

THE HIGH ENERGY NEUTRINO WINDOW ON THE UNIVERSE



25TH ANNIVERSARY OF RENCONTRES DU VIETNAM | AUGUST 5-11, 2018 | ICISE | QUY NHON, VIETNAM



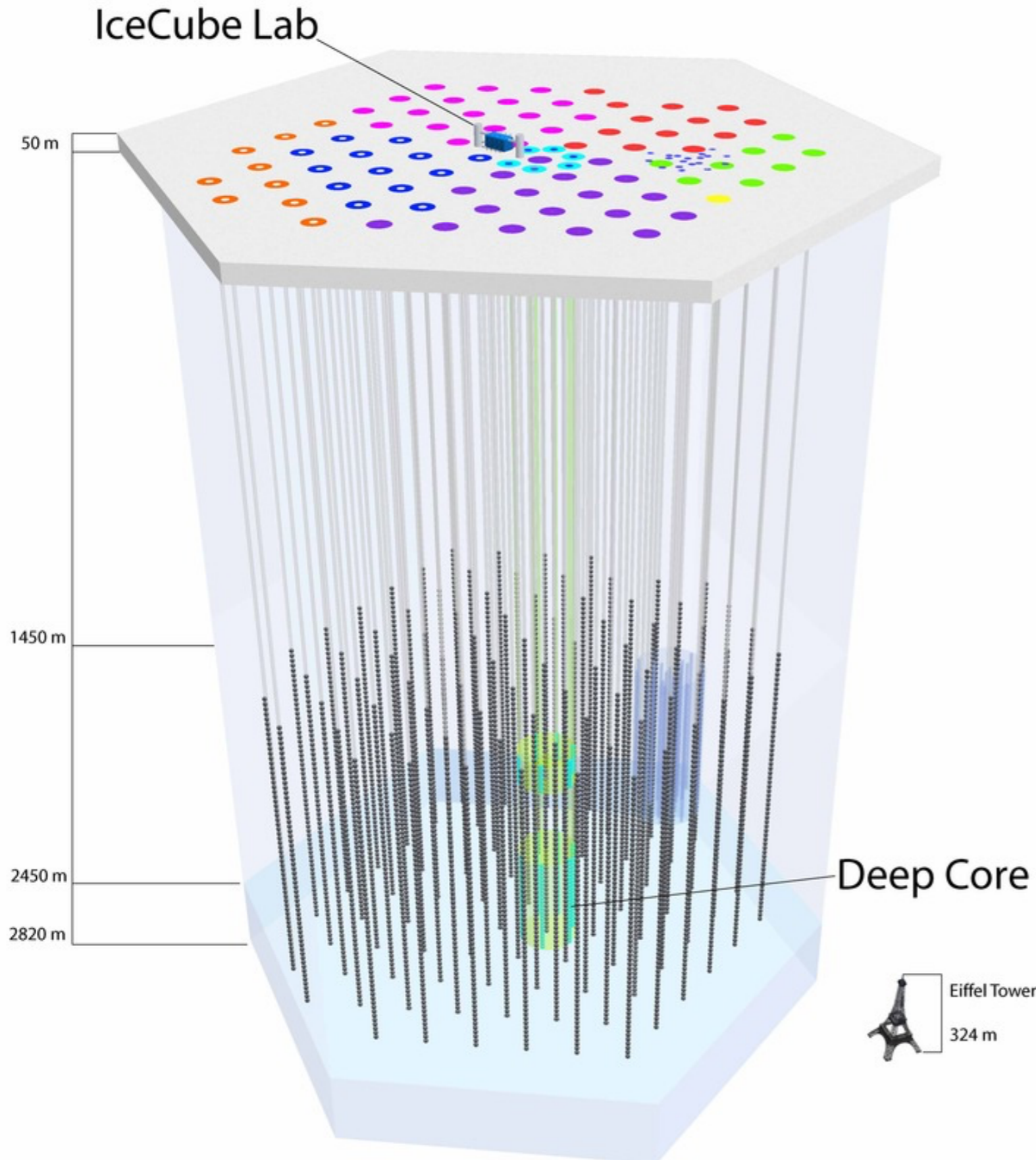
Elisa Resconi (TU Munich)

with Paolo Padovani (ESO), Paolo Giommi (ASI, Rome), Bruno Arsioli (UNICAMP, Brazil), Narek Sahakyan (ICRANET-Armenia), and

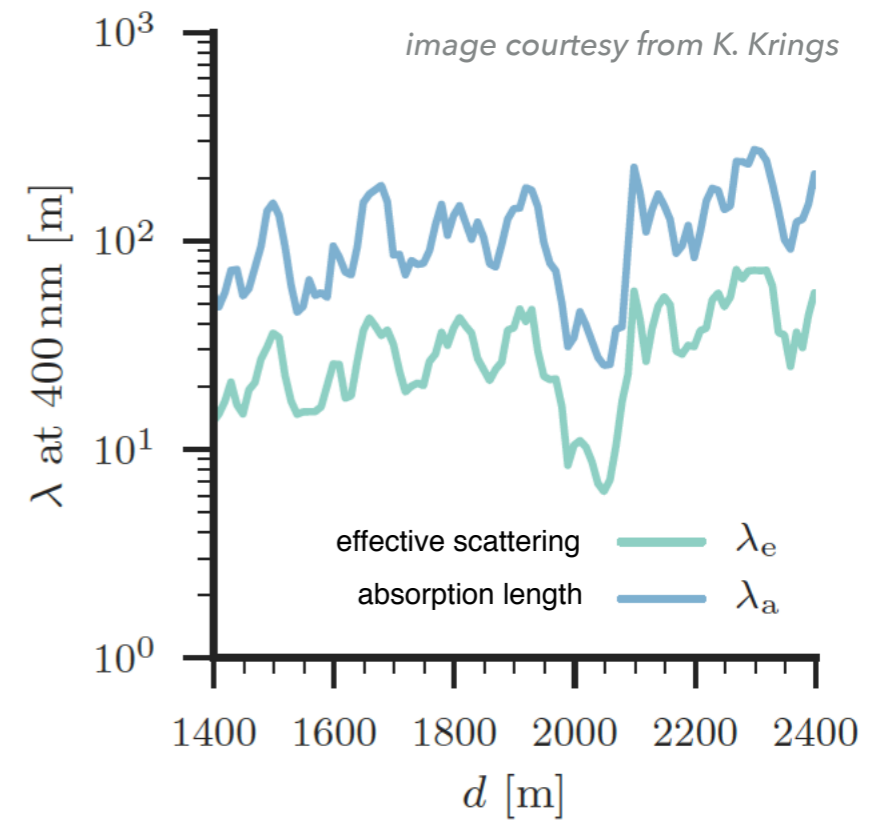
the IceCube Collaboration

IN THIS TALK

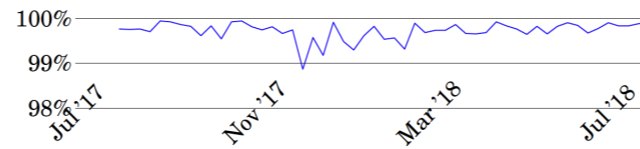
- ▶ The IceCube Neutrino Observatory
- ▶ IceCube high energy cosmic neutrinos
- ▶ IceCube-170922A: the neutrino alert
- ▶ IceCube 2014-2015: the neutrino flare
- ▶ The dissection of the region around IceCube-170922A
- ▶ Conclusions



Digital Optical Modules

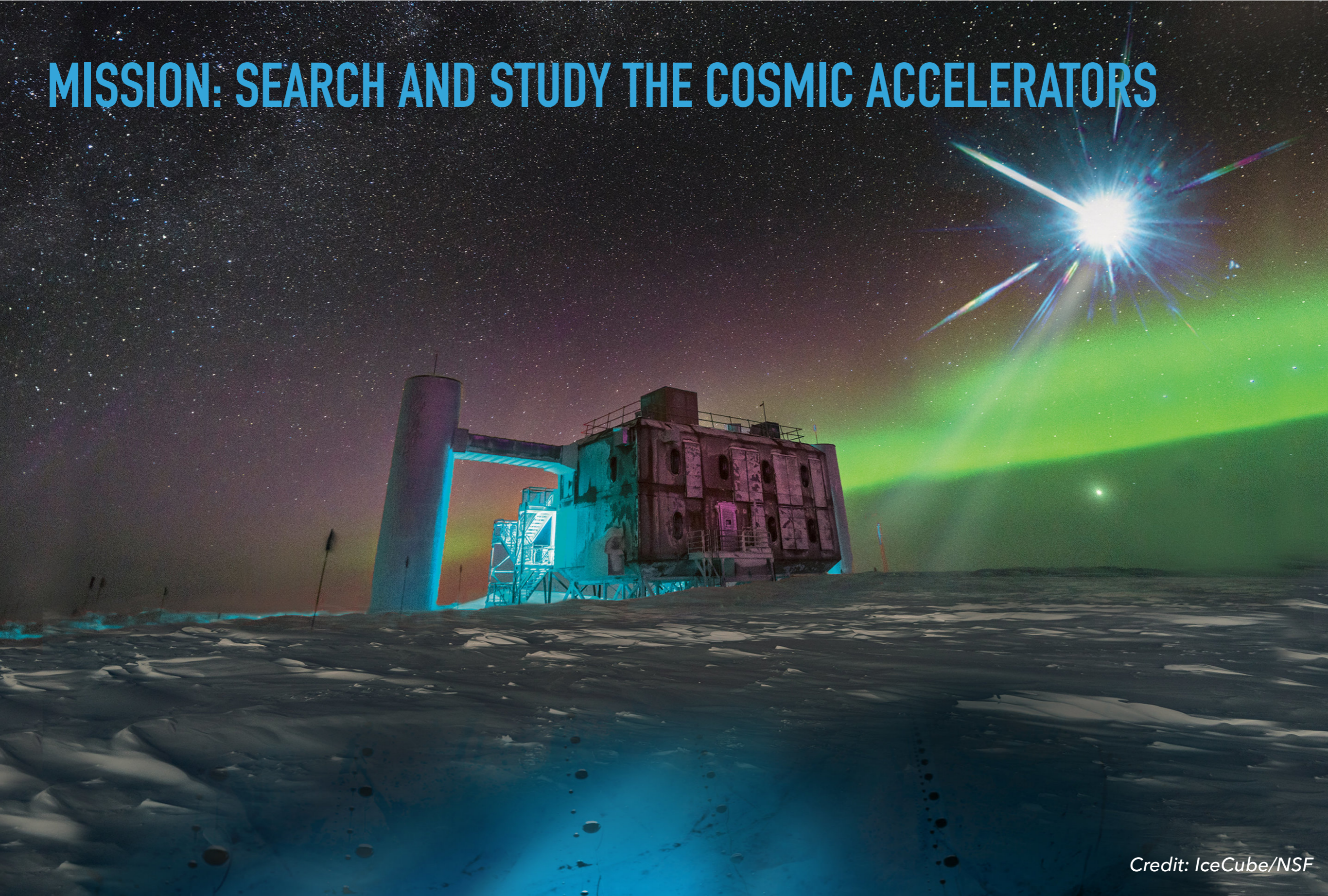


Uptime

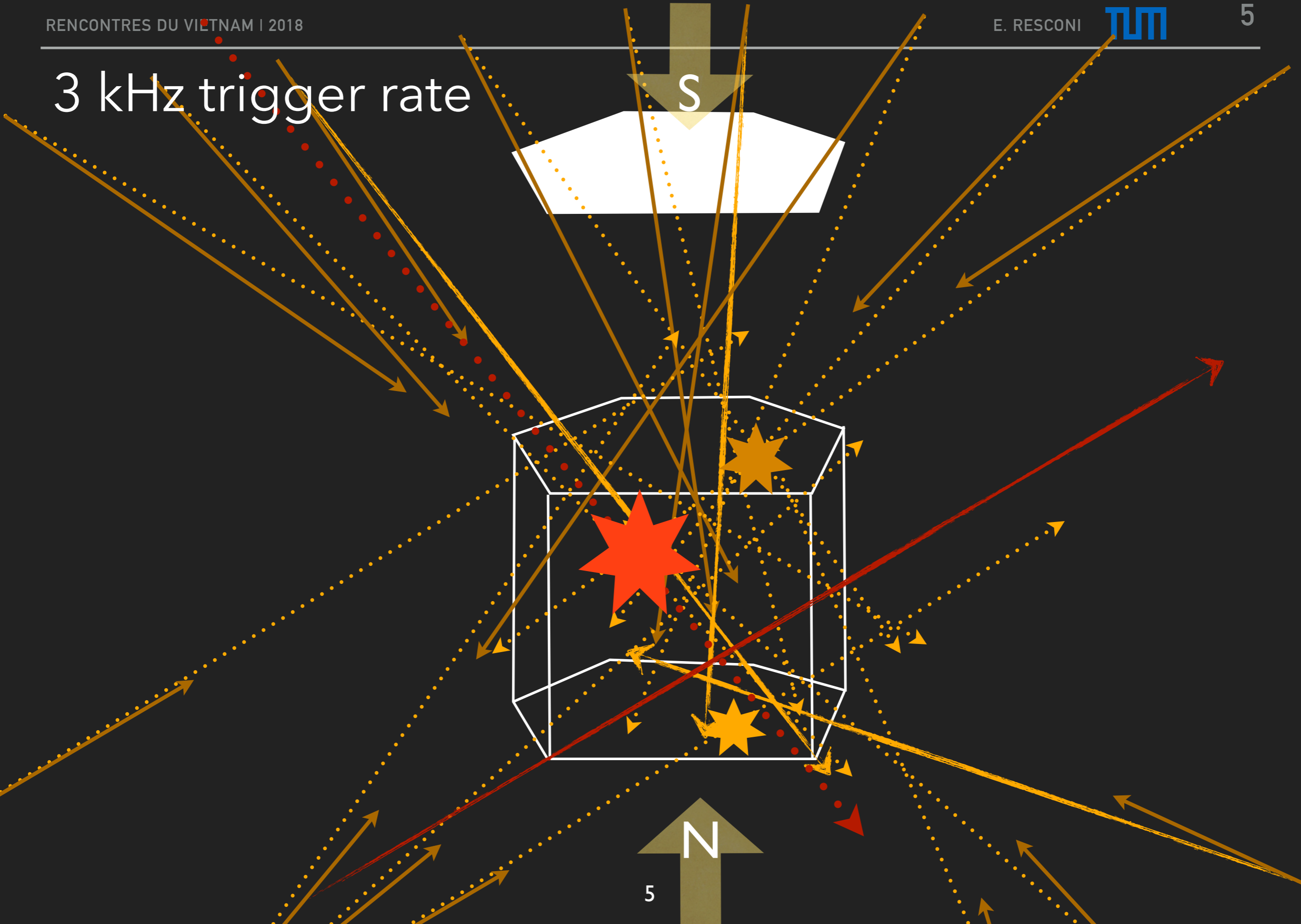


99.91%

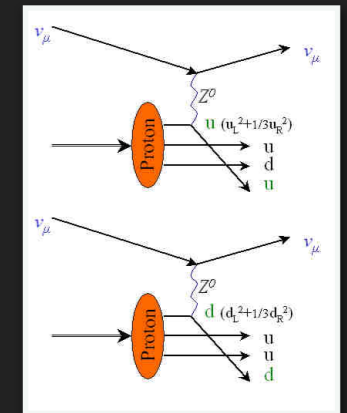
MISSION: SEARCH AND STUDY THE COSMIC ACCELERATORS



3 kHz trigger rate



NEUTRINO INTERACTION: TWO CHANNELS

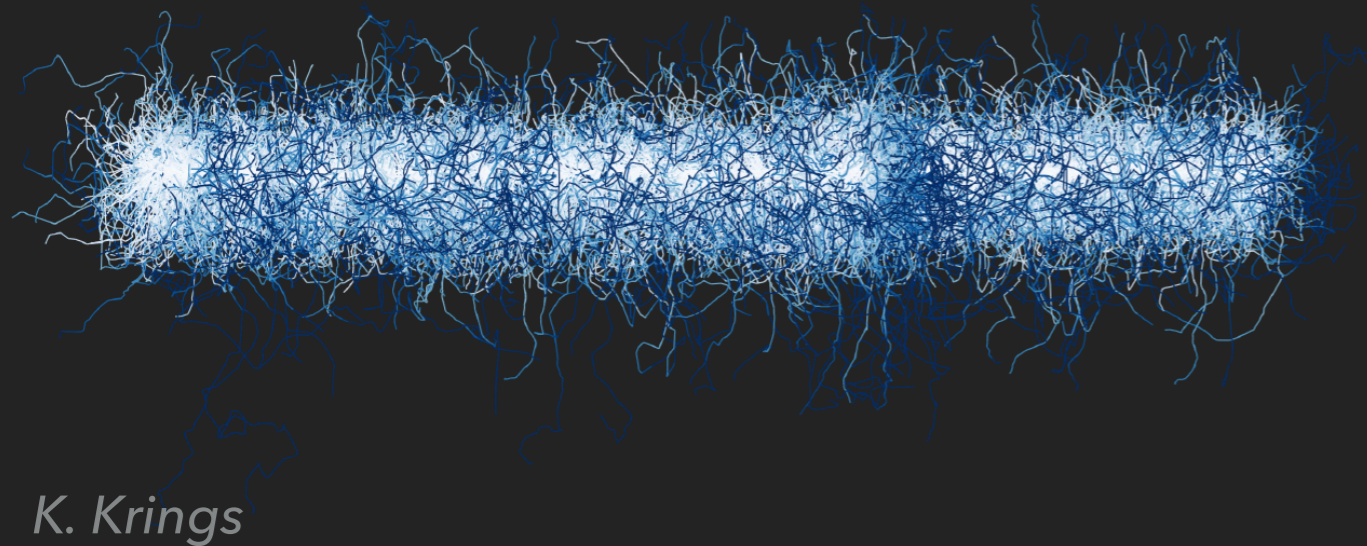


$$\nu_{\mu} + N \rightarrow \mu + X$$

$$\nu_e + N \rightarrow e + X$$

$$\nu_x + N \rightarrow \nu_x + X$$

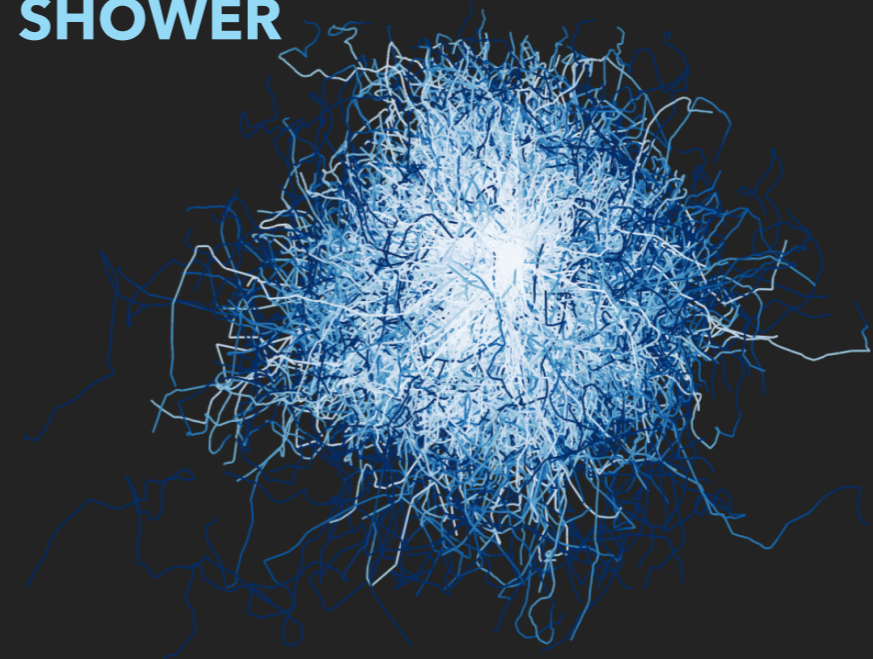
TRACK



K. Krings

1 TeV muon

SHOWER



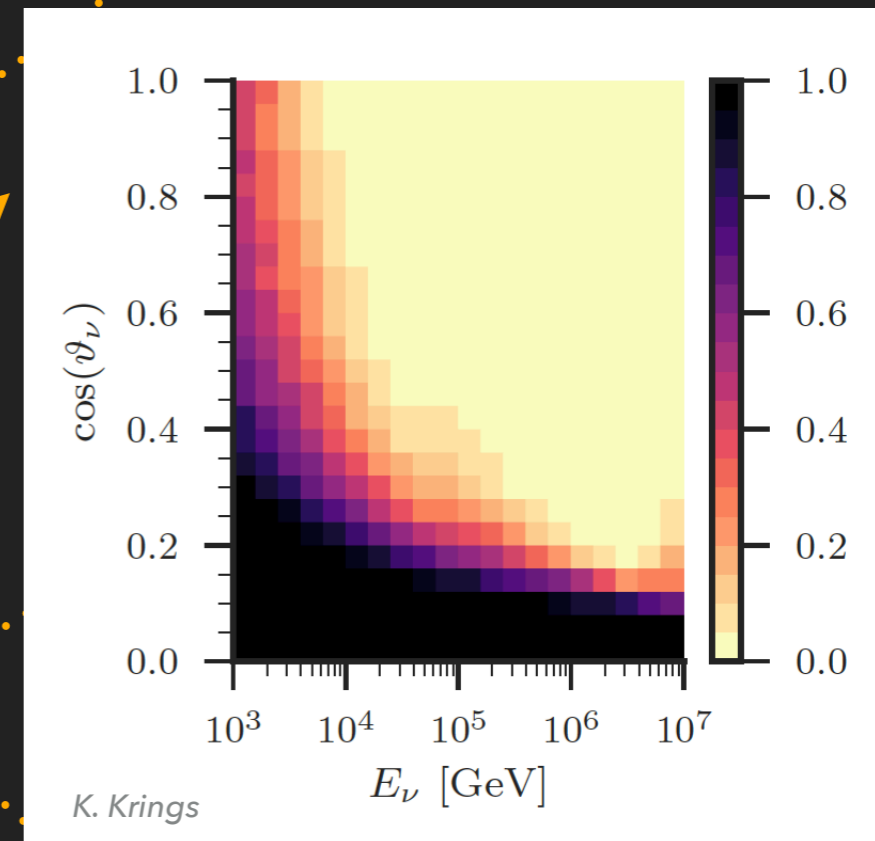
1 TeV electromagnetic cascade

COSMIC NEUTRINOS

(1)

HOW TO?

self-VETO
↓
atmospheric neutrino-VETO



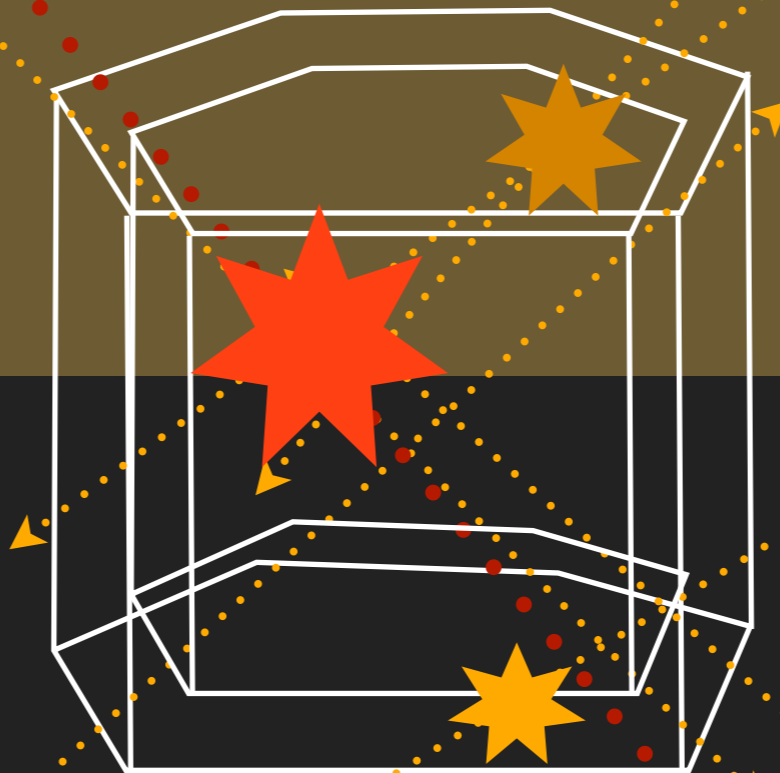
[S. Schönert, T. K. Gaisser, E.R., O. Schulz, PRD (2009),
T. K. Gaisser, K. Jero, A. Karle, and J. van Santen, Phys. Rev. D (2014)]

COSMIC NEUTRINOS

(2)

HOW TO?

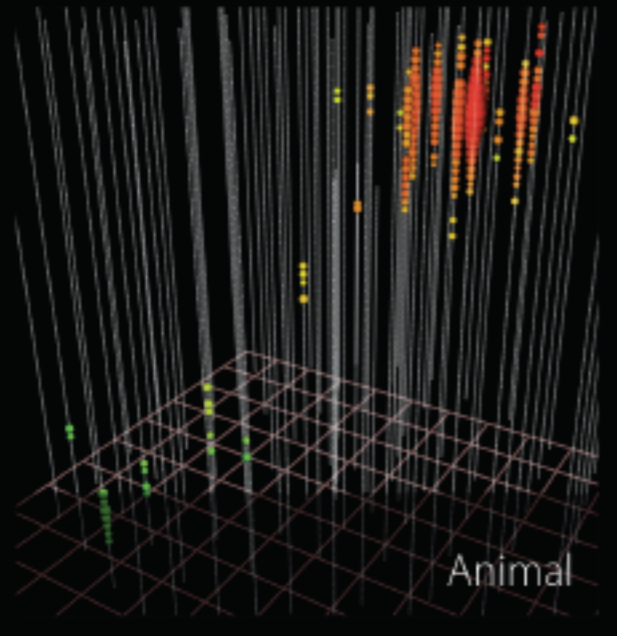
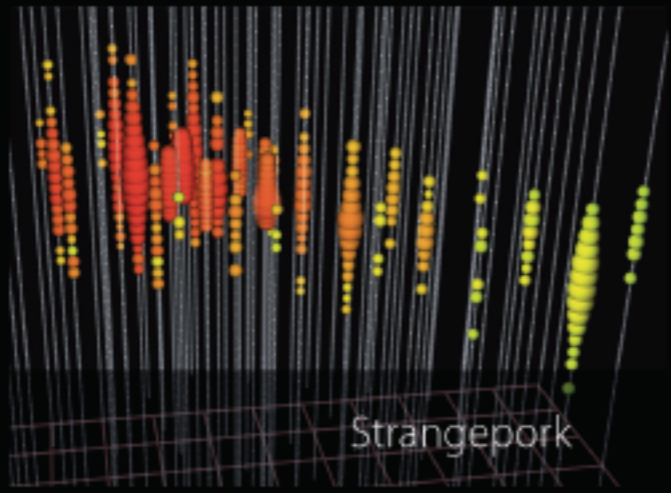
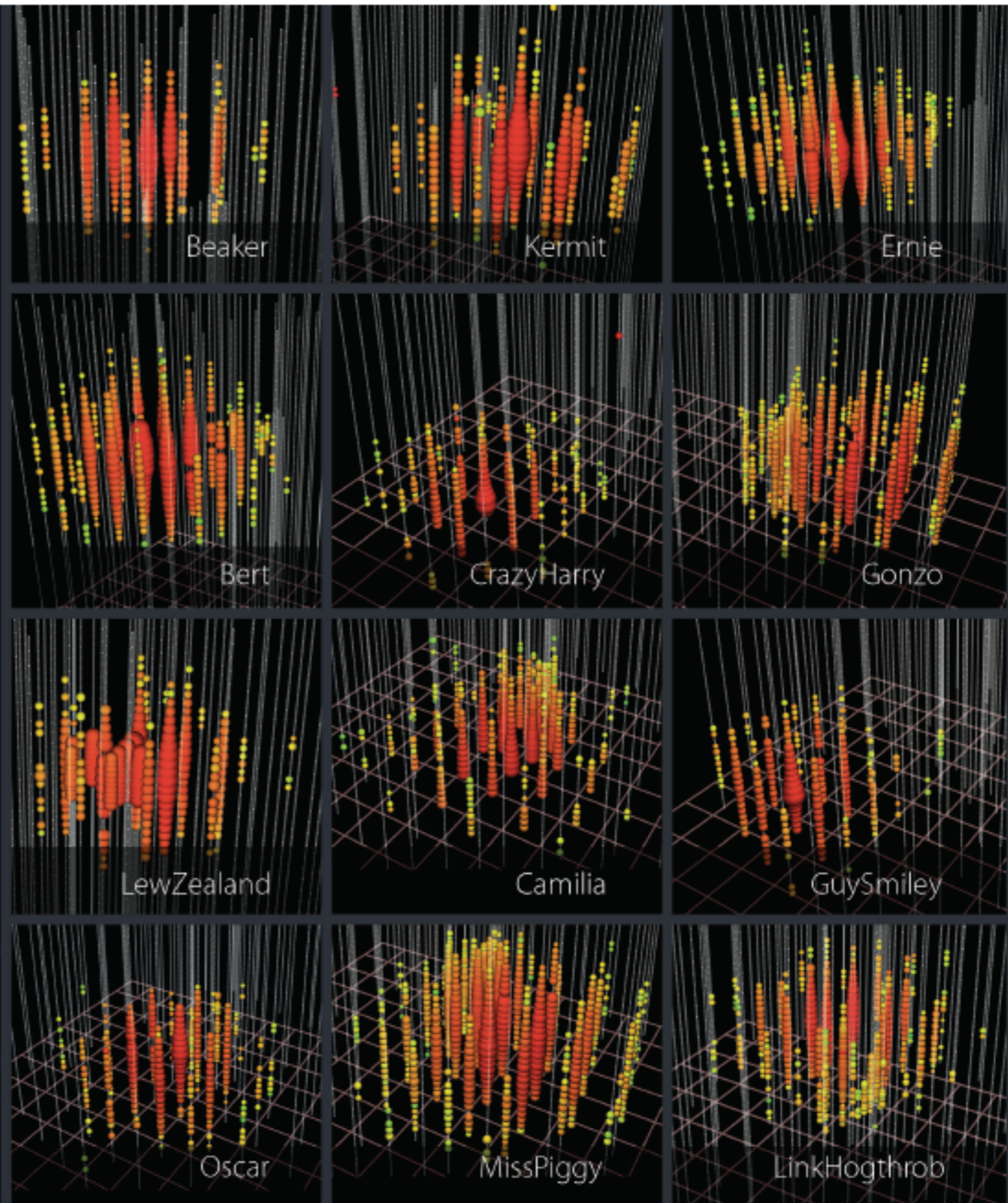
downward-VETO



Examples of events:

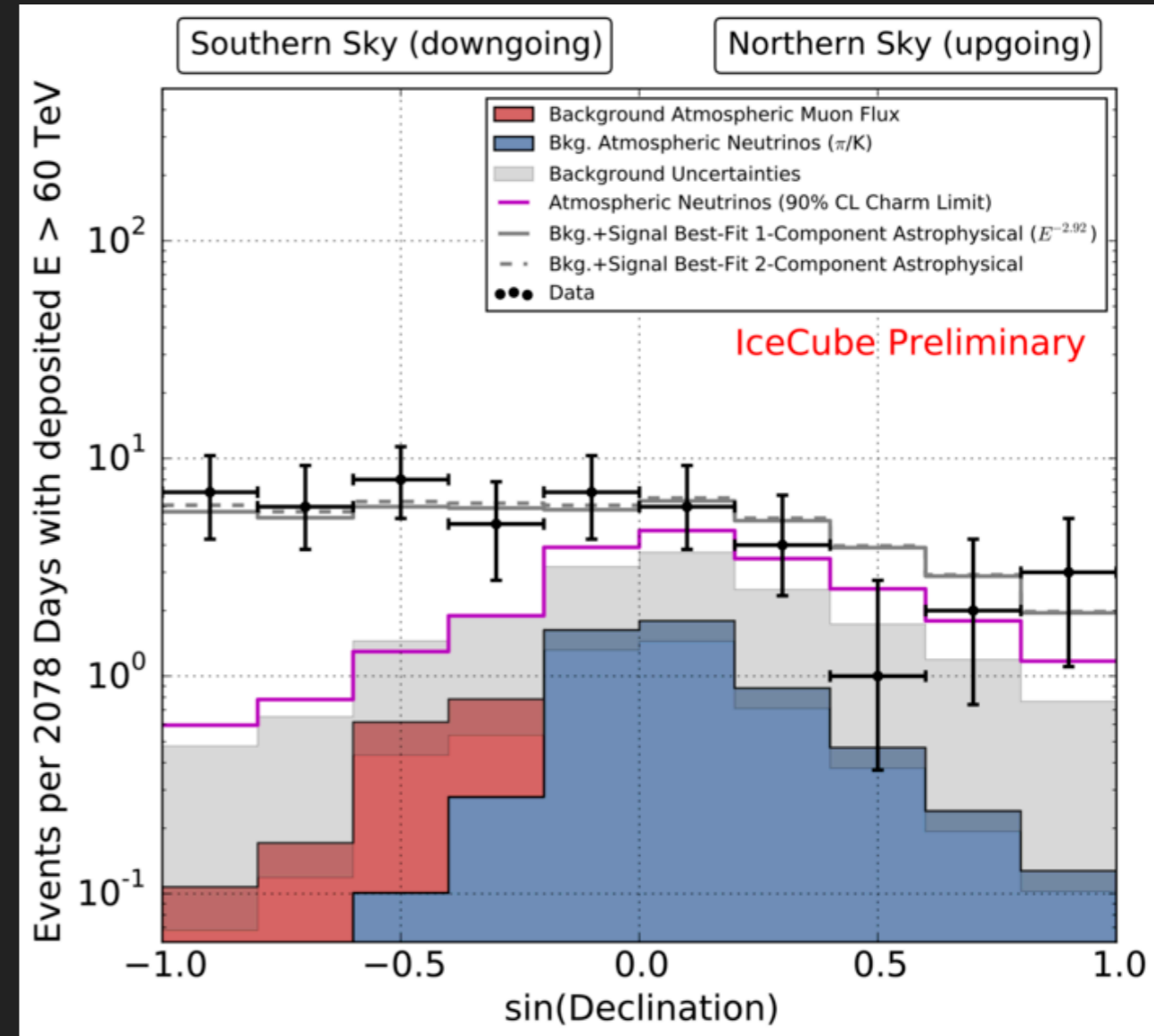
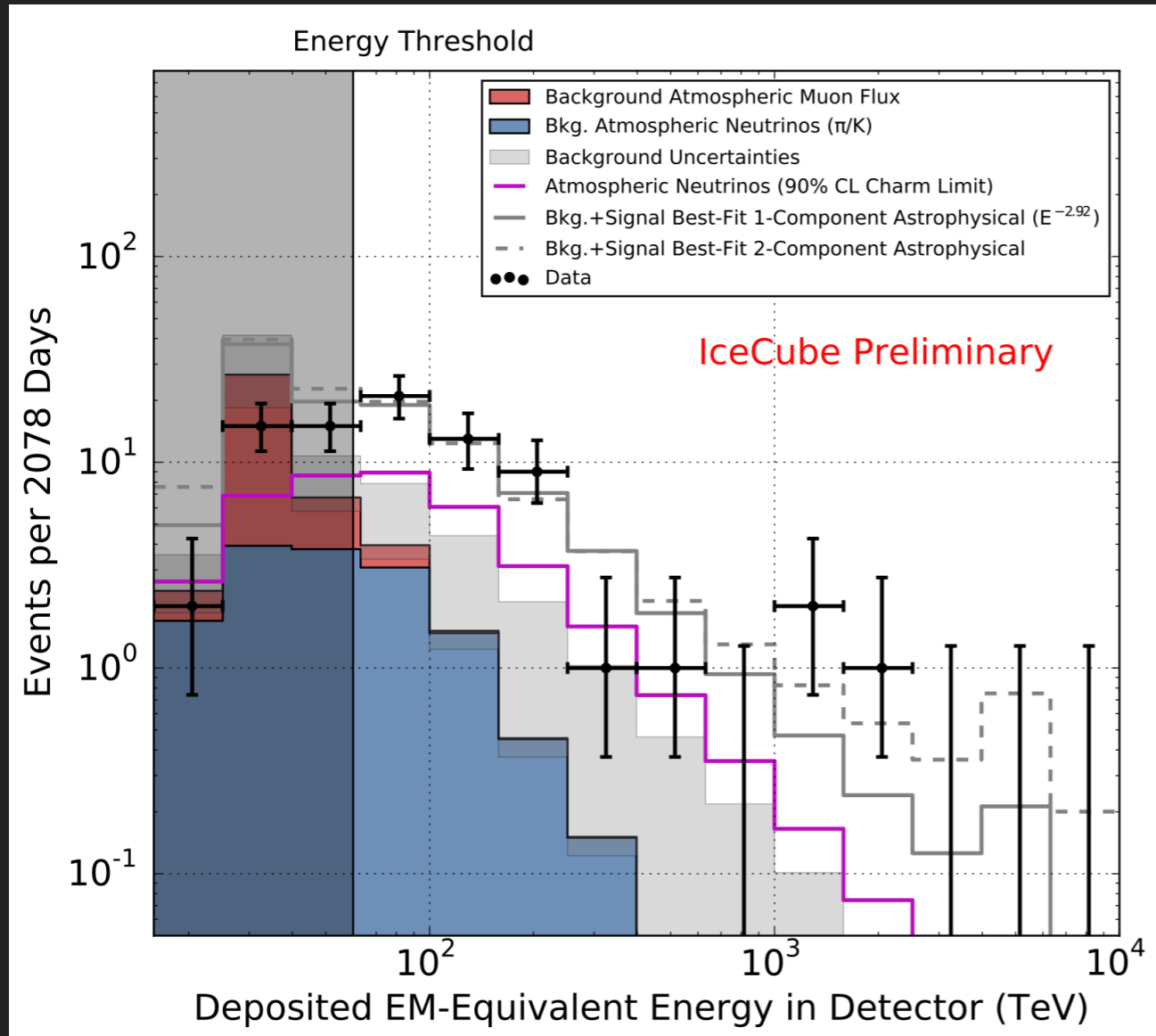
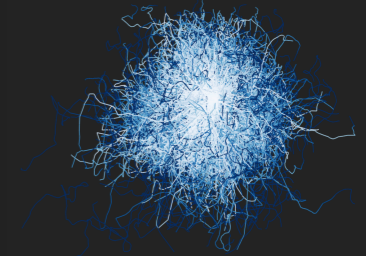
charge threshold > 6000 p.e.
& < 3 p.e. in veto region

2078-day sample: 82 events



DISCOVERY OF HIGH ENERGY COSMIC NEUTRINOS

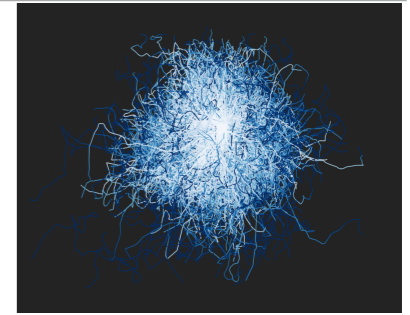
[The IceCube Coll., Science 2013, The IceCube Coll., ICRC'17]



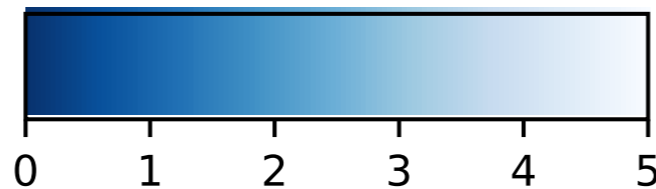
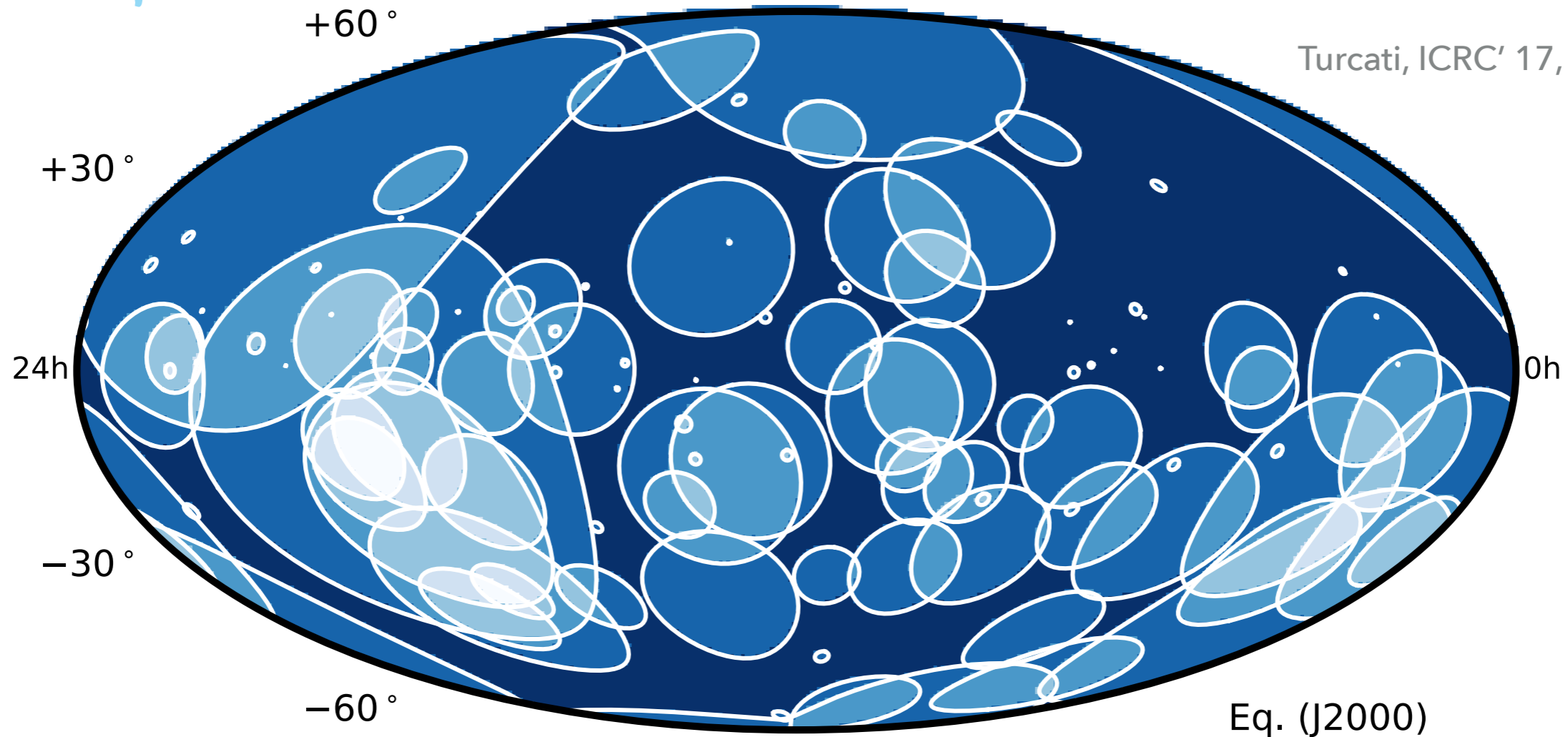
$$E^2\phi(E) = 2.46 \pm 0.8 \times 10^{-8} (E/100\text{TeV})^{-0.92} \text{GeVcm}^{-2}\text{s}^{-1}\text{sr}^{-1} > 5 \sigma \text{ excess}$$

ORIGIN OF HIGH ENERGY COSMIC NEUTRINOS?

poor pointing



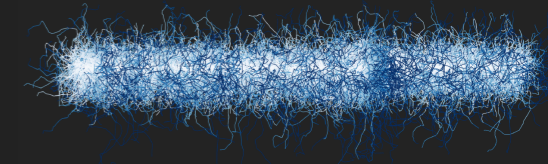
Turcati, ICRC' 17, PoS 998



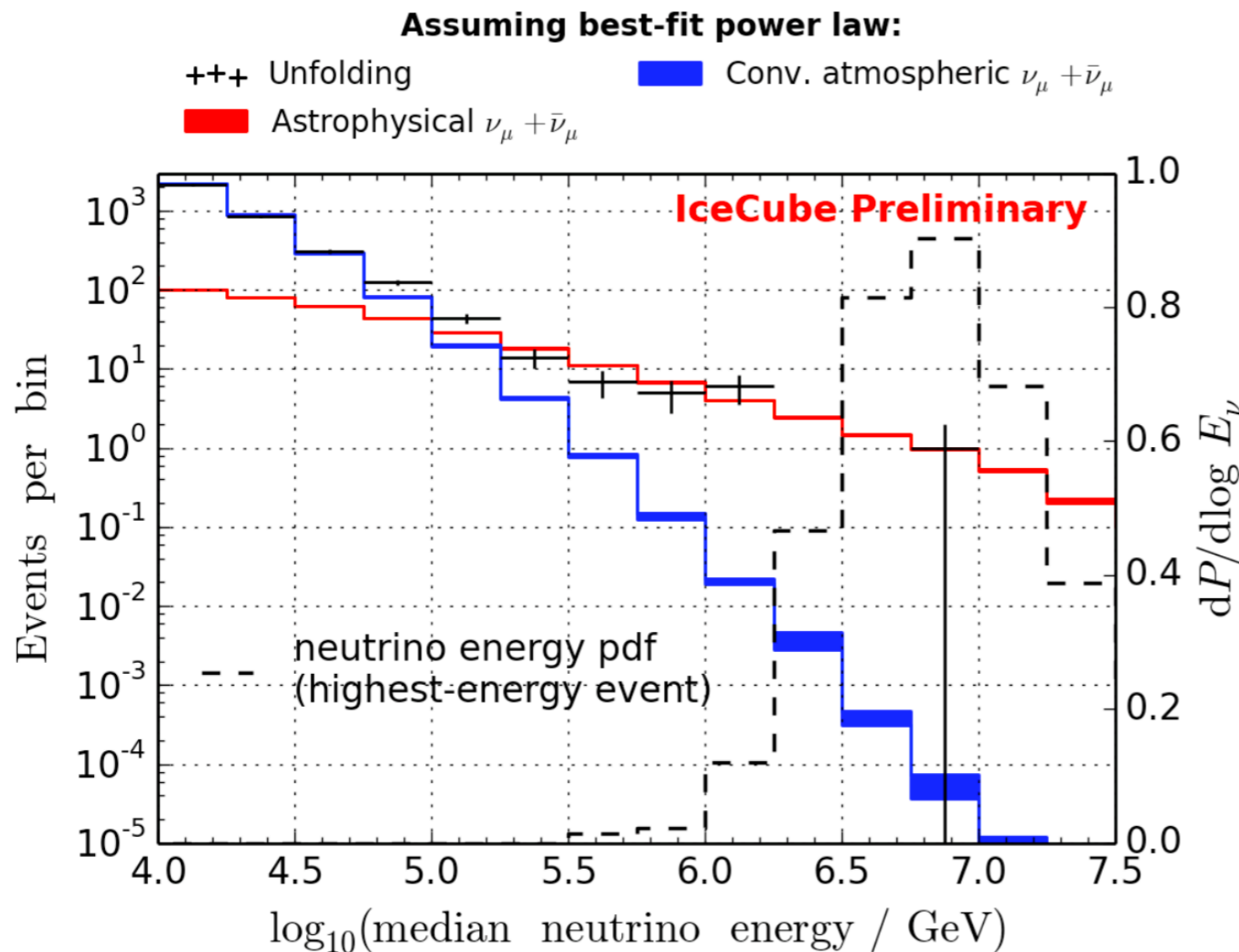
All tests compatible with background fluctuations

HIGH ENERGY COSMIC NEUTRINOS

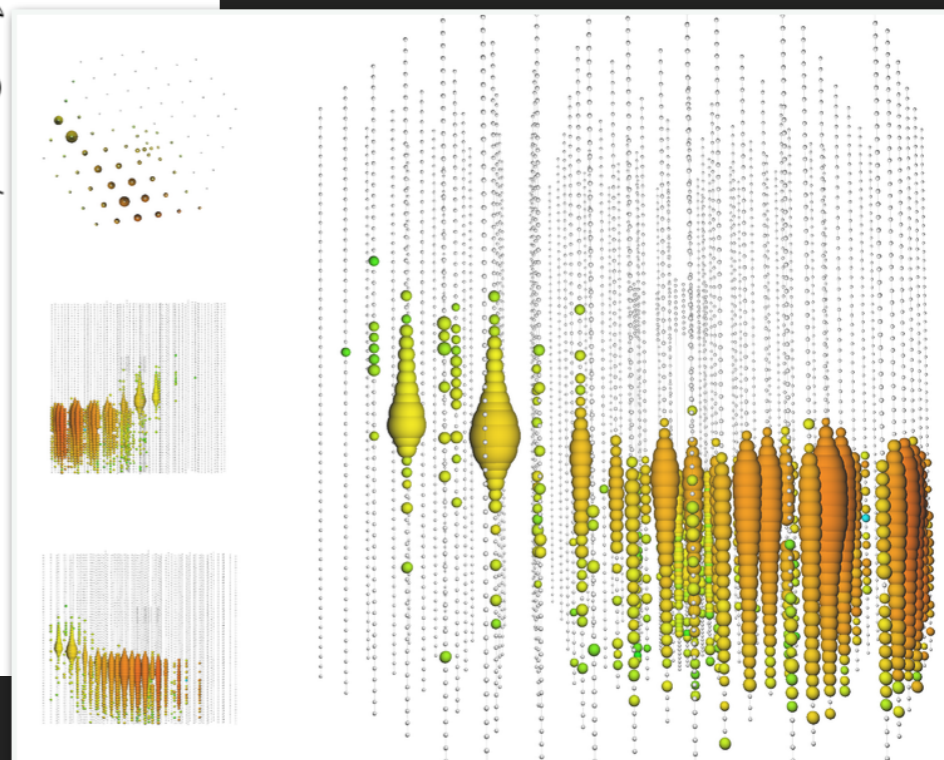
[The IceCube Coll., ICRC'17] Using through going (\uparrow) muons only



~ 550 cosmic neutrinos in a background of ~340,000 atmospheric atmospheric background: less than one event/deg²/year

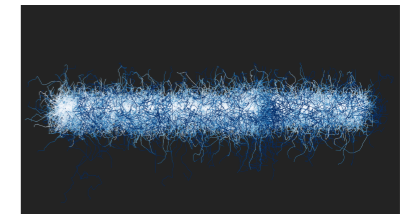


2.6 PeV deposited interaction outside the detector

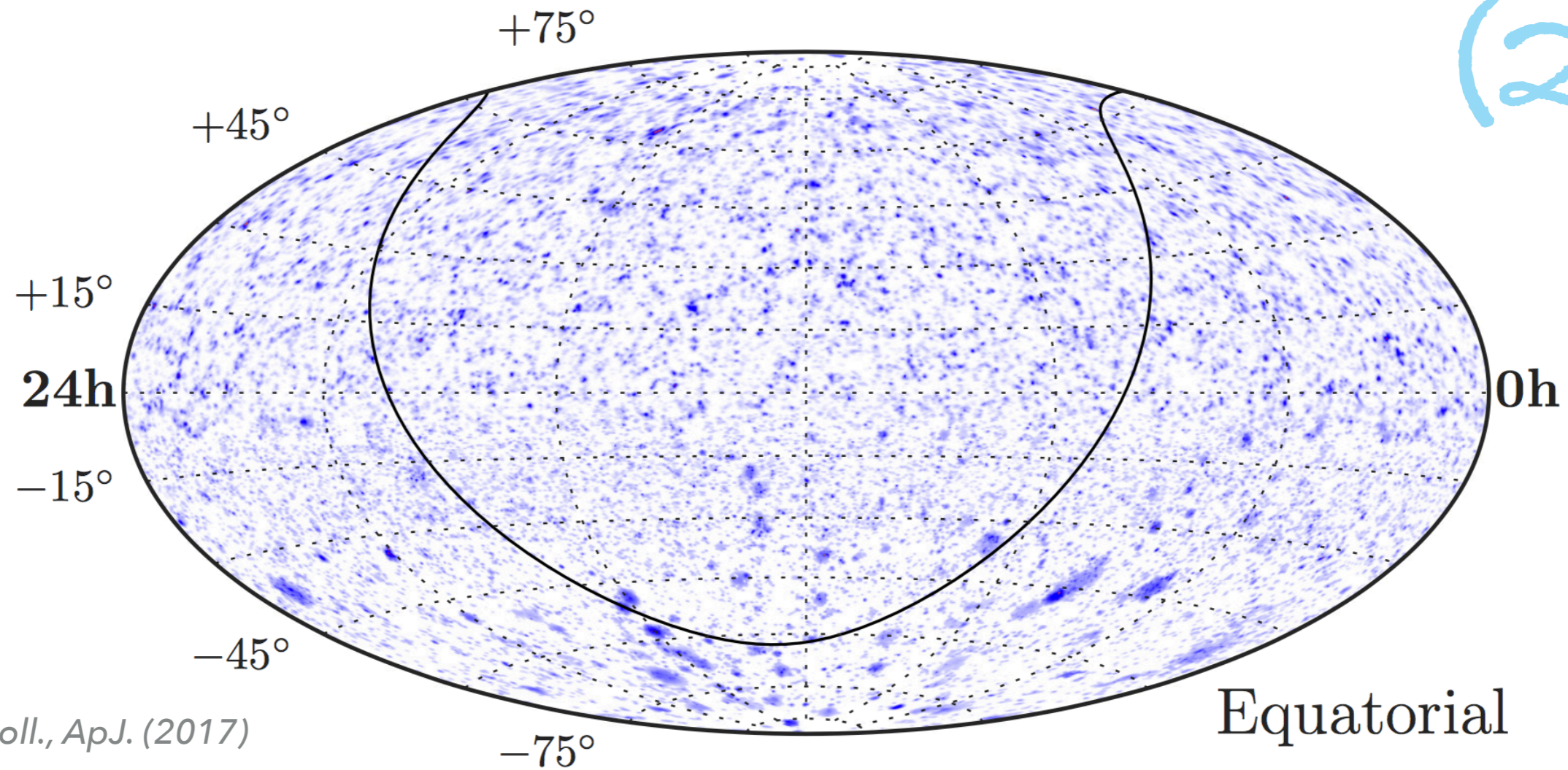


ORIGIN OF HIGH ENERGY COSMIC NEUTRINOS?

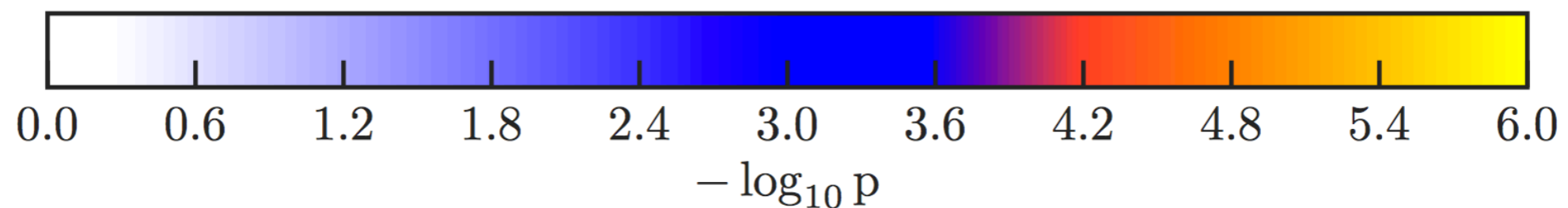
Using through going, muons only



(2)

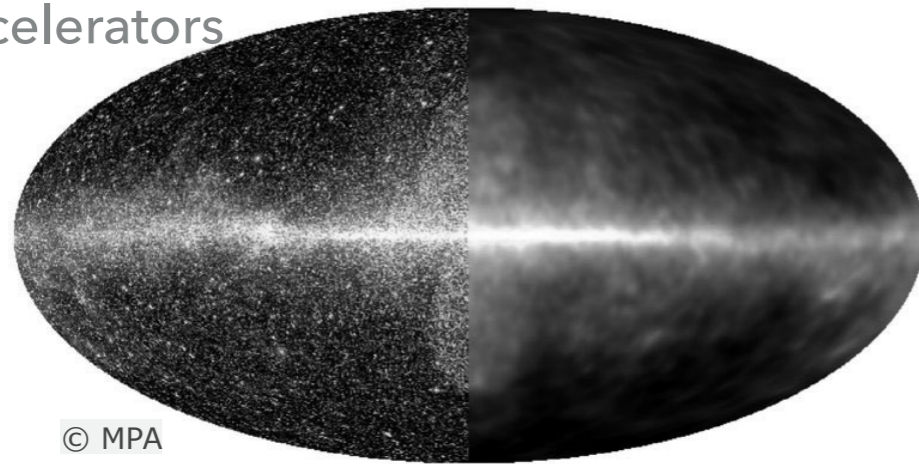


All tests compatible with background fluctuations

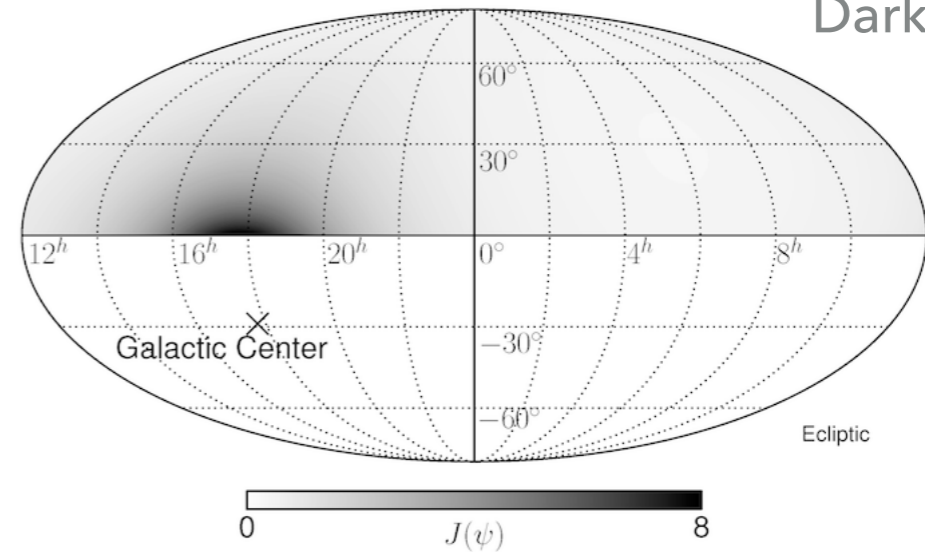


ORIGIN OF HIGH ENERGY COSMIC NEUTRINOS?

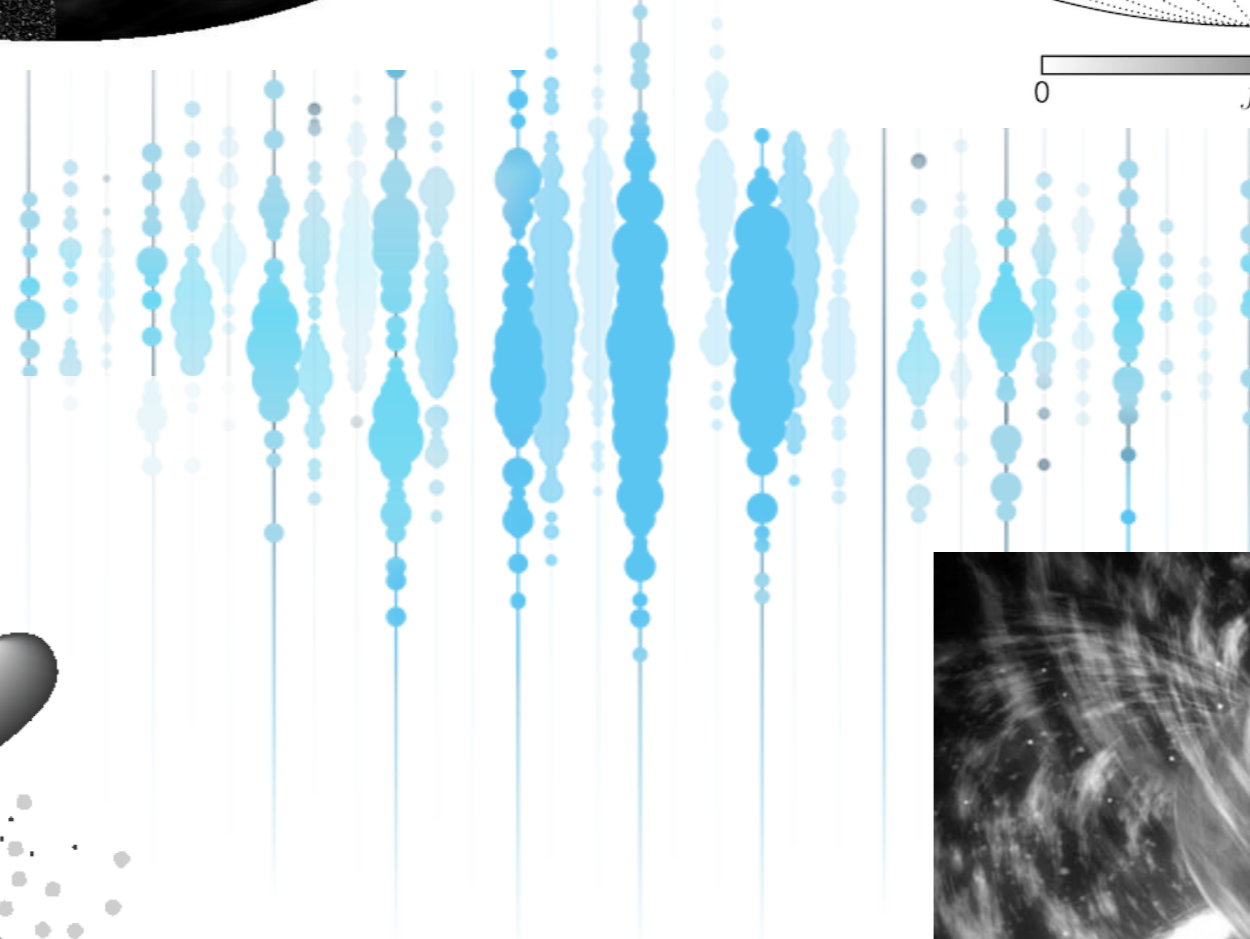
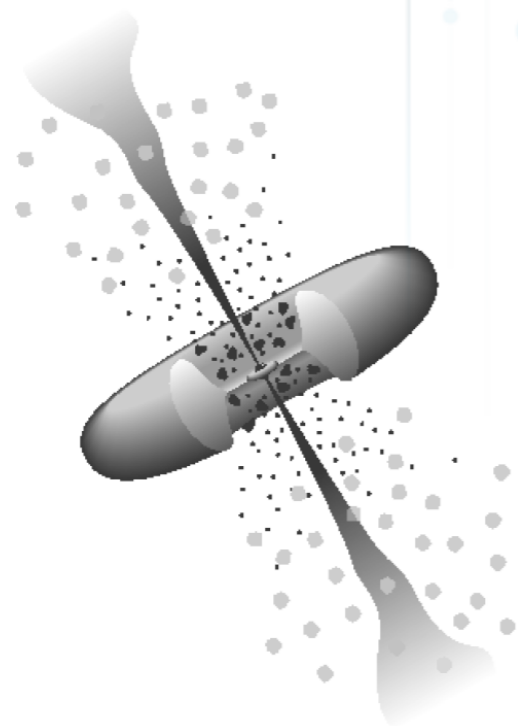
Galactic accelerators



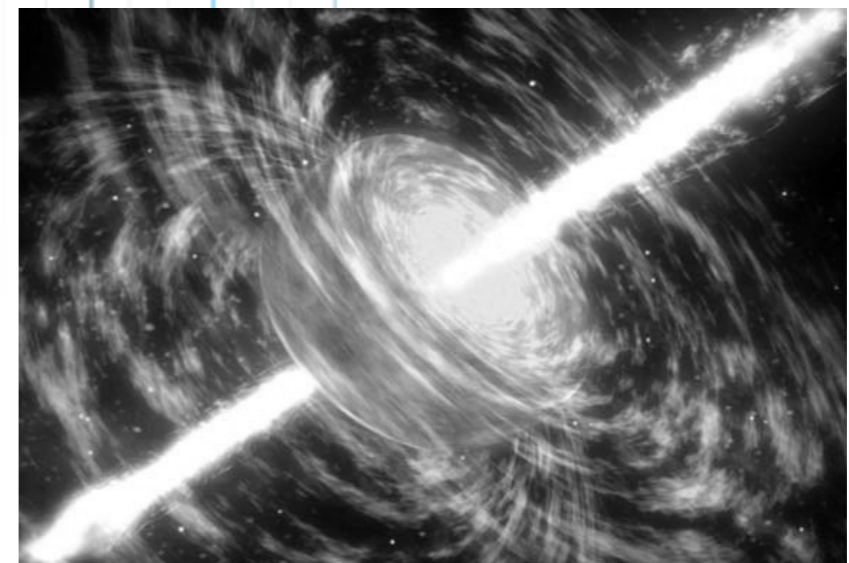
Dark Matter



AGN, Blazars

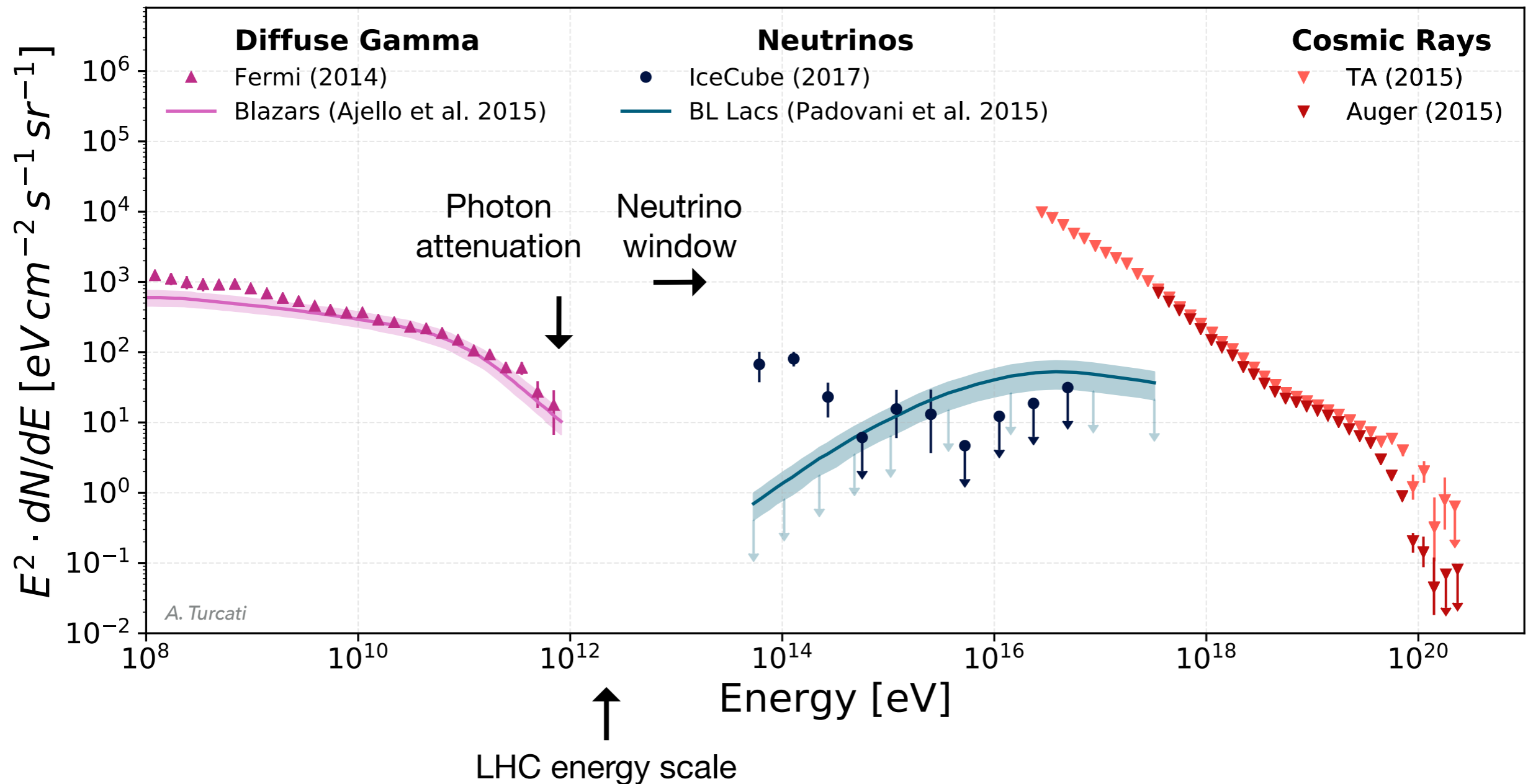


Gamma Ray Bursts



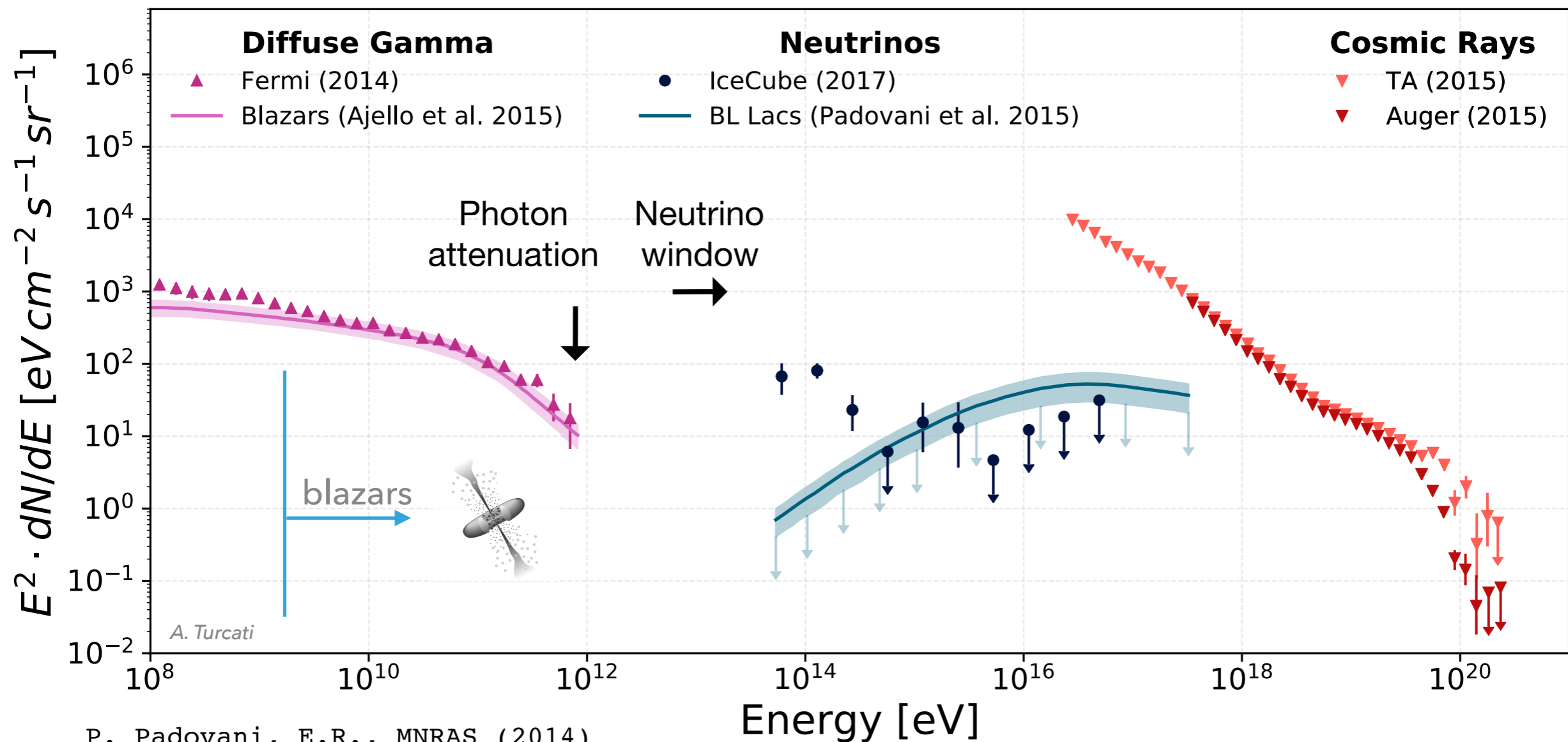
THE OBSERVATIONS: HYBRID SPECTRAL ENERGY DISTRIBUTION

SAME ENERGY FLUX FOR ALL THE THREE MESSENGERS:
SUGGESTING A COMMON ORIGIN?



THE OBSERVATIONS: HYBRID SPECTRAL ENERGY DISTRIBUTION

A COMMON ORIGIN? BLAZARS ...



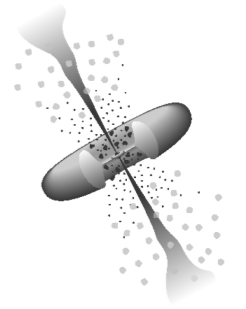
P. Padovani, E.R., MNRAS (2014)

M. Petropoulou, S. Dimitrakoudis, P. Padovani, A. Mastichiadis, E.R., MNRAS (2015)

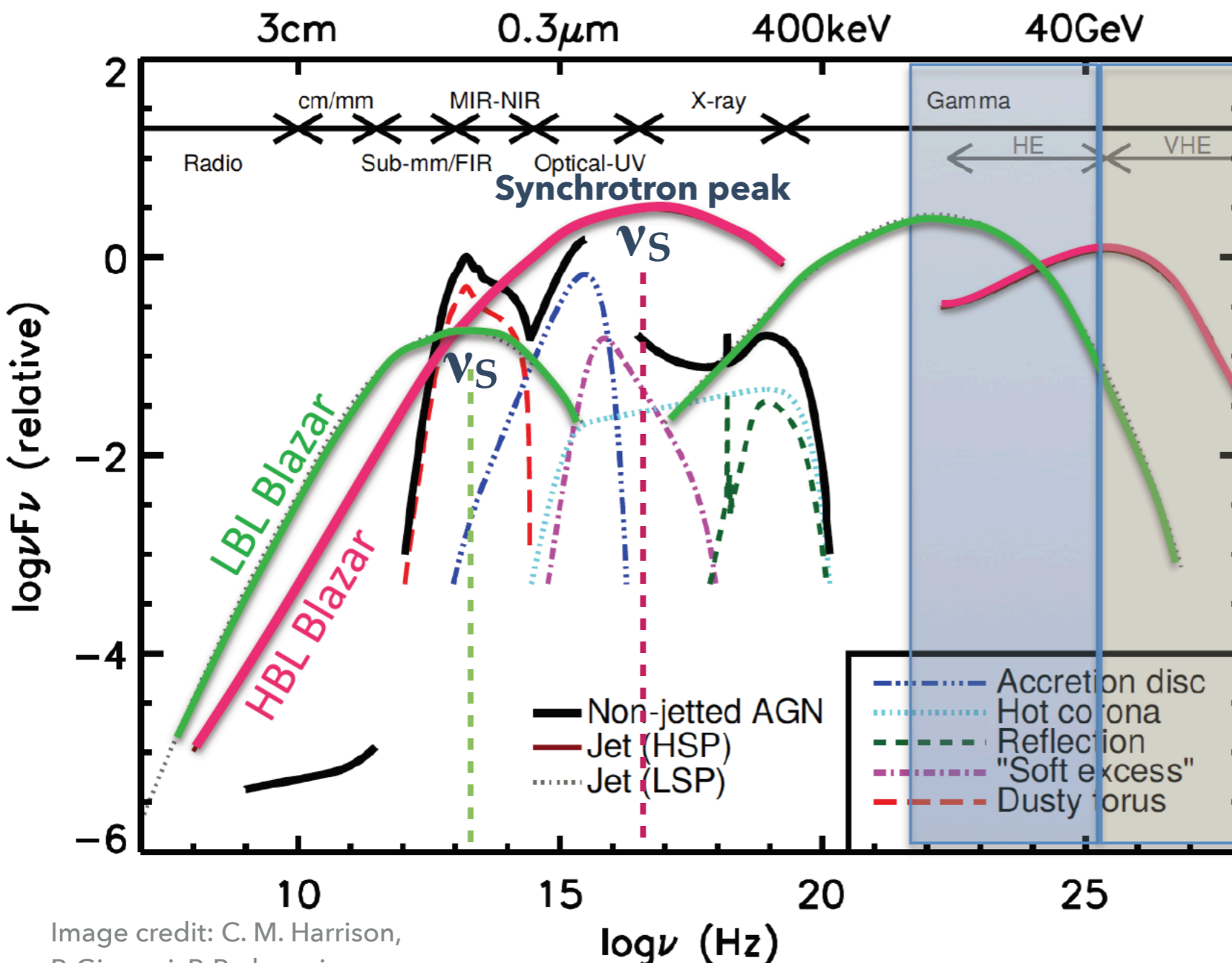
P. Padovani, M. Petropoulou, P. Giommi, E.R., MNRAS (2015)

P. Padovani, E.R., P. Giommi, B. Arsioli, Y. L. Chang, MNRAS (2016)

BLAZARS: CLASSIFICATION (NO SEQUENCE)



Jet dominated AGN [Blandford & Rees 1978; Urry & Padovani 1995]. The radiation output is mostly due to non-thermal radiation from a relativistic jet, ~ few% of all AGN



❖ **Flat Spectrum Radio Quasars:** broad emission features (emission lines) in the optical spectrum

- ❖ **BL Lacs:** no broad emission lines.
- **LBL/LSP**, $\nu_s < 10^{14}$ Hz,
 - **IBL/ISP**, 10^{14} Hz $< \nu_s < 10^{15}$
 - **HBL/HSP**, $\nu_s > 10^{15}$ Hz

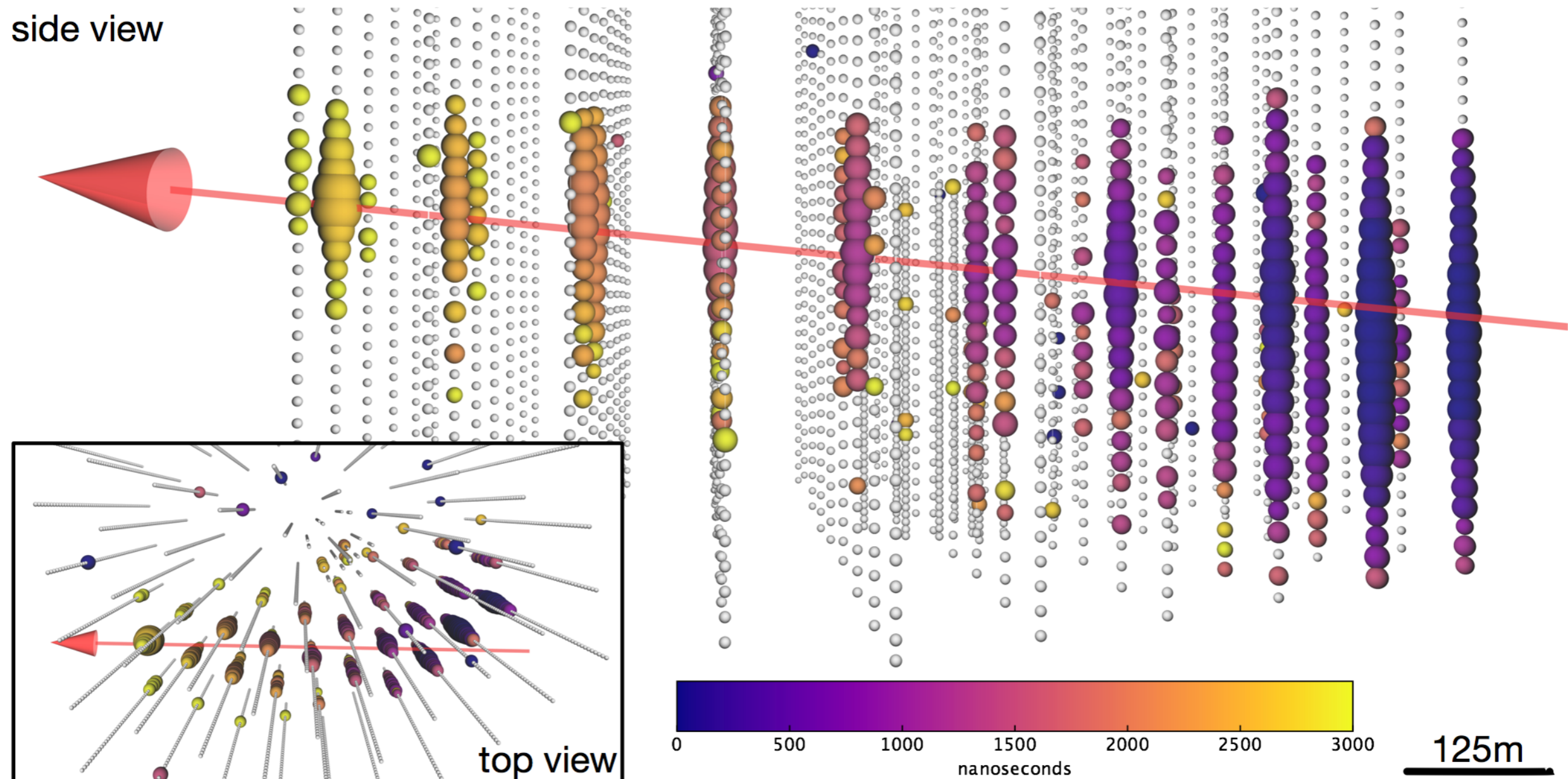
$$E_{em}(FSRQ) < E_{em}(BL Lacs)$$

Image credit: C. M. Harrison, P. Giommi, P. Padovani

ICECUBE-170922A: THE NEUTRINO ALERT

"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A," The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. *Science* 361, 2018

side view



ICECUBE-170922A: POINTING TO THE BLAZAR (TXS 0506+056)

"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A," The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. *Science* 361, 2018

Event occurred on the 22nd Sept 2017, 20:54:30 UTC

First notice sent **43s later!**

Revised coordinates sent 4 hours later

- Follow-up responses
GCN 21917 - Integral - No detection [...]
- ATel 10791 - **Fermi - increased gamma-ray activity of TXS 0506+056** (RA 77.36 deg, Dec +5.69 deg)
- ATel 10817 - The First-time **detection of VHE gamma rays by MAGIC**

....and observations and reports by many more telescopes: AGILE, ASAS-SN, Kapteyn, Kanata, Kiso, Liverpool, Subaru, VERITAS, VLT



ICECUBE-170922A: POINTING TO THE BLAZAR (TXS 0506+056)

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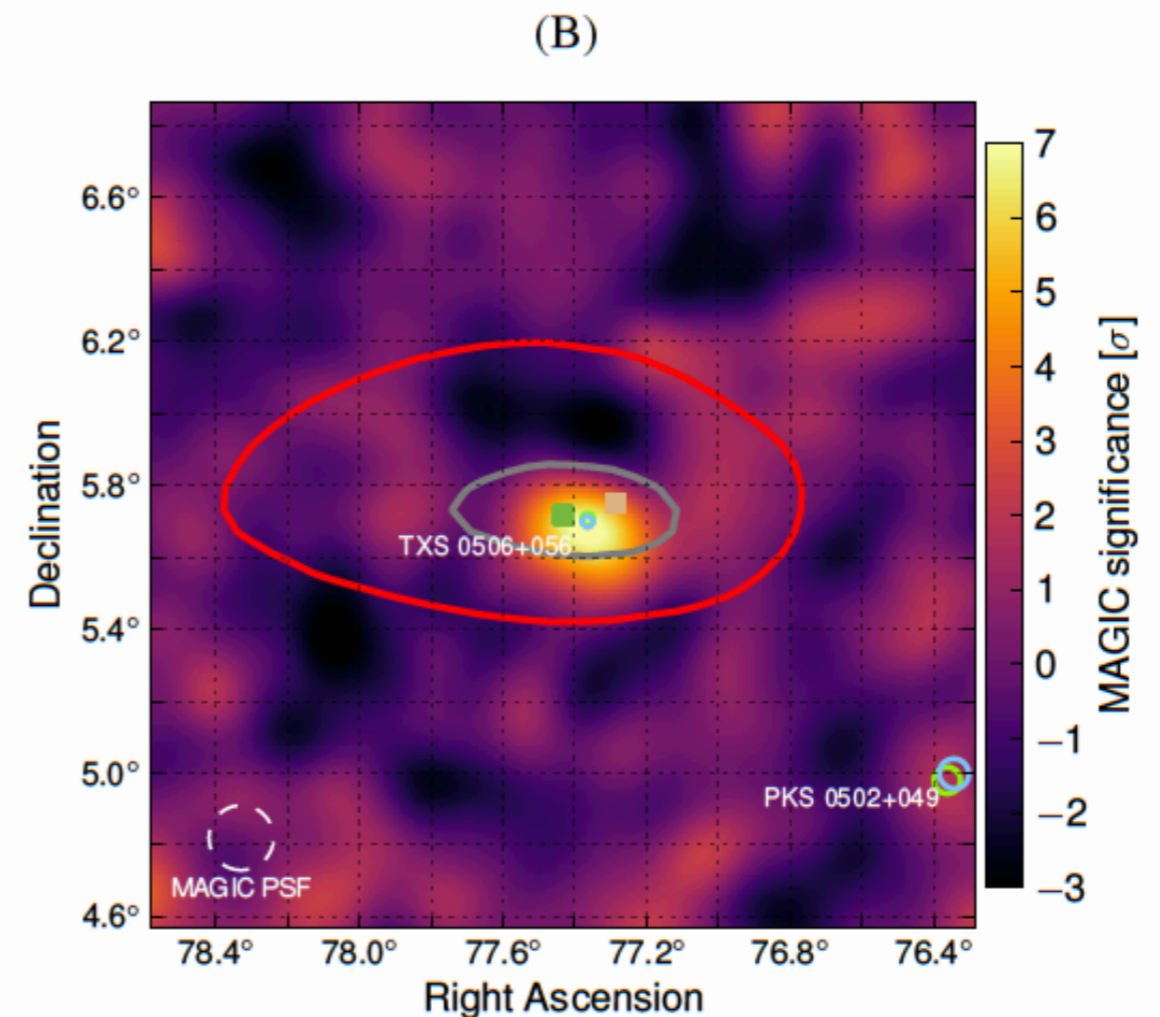
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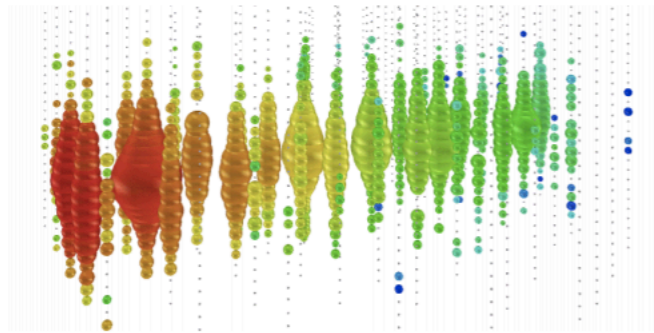
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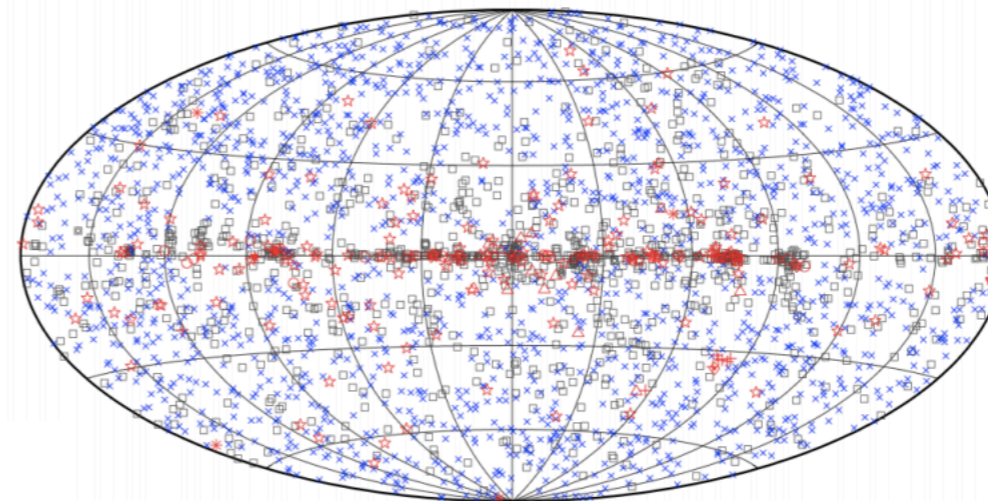
ICECUBE-170922A VS TXS 0506+056: RANDOM COINCIDENCE?

"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A," The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. *Science* 361, 2018

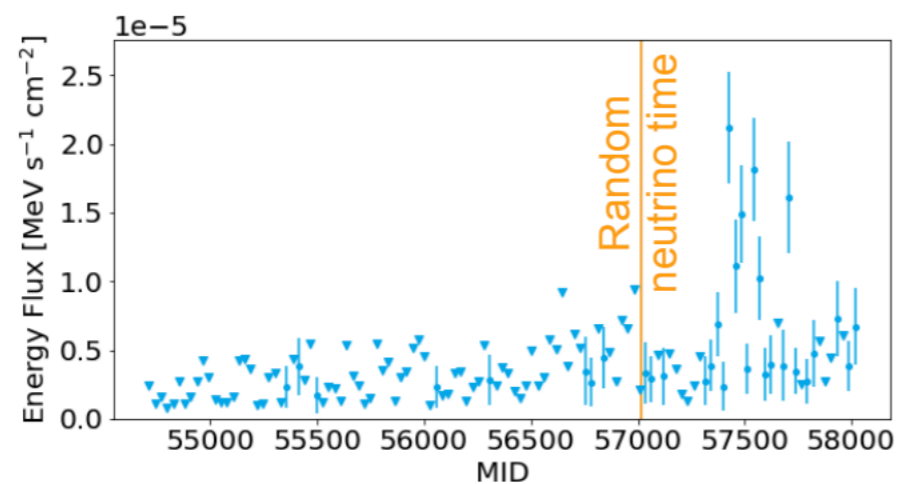
Excluded with 99.73%CL



Step I: Draw a random neutrino from a representative sample of high-energy muon-track events



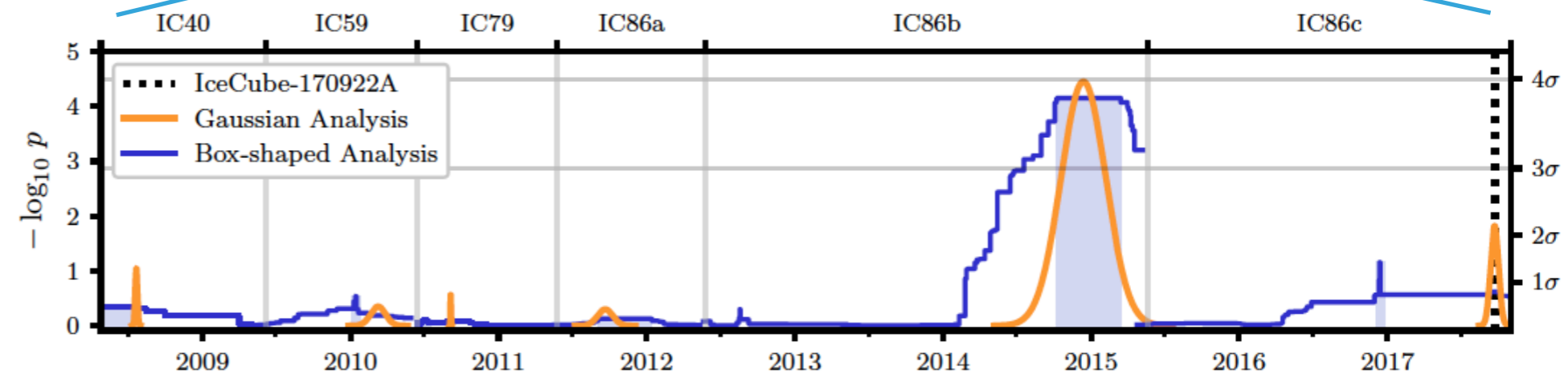
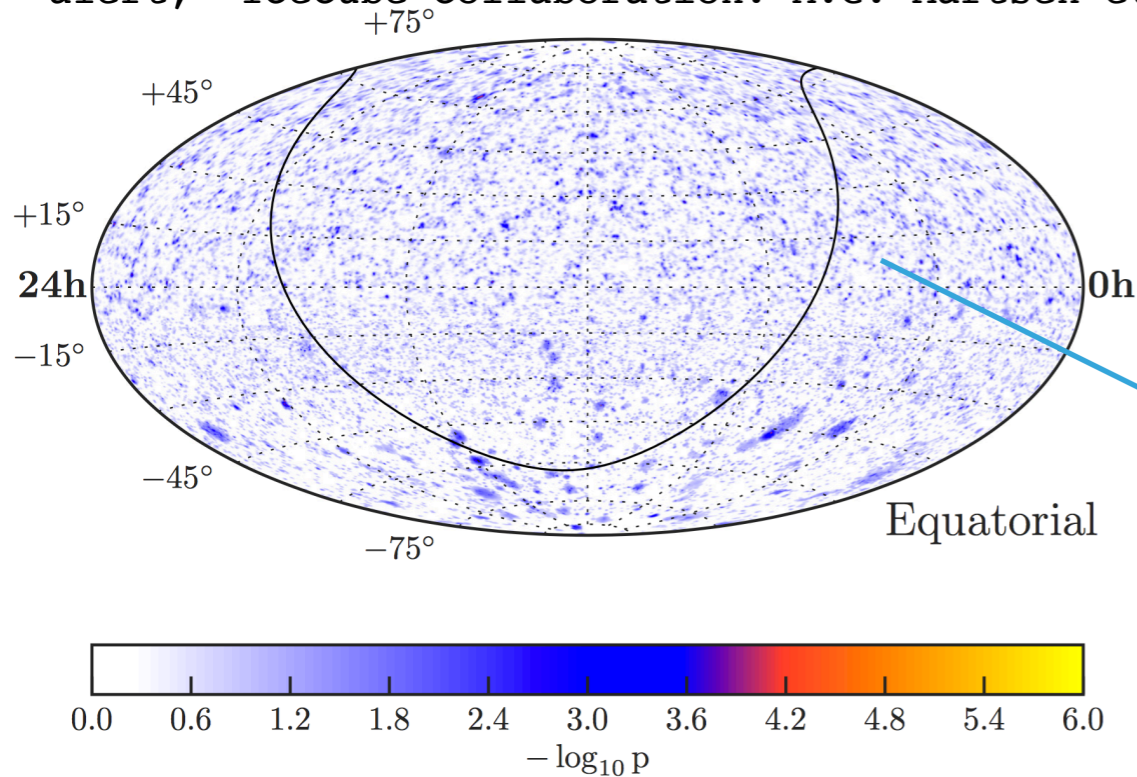
Step II: Are there any extragalactic Fermi source close in space to the neutrinos?



Step III: What is the gamma-ray energy flux in the time bin when the neutrino arrives?

THE ICECUBE FOLLOWUP: THERE ARE MORE NEUTRINOS!

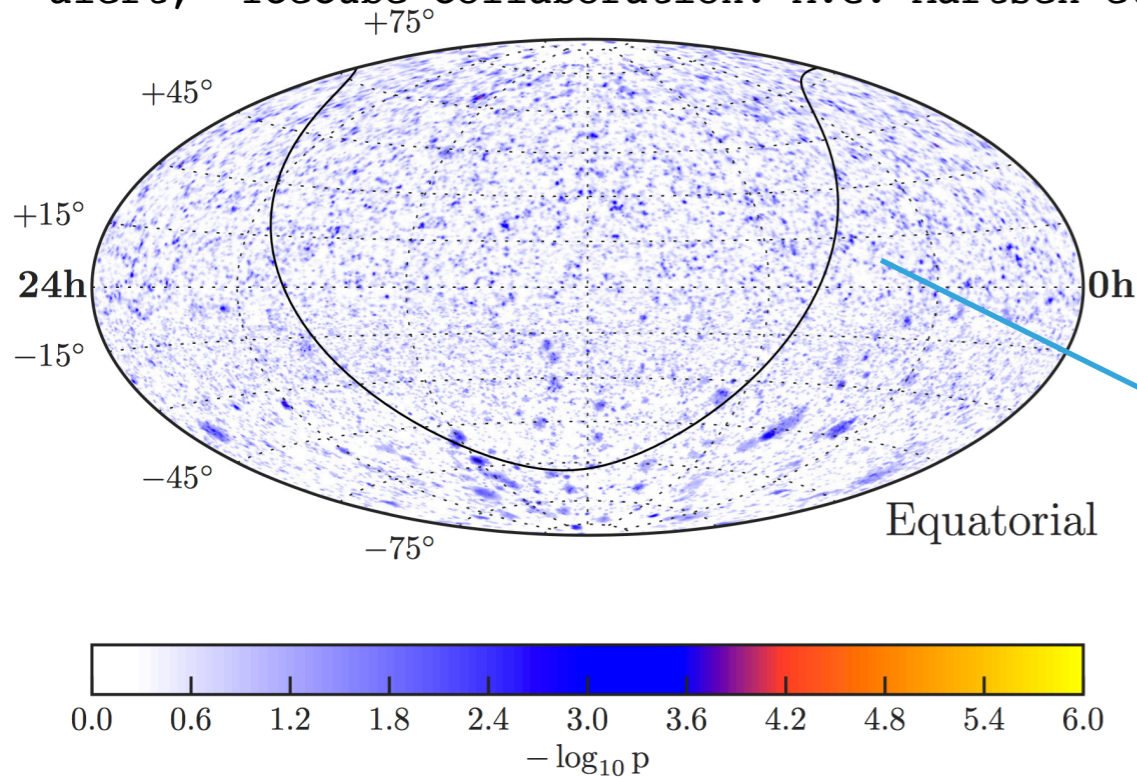
"Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert," IceCube Collaboration: M.G. Aartsen et al. *Science* 361, 147-151 (2018).



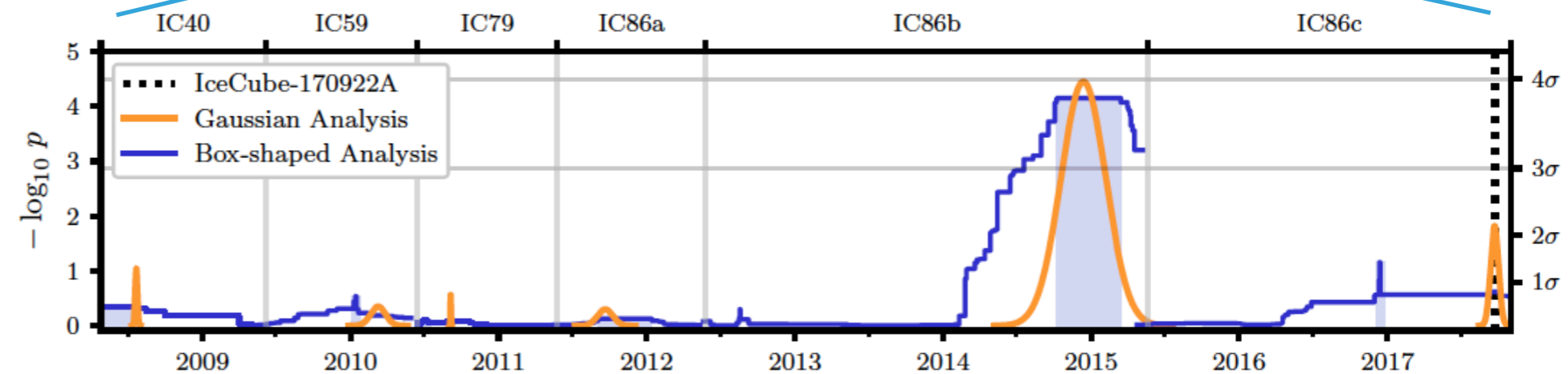
Al Samarai, Kintscher, Krammer, Wood

THE ICECUBE FOLLOWUP: BACKGROUND FLUCTUATION?

"Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert," IceCube Collaboration: M.G. Aartsen et al. *Science* 361, 147-151 (2018).

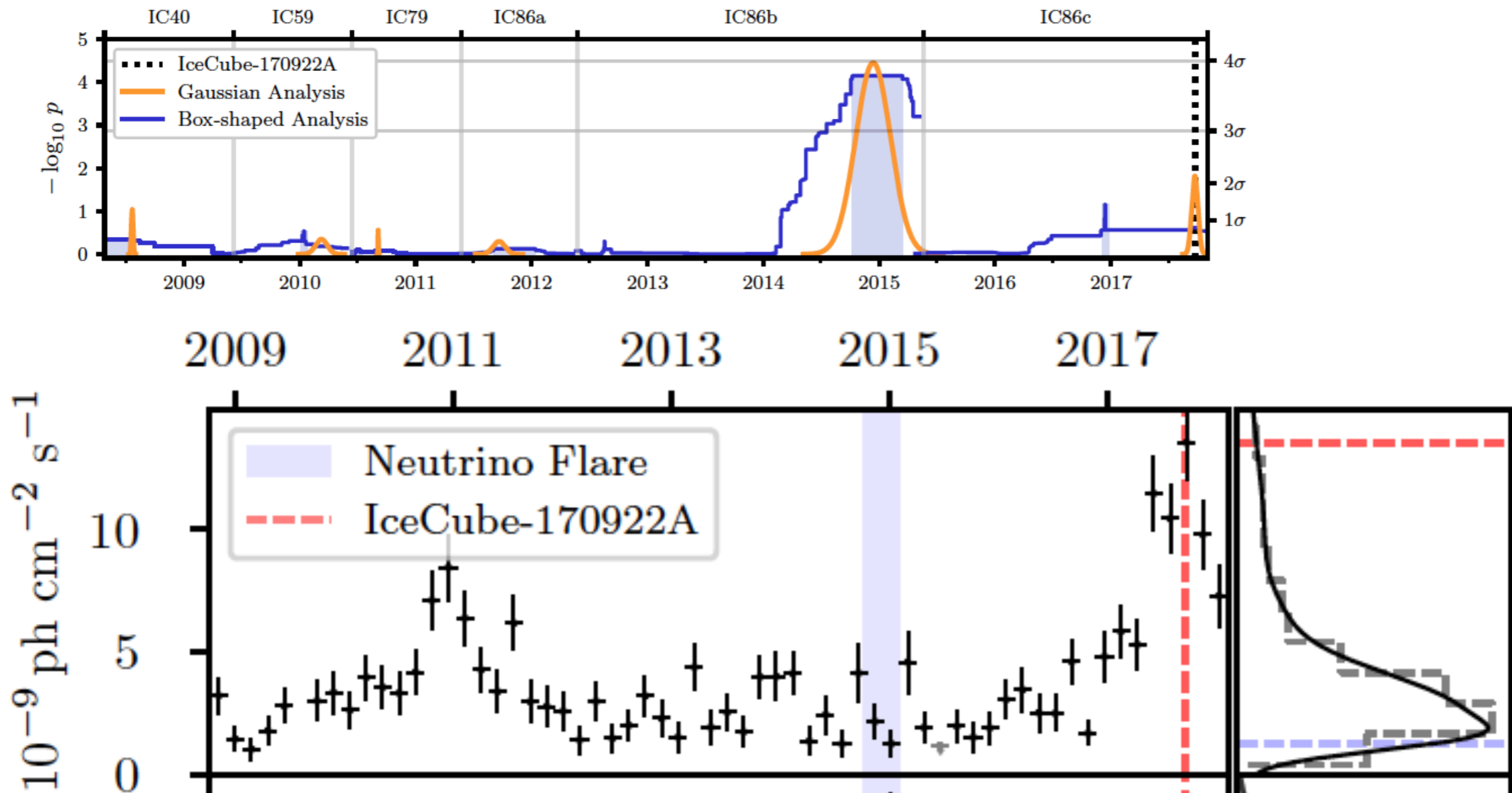


Excluded with 99.95% CL



THE ICECUBE FOLLOWUP: WHAT ABOUT THE GAMMA-RAYS?

"Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert," IceCube Collaboration: M.G. Aartsen et al. *Science* 361, 147-151 (2018).



lack of an accompanying simultaneous gamma-ray enhancement

LET'S DISSECT THE REGION AROUND ICECUBE-170922A



(1) first association neutrino alert and a BL Lac in a flaring state;

➔ *The IceCube Coll. & partners, "Multi-messenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A", Science 2018*

(2) the evidence of a neutrino flaring activity during 2014 - 2015 from the same direction;

➔ *The IceCube Coll., "Neutrino emission from the direction of the blazar TXS 0506+056 prior to the IceCube-170922A alert", Science 2018*

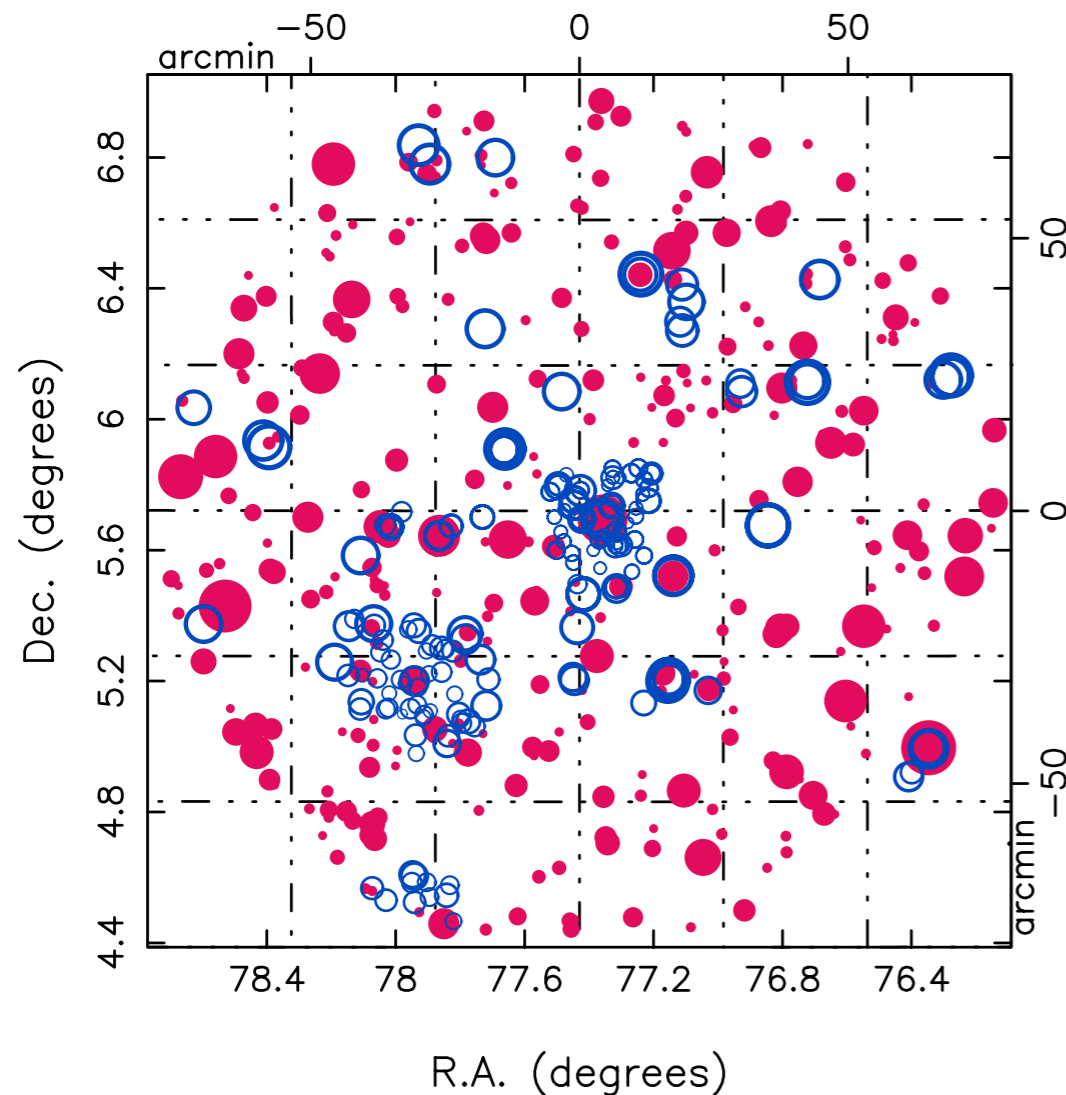
(3) the lack of an accompanying simultaneous gamma-ray enhancement;

(4) the contrasting flaring activity of a neighbouring bright gamma-ray source during 2014-2015.

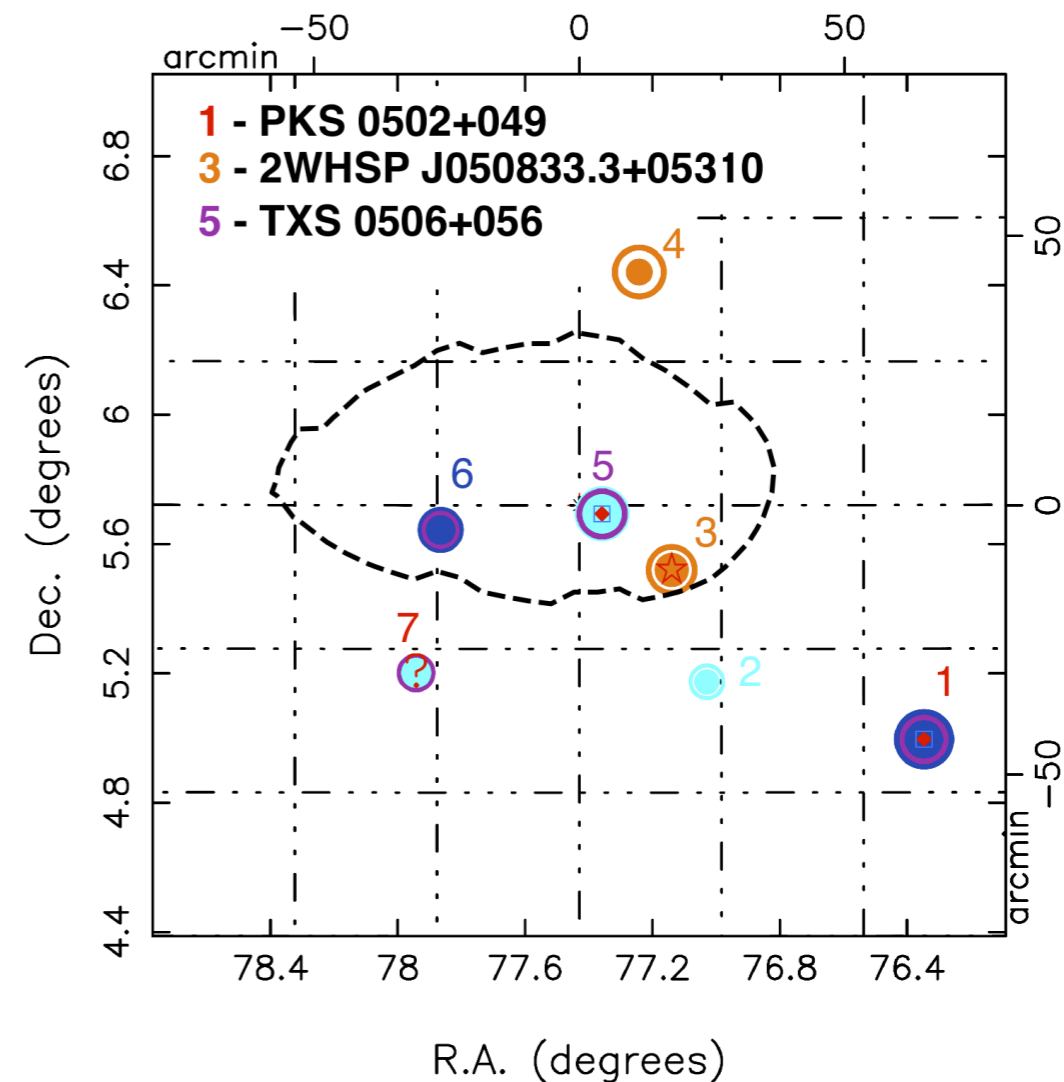
➔ *P. Padovani, P. Giommi, E.R., T. Glauch, B. Arsioli, N. Sahakyan, M. Huber, "Dissecting the region around IceCube-170922A: TXS 0506+056 as the first cosmic neutrino source", MNRAS 2018 (<https://arxiv.org/abs/1807.04461>)*

ICECUBE-170922A; THE REGION ($R = 80$ ARCMIN) AROUND

P. Padovani, P. Giommi, E.R., et al. *MNRAS* (2018)



637 radio (red) and/or X-ray (blue) sources;



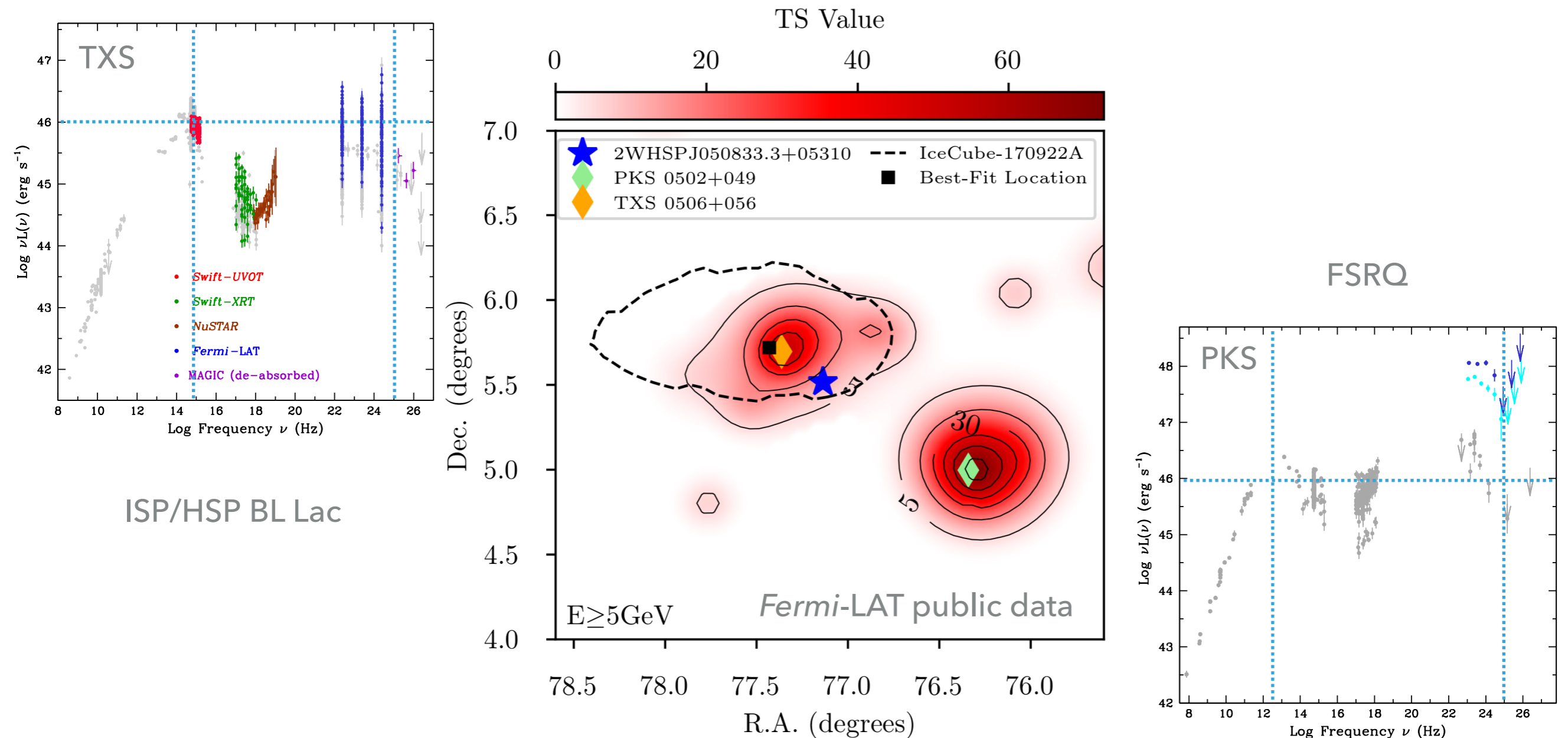
7 radio AND X-ray sources;

all 7 show X-ray to-radio flux ratio blazar-like.

GAMMA-RAY EMISSION NEAR ICECUBE-170922A: TXS AND PKS

P. Padovani, P. Giommi, E.R., et al. *MNRAS* (2018)

MJD 55762 - 55842 (July 20 - October 8, 2011)

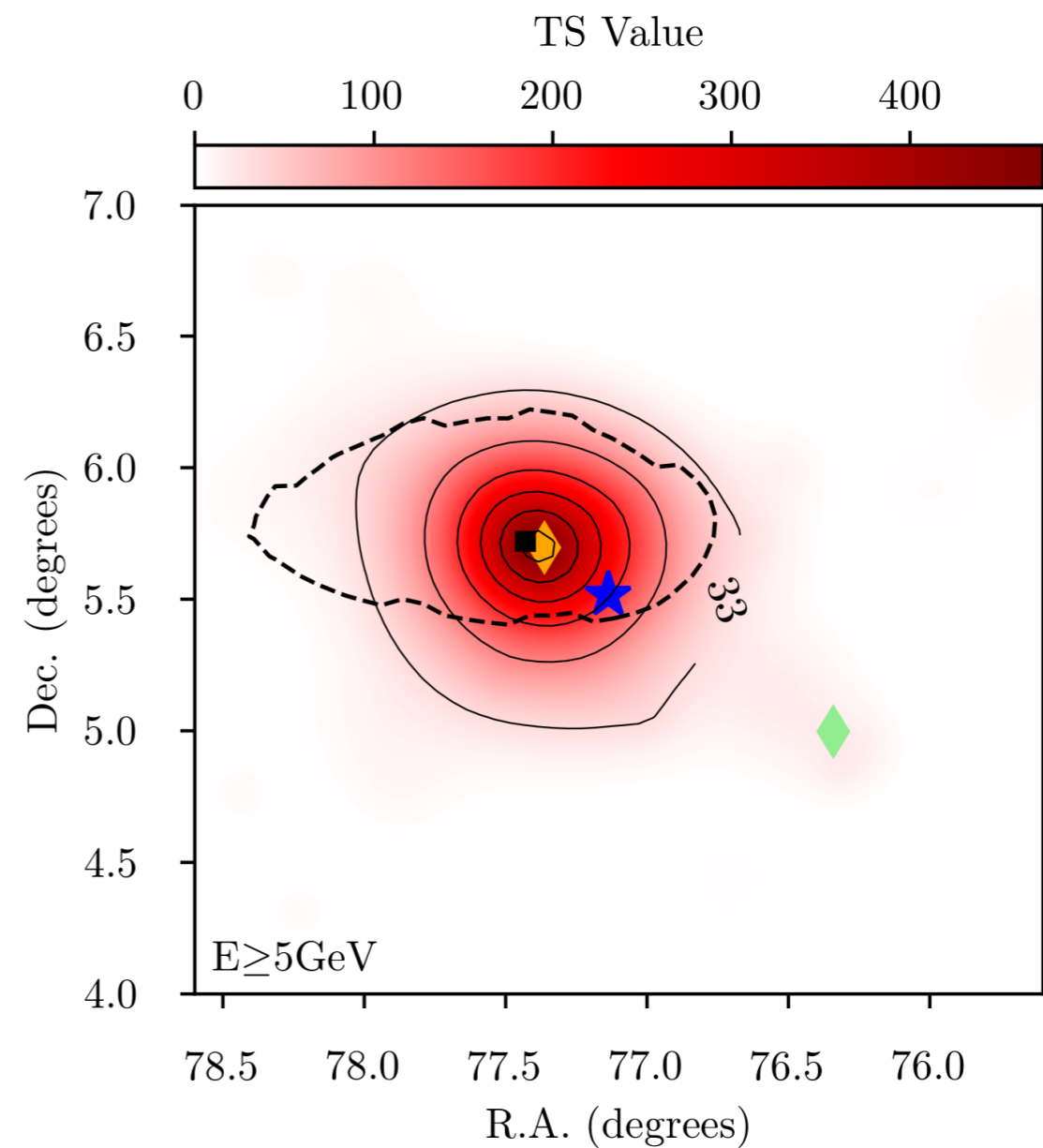
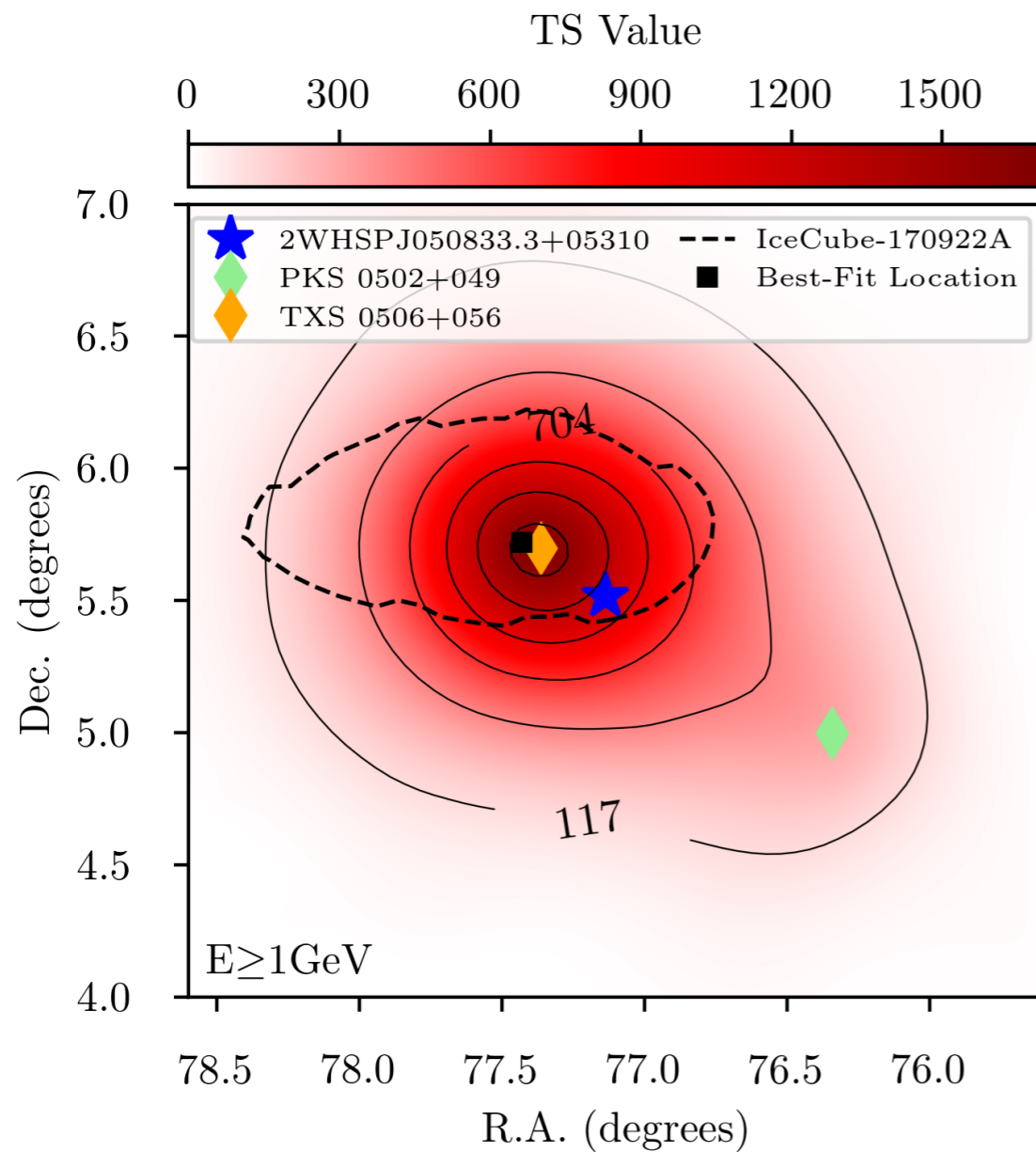


ISP/HSP BL Lac

FSRQ

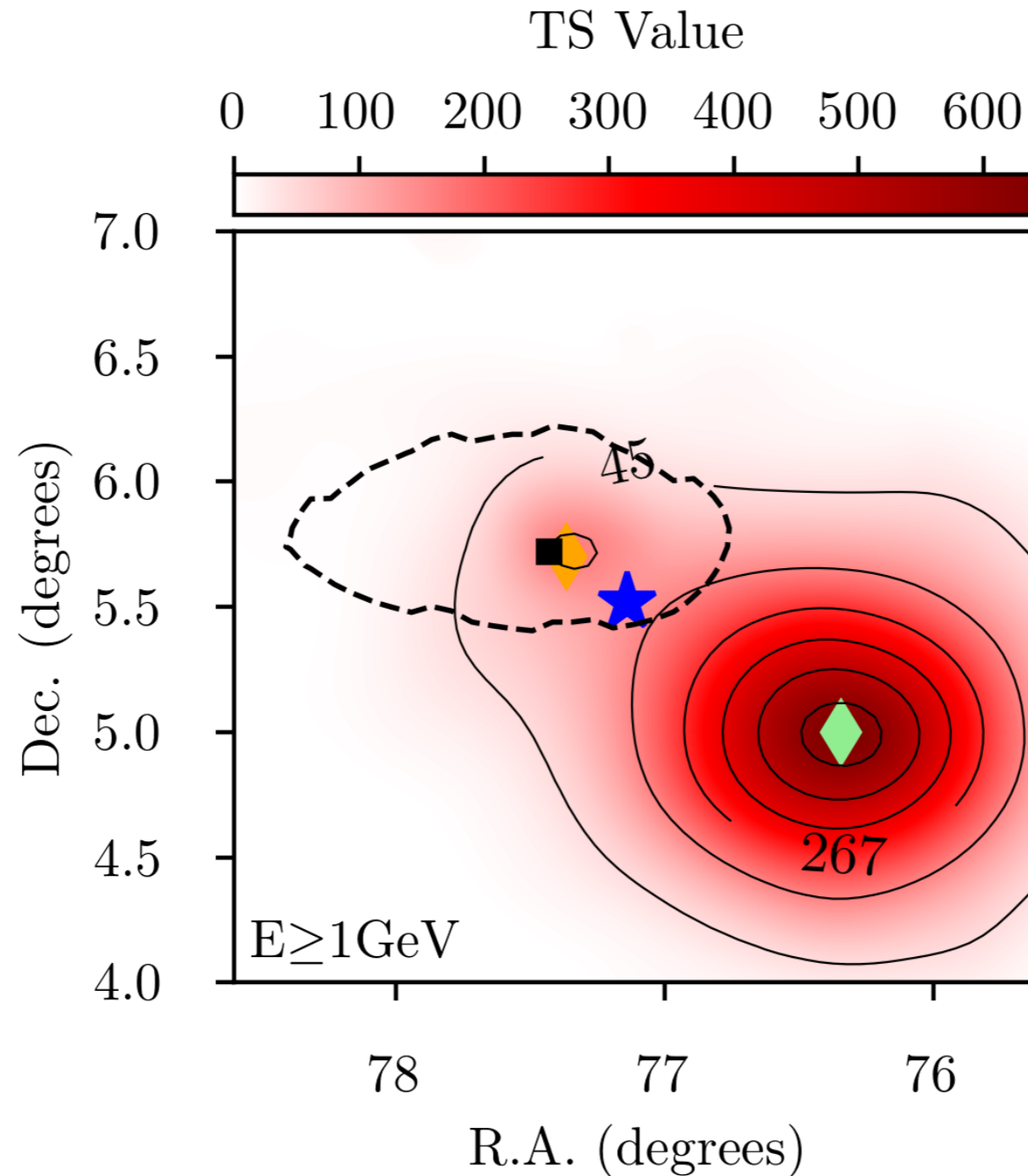
GAMMA-RAY EMISSION NEAR ICECUBE-170922A: NEUTRINO ALERT TIME

P. Padovani, P. Giommi, E.R., et al. *MNRAS* (2018)



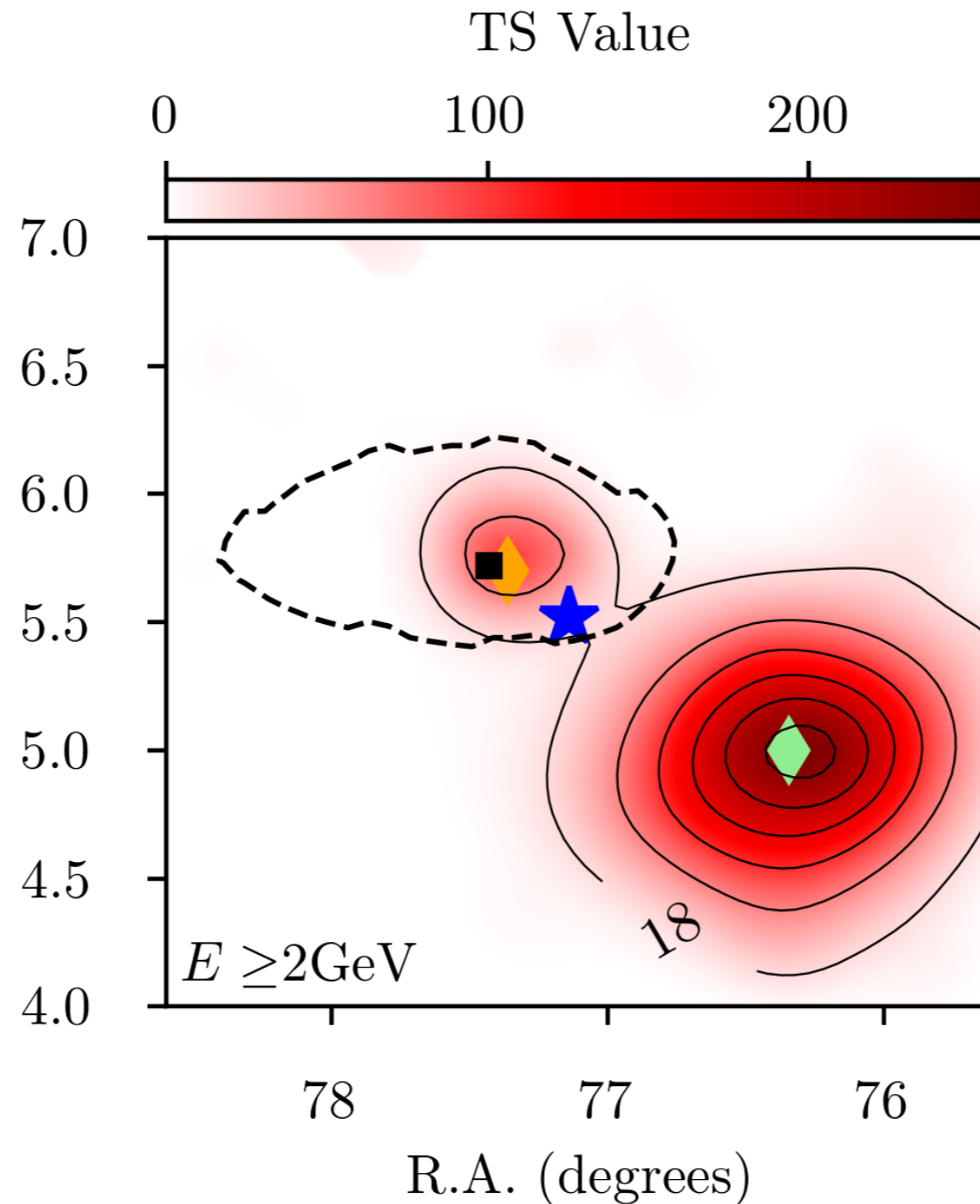
GAMMA-RAY EMISSION NEAR ICECUBE-170922A: NEUTRINO FLARE TIME

P. Padovani, P. Giommi, E.R., et al. *MNRAS* (2018)



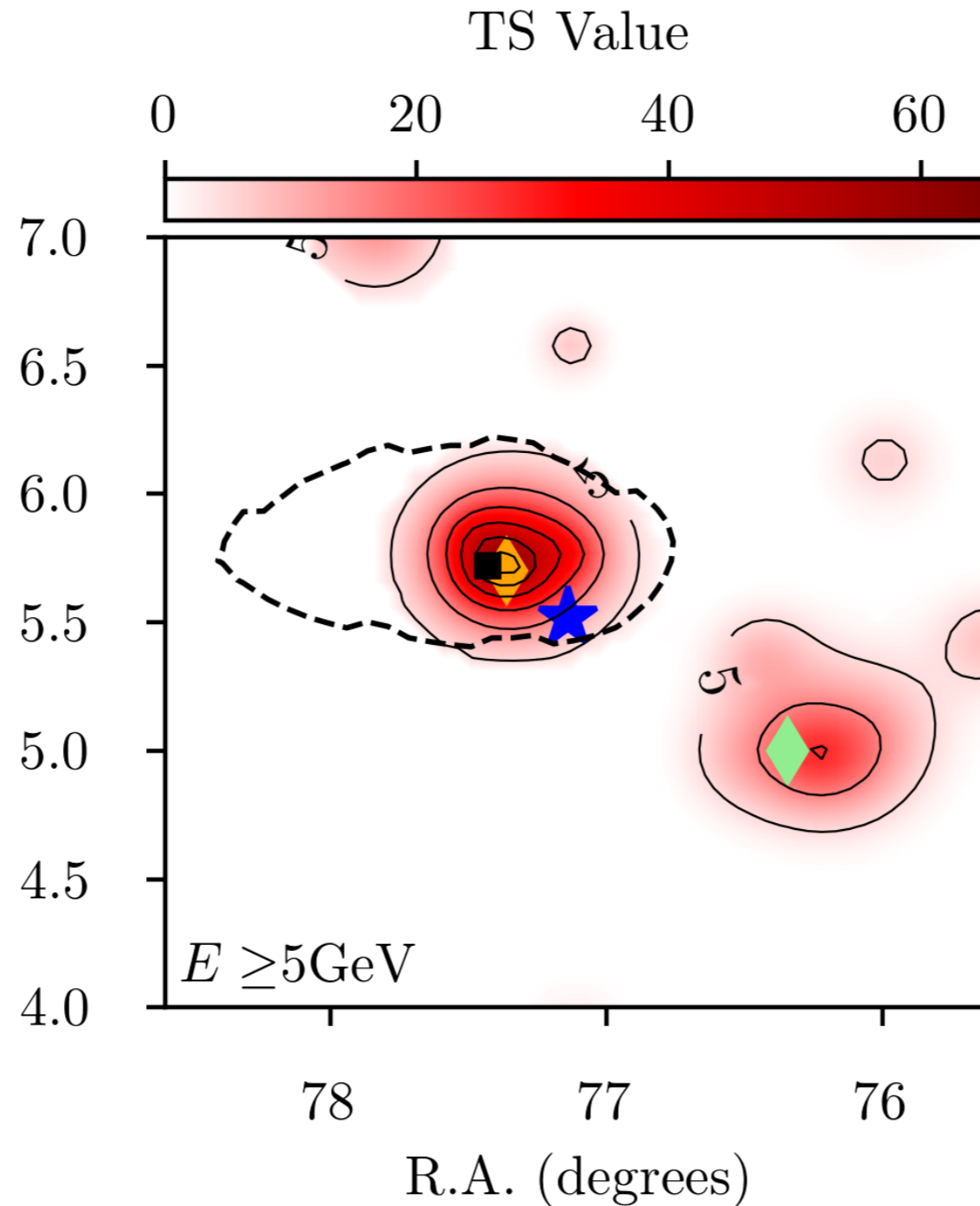
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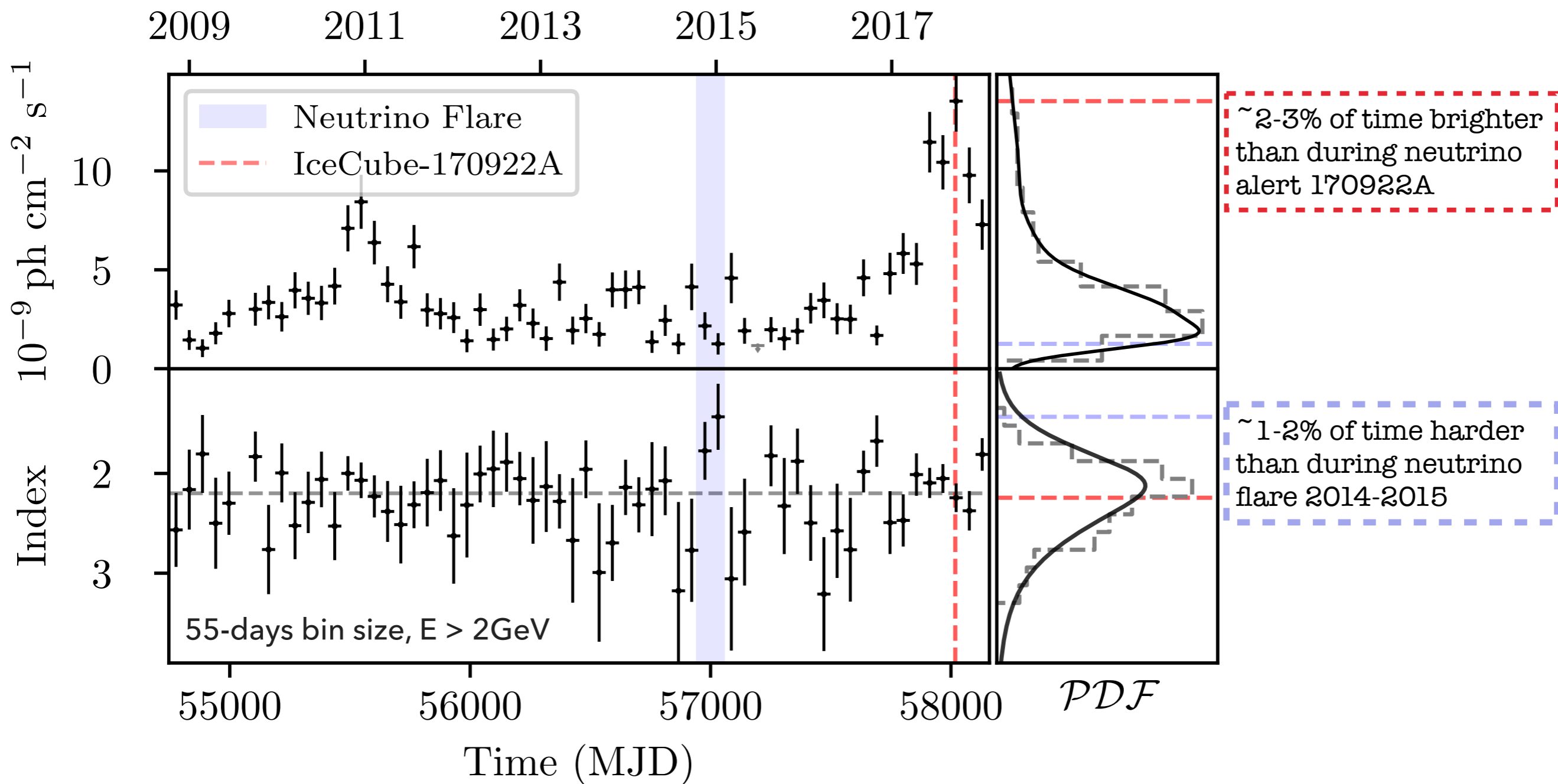


GAMMA-RAY EMISSION NEAR ICECUBE-170922A: NEUTRINO FLARE TIME

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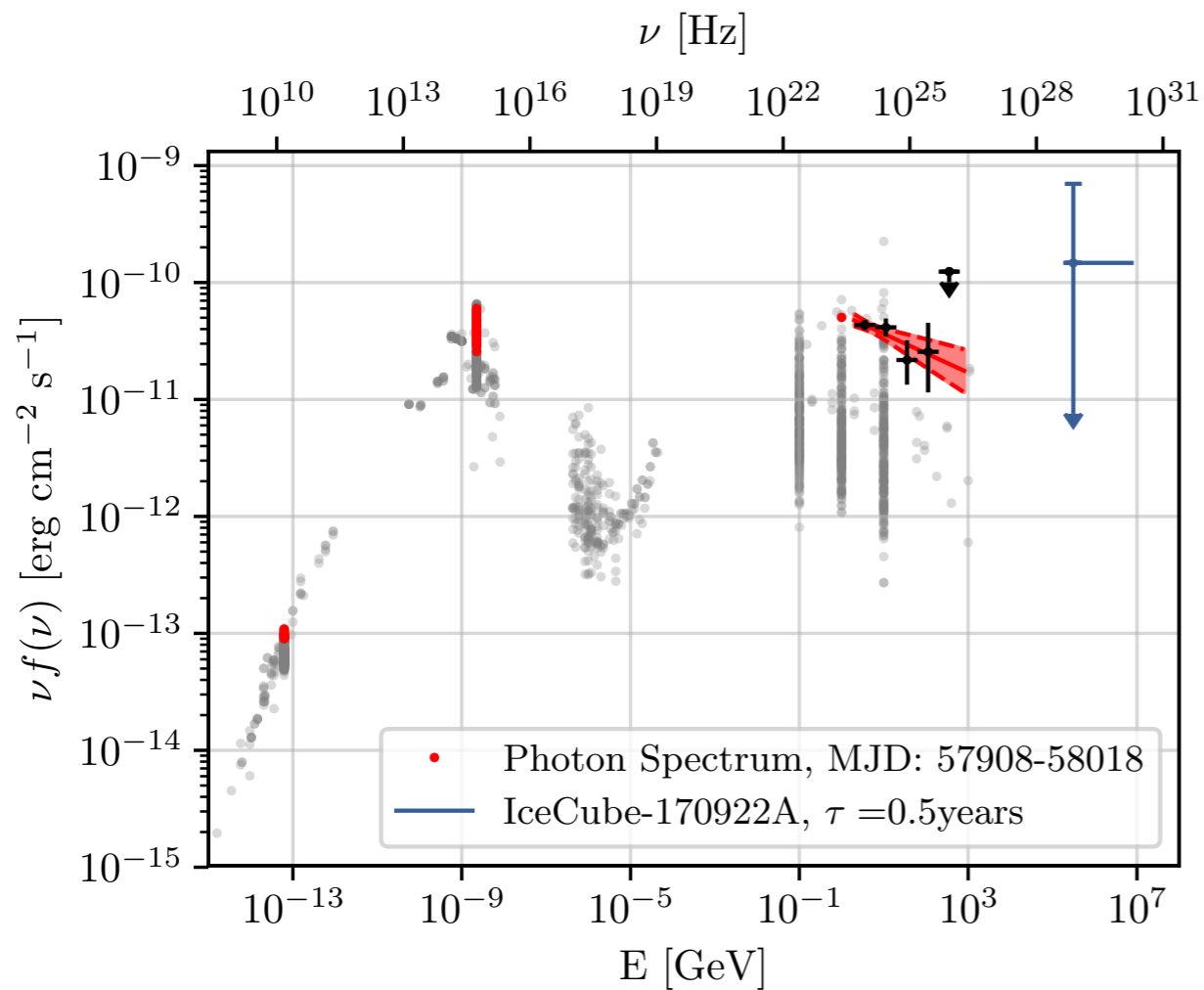


GAMMA-RAY LIGHT CURVES: TXS 0506+056

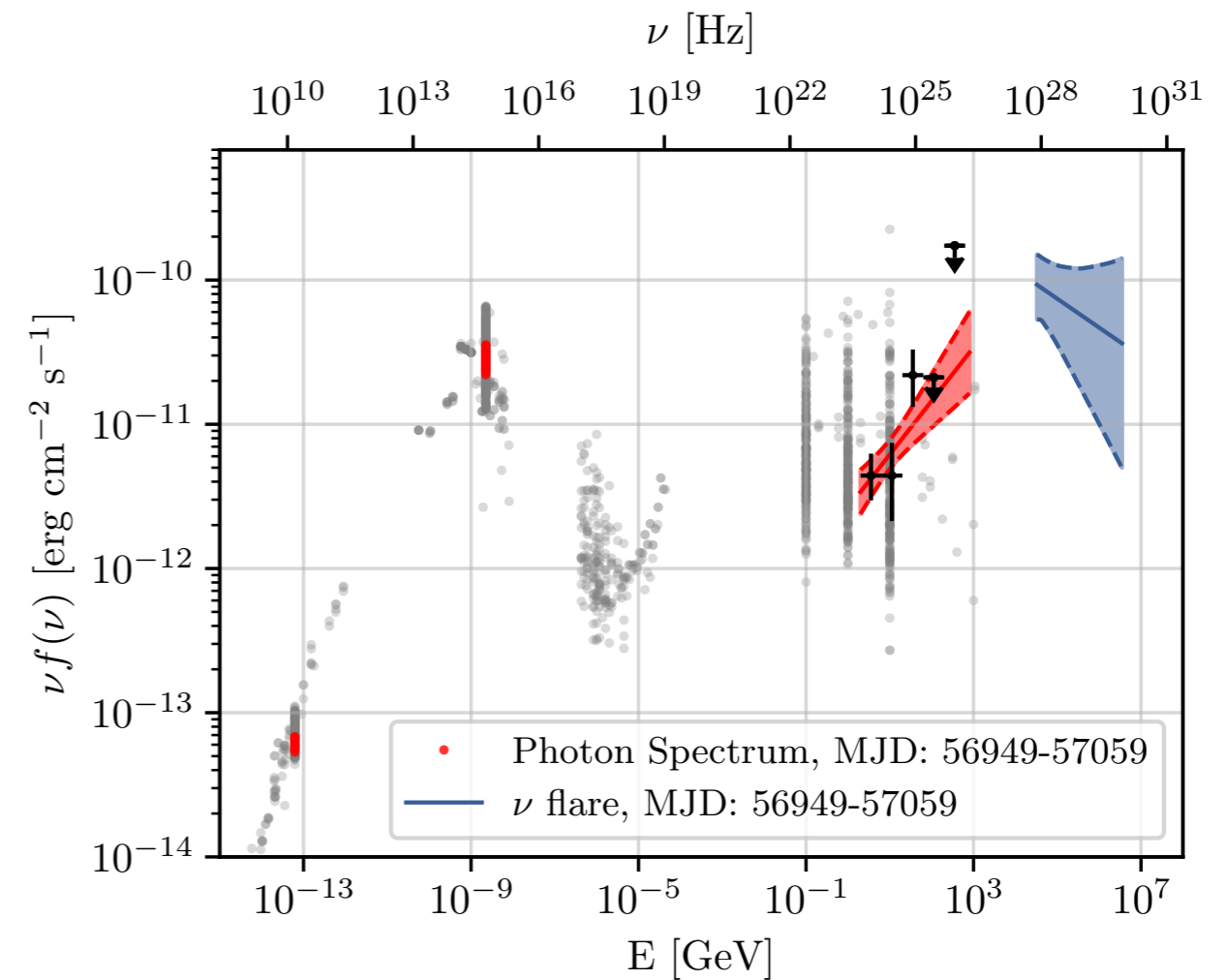


THE PHOTON - NEUTRINO SPECTRAL ENERGY DISTRIBUTION OF TXS 0506+056

Neutrino alert 179022A



Neutrino 'flare, 2014-2015



IN SUMMARY

The IceCube South Pole neutrino observatory detects HE **cosmic neutrinos** since 2013.

Recently

- ▶ first association neutrino alert and a blazar in a flaring state (3σ);
- ▶ the evidence of a neutrino flaring activity during 2014 - 2015 from the same direction (3.4σ);
- ▶ MM studies revealed that TXS 0506+056 best and only candidate for the neutrino alert & the neutrino excess in 2014-2015;
- ▶ as a consequence TXS 0506+056 is the **first cosmic accelerator**.

A new window on the universe has been opened at the highest energies.

OPEN QUESTIONS:

- ▶ Why the TXS 0506+056 as first source?
- ▶ Are there other blazars associated to neutrinos?
- ▶ How does acceleration works above 10^{15} eV?
- ▶ How to connect acceleration and radiative part in the source?
- ▶ What is the physics that power blazars?

IN SUMMARY

The IceCube South Pole neutrino observatory detects TeV cosmic neutrinos since 2013.

Recently

- ▶ first association neutrino alert and blazar in a flaring state (3σ);
- ▶ the evidence of a neutrino flaring activity during 2014 - 2015 from the same direction (5.1σ);
- ▶ TXS 0506-057 the best and only candidate for the neutrino alert & the neutrino excess in 2014-2015.

A new window on the universe has been opened at the highest energies.

Much more to come up soon.

WELCOME TO MULTI-MESSENGER ASTRONOMY