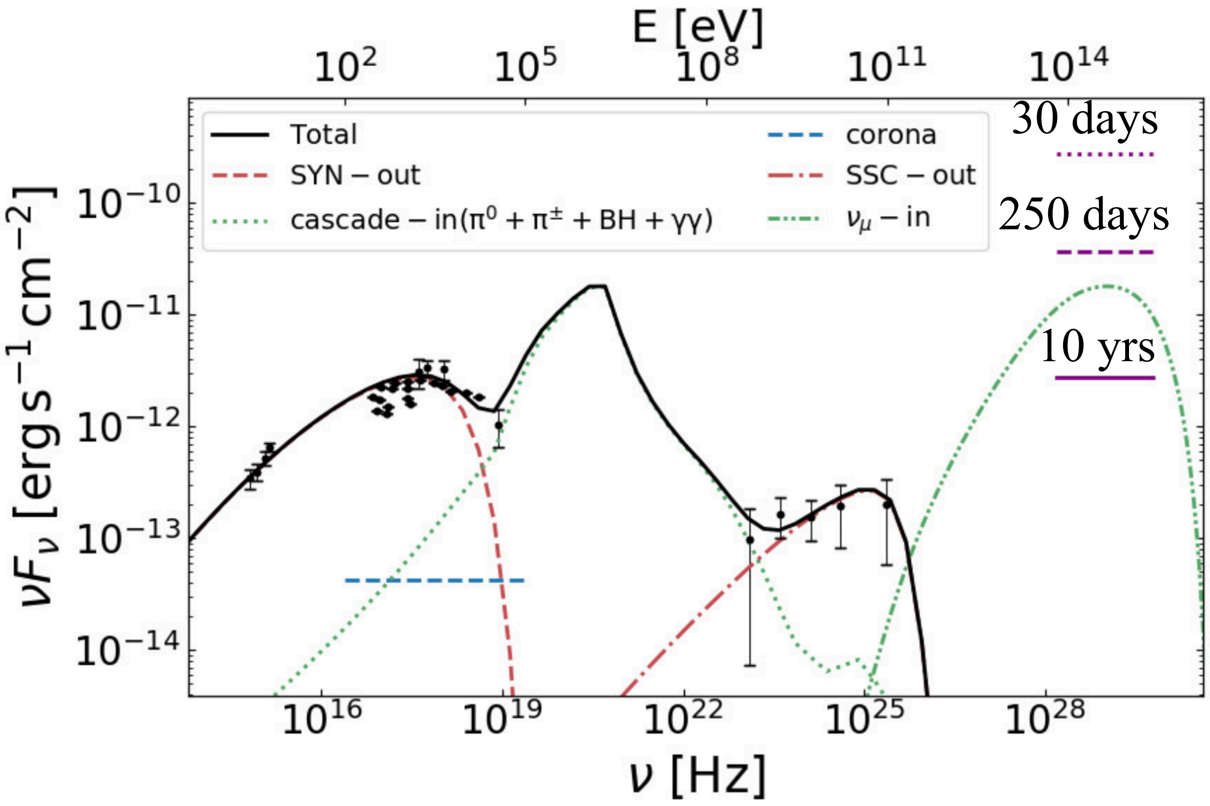
$$L(E) = L_{1\mathrm{keV}}(E/1\ \mathrm{keV})^{1-\alpha}, \quad 0.1\ \mathrm{keV} < E < 100\ \mathrm{keV}$$

$$L_{1\mathrm{keV}} = L_{\mathrm{BLR}} = 5\times10^{43}\ \mathrm{erg/s} \qquad \alpha = 1$$

The inner-outer blob model for "orphan" neutrino flare



TXS 0506+056 — 14-15 neutrino flare



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Xue et al. 2021, ApJ, 906, 51

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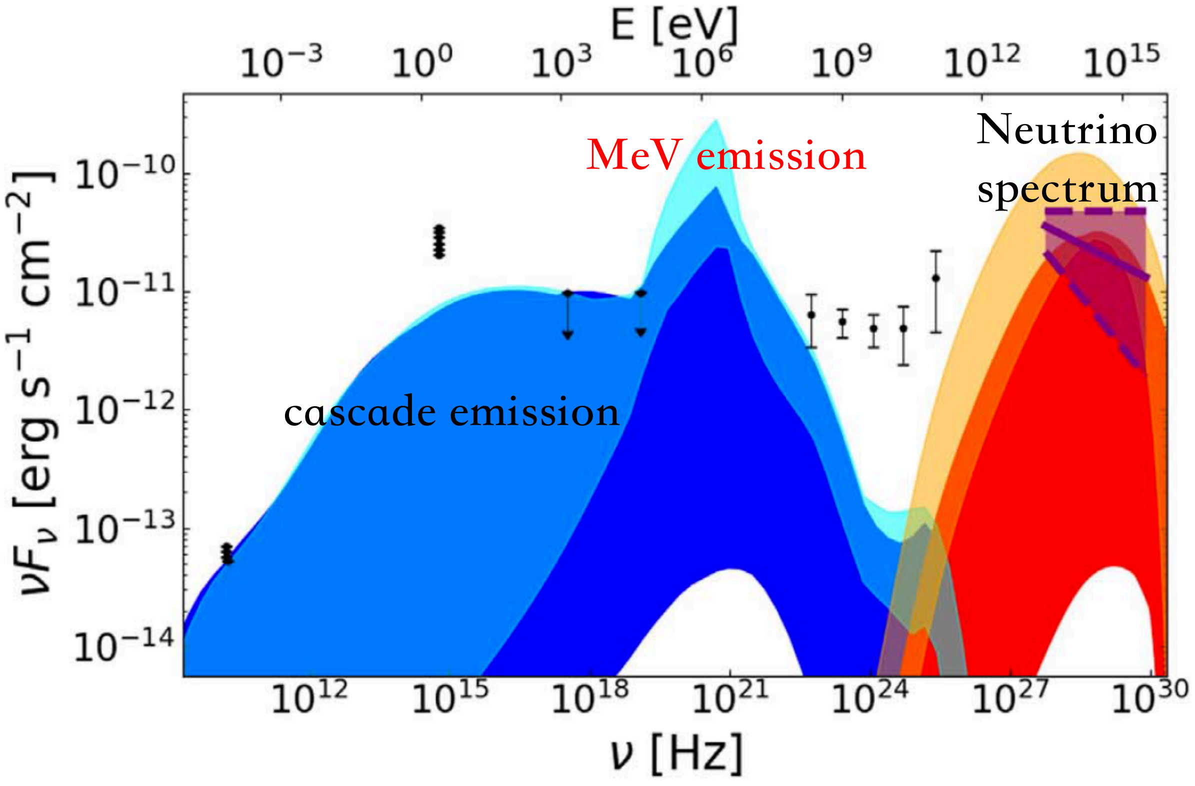

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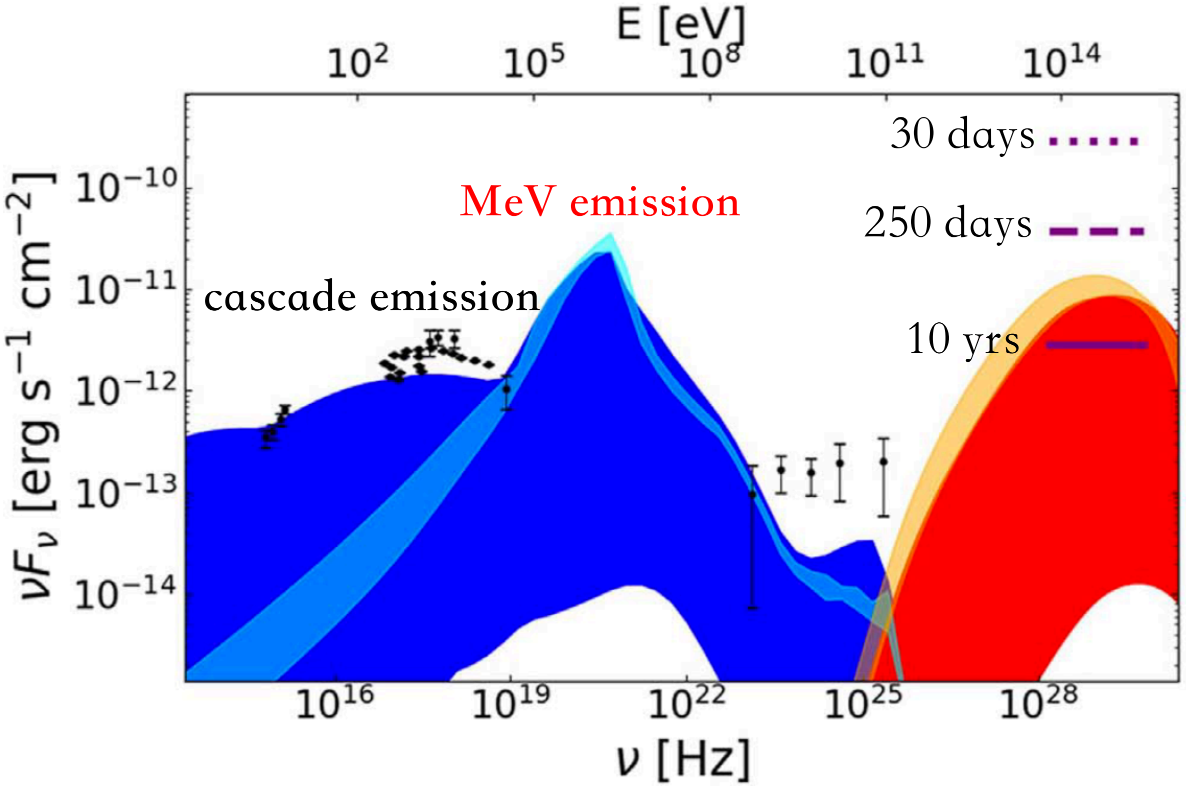
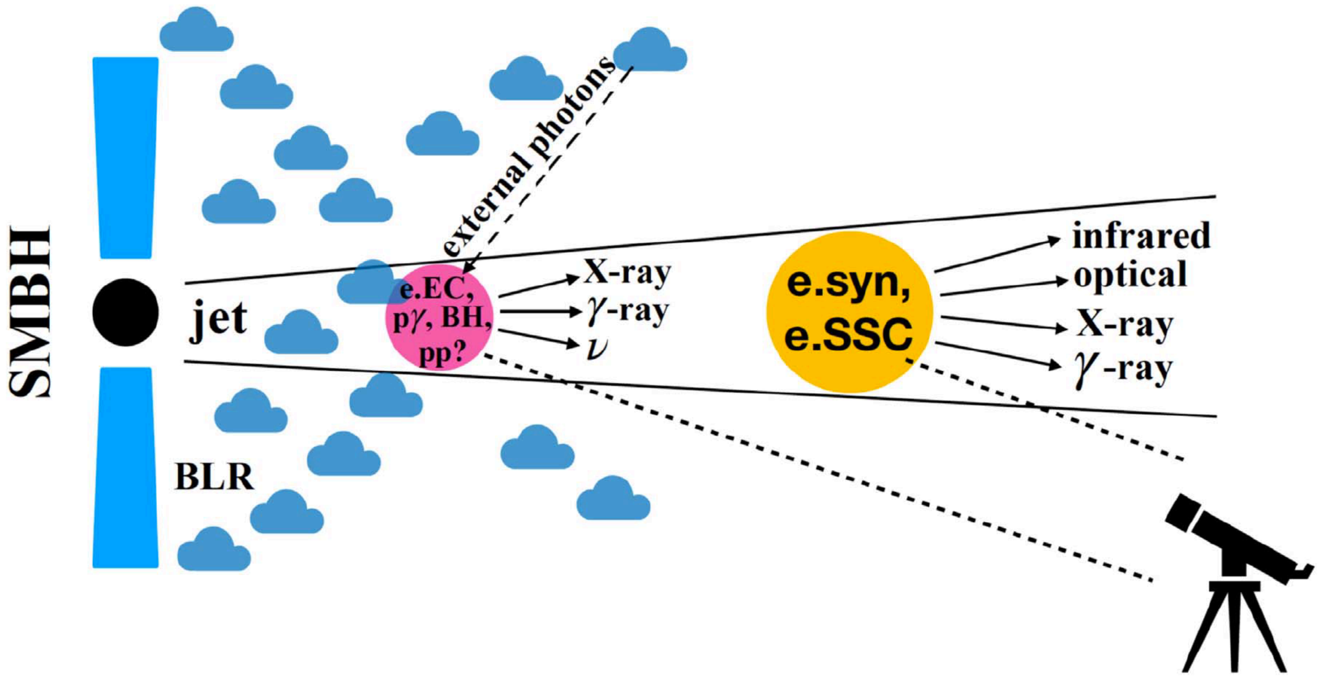


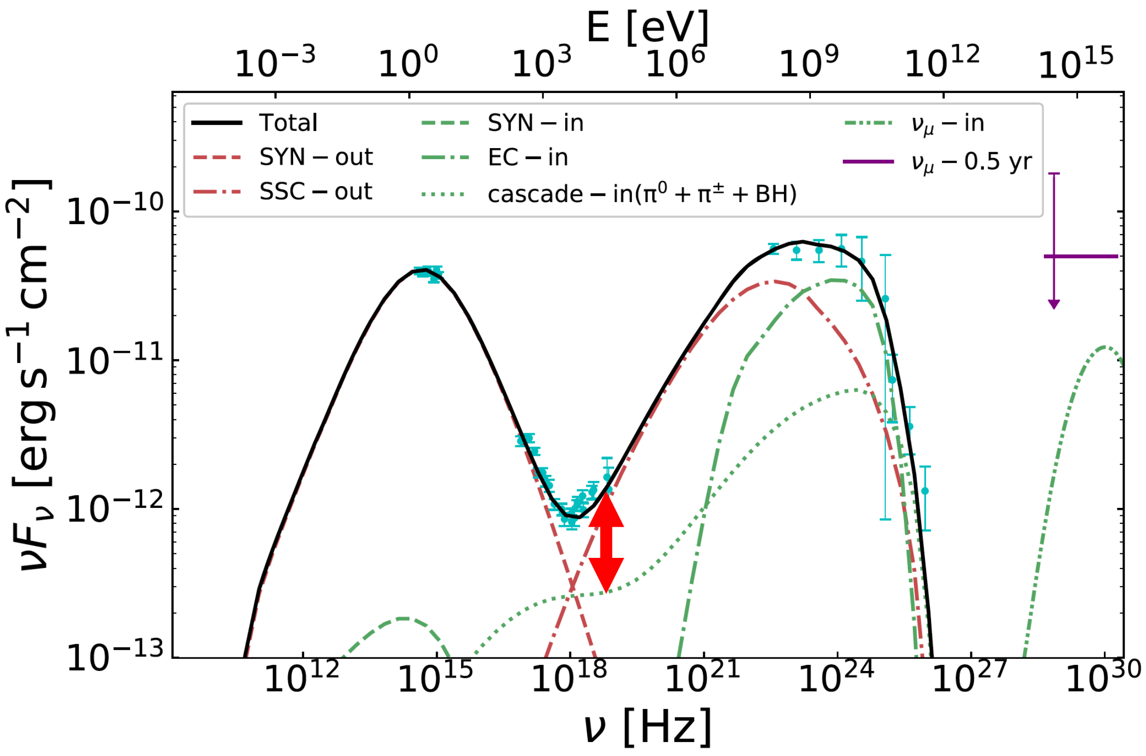
$\delta_D \in [10,30]$; $r_{in}^{AGN} \in [10^{-4}, 10^{-3}]$ pc; $B_{in} \in [1, 100]$ G; $\eta \in [1, 100]$; $L_{p,inj} \in [10^{45}, 10^{47}]$ erg/s

The inner-outer blob model for IC-170922A



Xue et al. 2019, ApJ, 886, 23

Assuming $L_{p,inj} = L_{Edd}$ $\sim 0.3\ yr^{-1}$



Summary

- If it is believed that blazars can radiate high-energy neutrinos, multiple dissipation regions must be considered;
- Our inner-outer blob model is a unified physical picture for the high-energy neutrino events and “orphan” neutrino flares from blazars;
- In the future, sensitive MeV gamma-ray instrument may be able to catch the MeV flare around the arrival time of a neutrino event from a blazar and serve as a critical test to the inner–outer blob model for the blazar’s “orphan” neutrino flares with simultaneous multiwavelength observation.

Thanks for your attention!