Limits on the out-of-plane diffuse gamma rays

Ie. Vovk
ICRR, University of Tokyo, Japan

07.12.2022
Cosmic rays in the multi-messenger era
Paris, France

Introduction

ICRR
Institute for Cosmic Ray Research
University of Tokyo

Dominant all-sky (diffuse) components in the measured γ-ray emission: galactic and extragalactic

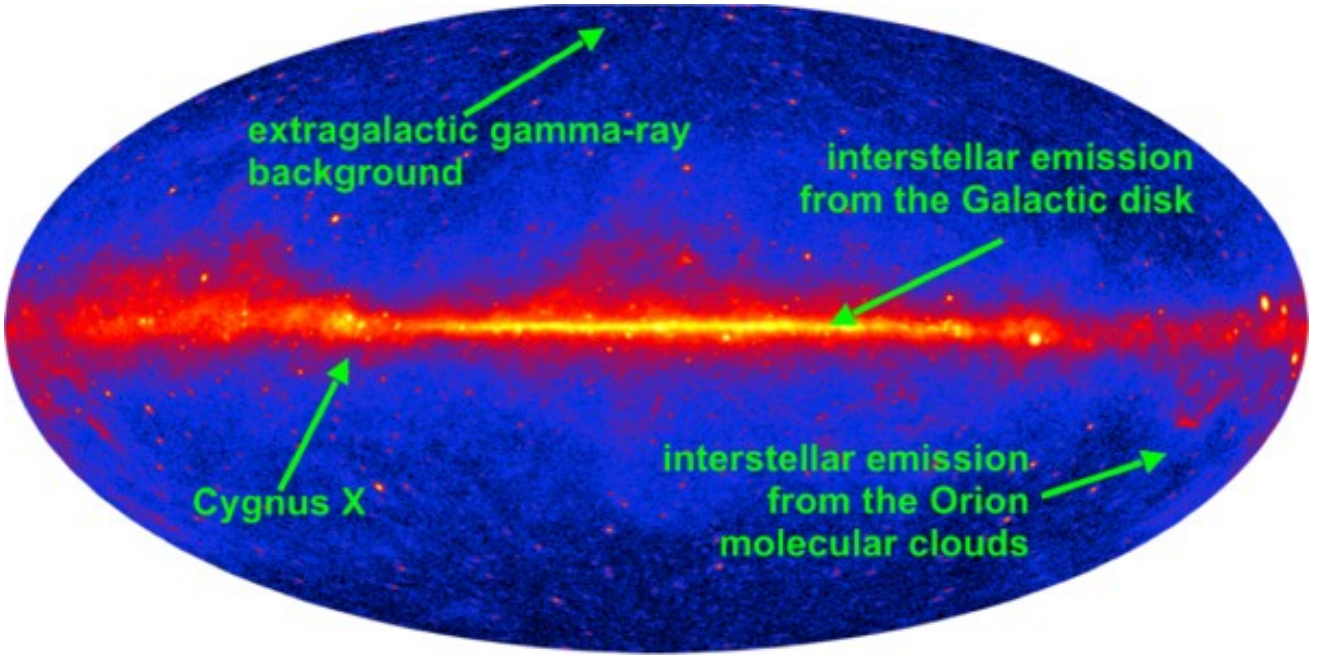


Image credit: NASA/DOE/Fermi LAT Collaboration

Extragalactic diffuse emission: nonthermal perspective of the cosmos, complementary to extragalactic cosmic ray and neutrino measurements

Introduction

Different ways to talk about the (diffuse) background emission:

- *Diffuse Galactic emission*: CR interactions with interstellar gas and radiation fields
- *Extragalactic gamma-ray background*: sum of all the sources (resolved / unresolved) from the edge of the Milky Way
- *Isotropic diffuse gamma-ray background*: residual all-sky radiation after subtracting the resolved sources and galactic emission

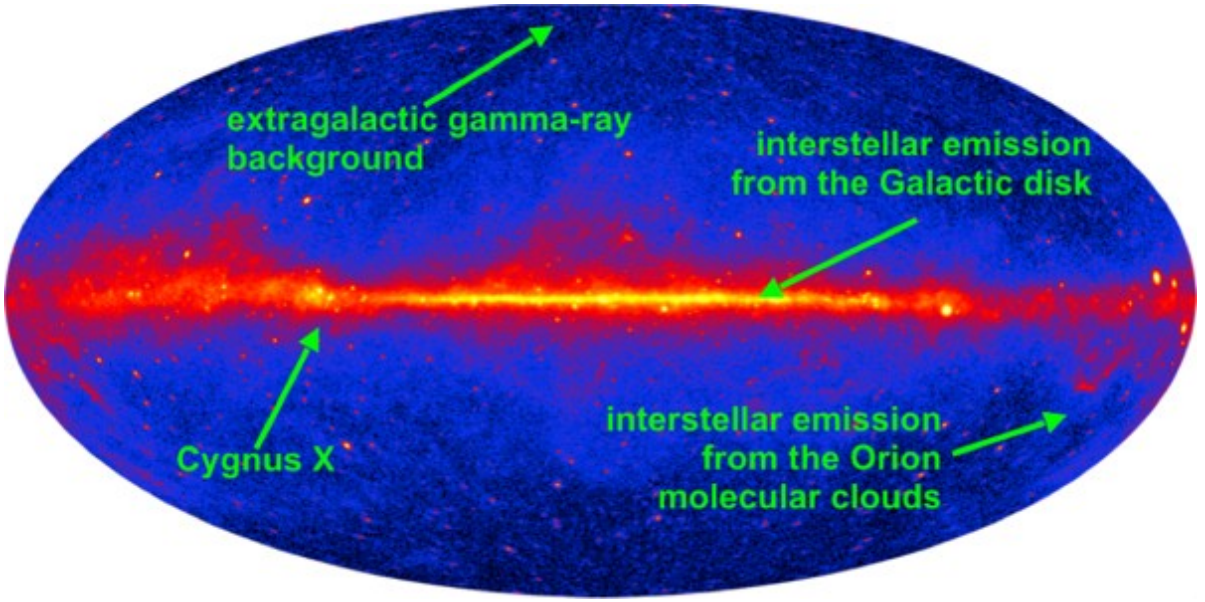


Image credit: NASA/DOE/Fermi LAT Collaboration

Isotropic diffuse background is model-dependent
(more sensitive telescopes may reduce it resolving sources)

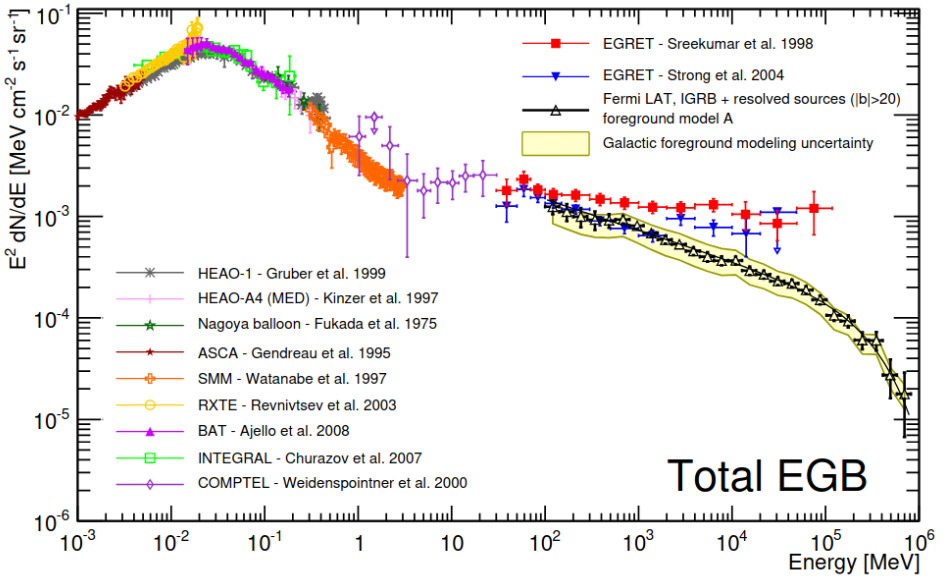
Extragalactic background is fundamental

Introduction

Isotropic diffuse γ-ray emission was discovered by the SAS-2 satellite (Fichtel+ ‘75, ‘78)
Refined by EGRET (Sreekumar+ ‘98; Strong+ ‘04) and later Fermi/LAT (Ackermann+ ‘15)

These measurements are rather an upper limit on EGB (= IGRB + extragal. src) as IGRB may itself contain galactic contributions

E.g. CR interactions with gas / radiation fields in the MW halo (Feldmann+ ‘13, Keshet et al. ‘04) , unresolved Galactic sources (e.g. Faucher-Giguere & Loeb ‘10), CR interactions with solar system debris and the solar radiation field (Moskalenko & Porter ‘09, Moskalenko+ ‘06, Orlando & Strong ‘07, ‘08)



Ackermann+ ‘15

Above ~100 GeV contribution of extragalactic sources vanishes due to γγ absorption on EBL (Gould & Schreder ‘67, Franceschini+ ‘08)

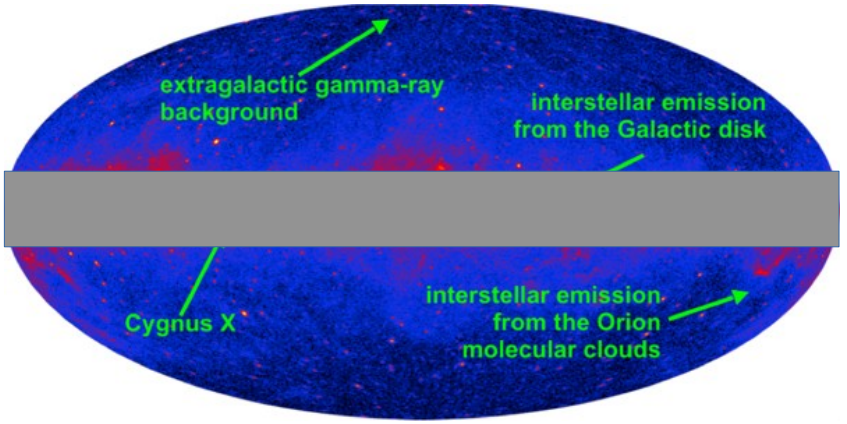
IGRB measurement challenge

Institute for Cosmic Ray Research
University of Tokyo

Diffuse GeV-TeV γ-ray flux is dominated by emission from CR interactions in the interstellar medium
(Ackermann+ ‘12, Acero+ ‘16, Lipari & Vernetto ‘18, Neronov & Semikoz ‘20)

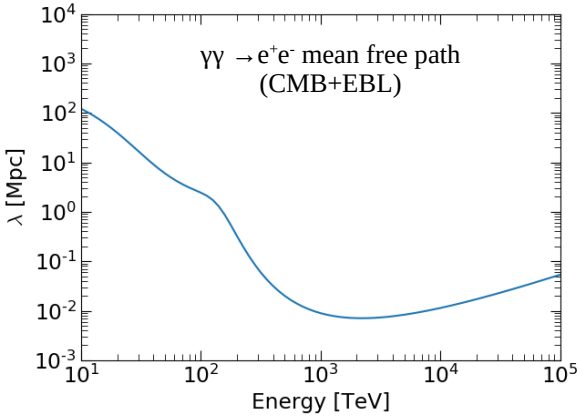
EBG / IGRB measurement challenge:

- large FoV instrument + Gal. diffuse model
- high galactic latitude observations



EBG horizon > 1 TeV:

- local sources (CR / DM halos, unresolved sources)
- EM cascades (e.g. from UHERCs)



IGRB / EGB measurement challenge

ICRR
Institute for Cosmic Ray Research
University of Tokyo

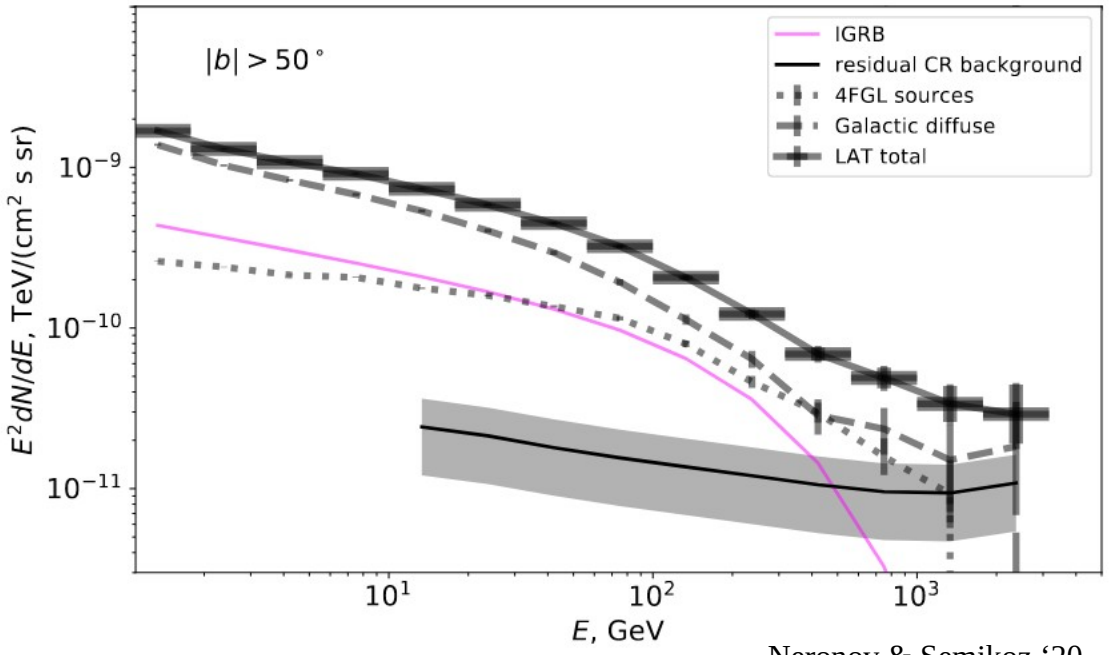
High Galactic latitude flux is dominated by emission from the local interstellar medium, but can also contain contributions from nearby very extended sources (Neronov et al. 2018; Bouyahiaoui et al. 2019).

Local ISM emission:

- pion decay flux from CR protons (dominates; Lipari & Vernetto ‘18)
- IC from CR electrons (suppressed: Klein-Nishina cross section decrease + CR electron spectrum softening > TeV; Aharonian+ ‘08; Adriani+ ‘18; Ambrosi+ ‘17)

Other possible contributions:

- Local CR bubble (Bouyahiaoui+ ‘19)
- MW CR halo (Taylor+ ‘14)
- DM (e.g. Esmaili & Serpico ‘13; Murase+ ‘15; Kachelriess+ ‘18)



Neronov & Semikoz ‘20

IGRB @ PeV?

ICRR
Institute for Cosmic Ray Research
University of Tokyo

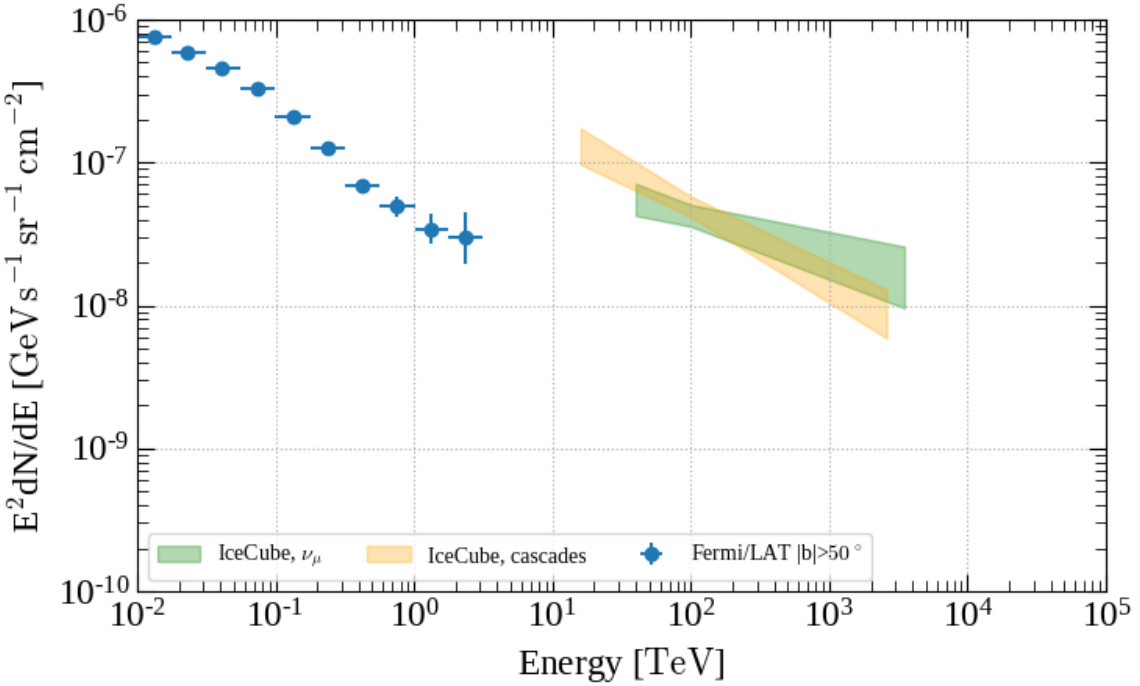
With CR origin of diffuse γ rays, 0.1-1 PeV flux may:

- clarify the nature of the “knee” and on and Pevatrons properties
- constrain the Galactic component of the astrophysical neutrino flux

Still, no measurements of the multi-TeV flux at high Galactic latitudes have been reported so far.

Diffuse neutrino vs gamma rays

Measured neutrino / IGRB fluxes roughly match



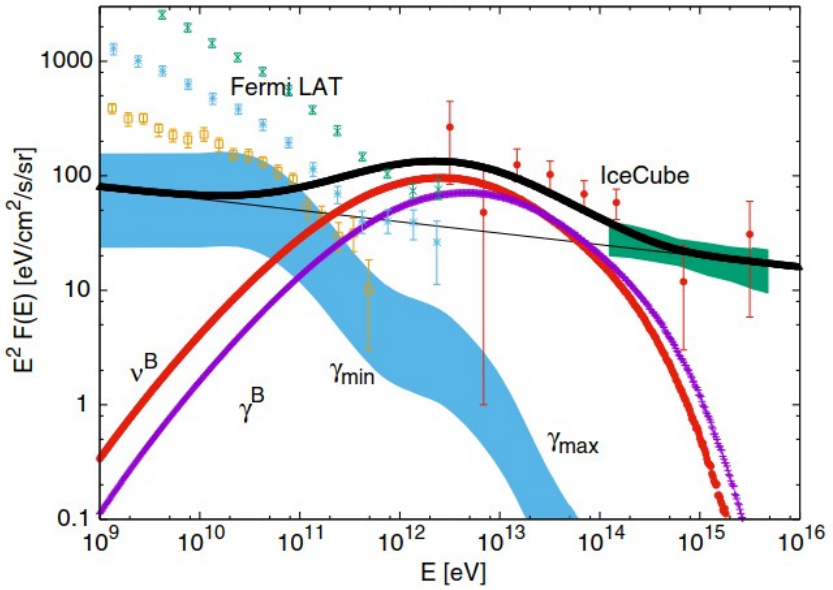
For common local CR-origin an similar flux of sub-PeV gamma rays is expected
For extragalactic neutrino sources, propagation effects suppress the sub-PeV gammas

Neutrino / gamma ray sources

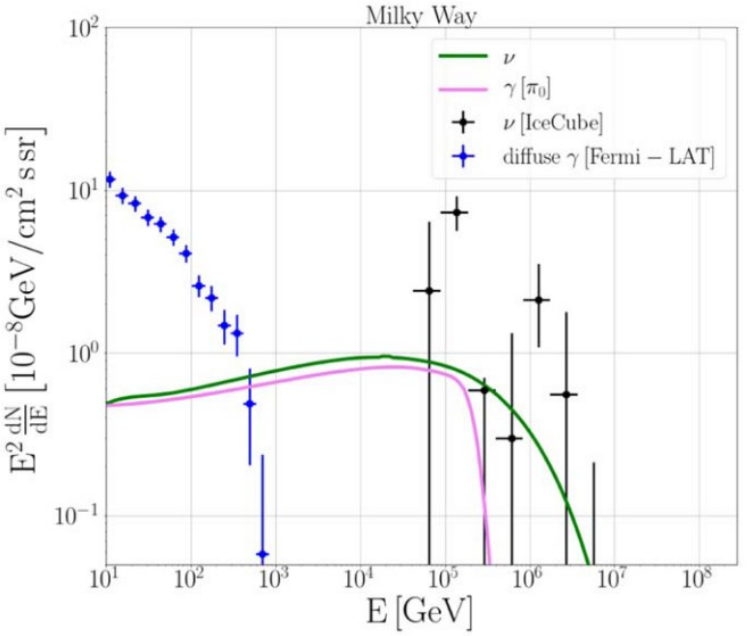
Sub-PeV energy neutrino spectrum is inconsistent with diffuse gamma-ray flux from blazars.
But no arrival direction correlation with Galactic plane either.

→ *Other emission sources?*

Local Pevatron (Bouyahiaoui+ ‘20)



CR halo (Recchia+ ‘21)

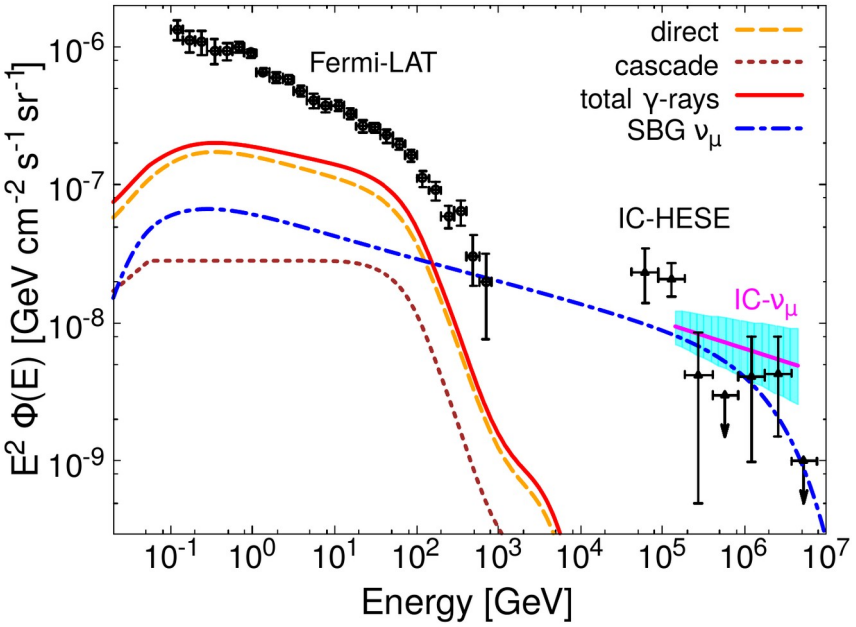


Neutrino / gamma ray sources

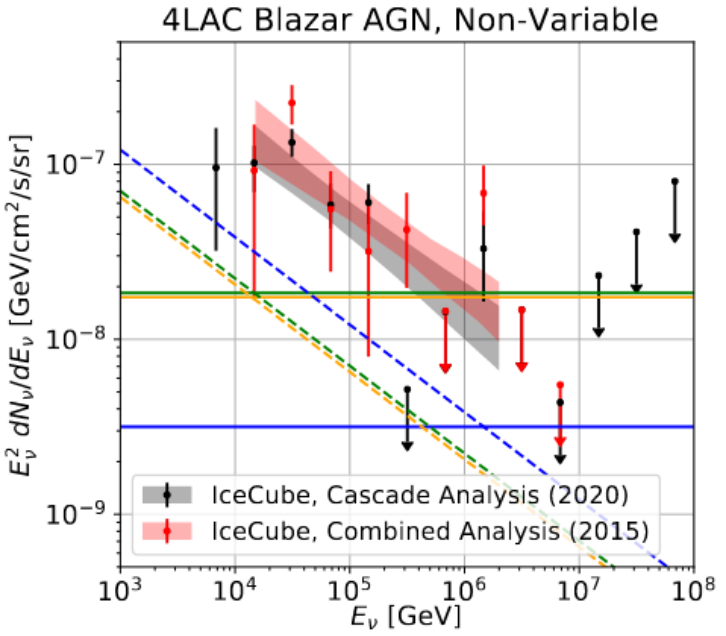
Sub-PeV energy neutrino spectrum is inconsistent with diffuse gamma-ray flux from blazars.
But no arrival direction correlation with Galactic plane either.

→ *Other emission sources?*

Starburst galaxies (Peretti+ '20)



AGNs (Smith+ '21)

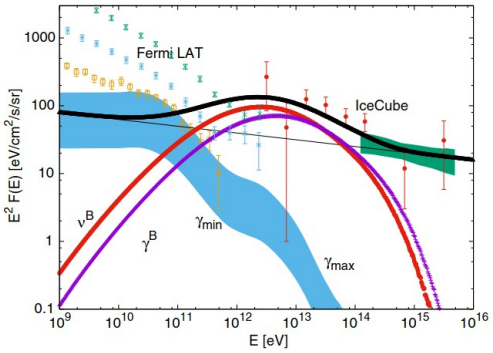


Neutrino / gamma ray sources

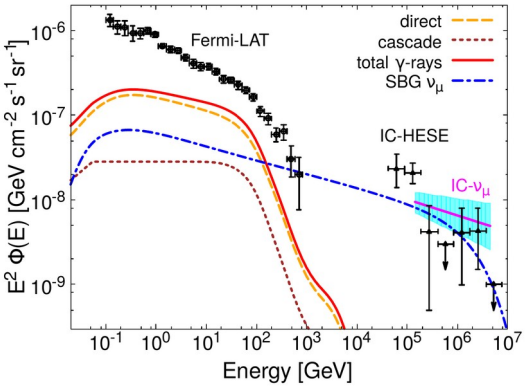
Sub-PeV energy neutrino spectrum is inconsistent with diffuse gamma-ray flux from blazars.
But no arrival direction correlation with Galactic plane either.

→ *Other emission sources?*

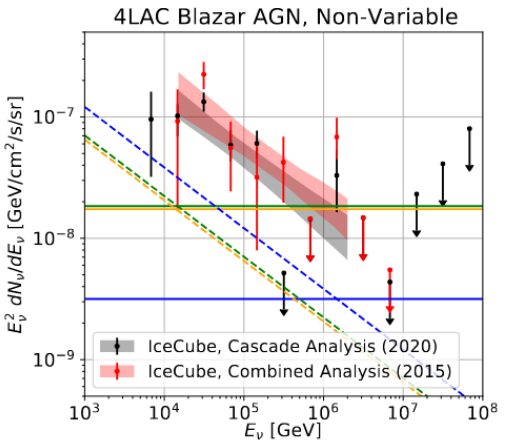
Local Pevatron (Bouyahiaoui+ ‘20)

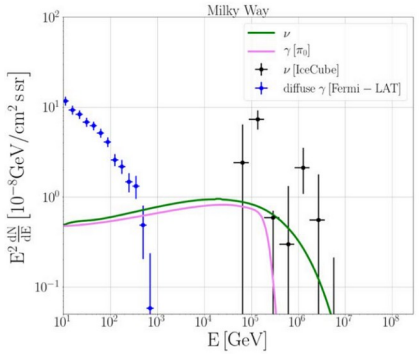


Starburst galaxies (Peretti+ ‘20)



AGNs (Smith+ ‘21)



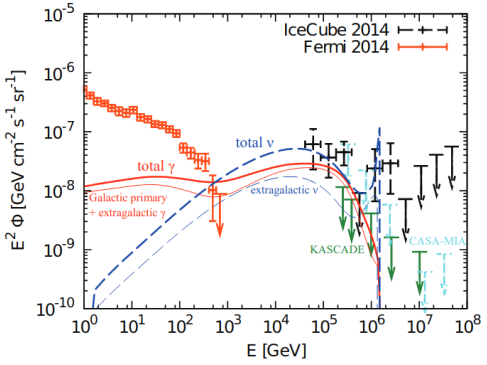


CR halo (Recchia+ ‘21)

Different TeV gamma-ray signal in each case

↓

Sub-PeV measurements of the diffuse gamma-ray flux may be decisive to clarify the origin of both neutrino and gamma-ray emission.



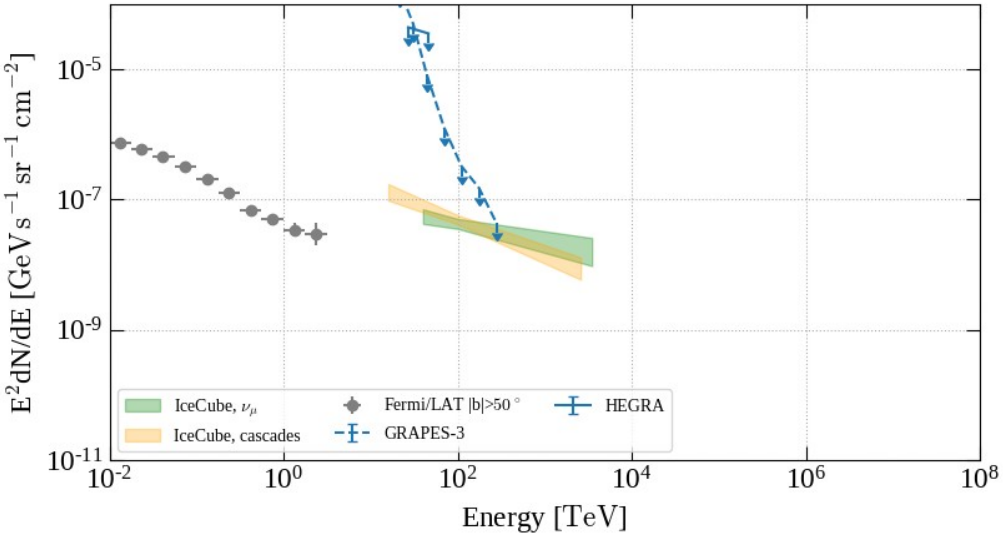
Dark matter (Murase+ ‘15)

IGRB (high-latitude) TeV limits

Galactic diffuse emission above few tens of TeV was reported by several collaborations
However the is no detection of the corresponding all-sky (or high-latitude) diffuse emission.

First EGB limits below < 300 TeV:

- HEGRA (array of cherenkov telescopes and particle detectors; Aharonian+ '02)
- GRAPES-3 (surface + shielded muon detectors; Minamino+ '09)



Relatively small detectors, but exactly in the IceCube energy range

Stronger constraints in the multi-TeV band expected from Tibet-ASγ, HAWC and LHAASO and CTA

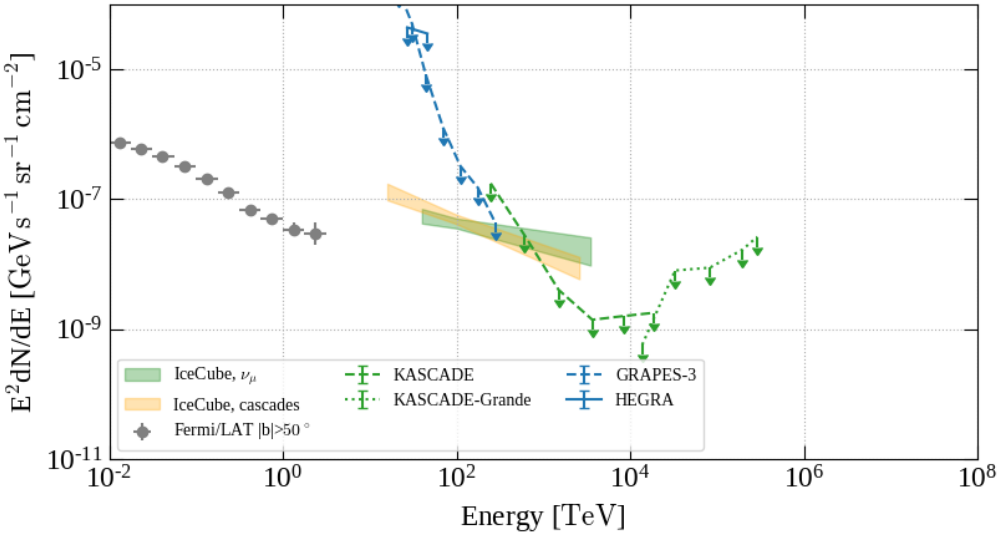
IGRB (high-latitude) PeV limits

Institute for Cosmic Ray Research
University of Tokyo

However the is no detection of the corresponding all-sky (or high-latitude) diffuse emission.
Limits reported assume all-sky diffuse emission isotropy

EGB limits @ PeV energies:

- CASA-MIA (Chantell+ ‘97)
- KASCADE (Apel+ 17)
- KASCADE GRANDE (extended version optimized for EeV energies; Apel+ 17)



Constrain the highest energy part of the IceCube spectrum

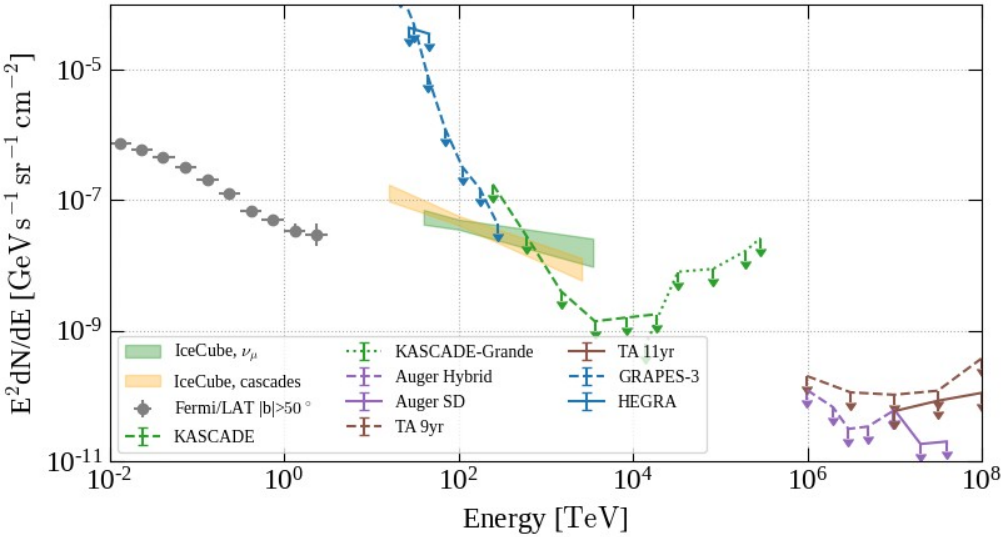
IGRB (high-latitude) EeV limits

ICRR
Institute for Cosmic Ray Research
University of Tokyo

However the is no detection of the corresponding all-sky (or high-latitude) diffuse emission.
Limits reported assume all-sky diffuse emission isotropy

EGB limits above EeV energies:

- Telescope Array (Abbasi+ '19, Kalashev+ '21)
- Pierre Auger Observatory (Savina+ '21, Abreu+ '22)



Constrain possible IceCube extrapolation to / above EeV

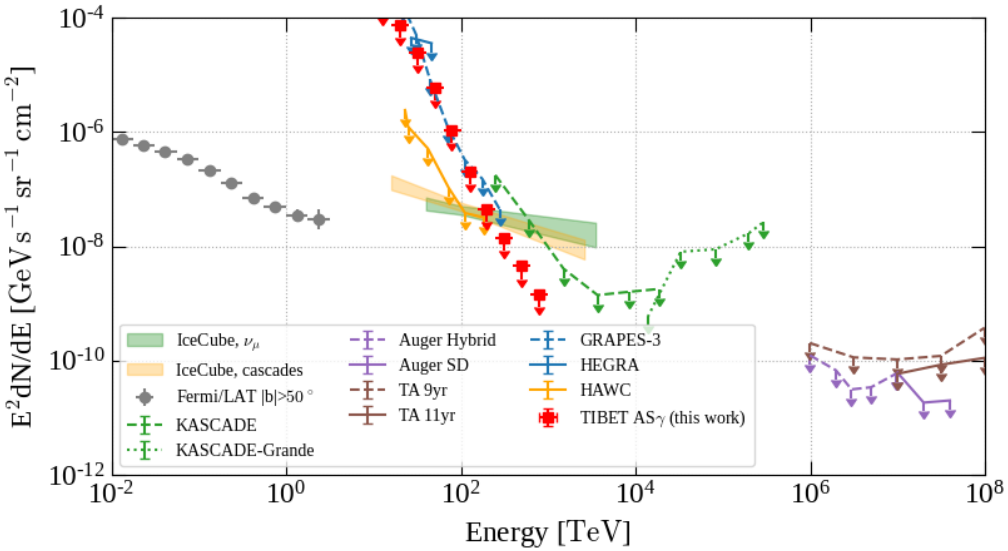
New IGRB sub-PeV limits

Institute for Cosmic Ray Research
University of Tokyo

However the is no detection of the corresponding all-sky (or high-latitude) diffuse emission.
Limits reported assume all-sky diffuse emission isotropy

New EGB limits at sub-PeV energies:

- Tibet-ASγ (Gal.Plane survey by-product; Neronov+ '21)
- HAWC (Albert+ ‘22)



Constrain most of the IceCube energy range

Further improvement expected from LHAASO and CTA

Galactic origin of PeV neutrino?

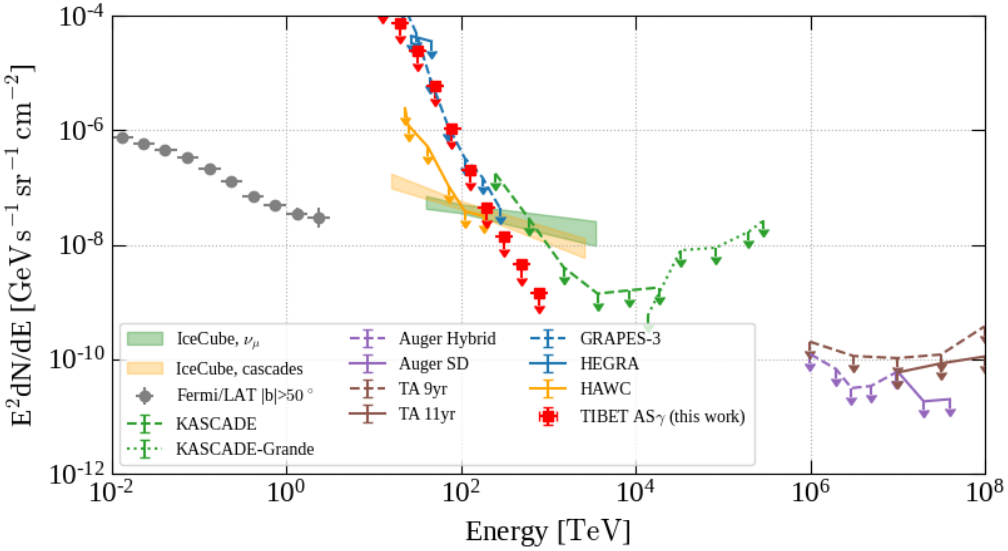
Softer neutrino spectrum in the 10 – 300 TeV range (Aartsen+ ‘20, Abbas+ ‘20) may be of Galatic origin.

However, a large signal from the Galactic plane is inconsistent with arrival directions of neutrino events (Albert et al. 2018)

IceCube flux extrapolation overshoots the GeV IGRB extrapolation.

Tibet-ASg and HAWC diffuse emission limits:

- Galatic contribution < 10% @PeV,
- likely subdominant already from 100 TeV



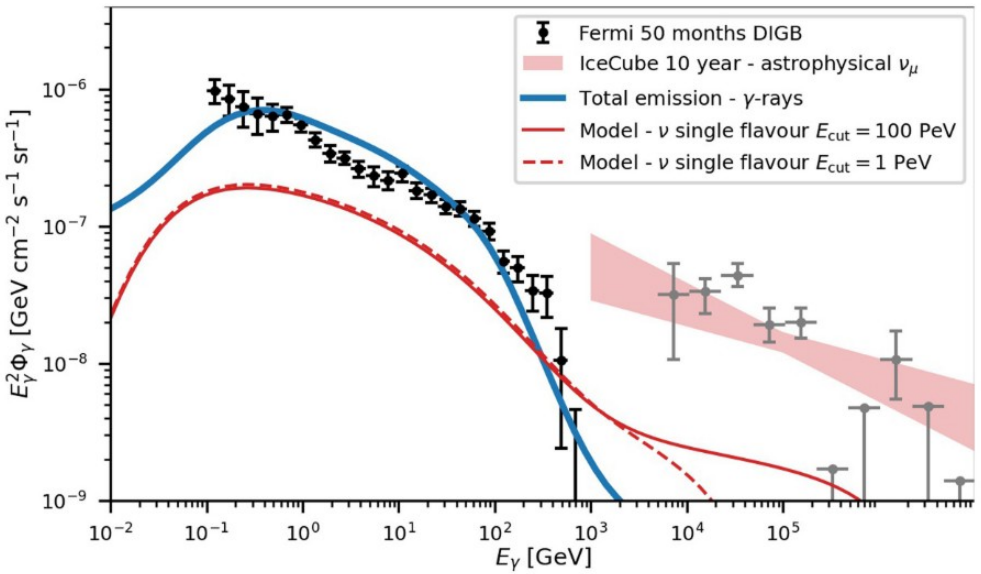
It seems IceCube flux > 100 TeV is (mostly) extragalactic

Extragalactic origin of PeV neutrino?

Institute for Cosmic Ray Research
University of Tokyo

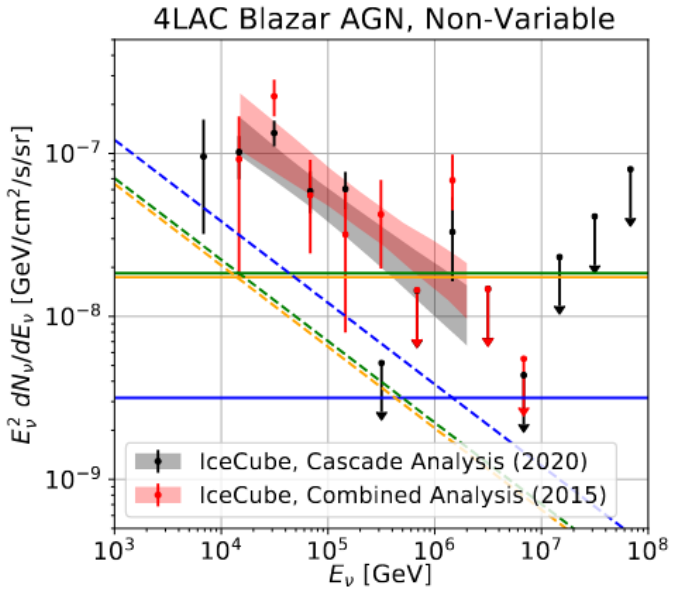
Harder neutrino spectrum above 200 TeV (Aartsen et al. 2016; Stettner 2020) is consistent with single extragalactic source population responsible PeV neutrinos and GeV range γ rays (Murase et al. 2013).

Startburst galaxies may explain IGRB, but not neutrinos...



Roth+ ‘21

...blazars do not work too



Smith ‘21

Radio-brightest blazars (Plavin et al. 2020, 2021)?

Non-blazar AGNs (Smith+ ‘21)?

UHECR sources (Kachelrieß et al. 2017)?

Summary

ICRR
Institute for Cosmic Ray Research
University of Tokyo

- High galactic latitude (all-sky, isotropic) gamma ray background has been measured / constrained from GeV to EeV energies.
- It’s nature is still being debated, with AGNs and star-forming galaxies considered as main candidates.
- Possible relation of the all-sky diffuse gamma-ray and neutrino flux is under debate.
- New sub-PeV limits strongly constrain the possible Galactic contribution to the all-sky neutrino flux.
- Gamma-ray background measurements @ 10 TeV would be crucial to determine local, Galactic contribution to the 10-100 TeV neutrino flux.