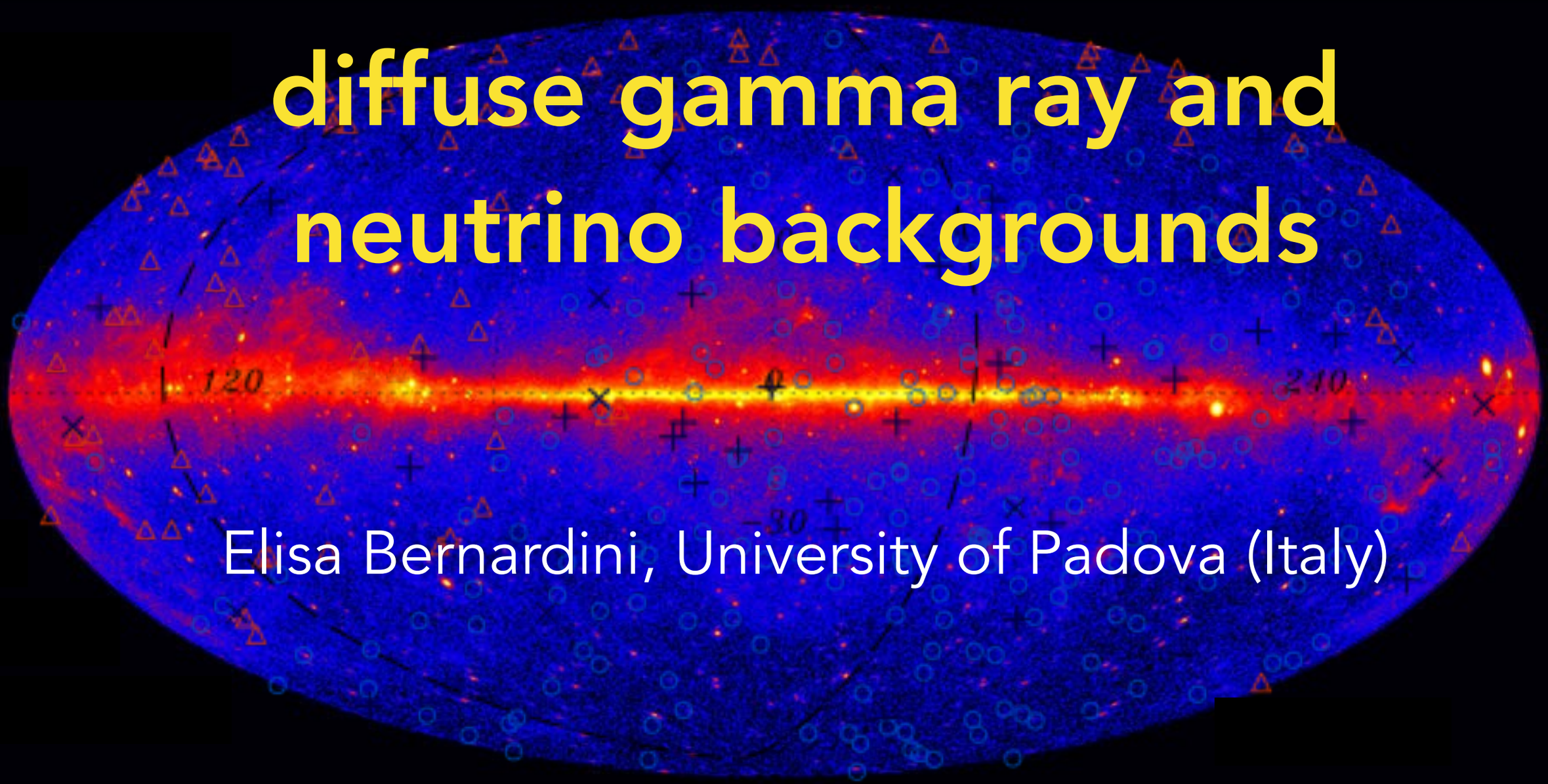
On correlation between diffuse gamma ray and neutrino backgrounds



Elisa Bernardini, University of Padova (Italy)

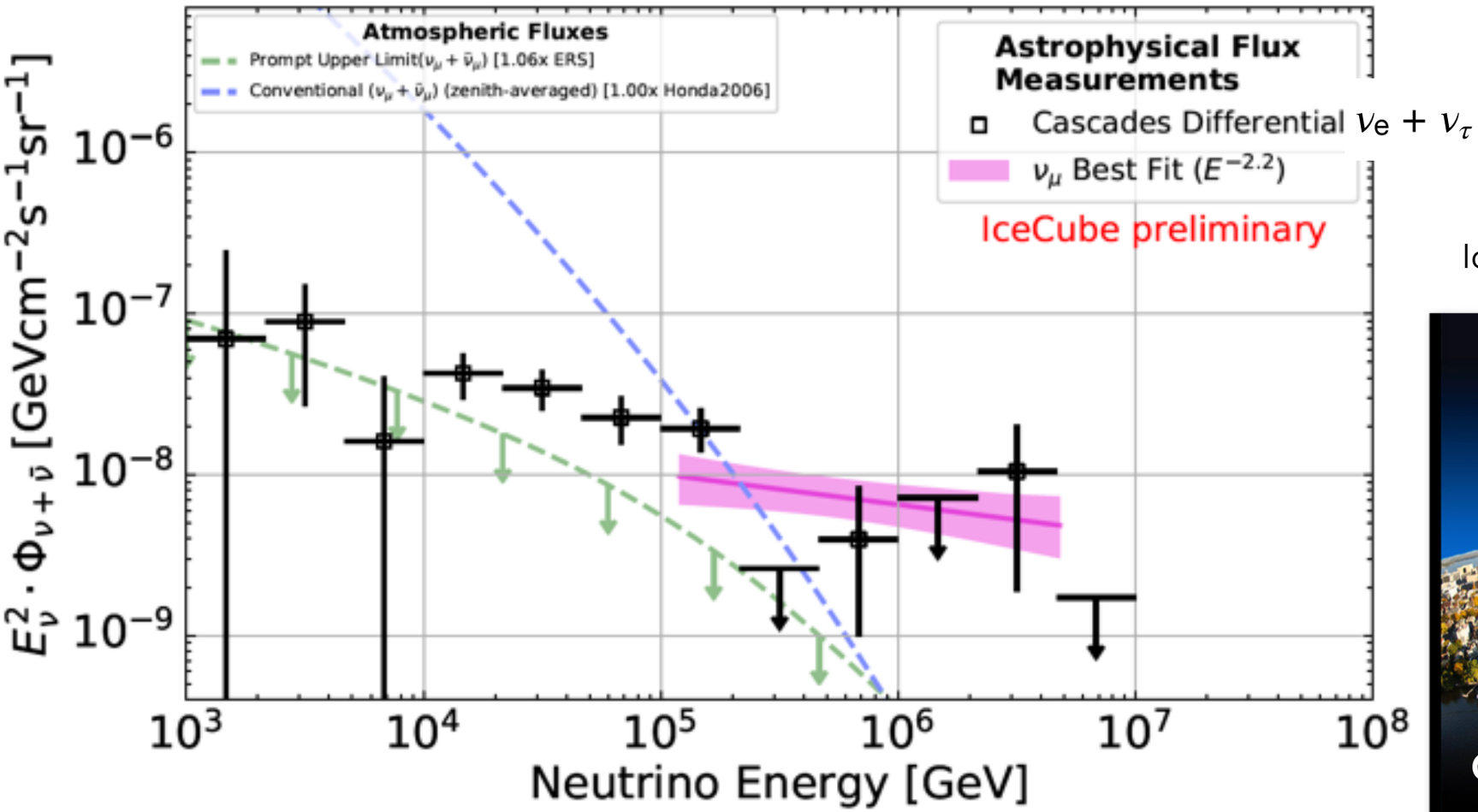
Sixteen Marcel Grossmann Meeting — 5-10 July 2021

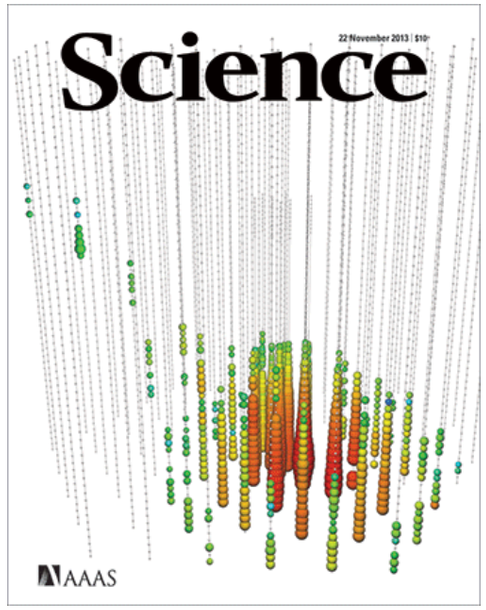
https://indico.icranet.org/event/1/overview

Cosmic neutrinos: a new key player

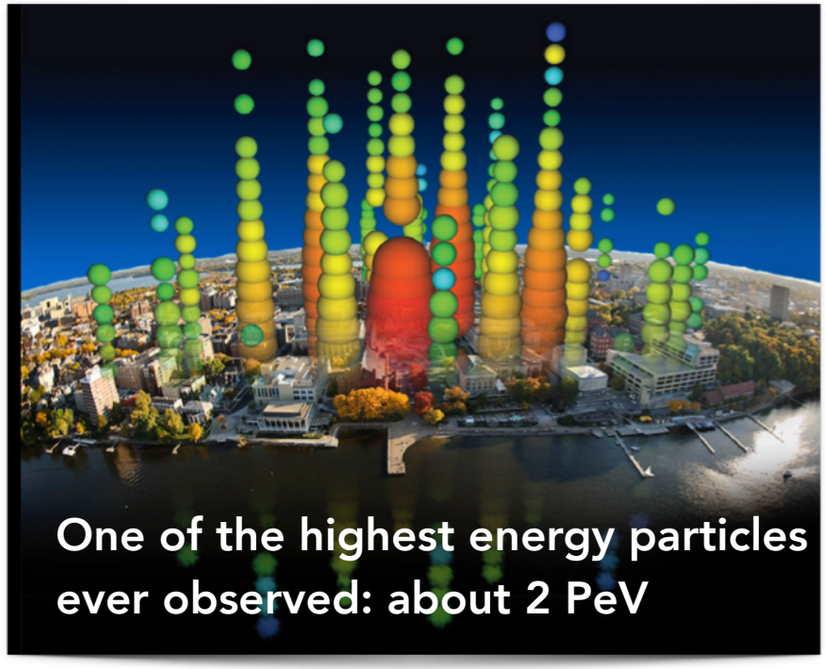
In 2013 IceCube has discovered diffuse cosmic neutrinos with energies greater than about 30 TeV: a new observational window is available!

F. Halzen, NeuTel2021





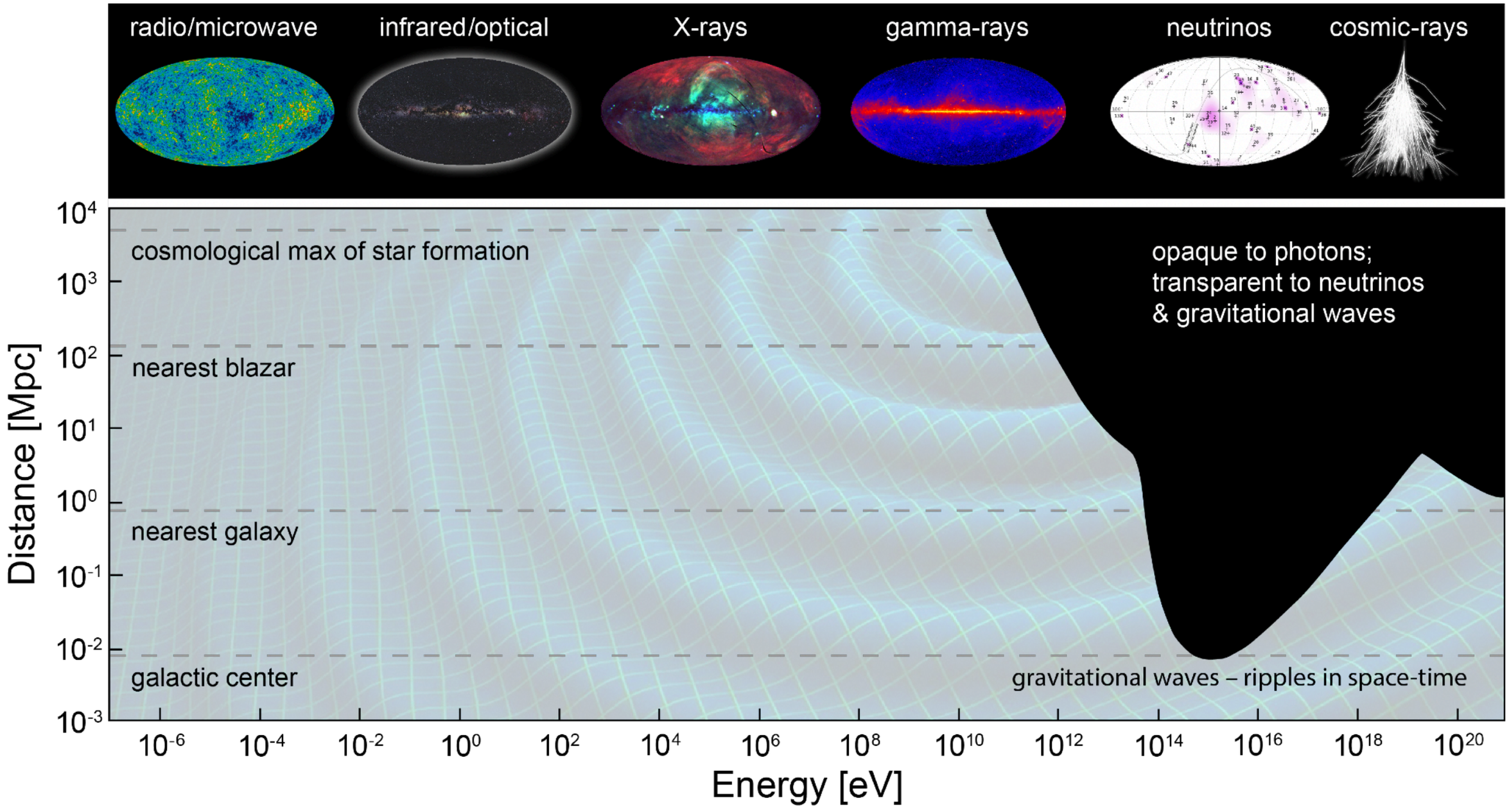
IceCube, Science 342, 1242856 (2013)



from F. Halzen

Messages from the Universe

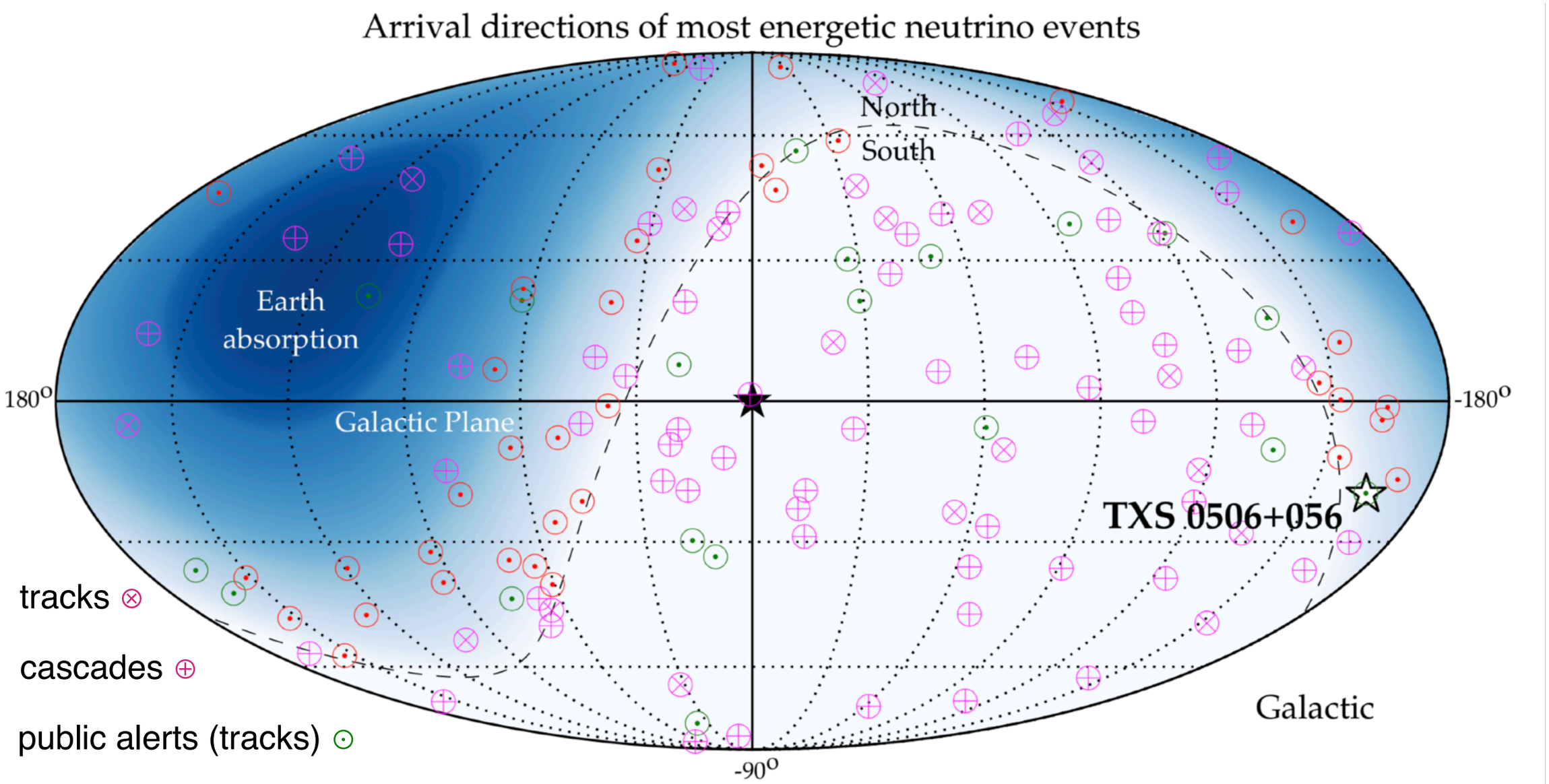
The Universe is opaque to photons above about 100 TeV energies. Protons at EeV energies interact with the cosmic microwave background. Only neutrinos and gravitational waves reach us from remote regions.



Elisa Bernardini — University of Padova (Italy)

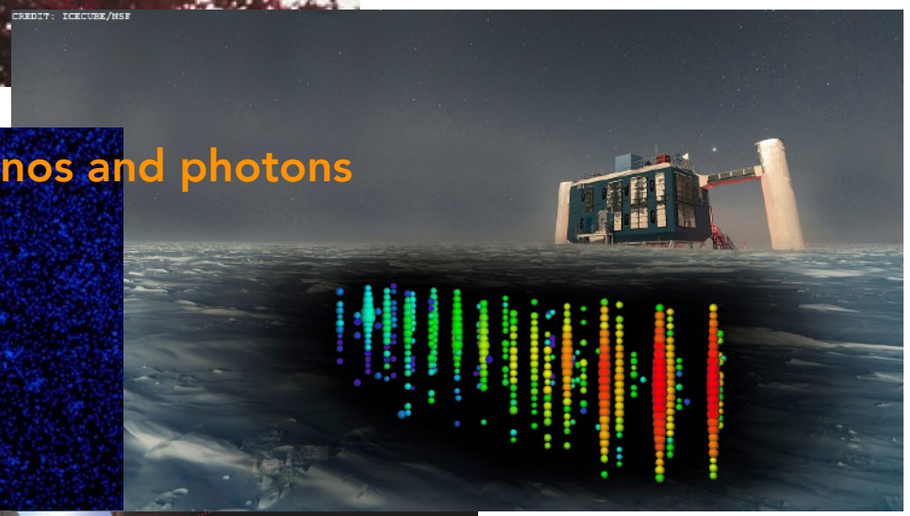
Extragalactic neutrinos

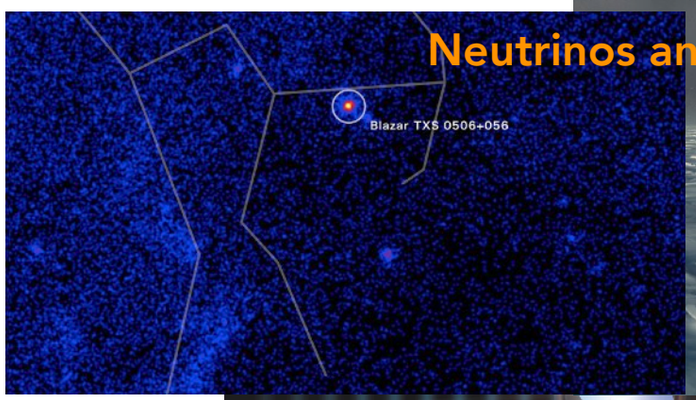
Inspection of the event directions reveals no obvious accumulation either around individual sources or the Galactic plane. The distribution of arrival directions suggests dominant extragalactic source populations.



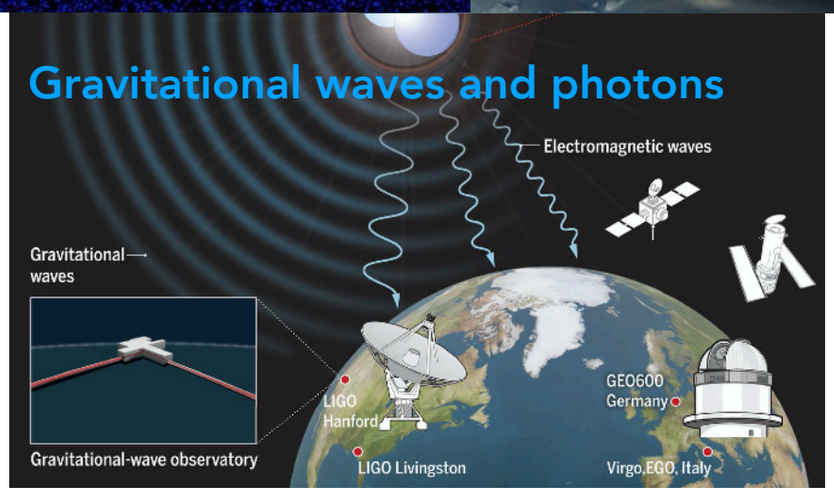
Multi-messenger era

SN 1987A associated with a burst of MeV neutrinos



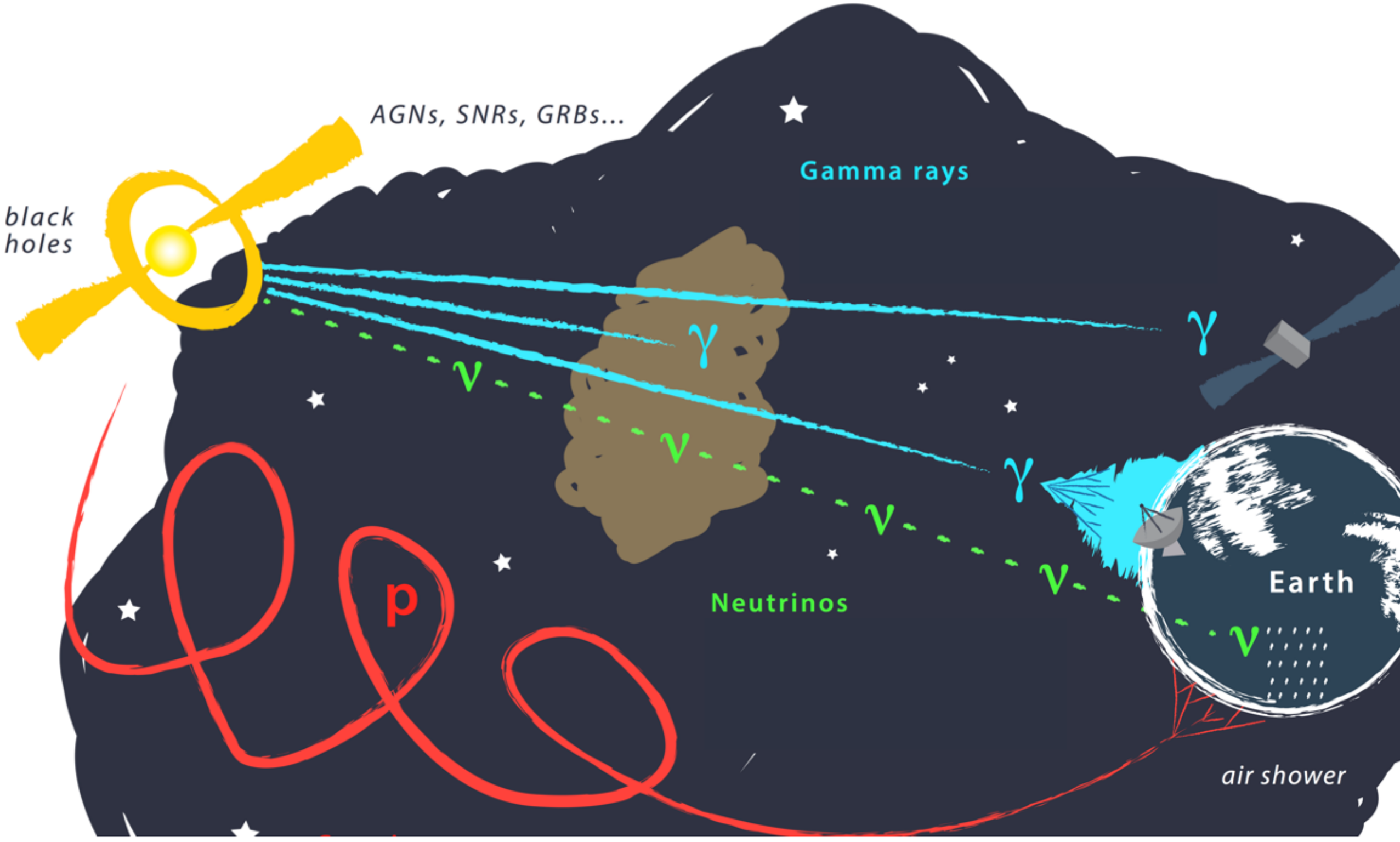


A high-energy neutrino **IceCube170922A** associated with the gamma-ray Blazar **TXS 0506+056**

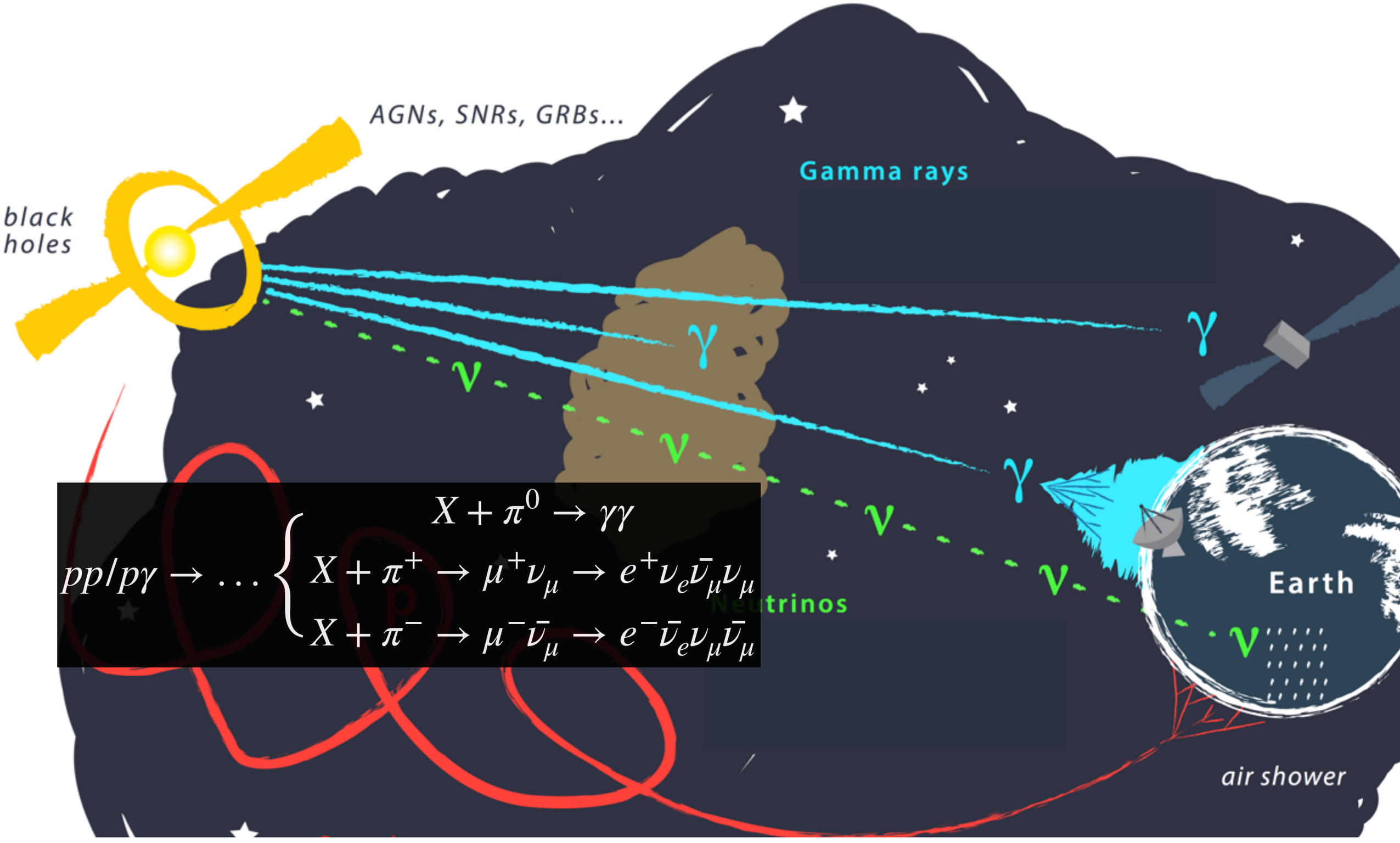


Gravitational wave **GW170817** associated with the **GRB 170817A**

Connecting cosmic messengers

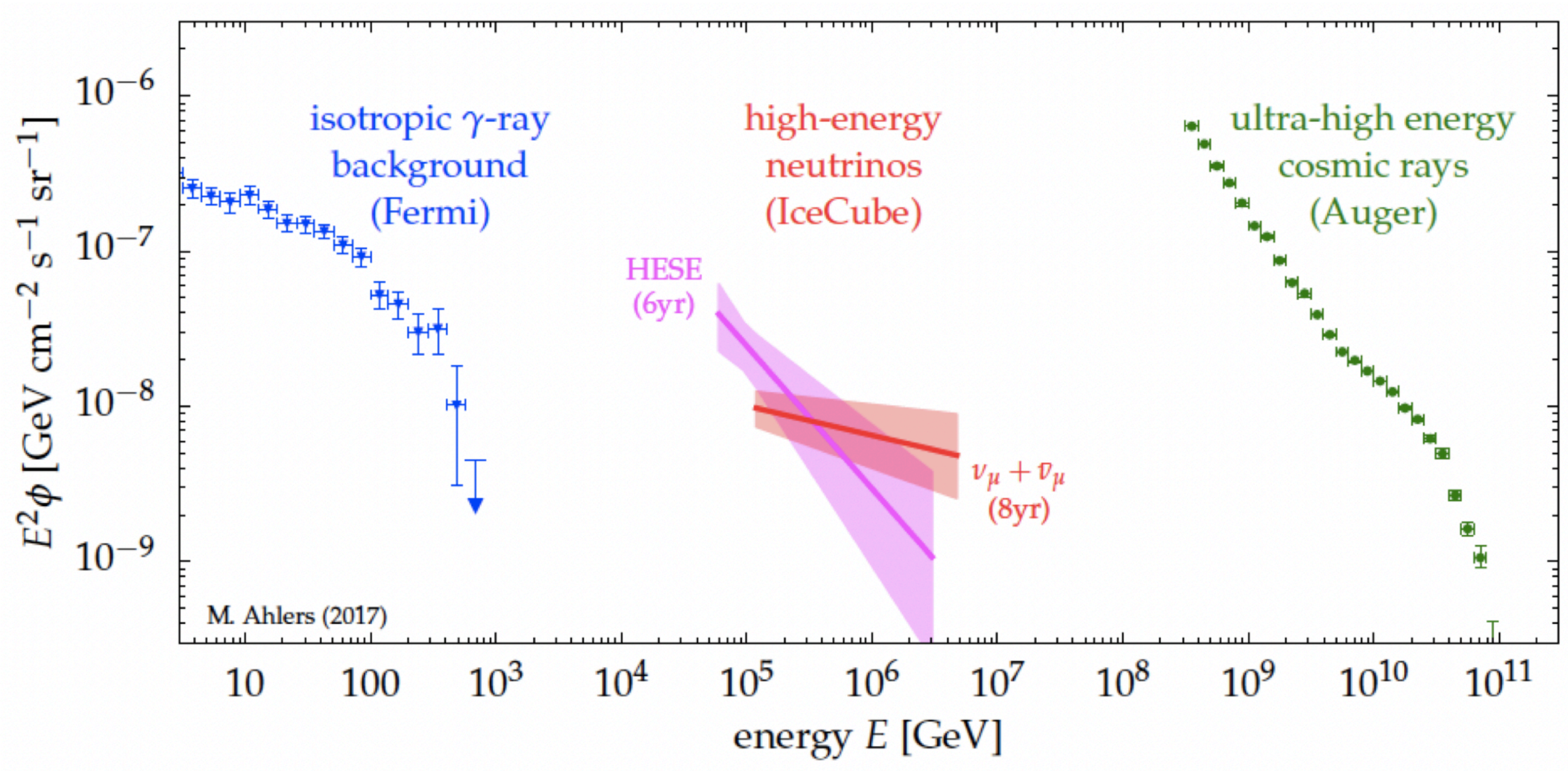


Connecting cosmic messengers



Multi-Messenger backgrounds

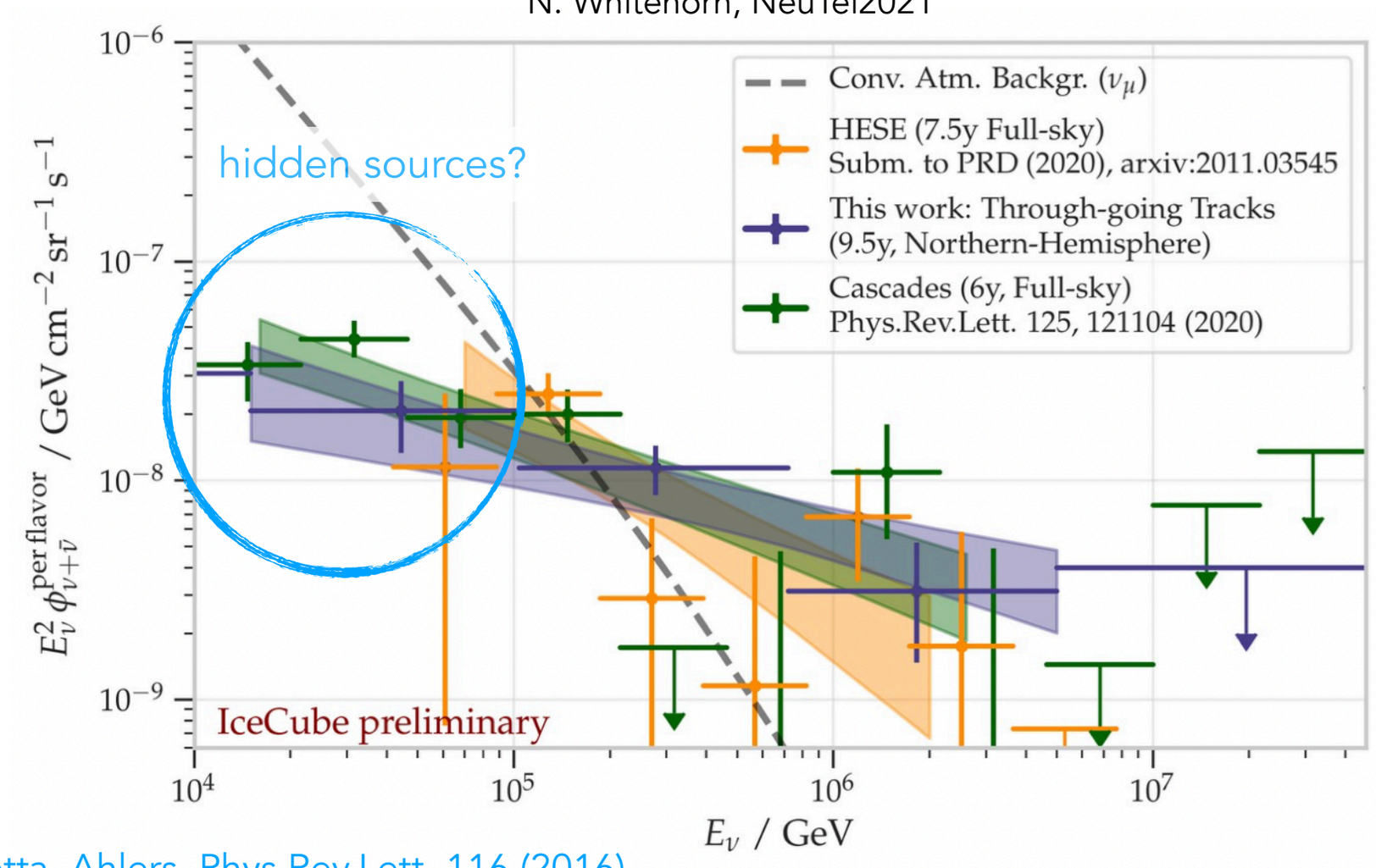
Diffuse cosmic ray, γ-ray, and neutrino fluxes show similar energy content despite their different energy regimes. This correspondence suggests an intriguing multi-messenger relationship.



More on diffuse neutrinos E>10 TeV

Different channels for neutrino interactions can be distinguished, allowing to test the spectrum for different neutrino flavors, sky regions and energy ranges. Data seems compatible with a simple power-law with roughly an index -2.4.

N. Whitehorn, NeuTel2021

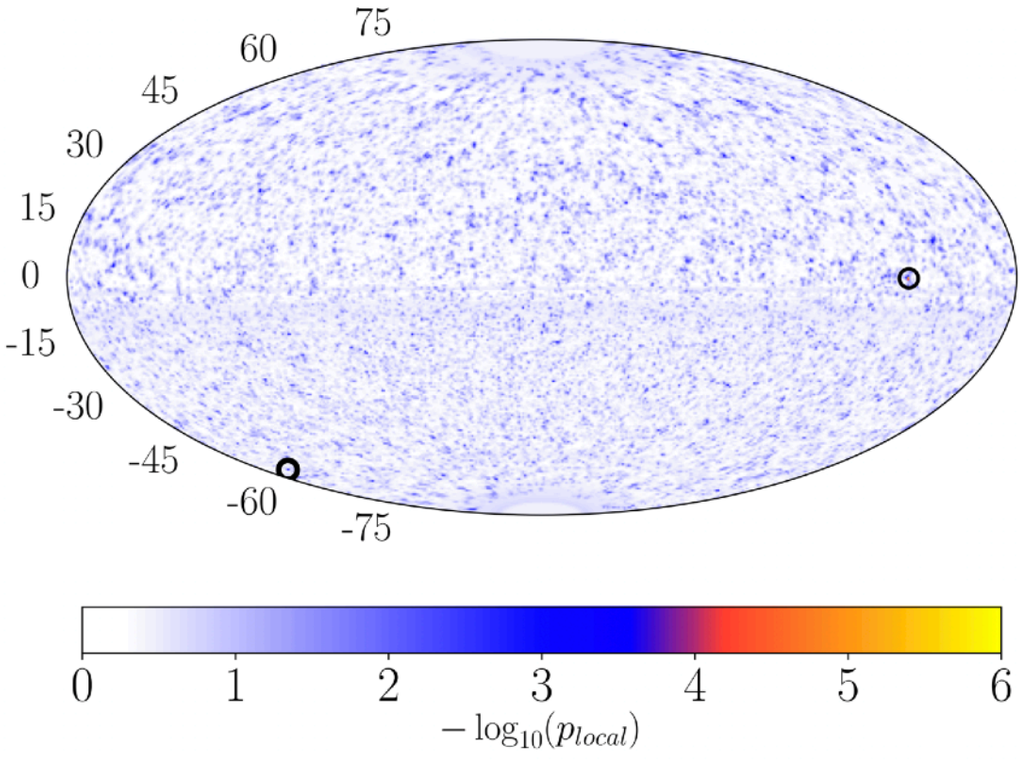


e.g. Murase, Guetta, Ahlers, Phys.Rev.Lett. 116 (2016)

Inspecting the neutrino data alone

Long exposure sky maps as well as stacking analyses of source catalogs do not suggest specific source classes to be responsible for the observed diffuse (unresolved) high-energy neutrino flux

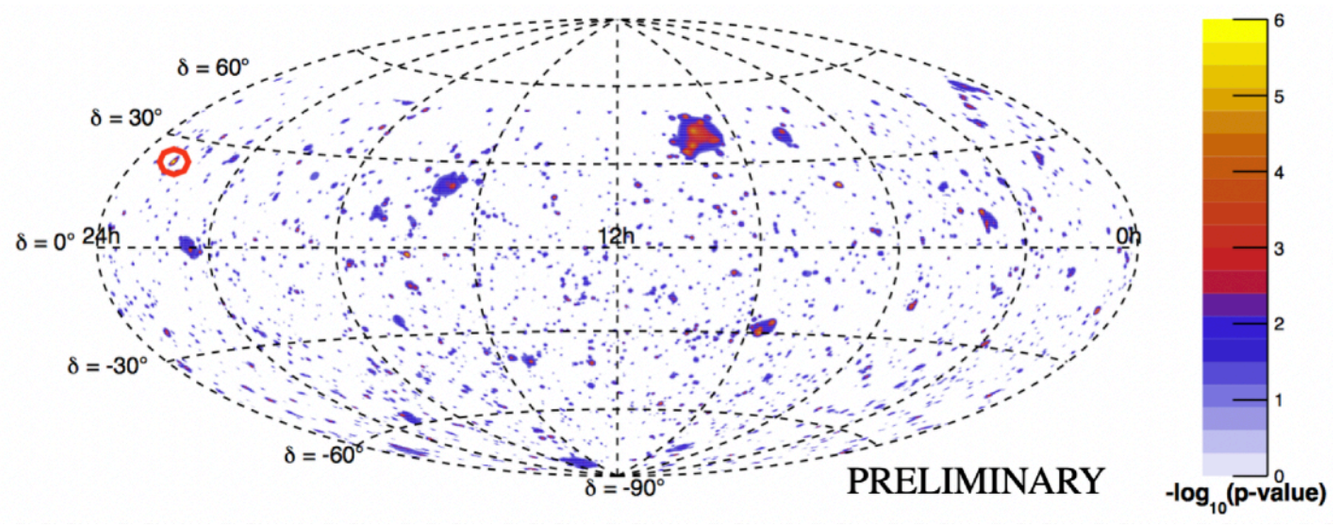
Hottest spot near Seyfert galaxy NGC 1068, inconsistent with background at **9.9% post-trial**



10 years of data

IceCube Coll. Phys. Rev. Lett. 124, 051103 (2020)

Hottest spot inconsistent with background at **23% post-trial**



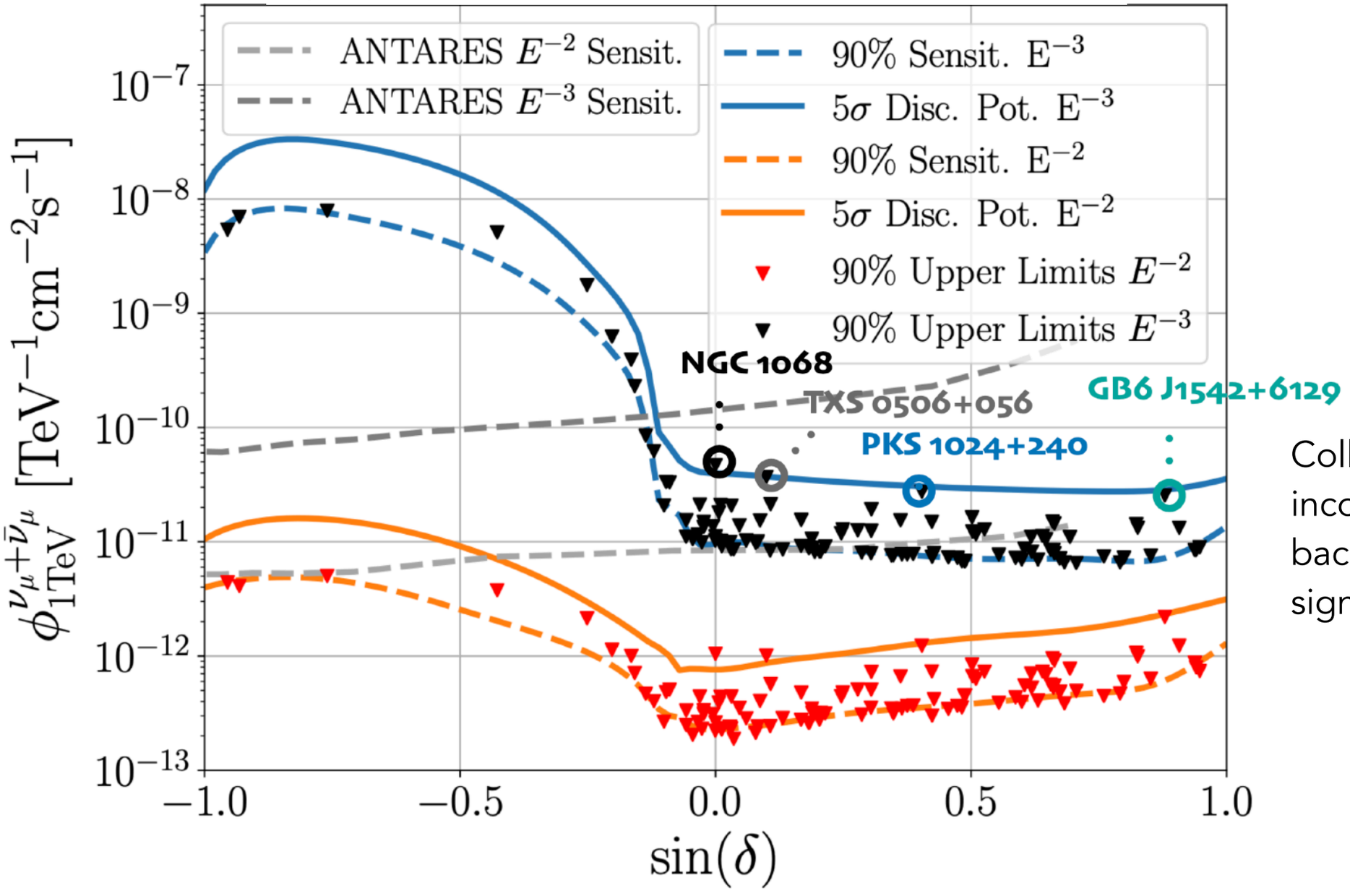
11 years of data

Antares Coll. arXiv:1908.08248

Testing source catalogs

Pre-selecting sky directions based on multi-wavelength data, allows to dramatically reduce trial factors. Potential neutrino sources start to emerge at 3σ level.

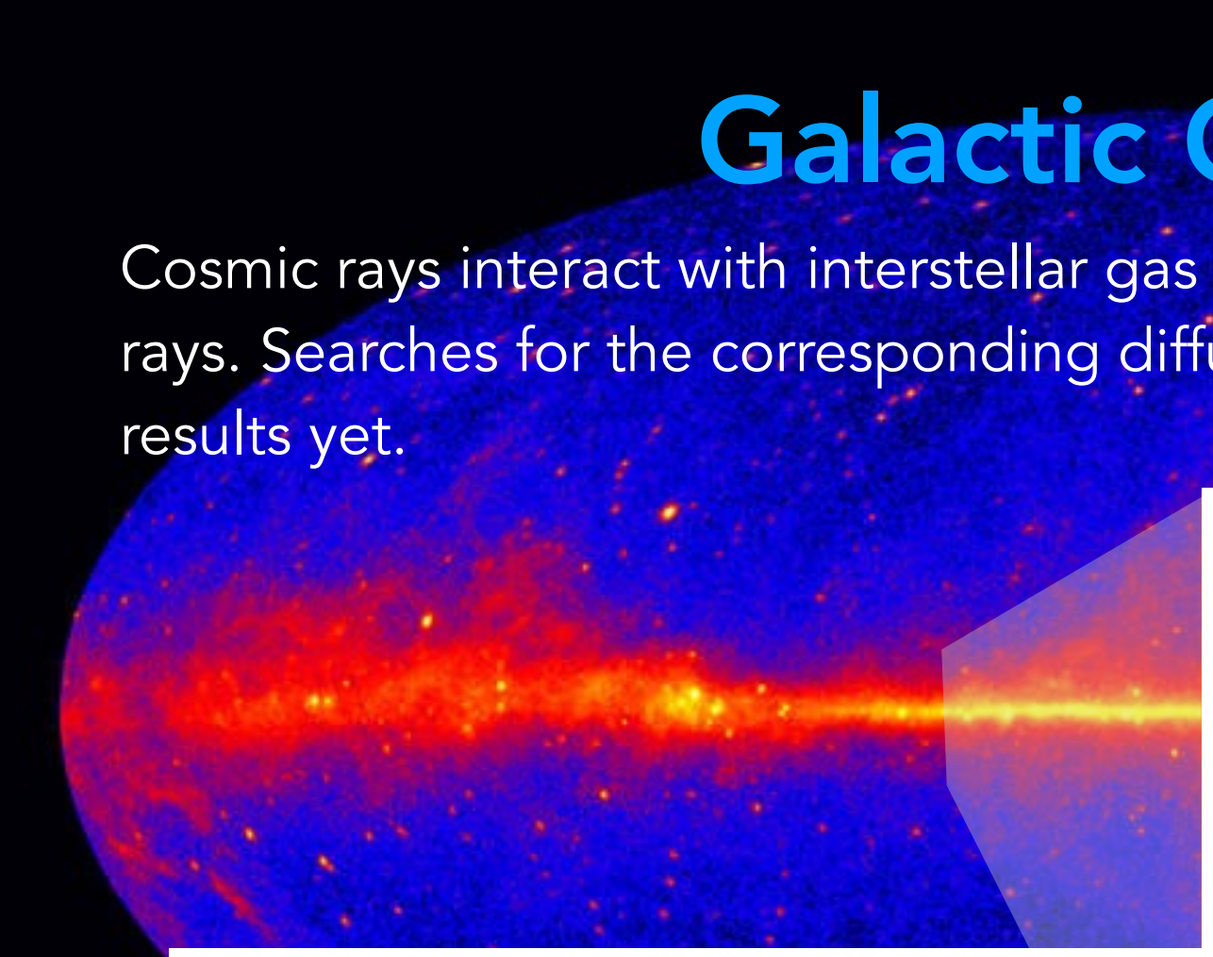
10 years of data, IceCube Coll. Phys. Rev. Lett. 124, 051103 (2020)

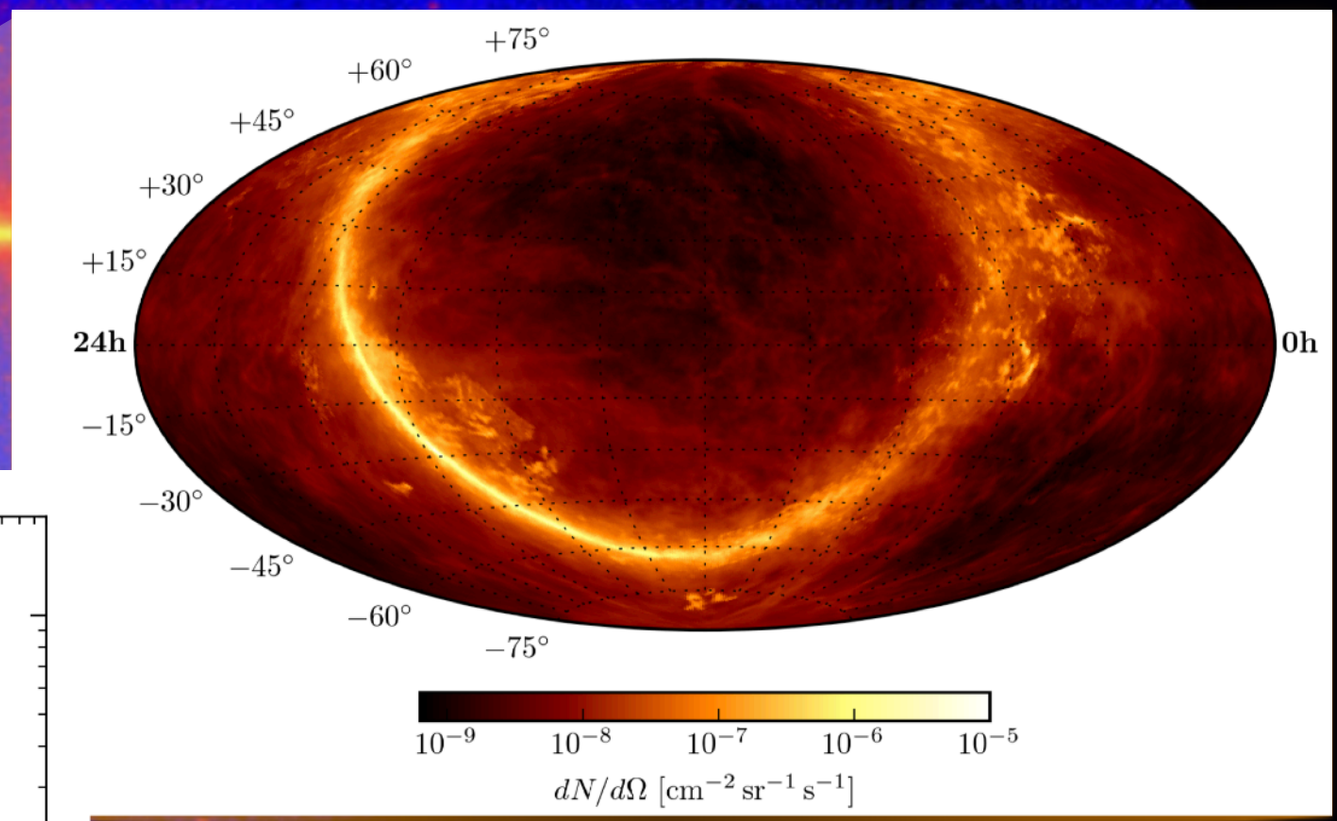


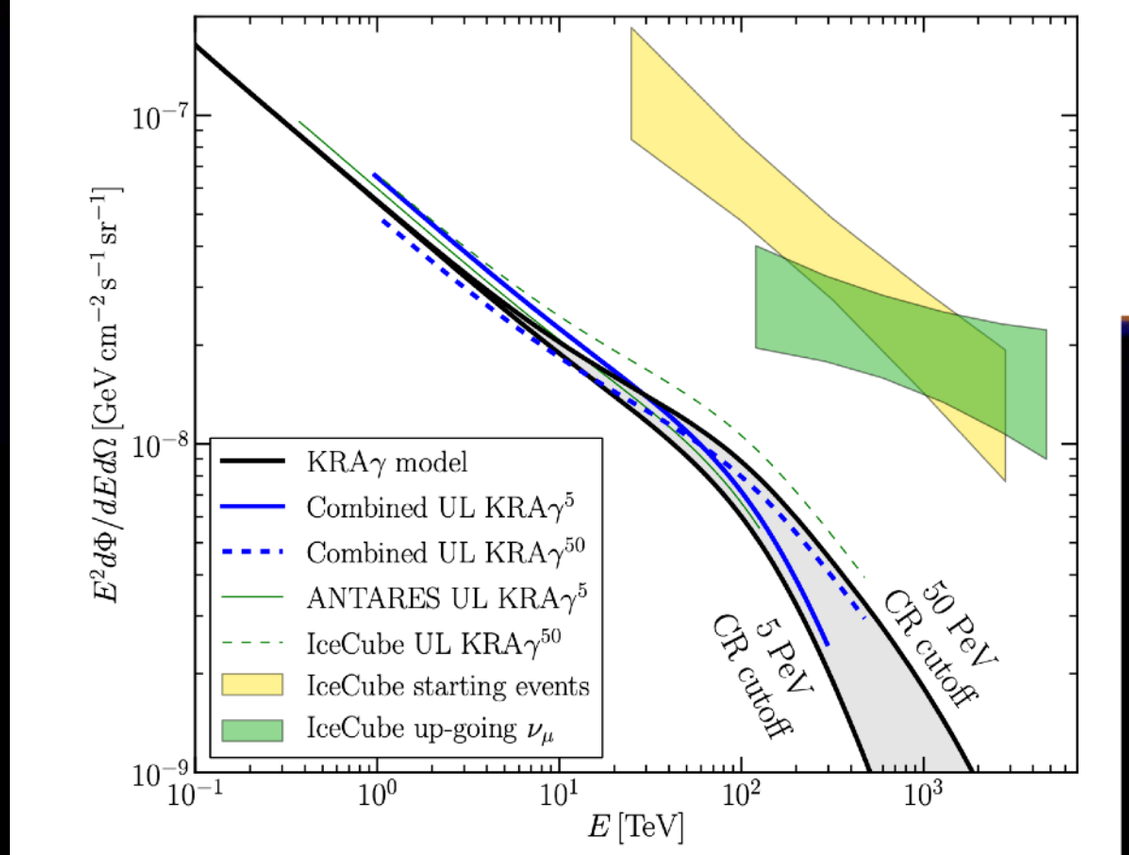
Collectively inconsistent with background at 3.3 σ significance post-trial

Galactic Cosmic Rays

Cosmic rays interact with interstellar gas and radiation leading to diffuse gamma-rays. Searches for the corresponding diffuse neutrinos do not yield positive results yet.



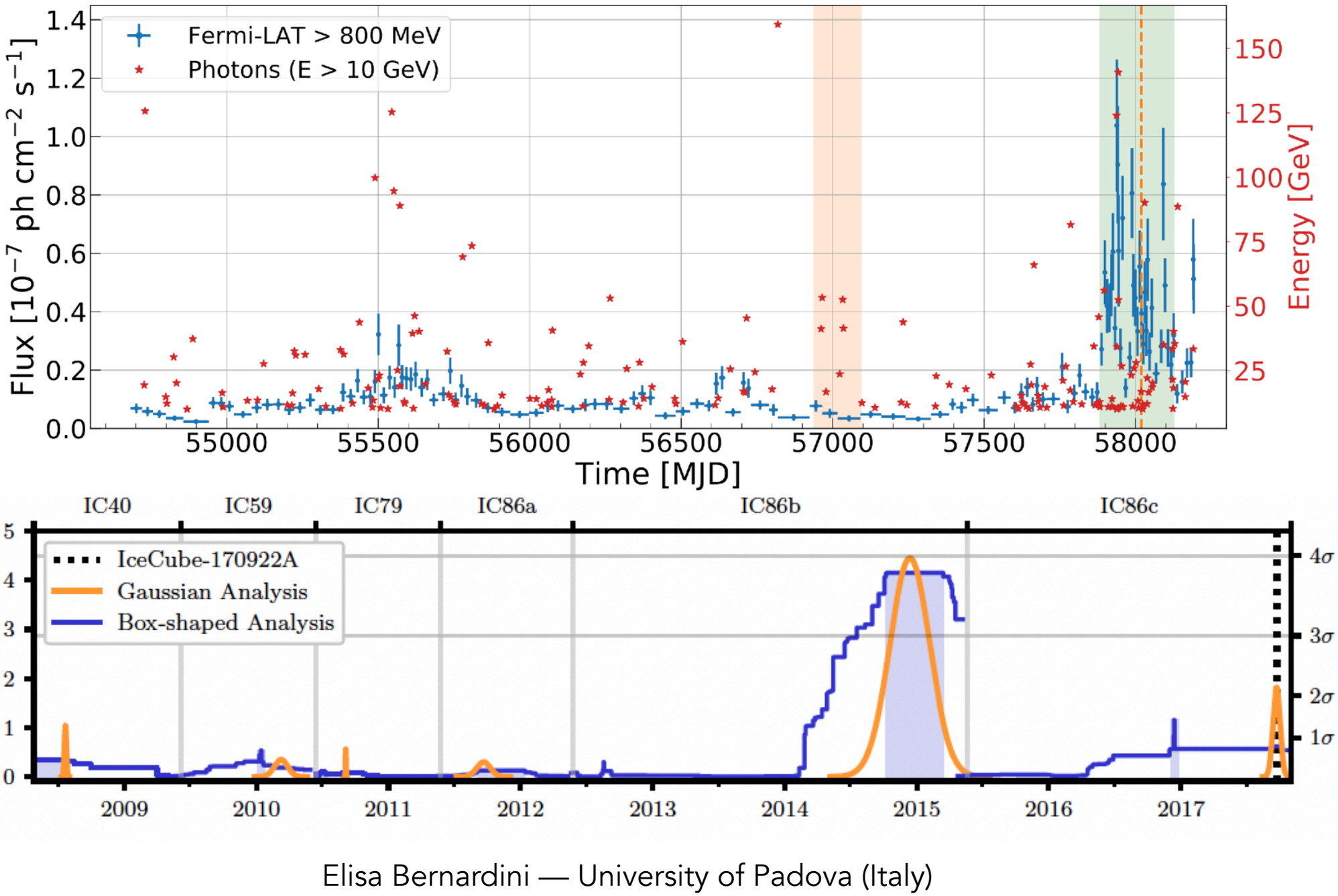




Neutrino flux per unit of solid angle of the KRA$_\gamma^5$ model (Gaggero et al. 2015a), shown in equatorial coordinates.

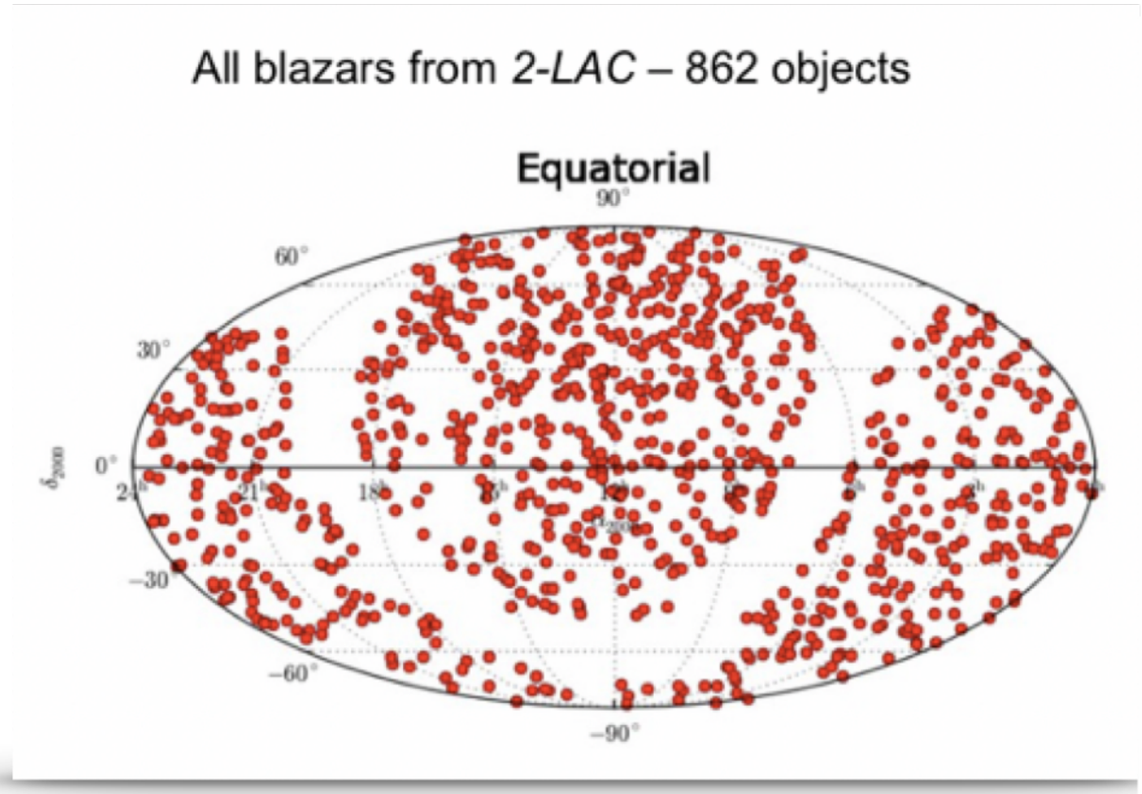
TXS 0506+056

The so far most convincing source associated with a high-energy neutrino challenges interpretation: simple one-zone γ-ray Blazar models do not work. Moreover, earlier lower energy neutrinos appeared in a γ-ray dark period.

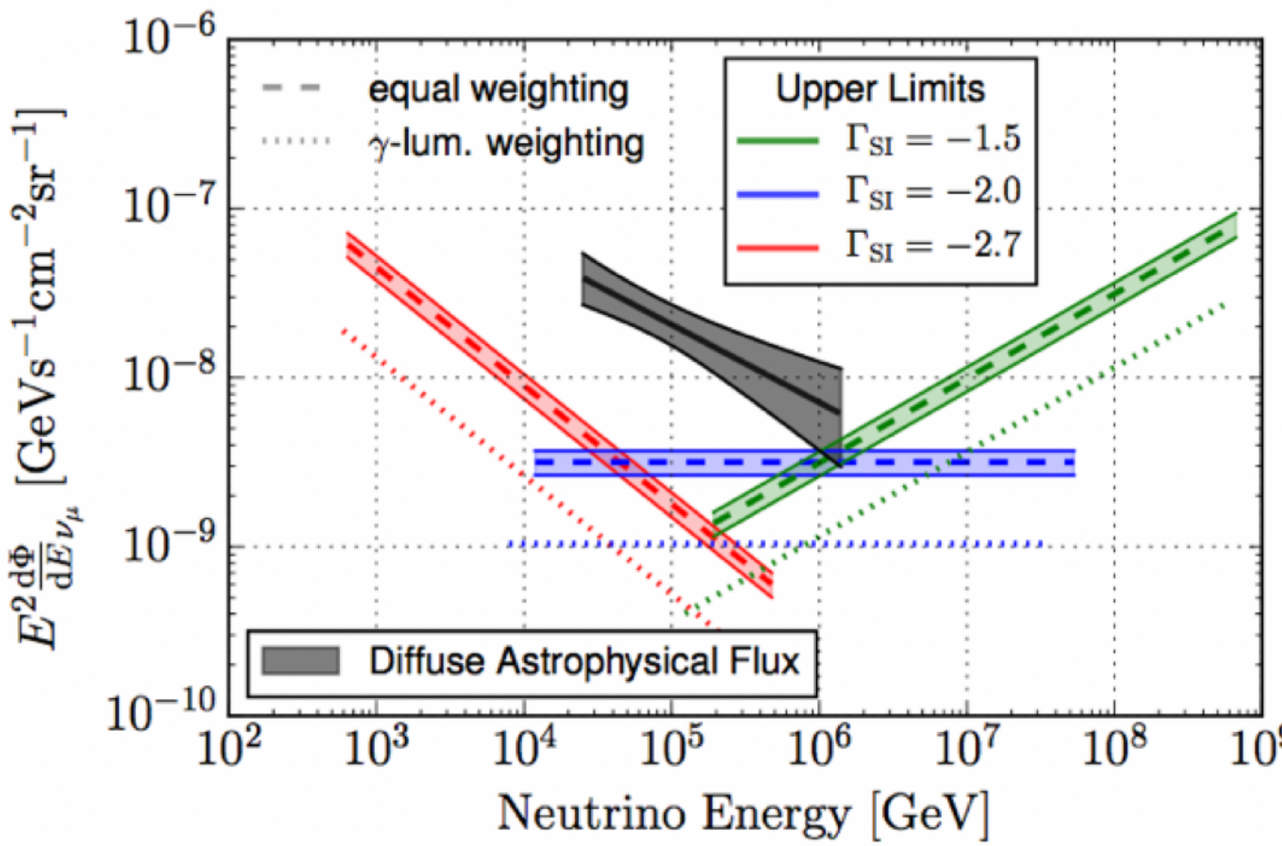


Contribution from γ-ray Blazars

Blazars dominate the diffuse γ-ray background above 10 GeV. A Stacking analysis allows to evaluate the contribution of Fermi-LAT Blazars to the diffuse neutrino flux. Fermi LAT blazars can only be responsible for a small fraction of the observed neutrinos. Similar conclusions are derived for different source populations, e.g. Gamma-ray Bursts.

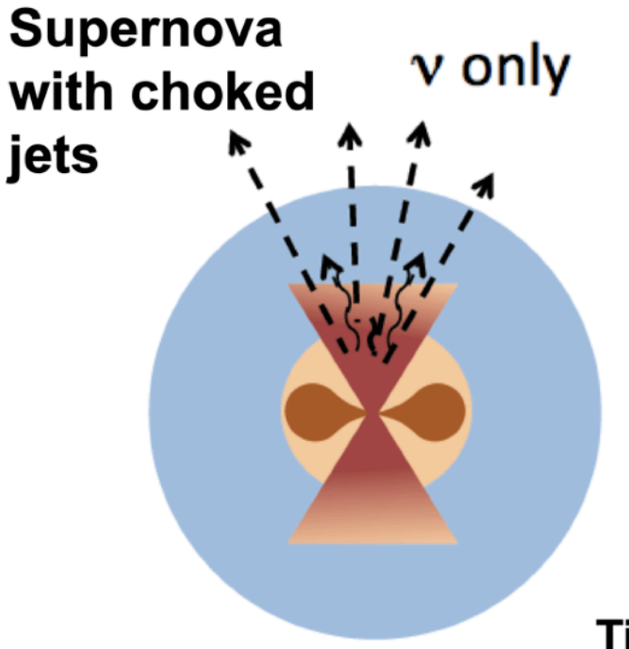


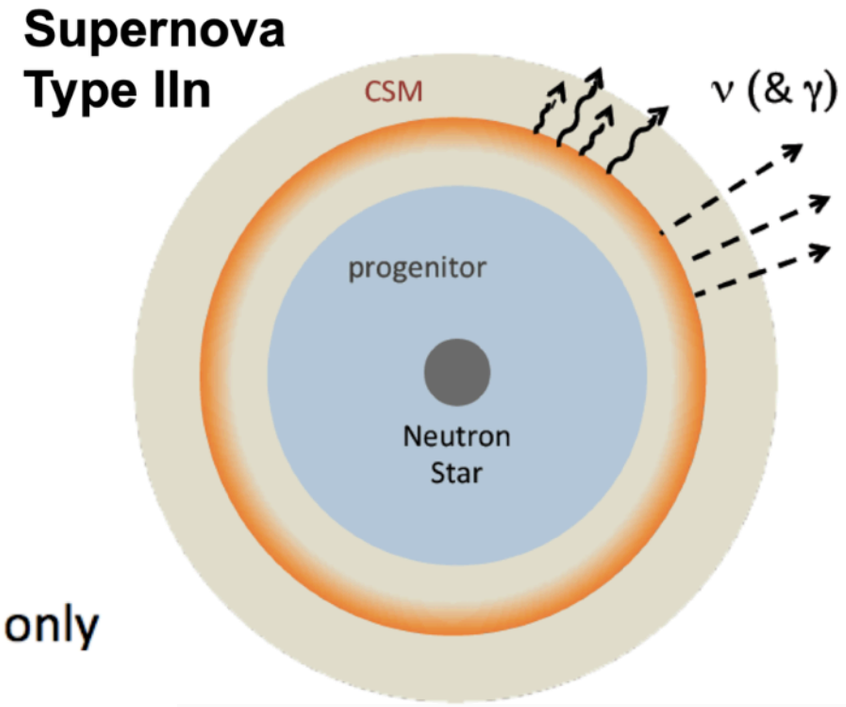
IceCube, ApJ, 835 (2017)

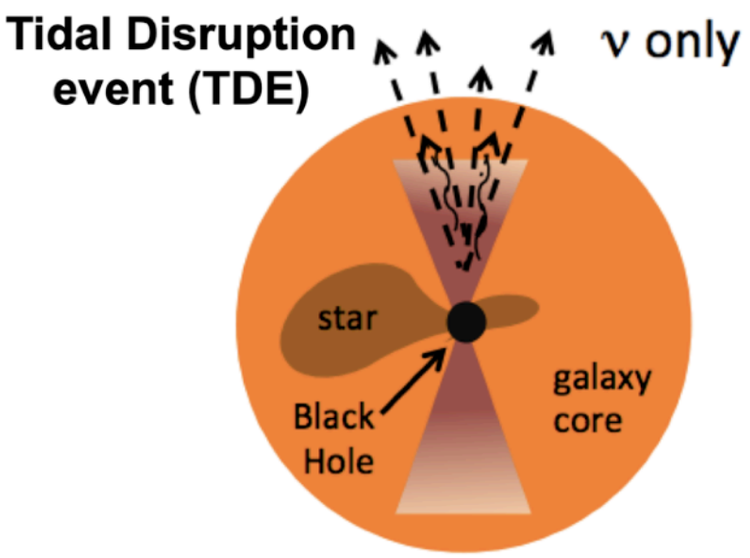


Other interesting transients

Different source populations might dominate in different energy regions, for example AGN cores, Starbursts Galaxies, Low-luminosity GRBs, TDE etc. emitting at low energies, while Blazars emit at high energies.

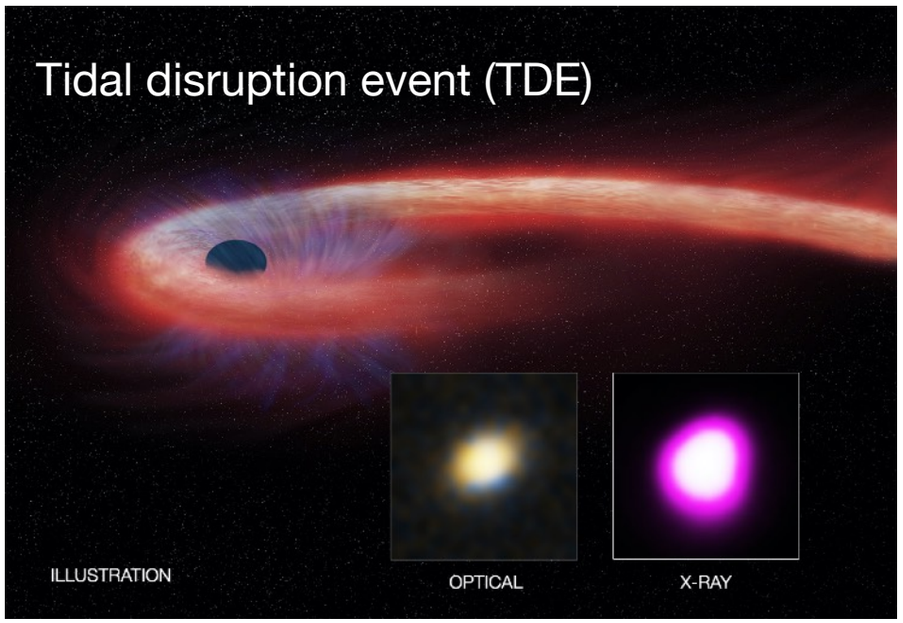






Tidal Disruption Events

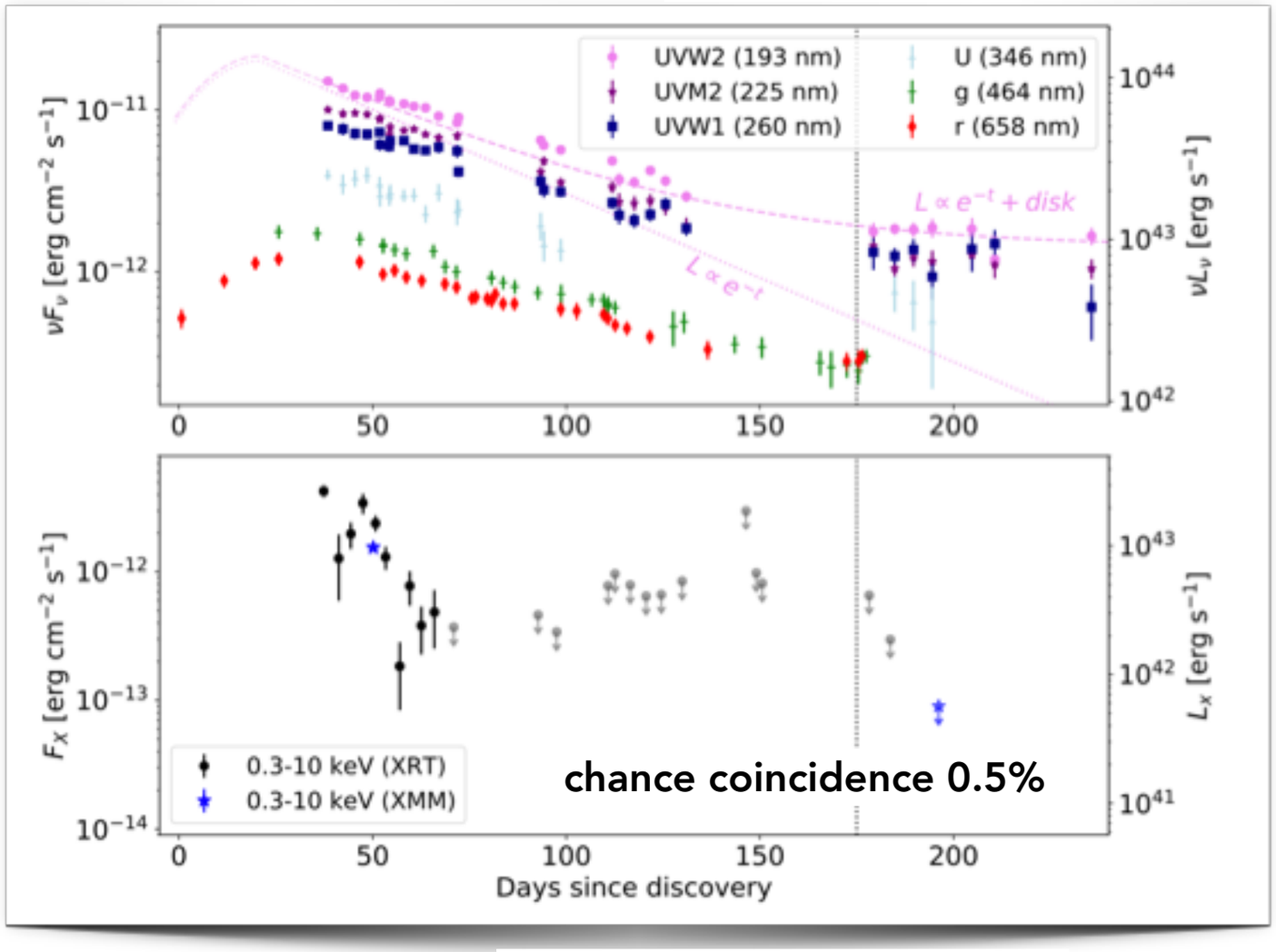
Stars torn apart by tidal forces in the vicinity of a supermassive black hole can launch jet-like outflows: tidal disruption events (TDE). Possible contribution to the total diffuse high-energy neutrino flux not conclusive yet but estimated to be sub-dominant.



e.g. Biehl, Boncioli, Lunardini & Winter 201

Murase et al Astrophys.J. 902 (2020)

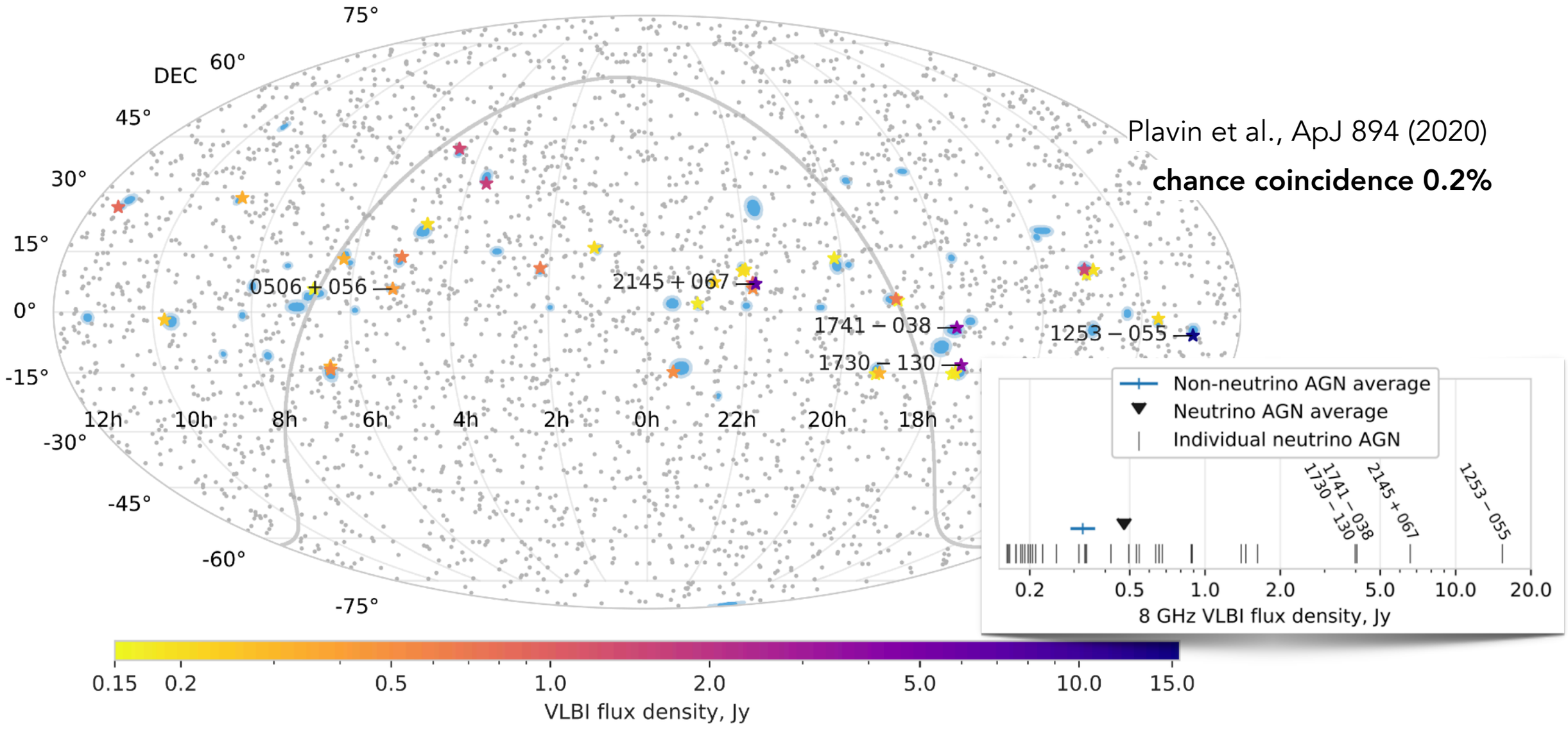
IceCube-191001A



R. Stein et al. arXiv:2005.05340

Blazars in enhanced radio emission

Two of the highest energy IceCube events found during bright radio flares of Blazars (TXS 0506+056, PKS 1502+106). A study of the correlations of high-energy neutrinos and AGNs based with radio data suggest correlations with location of bright blazar and neutrino emission during radio enhanced emission).



Plavin et al., ApJ 894 (2020)

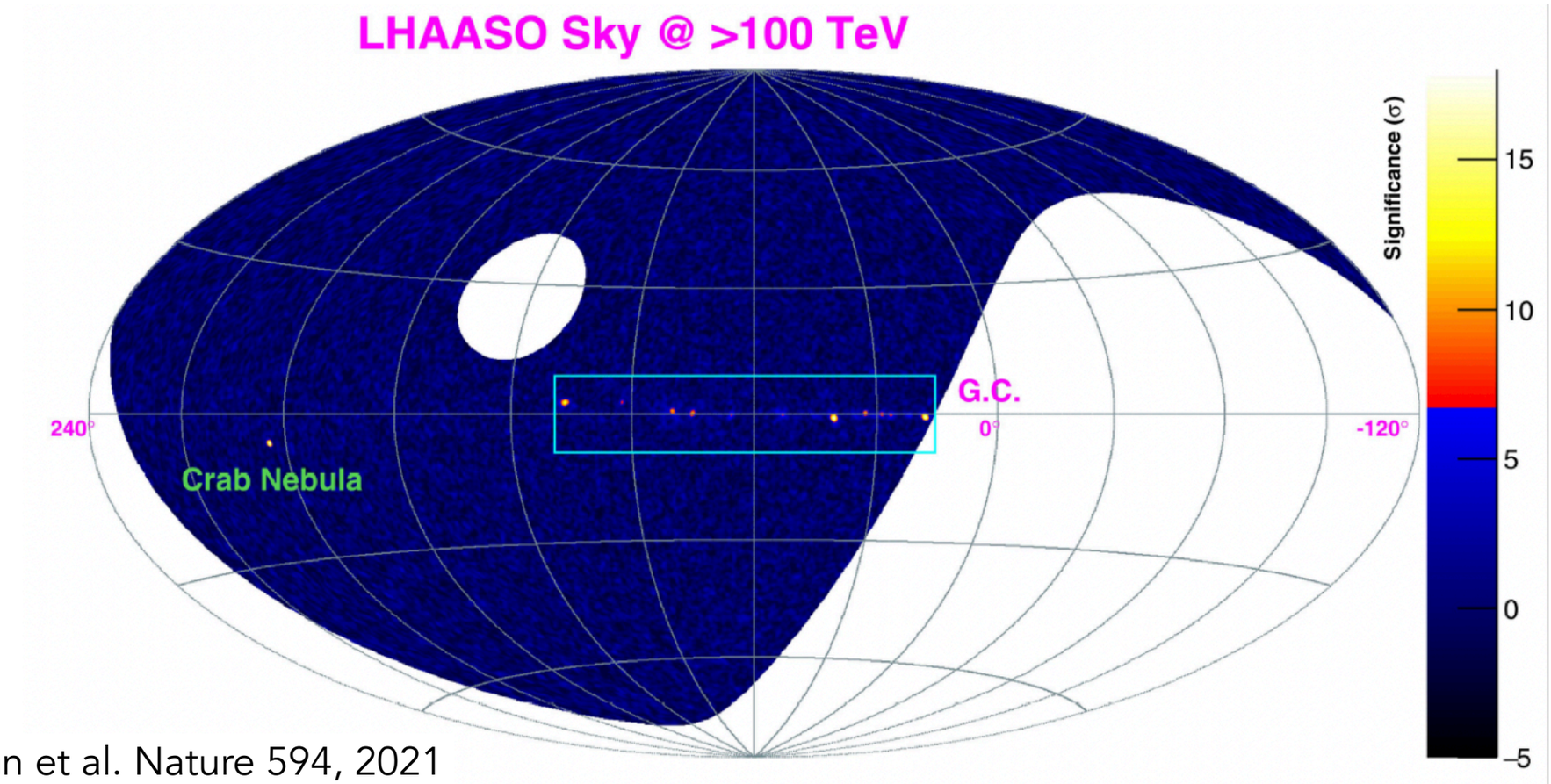
chance coincidence 0.2%

Conclusions

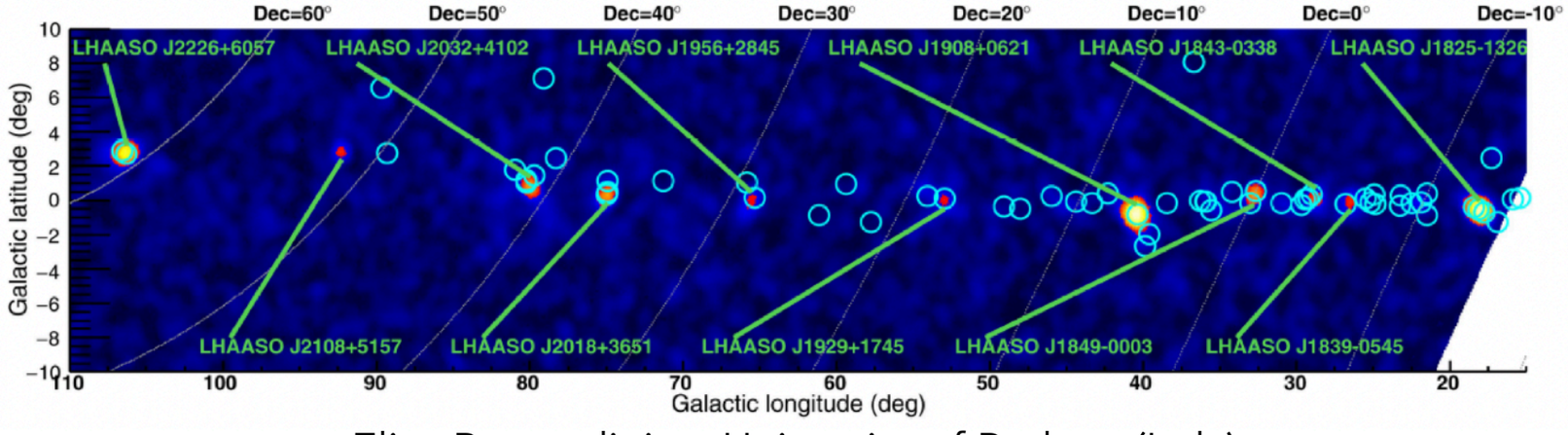
- Galactic component to the diffuse neutrino flux (E>10 TeV) disfavoured, but more to happen:
    - diffuse γ-ray backgrounds at E>100 TeV (Tibet, LHAASO), hadronic fraction?
    - new instruments complementary to IceCube (KM3NeT, GVD) awaited
- Populations of bright jetted extragalactic sources (Blazars, GRBs…) seem not to dominate the diffuse neutrino flux. Are we testing the right sources?
- Other source classes do not seem to be more favourable concert masters (e.g tidal disruption events): more likely several populations are playing a role.
- More wavelengths to be explored using large coverage data (e.g. radio seems promising).
- Realtime programs (follow-up pf alerts) are delivering a set of interesting and rather different best-bets, questing for more multi-messenger data to solve the puzzle.

Galatic PeVatrons

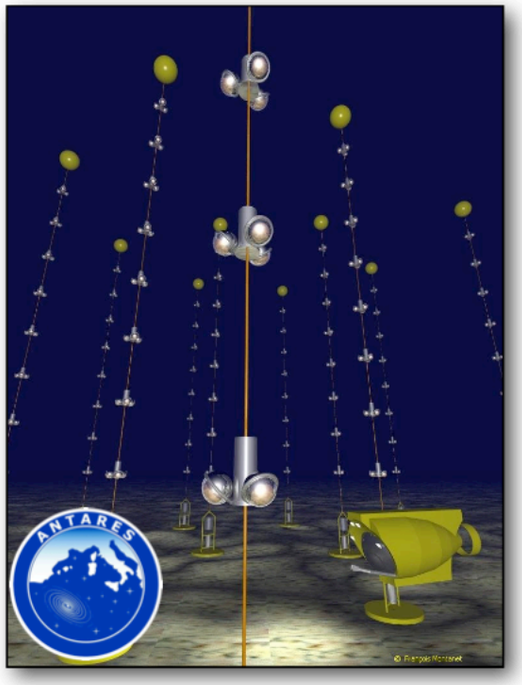
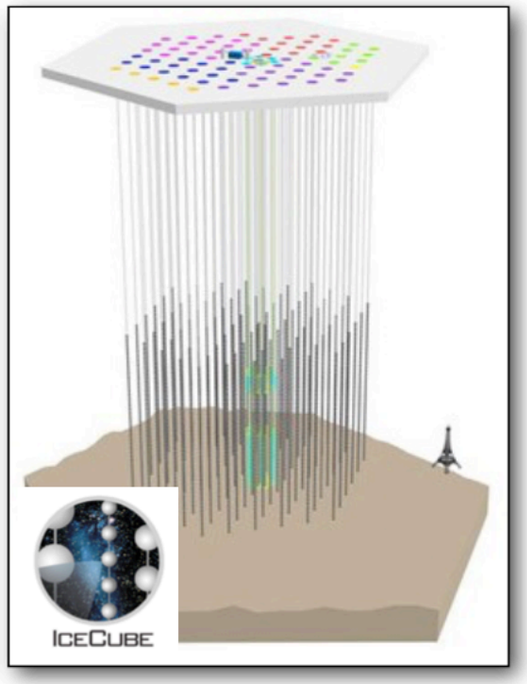
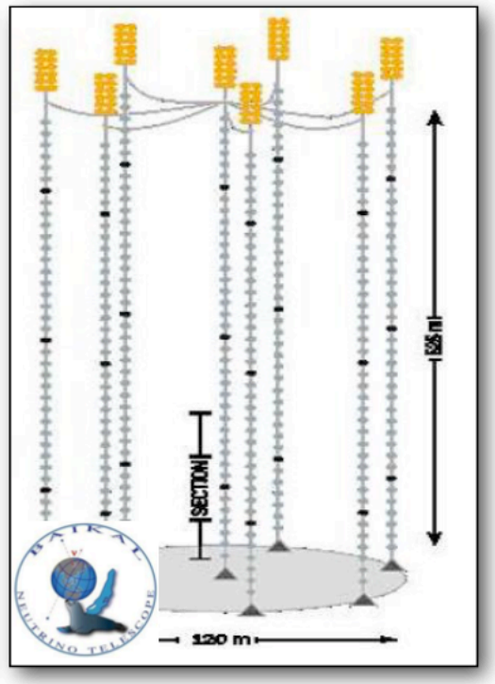
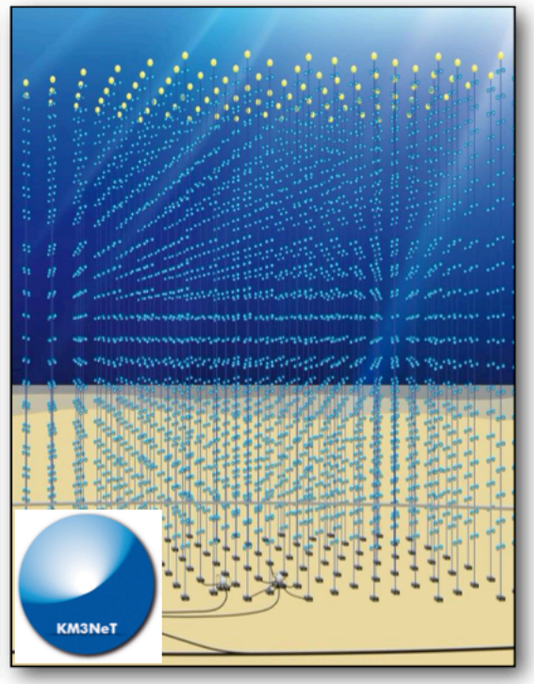
Existence of PeVatrons confirmed by most recent data at energies greater than 100 TeV. The production mechanisms (hadronic or leptonic) of gamma-rays from the LHAASO sources are not clear yet. Neutrinos?



Cao, Aharonian et al. Nature 594, 2021

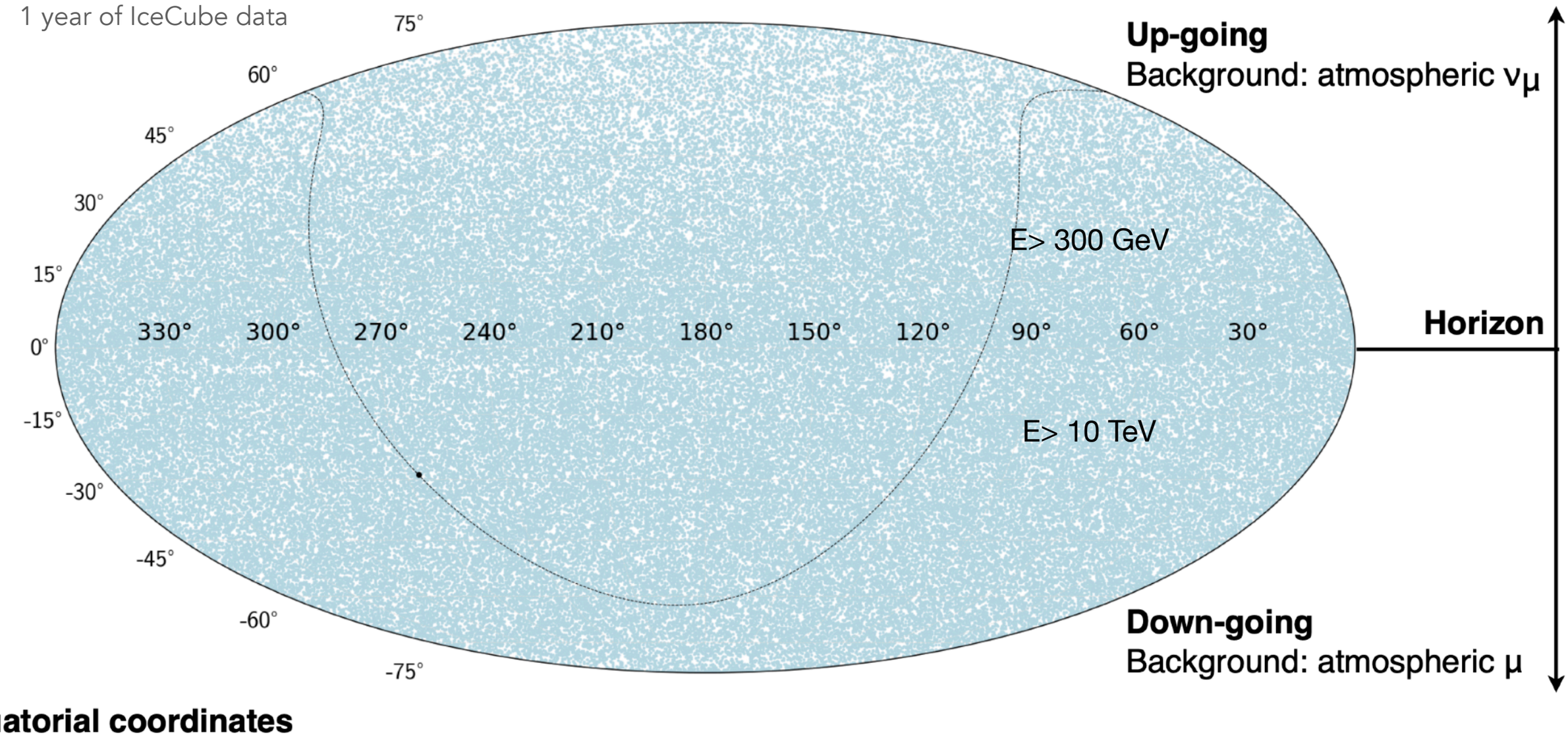


The neutrino players

Antares	IceCube	Baikal-GVD	KM3NeT/ARCA
			
Mediterranean	South Pole	Lake Baikal	Mediterranean
2008–2019	fully instrumented since 2011	under construction (3 out of 8 clusters)	under construction (3 out of 230 DUs)
~0.01 km^3	~1 km^3	~0.4 km^3 (Phase 1) ~1km^3	~0.1 km^3 (Phase 1) ~1 km^3
885 OMs (10″)	5160 OMs (10″)	2304 OMs (10″)	4140 OMs (31x3″)

Inspecting the neutrino data alone

Allowing for more background and larger signal efficiencies it is possible to search for individual astrophysical sources as localised event excesses. IceCube collects oder hundred of thousands neutrino candidates (tracks) per year.



Glashow resonance event

Elisa Bernardini — University of Padova (Italy)