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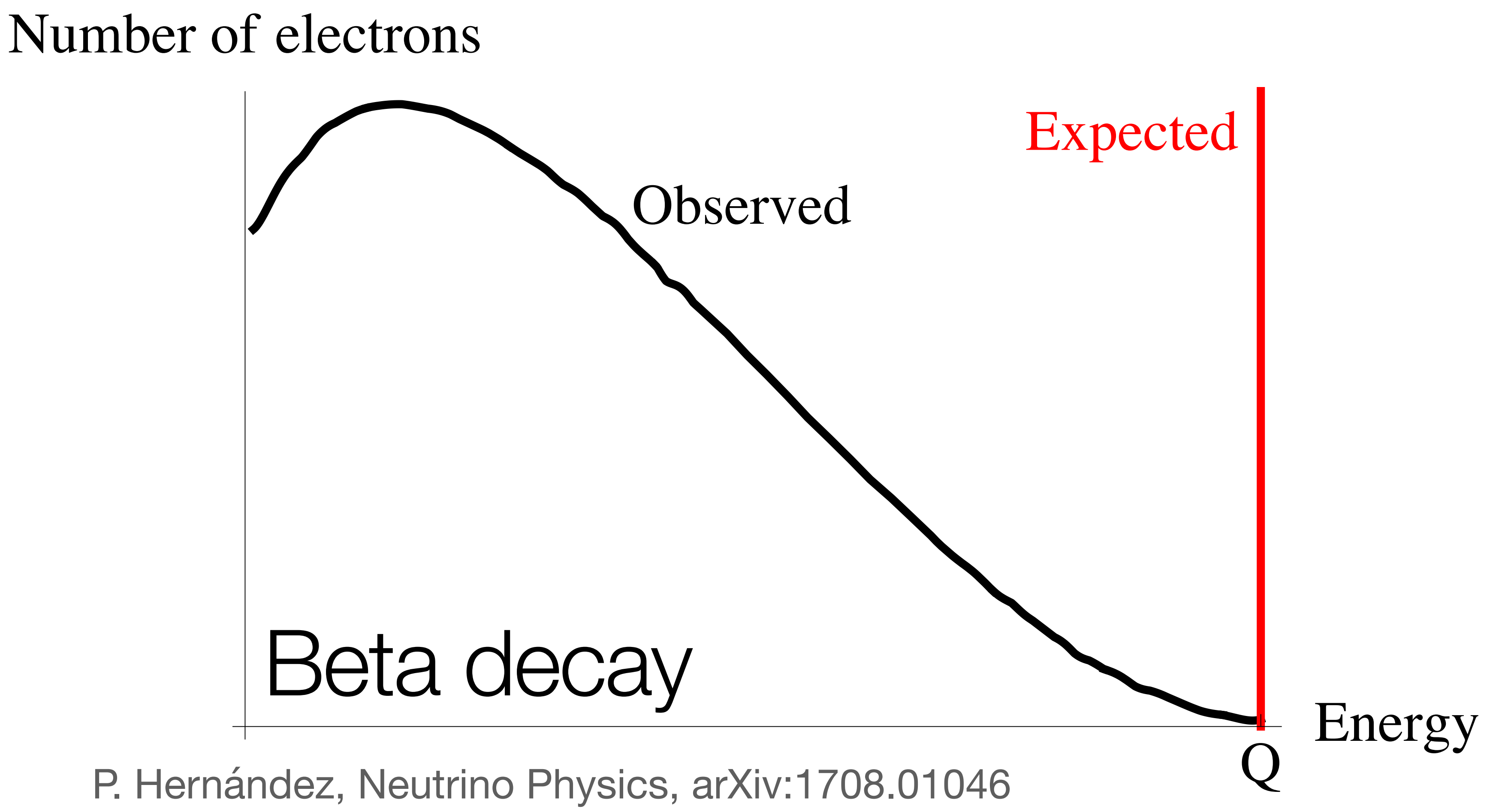
Using Natural Neutrinos to Probe Nature Properties

Rasmi E. Hajjar Muñoz

CCAPP SYMPOSIUM

Neutrinos!

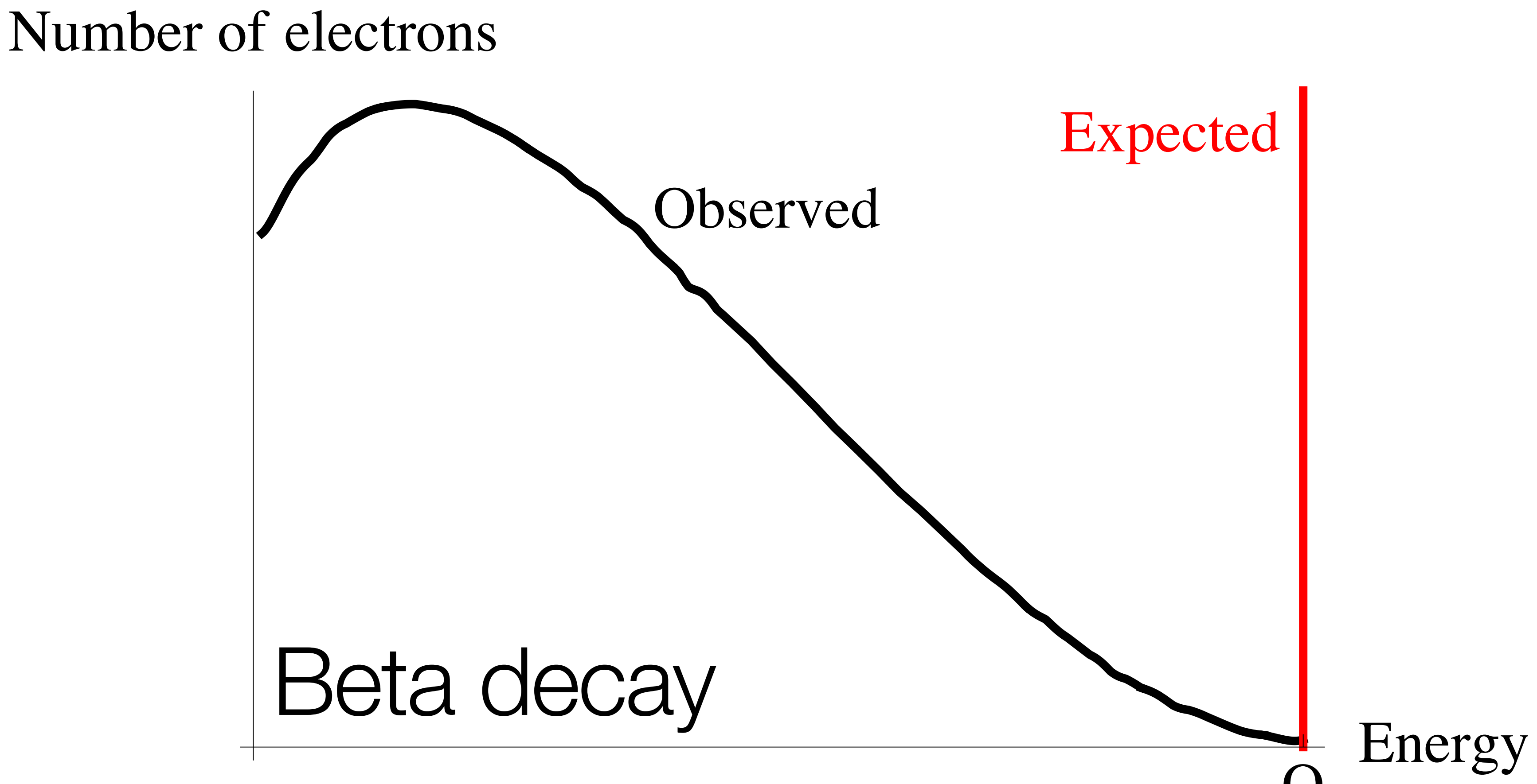
Neutrinos!



P. Hernández, Neutrino Physics, arXiv:1708.01046

First neutrino detection:
Project Poltergeist,
neutrinos from Savannah
River reactor, 1950s

Neutrinos!



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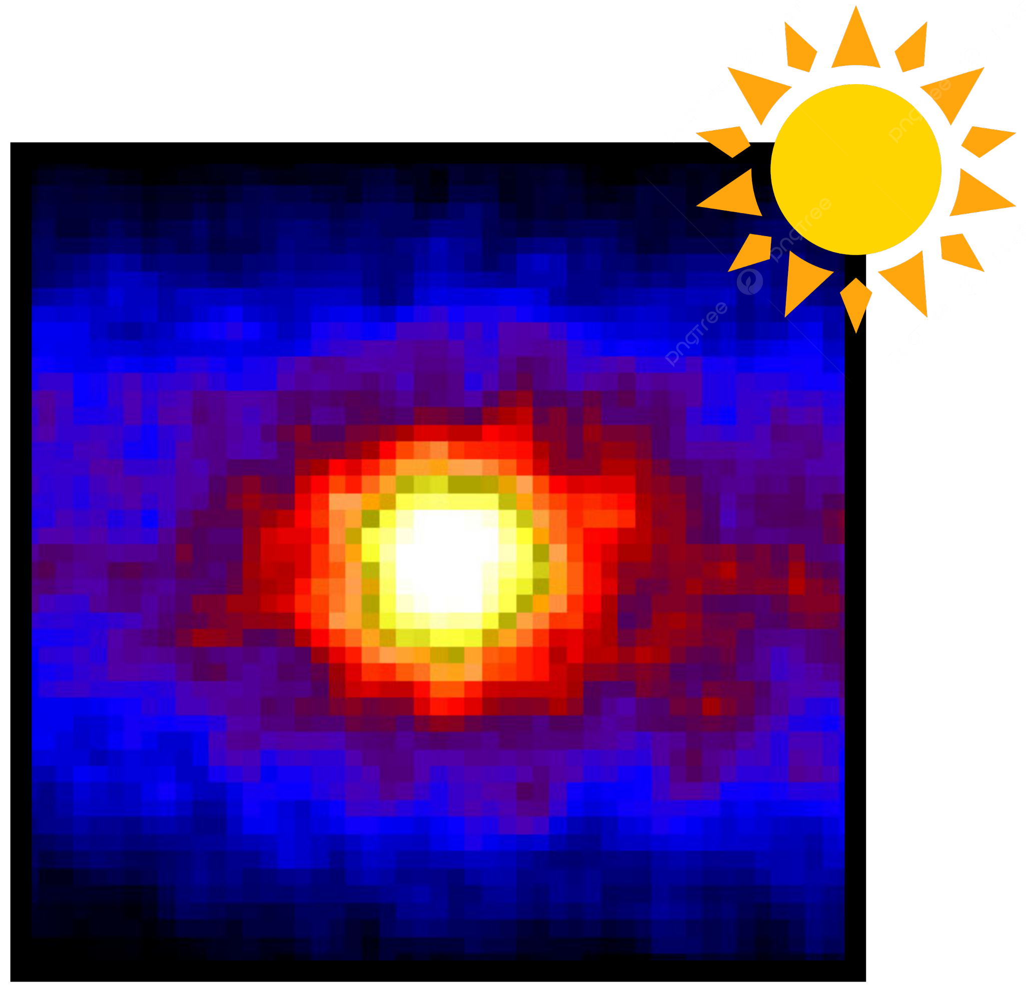

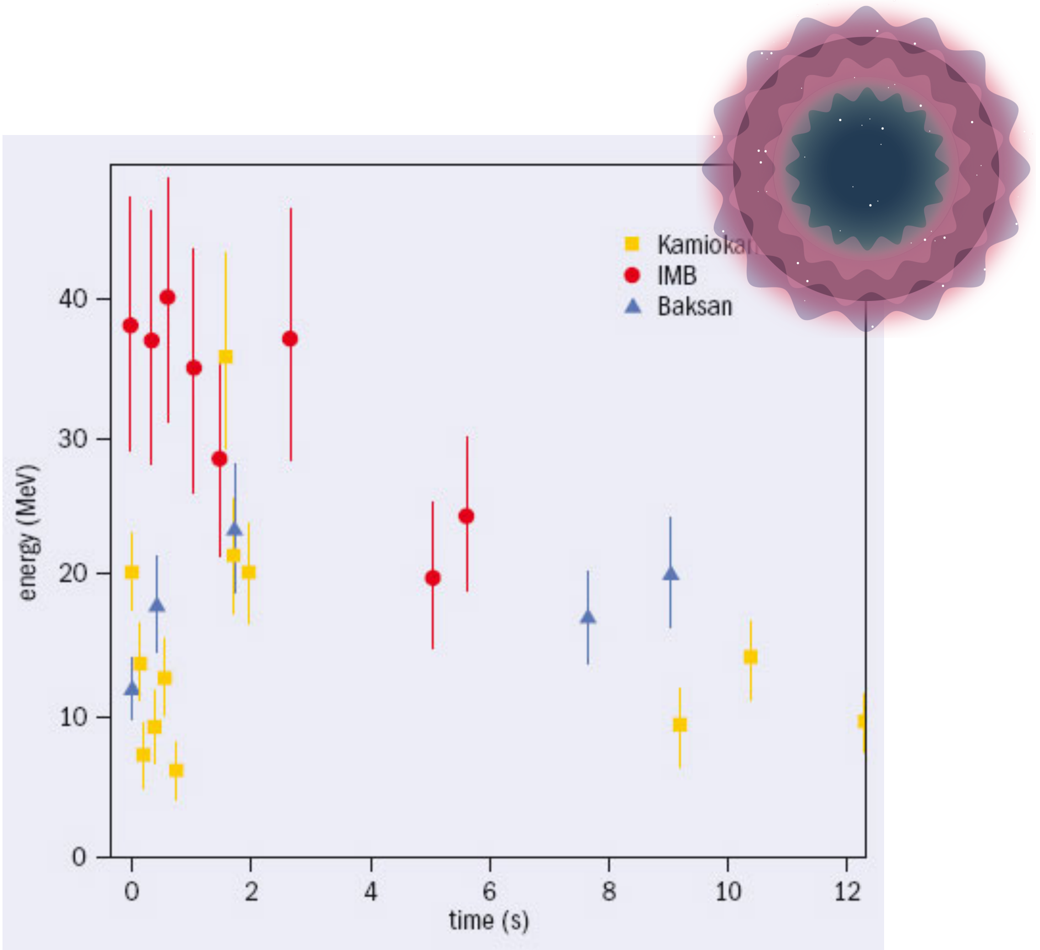

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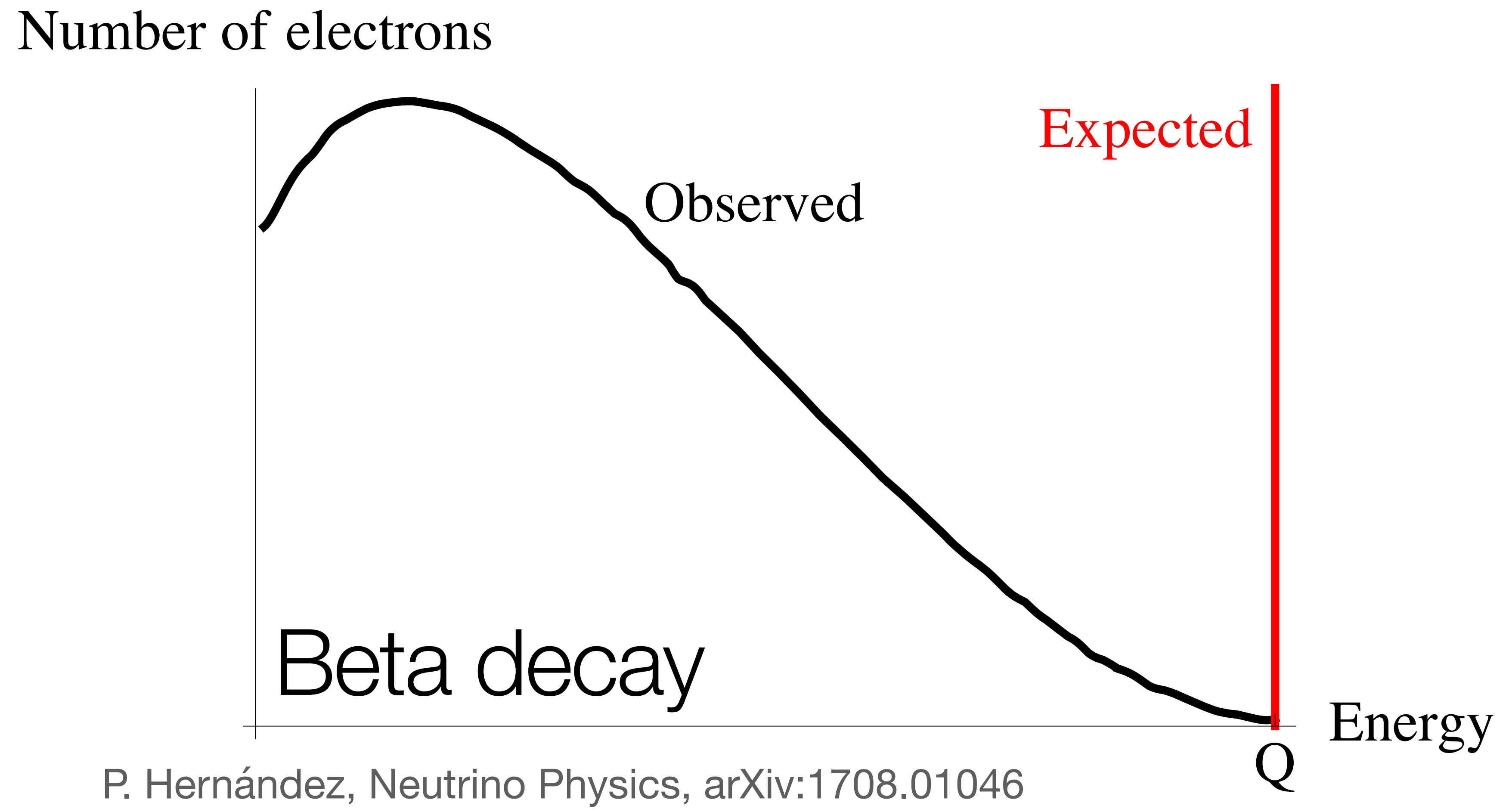

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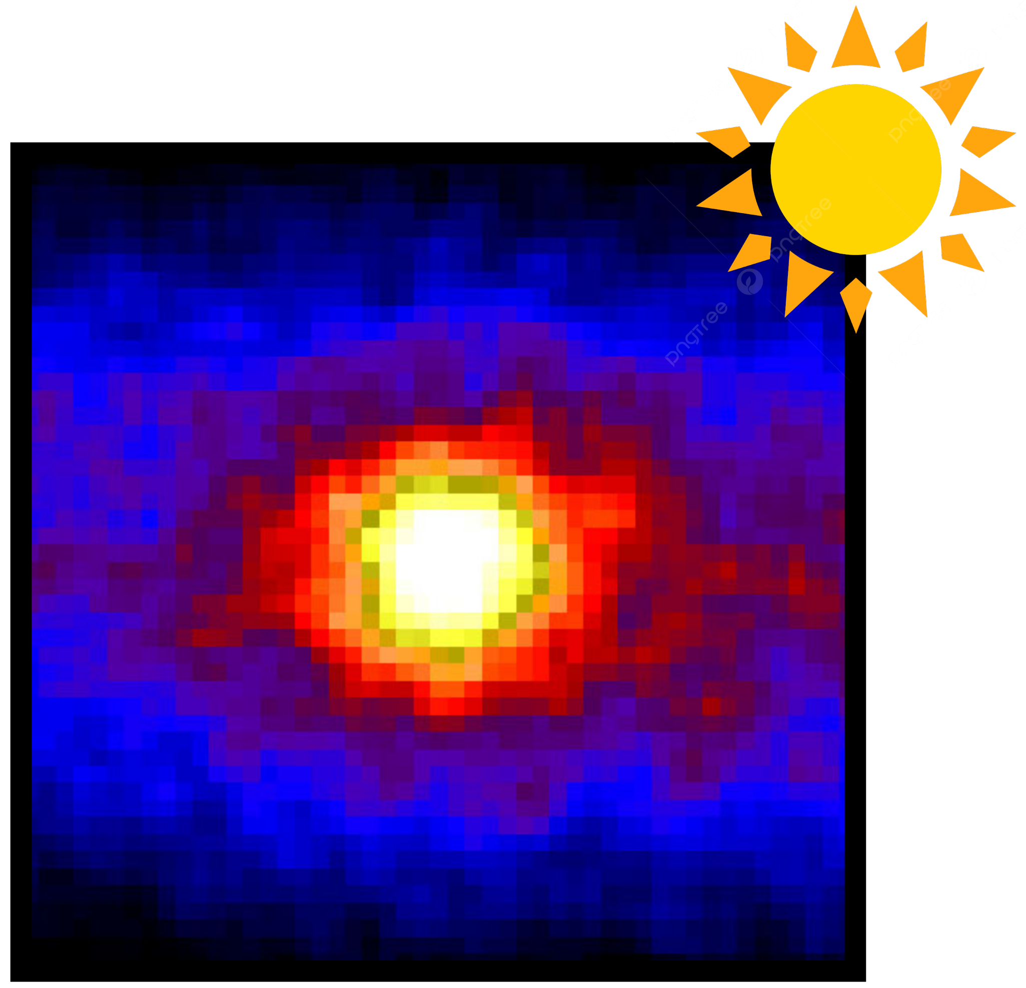
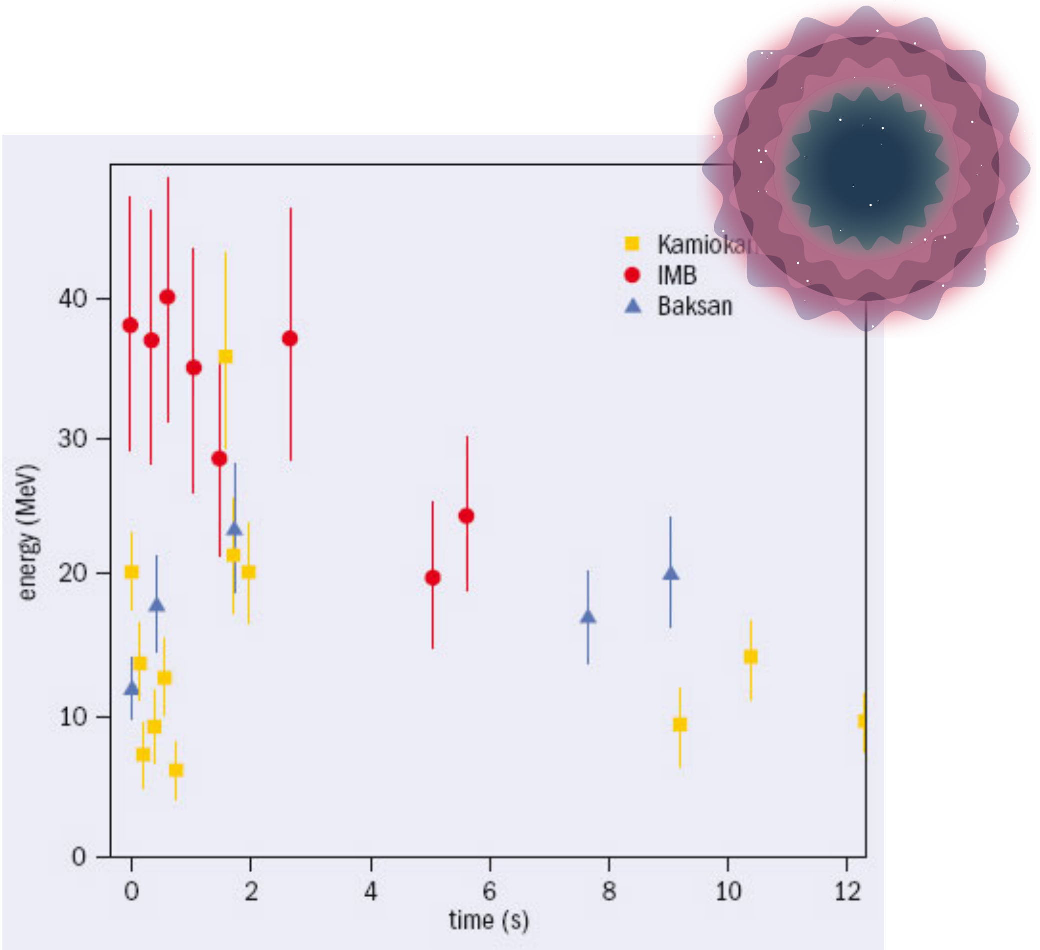


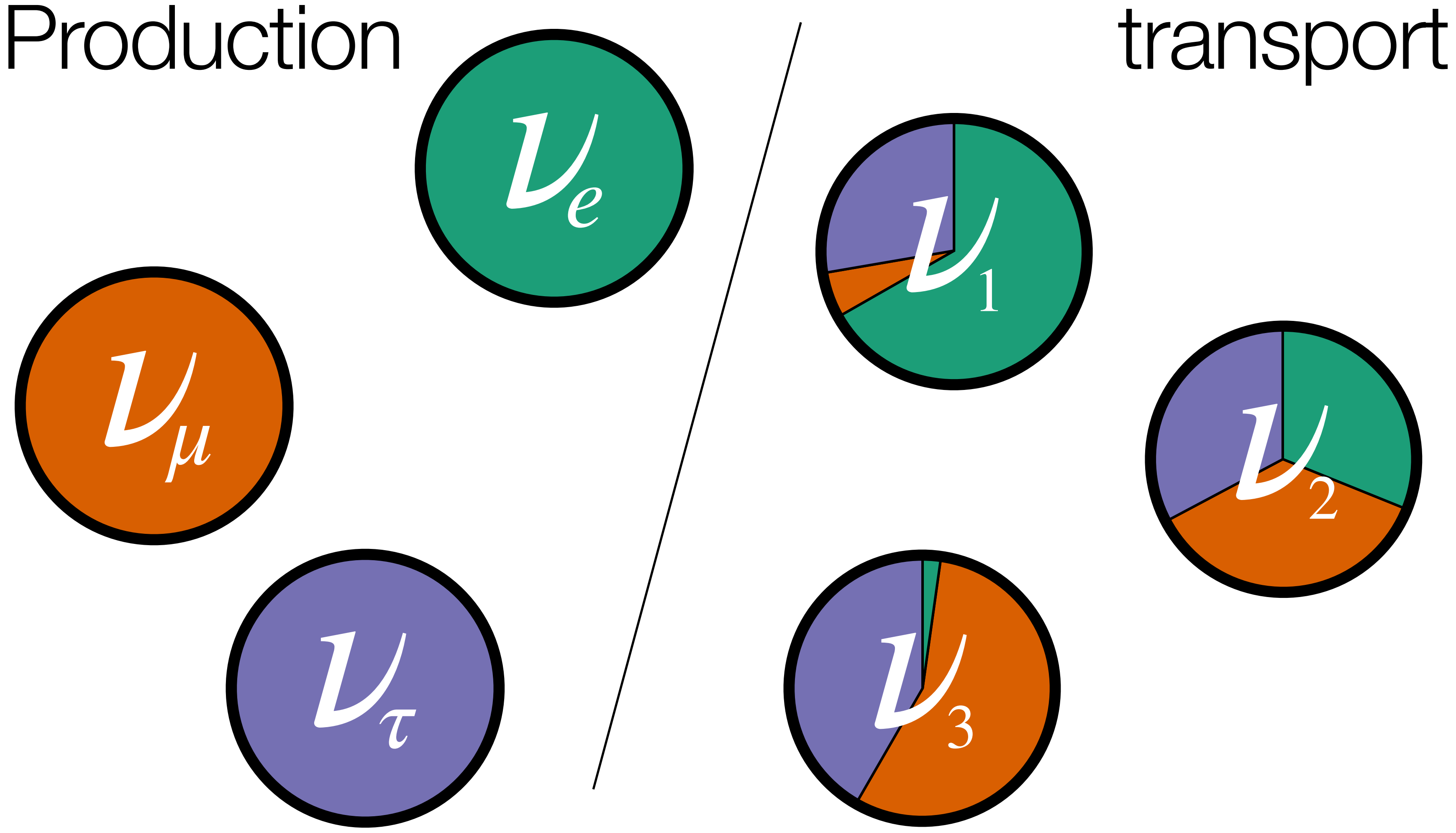


Neutrino Oscillations

$$P(\nu_\alpha \to \nu_\beta) \neq 0 \qquad \alpha, \beta \in \{e, \mu, \tau\}$$

Detection/
Production

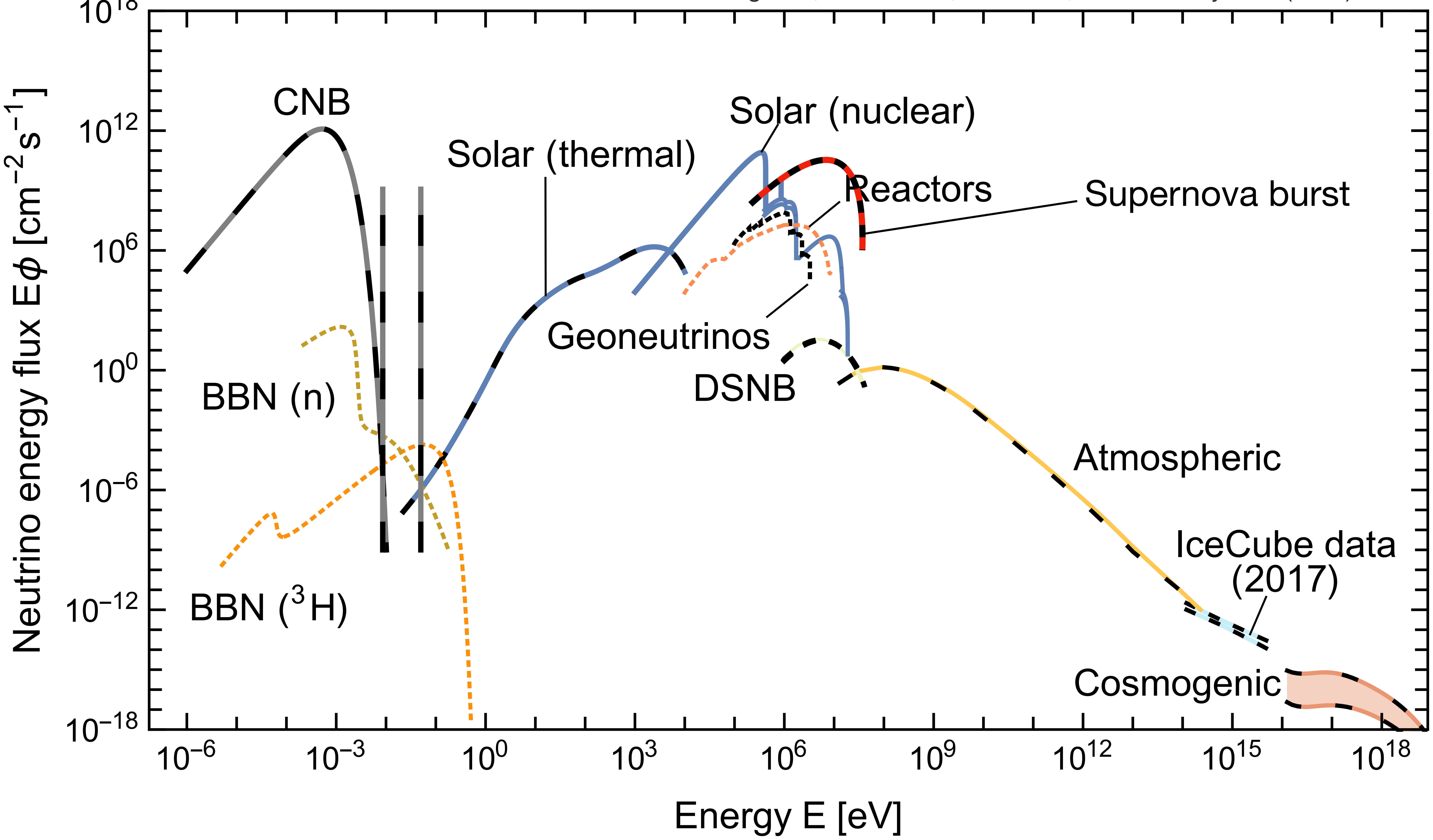
Vacuum
transport



$$\Delta m^2_{21} \simeq 7.5 \cdot 10^{-5} \text{ eV}^2$$
$$|\Delta m^2_{31}| \simeq 2.5 \cdot 10^{-3} \text{ eV}^2$$

Natural neutrino sources

E. Vitagliano, I. Tamborra, G. Raffelt, *Rev.Mod.Phys.* 92 (2020) 45006



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UHE Neutrinos

Limits on Dark Matter lifetime

τ_{DM}

Atmospheric Neutrinos

Neutrino Mass Ordering Determination

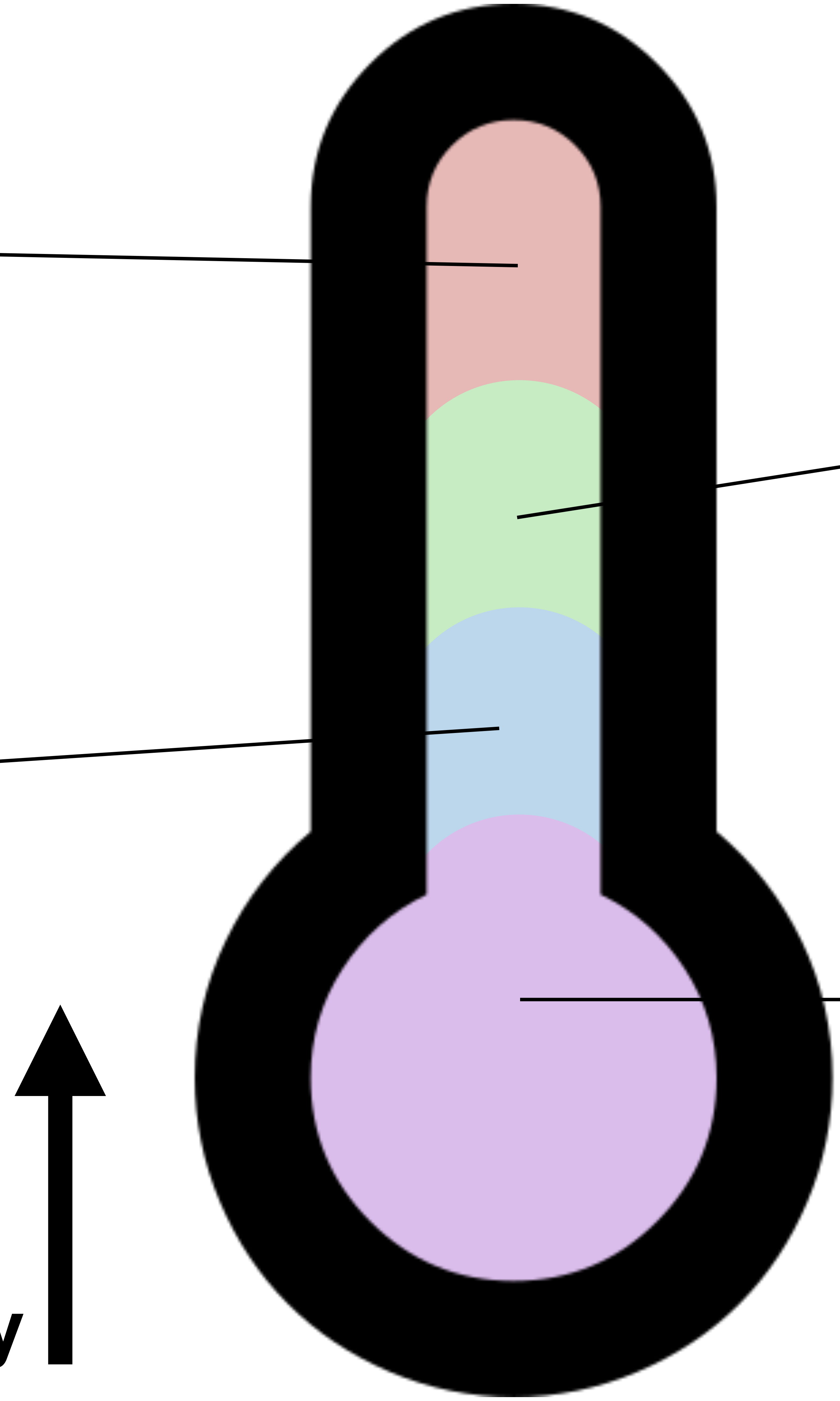
$\mathrm{sign}(\Delta m^2_{31})$

Supernova Neutrinos

Determination of solar mixing parameters $\Delta m^2_{21}, \theta_{12}$

SN neutrino Earth tomography

$\rho_\oplus$

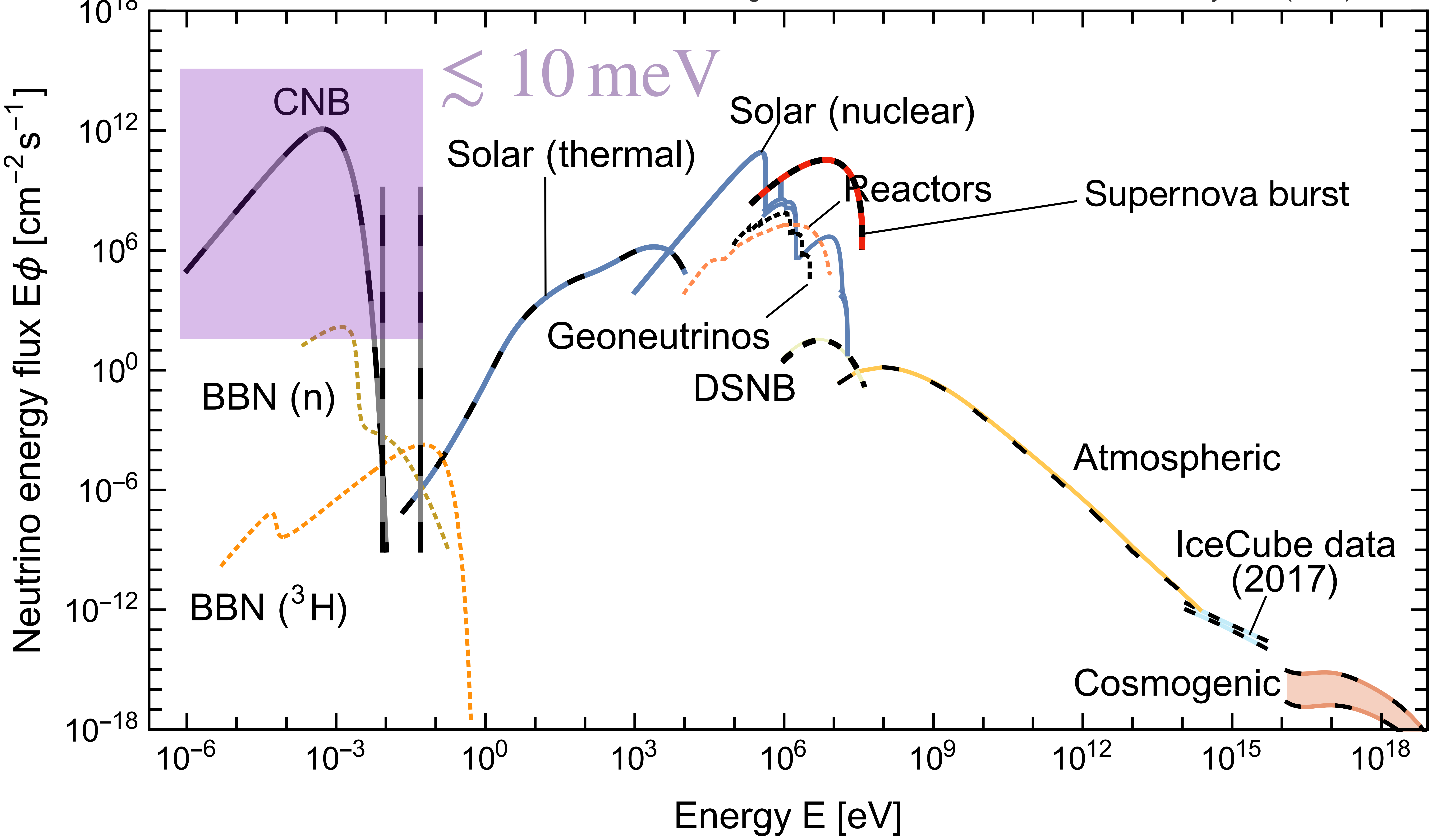


Cosmic Neutrino Background

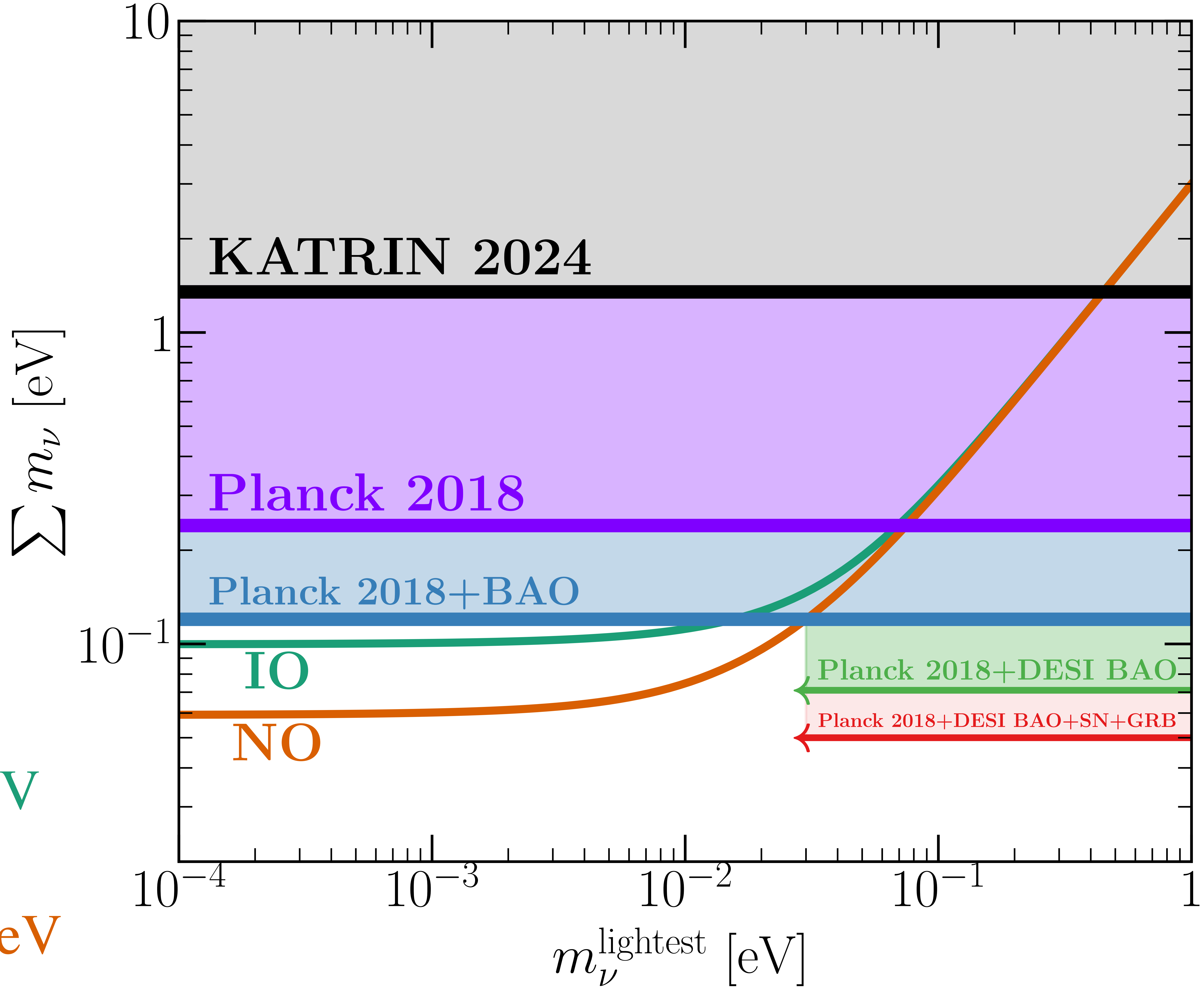
Inspecting CMB upper bound on neutrino masses $\sum m_\nu$

Natural neutrino sources

E. Vitagliano, I. Tamborra, G. Raffelt, *Rev.Mod.Phys.* 92 (2020) 45006



Cosmo bounds: neutrino mass



$$\sum m_\nu^{\mathrm{KATRIN}} < 1.35\,\mathrm{eV}$$

$$\sum m_\nu^{\mathrm{cosmo}} < \begin{cases} 0.07\,\mathrm{eV} \\ 0.05\,\mathrm{eV} \end{cases}$$

$$\sum m_\nu^{\mathrm{IO}} \geq 0.1\,\mathrm{eV}$$

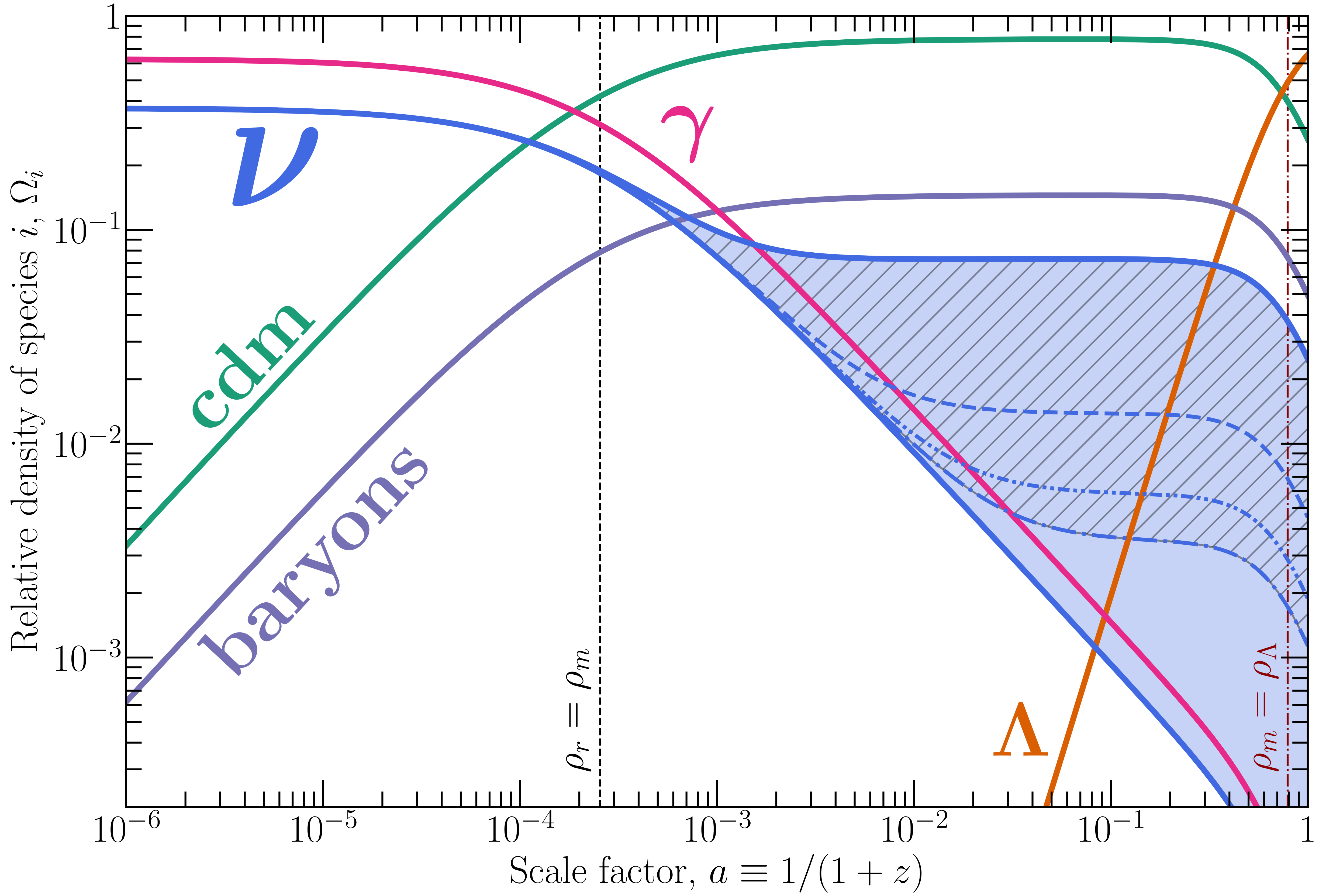
$$\sum m_\nu^{\mathrm{NO}} \geq 0.06\,\mathrm{eV}$$

Cosmo bounds: where do they come from?

Cosmological observables are predictions of:

Energy

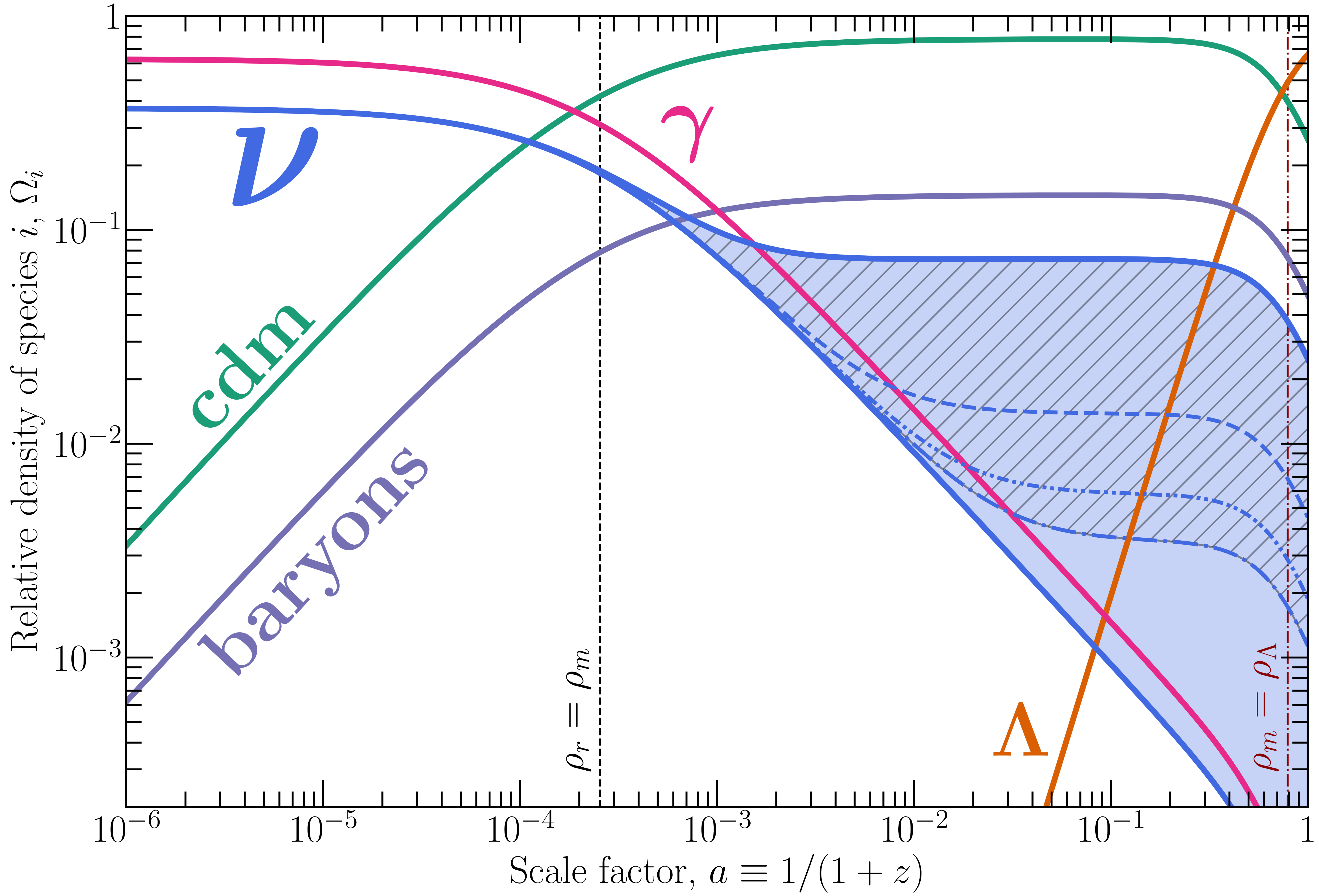
$$G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

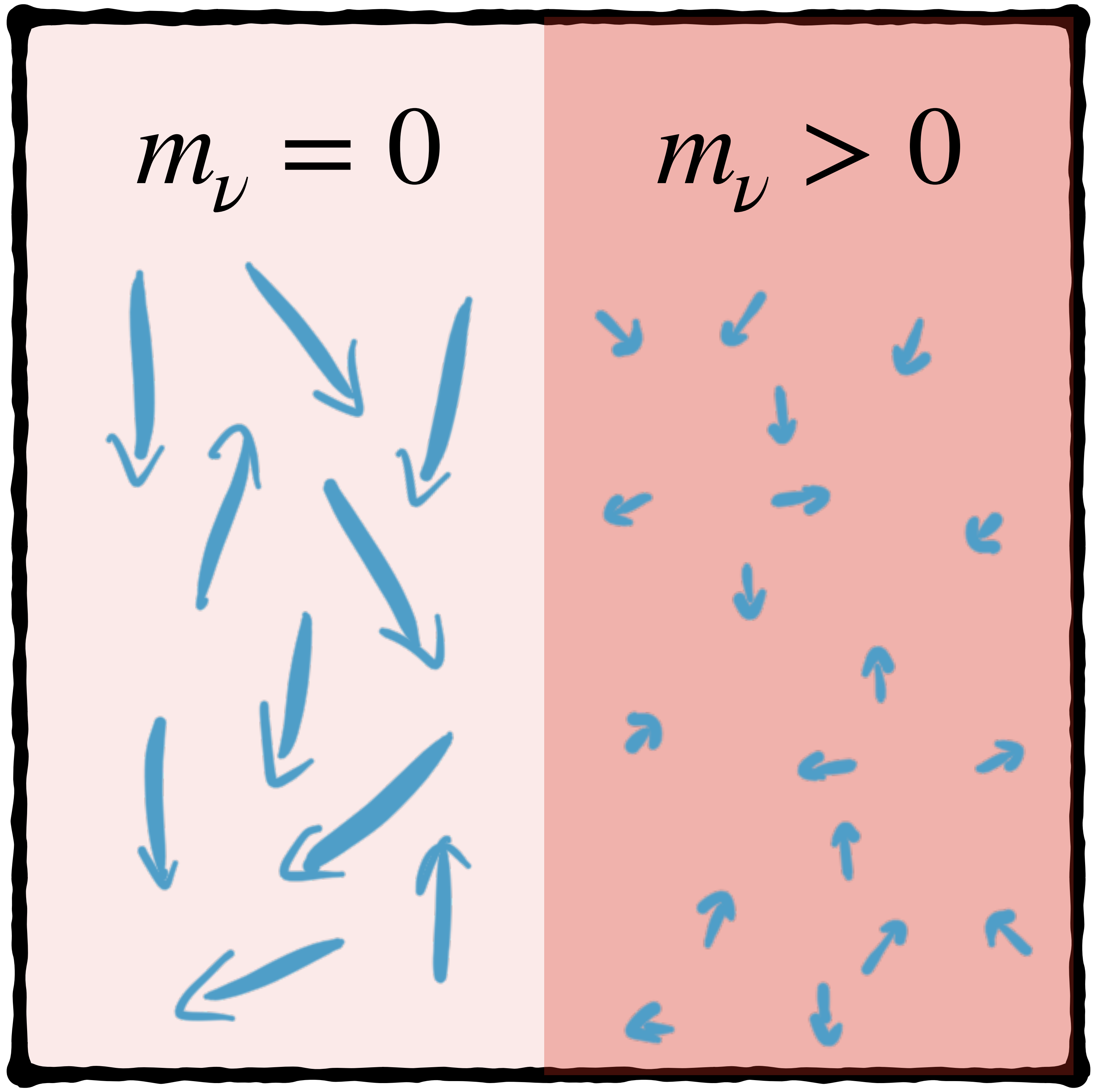


Cosmo bounds: where do they come from?

Cosmological observables are predictions of:

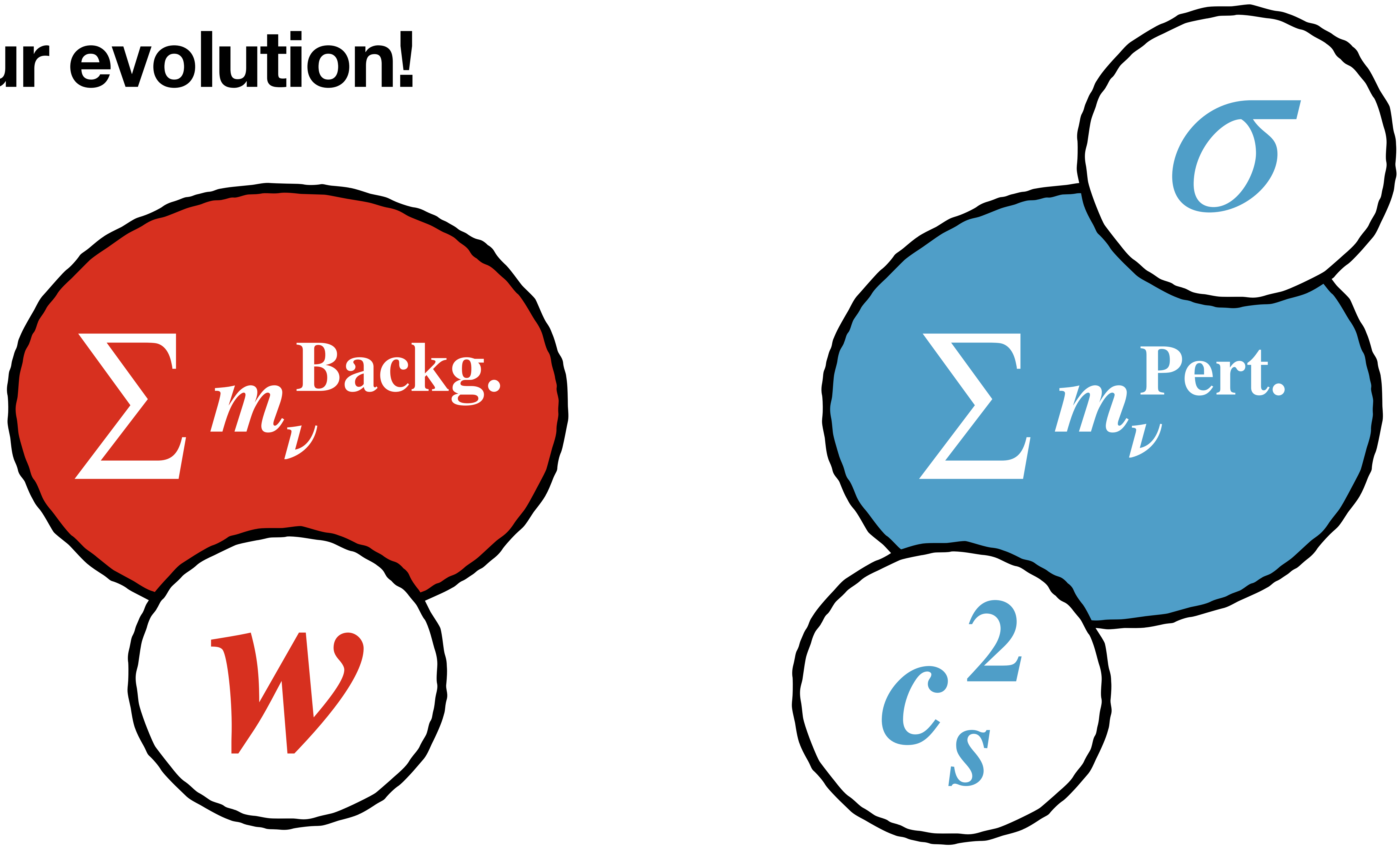
Energy $G_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$ $\quad \delta G_{\mu\nu} = 8\pi G\, \delta T_{\mu\nu}$



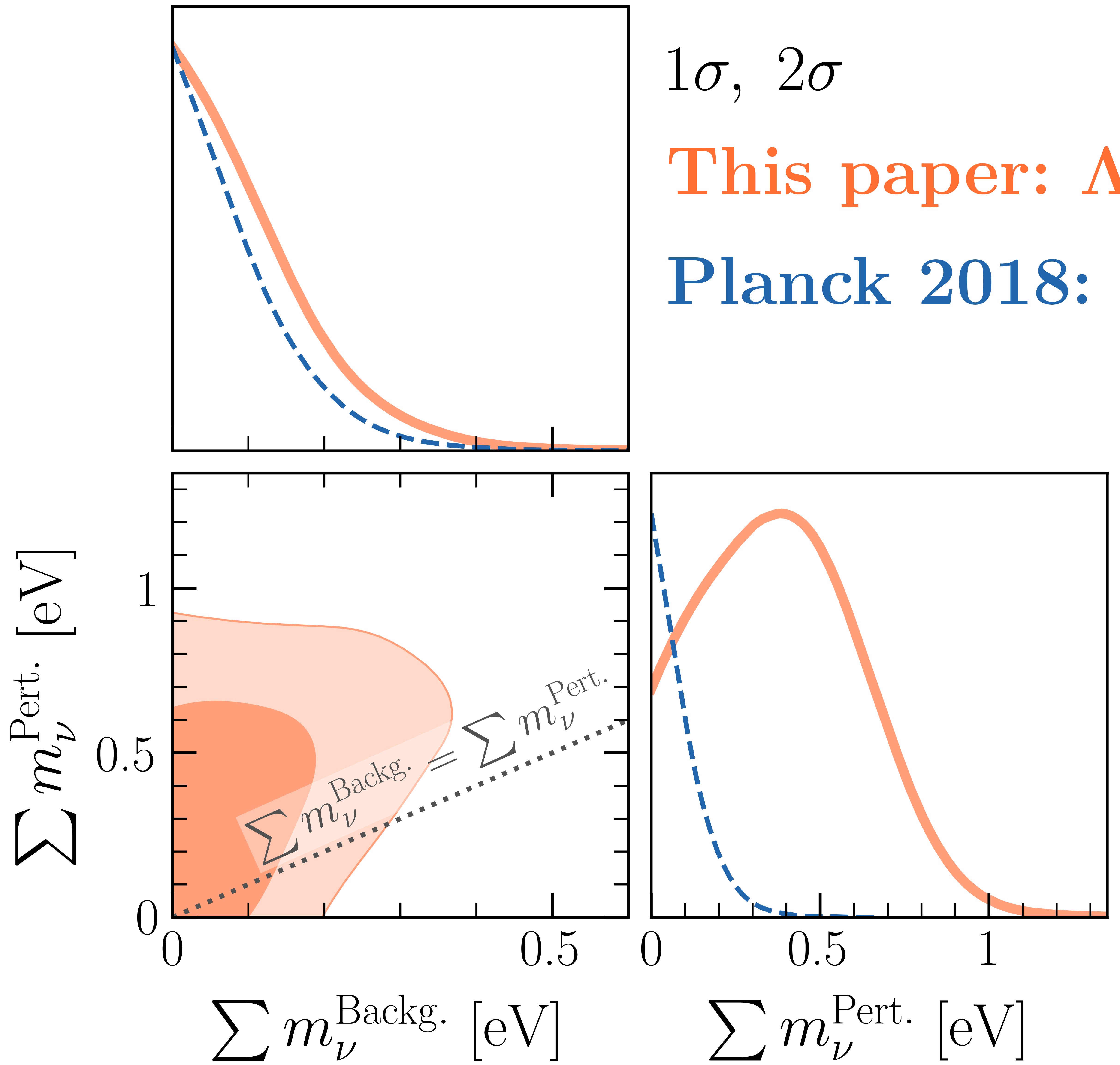


KINEMATICS

Our evolution!



Cosmological inference of neutrino masses

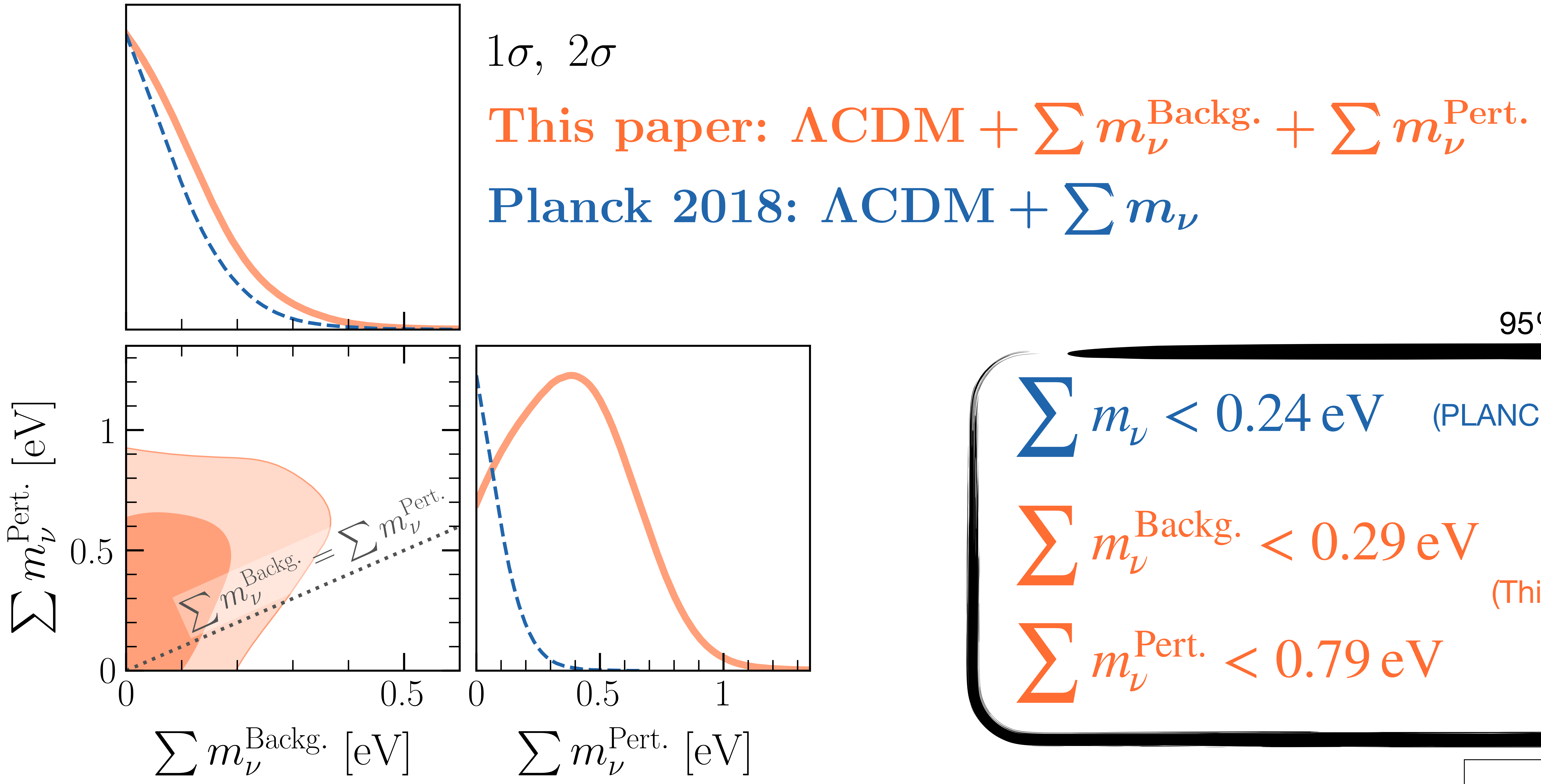


$1\sigma,\ 2\sigma$

This paper: Λ**CDM** $+ \sum m_\nu^{\rm Backg.} + \sum m_\nu^{\rm Pert.}$

Planck 2018: Λ**CDM** $+ \sum m_\nu$

CMB Bound is Background



95% CL

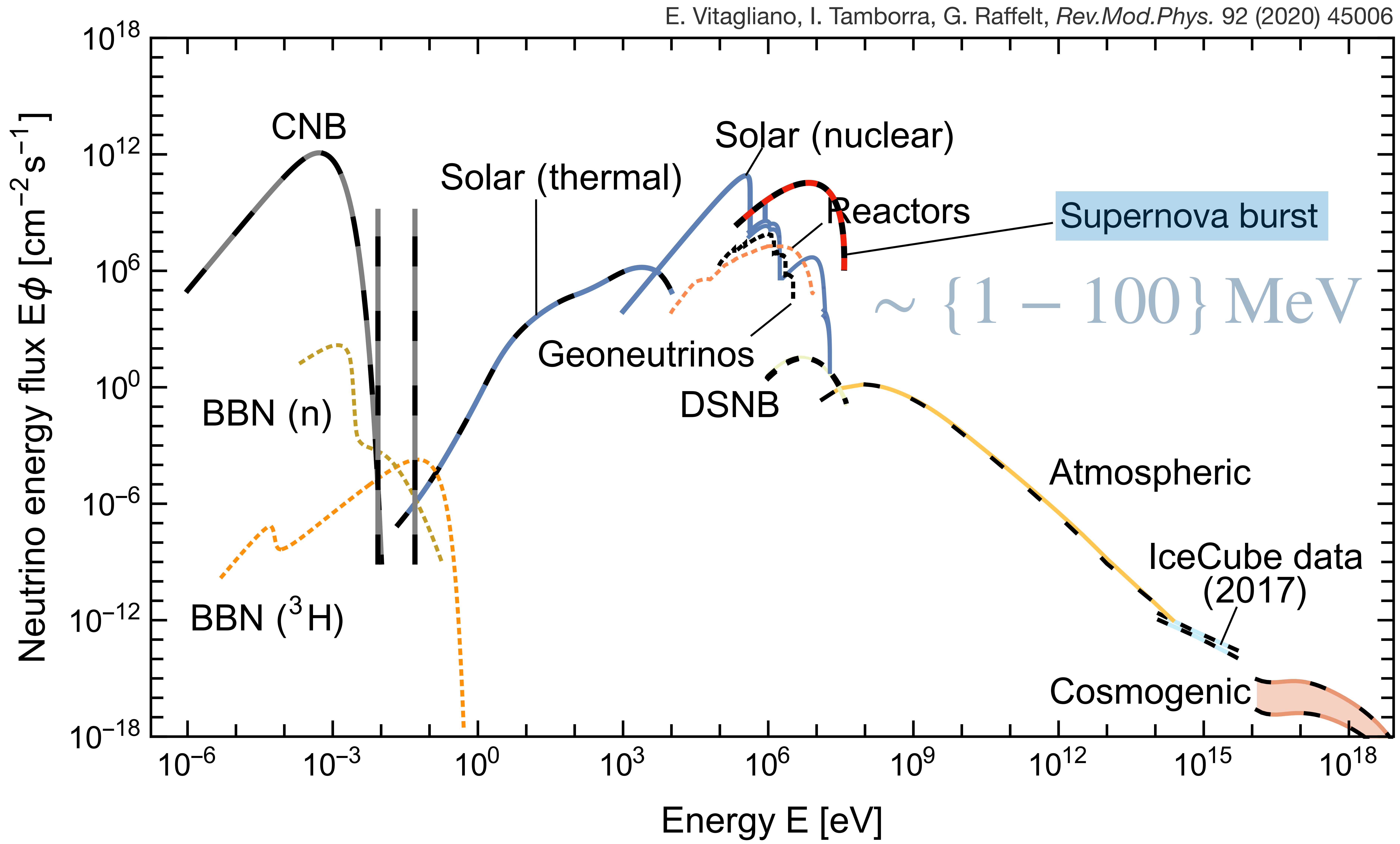
$\sum m_\nu < 0.24\,\mathrm{eV}$ (PLANCK 2018)

$\sum m_\nu^{\mathrm{Backg.}} < 0.29\,\mathrm{eV}$

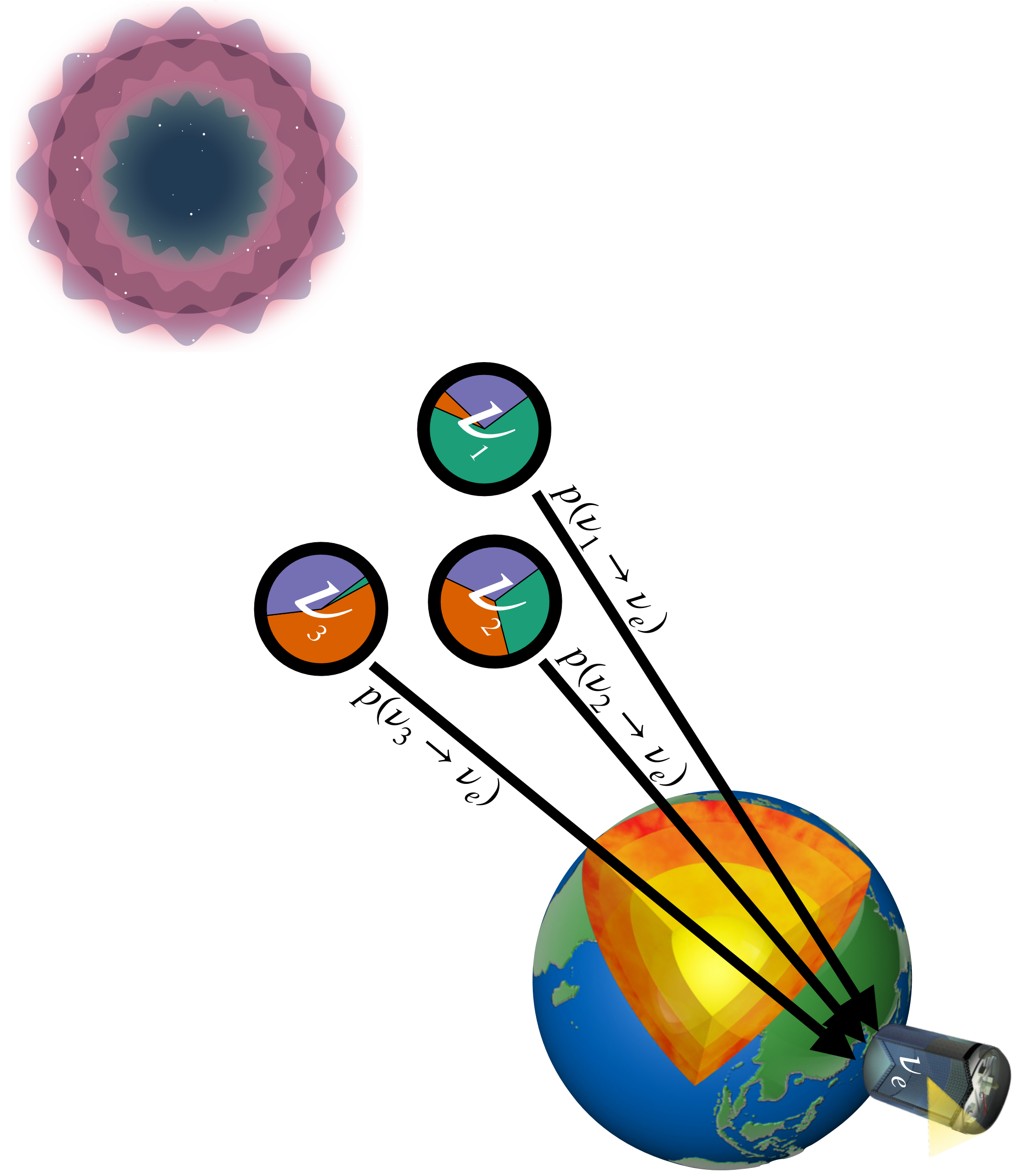
(This work)

$\sum m_\nu^{\mathrm{Pert.}} < 0.79\,\mathrm{eV}$

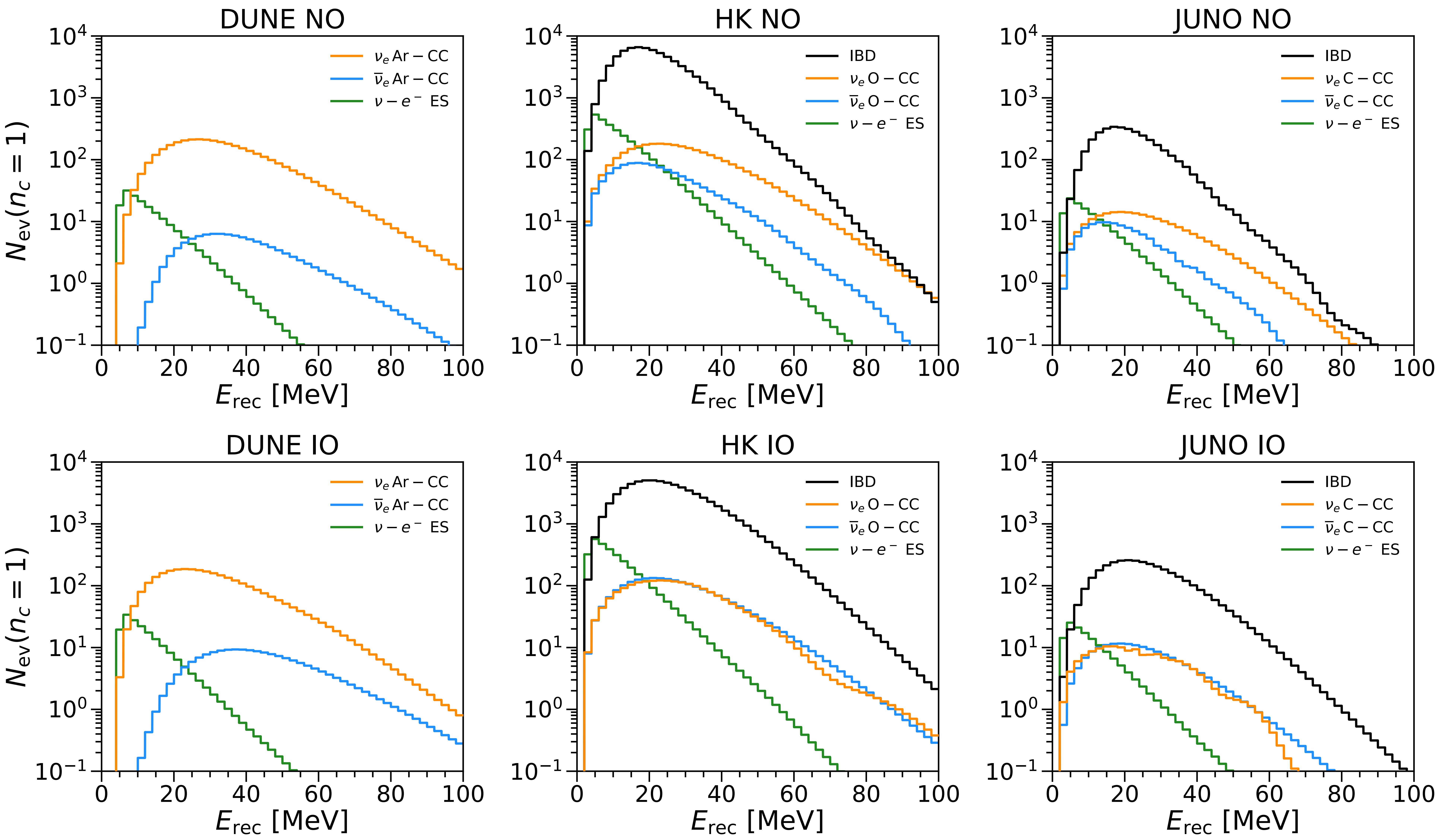
Natural neutrino sources



Future detection of Supernova neutrinos



Earth Matter Effects

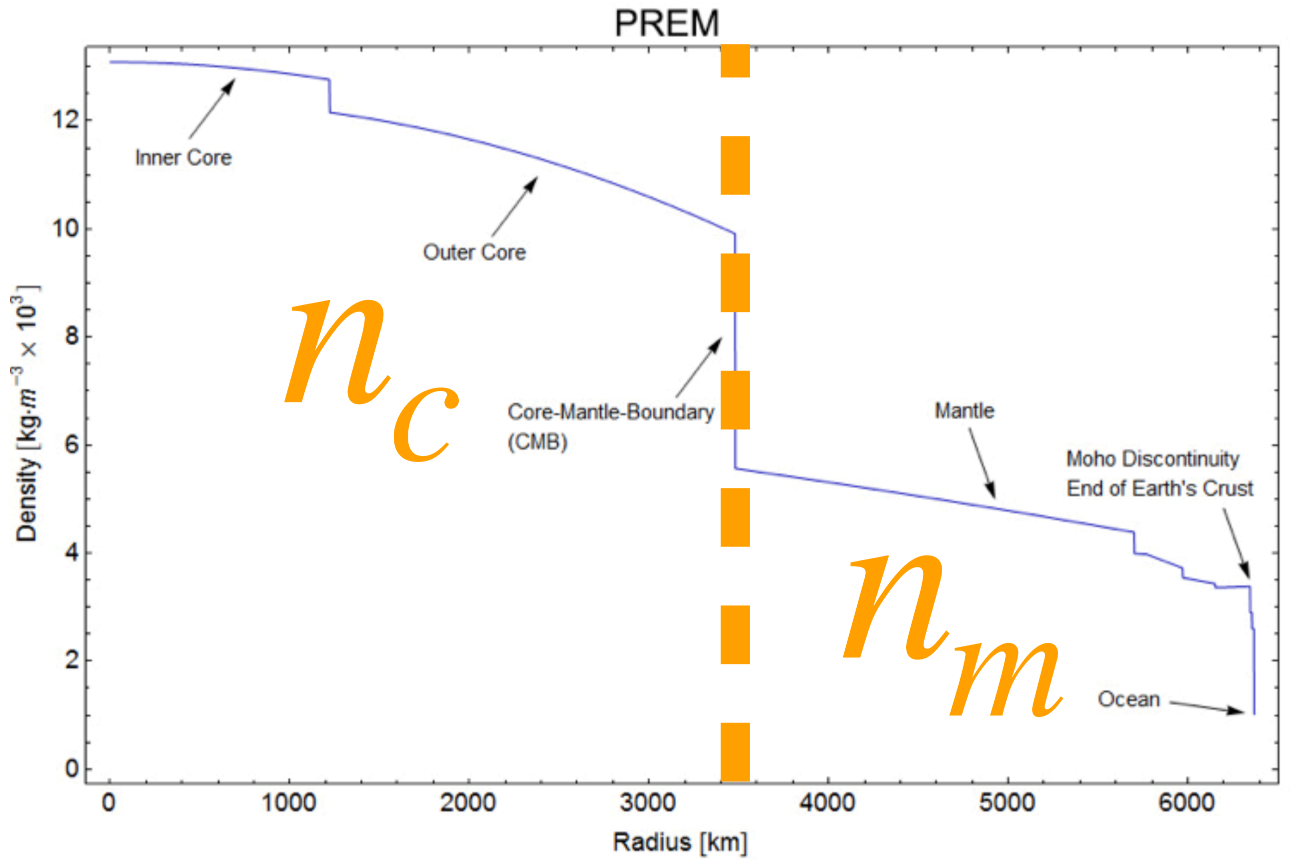


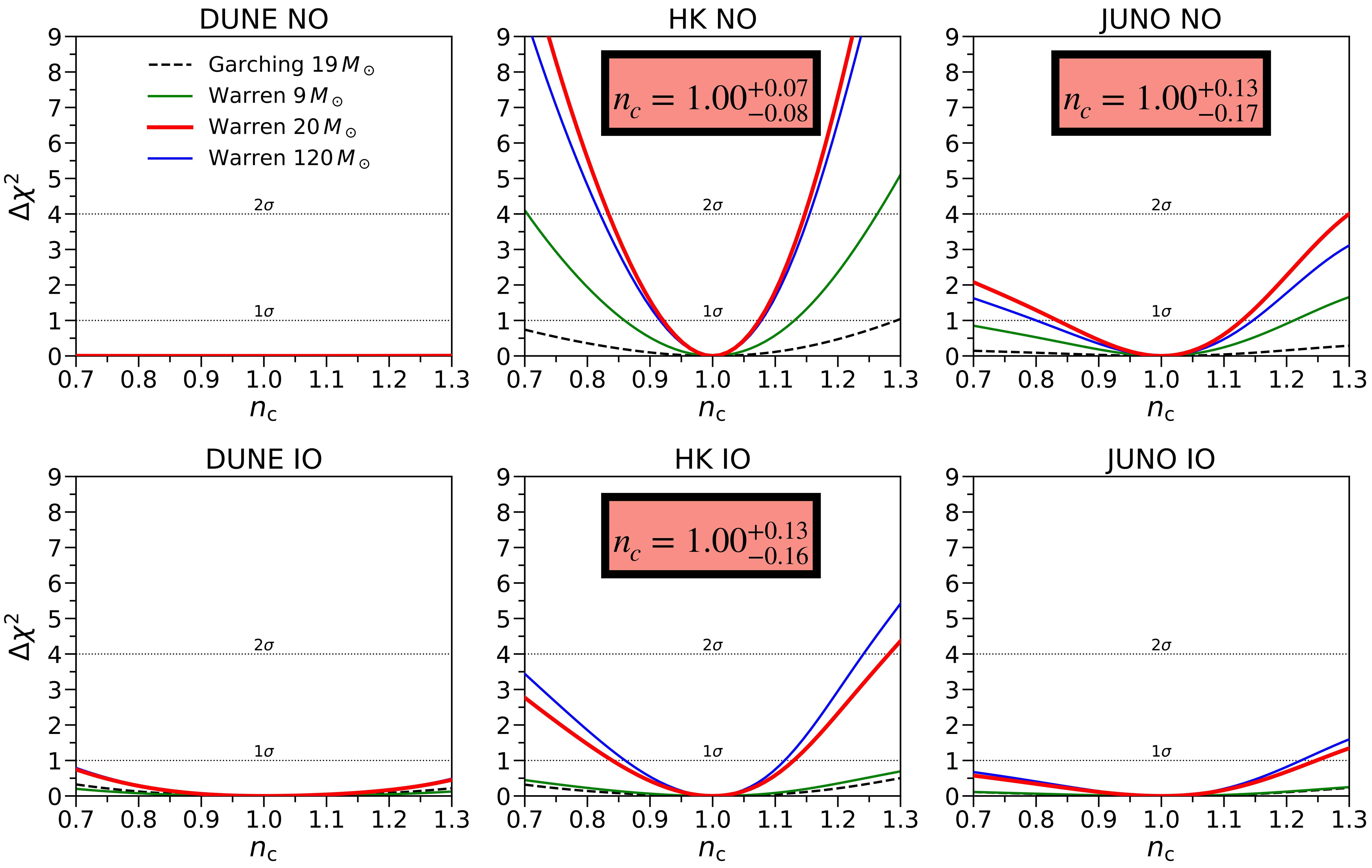
- Warren20, $c_z = -1$, $d_{\rm SN} = 10$ kpc

Sensitivity to Earth density profile

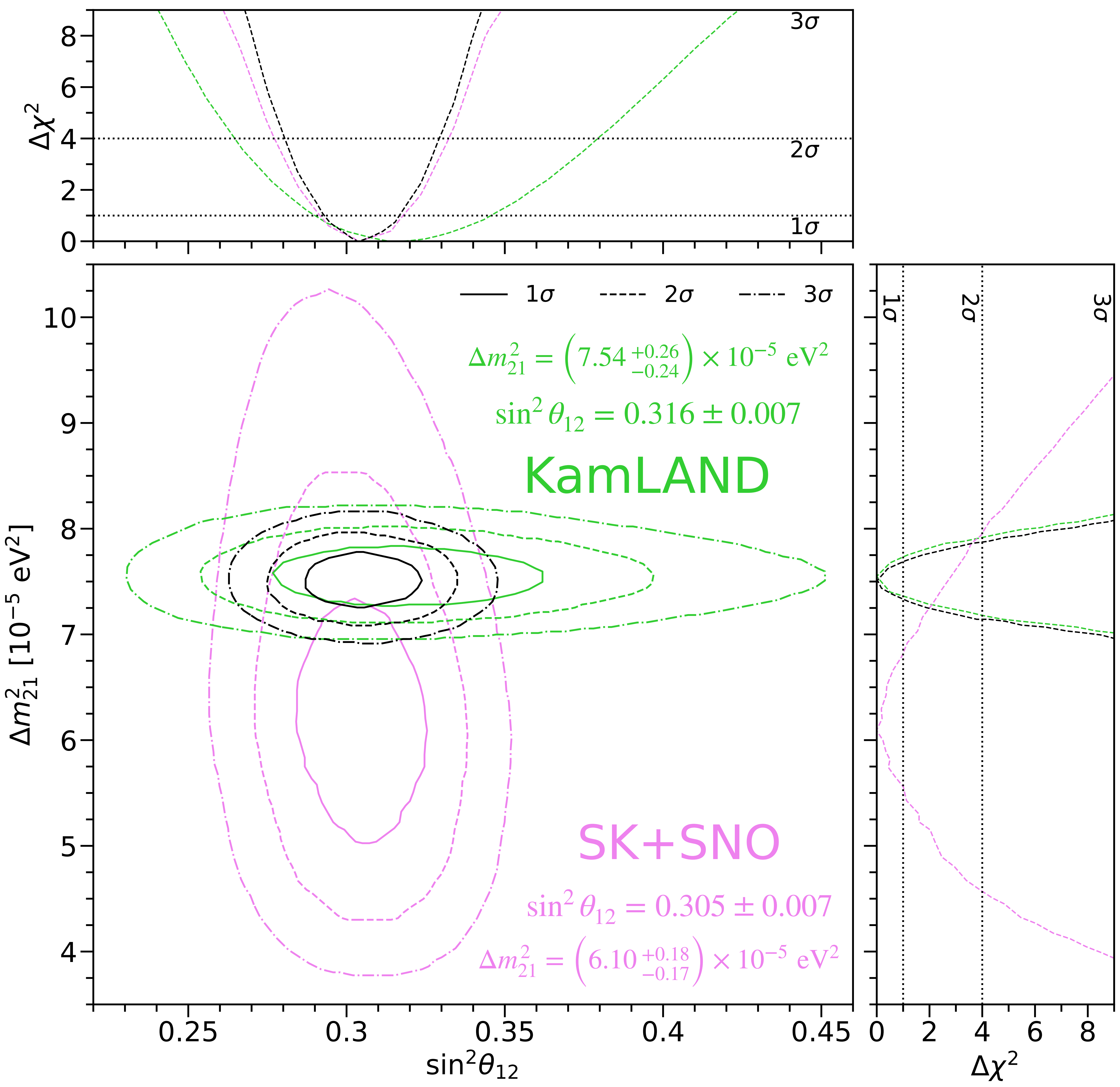
Warren $20M_\odot$

- Sensitivity for different models of SN neutrino burst.
- $c_z = -1$, $d_{\rm SN} = 10$ kpc
- n_c normalization of PREM core



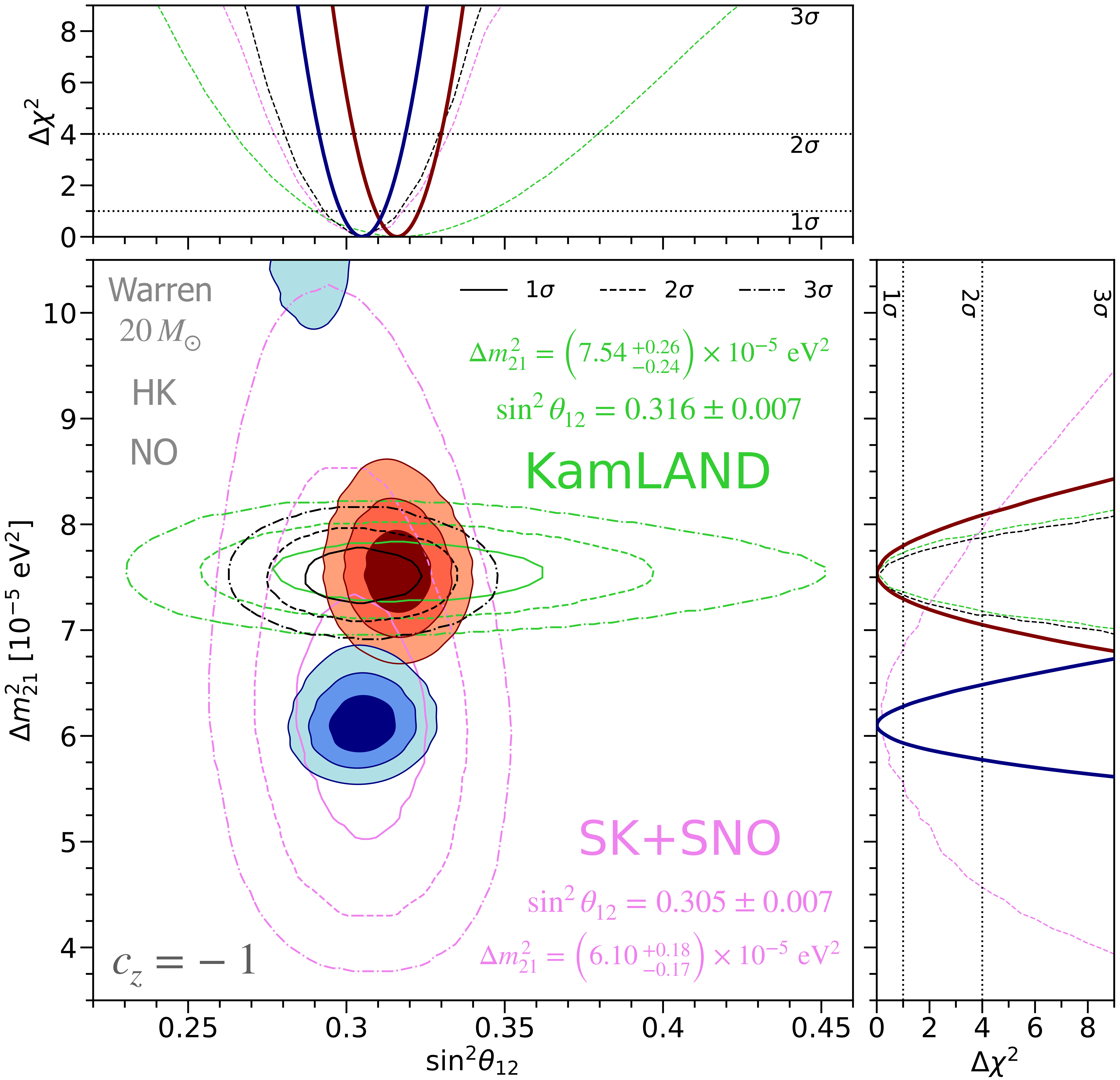


Sensitivity to solar mixing parameters



- Forecasts for a SN burst at 10 kpc.
- Current KamLAND allowed regions
- Current SK+ SNO allowed regions

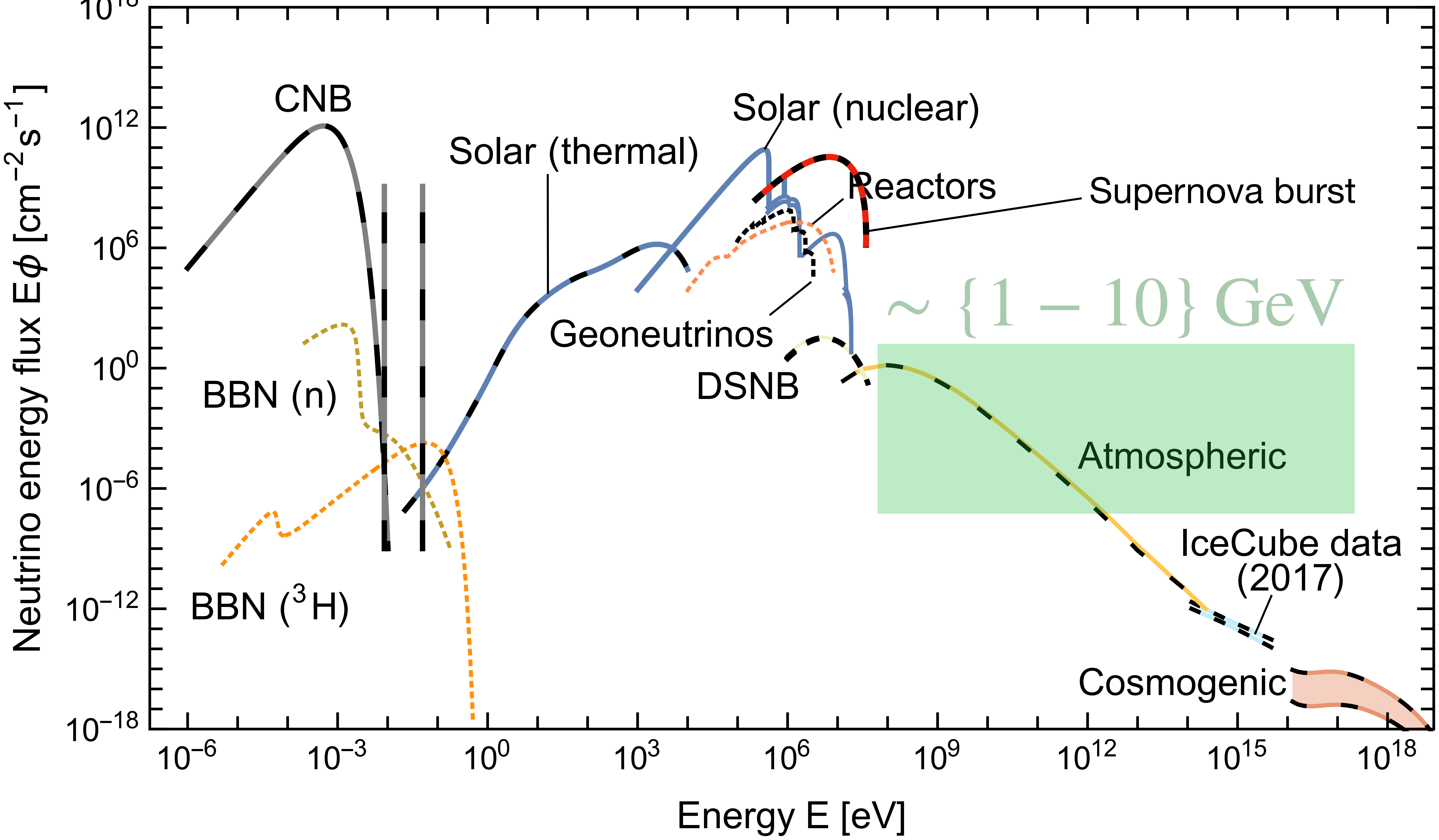
Sensitivity to solar mixing parameters



- Forecasts for a SN burst at 10 kpc.
- Current KamLAND allowed regions
- Current SK+ SNO allowed regions
- Forecast assuming as "true=nature" value KamLAND best fit
  - Alleviate tension between reactor vacuum and solar matter effects.
- Forecast assuming as "true=nature" value SK+SNO best fit
  - Increase tension between reactor vacuum and solar matter effects.

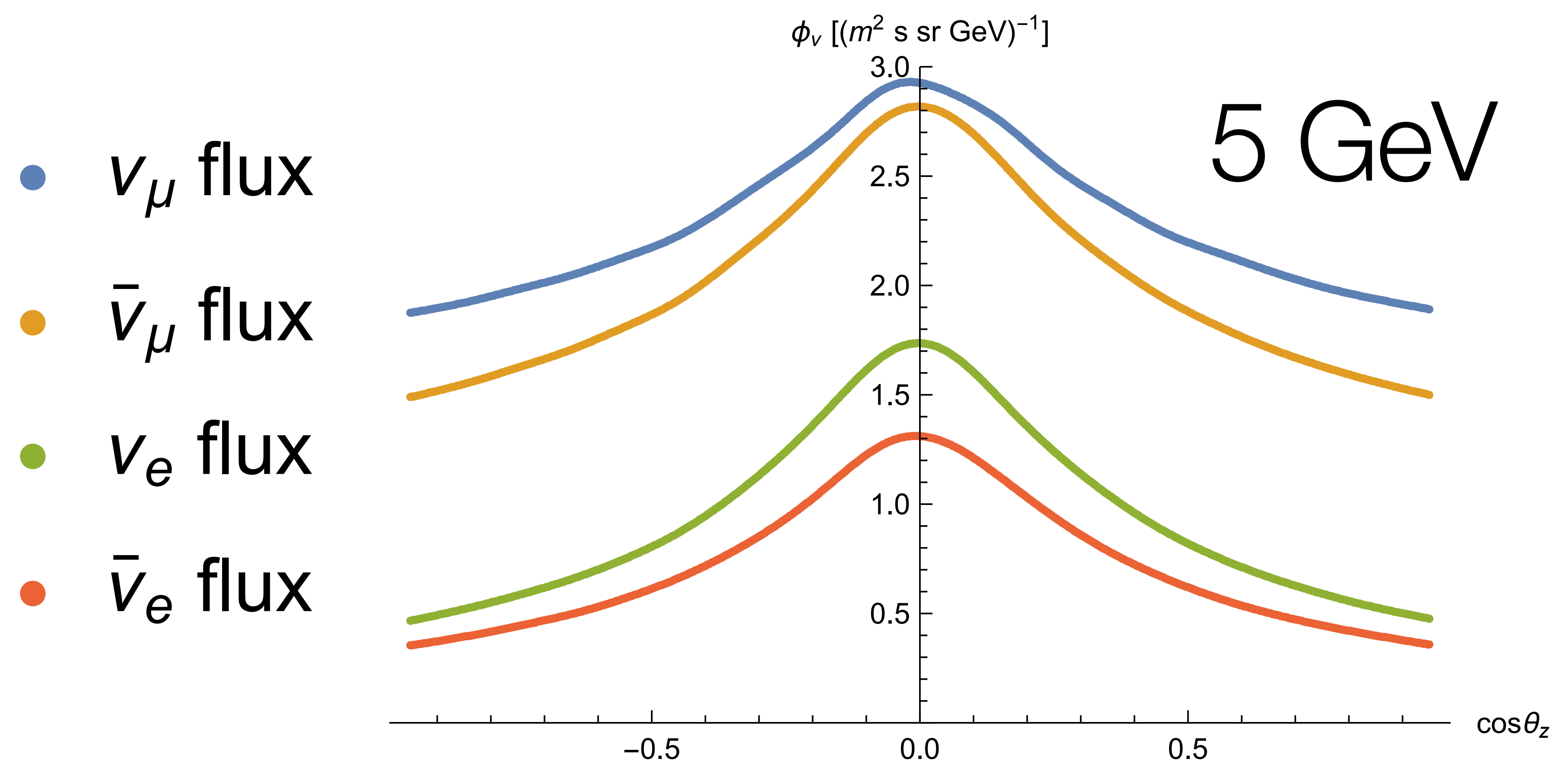
Natural neutrino sources

E. Vitagliano, I. Tamborra, G. Raffelt, *Rev.Mod.Phys.* 92 (2020) 45006



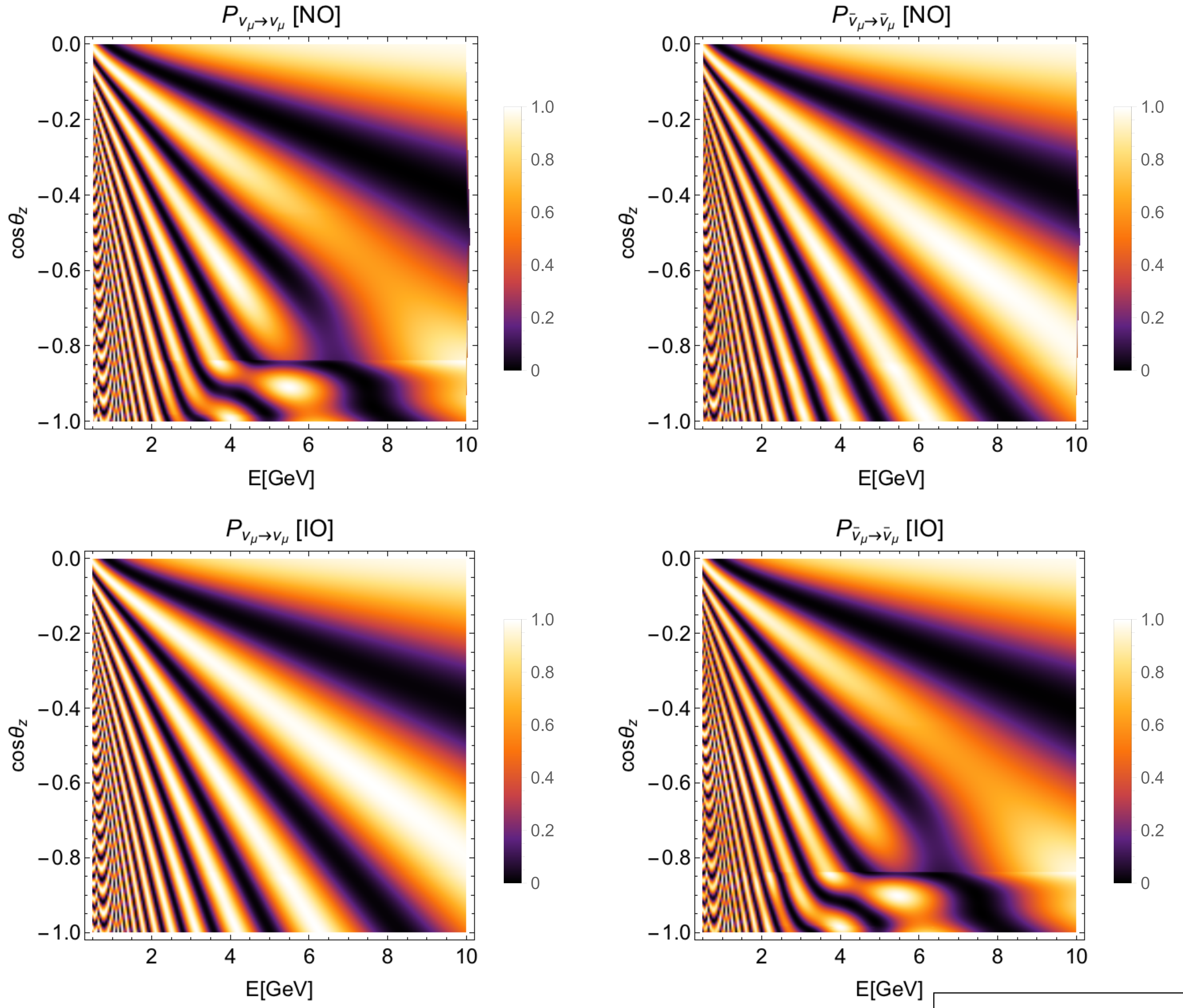
Atmospheric fluxes

Neutrinos from CR-atm interactions



$$\tan 2\theta^m = \frac{\tan 2\theta}{1 - \frac{A_{CC}}{\Delta m^2 \cos 2\theta}}$$

$$A_{CC}(x) = \pm 2\sqrt{2} E G_F N_e(x)$$



Ordering sensitivity @ DUNE

χ_i^2 poisson between True Ordering and Wrong Ordering

Muon capture in Argon:

$$\nu_\mu + n \longrightarrow \mu^- + p$$

capture (74%)

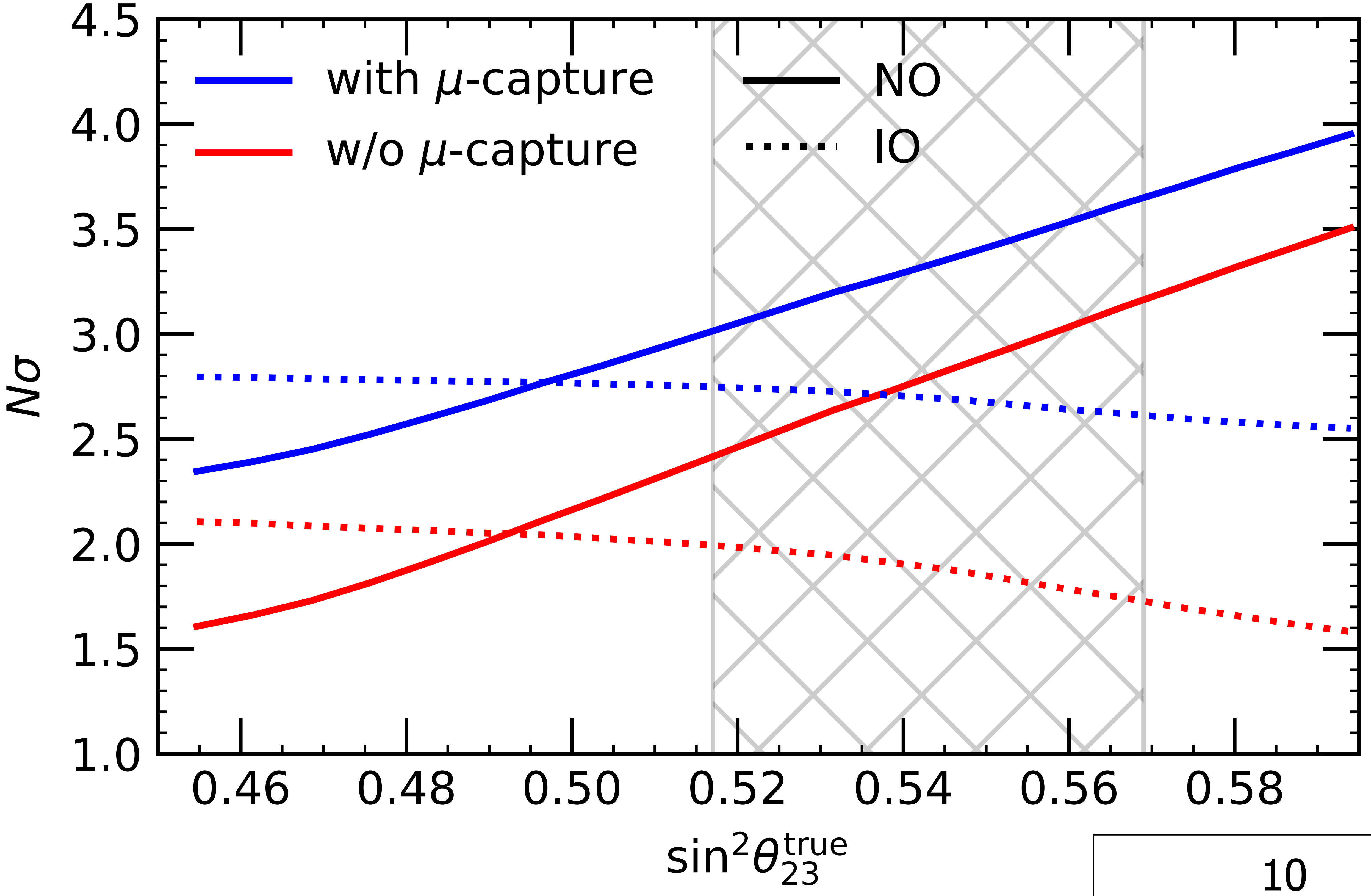
$$e^- + \bar{\nu}_e + \nu_\mu \ (26\%)$$

$$\bar{\nu}_\mu + p \longrightarrow \mu^+ + n$$

$$e^+ + \nu_e + \bar{\nu}_\mu \ (100\%)$$

$$\chi_A^2(\sin^2\theta_{23}^{\rm true}) = \min_{{\rm sys},\Delta m_{31}^2,\theta_{13},\theta_{23}} \left\{ \chi^2_{\mu^- + \mu^+} + \chi^2_{e^- + e^+} \right\}$$

$$\chi_B^2(\sin^2\theta_{23}^{\rm true}) = \min_{{\rm sys},\Delta m_{31}^2,\theta_{13},\theta_{23}} \left\{ \chi_\mu^{2,{\rm cap}} + \chi_\mu^{2,{\rm rest}} + \chi^2_{e^- + e^+} \right\}$$



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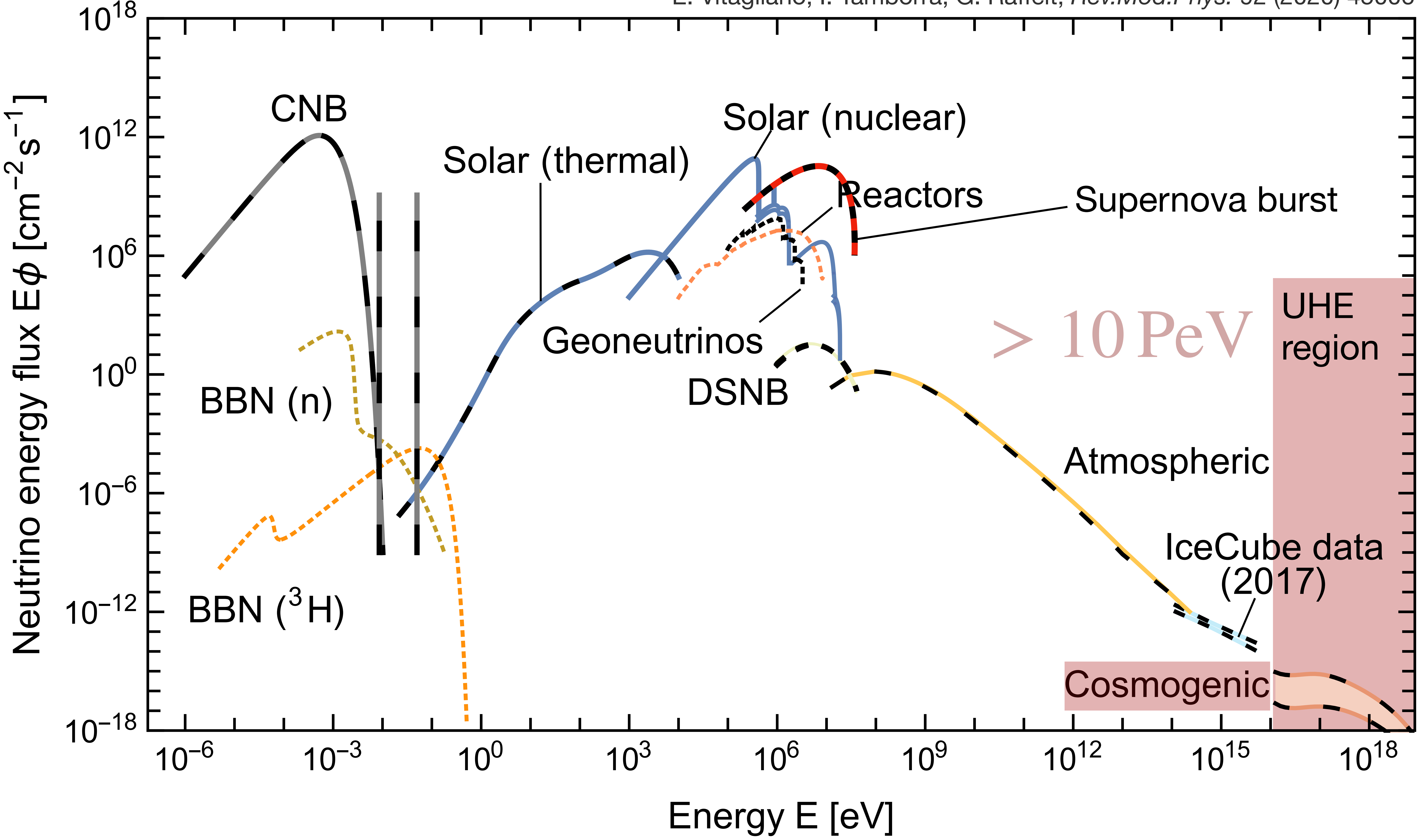


Ultra-High-Energy neutrino flux

- High energy ν flux is unknown. Possible contributions:

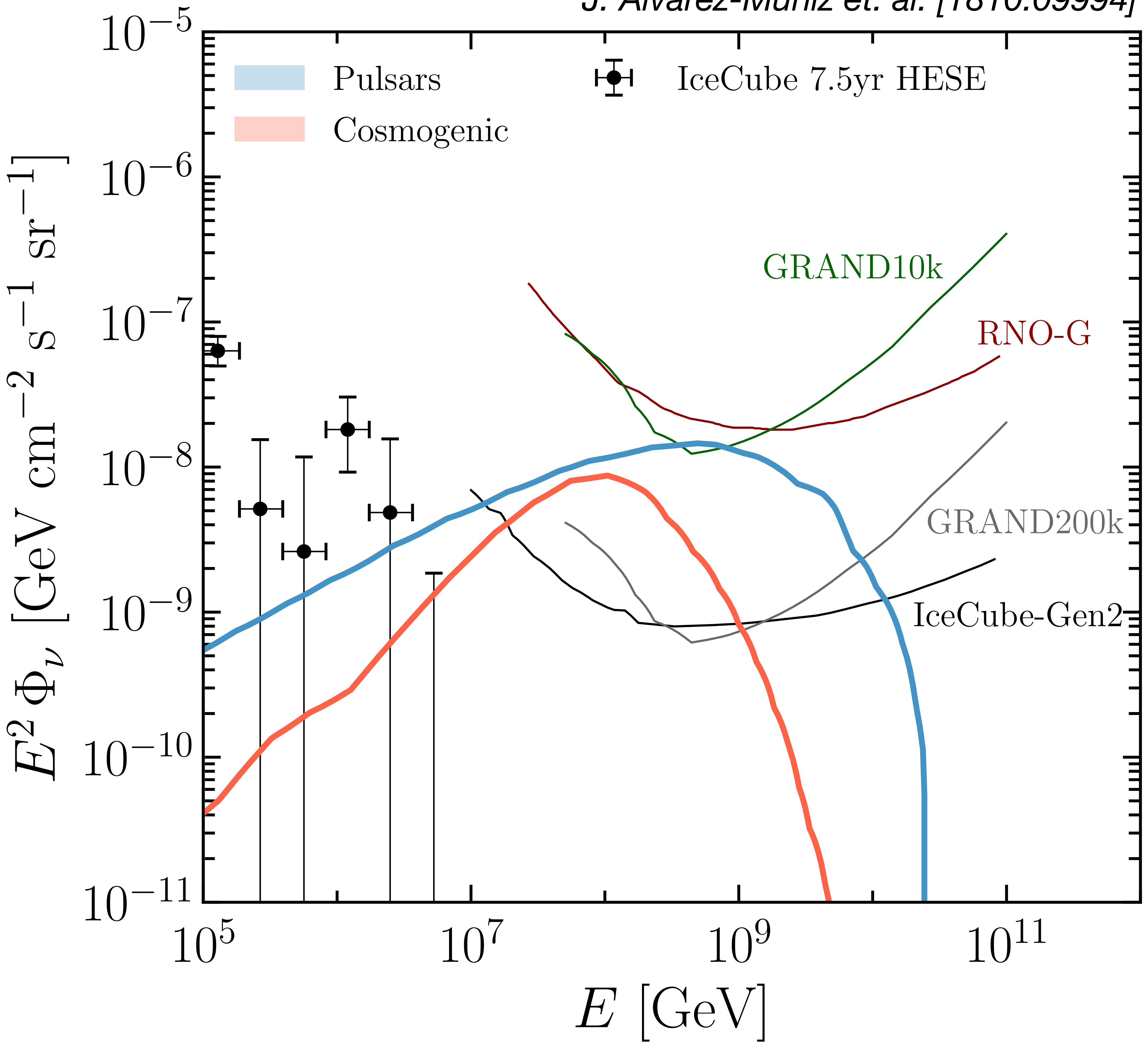
Cosmogenic

guaranteed but uncertain magnitude, come from CRs interacting with CMB

Newborn Pulsars

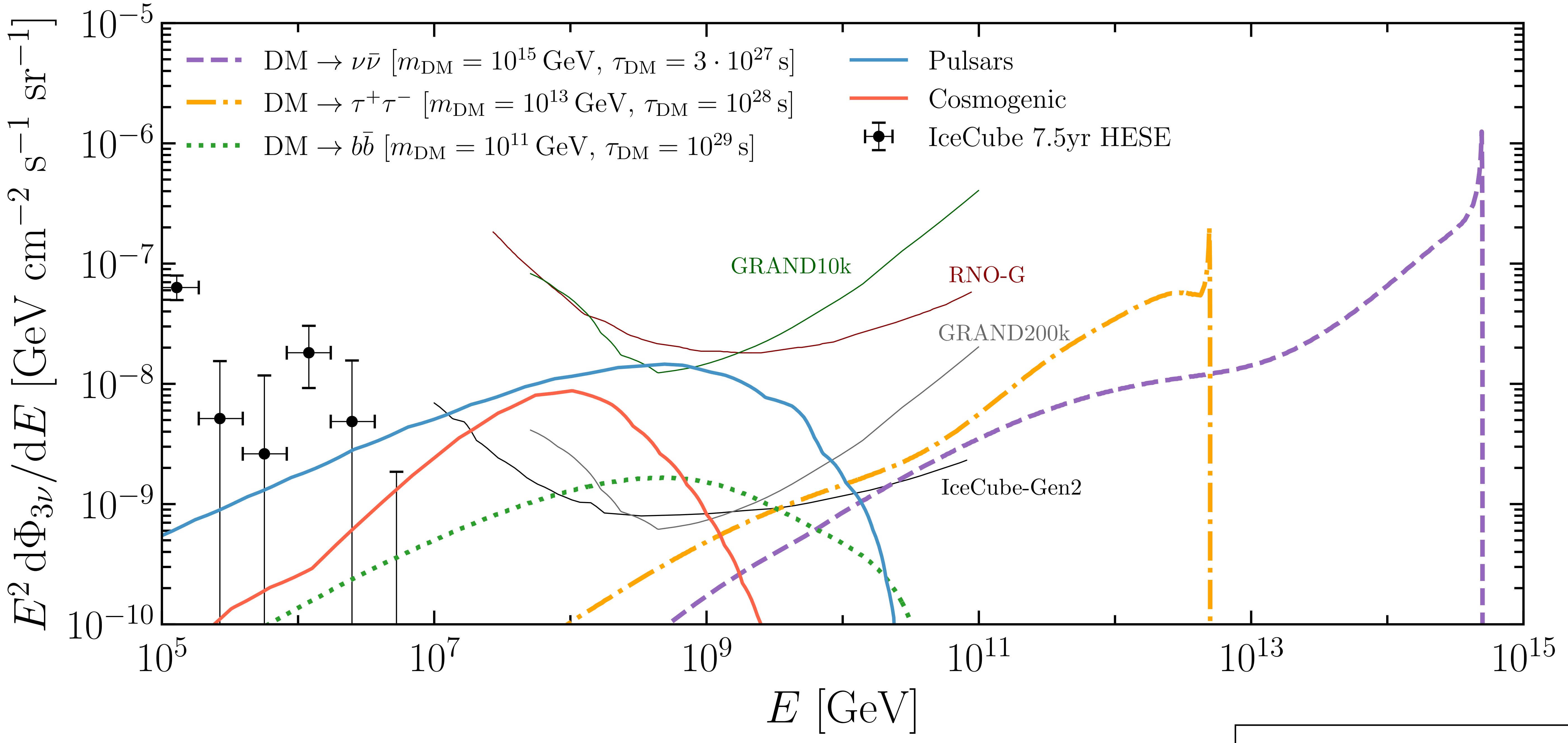
higher expected astrophysical contribution in literature for neutrino radio telescopes

colored regions from J. Álvarez-Muniz et. al. [1810.09994]



Why Heavy Decaying Dark Matter?

Produced neutrino fluxes via decay on the reach of future radio neutrino telescopes



Forecasted limits on HDDM

$N_{\mathrm{astro}} = 0$
Cosmogenic
Pulsars

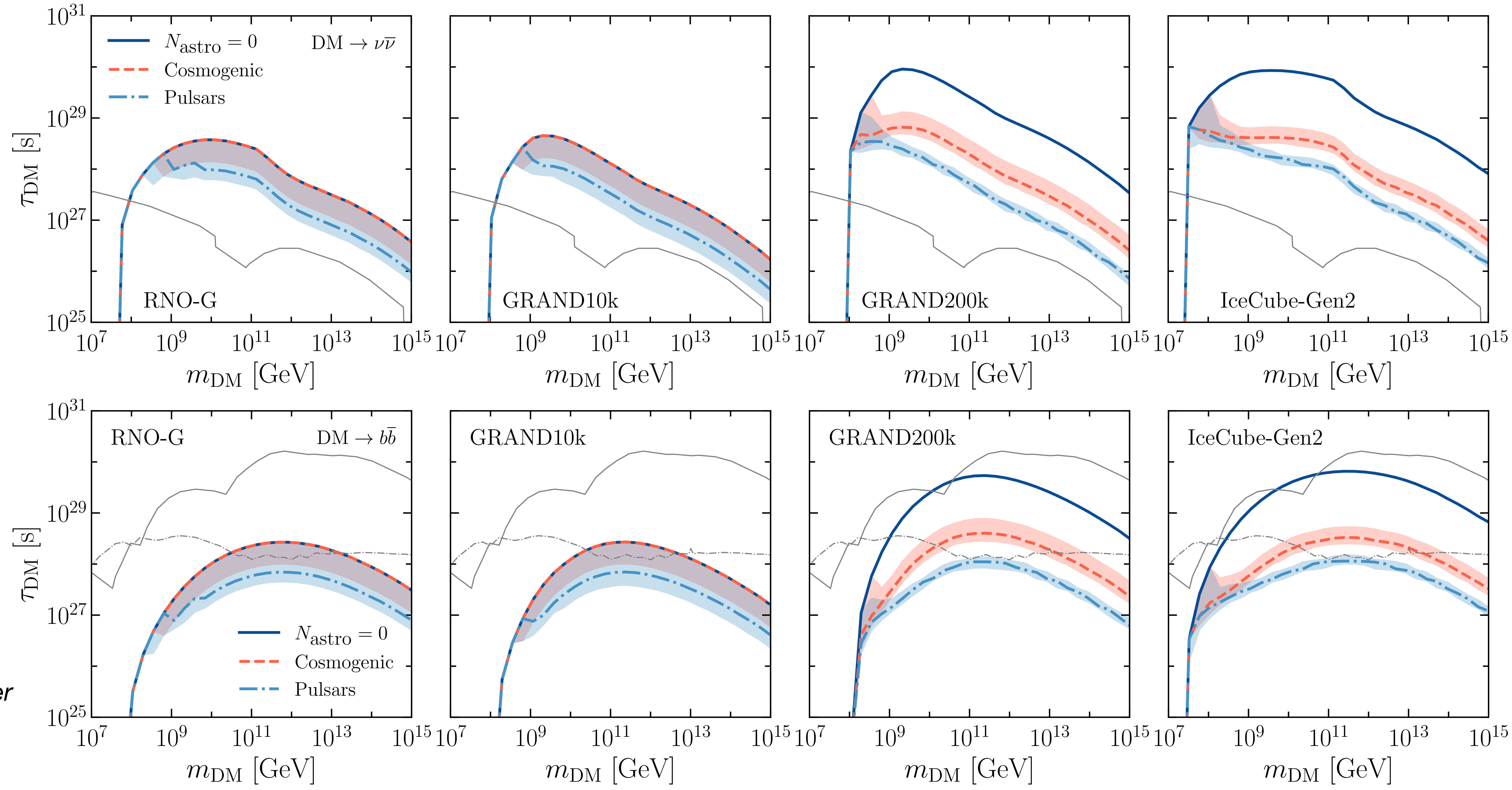
T_{obs} = 3 years

$$\mathrm{DM} \to \nu\overline{\nu}$$

a) IceCube + PAO + ANITA A. Esmaili et. al. [1205.5281]

$$\mathrm{DM} \to b\overline{b}$$

b) galactic Multi-Messenger K. Ishiwata et. al. [1907.11671]
c) extragalactic Multi-Messenger K. Ishiwata et. al. [1907.11671]



Summary

CNB

One can infer neutrino properties through their impact on cosmological observables

The CMB limit from Planck 2018 is mainly a limit on the neutrino background evolution

Supernova

A galactic supernova is expected soon.

We can exploit high neutrino flux in order to determine Earth internal composition and neutrino mixing parameters

Atmospheric

Atmospheric neutrinos are the ones generated by CR interactions with the atm

We can use this constant flux and Earth matter effects to detemine the Ordering

UHE

UHE neutrino fluxes are small, although KM3NeT event might be the first one

One could use future radio detectors to constrain the lifetime of HDM, being complementary to gamma ray limits