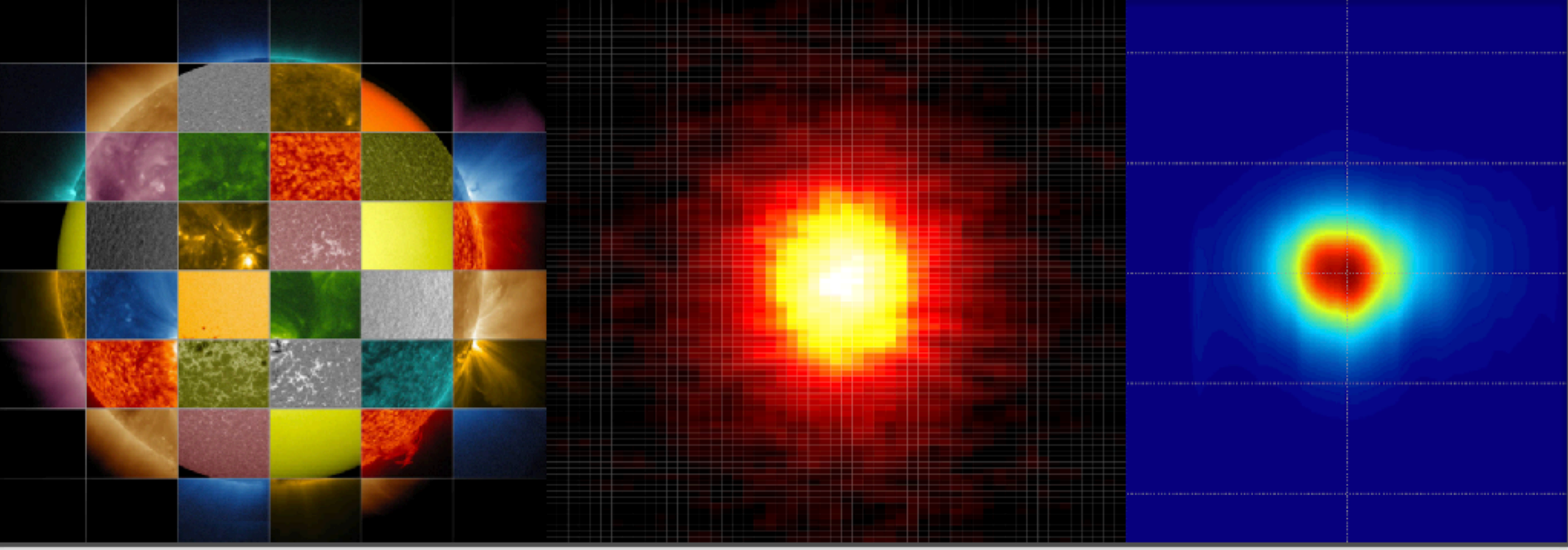


Credits: NASA/SDO/Goddard Space Flight Center, SuperKamiokande, Chang'E-1 Solar Wind Ion Detector (F. Nozzoli and P. Giommi)

ELISA RESCONI (TUM)

NEUTRINO ASTRONOMY– HIGH ENERGY

THE IDEA

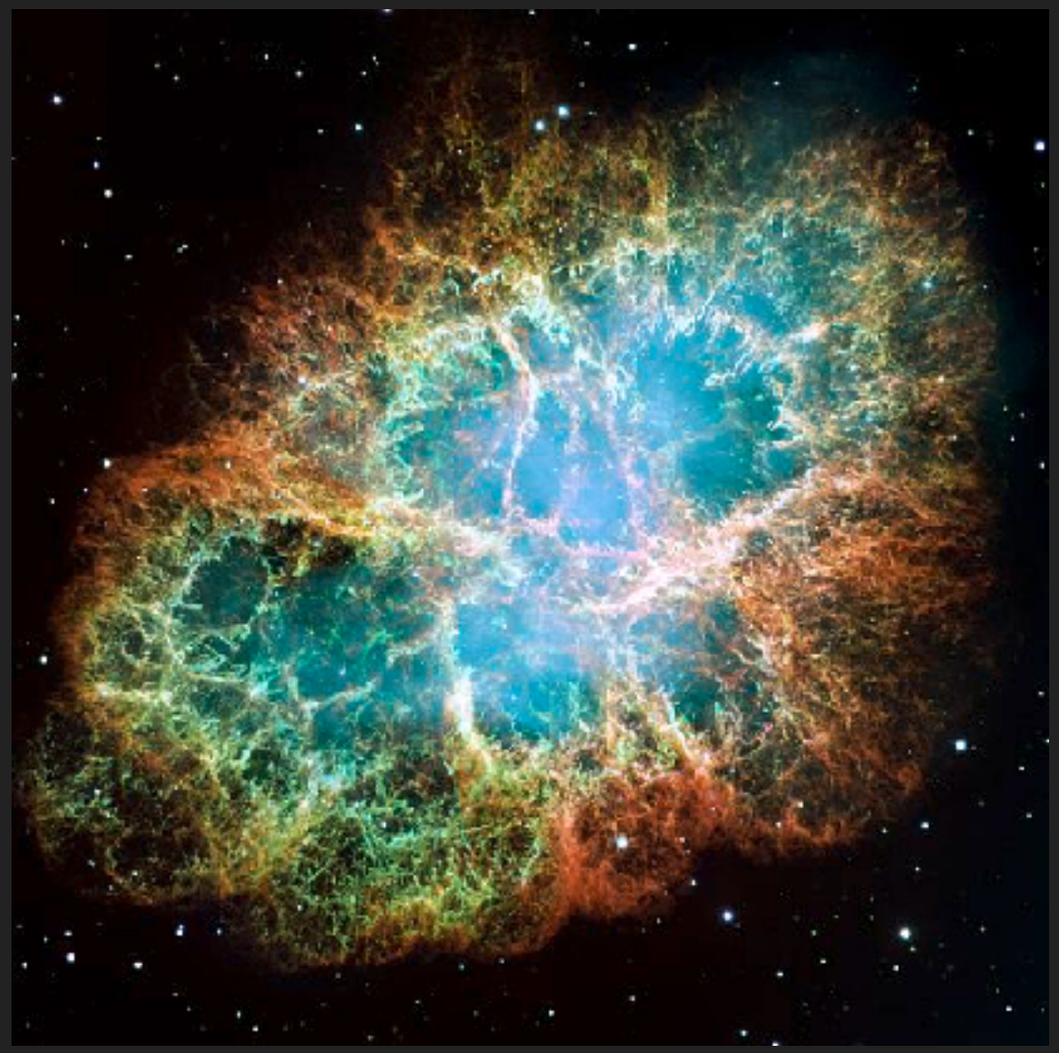
K. Greisen, "Cosmic ray showers," Ann. Rev. Nucl. Part. Sci. 10 (1960) 63–108.
F. Reines, "Neutrino interactions," Ann. Rev. Nucl. Part. Sci. 10 (1960) 1–26.
M. A. Markov, "On high energy neutrino physics," Proc. Int. Conference on High Energy Physics at Rochester (1960) 578–581.

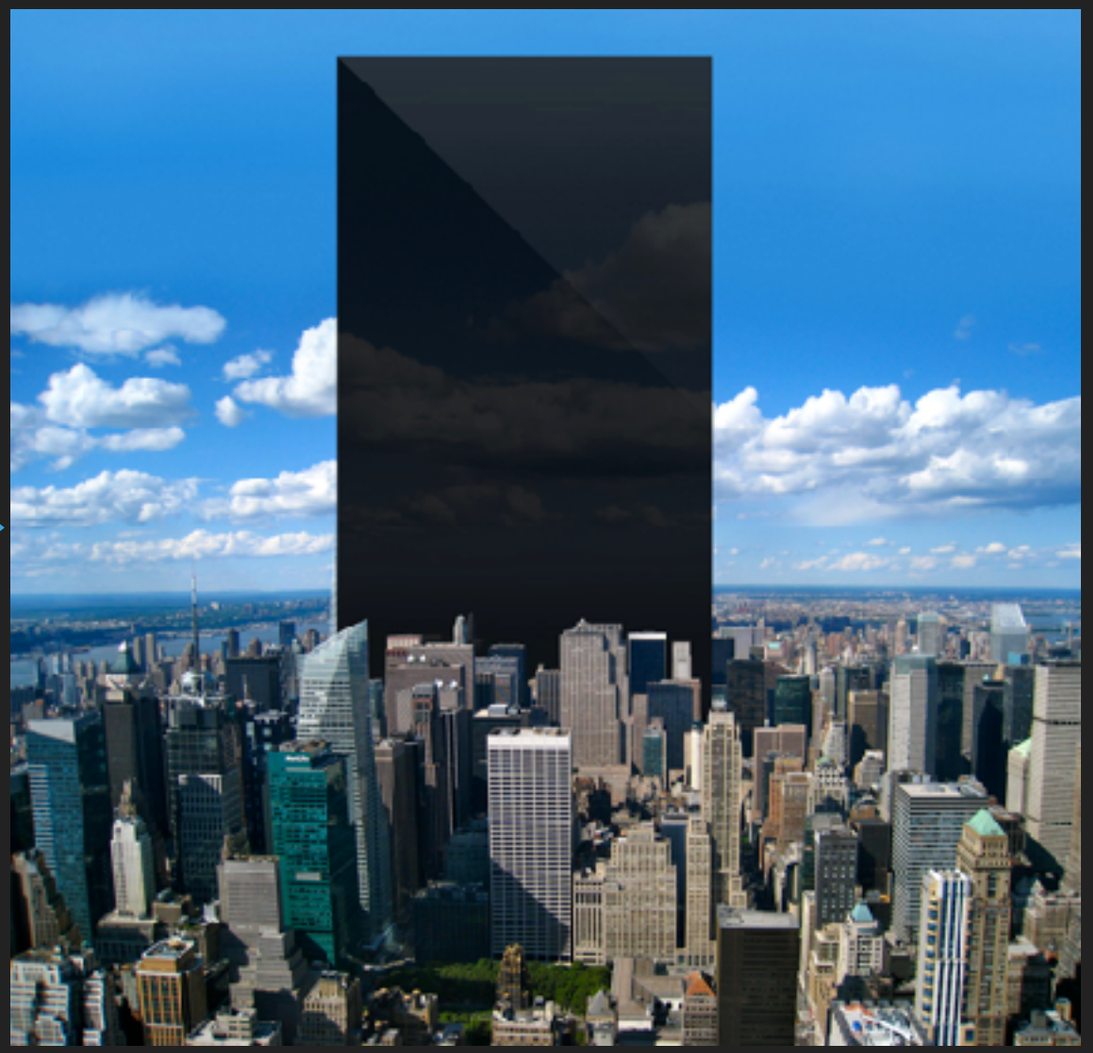
- *interest in the possibility of detecting cosmic neutrinos ,,stems from the **weak interaction of neutrinos** with matter, which means that **they propagate essentially unchanged in direction and energy** from their point of origin [..] and so carry information which may be unique in character." (F. Reines)*

- *use a large volume of water in **mine** (Greisen)*

- *use the **deep ocean** or water in a lake to study atmospheric neutrinos (Markov)*

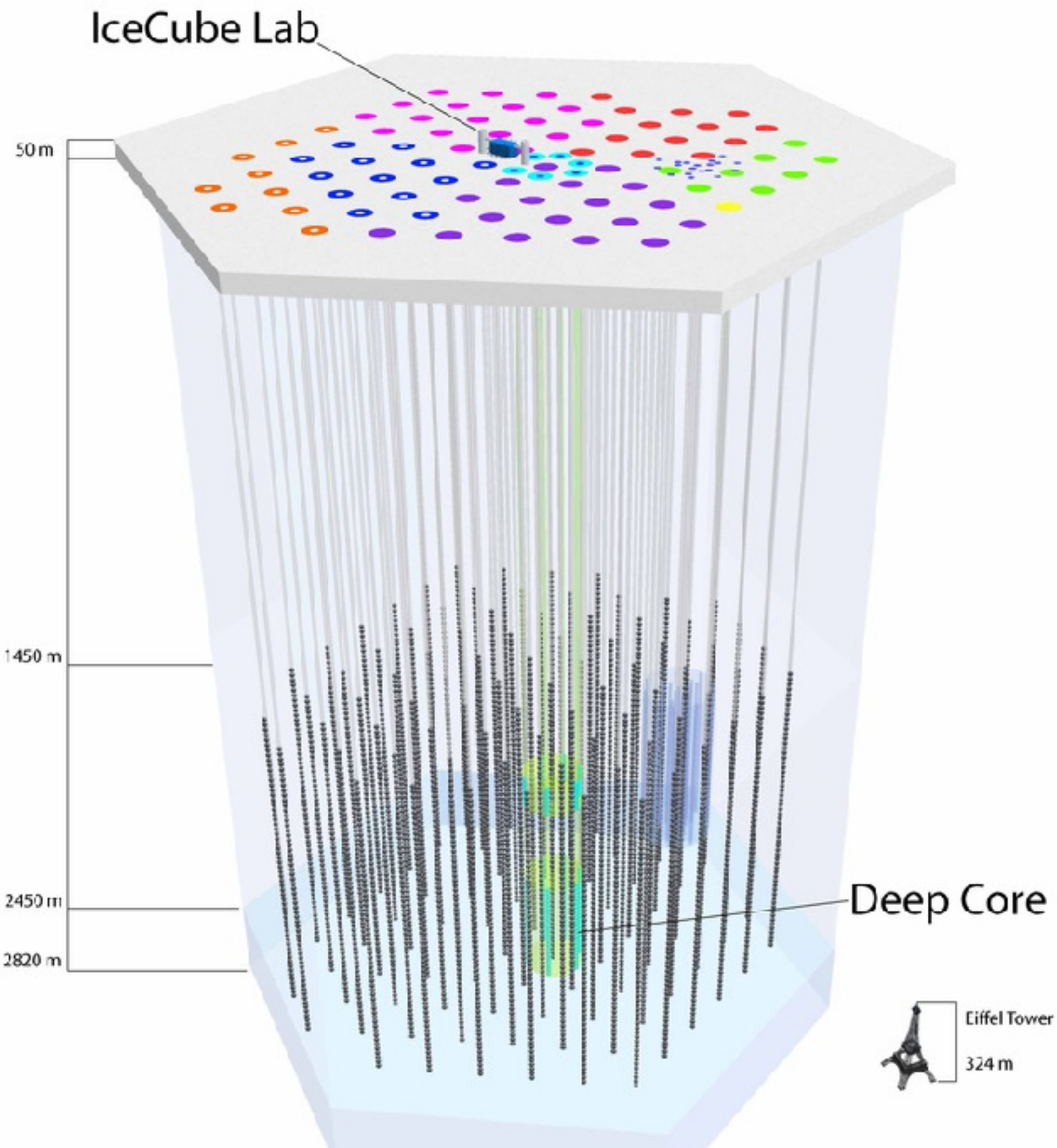
THE SCALE: KM3





http://www.stupidcalculations.com/

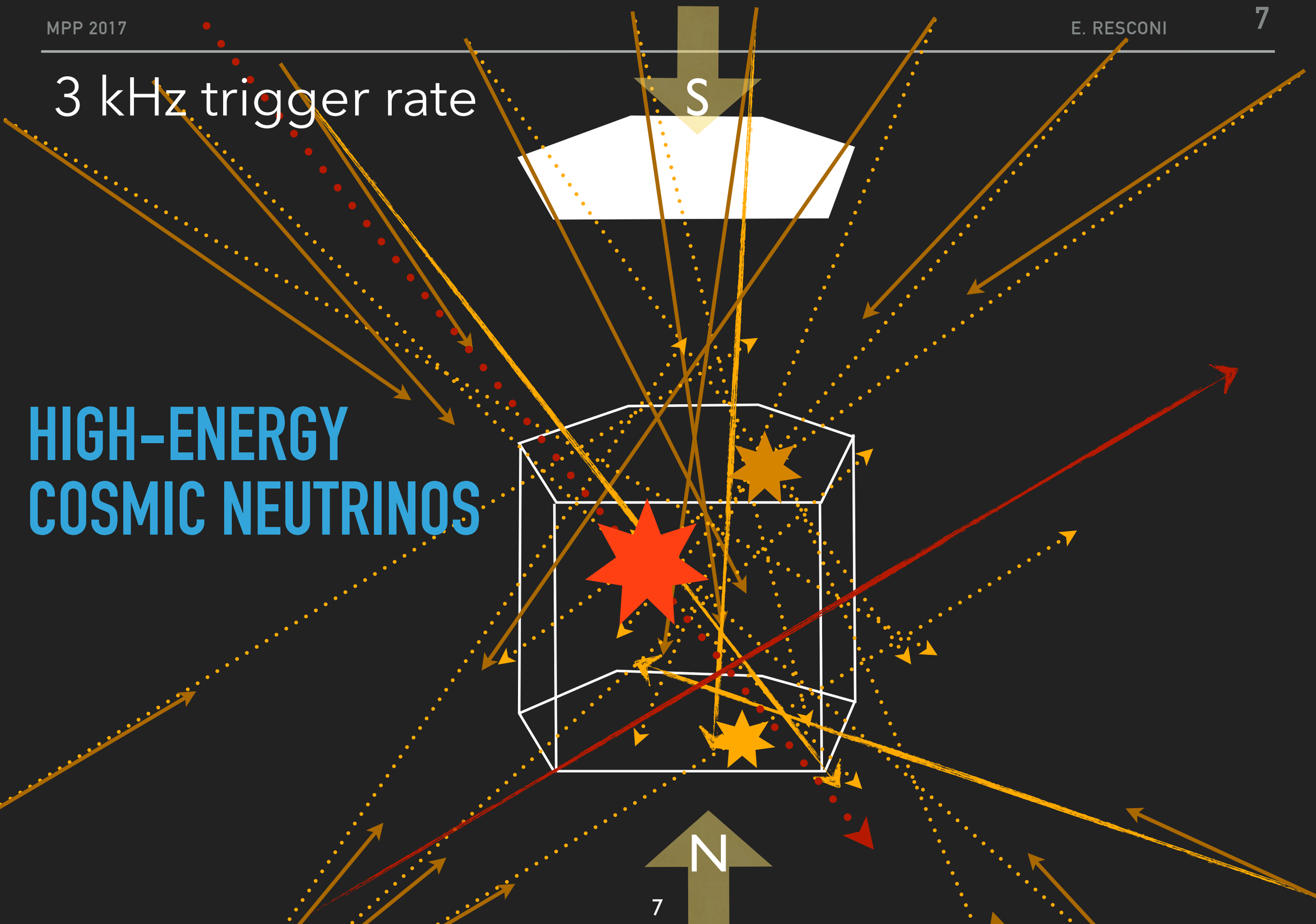
ICECUBE


IceCube Lab
50 m
1450 m
2450 m
2820 m
Deep Core
Eiffel Tower
324 m

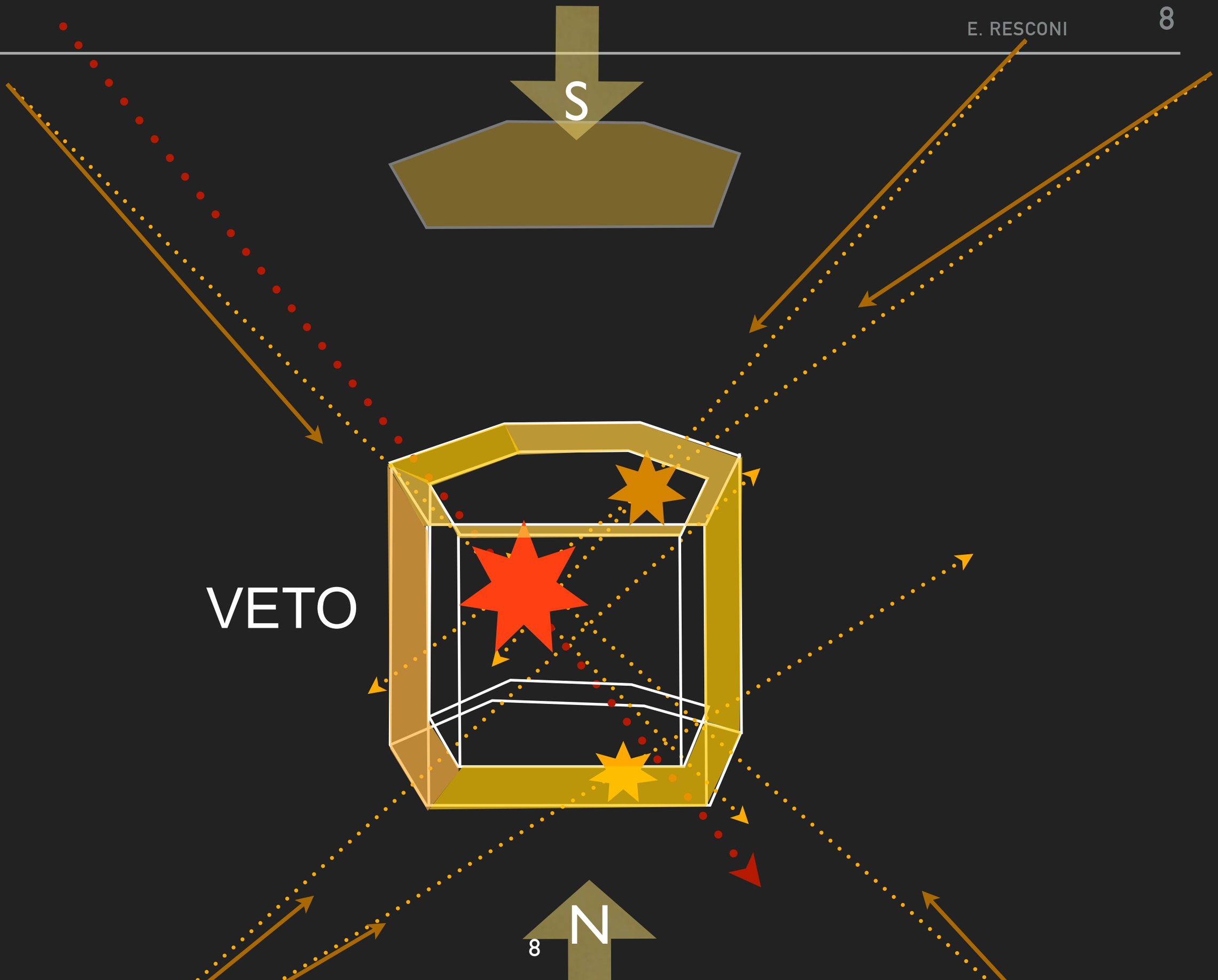
Martin Wolf, 20.09.17

December 2010

3 kHz trigger rate



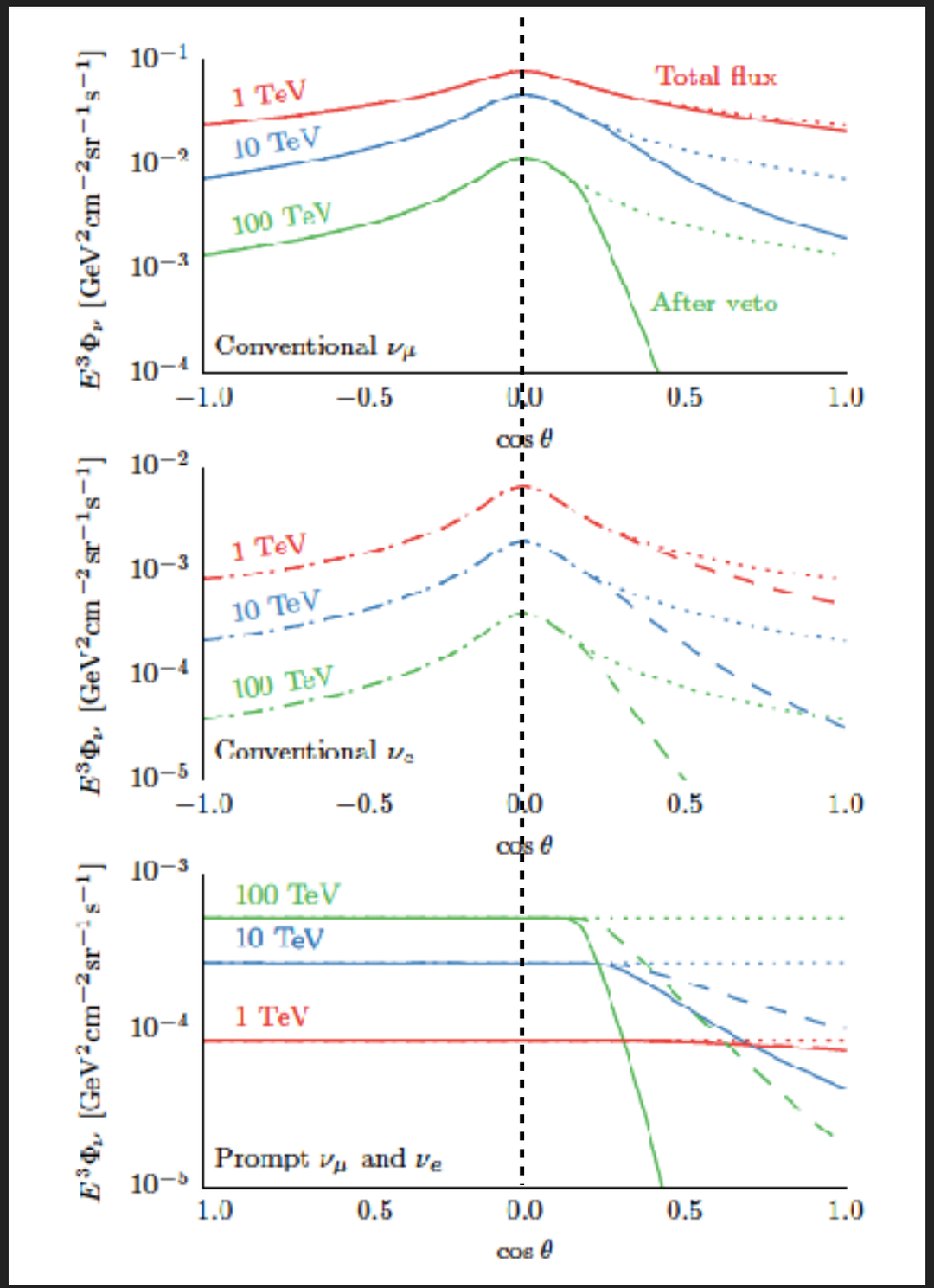
HIGH-ENERGY COSMIC NEUTRINOS

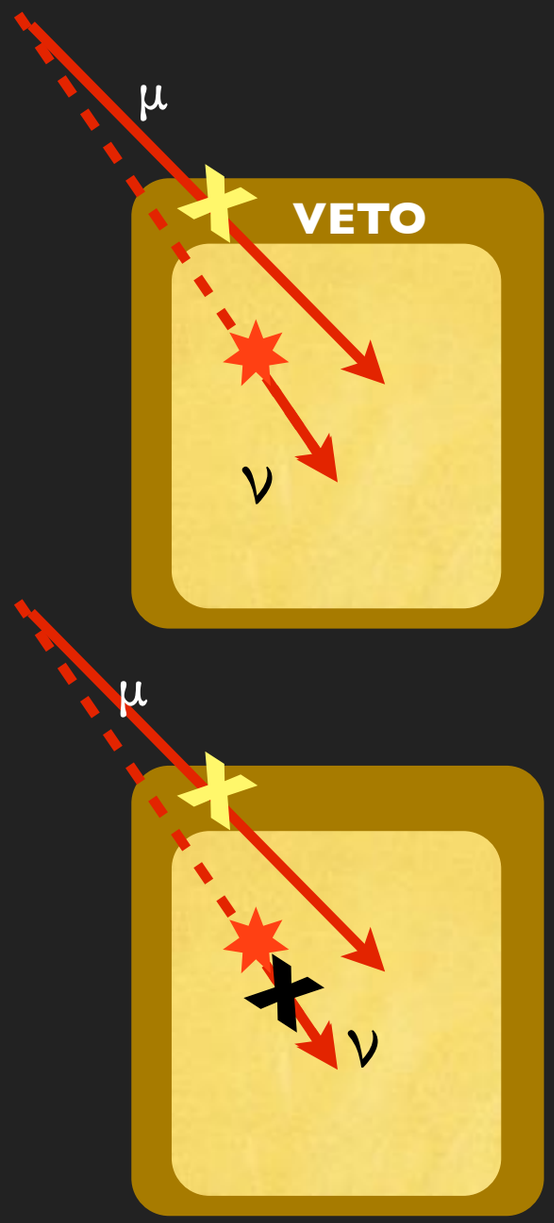

S
VETO
8
N

ATMOSPHERIC NEUTRINOS 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)]

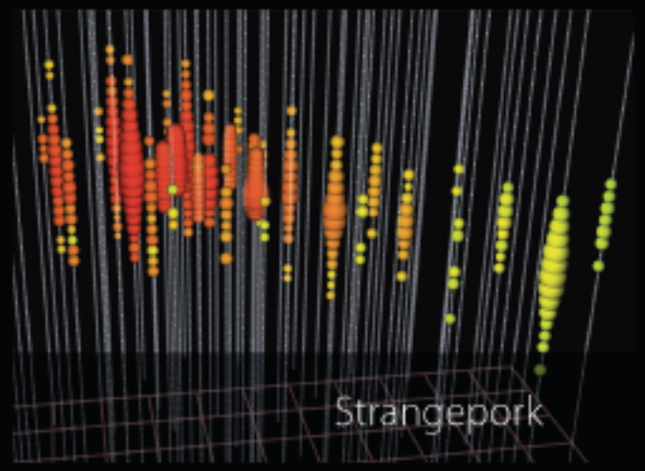


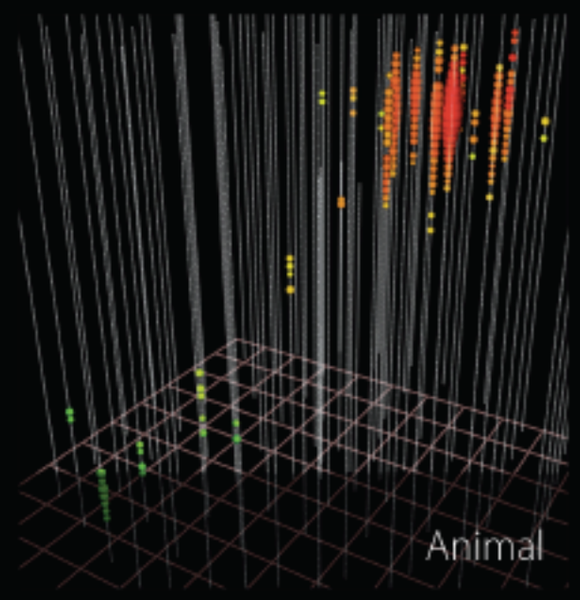


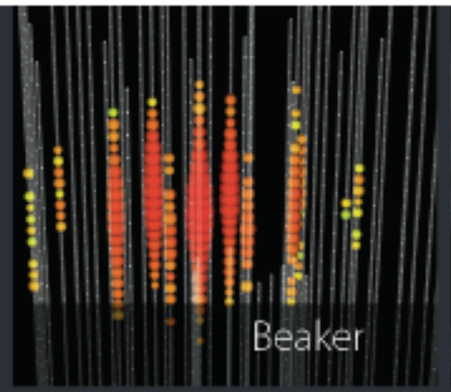
Examples of events:

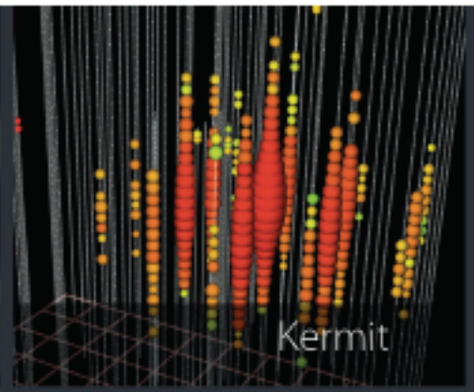
charge threshold > 6000 p.e.
& < 3 p.e. in veto region

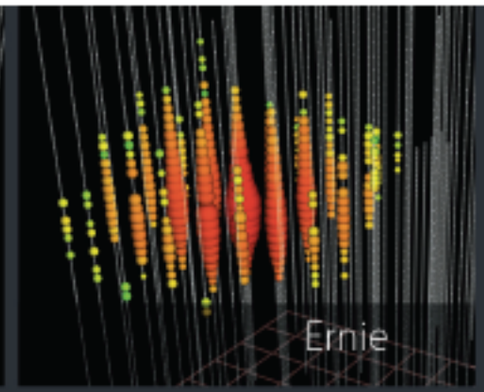
2078-day sample: 82 events

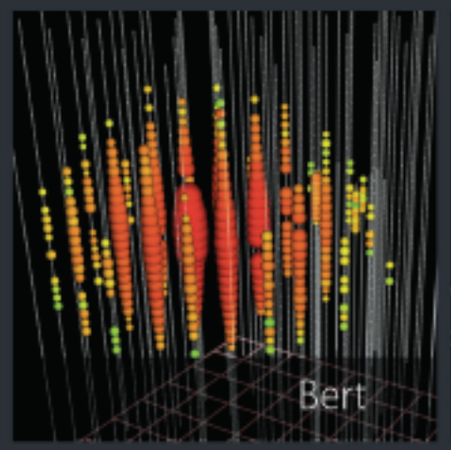


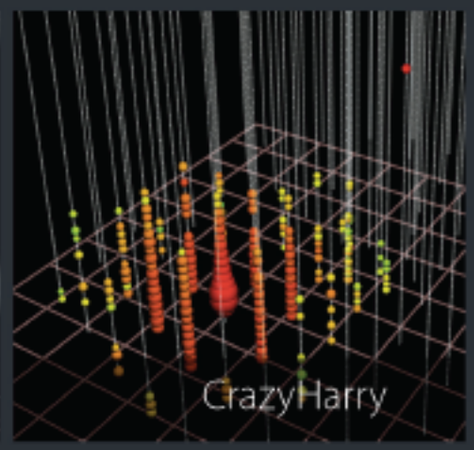


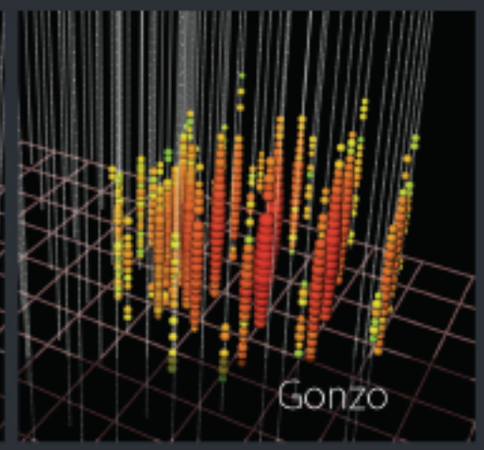


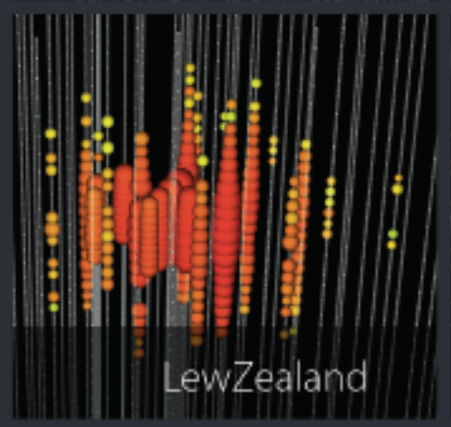


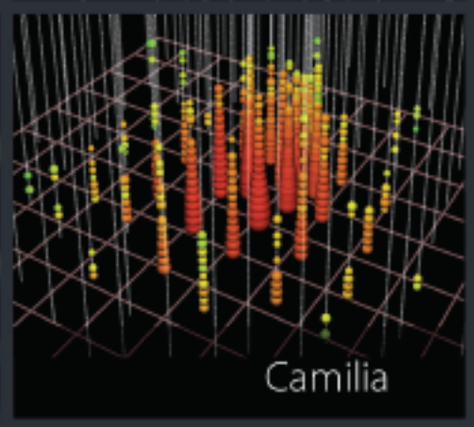


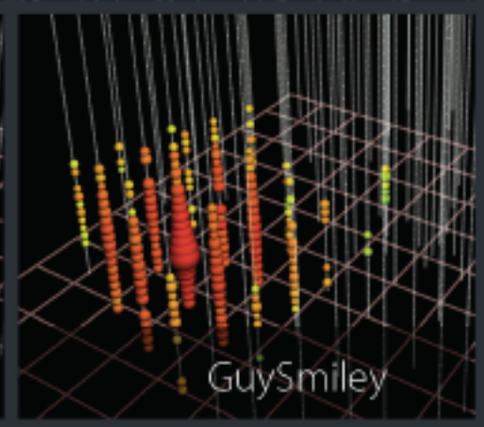


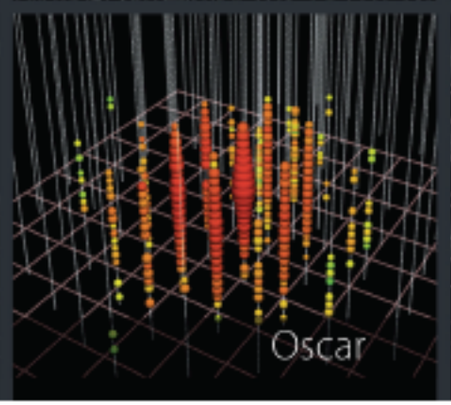


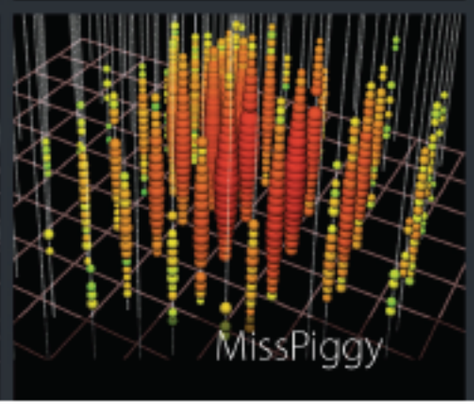


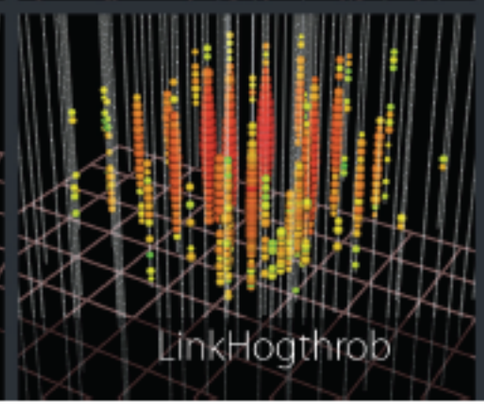






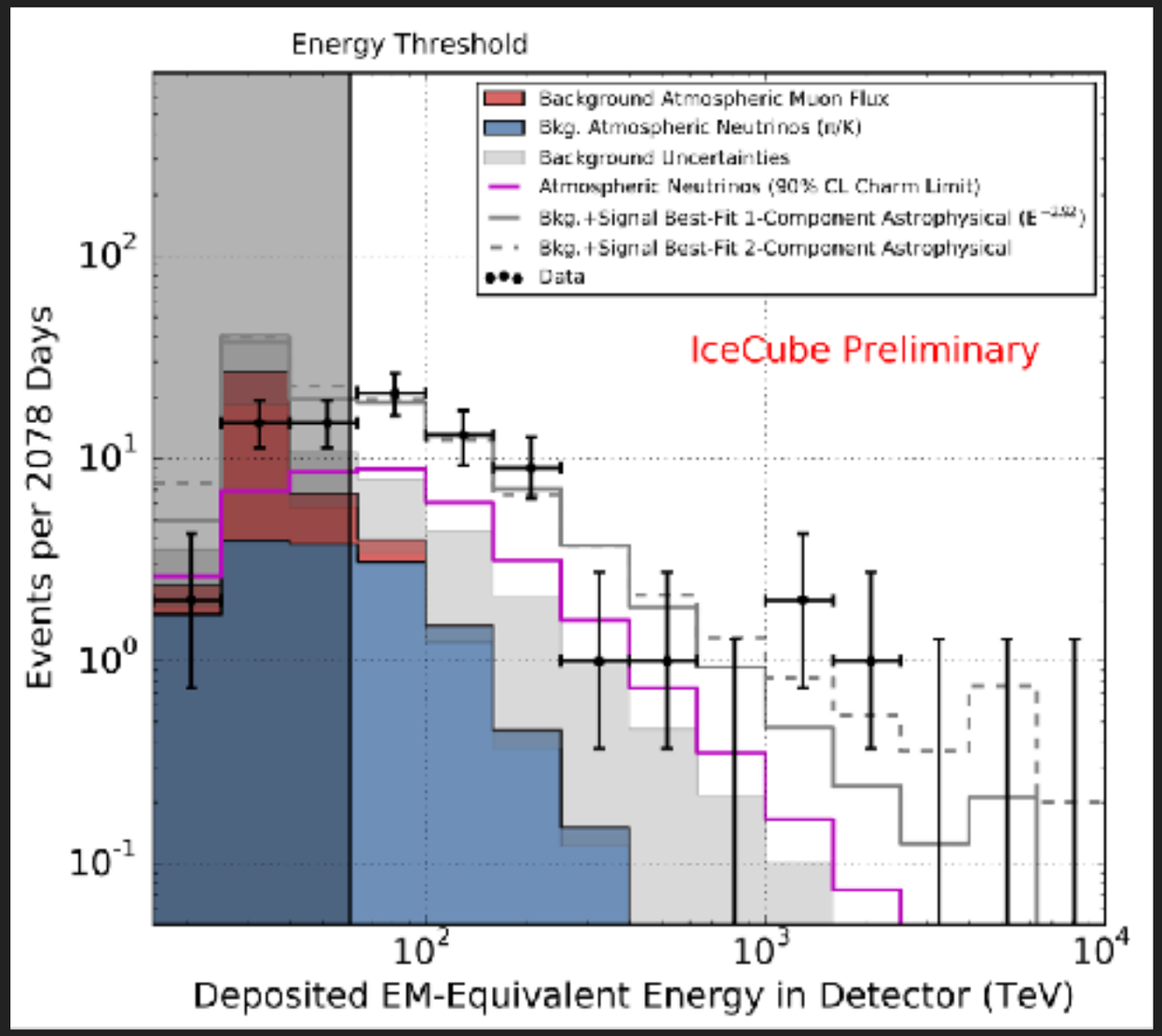


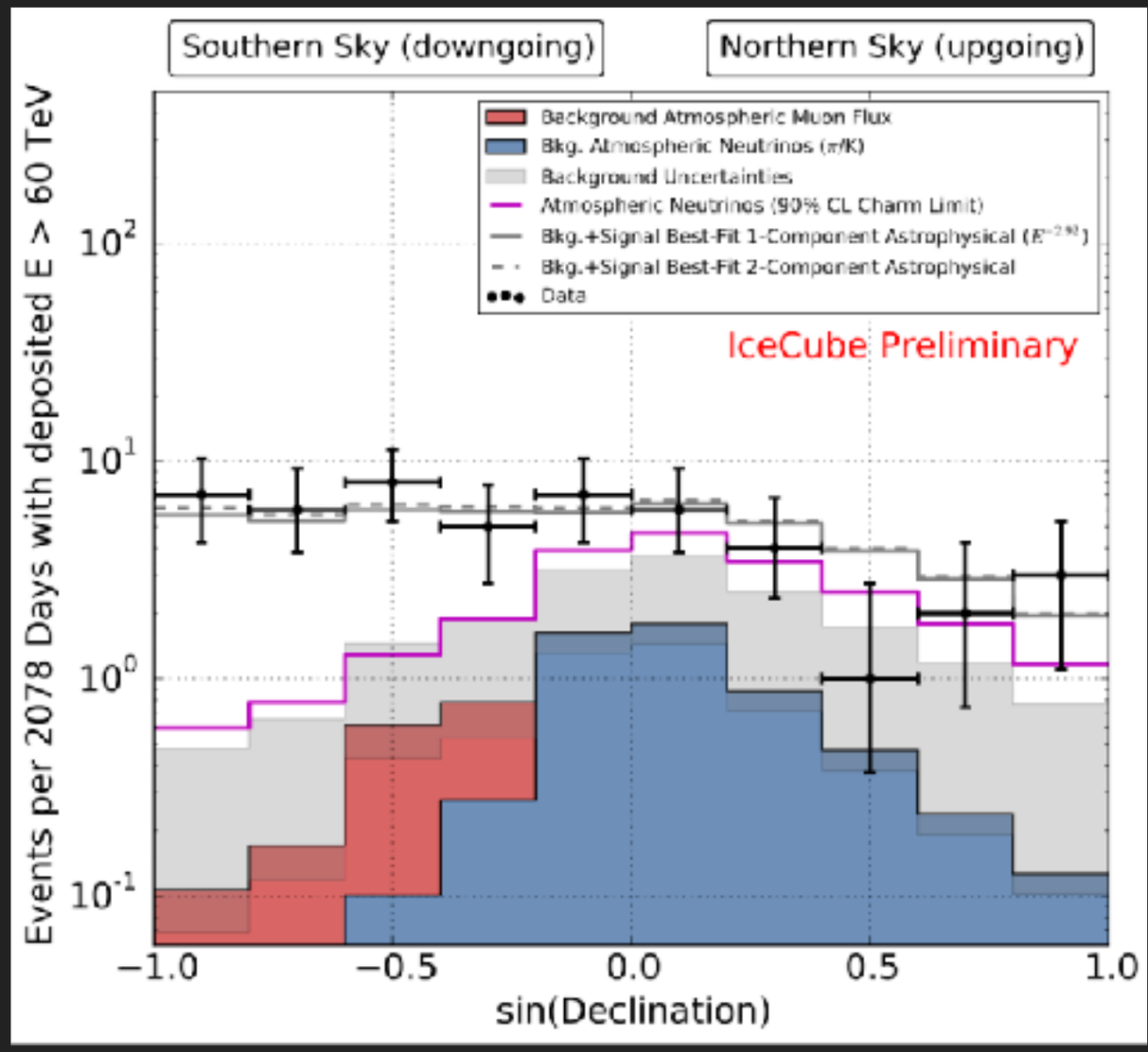




DISCOVERY OF HIGH ENERGY COSMIC NEUTRINOS

[The IceCube Coll., ICRC'17]



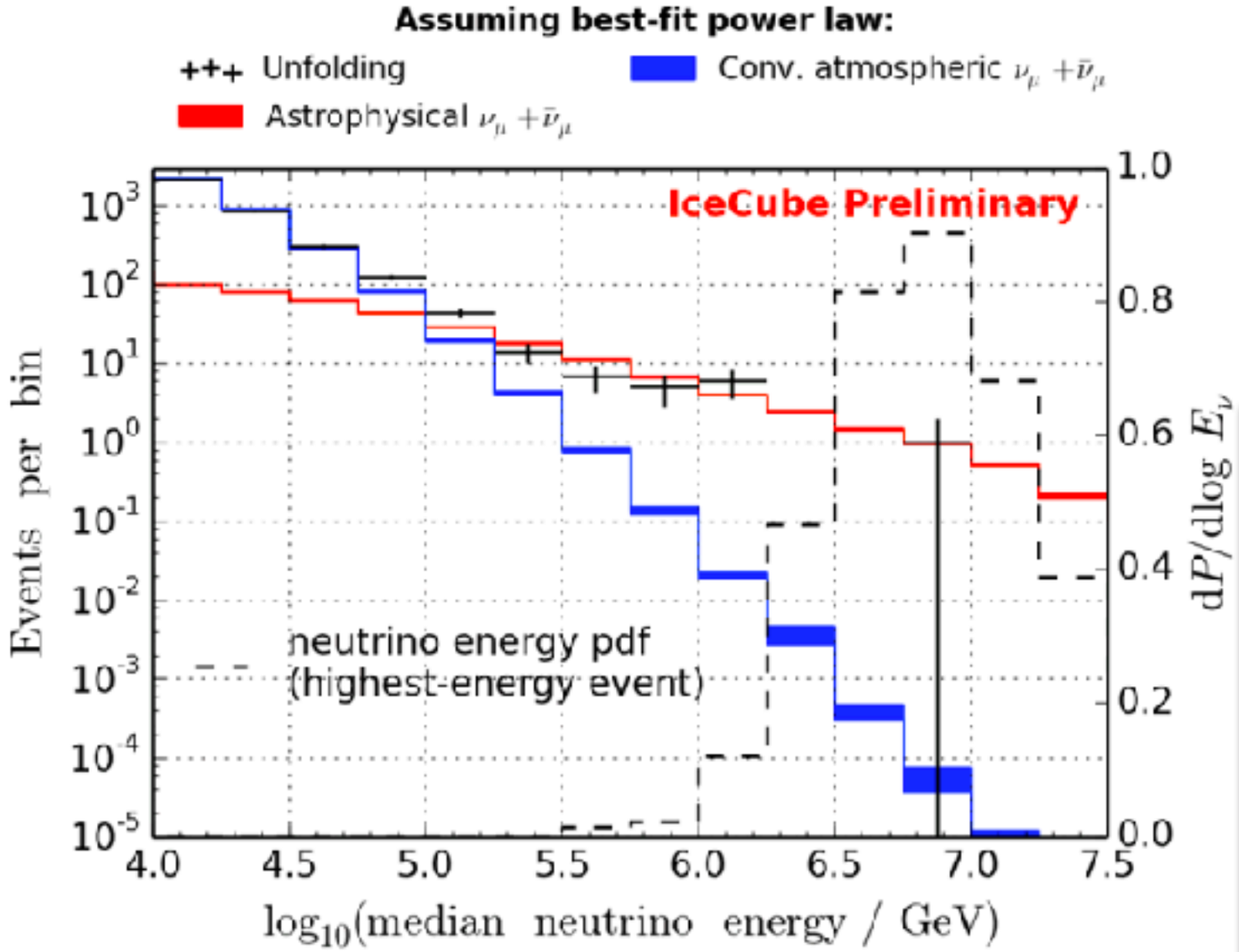


$E^2\varphi(E) = 2.46 \pm 0.8 \times 10^{-8} (E/100\text{TeV})^{-0.92} \text{GeV cm}^{-2} \text{s}^{-1} \text{sr}^{-1}$ (single component hypothesis) > 5 σ excess

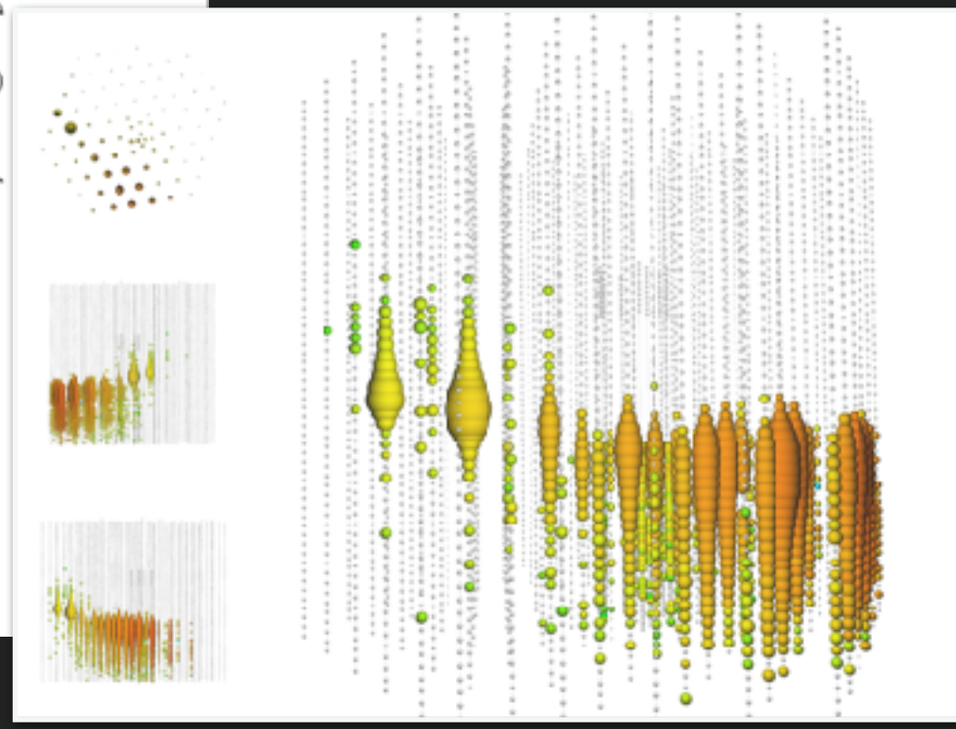
DISCOVERY OF HIGH ENERGY COSMIC NEUTRINOS

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

~ 550 cosmic neutrinos in a background of ~340,000 atmospheric atmospheric background: less than one event/deg^2/year



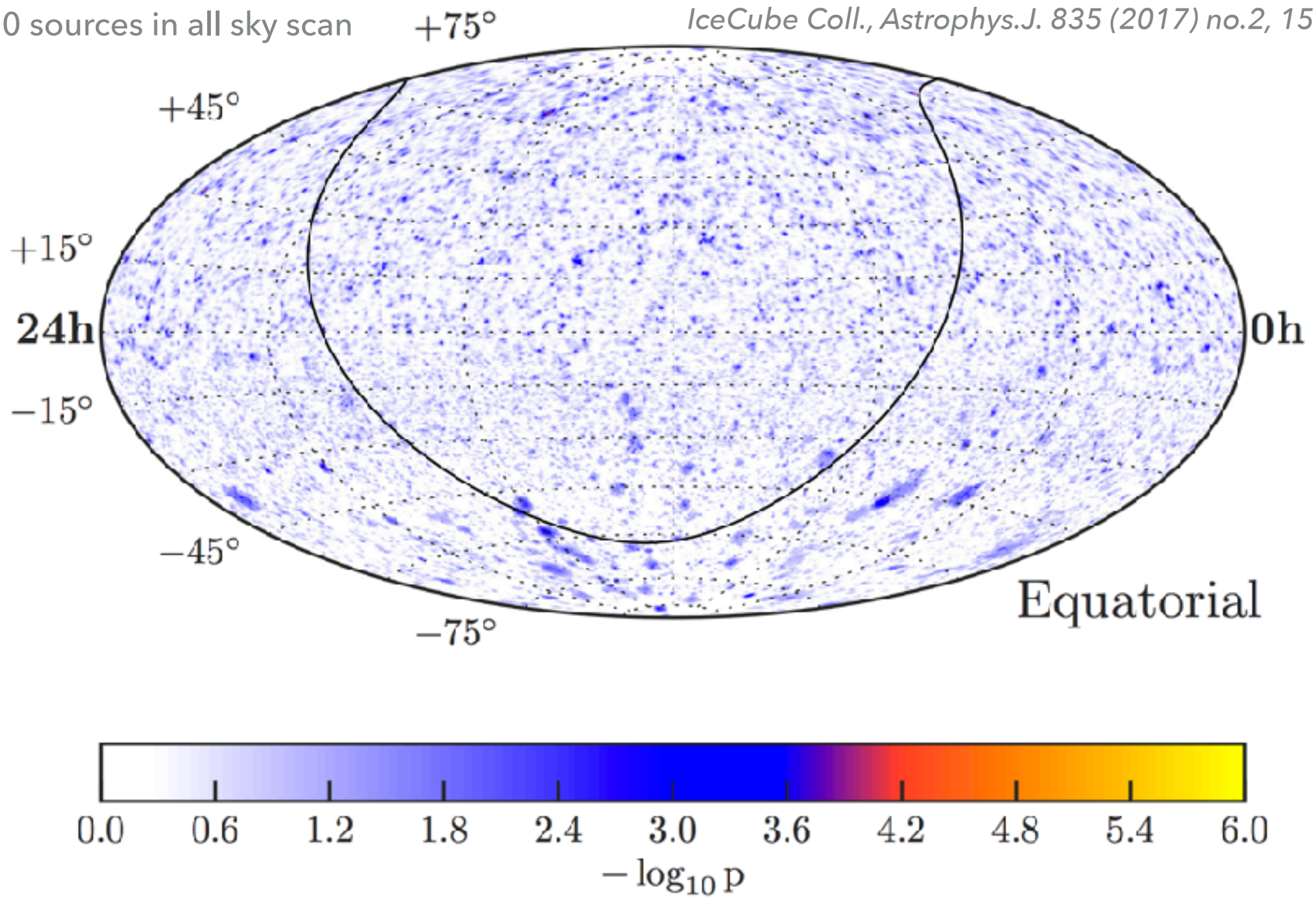
2.6 PeV deposited
interaction outside the detector



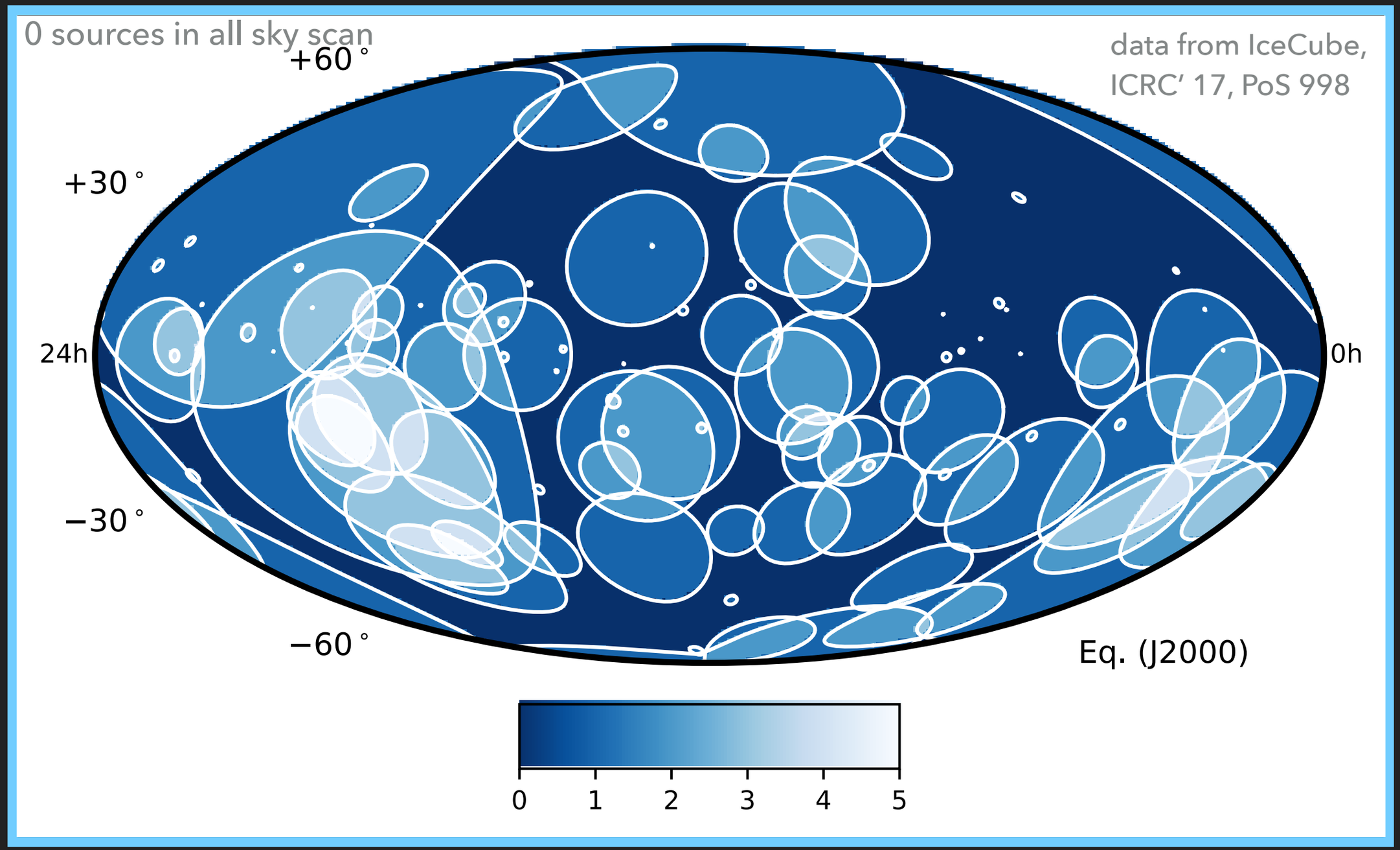
THE OBSERVATIONS: 10^{12}–10^{15} eV SKY IN NEUTRINOS

0 sources in all sky scan

IceCube Coll., Astrophys.J. 835 (2017) no.2, 151

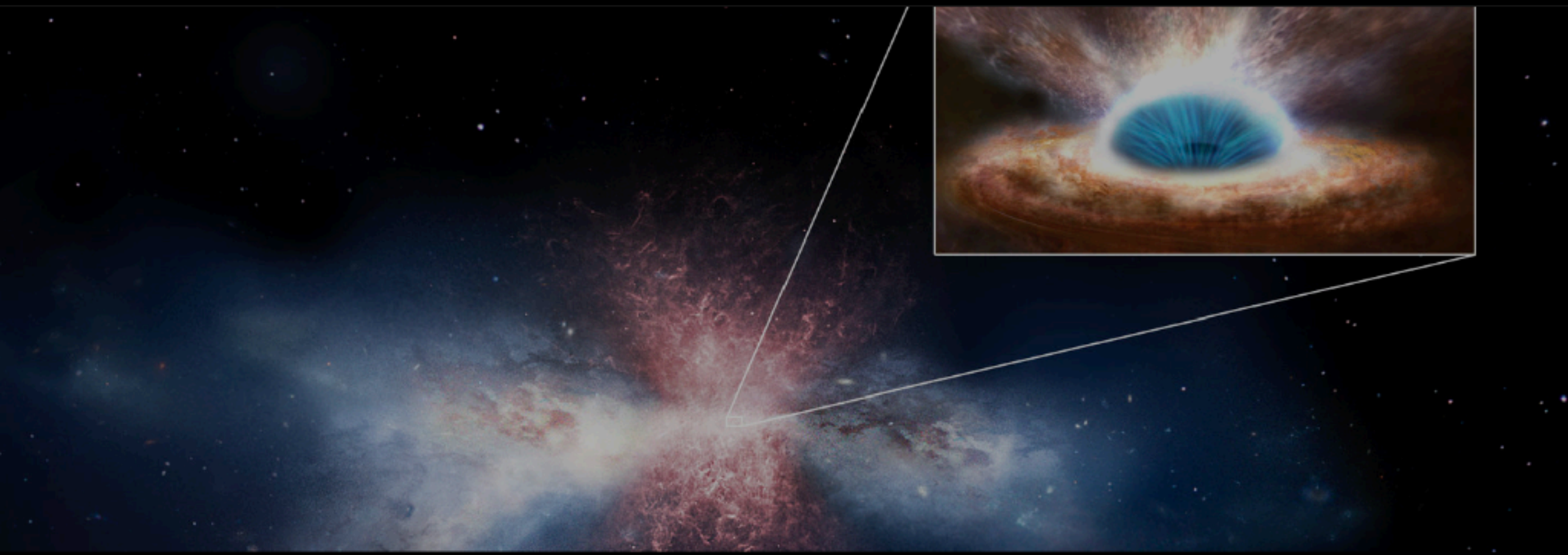


THE OBSERVATIONS: 10^{12}–10^{15} eV SKY IN NEUTRINOS



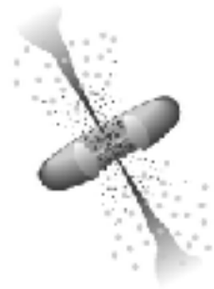
– BLAZARS –

AMONG THE MOST ENERGETIC PHENOMENA IN THE UNIVERSE



MOST PROBABLE CANDIDATE SOURCES FOR NEUTRINOS?

BLAZARS: CLASSIFICATION



[Padovani, Giommi, '95]

Jet dominated AGN. The radiation output is mostly due to non-thermal radiation from a relativistic jet, ~ few% of all AGN

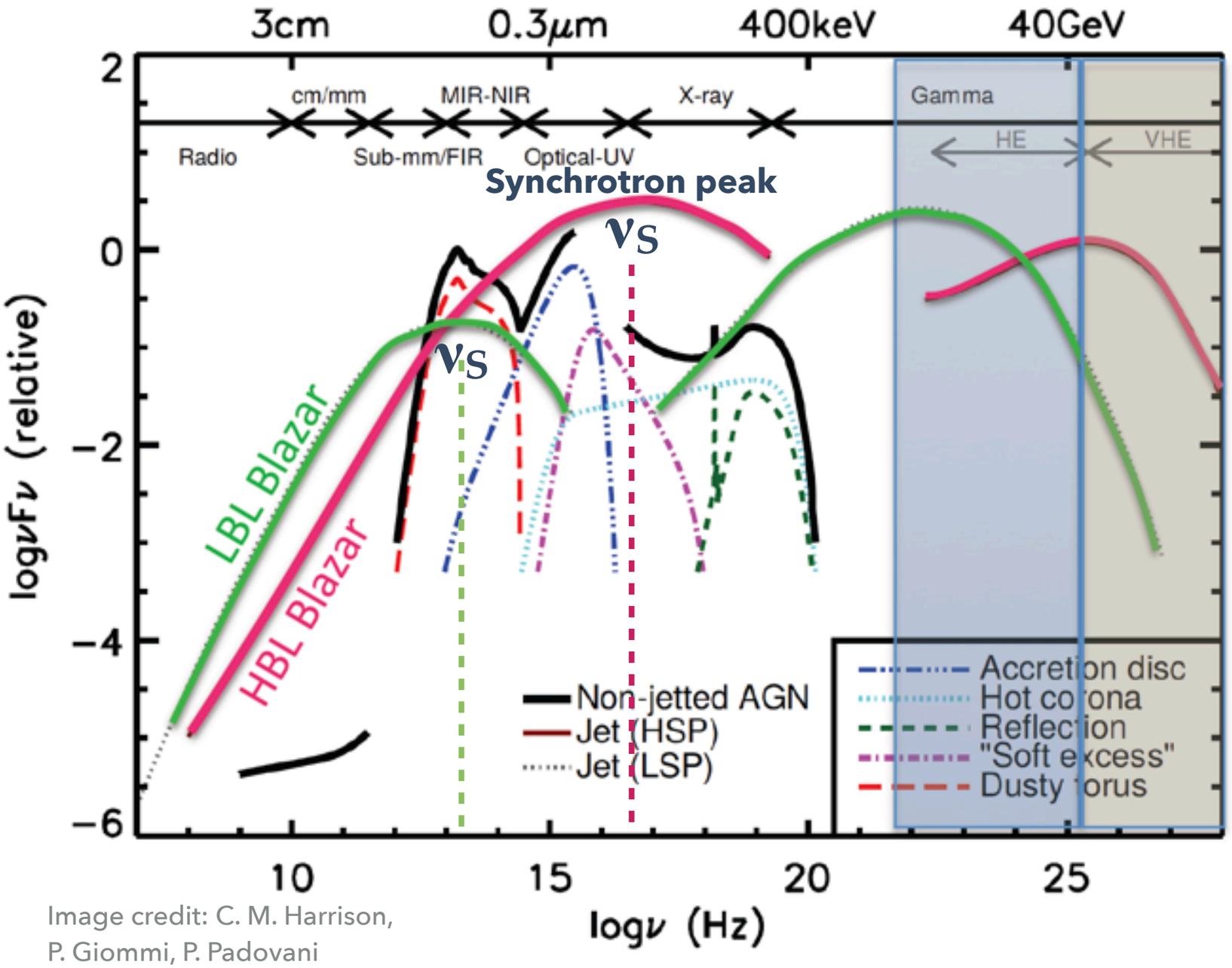


Image credit: C. M. Harrison, P. Giommi, P. Padovani

- **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

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

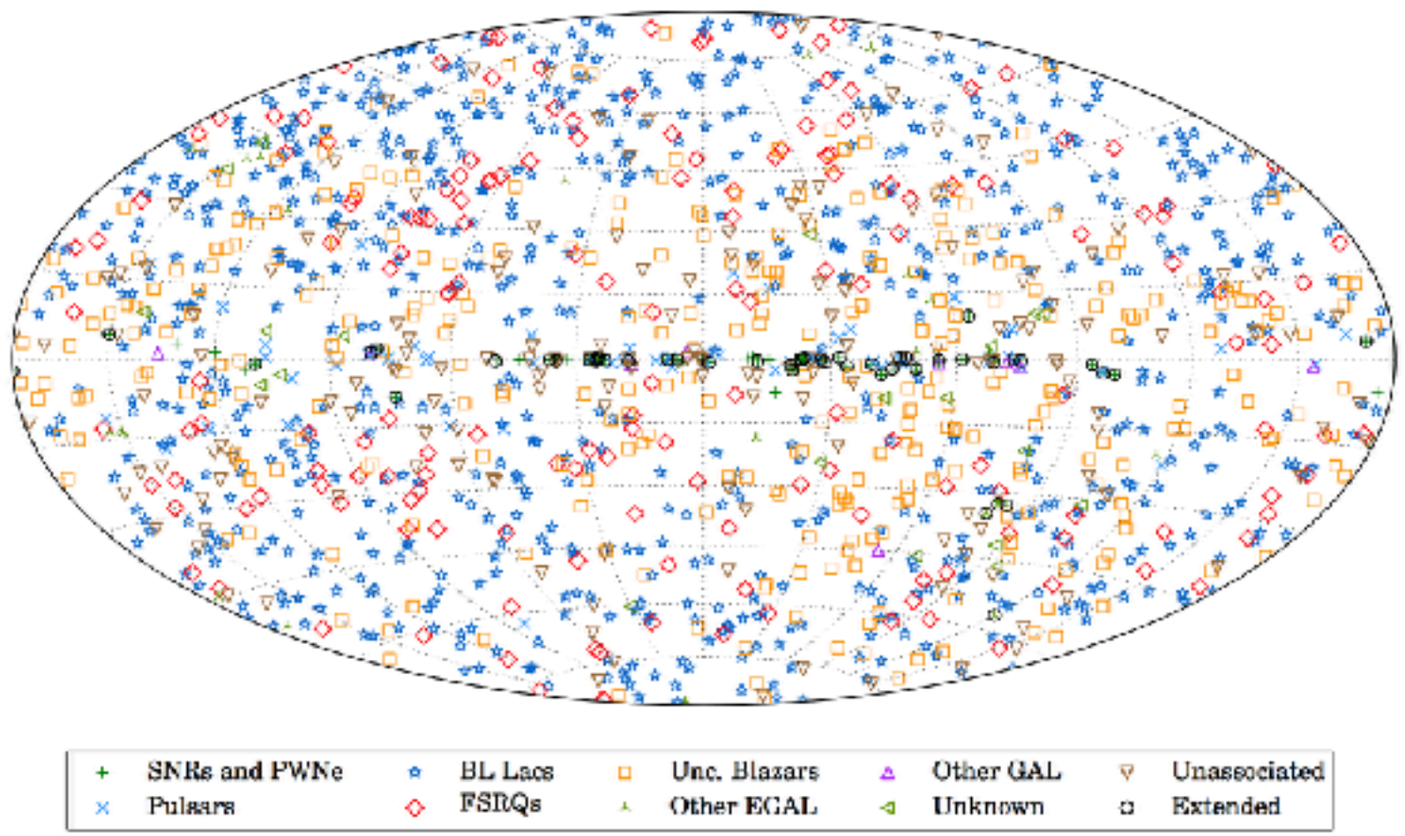
THE CATALOGUES: AT HIGH ENERGY DOMINATED BY BL LACS / HSP

Bzcat5; 2WHSP; 2FHL; 3FHL [10GeV– 2TeV]

[Massaro et al. (2015); Y. L. Chang et al., A&A (2017); Fermi Collaboration, arXiv:1702.00664]

3FHL: 1556 objects

BL Lac	712
FSRQ	141
blazar candidate	309
SFR, SBG	1, 4
SNR	17
PWN	8



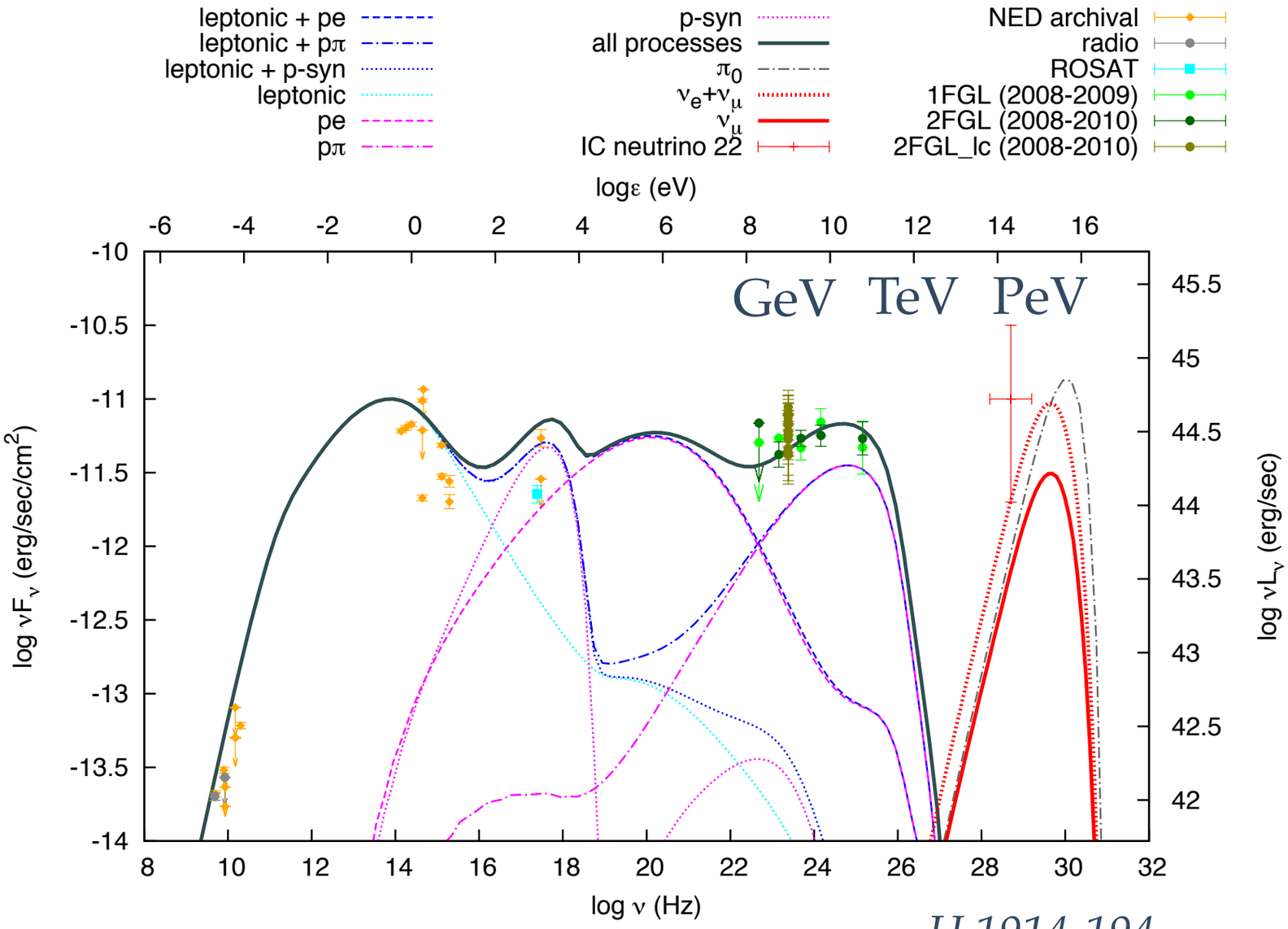
As of today, well over 4,000 blazars are known. This number is increasing rapidly but it remains a small percentage of the over one million AGN known

EXTREME BLAZARS: NEUTRINO CONNECTION?

γ ∝ ν for HSP

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

z	0,137
B(G)	5
R(cm)	3×10^{15}
δ	18
$\ell_{(e,inj)}$	6×10^{-5}
$\ell_{(p,inj)}$	10^{-2}
$\gamma_{\nu\gamma}$	2,0



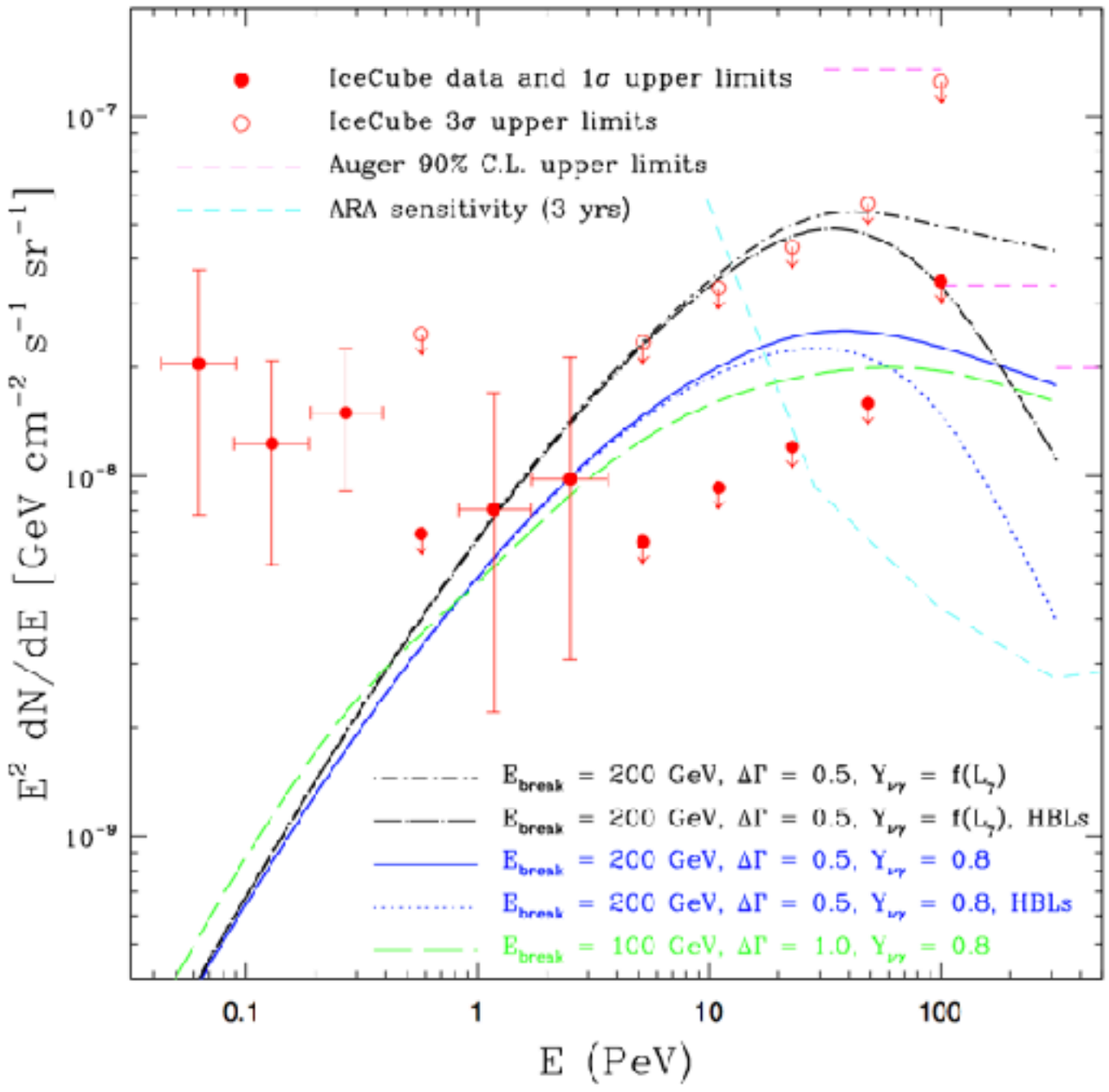
BL LACS AS A CLASS: THE HYPOTHETICAL NEUTRINO BACKGROUND

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

- Based on Monte Carlo simulations - *blazar simplified view* (BSV)
- BSV - reproduces X-ray, γ-ray blazar surveys, extragalactic γ-ray background > 10 GeV
- the neutrino background is derived by summing up at a given energy the fluxes of each BL Lac in the simulation, all characterised by their own redshift, synchrotron peak energy, γ-ray flux, etc
- hadronic component “calibrated” on few candidates (over-predicting by construction)

BL LACS AS A CLASS: COMPONENT OF THE NEUTRINO BACKGROUND

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



THE SEARCHES: EXTREME BLAZARS FOR EXTREME MESSENGERS?

(Gamma) Photons

↳Secondaries

↳Not charged

↳Interact, limited horizon

Reconstruction:

↳excellent angular resolution

↳excellent energy resolution

(HE) Neutrinos

↳Secondaries

↳Not charged

↳Three flavours

↳Interact weakly, nearly unlimited horizon

Reconstruction:

↳poor angular resolution in shower, good in tracks

↳poor energy resolution in tracks, good in showers

(UHE) Cosmic Rays

↳Primaries

↳Charged

↳Composition

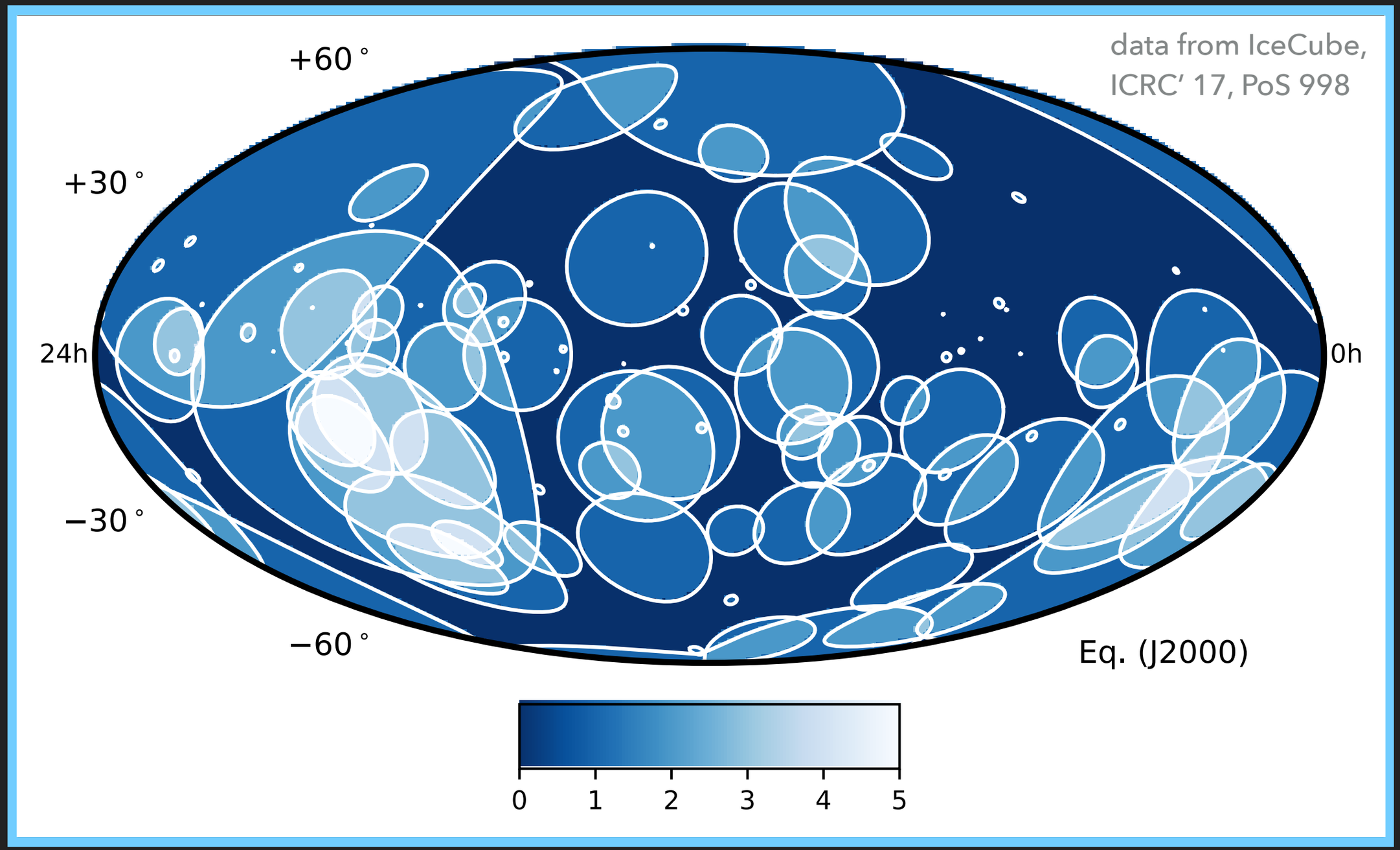
↳Interact, limited horizon

Reconstruction:

↳good angular resolution, bending

↳good energy resolution

ICECUBE: 10^{12}–10^{15} EV SKY IN NEUTRINOS

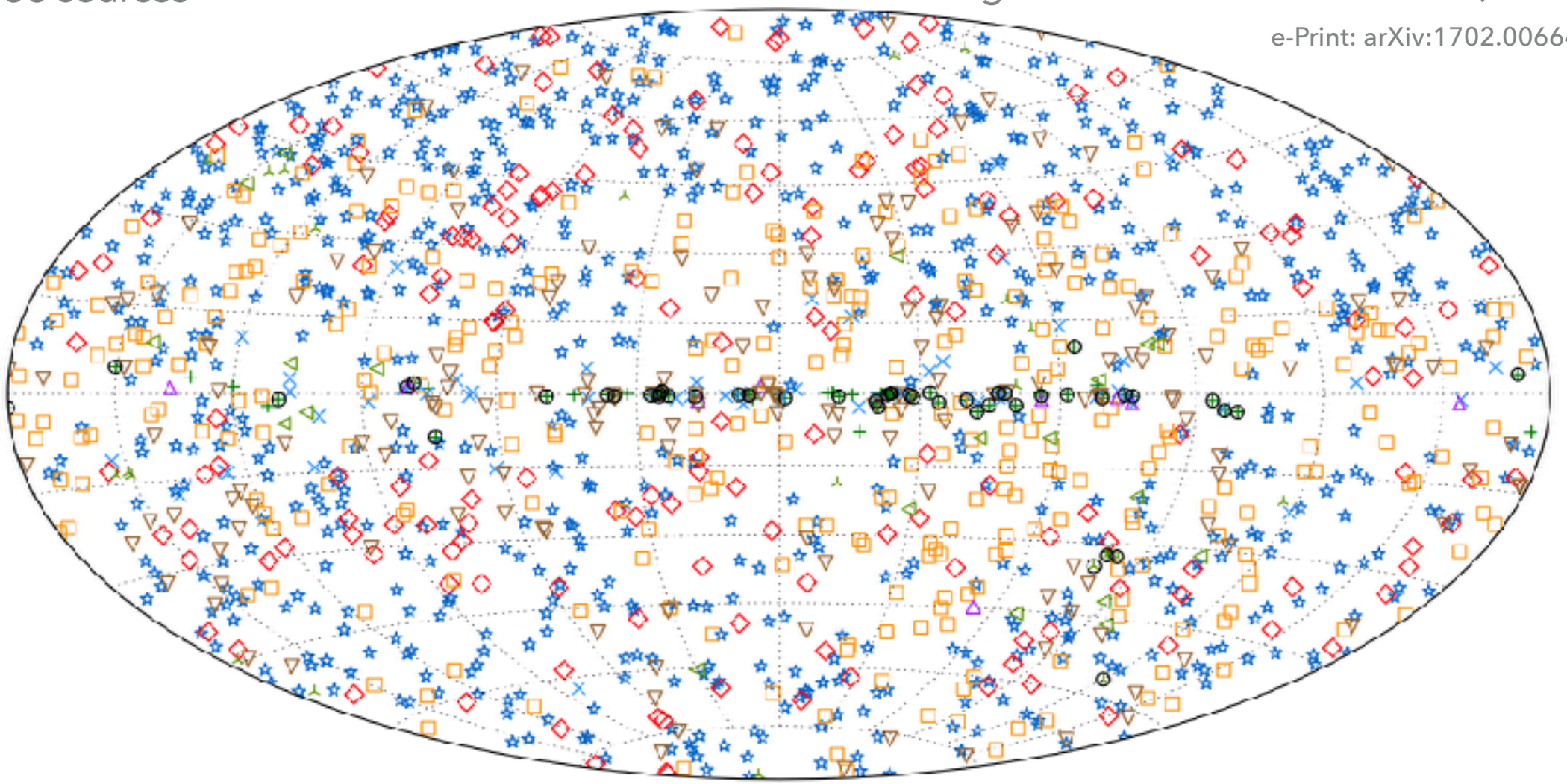


FERMI: 10^{10}–10^{12} eV SKY IN PHOTONS

1556 sources

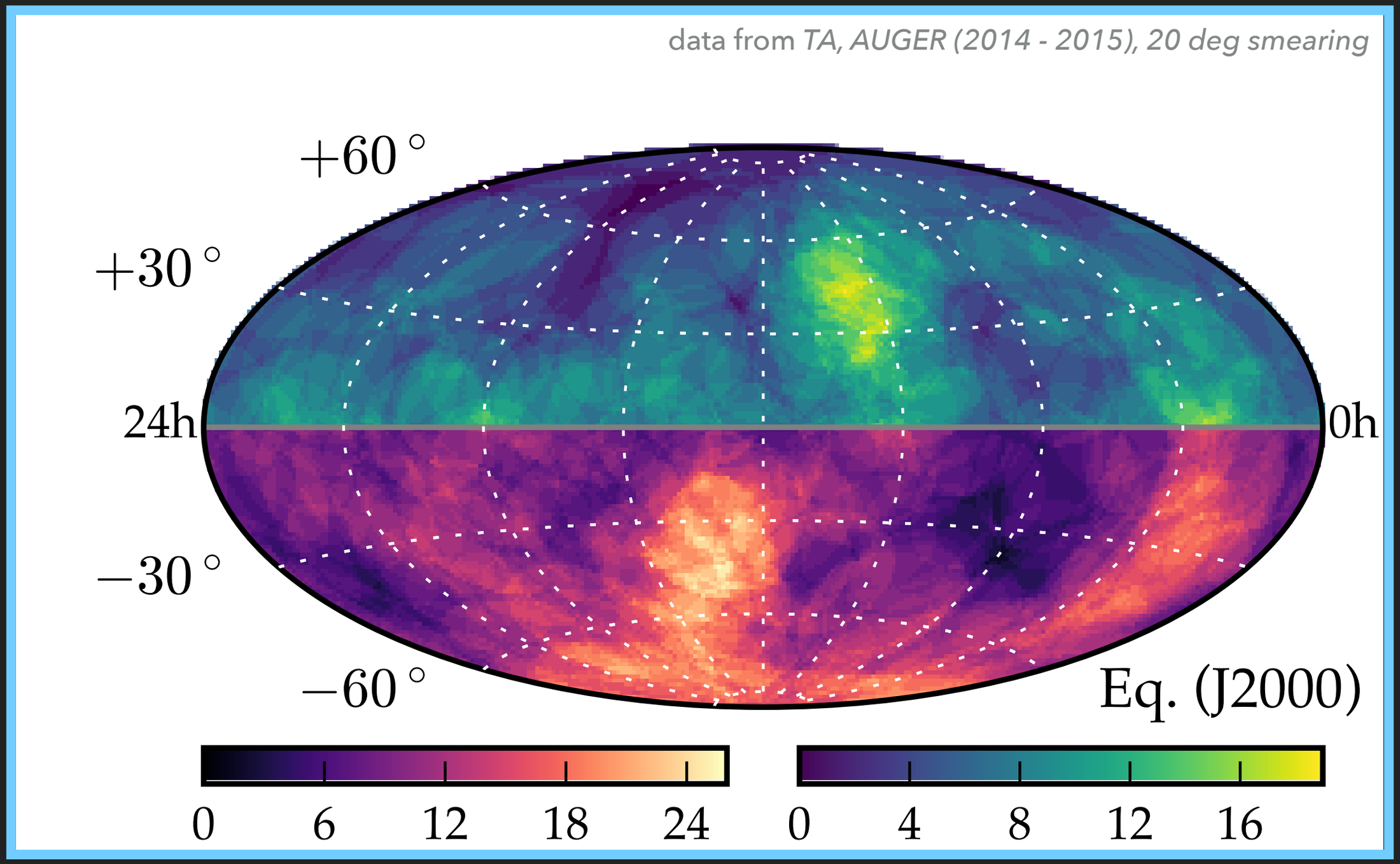
Third Catalog of Hard Fermi-LAT Sources (3FHL)

e-Print: arXiv:1702.00664

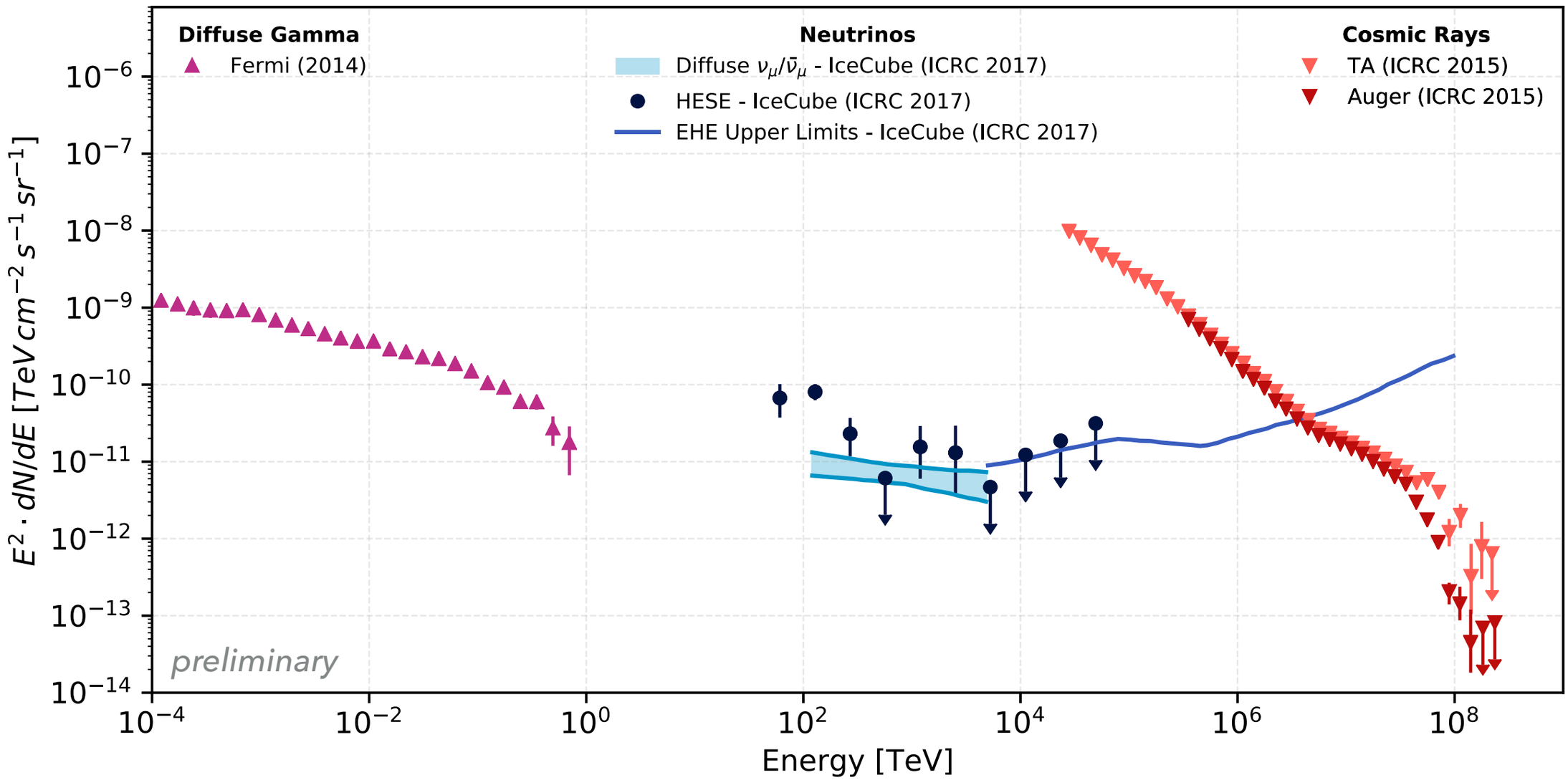


Galactic Coordinates

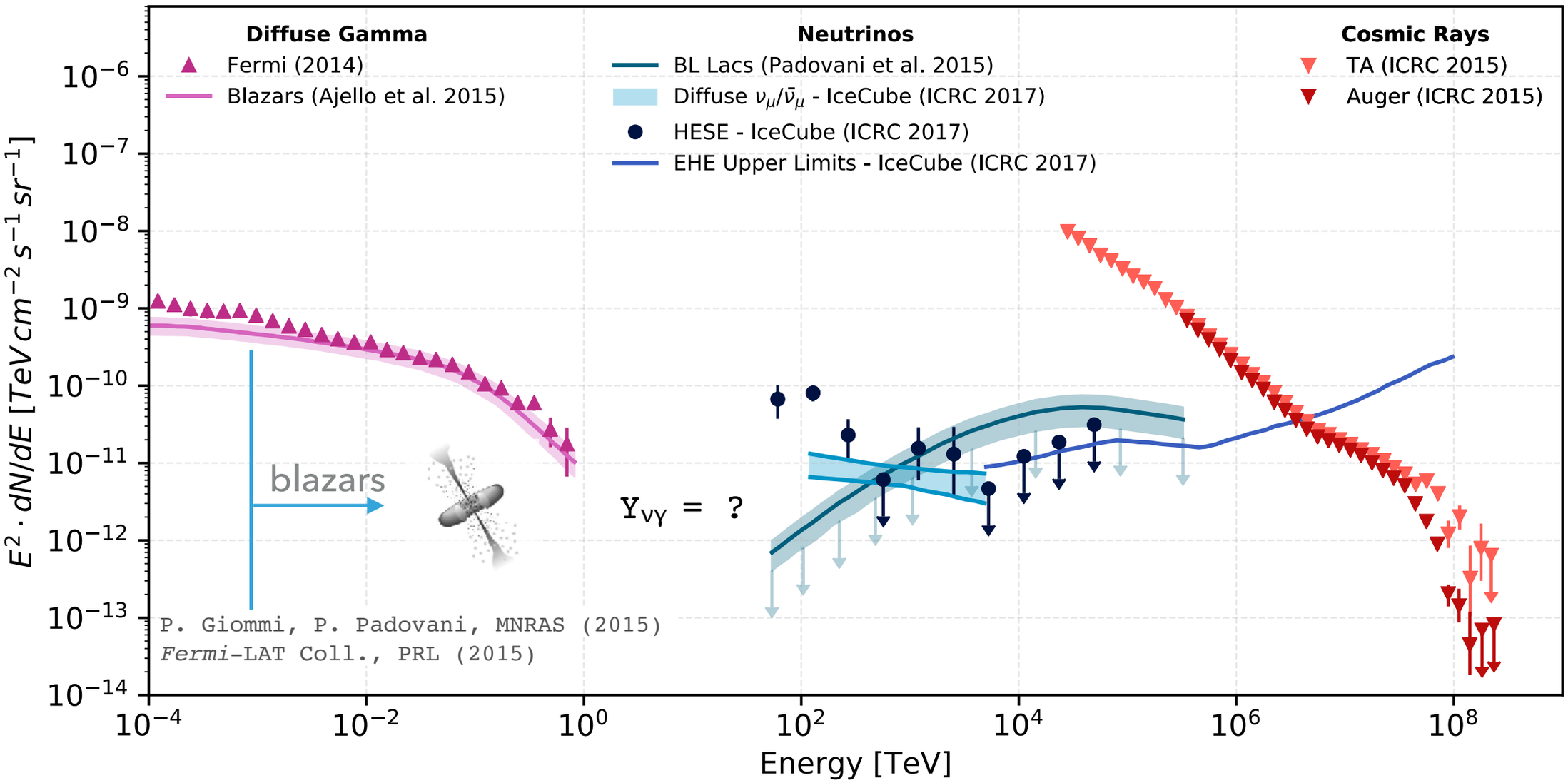
AUGER, TA: 10^{18}–10^{20} eV SKY IN COSMIC RAYS



HYBRID SPECTRAL ENERGY DISTRIBUTION



HYBRID SPECTRAL ENERGY DISTRIBUTION

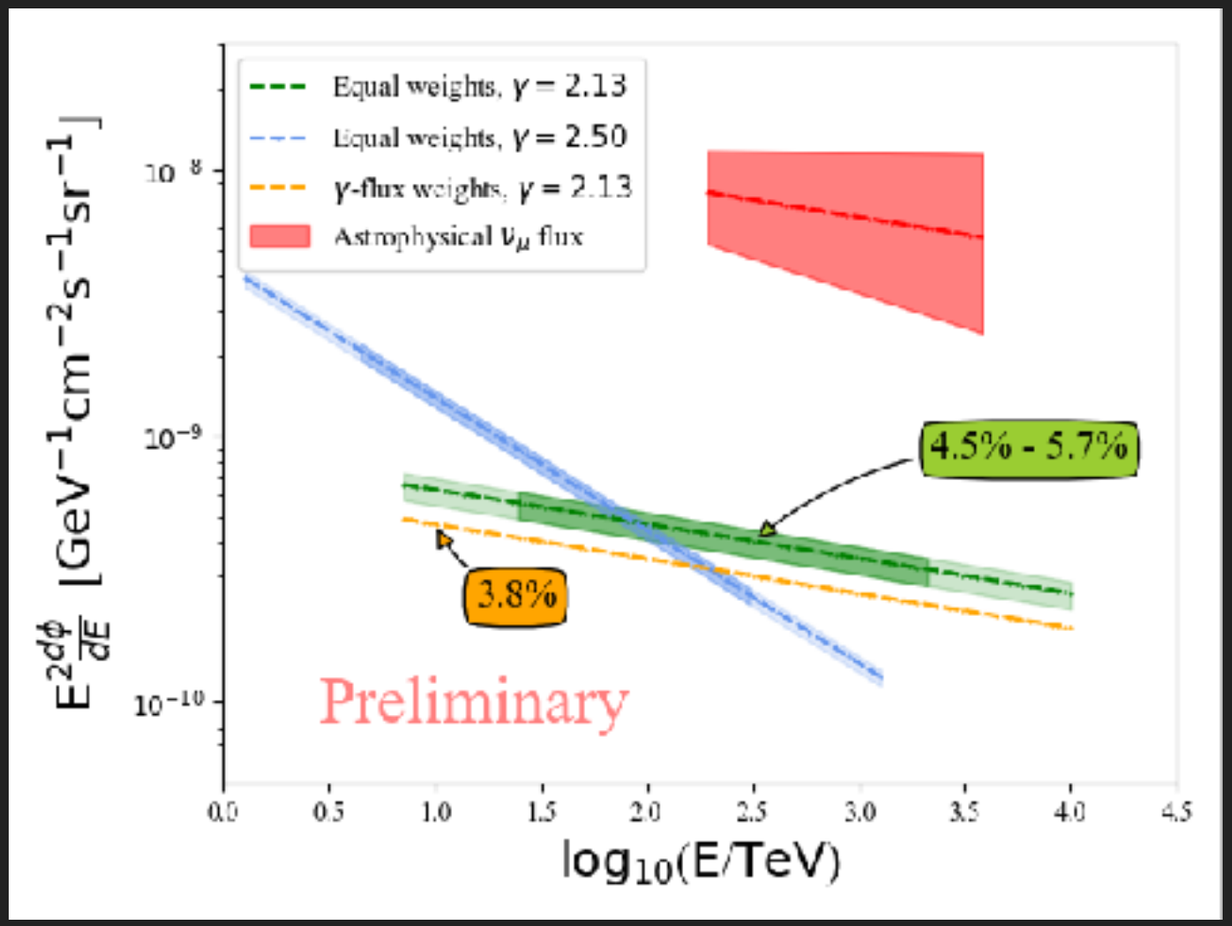


THE SEARCHES

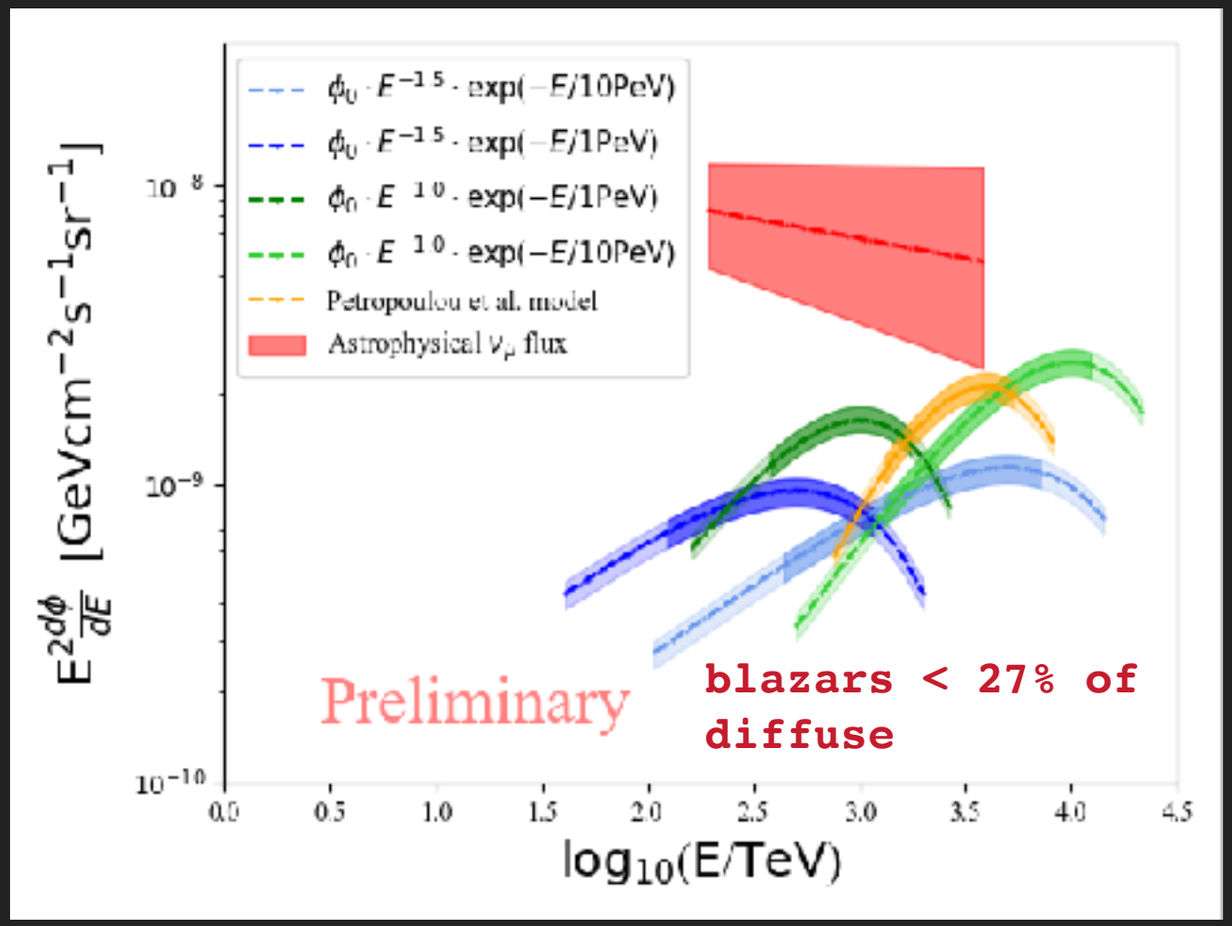
1- Blazars: interpreting upper limits

[IceCube, PoS(ICRC2017)994]

Stacking based on 7 years through going muon sample and 2FHL, 2WHSP, 3LAC catalogues



Unbroken power law assumption



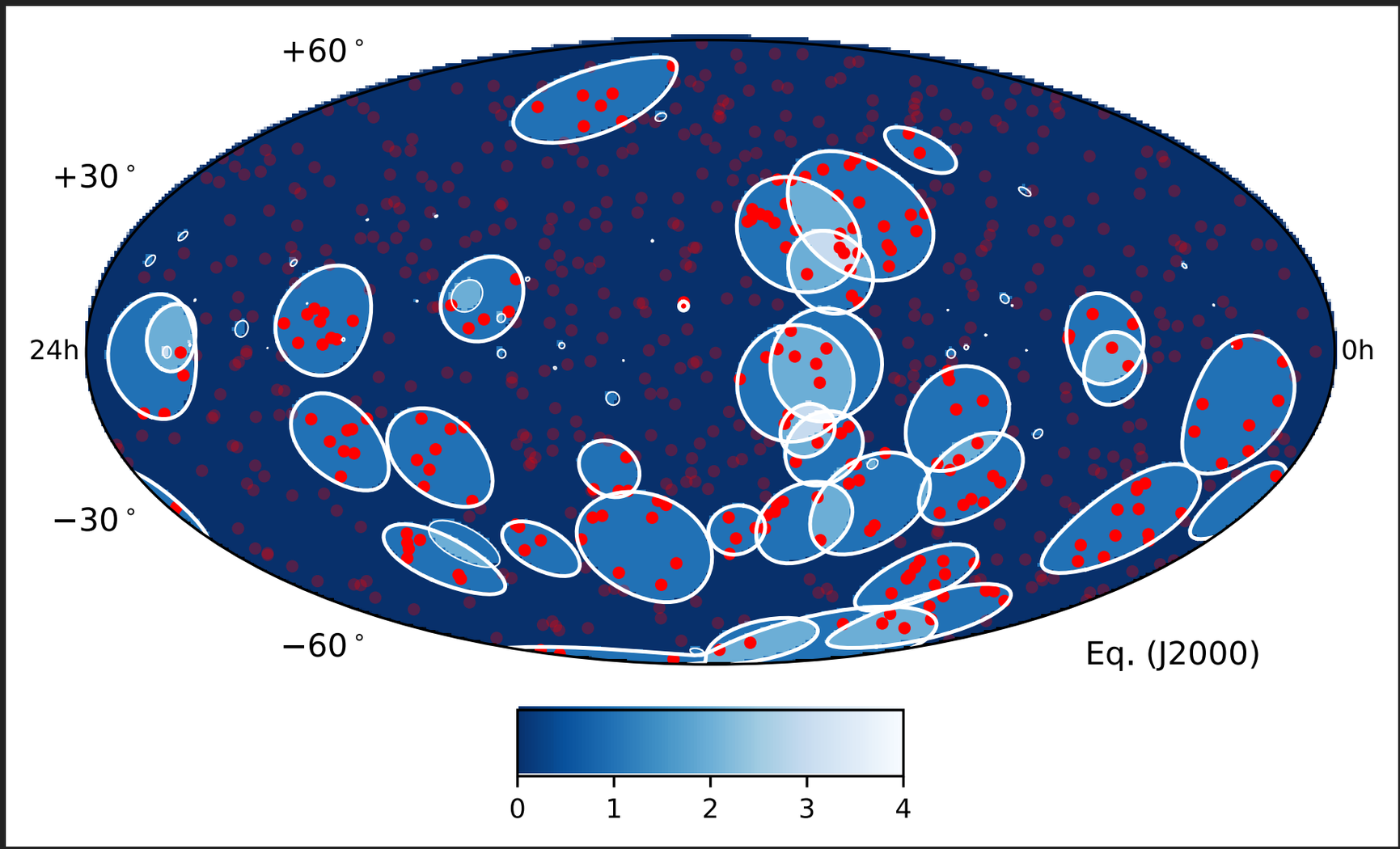
Model dependent assumption

THE SEARCHES

2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]

Neutrinos filter (2FHL, 2WHSP, 3LAT)

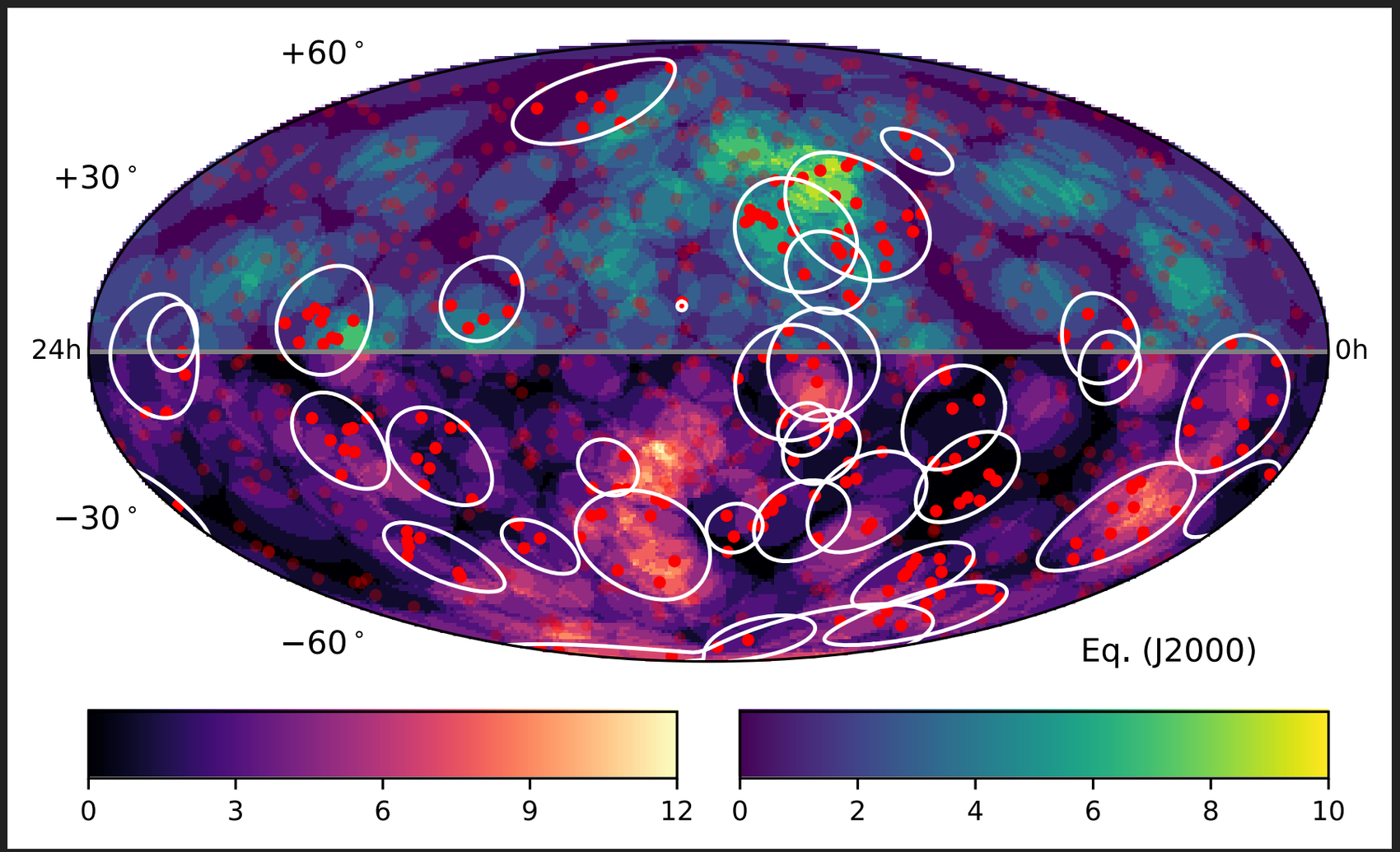


THE SEARCHES

2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]

Neutrinos filter updated to 3FHL, 6 years IceCube HESE

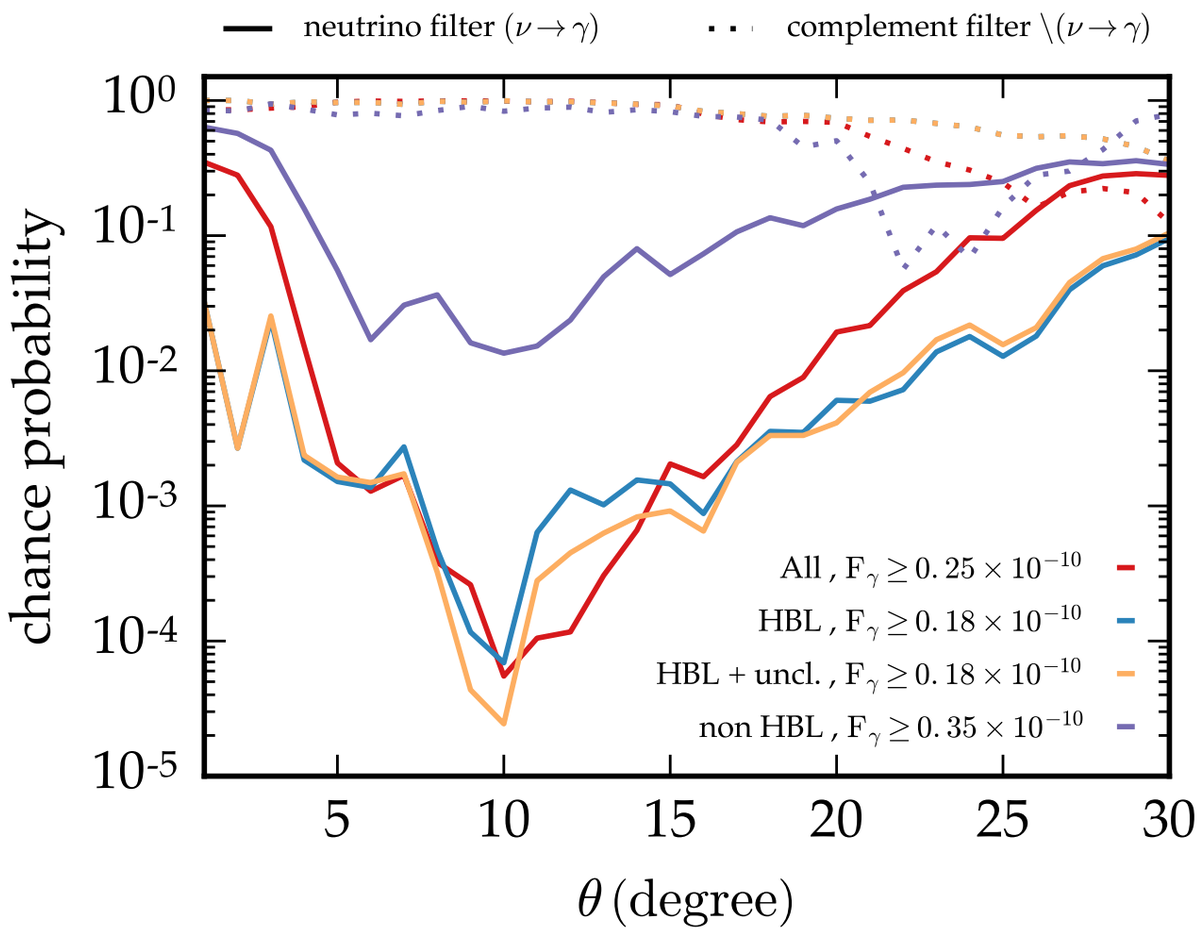


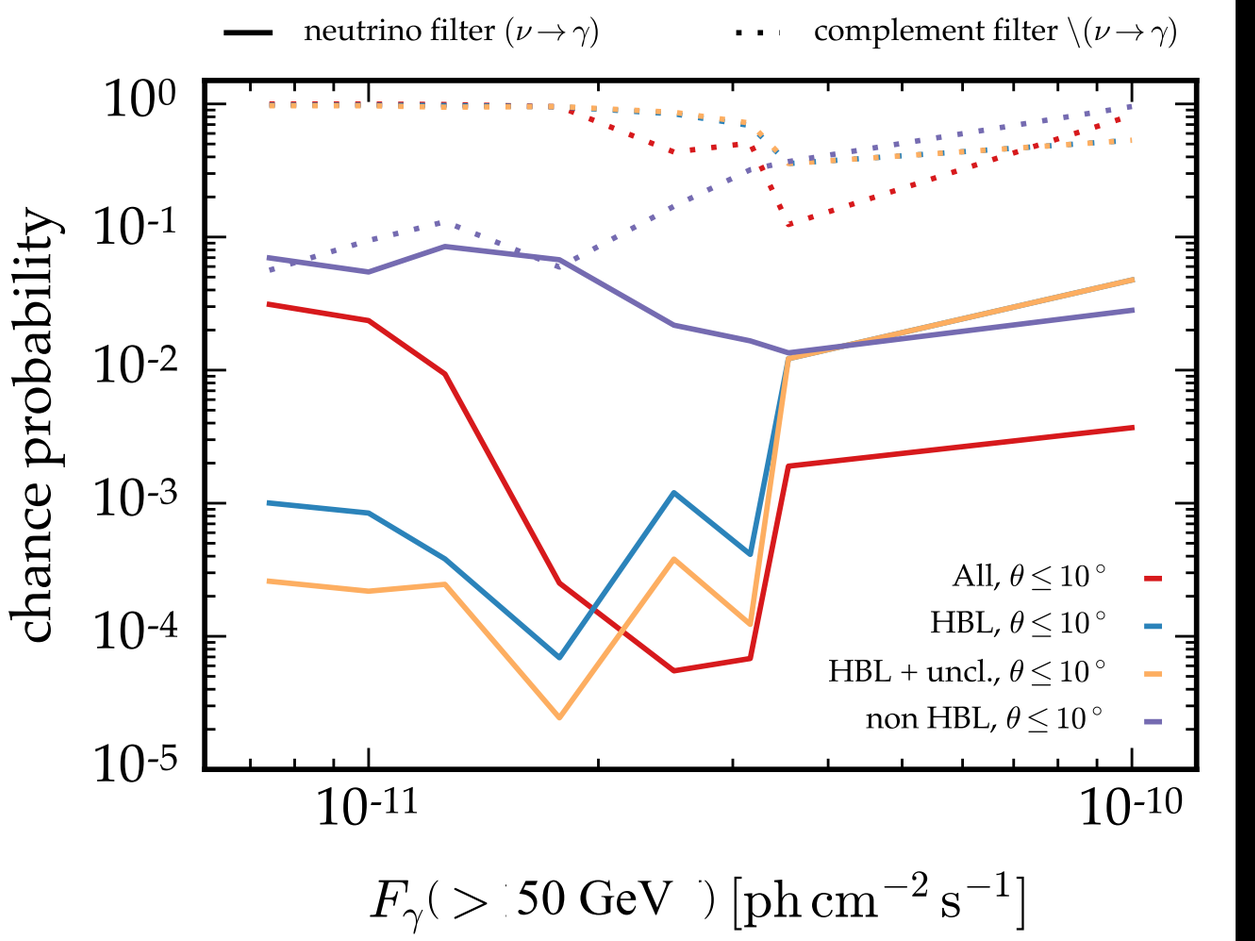
THE SEARCHES

2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]

2FHL, 4 years HESE, 2.9 σ (trial corrected)



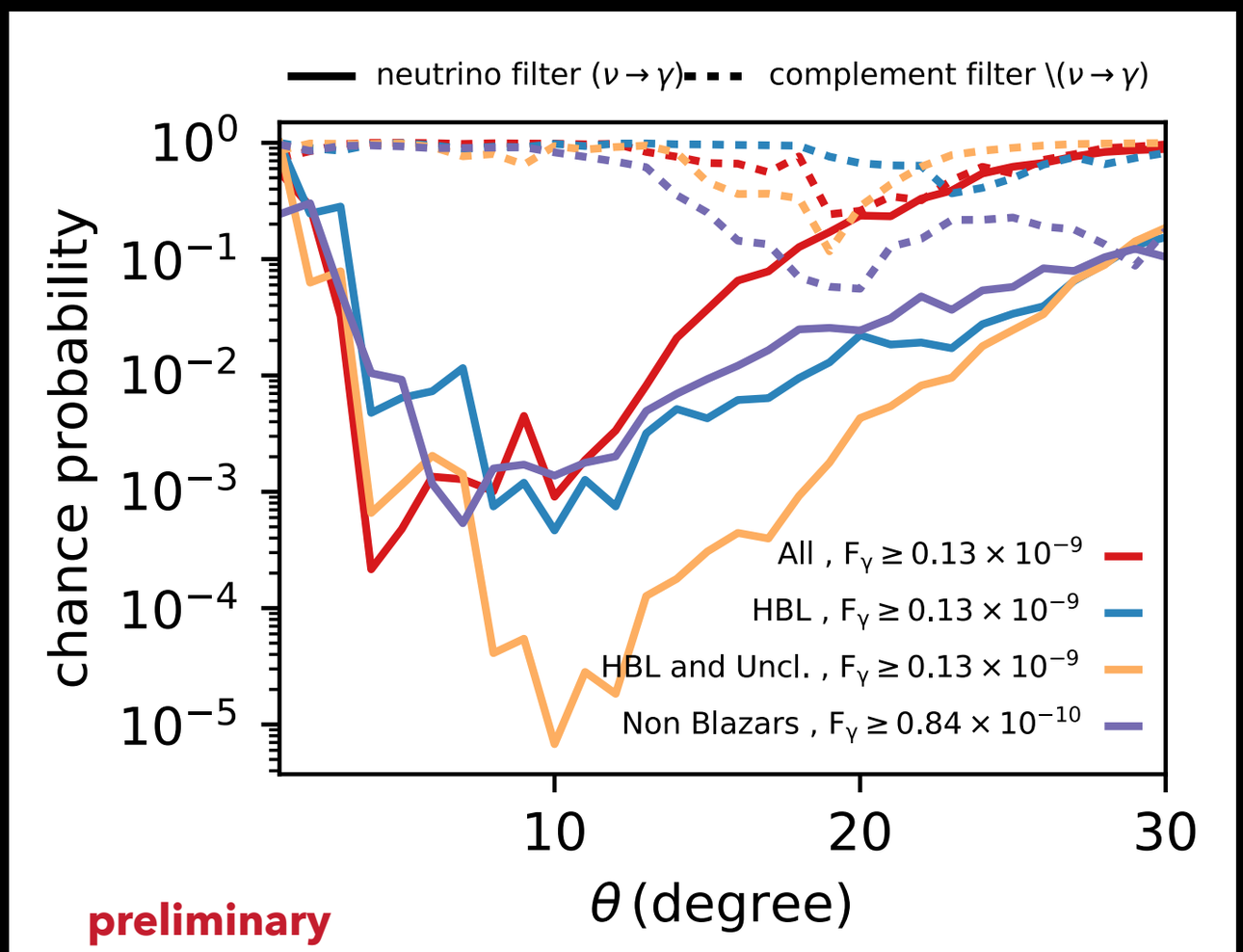


THE SEARCHES

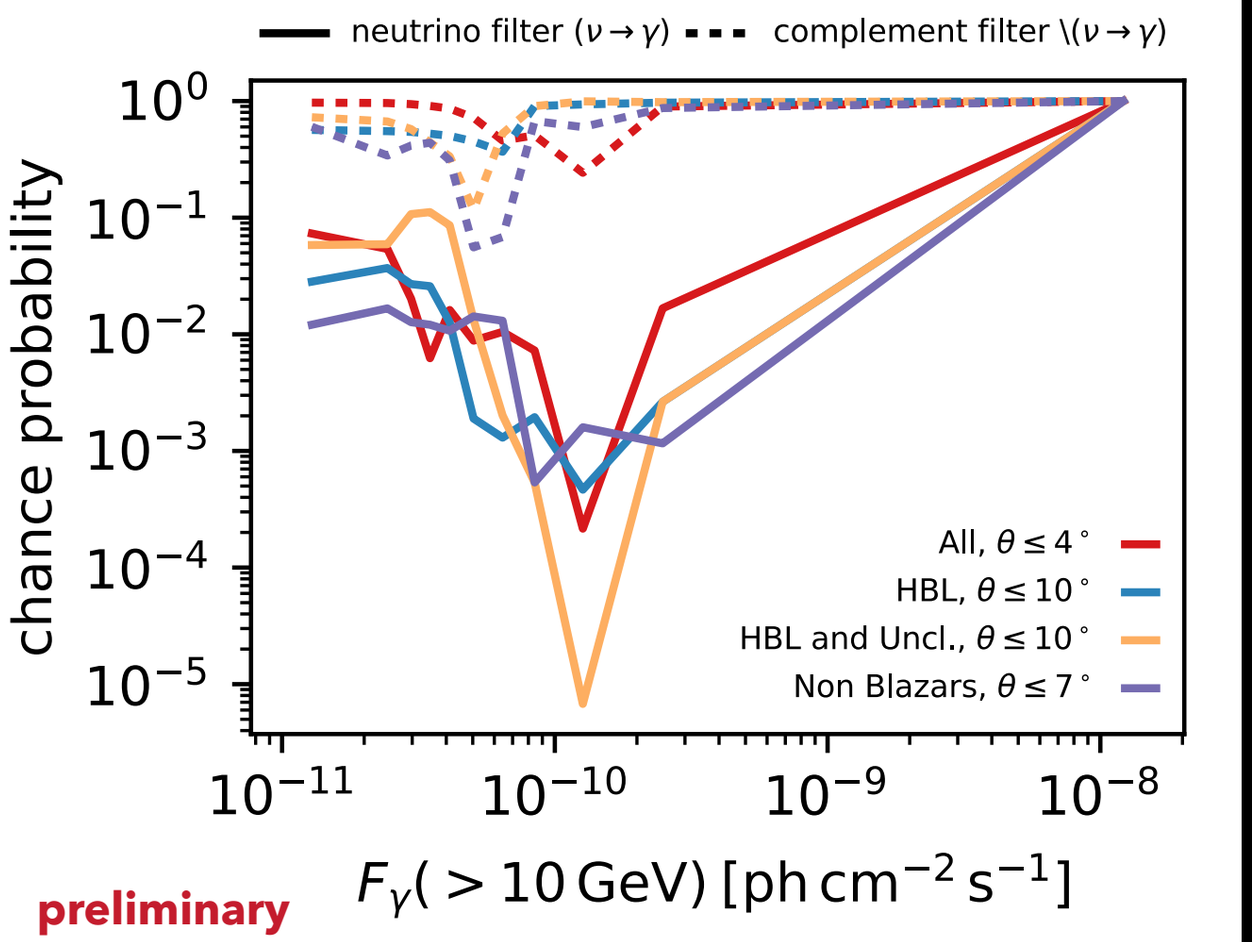
2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]

3FHL, 4 years HESE, 3.35 σ (trial corrected)



preliminary



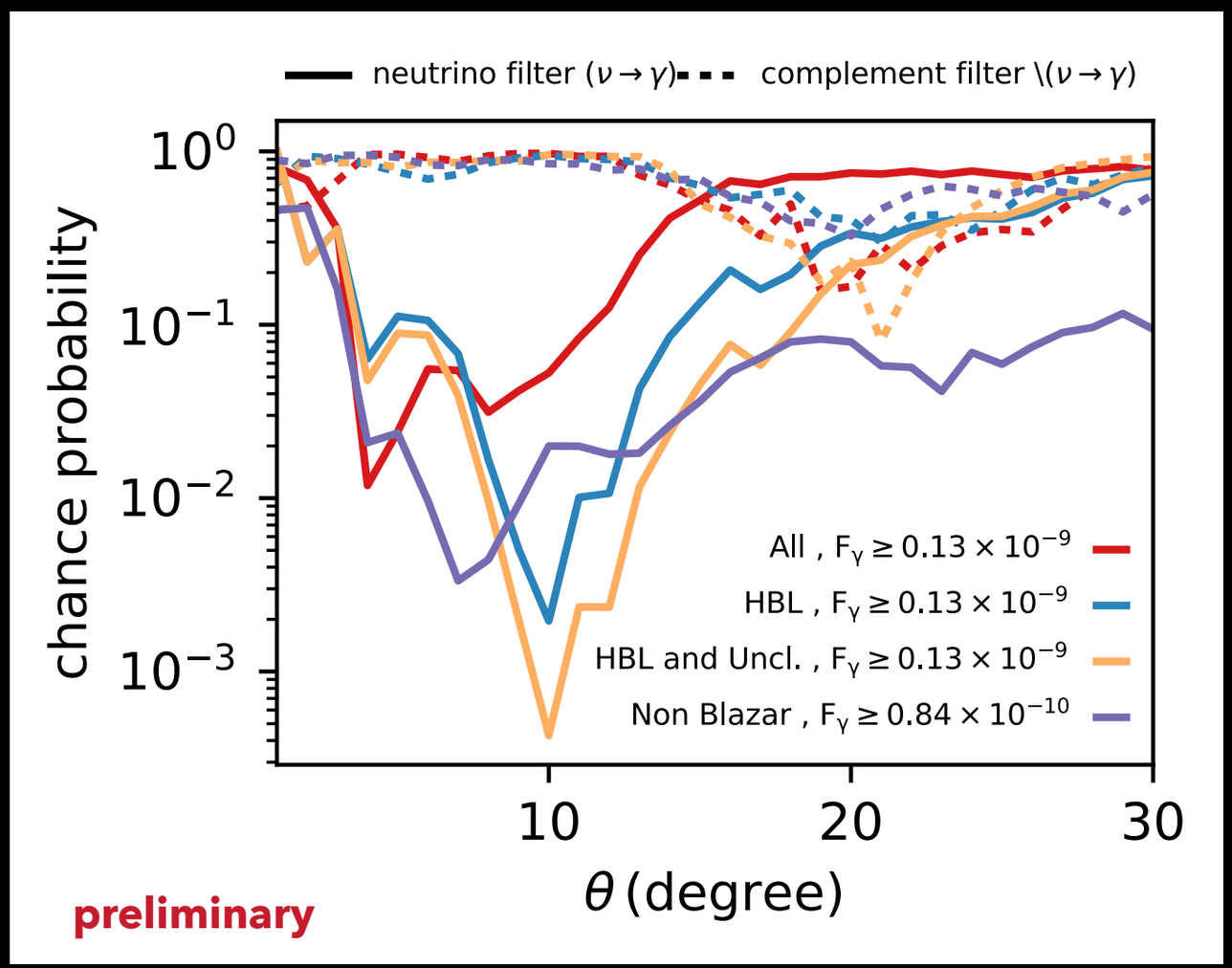
preliminary

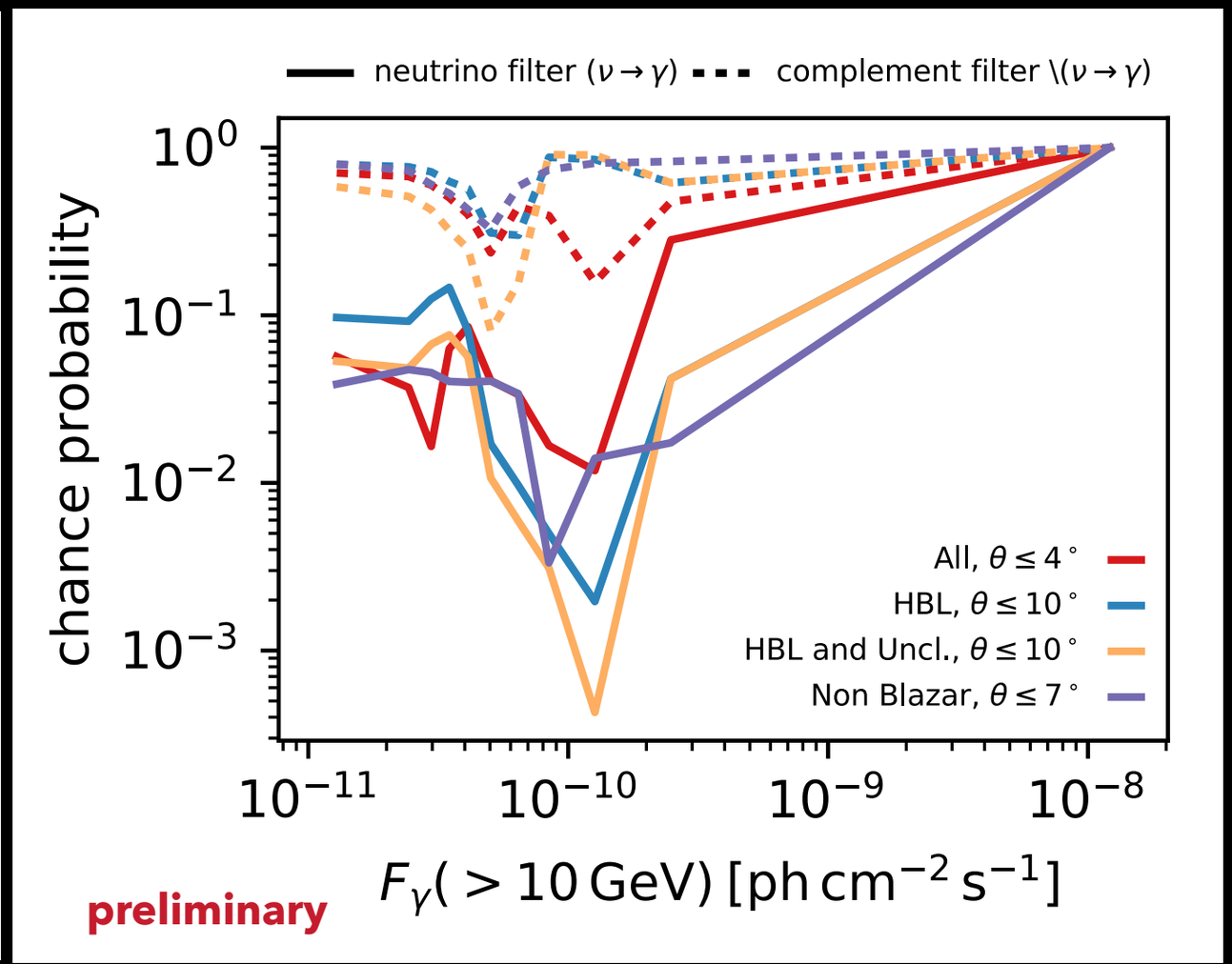
THE SEARCHES

2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]

3FHL, 6 years HESE, 2.3 σ (trial corrected)

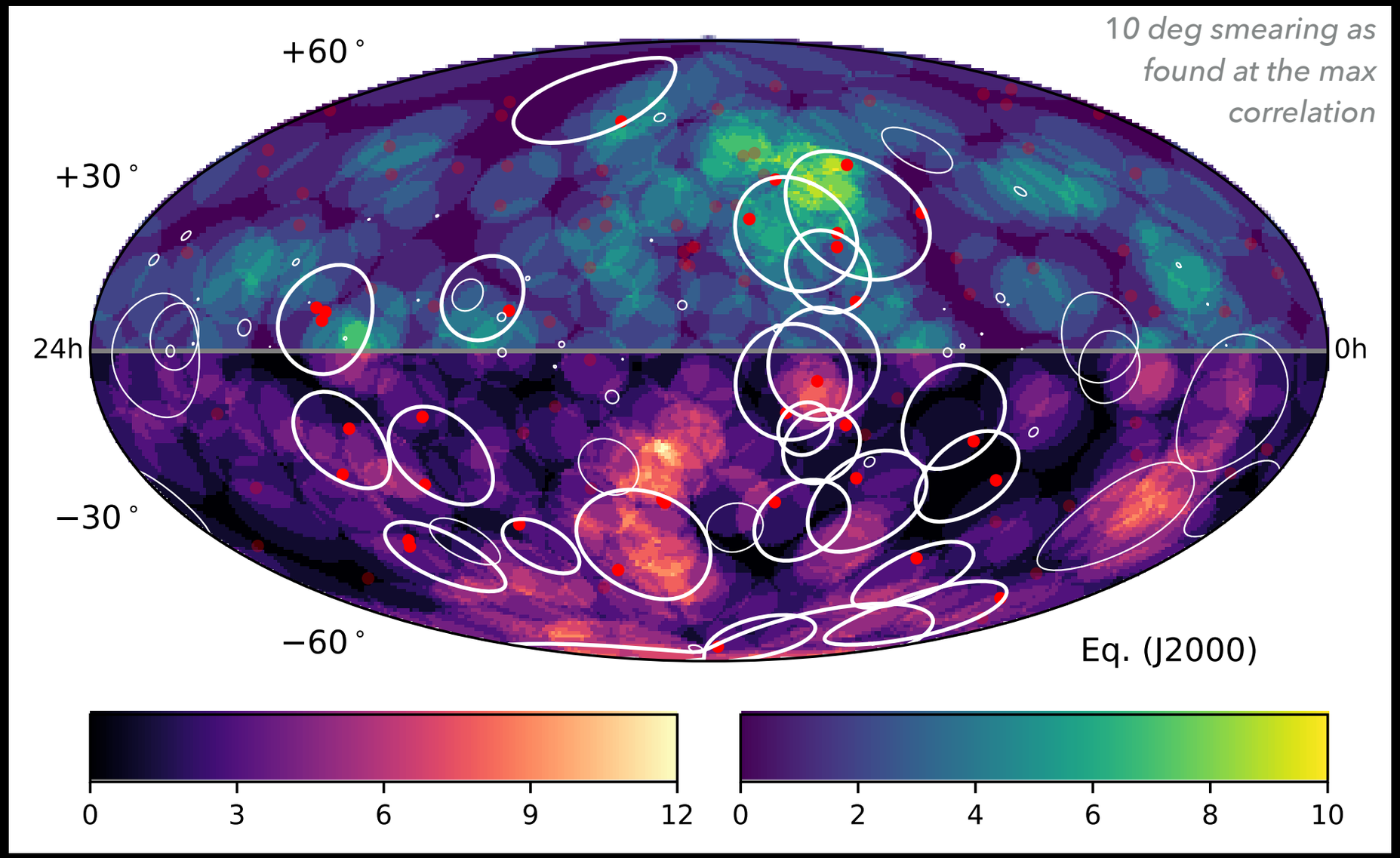




THE SEARCHES

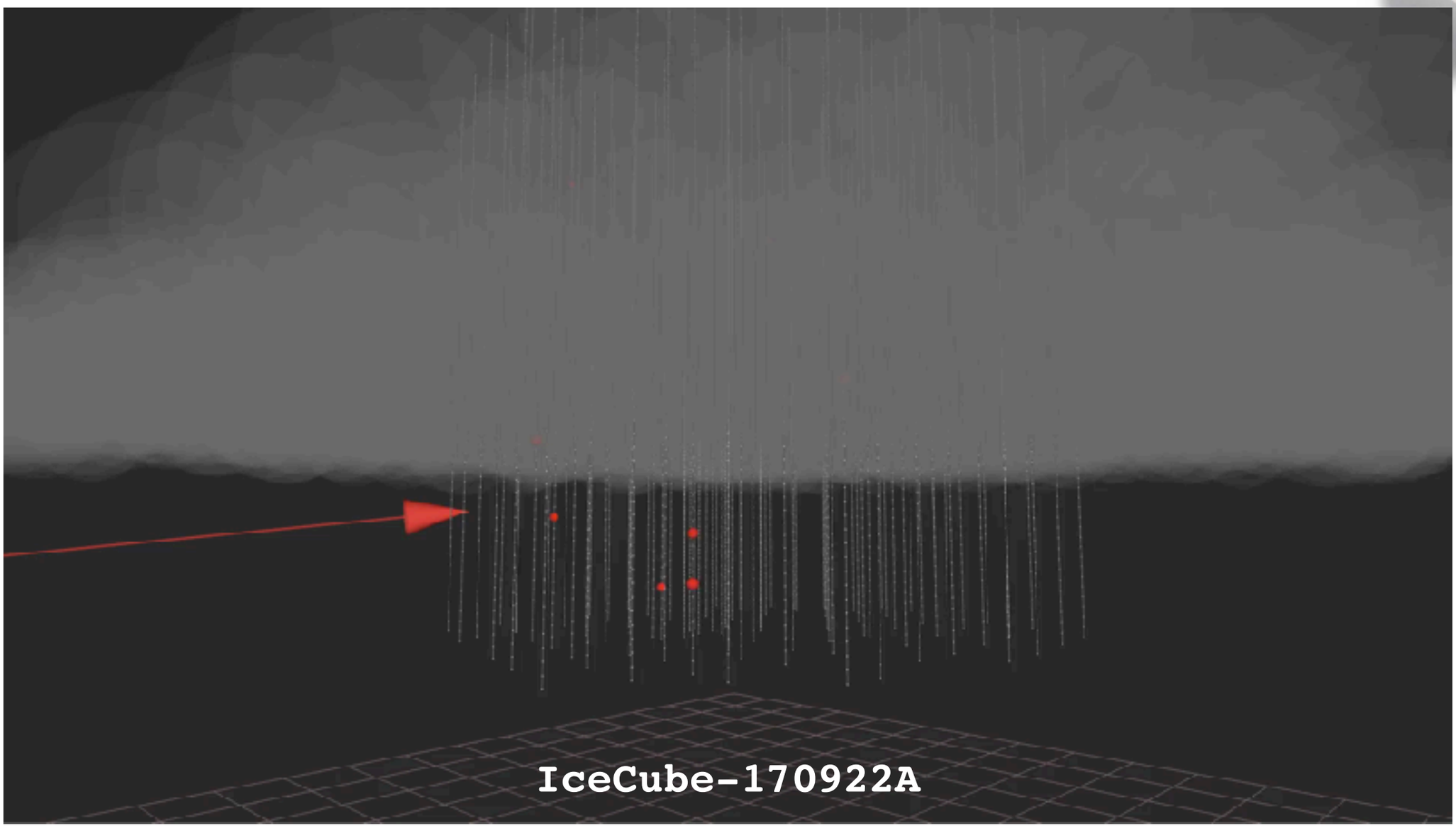
2- Blazars: the neutrino filter

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]



THE SEARCHES

3- Blazars: on line alert

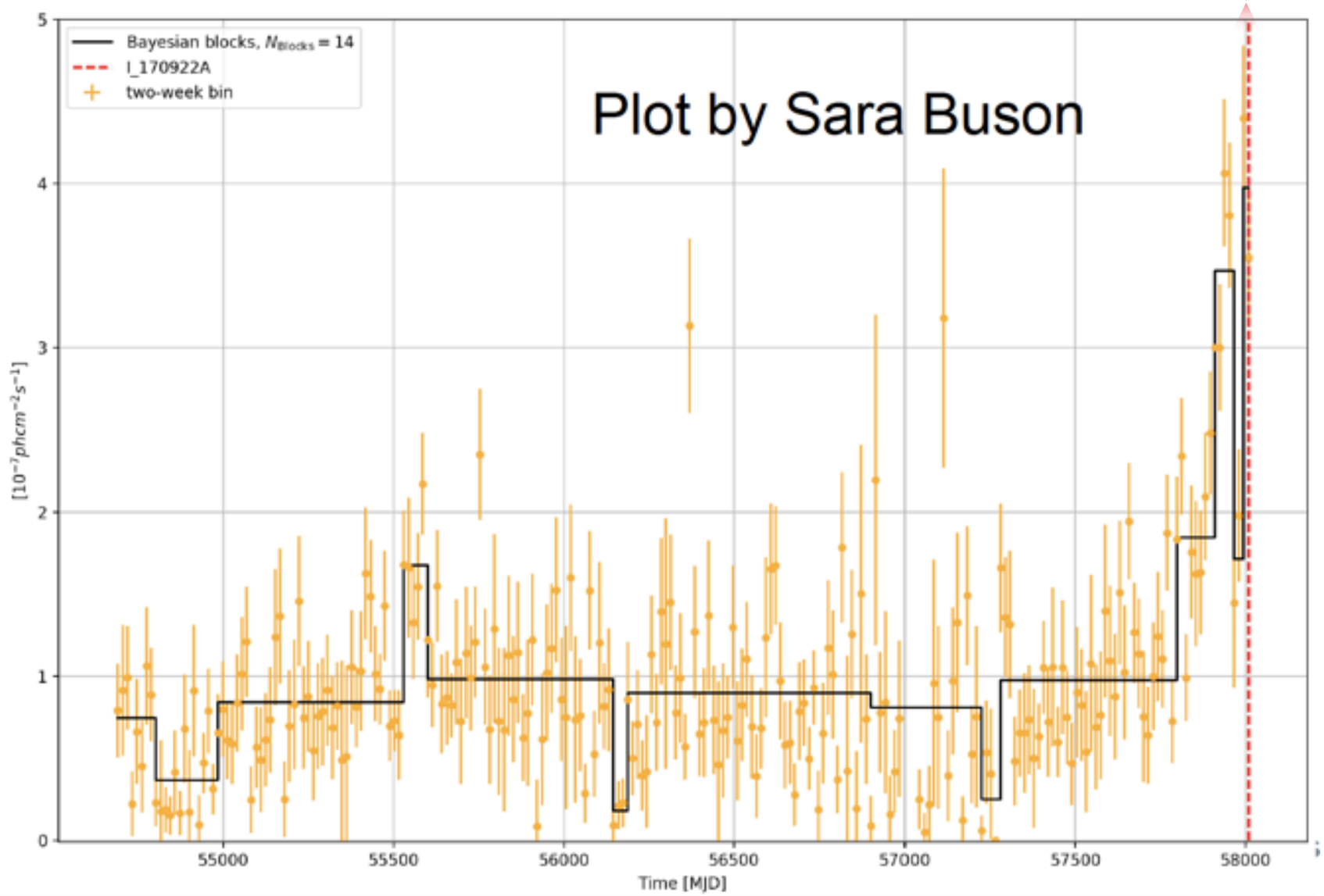


THE SEARCHES

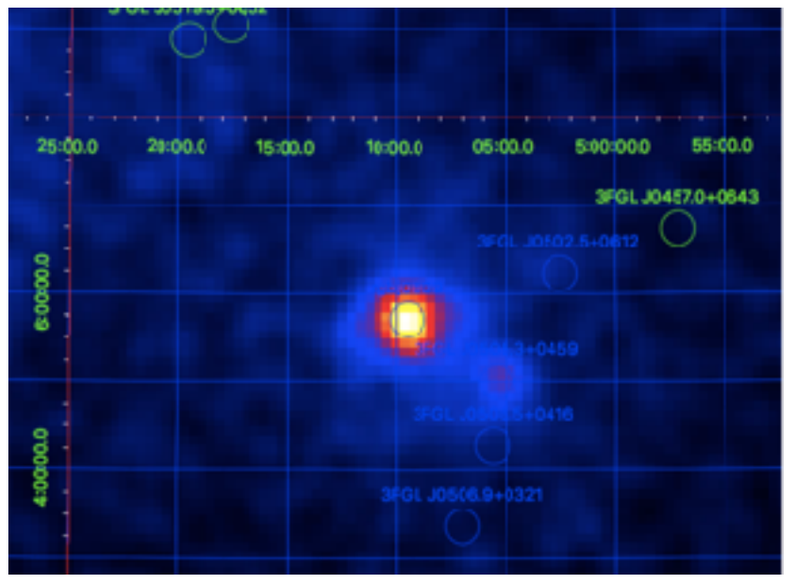
detection of a flare from Fermi, Swift, Agile, ESO / Very Large Telescope (VLT) and ...

3- Blazars: on line alert

IceCube-170922A



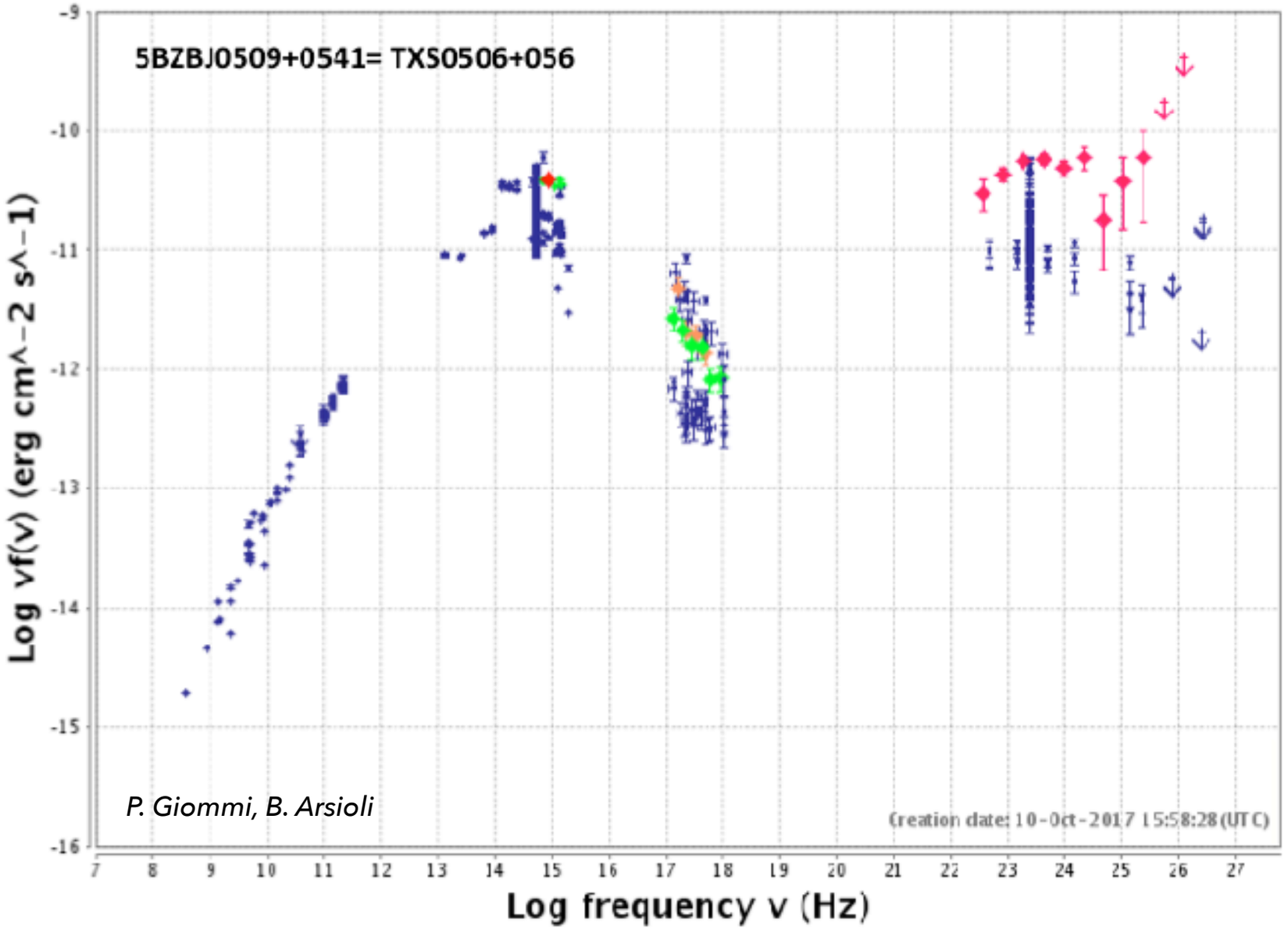
TXS 0506+056



THE SEARCHES

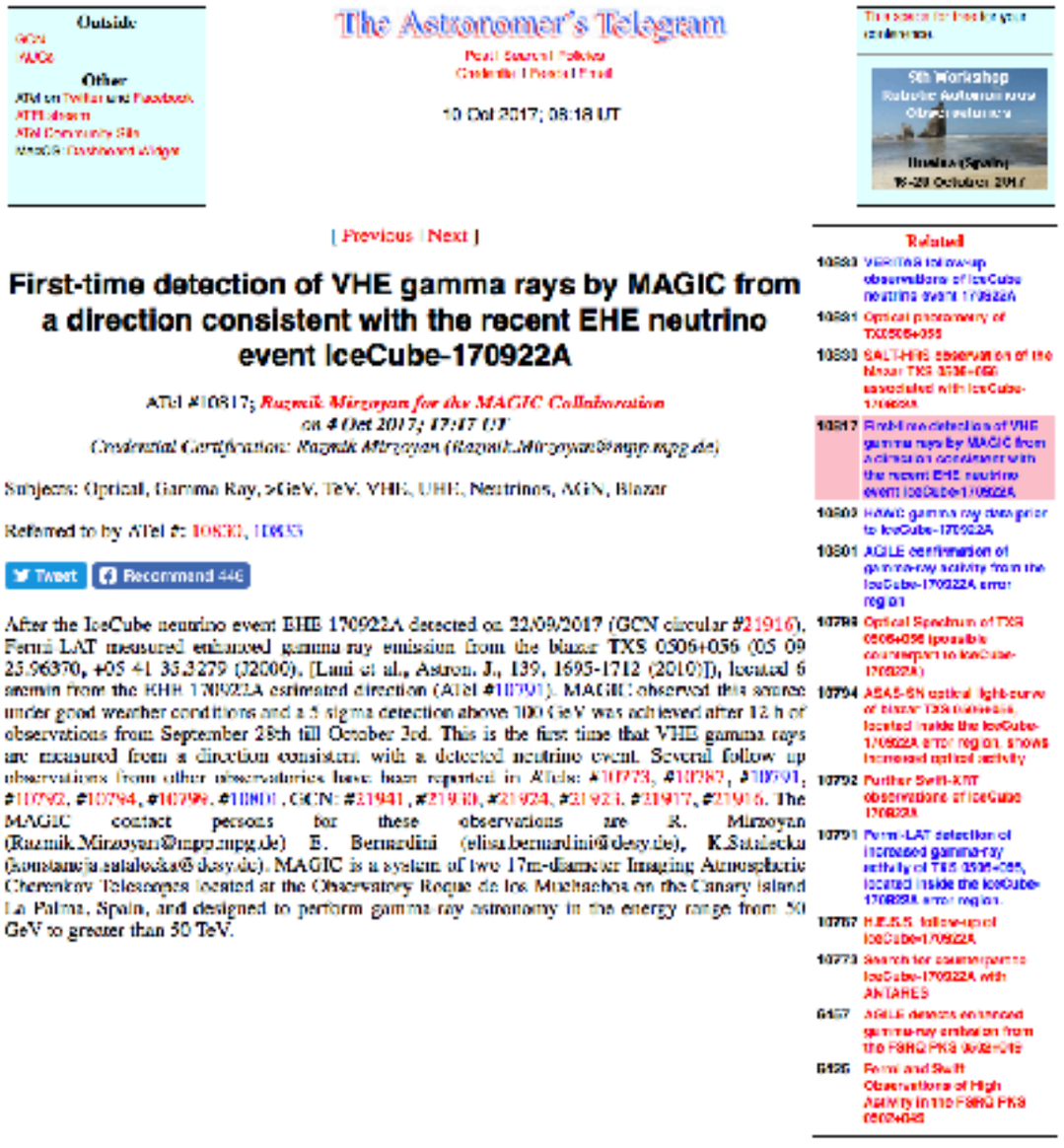
detection of a flare from Fermi, Swift, Agile, ESO / Very Large Telescope (VLT) and

3- Blazars: on line alert



THE SEARCHES

seen also by MAGIC (Major Atmospheric Gamma Imaging Cherenkov)



Outside
GCN
AAS

Other
ATel on Twitter and Facebook
ATel Search
ATel Community Site
Mobile Dashboard Widget

The Astronomer's Telegram
Peer Reviewed Publication
Credential Posted Email

10 Oct 2017; 08:18 UT

| Previous | Next |

First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A

ATel #10817; *Razmik Mirzoyan for the MAGIC Collaboration*
on 4 Oct 2017; 17:17 UT
Credential Certification: Razmik Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de)

Subjects: Optical, Gamma Ray, >GeV, TeV, VHE, UHE, Neutrinos, AGN, Blazar

Referred to by ATel #: 10830, 10835

Tweet | Recommend 446

After the IceCube neutrino event EHE 170922A detected on 22/09/2017 (GCN circular #21916), Fermi LAT measured enhanced gamma ray emission from the blazar TXS 0506+056 (05 09 25.96370, +05 41 35.3279 (J2000), [Lani et al., Astron. J., 139, 1695-1712 (2010)]), located 6 arcmin from the EHE 170922A estimated direction (ATel #10791). MAGIC observed this source under good weather conditions and a 5 sigma detection above 100 GeV was achieved after 12 h of observations from September 28th till October 3rd. This is the first time that VHE gamma rays are measured from a direction consistent with a detected neutrino event. Several follow up observations from other observatories have been reported in ATels: #10773, #10782, #10791, #10792, #10794, #10799, #10810, GCN: #21941, #21930, #21924, #21923, #21917, #21916. The MAGIC contact persons for these observations are R. Mirzoyan (Razmik.Mirzoyan@mpp.mpg.de) E. Bernardini (elisa.bernardini@desy.de), K.Satalecka (konstanca.satalecka@desy.de). MAGIC is a system of two 17m-diameter Imaging Atmospheric Cherenkov Telescopes located at the Observatorey Roque de los Muchachos on the Canary island La Palma, Spain, and designed to perform gamma ray astronomy in the energy range from 50 GeV to greater than 50 TeV.

5th Workshop
Robotic Autonomous Observatories
Malaga (Spain)
16-20 October 2017

Related
10830 VERITAS follow-up observations of IceCube neutrino event 170922A
10831 Optical photometry of TXS0506+056
10830 SALT-HRS observation of the blazar TXS 0506+056 associated with IceCube-170922A
10817 First-time detection of VHE gamma rays by MAGIC from a direction consistent with the recent EHE neutrino event IceCube-170922A
10803 HAWC gamma ray monitor prior to IceCube-170922A
10801 AGILE confirmation of gamma-ray activity from the IceCube-170922A error reg 01
10799 Optical Spectrum of TXS 0506+056 (possible counterpart to IceCube-170922A)
10794 ASAS-SN optical light-curve of blazar TXS 0506+056, located inside the IceCube-170922A 90% reg 01, shows increased optical activity
10792 Further Swift-XRT observations of IceCube 170922A
10791 Fermi-LAT detection of increased gamma-ray activity of TXS 0506+056, located inside the IceCube-170922A error region
10787 H.E.S.S. follow-up of IceCube-170922A
10773 Search for counterparts to IceCube-170922A with ANTARES
6457 AGILE detects an enhanced gamma-ray emission from the FSRQ PKS 0454+844
6426 Fermi and Swift Observations of High Activity in the FSRQ PKS 0602+048

| Telegram Index |

R. E. Rutledge, Editor-in-Chief rrutledge@astronomerstelegram.org
Derek Fox, Editor dfox@astronomerstelegram.org

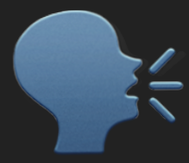
THE SEARCHES

is this a significant coincidence?

is this the first HE neutrino source?

is this a CR sources? how acceleration works?

WE NEED MORE COSMIC NEUTRINOS!!!!!!!



THE FUTURE

ICECUBE -GEN2, PHASE 1: PROPOSAL SUBMITTED TO NSF FOR NEW CALIBRATIONS => IMPROVED RESOLUTIONS

IceCube-Gen2

PINGU

↳Atmospheric mix. param.

↳Neutrino Mass Ordering

HE array

↳Neutrino astronomy

HE surface array

↳Cosmic ray

KM3NeT

ORCA

↳Atmospheric mix. param.

↳Neutrino Mass Ordering

ARCA

↳Neutrino astronomy

GVD

Focus on UHE showers

↳Neutrino astronomy

STRONG INTEREST FROM A LARGE INTERNATIONAL COMMUNITY

FINAL REMARKS

- The infancy of multi-messenger astronomy
- Rich set of observations in all messengers: best time ever for multi-messenger astronomy
- Many scenarios: equally probable?
- Many searches, few hints, a lot to discover
- We need more / larger neutrino talescopes
  - GVD, KM3NeT, IceCube-Gen2 and ....

UNDER INVESTIGATION

OCEAN NETWORK CANADA: A NEW OPPORTUNITY?

Short-term: measurement of the *in-situ* optical properties

Long-term: if optical properties good (and they will be good) run forecasts for

- Multimessenger
- Atmospheric neutrinos
- Neutrino beam lines

"neutrinos are never boring!" (F. Halzen)

THE POPULATION

(space number density as a function of luminosity and redshift)

Cosmic evolution is different for HSP

[M. Ajello 2013, P. Giommi et al. 1999; V. Beckmann et al. 2003]

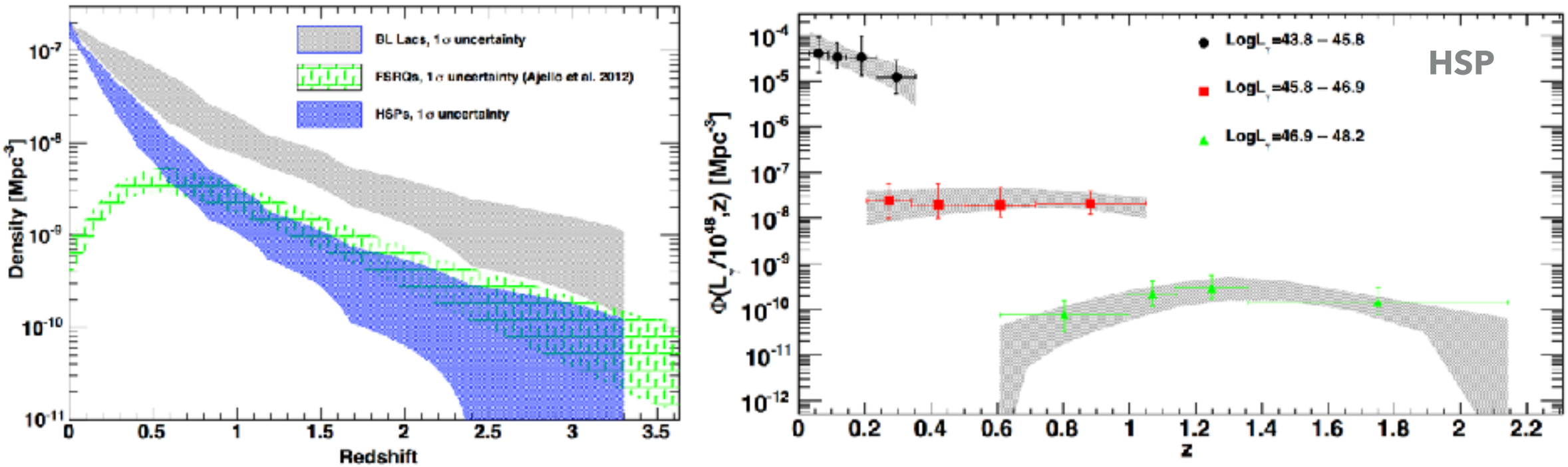
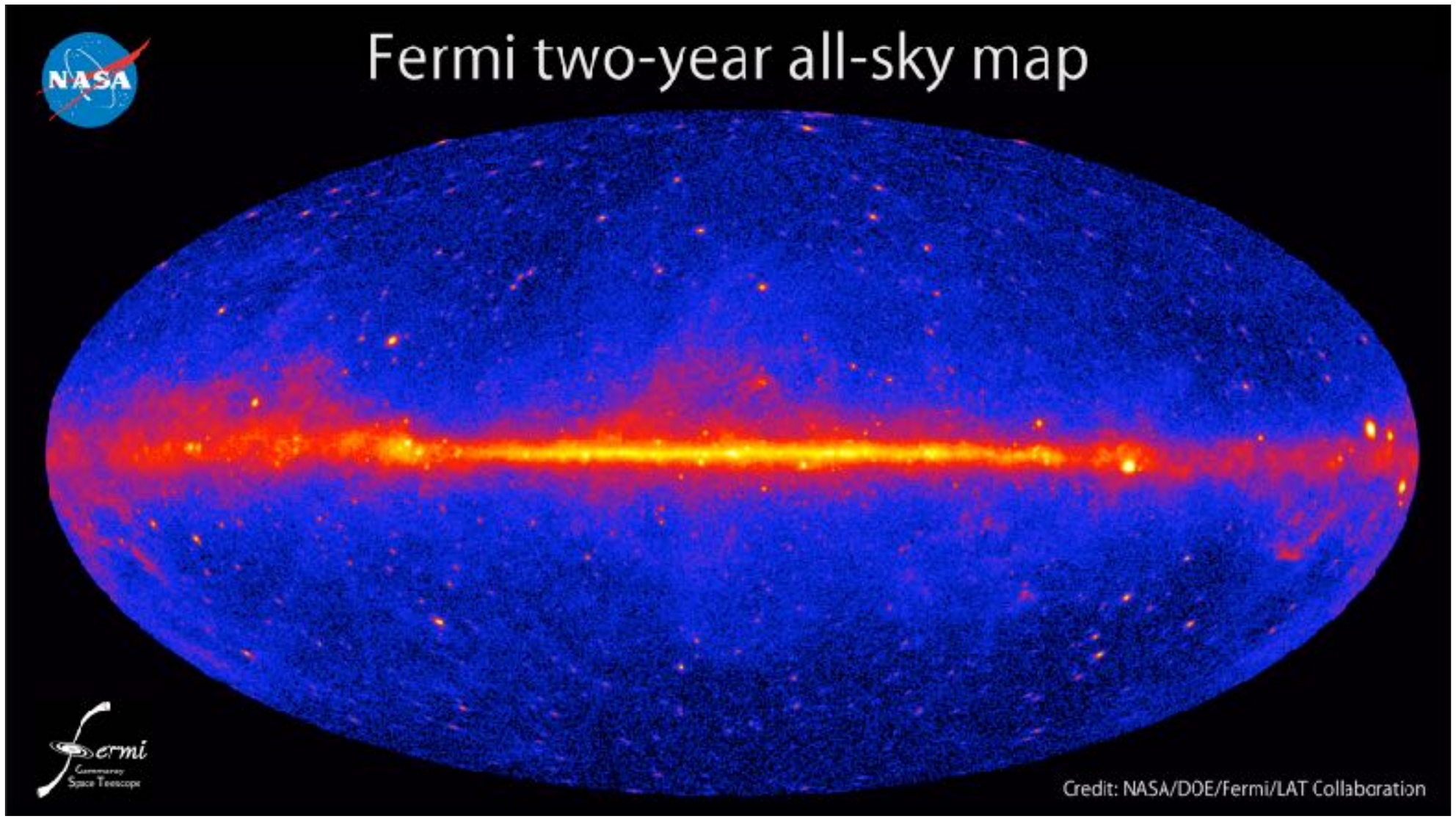


Fig. 10.— Number density (per unit co-moving volume) of BL Lacs, FSRQs and HSPs.

… the evolution of BL Lacs slows down with luminosity, becoming negative for objects with Lγ ≤$10^{45.5}$ erg s^{-1}[…] Subdividing the sample in HSP, ISP and LSP objects we find that the **negative evolution is in fact isolated to the HSP population**, while the ISP and LSP evolve positively from the lowest luminosities.

THE SCENARIOS

2- The Galaxy: also a MM source

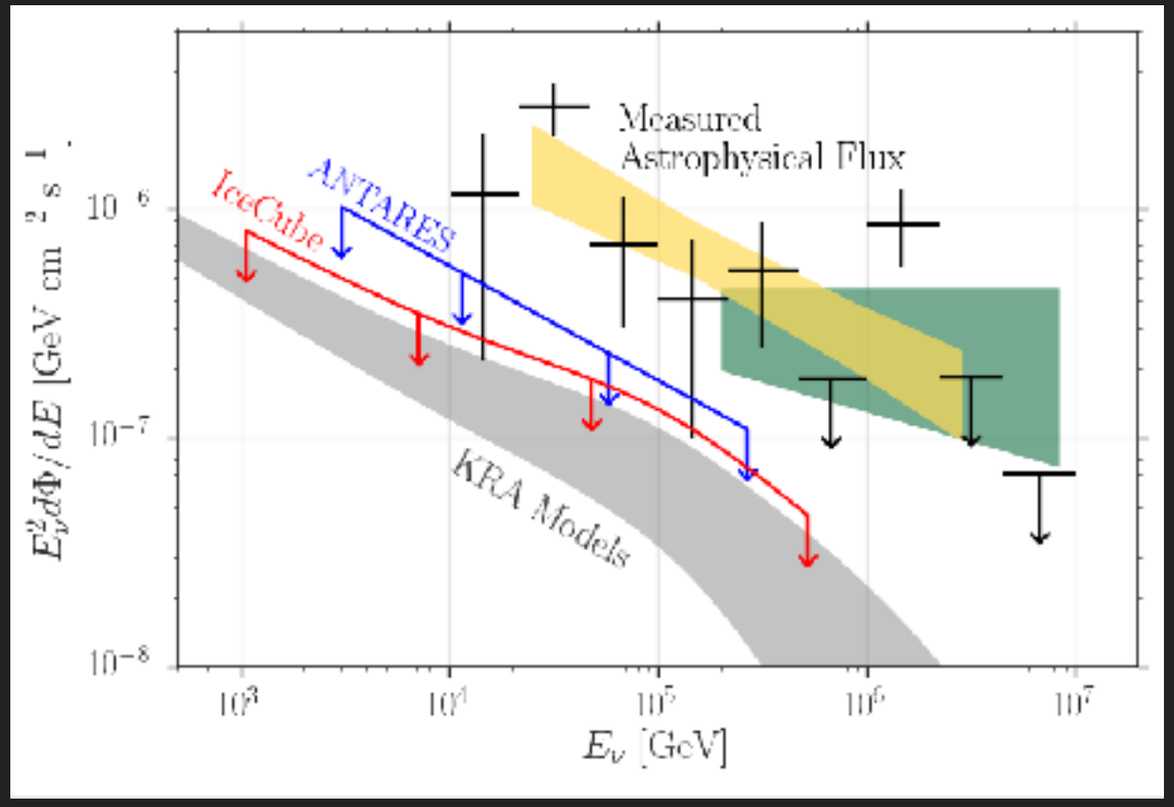


THE SEARCHES

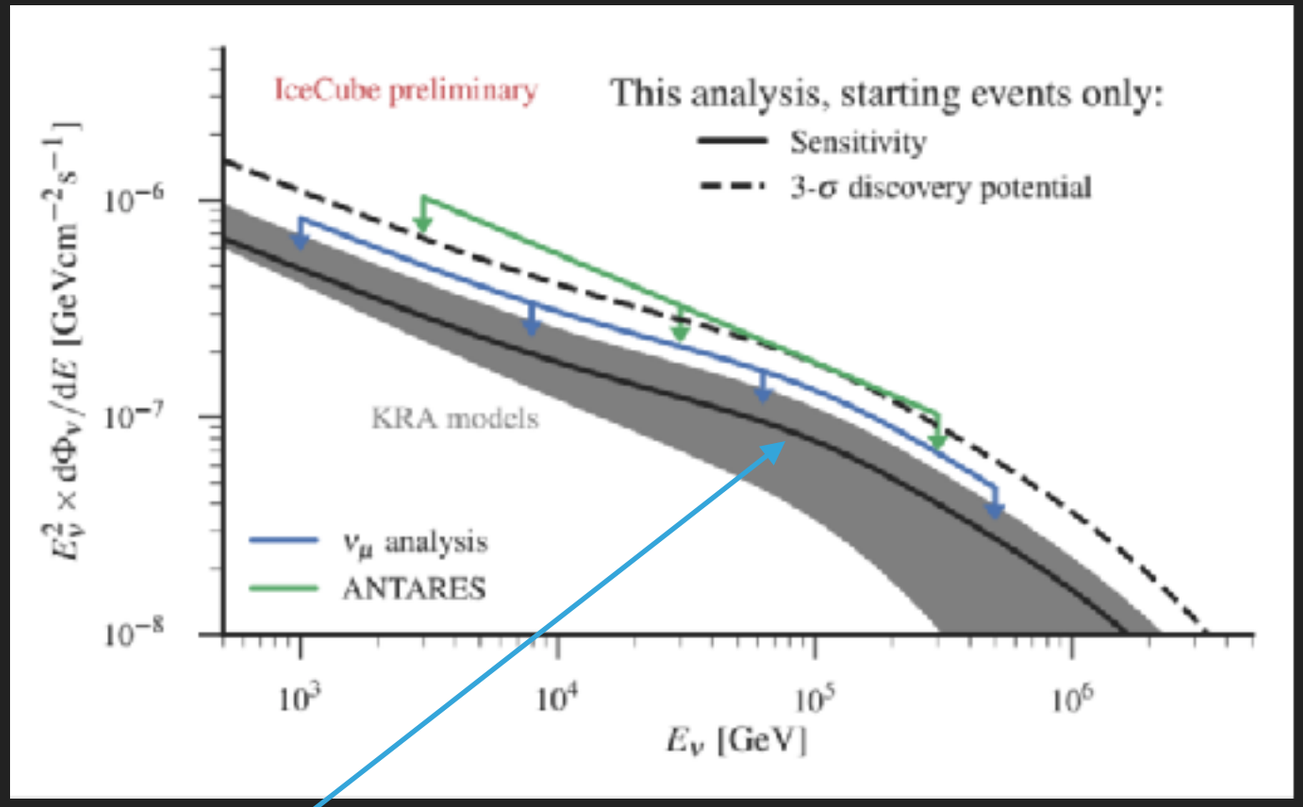
2- The Galaxy: is a MM source

[D. Gaggero et al., ApJL (2015)]

The IceCube Coll., PoS(ICRC2017)1005



The IceCube Coll., PoS(ICRC2017)995

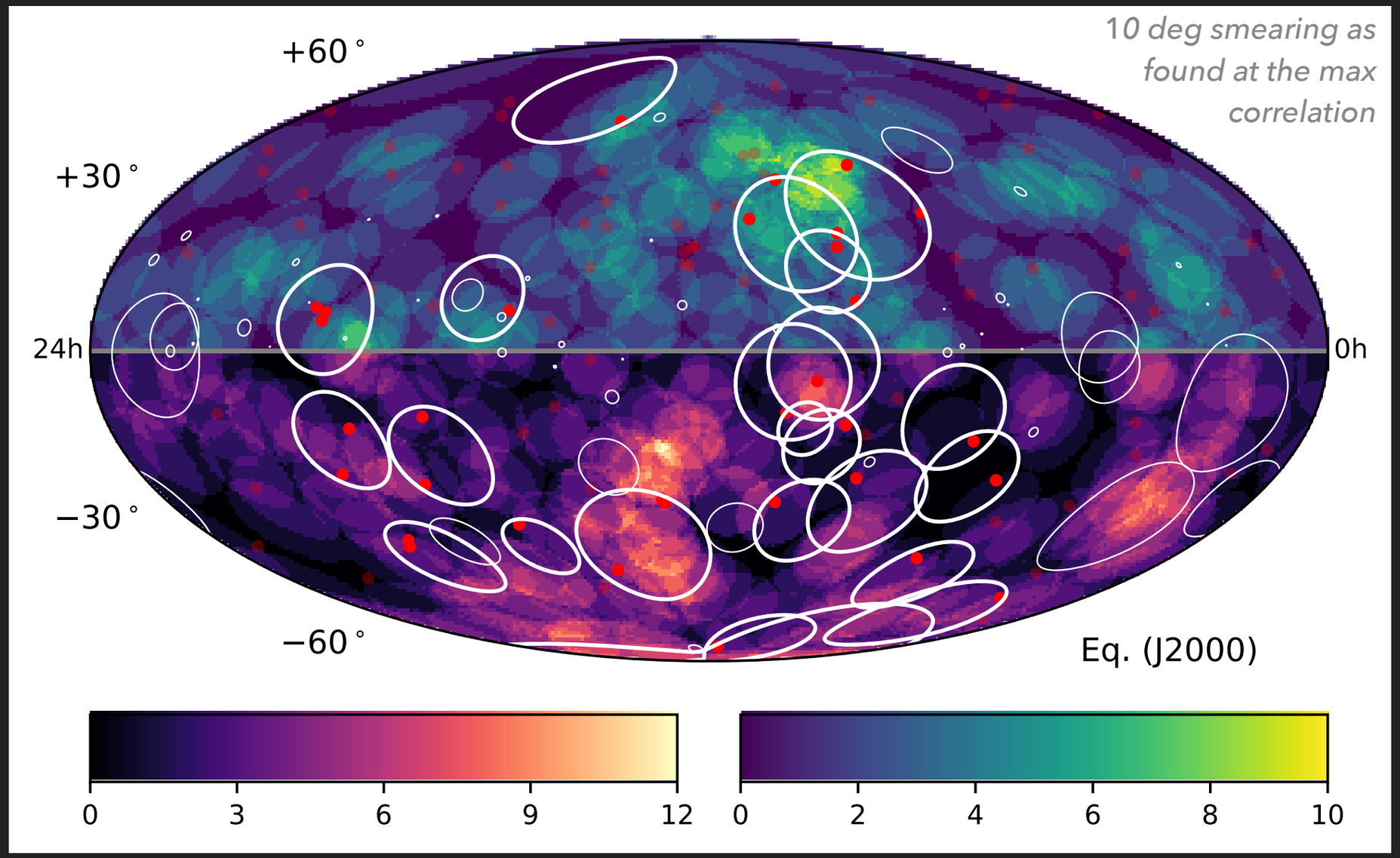


Entering in the model prediction soon with IceCube ….

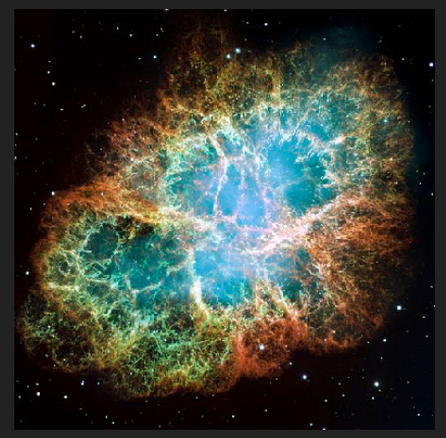
THE SEARCHES

1- Blazars

[P. Padovani et al., MNRAS (2016); E.R. et al., MNRAS (2017); E.R. et al., PoS(ICRC2017)1016]



THE SCALE: KM3

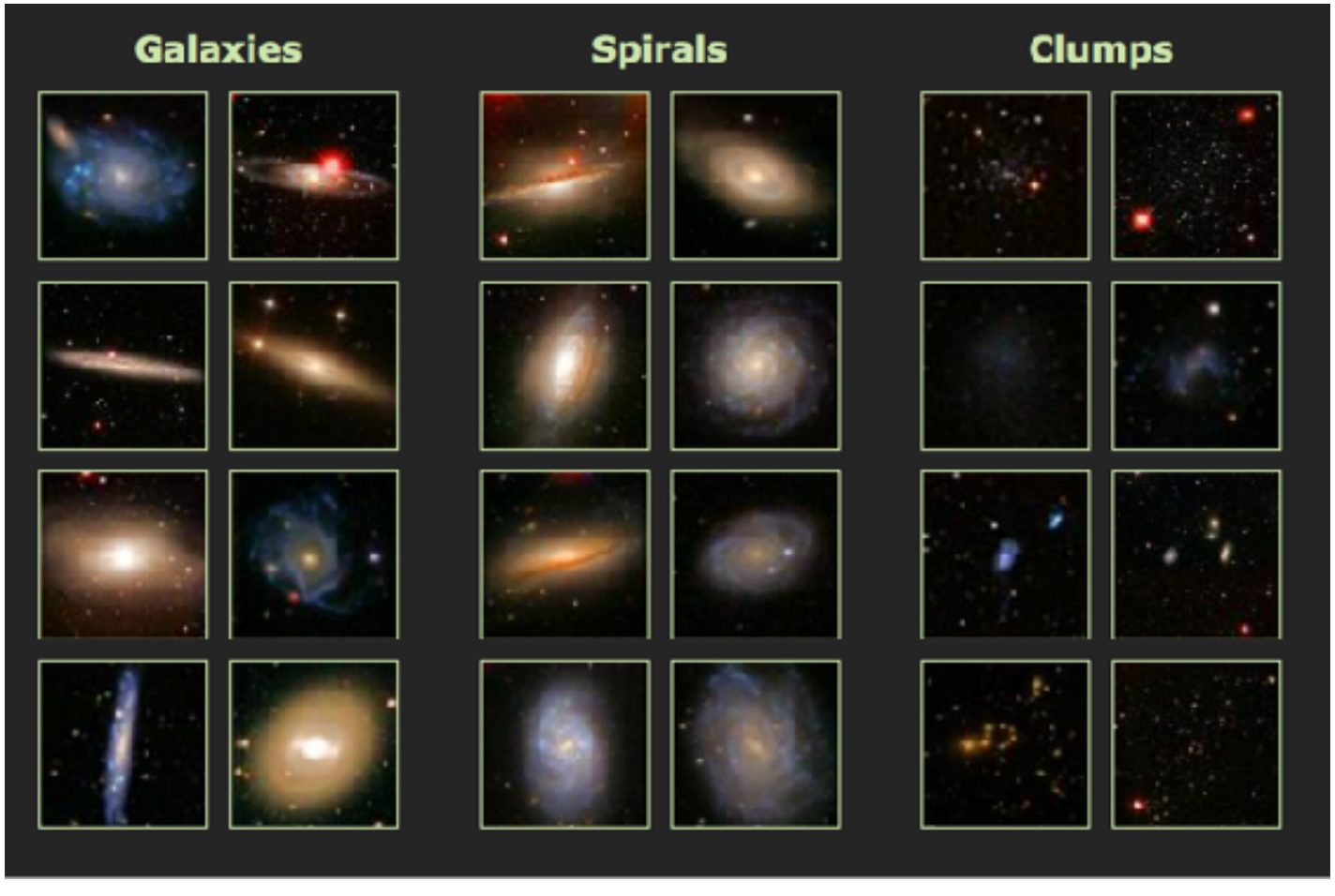


- compare with TeV sources of γ-rays
- Crab Nebulae (~TeV): $dNv / d\ln(E) \sim 3 \times 10^{-11} cm^{-2} s^{-1}$
- neutrino cross section is $\sim 10^{-35}$ cm^2
- One km^3 of water contains 6×10^{38} target nucleons
- ~ 10 neutrino interactions per year
- few background neutrino-induced muon.

SLOAN DIGITAL SKY SURVEY HAS CHANGED THE FACE OF ASTRONOMY

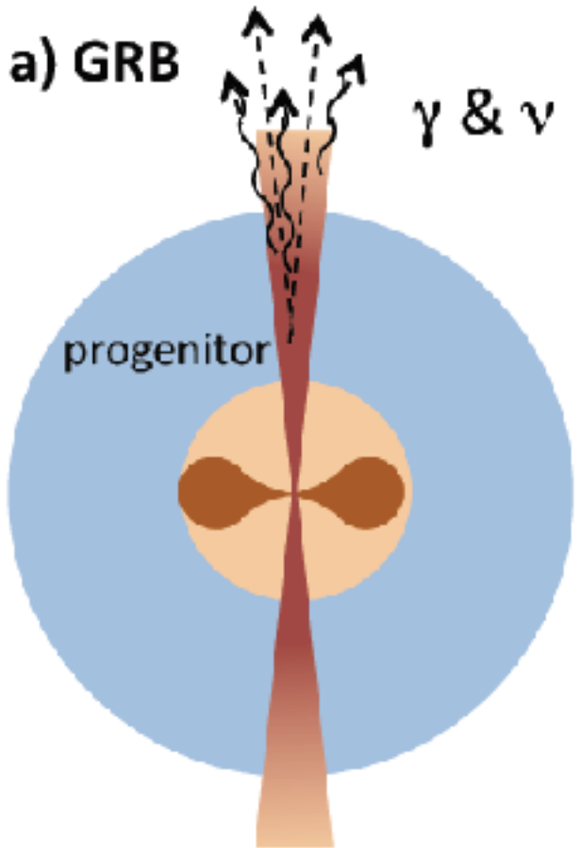
http://www.uchicago.edu/features/20080218_sloan/

- The SDSS began taking data in 1998, following years of planning by scientists at Chicago and elsewhere. The planners include Donald York, the survey's founding director and the Horace B. Horton Professor in Astronomy & Astrophysics and the College, and current director Richard Kron, Professor in Astronomy & Astrophysics and the College. **"Everybody said we were crazy,"** York recalled. But now, added Kron: **"Other collaborations look to us to see how we've done it."**

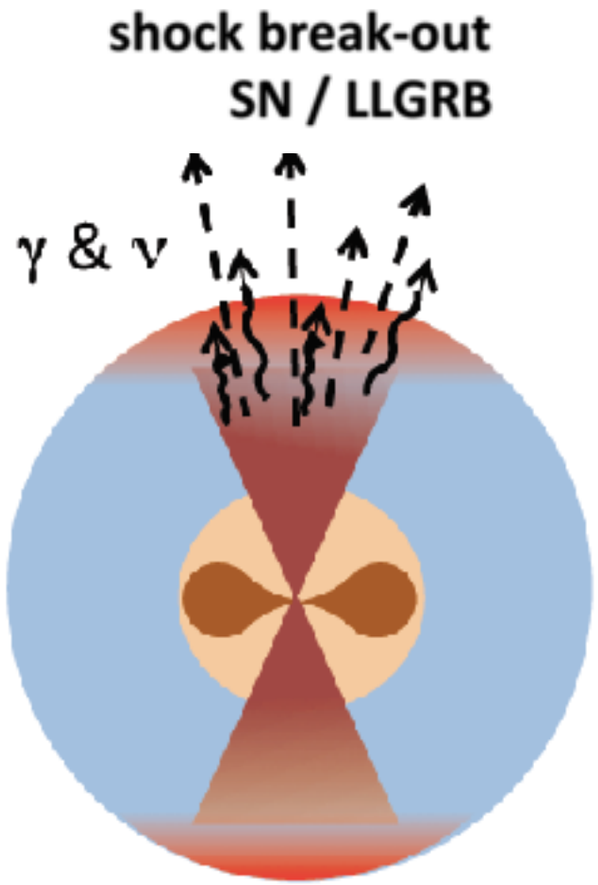


THE SCENARIOS

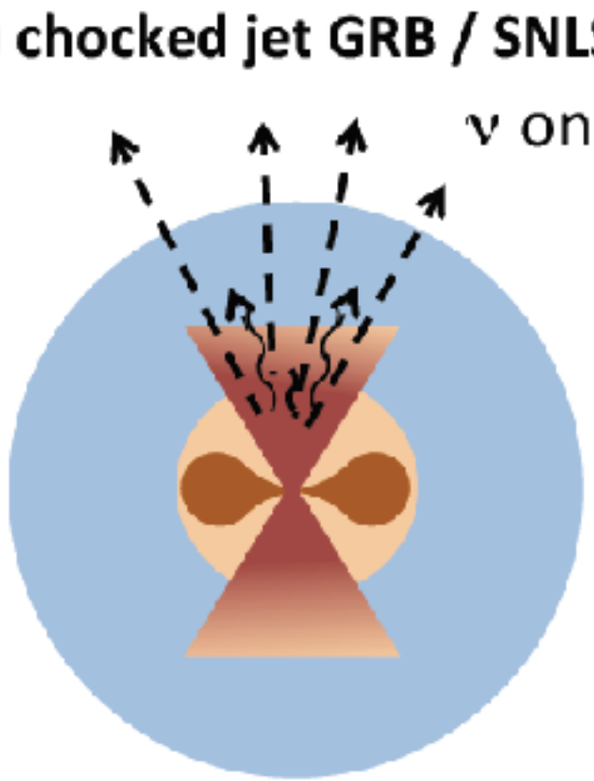
2- Stellar collapses



[E. Waxman & J. Bahcall, (1997)]



[Murase et al, ApJL,651 (2006)]



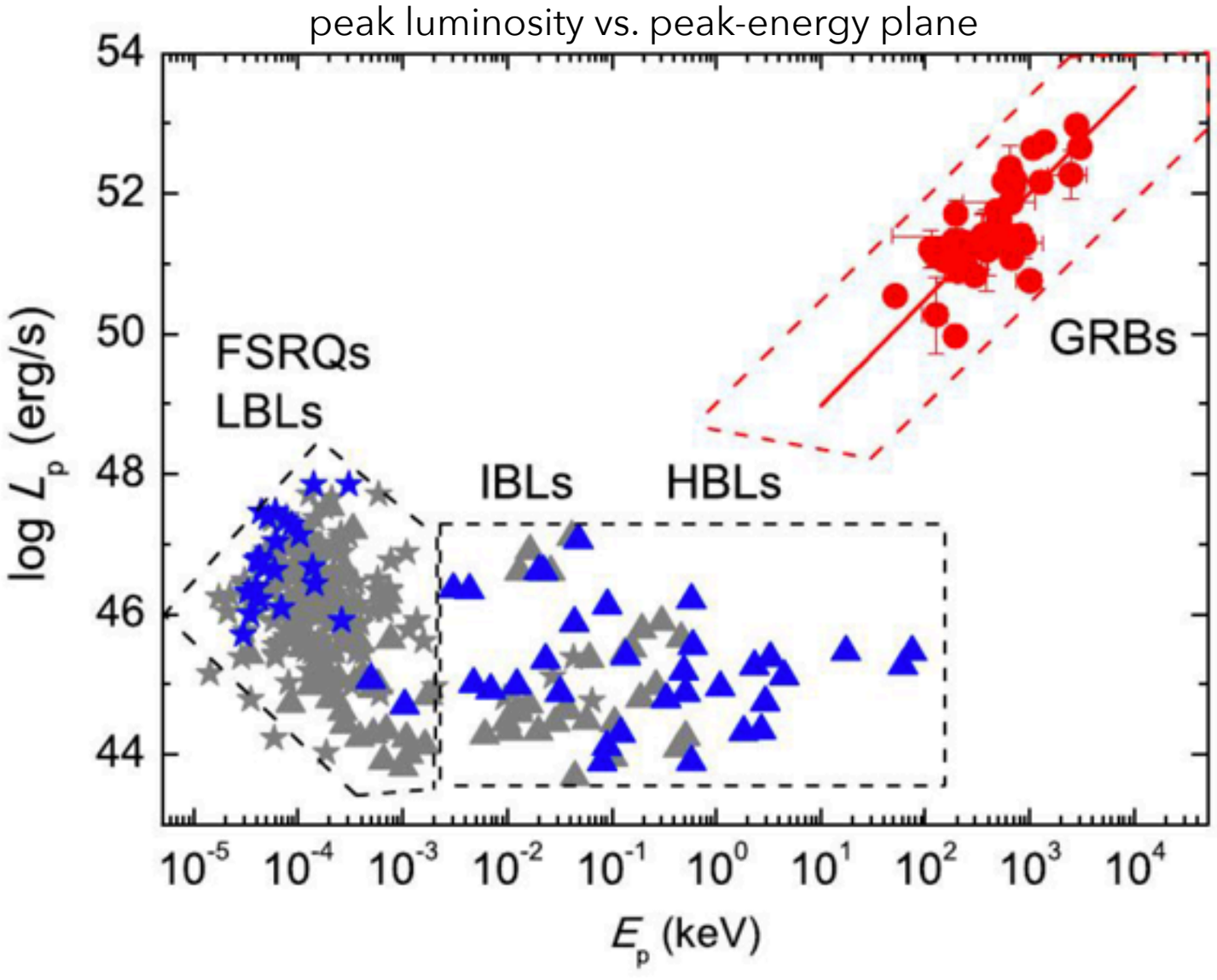
[Ando, Beacom, (2005)
Razzaque, Meszaros,(2004)]

credit to Anna Franckowiak

THE SCENARIOS

2- Stellar collapses: GRBs

[F. Lyu, et al., (2014); H.F. Yu, H.J. Eerten, J. Greiner, et al.,(2015)]



Physical understanding of GRBs incomplete:

(i) most γ-ray spectra of the prompt emission are too sharp to be consistent with synchrotron emission;

(ii) simultaneous optical/ γ-ray observations of the prompt emission suggest that the emission is non-isotropic in the co-moving blast-wave frame;

(iii) plateaus in the X-ray light curves of GRB afterglows as well as bright supernovae related to GRBs suggest energy injection over days to weeks, rather than seconds, giving preference to magnetic models rather than black hole formation.

THE SCENARIOS

3- Star-forming galaxies, starburst galaxies

[D.A. Perley et al., arXiv:1602.00770; S. Ohm, arXiv:1601.06386; X. Wang and B. D. Fields arXiv:1612.07290; A. Loeb, E. Waxman, JCAP(2006)]

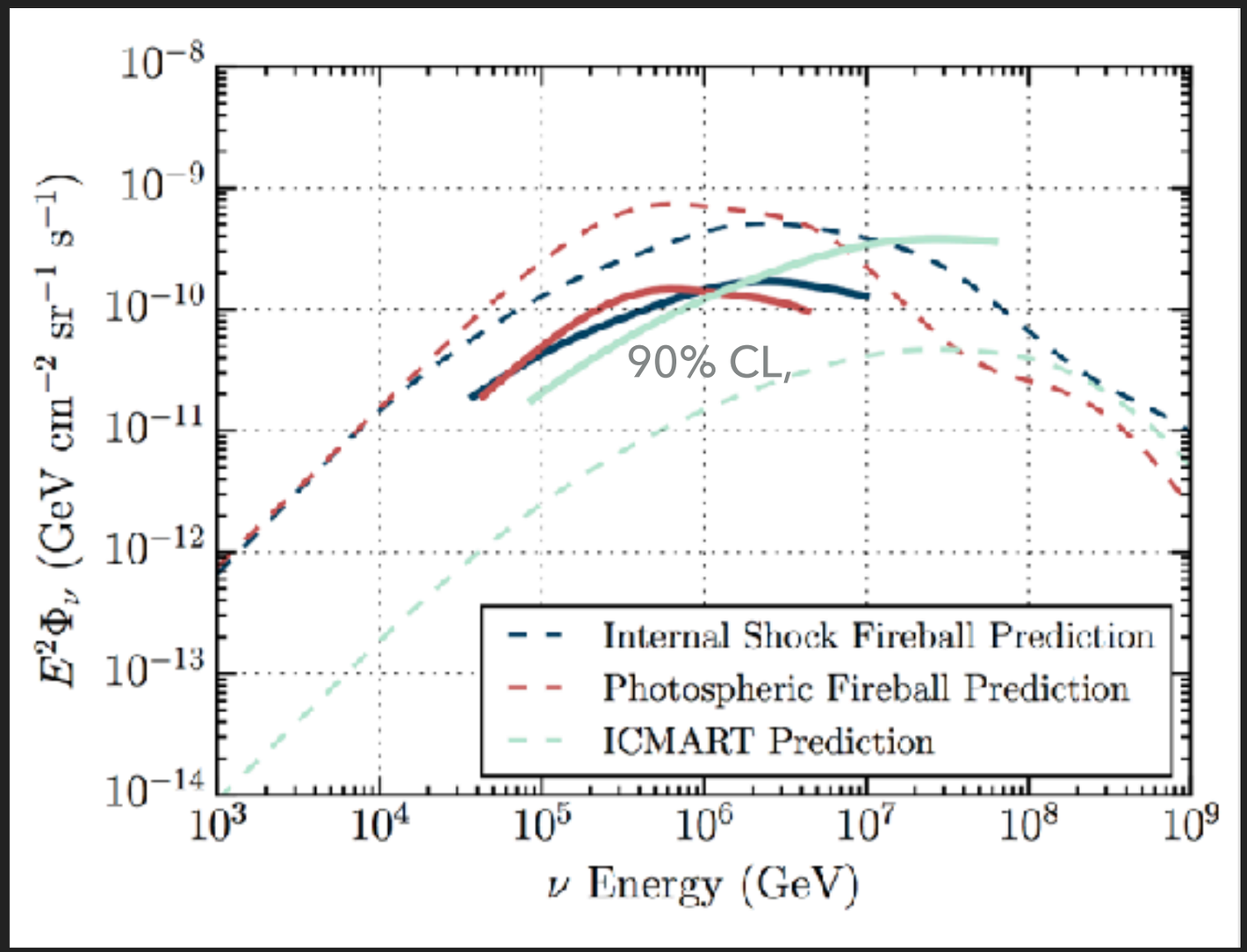
- Long-duration GRBs: host galaxies are star-forming
- Star-forming galaxies as proton calorimeters, high-energy neutrinos and photons sources
- CR as important star-formation regulator or even galaxy formation
- Few objects detected in γ-rays: M82, NGC253, NGC4945, NGC1068, Circinus and the ultraluminous infrared galaxy Arp220
- Evolve cosmologically with peak z~1-2:
  - if UHECRs sources, where is the diffuse produced by the far away objects?

THE SEARCHES

2- Stellar collapses: GRBs

[IceCube Coll., Nature, (2012); IceCube Coll., ApJ (2017); ANTARES Eur.Phys.J. C77 (2017) no.1, 20]

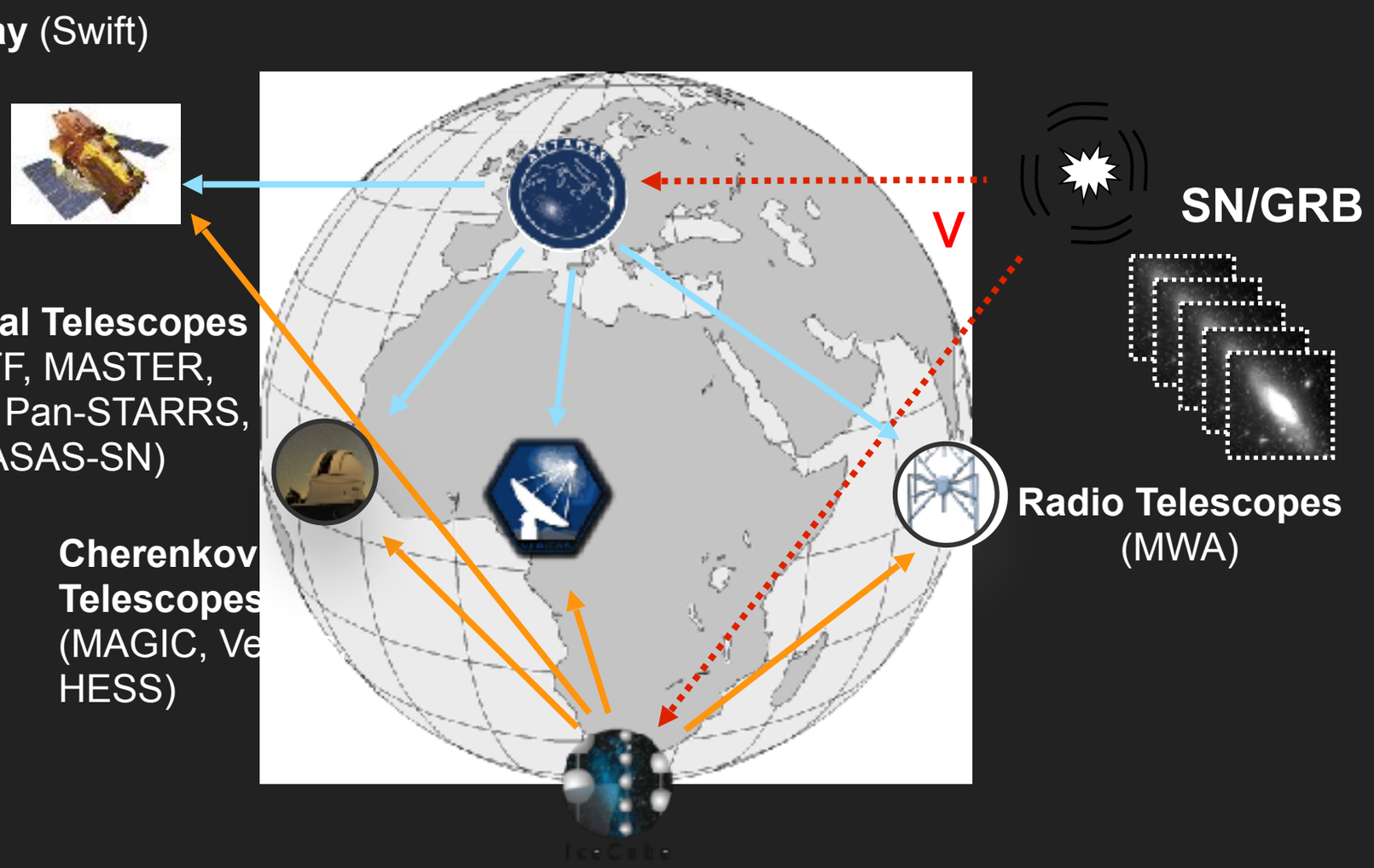
constraining single-zone fireball models of GRB neutrino



THE SEARCHES

2- Stellar collapses

[IceCube, MAGIC, VERITAS, arXiv: 1610.01814
ANTARES JCAP 1602 (2016)
Ackermann et al.arXiv:0709.2640
IceCube A&A 539, A60 (2012)]



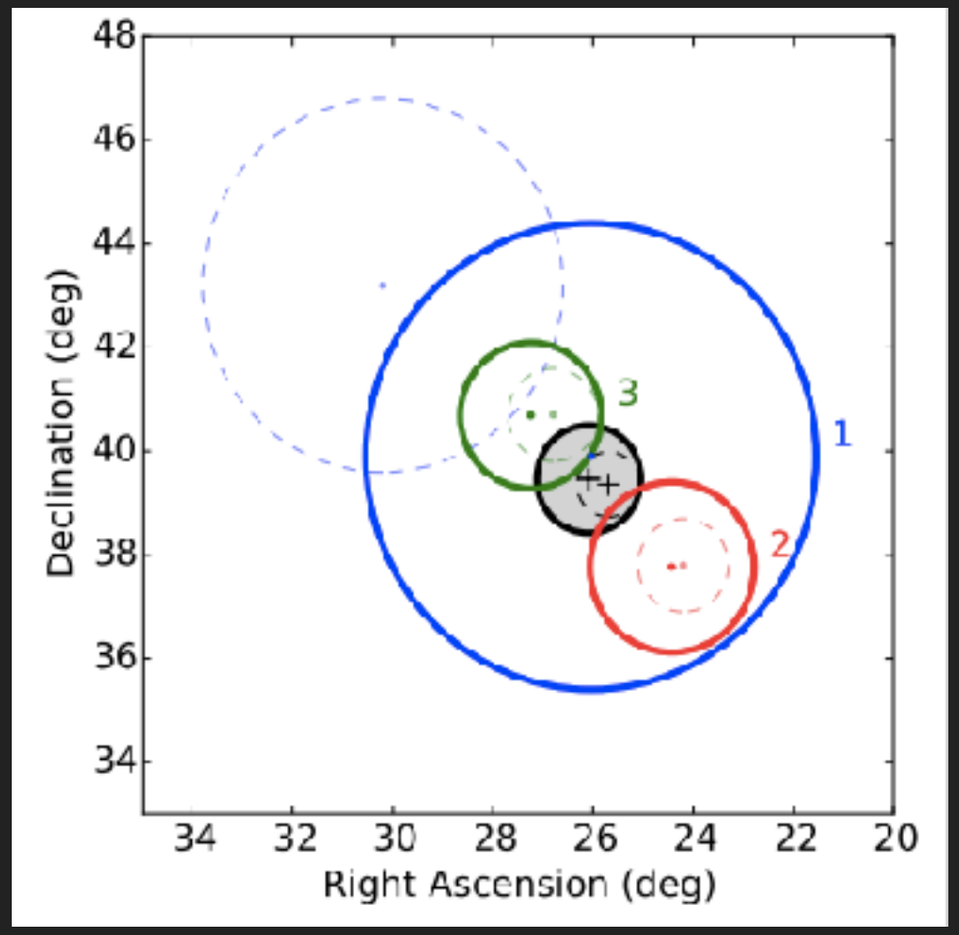
credit to Anna Franckowiak

THE SEARCHES

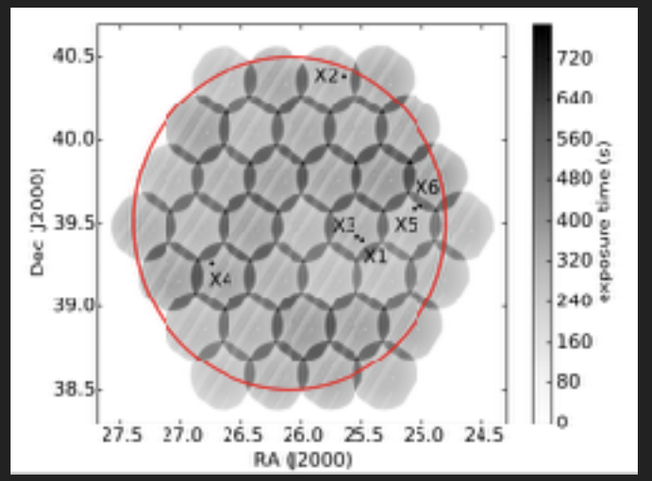
2- Stellar collapses

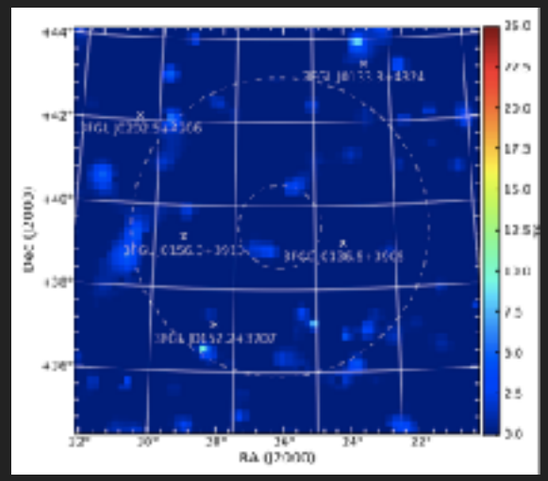
[IceCube, ASAS-SN, AMON, Fermi, VERITAS, HAWC, LCO, Swift, MASTER, arXiv:1702.06131]

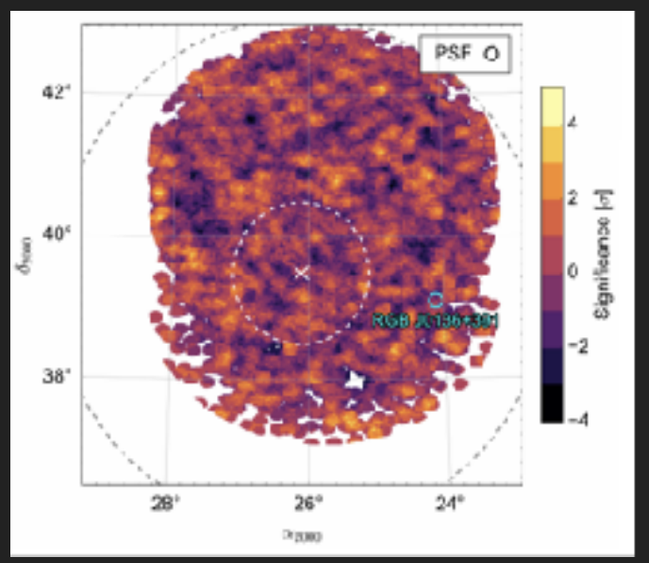
> Expected from background once every 13.7 yrs

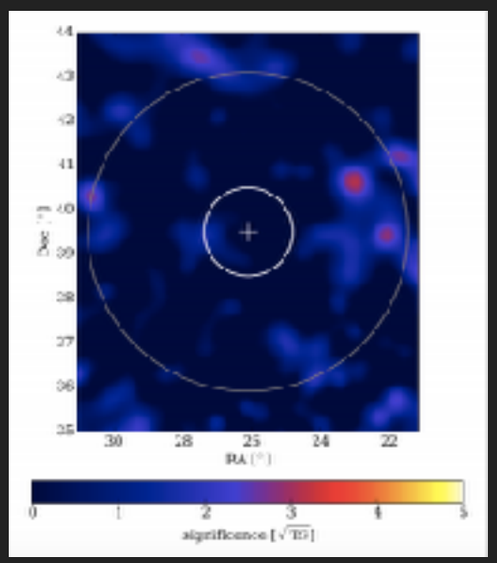


credit to Anna Franckowiak







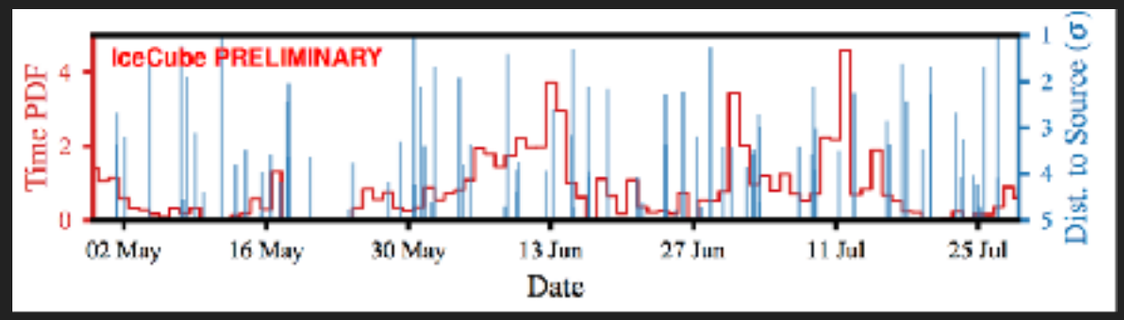


> no obvious counterpart found

THE SEARCHES

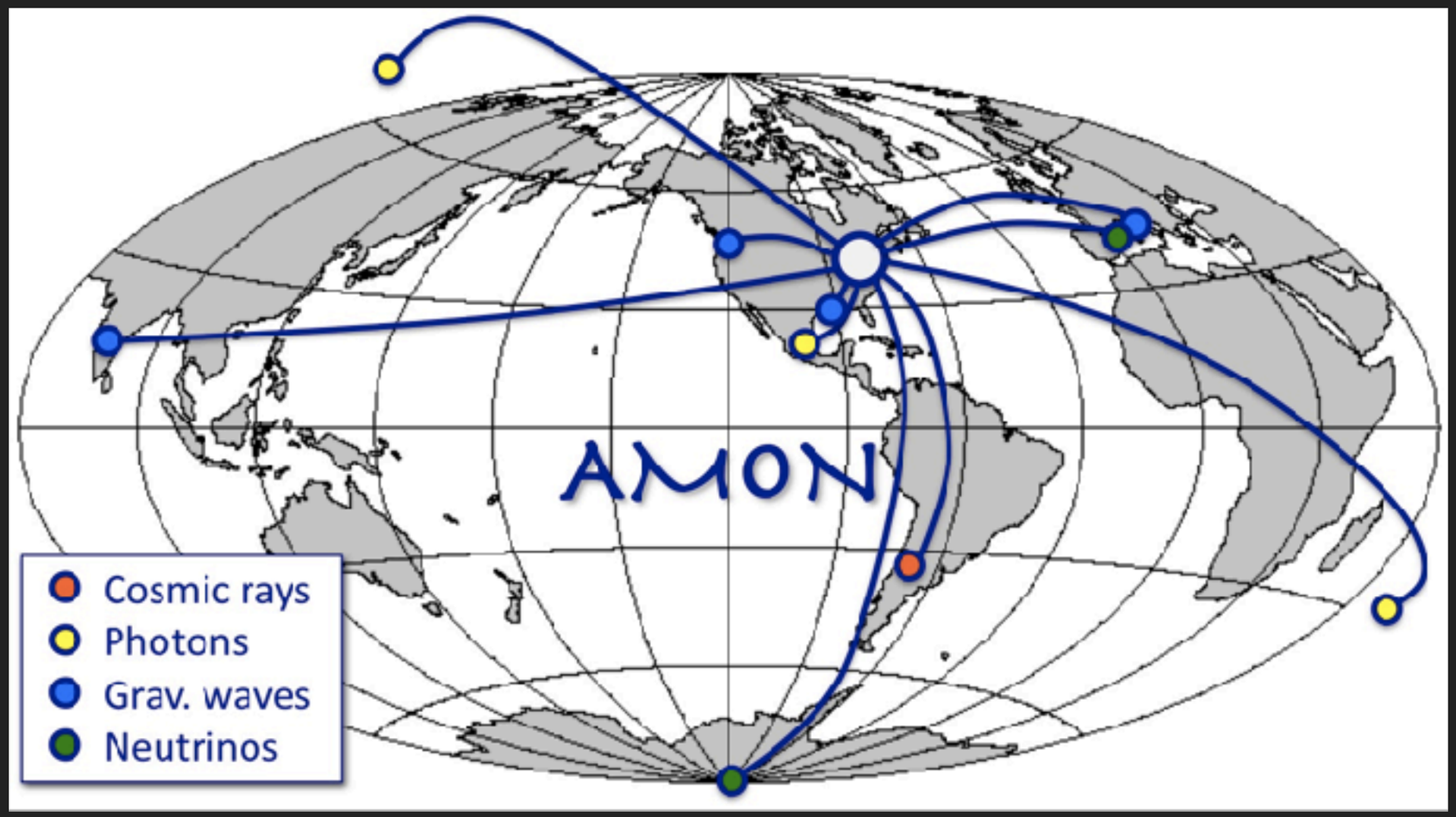
2- Flares and transients

M. Santander for IceCube, FACT, Magic, Veritas PoS(ICRC2017)618



IceCube, FACT, Magic, PoS(ICRC2017)969

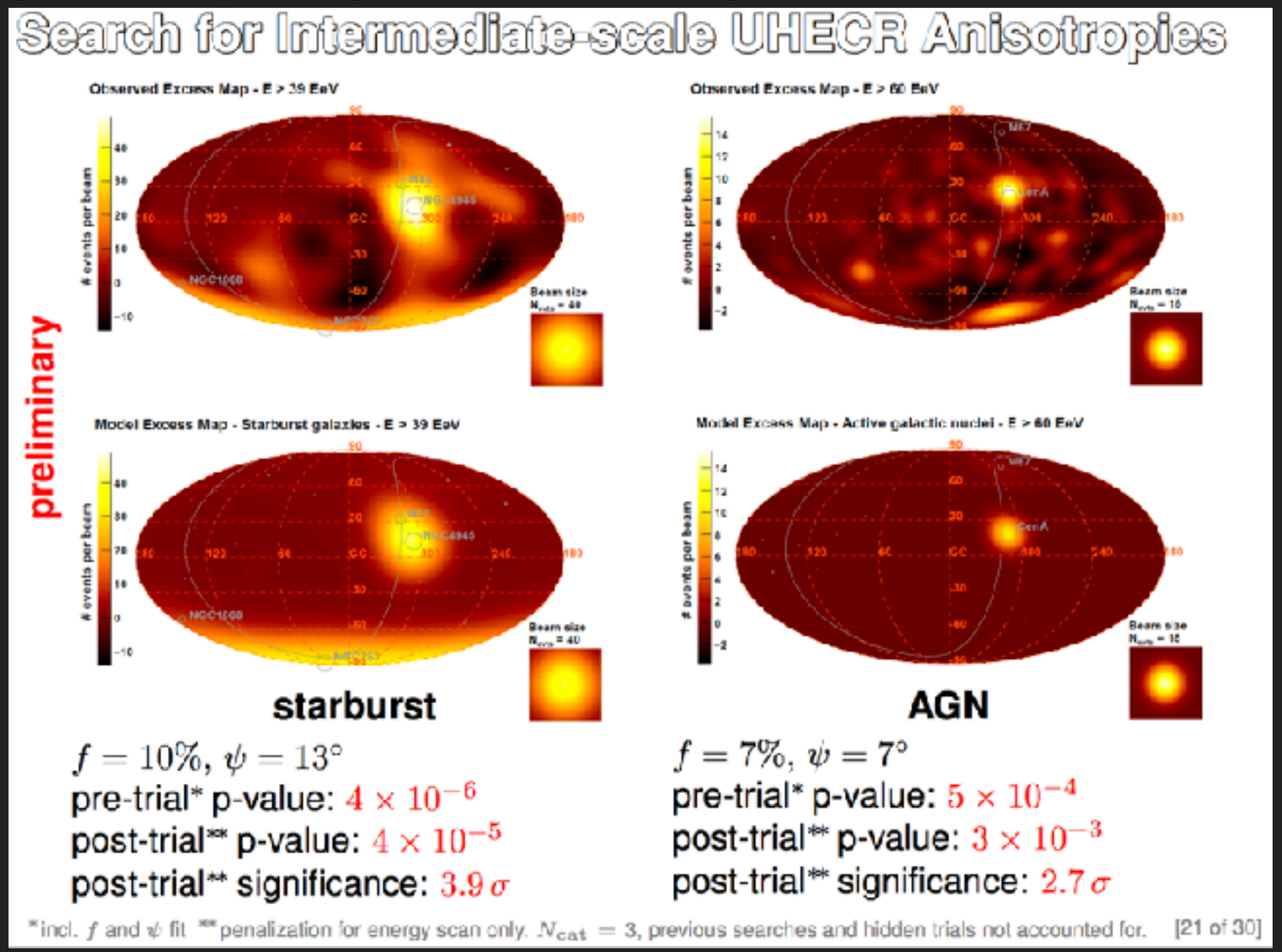
http://amon.gravity.psu.edu
Smith et al., Astropart. Phys., 45 (2013)



THE SEARCHES

3- Star-forming galaxies, starburst galaxies

[Michael Unger, Auger Coll., ICRC 2017]

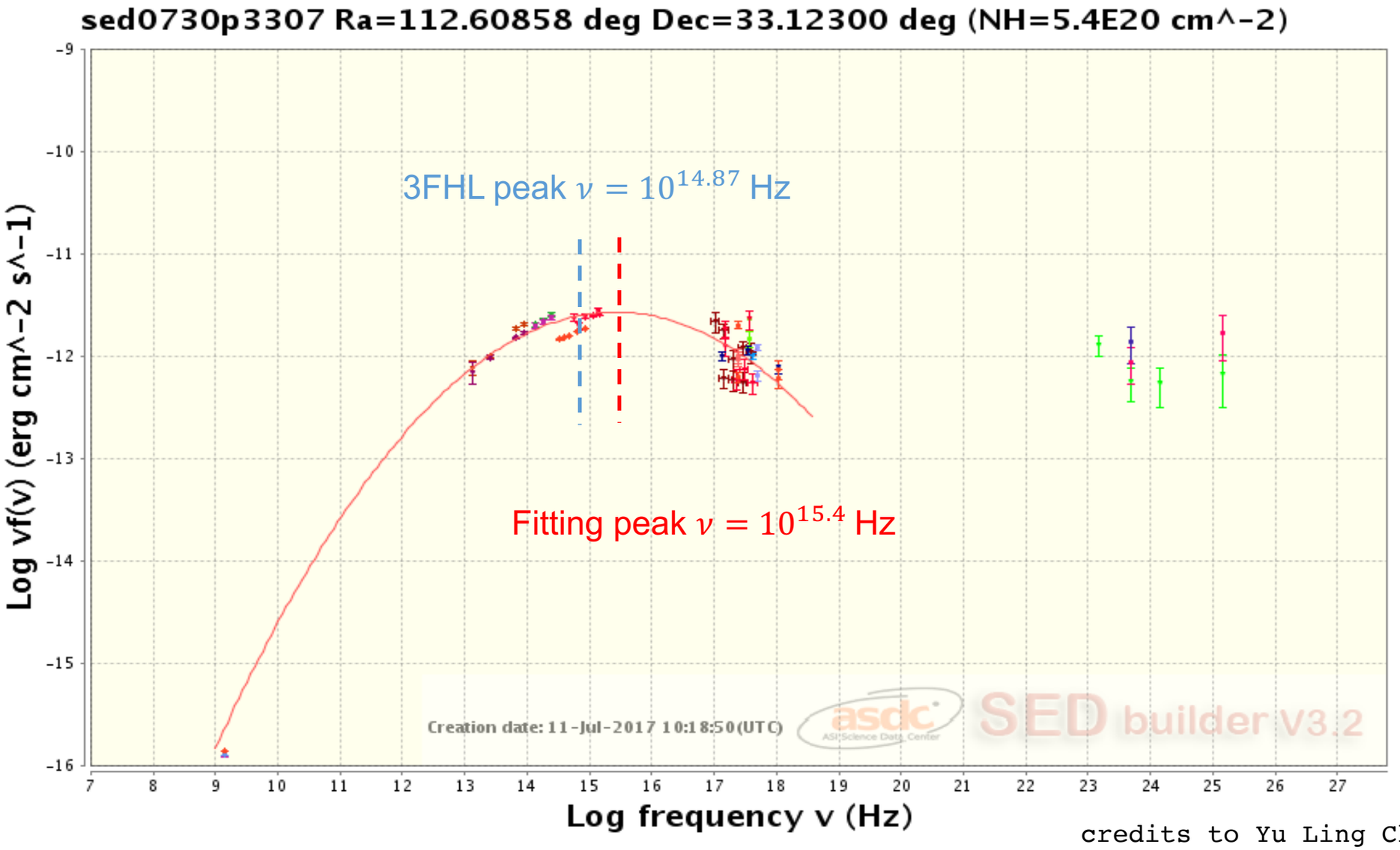


Note:

- NGC 4945, NCS 1068 (Seyfert galaxy with star forming component)
- 2FHL vs UHECRs tested in E.R et al., MNRAS (2017)

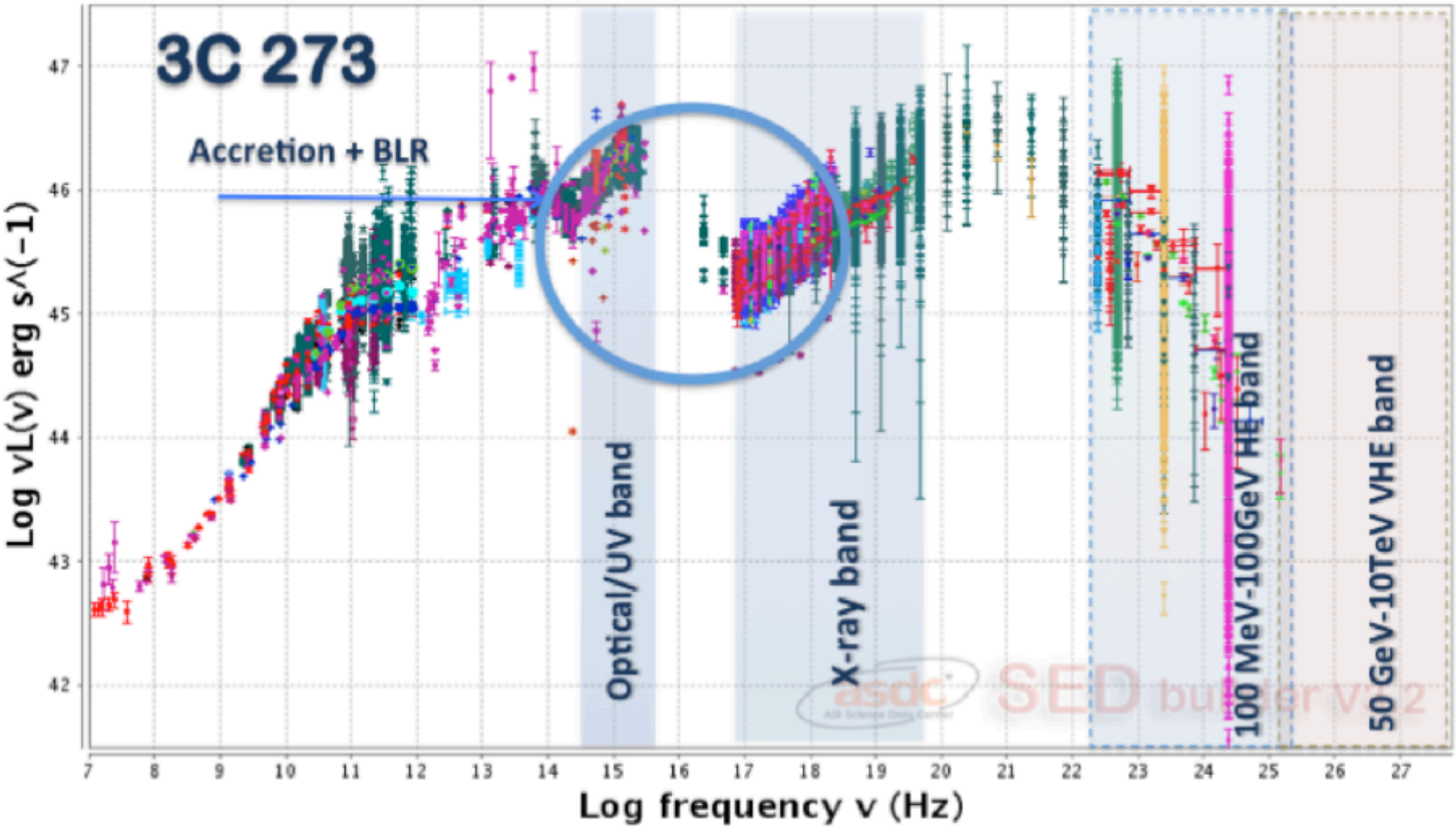
THE SCENARIOS

1- Blazars: multi-wavelength analysis, time domain very important



credits to Yu Ling Chang

Institute for Advanced Study
Technical University of Munich



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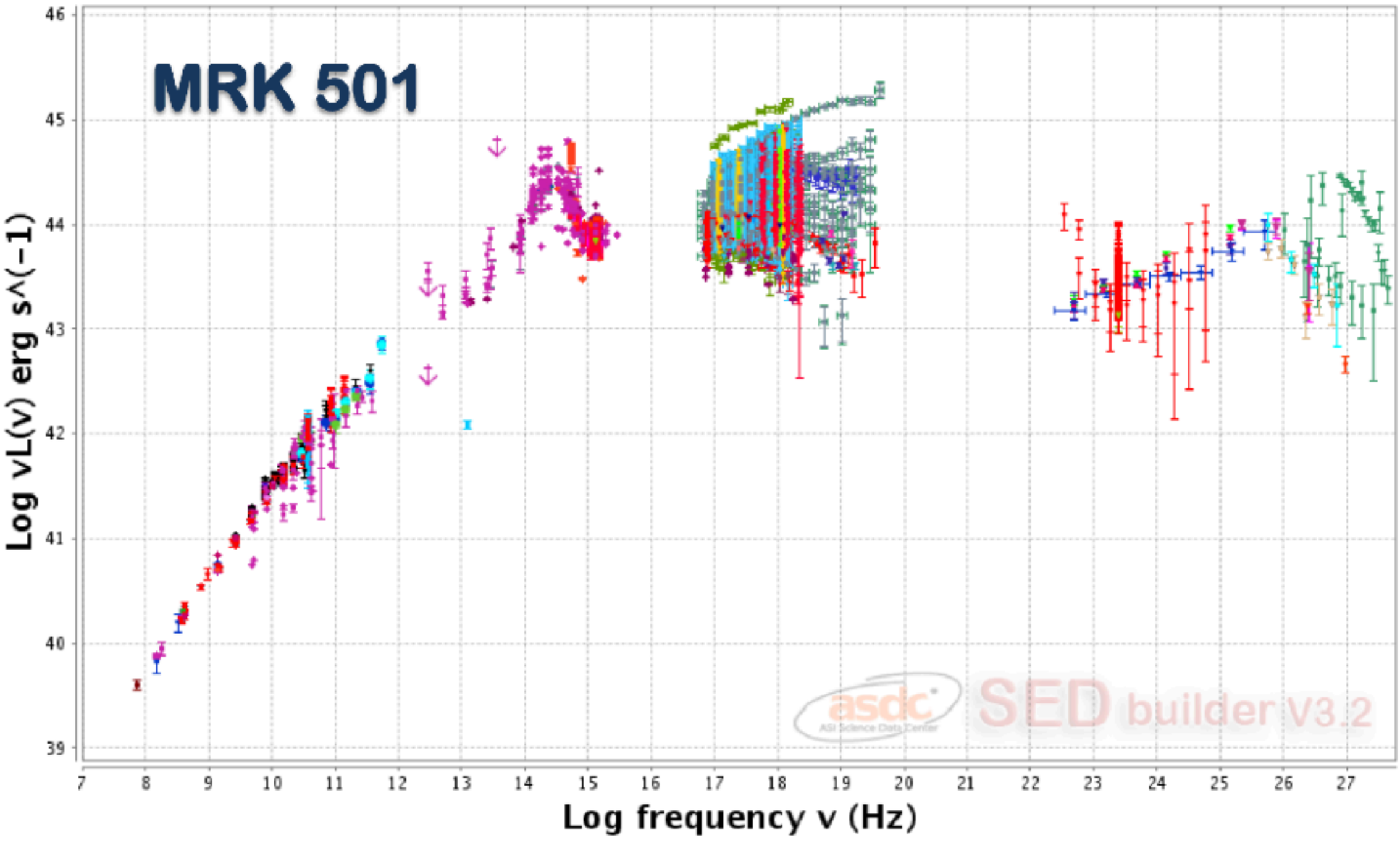

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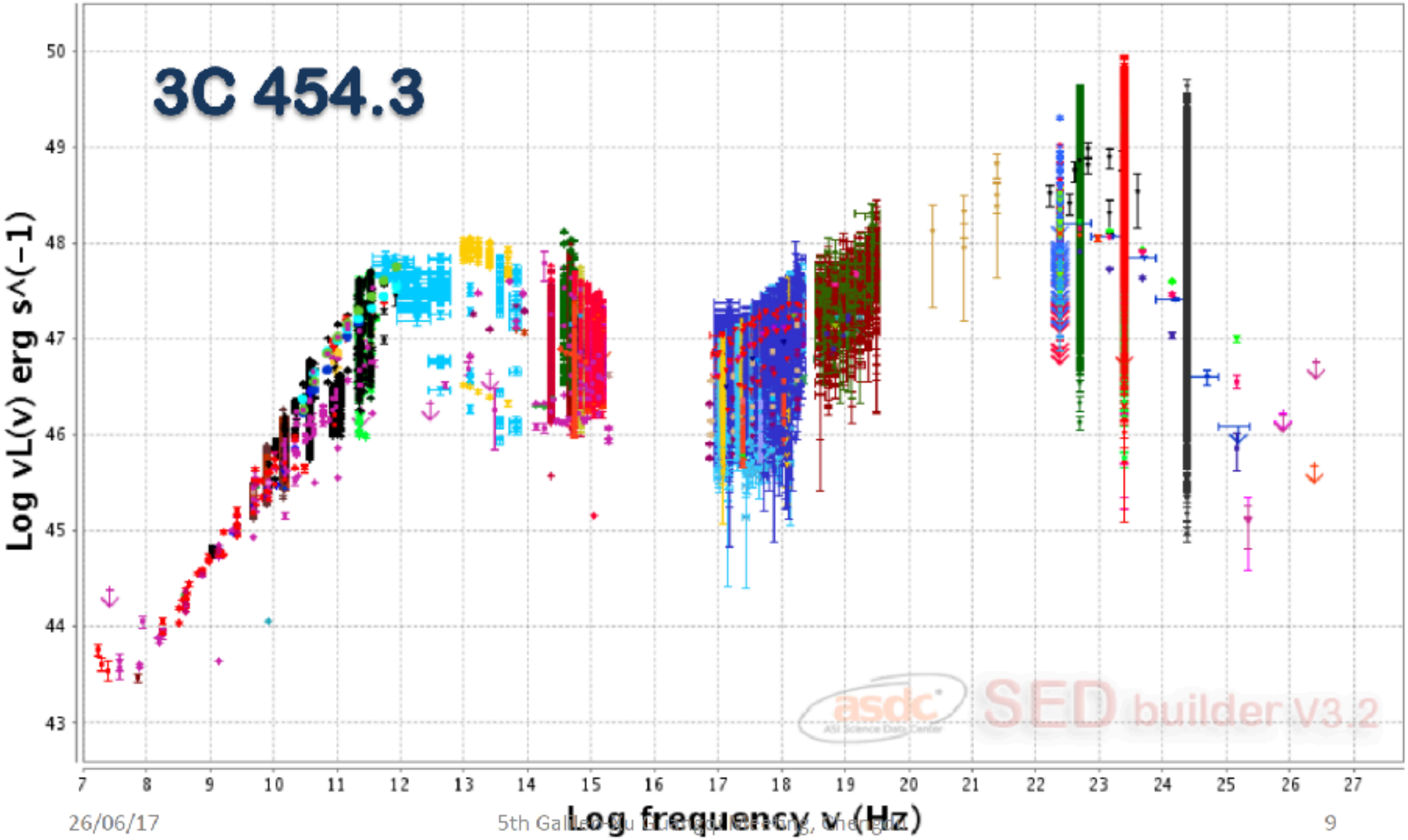

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