Bump-hunting in the diffuse flux of high-energy cosmic neutrinos

Damiano F. G. Fiorillo

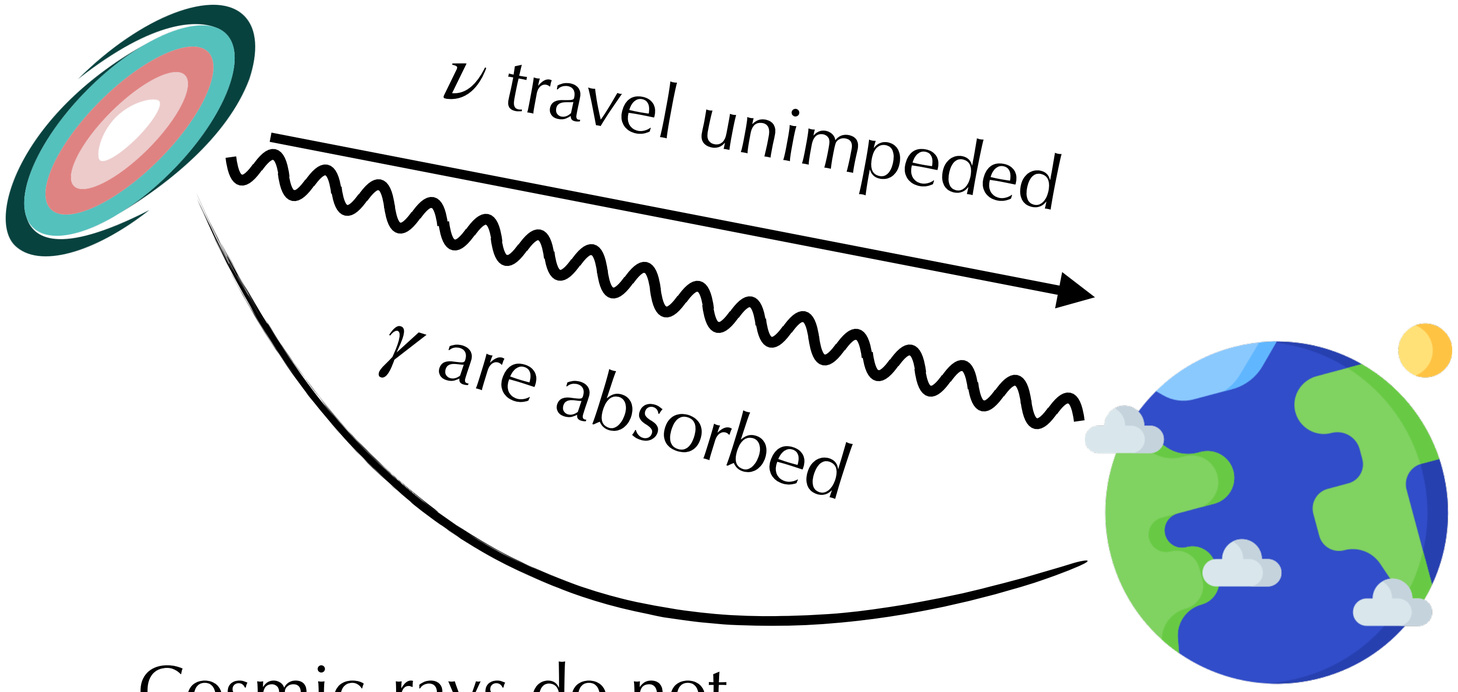
based on arXiv:2301.00024, with Mauricio Bustamante

CERN Neutrino Platform Pheno Week 2023

KØBENHAVNS UNIVERSITET
UNIVERSITY OF COPENHAGEN

VILLUM FONDEN

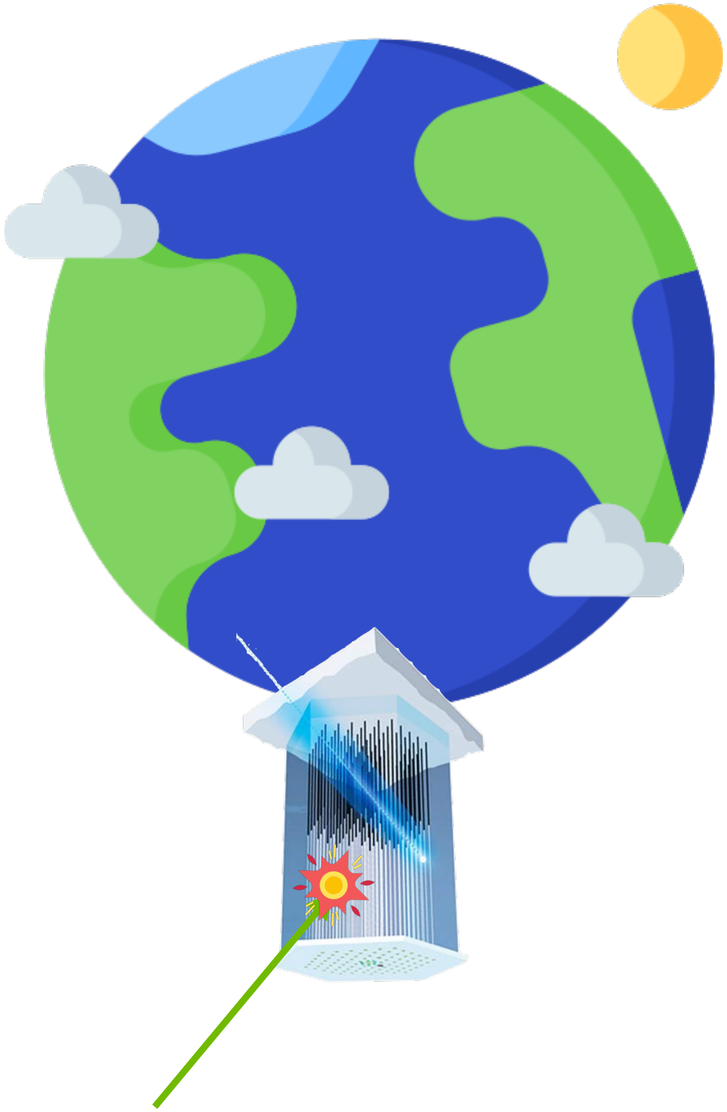
Multimessenger astrophysics

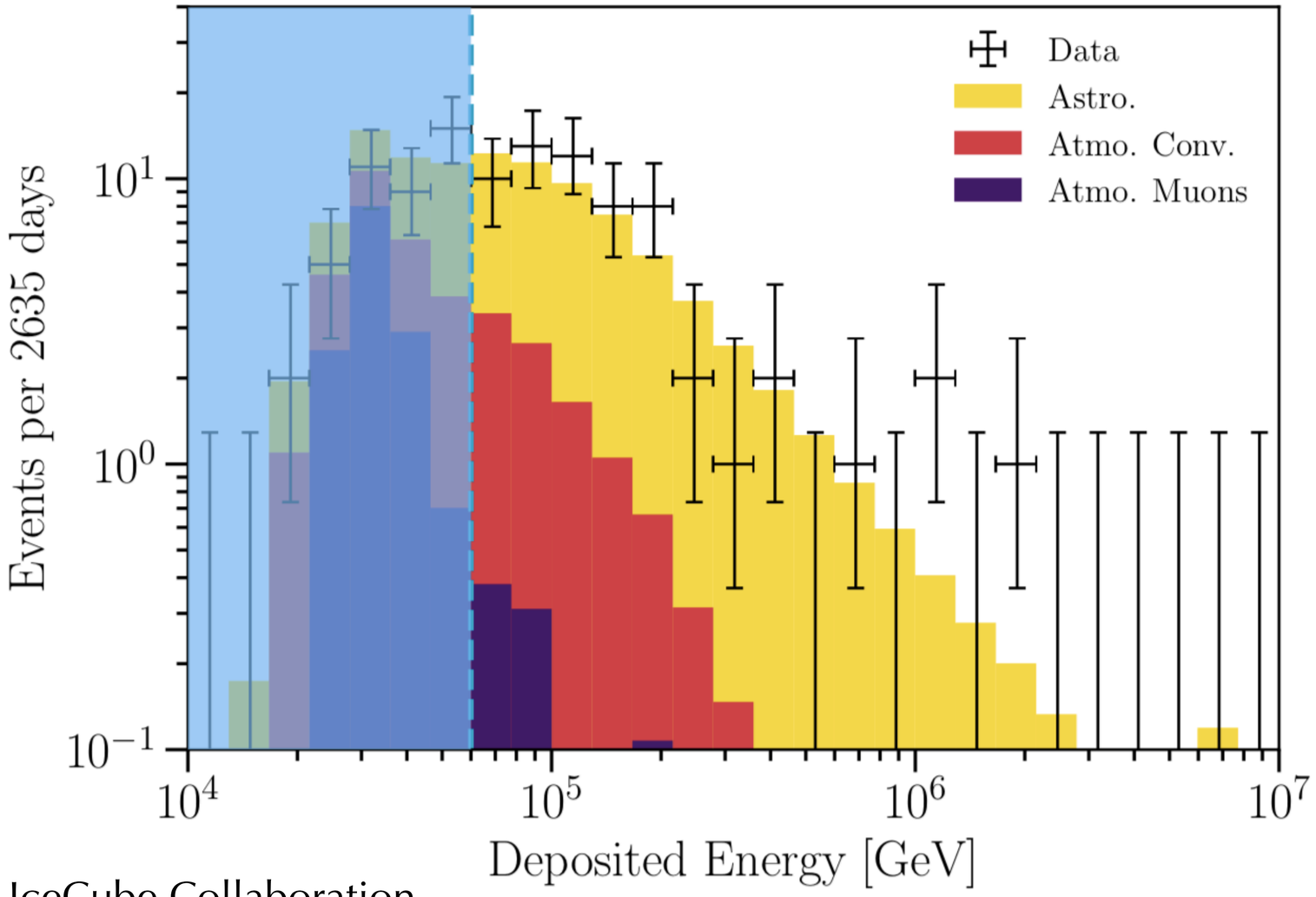


- Astrophysical sources of cosmic-rays

Cosmic-rays do not
point back to sources

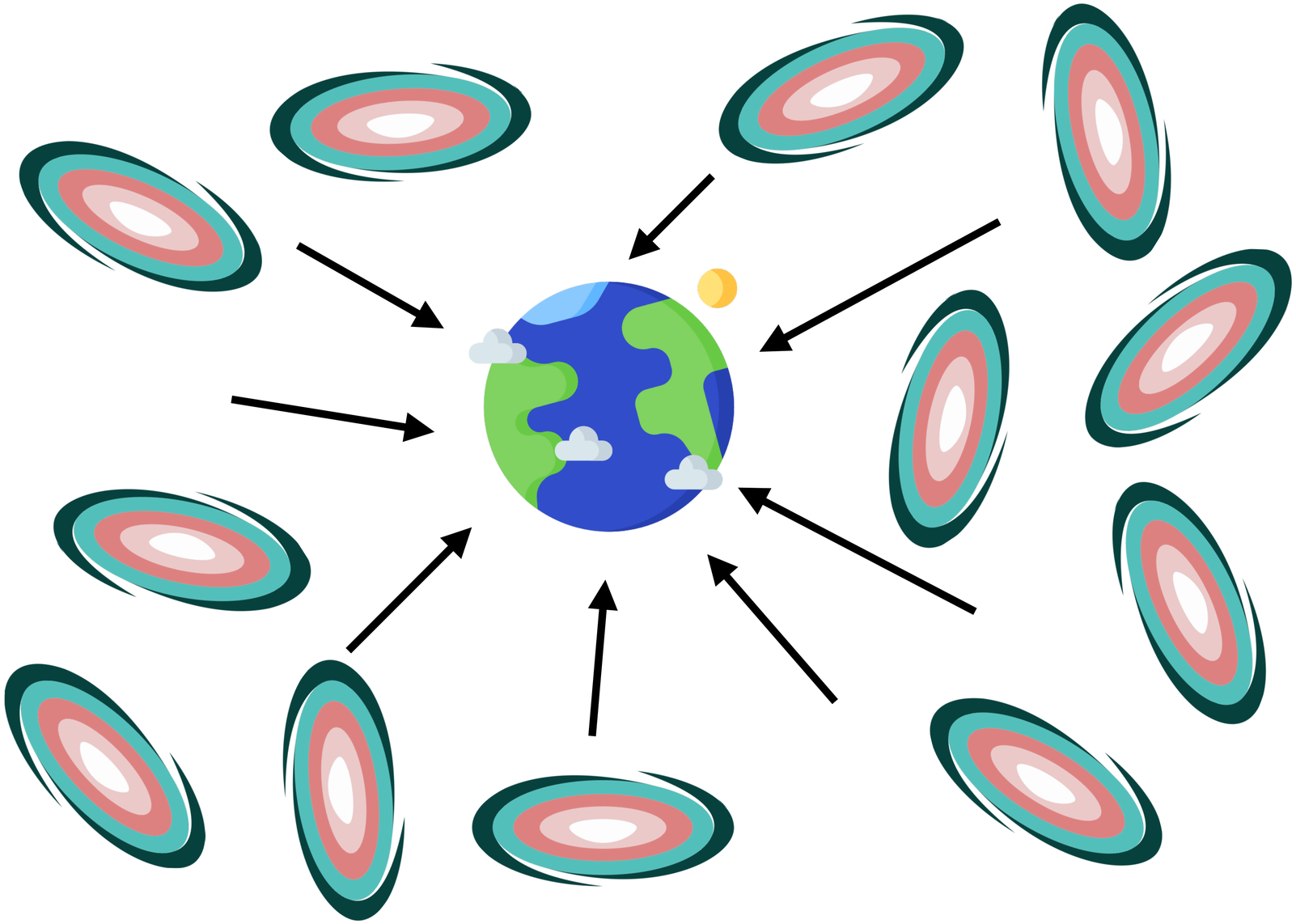
High-energy starting events (HESE)





IceCube Collaboration, 2011.03545

Cosmic neutrinos



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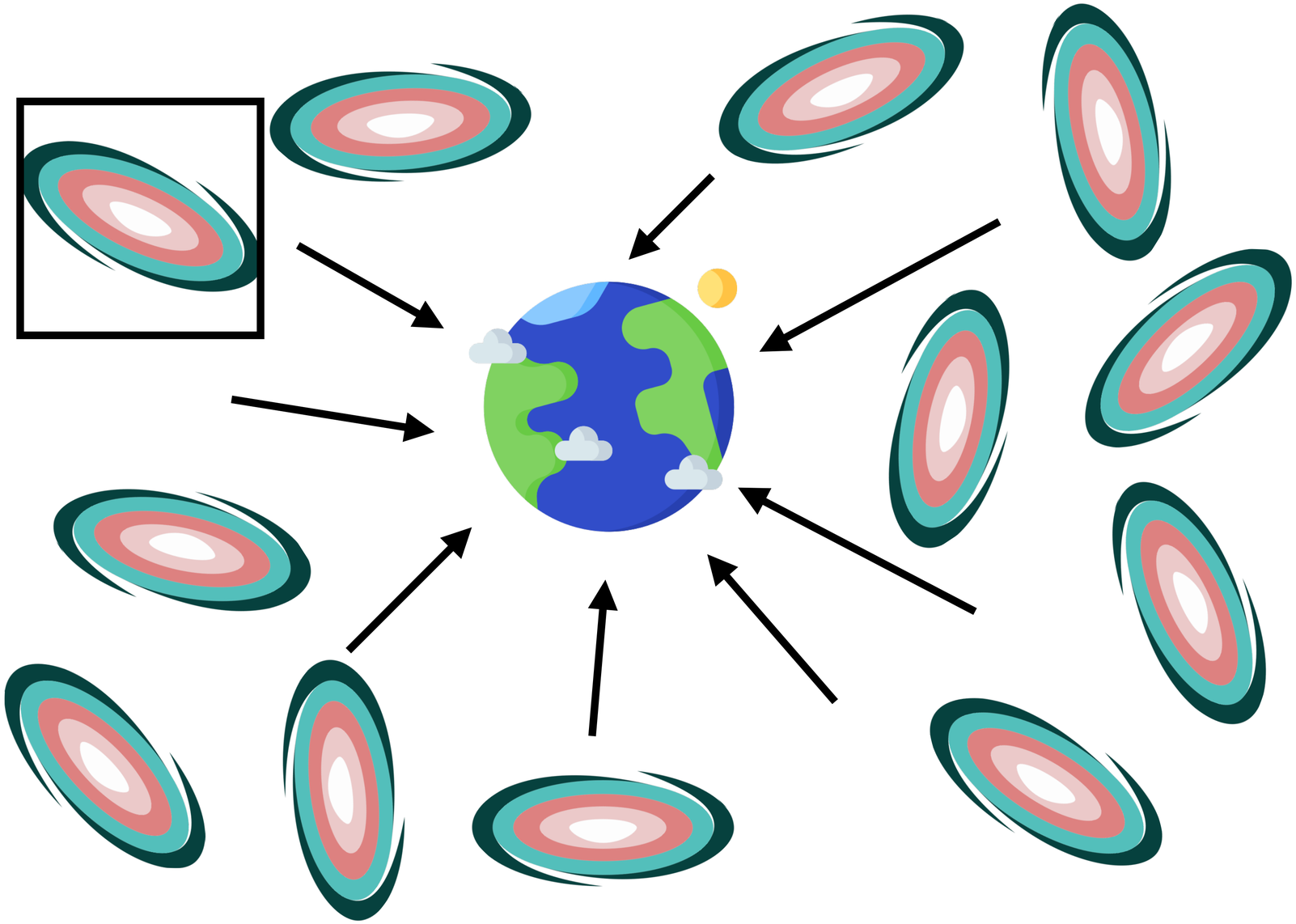
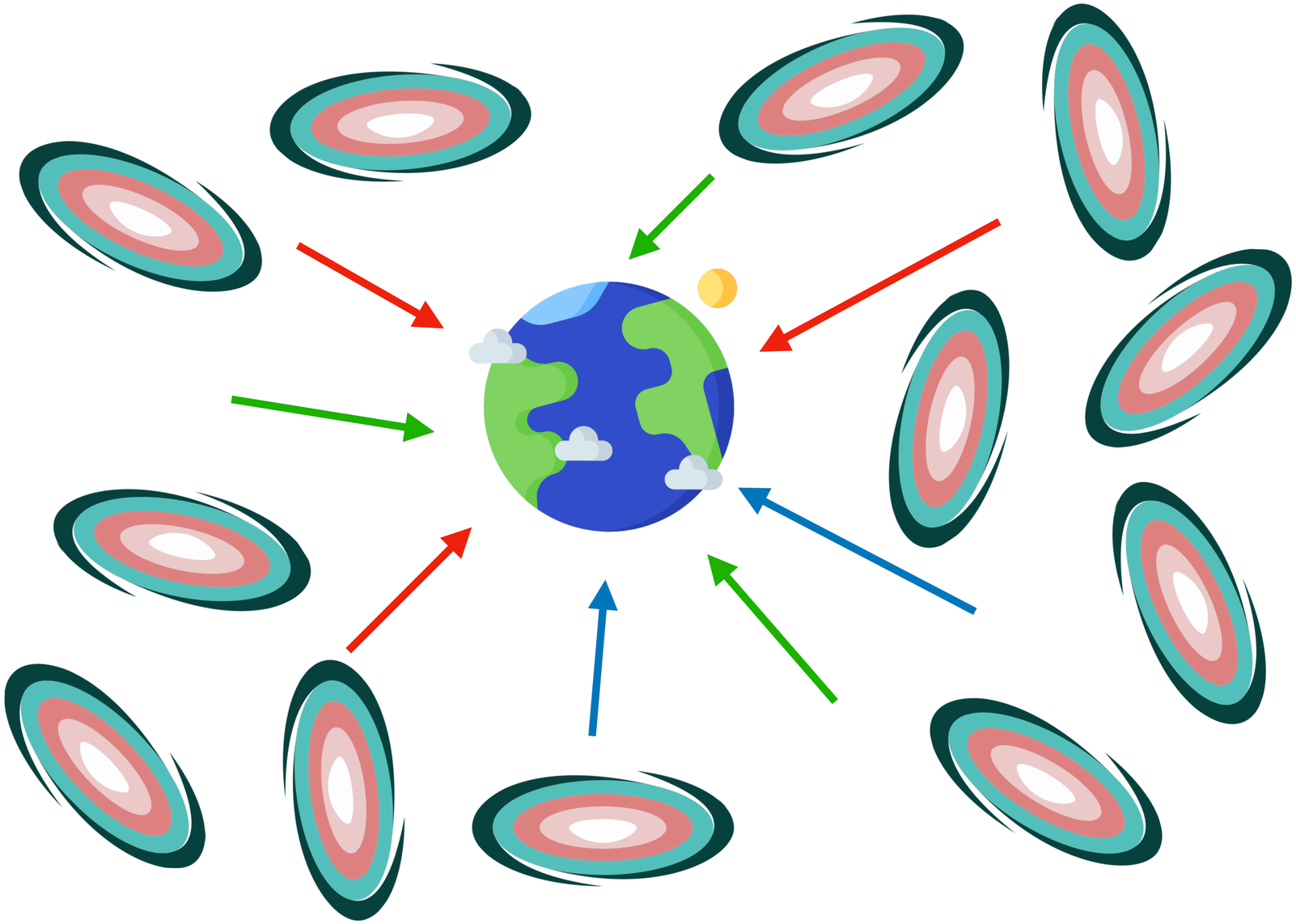


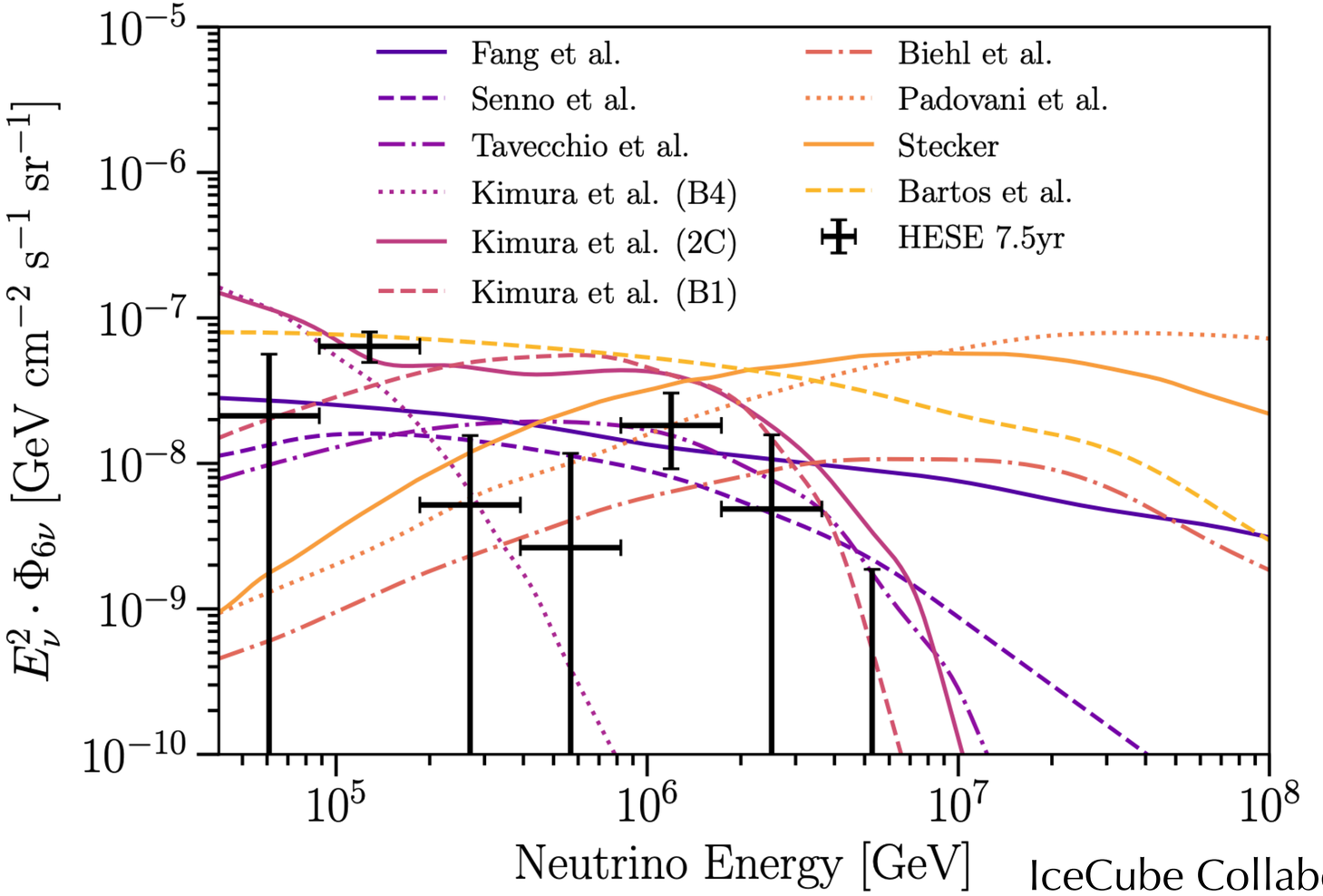
- **Position**
  - Point source discovery (NGC 1068)
- **Timing**
  - Transients discovery (TXS 0506+056, AT2019dsg, …)

Cosmic neutrinos



- **Position**
  - Point source discovery (NGC 1068)
- **Timing**
  - Transients discovery (TXS 0506+056, AT2019dsg, …)
- **Flavor**
- **Energy**

Diffuse neutrino flux

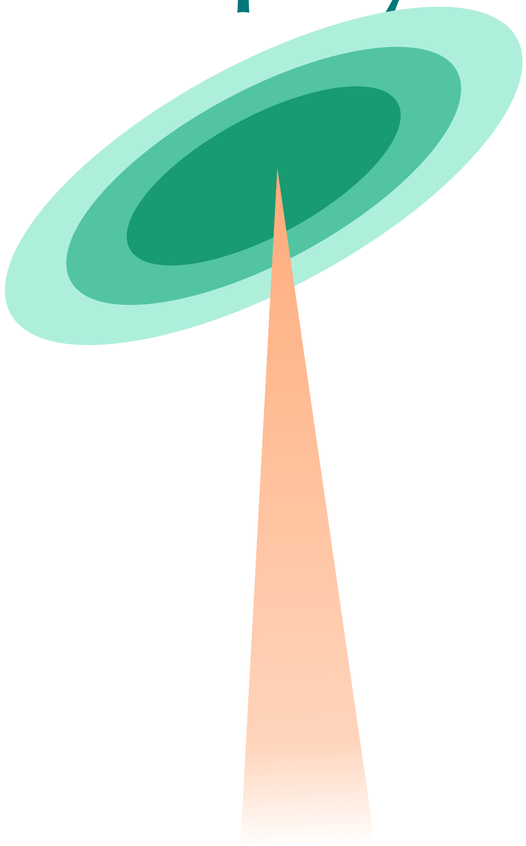


- Consistent with power-law spectrum $\propto E_\nu^{-2.87}$
- Uncertainties too large to discriminate models

IceCube Collaboration, 2011.03545

Neutrinos as astrophysical messengers

Two production mechanisms
for neutrinos



Neutrinos as astrophysical messengers

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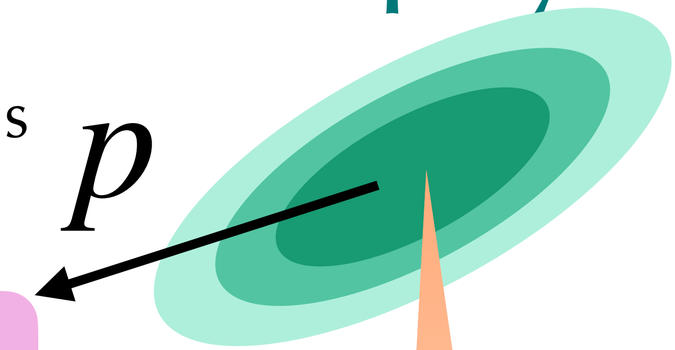


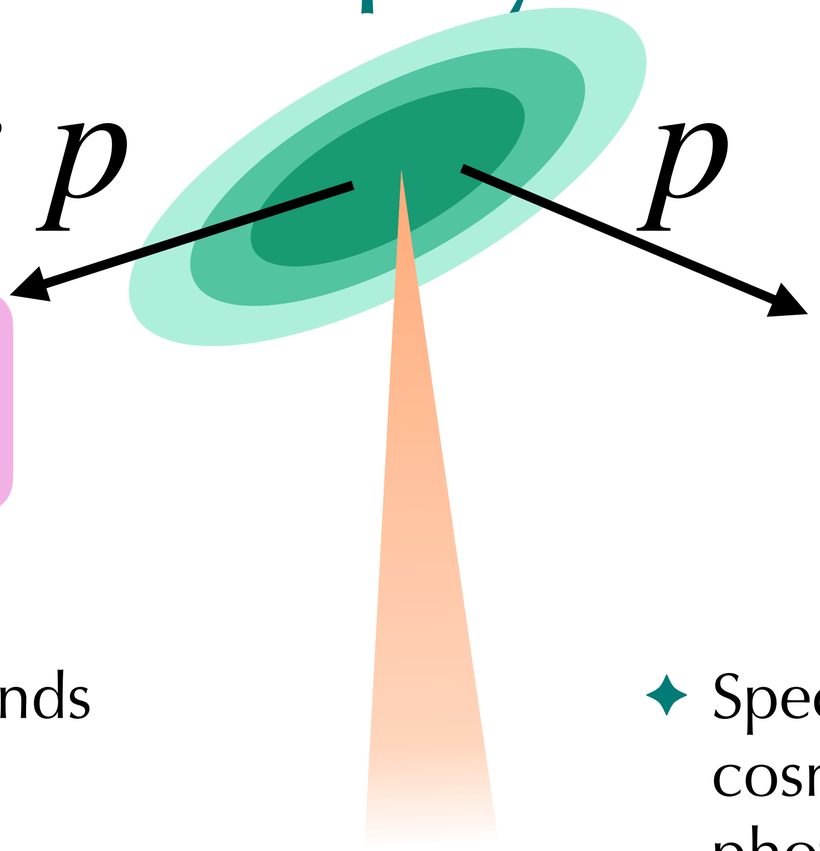
Proton target (interstellar or intergalactic gas,…)

pp

- Spectral shape depends only on cosmic-ray spectrum
- Typically $E^{-\gamma}$ ($\gamma > 2$?) up to a maximum energy

Neutrinos as astrophysical messengers

Two production mechanisms for neutrinos



Proton target (interstellar or intergalactic gas,…)

pp

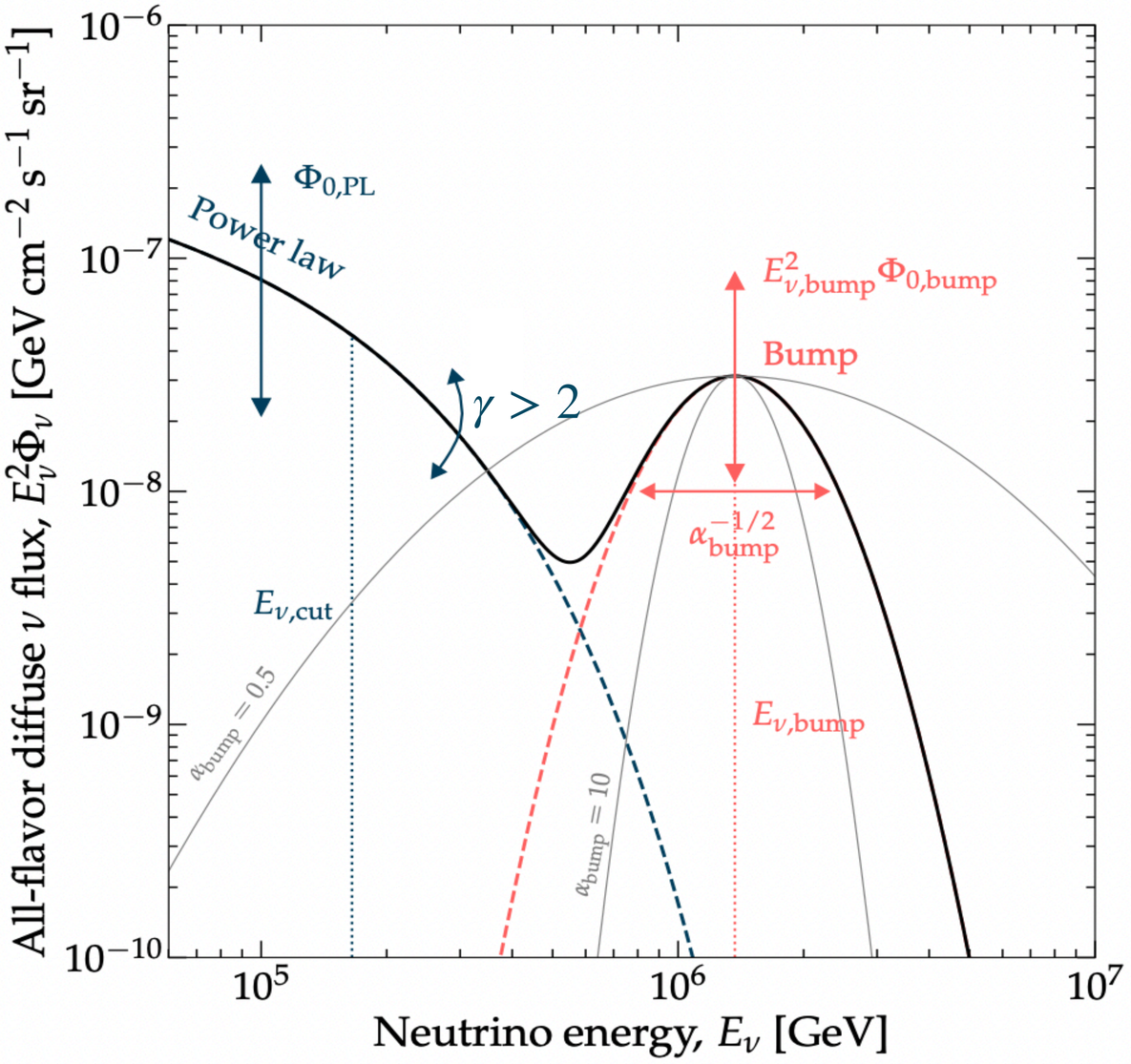
- Spectral shape depends only on cosmic-ray spectrum
- Typically $E^{-\gamma}$ ($\gamma > 2$?) up to a maximum energy

Photon target (synchrotron photons, infrared light, …)

$p\gamma$

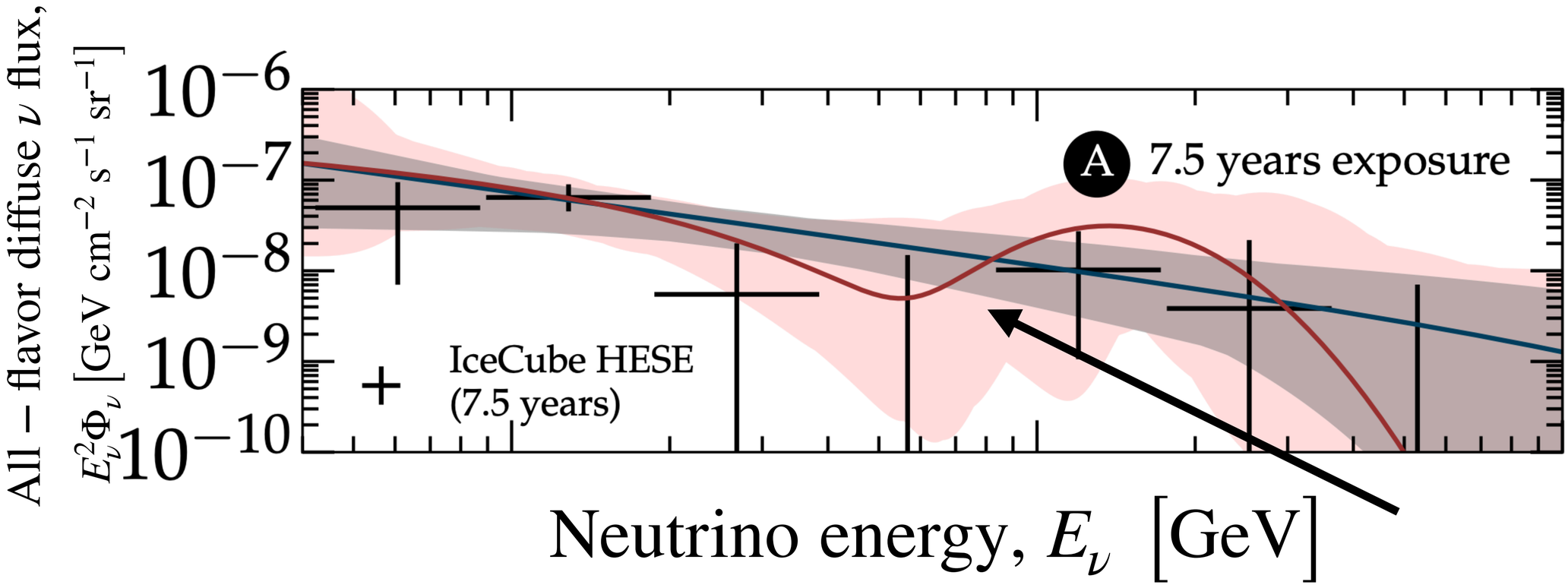
- Spectral shape depends both on cosmic-ray spectrum and photon spectrum
- Typically $E^{-\gamma}$ ($\gamma < 2$?) up to a maximum energy

Comparison with data



- Need for a flexible parameterization to compare with data
- **Power-law with cutoff** (ex. *pp* with soft CR spectrum)
- **Bump** (ex. $p\gamma$ with scattering efficiency growing with energy)

Present-day data

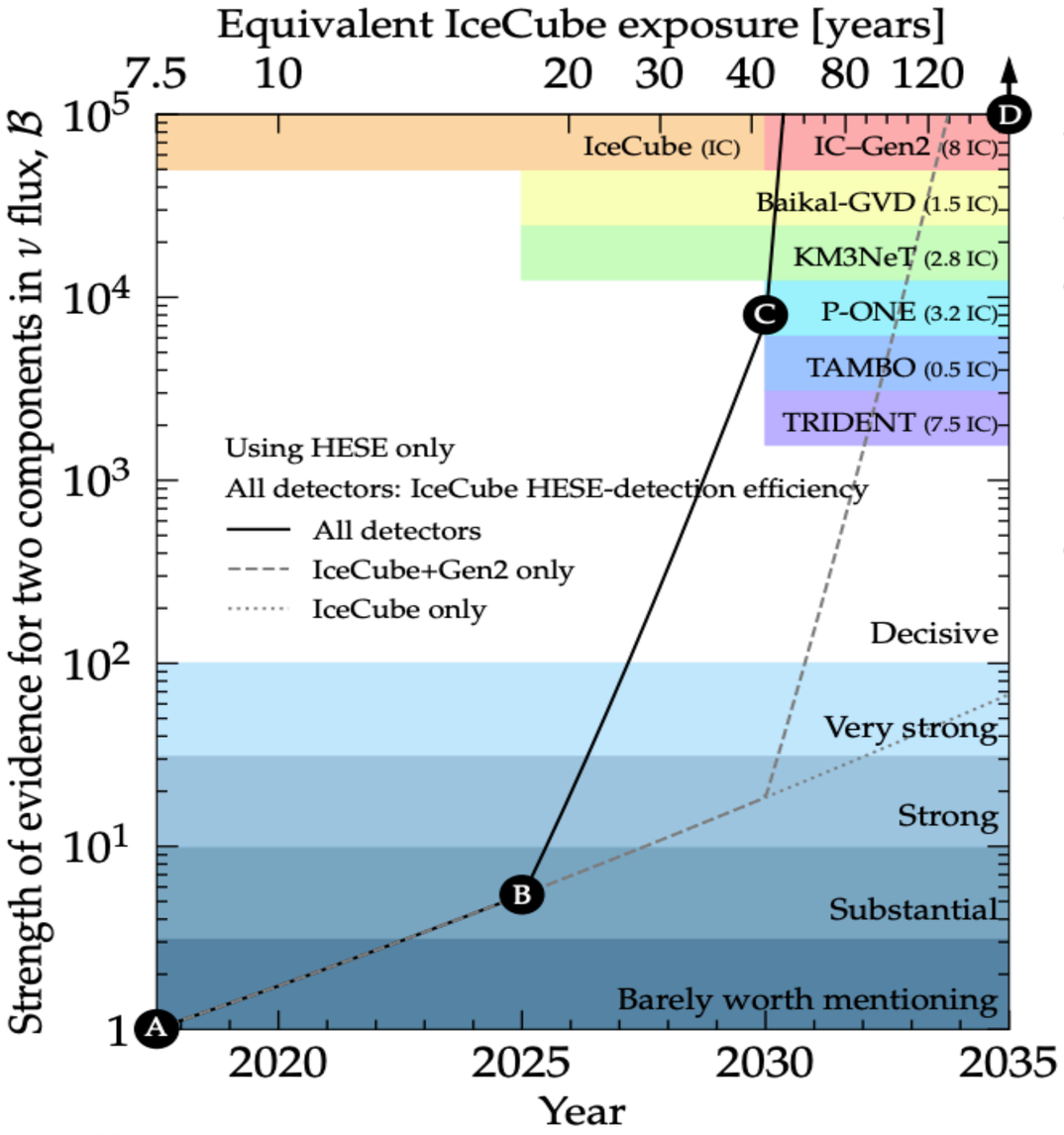


No statistical preference — low statistics!

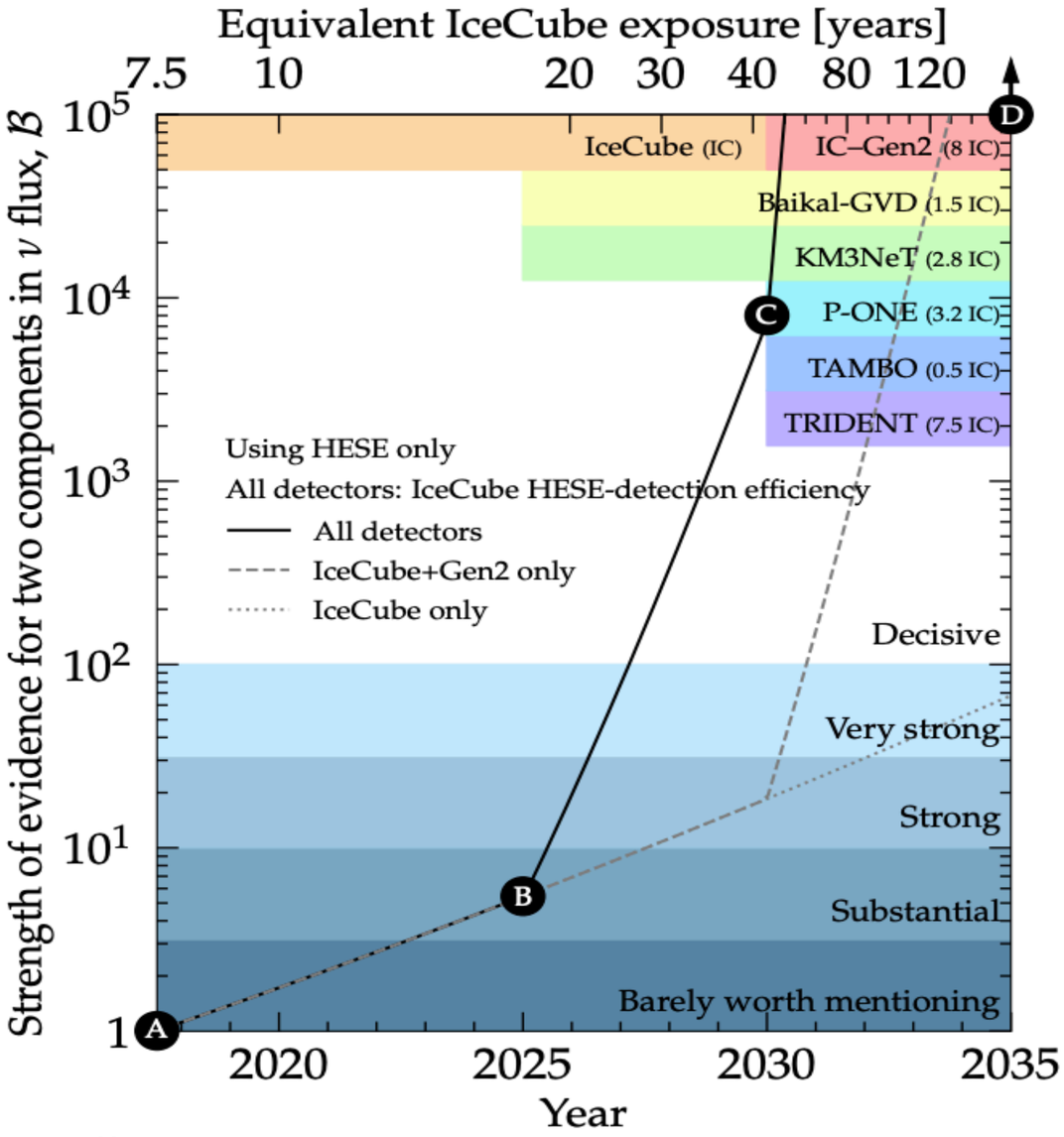
Future data

- How much exposure it takes to clearly distinguish a bump?
- If we keep seeing a power law, what do we learn?

Future data


Equivalent IceCube exposure [years]
7.5
10
20
30
40
80
120
Strength of evidence for two components in ν flux, B
10^5
10^4
10^3
10^2
10^1
1
IceCube (IC)
IC–Gen2 (8 IC)
Baikal-GVD (1.5 IC)
KM3NeT (2.8 IC)
P-ONE (3.2 IC)
TAMBO (0.5 IC)
TRIDENT (7.5 IC)
Using HESE only
All detectors: IceCube HESE-detection efficiency
All detectors
IceCube+Gen2 only
IceCube only
Decisive
Very strong
Strong
Substantial
Barely worth mentioning
A
B
C
D
2020
2025
2030
2035
Year

Future data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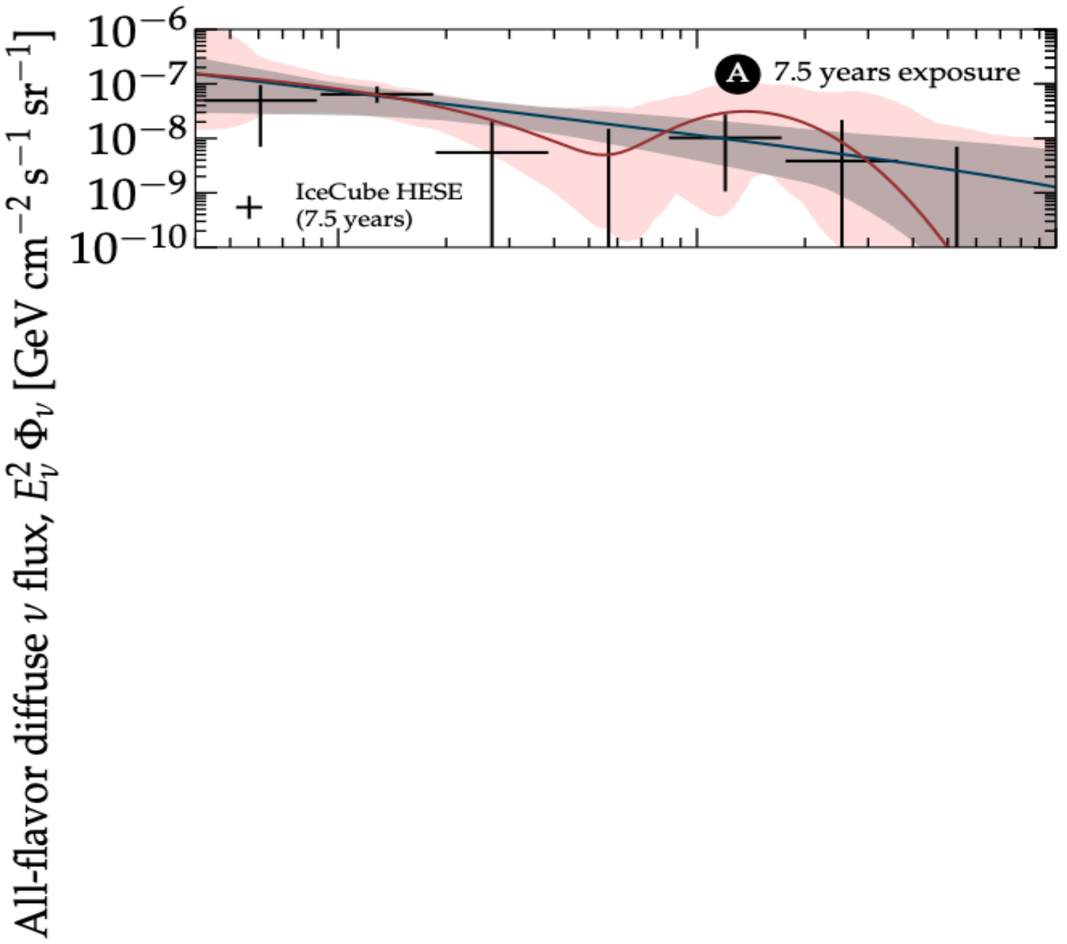
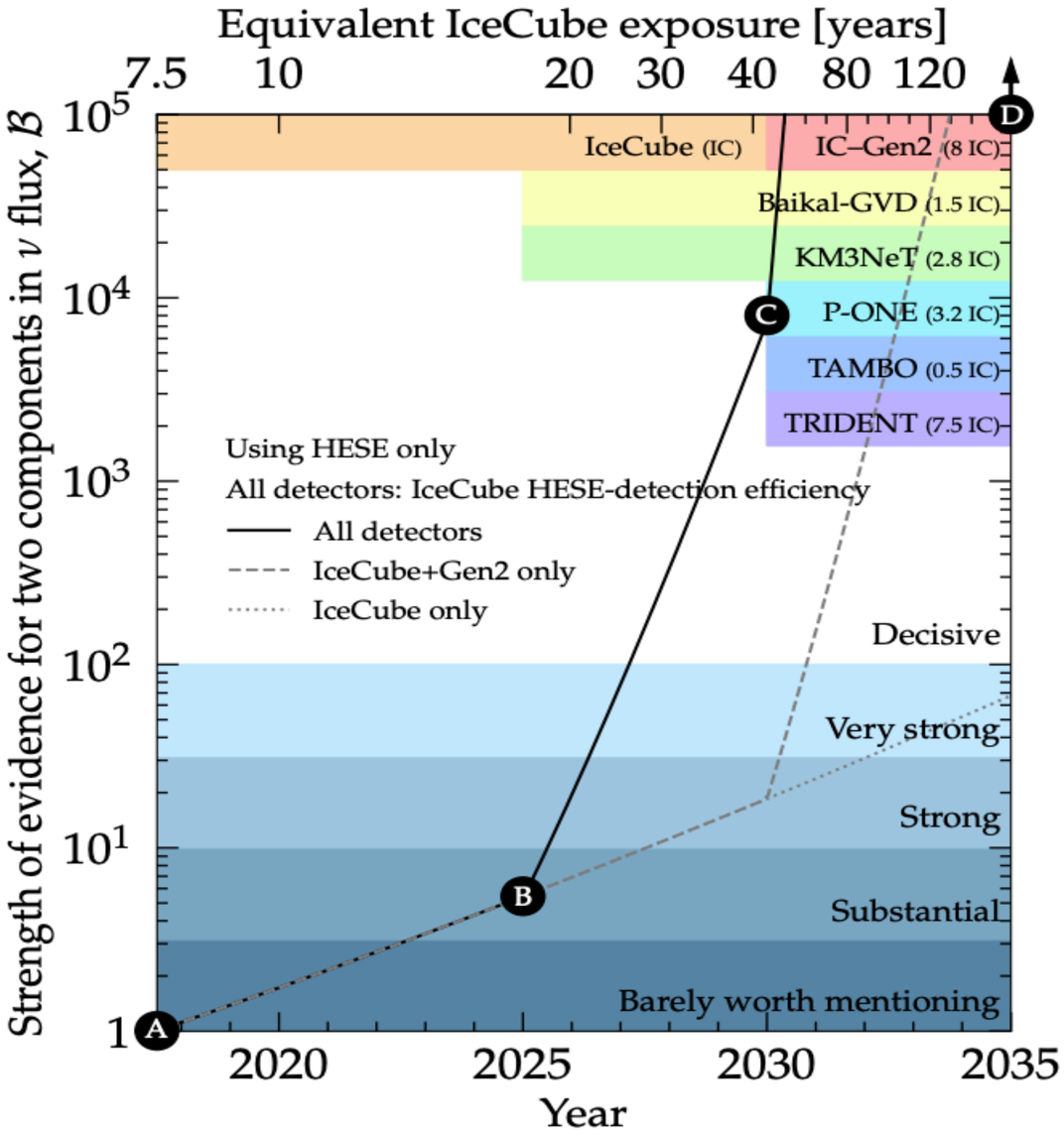

All-flavor diffuse ν flux, $E_\nu^2 \Phi_\nu$ [GeV cm^{-2} s^{-1} sr^{-1}]
A 7.5 years exposure
IceCube HESE
(7.5 years)
Neutrino energy, E_ν [GeV]

Future data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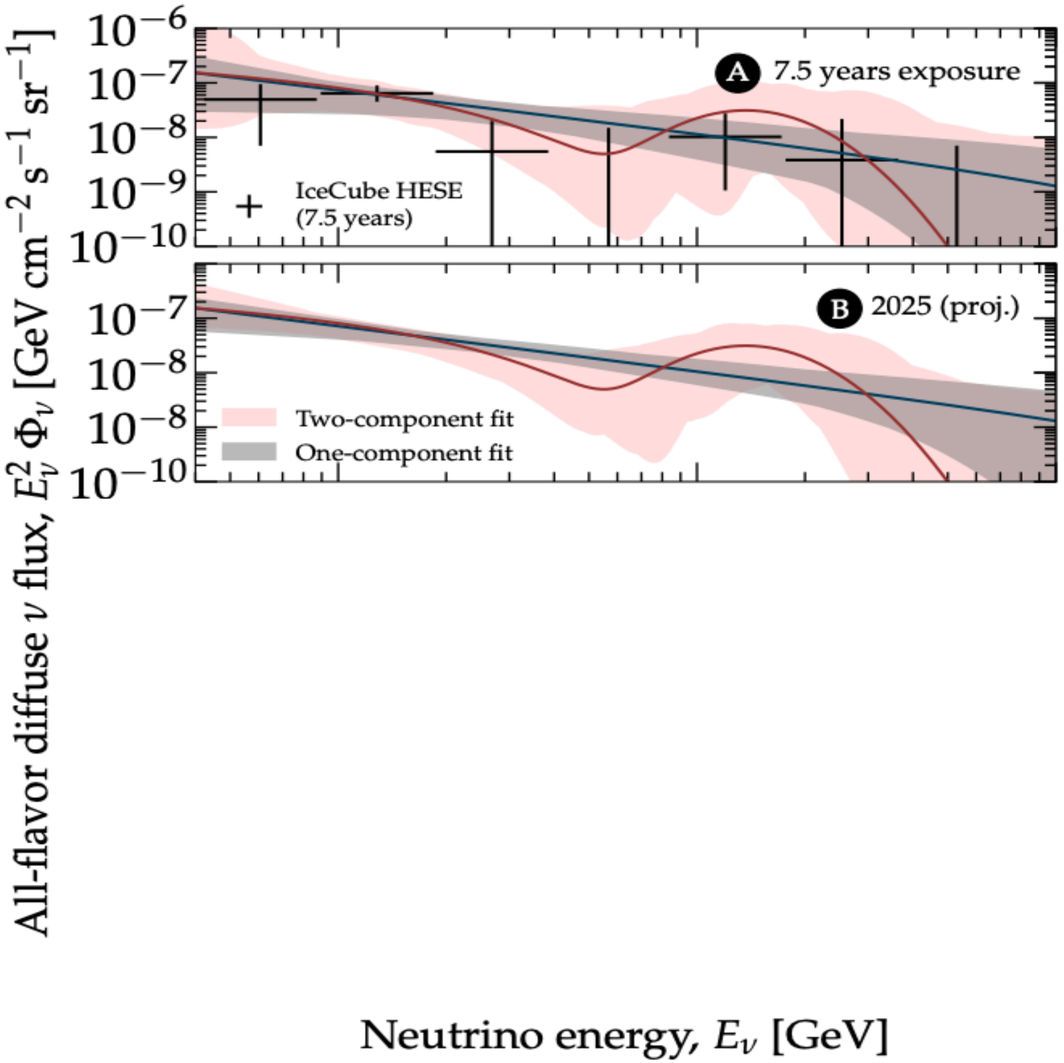
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Two-component fit
One-component fit
Neutrino energy, E_ν [GeV]

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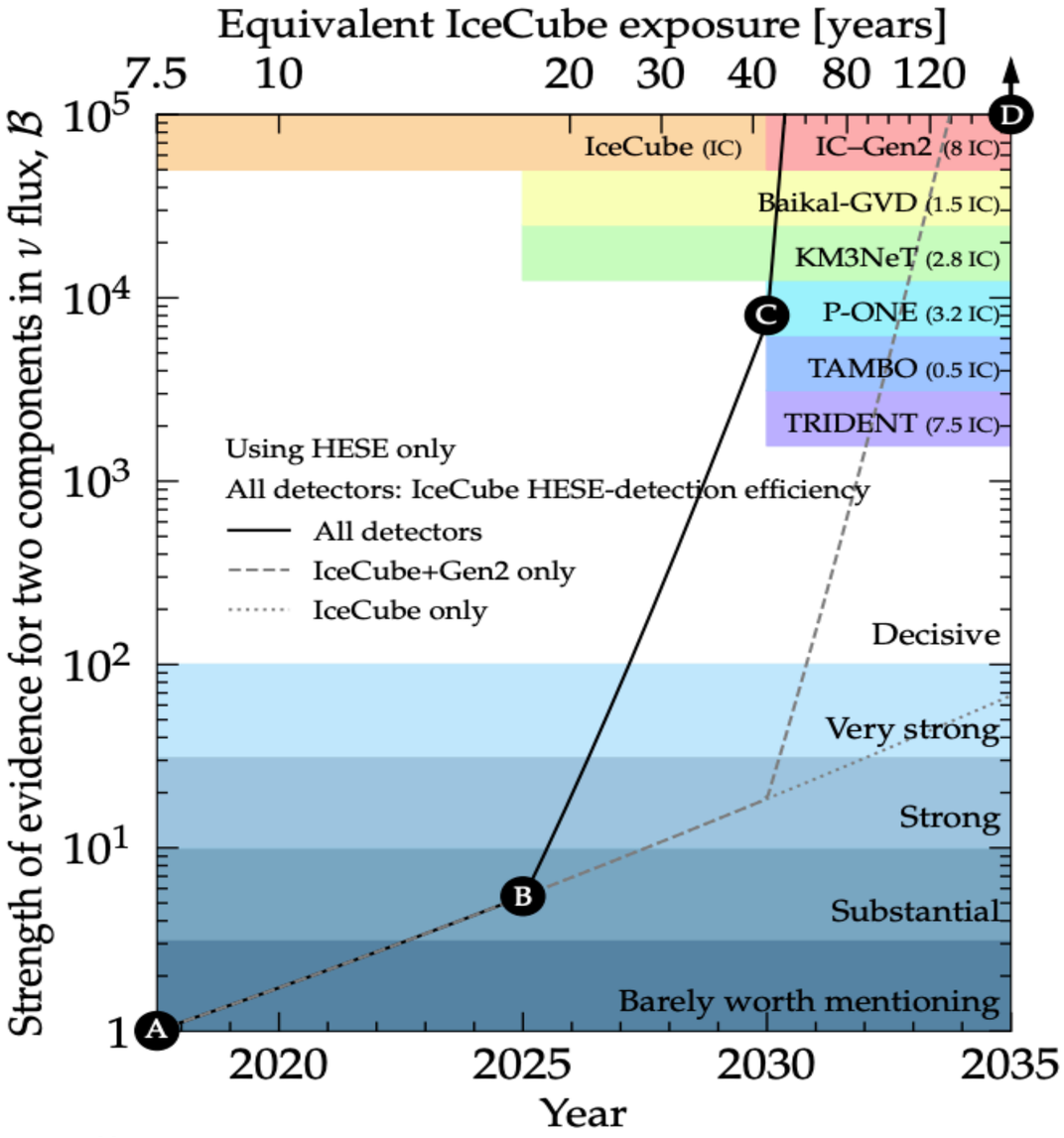
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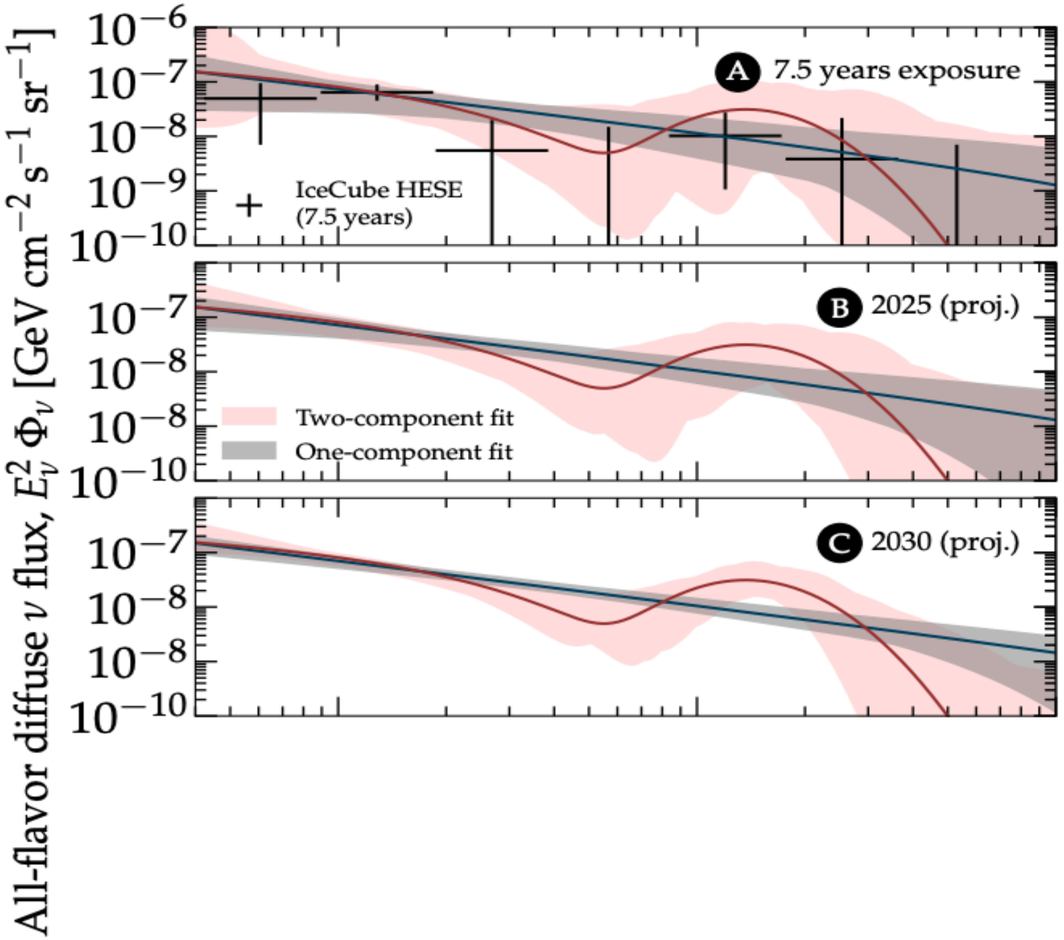
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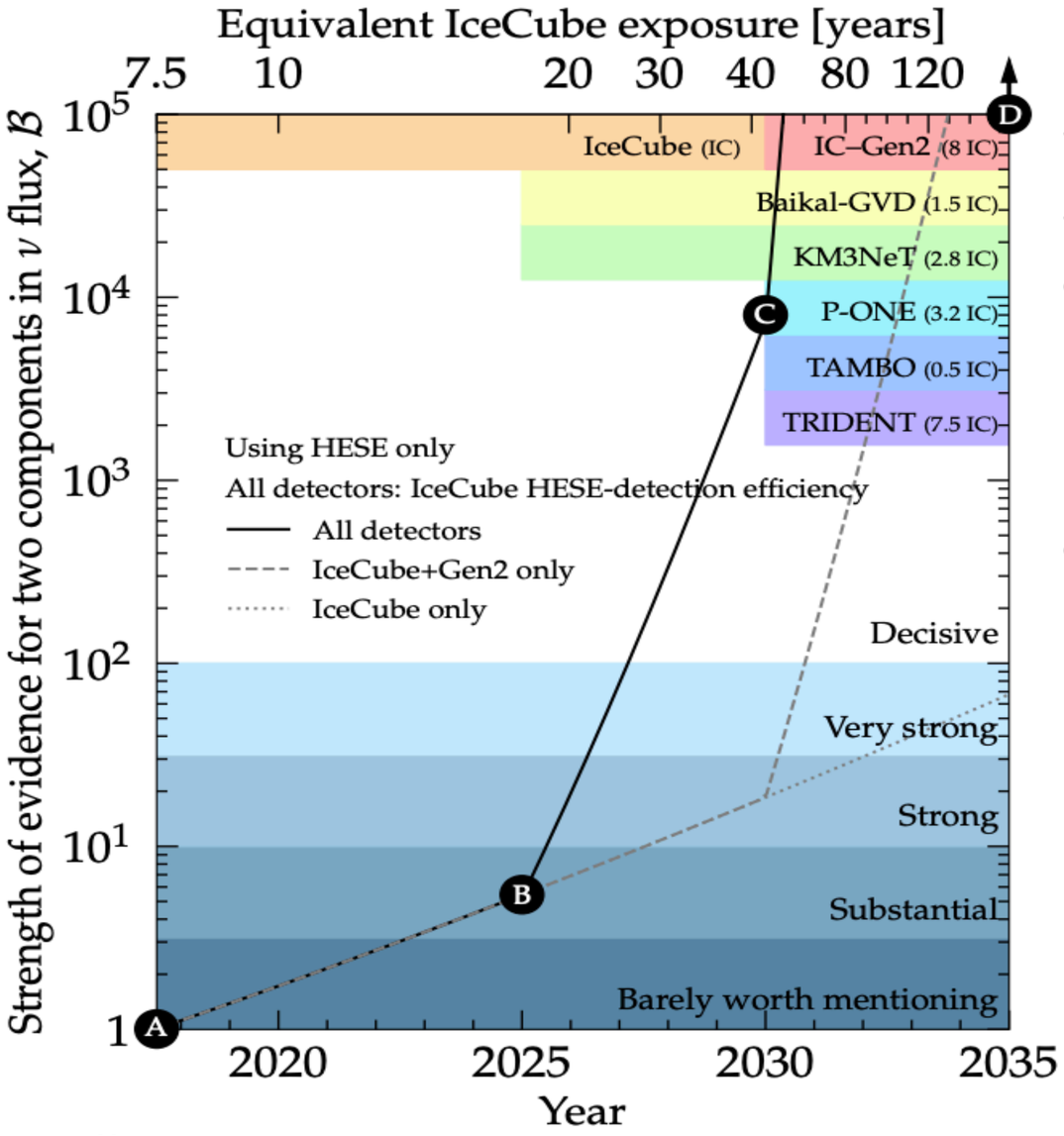
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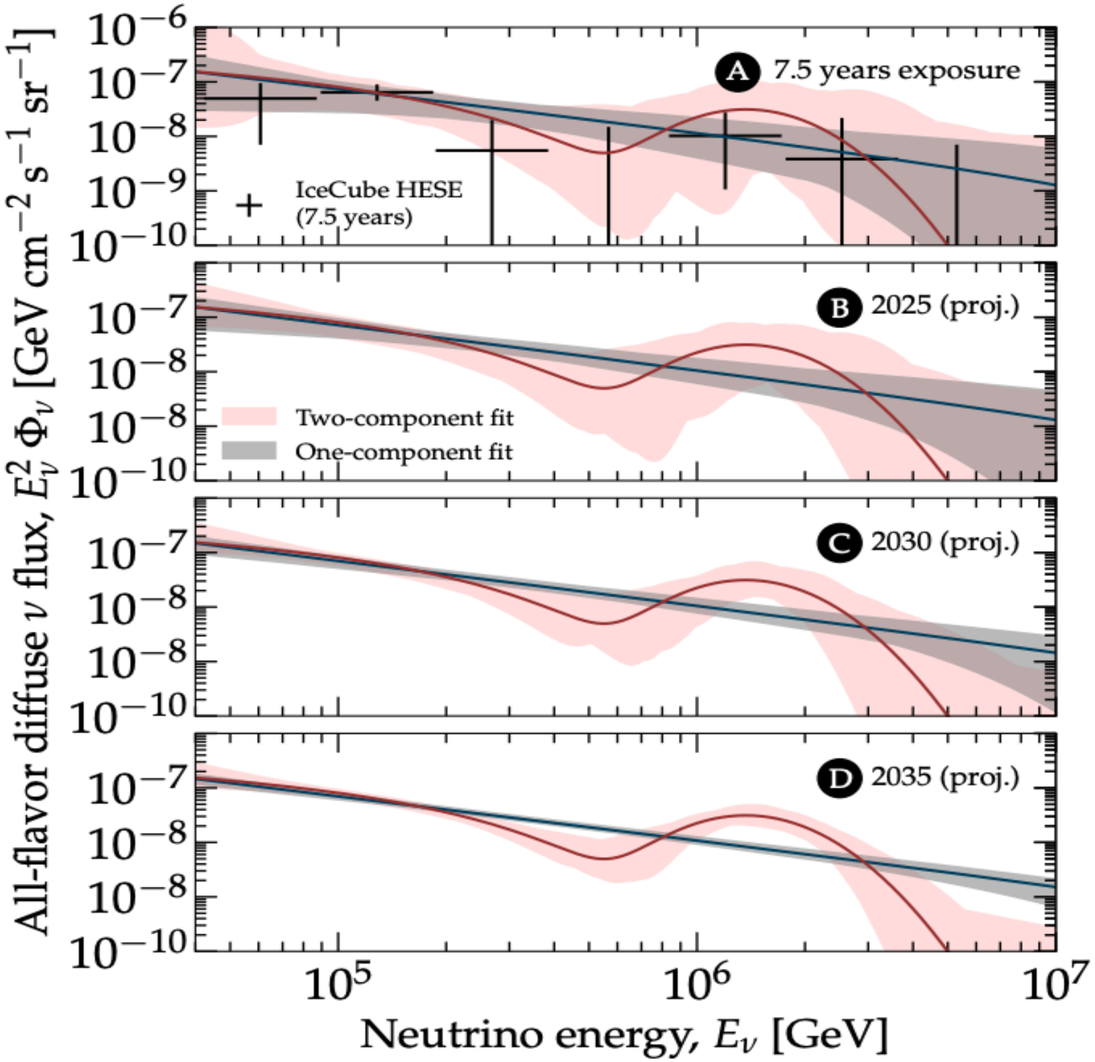
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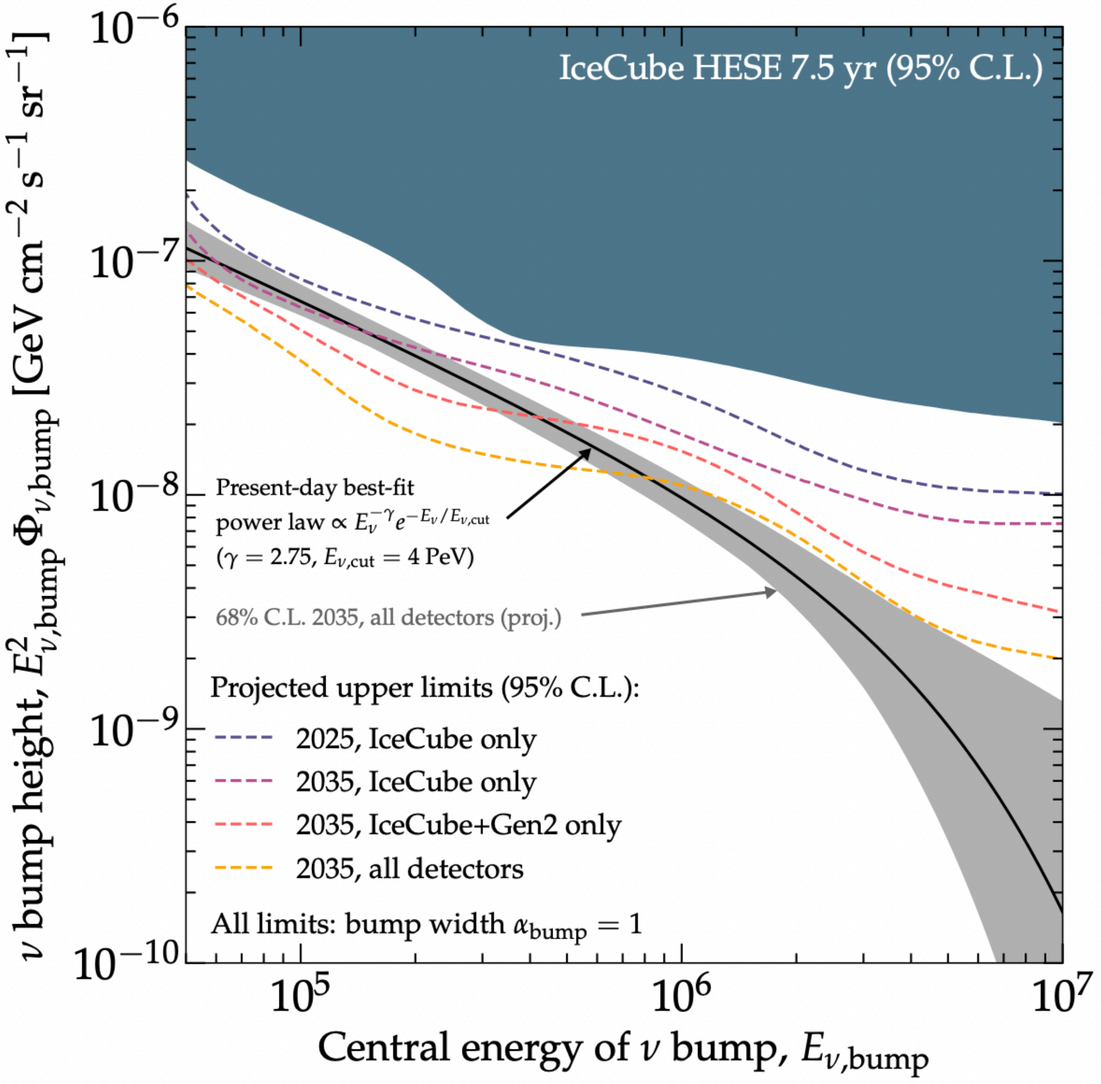
Pure power-law scenario



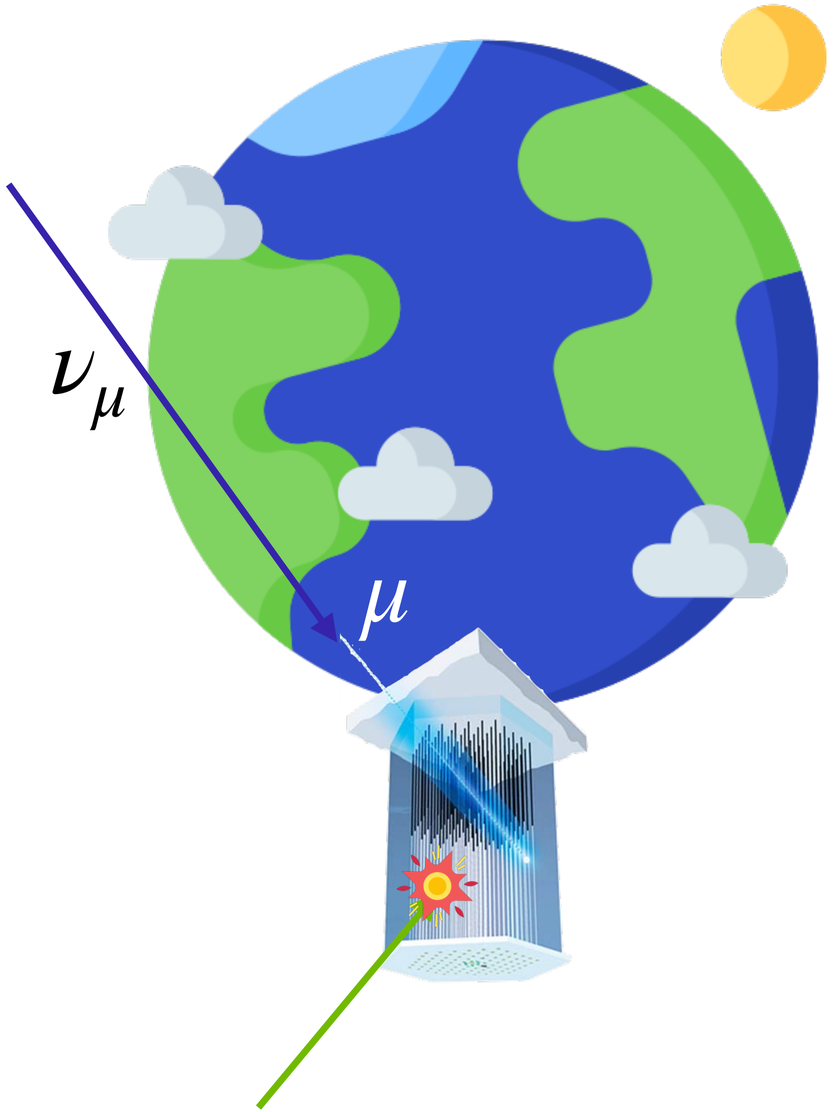
- Data might still be consistent with a power-law!
- Bounds on bump contribution to the diffuse flux

Conclusions

- In 10 years high-energy neutrino statistics larger by an order of magnitude
- Tiny spectral features can be probed
- Model discrimination between 1 vs 2 populations

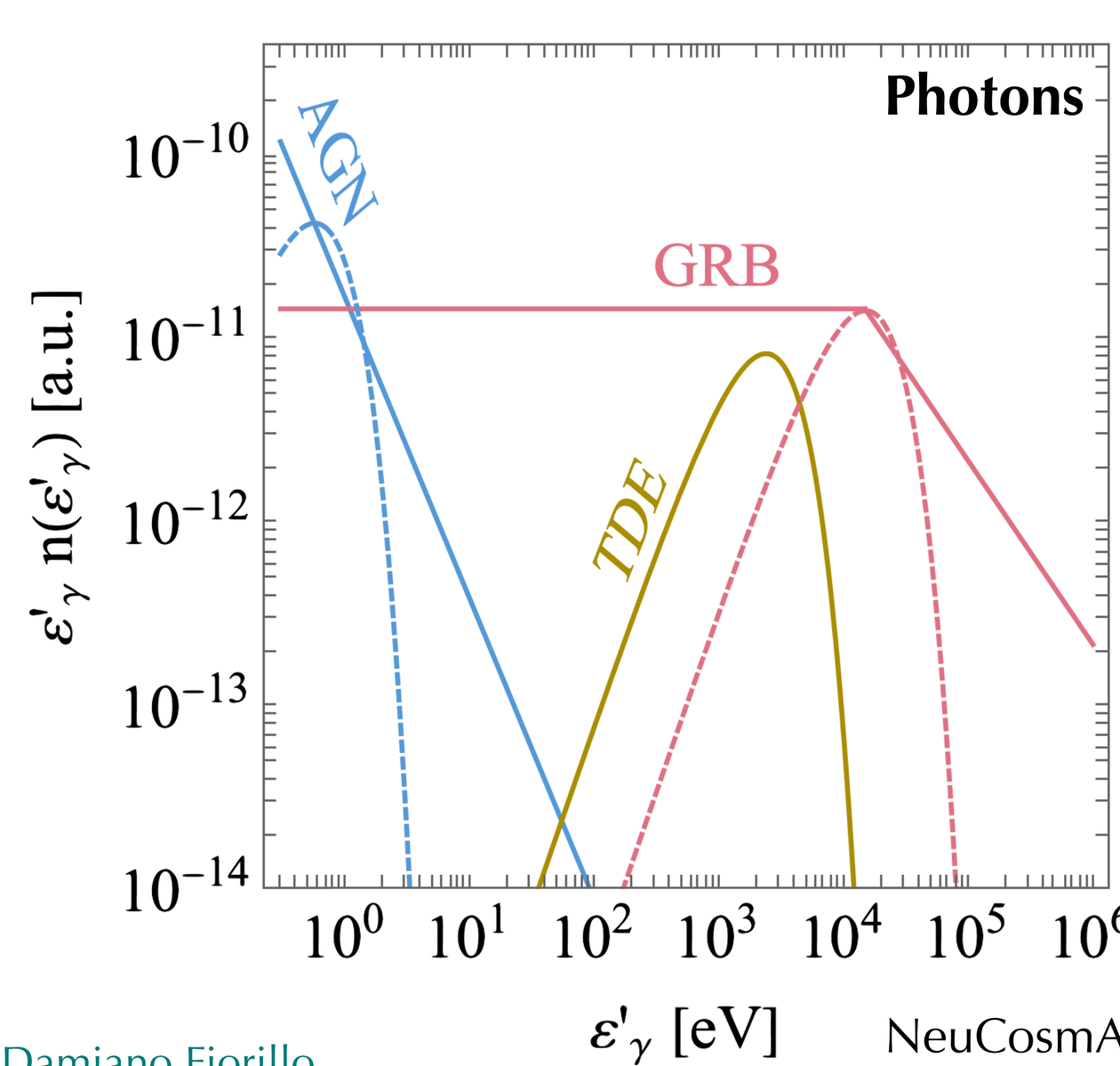
Backup slides

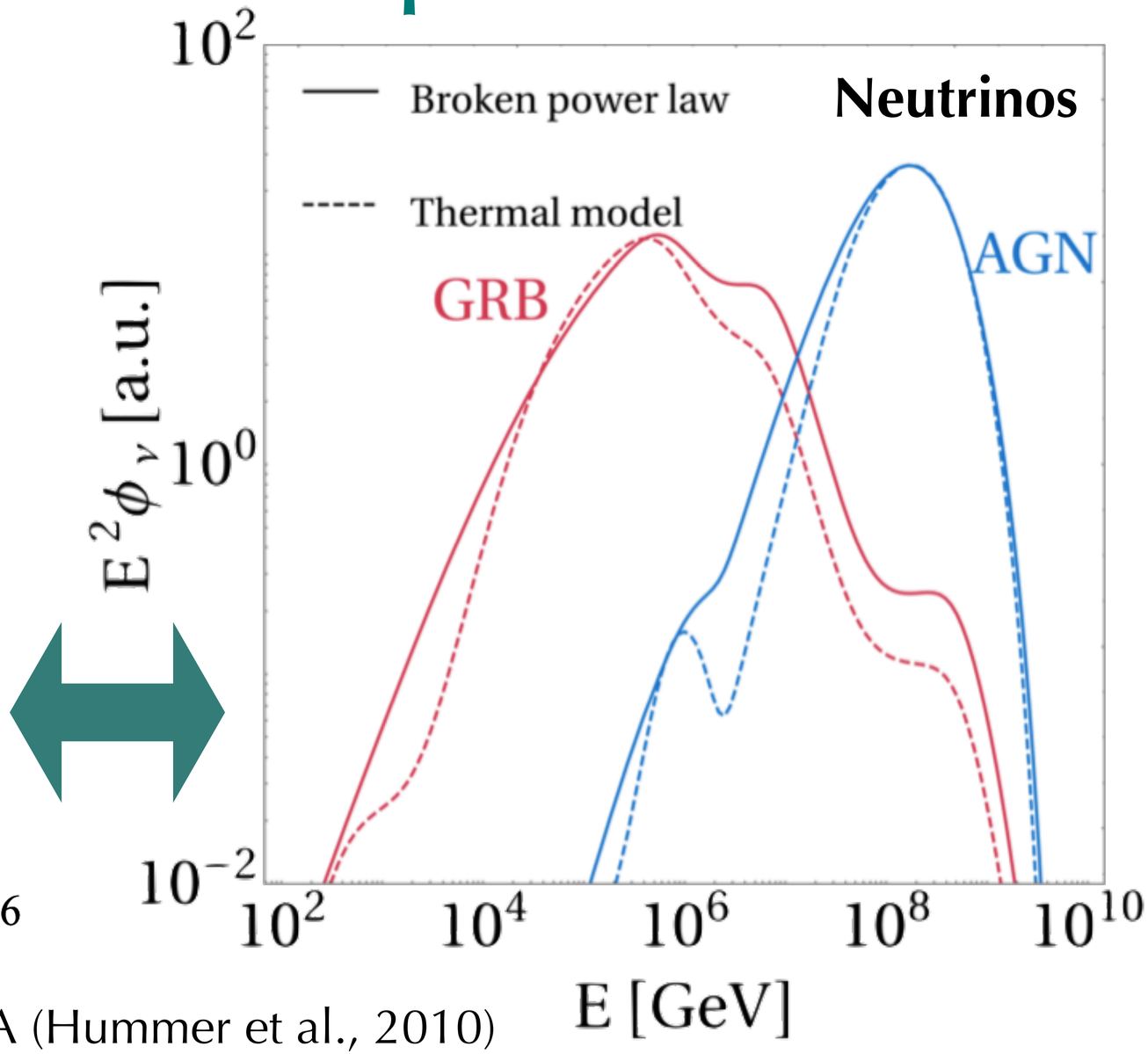
IceCube



- **Tracks** allow precise angular reconstruction
- **Cascades** allow precise energy reconstruction

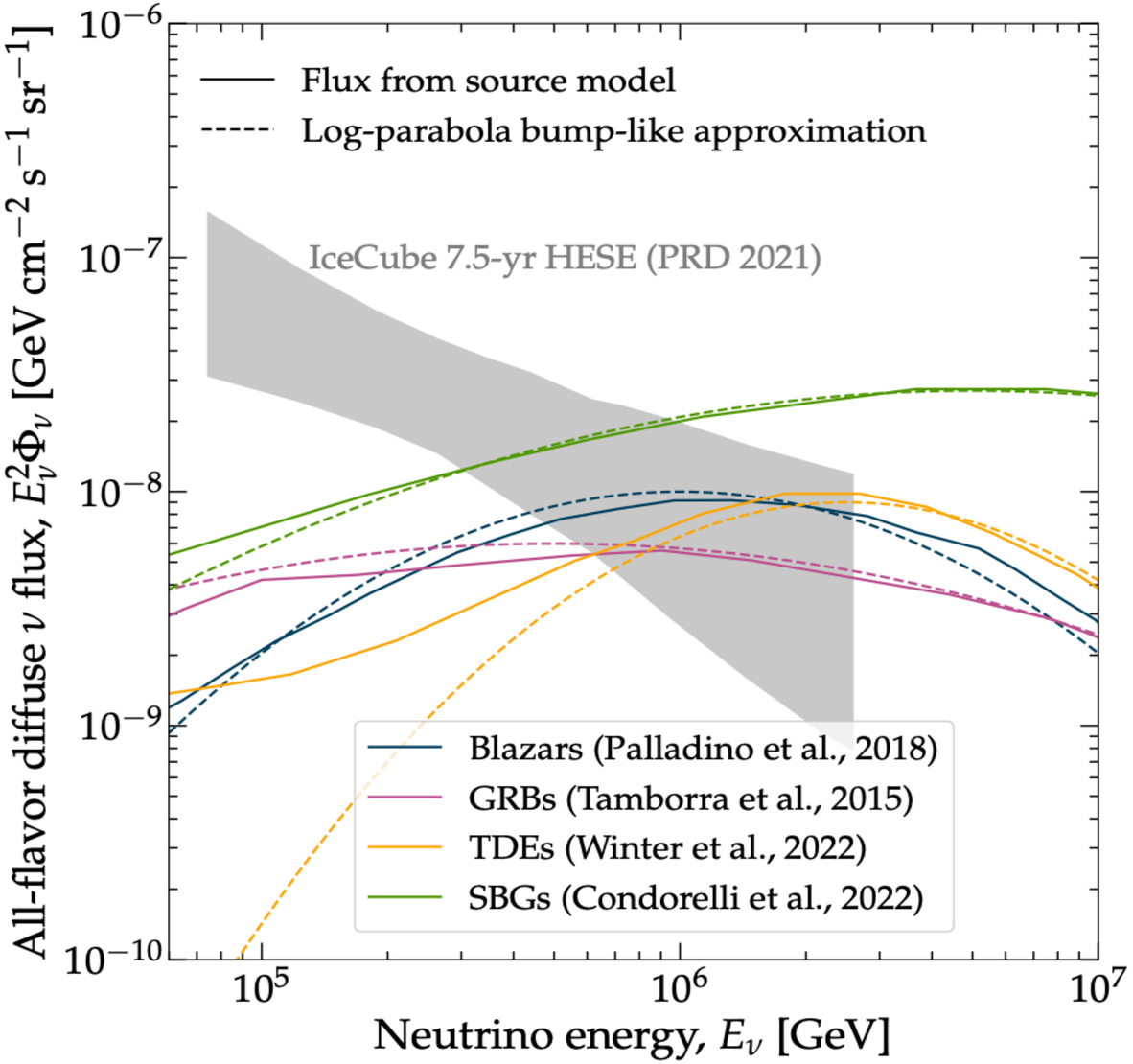
Photohadronic neutrino production





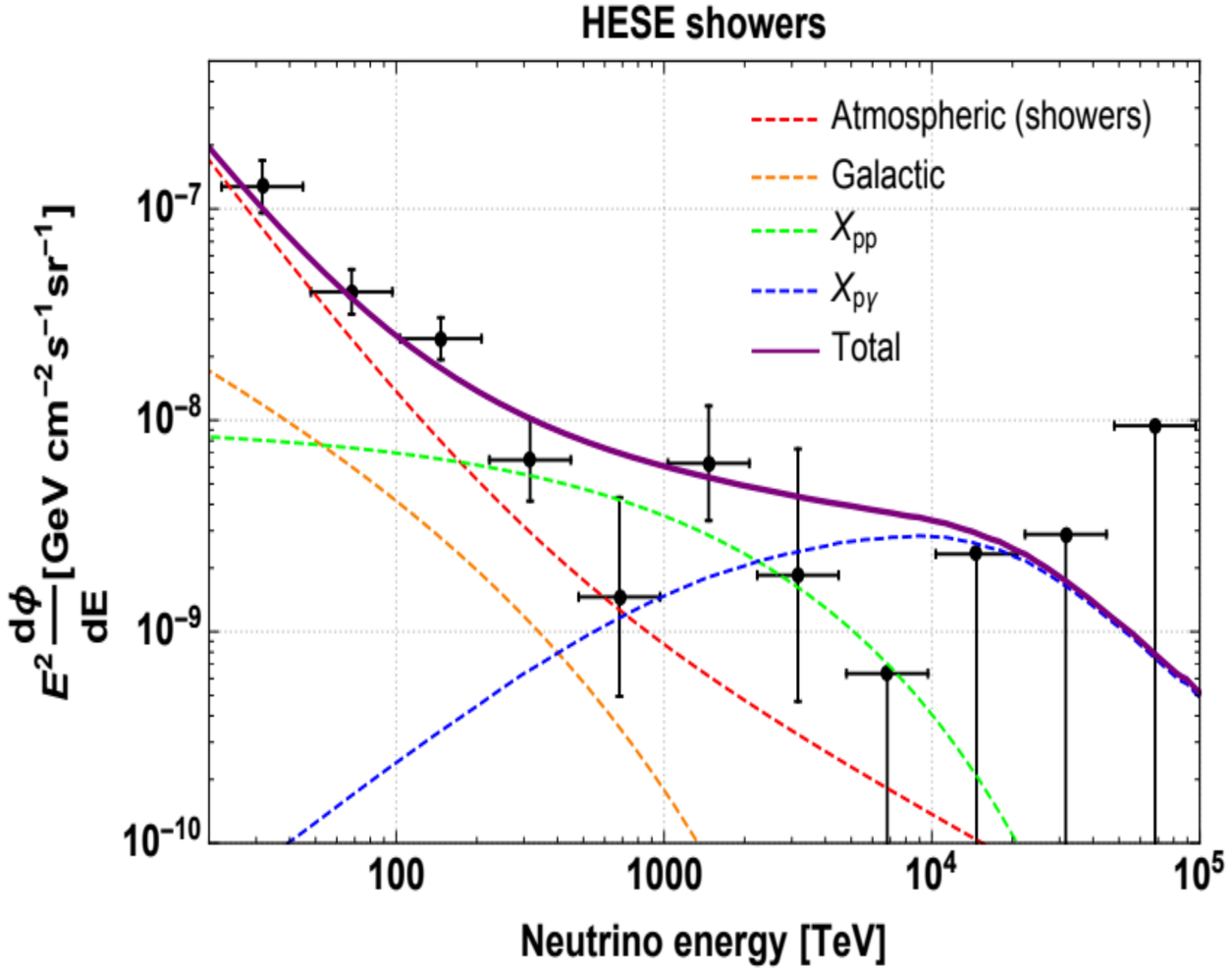
NeuCosmA (Hummer et al., 2010)

Bump neutrino spectrum

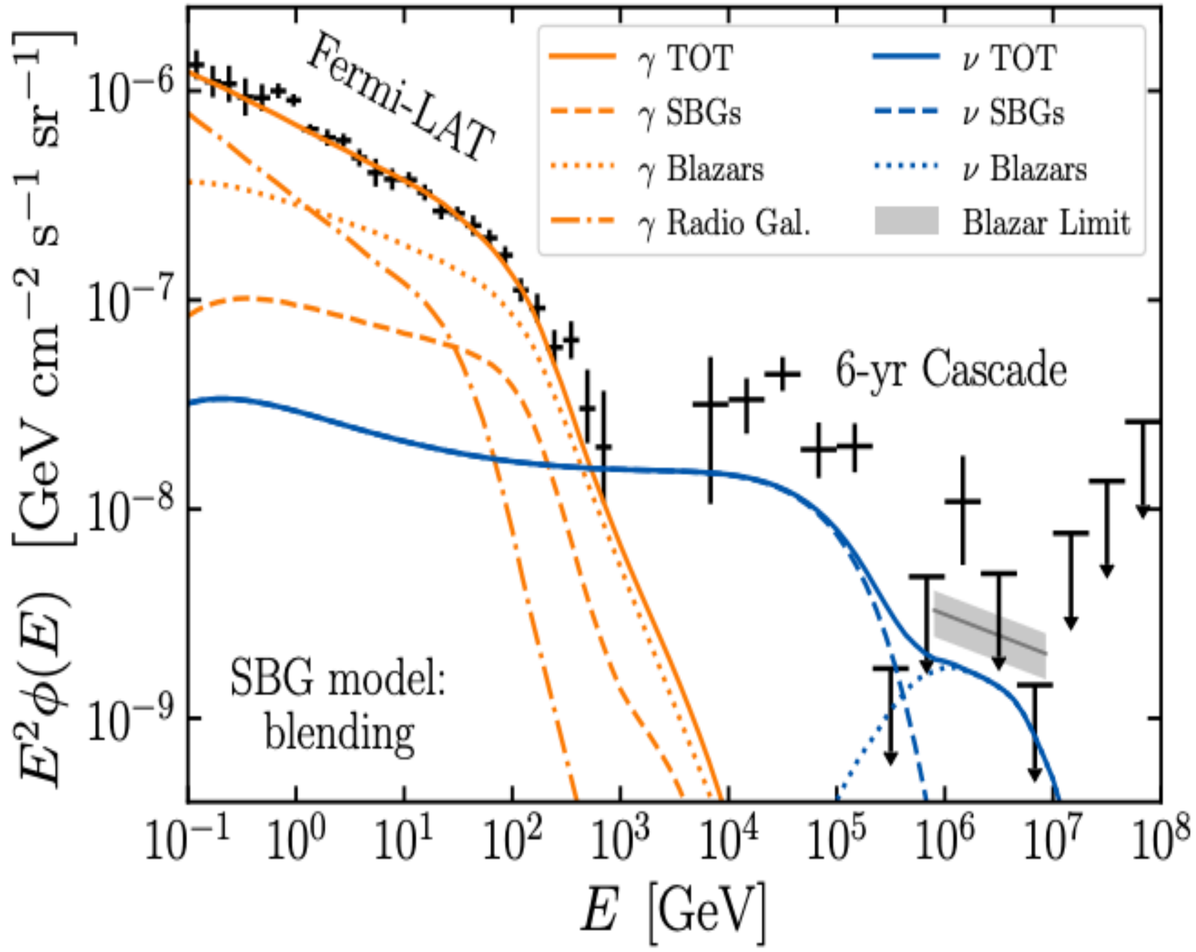


- pp sources can have bump spectrum if proton spectrum is hard ($\gamma < 2$)
- $p\gamma$ sources typically have bump spectrum — diffuse can be more complicated

Theoretical motivation

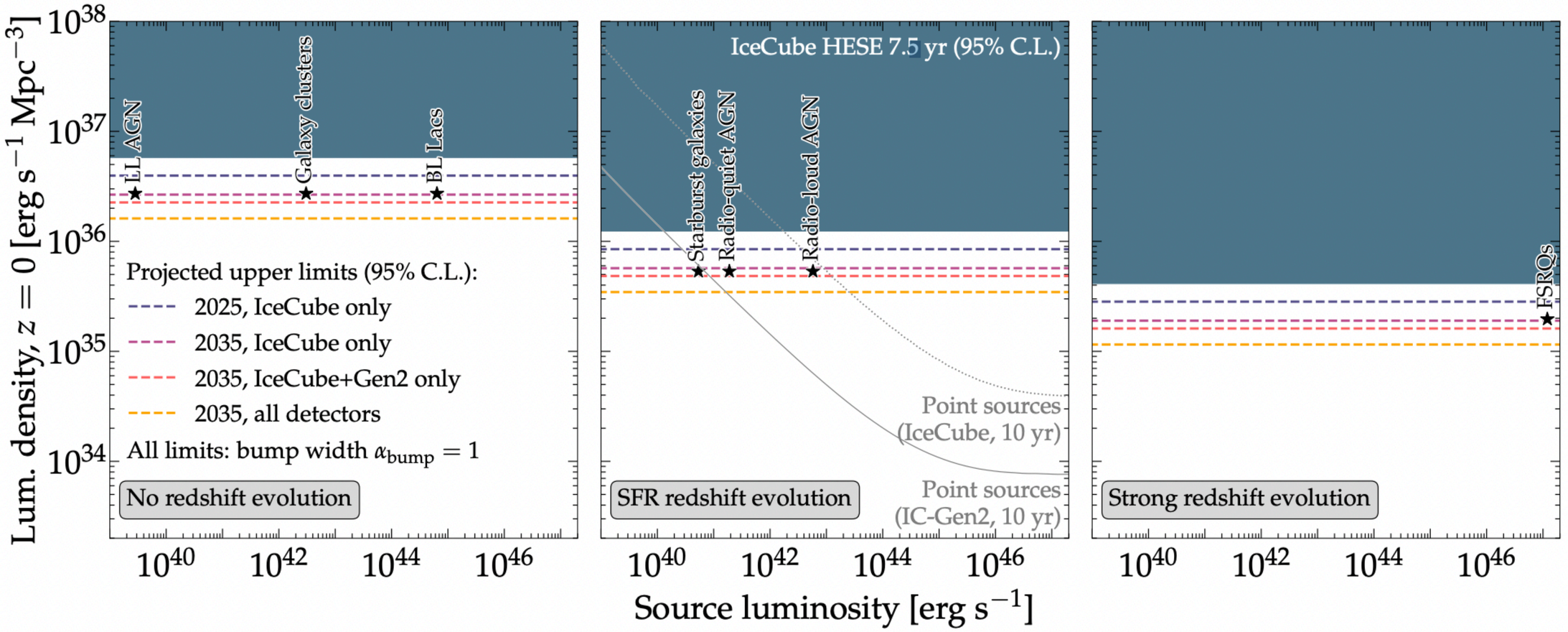


Palladino et al., 1801.07277



Ambrosone et al., 2011.02483

Source populations



Impact of bump width