

Dissecting the region around IceCube-170922A

The blazar TXS 0506+056 as the first cosmic neutrino source

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<https://arxiv.org/pdf/1807.04461.pdf>

VLVnT 2018

Dubna, 2nd of October, 2018

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T.Glauch, B. Arsioli, N. Sahakyan, M. Huber

A brief history of IceCube's observations

- On September 22, 2017 **one** high energetic “**EHE**” neutrino event with most likely energy of ~ 290 TeV [1]
- Archival searches revealed a “**neutrino flare**” of $\sim 13 \pm 5$ event in a time period of ~ 110 (158) days between MJD 56949 and 57059 (October 19, 2014 – February 6, 2015) at a position very well consistent with the “EHE” event [2]

...and the pressing questions

- Which is/are the possible counterpart(s)?
- What is their time and energy behaviour?
- How are the two observations connected?

Identifying possible counterparts

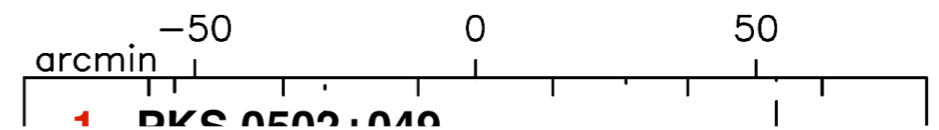
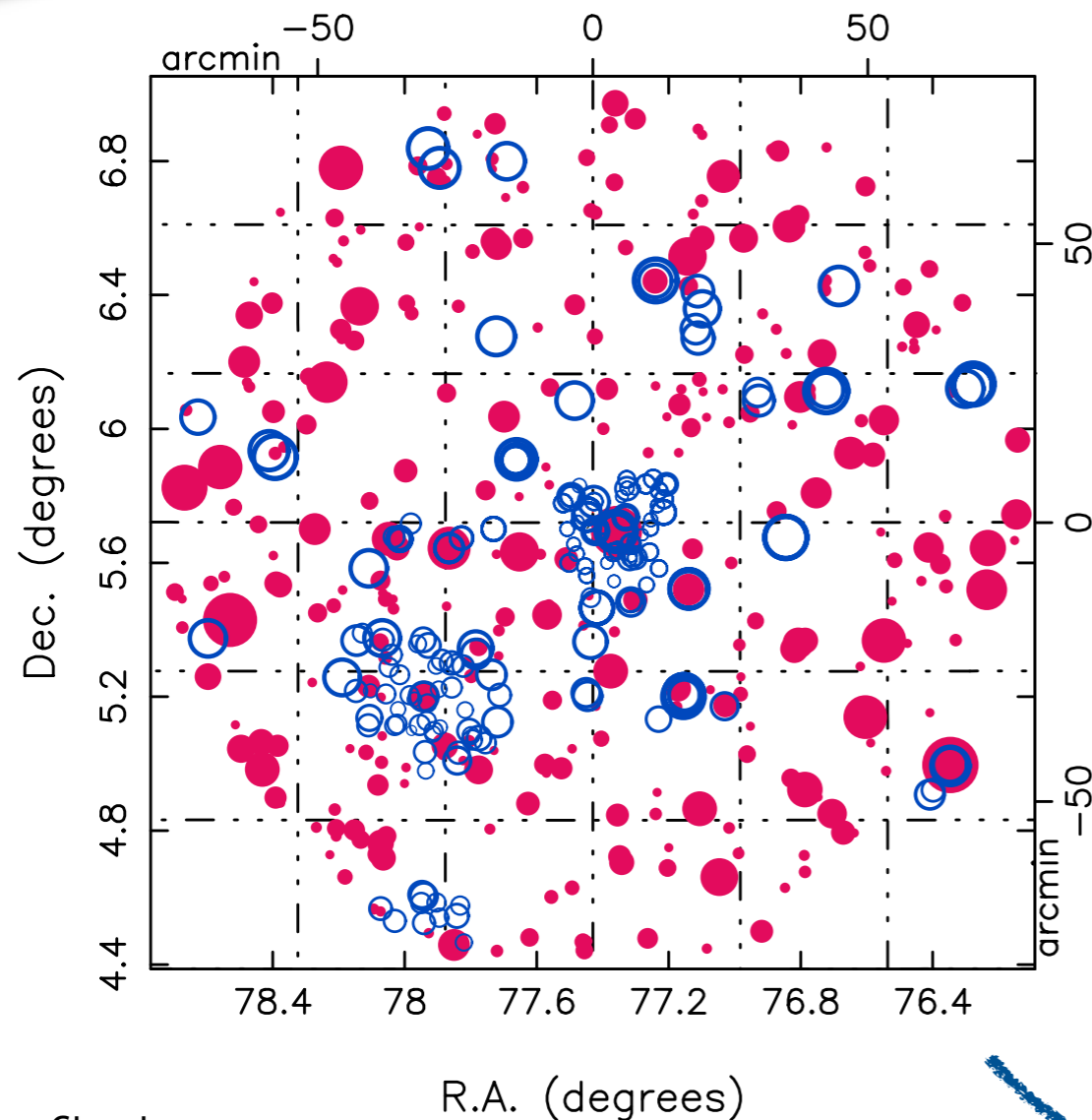
Sources in the Region

Radio: 637 (red)
X-Ray: 297 (open blue)

- Identify **7** interesting objects with,
- Non-Thermal Emission
 - Radio **and** X-Ray Emission
 - A blazar-like ratio of x-ray/radio emission

Analysis is based on the VOU-Blazar tool developed by the United Nations Open Universe initiative [<http://www.openuniverse.asi.it/>]

- *Input data combines 28 radio, X-ray and γ -ray catalogs, as well as additional data points from Swift observations from follow-up observations of IceCube-170922A*

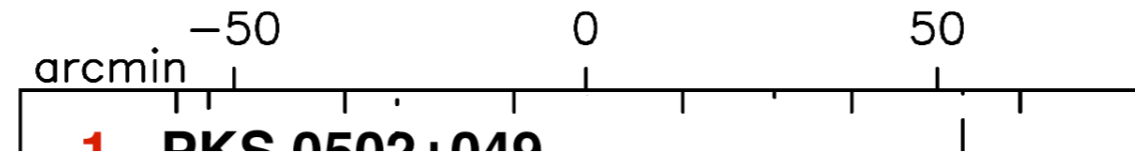


90% Contour

Examine the remaining candidates

Exclude four objects through visual inspection of the SEDs

**Steep Radio
Spectrum Object**



HBL Candidate

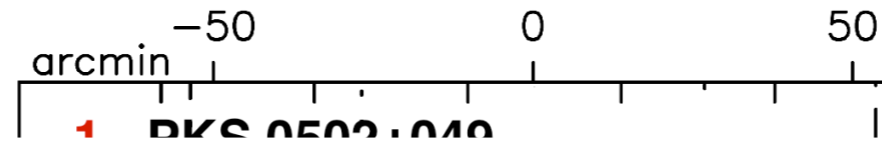
**Nearby Elliptical
Galaxy**

Galaxy Cluster

The remaining 3 candidate sources

TXS 0506+056

- IBL/HBL source
- $z=0.3366$
- **Top 4%** brightest γ -ray objects in Fermi 3LAC
- Radio: 1Jy at 6cm, 537mJy at 20cm, **Top 0.3%** in NVSS



2WHSP J050833.3+05310

- HBL source
- Only a 2 sigma gamma-ray detection between MJD 55900 - 56300

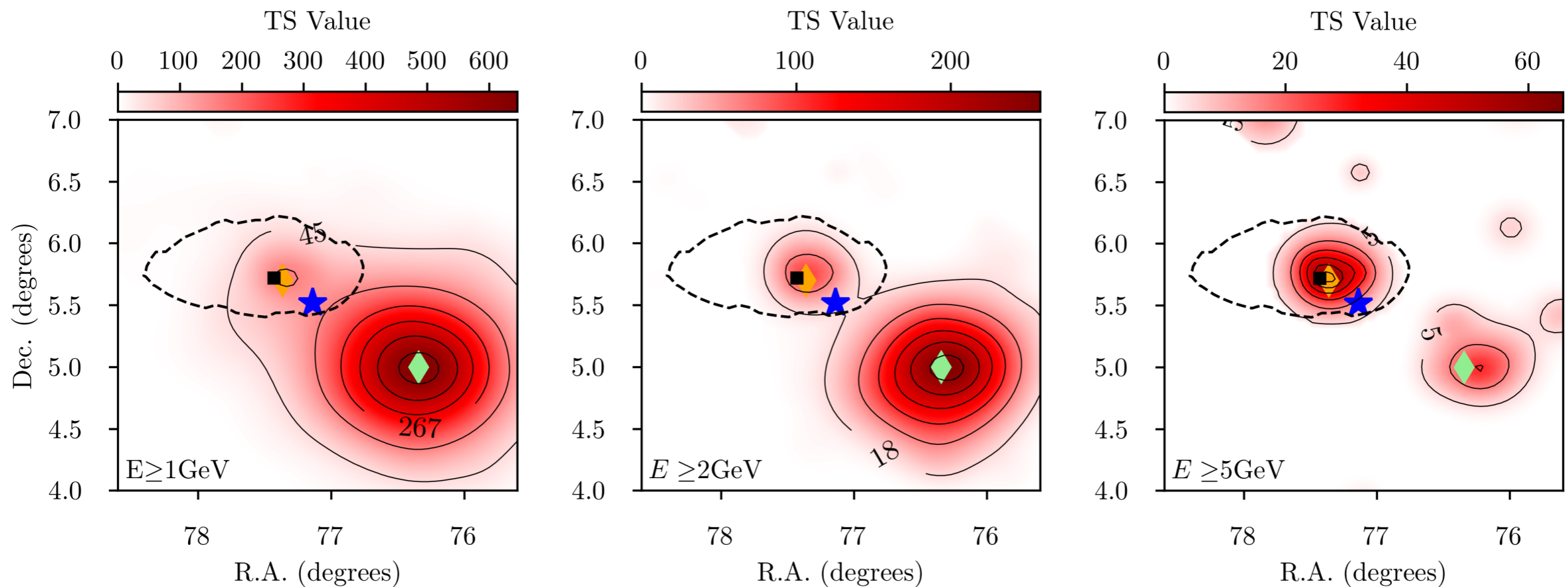
PKS 0502+049

- LBL/FSRQ source
- $z=0.954$

The γ -ray sky during the ν -flare

- Two significant gamma ray emitters at a distance of ~ 1.2 degrees
- PKS 0502+049 dominates at **low energies** ($E_b = 934$ MeV) and is **extremely variable**
- TXS 0506+056 dominates at **high energies** (above ~ 3 GeV)

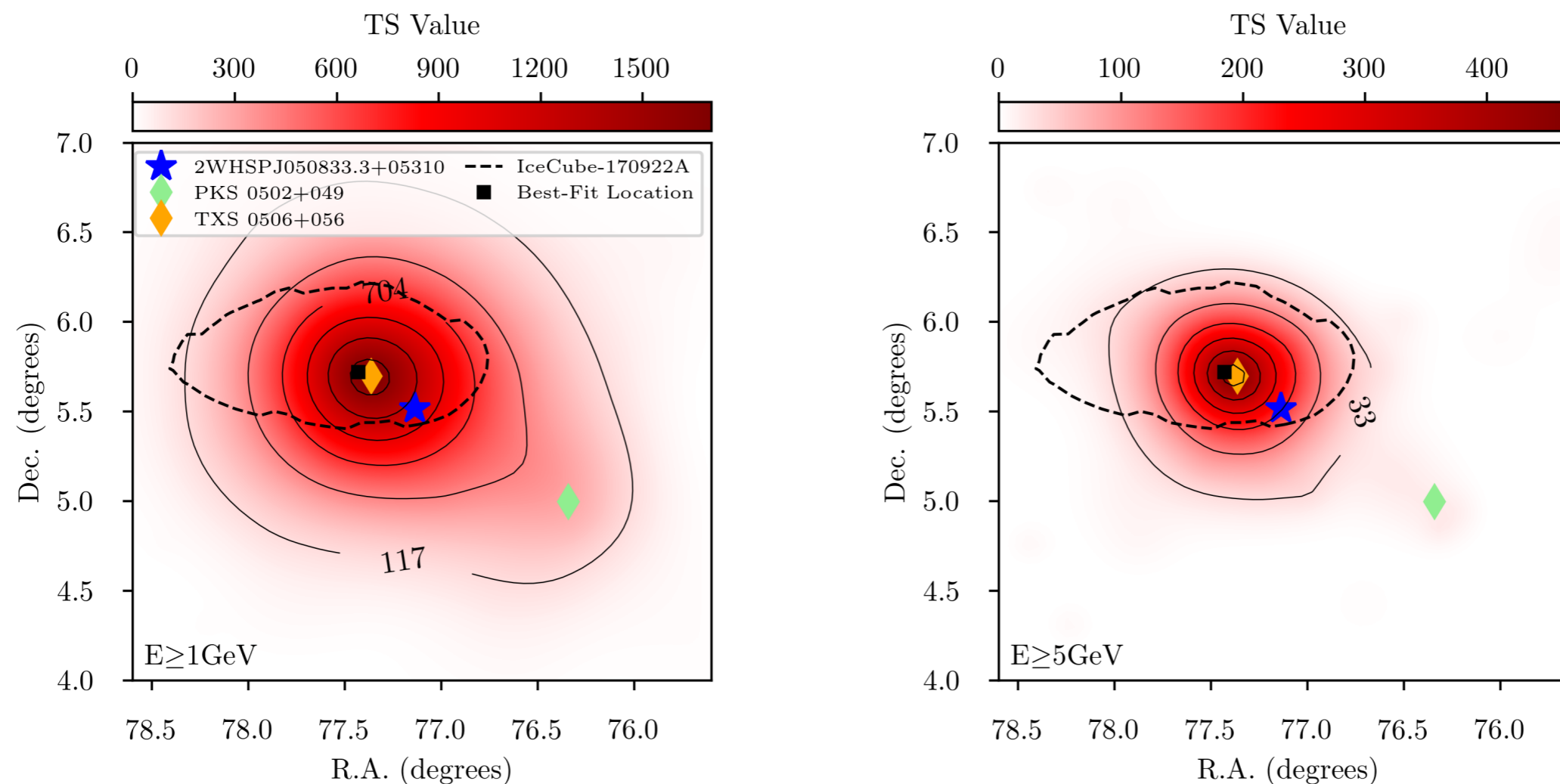
Test-Statistic Maps for MJD 56949 - 57059



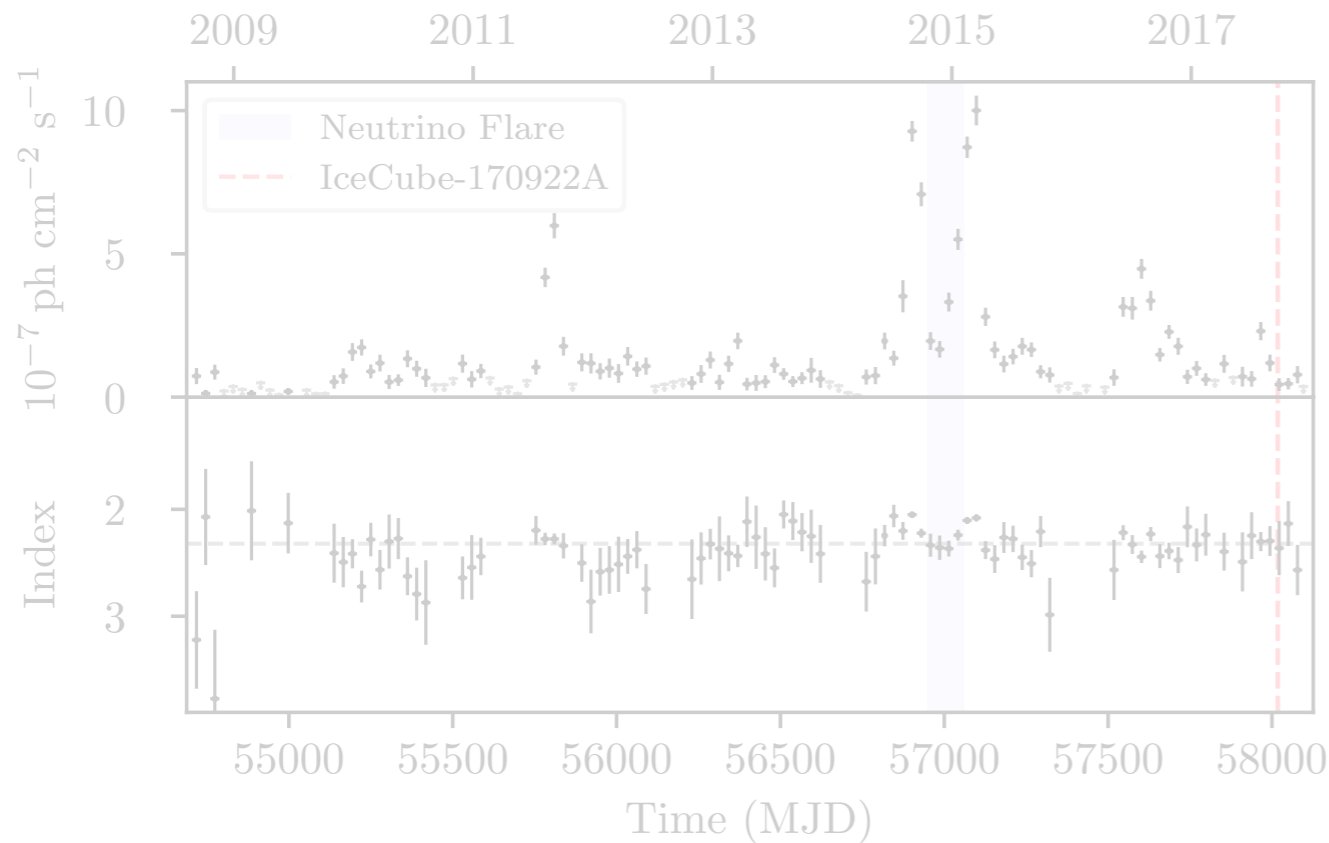
The γ -ray sky during the EHE Event

- Two significant gamma-ray emitters at a distance of ~ 1.2 degrees
- TXS 0506+056 dominates at **all energies**

Test-Statistic Maps for MJD 57908 - 58018



Time dependence of TXS 0506+056



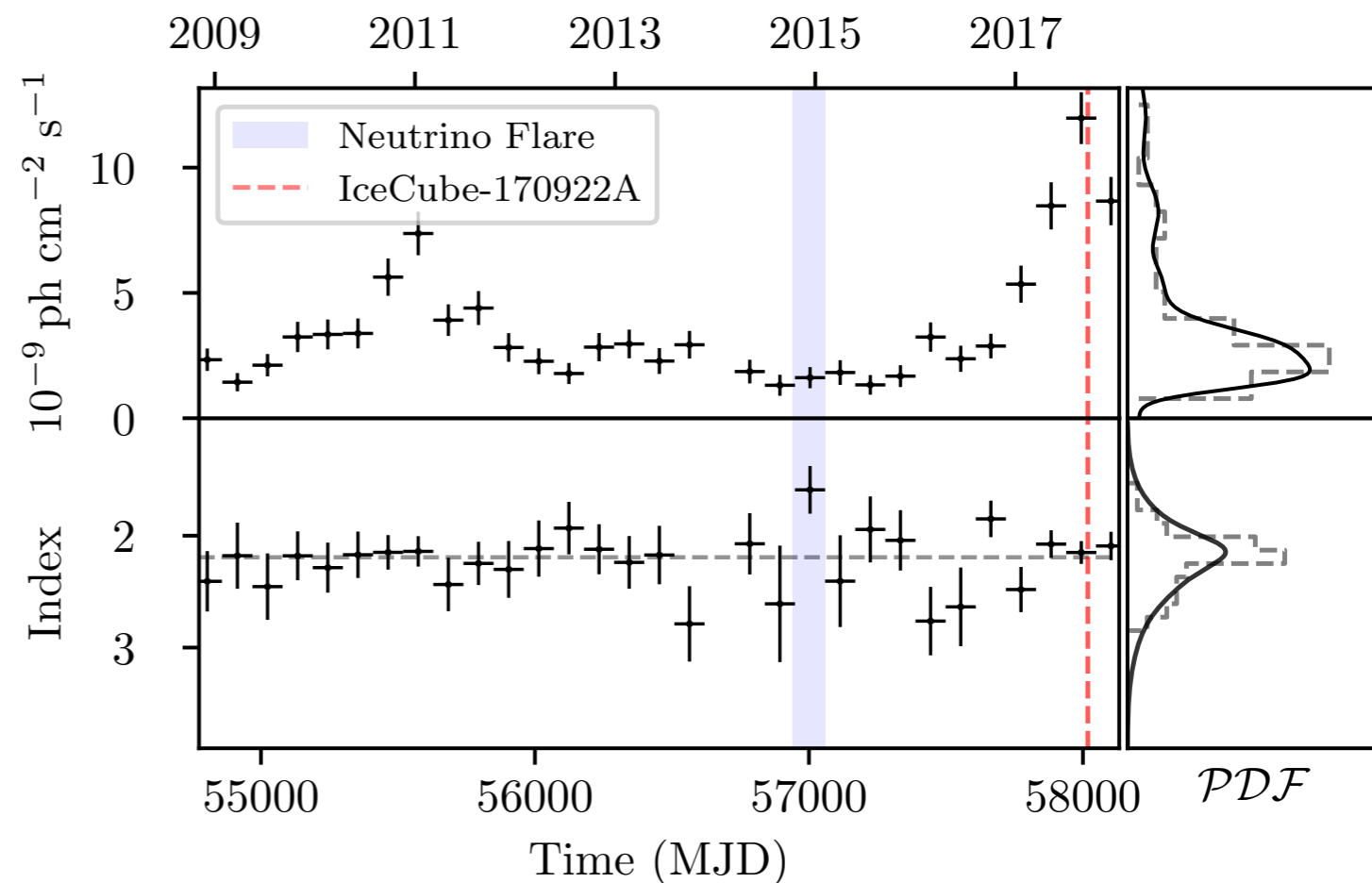
TXS 0506+056

110-day light curve > 2 GeV to study high-energy behaviour and to avoid any modelling bias

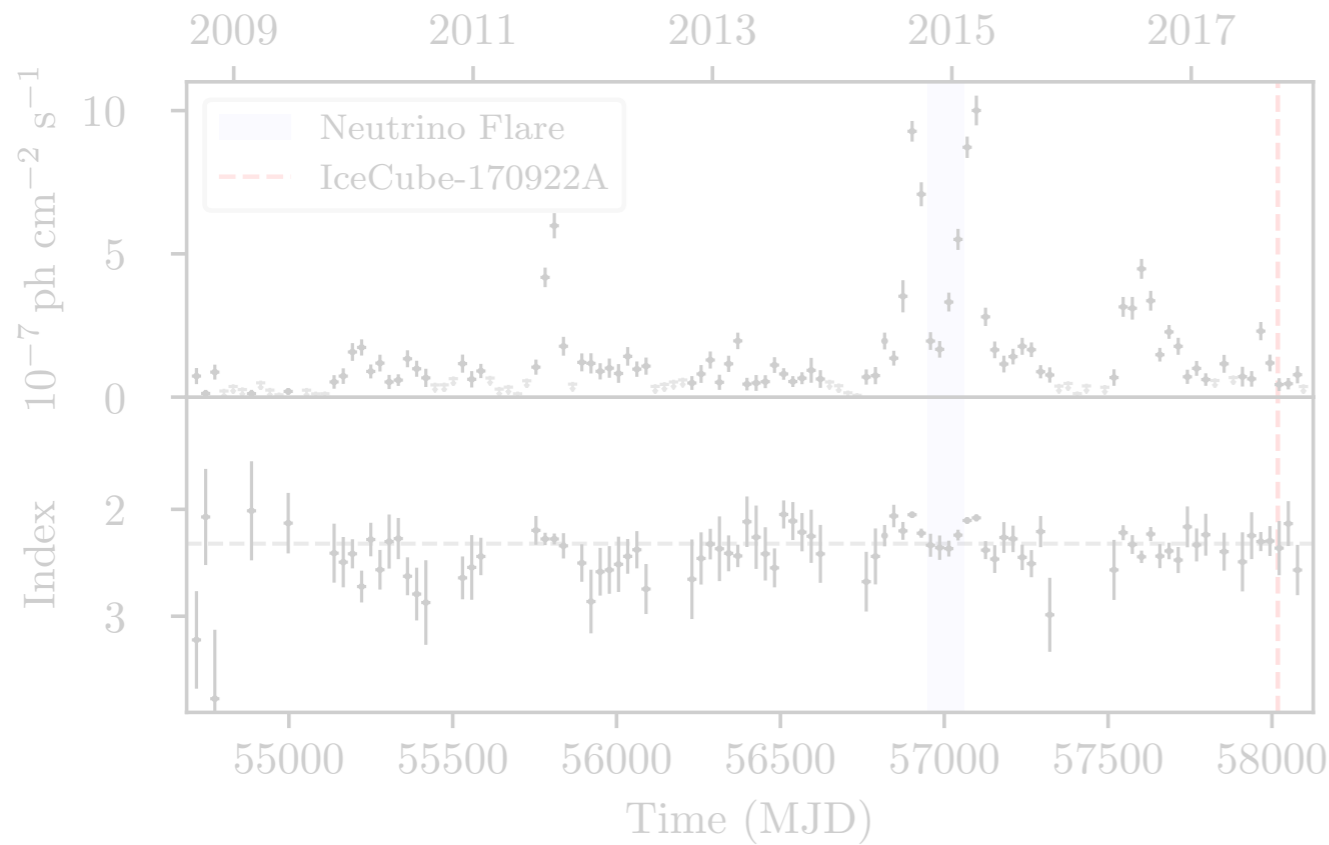
- EHE and γ -ray chance probability $\sim 3\sigma$ [1] (**high γ -flux** state)
- ν - flare significance $\sim 4\sigma$ [2] (**low γ -flux**, but indication for **high-energy** emission)

PKS 0502+049

28-day light curve above 100 GeV
There are two significant flare right **before** and **after** the neutrino flare!



Time dependence of TXS 0506+056



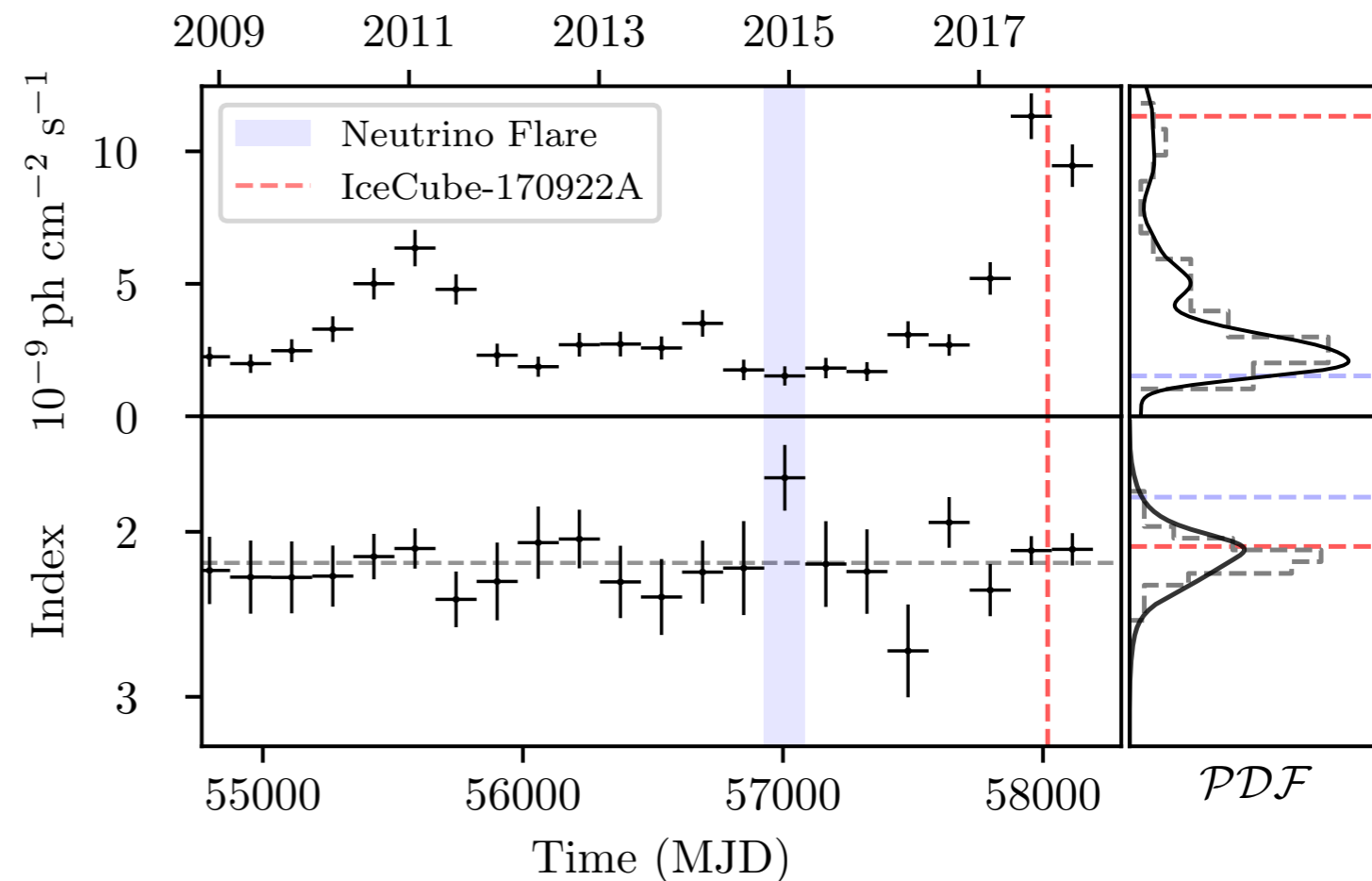
TXS 0506+056

158-day light curve > 2 GeV to study high-energy behaviour and to avoid any modelling bias

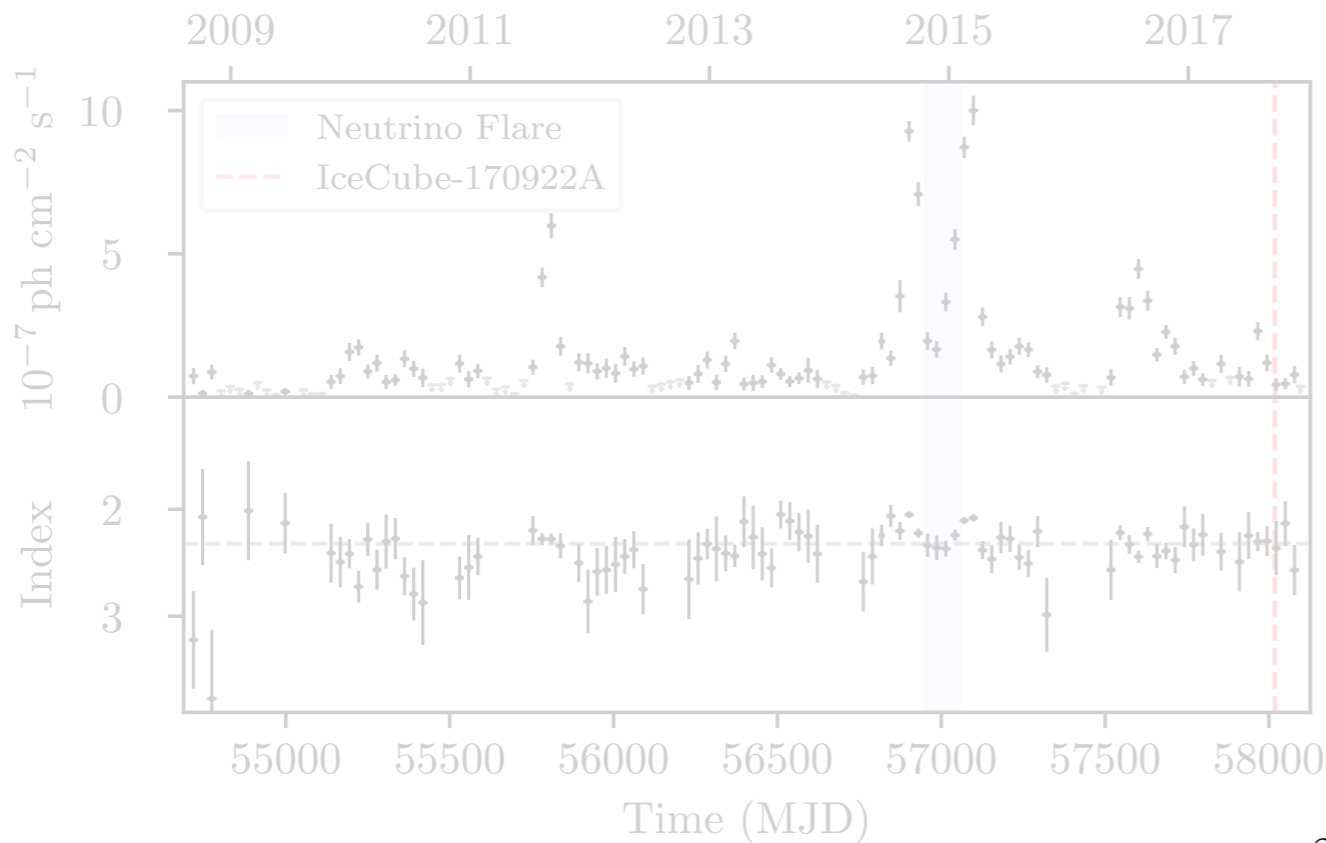
- EHE and γ -ray chance probability $\sim 3\sigma$ [1] (**high γ -flux** state)
- ν - flare significance $\sim 4\sigma$ [2] (**low γ -flux**, but indication for **high-energy** emission)

PKS 0502+049

28-day light curve above 100 GeV
There are two significant flare right **before** and **after** the neutrino flare!



High-energy photons during the ν -flare



TXS 0506+056

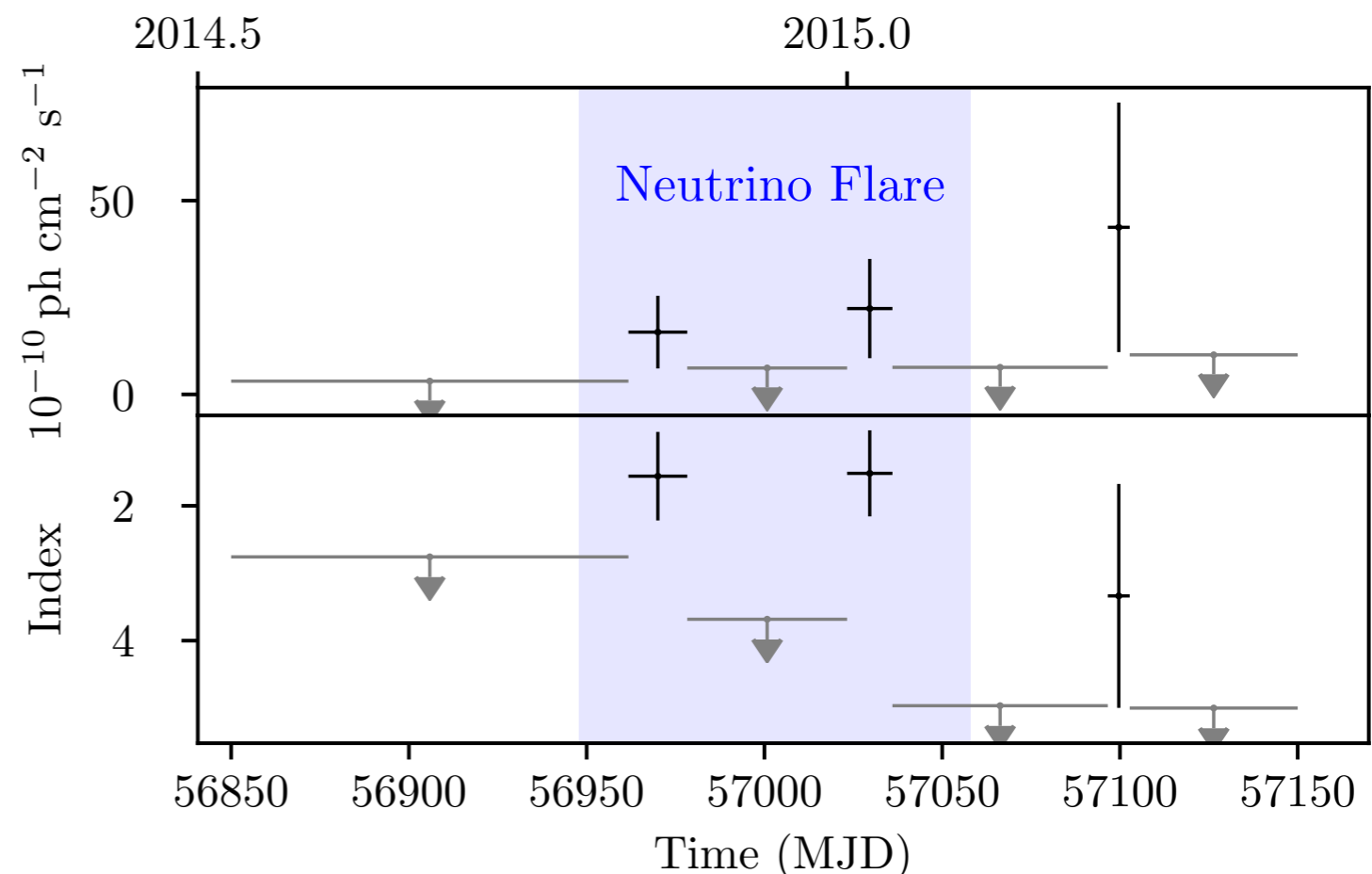
Zoom in light curve during the ν - flare and only look for events with energy >10 GeV. Identify two time periods with significant emission

MJD 56962 – 56978

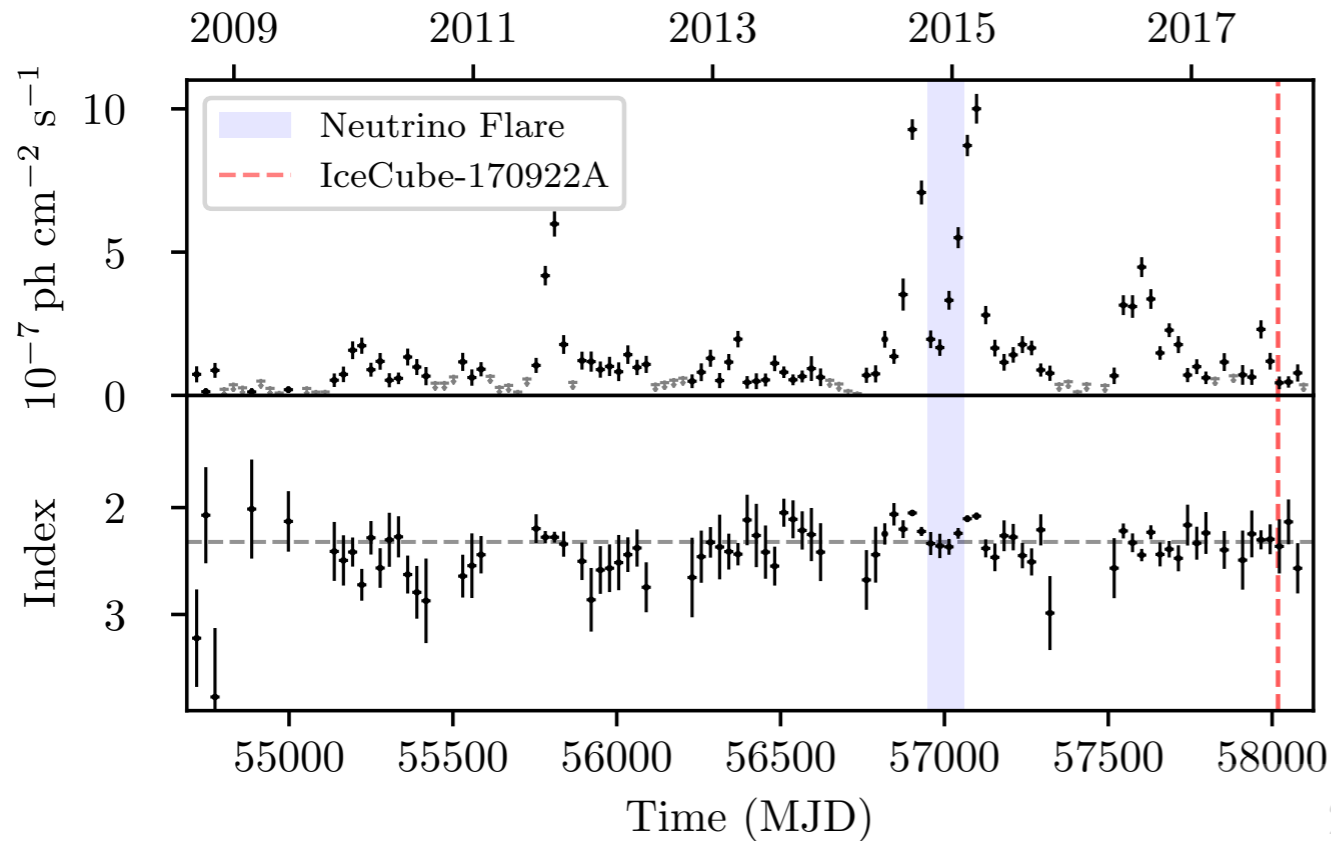
MJD 57023 – 57036

PKS 0502+049

28-day light curve above 100 GeV
There are two significant flare right **before** and **after** the neutrino flare!



Time dependence of PKS 0502+049



TXS 0506+056

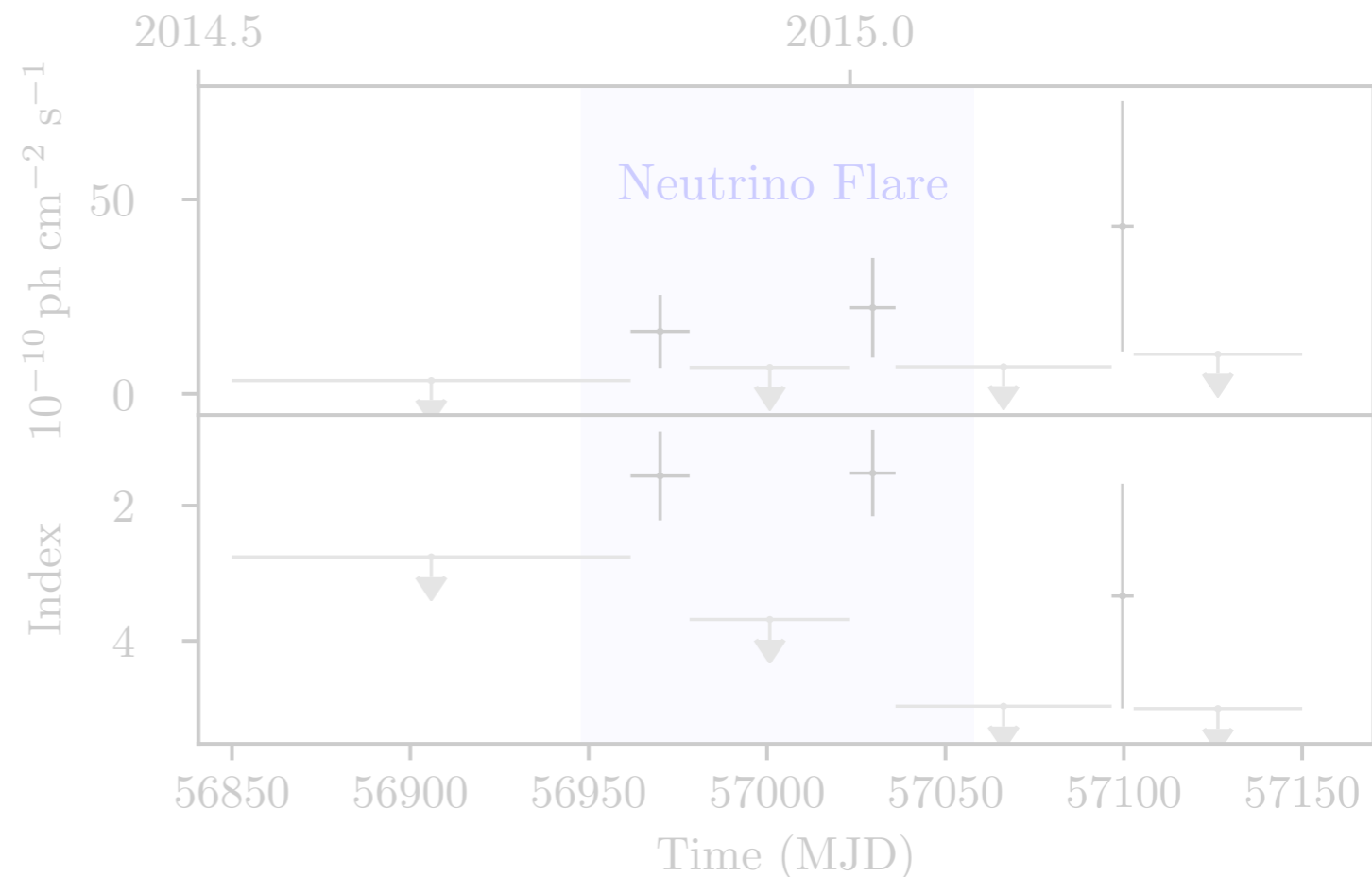
Zoom in light curve during the ν - flare and only look for events with energy >10 GeV. Identify two time periods with significant emission

MJD 56962 – 56978

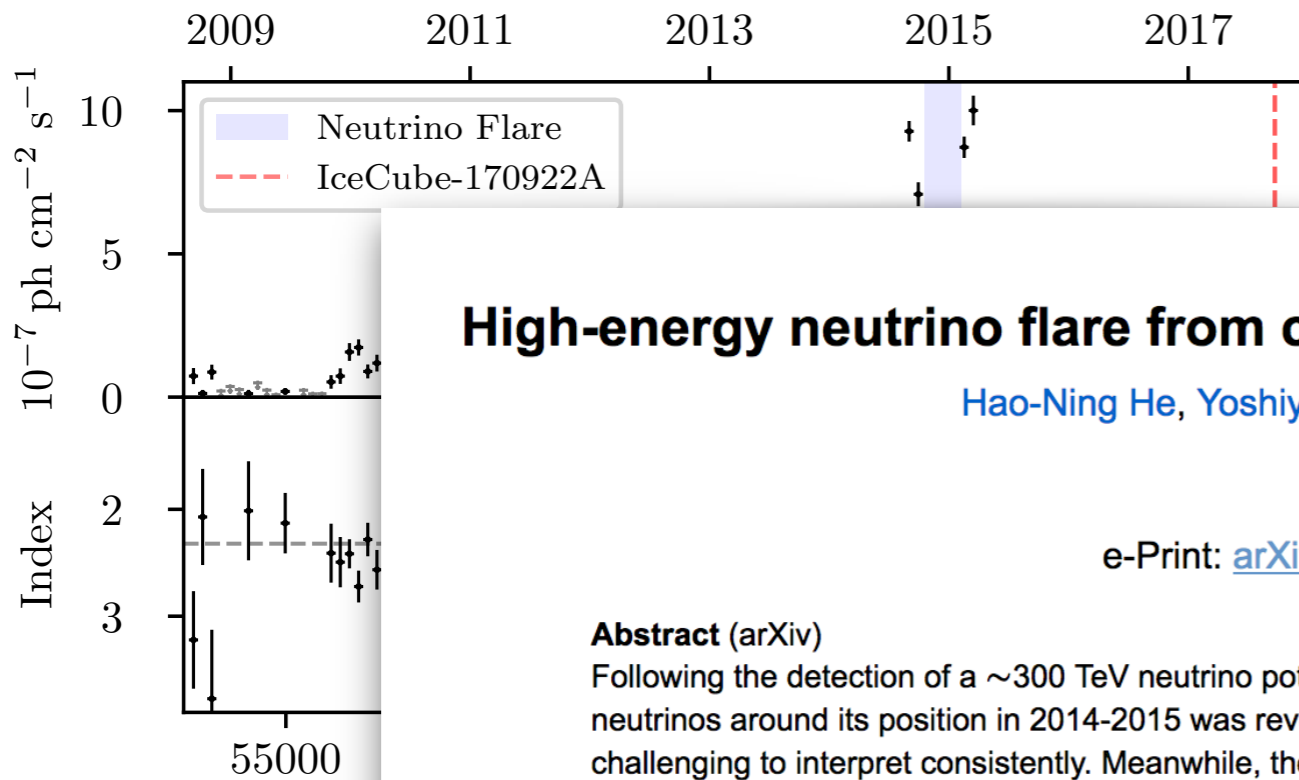
MJD 57023 – 57036

PKS 0502+049

28-day light curve above 100 GeV
There are two significant flare right **before** and **after** the neutrino flare!



Time dependence of PKS 0502+049



TXS 0506+056

110-day light curve > 2 GeV to study

High-energy neutrino flare from cloud-jet interaction in the blazar PKS 0502+049

Hao-Ning He, Yoshiyuki Inoue, Susumu Inoue, Yun-Feng Liang

Aug 13, 2018 - 5 pages

e-Print: [arXiv:1808.04330](https://arxiv.org/abs/1808.04330) [astro-ph.HE] | [PDF](#)

Abstract (arXiv)

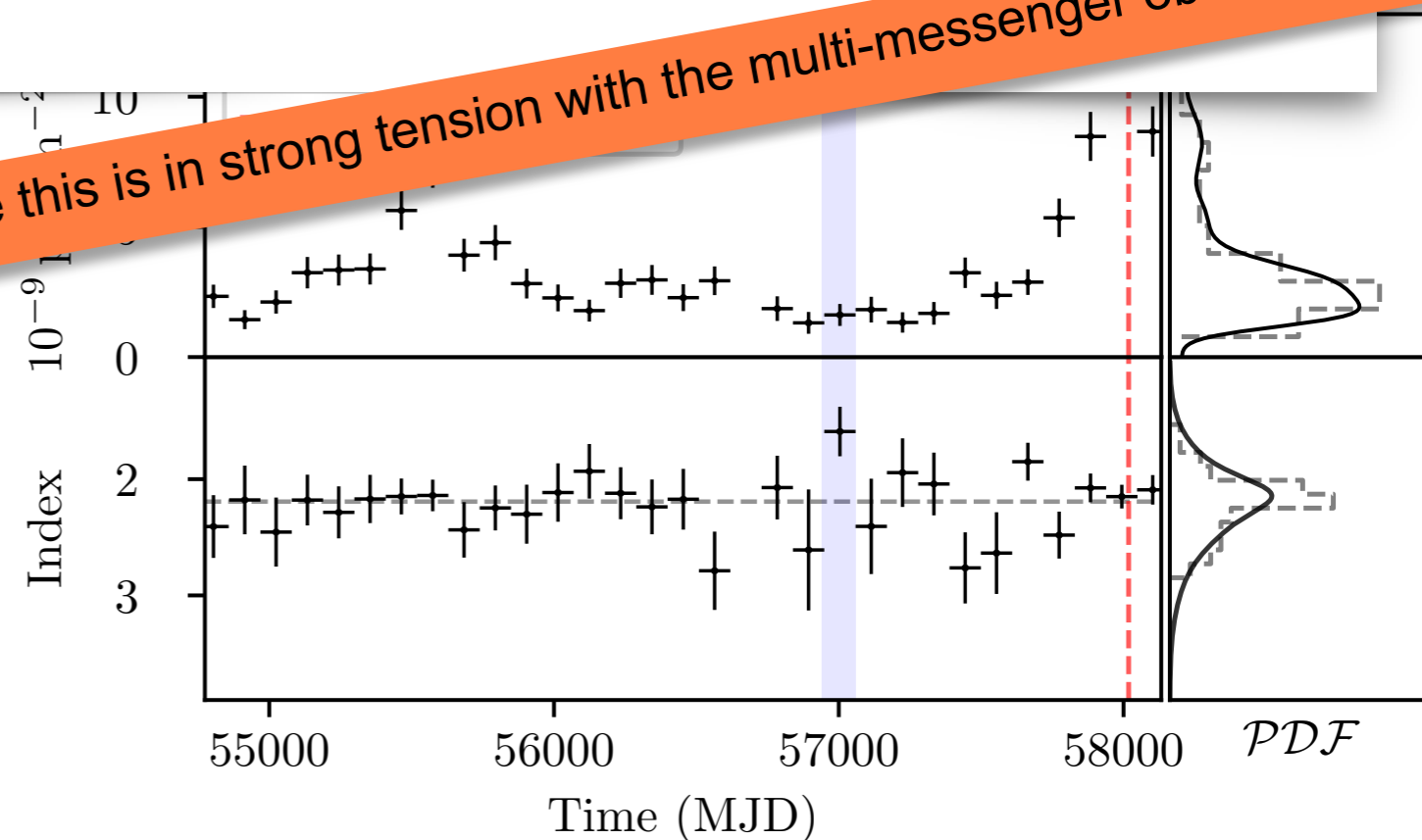
Following the detection of a ~ 300 TeV neutrino potentially associated with the flaring blazar TXS 0506+056, an excess of neutrinos around its position in 2014-2015 was revealed by IceCube. However, its contemporaneous quiescence in γ -rays is challenging to interpret consistently. Meanwhile, the blazar PKS 0502+049, positioned within the neutrino localization uncertainties, was seen to be flaring in γ -rays. We show that dense, line-emitting gas clouds that interact with its jet and induce cosmic ray acceleration and hadronuclear interaction can plausibly explain the 2014-2015 neutrino flare.

PKS 0502+049

28-day light curve above 100 GeV

There are two significant flare **before** and **after** the neutrino flare!

Something like this is in strong tension with the multi-messenger observations

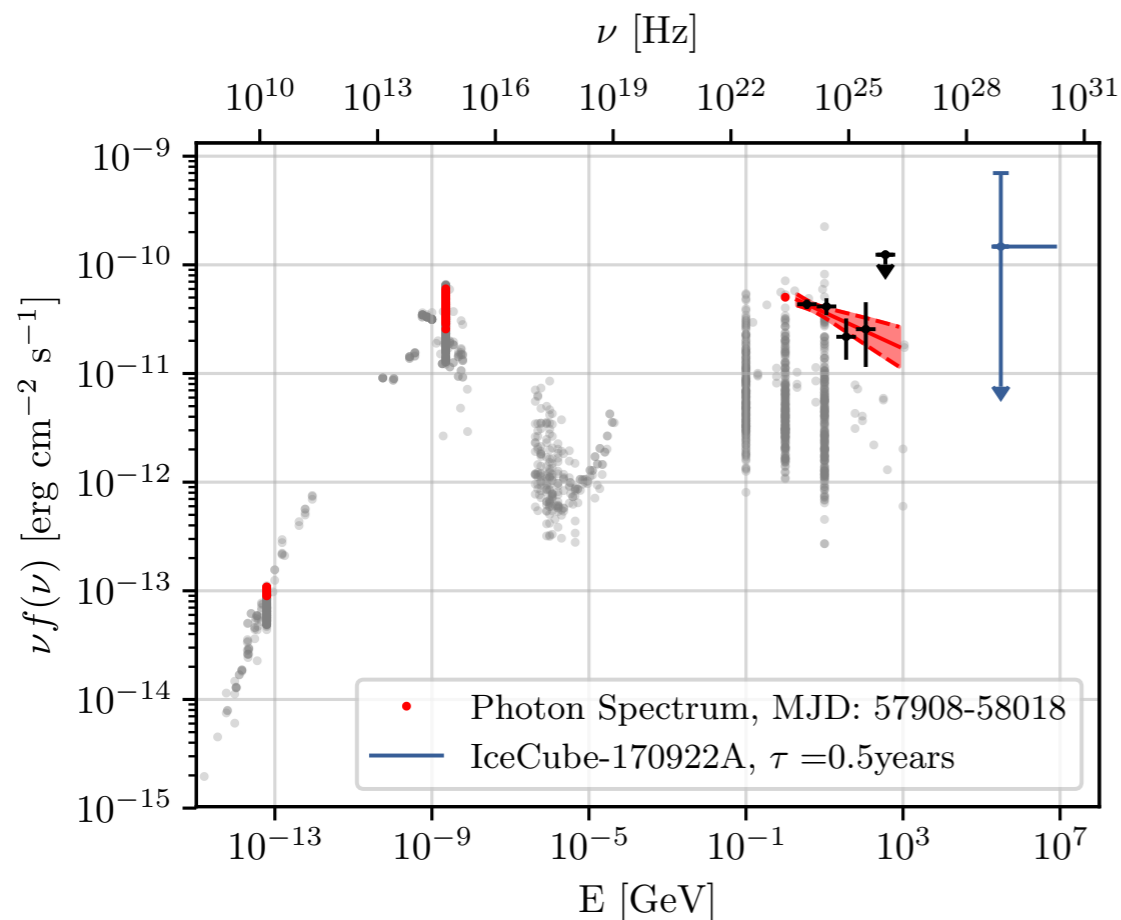


Energetic Reconnection of the SED?

The hybrid SEDs combines all the publicly available data for TXS 0506+056 from radio to gamma-ray with the neutrino information*
(Video available on <https://youtu.be/IFBciGIT0mE>)

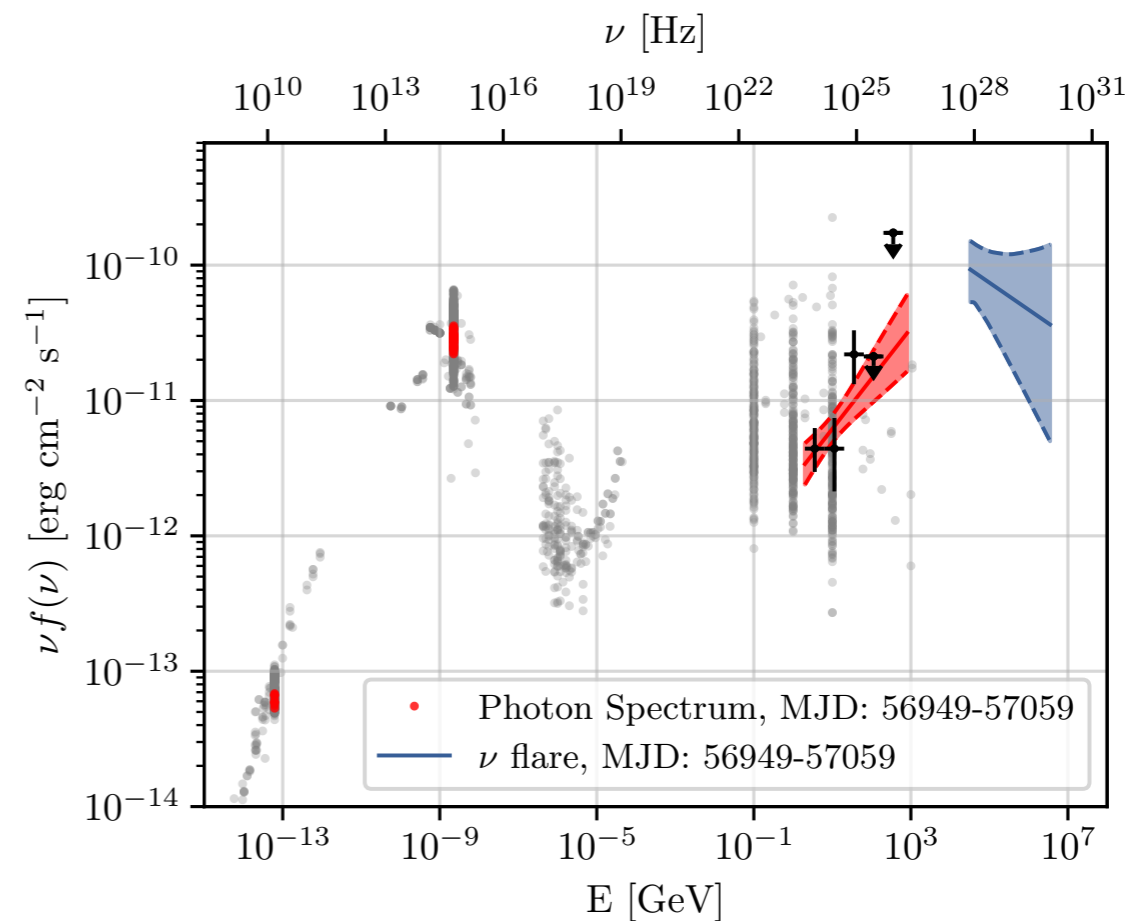
MJD 58018 (EHE Event):

- Soft Gamma-Ray spectrum (2.24)
- One Neutrino Event with Energy $E \sim 200$ TeV, around $\sim 3\sigma$ significance



MJD 57004±55 (ν-flare):

- Hard Gamma-Ray Spectrum (~ 1.5)
- Large Flare in Neutrinos (4σ significance)



* **Radio, Optical:** OVRO, CRTS, ASAS
X-Ray, Optical, UV: Swift and NuSTAR
Gamma-Ray: Fermi LAT

$$L_\gamma(> 2 \text{ GeV}) \sim 10^{46} \text{ erg s}^{-1}$$

$$L_\nu \sim 1.4_{-0.5}^{+0.6} \times 10^{47} \text{ erg s}^{-1}$$

Energetic Reconnection of the SED?

*What if we model the spectrum down to 100 MeV?
..or use a time-window of 158 days*

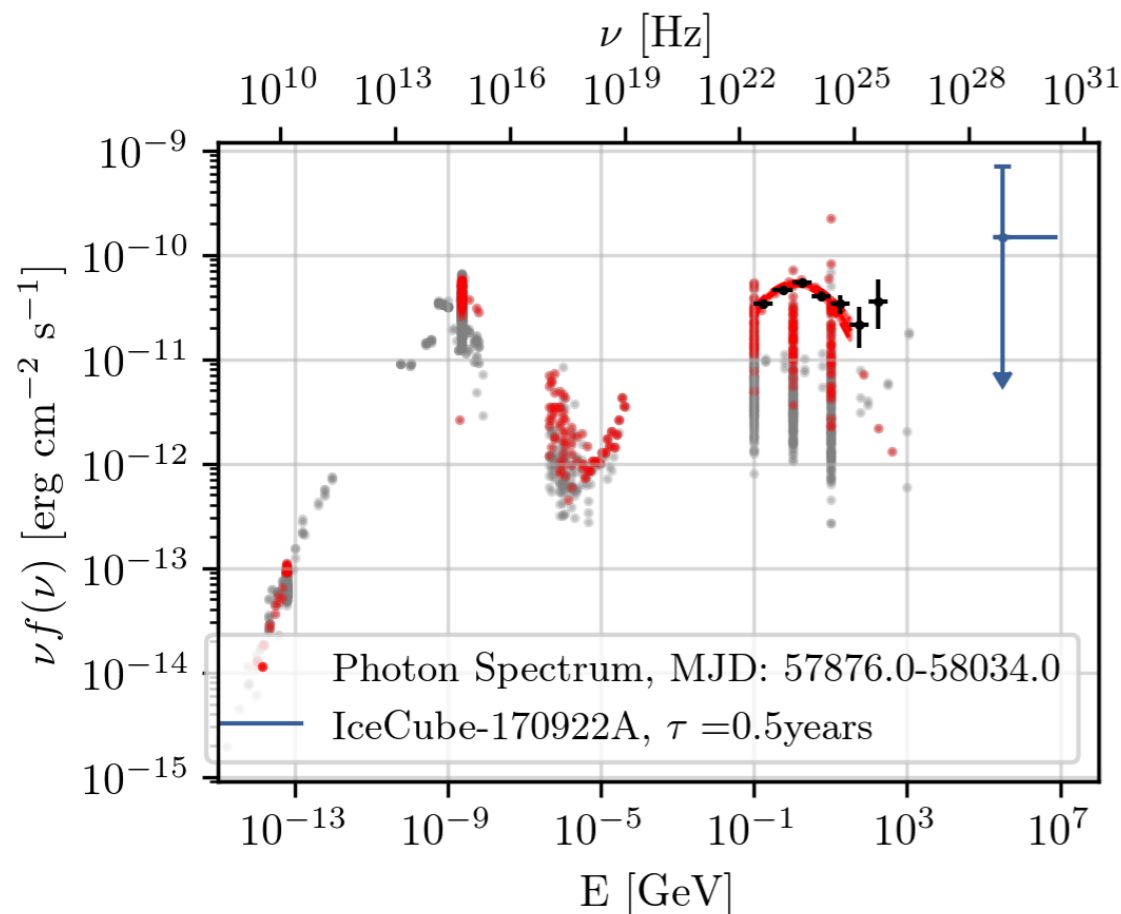
1. Observation:

The lower energy part of the γ -ray spectrum is well modelled with a log-parabola spectrum

MJD 58018 (EHE Event)

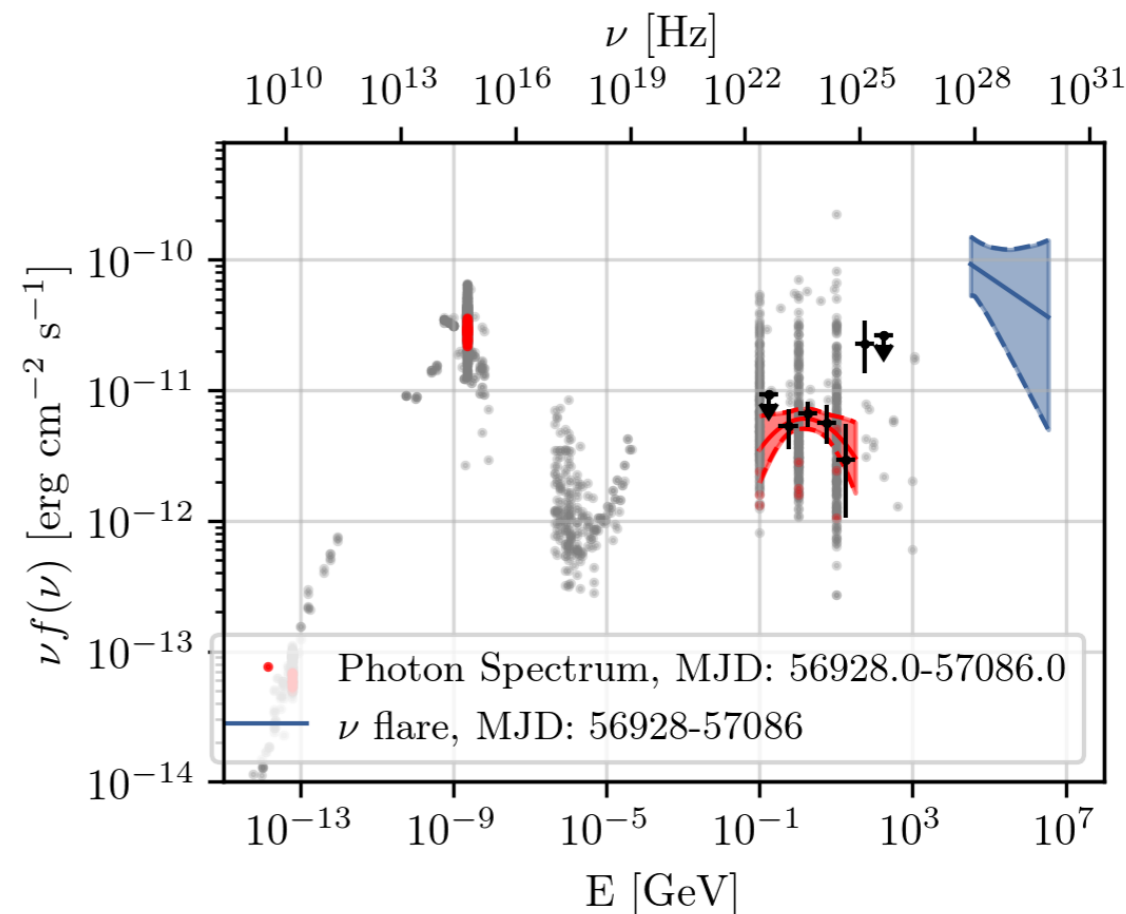
Well described by a log-parabola

(One high energy photon > 100 GeV around 75 days before the EHE event)



MJD 57004±55 (ν -flare):

High-energy bin (~ 31 GeV - 100 GeV) in $\sim 2\sigma$ tension with the low-energy component



* **Radio, Optical:** OVRO, CRTS, ASAS
X-Ray, Optical, UV: Swift and NuSTAR
Gamma-Ray: Fermi LAT

Conclusions

- Everything points to a **unique** counterpart **TXS 0506+056** for the IceCube Observations
- The light curve of TXS 0506+056 shows a **large flux/soft spectrum** state during the EHE event and hints for additional high energy gamma-ray emission during the v-flare
- Despite the γ -ray behaviour being different in the two time periods the overall SED *can* be **energetically reconnected** for both cases

Backup

