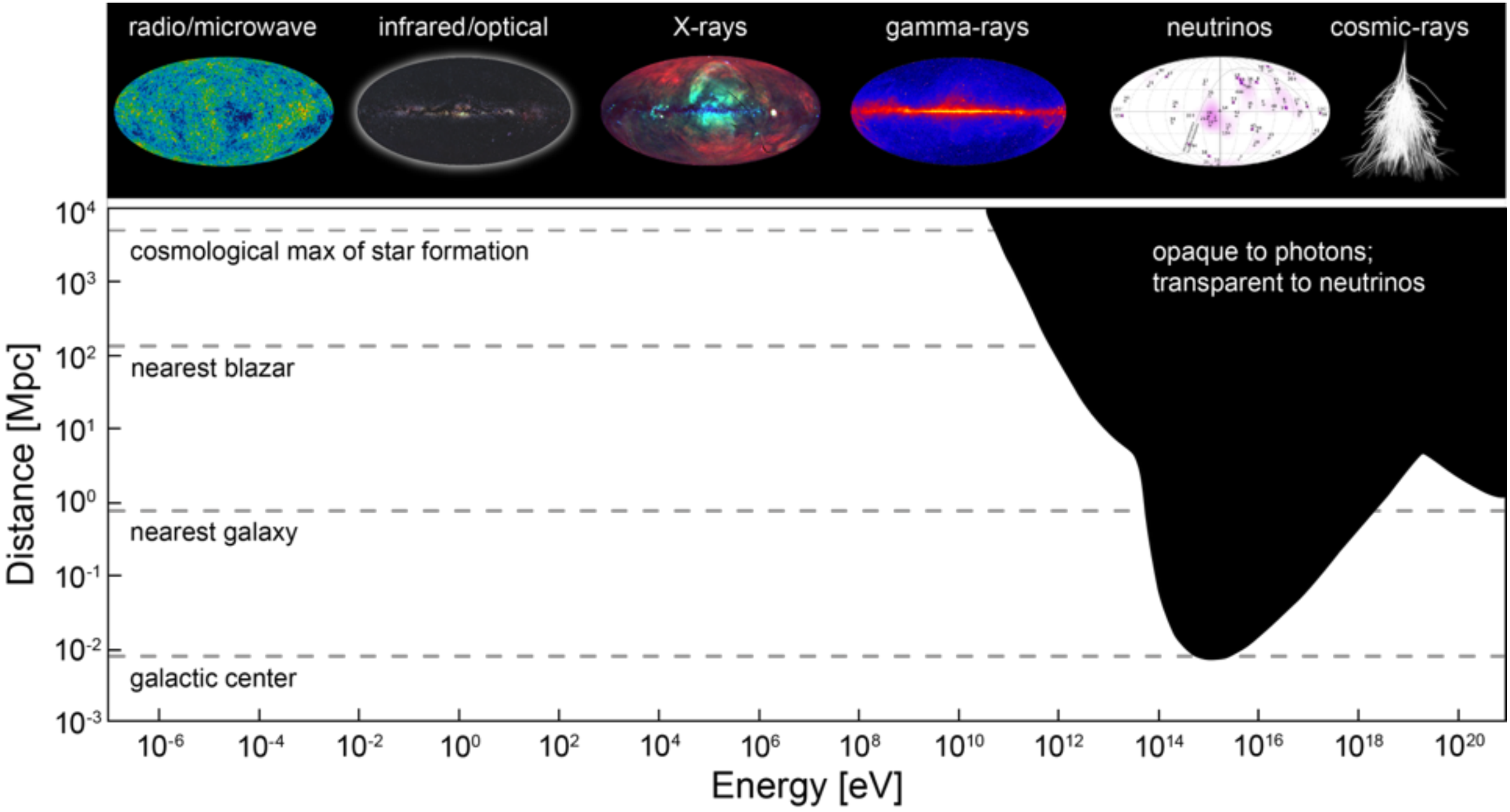
Neutrino Astronomy fast-forward

Marek Kowalski (DESY & Humboldt University Berlin)

TeVPA 2017, Columbus, Ohio

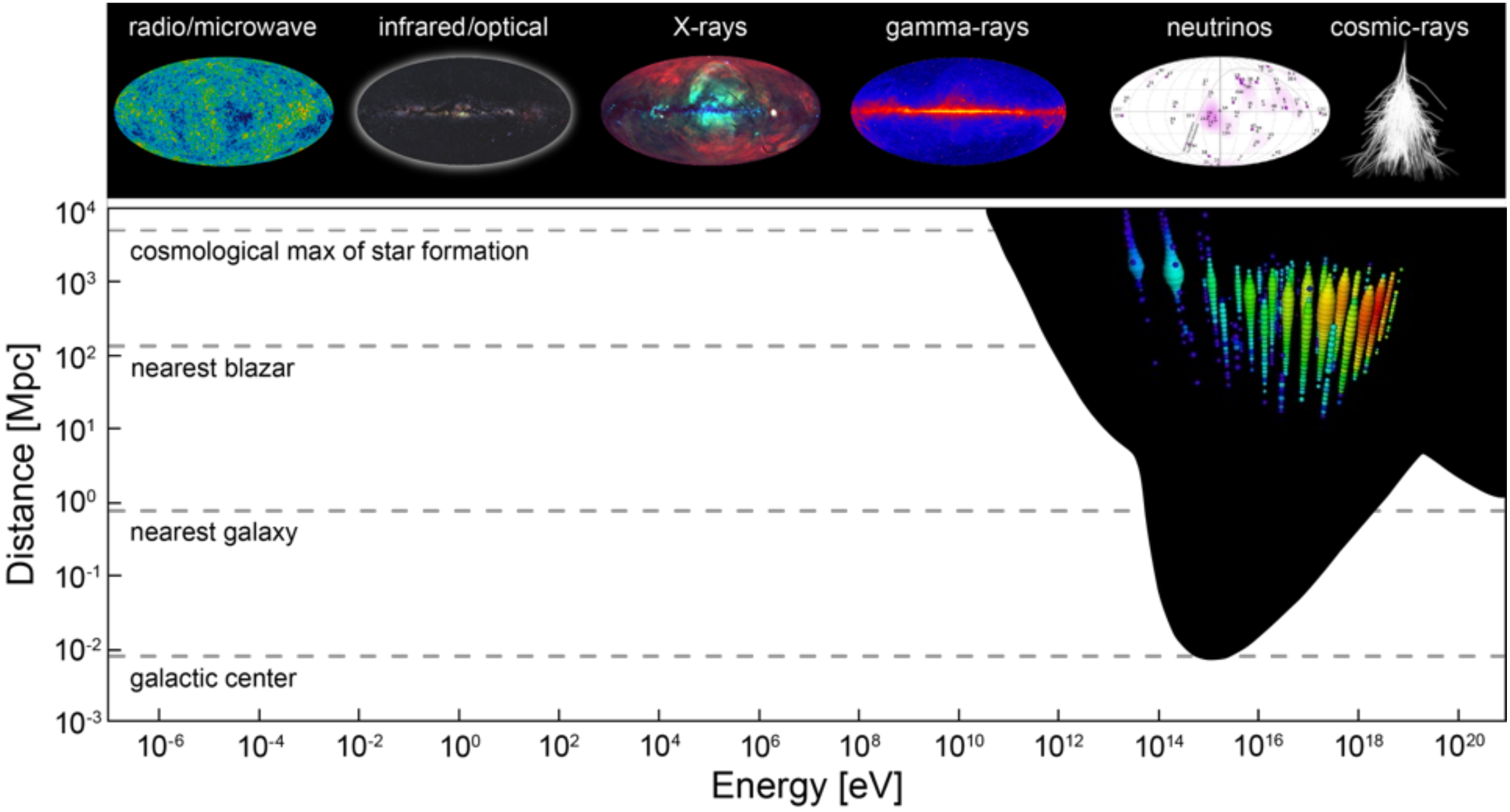
Credit: M. Wolf/NSF

The promised land



The Universe is opaque to EM radiation for ¼ of the spectrum,
i.e. above 10-100 TeV where IceCube sees cosmic neutrinos.

The promised land



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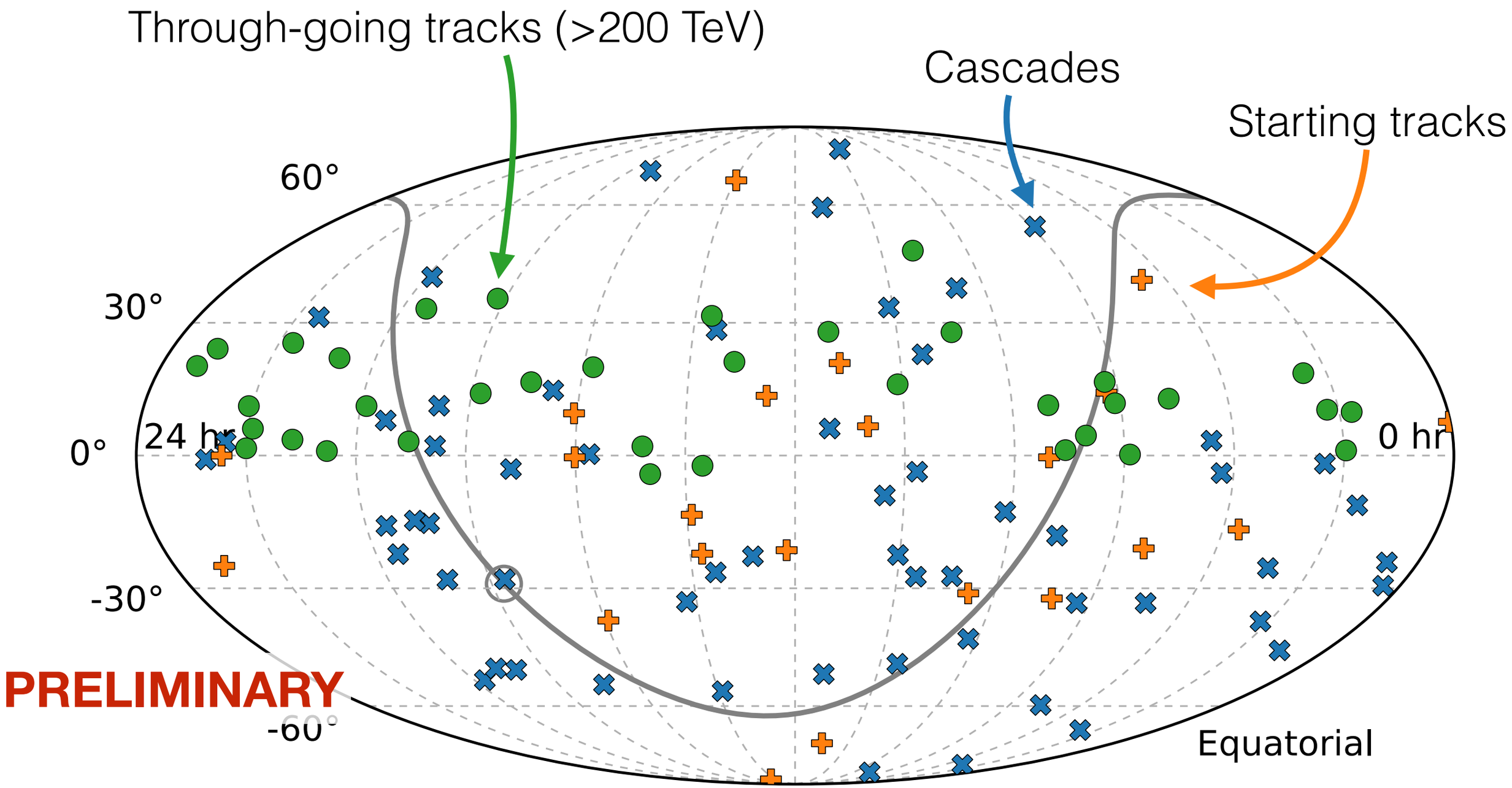
High-energy neutrinos on the sky observed by IceCube



IceCube, 2017

No evidence of clustering in high-energy neutrino directions

mostly isotropic ⟹ neutrinos of extragalactic origin

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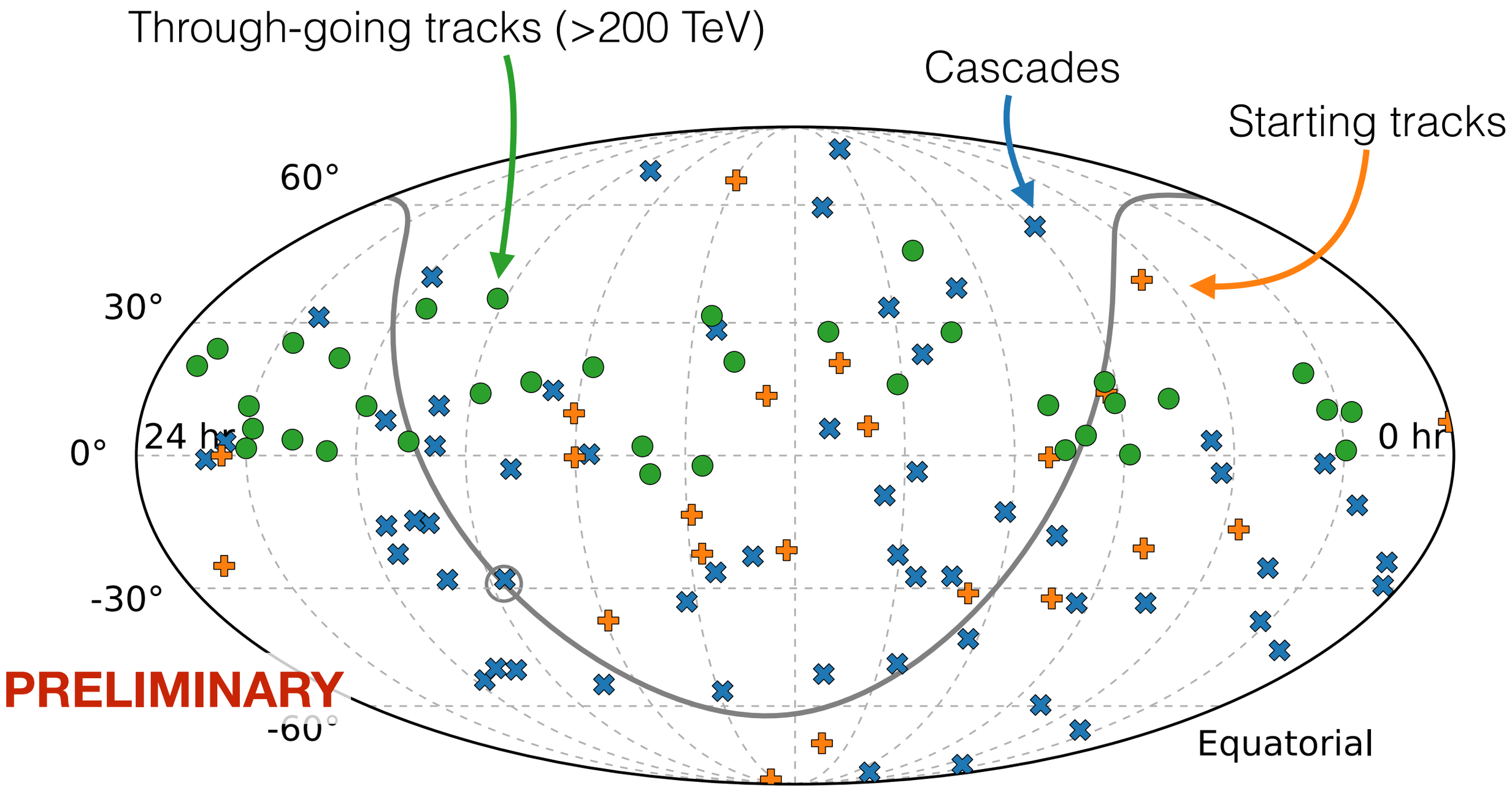
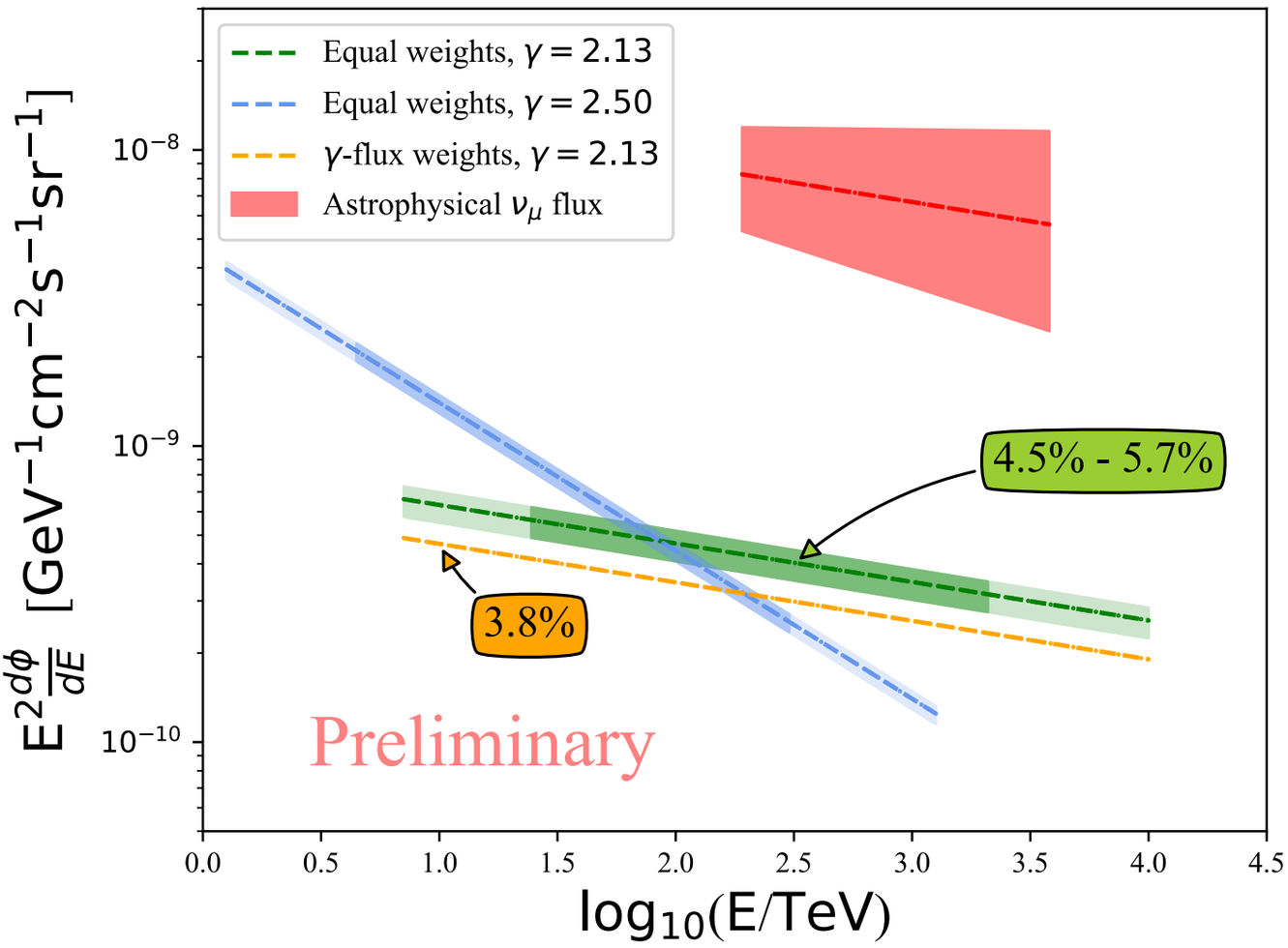


IceCube, 2017

Event numbers: brightest point source vs all

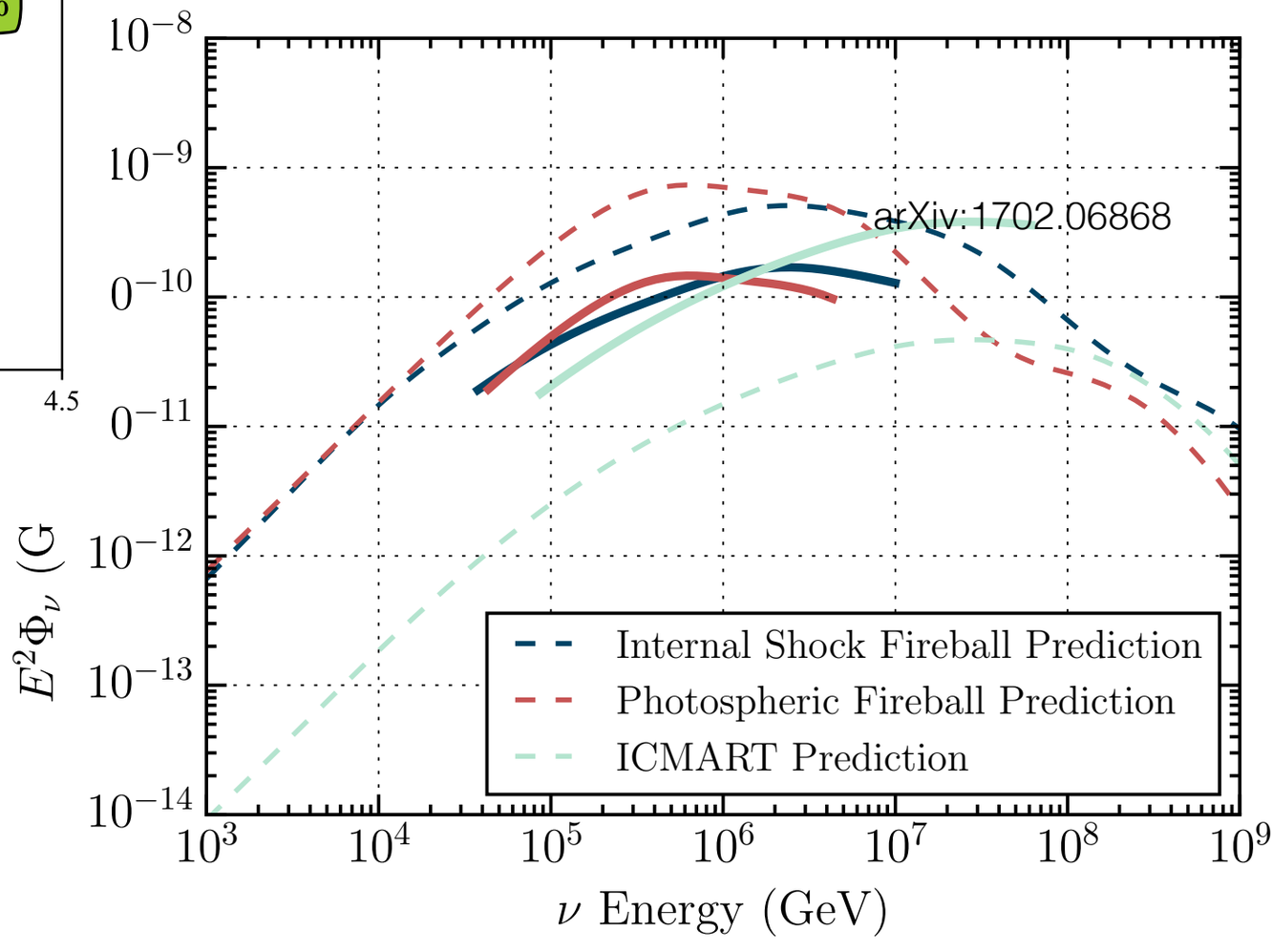
$N_{ps} \sim 10^{-2}\ (n/10^{-7}\ Mpc^{-3})^{-1/3} \times N_{diff}$

High-energy neutrinos on the sky: Constraints on source candidates



Blazars account for < 6% of the observed neutrino f

but up to 85% of the Fermi flux

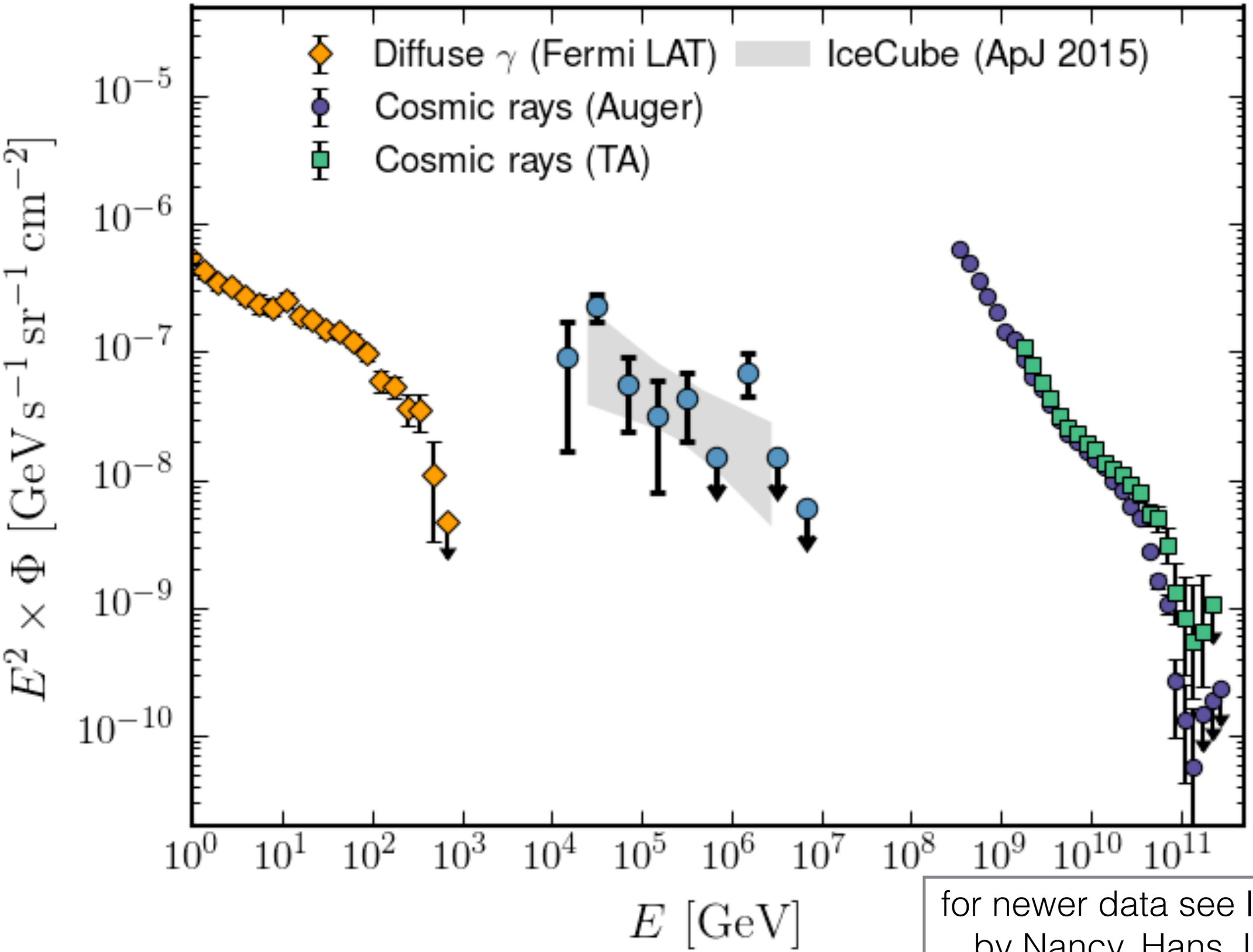


Prompt emission from GRBs account for <1% of the observed neutrino flux.

benchmark sensitivity from Weizmann 2017: $\Phi = 10^{-13}$ E^{-2} TeV cm^{-2}s^{-1}

⇒allows to probe all source classes

Understanding the spectrum



for newer data see IC talks by Nancy, Hans, Lu Lu

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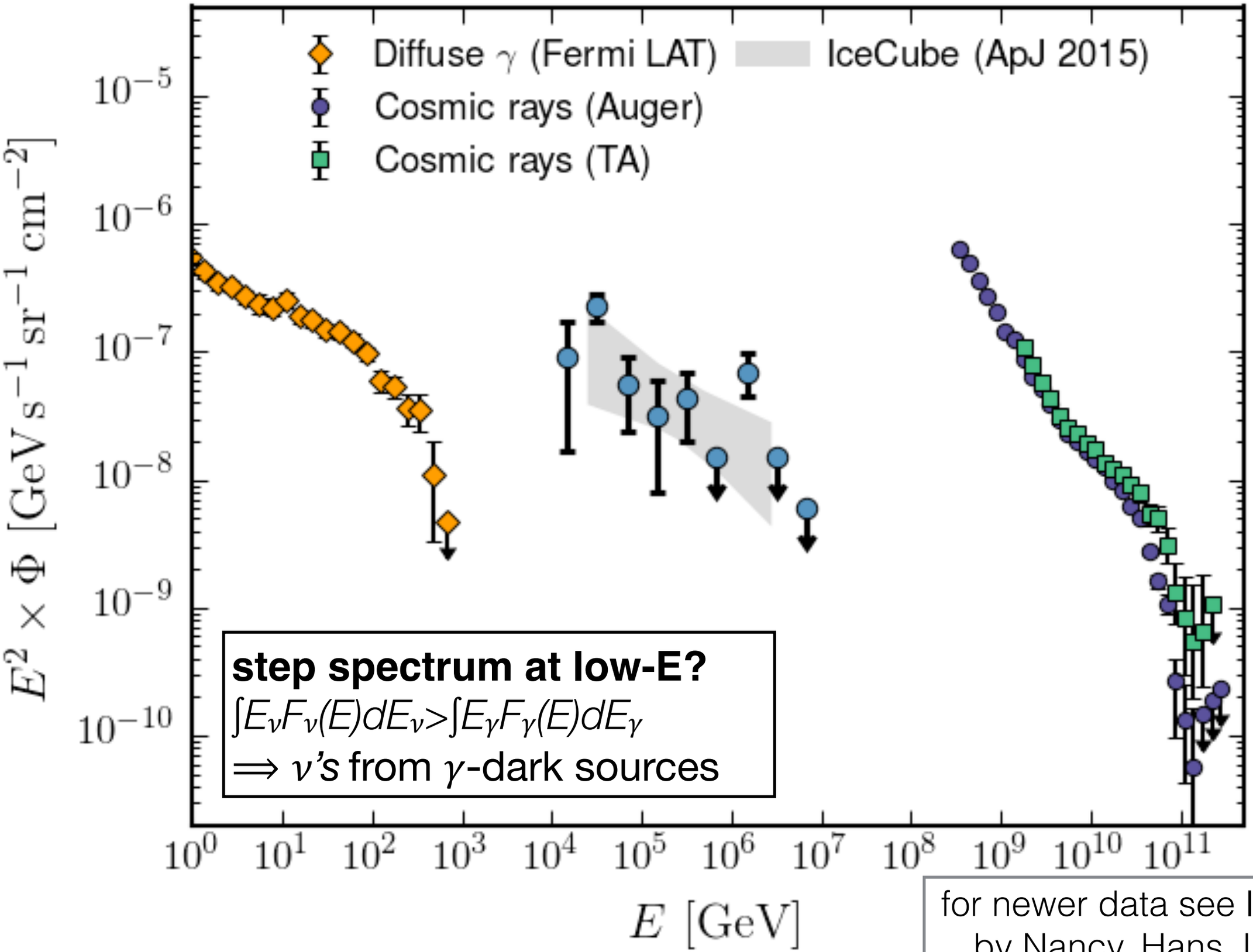

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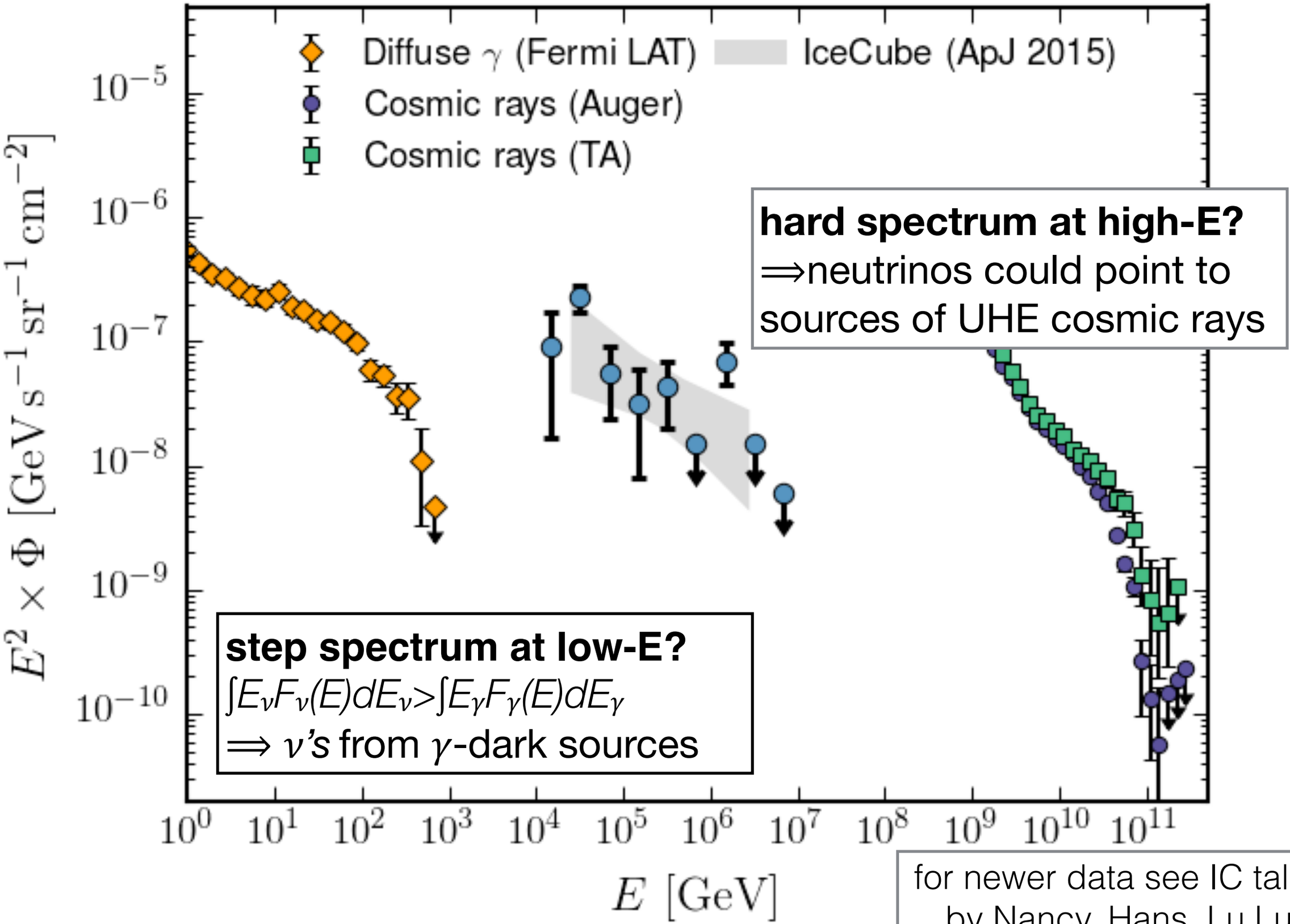
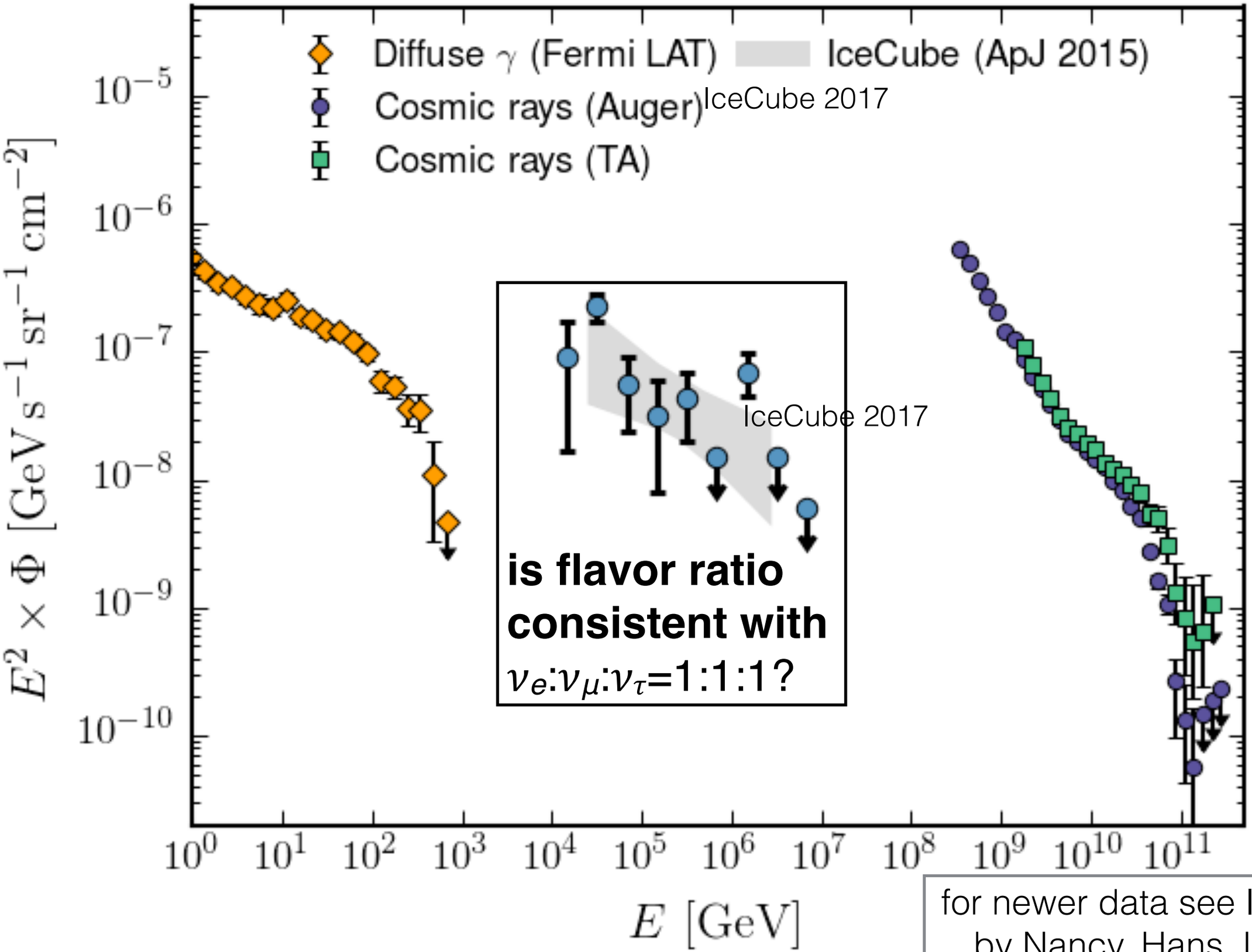


hard spectrum at high-E?
⟹neutrinos could point to sources of UHE cosmic rays

step spectrum at low-E?
$\int E_\nu F_\nu(E) dE_\nu > \int E_\gamma F_\gamma(E) dE_\gamma$
⟹ ν's from γ-dark sources

for newer data see IC talks by Nancy, Hans, Lu Lu

Understanding the spectrum and composition

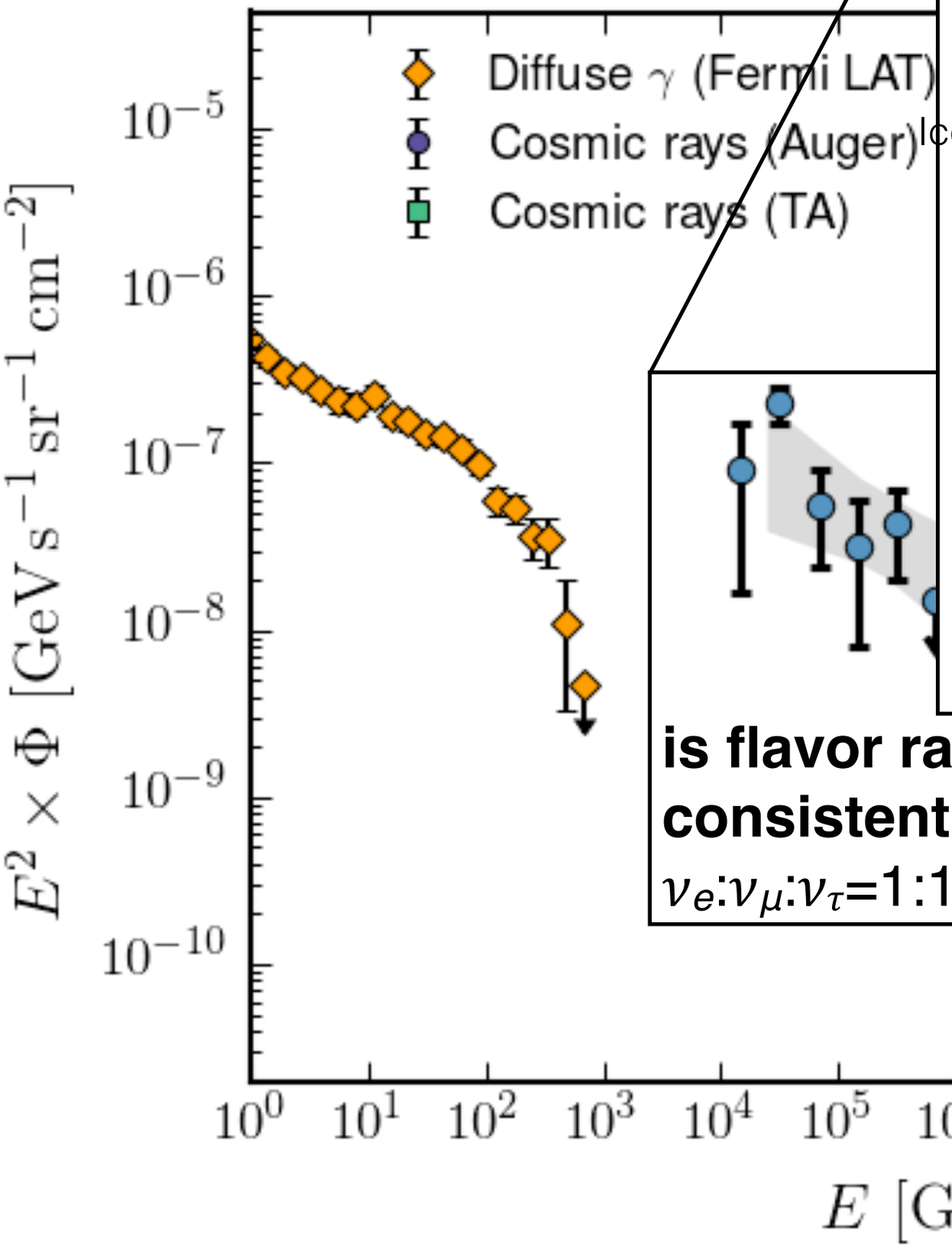


IceCube 2017

is flavor ratio consistent with ν_e:ν_μ:ν_τ=1:1:1?

for newer data see IC talks by Nancy, Hans, Lu Lu

Understanding the spectrum and C



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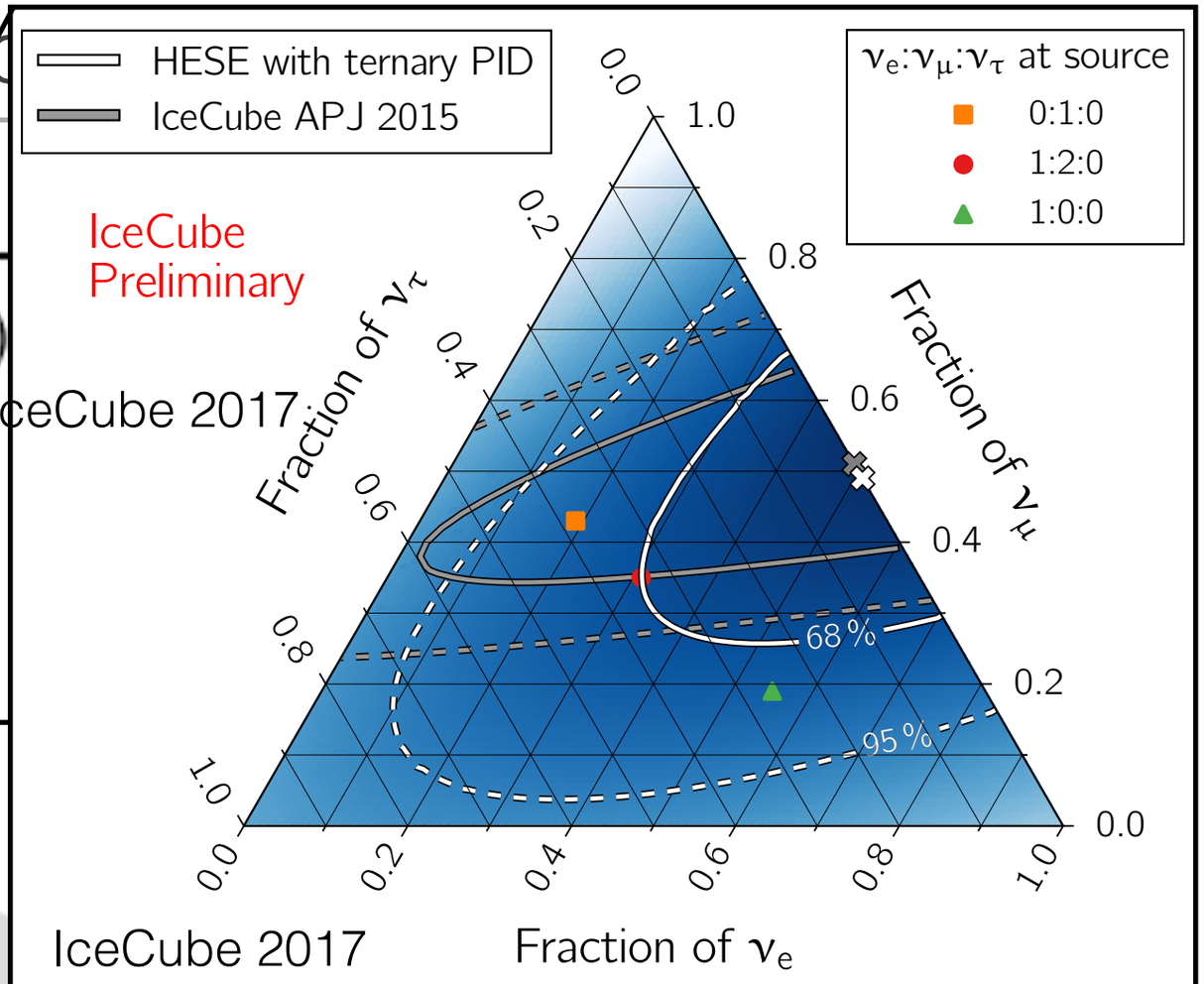


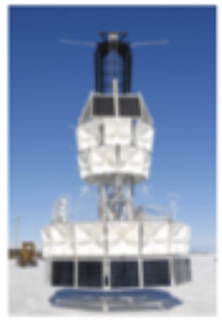
Zero tau neutrinos observed so far, consistent with fluctuation (p=9%)

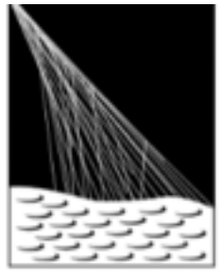
for newer data see IC talks by Nancy, Hans, Lu Lu

Emerging tasks for high-energy neutrino astrophysics

- Resolve the sources of IceCube's high energy astrophysical neutrinos
- Identify the sources of the highest energy cosmic rays
- Decipher the production mechanisms of high energy cosmic particles
- Obtain a unique multi-messenger view into the explosion of stars and the evolution of stellar remnants
- Explore active galaxies and the very high-energy Universe when it was most active
- Study of galactic and extra galactic propagation of CR with neutrinos as tracers
- Test nuclear, neutrino and BSM physics

Future project overview

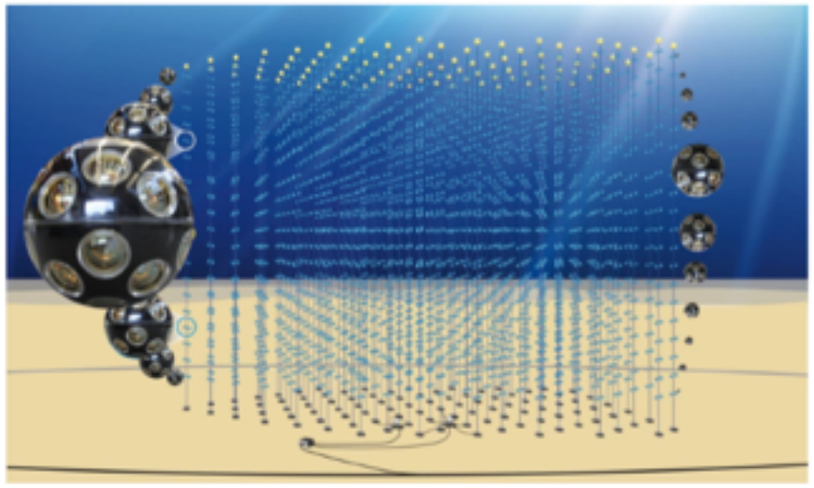




complementarity,
sensitivity to
neutrino sources
"precision frontier"

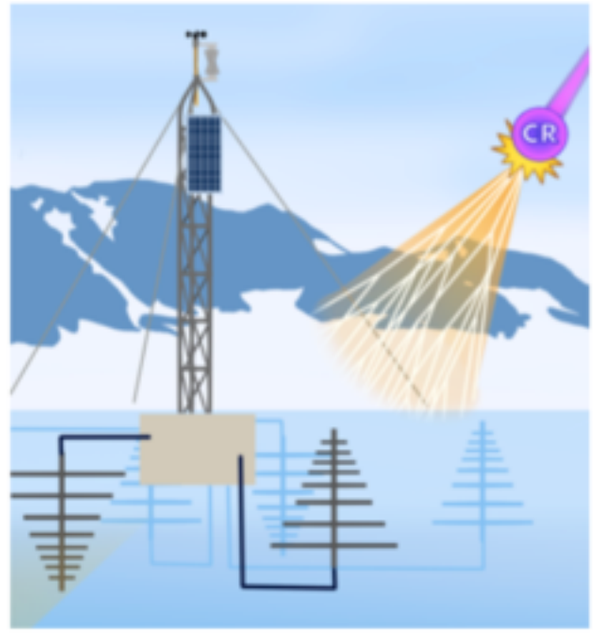
sensitivity at EeV
and beyond
"energy frontier"

Present neutrino detectors

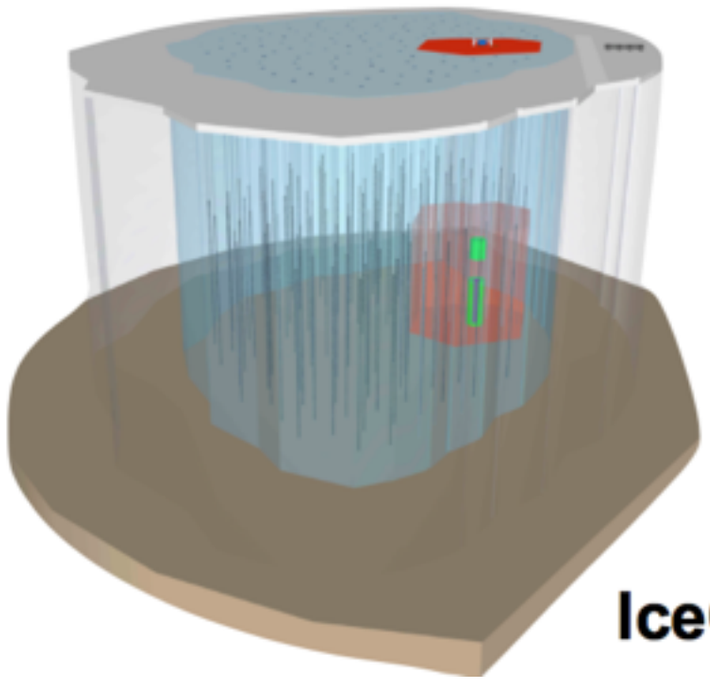


KM3NeT, GVD

sensitivity at
PeV energies
"intensity frontier"



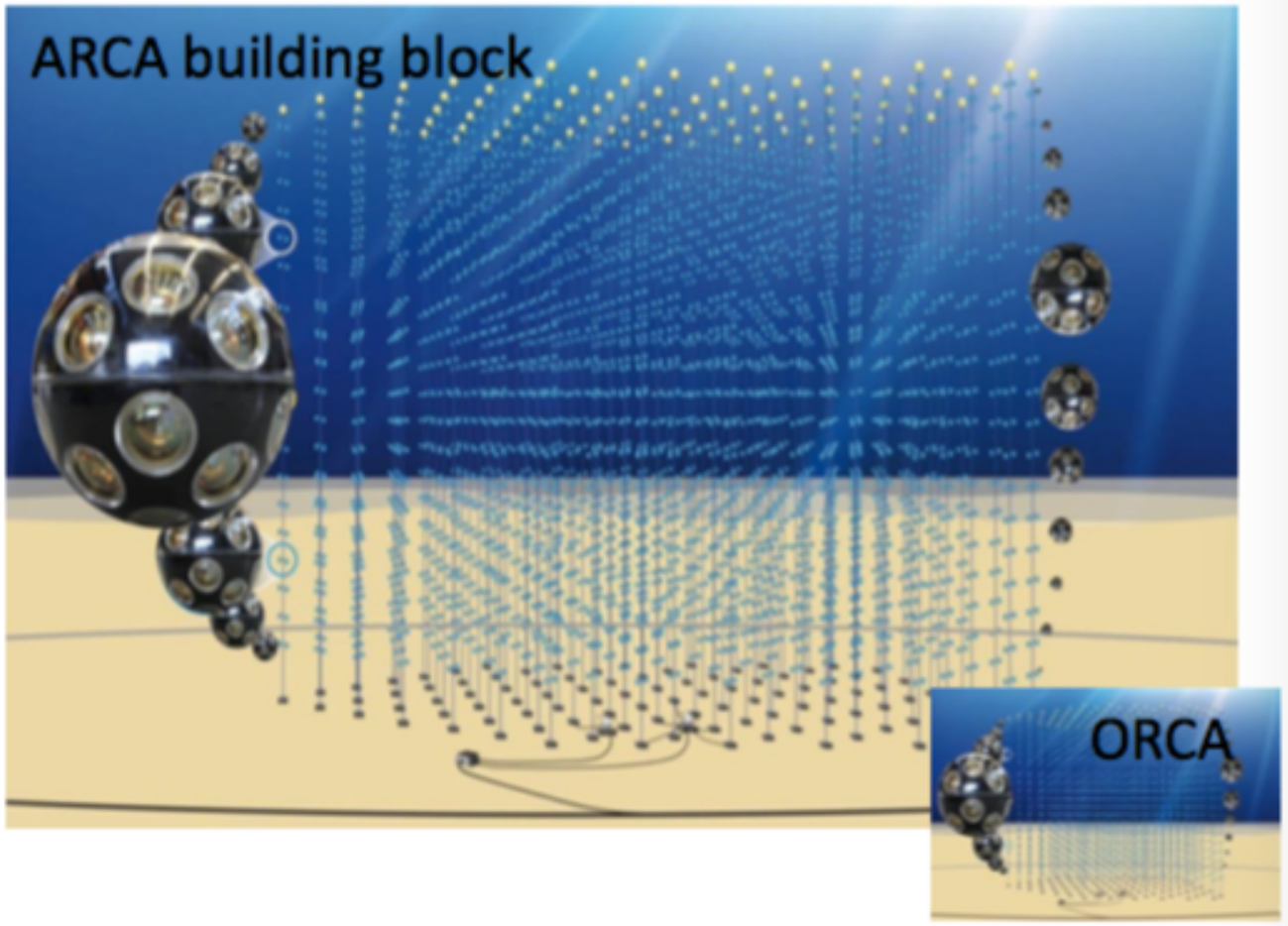
**ARA, ARIANNA,
EVA, GRAND**



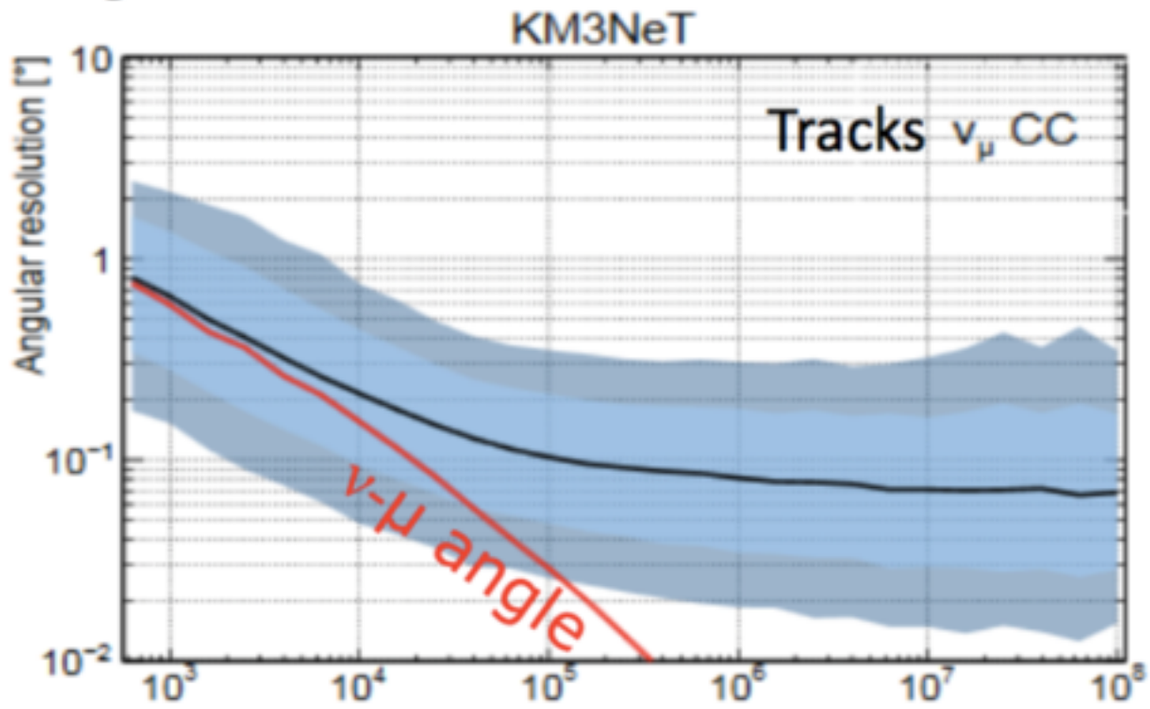
IceCube-Gen2

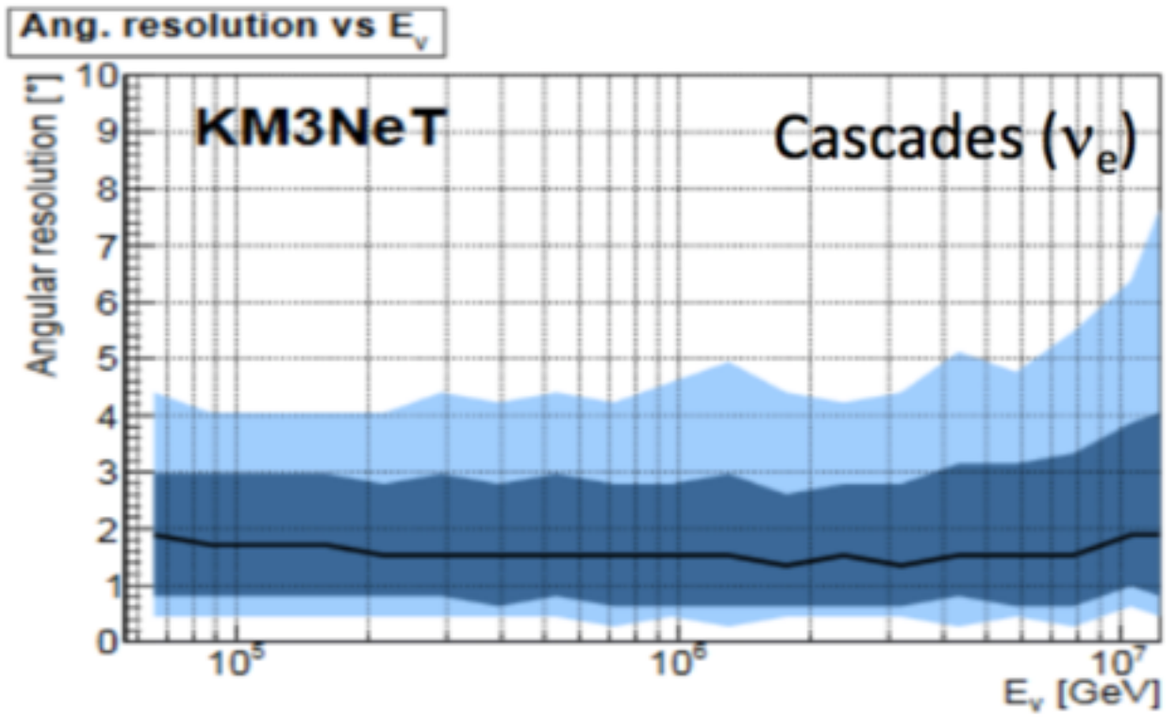
credit: M. Ackermann

KM3NeT



Opposite hemisphere to IC, similar energy range, but better angular resolution





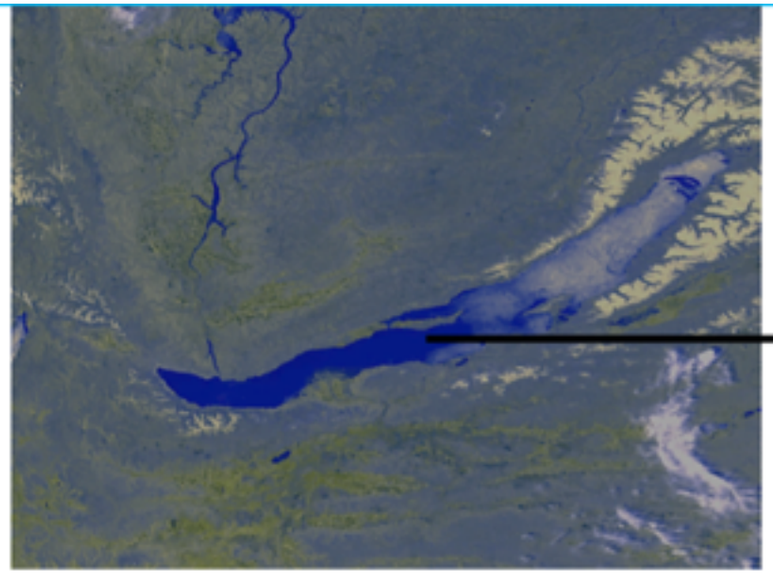
KM3NeT 2.0 under construction

Two sub-arrays:

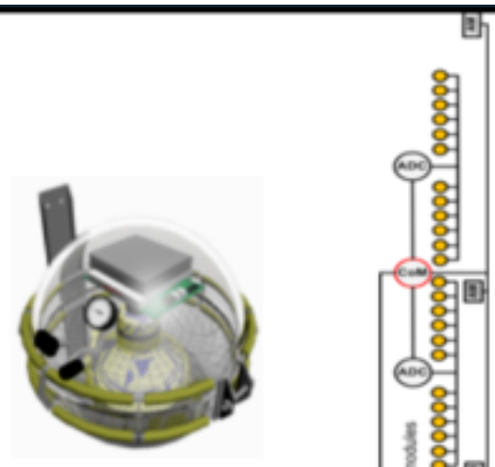
- **ARCA**: 2 sparse building blocks in Italy for cosmic neutrinos
- **ORCA**: 1 dense building block in France for oscillation

https://arxiv.org/abs/1601.07459

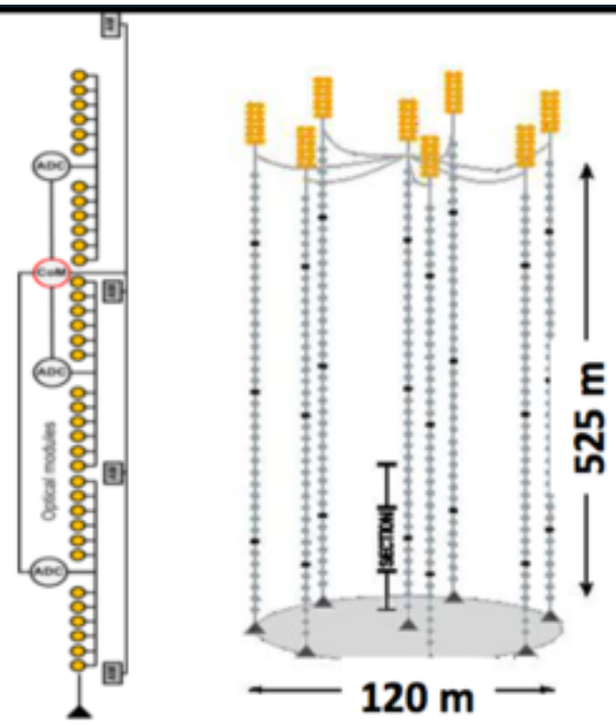
Giant Volume neutrino Detector (GVD)



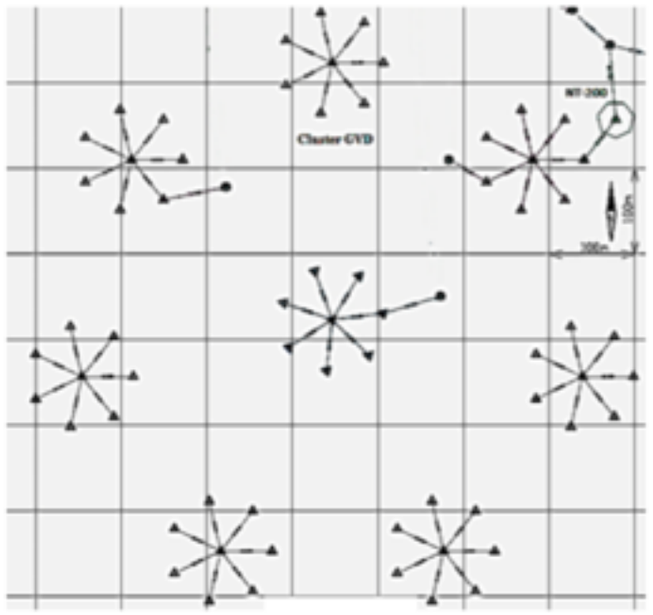
- Located at Lake Baikal
- 2 out of 8 clusters installed and operational



Optical module



String: 36 OMs Cluster: 8 strings



GVD-1: 8 clusters

	GVD-1	GVD-4
OMs	2304	10368
Clusters (8 Strings)	8	27
Depths, m	750 – 1275	600 – 1300
Eff. Volume (E_{SH} > 100 TeV)	0.4 km^3	1.5 km^3

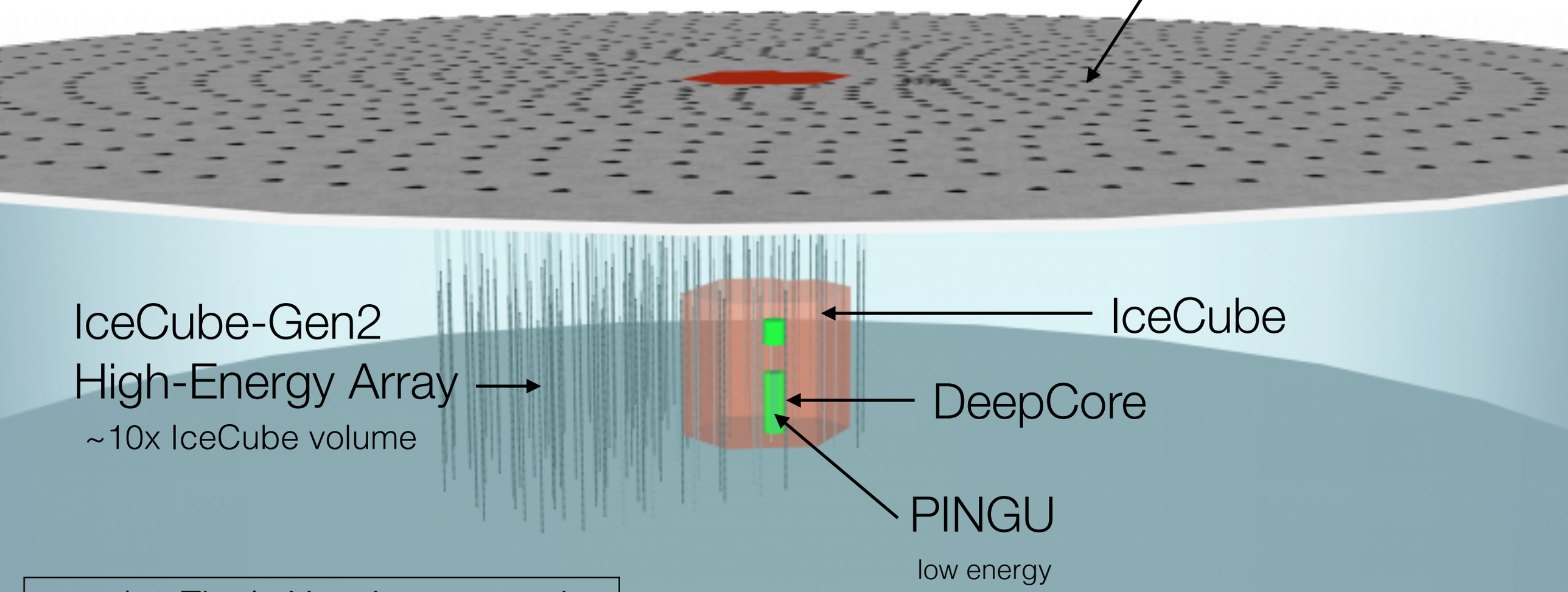
Directional resolution
Cascades: 3° – 5°
Muons: 0.25°

The IceCube-Gen2 facility

A wide band neutrino observatory (MeV – EeV) using several detection technologies – optical, radio, and surface veto – to maximize the science

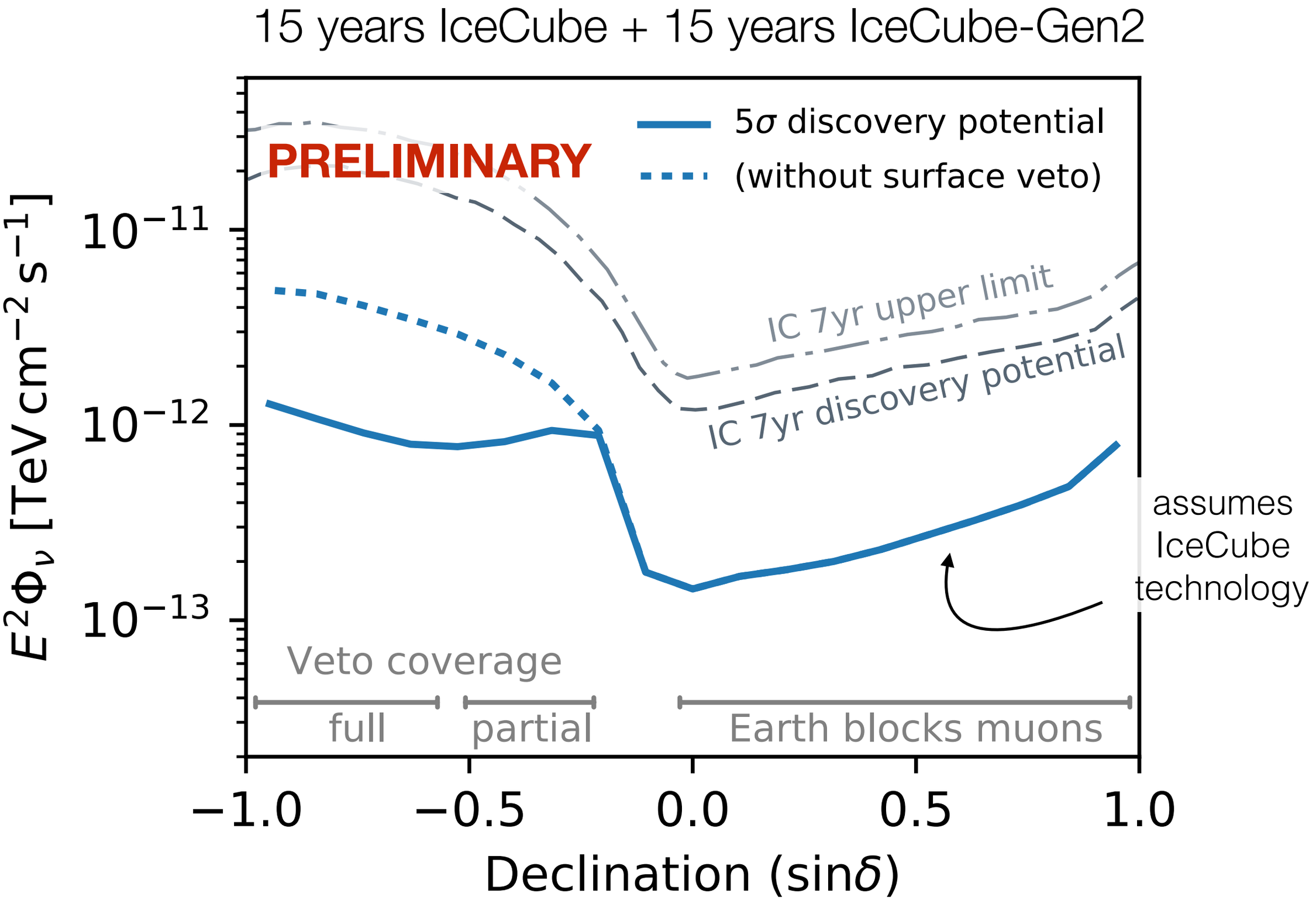
Multi-component observatory:

- IceCube-Gen2 High-Energy Array
- Surface air shower detector
- Sub-surface radio detector
- PINGU



see also Tienlu Yuan's presentation

Identifying the sources of IceCube's neutrinos



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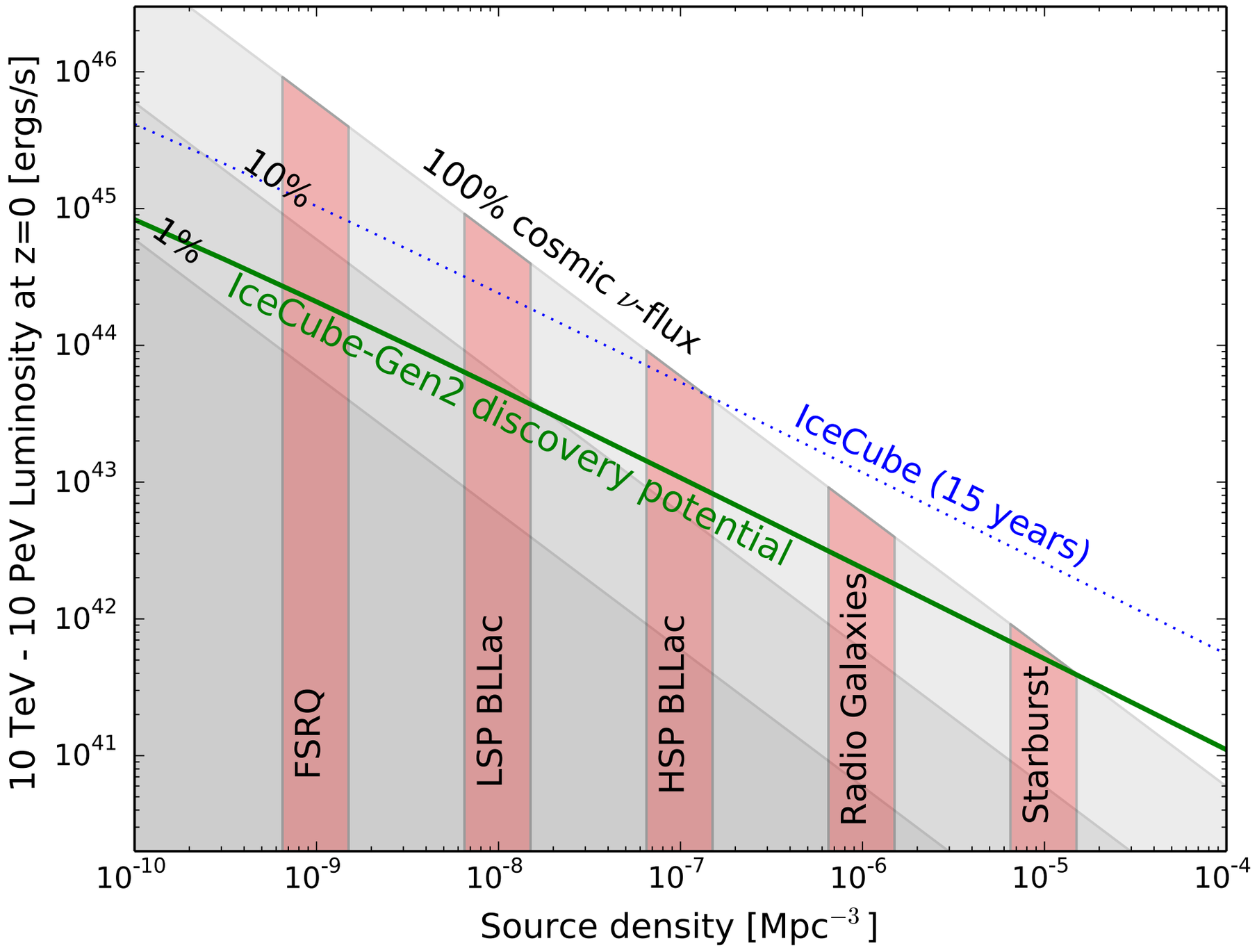
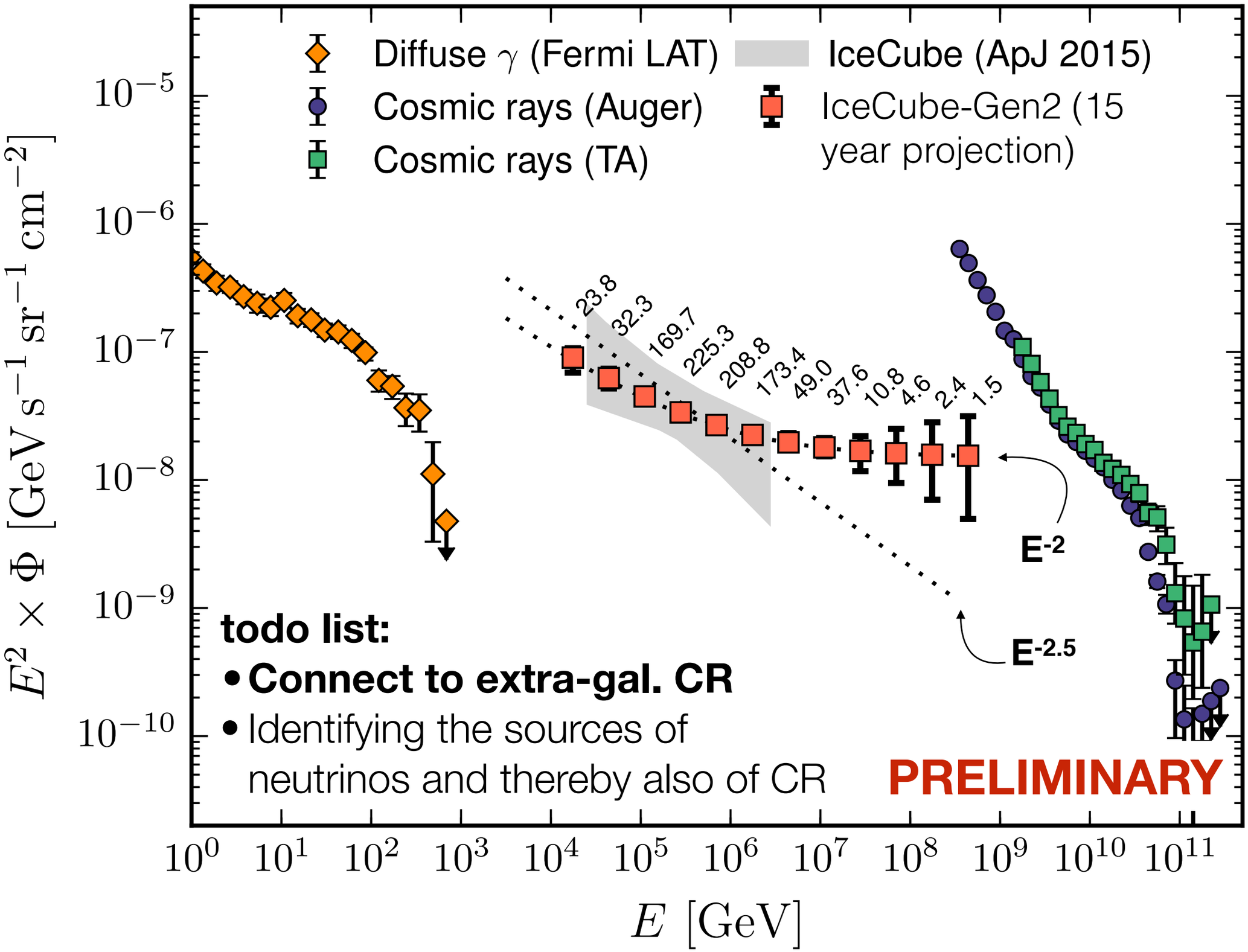


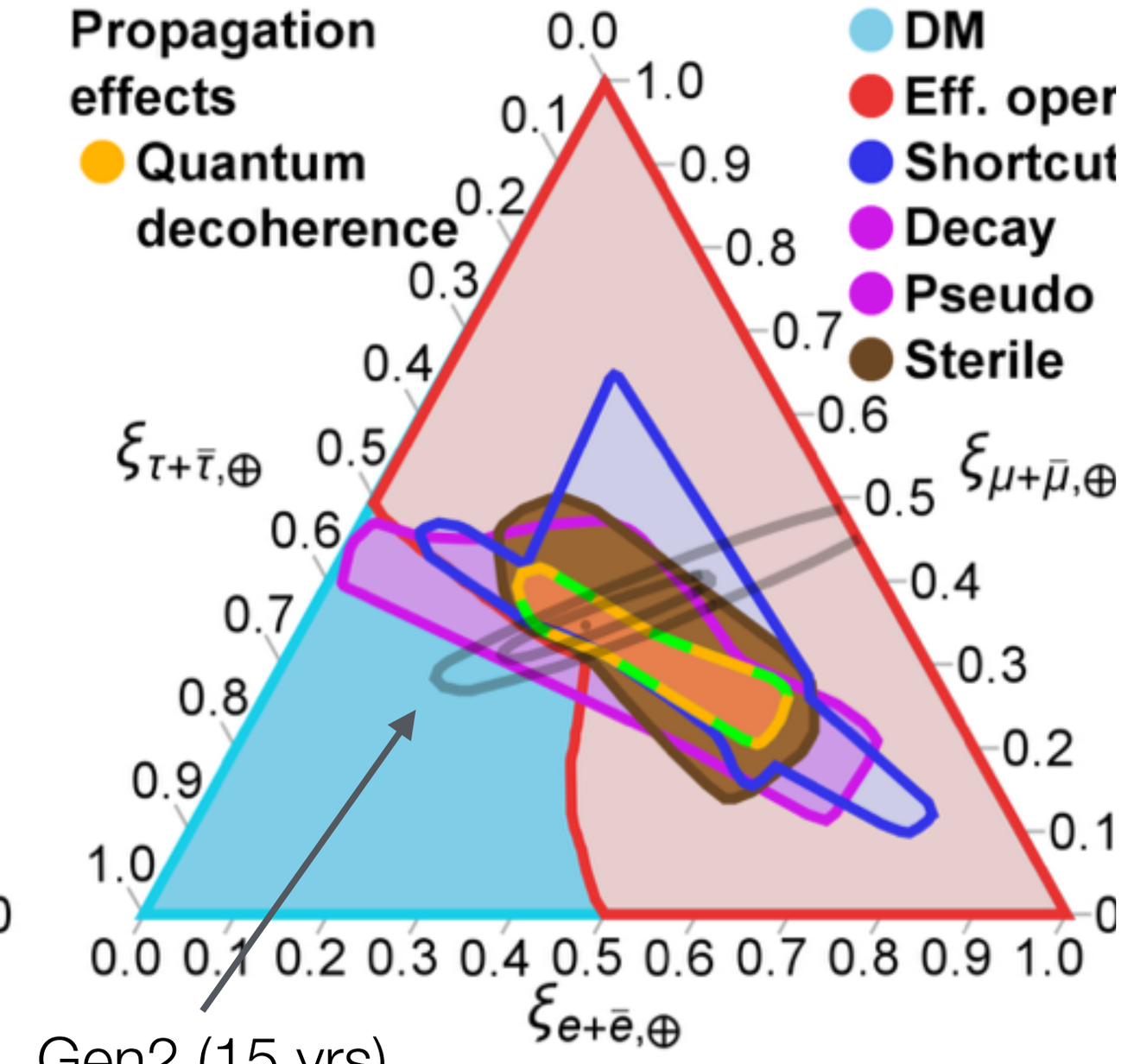
IC-Gen2 will have sufficient sensitivity to detect all reasonable source scenarios

*Sensitivity for source catalog search

Connecting HE neutrinos to UHE cosmic rays



Flavor triangle and BSM physics

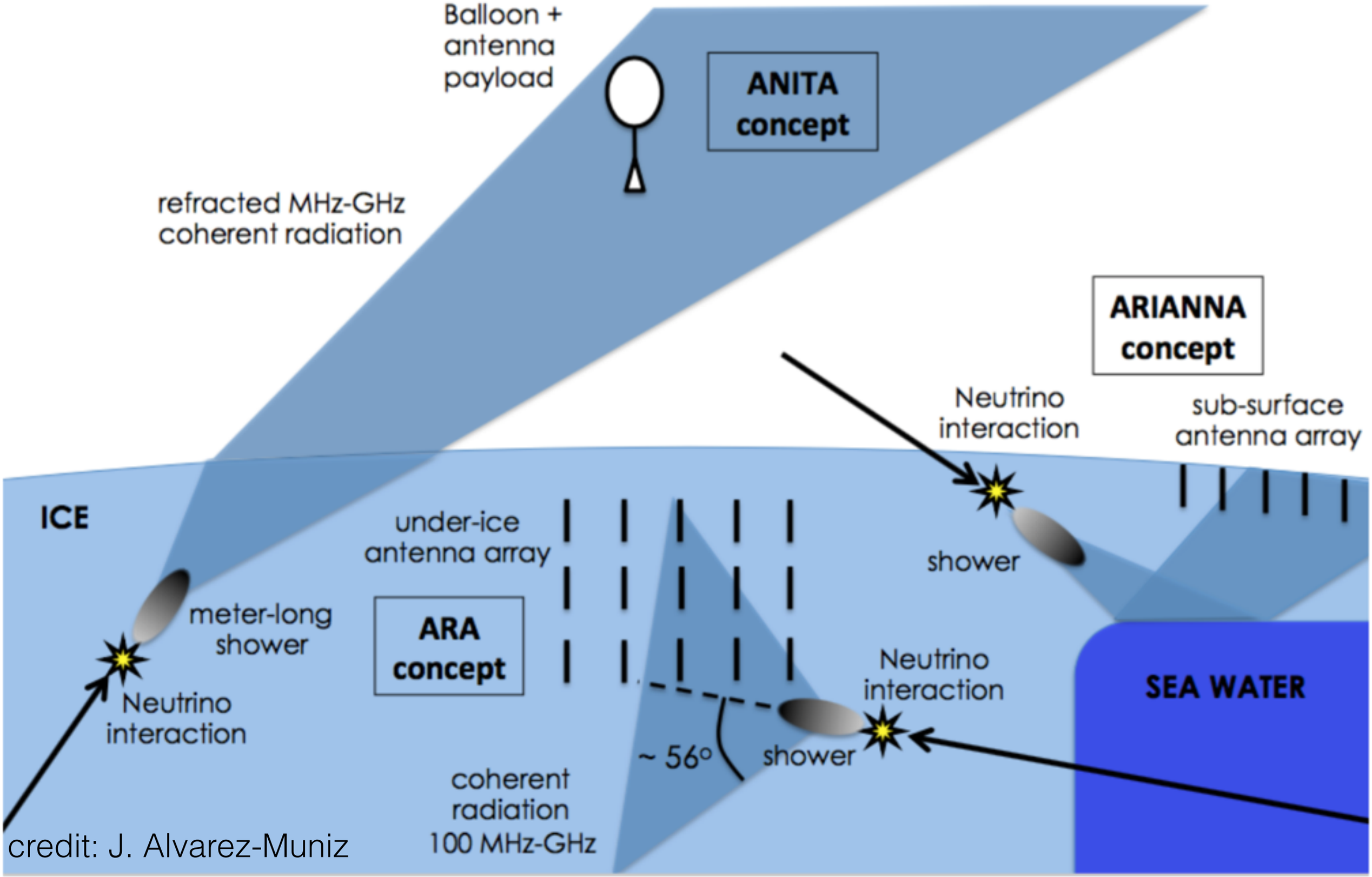


Gen2 (15 yrs)

Scenario	Exclusion by IceCube	Exclusion by IceCube-Gen2
Complete flavor triangle	42%	96%
Standard mixing	2%	73%
Non-standard neutrino production	17%	93%
NSI at production	5%	84%
Matter effetcs	0%	71%
Pseudo-Dirac neutrino	14%	85%
Decay	14%	85%
Quantum decoherence	2%	73%
Sterile neutrino	10%	86%
Effective operator	36%	94%
Interaction with DM	42%	96%
Shortcut through extra dimension	11%	80%
NSI in Earth matter	30%	92%
NSI at detection	11%	89%

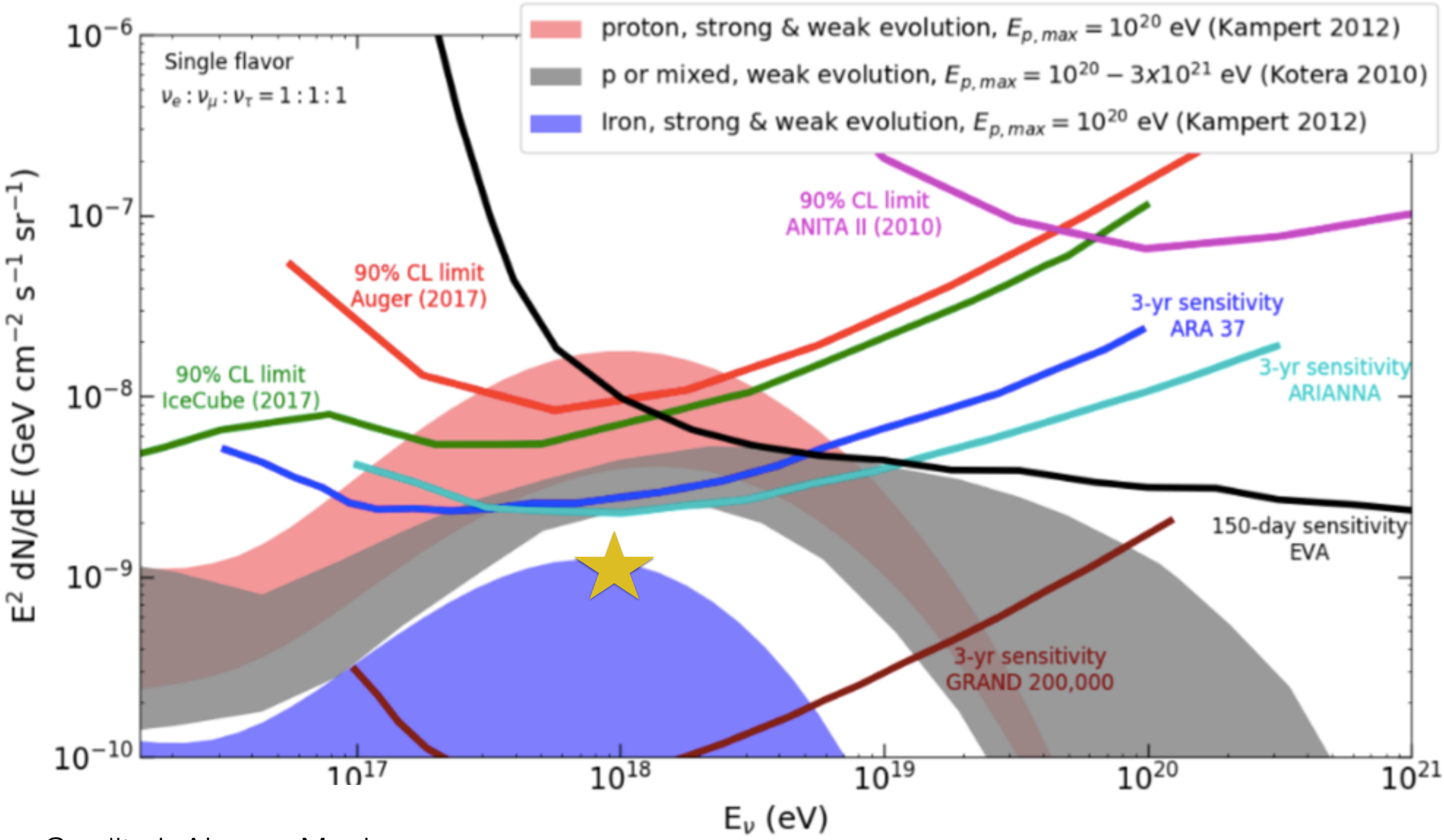
Rasmussen et al. (1707.07684)

The energy front with the radio technique



credit: J. Alvarez-Muniz

Sensitivity of future radio detectors



Credit: J. Alvarez-Muniz

★ 10^{-9} GeV cm^{-2}s^{-1}sr^{-1} @10^{9} GeV benchmark point from Weizmann workshop 2017

Neutrino astronomy project timeline & Milestones

first Northern km^3-detector

IC upgrade (Gen2 Phase I)

20 years of IC; completion of IC-Gen2

… 2017 2018 2019 2020 2021 2022 2023 2024 2025 … 2031

Gen2 Phase 1 (7 string) deployment

IC-Gen2

R&D / Design Production Deployment (8km^3)

Prod. & Deployment ARCA (2 blocks, 1.2km^3)

KM3NeT

Prod. & Deploy ORCA

GVD

Prod. & Deploy (8 clusters, 0.4km^2)

Conclusions

- High-energy extra-galactic neutrinos observed, opening a unique view on the high-energy Universe
- Sources not yet resolved, new multi-messenger methods being developed
- As old questions are answered, new ones emerge, i.e. the spectrum appears to be complex
- Construction and Planning of new projects underway to cover full sky and large energy range, optimized for neutrino astronomy in the next decades

2018 TeV Particle Astrophysics

27–31 August 2018 | Berlin

TeVPA

http://tevpa2018.desy.de