Searching for new physics with high-energy astrophysical neutrinos



Carlos Argüelles

IPA, October 16th, 2026

HARVARD UNIVERSITY

The NSF Institute for Artificial Intelligence and Fundamental Interactions

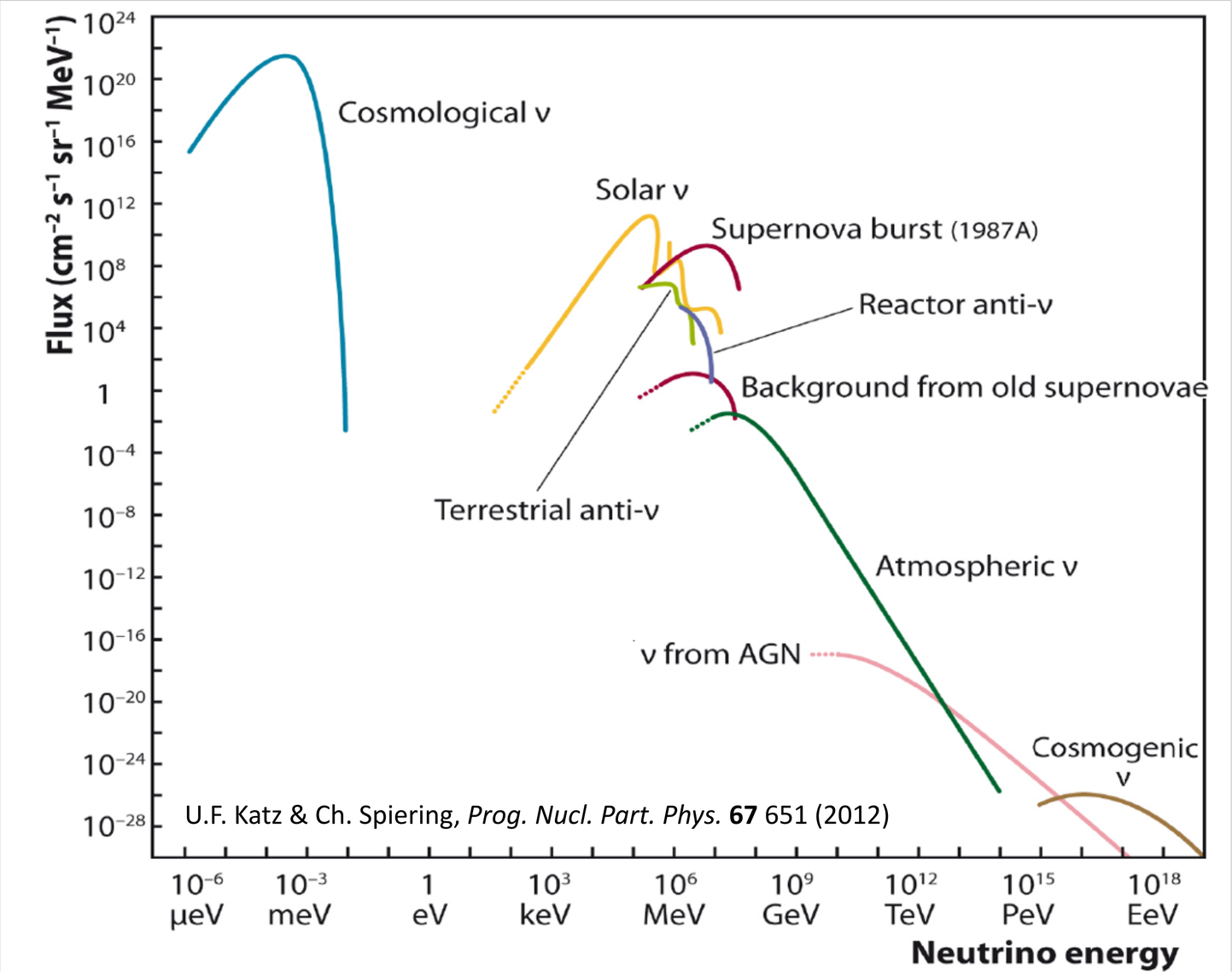
JOHN TEMPLETON FOUNDATION

NSF

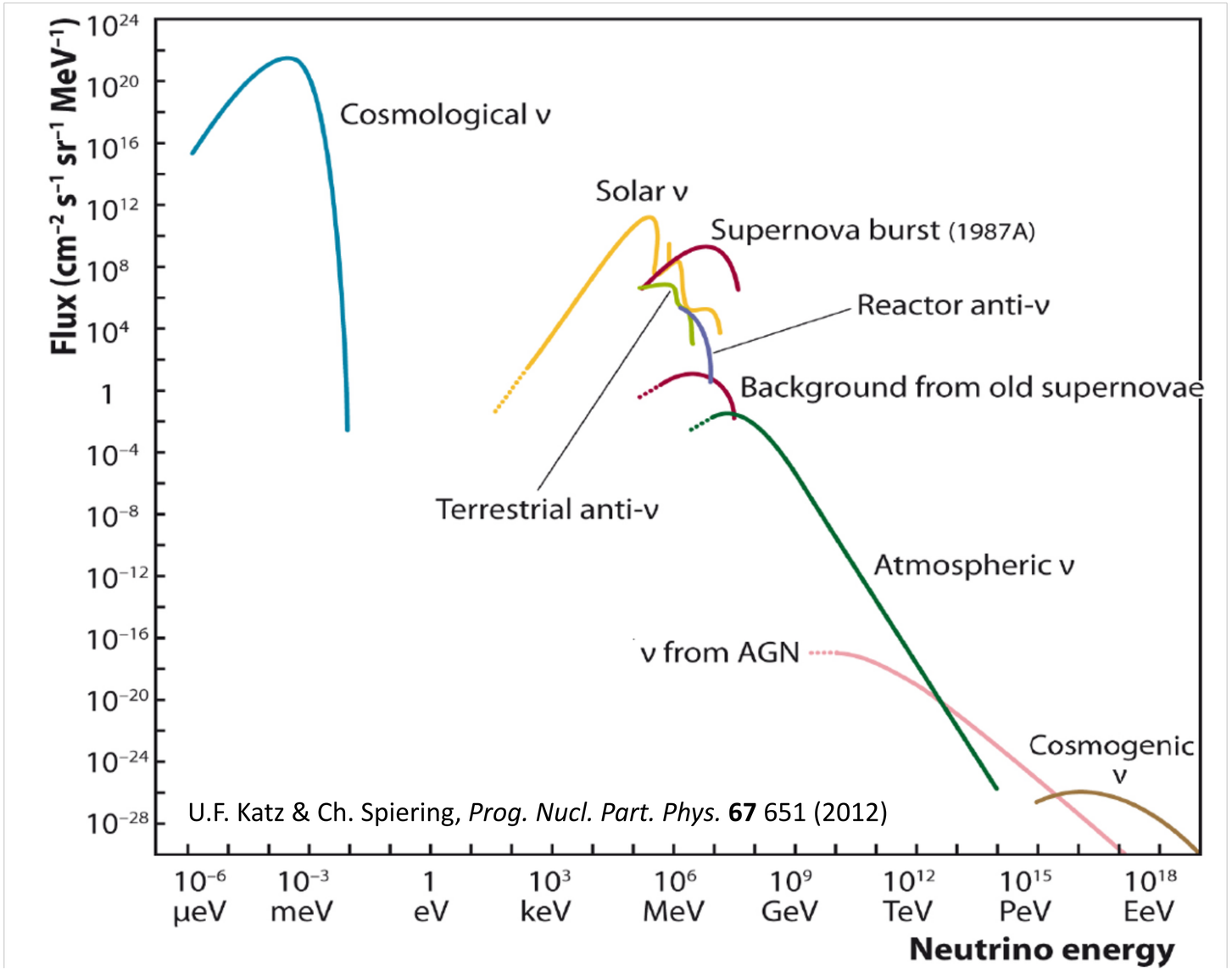
RESEARCH CORPORATION for SCIENCE ADVANCEMENT

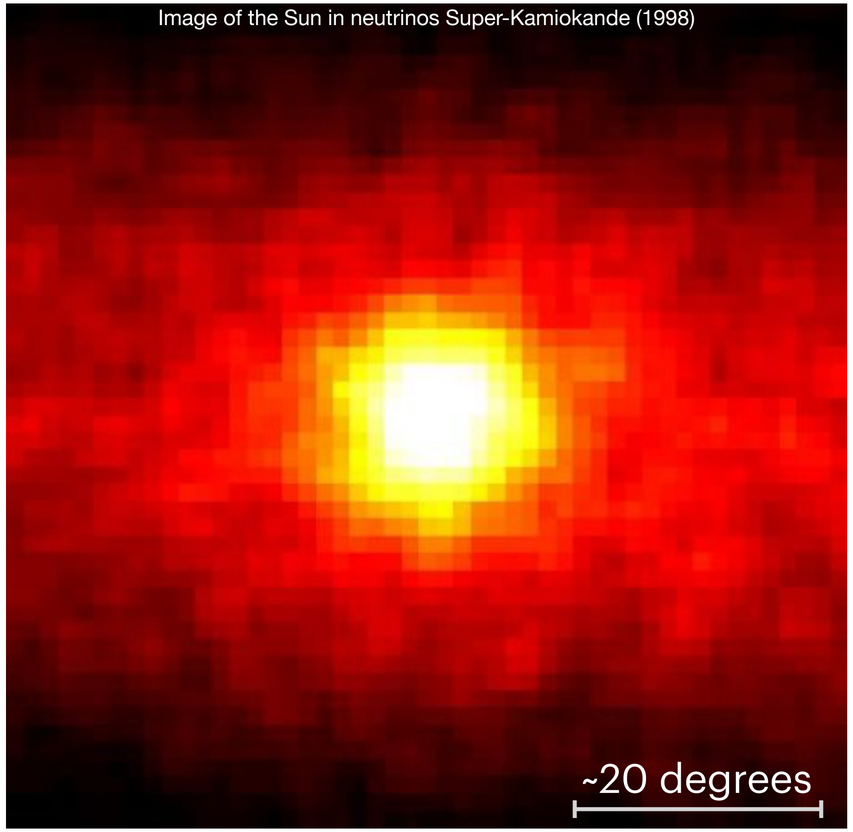
the David & Lucile Packard FOUNDATION

The nature of neutrino masses is one of the biggest problems in particle physics.

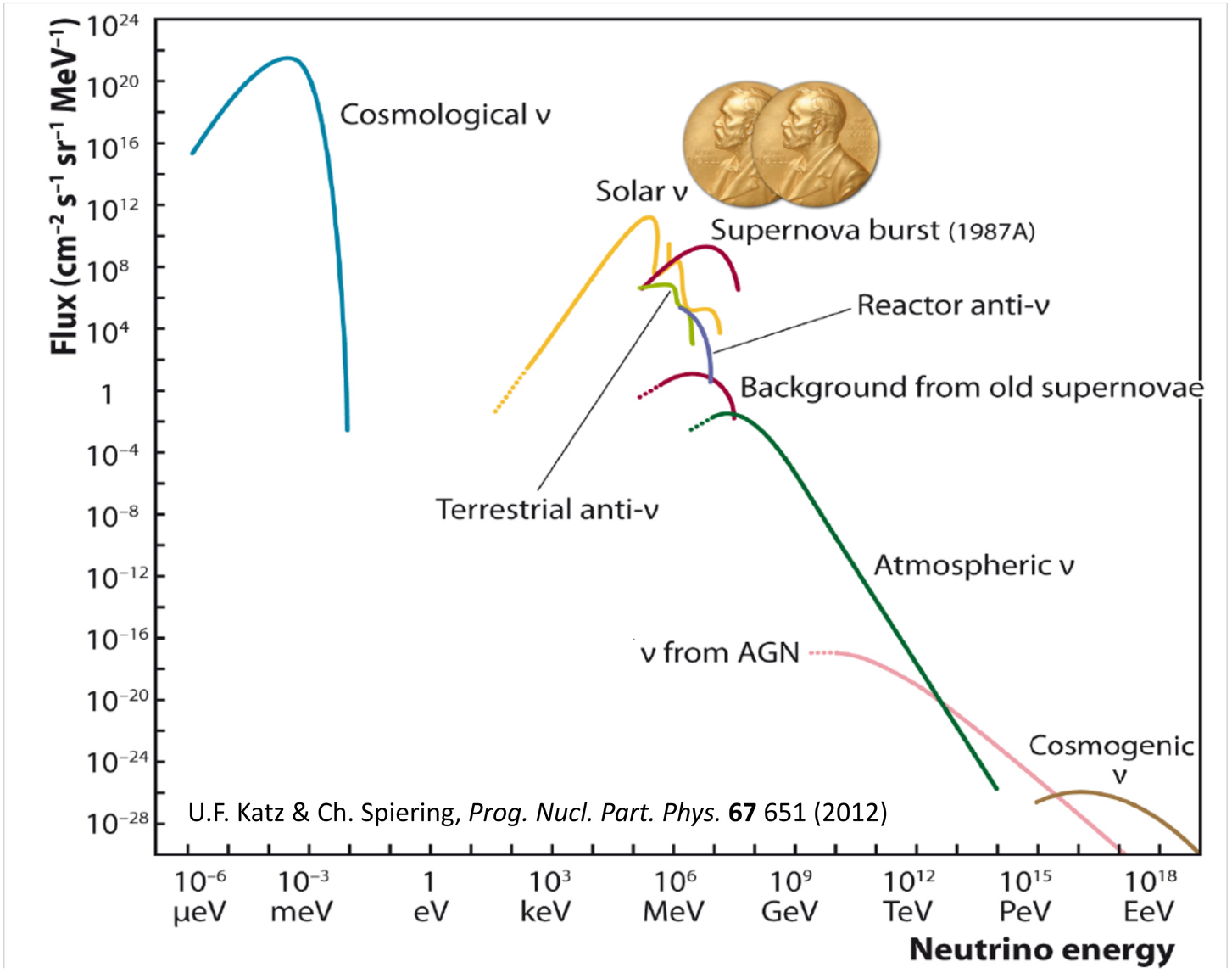


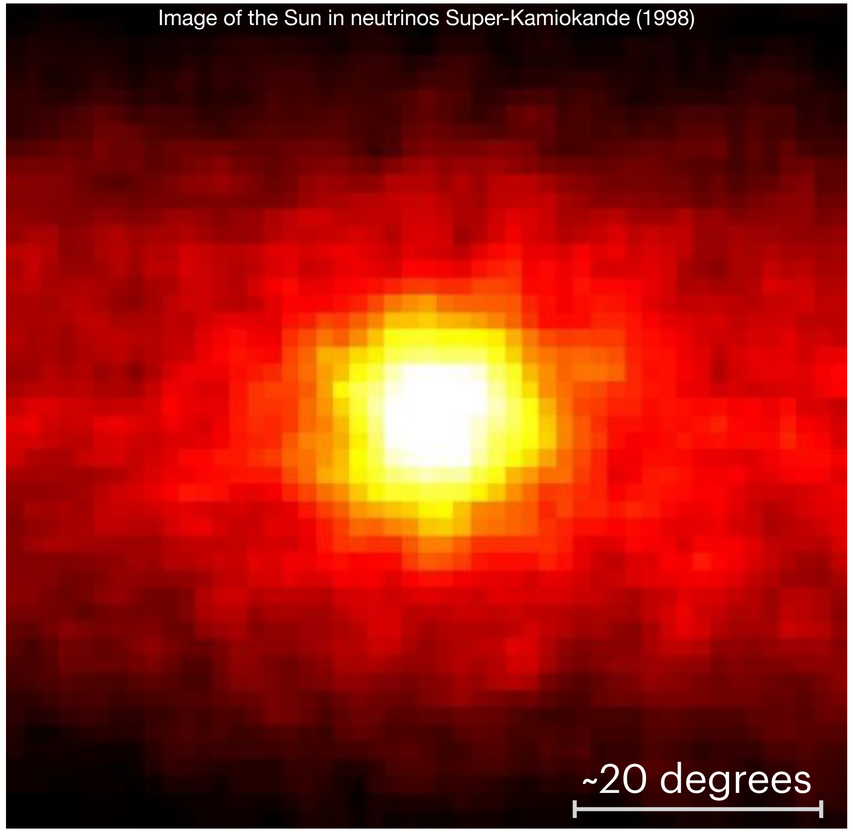
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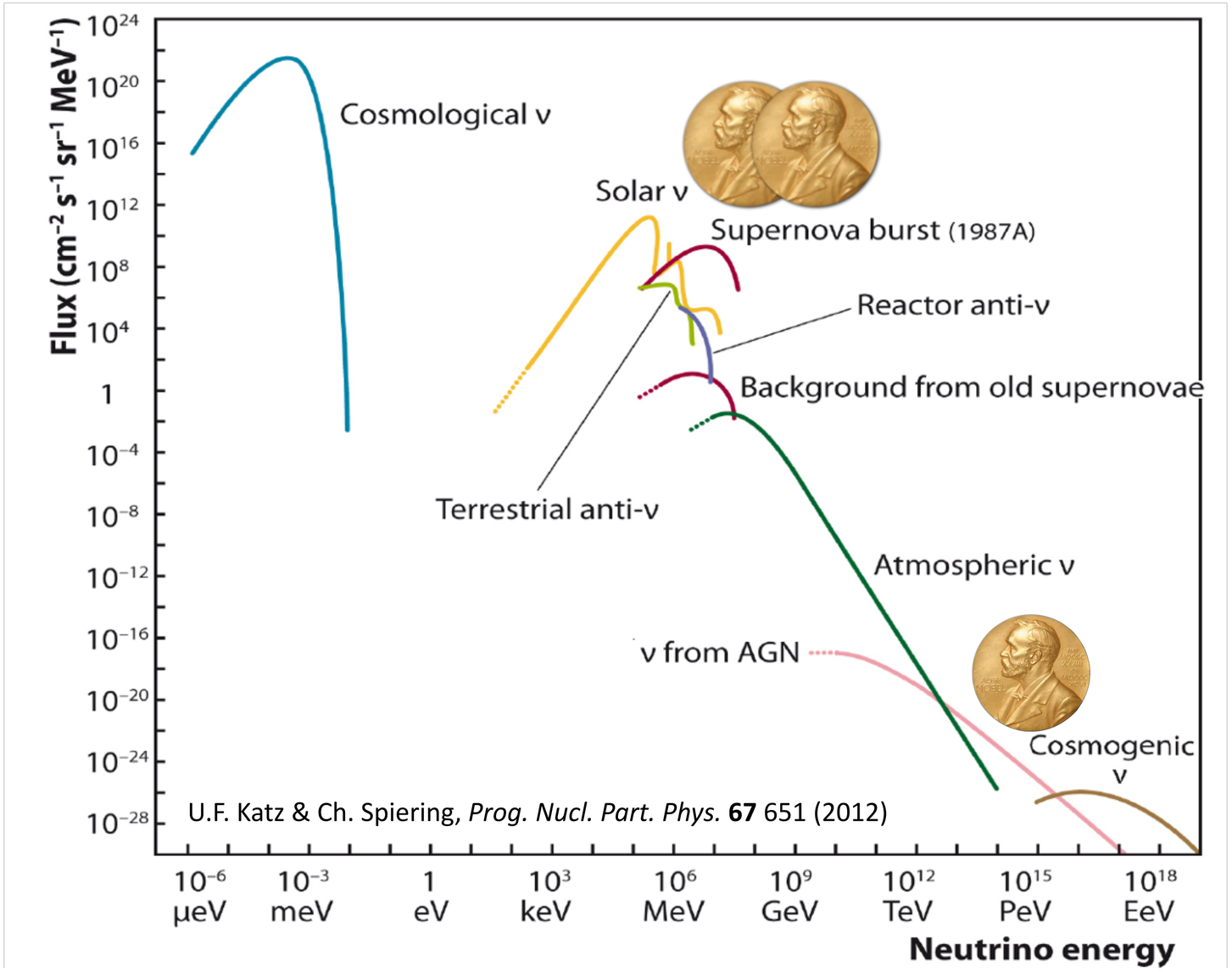


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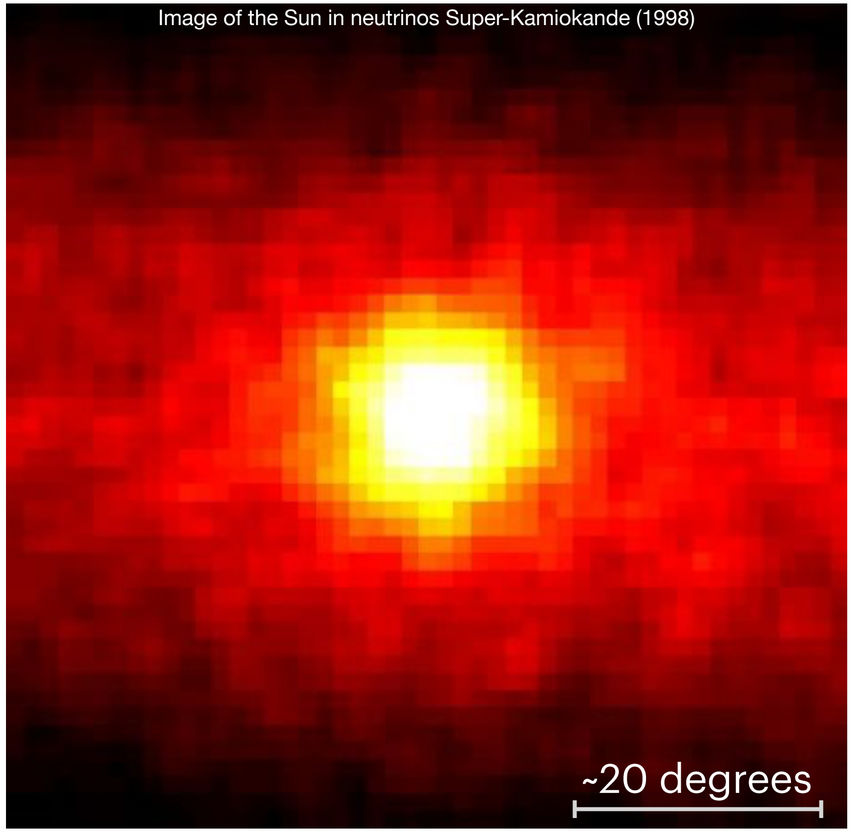




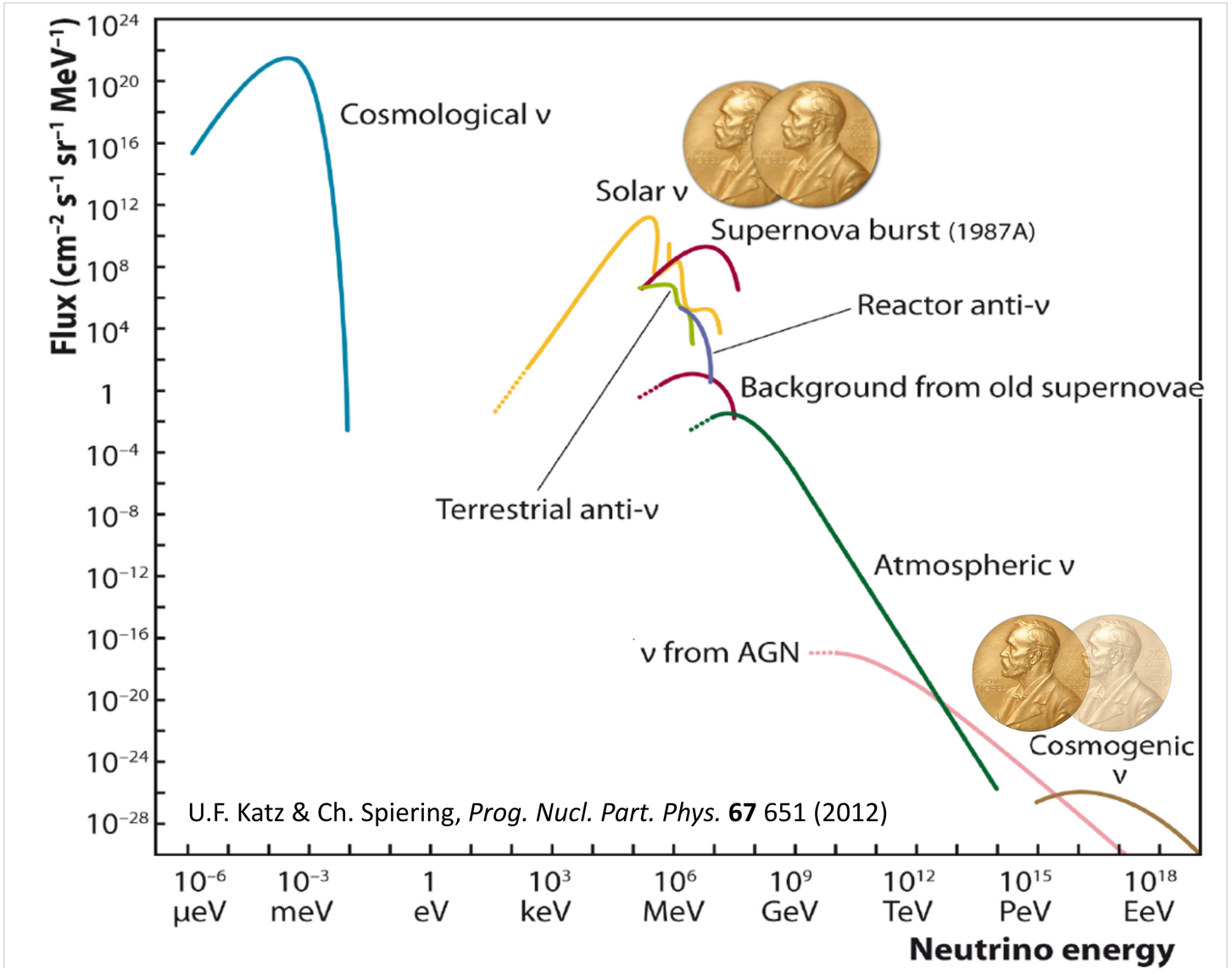
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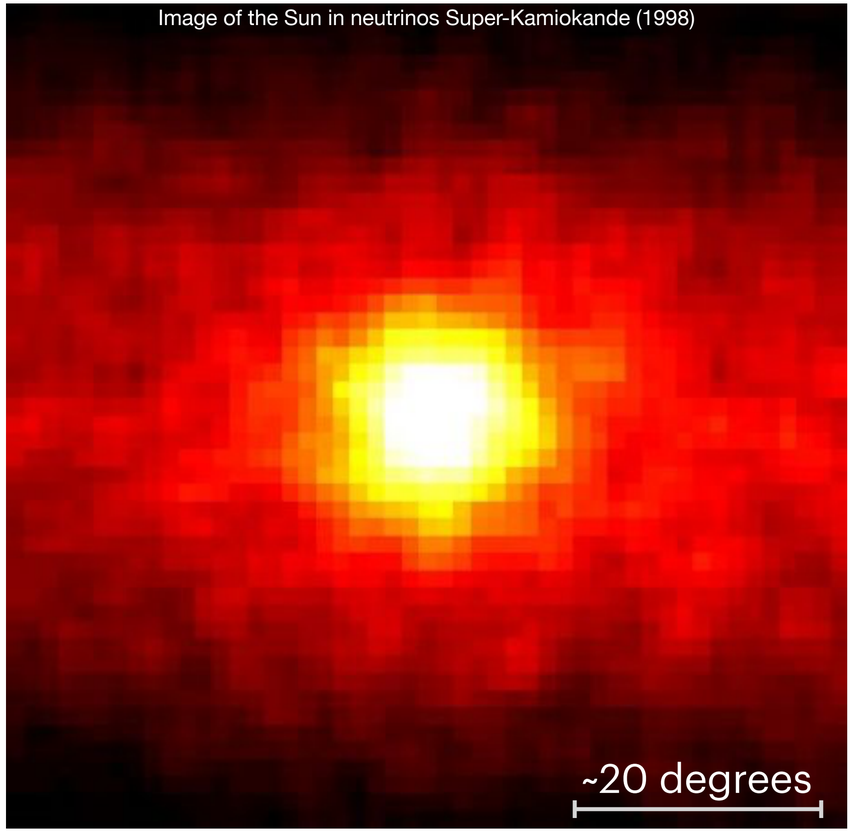


U.F. Katz & Ch. Spiering, *Prog. Nucl. Part. Phys.* **67** 651 (2012)



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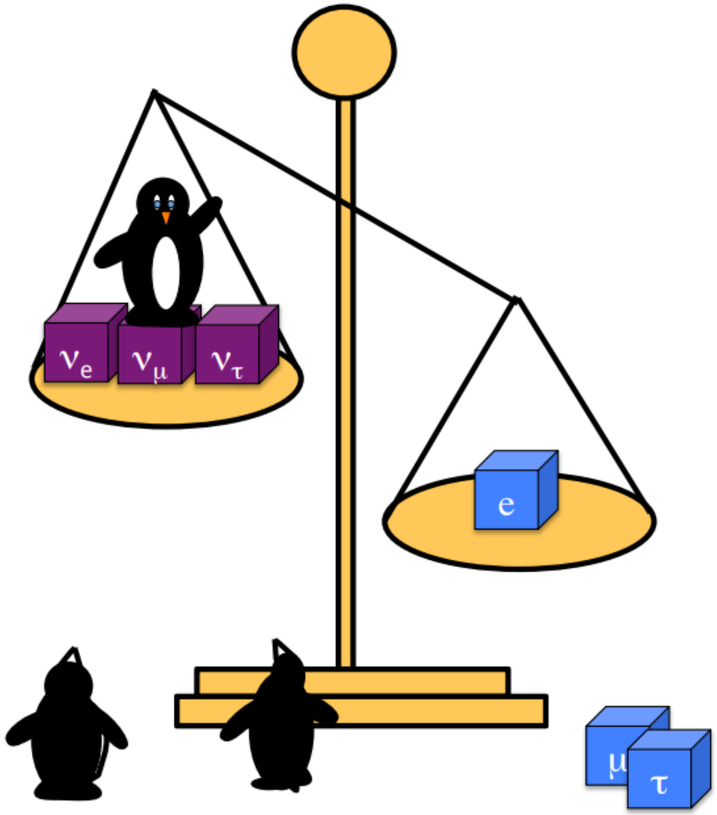
Outline for the rest of this talk

1. Neutrino Physics at Ultra-long Baselines
2. Neutrino Flavor at Very-High Energies
3. Neutrino Cosmography
4. Next-generation Frontier

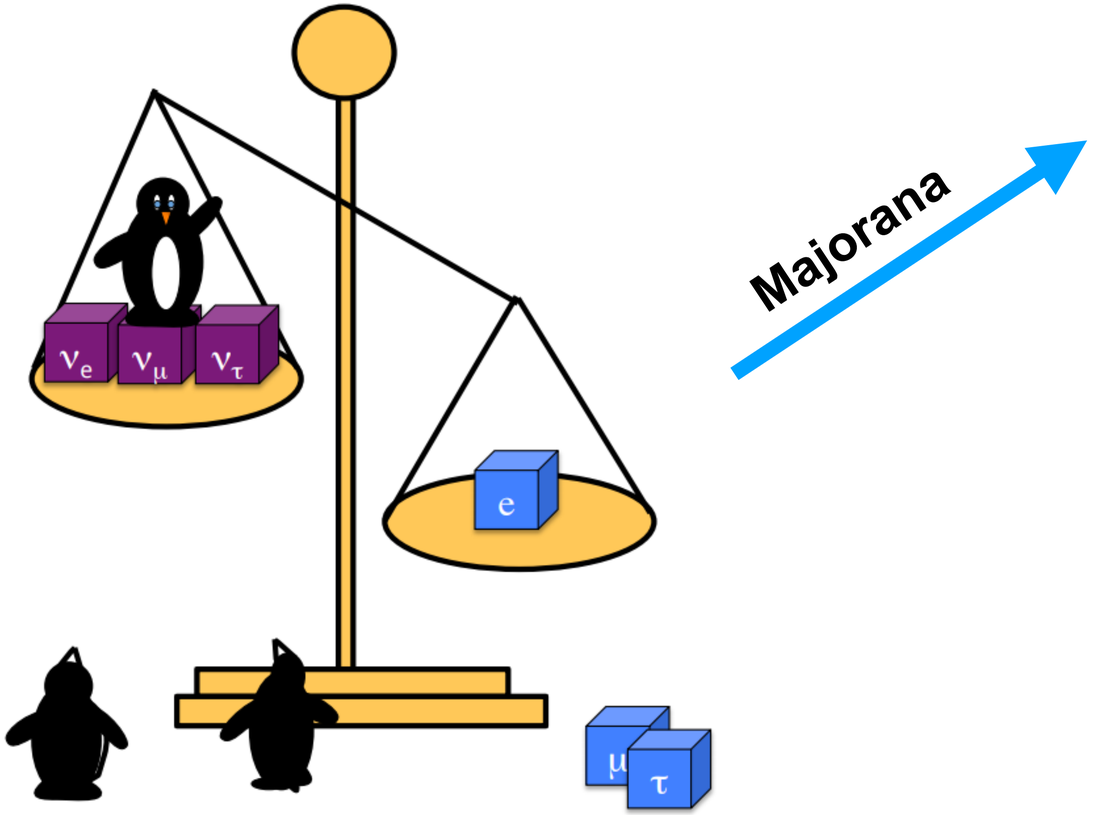
Neutrino Physics At Ultra-long Baselines

What is the origin of neutrino mass?

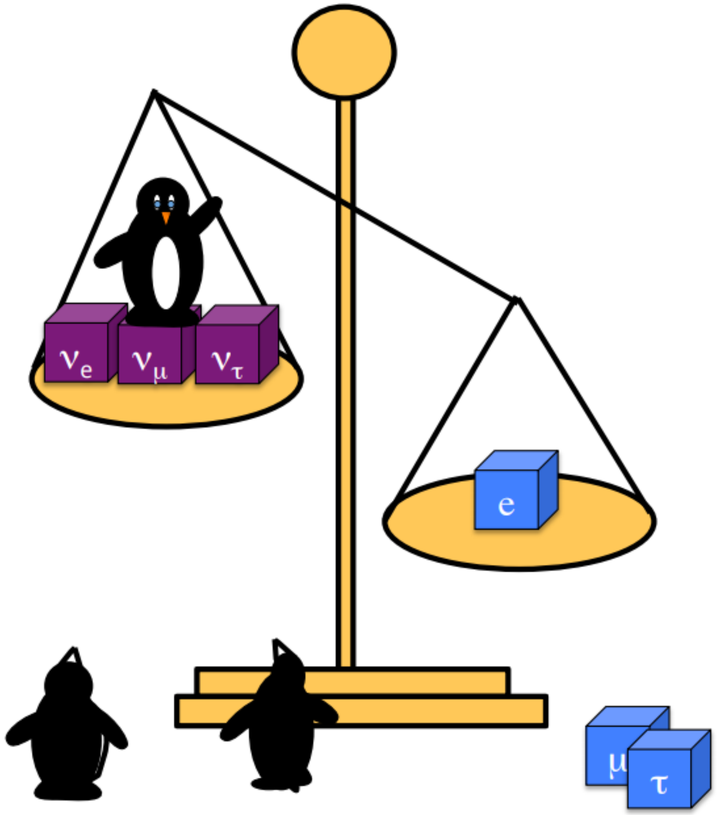
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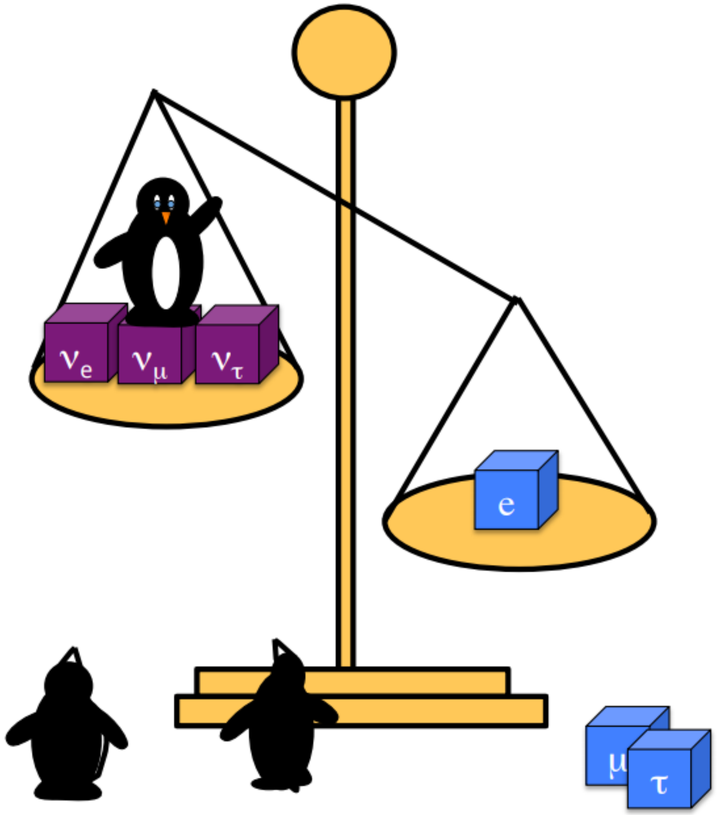


Majorana

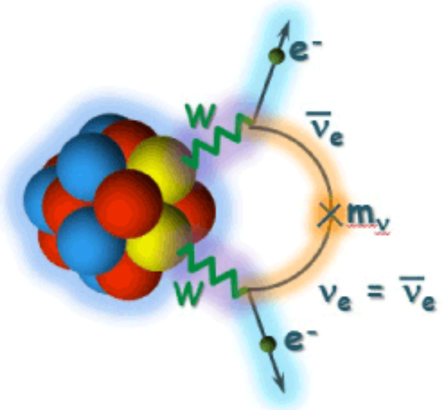
Dirac-like

Arkani-Hamed et al, 2007
Ooguri & Vafa, 2017
Hamada & Shiu, 2017
Gonzalo, Ibañez, Valenzuela, 2021
Vafa, 2024

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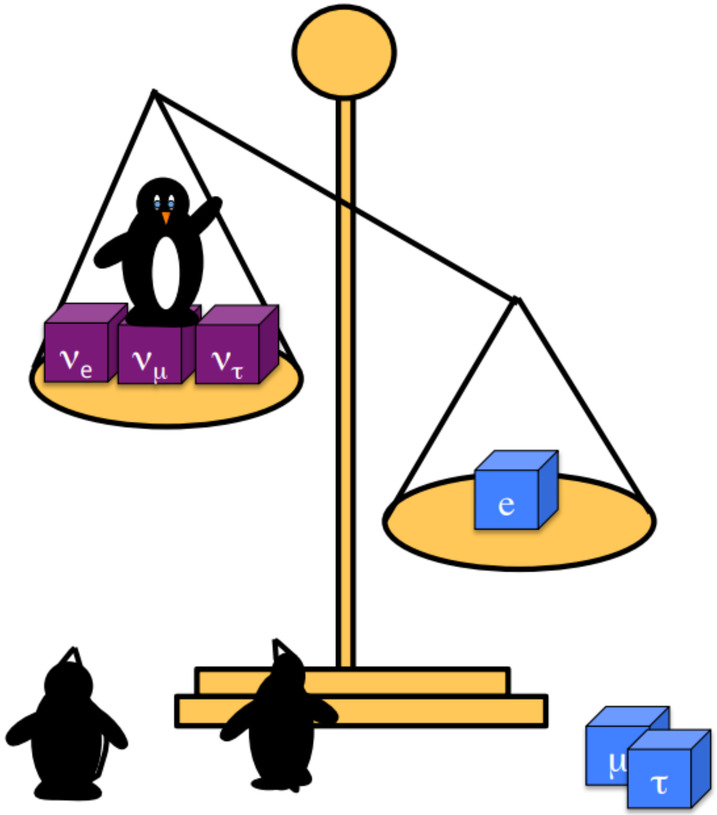


Neutrinoless
double beta decay

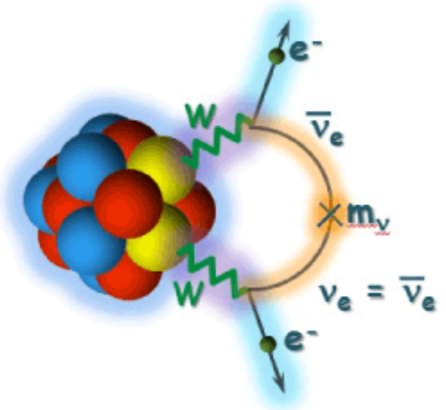
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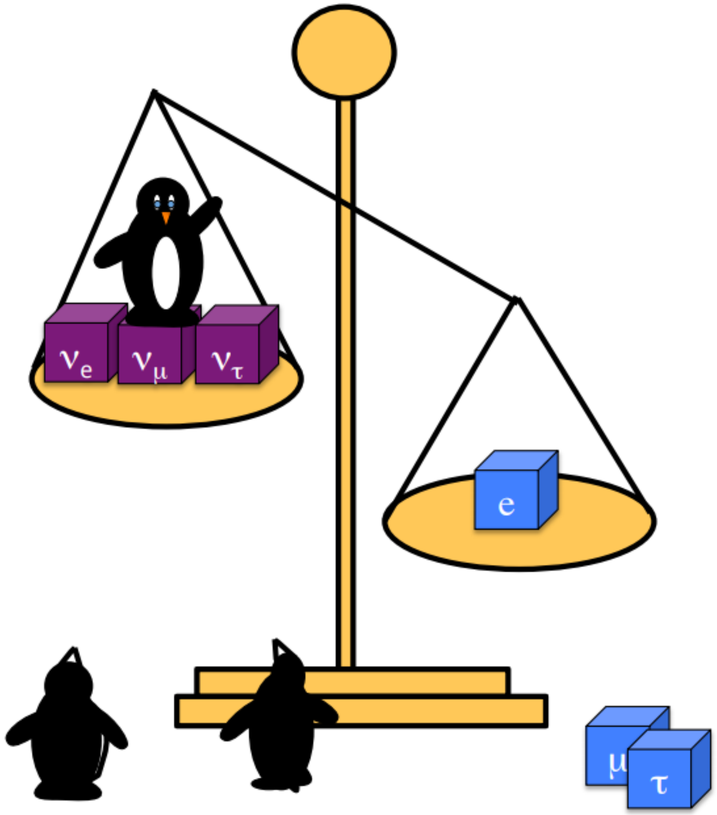
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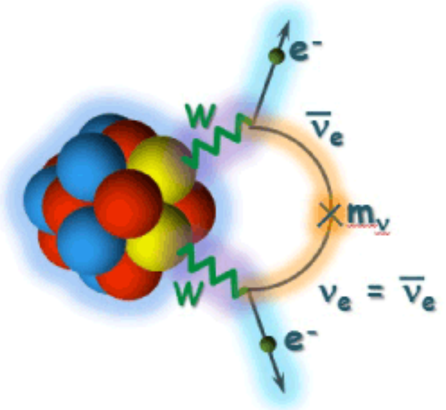
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What is the origin of neutrino mass?



Majorana



Neutrinoless
double beta decay

Dirac-like

If exactly Dirac: combine measurements from Cosmology or direct neutrino mass measurements and neutrinoless double beta decay.

If Quasi-Dirac: ultra long-baseline neutrino oscillation measurements

Neutrino telescopes!

Arkani-Hamed et al, 2007
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Theory of neutrino masses

Beacom et al, 2003 (arXiv:hep-ph/0307151
Shoemaker & Murase, 2015 (arXiv:1512.07228)
Esmaili, 2012

$$2\mathscr{L}_{\text{mass}} = m_D \overline{N_R}\nu_L + m_D \overline{\nu_L^C} N_R^C + m_R \overline{N_R^C} N_R + \text{h.c.}$$

J. W. Valle Phys.Rev.D 28 (1983) 540

Dirac See Saw Scenario: Z. K. Silagadze, *Phys. Atom. Nucl. 60, 272* (1997); A. S. Joshipura, S. Mohanty, and S. Pakvasa *Phys. Rev. D 89, 033003* (2014); P.-H. Gu and H.-J. He JCAP 12, 010; E. Ma and R. Srivastava *Phys. Lett. B 741, 217* (2015); J. W. F. Valle and C. A. Vaquera-Araujo *Phys. Lett. B 755, 363* (2016); S. Centelles Chuli´a, R. Srivastava, and J. W. F. Valle *Phys. Rev. D 98, 035009* (2018); Z. G. Berezhiani and R. N. Mohapatra, *Phys. Rev. D 52, 6607* (1995), …

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Lepton-number breaking term.

J. W. Valle Phys.Rev.D 28 (1983) 540

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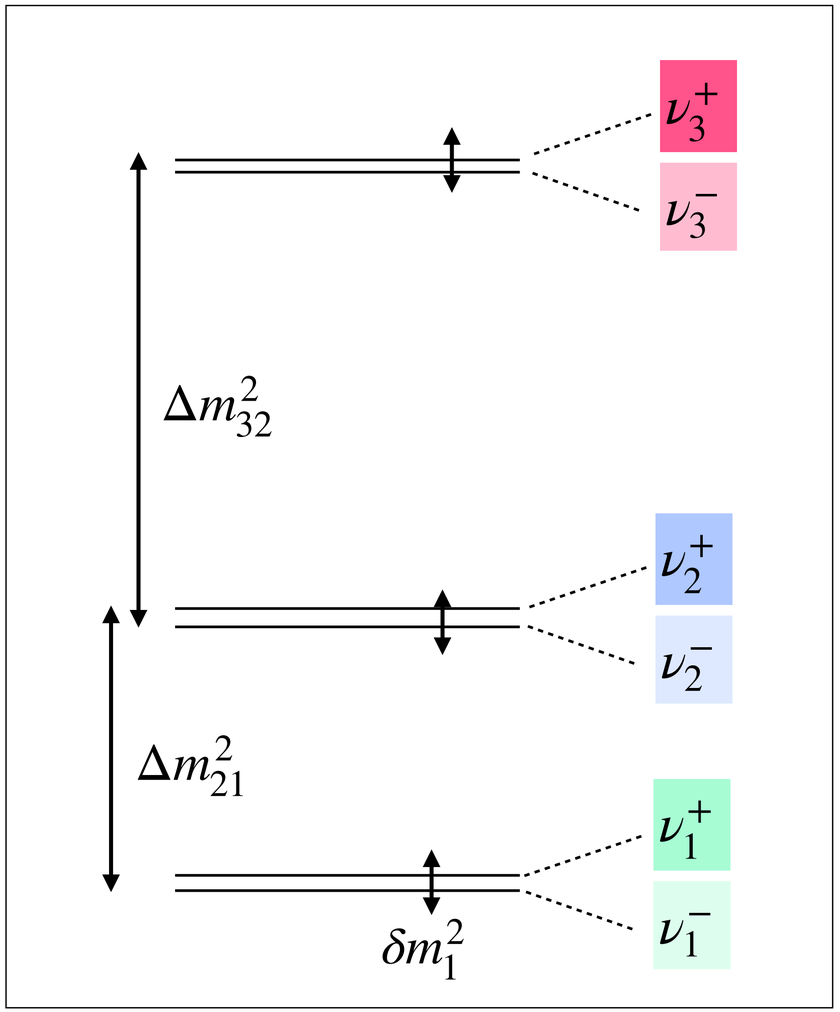
Lepton-number breaking term.

Dirac neutrinos: $M_R = 0$
See-saw scenario: $M_R \gg M_D$
Quasi-Dirac scenario: $M_R \ll M_D$

J. W. Valle Phys.Rev.D 28 (1983) 540

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Neutrino hyper-fine mass structure



Hyperfine splitting:

$$\delta m_j^2 \sim 10^{-22} - 10^{-12}\mathrm{eV}^2$$

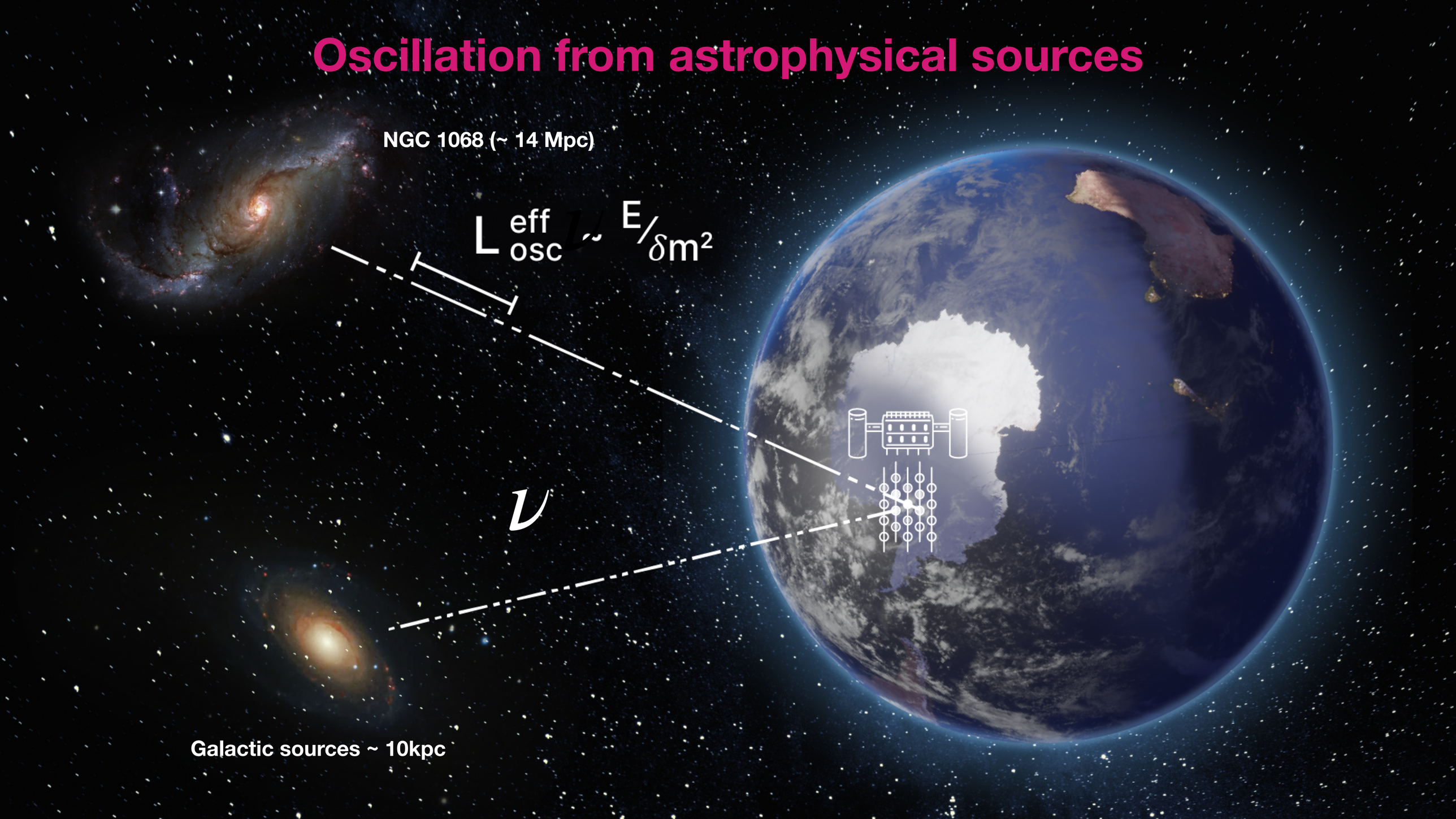
Oscillations from active to sterile neutrinos

$|\nu_j^{\pm}\rangle =$ 

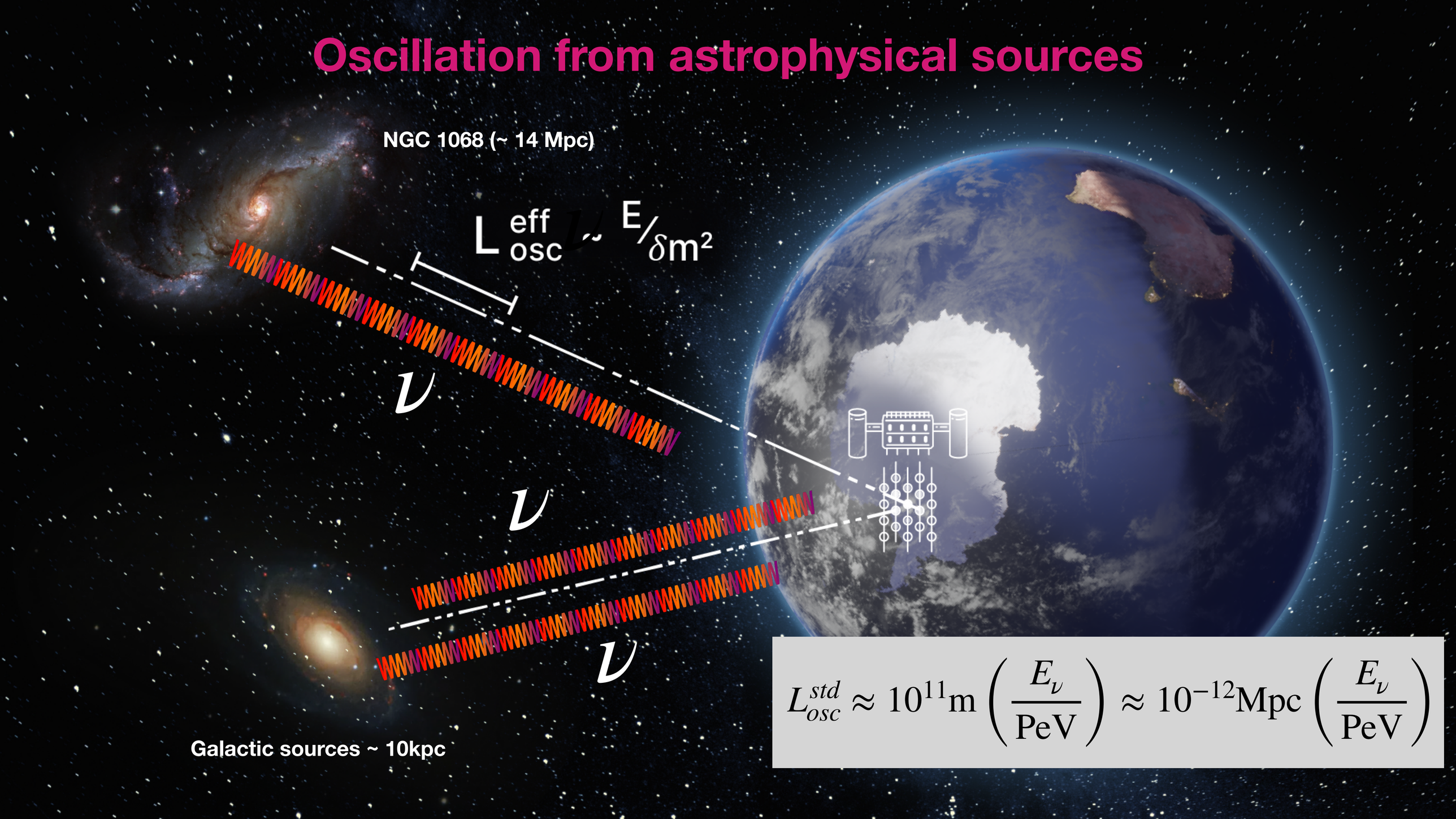
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Oscillation from astrophysical sources

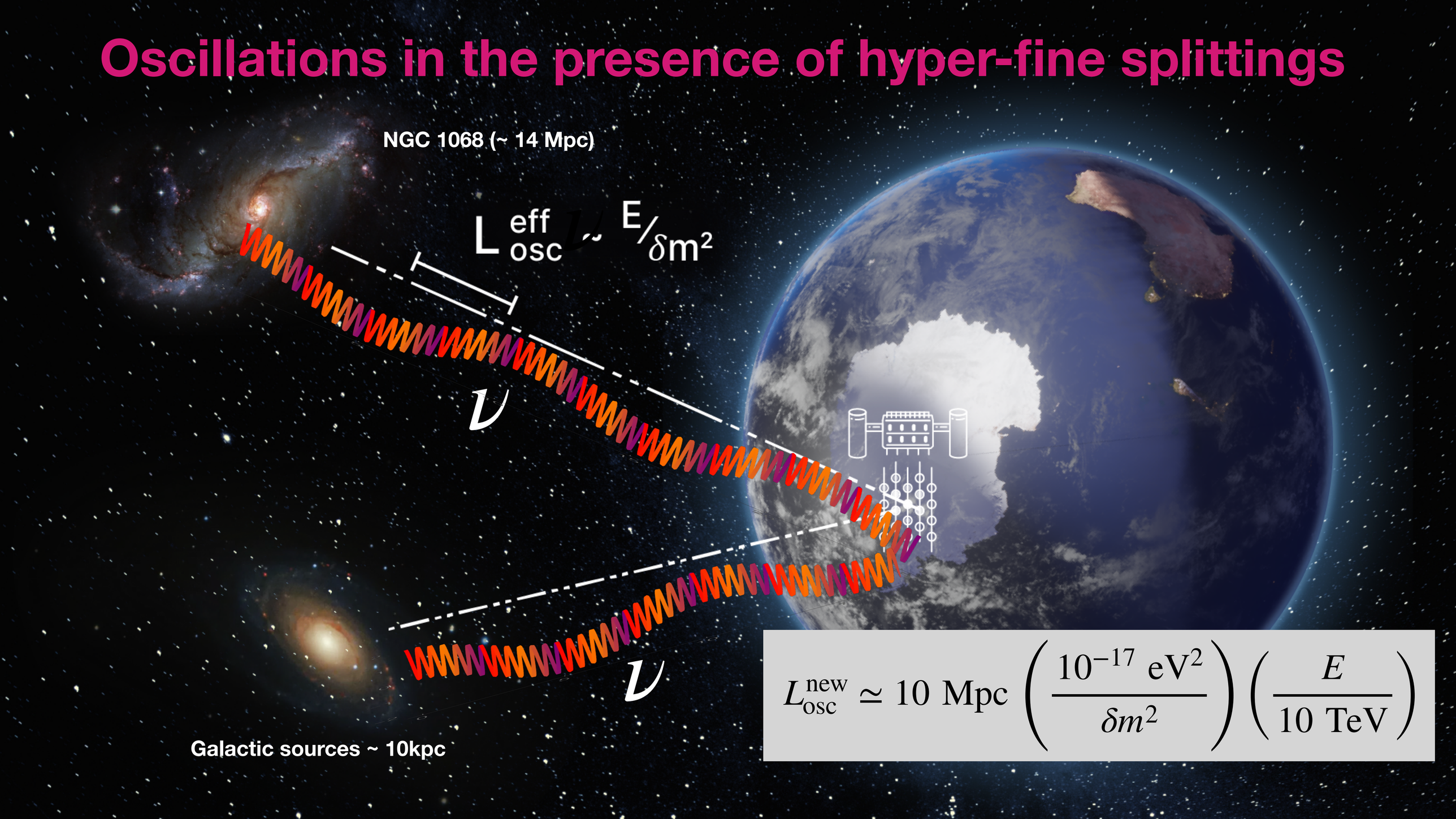


Oscillation from astrophysical sources



$$L_{osc}^{std} \approx 10^{11}\mathrm{m}\left(\frac{E_\nu}{\mathrm{PeV}}\right) \approx 10^{-12}\mathrm{Mpc}\left(\frac{E_\nu}{\mathrm{PeV}}\right)$$

Oscillations in the presence of hyper-fine splittings



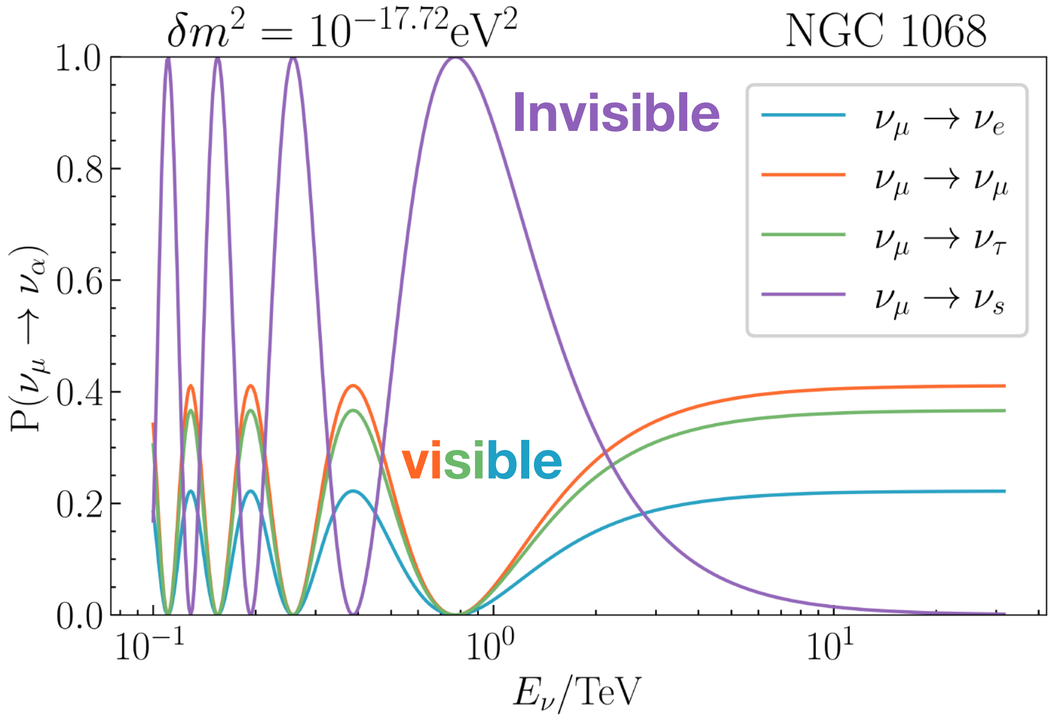
$$L_{\rm osc}^{\rm new} \simeq 10\ {\rm Mpc} \left(\frac{10^{-17}\ {\rm eV}^2}{\delta m^2}\right)\left(\frac{E}{10\ {\rm TeV}}\right)$$

Oscillations observable in spectra of sources

$$P_{\alpha\beta} = \frac{1}{2}\sum_{j=1}^{3} |U_{\beta j}|^2 |U_{\alpha j}|^2 \left[1 + \cos\left(\frac{\delta m_j^2 L_{\rm eff}}{2E_\nu}\right)\right]$$

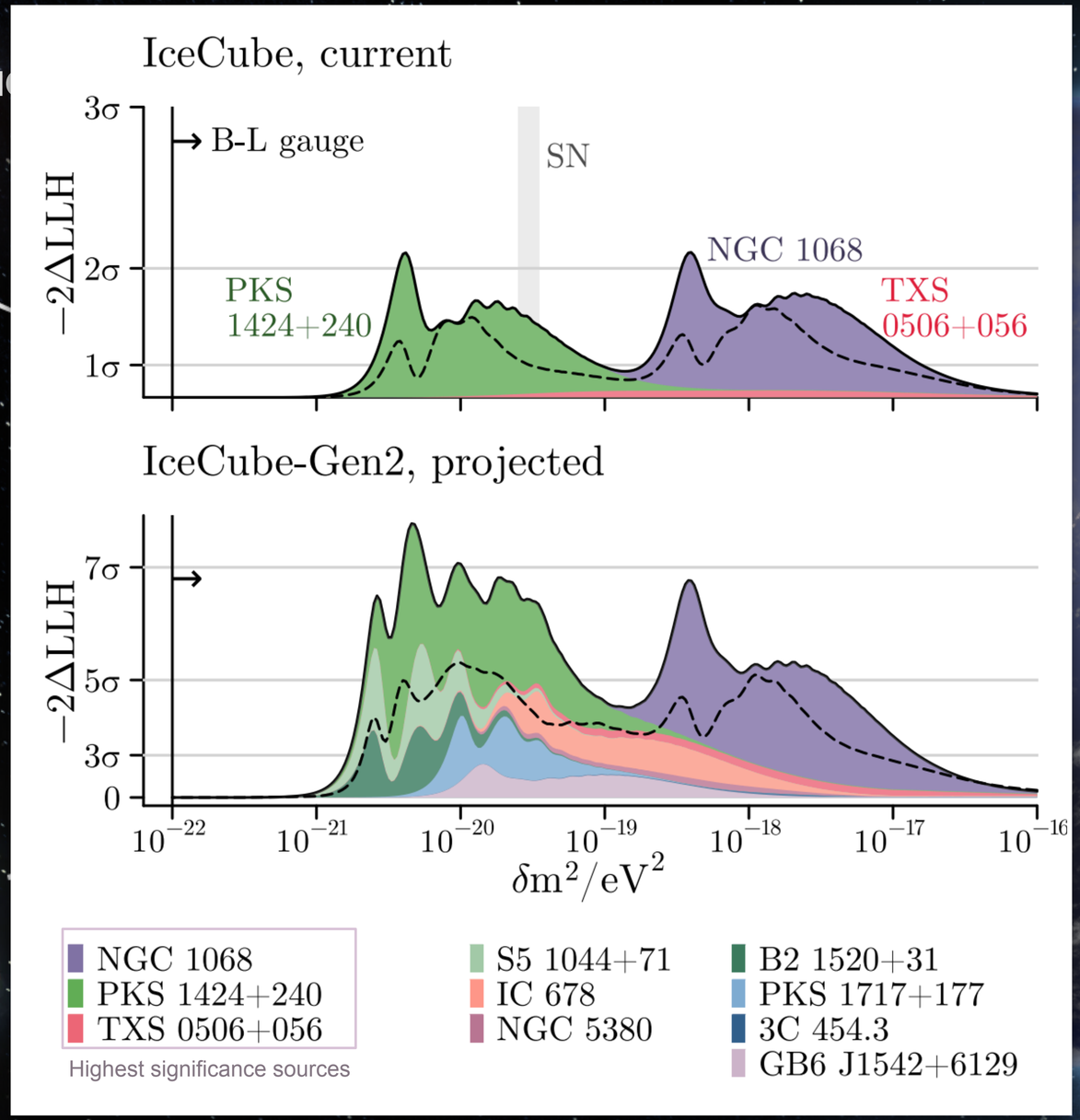
$L \sim 14$ Mpc

$\delta m^2 \sim 10^{-18}\mathrm{eV}^2$



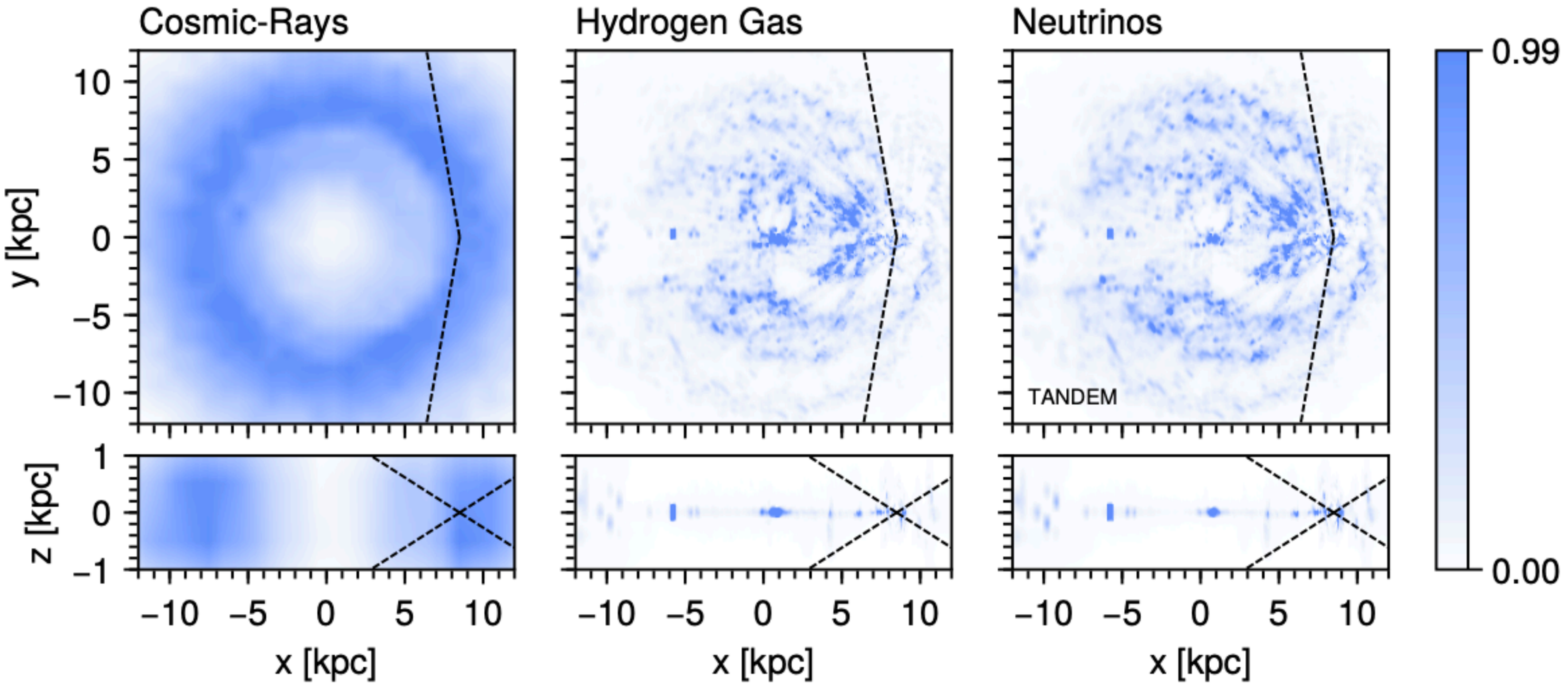
Carloni, Martínez-Soler, CA, Babu, Bhupal Dev *Phys.Rev.D* 109 (2024) L051702

Sensitivity to hyper-fine splittings with extragalactic sources



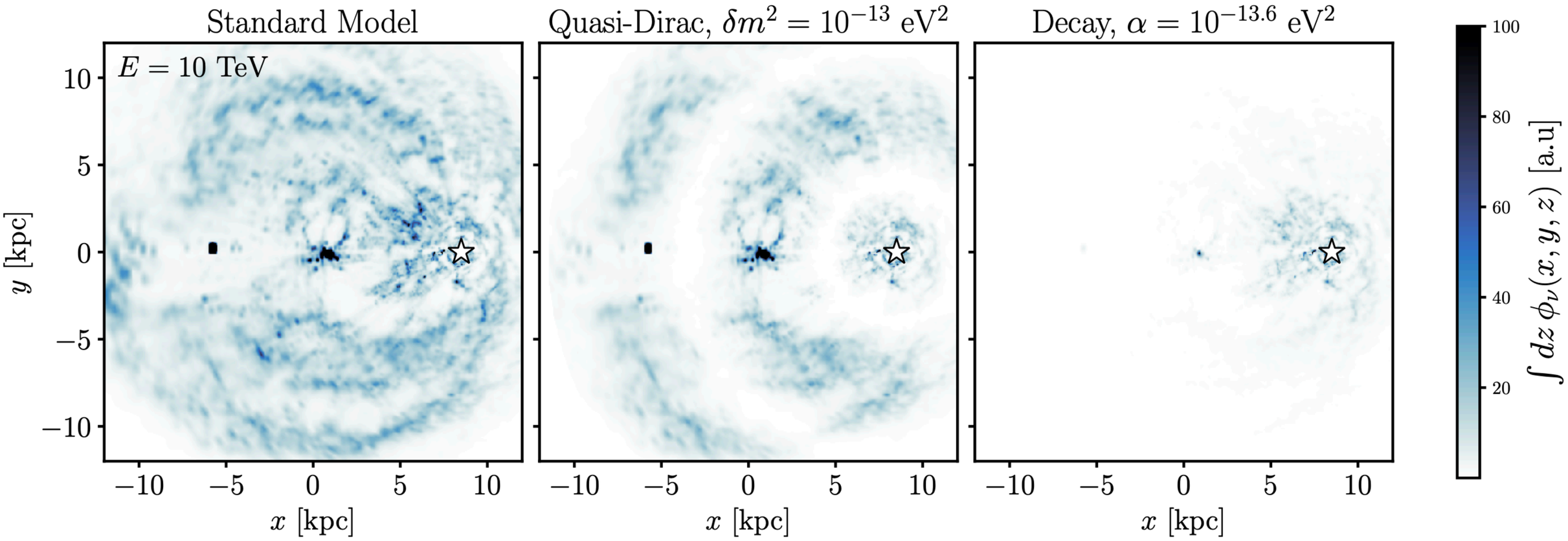
Carloni, Martínez-Soler, CA, Babu, Bhupal Dev, *Phys. Rev. D.* 109, L051702 (2024)

Neutrino emission in our galaxy



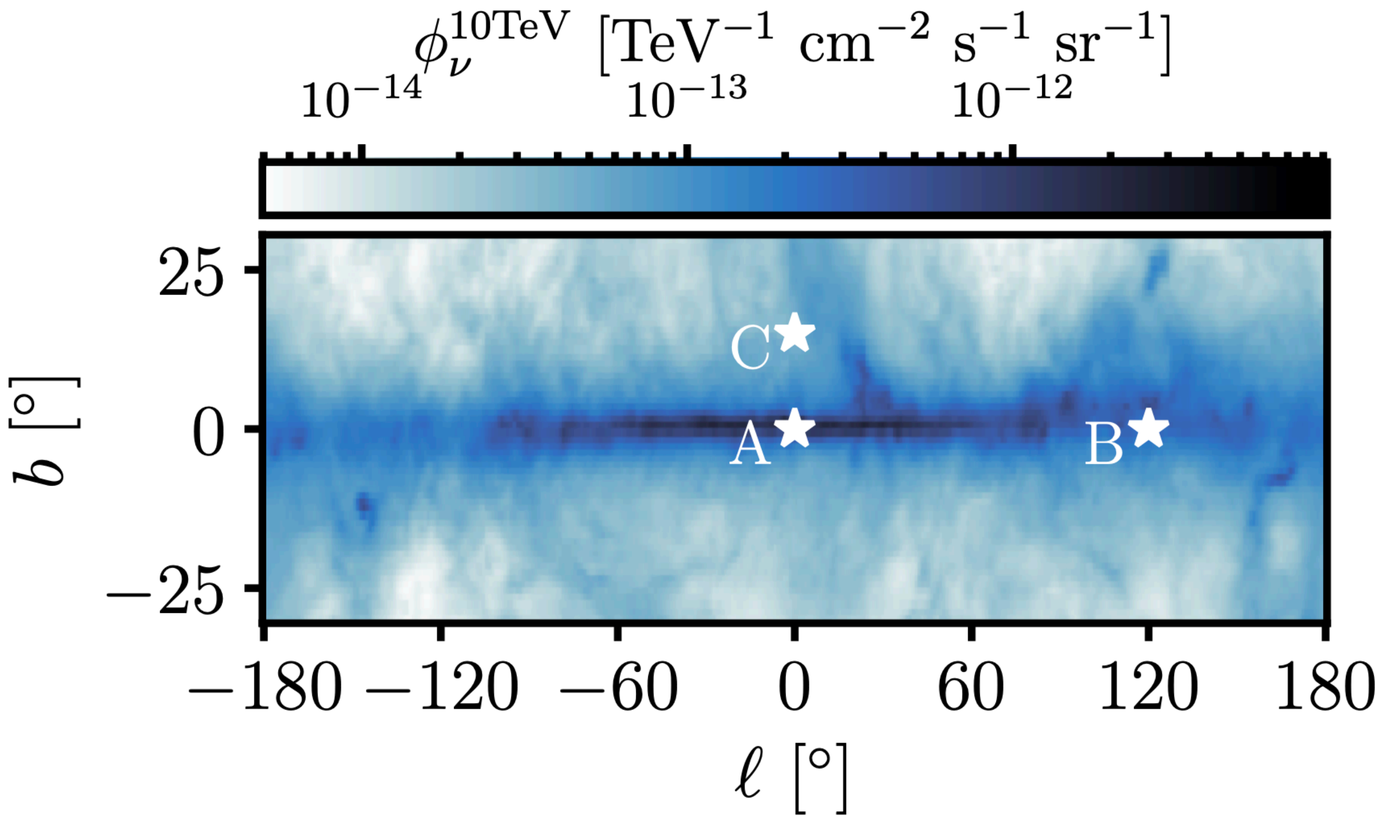
M. MacDonald, K. Carloni, CA, I. Martínez-Soler, R. Alves Batista (to appear soon)!

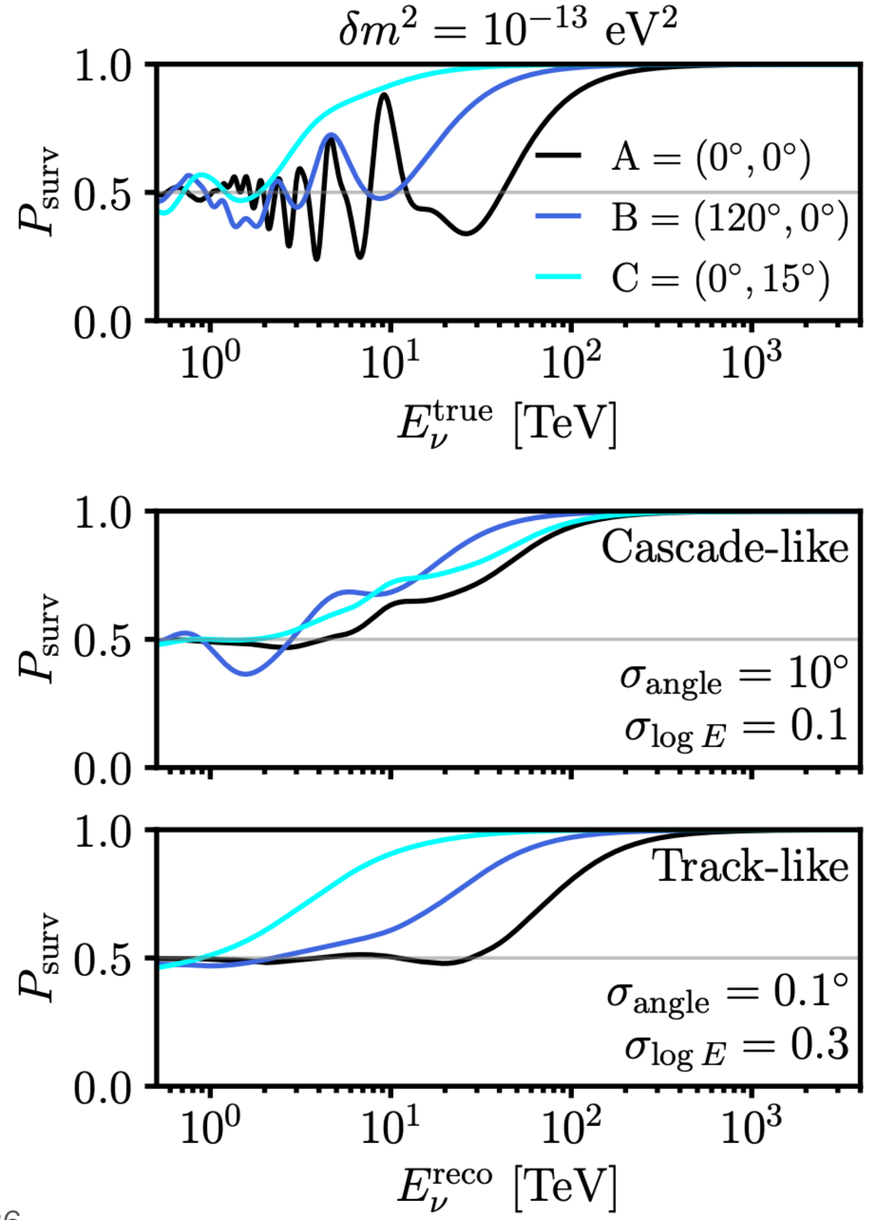
Effect of oscillations in galactic neutrino distributions



M. MacDonald, K. Carloni, CA, I. Martínez-Soler, R. Alves Batista (arXiv:2512.10744)

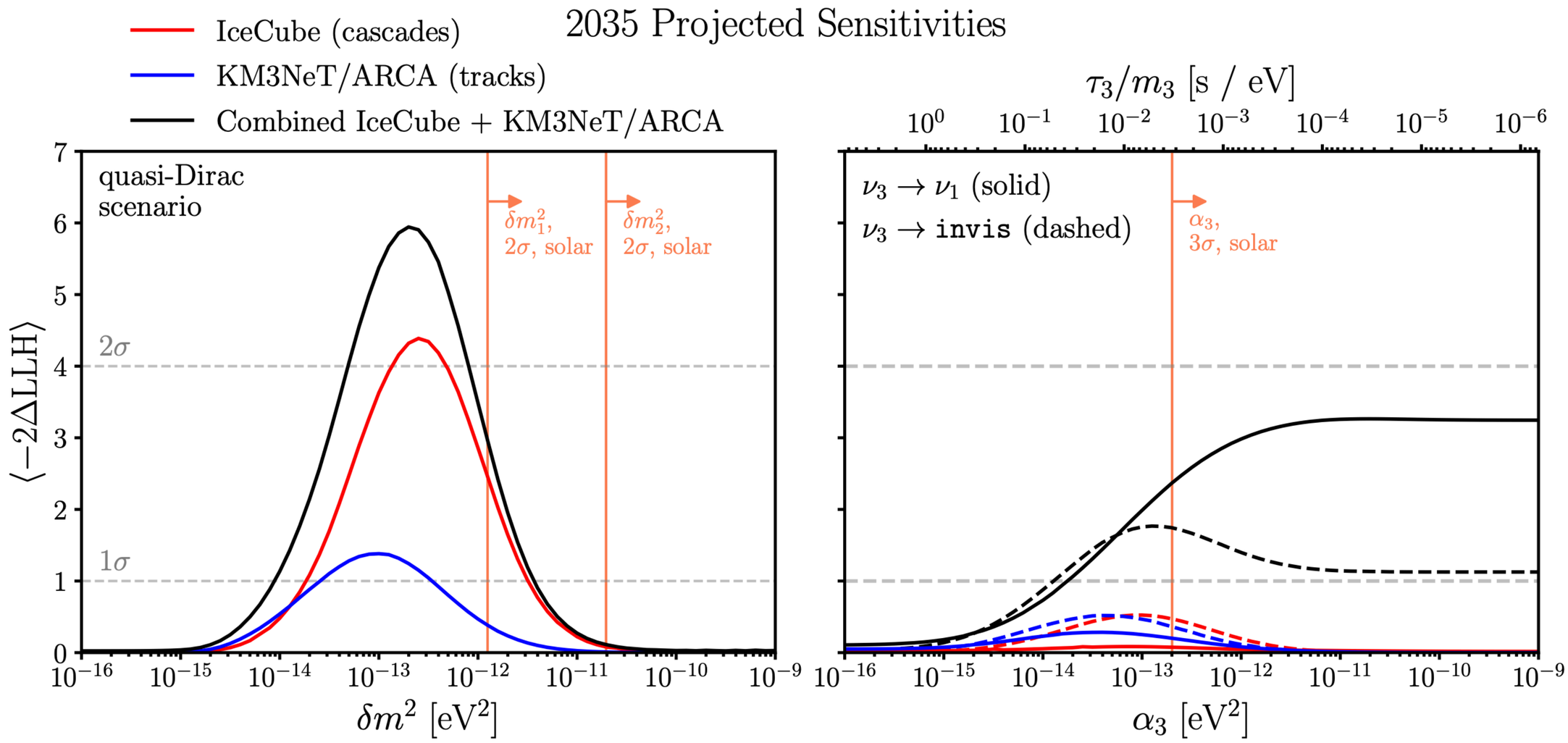
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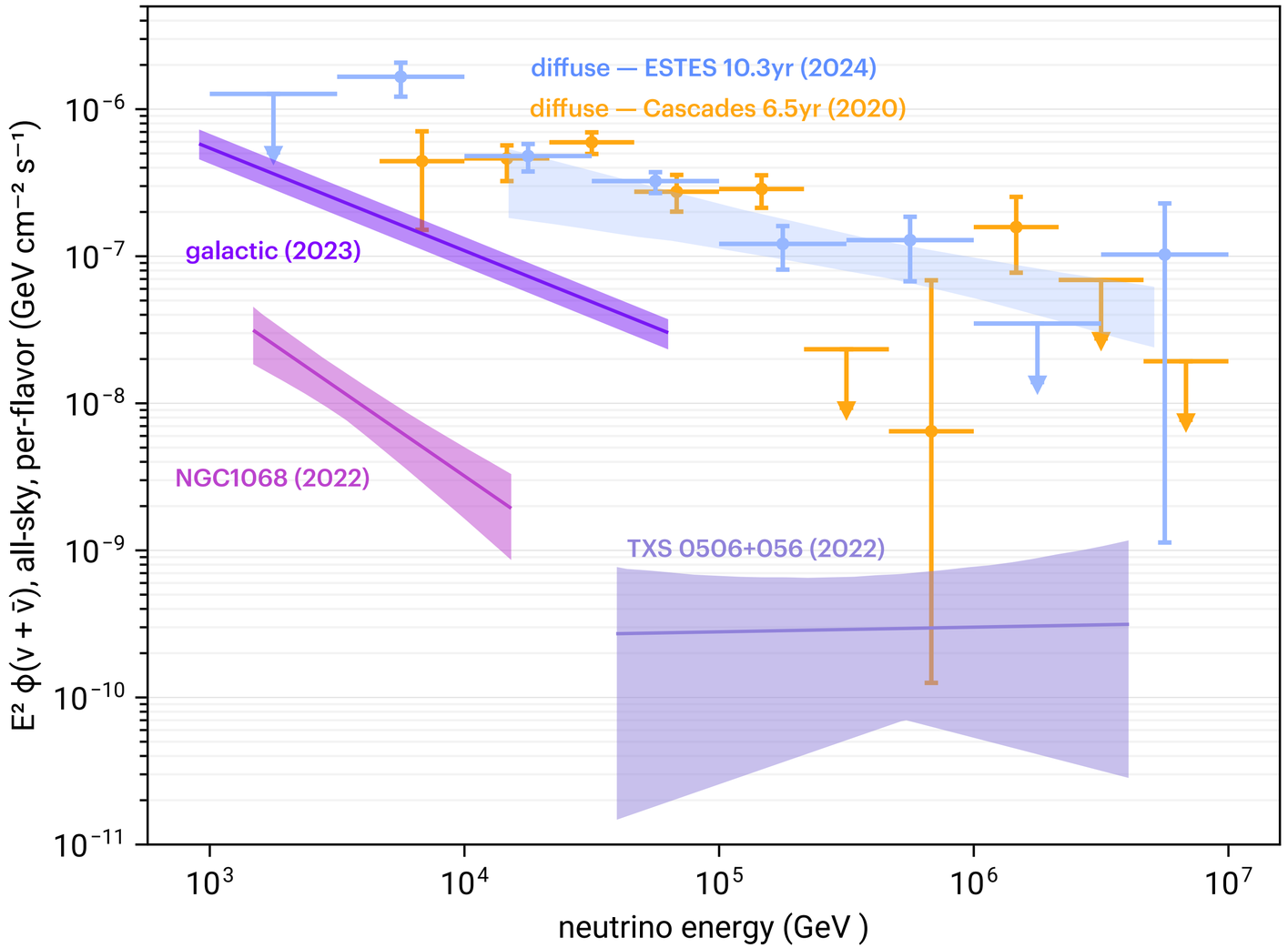
Observable distributions of galactic neutrino oscillations



Given that the oscillation length is comparable to the source size, oscillation sensitivity is suppressed.
On going IceCube analysis, expected to have ~ 2 sigma sensitivity.

M. MacDonald, K. Carloni, CA, I. Martínez-Soler, R. Alves Batista (arXiv:2512.10744)

What about the all-sky, unassociated neutrinos?

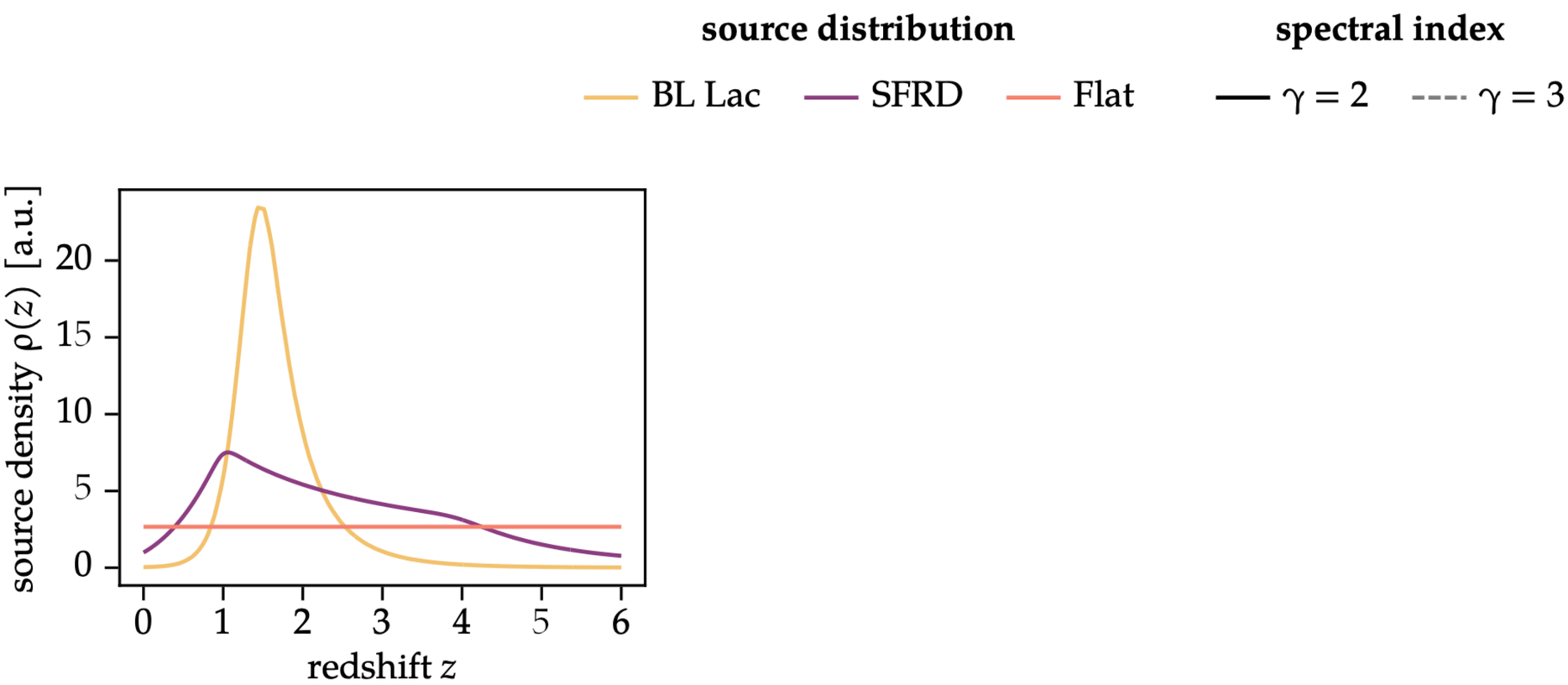


Sources are very stat. limited

What about all of those “diffuse neutrinos”?

K. Carloni, J. Porto, CA, B. Dev, S. Jana (arXiv:2503.19960, *Phys.Rev.D* 113 (2026) 11, 115004)

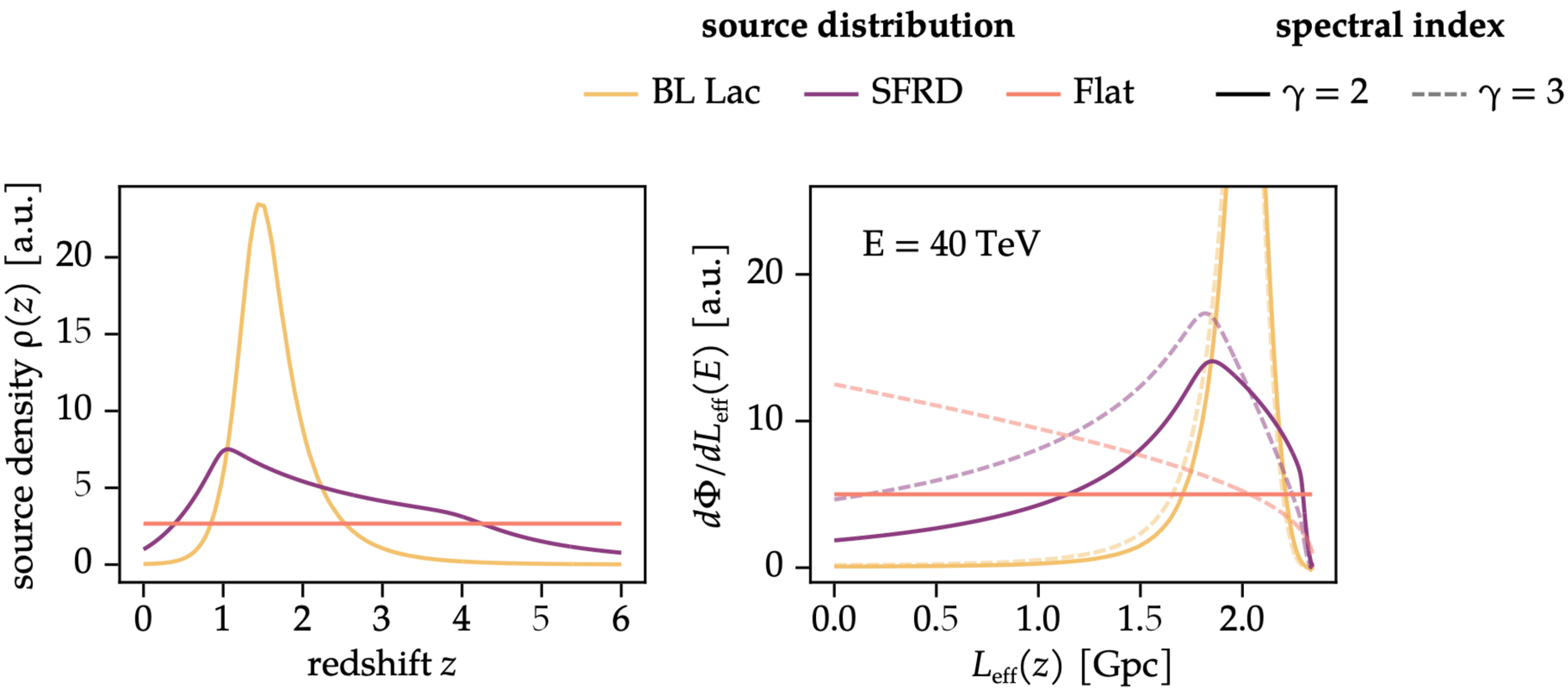
Astrophysical neutrino cosmic distribution



See Capel et al. *Phys. Rev. D 101, 123017* (2020)
K. M. Groth and M. Ahlers *Phys. Rev. D* 111, 103052 (2025) for source distribution inference

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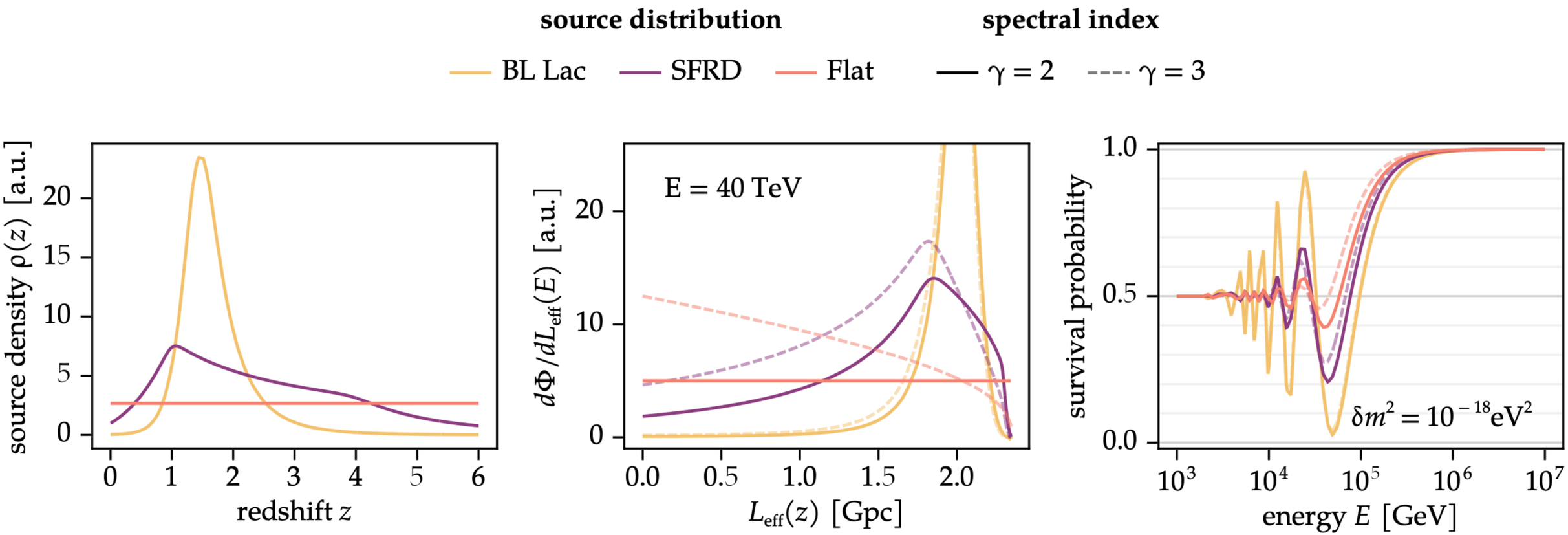
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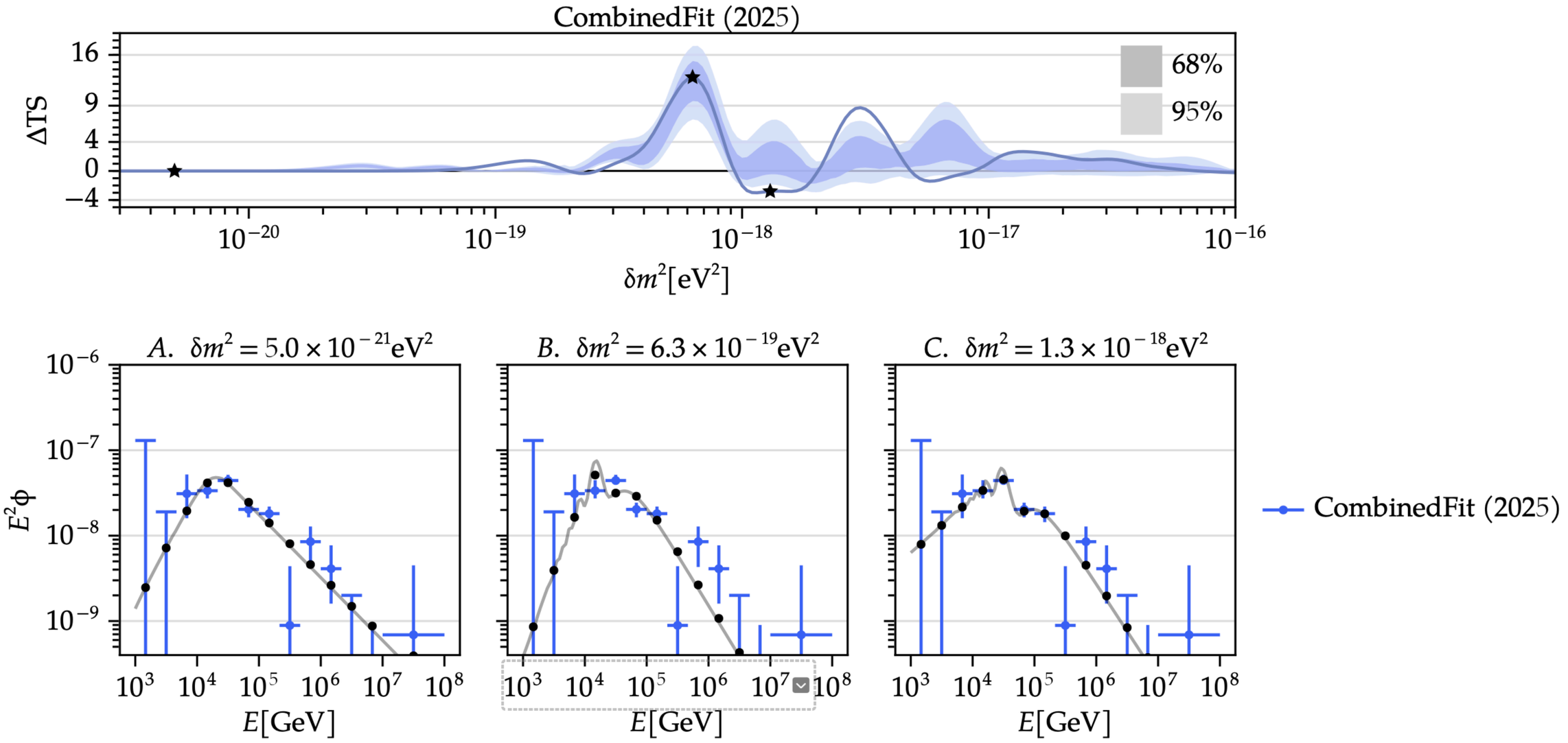
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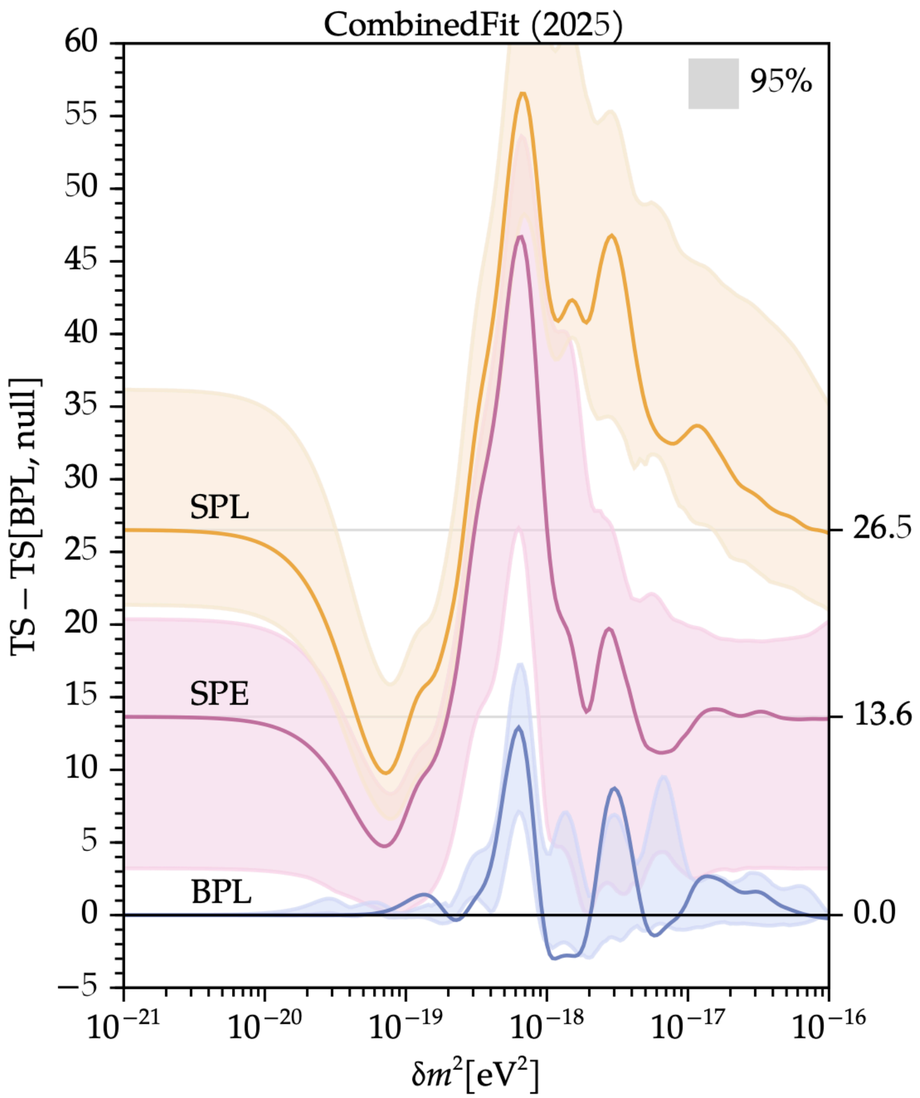
K. Carloni, J. Porto, CA, B. Dev, S. Jana (arXiv:2503.19960, *Phys.Rev.D* 113 (2026) 11, 115004)

Fit to the all-sky neutrino data



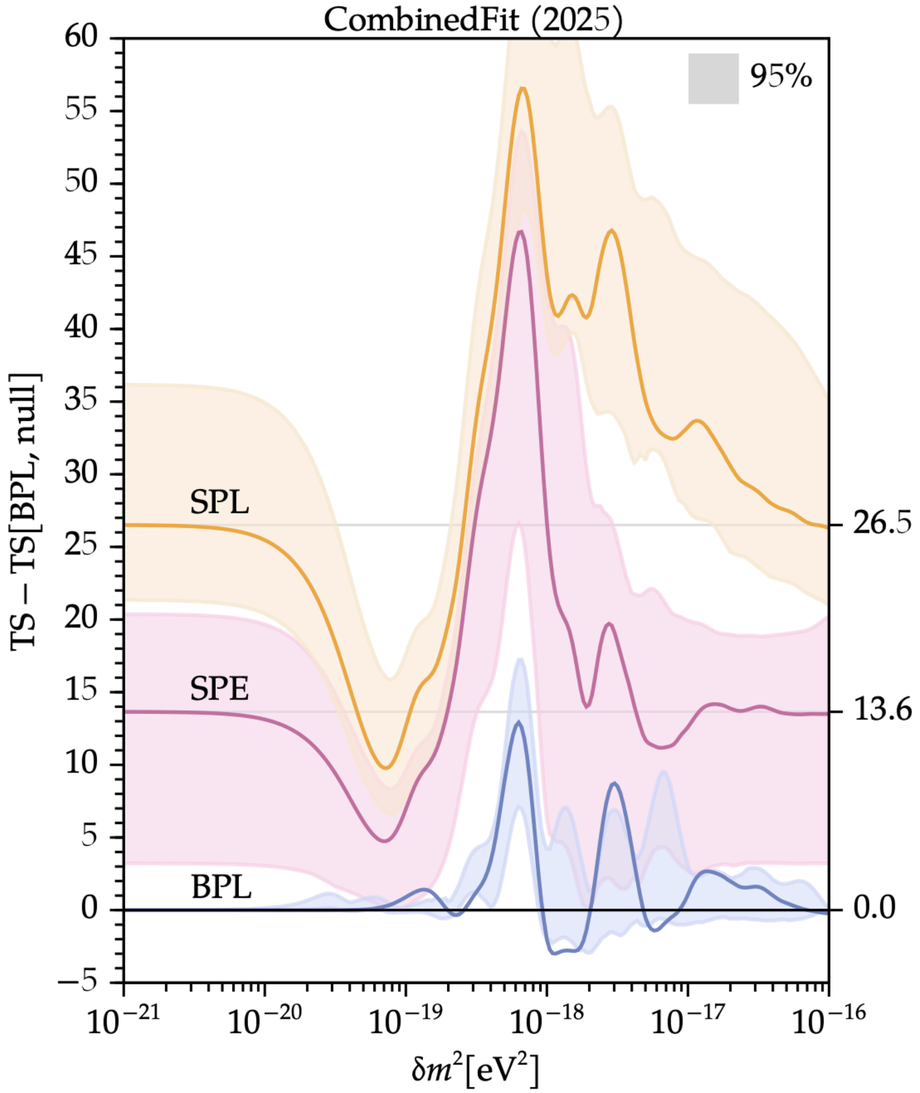
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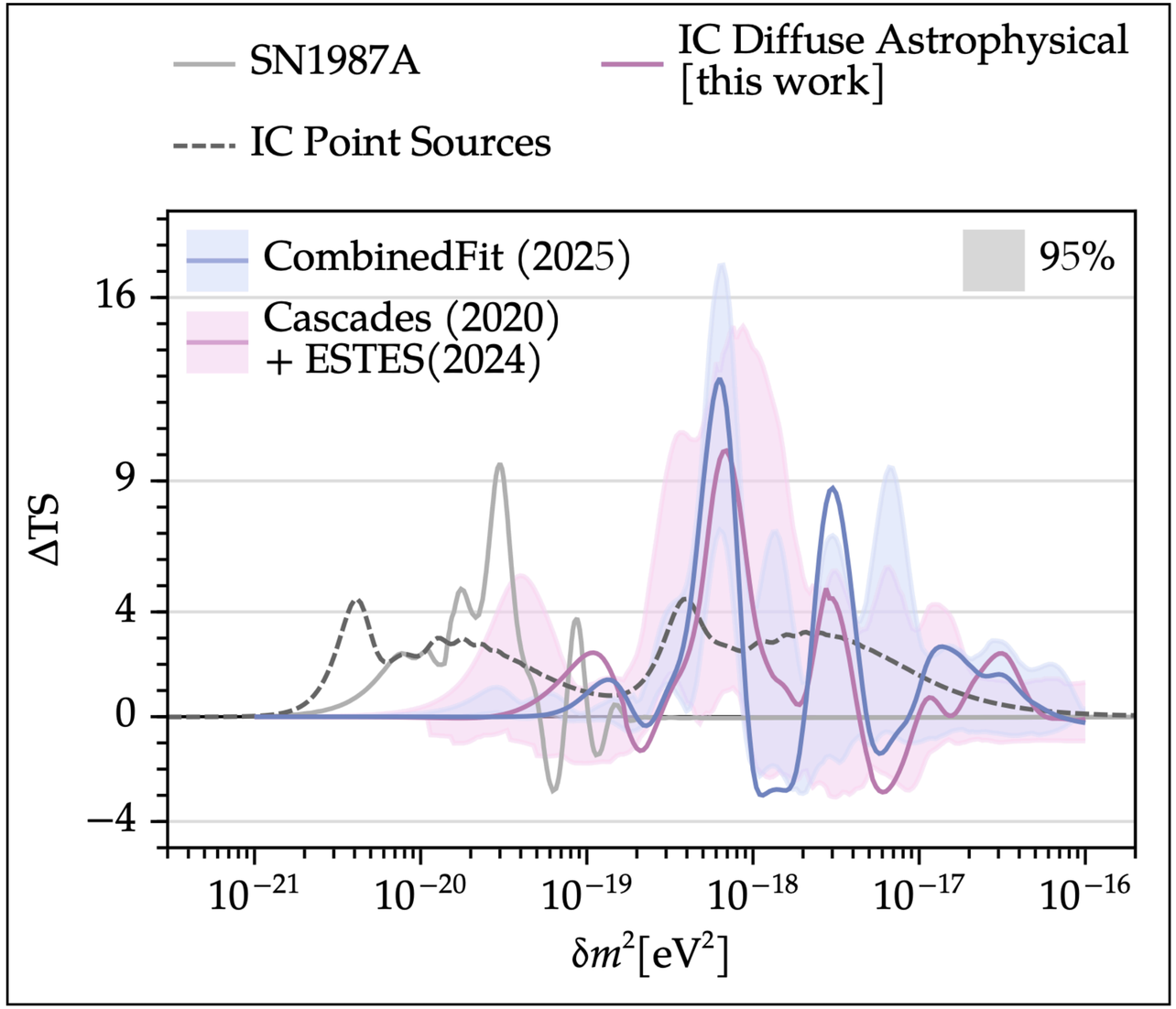
New Constraints on Hyper-fine Splittings



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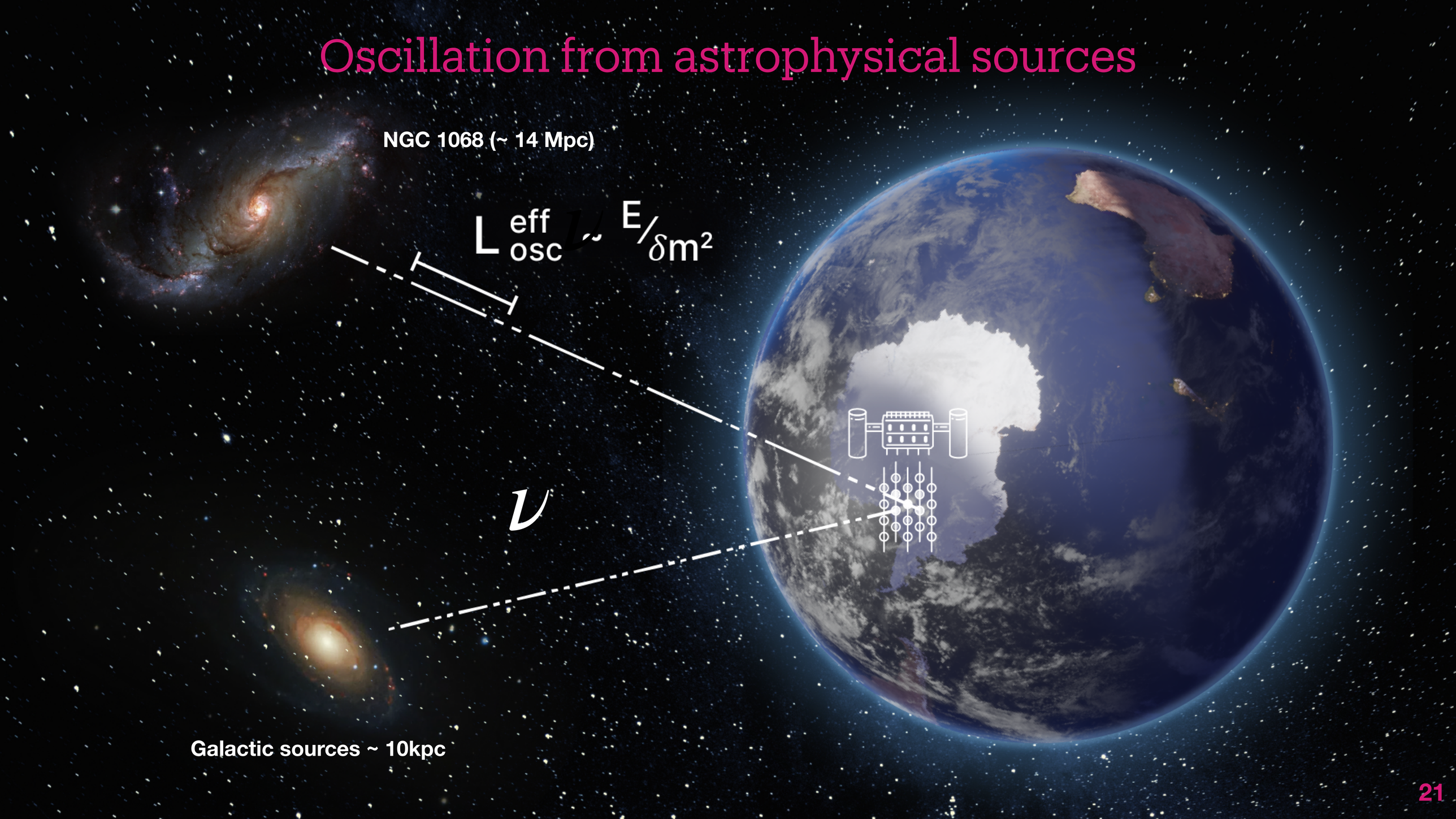




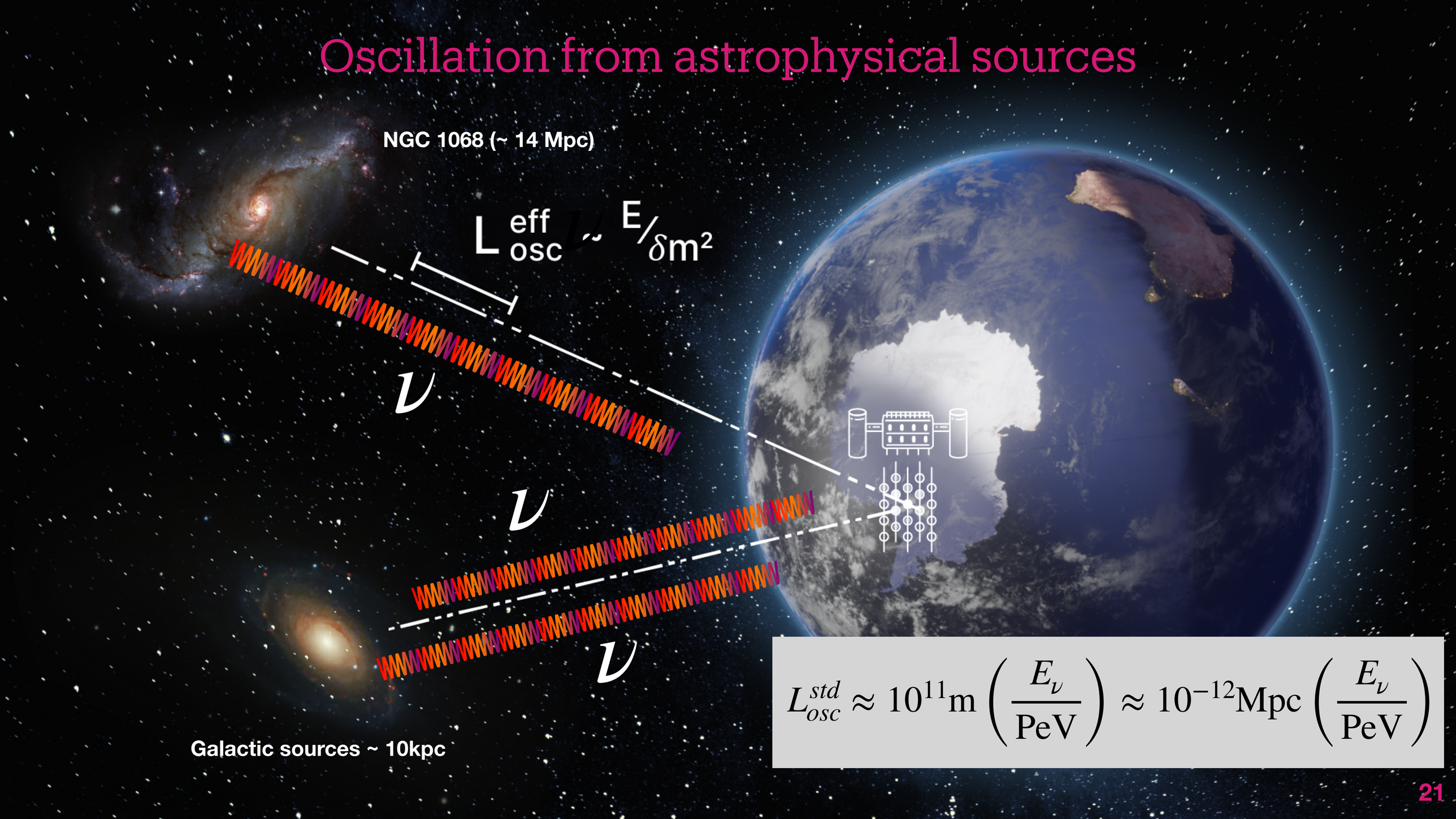
K. Carloni, J. Porto, CA, B. Dev, S. Jana (arXiv:2503.19960, *Phys.Rev.D* 113 (2026) 11, 115004)

Neutrino Flavor At Very-High Energies

Oscillation from astrophysical sources

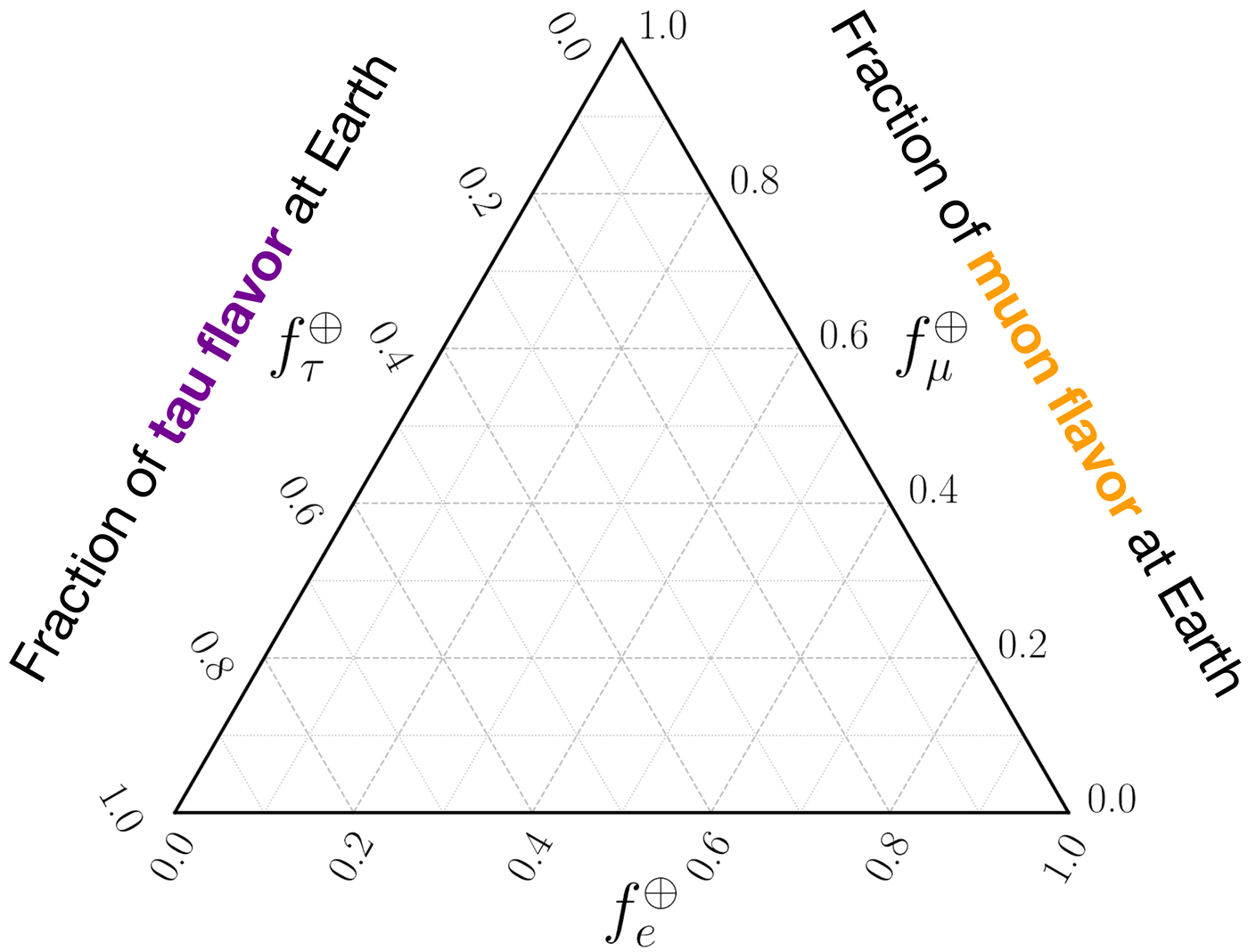


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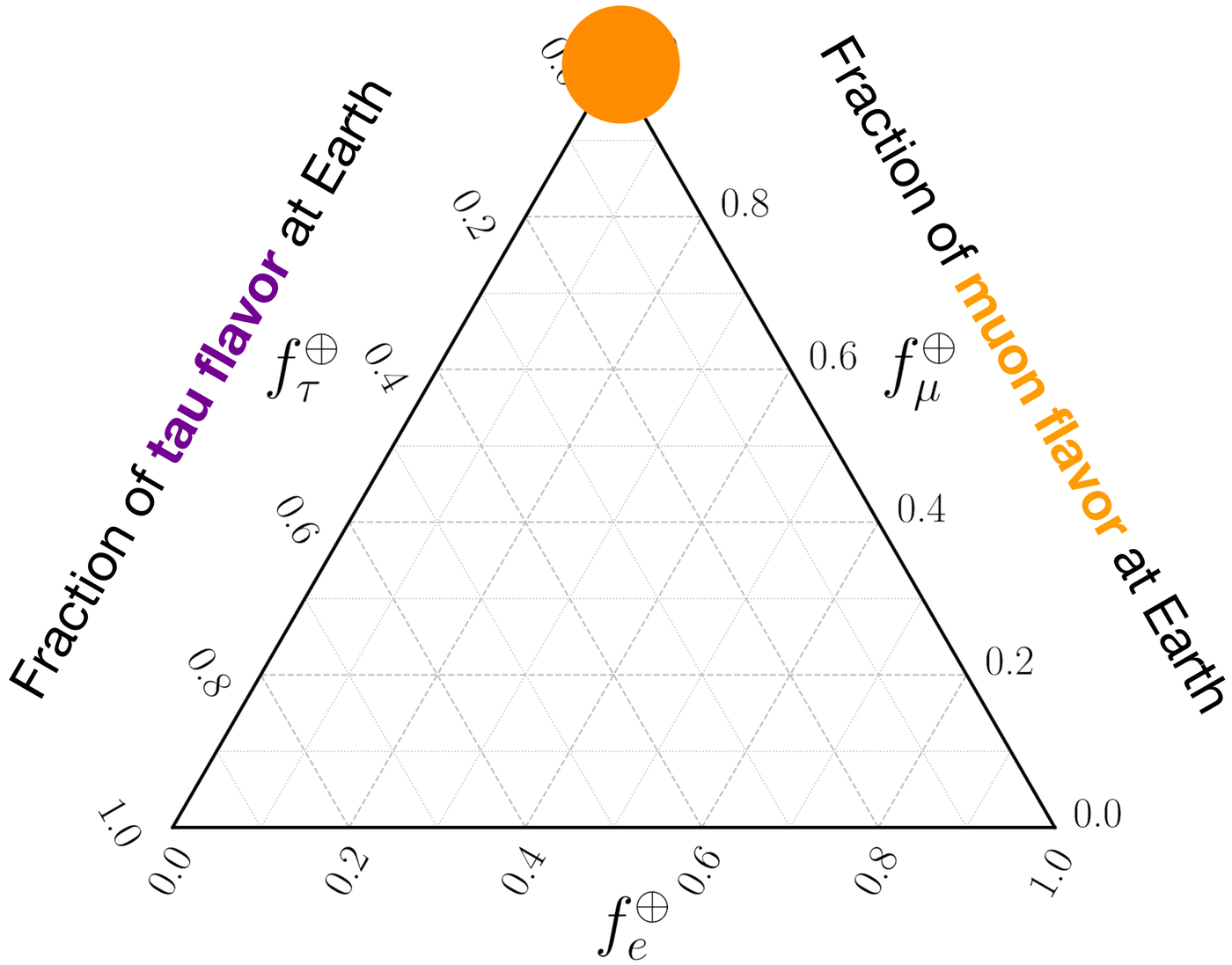
$$L_{osc}^{std} \approx 10^{11}\mathrm{m}\left(\frac{E_\nu}{\mathrm{PeV}}\right) \approx 10^{-12}\mathrm{Mpc}\left(\frac{E_\nu}{\mathrm{PeV}}\right)$$

Oscillations are very fast: we measure flavor averages at Earth



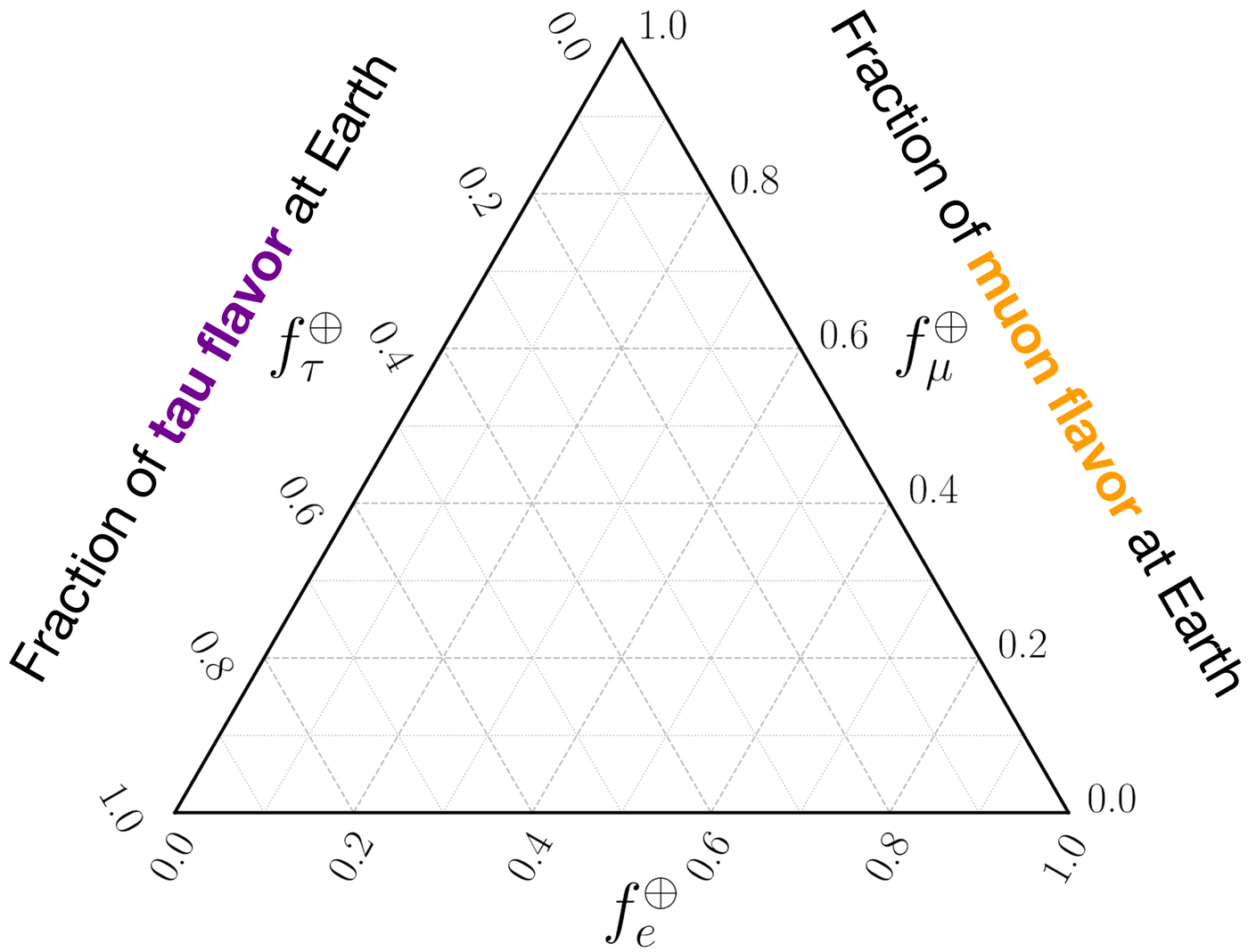
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100% muon neutrino

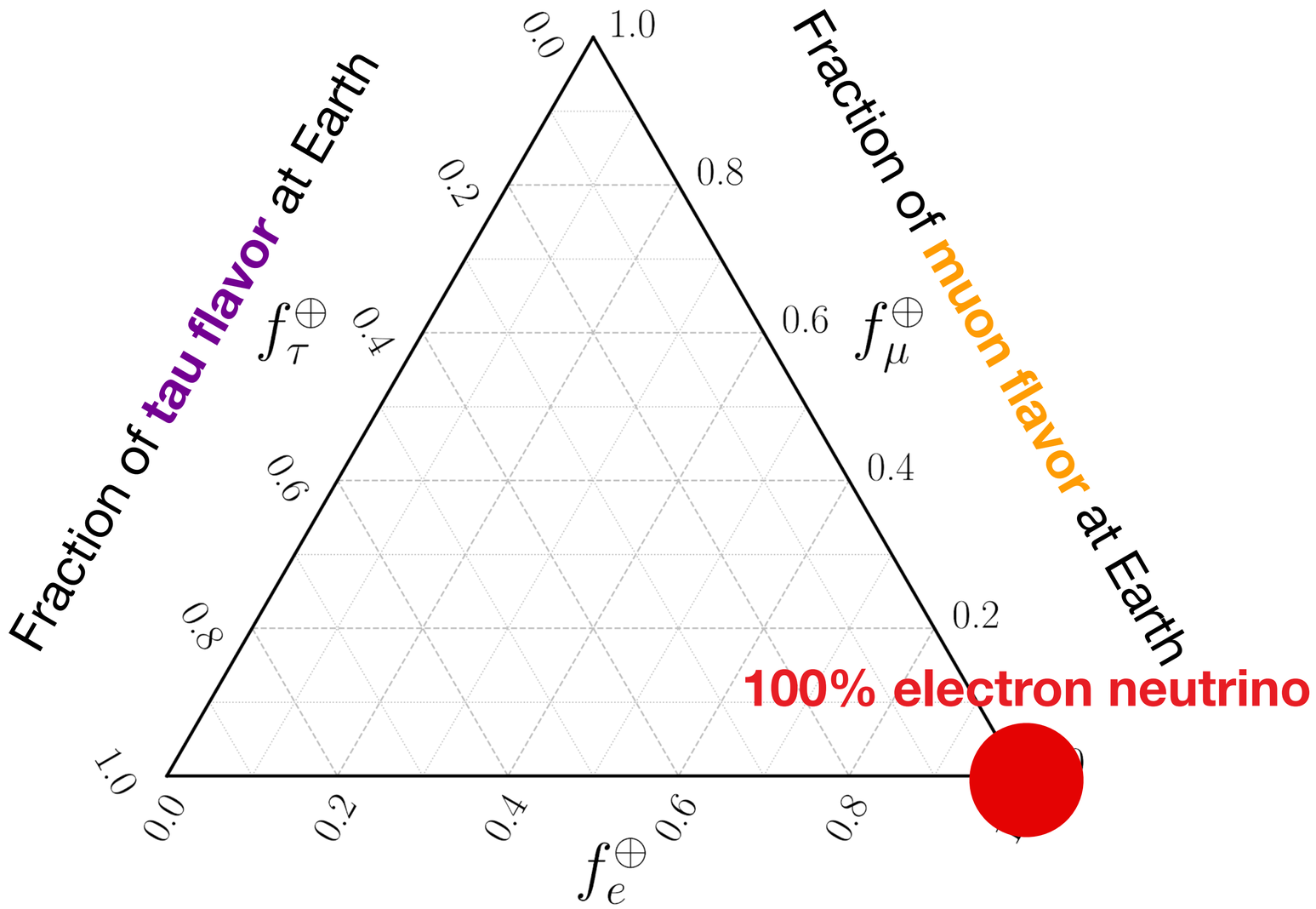


Fraction of **electron flavor** at Earth

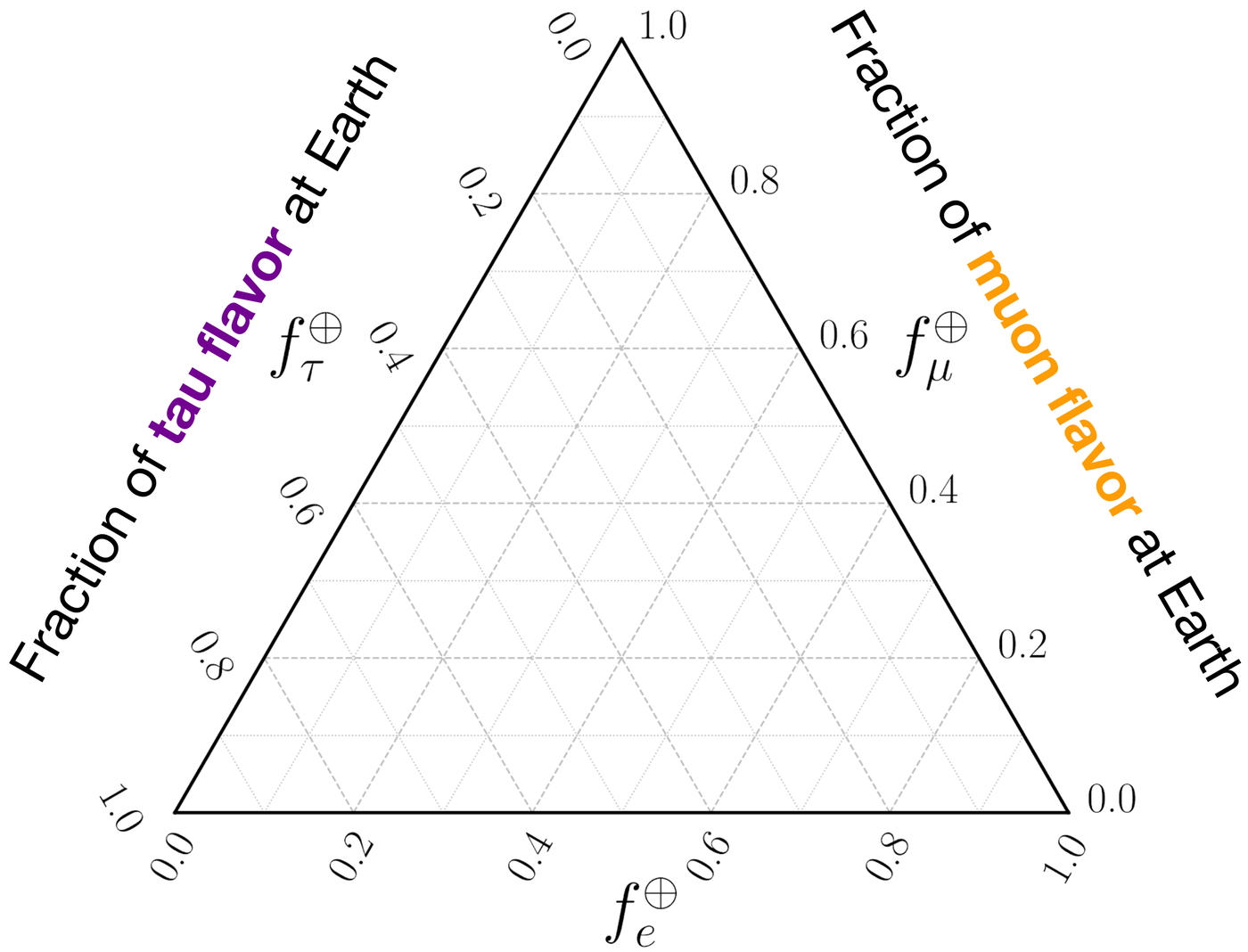
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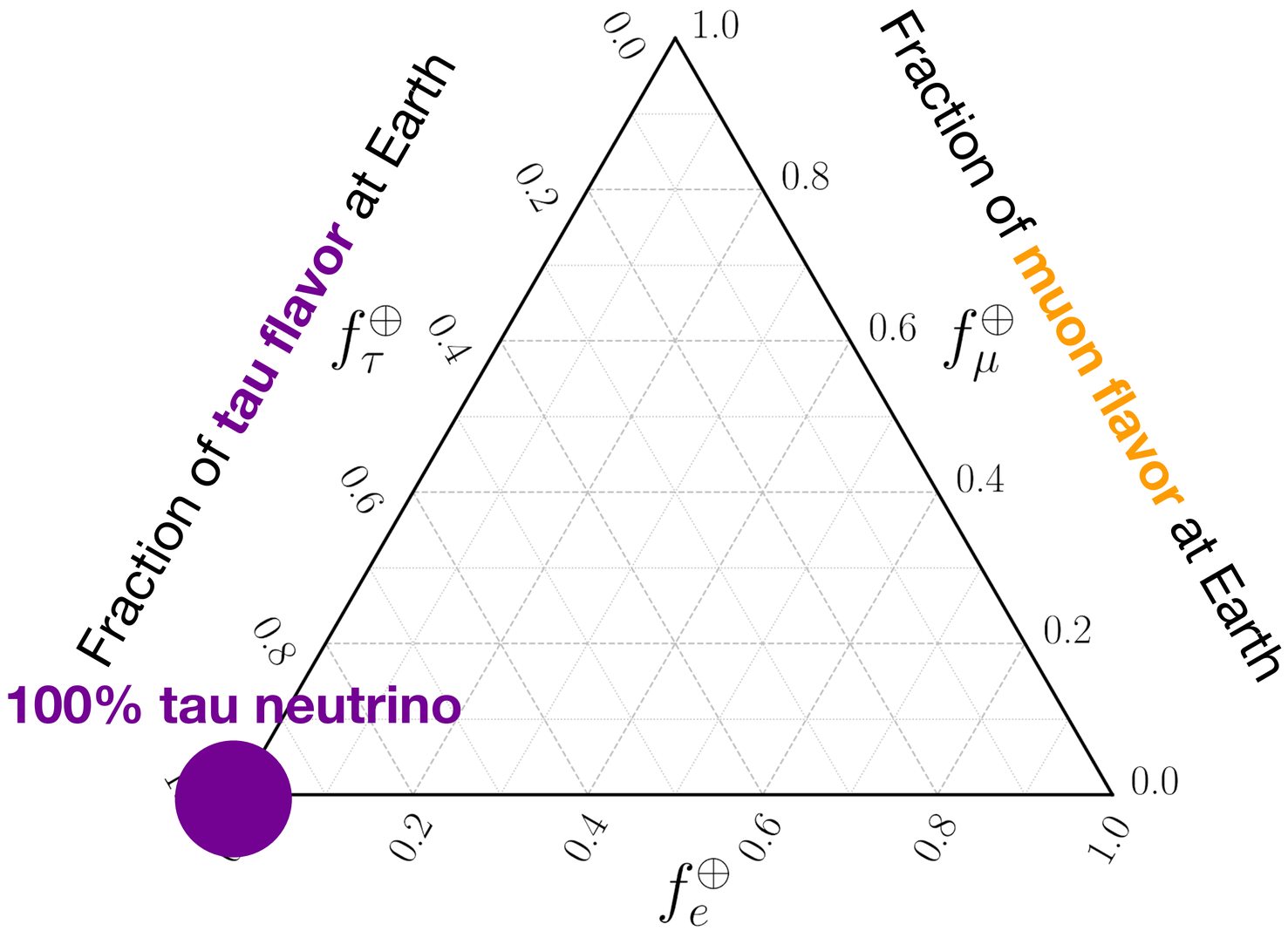
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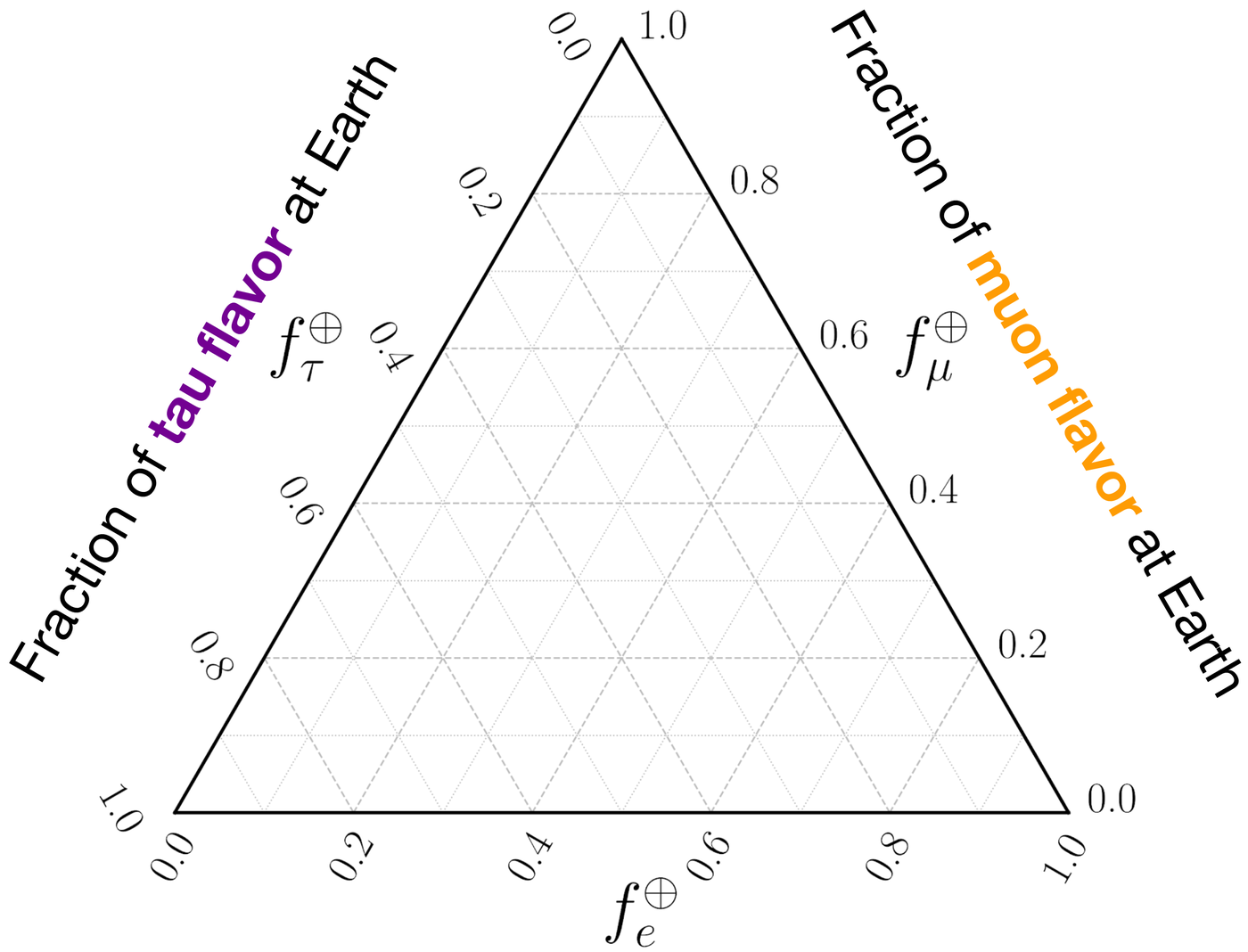
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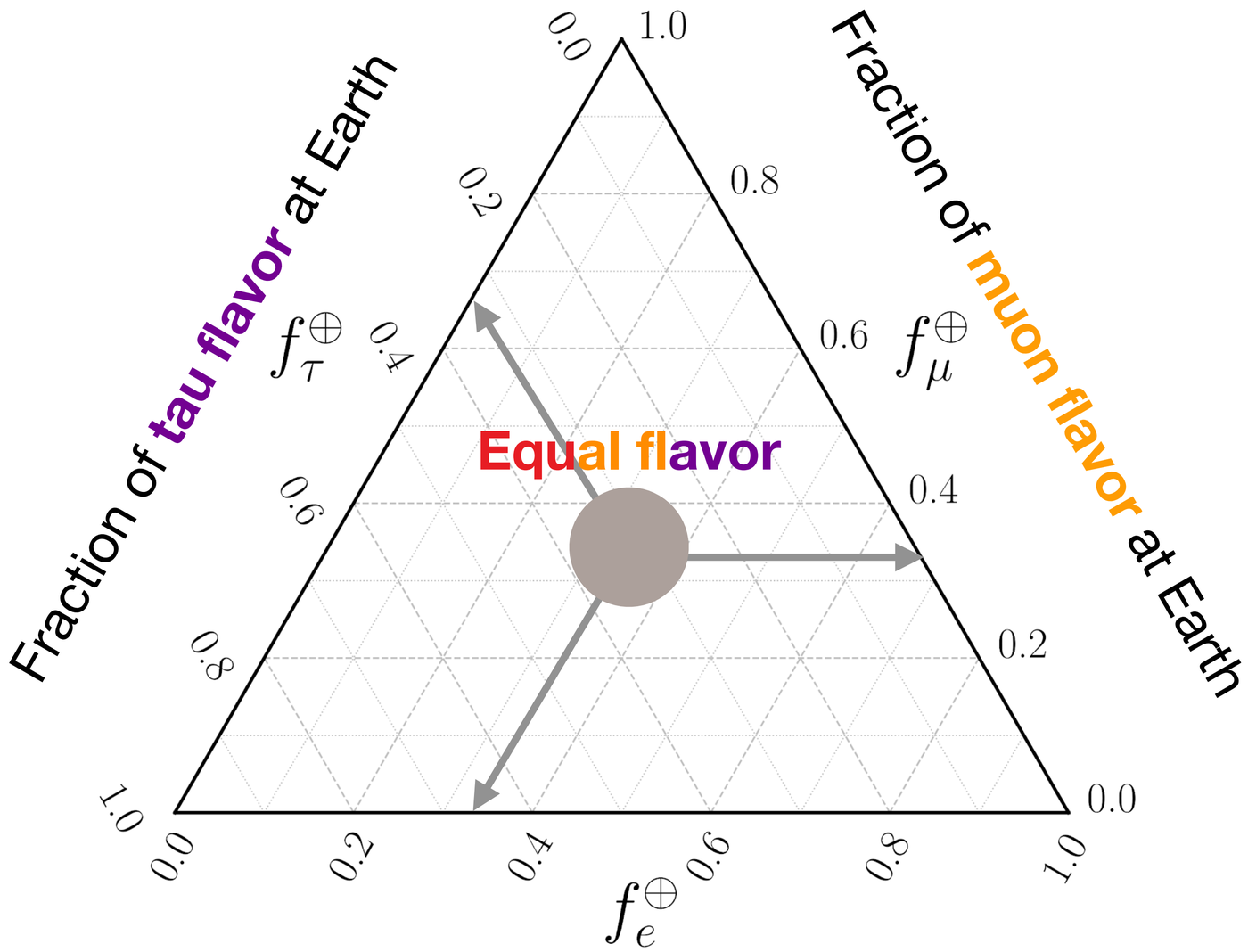
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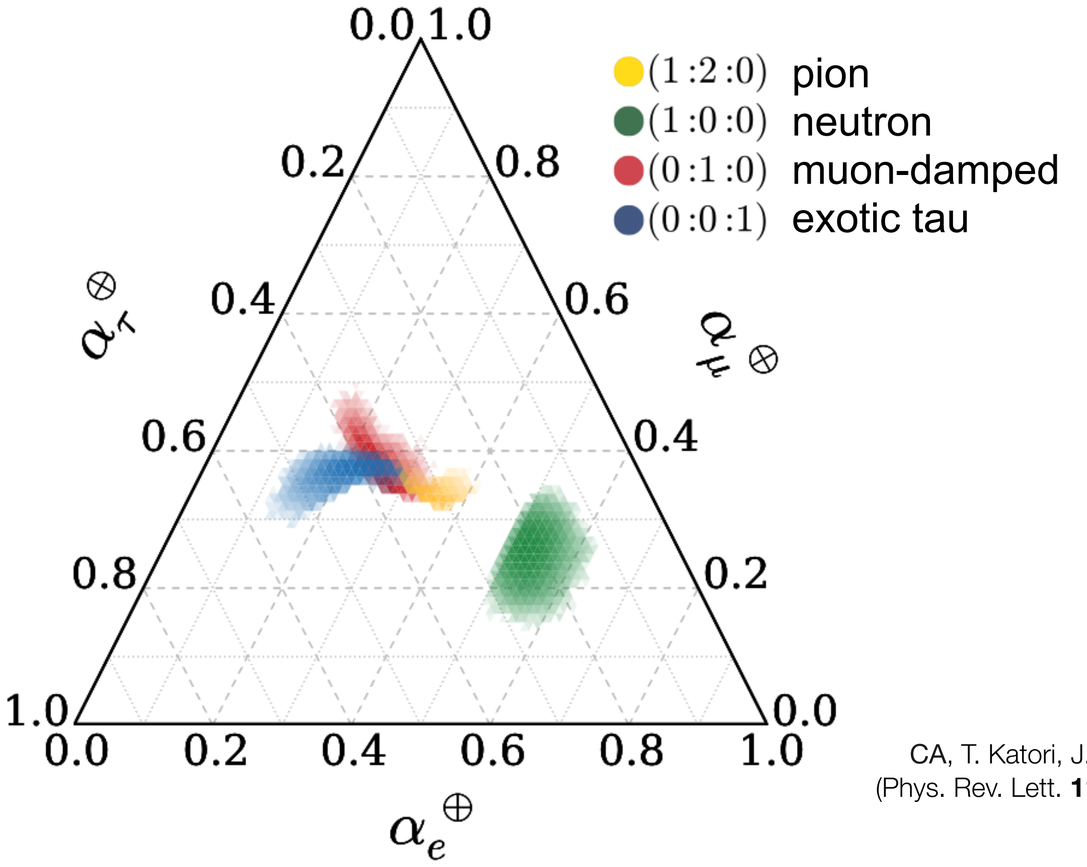


Oscillations are very fast: we measure flavor averages at Earth



After Flavor Oscillations: Where Would different sources end up?

Measuring a flavor composition outside of these regions points to new physics!

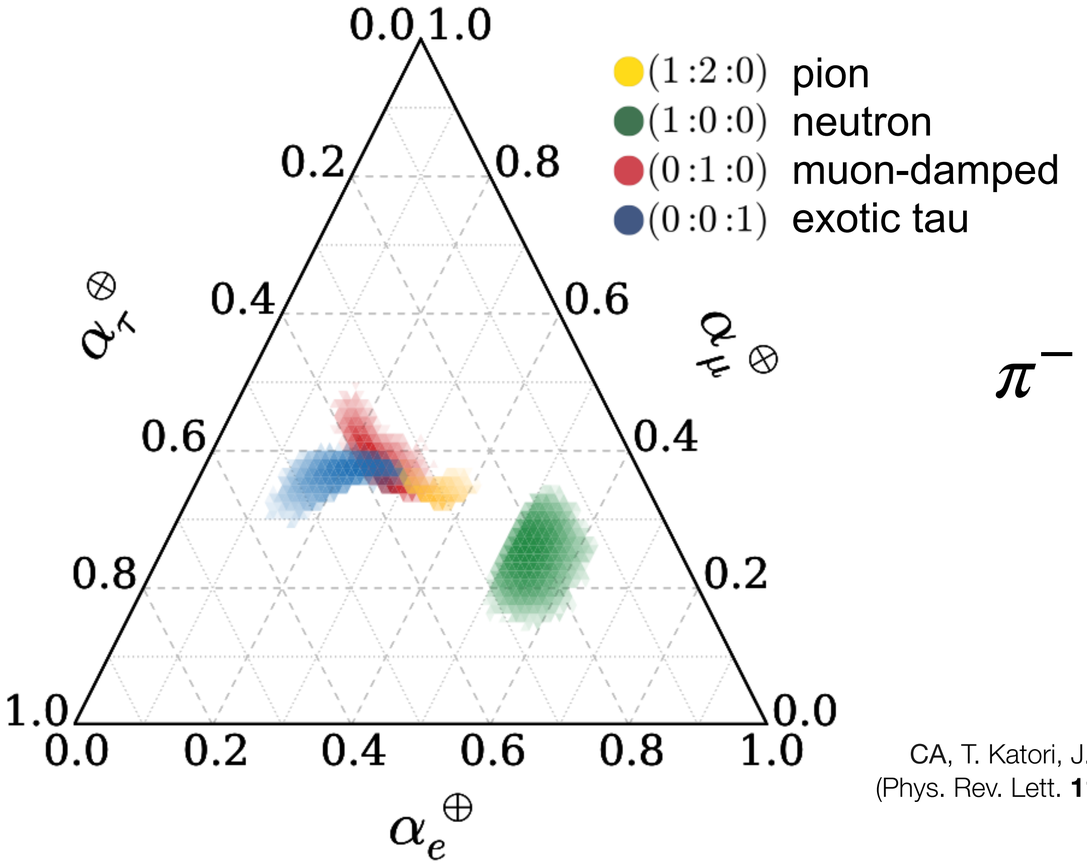


CA, T. Katori, J. Salvado
(Phys. Rev. Lett. **115**, 161303)

See also Bustamante et al. PRL 115, 161302 (2015); Rasmussen et al. 1707.07684; Palomares-Ruiz 1411.2998; Palladino et al 1502.02923; Bustamante et al 1610.02096; Brdar et al. 1611.04598; Farzan & Palomares-Ruiz 1810.00892; CA et al. 1909.05341; Learned & Pakvasa hep-ph/9405296 ..

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$$\pi^- \to \mu^- \bar{\nu}_\mu$$

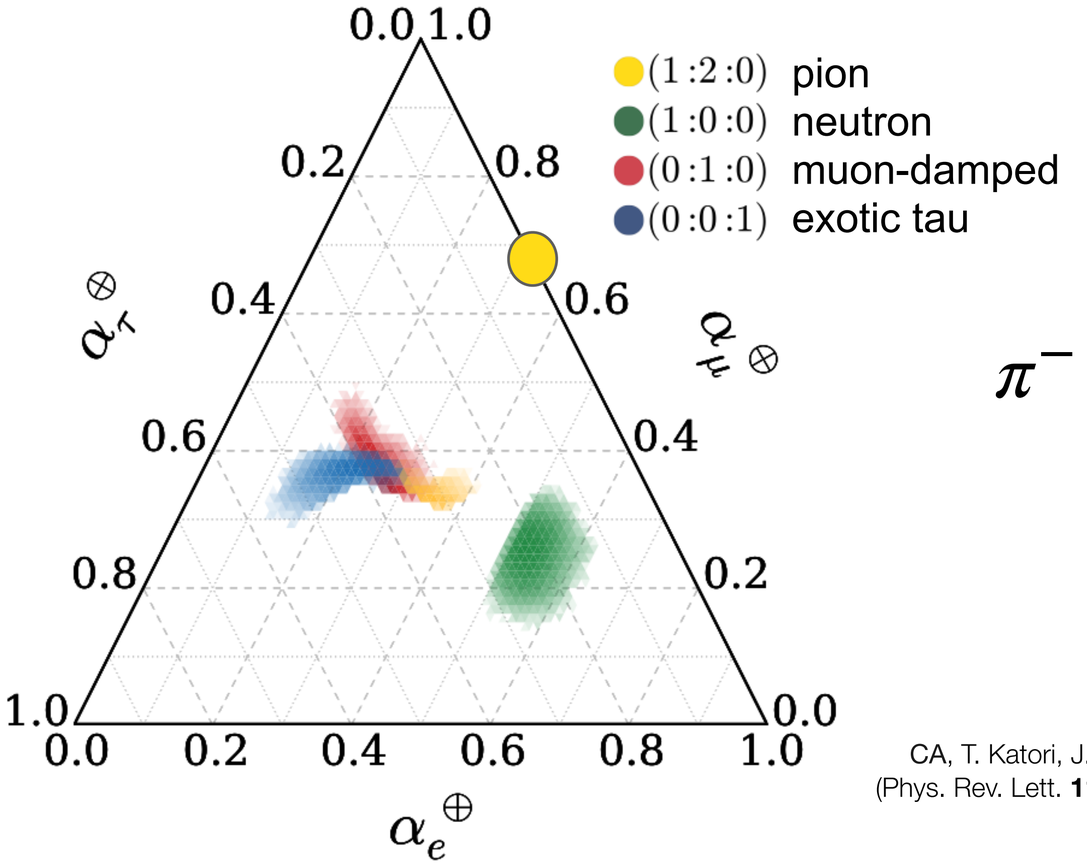
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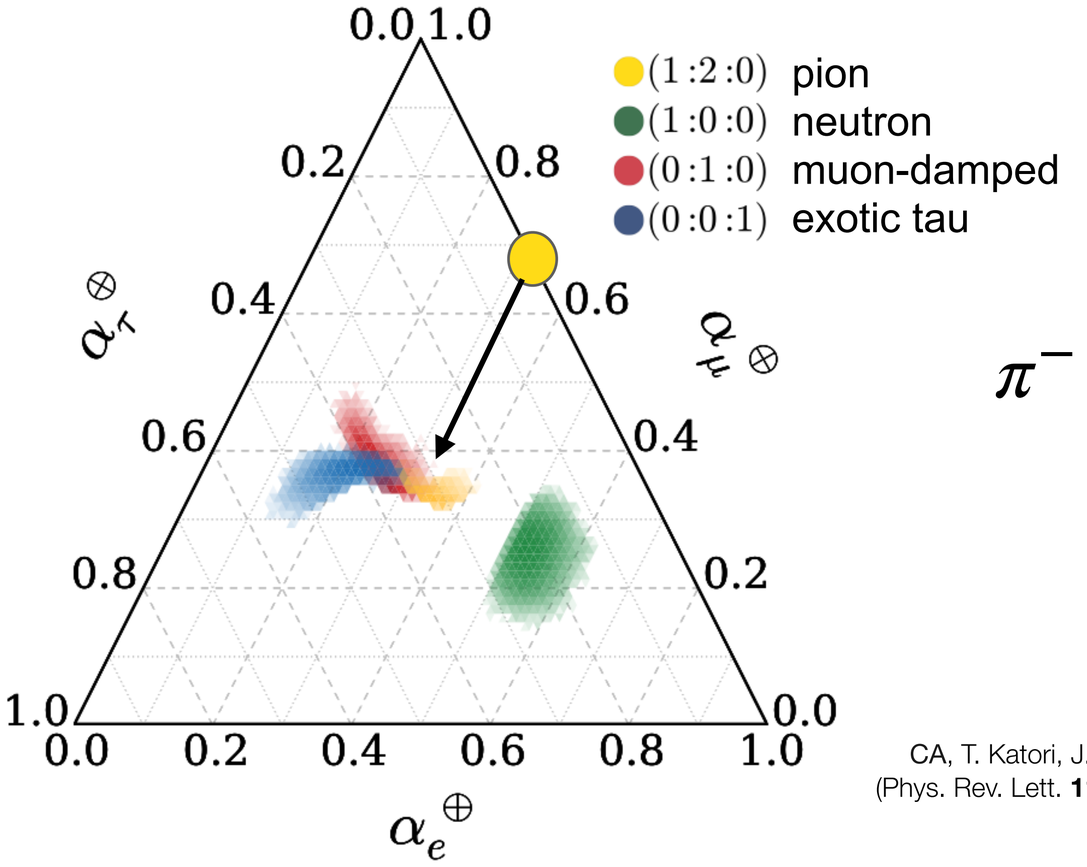
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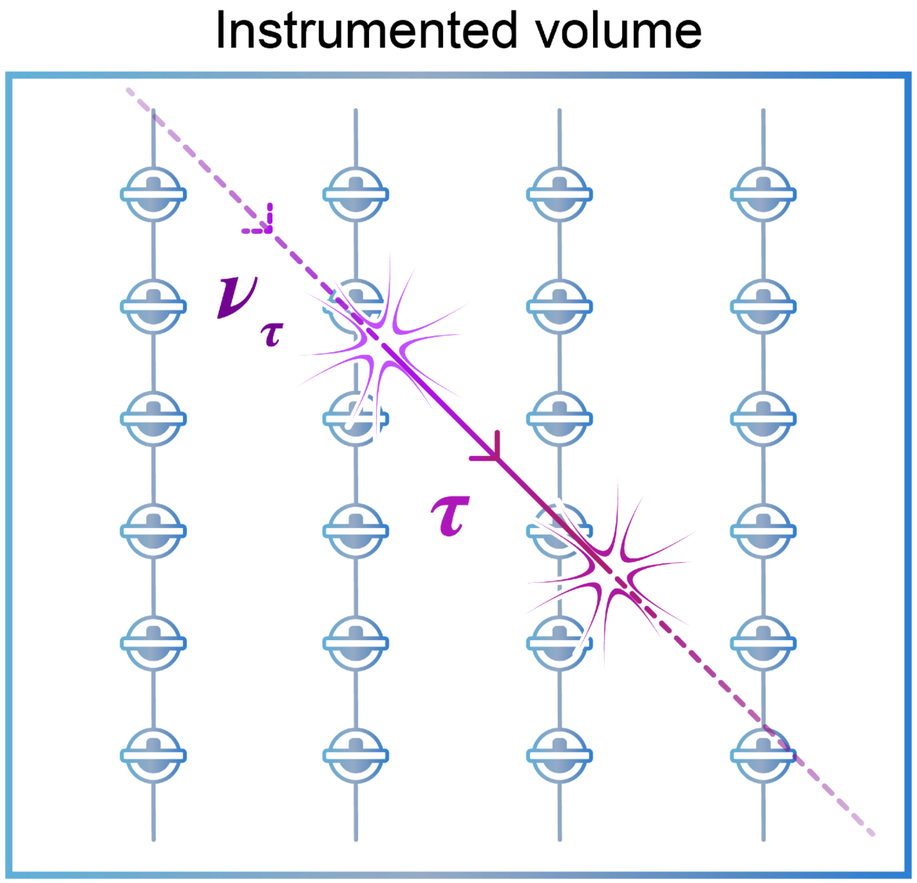
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Tau neutrinos are dominantly produced through oscillations



Tau neutrino measurements important to test oscillation physics

Identification by observing displaced vertecies

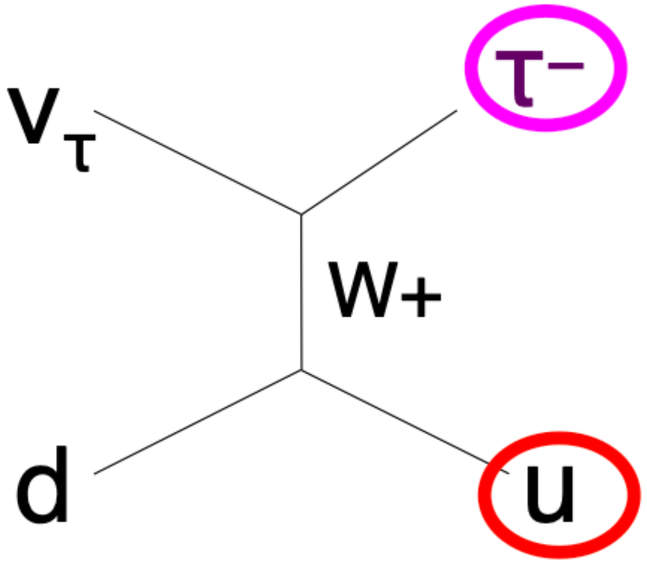
$$L_\tau \approx 50\text{m} \left(\frac{E}{\text{PeV}} \right)$$

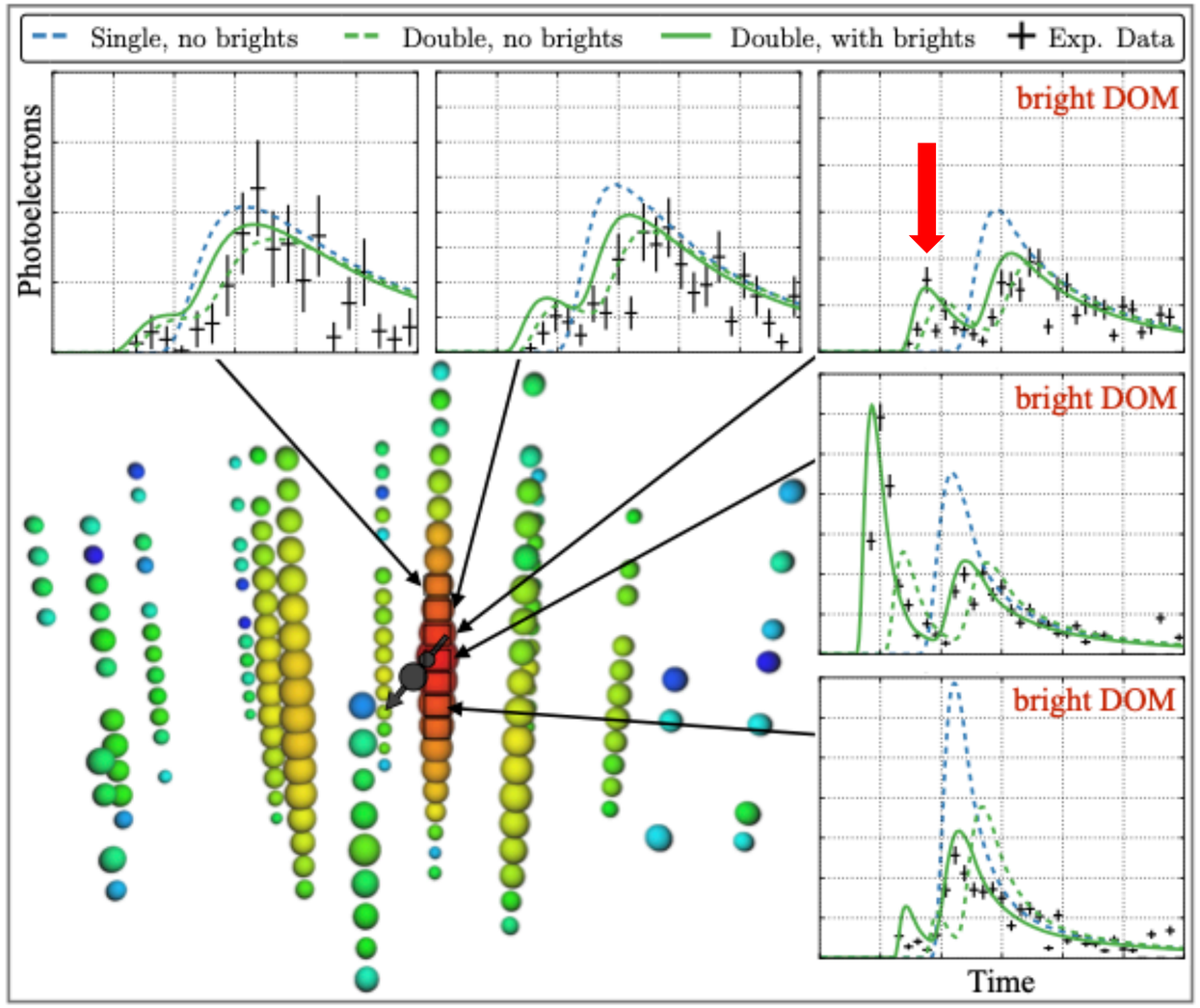
Key observation in IceCube: tau neutrinos

Total deposited energy ~ 90 TeV.

First “bang” in time (shower)

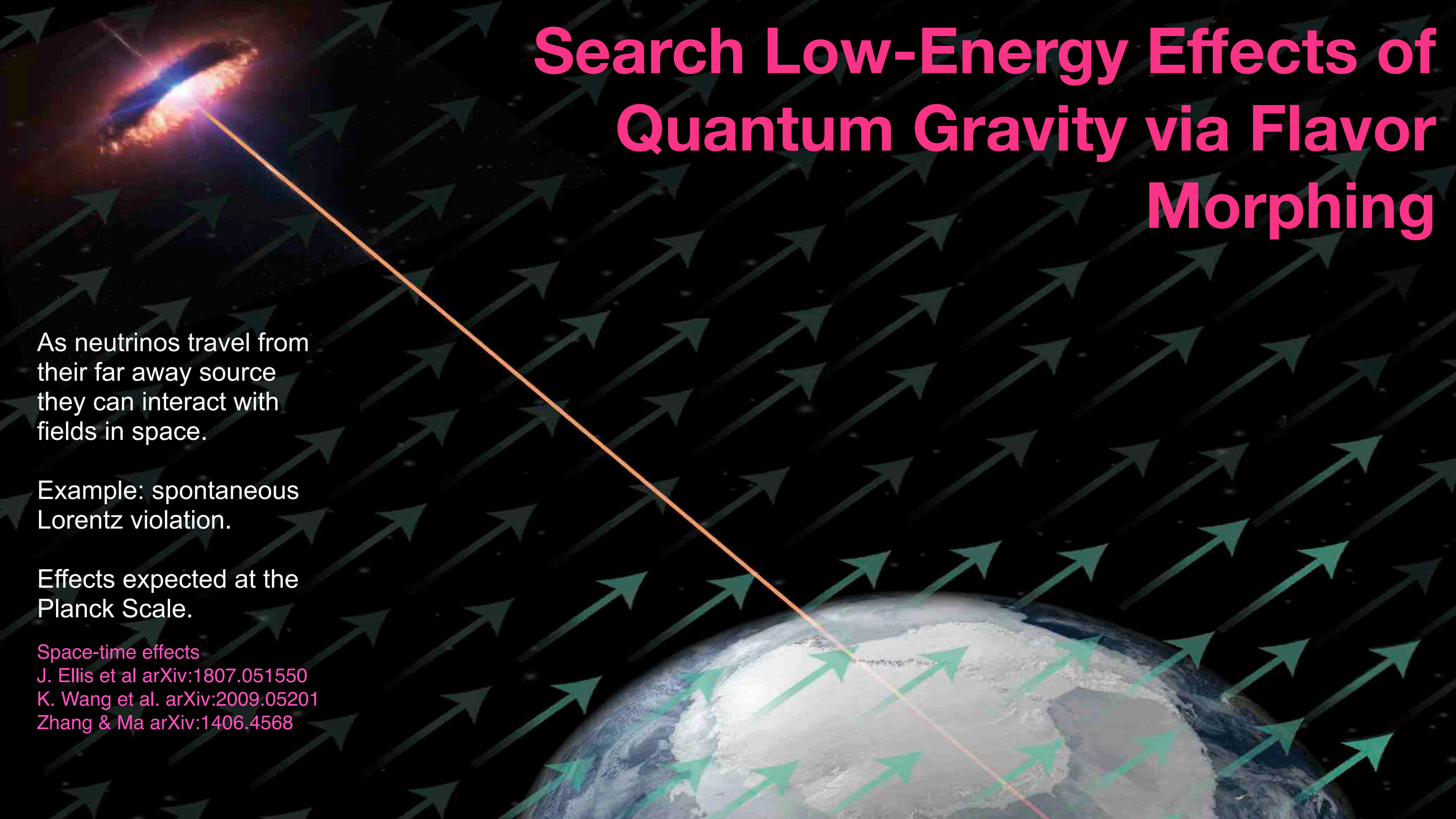
Second “bang” in time (tau decay)





IceCube, Eur. Phys. J. C 82, 1031 (2022); see also IceCube Phys.Rev.Lett. 132 (2024) 15, 151001

Search Low-Energy Effects of Quantum Gravity via Flavor Morphing



As neutrinos travel from their far away source they can interact with fields in space.

Example: spontaneous Lorentz violation.

Effects expected at the Planck Scale.

Space-time effects
J. Ellis et al arXiv:1807.051550
K. Wang et al. arXiv:2009.05201
Zhang & Ma arXiv:1406.4568

Flavor triangle trajectories in the presence of new physics

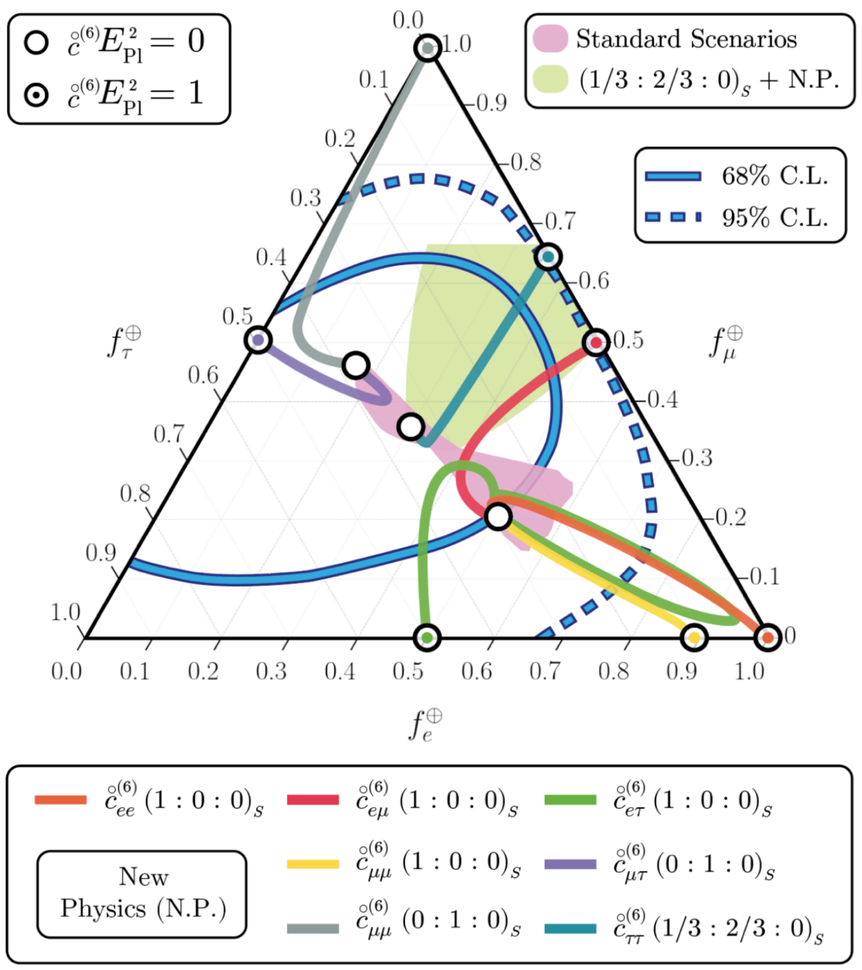
Introduce effective operators with given flavor structure

$$H \supset \frac{E_\nu^d}{\Lambda^{d-1}} \mathcal{O}_{\alpha\beta}$$

$(1:2:0)$ **pion**

$(0:1:0)$ **neutron**

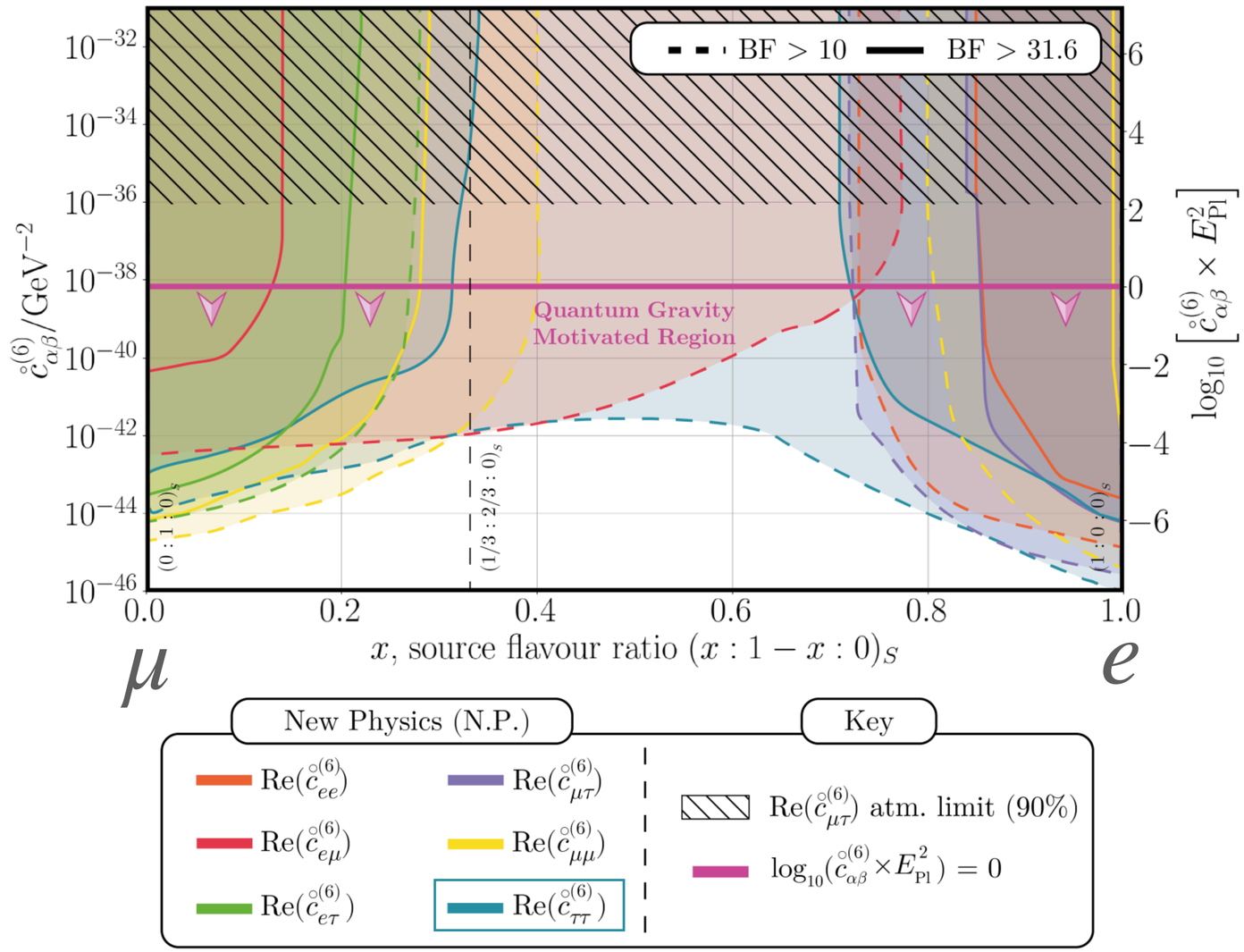
$(1:0:0)$ **muon-damped**



IceCube collaboration *Nature Physics* (2022) arXiv:2111.04654

See also IceCube Physical Review Letters 137 (2026), for improved lower energy flavor measurements from IceCube.

Planck-scale sensitivity with astrophysical neutrino flavor



IceCube collaboration *Nature Physics* (2022) arXiv:2111.04654

Dimension-six operator scale constraint beyond Planck scale for some operators.

Horizontal axis represents astrophysical uncertainty on the initial electron to muon ratio.

Neutrino Cosmography

What is the physics that is opened up by seeing a constellation of neutrino sources?

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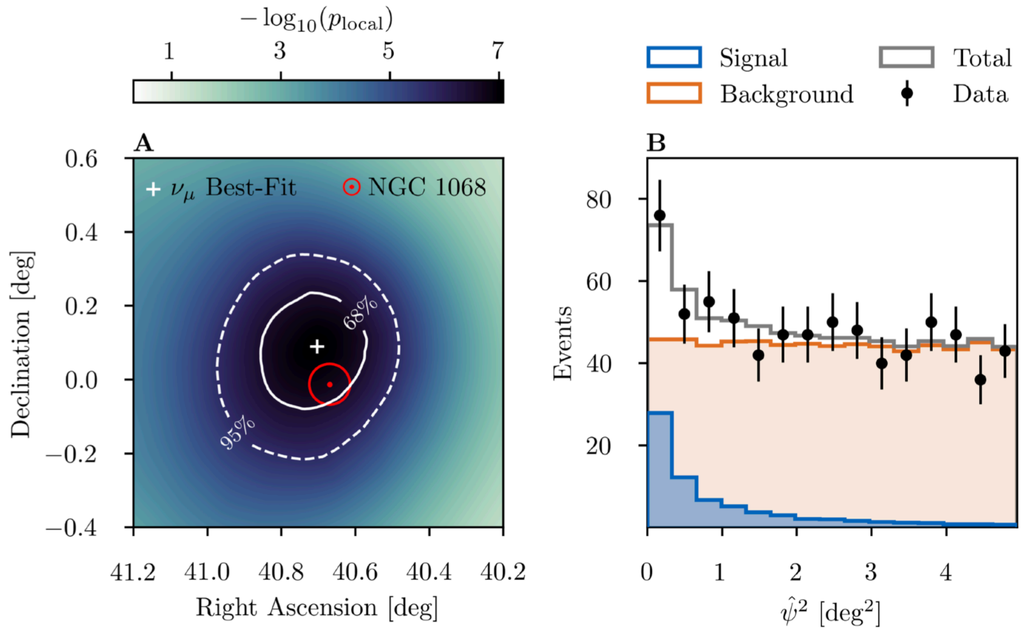
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RESEARCH ARTICLE | NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068



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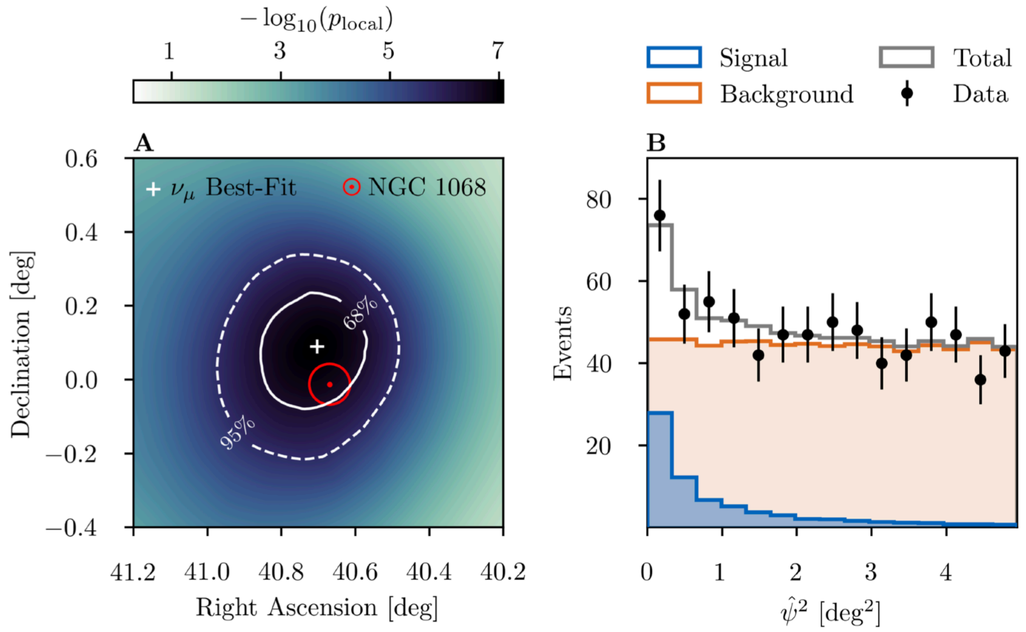
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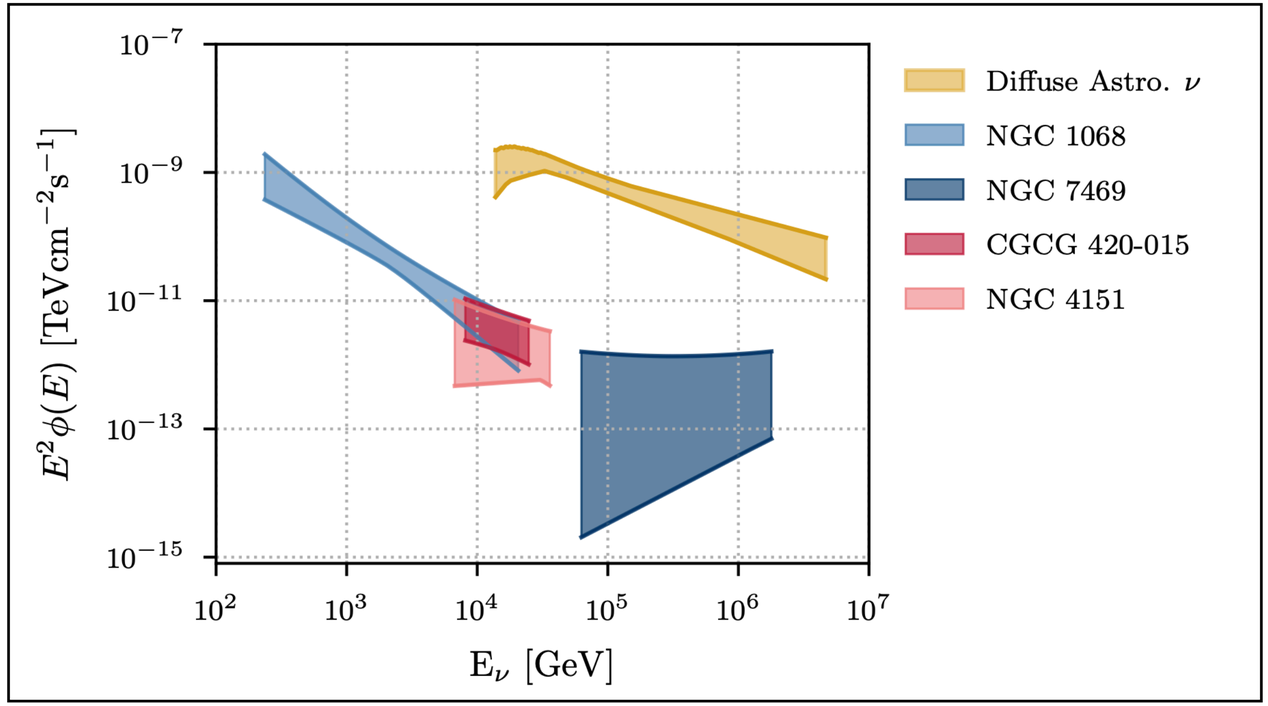
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RESEARCH ARTICLE | NEUTRINO ASTROPHYSICS

Evidence for neutrino emission from the nearby active galaxy NGC 1068



Correlation with population of X-ray bright Seyfert Galaxies



IceCube Coll., *Astrophys.J.* **988** (2025)

Murase, Kimura & Meszaros, Phys. Rev. Lett. 125 (2020); Kheirandish, Murase & Kimura, Astrophys.J. 922 (2021)

Measurement of the Hubble Parameter With Neutrinos

Observed sources by IceCube show correlation between neutrino and X-ray luminosities

$$L_\nu = \kappa L_X^\beta$$

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UNO
Standarize

Neutrino and X-ray luminosities trace the same disk corona

Stecker, Done et al, 91’
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TRES
Measure

Use other galaxies in the Hubble flow to determine $d_L(z; H_0)$

Gonzalo Herrera

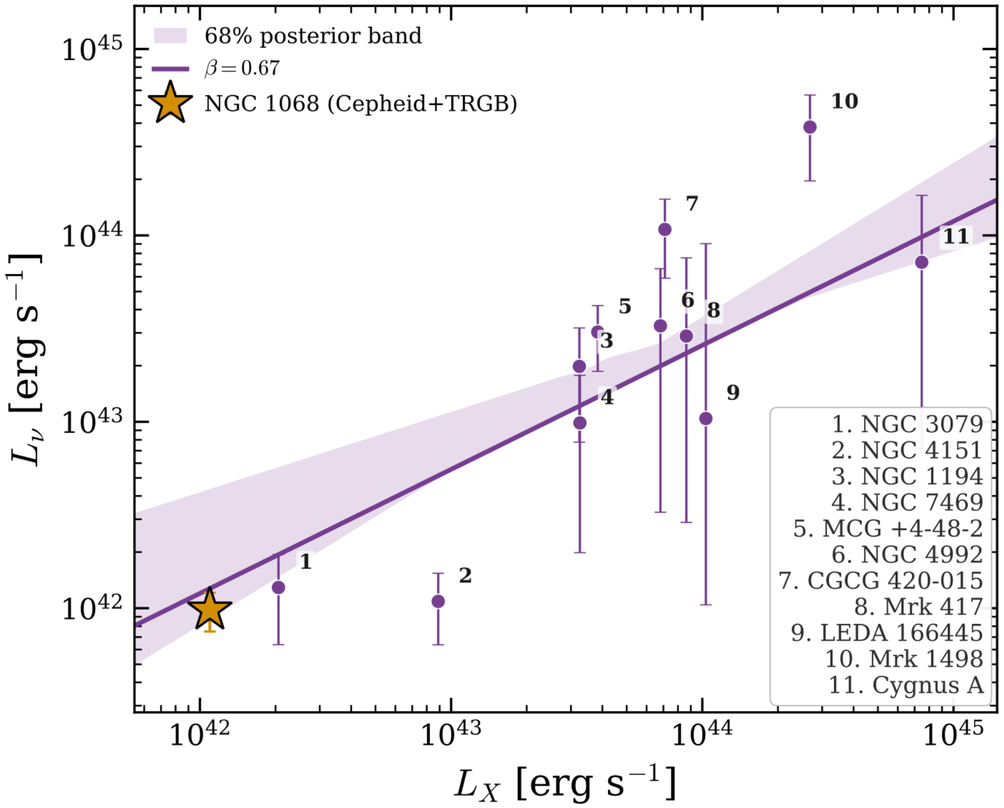


Nicholas Kamp



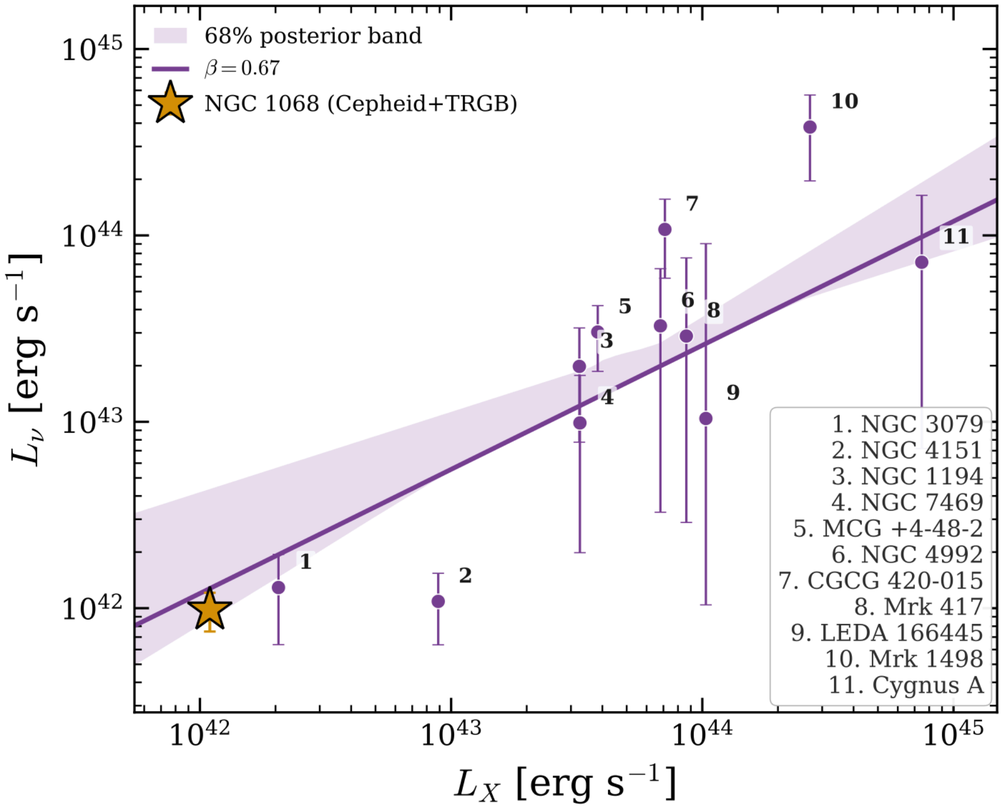
A first measurement of H_0 with neutrinos

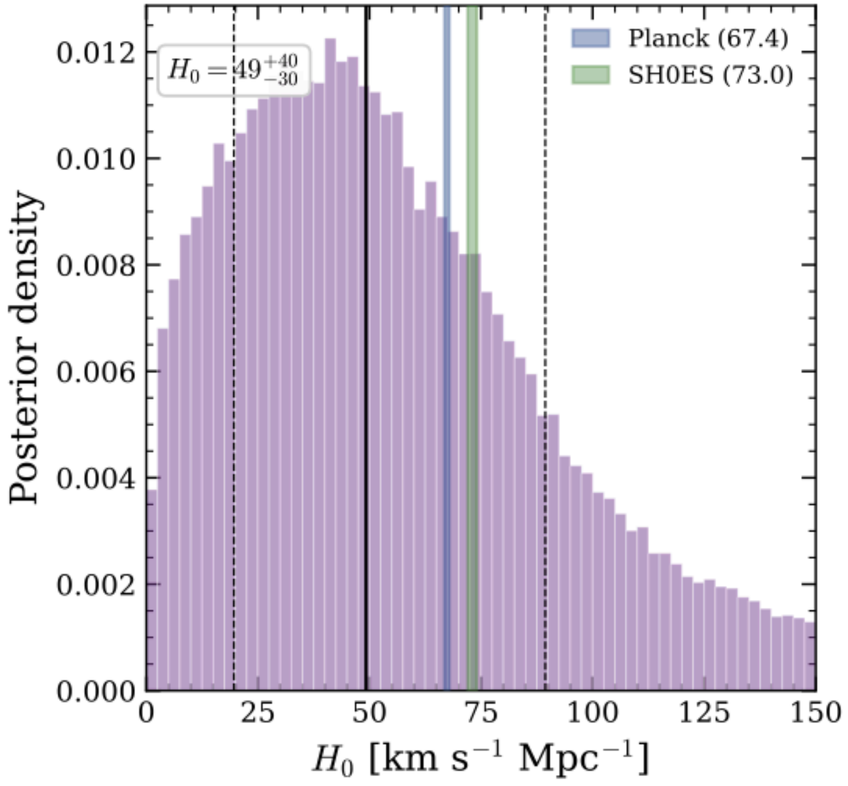
First measurement using Northern-sky sources and existing data. Large errors.



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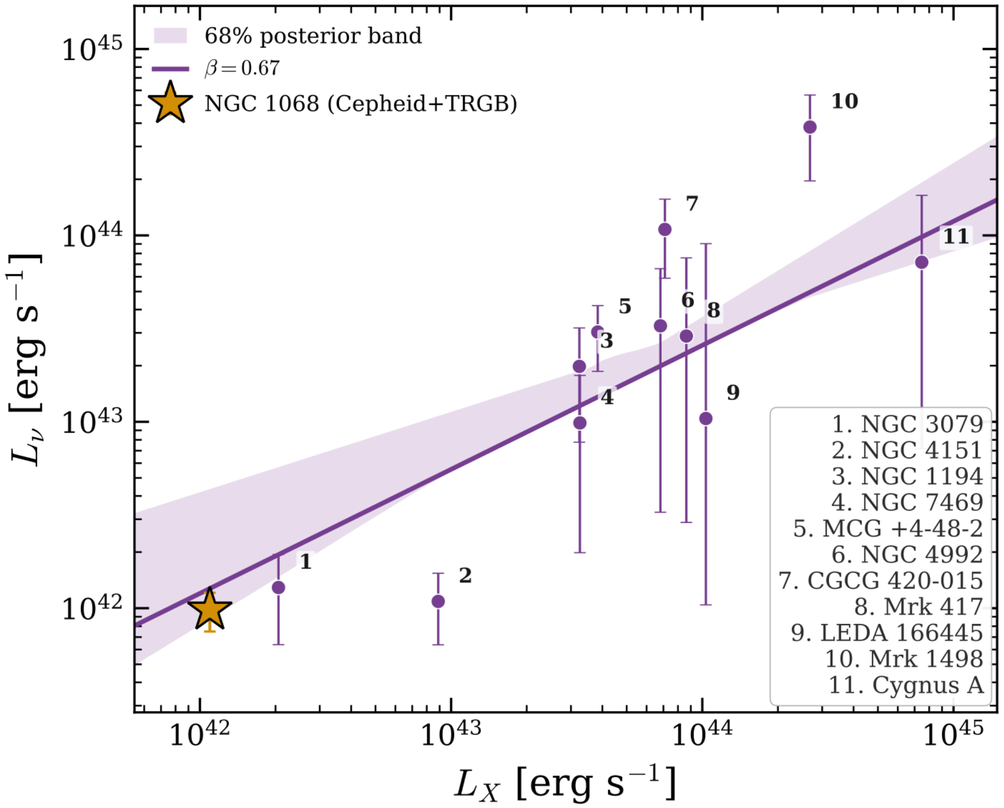
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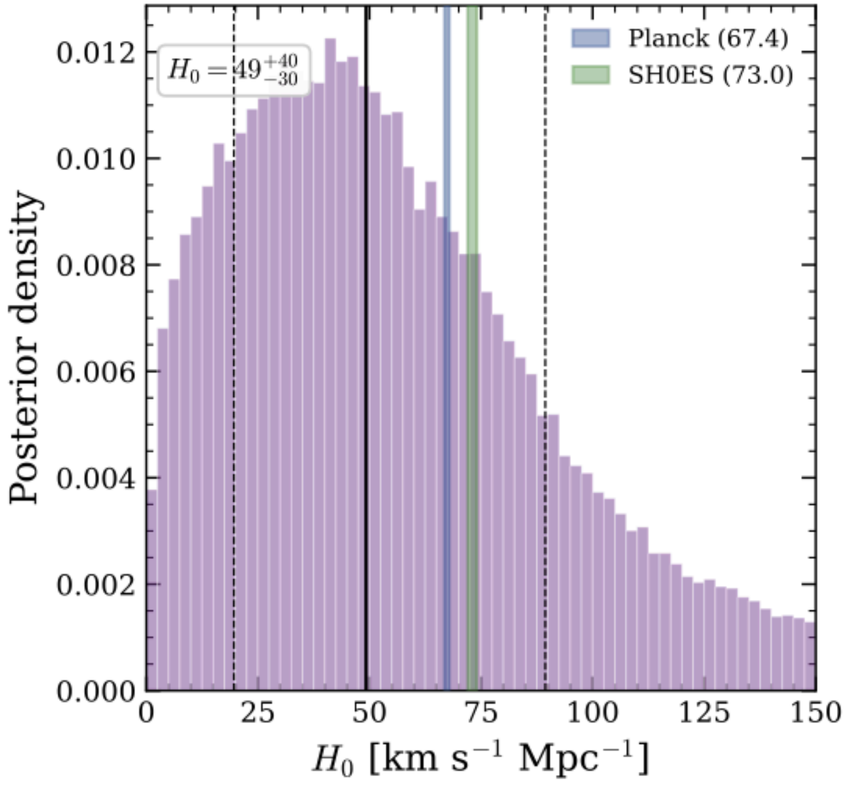


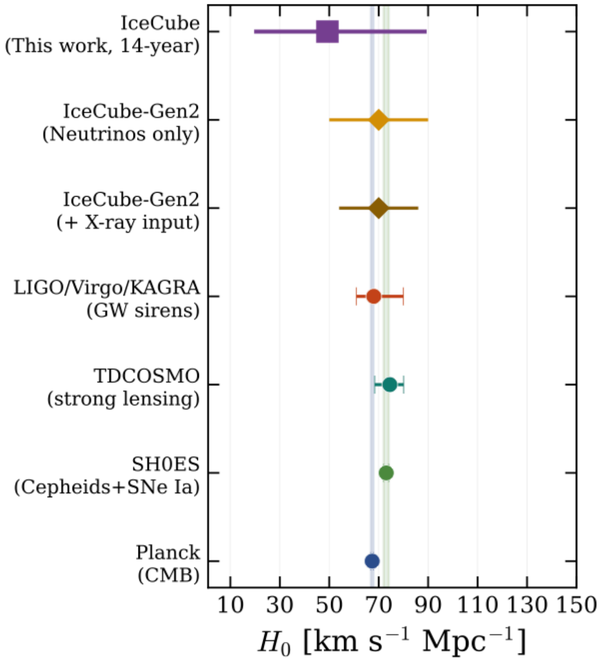


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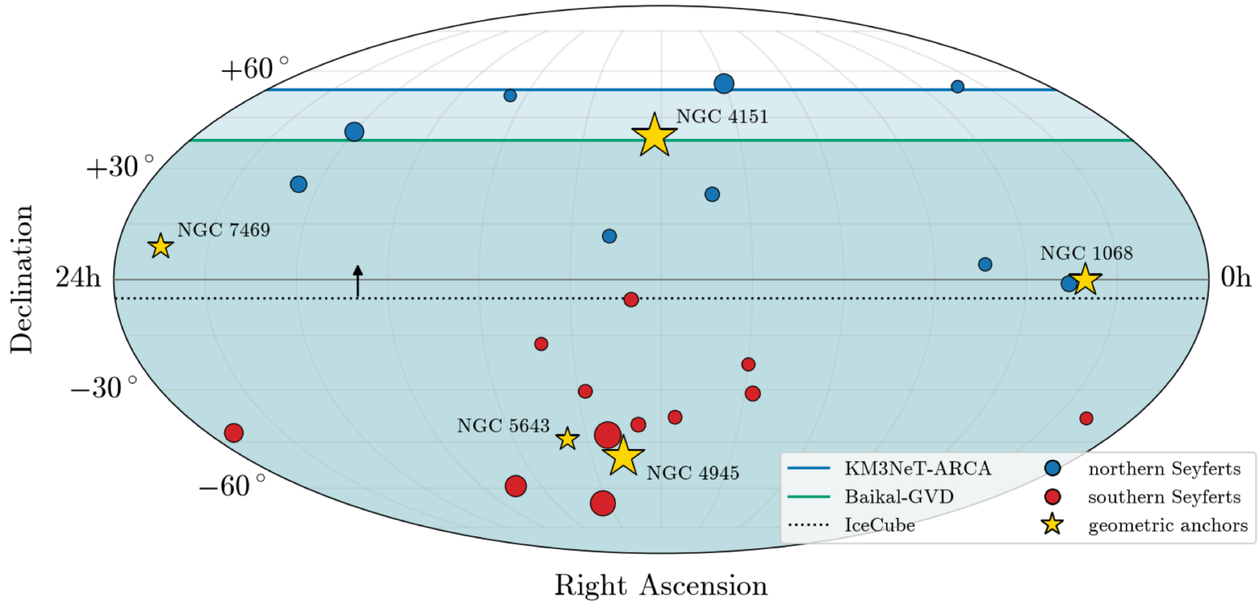


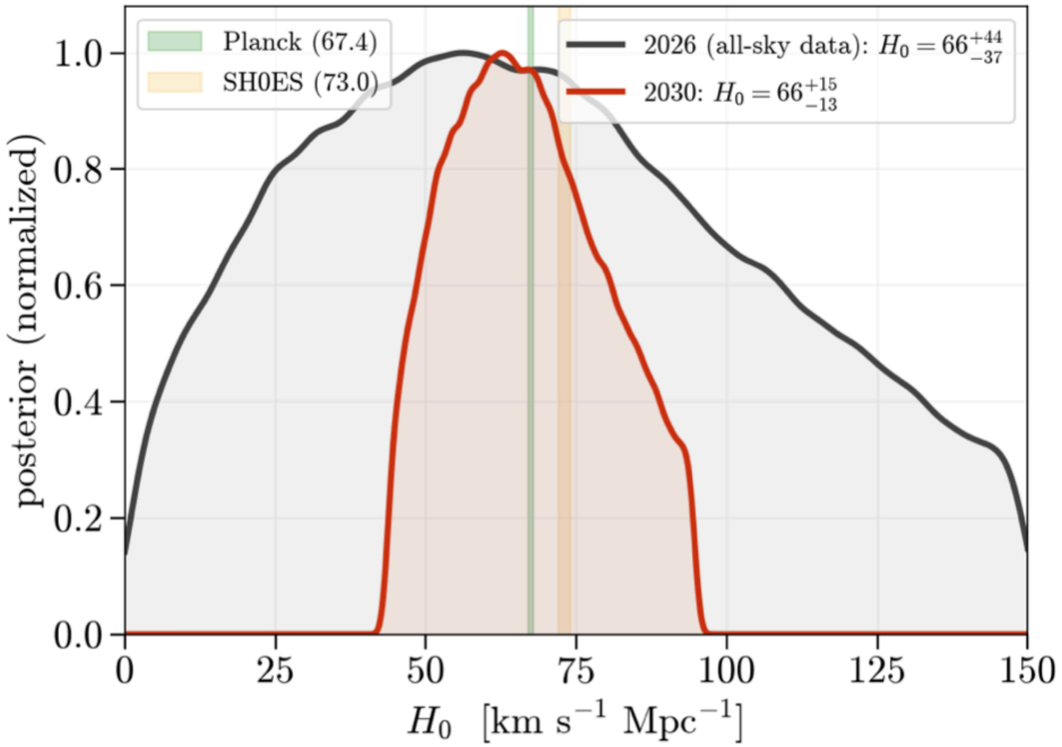




A slightly improved measurement of H_0 with neutrinos

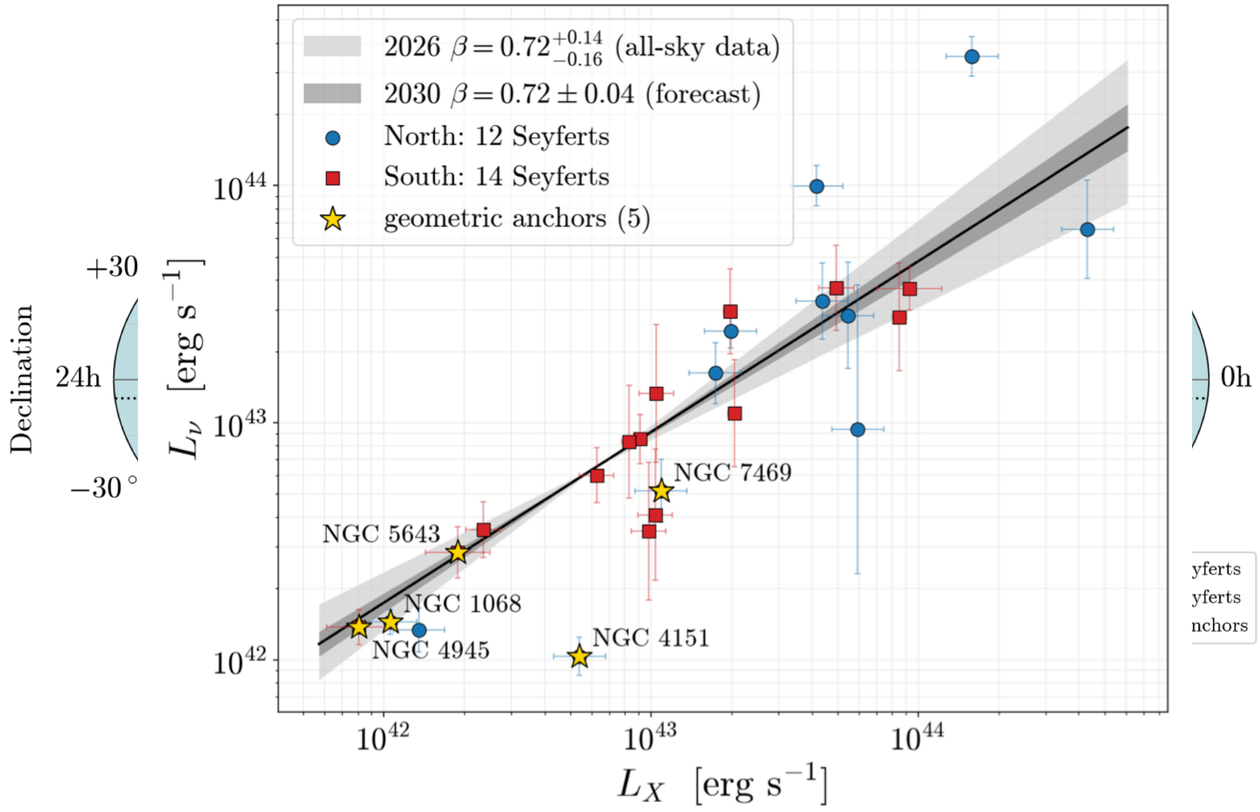
Inclusion of recent southern Seyferts and additional geometrical anchors improves precision.

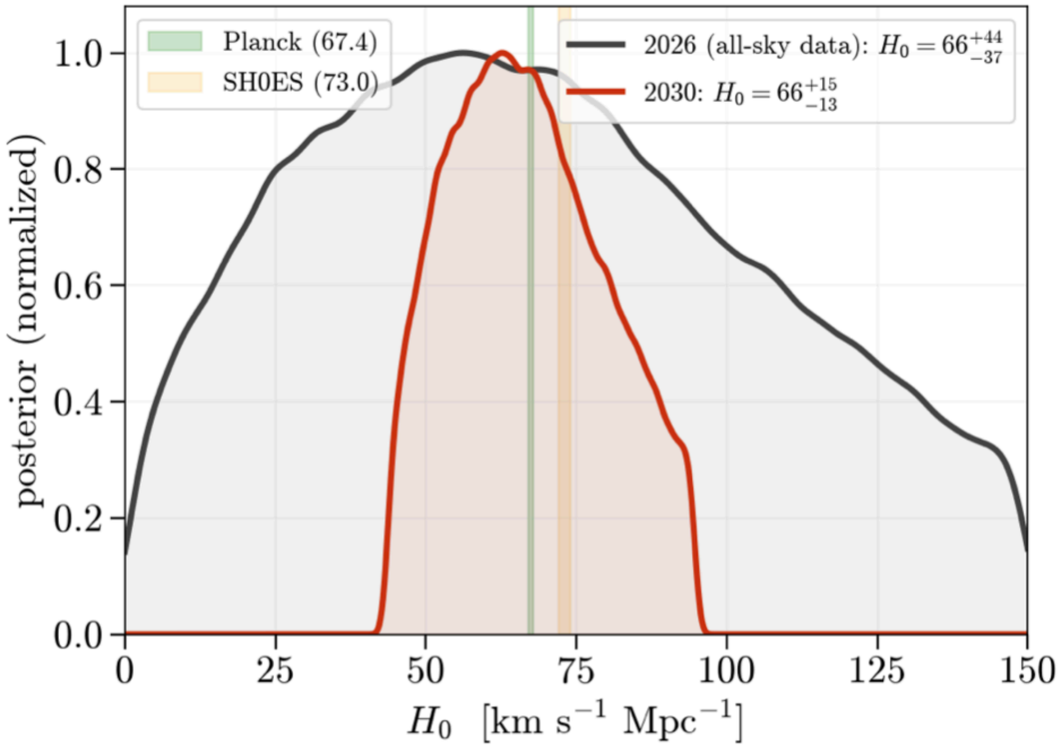




A slightly improved measurement of H_0 with neutrinos

Inclusion of recent southern Seyferts and additional geometrical anchors improves precision.





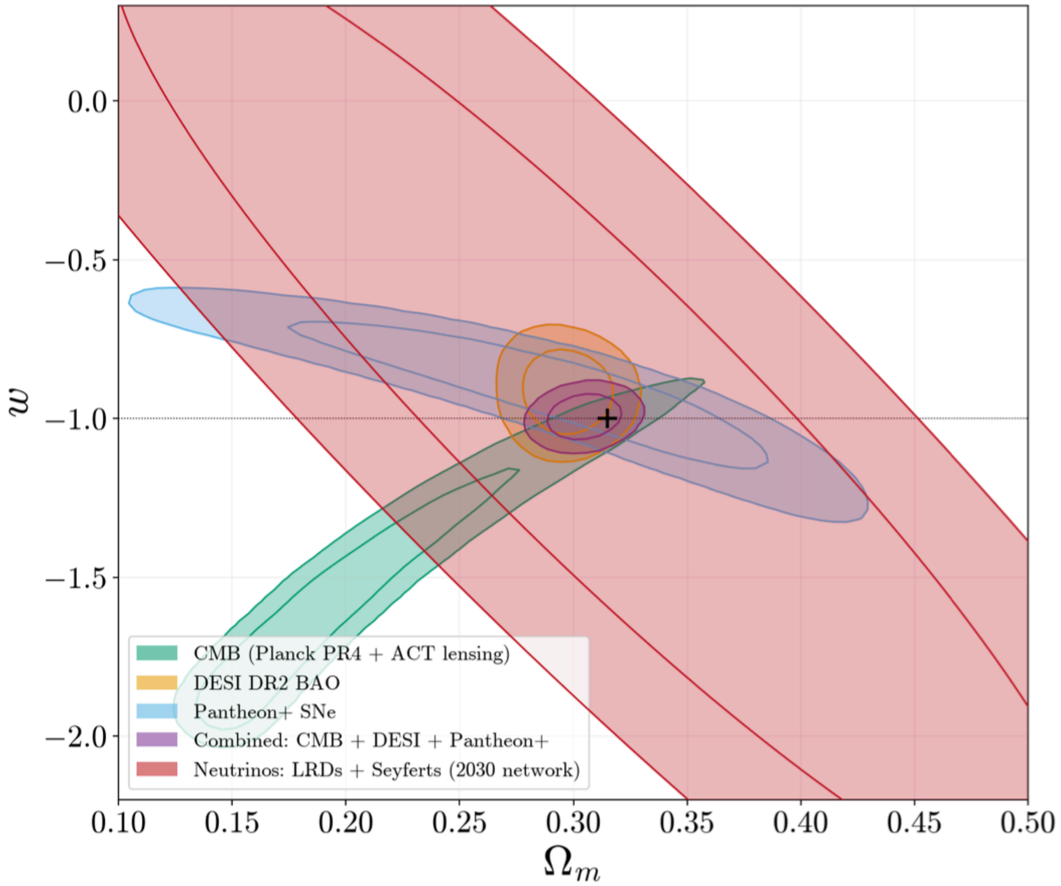
Forecast assumes IceCube, KM3NeT, and Baikal as a network of neutrino telescopes and improved X-ray measurements

Potential to measure other cosmological parameters

If other high-redshift objects end up been correlated with neutrinos, such as “Little red dots,” then this opens up the possibility of enhanced neutrino cosmography.

Potential to measure other cosmological parameters

If other high-redshift objects end up been correlated with neutrinos, such as “Little red dots,” then this opens up the possibility of enhanced neutrino cosmography.



Optimistic, forecast assumes 30% of the diffuse flux is LRDs composed of O(100) detected sources.

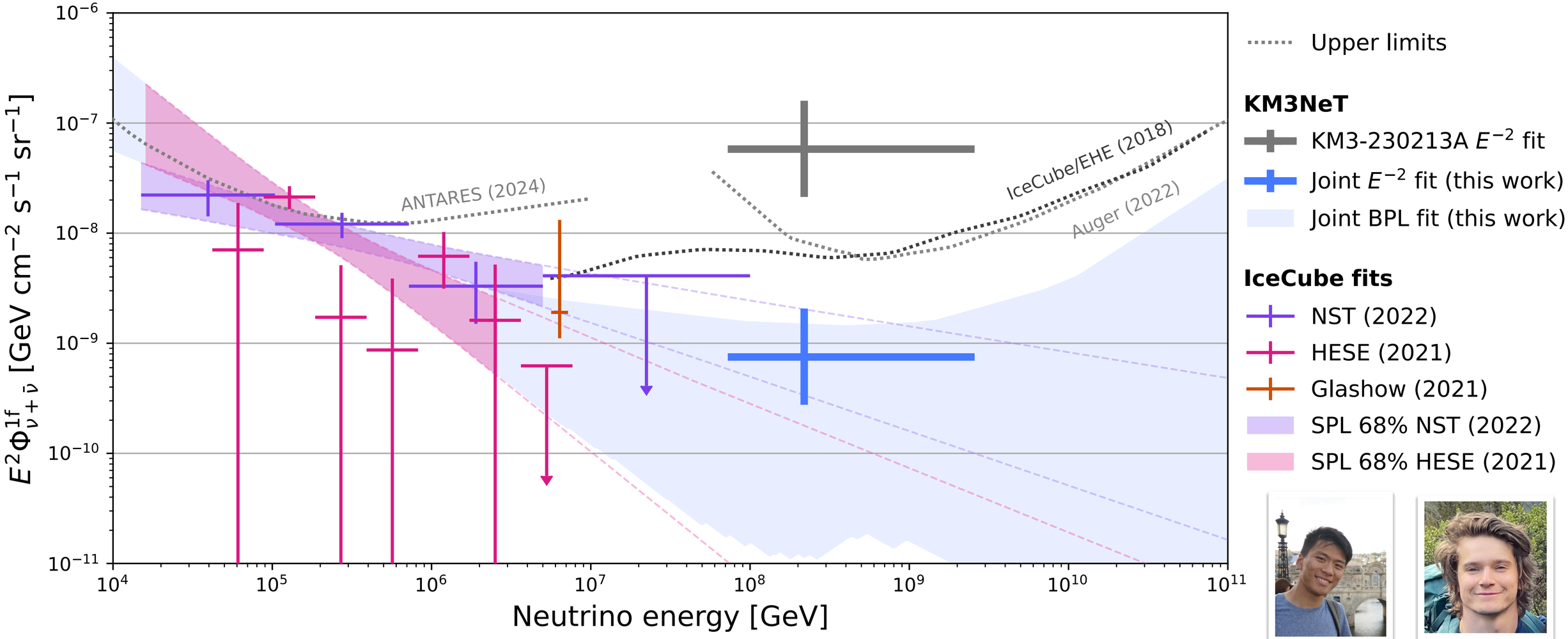
Also assumes IceCube, KM3NeT, and Baikal as a network of neutrino telescopes.



Pavel Zhelnin

Next-generation Frontier

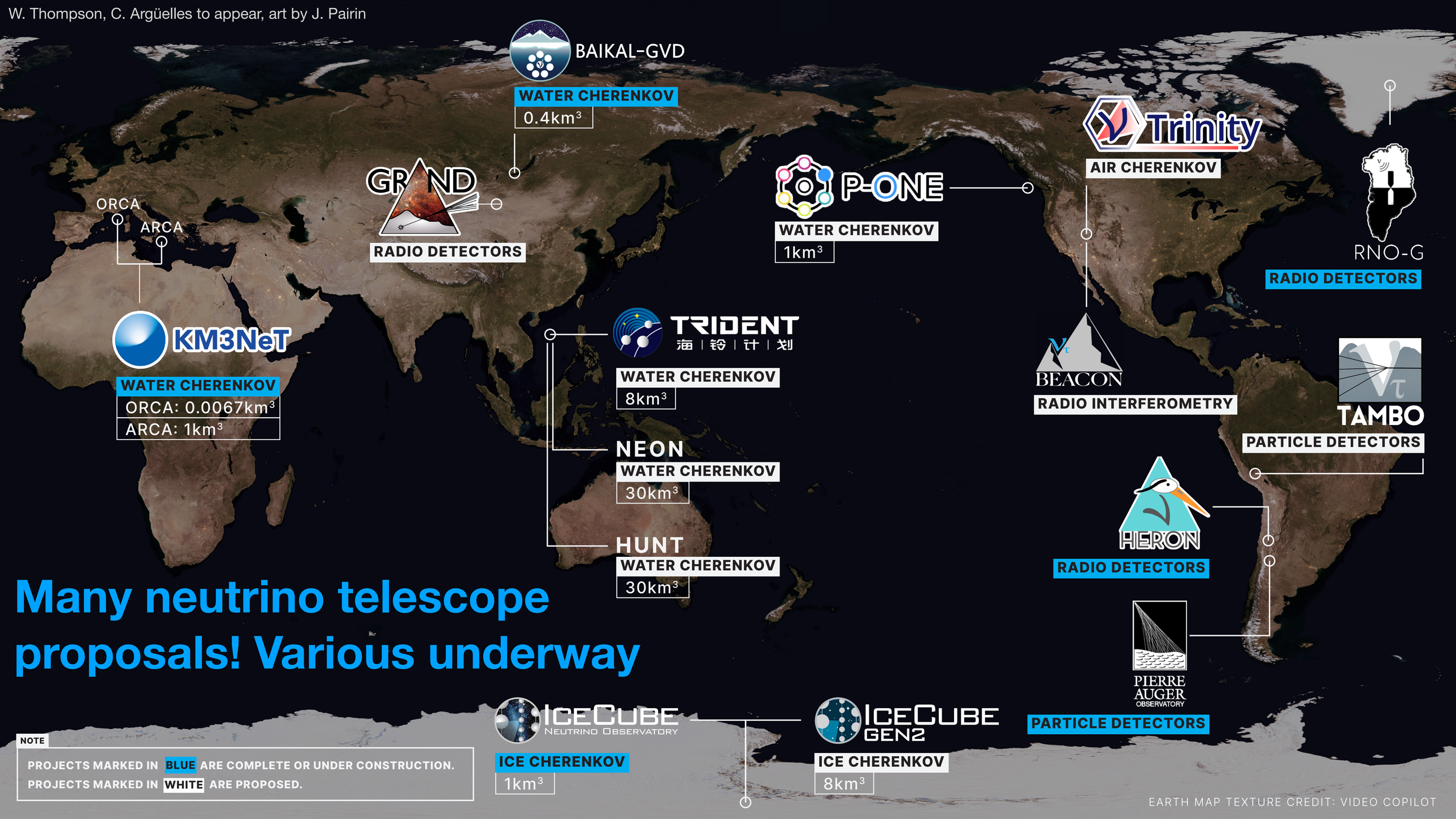
KM3-230213A Within the Global Landscape



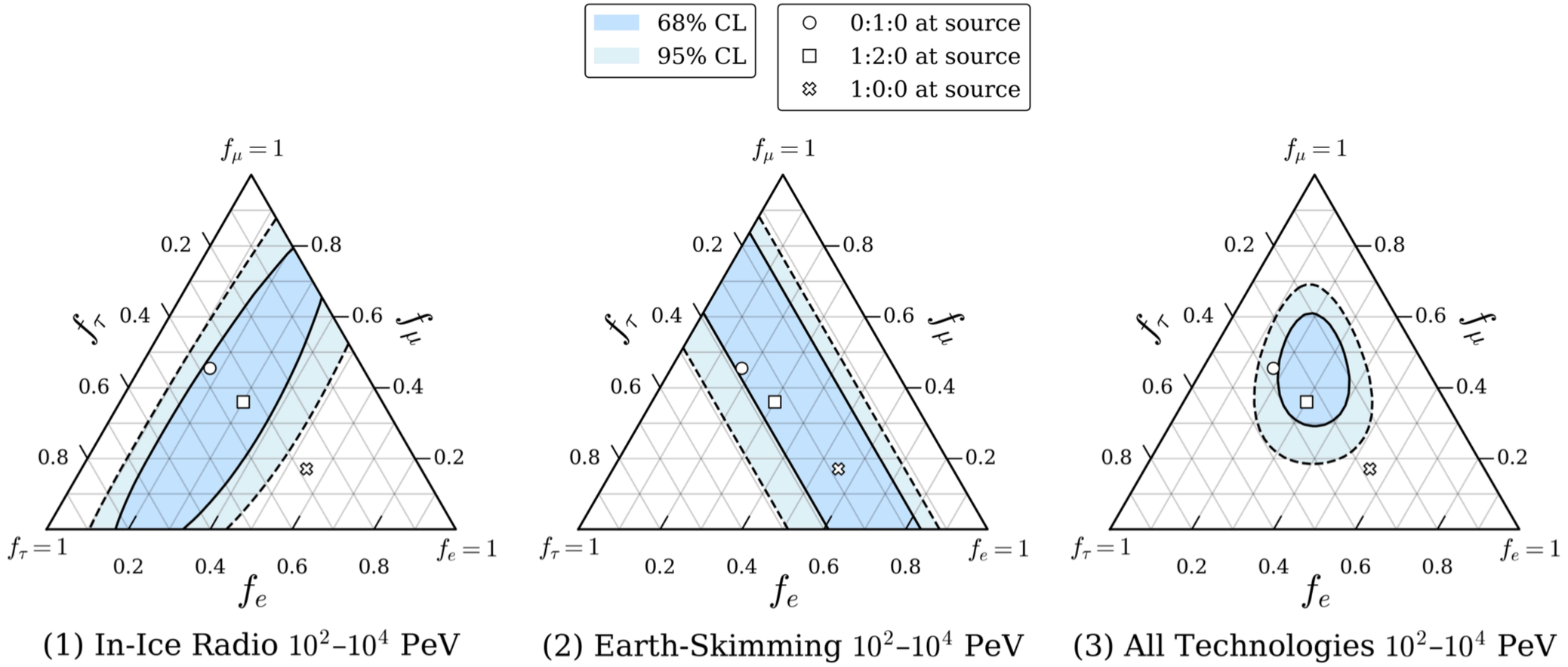
KM3NeT, *Phys. Rev. X* 15, 031016

Alex Wen

Nick Kamp


W. Thompson, C. Argüelles to appear, art by J. Pairin
BAIKAL-GVD
WATER CHERENKOV
0.4km³
GRAND
RADIO DETECTORS
ORCA
ARCA
KM3NeT
WATER CHERENKOV
ORCA: 0.0067km³
ARCA: 1km³
P-ONE
WATER CHERENKOV
1km³
Trinity
AIR CHERENKOV
RNO-G
RADIO DETECTORS
TRIDENT
海 | 铃 | 计 | 划
WATER CHERENKOV
8km³
BEACON
RADIO INTERFEROMETRY
TAMBO
PARTICLE DETECTORS
NEON
WATER CHERENKOV
30km³
HUNT
WATER CHERENKOV
30km³
HERON
RADIO DETECTORS
PIERRE AUGER OBSERVATORY
PARTICLE DETECTORS
Many neutrino telescope proposals! Various underway
ICECUBE NEUTRINO OBSERVATORY
ICE CHERENKOV
1km³
ICECUBE GEN2
ICE CHERENKOV
8km³
NOTE
PROJECTS MARKED IN BLUE ARE COMPLETE OR UNDER CONSTRUCTION.
PROJECTS MARKED IN WHITE ARE PROPOSED.
EARTH MAP TEXTURE CREDIT: VIDEO COPILOT

Next-generation proposals flavor sensitivites



(1) In-Ice Radio 10^2–10^4 PeV

(2) Earth-Skimming 10^2–10^4 PeV

(3) All Technologies 10^2–10^4 PeV

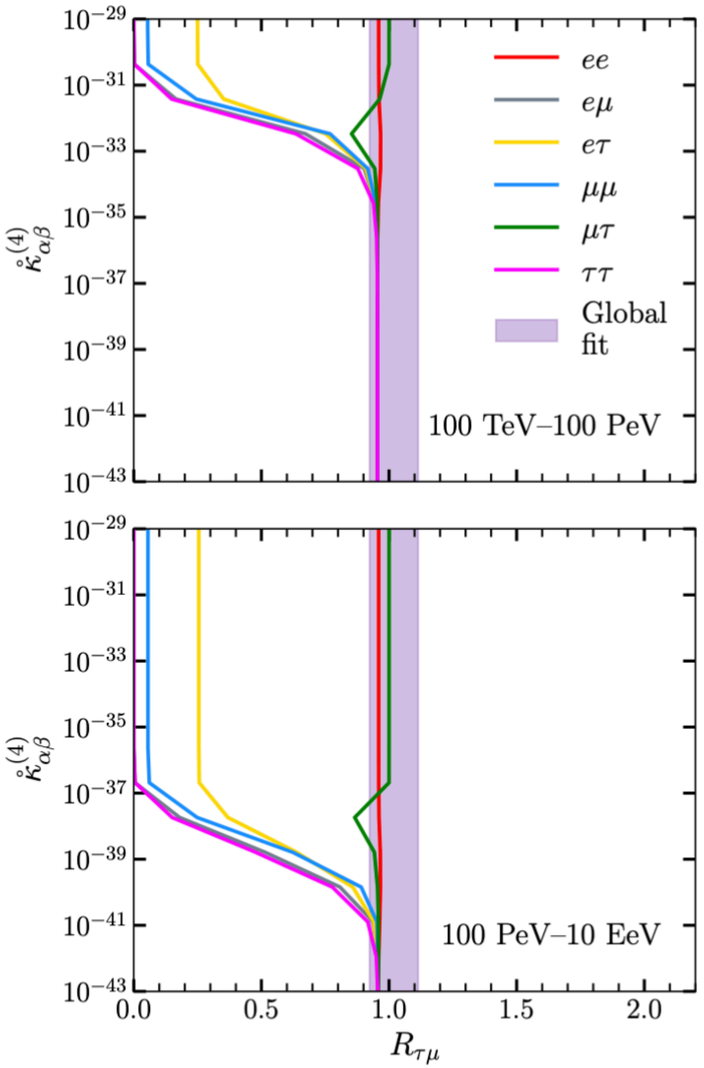
ARIANNA, ARA, RNO-G, IceCube-Gen2

TAMBO-5k, POEMMA, Trinity, AUGER, GRAND200k

UHE Neutrinos Will Provide Strongest Test of LV

Today

Future



Measured muon to tau ratio

dim.	method	type	sector	limits	ref.
3	CMB polarization	astrophysical	photon	$\sim 10^{-44}$ GeV	[1]
	He-Xe comagnetometer	tabletop	neutron	$\sim 10^{-34}$ GeV	[2]
	torsion pendulum	tabletop	electron	$\sim 10^{-31}$ GeV	[3]
	muon $g-2$	accelerator	muon	$\sim 10^{-24}$ GeV	[4, 5]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{a}^{(3)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{a}^{(3)}_{\mu\tau})\rvert < 2.9\times10^{-24}$ GeV (99% C.L.) $< 2.0\times10^{-24}$ GeV (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(3)}_{\alpha\beta}\rvert \lesssim 10^{-29}$ to 10^{-30} GeV (sensitivity)	this work
4	GRB vacuum birefringence	astrophysical	photon	$\sim 10^{-38}$	[7]
	laser interferometer	LIGO	photon	$\sim 10^{-22}$	[8]
	sapphire cavity oscillator	tabletop	photon	$\sim 10^{-18}$	[9]
	Ne-Rb-K comagnetometer	tabletop	neutron	$\sim 10^{-29}$	[10]
	trapped Yb^+ ions	tabletop	electron	$\sim 10^{-21}$	[11]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{c}^{(4)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{c}^{(4)}_{\mu\tau})\rvert < 3.9\times10^{-28}$ (99% C.L.) $< 2.7\times10^{-28}$ (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(4)}_{\alpha\beta}\rvert \lesssim 10^{-38}$ to 10^{-39} (sensitivity)	this work
5	GRB vacuum birefringence	astrophysical	photon	$\sim 10^{-34}$ GeV^{-1}	[7]
	ultra-high-energy cosmic ray	astrophysical	proton	$\sim 10^{-22}$ to 10^{-18} GeV^{-1}	[12]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{a}^{(5)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{a}^{(5)}_{\mu\tau})\rvert < 2.3\times10^{-32}$ GeV^{-1} (99% C.L.) $< 1.5\times10^{-32}$ GeV^{-1} (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(5)}_{\alpha\beta}\rvert \lesssim 10^{-46}$ to 10^{-47} GeV^{-1} (sensitivity)	this work
6	GRB vacuum birefringence	astrophysical	photon	$\sim 10^{-31}$ GeV^{-2}	[7]
	ultra-high-energy cosmic ray	astrophysical	proton	$\sim 10^{-42}$ to 10^{-35} GeV^{-2}	[12]
	gravitational Cherenkov radiation	astrophysical	gravity	$\sim 10^{-31}$ GeV^{-2}	[13]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{c}^{(6)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{c}^{(6)}_{\mu\tau})\rvert < 1.5\times10^{-36}$ GeV^{-2} (99% C.L.) $< 9.1\times10^{-37}$ GeV^{-2} (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(6)}_{\alpha\beta}\rvert \lesssim 10^{-54}$ to 10^{-57} GeV^{-2} (sensitivity)	this work
7	GRB vacuum birefringence	astrophysical	photon	$\sim 10^{-28}$ GeV^{-3}	[7]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{a}^{(7)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{a}^{(7)}_{\mu\tau})\rvert < 8.3\times10^{-41}$ GeV^{-3} (99% C.L.) $< 3.6\times10^{-41}$ GeV^{-3} (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(7)}_{\alpha\beta}\rvert \lesssim 10^{-62}$ to 10^{-65} GeV^{-3} (sensitivity)	this work
8	gravitational Cherenkov radiation	astrophysical	gravity	$\sim 10^{-46}$ GeV^{-4}	[13]
	neutrino oscillation	atmospheric	neutrino	$\lvert\mathrm{Re}\,(\mathring{c}^{(8)}_{\mu\tau})\rvert, \lvert\mathrm{Im}\,(\mathring{c}^{(8)}_{\mu\tau})\rvert < 5.2\times10^{-45}$ GeV^{-4} (99% C.L.) $< 1.4\times10^{-45}$ GeV^{-4} (90% C.L.)	[6]
	ultra-high-energy neutrinos	astrophysical	neutrino	$\lvert\kappa^{(8)}_{\alpha\beta}\rvert \lesssim 10^{-71}$ to 10^{-74} GeV^{-4} (sensitivity)	this work

CA, V. Brdar, S. R. Mir (2026, to appear)

Take-home message

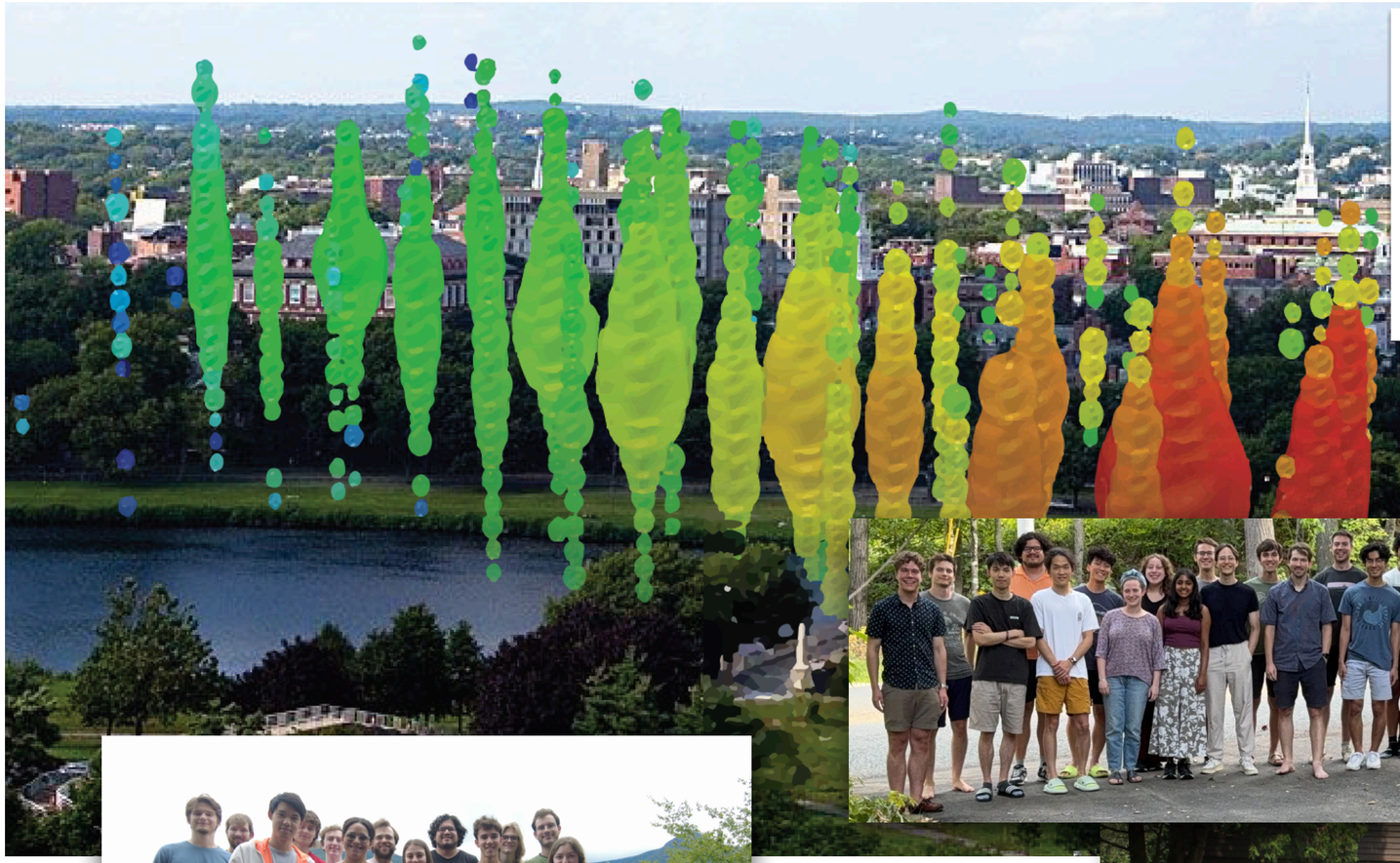
❖Astrophysical neutrinos could give us evidence for Dirac-like neutrinos.

❖High-energy neutrino flavor constraints are an important test of Lorentz symmetry.

❖A population of neutrino sources can measure the Hubble constant and other cosmological parameters.

❖Ultra-high-energy flavor measurements are expected to be the “ultimate” test of Lorentz symmetry.

❖Many neutrino telescopes are underway: IceCube, KM3NeT, TAMBO, and many others!











ICECUBE SOUTH POLE NEUTRINO OBSERVATORY

KM3NeT

TAMBO

CIFAR

Thanks!

The NSF Institute for Artificial Intelligence and Fundamental Interactions

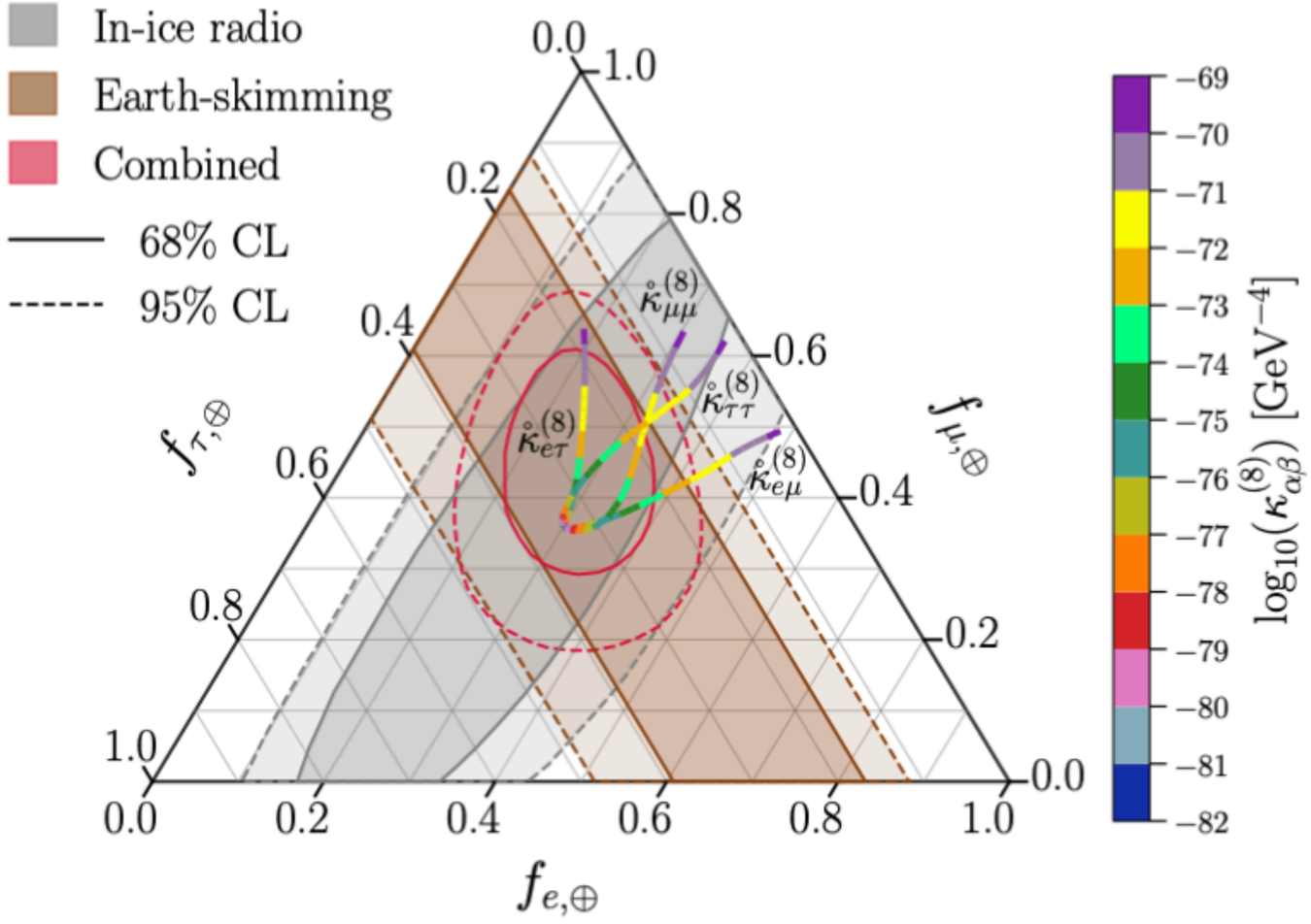
NSF

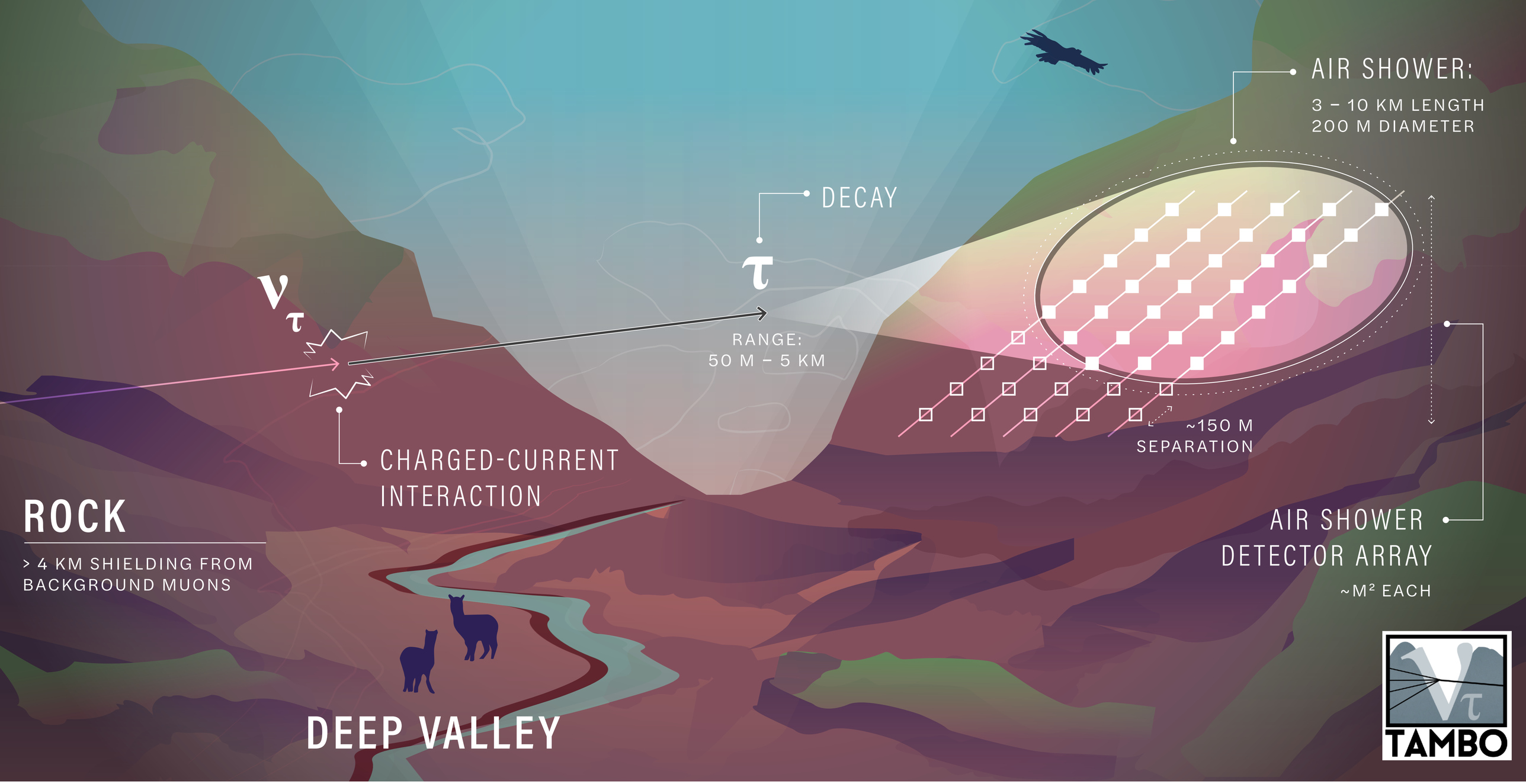
RESEARCH CORPORATION *for* SCIENCE ADVANCEMENT

the David & Lucile Packard FOUNDATION

JOHN TEMPLETON FOUNDATION

Bonus slides

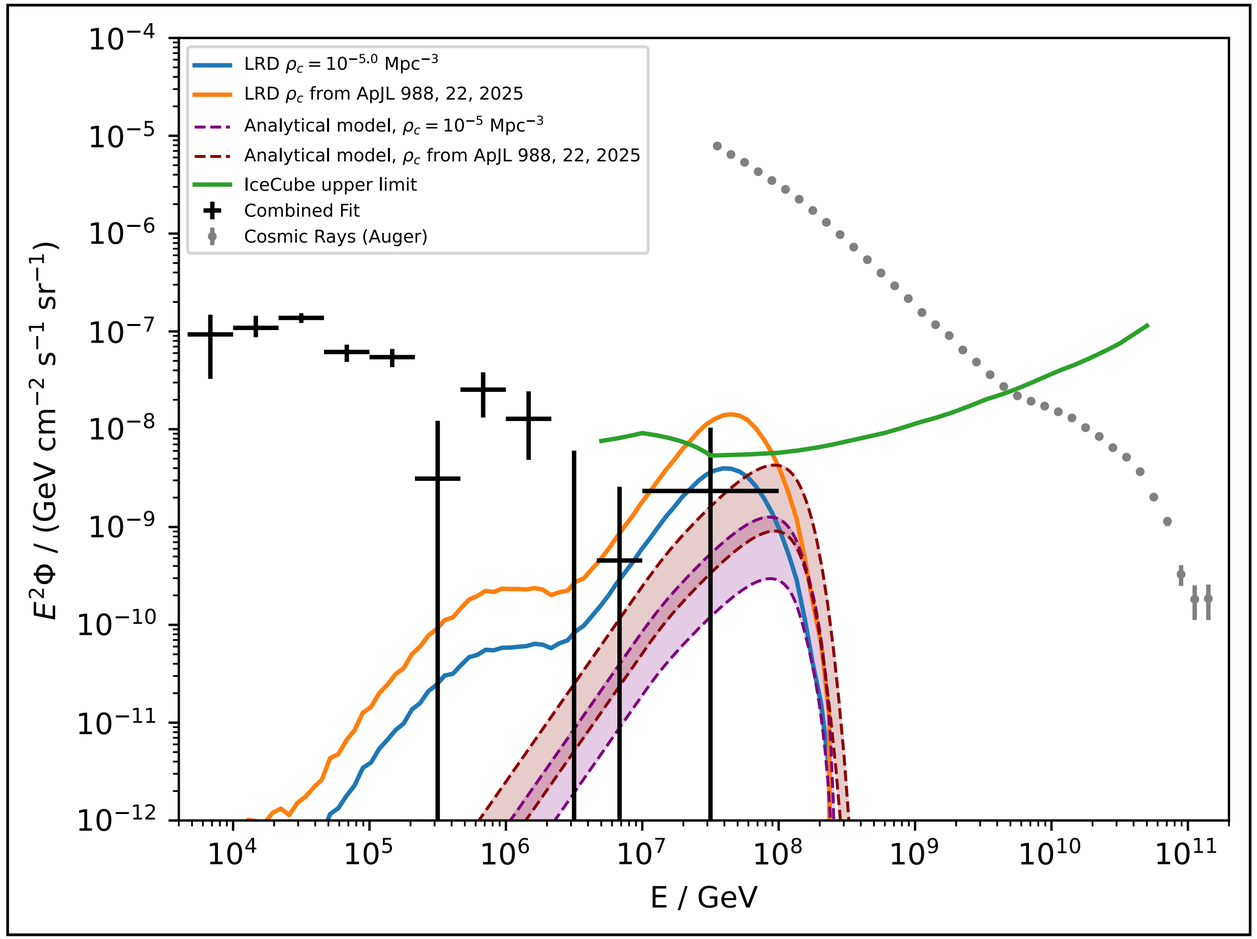

In-ice radio
Earth-skimming
Combined
68% CL
95% CL
$\mathring{\kappa}^{(8)}_{\mu\mu}$
$\mathring{\kappa}^{(8)}_{\tau\tau}$
$\mathring{\kappa}^{(8)}_{e\tau}$
$\mathring{\kappa}^{(8)}_{e\mu}$
$f_{e,\oplus}$
$f_{\mu,\oplus}$
$f_{\tau,\oplus}$
$\log_{10}(\kappa^{(8)}_{\alpha\beta})$ [GeV^{-4}]


AIR SHOWER:
3 – 10 KM LENGTH
200 M DIAMETER
DECAY
τ
ν_τ
RANGE:
50 M – 5 KM
~150 M
SEPARATION
CHARGED-CURRENT
INTERACTION
ROCK
> 4 KM SHIELDING FROM
BACKGROUND MUONS
AIR SHOWER
DETECTOR ARRAY
~M² EACH
DEEP VALLEY
TAMBO

Next-generation proposal in context

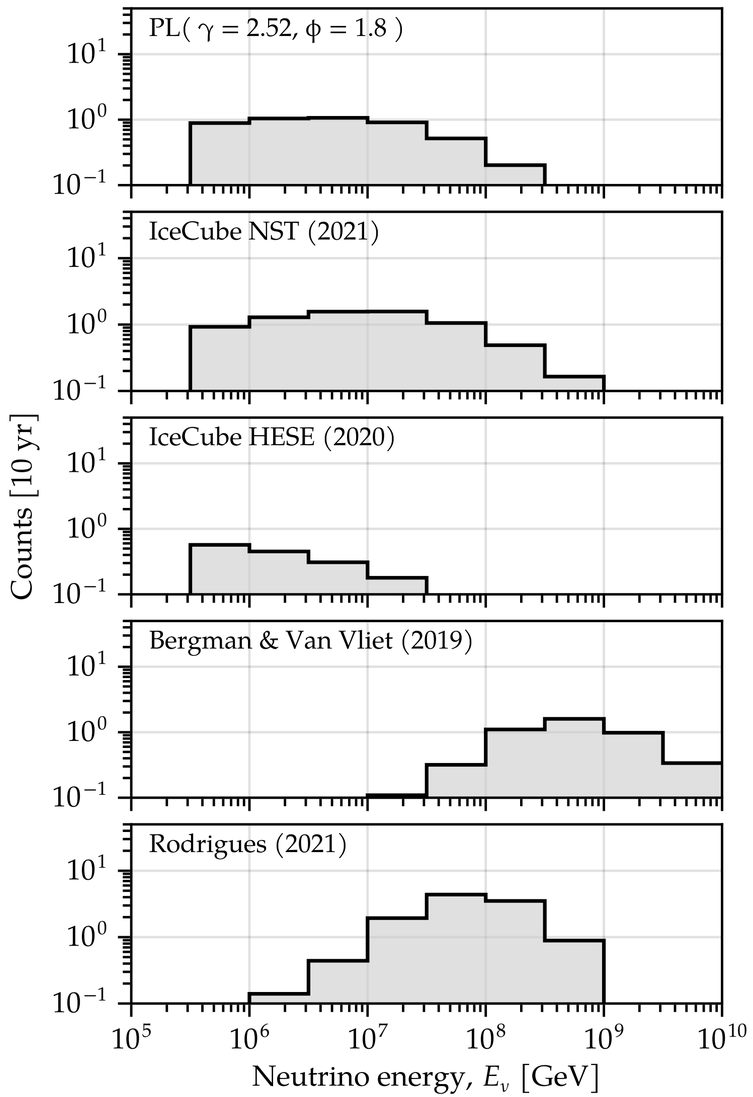


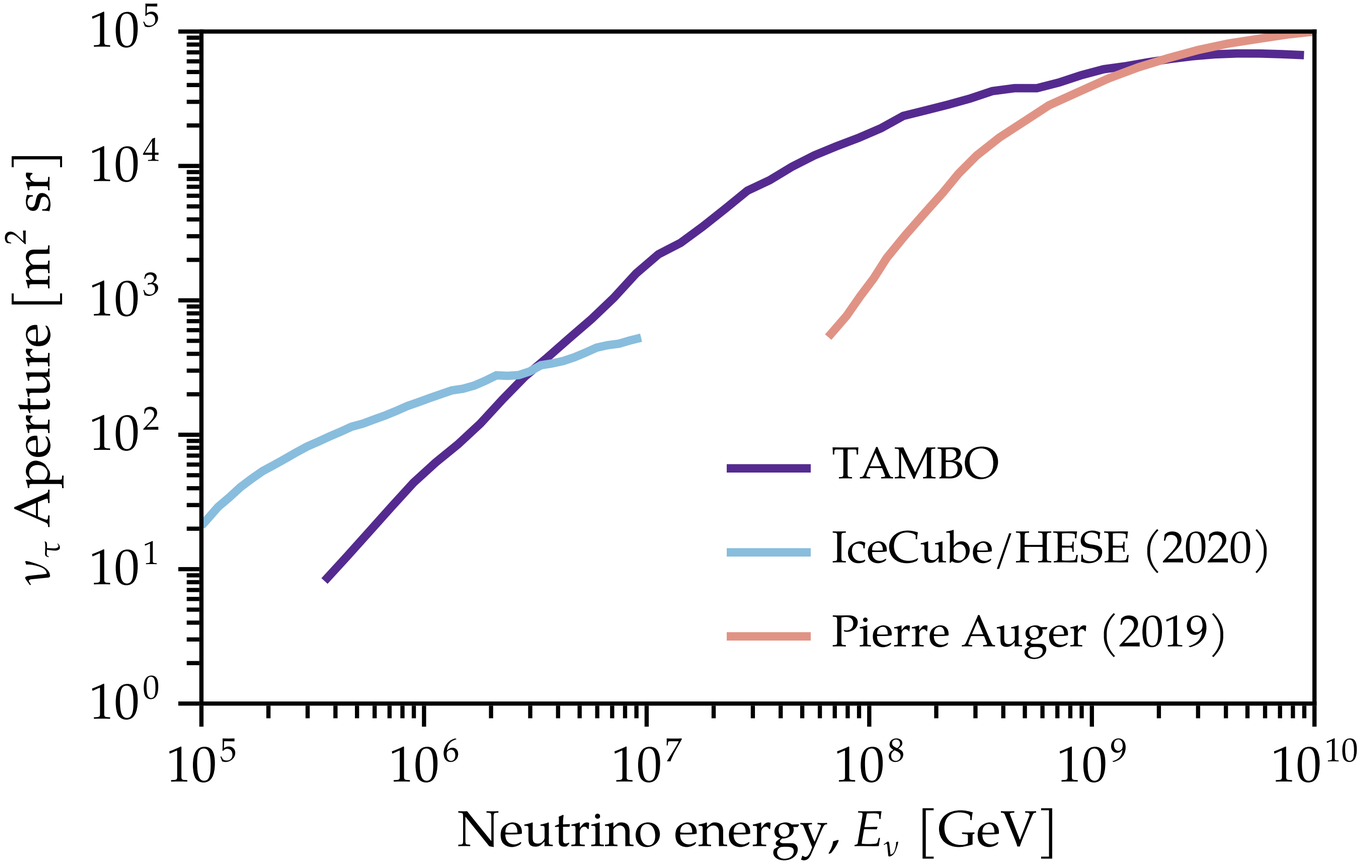
"Little red dots" discovered by JWST in 2024, 5 ≲z ≲10



Kuze et al. *Phys.Rev.D 113* (2026) 083048

TAMBO Rates Under Different Models





THE TAMBO COLLABORATION

UNITED KINGDOM
University of Cambridge

DENMARK
Niels Bohr Institute, University of Copenhagen

BELGIUM
Université catholique de Louvain

CANADA
Queen's University

SPAIN
Instituto de Física Corpuscular (IFIC), CSIC / Universitat de València
Universidad de Oviedo
Universidade de Santiago de Compostela (IGFAE)

ITALY
INFN, Sezione di Padova

TAIWAN
Academia Sinica

UNITED STATES
Harvard University
Los Alamos National Laboratory
Ohio State University
Swarthmore College
University of Hawaii at Manoa
University of Nevada, Las Vegas

MEXICO
Universidad Nacional Autónoma de México (UNAM)

EL SALVADOR
Universidad de El Salvador (UES)

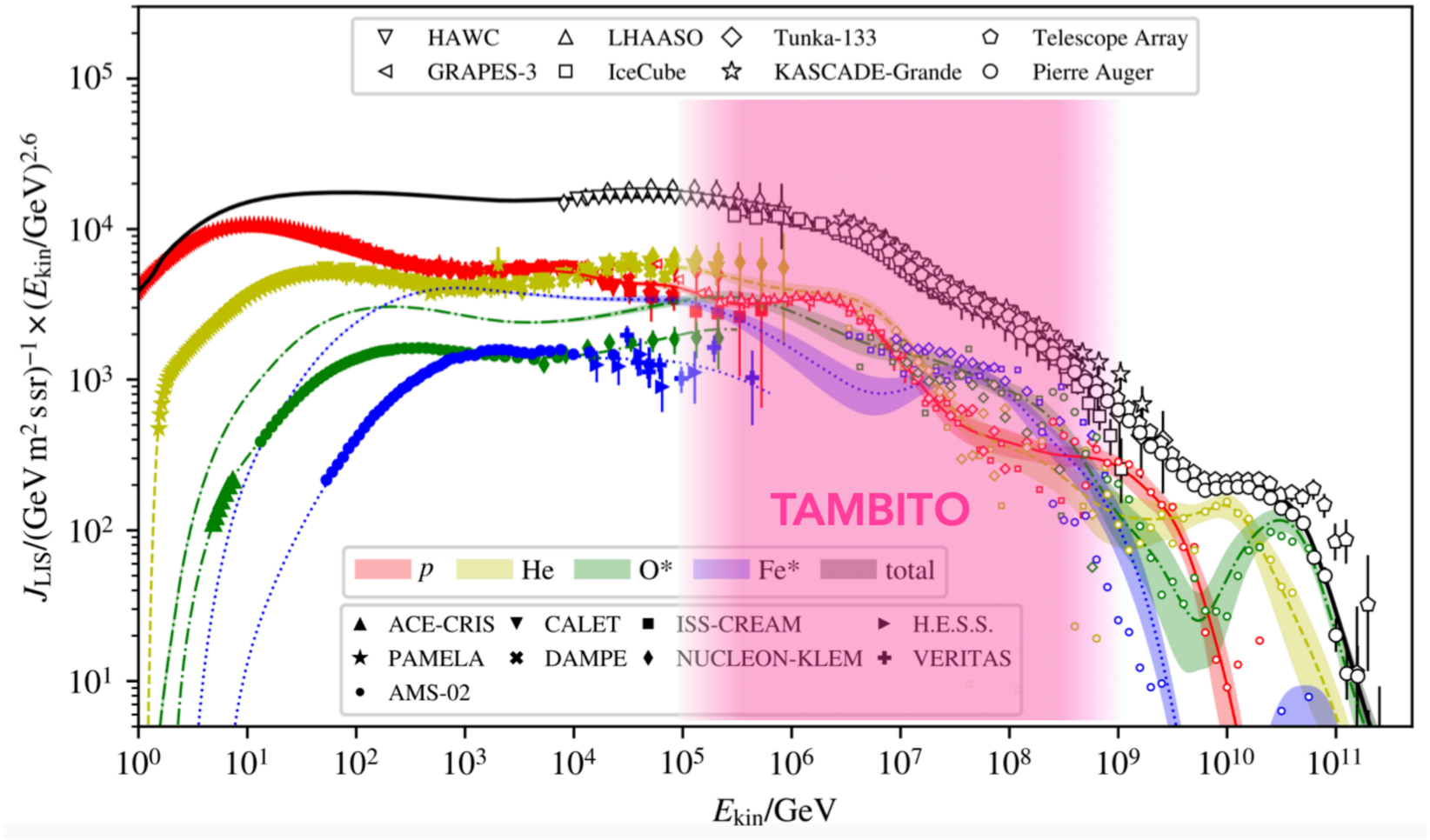
PERU
Comisión Nacional de Investigación y Desarrollo Aeroespacial (CONIDA)
Instituto Geofísico del Perú (IGP)
Pontificia Universidad Católica del Perú (PUCP)
Universidad Católica San Pablo
Universidad Continental
Universidad Nacional Mayor de San Marcos
Universidad Nacional San Antonio de Abad (UNSAAC)
Universidad Nacional de Ingeniería
Universidad Nacional de San Agustín
Universidad de Ingeniería y Tecnología (UTEC)
Universidad del Pacífico



FUNDING

John Templeton Foundation · Harvard University · UTEC · PUCP Legacy support: CIFAR

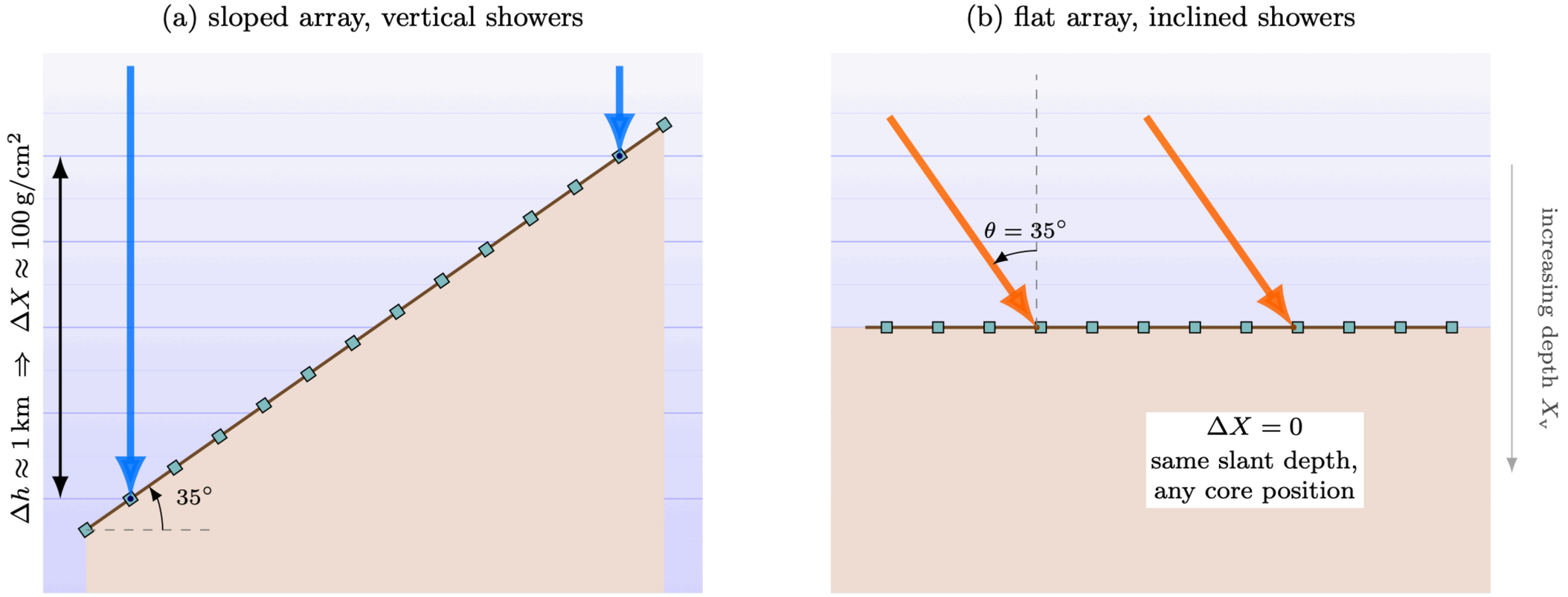
Cosmic ray energy range for TAMBITO/TAMBO



[Dembinski et al, PoS(ICRC2025)248]

New Opportunities for cosmic-ray physics

Not just a rotation! For flat arrays, the amount of matter traversed is decided by the zenith angle.
For an inclined array, these decouple.



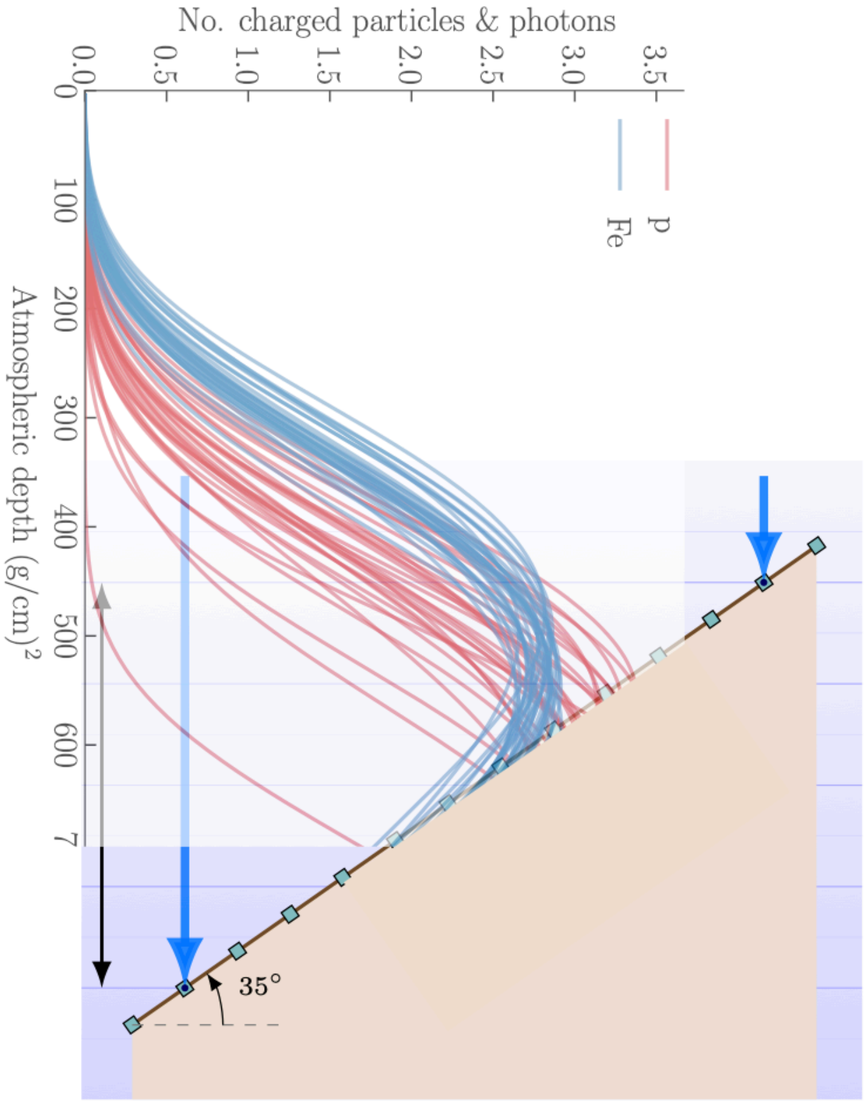
horizontal lines: iso-depth layers of the stratified atmosphere ($X_\mathrm{v} = \mathrm{const}$)

New Opportunities for cosmic-ray physics

- TAMB(IT)O can study the **knee-2nd knee region** of the cosmic ray spectrum

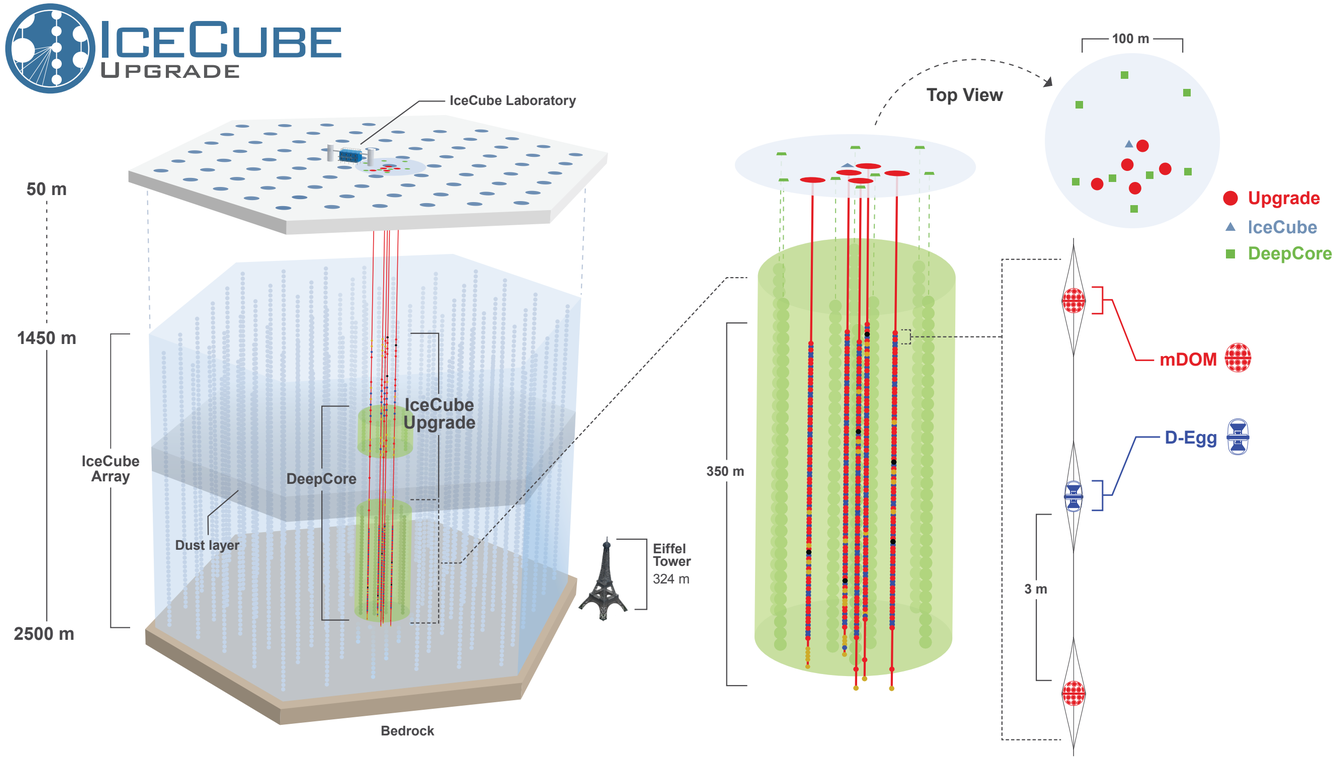
- The inclined array may provide **new ways of testing longitudinal shower development** and probing mass composition

- Studies in progress!



The IceCube Upgrade

Phase 1: Installed 5 new functioning strings in the ice. Completed December 2026.





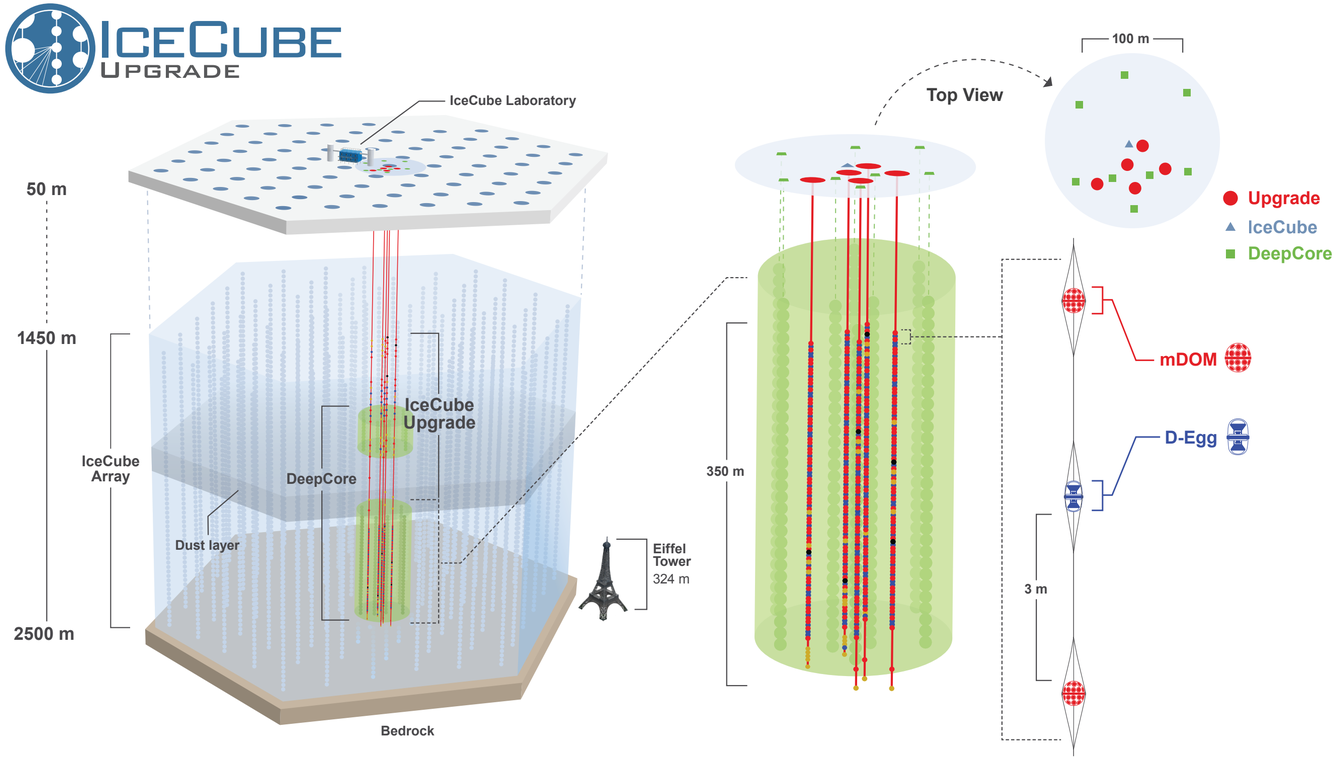


New detector technologies.
Better low energy reconstruction.
Improved flavor identification.

Inspired by DMIce (A. Hubbard, R. Maruyama, and the DM-Ice project)

The IceCube Upgrade

Phase 1: Installed 5 new functioning strings in the ice. Completed December 2026.

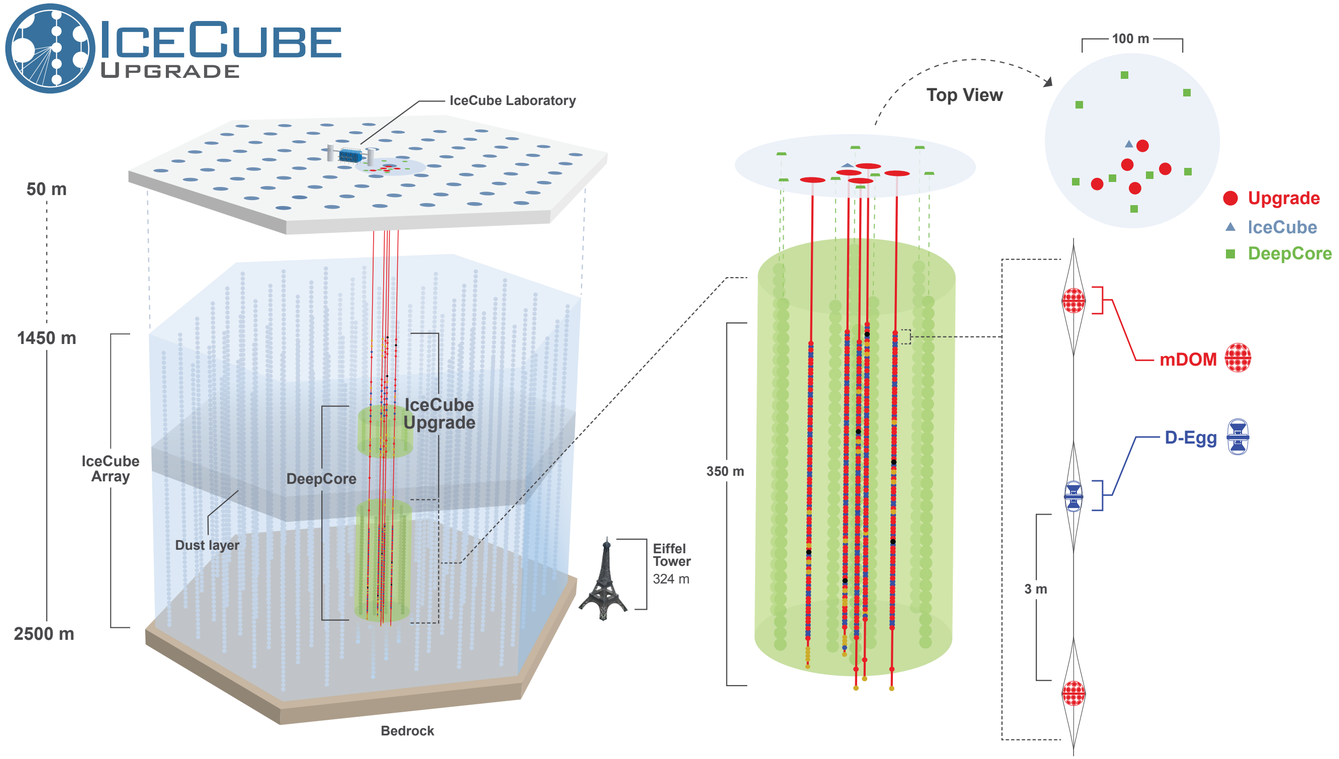


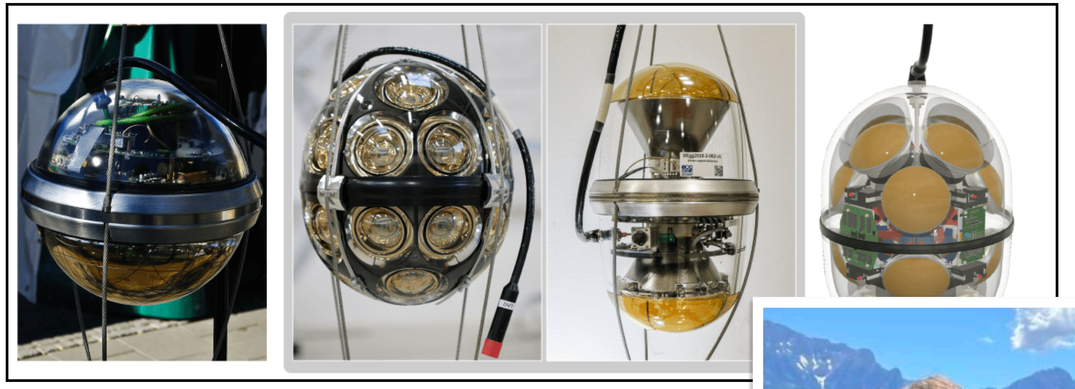


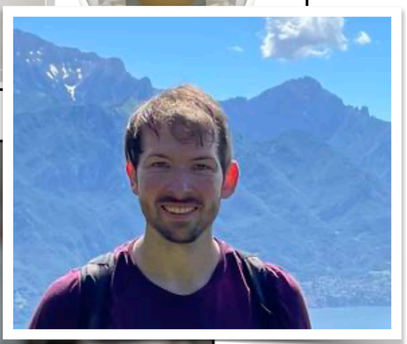
Inspired by DMIce (A. Hubbard, R. Maruyama, and the DM-Ice project)

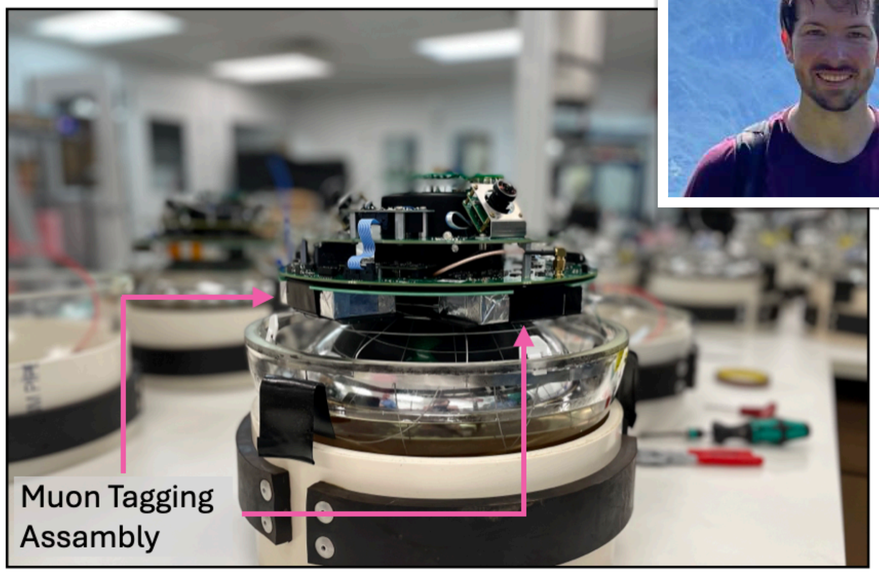
The IceCube Upgrade

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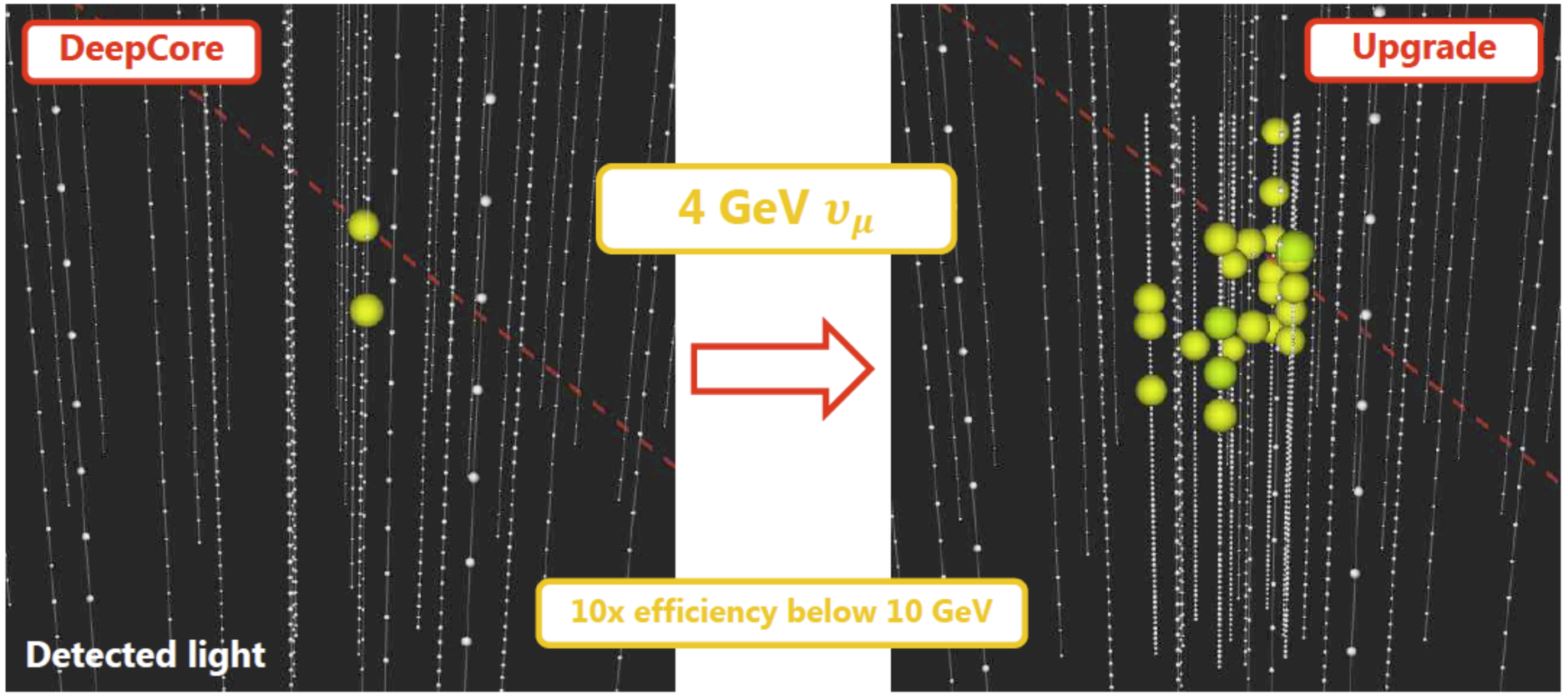






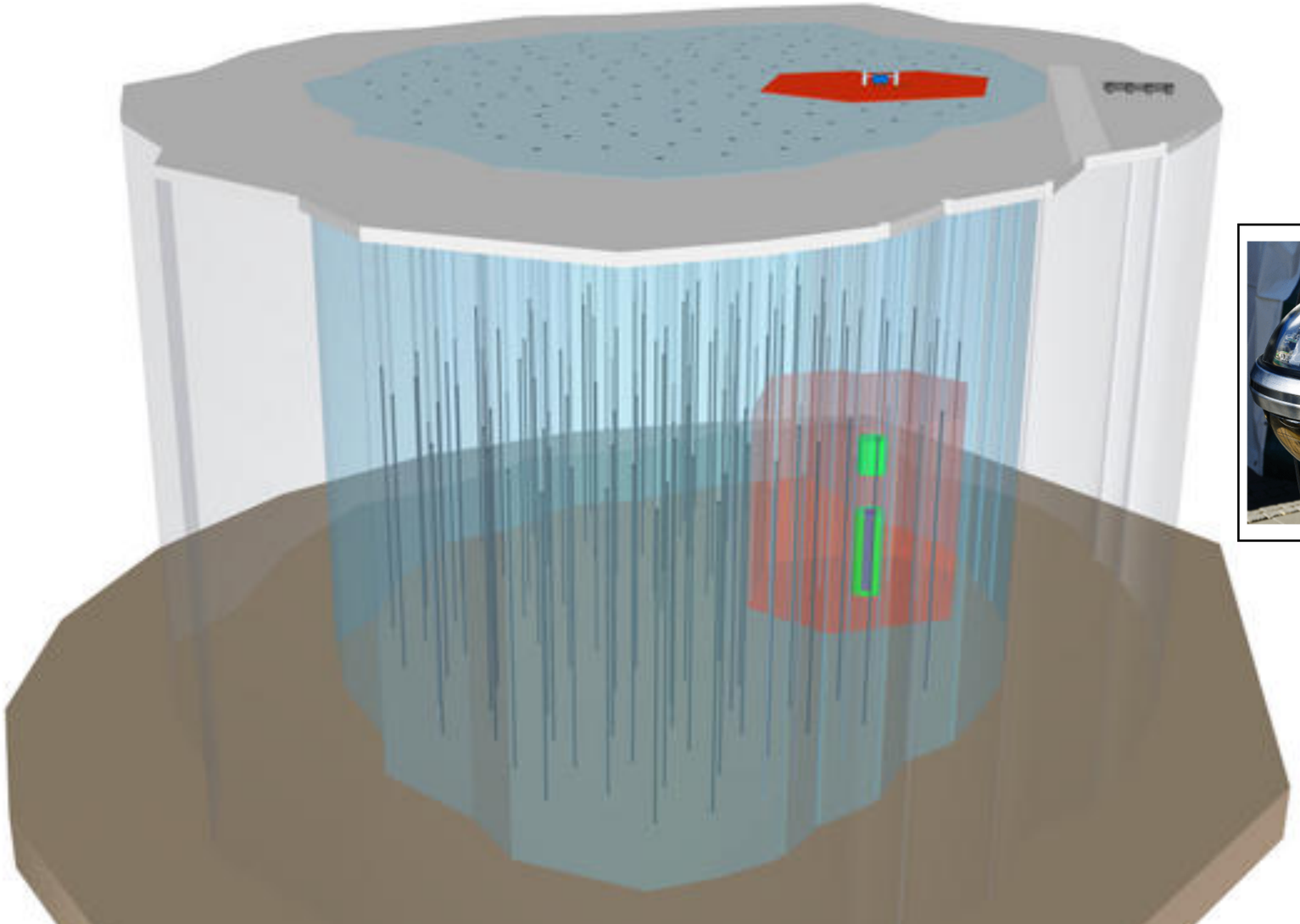
Inspired by DMIce (A. Hubbard, R. Maruyama, and the DM-Ice project)

Improved light-collection for low-energy events

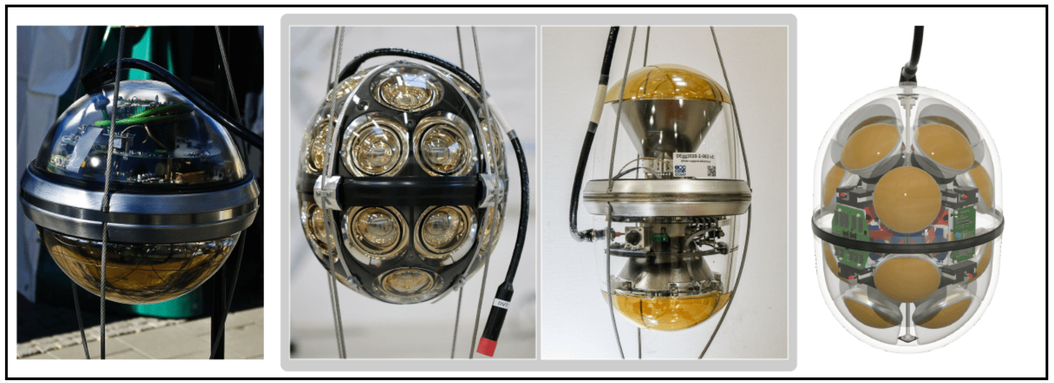


*DeepCore (shown on the left) is the current low-energy extension of IceCube

IceCube Gen-2



Phase 2: x8 the volume of present IceCube, plus additional detectors.

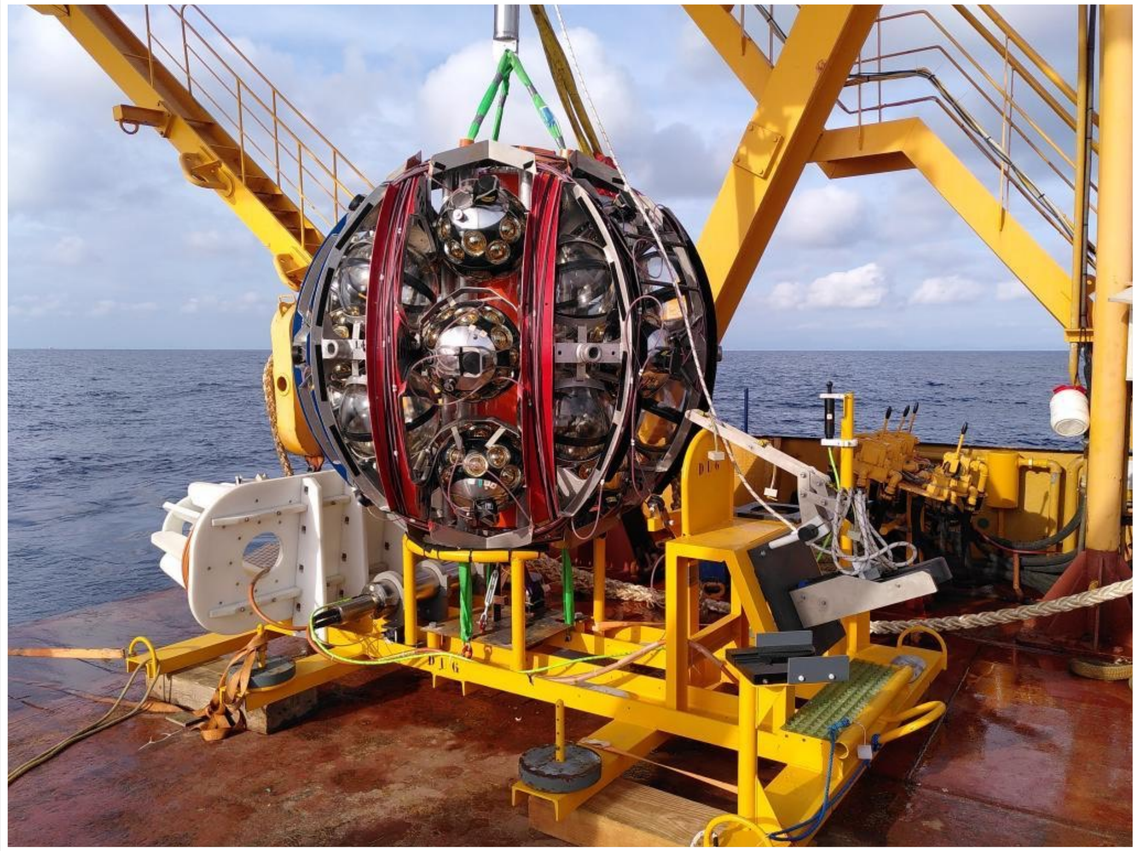


T. Zhu, A. Jin, CA *JINST* 20 (2025) 05, P05001

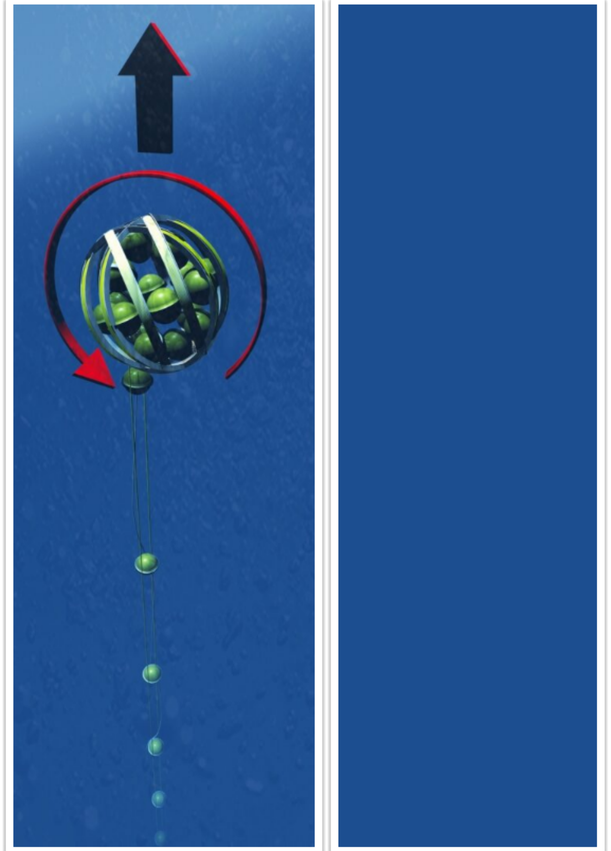
KM3NeT: Water Neutrino Telescope



31 3” photo-multiplier tubes per Digital Optical Module (DOM)



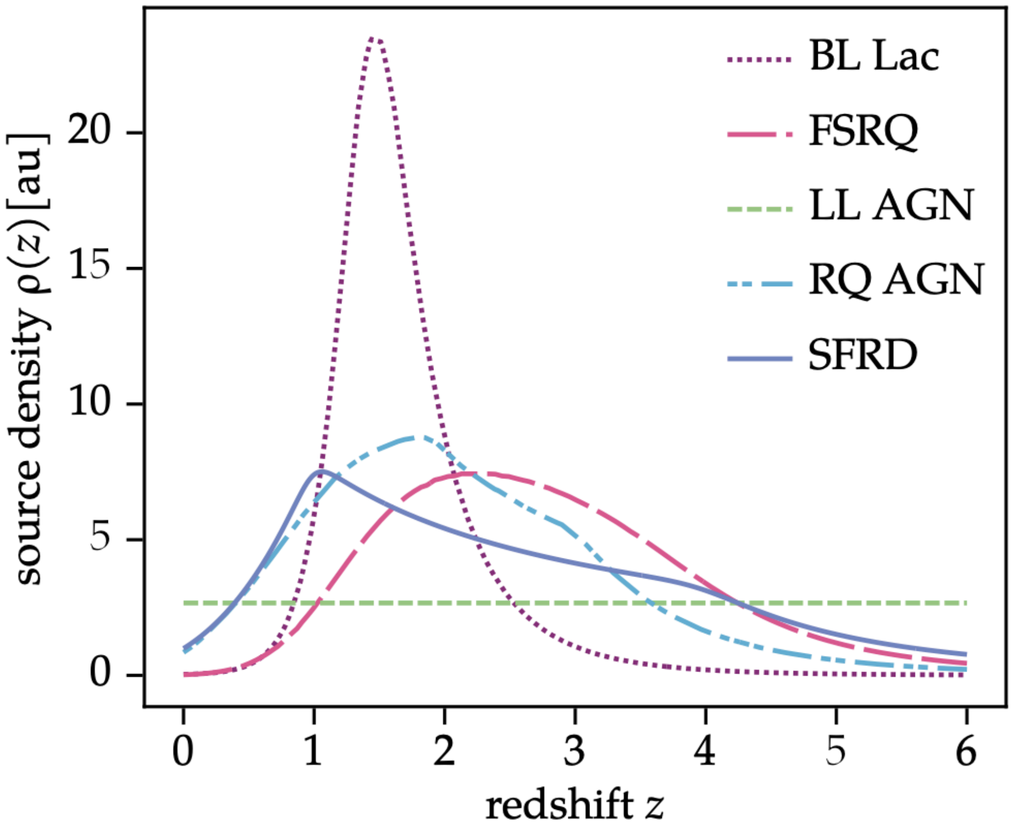
18 DOMs per Detection Unit (DU)

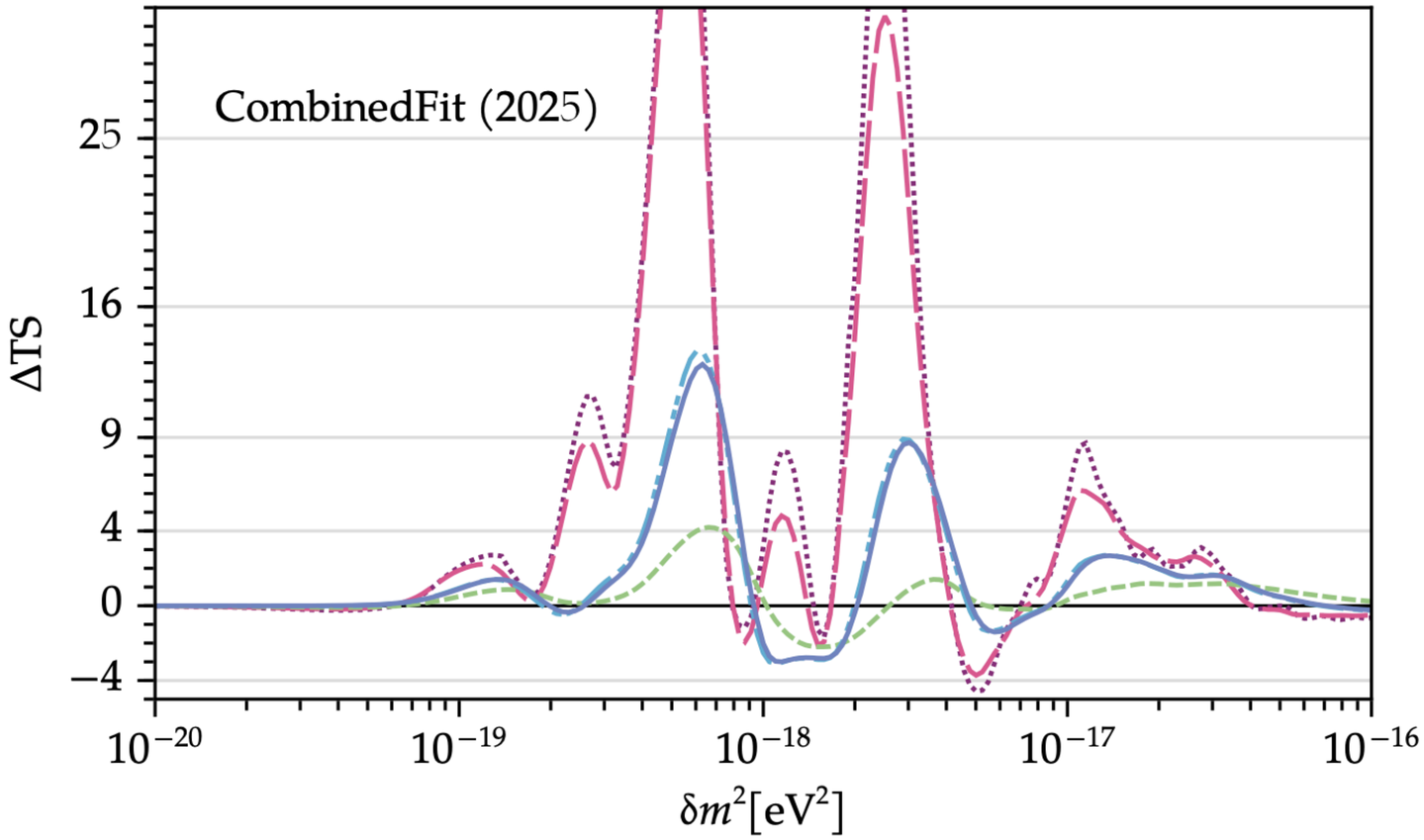


Each DU is unraveled before reaching the sea floor

50 strings already deployed near Sicily!

Effect due to redshift anzats

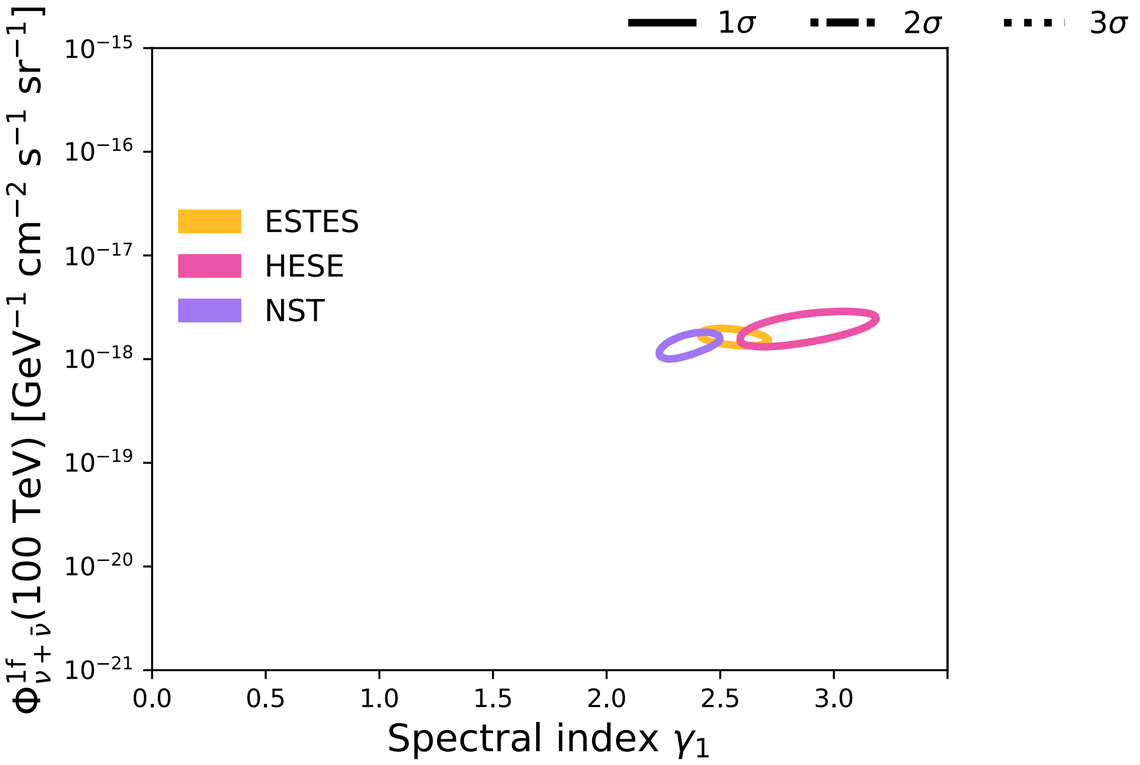




K. Carloni, J. Porto, CA, B. Dev, S. Jana
(arXiv:2503.19960, to appear in PRD)

Is there tension between KM3-230213A and null observations from IceCube and Auger?

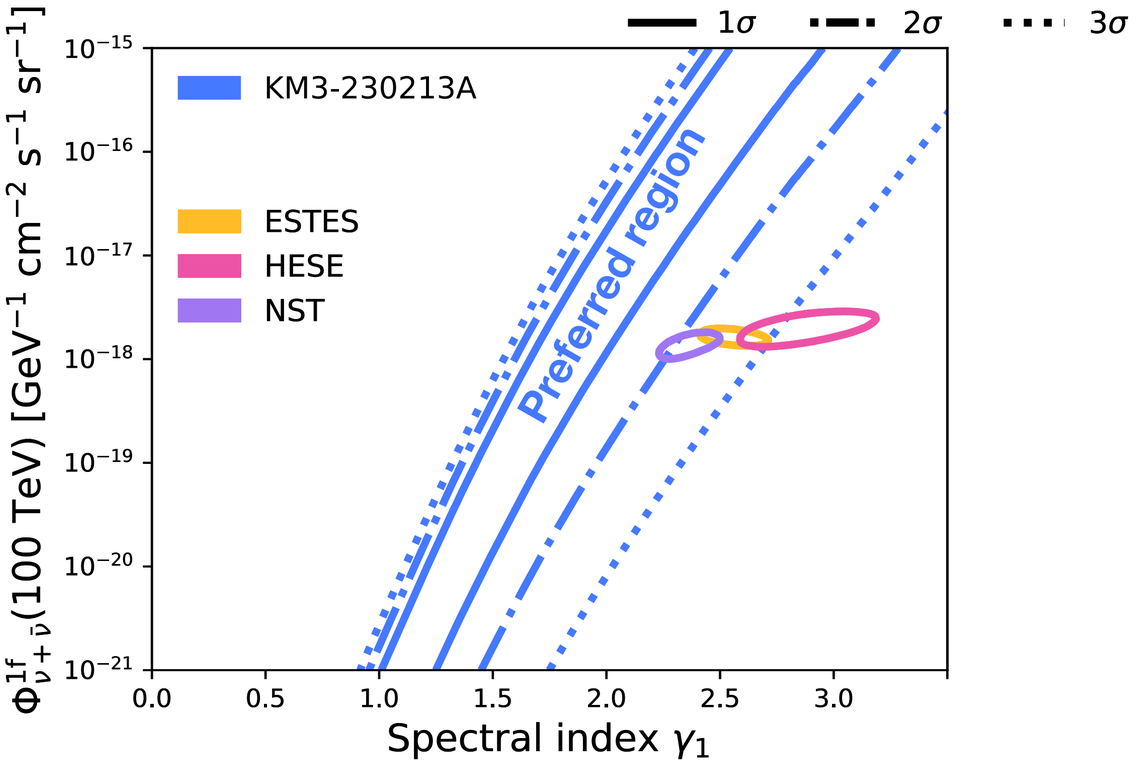
We consider a generic single-power-law flux model in the UHE region



KM3NeT 2502.08173 See also Li+ 2502.04508 [1] Maltoni Schwetz 2003 [2] Gelman+ 1996

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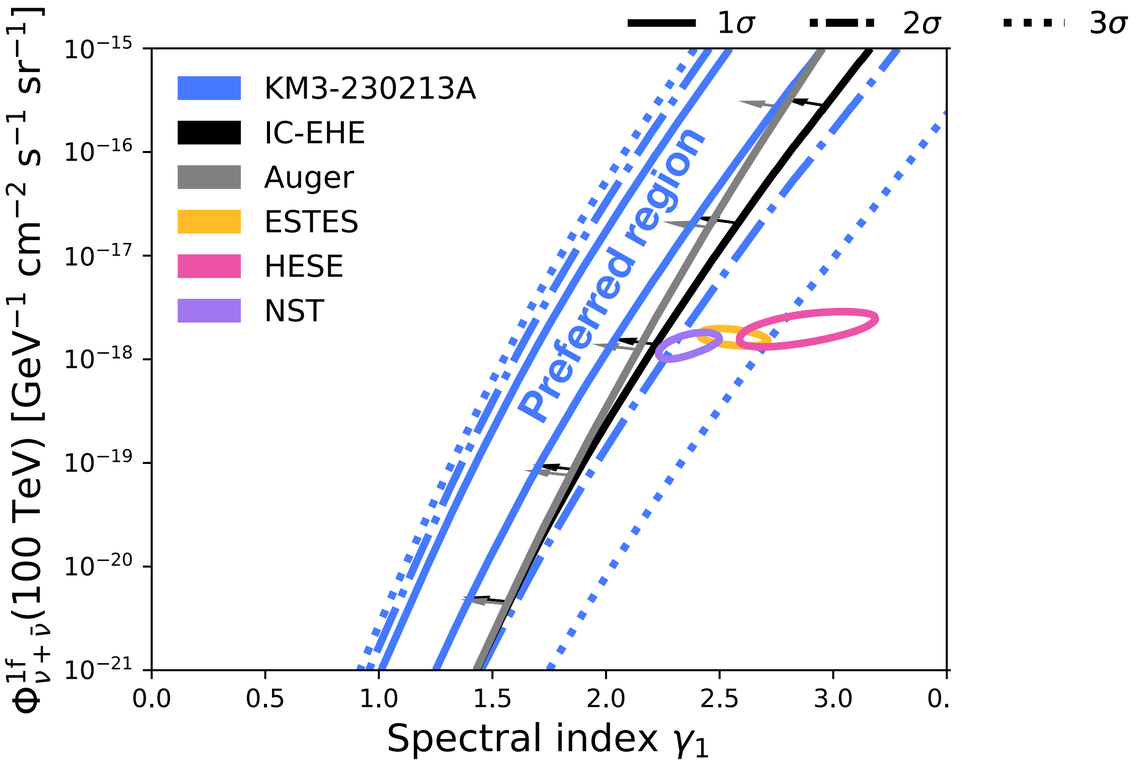
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KM3NeT 2502.08173 See also Li+ 2502.04508 [1] Maltoni Schwetz 2003 [2] Gelman+ 1996

Is there tension between KM3-230213A and null observations from IceCube and Auger?

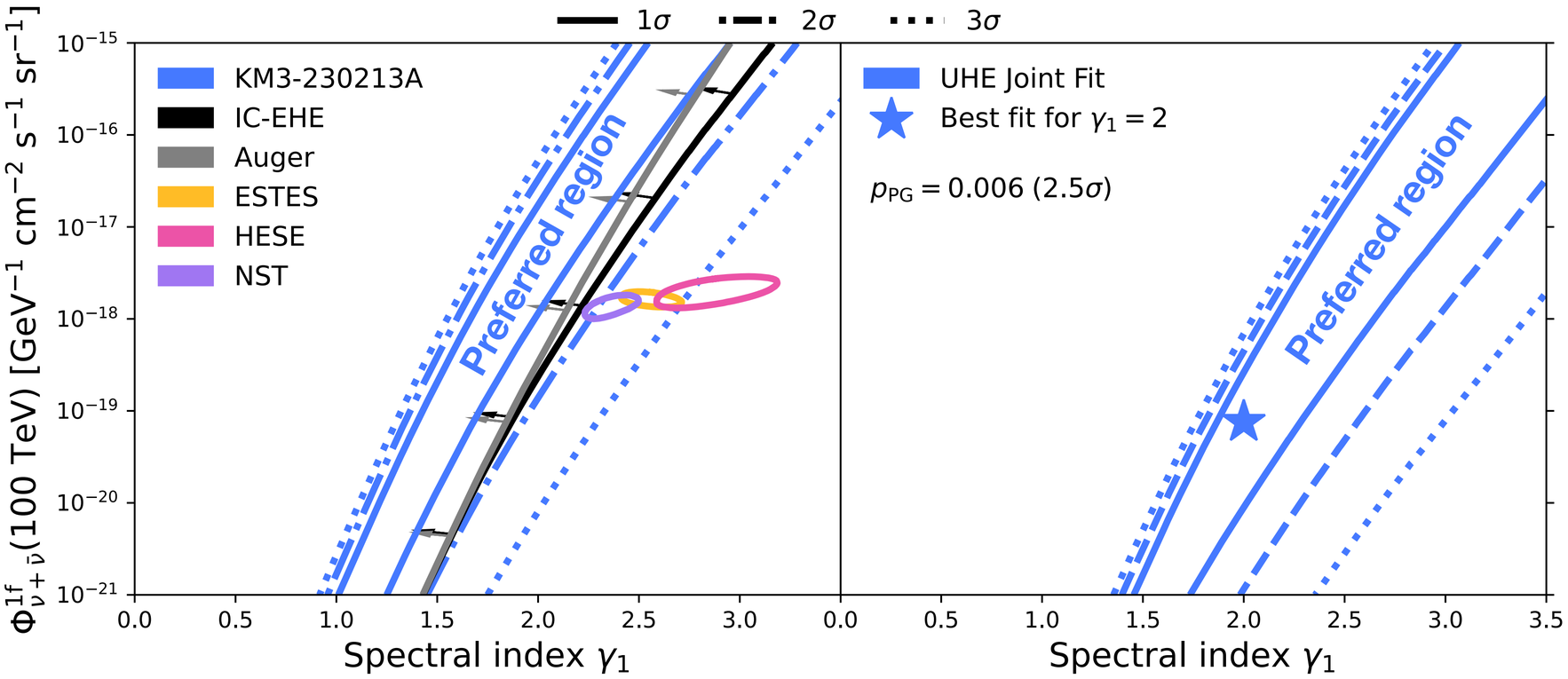
We consider a generic single-power-law flux model in the UHE region



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We consider a generic single-power-law flux model in the UHE region

Frequentist test

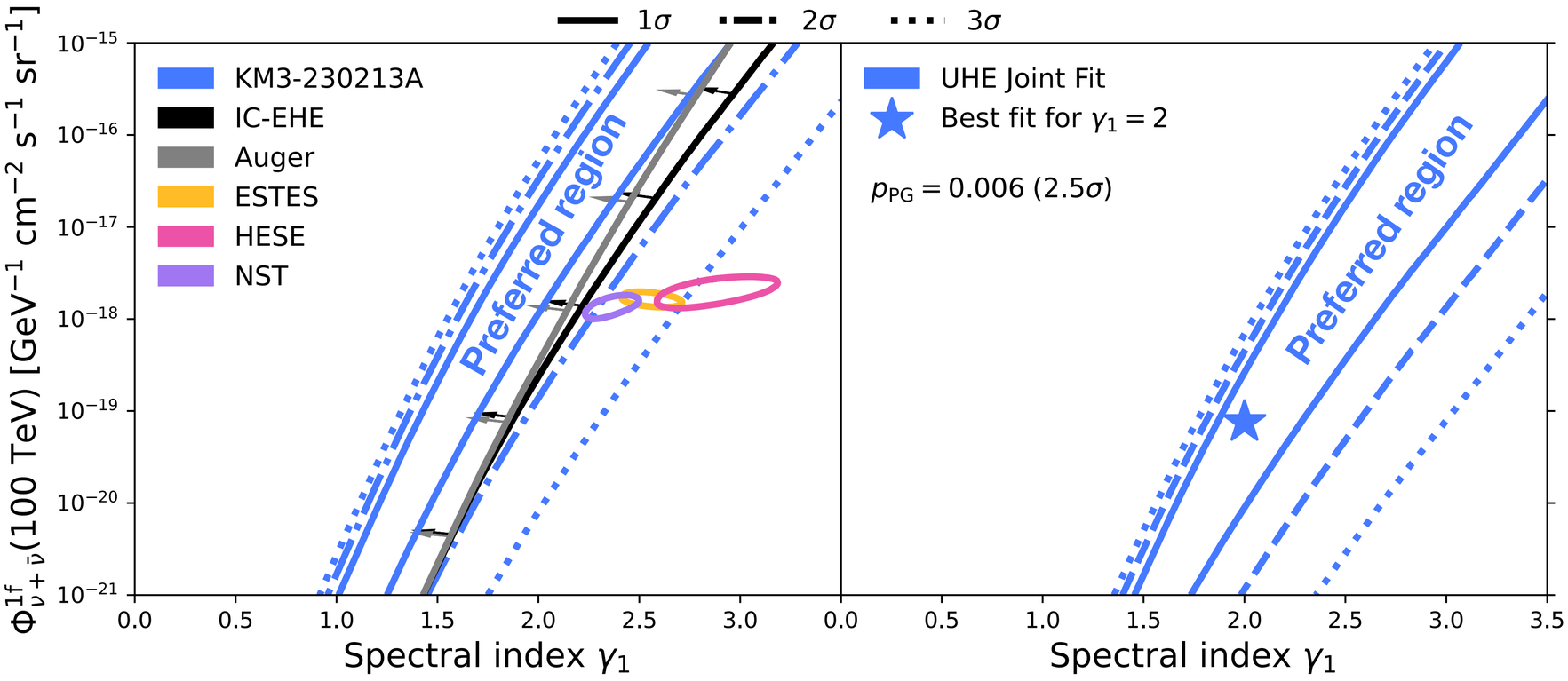
Parameter goodness of fit [1]

$$z_{\rm PG} = 2.5\sigma$$

Bayesian test

Posterior predictive check [2]

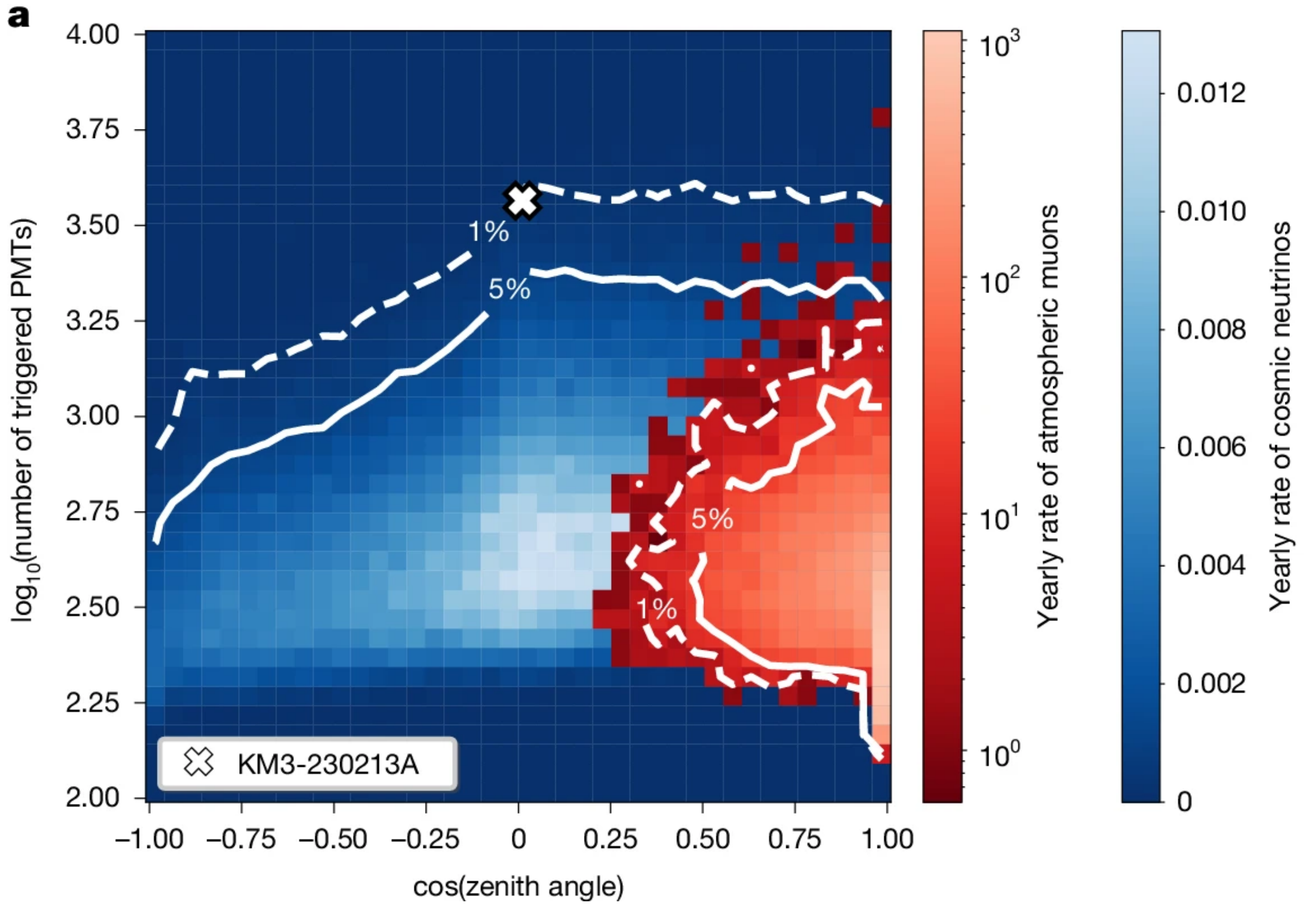
$$z_{\rm PPC} = 2.5\sigma$$

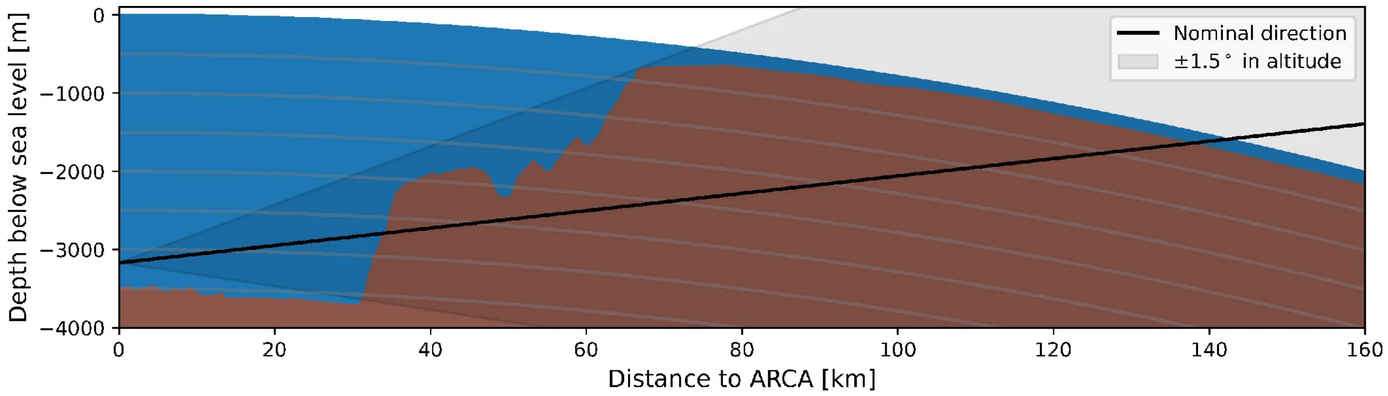


KM3NeT 2502.08173 See also Li+ 2502.04508 [1] Maltoni Schwetz 2003 [2] Gelman+ 1996

Backgrounds

- $\theta_{\text{zenith}} = 0.6° \pm 1.5°$, where the angular uncertainty is dominated by uncertainties in the absolute position of DUs

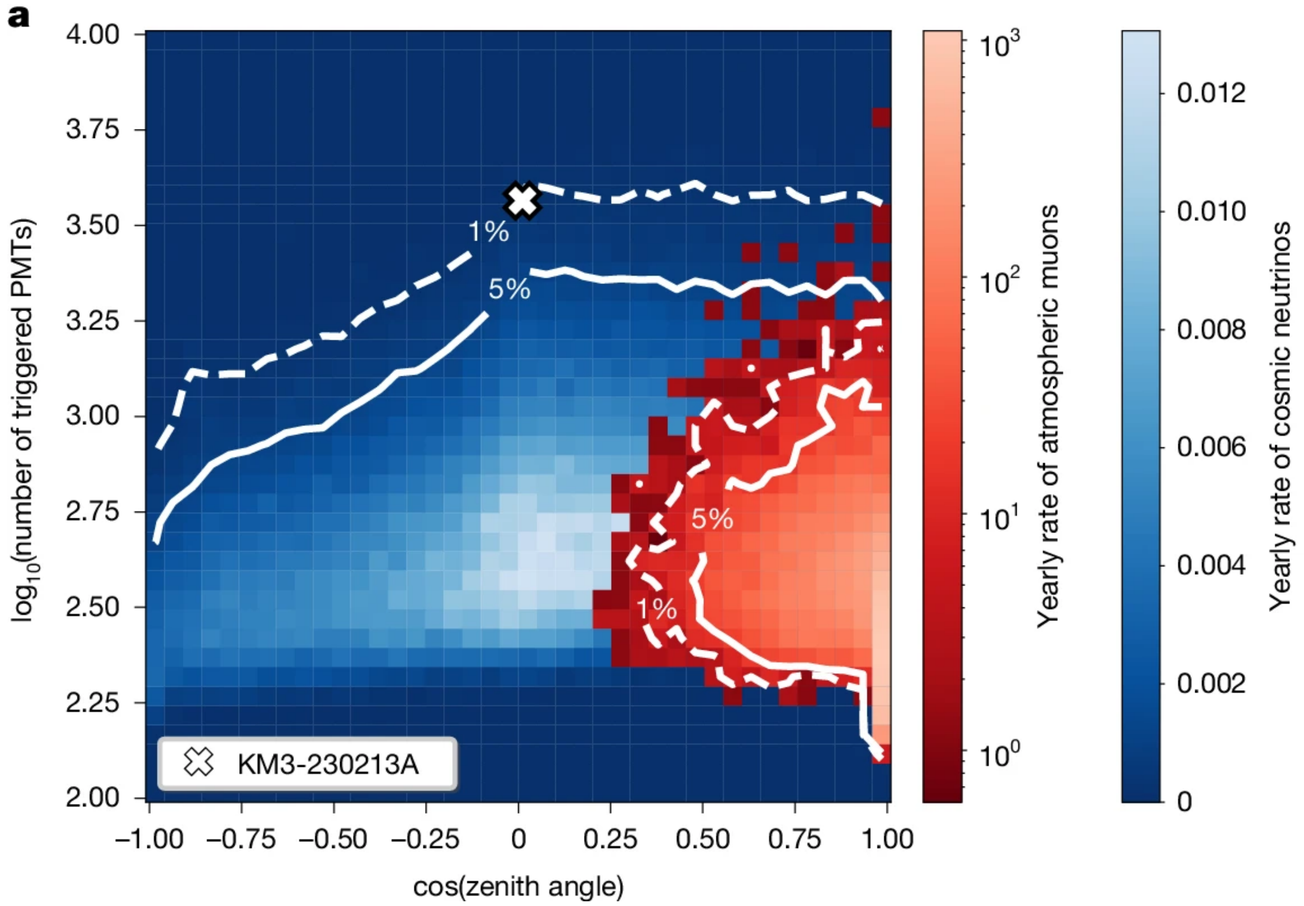


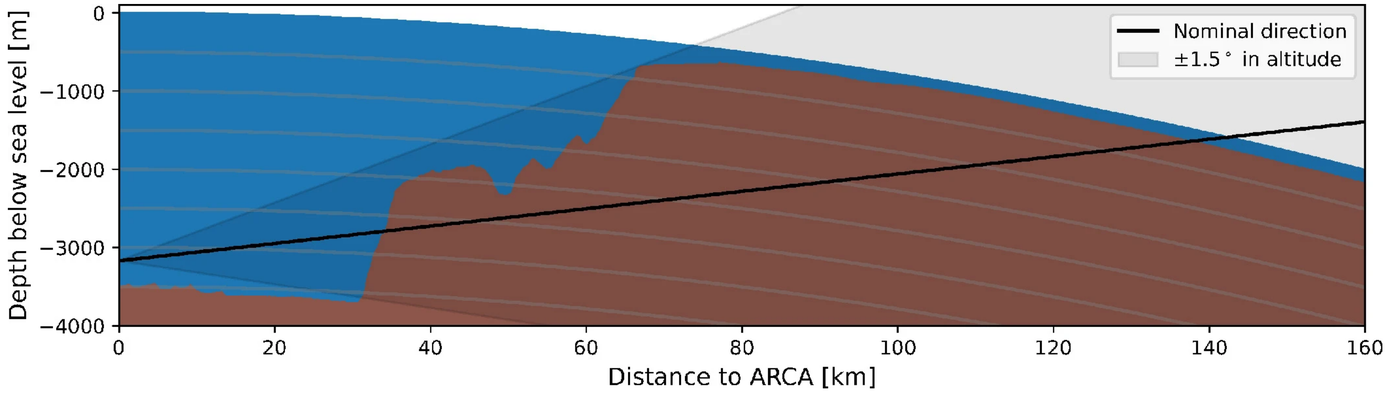


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Backgrounds

- $\theta_{\text{zenith}} = 0.6° \pm 1.5°$, where the angular uncertainty is dominated by uncertainties in the absolute position of DUs
- Considering the natural overburden, an upper limit on the atmospheric muon background at 100 PeV:

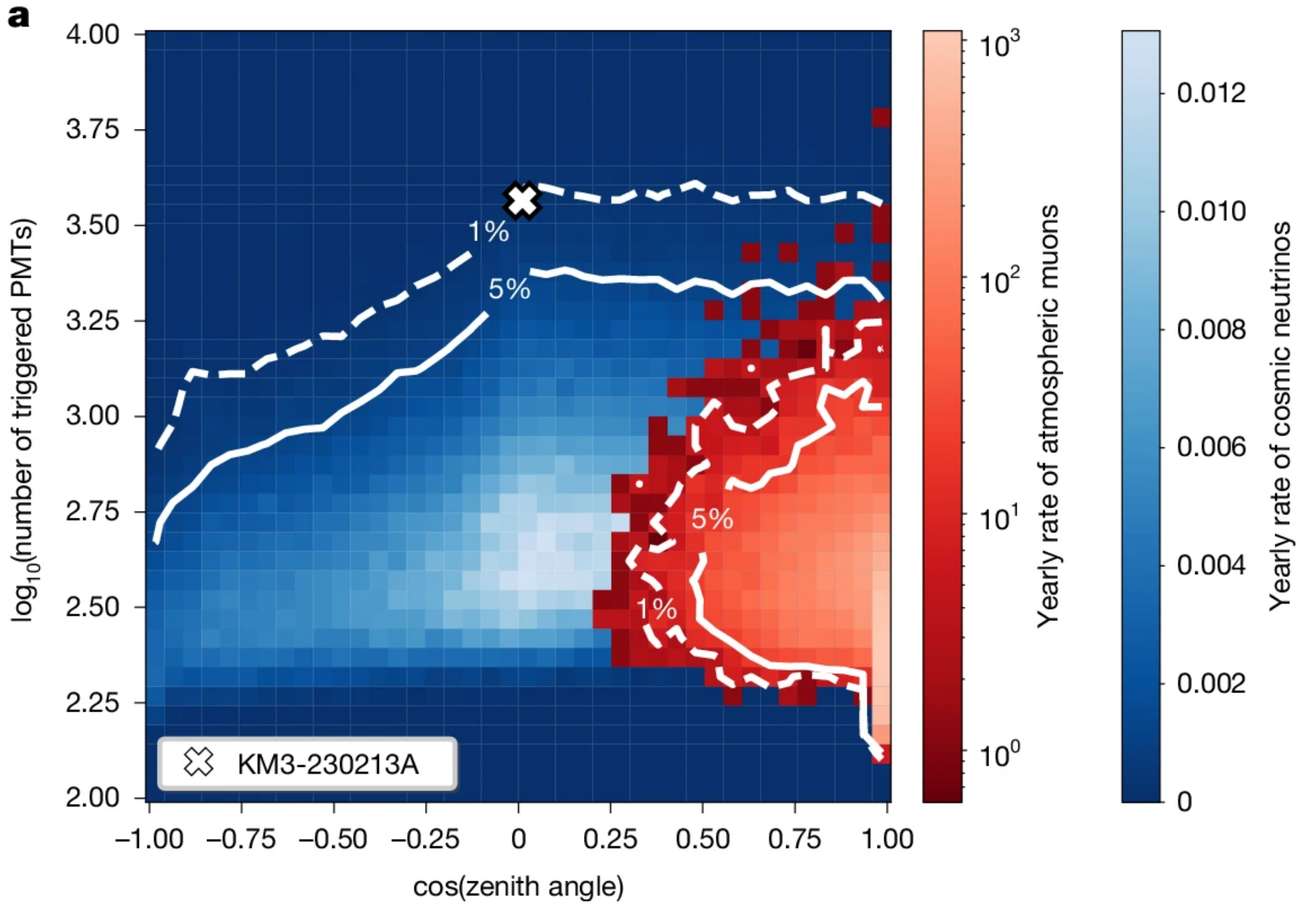


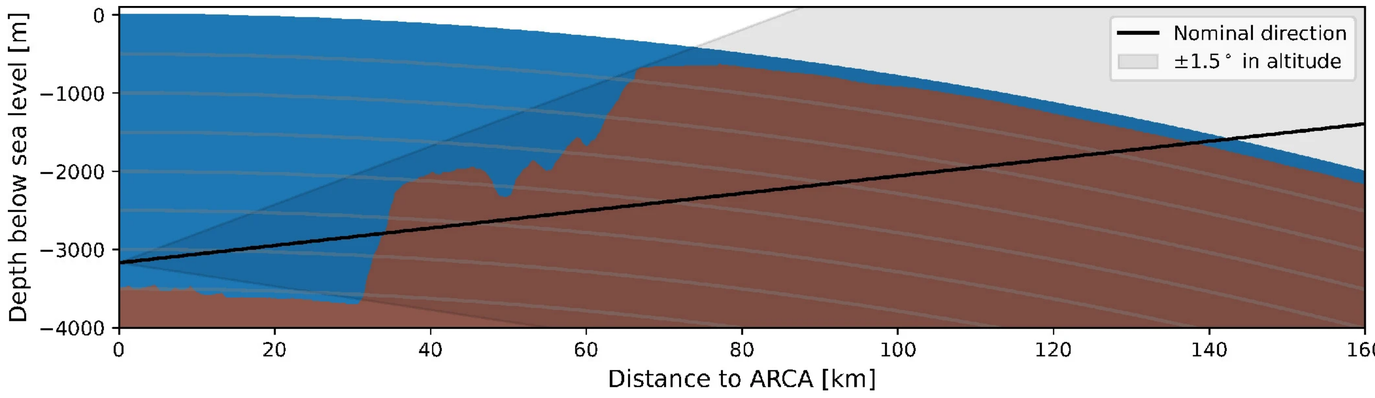


KM3NeT Nature 2025

Backgrounds

- $\theta_{\text{zenith}} = 0.6° \pm 1.5°$, where the angular uncertainty is dominated by uncertainties in the absolute position of DUs
- Considering the natural overburden, an upper limit on the atmospheric muon background at 100 PeV:
  - $\ll 10^{-10}$ events per year within 2σ of the reconstructed direction

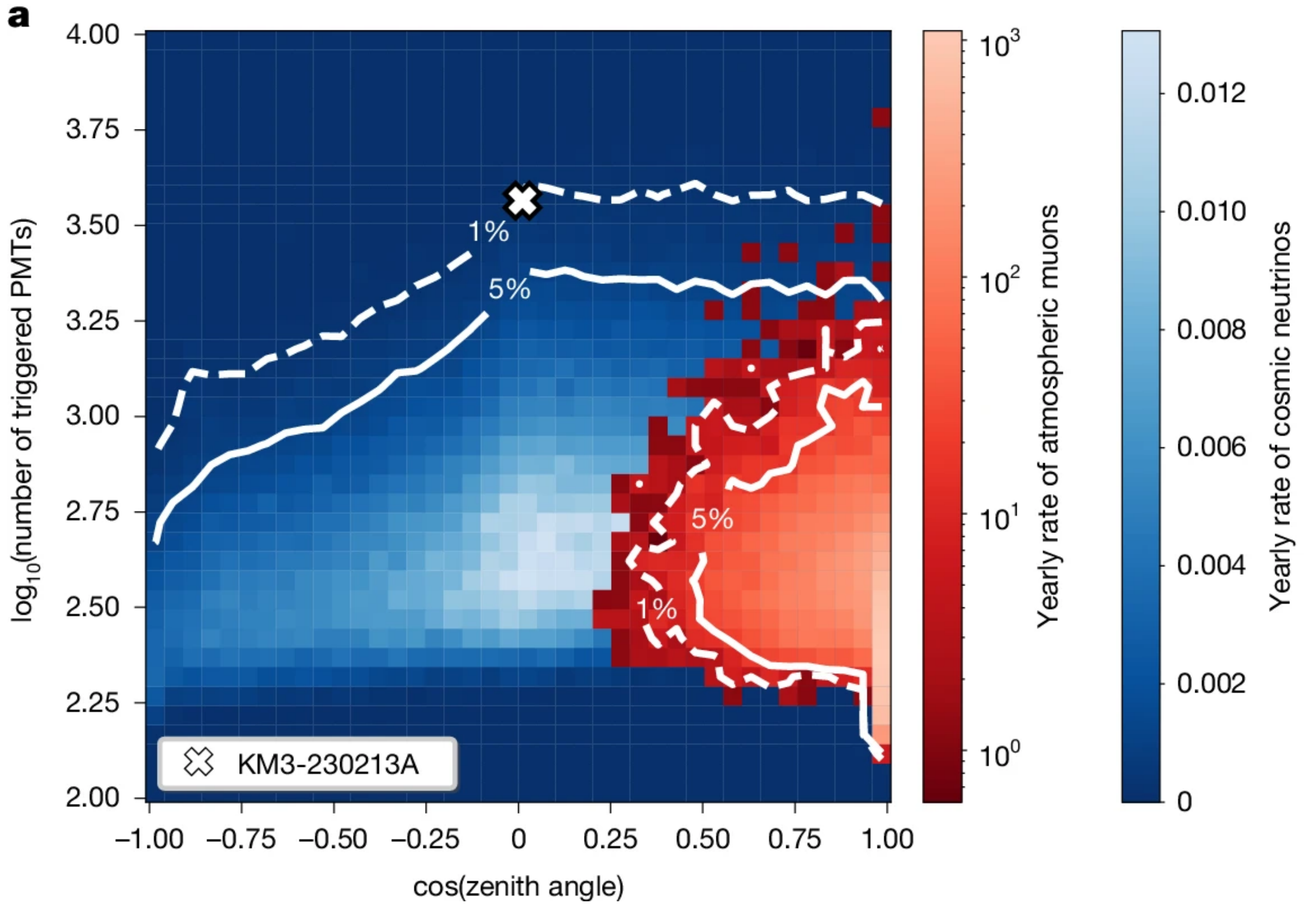


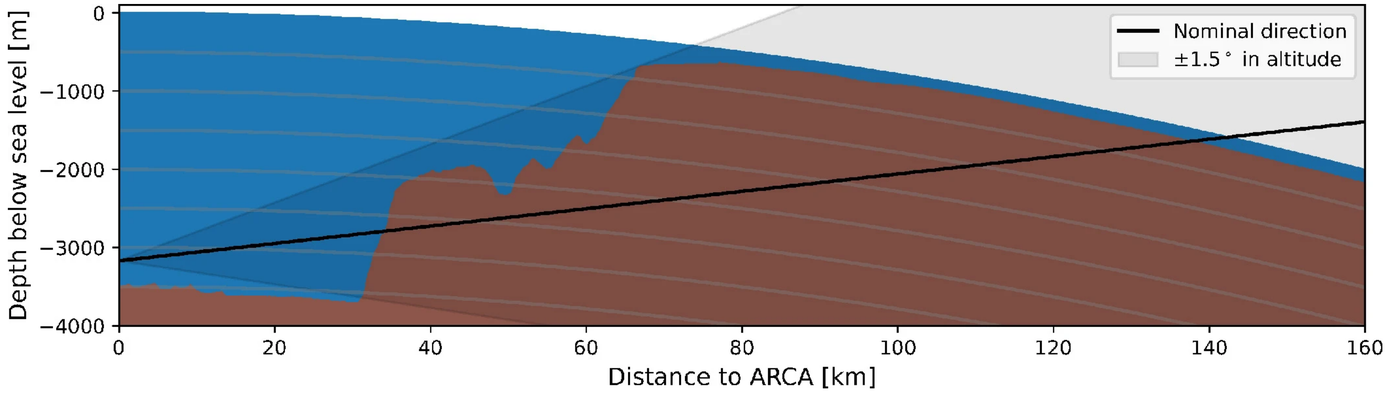


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Backgrounds

- $\theta_{\text{zenith}} = 0.6° \pm 1.5°$, where the angular uncertainty is dominated by uncertainties in the absolute position of DUs
- Considering the natural overburden, an upper limit on the atmospheric muon background at 100 PeV:
  - $\ll 10^{-10}$ events per year within 2σ of the reconstructed direction
  - $\ll 10^{-4}$ events per year within 5σ of the reconstructed direction

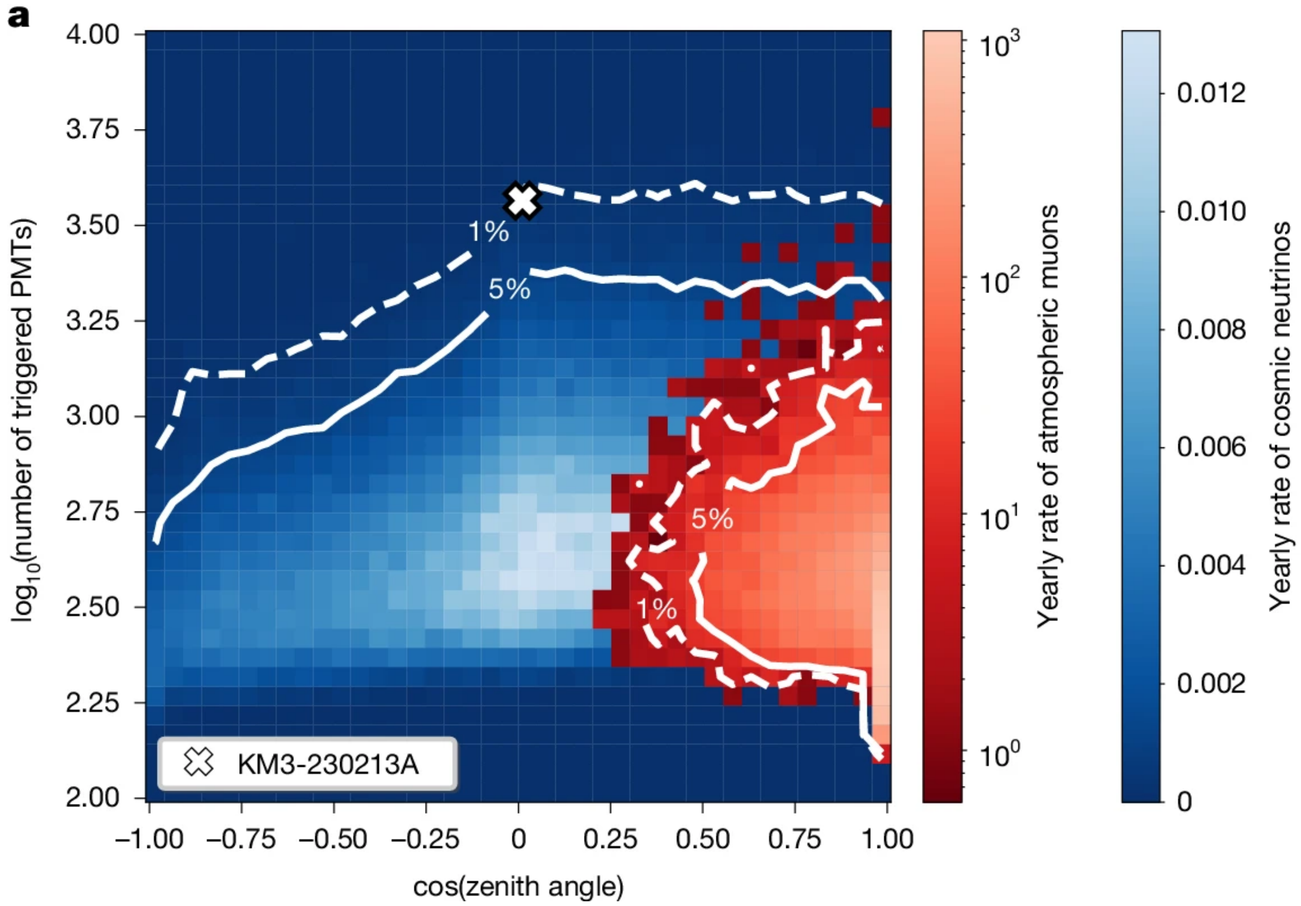


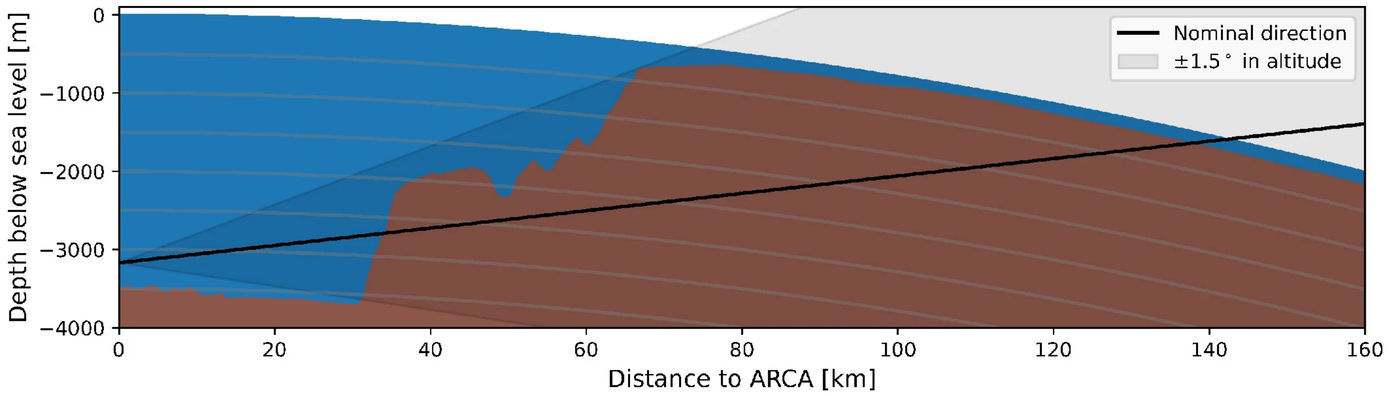


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Backgrounds

- $\theta_{\text{zenith}} = 0.6° \pm 1.5°$, where the angular uncertainty is dominated by uncertainties in the absolute position of DUs
- Considering the natural overburden, an upper limit on the atmospheric muon background at 100 PeV:
  - $\ll 10^{-10}$ events per year within 2σ of the reconstructed direction
  - $\ll 10^{-4}$ events per year within 5σ of the reconstructed direction
- Atmospheric neutrino background above 100 PeV is approximately $(1-5) \times 10^{-5}$ events per year, dominated by the prompt component





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