Galactic neutrinos

Andrii Neronov
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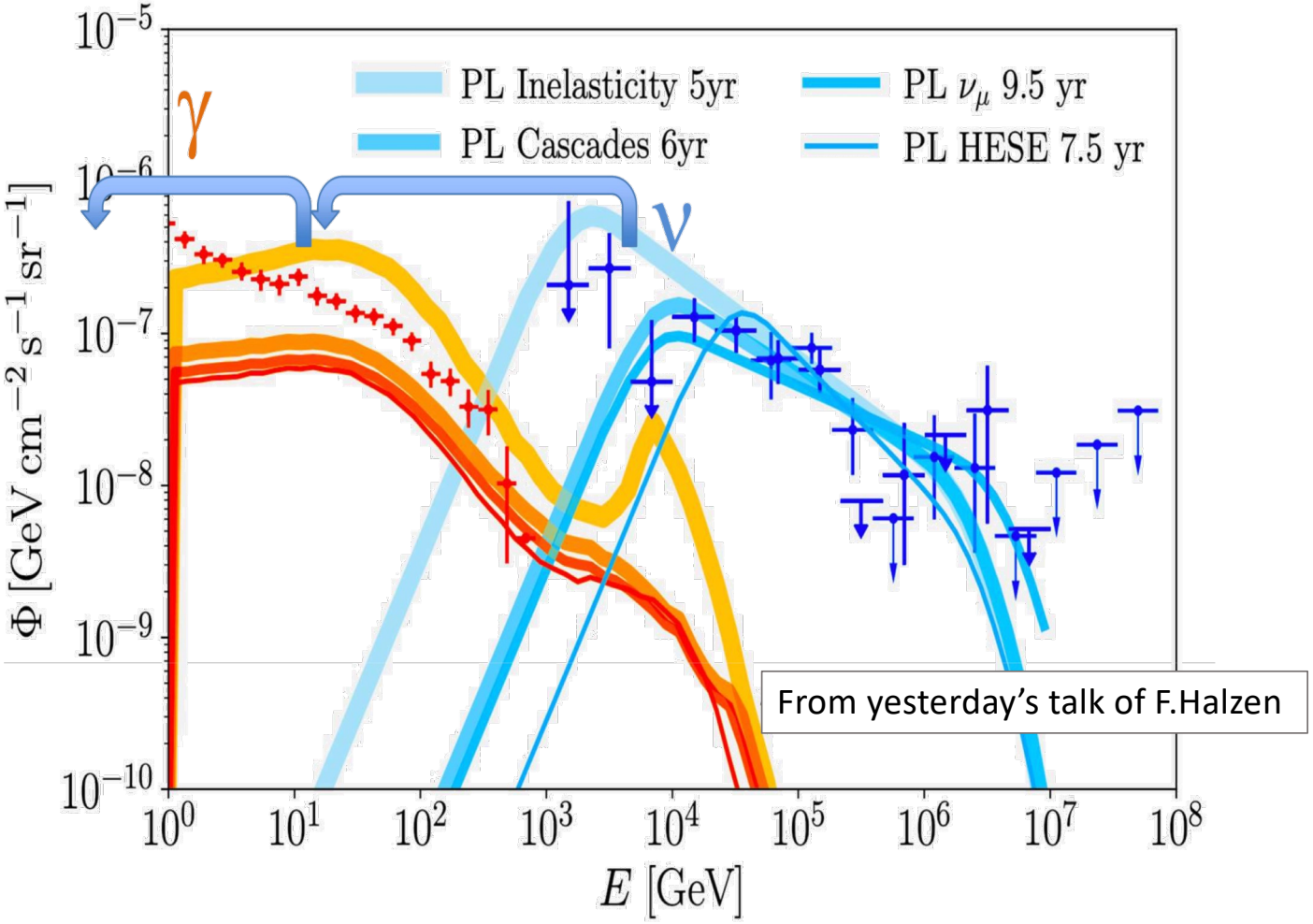

Galactic neutrinos

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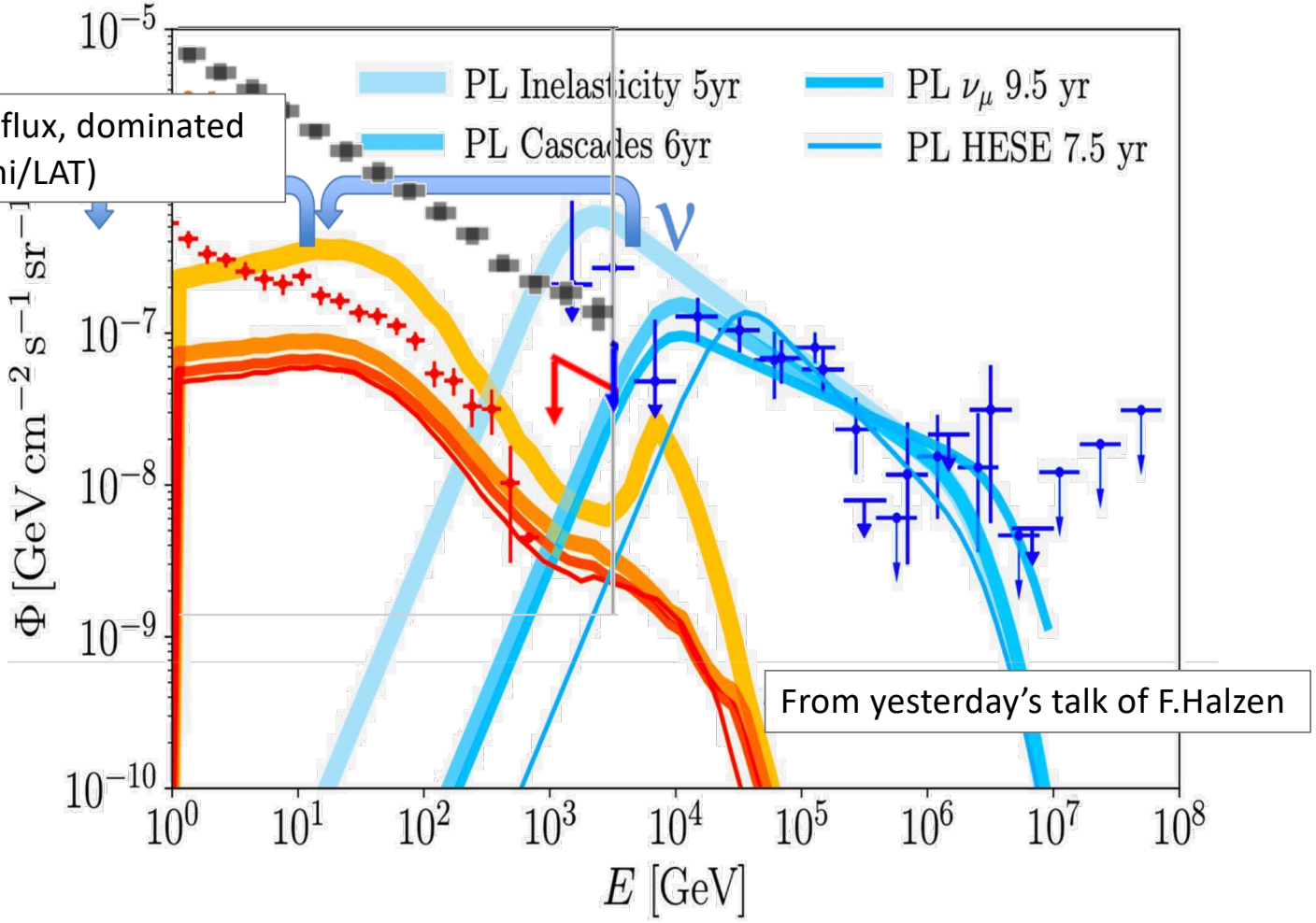
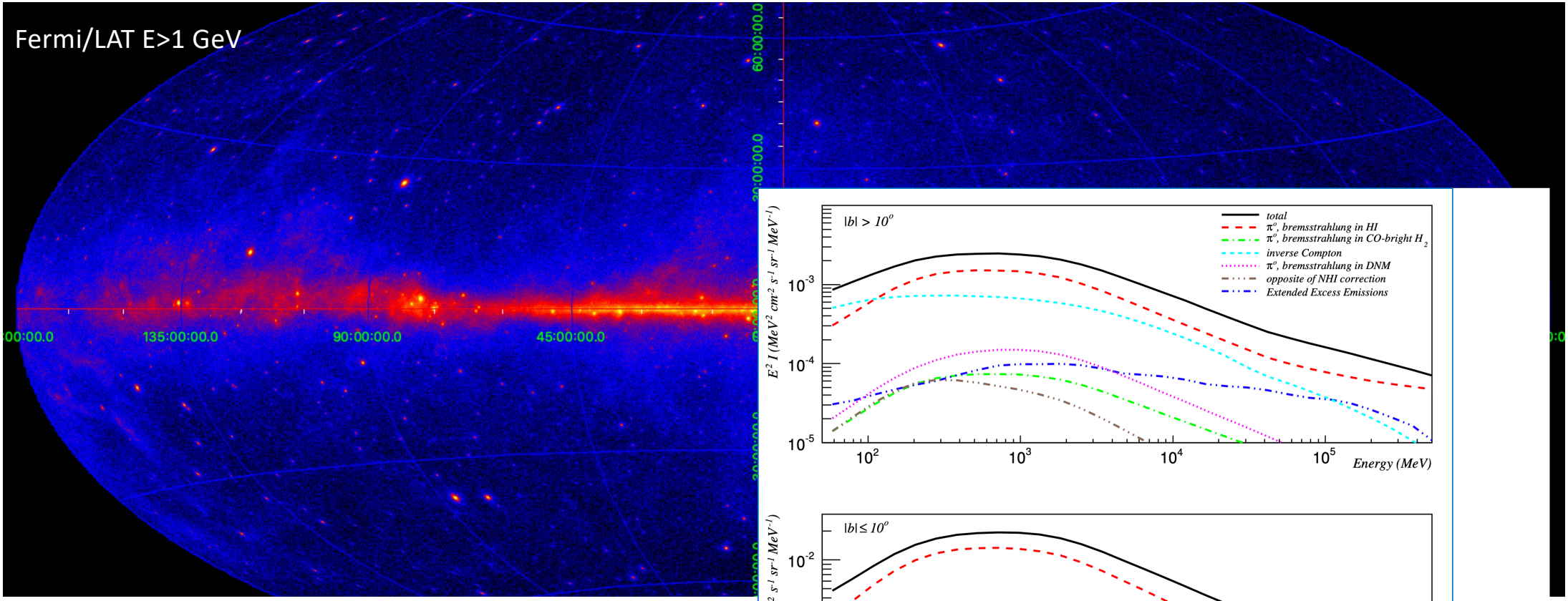
Sky-averaged γ-ray flux, dominated by the Galaxy (Fermi/LAT)



From yesterday's talk of F.Halzen

Diffuse emission from the interstellar medium

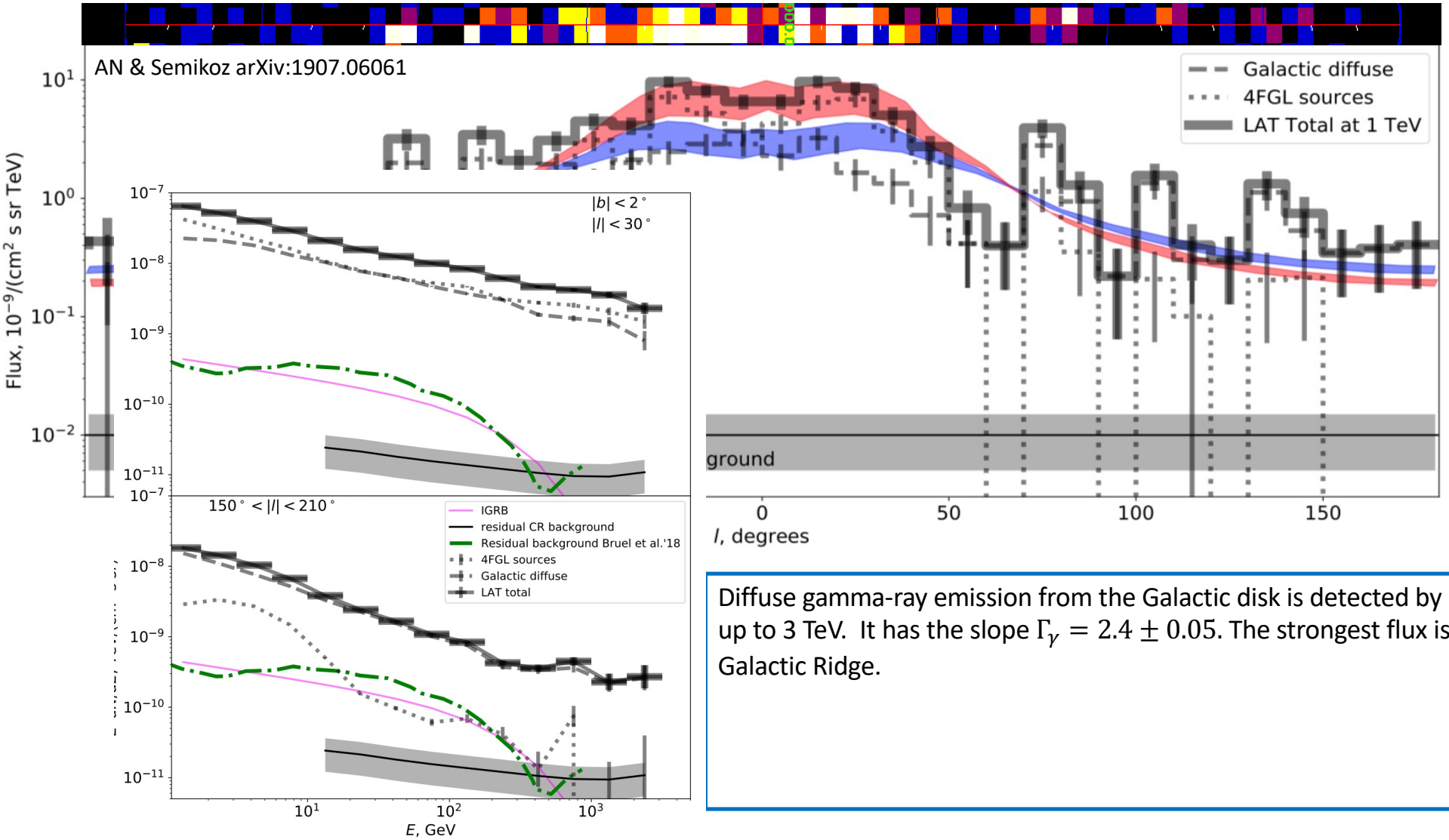


Galactic diffuse gamma-ray emission is dominated by pion decay flux from cosmic ray interactions in the interstellar medium, with moderate contribution from isolated sources.

Measurements of gamma-ray flux provide an estimate of Galactic neutrino flux in the GeV-TeV band.

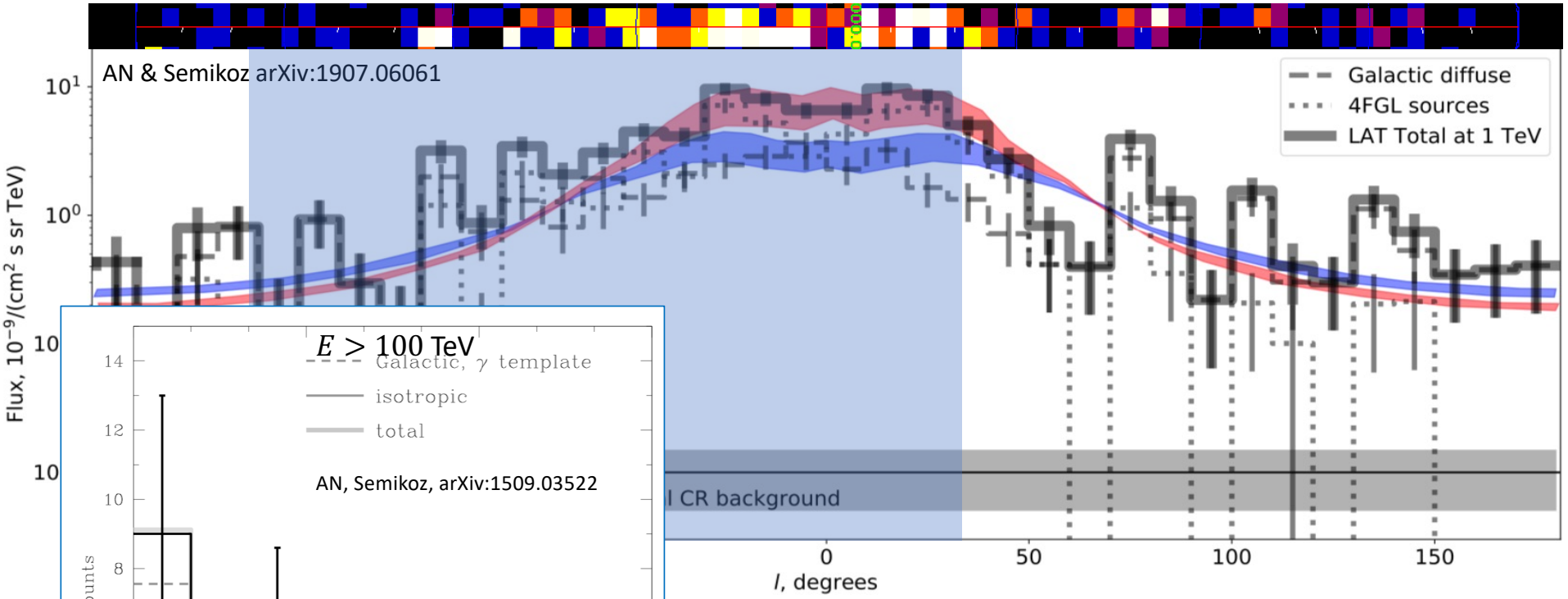
Fermi/LAT Collab. arXiv:1602.07246

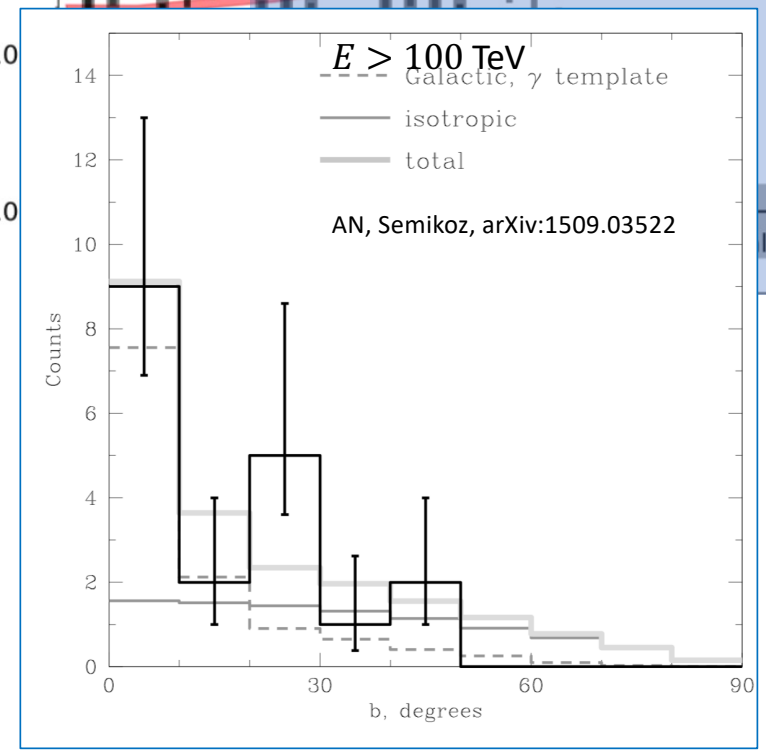
Diffuse emission from the interstellar medium



Diffuse gamma-ray emission from the Galactic disk is detected by Fermi/LAT up to 3 TeV. It has the slope $\Gamma_\gamma = 2.4 \pm 0.05$. The strongest flux is from the Galactic Ridge.

Diffuse emission from the interstellar medium





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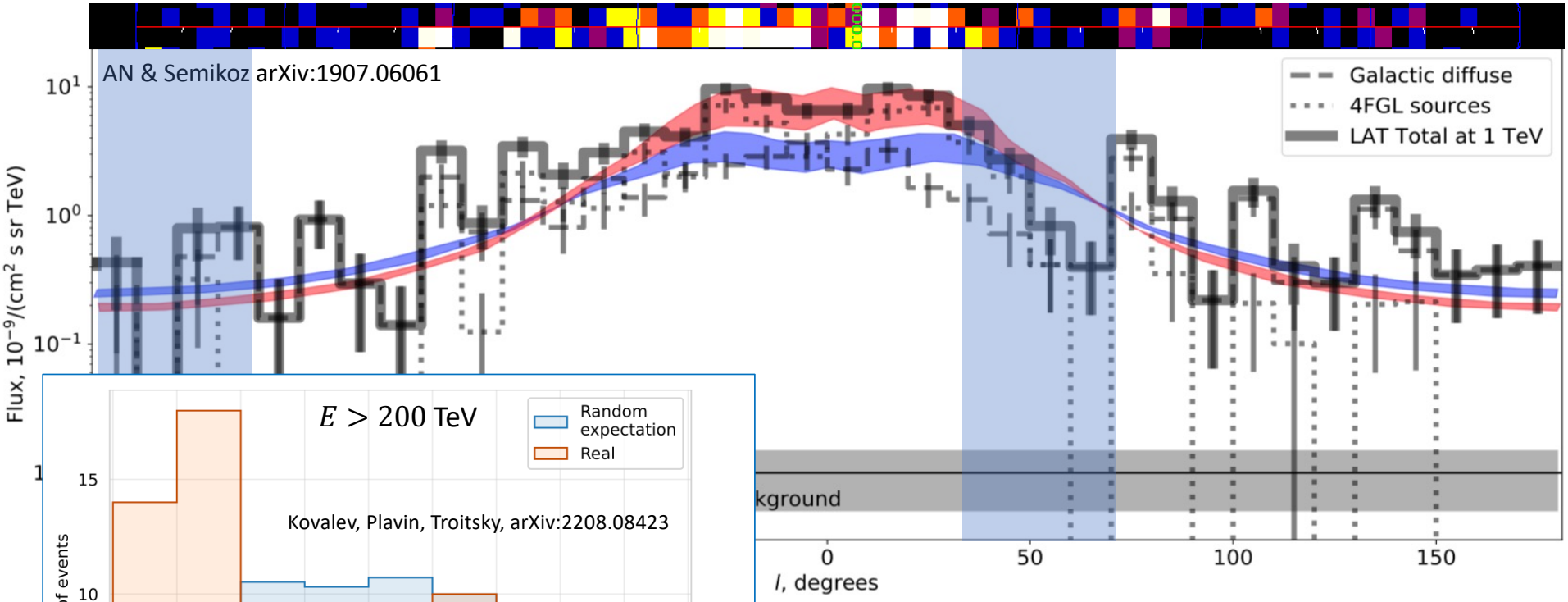
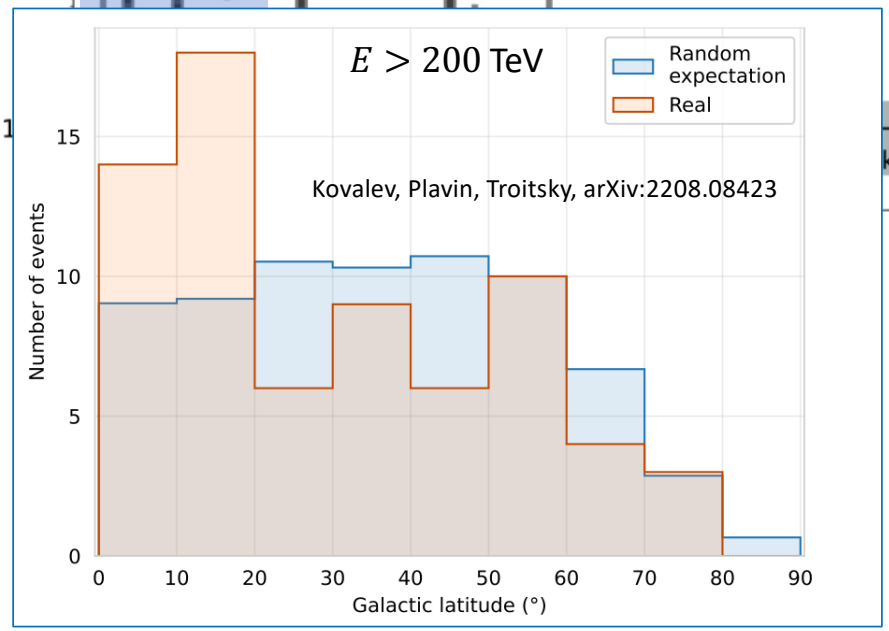
- *ANTARES observes a 2σ excess on the Galactic Ridge (poster by M.Lamoureux).*
- *An evidence for an excess toward low Galactic latitude in cascade channel in IceCube*

Diffuse emission from the interstellar medium





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- *ANTARES observes a 2σ excess on the Galactic Ridge.*
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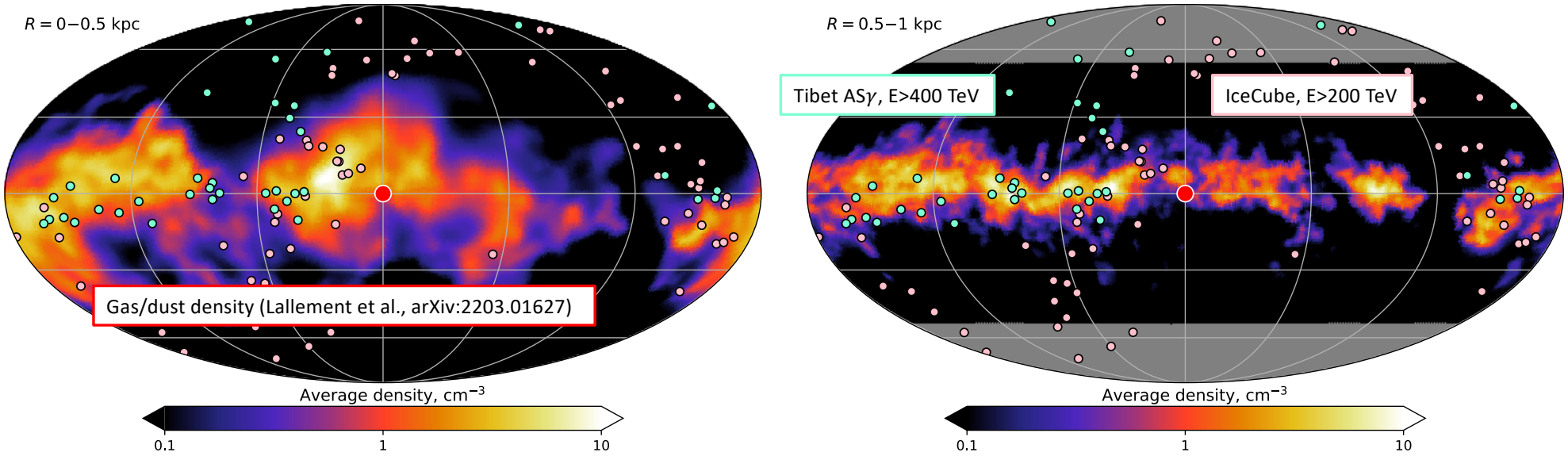
- *----------and in the muon neutrino channel*

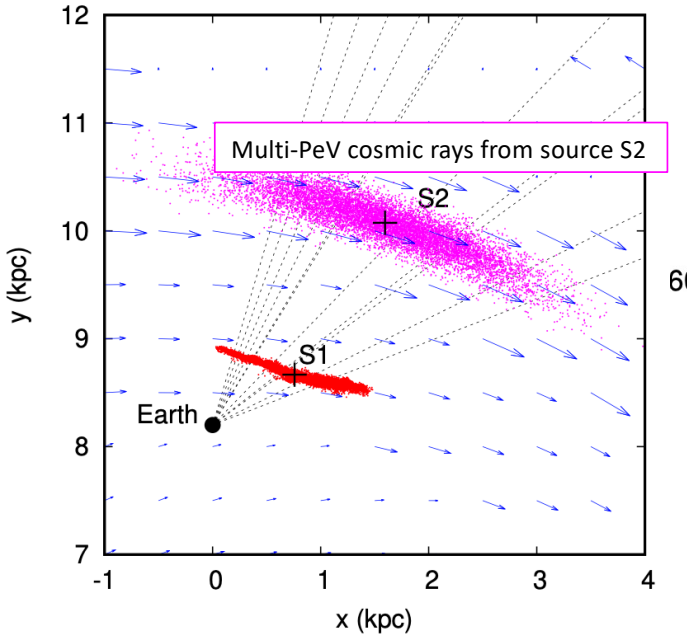
Diffuse emission from the interstellar medium



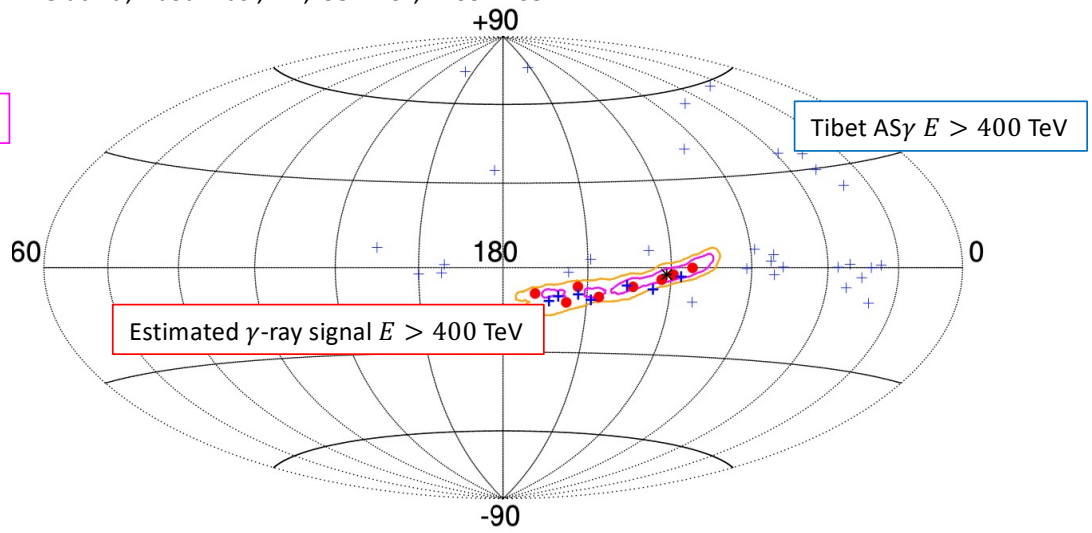
Excess in 20° Galactic latitude may indicate that the signal is coming from our “Galactic neighborhood”, rather than from the entire Galactic disk (that would be expected to give the signal within several degrees Galactic latitude).

Kovalev, Plavin, Troitsky, arXiv:2208.08423
Amenomori et al. arXiv:2104.05181
Koldobskiy, Semikoz, AN (in preparation)

Diffuse emission vs. isolated Galactic sources



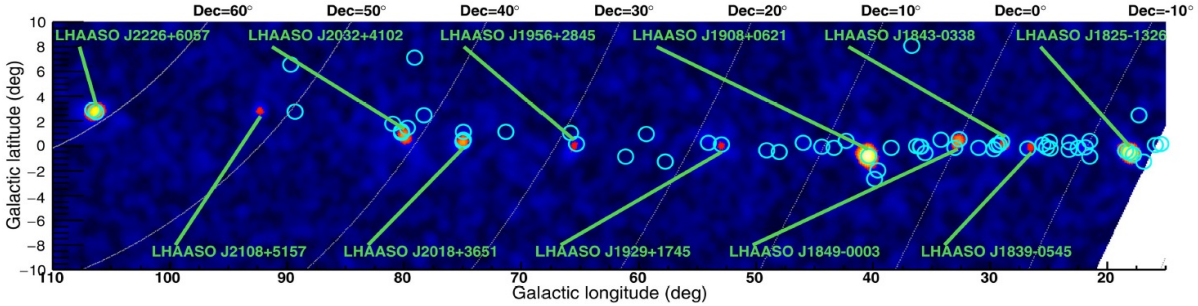
Giacinti, Abounnasr, AN, Semikoz, 2203.11052



- Cosmic rays are injected from (uncertain) sources. Neutrinos can be produced by interactions of protons and nuclei with gas and low-energy photons producing compact or even "point" source.
- Cosmic rays spread into interstellar medium diffusing in Galactic magnetic field (of uncertain geometry). Neutrinos can be produced in interactions with interstellar gas, producing an extended source.
- Cosmic rays ultimately escape form the Galactic halo. Their interactions in the interstellar medium contribute to large-scale diffuse emission.

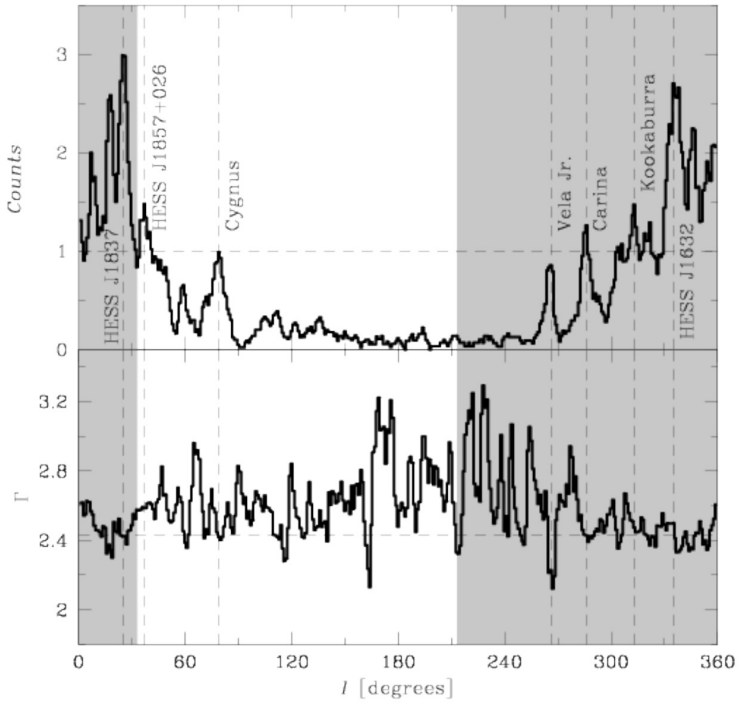
Isolated Galactic sources

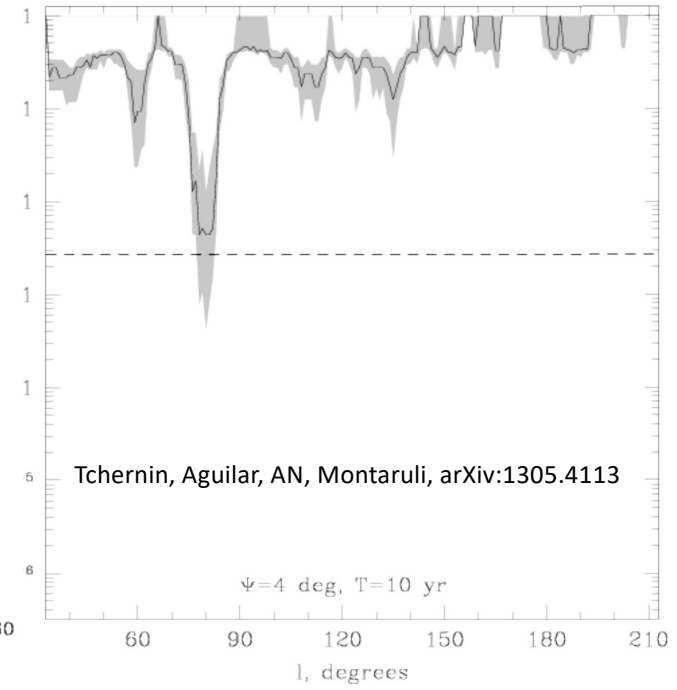
LHAASO Collab. Nature 594, 33, 2021



Gamma-ray observations in the TeV-PeV band limit the neutrino flux from isolated sources.

Cygnus X region appears to be the best candidate in the Northern sky.

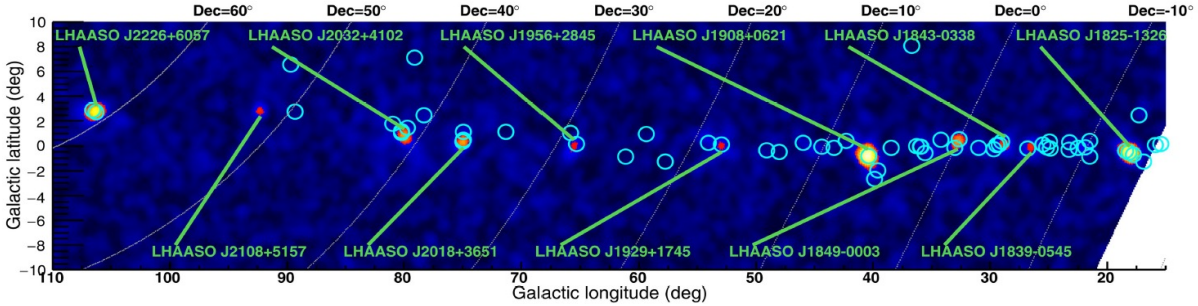


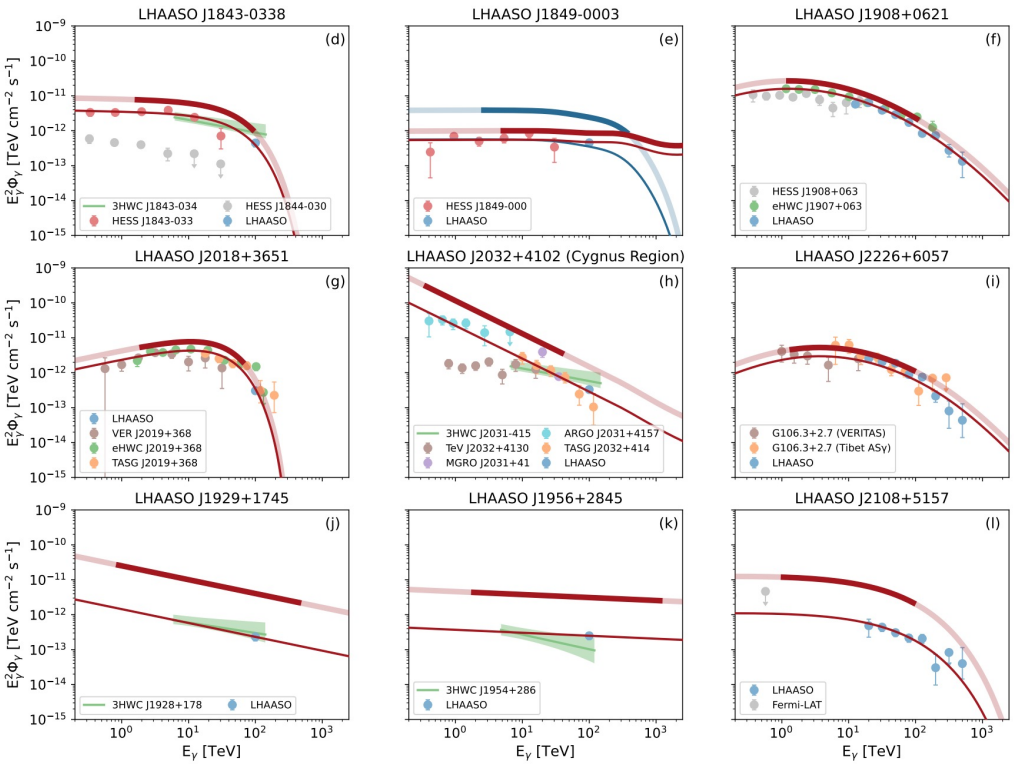


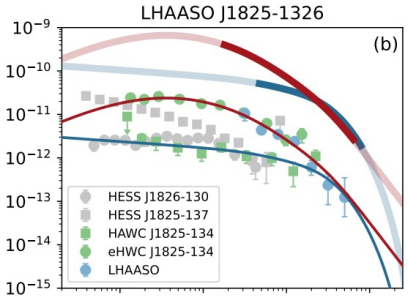
Tchernin, Aguilar, AN, Montaruli, arXiv:1305.4113

Isolated Galactic sources

LHAASO Collab. Nature 594, 33, 2021





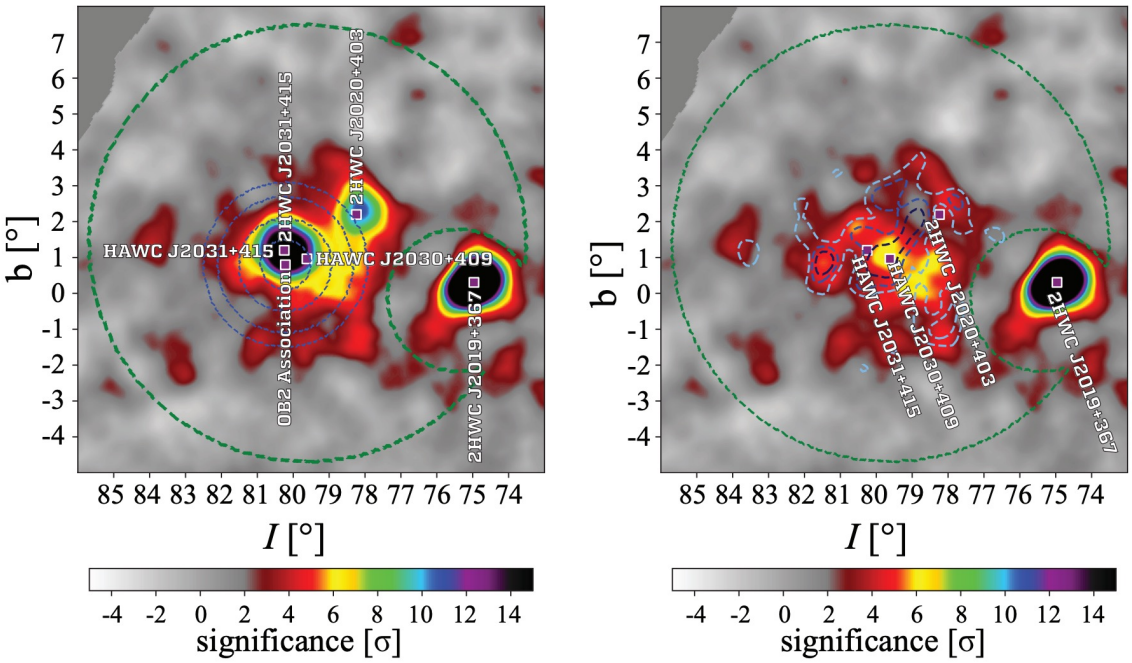


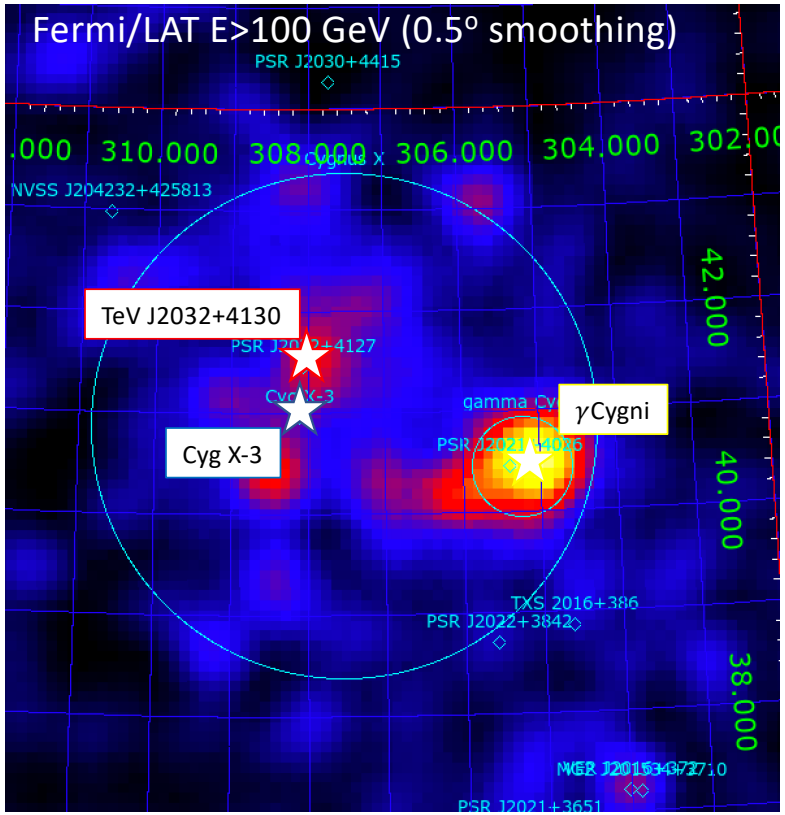
Huang, Li, arXiv:2112.14062

Decade-long exposure of IceCube in the track channel is not sufficient for detection of even the brightest HAWC / LHAASO Galactic gamma-ray source(s).

A closer look at Cygnus region

HAWC Collab. arXiv:2103.06820





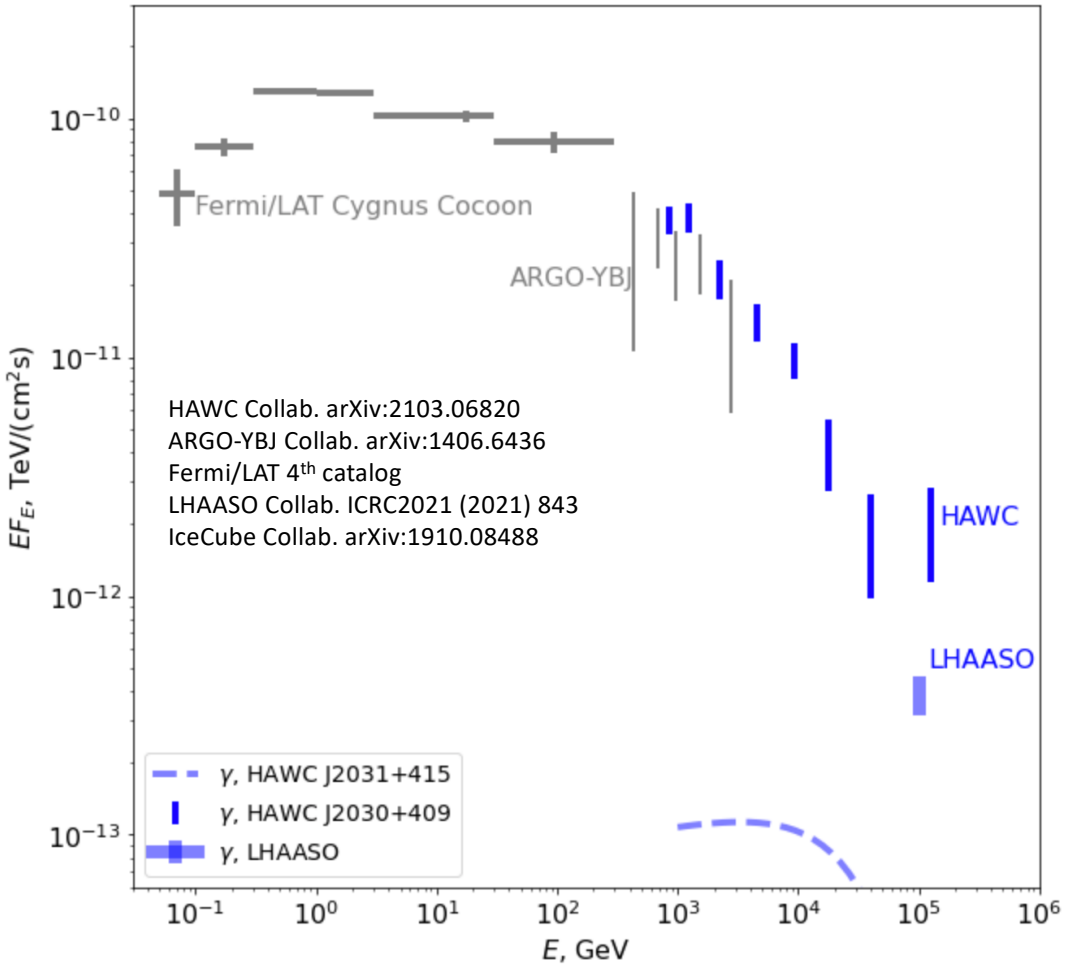
Composite source of complex morphology:

- more compact source HAWC J2031+415 (TeV J2032+4130)
- extended Cocoon HAWC J2030+409

Possible points of injection of cosmic rays:

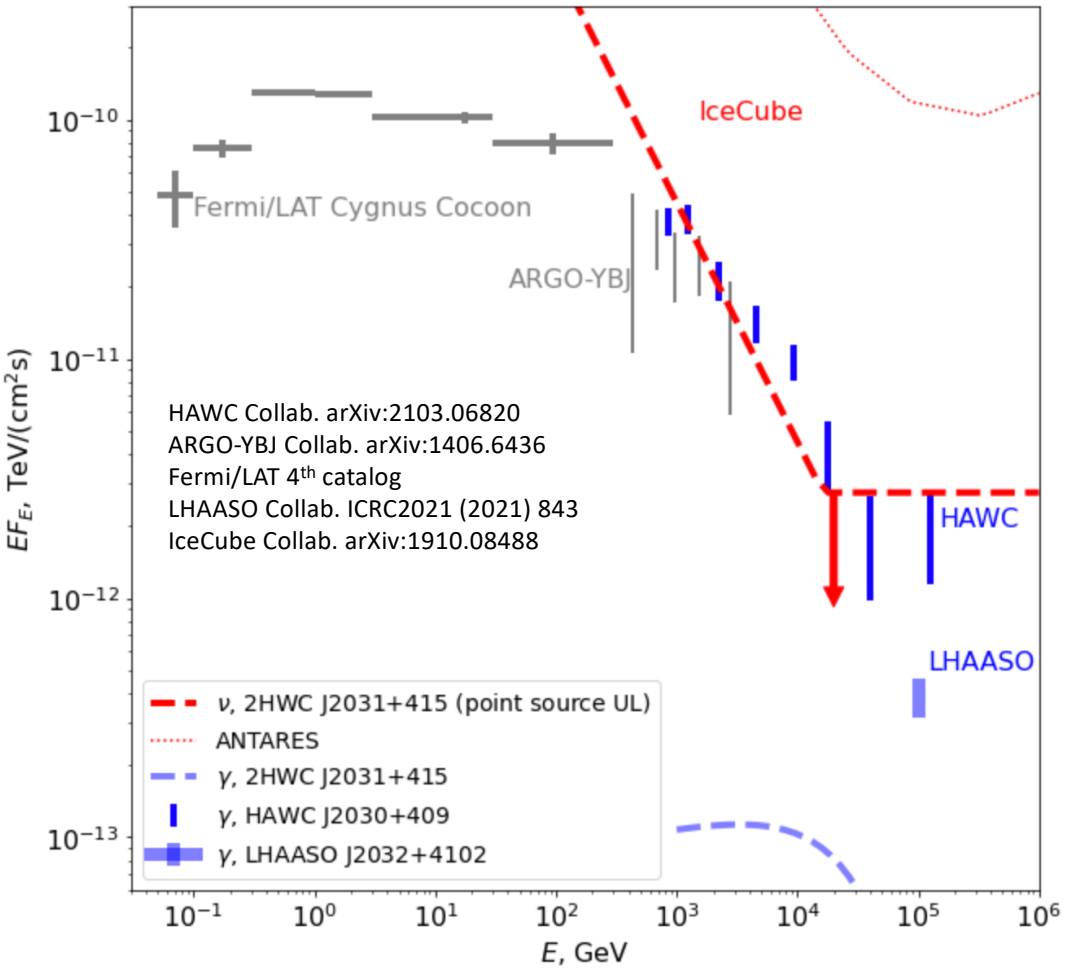
- Young (3-10 Myr) massive star association (Cyg OB2)
- First “unidentified TeV source” (TeV J2032+4130)
- Gamma-ray emitting microquasar (Cyg X-3)
- Gamma-Cygni supernova remnant

A closer look at Cygnus region



- The γ-ray flux is dominated by emission from extended Cocoon.
- Radio-to-X-ray synchrotron measurements show that TeV emission is of hadronic origin.
- In this case neutrino flux is expected to be comparable to γ-ray flux.

A closer look at Cygnus region



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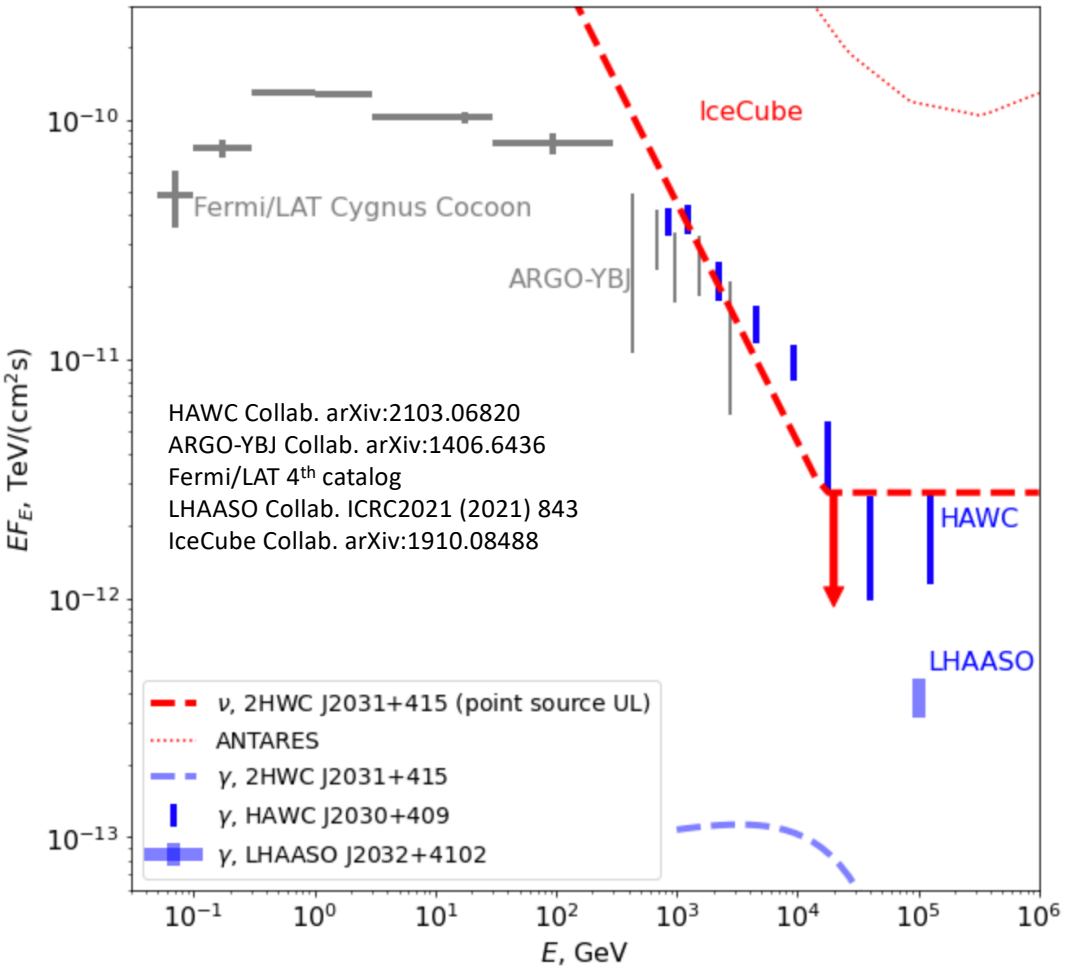
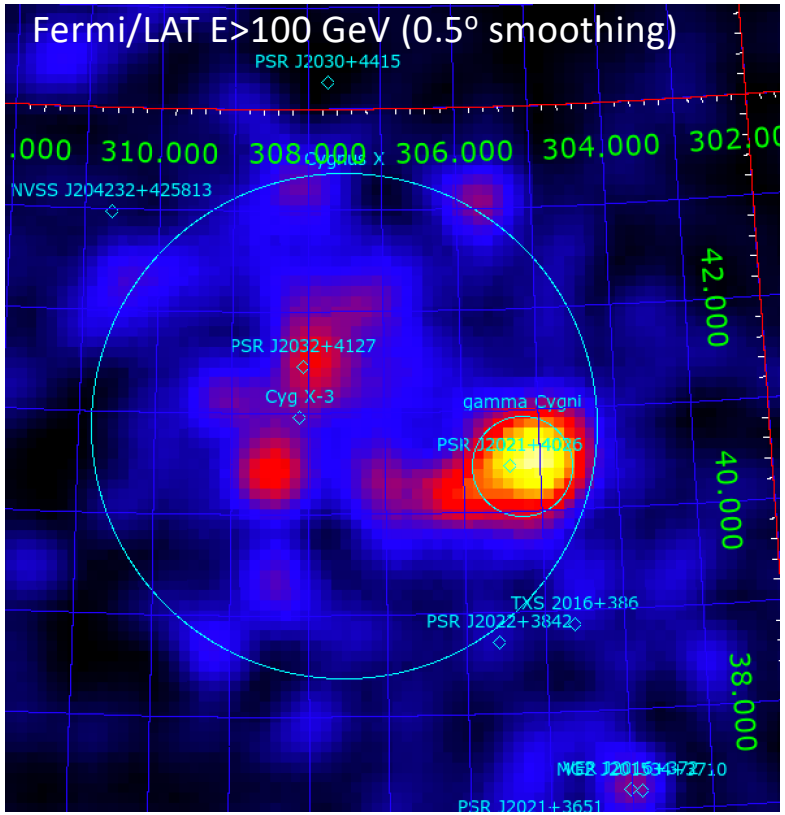
- IceCube 10-year analysis paper cites limit on neutrino flux for 2HWC J2031+415, considered as a point source.
- The neutrino flux limit for $\Gamma = 3$ powerlaw spectrum is just at the level of the γ-ray flux.
- An mild excess of 13 events is observed at the point source position.

A closer look at Cygnus region

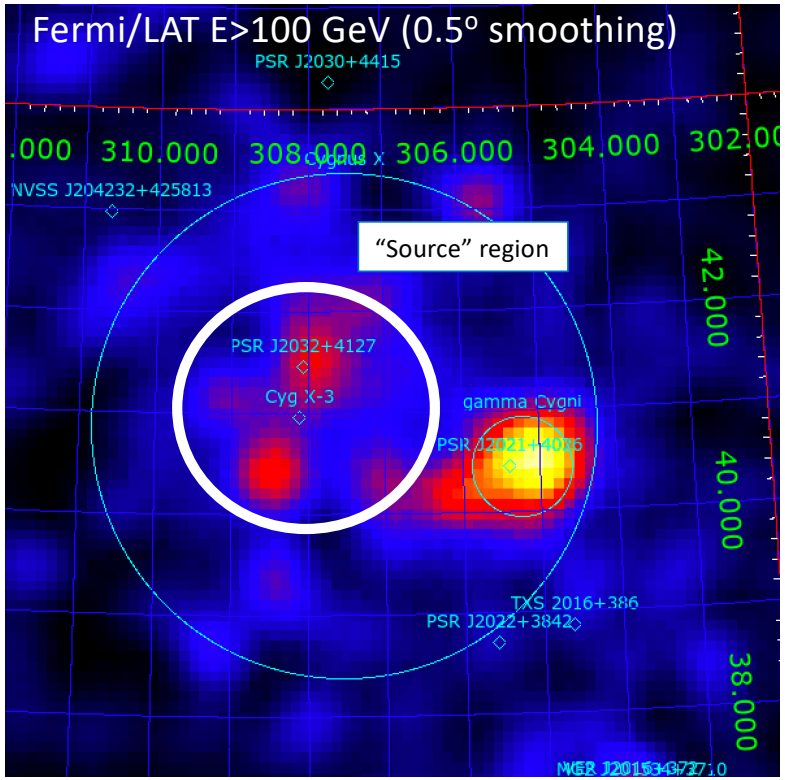




- ”point source” is not the right model
- “Gaussian” is perhaps also not the right model
- “Fermi/LAT template” is also not the right model: part of γ-ray emission may be leptonic

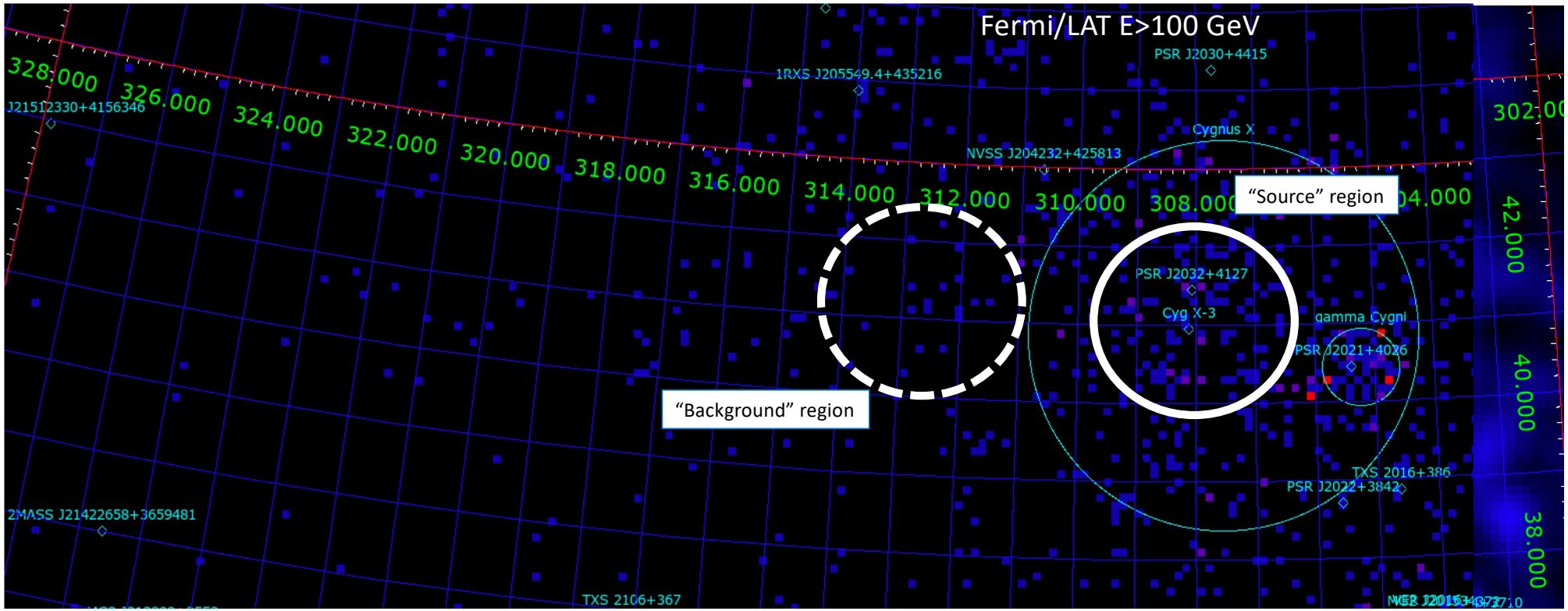
……. no reliable source model …….

Aperture photometry (“neutrinometry”?)



A spatial model independent approach is to estimate the signal using “aperture photometry”: count events in a region covering the source.

Aperture photometry (“neutrinometry”?)



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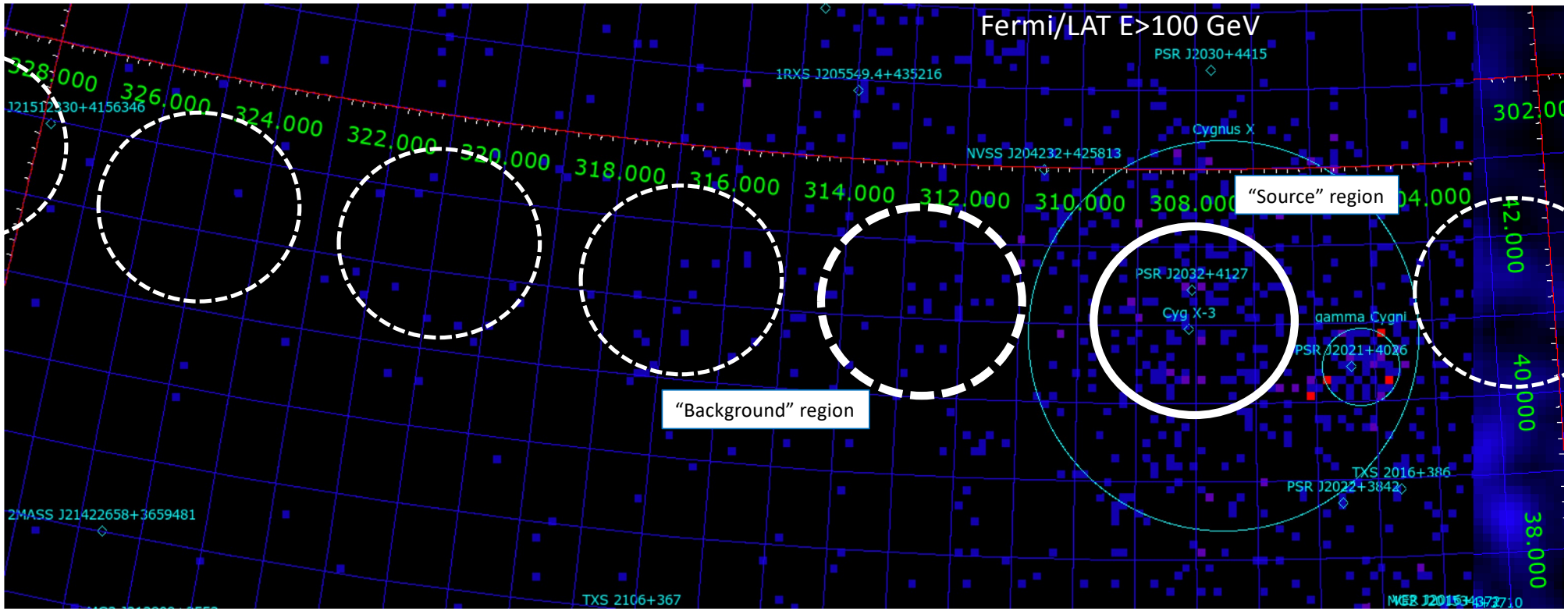

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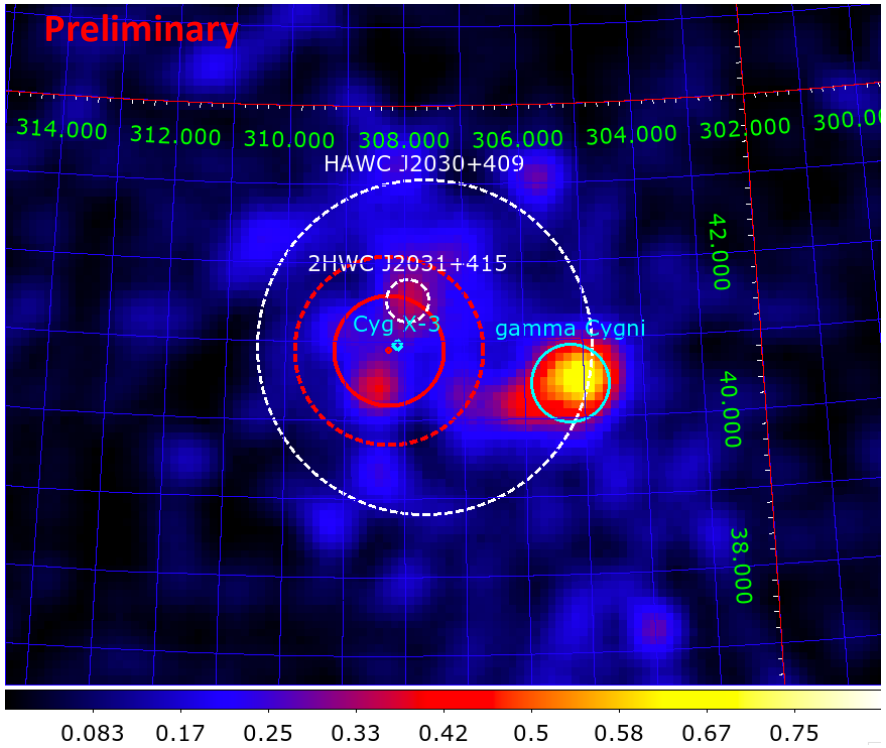
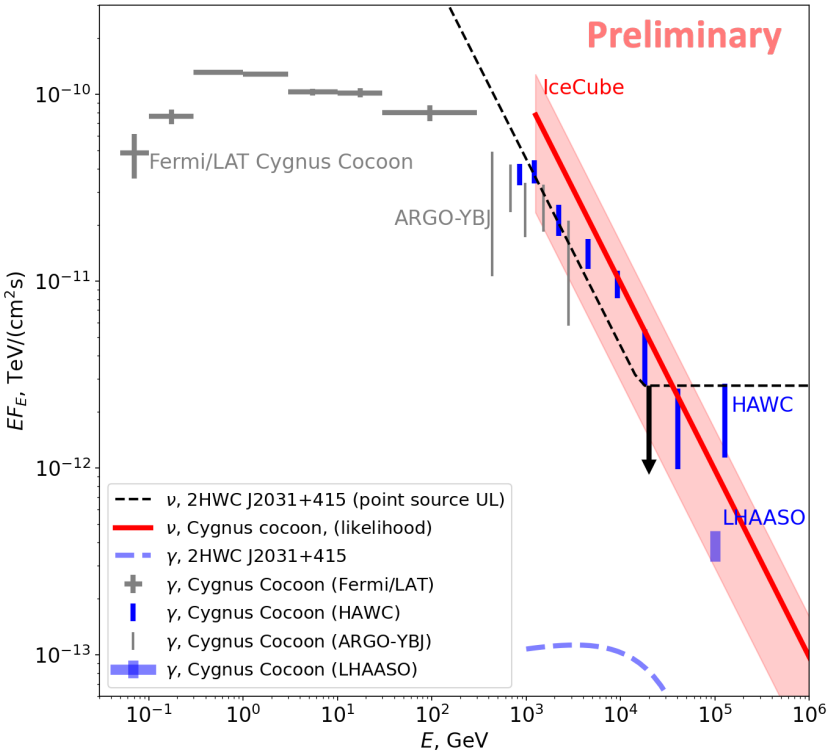
In IceCube, the background does not depend on RA.

Likelihood analysis of Cygnus X region





Source position is consistent with either HAWC or LHAASO extended source position.

Neutrino flux level is consistent with the γ-ray flux of the extended Cocoon source.

AN, Semikoz, Savchenko, (submitted)

Summary

- Three main classes of Galactic neutrino signal:
  - Large scale diffuse emission from interstellar medium and isolated sources
  - Isolated sources
    - Point sources: spots of injection of cosmic rays
    - Extended sources: tracing cosmic rays spreading along Galactic magnetic field

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- Gamma-ray measurements by Fermi/LAT, HAWC, LHAASO impose upper bounds on neutrino flux from Galactic sources

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- Sensitivity of neutrino telescopes is marginally sufficient for detection of Galactic diffuse emission
  - Fermi/LAT and Tibet ASγ data indicate that the slope of the average Galactic cosmic ray spectrum can be as hard as $\Gamma \simeq 2.5$
  - ANTARES observes a 2σ excess of evens from the direction of Galactic Ridge
  - IceCube possibly observes an excess of events at low Galactic latitudes $|b| < 20^{\circ}$

- Sensitivity of IceCube is marginally significant for detection of brightest γ-ray source(s)
  - Evidence for neutrino signal from Cygnus Cocoon