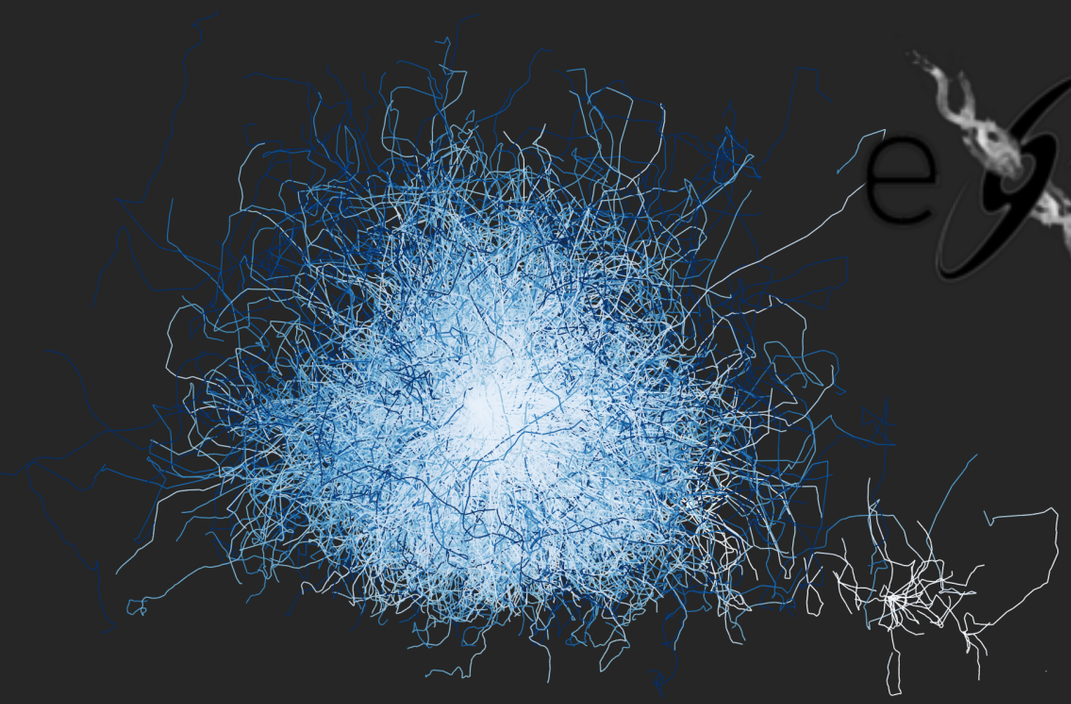


HOW ICECUBE DETECTS NEUTRINOS AND THE FIRST CANDIDATE SOURCE: A BLAZAR.

Extreme Blazars, Padova

24th of January, 2019

Elisa Resconi

Bundesministerium für Bildung und Forschung

DFG

SFB 1258 Neutrinos Dark Matter Messengers

Image: K. Krings (TUM)

LET ME SKIP THE BASICS: ICECUBE-240119A

```
TITLE:          GCN/AMON NOTICE
NOTICE_DATE:     Thu 24 Jan 19 03:44:35 UT
NOTICE_TYPE:     AMON ICECUBE HESE
RUN_NUM:        132077
EVENT_NUM:       9759013
SRC_RA:         307.1920d {+20h 28m 46s} (J2000),
                307.4895d {+20h 29m 57s} (current),
                306.4101d {+20h 25m 38s} (1950)
SRC_DEC:        -32.2914d {-32d 17' 28"} (J2000),
                -32.2270d {-32d 13' 36"} (current),
                -32.4582d {-32d 27' 28"} (1950)
SRC_ERROR:       73.79 [arcmin radius, stat+sys, 90% containment]
SRC_ERROR50:     25.19 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18507 TJD;    24 DOY;   19/01/24 (yy/mm/dd)
DISCOVERY_TIME:   13434 SOD {03:43:54.79} UT
REVISION:        0
N_EVENTS:         1 [number of neutrinos]
STREAM:          1
DELTA_T:         0.0000 [sec]
SIGMA_T:         0.0000 [sec]
FALSE_POS:       0.0000e+00 [s^-1 sr^-1]
PVALUE:          0.0000e+00 [dn]
CHARGE:          13555.75 [pe]
SIGNAL_TRACKNESS: 0.91 [dn]
SUN_POSTN:       306.17d {+20h 24m 40s}  -19.29d {-19d 17' 15"}
SUN_DIST:        12.99 [deg]   Sun_angle= -0.1 [hr] (East of Sun)
MOON_POSTN:      167.71d {+11h 10m 51s}   +9.45d {+09d 26' 47"}
MOON_DIST:       136.44 [deg]
GAL_COORDS:       10.59,-33.61 [deg] galactic lon,lat of the event
ECL_COORDS:      301.61,-12.84 [deg] ecliptic lon,lat of the event
COMMENTS:        AMON_ICECUBE_HESE.
```

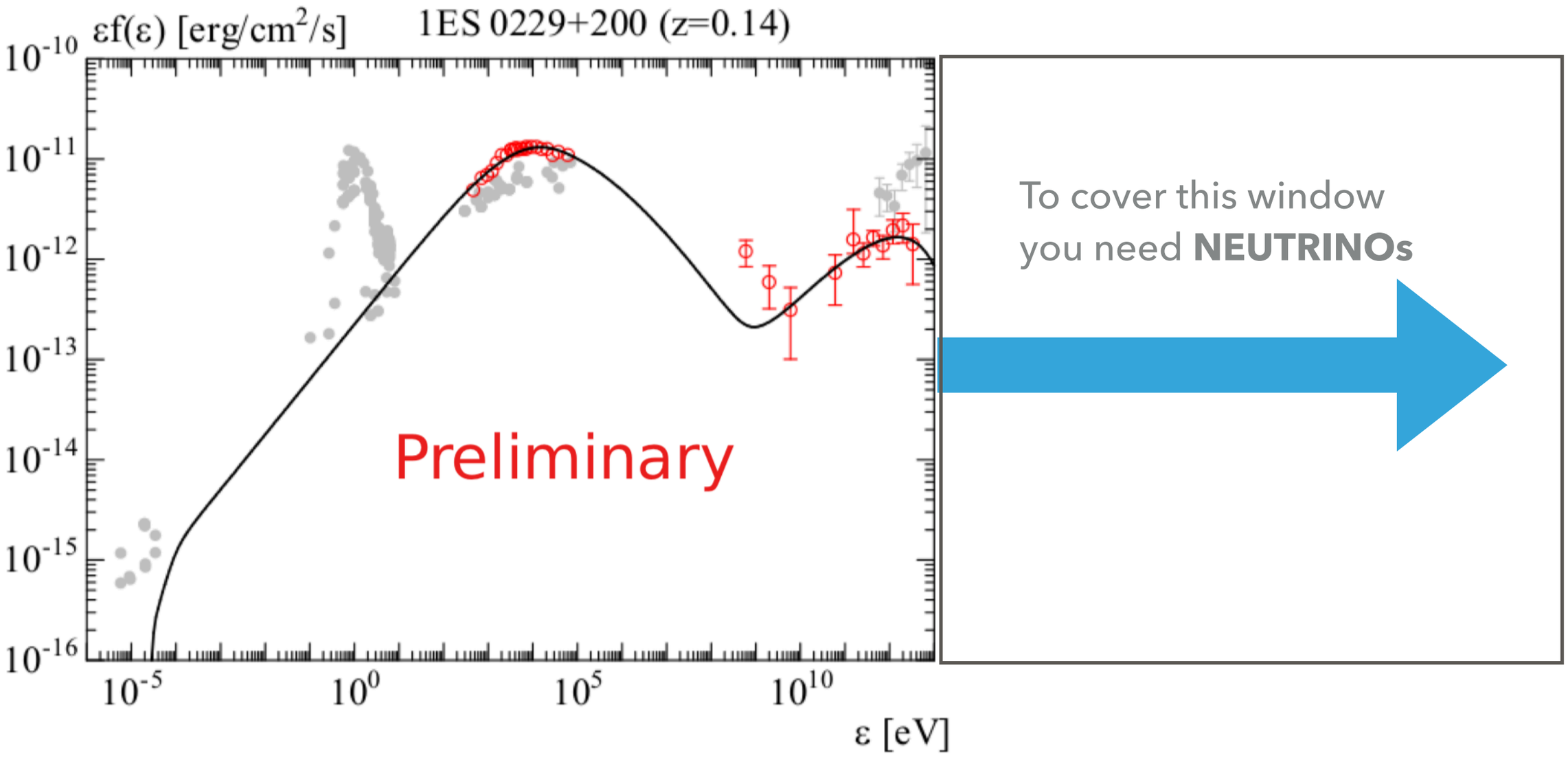
THIS IS AN EXTREME EVENT!

ANY EXTREME BLAZAR FROM THAT DIRECTION?

WHY DO WE CARE ABOUT NEUTRINOS?

THE UNIVERSE IS NOT TRANSPARENT TO PHOTONS >50–100TEV
BUT IT IS TRANSPARENT TO NEUTRINOS

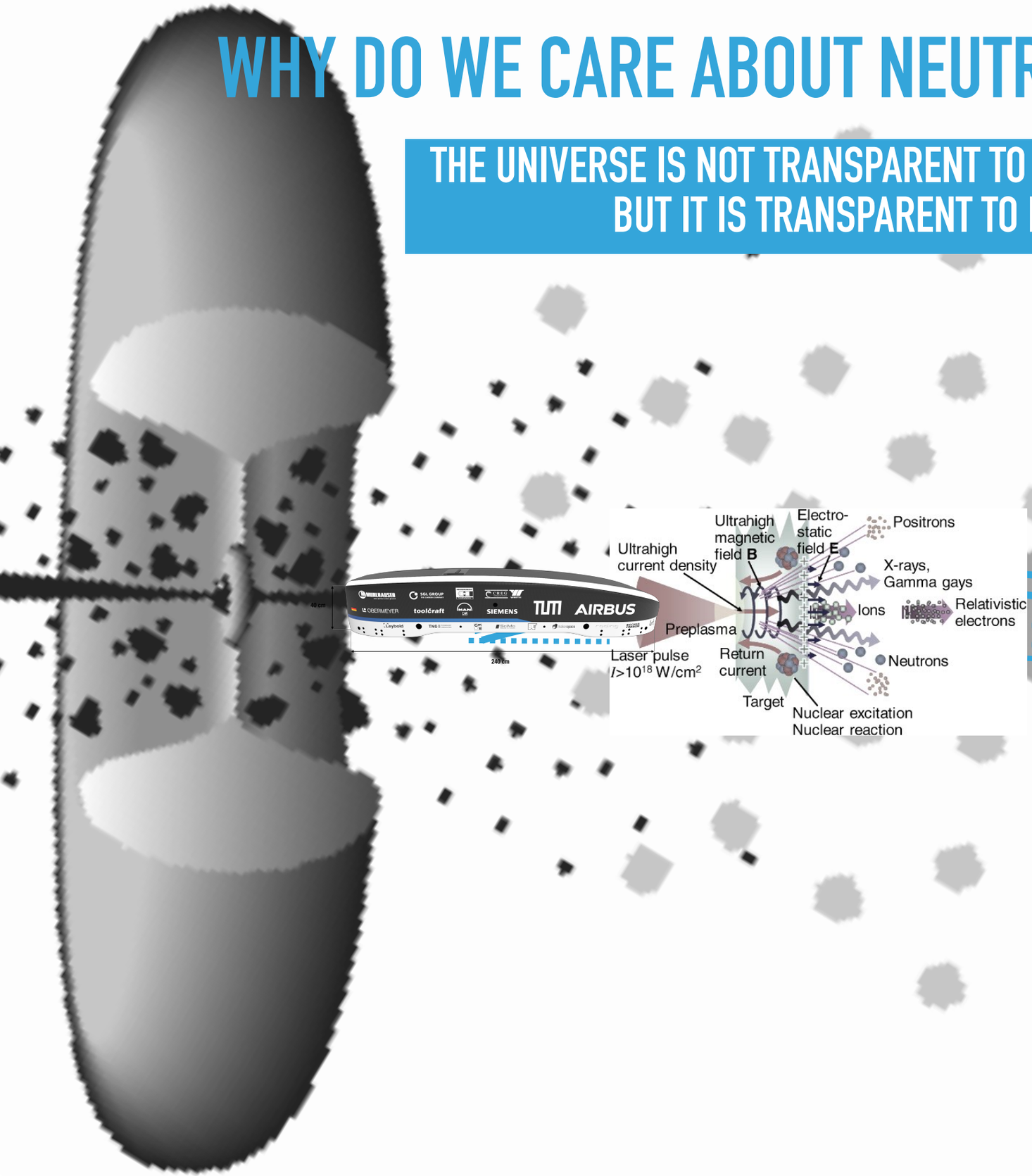
V. Fallah Ramazani et al., this conference



WHY DO WE CARE ABOUT NEUTRINOS? SOURCE SCENARIO

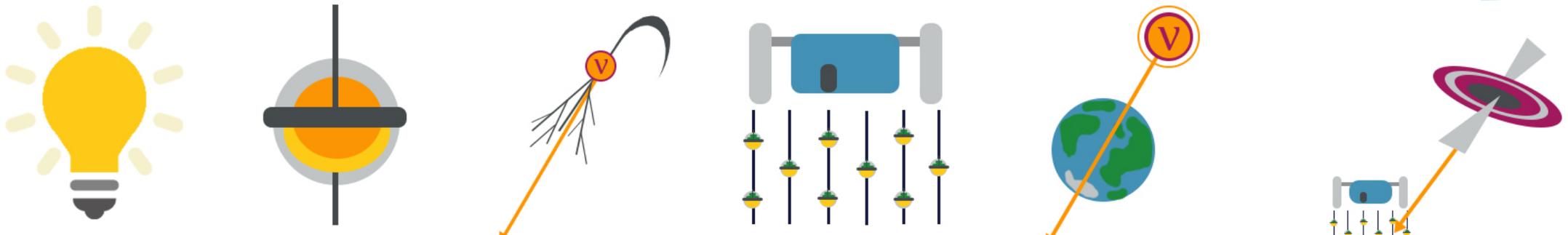
THE UNIVERSE IS NOT TRANSPARENT TO PHOTONS >50–100TEV
BUT IT IS TRANSPARENT TO NEUTRINOS

MESSENGERS



A History of Neutrino Astronomy in Antarctica

- 8 years, one (marginal) source -



1960 Vision

1988 Telescope in the Ice Envisioned

First attempt to build a neutrino telescope in the Pacific ocean - Failed

2000 AMANDA Completed

2000-2001 Atmospheric Neutrinos Detected

2011 IceCube Completed

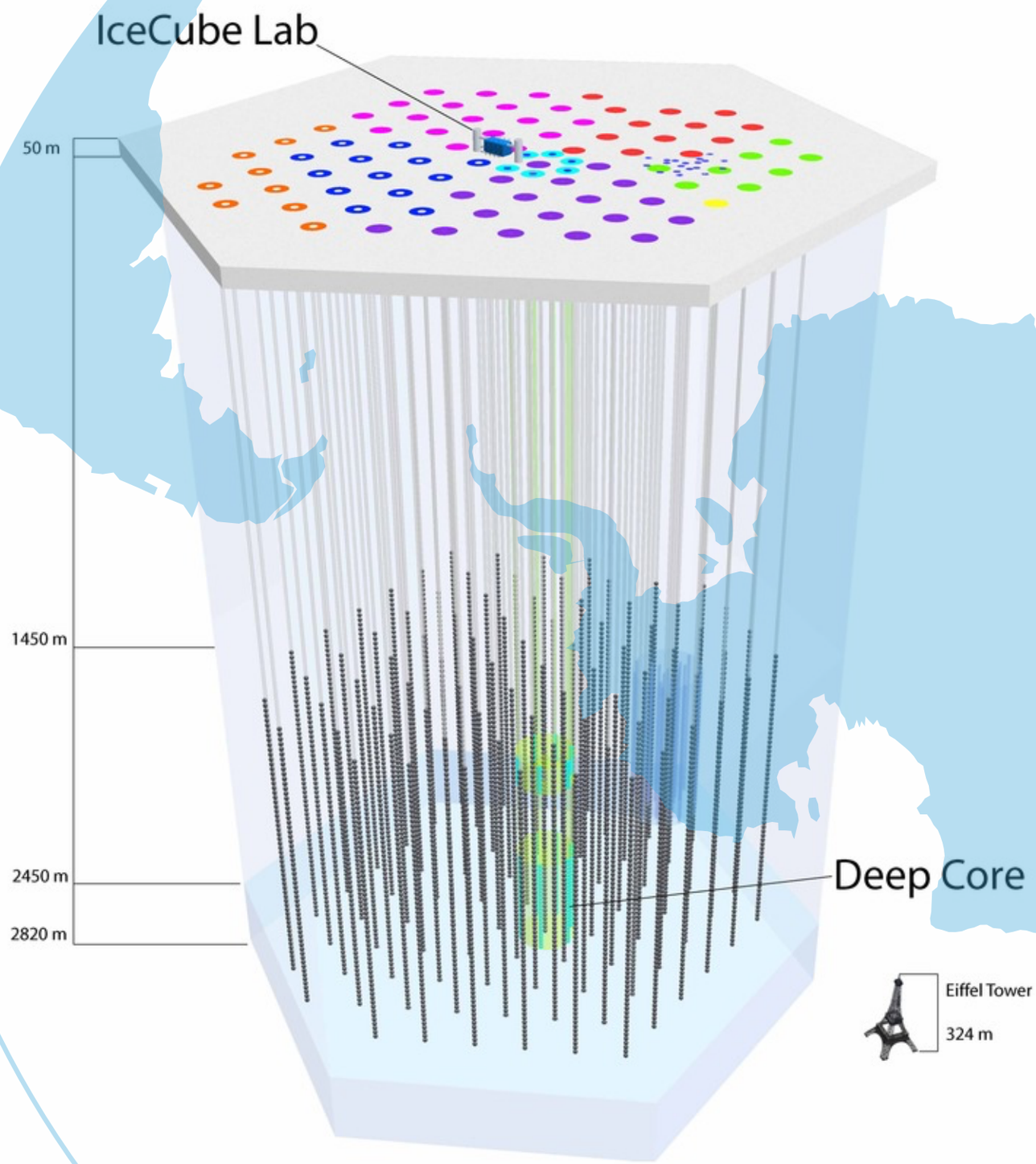
2013 Astrophysical Neutrinos Discovered

- Diffuse -

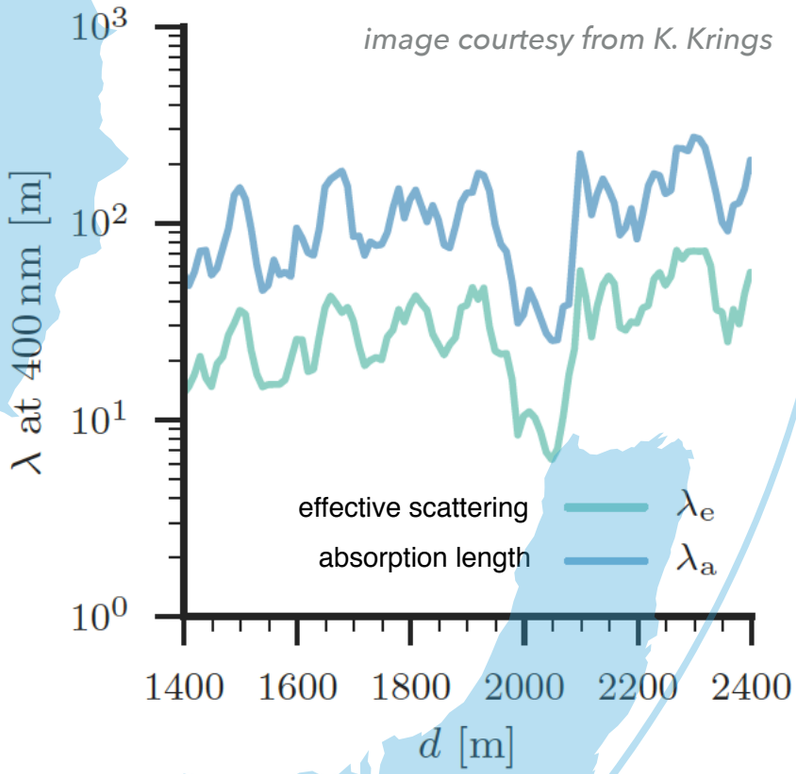
2018 First Source Identified

IceCube South Pole Neutrino Observatory

THE ICECUBE NEUTRINO OBSERVATORY



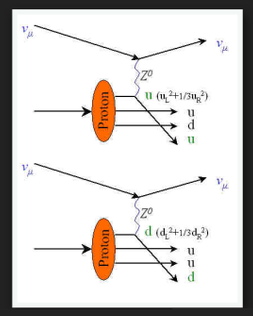
Digital Optical Modules

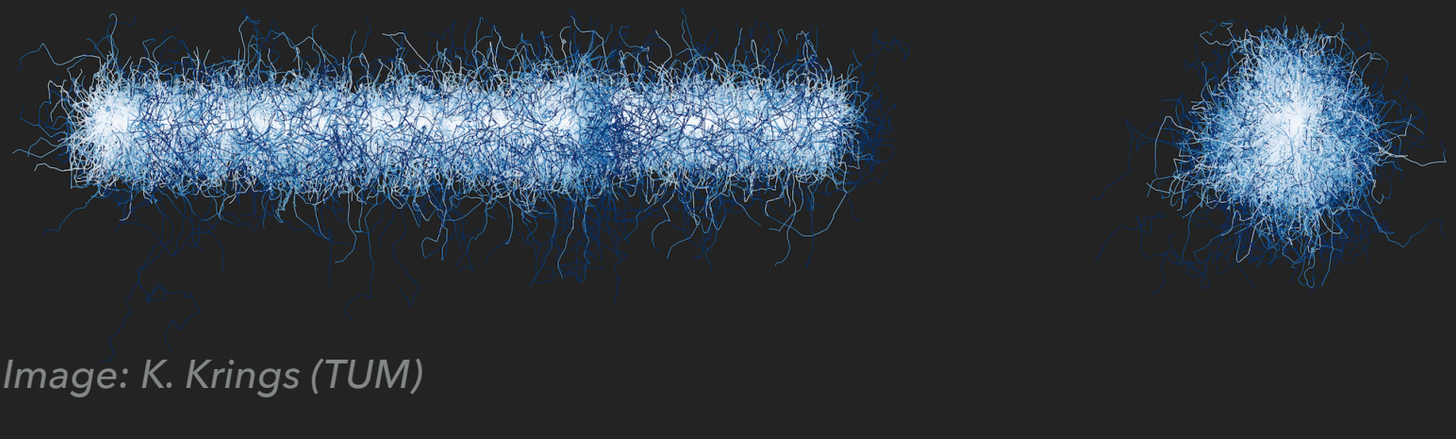


Martin Wolf

NEUTRINO INTERACTION CHANNELS

Photon path induced by a ν_μ ν_e ν_τ





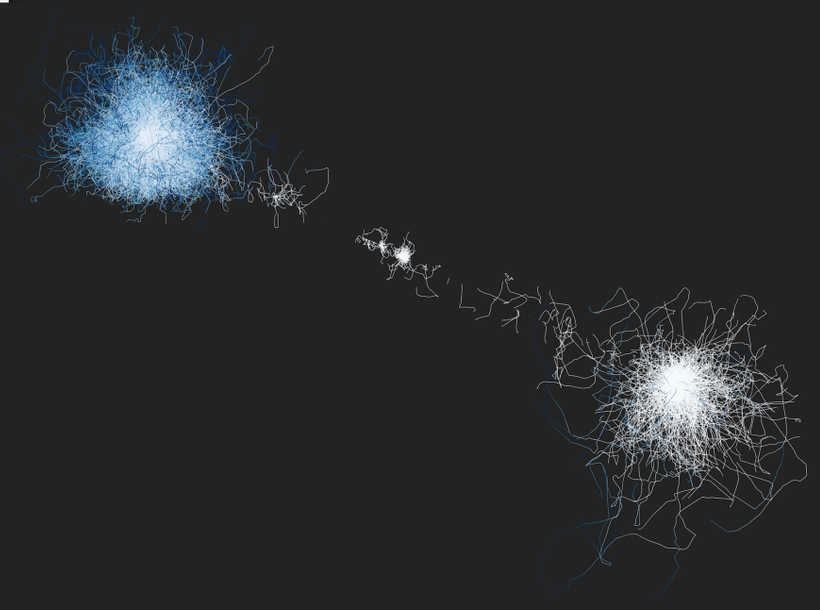
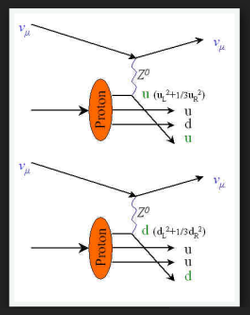
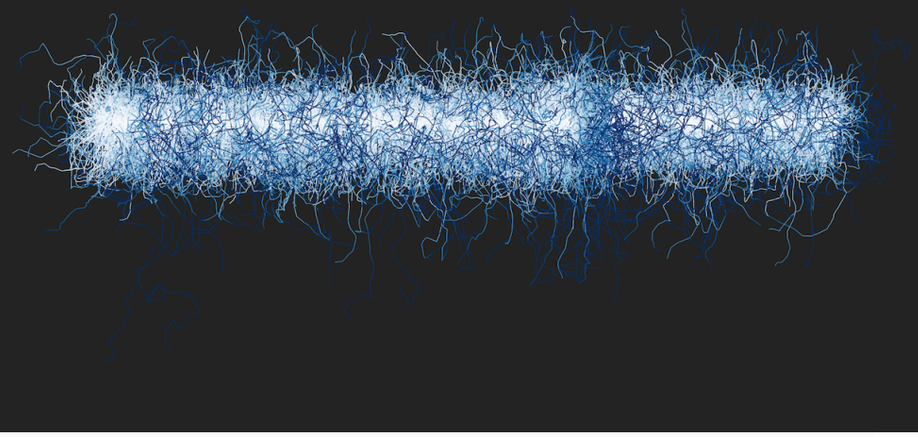


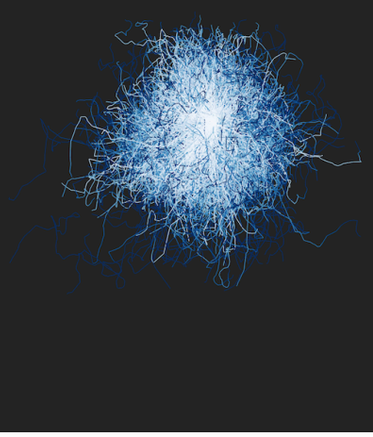
Image: K. Krings (TUM)

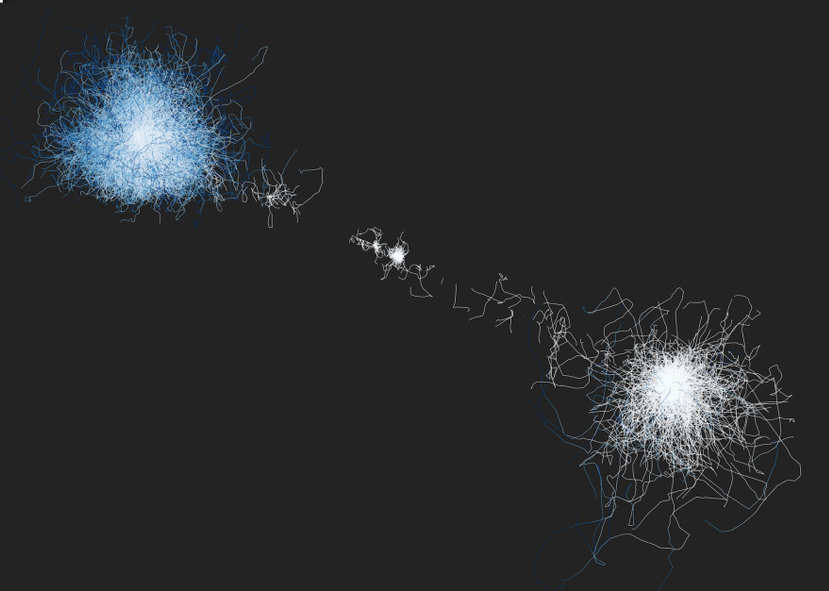
NEUTRINO INTERACTION CHANNELS

Photon path induced by a ν_μ ν_e ν_τ

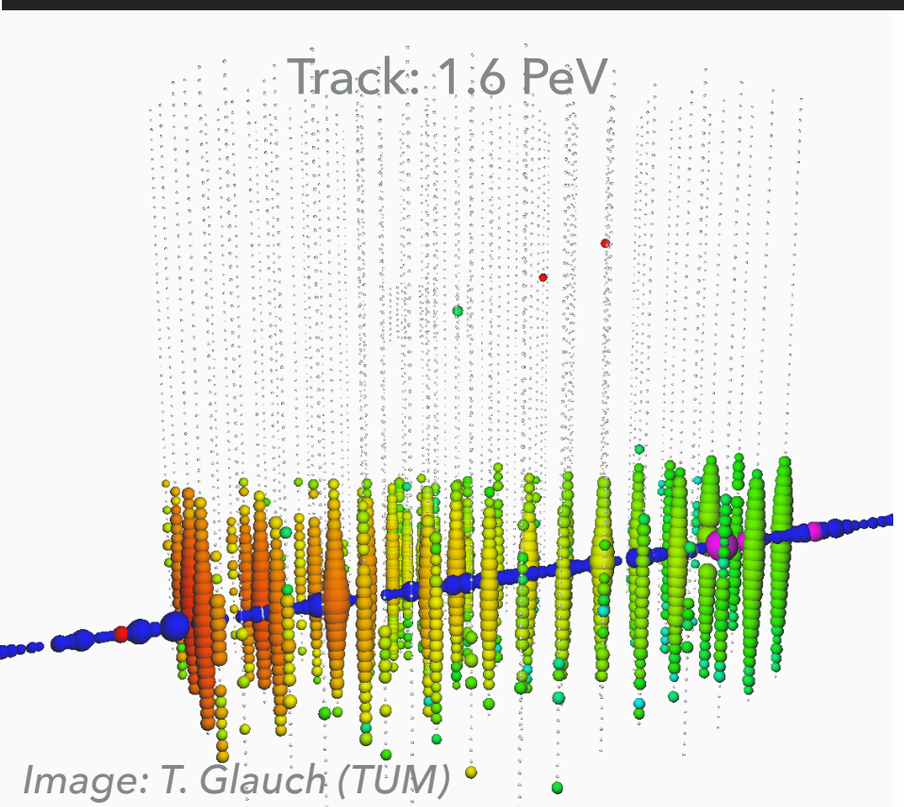




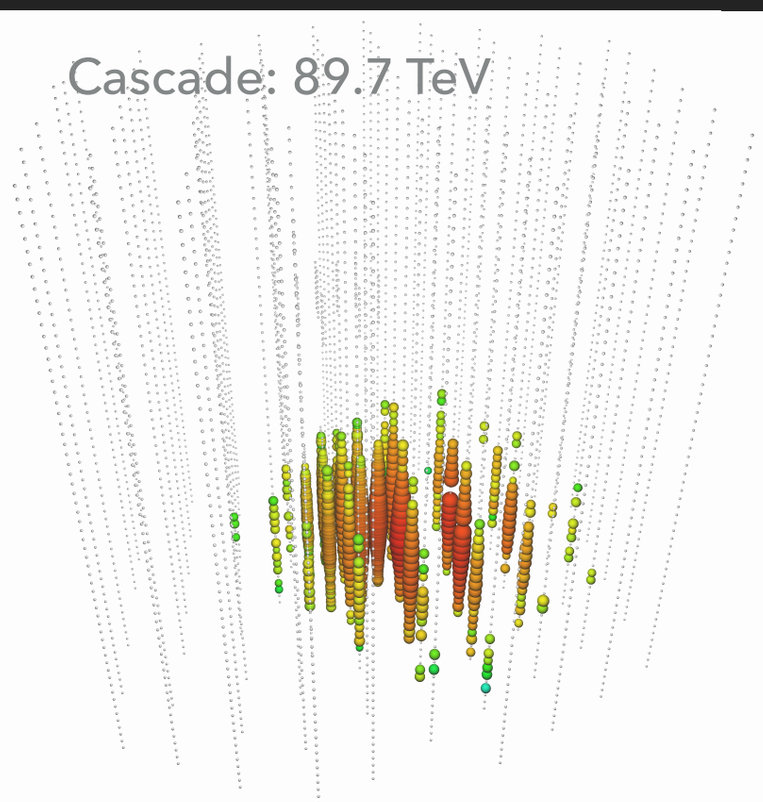




Track: 1.6 PeV



Cascade: 89.7 TeV



Double Bang: 11.7 PeV

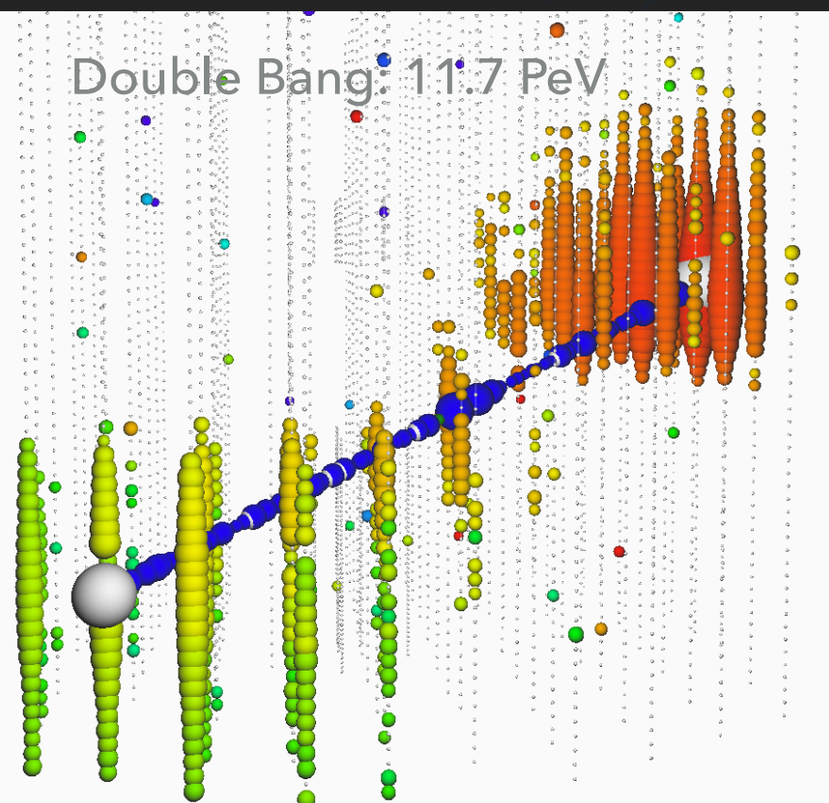
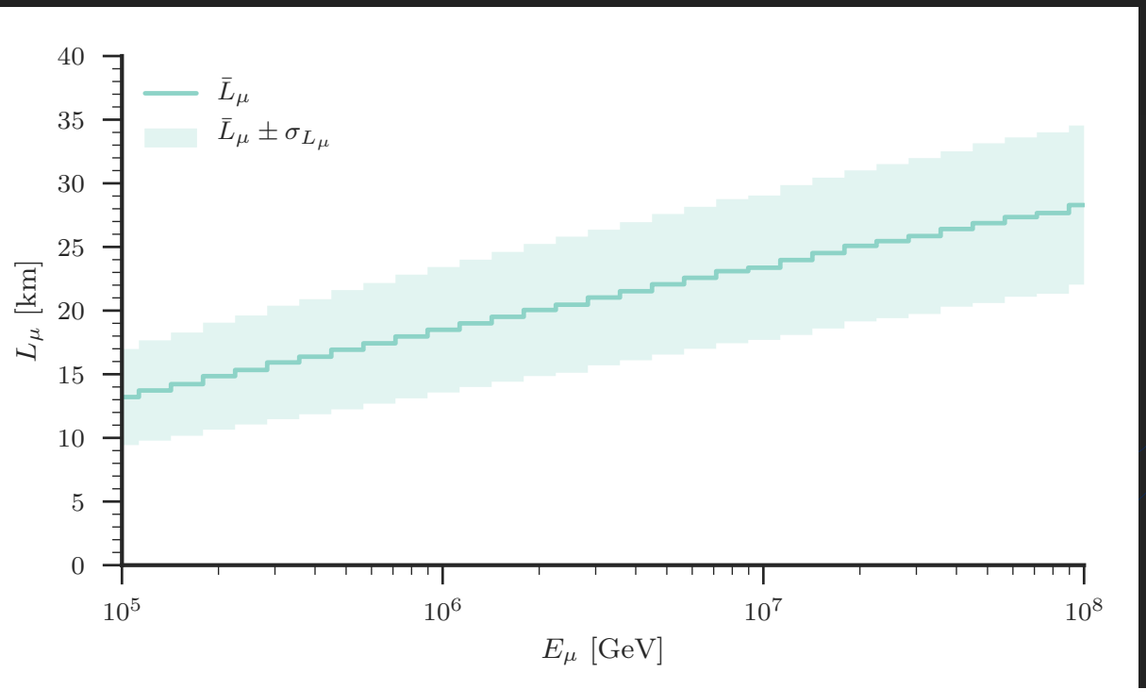
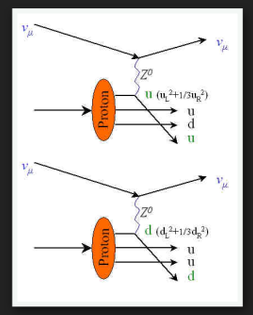
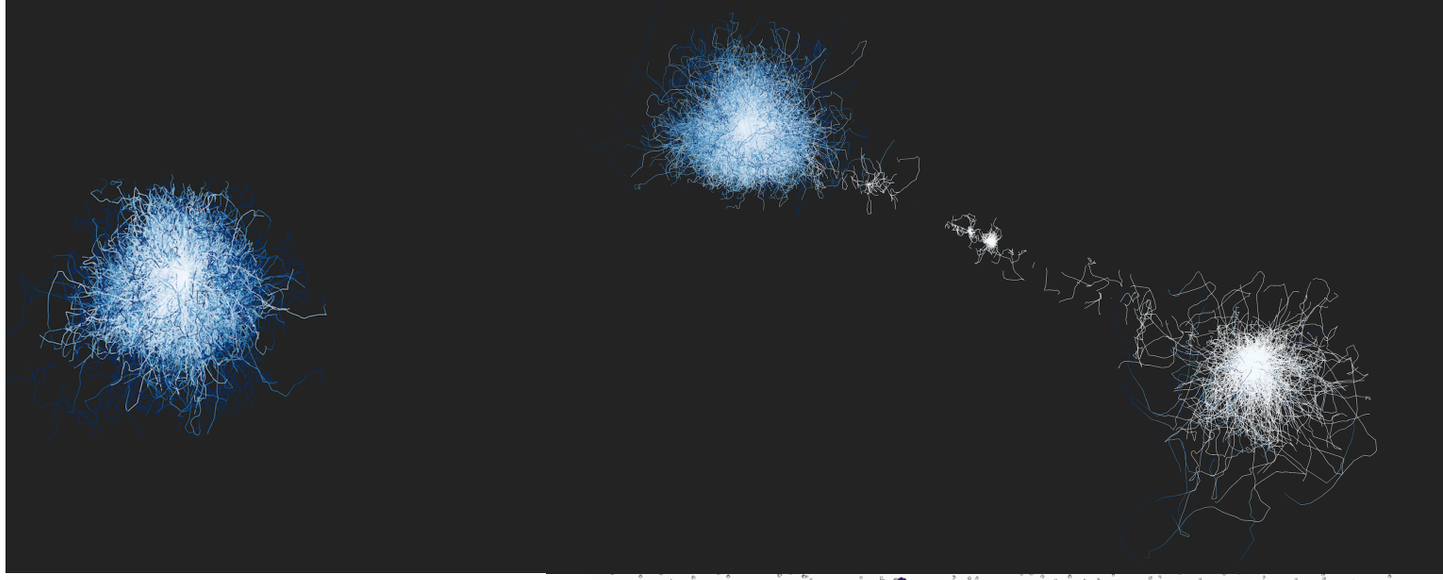


Image: T. Glauch (TUM)

NEUTRINO INTERACTION CHANNELS







Track: 1.6 PeV

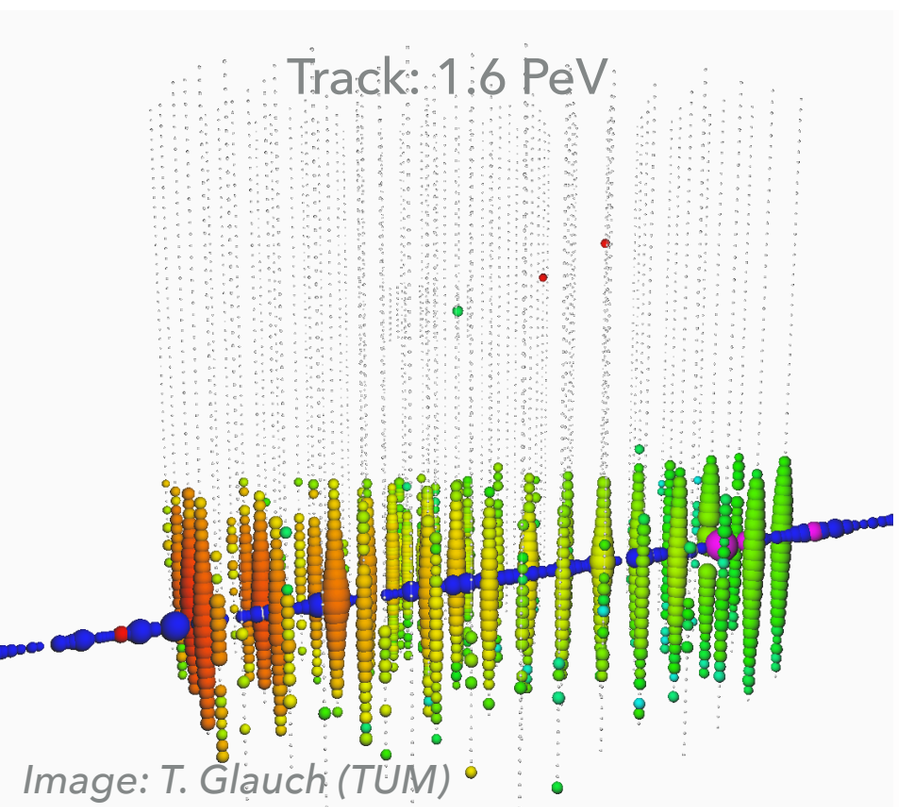
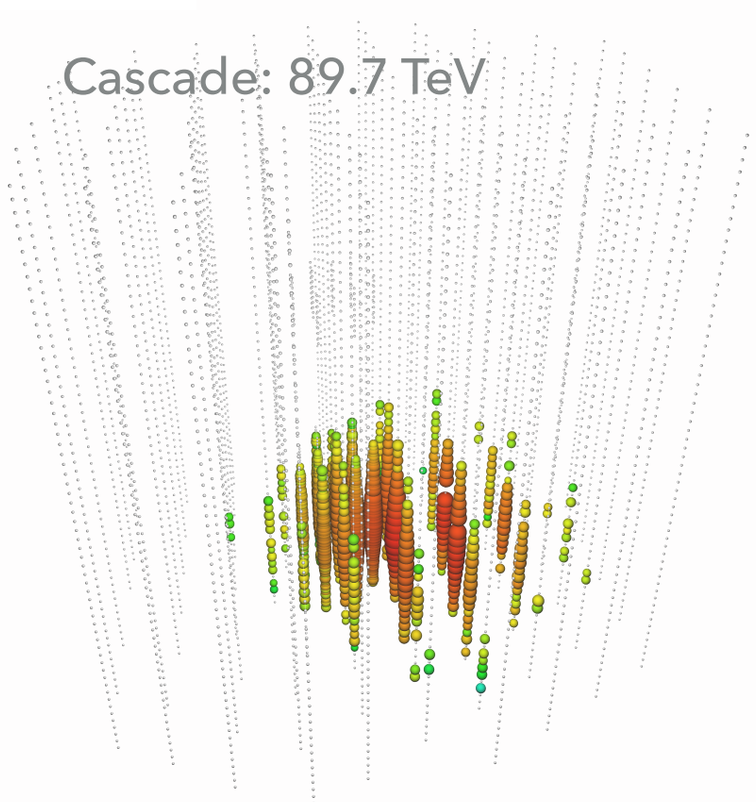
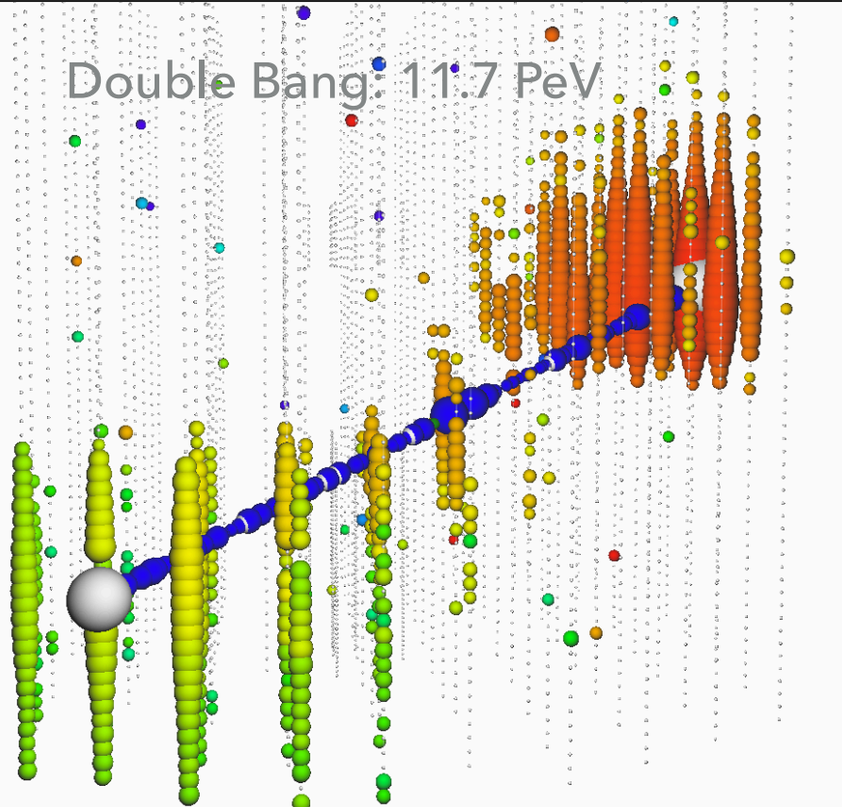


Image: T. Glauch (TUM)

Cascade: 89.7 TeV



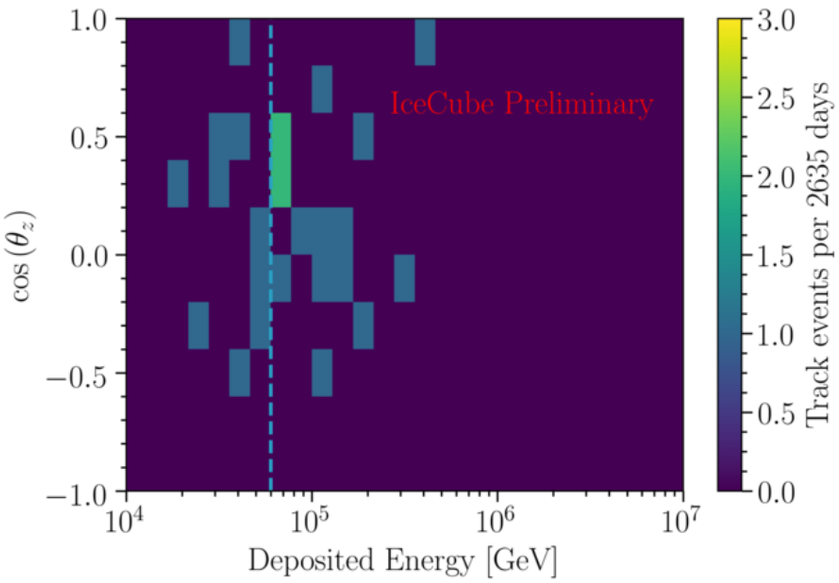
Double Bang: 11.7 PeV



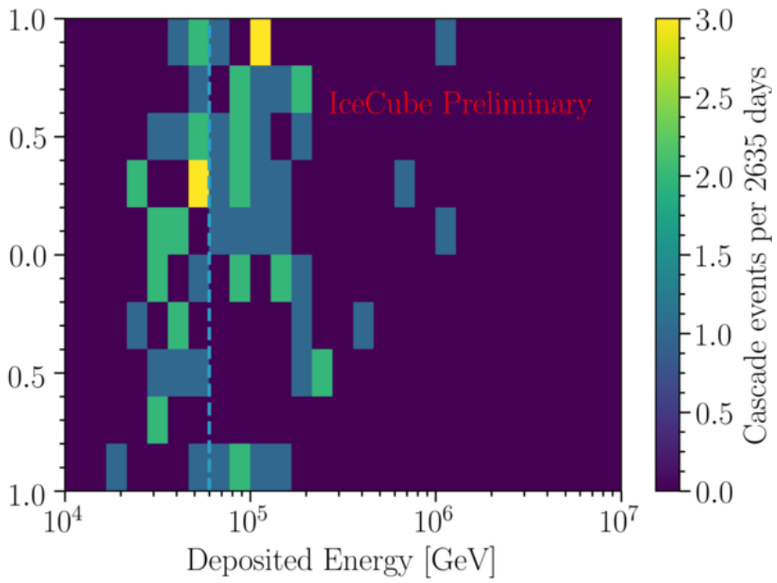
HIGH ENERGY, STARTING EVENTS, ALL FLAVOURS (2635 DAYS)

[IceCube Collaboration, Evidence for High-Energy Extraterrestrial Neutrinos at the IceCube Detector, Science(2013)]

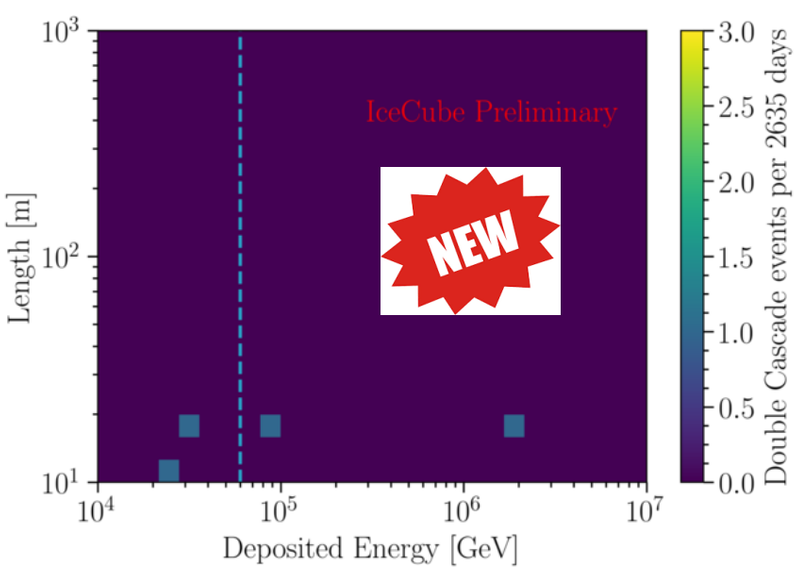
HE Starting Tracks
All energies: 26 events;
E > 60TeV: **16 events**

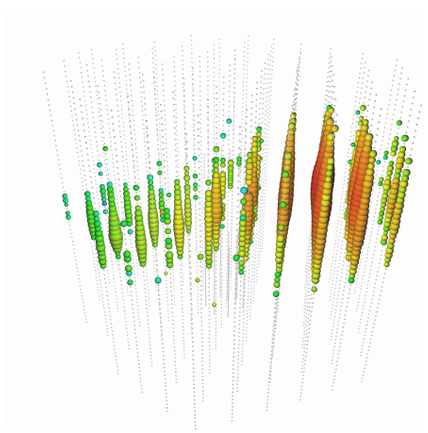


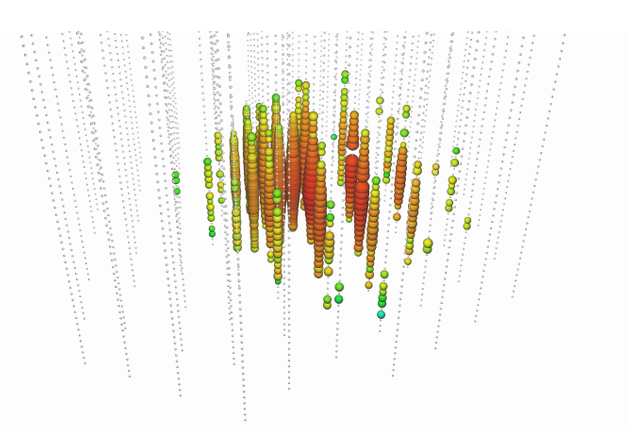
HE Starting Showers
All energies: 72 events;
E > 60TeV: **42 events**

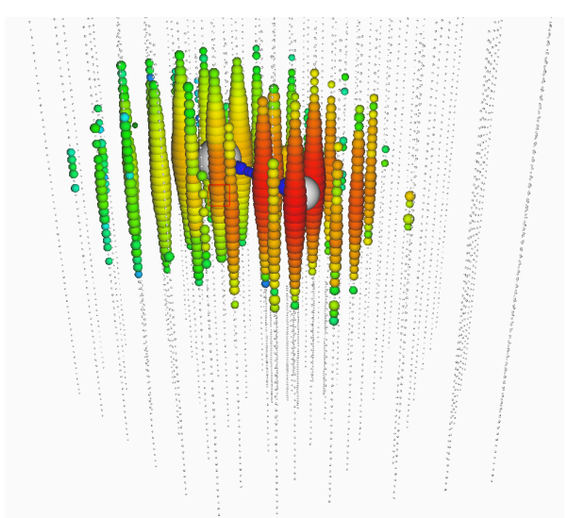


HE Starting Double Showers
All energies: 4 events;
E > 60TeV: **2 events**

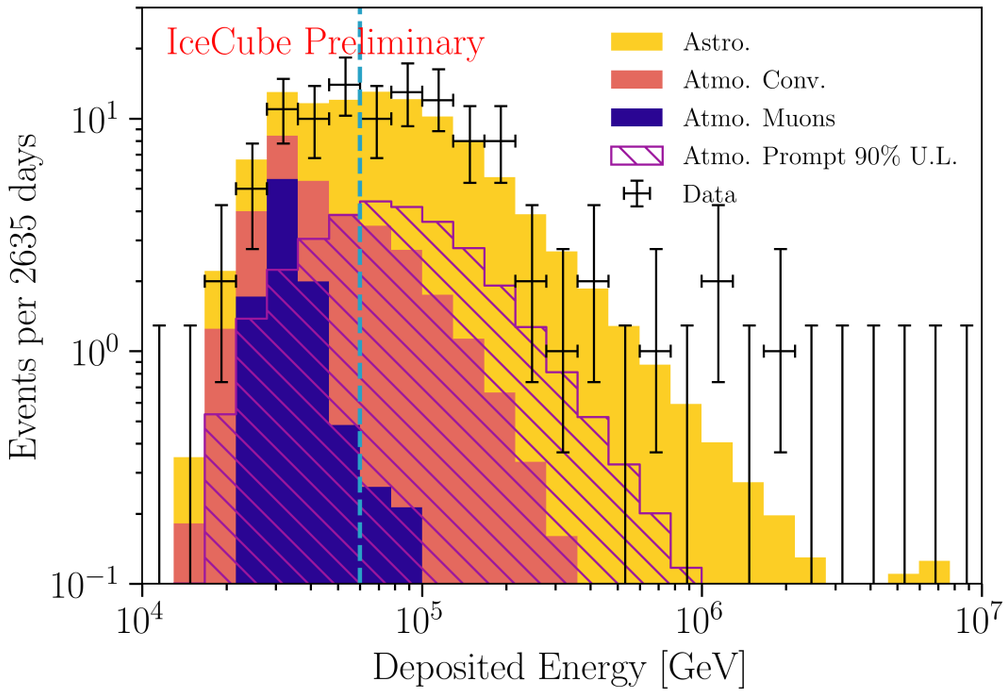


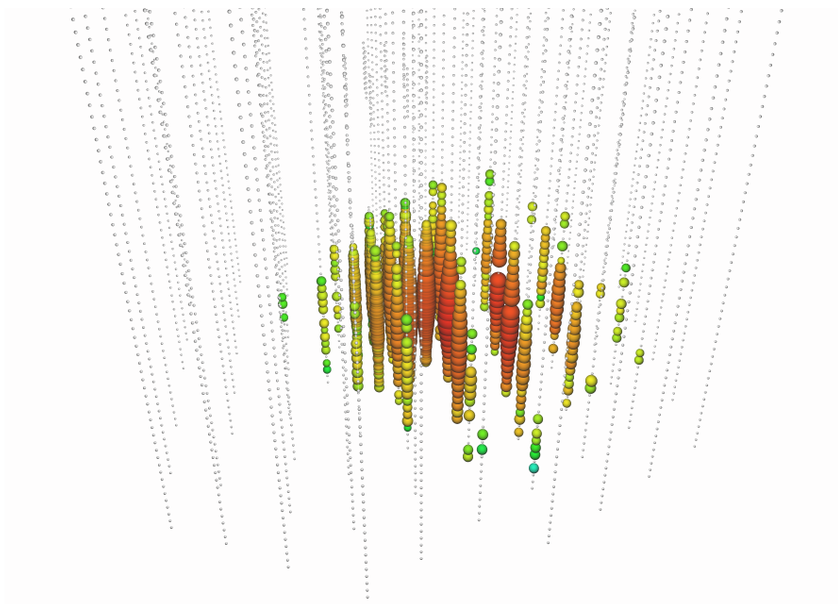


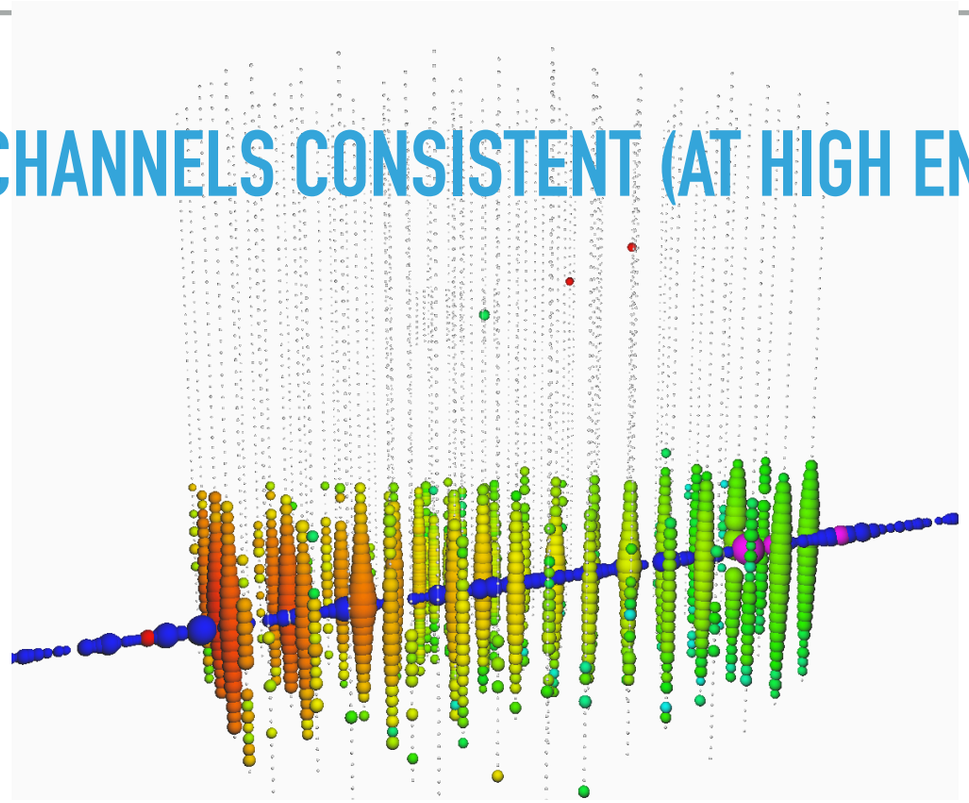


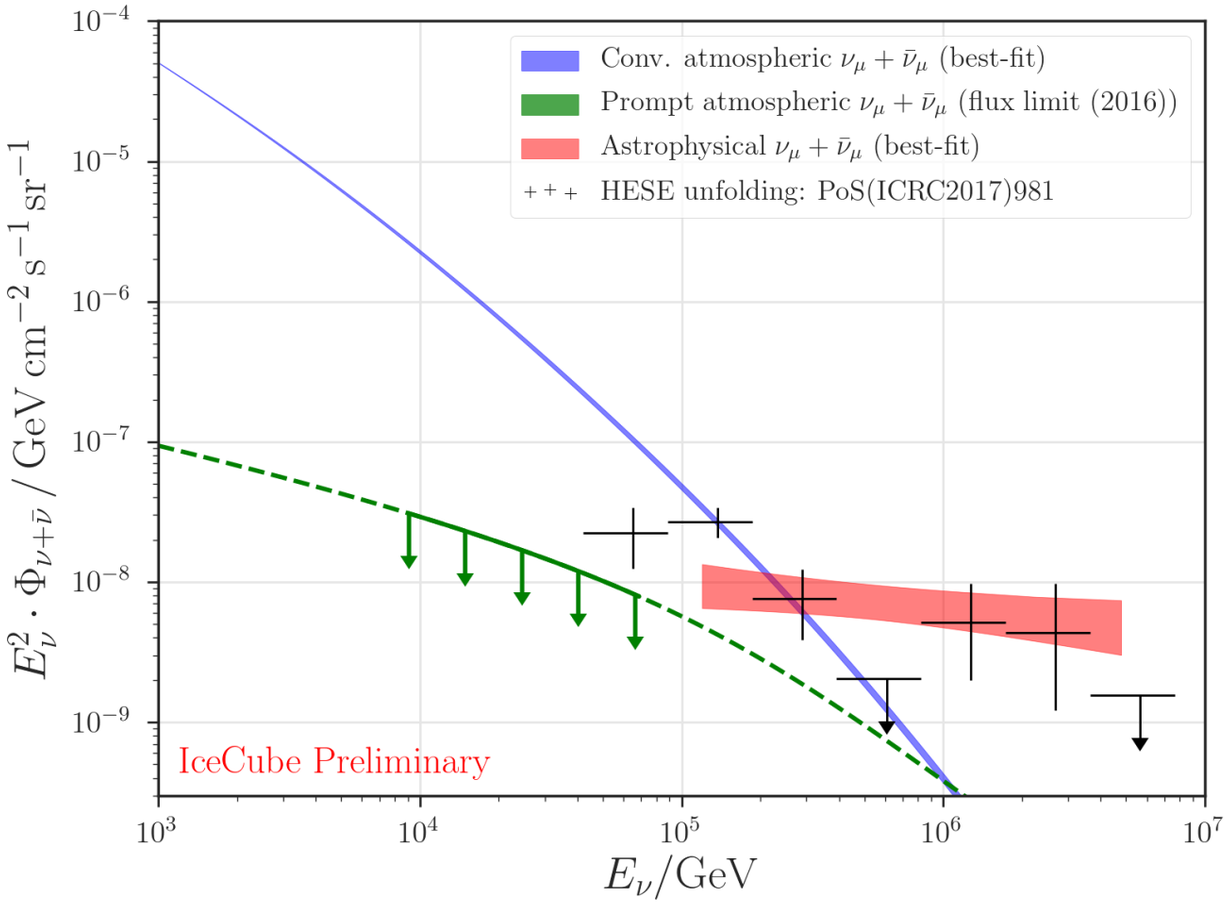


ASTROPHYSICAL DIFFUSE NEUTRINOS: ALL CHANNELS CONSISTENT (AT HIGH ENERGY)



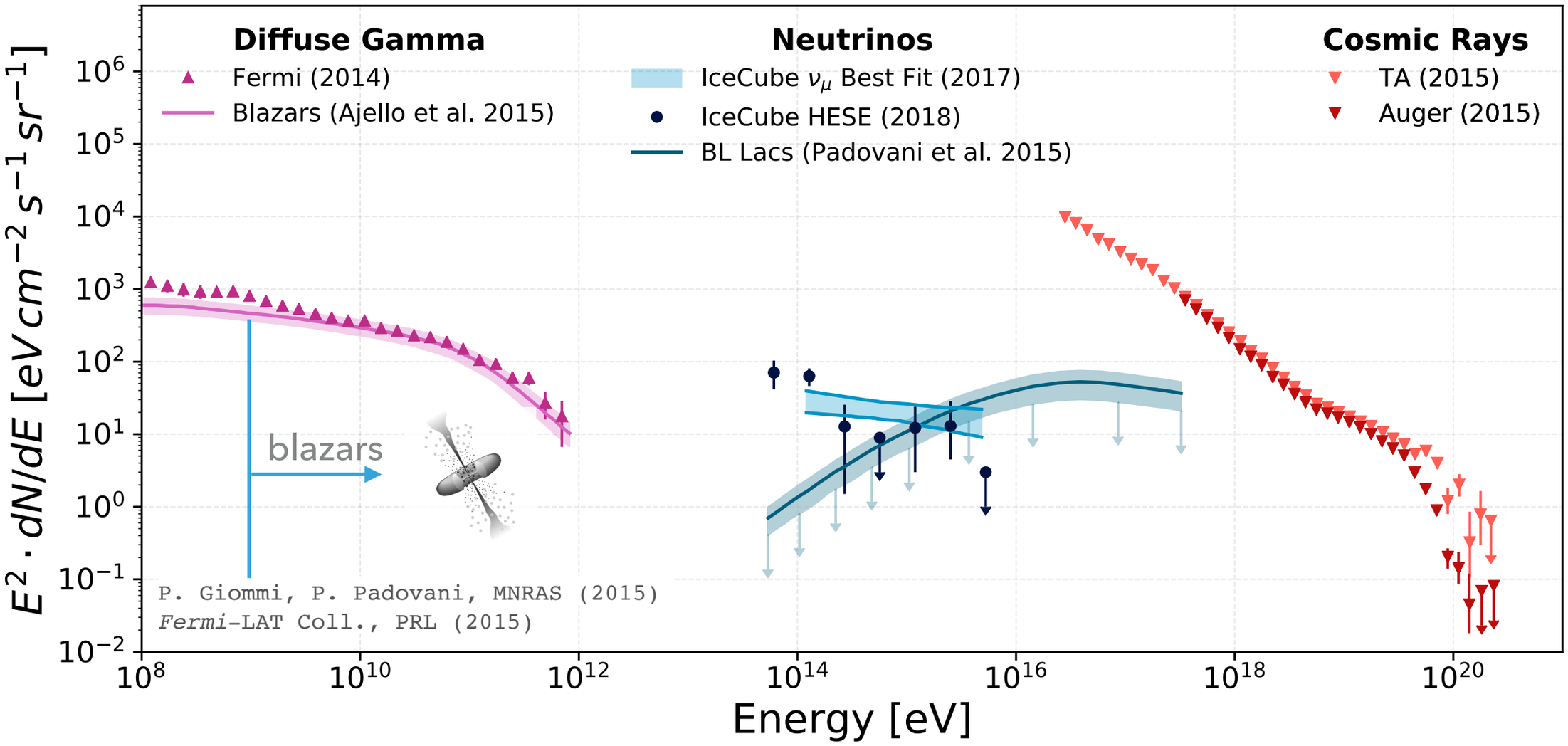






THE MULTI-MESSENGER OBSERVATIONS

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)



E.R., S. Coenders, P. Padovani, P. Giommi, L. Caccianiga, MNRAS (2017)

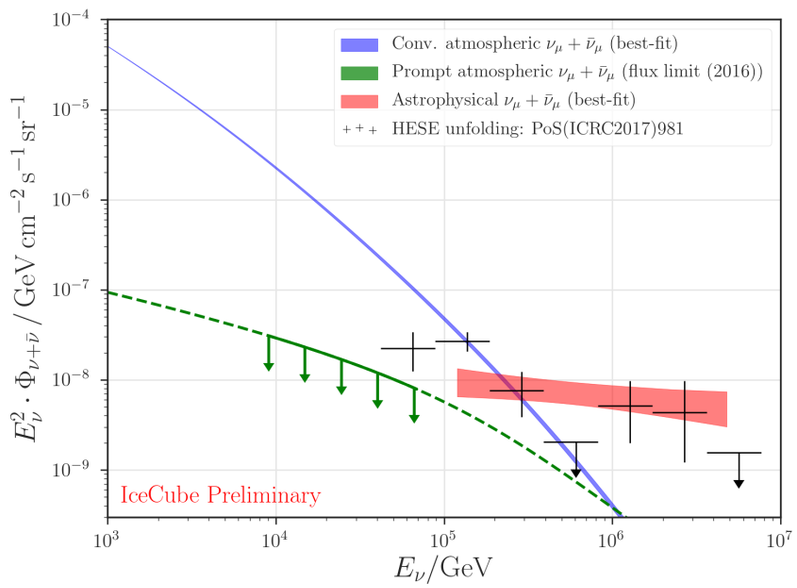
STACKING OF BLAZARS

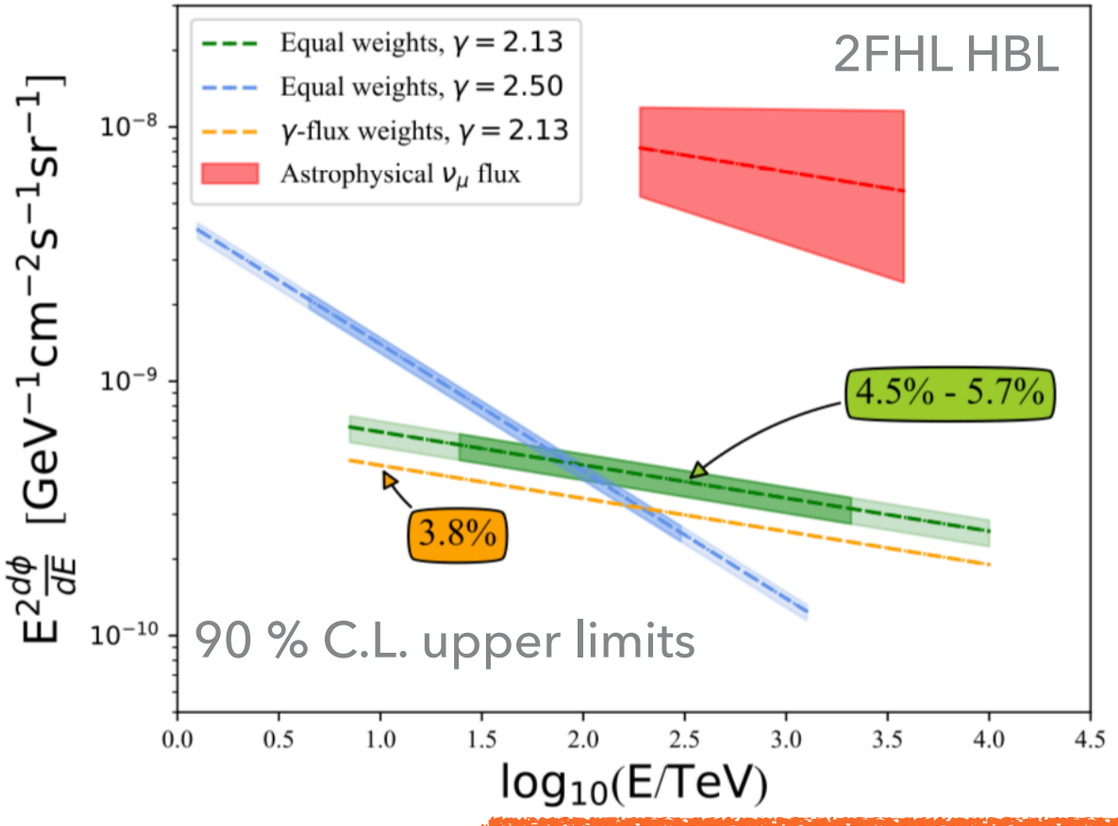
The IceCube Collaboration, Astrophys.J. 835 (2017) no.1, 45

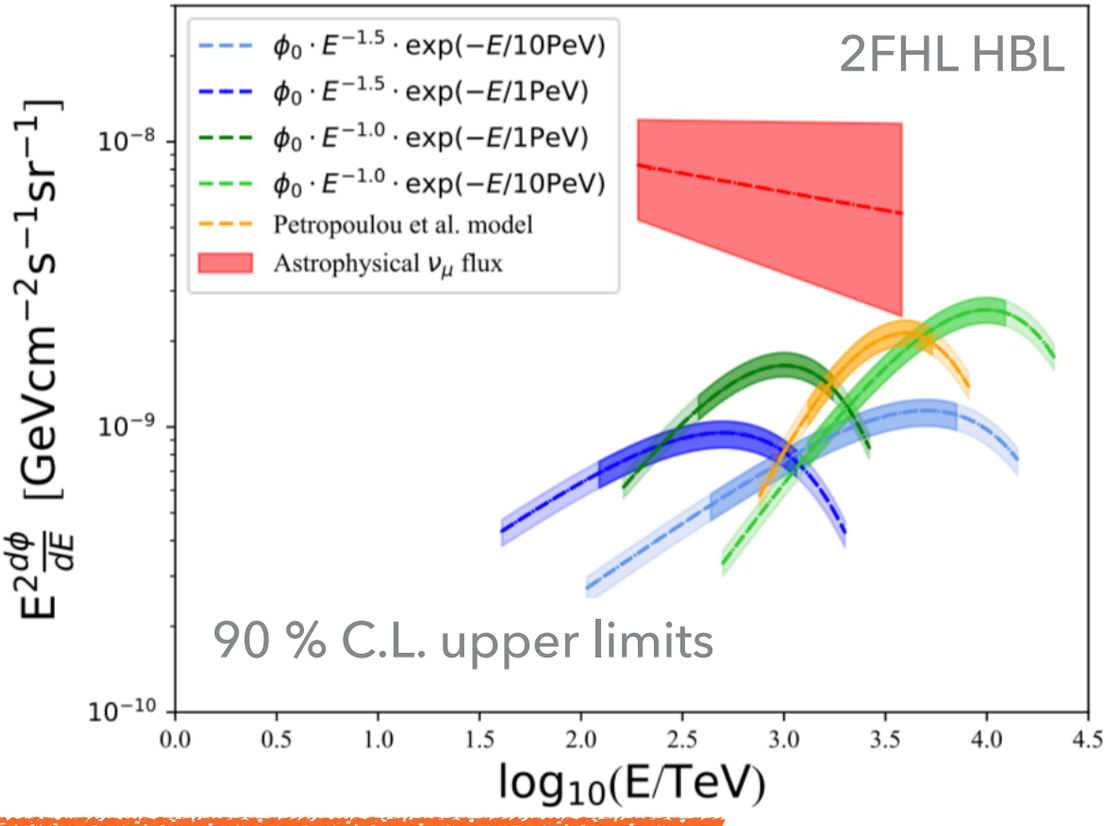
2LAC

The IceCube Coll., ICRC'17, M. Huber et al., https://pos.sissa.it/301/994/pdf

2WHSP 2FHL HBLS 3LAC FSRQS







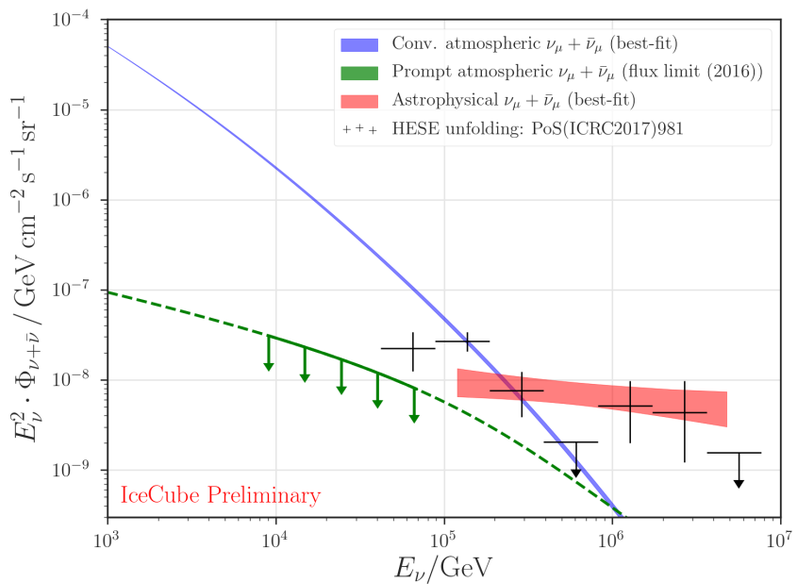
Different assumptions on the spectral shape of the blazars.

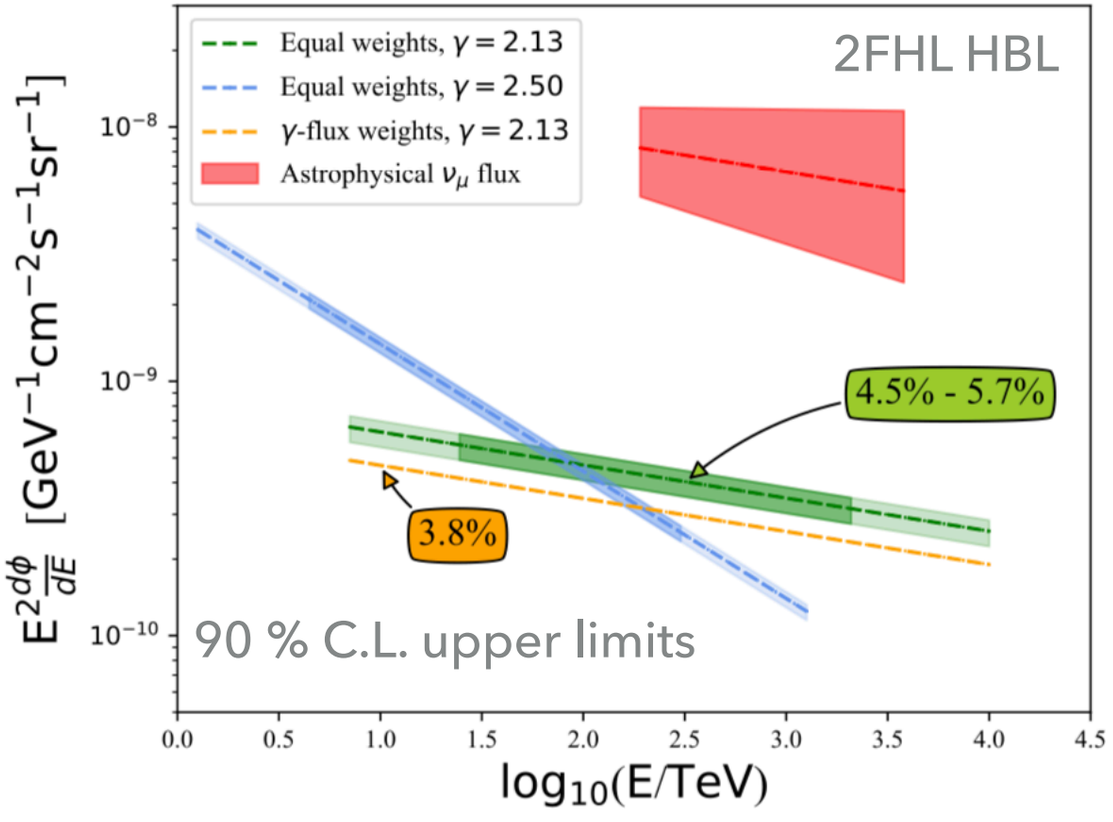
STACKING OF BLAZARS

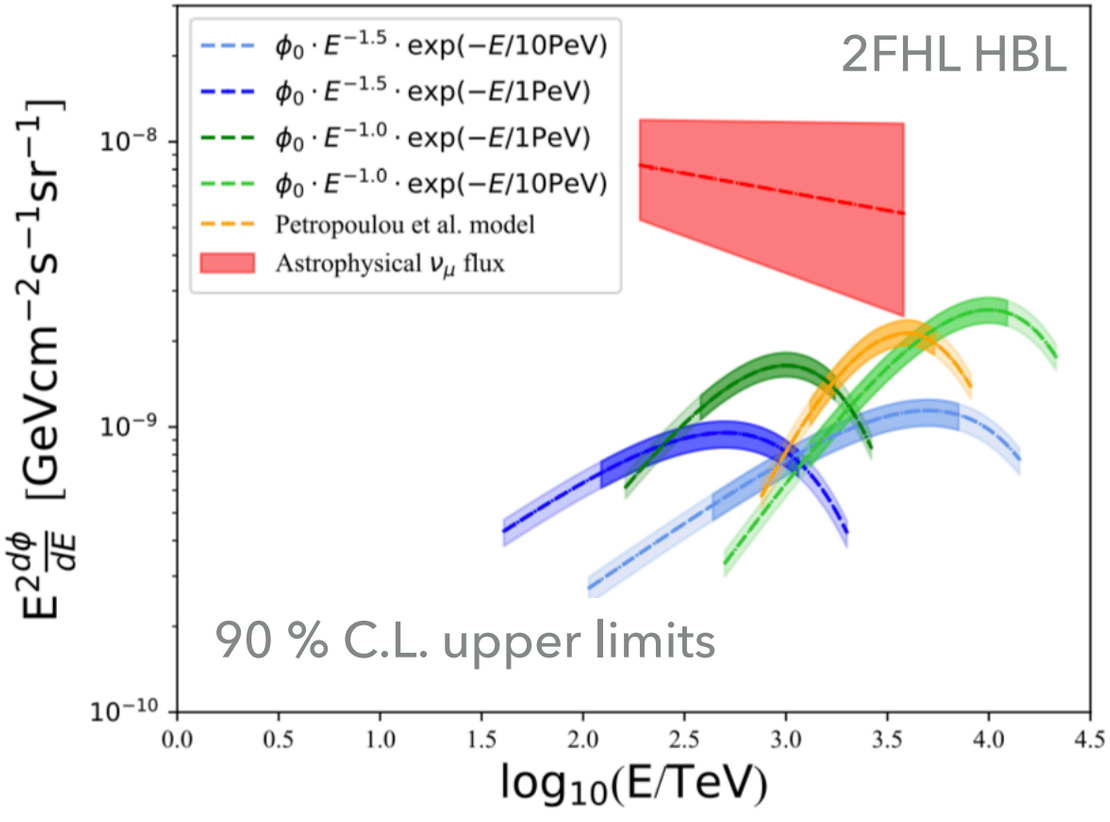
The IceCube Coll., ICRC'17, M. Huber et al., https://pos.sissa.it/301/994/pdf

2WHSP | 2FHL HBLS | 3LAC FSRQS

No detection => Blazars sources could still explain up to **~30 %** of the diffuse flux within certain energy ranges.



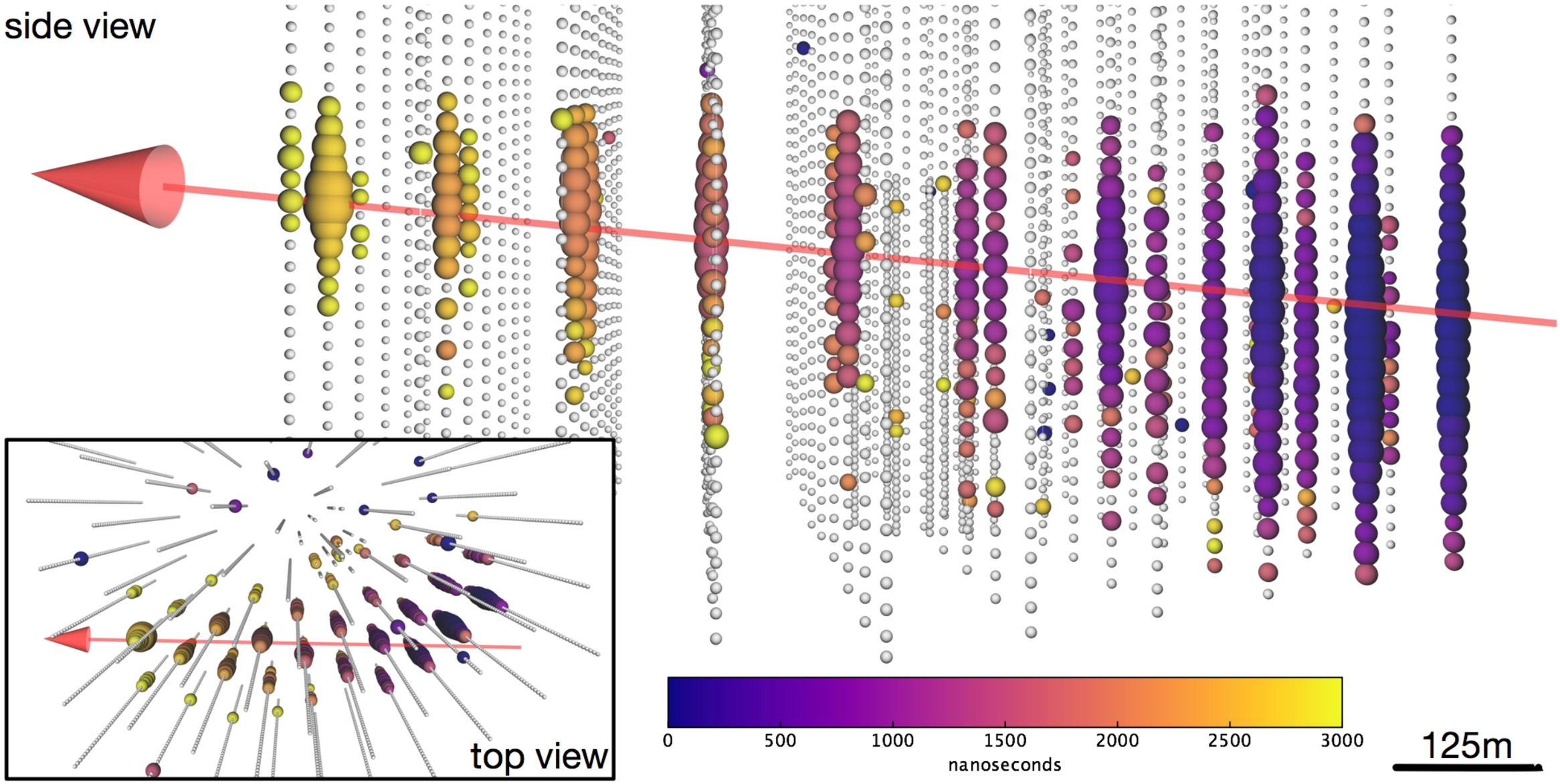




Different assumptions on the spectral shape of the blazars.

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



ICECUBE-170922A: THERE IS A COUNTERPART – A BLAZAR

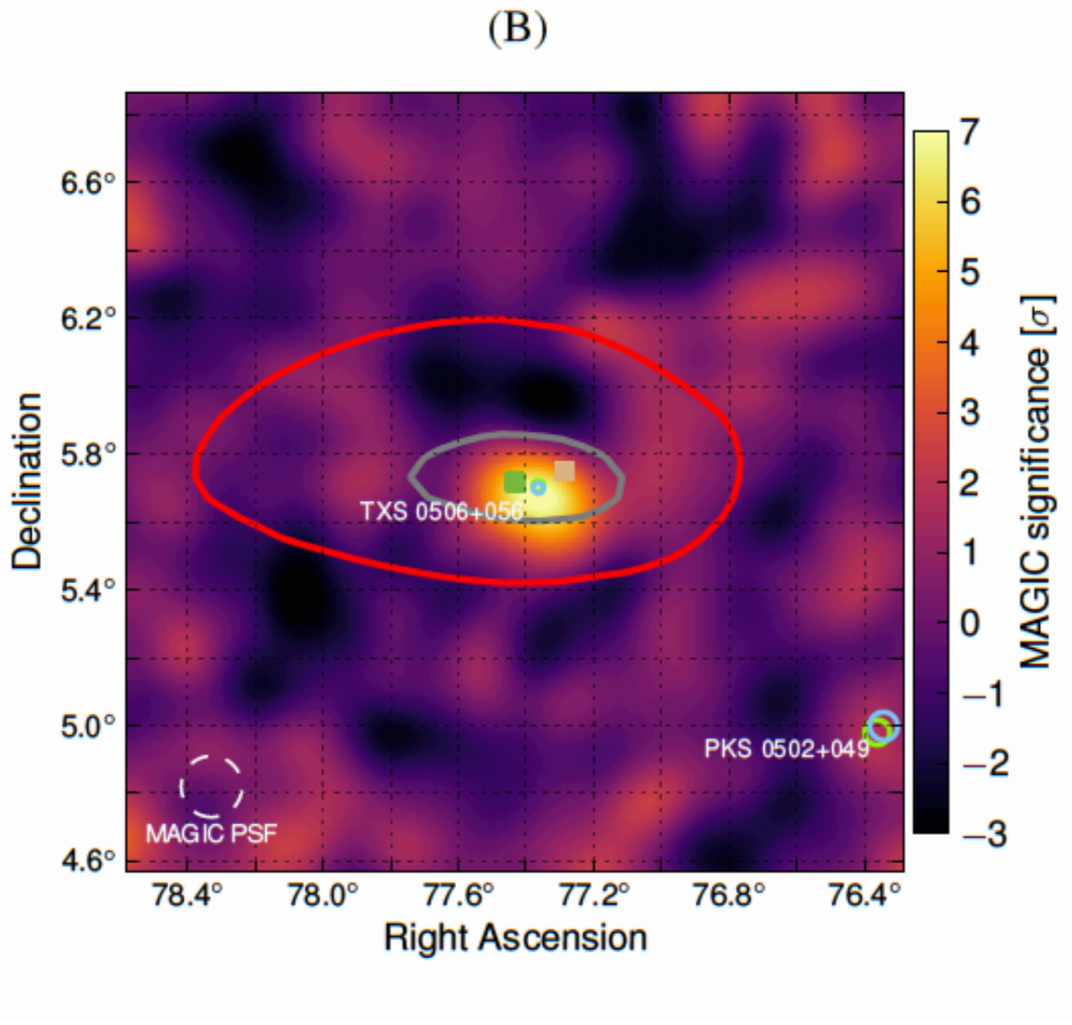
"Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A," The IceCube, Fermi-LAT, MAGIC, AGILE, ASAS-SN, HAWC, H.E.S.S, INTEGRAL, Kanata, Kiso, Kapteyn, Liverpool telescope, Subaru, Swift/NuSTAR, VERITAS, and VLA/17B-403 teams. *Science* 361, 2018

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**

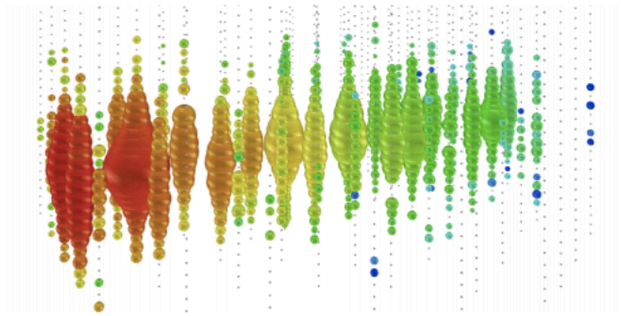
....and observations and reports by many more telescopes: AGILE, ASAS-SN, Kapteyn, Kanata, Kiso, Liverpool, Subaru, VERITAS, VLT



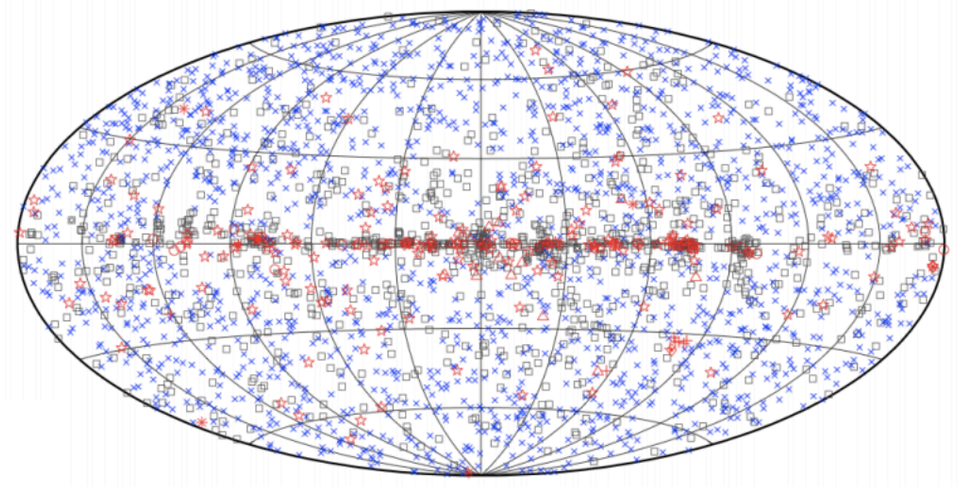
ICECUBE-170922A VS TXS 0506+056: RANDOM COINCIDENCE?

"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

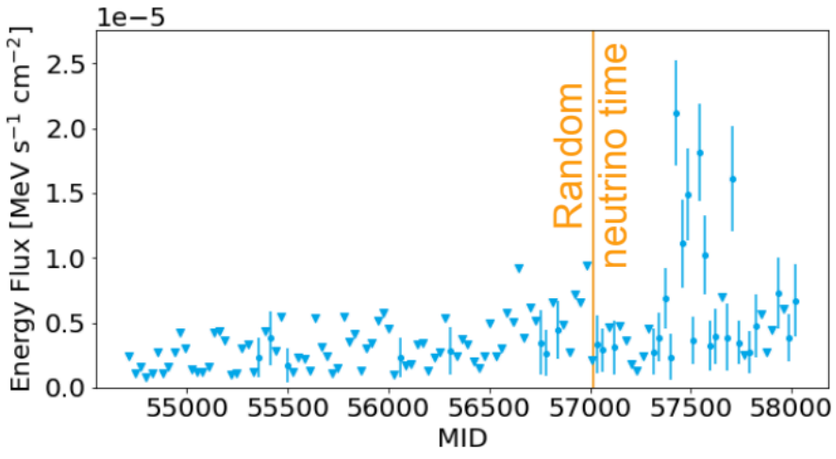
Excluded with 99.73%CL



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



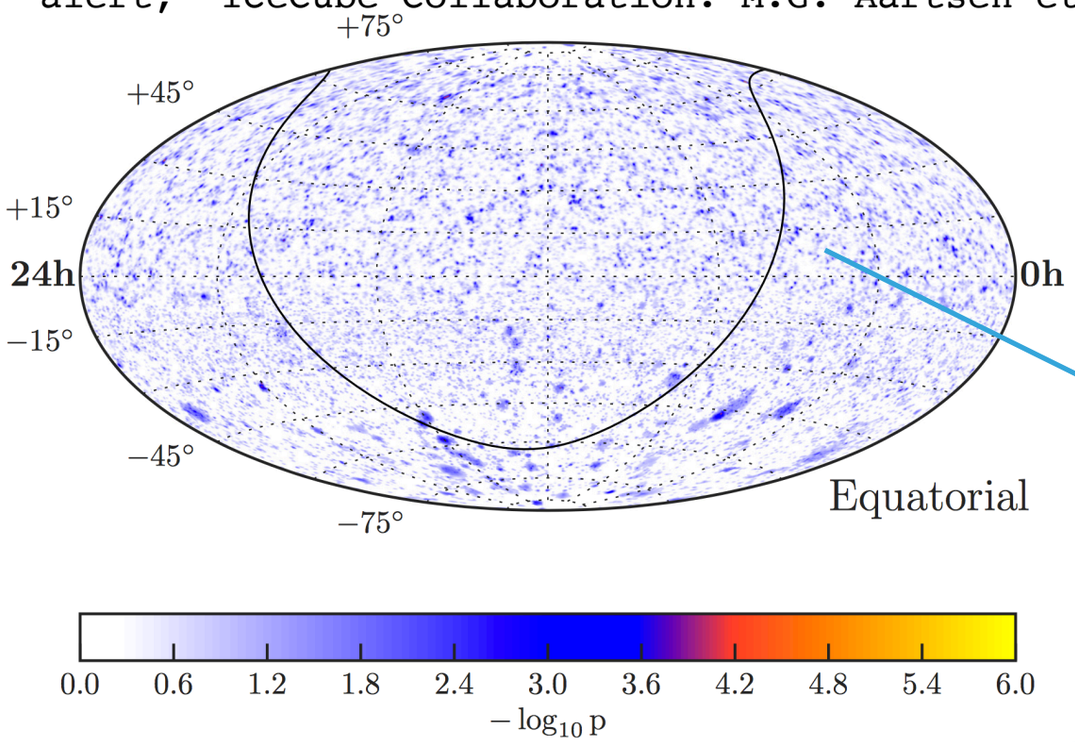
Step II: Are there any extra-galactic Fermi source close in space to the neutrinos?

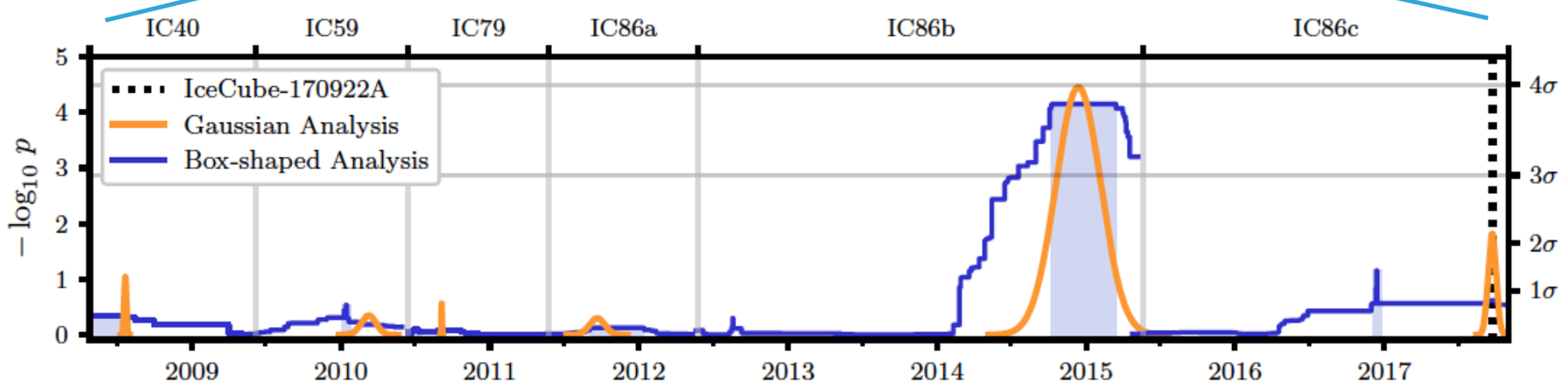


Step III: What is the gamma-ray energy flux in the time bin when the neutrino arrives?

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).

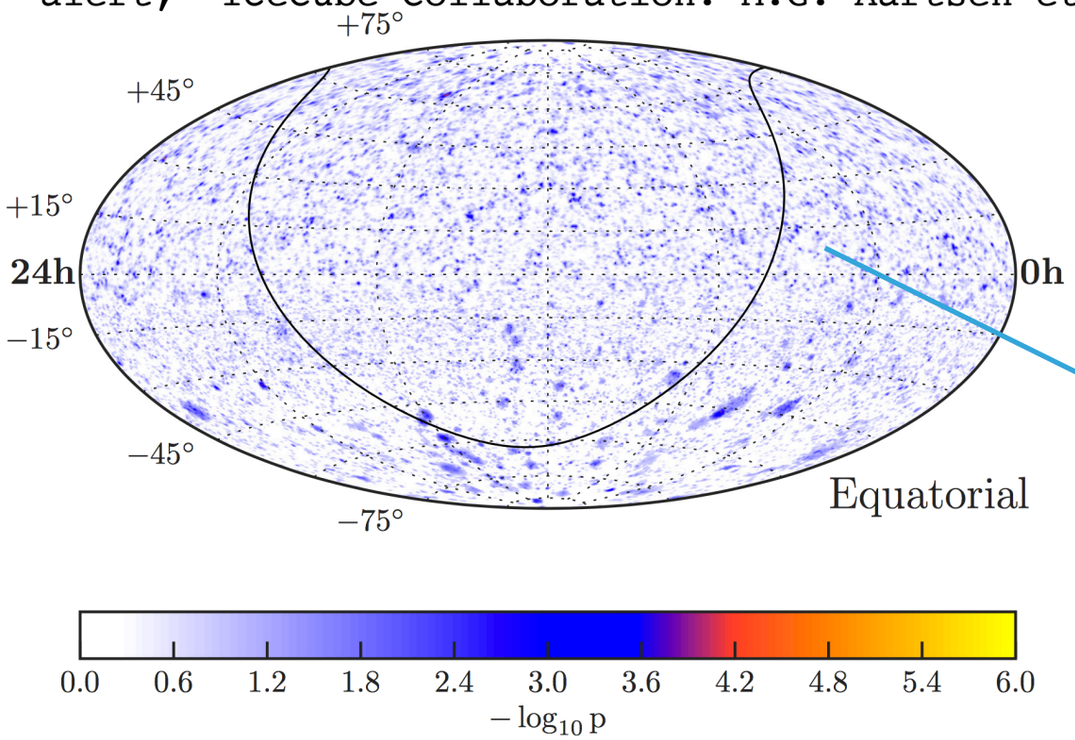


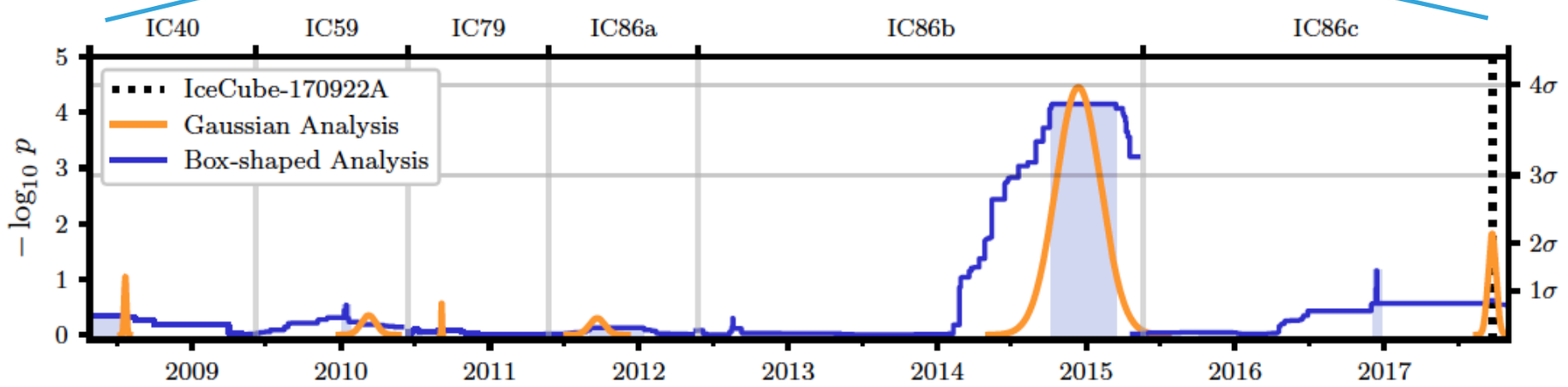


THE ICECUBE FOLLOWUP: BACKGROUND FLUCTUATION?

"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).

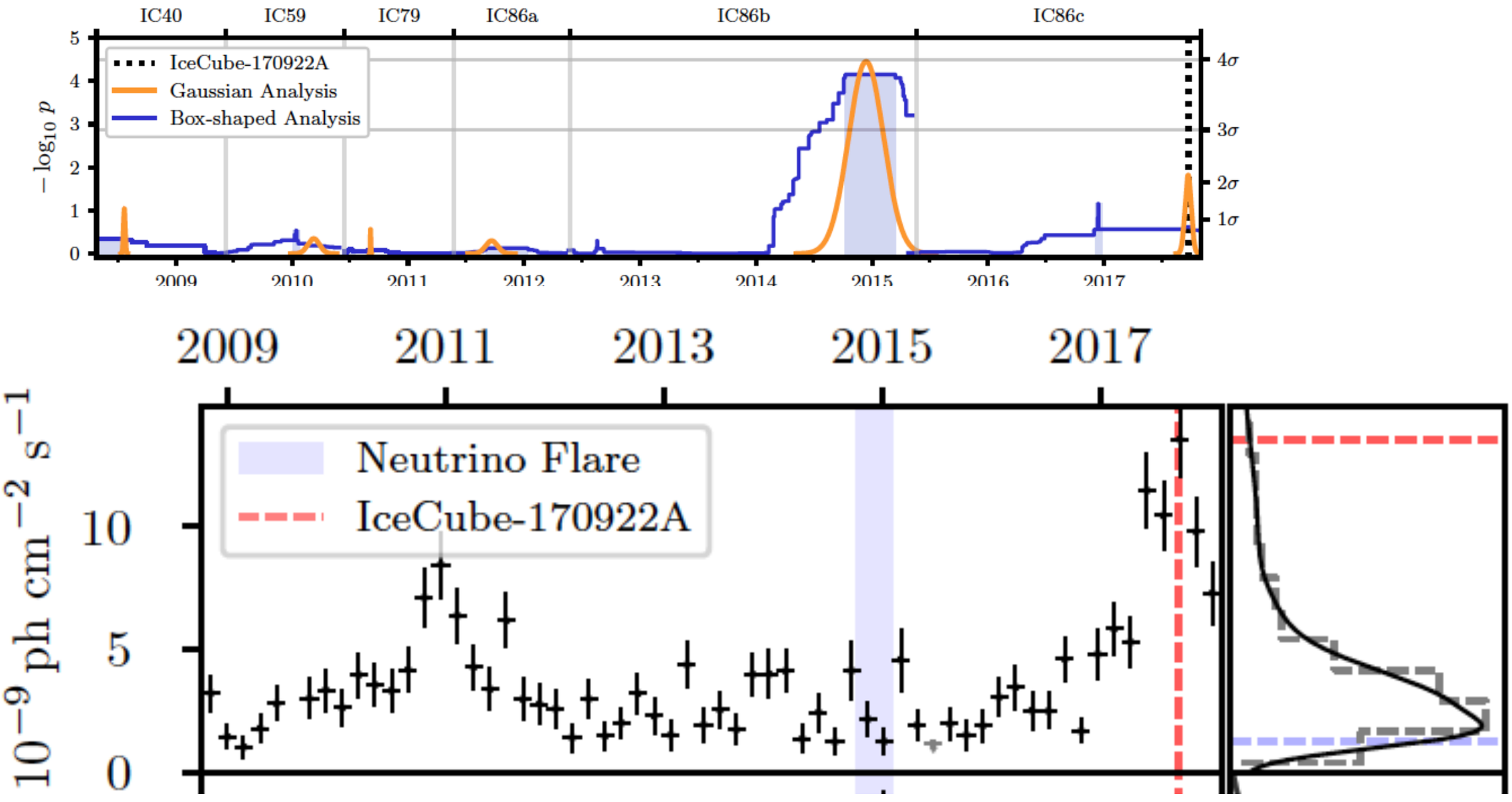
Excluded with 99.95% CL



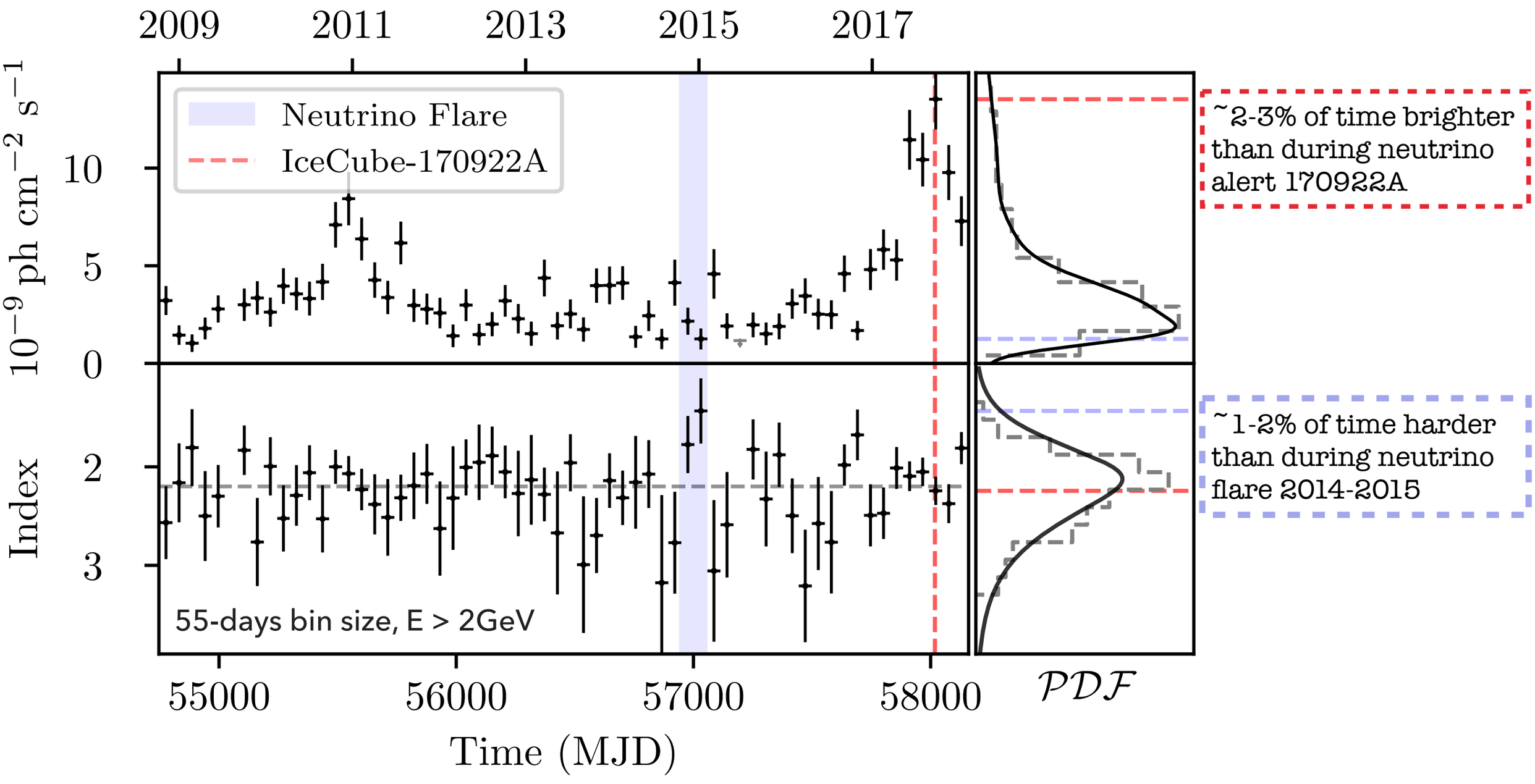


THE ICECUBE FOLLOWUP: WHAT ABOUT THE GAMMA-RAY?

"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).



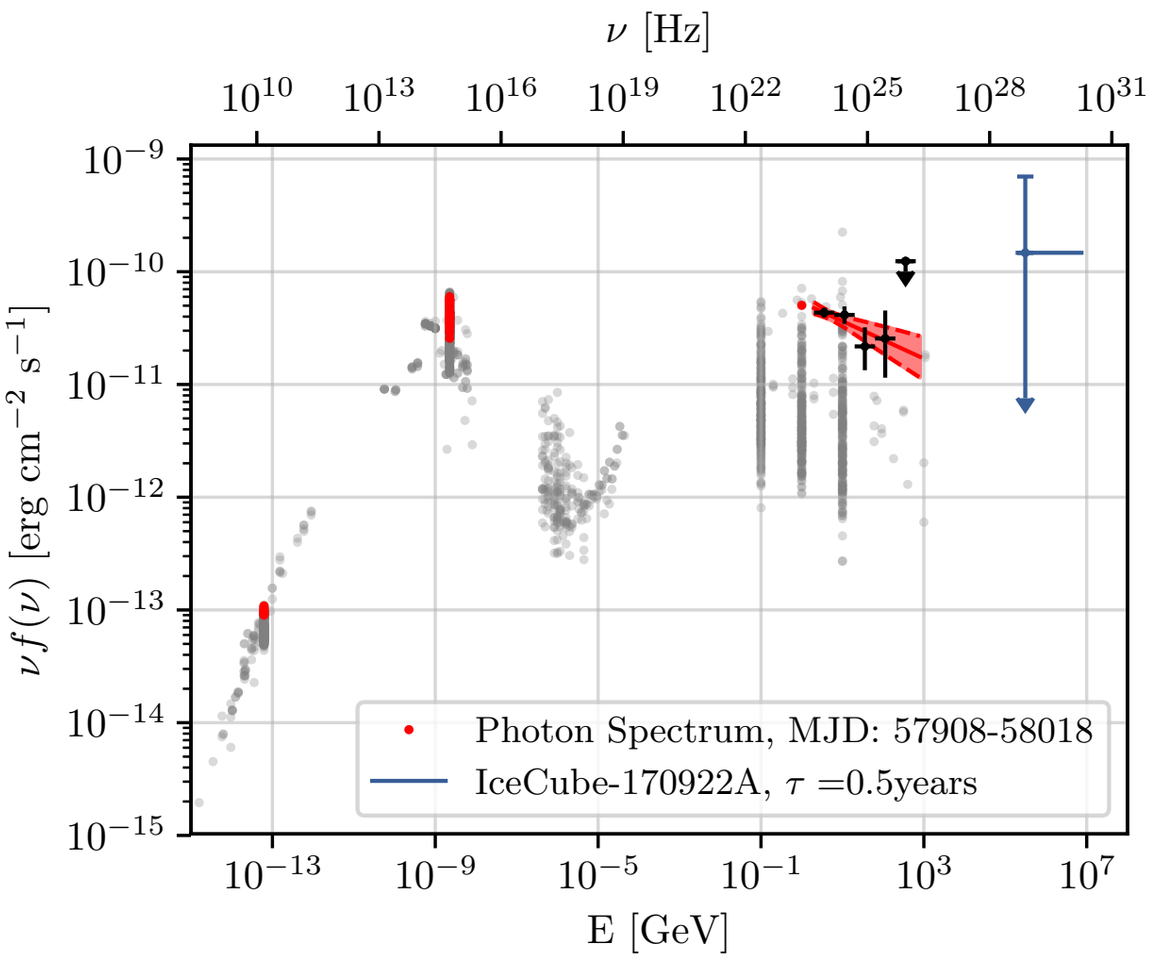
GAMMA-RAY LIGHT CURVES: TXS 0506+056



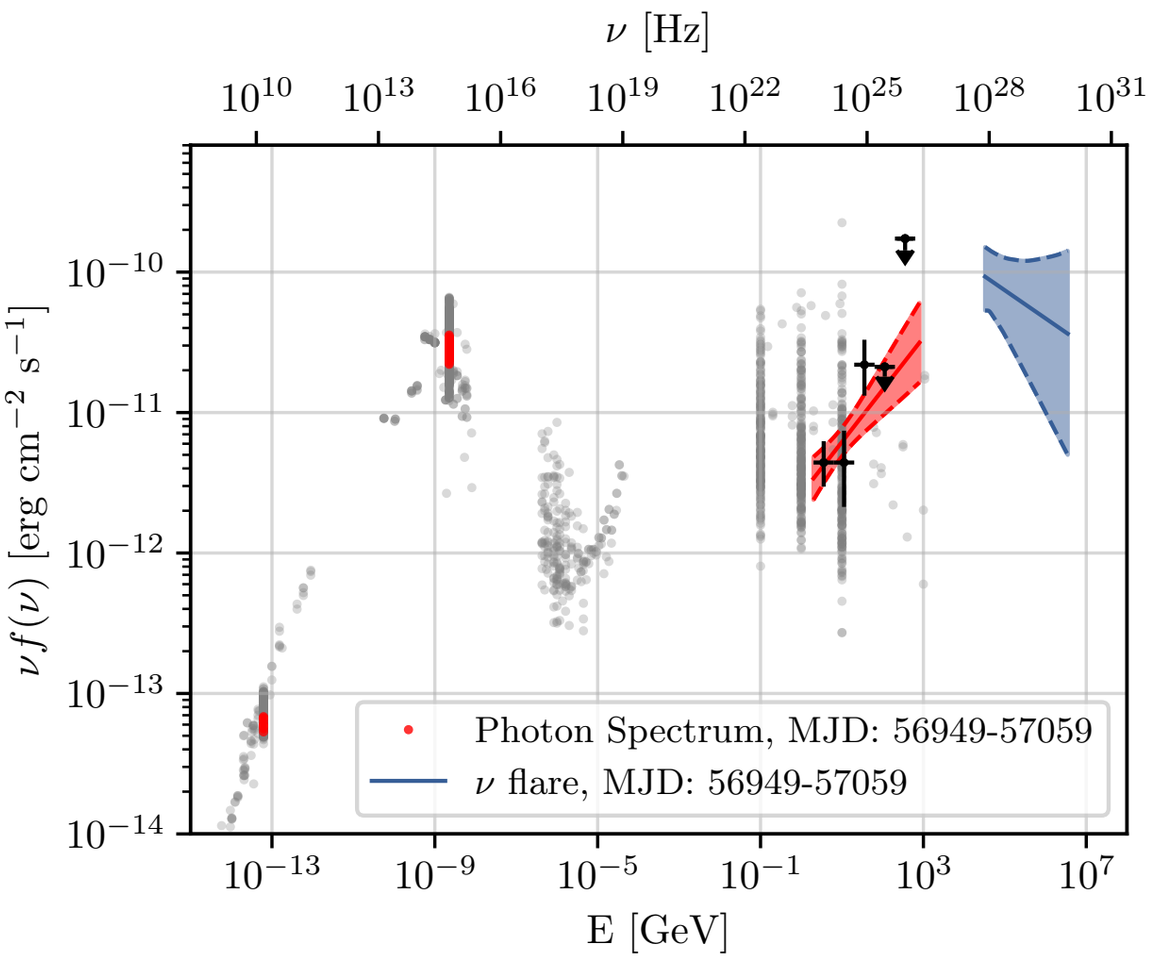
THE PHOTON – NEUTRINO SPECTRAL ENERGY DISTRIBUTION OF TXS 0506+056

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

Neutrino alert 179022A

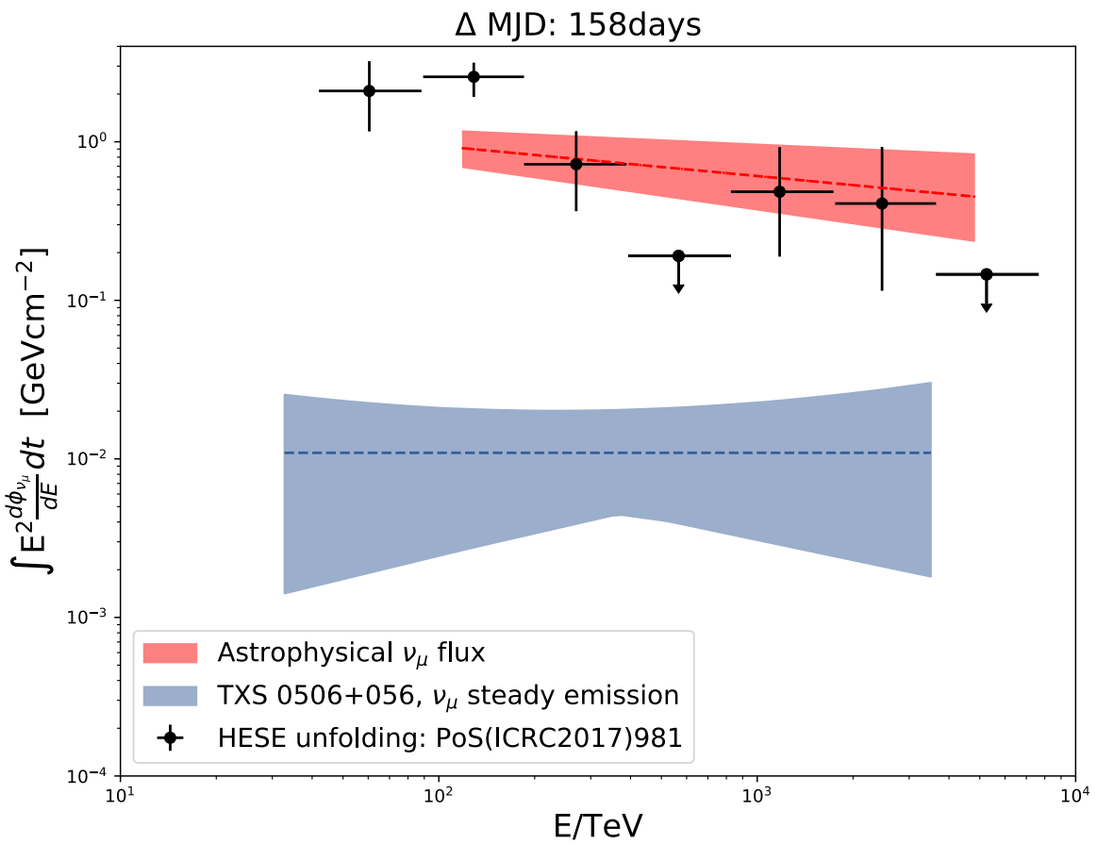


Neutrino 'flare, 2014-2015



IF TXS 05060+056 NEUTRINO SOURCE, WHAT IS ITS CONTRIBUTION?

Transient assumption



Steady assumption

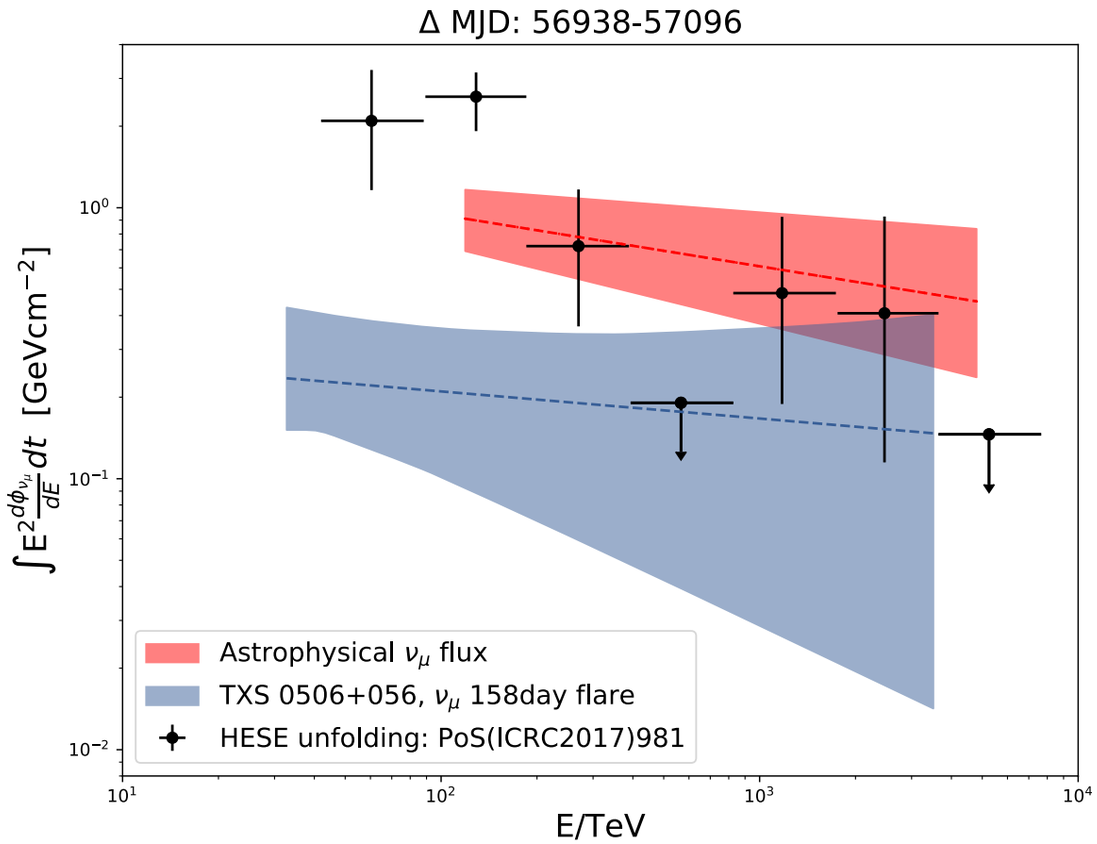
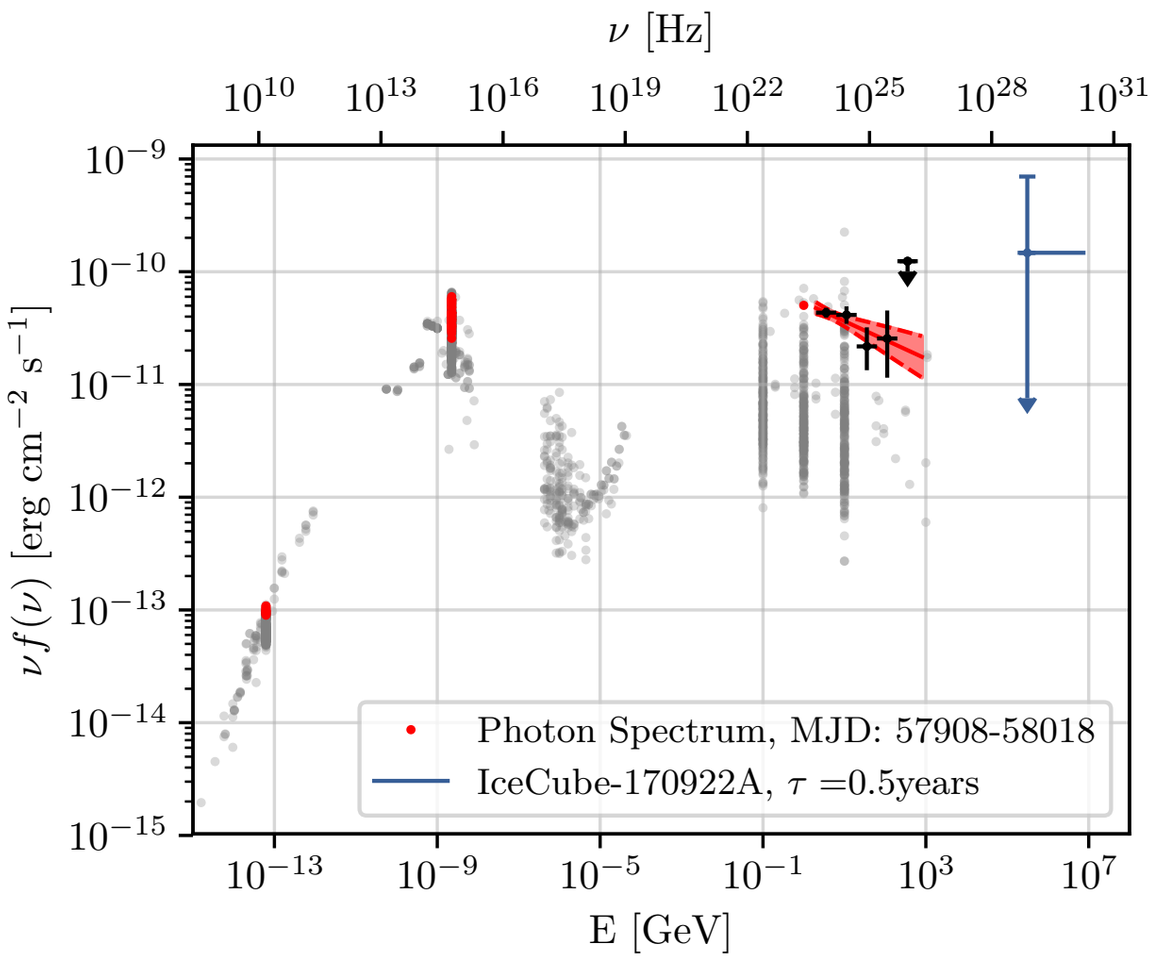


Image: M. Huber (TUM)

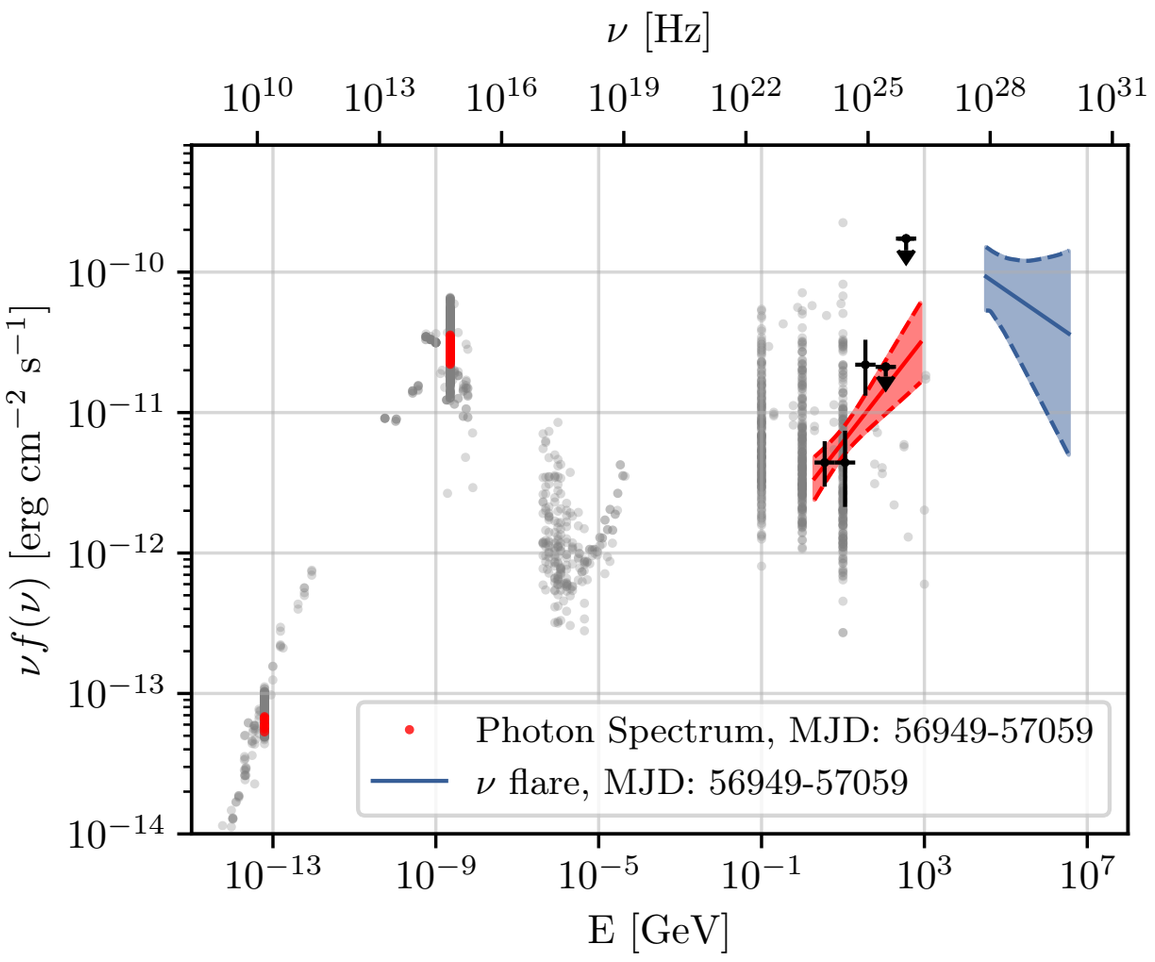
THE PHOTON – NEUTRINO SPECTRAL ENERGY DISTRIBUTION OF TXS 0506+056

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

Neutrino alert 179022A



Neutrino 'flare, 2014-2015



Compelling evidence of first HE neutrino sources

... limited by too few photons and too few neutrinos

IN SUMMARY

Neutrinos in IceCube are opening a new window into the cosmos:

- Diffuse cosmic neutrinos - two independent channels
- First double shower events
- First Glashow resonance candidate event
- Compelling evidence for the first non-stellar neutrino source: a blazar

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http://neutrino.pd.infn.it/NeutrinoTelescopes2019.html.

"NEUTRINO TELESCOPES" CONFERENCE, VENEZIA, MARCH 2019.

cta cherenkov telescope array

ICECUBE-240119A

```
TITLE:          GCN/AMON NOTICE
NOTICE_DATE:     Thu 24 Jan 19 03:44:35 UT
NOTICE_TYPE:     AMON ICECUBE HESE
RUN_NUM:        132077
EVENT_NUM:       9759013
SRC_RA:         307.1920d {+20h 28m 46s} (J2000),
                307.4895d {+20h 29m 57s} (current),
                306.4101d {+20h 25m 38s} (1950)
SRC_DEC:        -32.2914d {-32d 17' 28"} (J2000),
                -32.2270d {-32d 13' 36"} (current),
                -32.4582d {-32d 27' 28"} (1950)
SRC_ERROR:       73.79 [arcmin radius, stat+sys, 90% containment]
SRC_ERROR50:     25.19 [arcmin radius, stat+sys, 50% containment]
DISCOVERY_DATE:   18507 TJD;    24 DOY;   19/01/24 (yy/mm/dd)
DISCOVERY_TIME:   13434 SOD {03:43:54.79} UT
REVISION:        0
N_EVENTS:         1 [number of neutrinos]
STREAM:          1
DELTA_T:         0.0000 [sec]
SIGMA_T:         0.0000 [sec]
FALSE_POS:       0.0000e+00 [s^-1 sr^-1]
PVALUE:          0.0000e+00 [dn]
CHARGE:          13555.75 [pe]
SIGNAL_TRACKNESS: 0.91 [dn]
SUN_POSTN:       306.17d {+20h 24m 40s}  -19.29d {-19d 17' 15"}
SUN_DIST:        12.99 [deg]   Sun_angle= -0.1 [hr] (East of Sun)
MOON_POSTN:      167.71d {+11h 10m 51s}   +9.45d {+09d 26' 47"}
MOON_DIST:       136.44 [deg]
GAL_COORDS:       10.59,-33.61 [deg] galactic lon,lat of the event
ECL_COORDS:      301.61,-12.84 [deg] ecliptic lon,lat of the event
COMMENTS:        AMON_ICECUBE_HESE.
```

ANY EXTREME BLAZAR FOUND???

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*

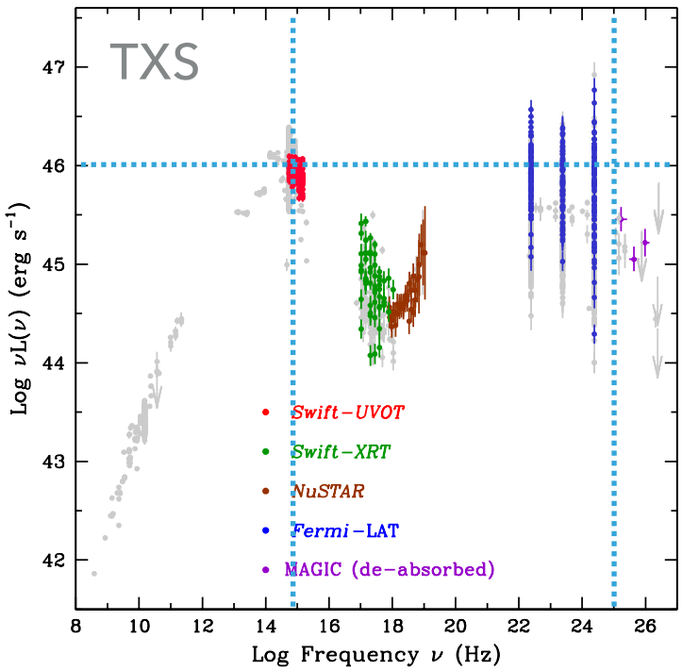
(3) the lack of an accompanying simultaneous gamma-ray enhancement;

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

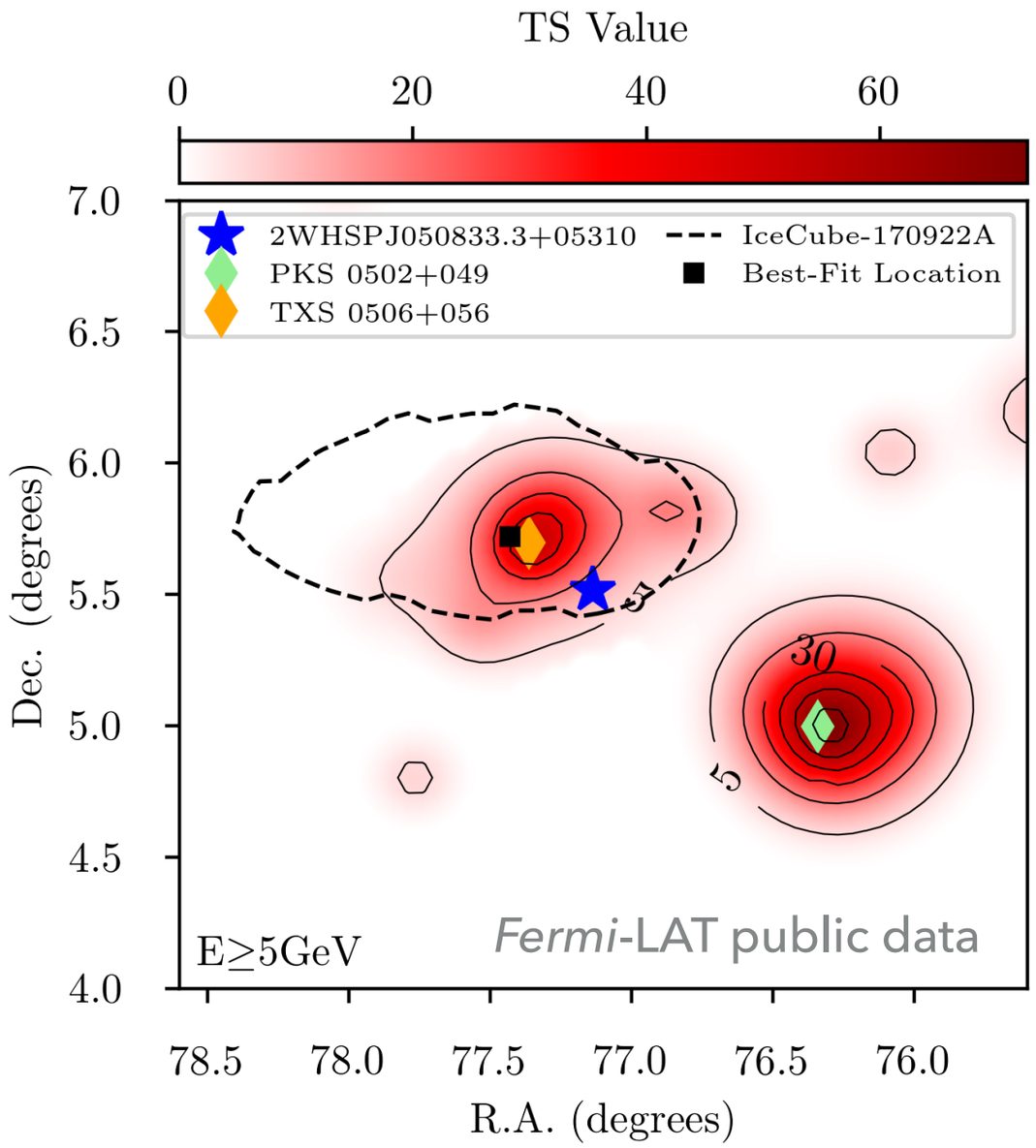
→ *P. Padovani, P. Giommi, E.R., T. Glauch, B. Arsioli, N. Sahakyan, M. Huber, "Dissecting the region around IceCube-170922A: TXS 0506+056 as the first cosmic neutrino source", MNRAS 2018*

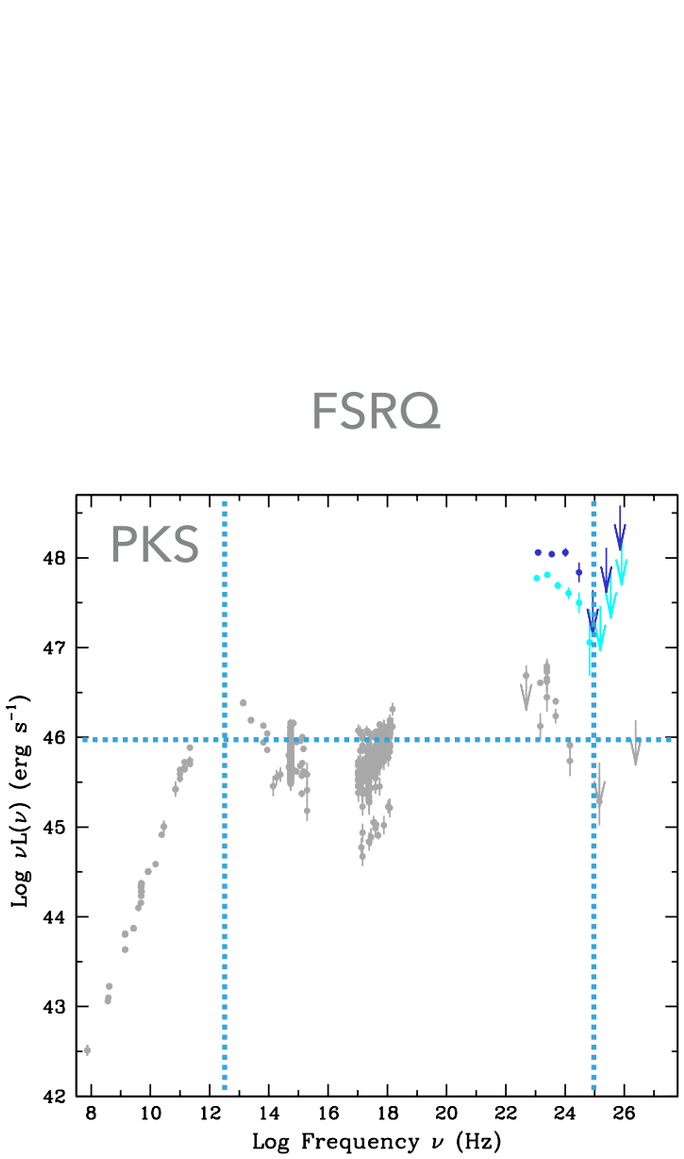
GAMMA-RAY EMISSION NEAR ICECUBE-170922A: TXS AND PKS

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



ISP/HSP BL Lac

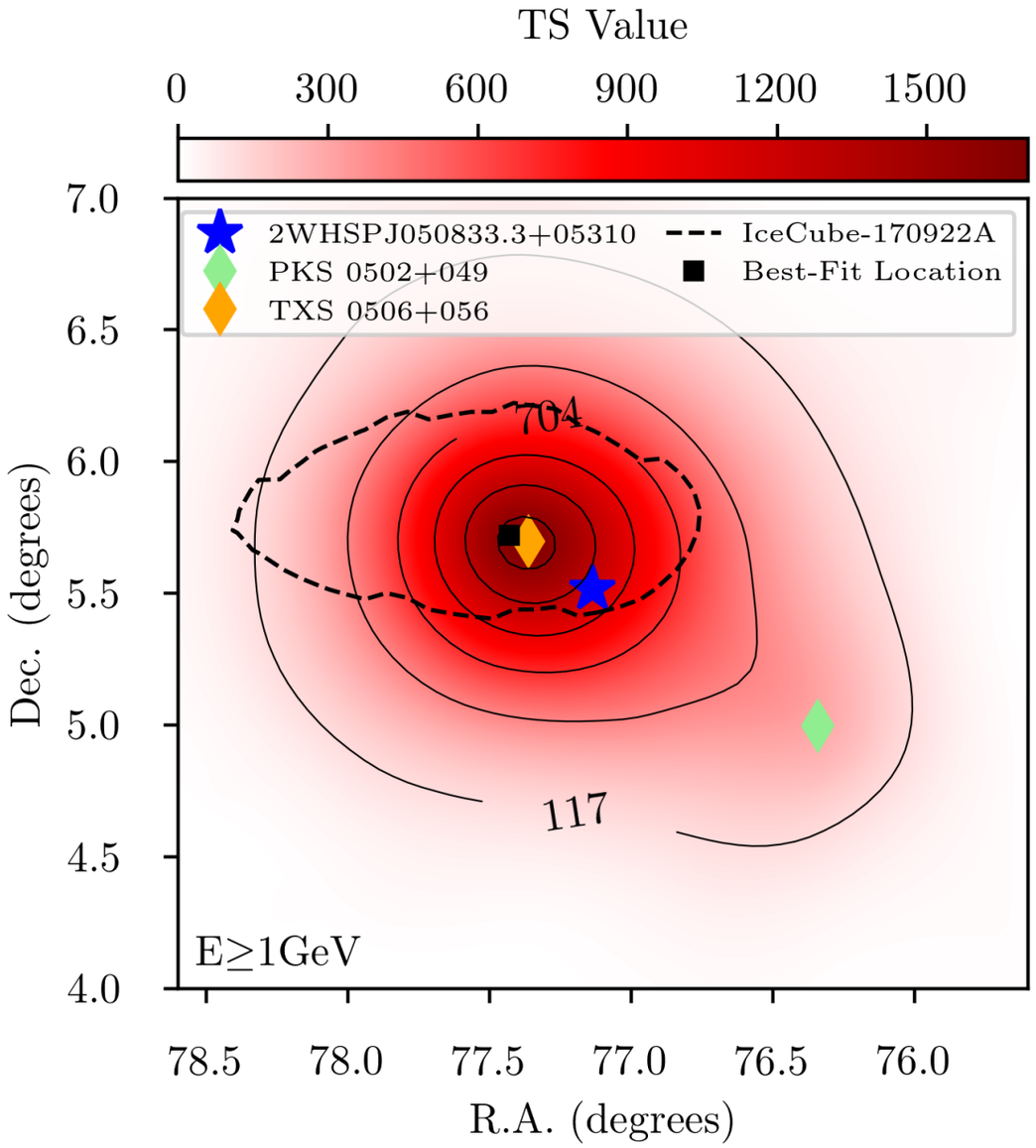


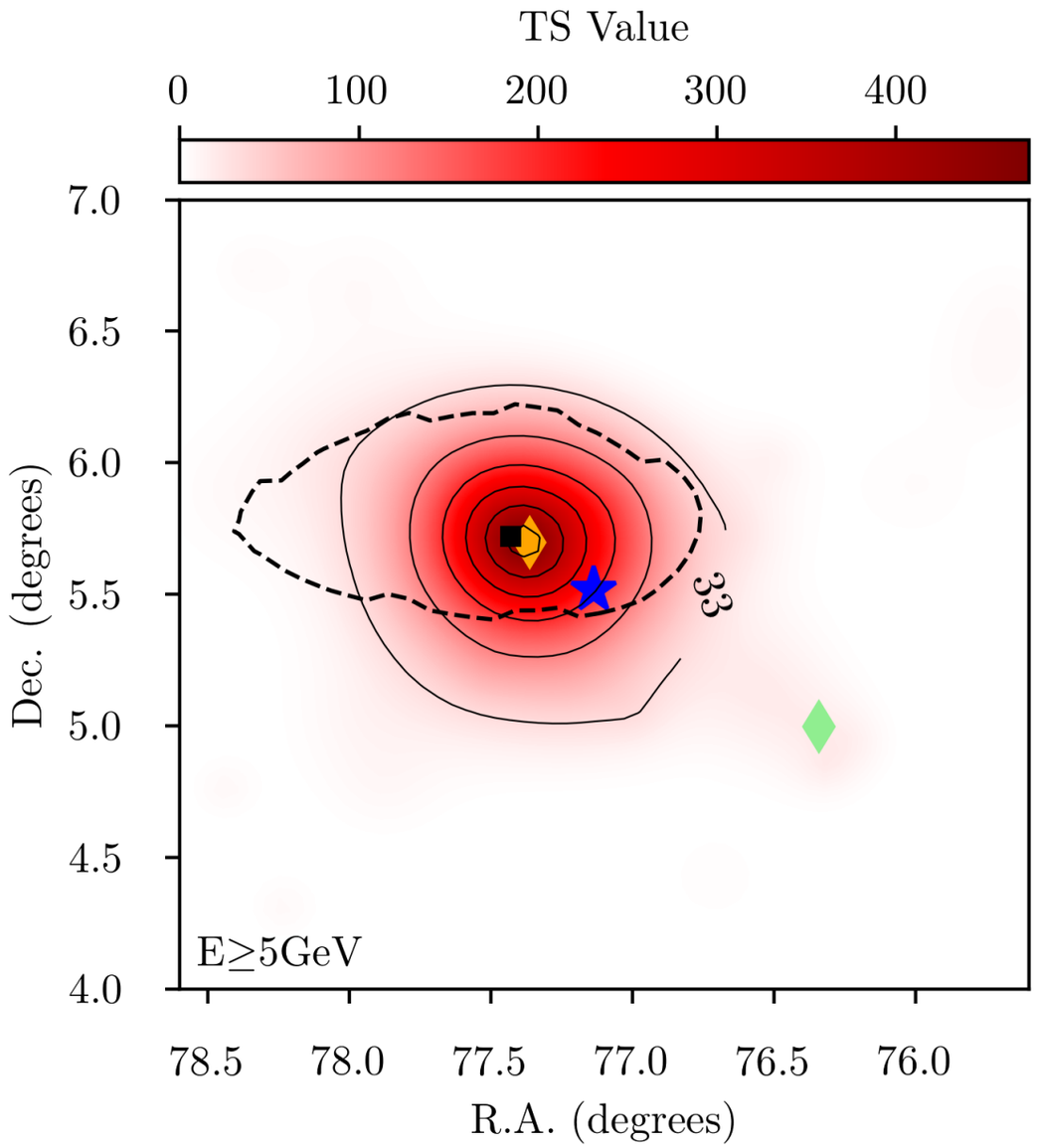


MJD 55762 - 55842 (July 20 - October 8, 2011)

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

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

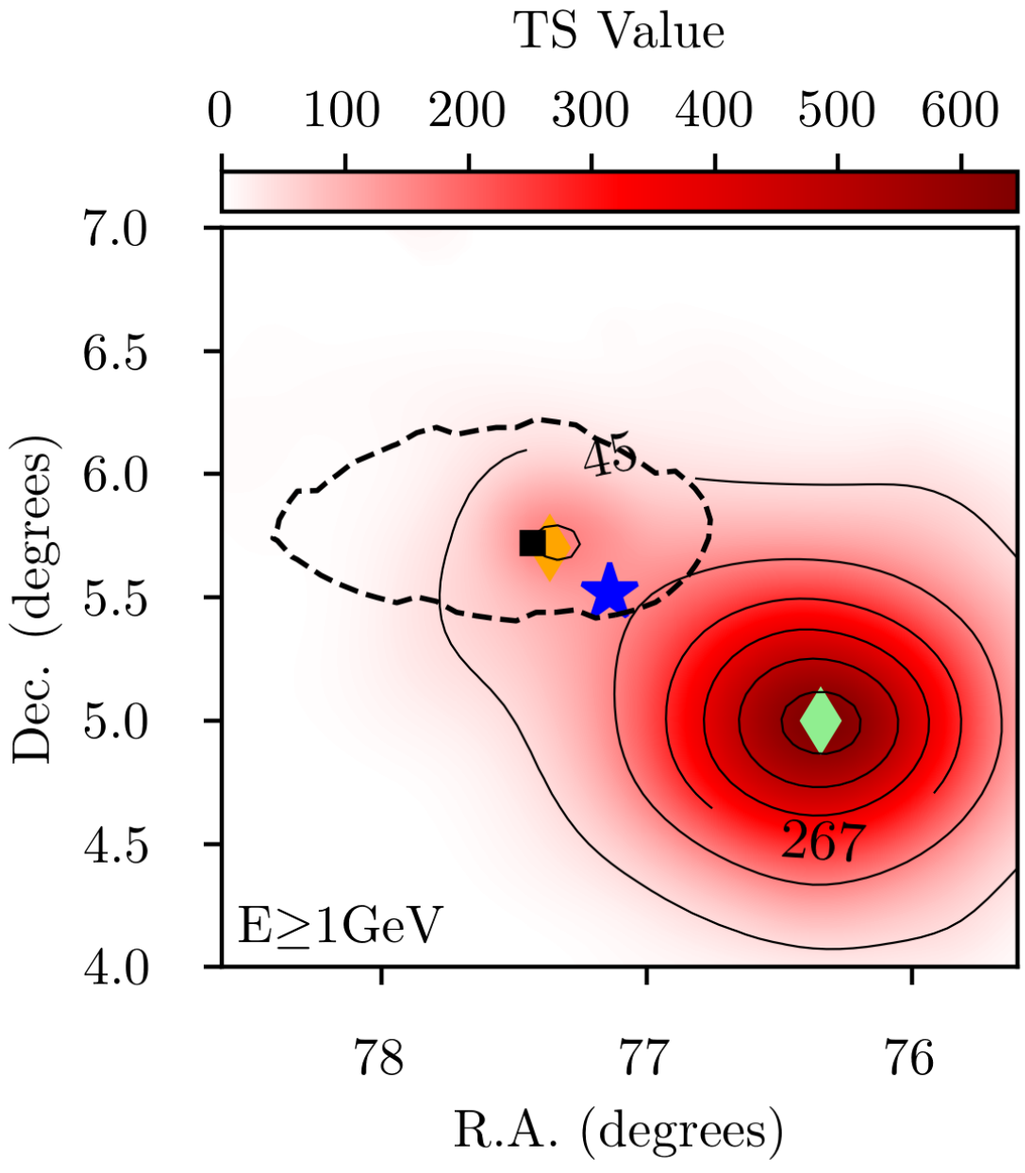




Neutrino alert time: MJD 57908 - 58018 (June 4 - September 22, 2017)

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

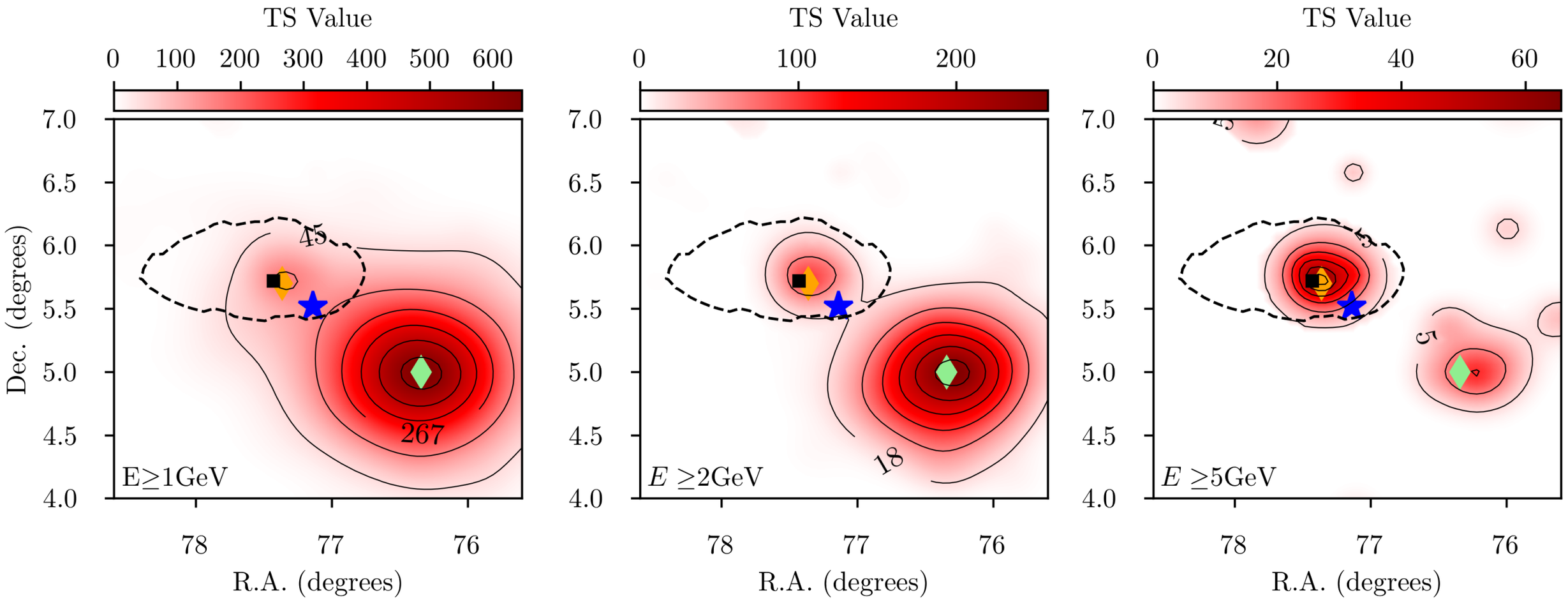
P. Padovani, P. Giommi, E.R., T. Glauch, B. Arsioli, N. Sahakyan, M. Huber, "Dissecting the region around IceCube-170922A: TXS 0506+056 as the first cosmic neutrino source", MNRAS 2018



Neutrino flare time: MJD 56949 - 57059 (October 19, 2014 - February 6, 2015)

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

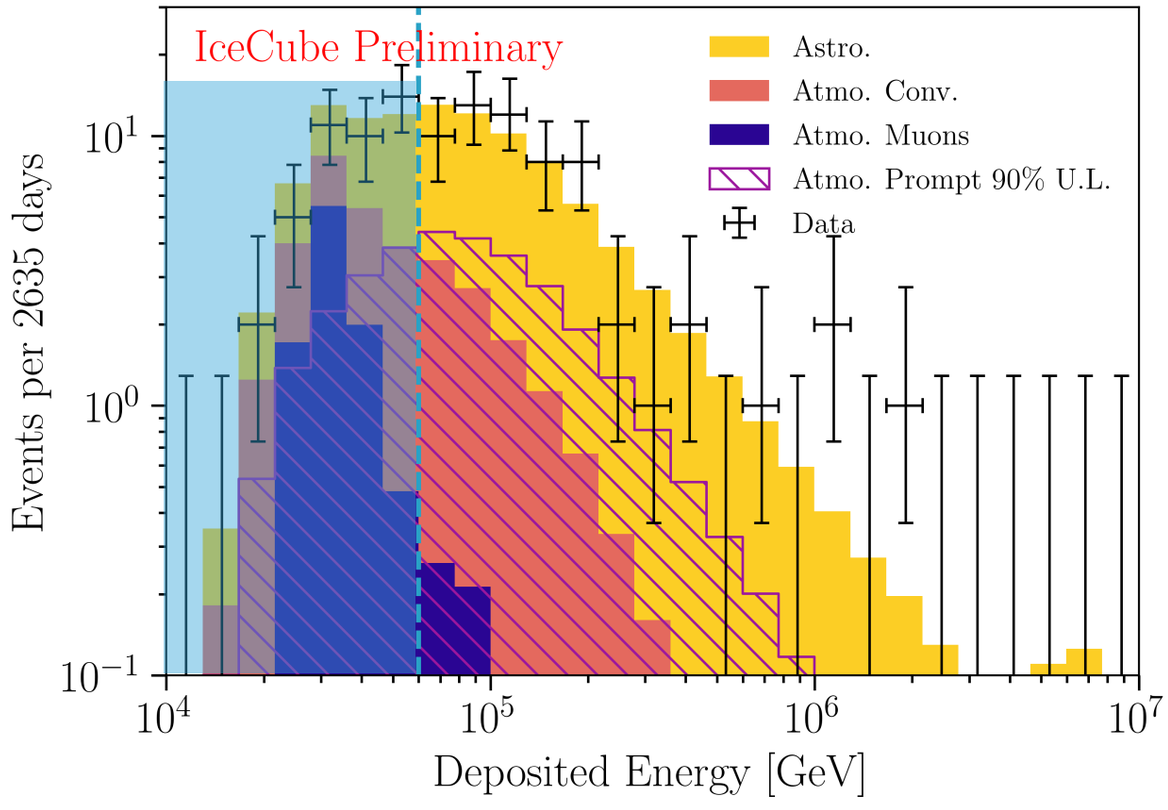
P. Padovani, P. Giommi, E.R., T. Glauch, B. Arsioli, N. Sahakyan, M. Huber, "Dissecting the region around IceCube-170922A: TXS 0506+056 as the first cosmic neutrino source", MNRAS 2018

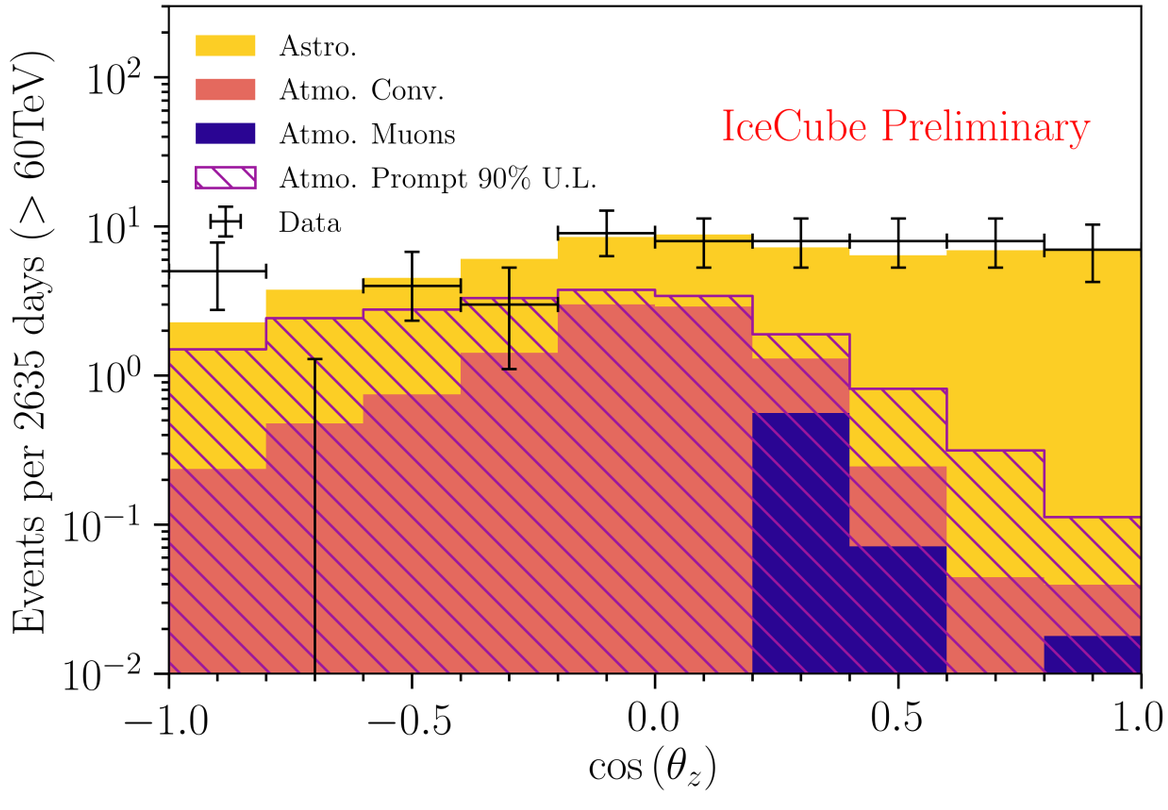


Neutrino flare time: MJD 56949 - 57059 (October 19, 2014 - February 6, 2015)

HIGH ENERGY, STARTING EVENTS, ALL FLAVOURS (2635 DAYS)

All energies: 102 events; E > 60TeV: 60 events

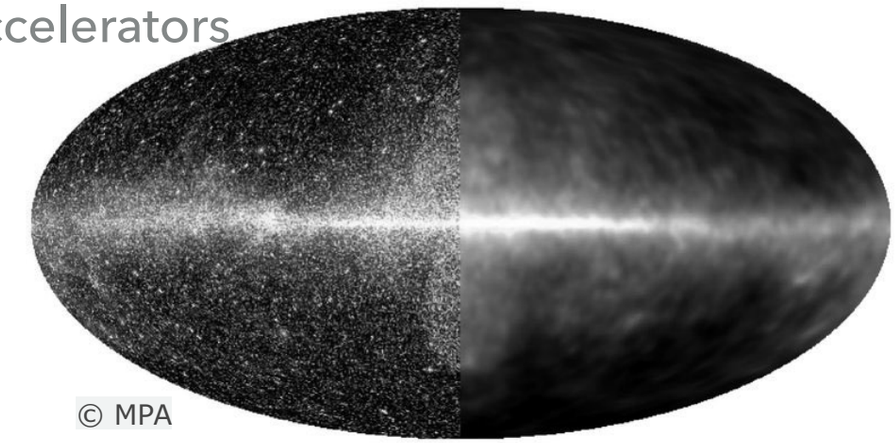




$2.19(+1.10,-0.55)\times E^{-2.91(+0.33,-0.22)}$

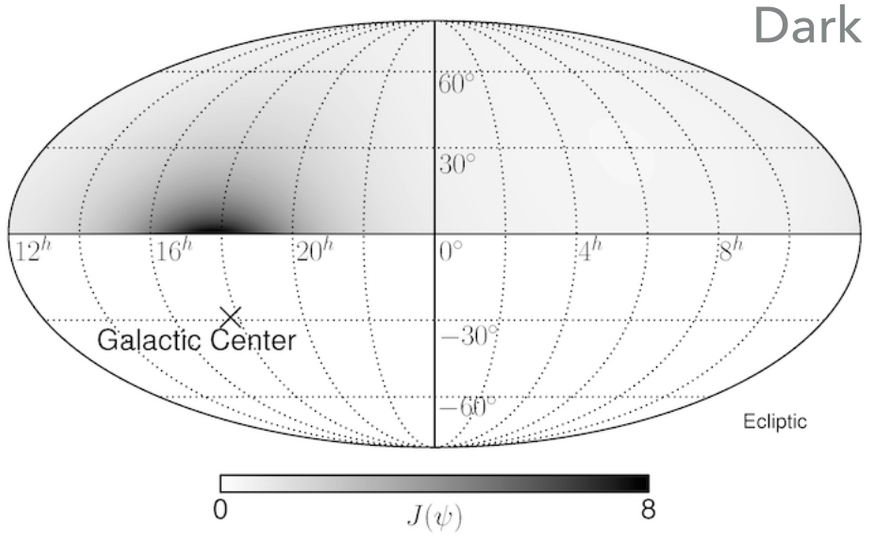
ORIGIN OF HIGH ENERGY COSMIC NEUTRINOS?

Galactic accelerators

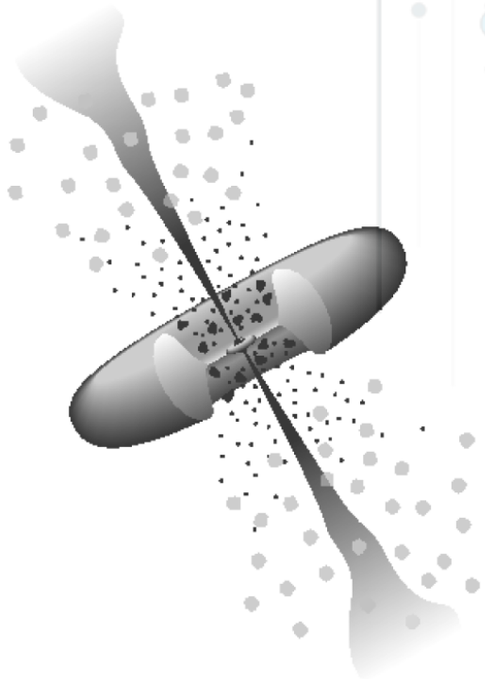


© MPA

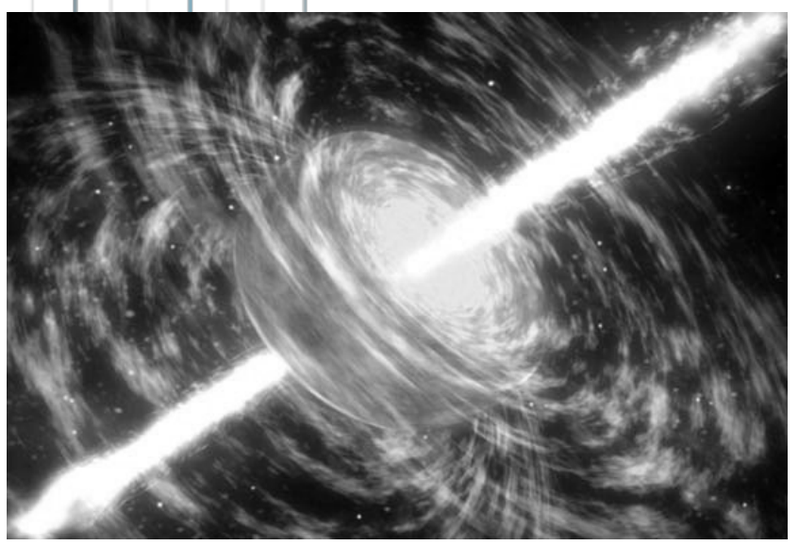
Dark Matter



AGN, Blazars



Gamma Ray Bursts



THE DISSECTION BASED ON THE OPEN UNIVERSE TOOL

http://www.openuniverse.asi.it

Open UNiverse for astronomy

UNITED NATIONS Office for Outer Space Affairs

Open Universe @ ASI | Space Astronomy » | Ground Astronomy » | Planetary Science » | Solar data » | ISS » | VO and General services » | Bibliography » | Cosmic Rays »
Astronomical tools » | Image galleries » | Open software » | Other Initiatives » | Educational contents »

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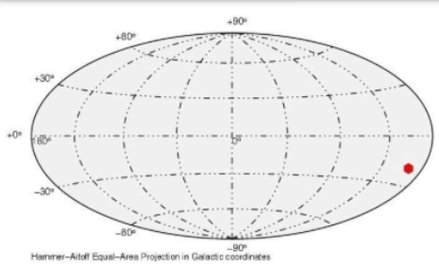
▽ OU Parameters



Aitoff coordinates type: **Galactic** - *Equatorial*

Source Name(s) : **5BZBJ0509+0541**

R.A.(J2000) = **05 09 25.96 (77.358167 deg)**

Dec.(J2000) = **+05 41 35.3 (5.693139 deg)**

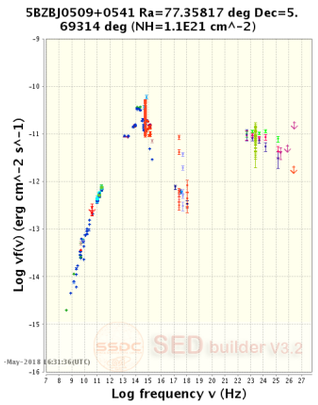
Version 1.1

Object name or coordinates: 5BZBJ0509+0541 (SSDC)

5BZBJ0509+0541

W | NED | SIMBAD

ESASky | SKY-MAP.ORG | Google Sky | SDSS SkyServer | Aladin Lite | Legacy Surveys | MAST Archive | SuperCOSMOS
Radio Surveys | SSDC Catalogs | Astronomical Catalogs | SkyMapper | CADC Archive | ESO Archive | NOAO Survey Data | NRAO Archive
ALMA Archive | ISDC - HEAVENS | SSDC Archive | Radio Telescope DC | INAF IA2 | Multi-freq. Explorer | VOU SED | SED builder
SED movie | Bibliographic Search



THE ICECUBE REALTIME ALERT SYSTEM

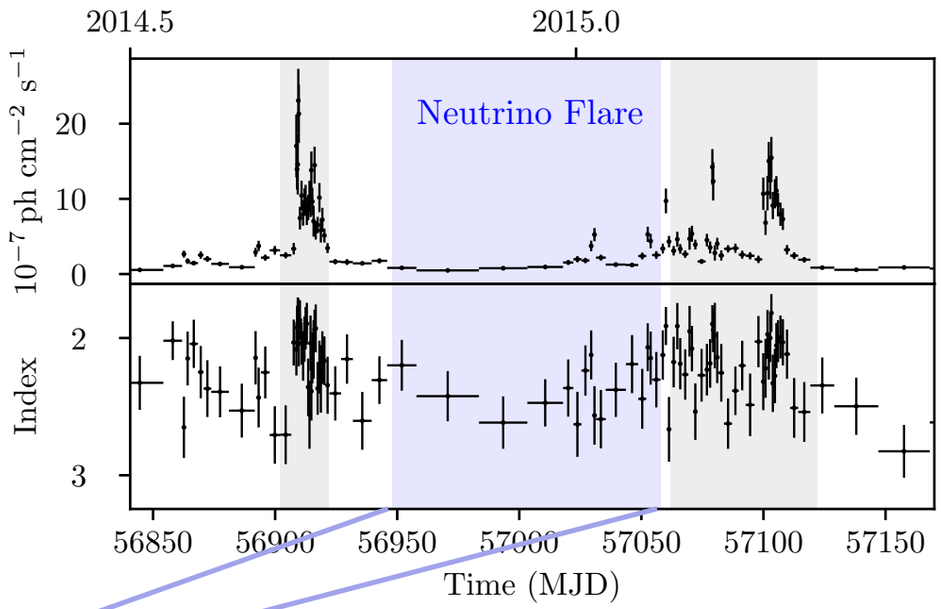
[The IceCube Coll., AstroParticle Phys (2017)]

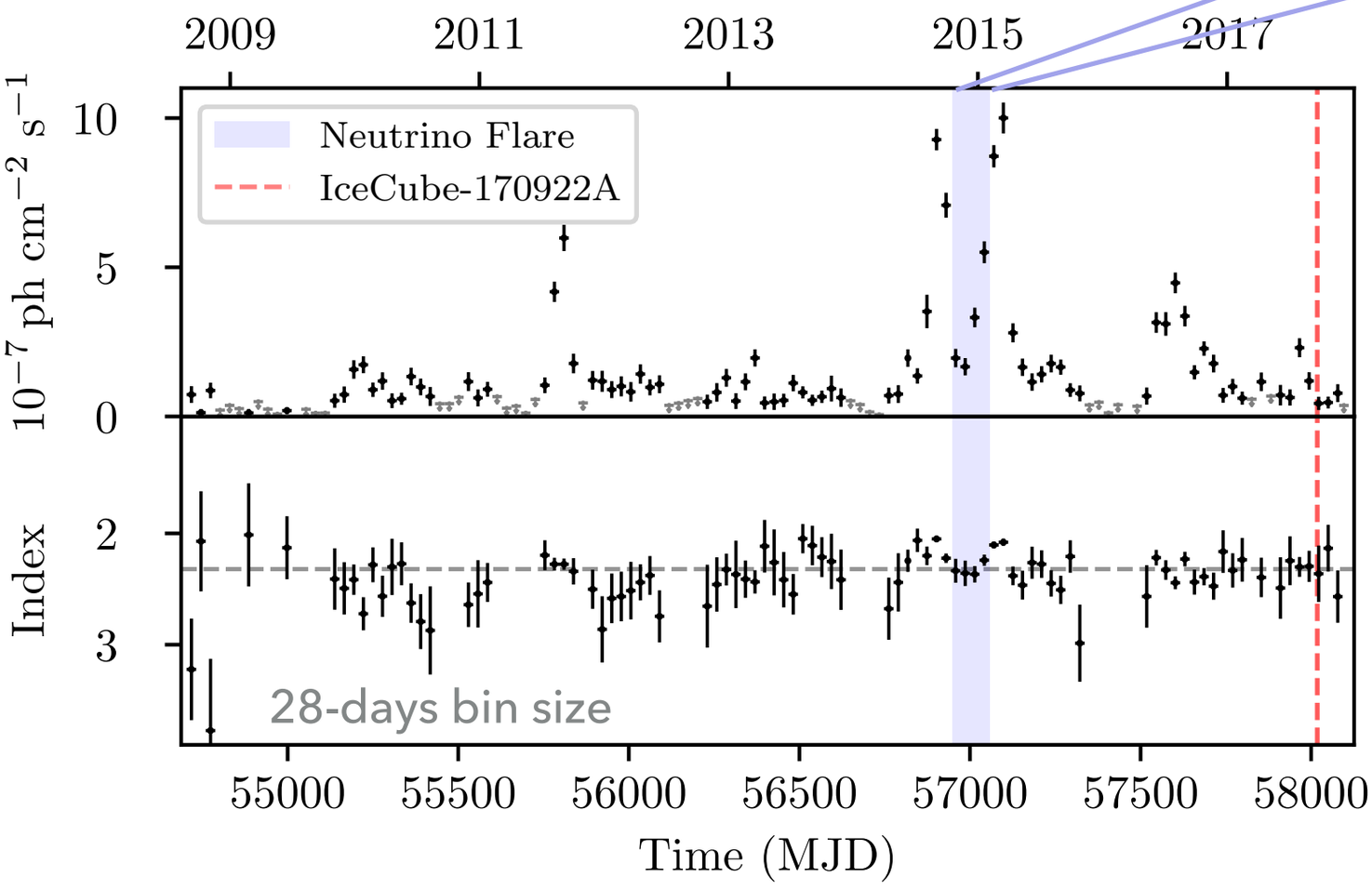
AMON ICECUBE_EHE EVENTS – Since June 2016 archiv		
EventNum_RunNum	Date	Time UT
17569642_130214	17/11/06	20:54:30.43
50579430_130033	17/09/22	18:39:39.21
80305071_129307	17/03/21	07:32:20.69
80127519_128906	16/12/10	20:06:40.31
26552458_128311	16/08/06	12:21:33.00
6888376_128290	16/07/31	01:55:04.00

same event

AMON ICECUBE_HESE EVENTS – Since April 2016 archived at ht		
EventNum_RunNum	Date	Time UT
34032434_130171	17/10/28	08:28:14.81
56068624_130126	17/10/15	1:34:30.06
32674593_129474	17/05/06	12:36:55.80
65274589_129281	17/03/12	13:49:39.83
38561326_128672	16/11/03	09:07:31.12
58537957_128340	16/08/14	21:45:54.00
6888376_128290	16/07/31	01:55:04.00
67093193_127853	16/04/27	05:52:32.00

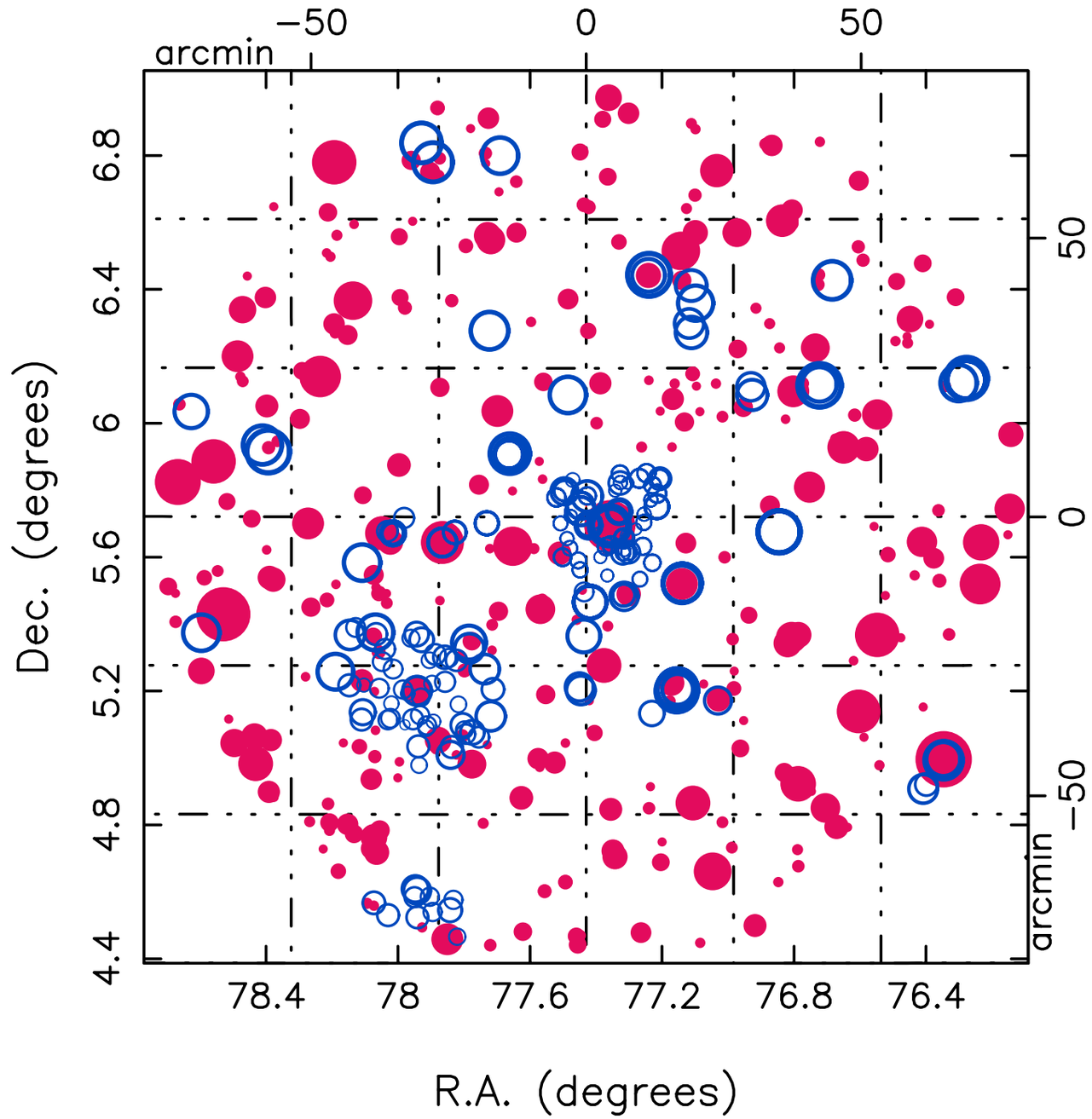
GAMMA-RAY LIGHT CURVES: PKS





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

- 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.



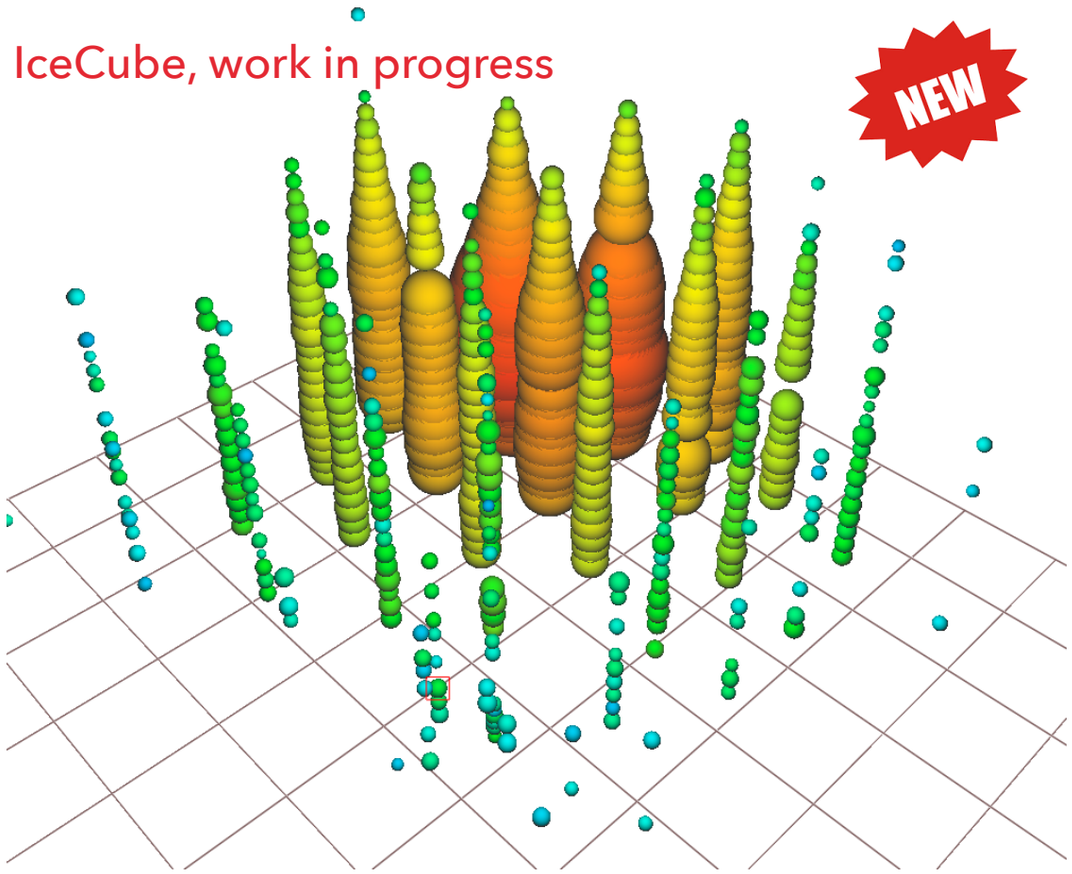
THE RECORD EVENT: HYDRANGEA -> GLASHOW RESONANCE EVENT CANDIDATE

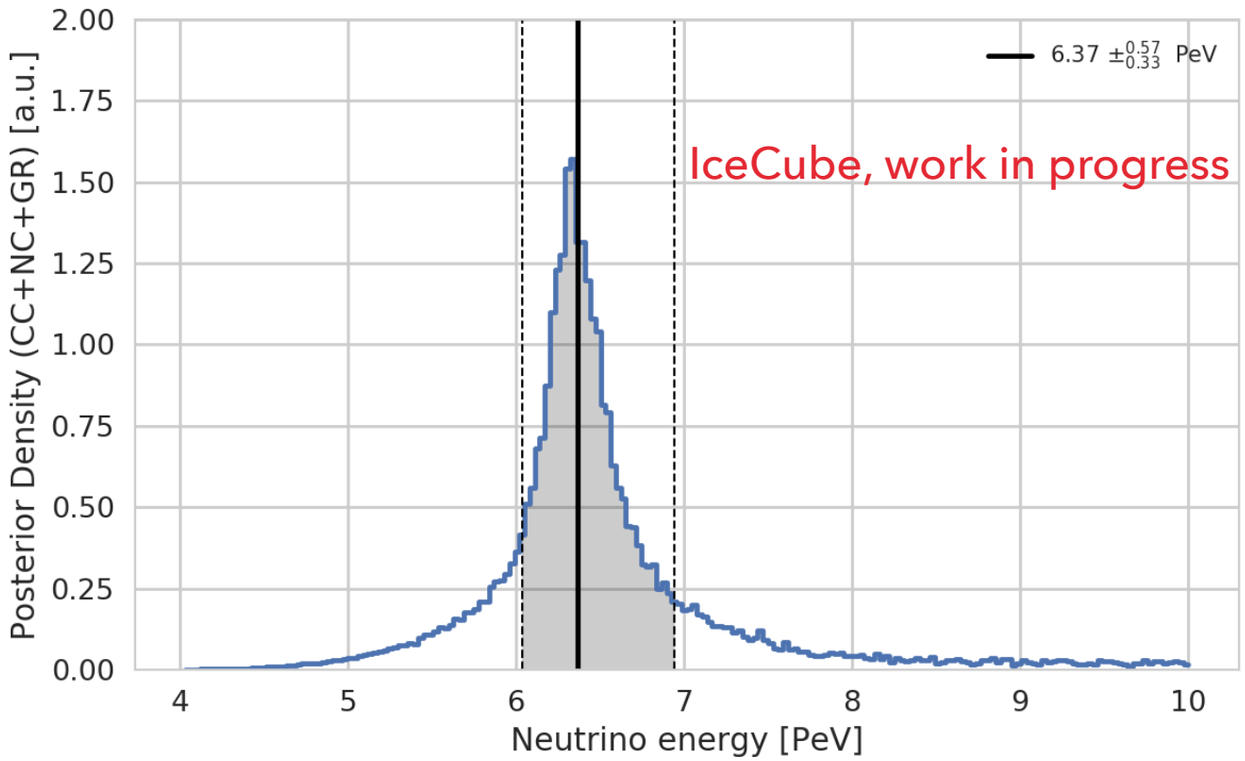
S.L. Glashow, Phys. Rev. 118B, 316 (1960)

$$\bar{\nu}_e e^- \rightarrow W^- \rightarrow \text{anything} \quad E_\nu \simeq 6.3 \text{ PeV}$$

Resonant scattering

IceCube, work in progress



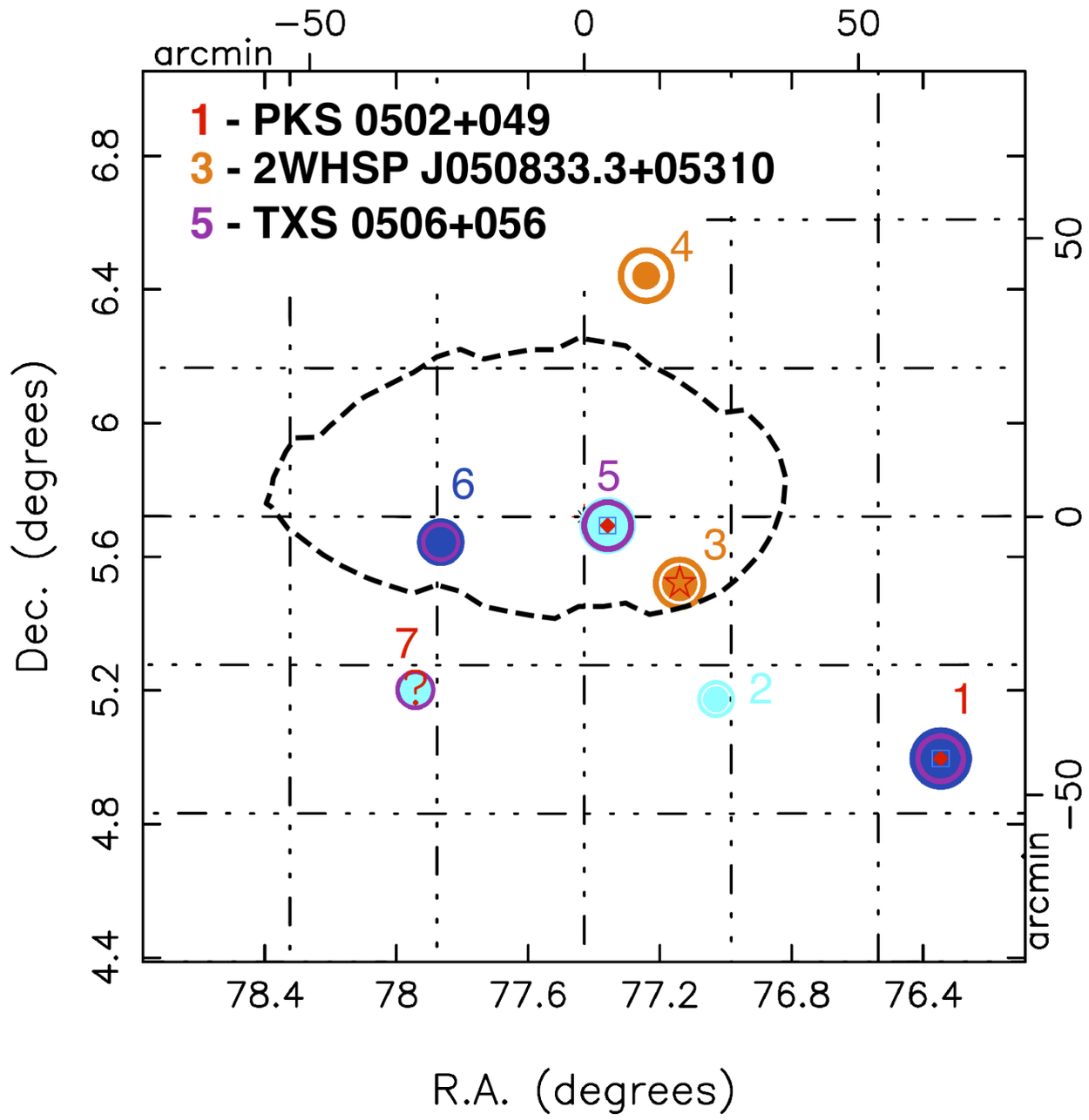


ν_e candidate, cosmic ray origin excluded at the > 5 sigma level

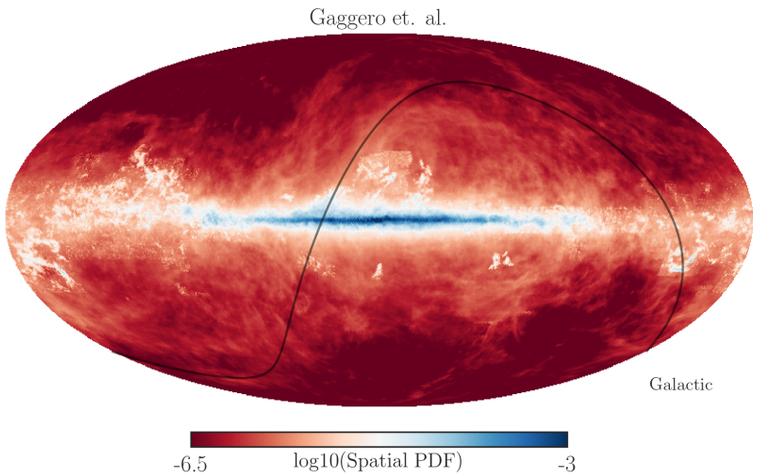
ICECUBE-170922A: THE REGION (R = 80 ARCMIN) AROUND

From detailed investigations of the SED:

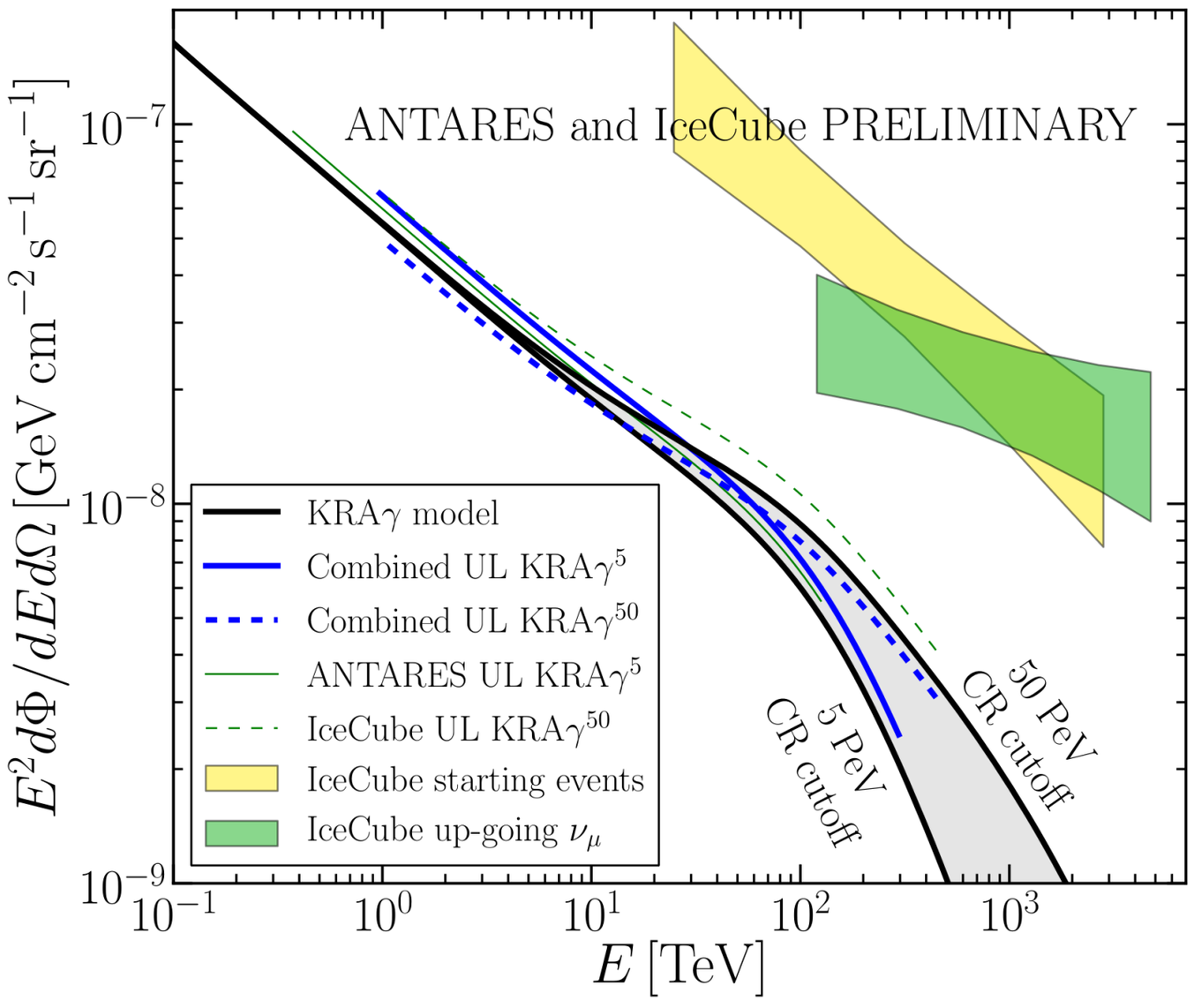
- 3 known objects:
  - (5) TXS 0506+056 (an IBL/HBL at z=0.3365, *Paiano et al. 2018*)
  - (1) PKS 0502+049 (an LBL/FSRQ at z=0.954)
  - (3) 2WHSPJ050833.3+05310 (an HBL)
- (4) HBL candidate
- (7) likely a cluster of galaxies
- (6) steep radio spectrum object
- (2) nearby (z = 0,03677) elliptical galaxy



CONSTRAINTS ON THE FROM THE GALACTIC PLANE NEUTRINO COMPONENT



NEW



https://arxiv.org/abs/1808.03531
Submitted to APJL

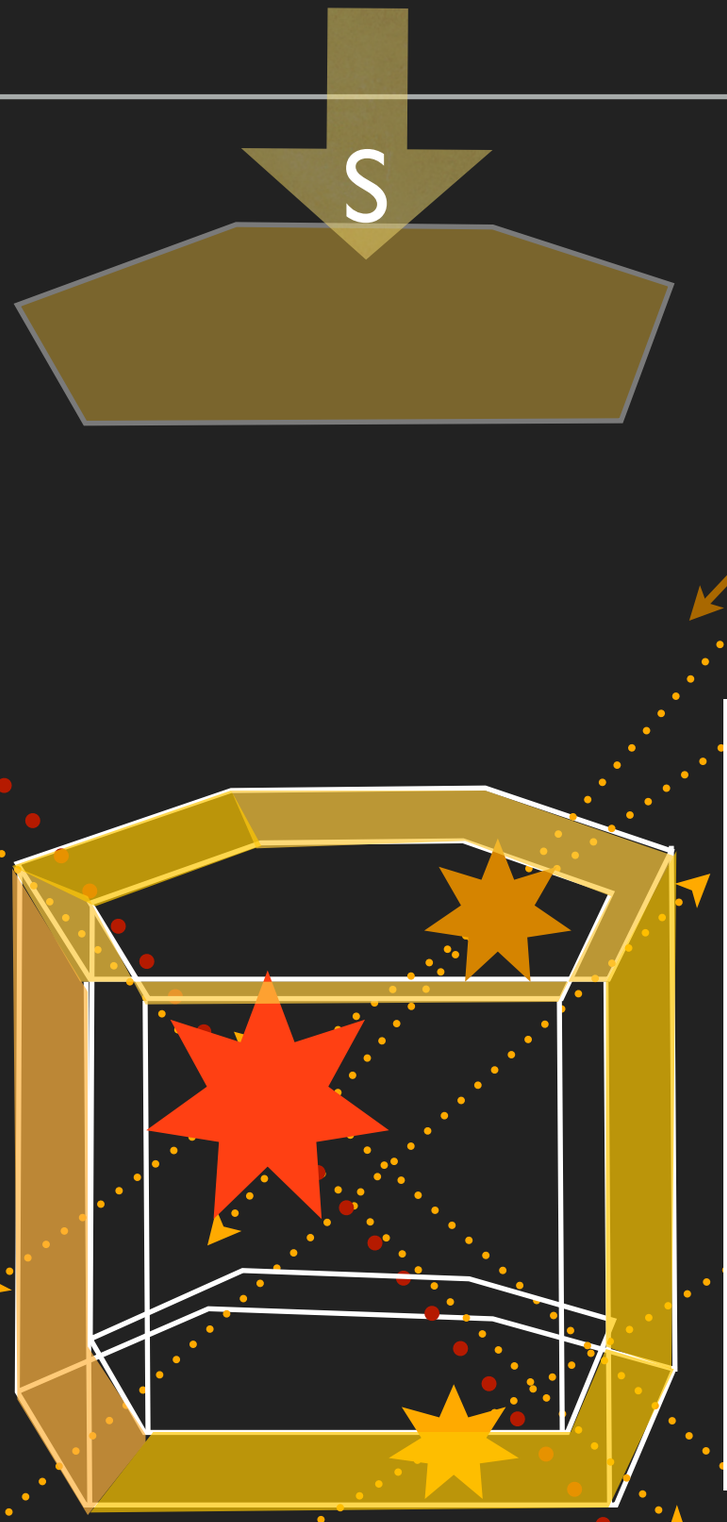
COSMIC NEUTRINOS (1)

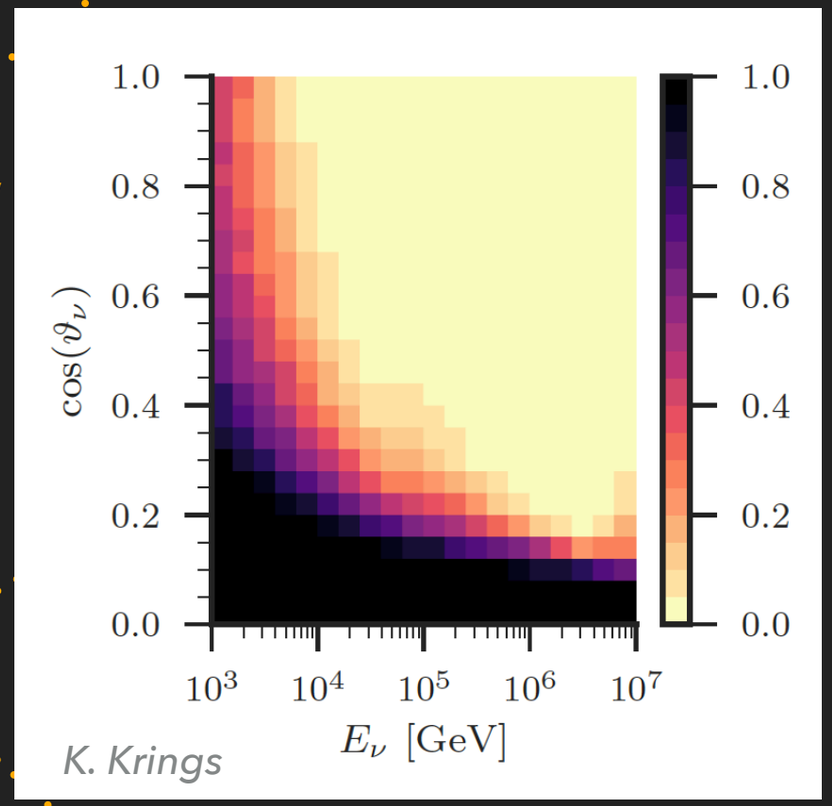
HOW TO?

self-VETO

↓

atmospheric neutrino-VETO





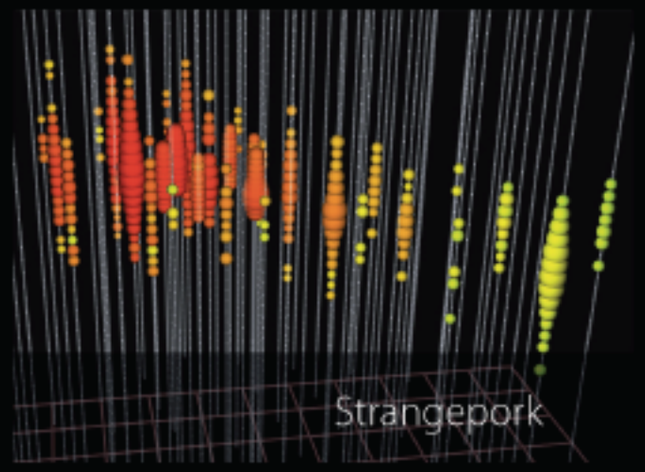
[S. Schönert, T. K. Gaisser, E.R., O. Schulz, PRD (2009),

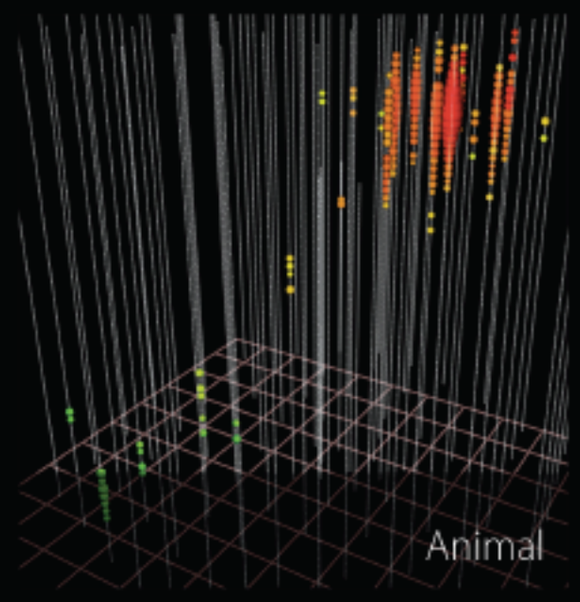
T. K. Gaisser, K. Jero, A. Karle, and J. van Santen, Phys. Rev. D (2014)]

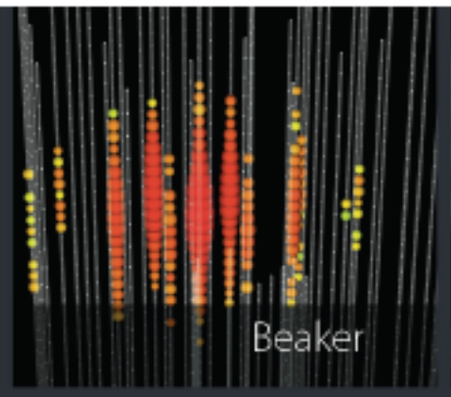
Examples of events:

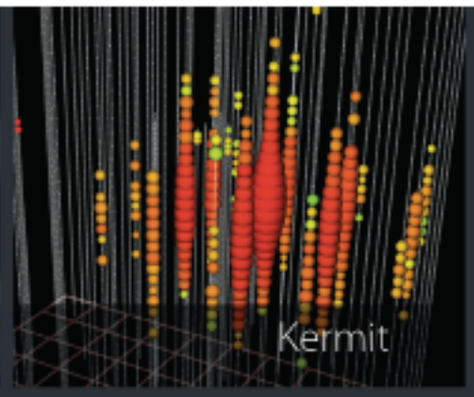
charge threshold > 6000 p.e.
& < 3 p.e. in veto region

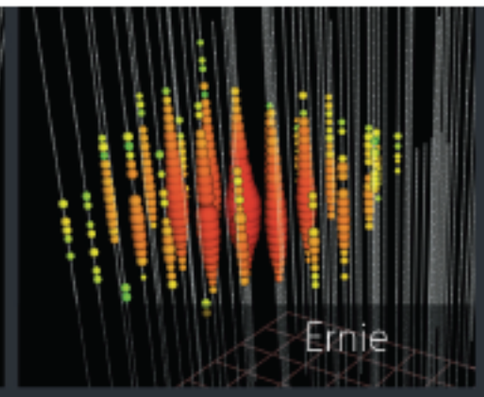
2078-day sample: 82 events

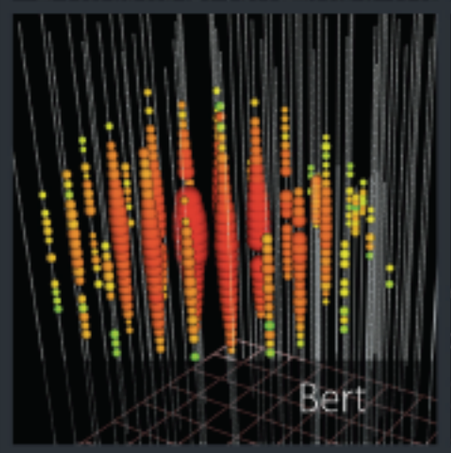


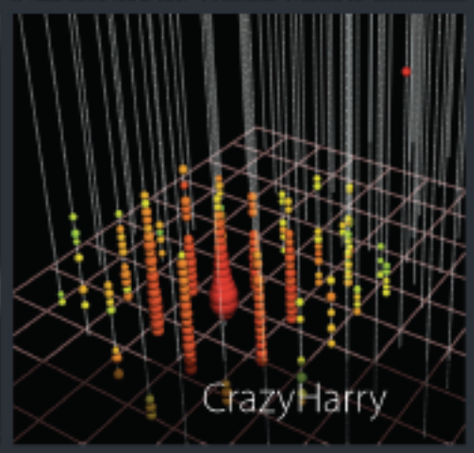


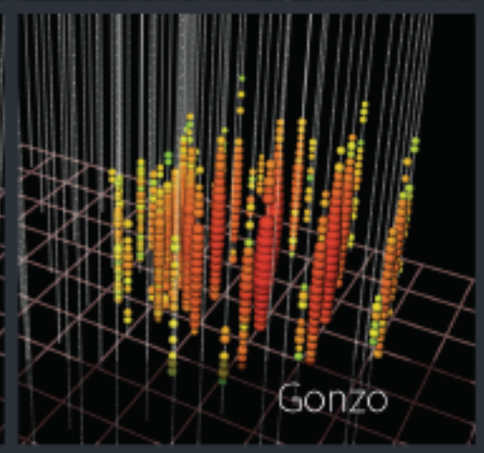


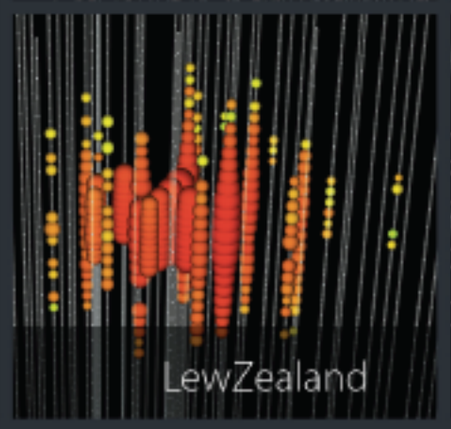


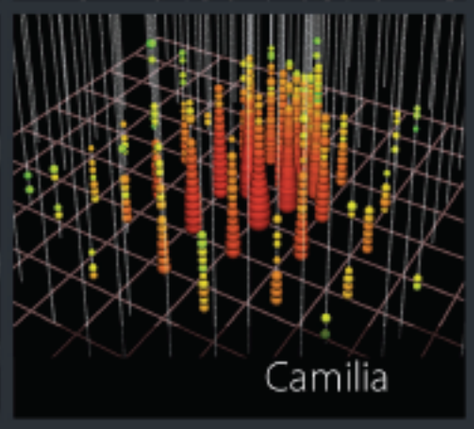


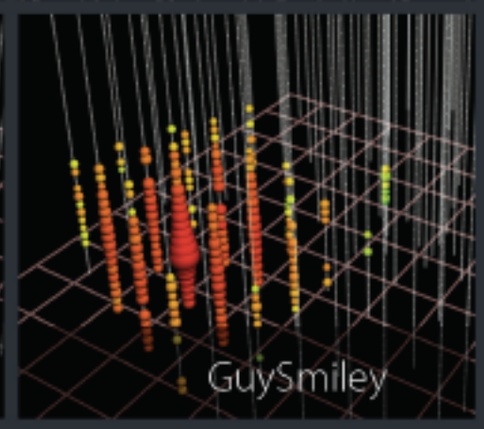


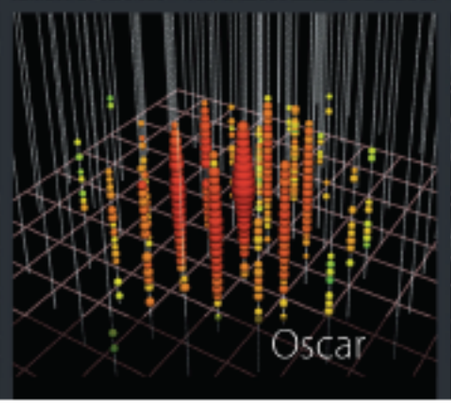


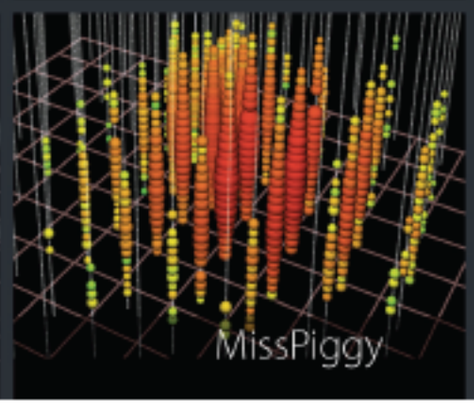


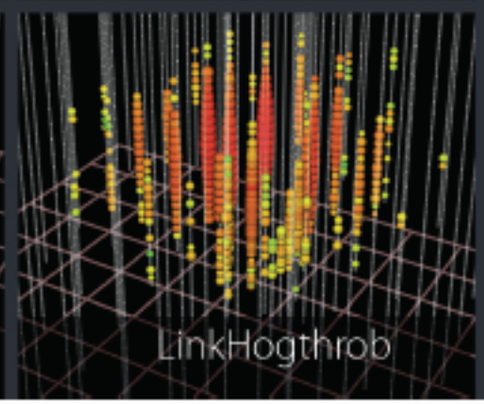












COSMIC NEUTRINOS (2)

HOW TO?

downward-VETO