Based on arXiv:2405.04568

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Boosted Relic Neutrino Background by Cosmic Reservoirs

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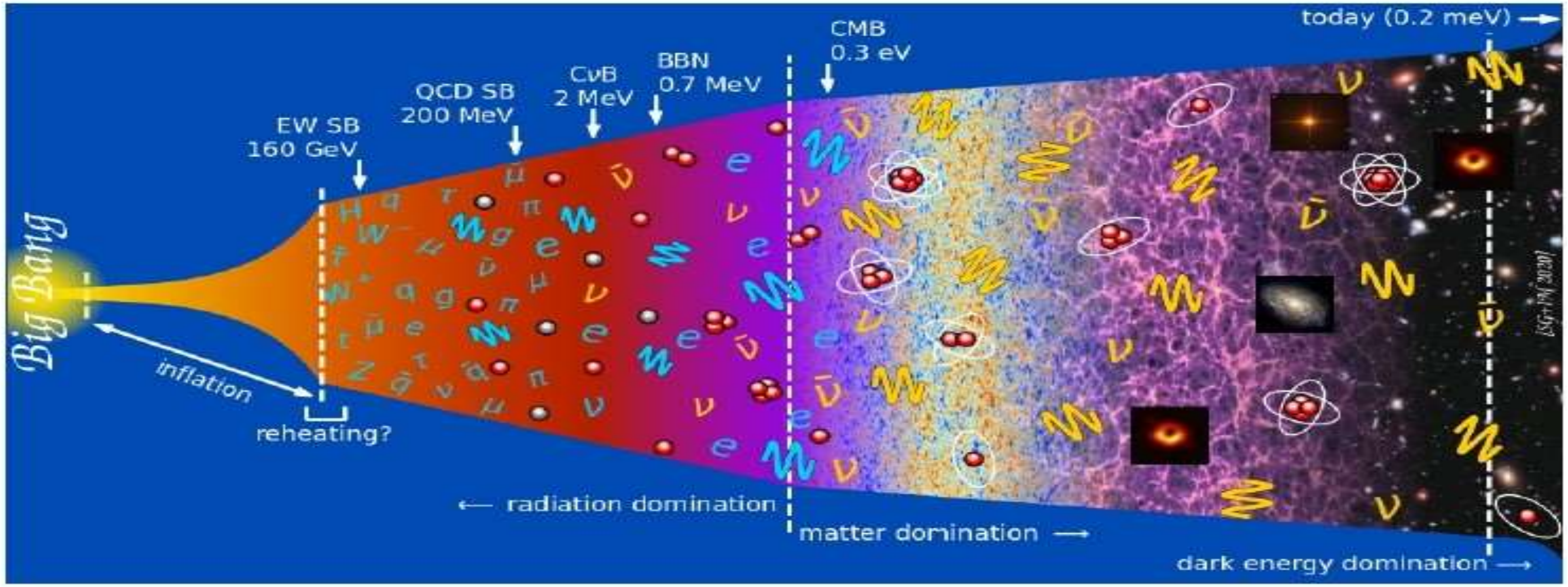
The Holy Grail of Neutrino Physics

- First evidence of Non-relativistic neutrinos
- Test of neutrino stability
- Early Universe (e.g. late time entropy injection)
- Dirac/Majorana nature
- Gravitational Clustering



Why is detecting the CνB so hard?

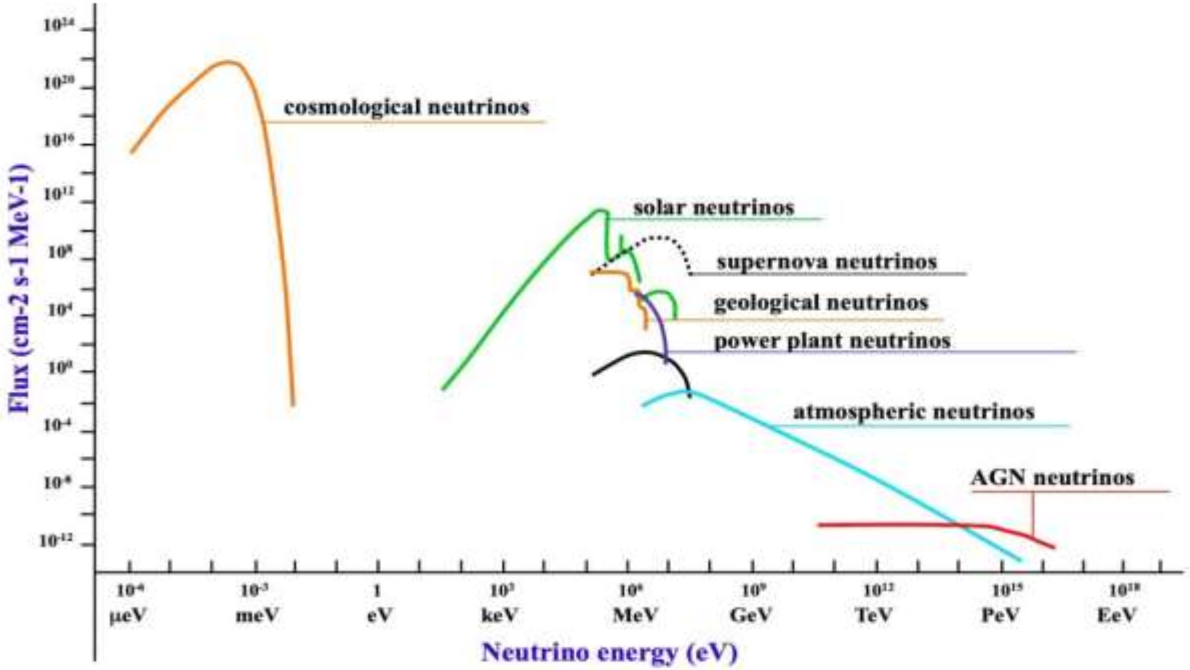
The "golden channel" is below threshold

$\bar{\nu}_e + p \rightarrow n + e^+$ $\qquad E_{Th} = 1.8 \text{ MeV}$

$T_{C\nu B} \sim 10^{-4} \text{eV}$

We need to satisfy these 3 conditions

- Threshold-less process
- Clear signature
- Experimentally detectable

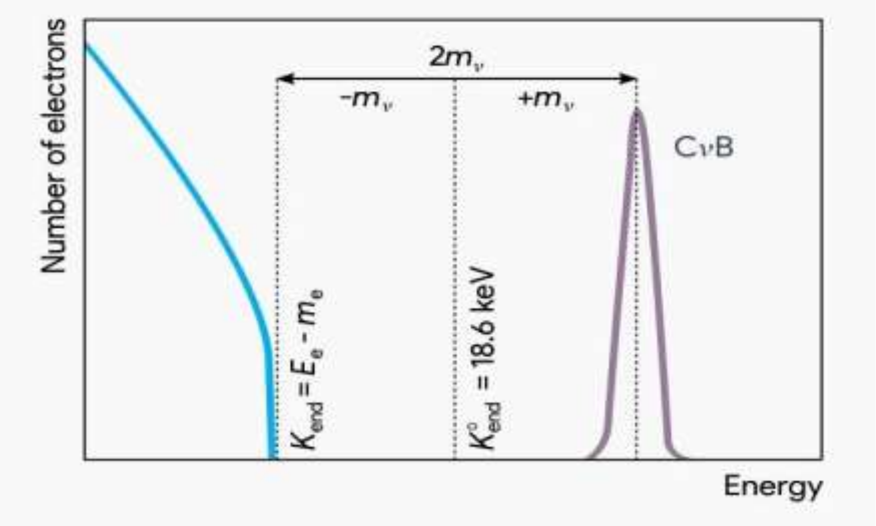


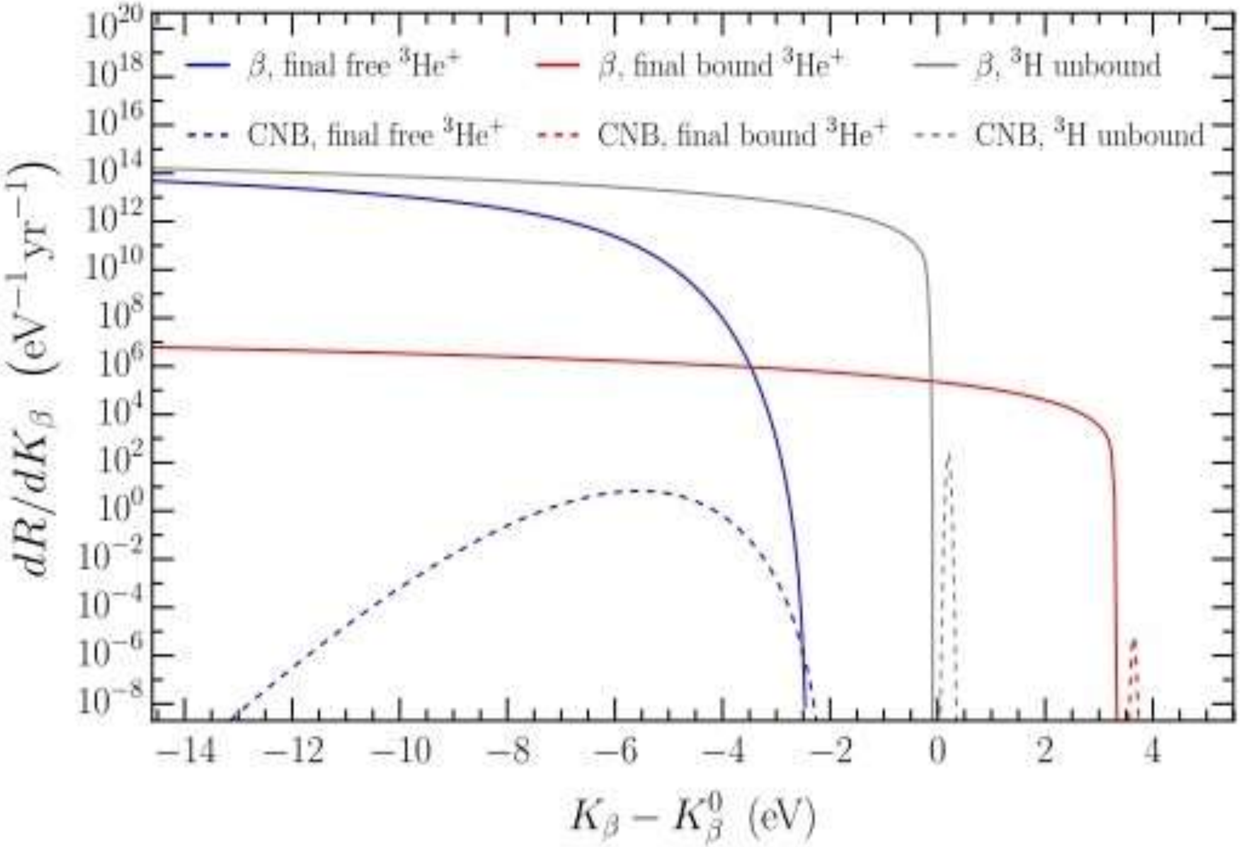
Possible way out: ν capture by β-decaying nuclei!
(Weinberg 1962)

PTOLEMY experiment

Signal $\nu_e + {}^3H \rightarrow {}^3He^+ + e^-$ (Graphene Substrate)

Background ${}^3H \rightarrow {}^3He^+ + e^- + \bar{\nu}_e$





- Meets all requirements but Heisenberg uncertainty broadens the spectrum
- We would need a much larger overdensity
- Motivation to explore alternative ways to detect CνB

Accelerating the CνB

Basic idea: Cosmic Rays up-scatter the CνB neutrinos, gain in signal if done by UHECRs

$$\frac{d\Phi_\nu}{dE_\nu} = D_{\rm eff}\, n_{\nu,0}\, \bar{\eta}_\nu \int_{E_{\rm CR}^{\rm min}(E_\nu)}^{E_{\rm CR}^{\rm max}} dE_{\rm CR} \frac{d\Phi_{\rm CR}}{dE_{\rm CR}} \frac{d\sigma_{\nu \rm CR}}{dE_\nu},$$

Ciscar-Monsalvatje, Herrera, Shoemaker, arXiv:2402.0098, bound on **local overdensity** $\eta_\nu = \frac{n_\nu}{n_{\nu_0}}$

- CR in the Milky way $\eta_\nu \sim 10^{13}$
- Blazars (TXS 0506+056) $\eta_\nu \sim 10^{10}$

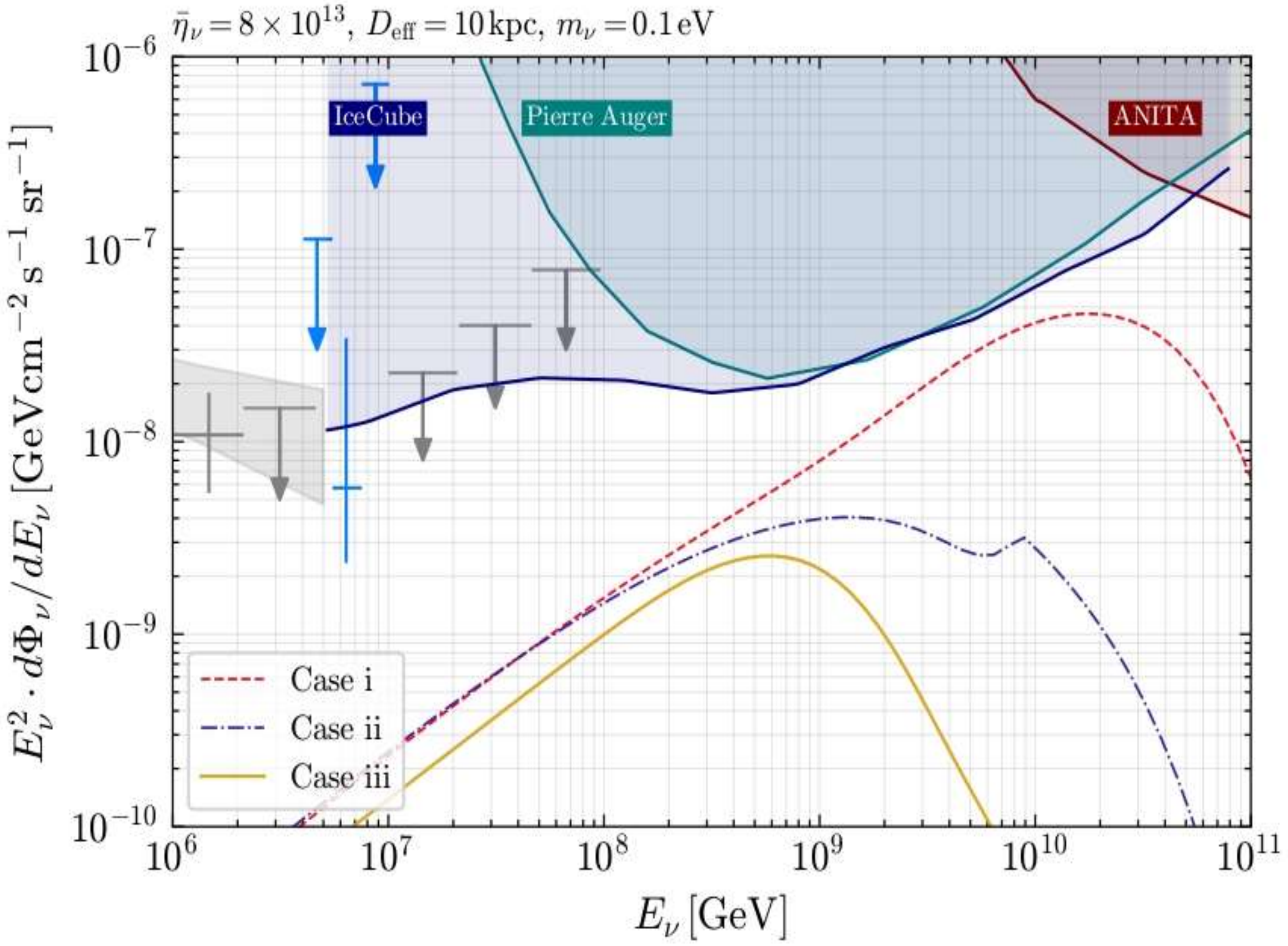
Can we do better?

1) More precise cross-section (Form factor+DIS) and CR composition (mixed)

2) New astrophysical sources (General idea: we need large D_{eff} to maximize the scatterings)

Neutrino flux from the Milky-Way

- Flux suppressed at high energy by the nuclear form factor
- DIS results in a bump, not present when mixed composition
- Bounds weakened by 1 order of magnitude



Galaxy clusters

Feng, Murase: 1704.00015

- AGN at the center inject UHECRs in the cluster
- Sizable $B \sim \mu G$ measured, Hillas criterion: UHECRs trapped
- Resilience time $\tau_{esc} \sim Gyr$

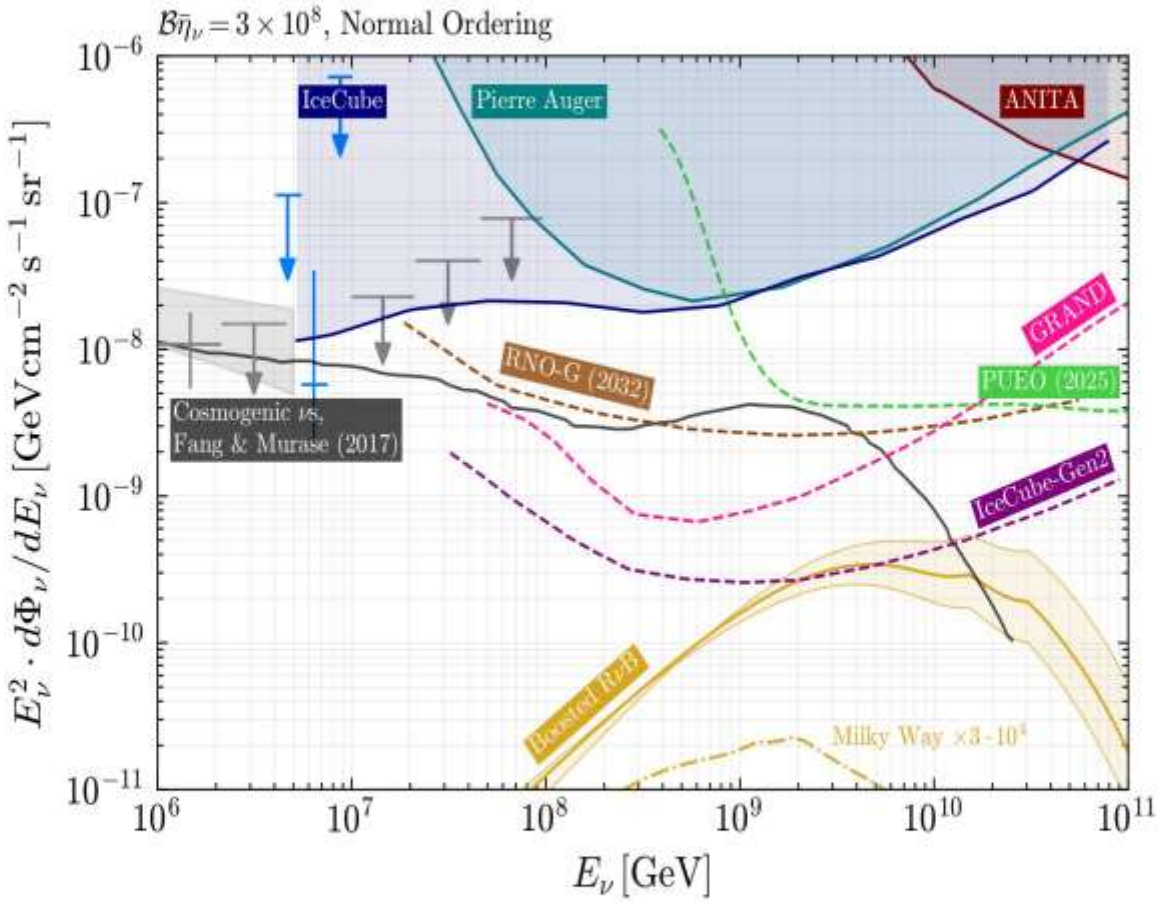
So a lot of up-scatterings with CνB neutrinos!

$$\frac{d\Phi_N}{dE_N} = K_N \left(\frac{E_N^{\max}}{E_N}\right)^{\alpha} e^{-E_N/E_N^{\max}}$$

Our working assumption: UHECR-flux measured at Pierre Auger Observatory comes from galaxy clusters

Neutrino flux from Galaxy Clusters

- Improve w.r.t previous bounds by many order of magnitudes, need $\eta_\nu > 10^8$
- Overdensity localized on the scale of a galaxy cluster (NO overclosure of the Universe)
- Cosmogenic neutrinos included,can be disentangles by different spectral shape (DIS)…but not only
- Mild dependence on injection index and trapping time (through E_{CR})

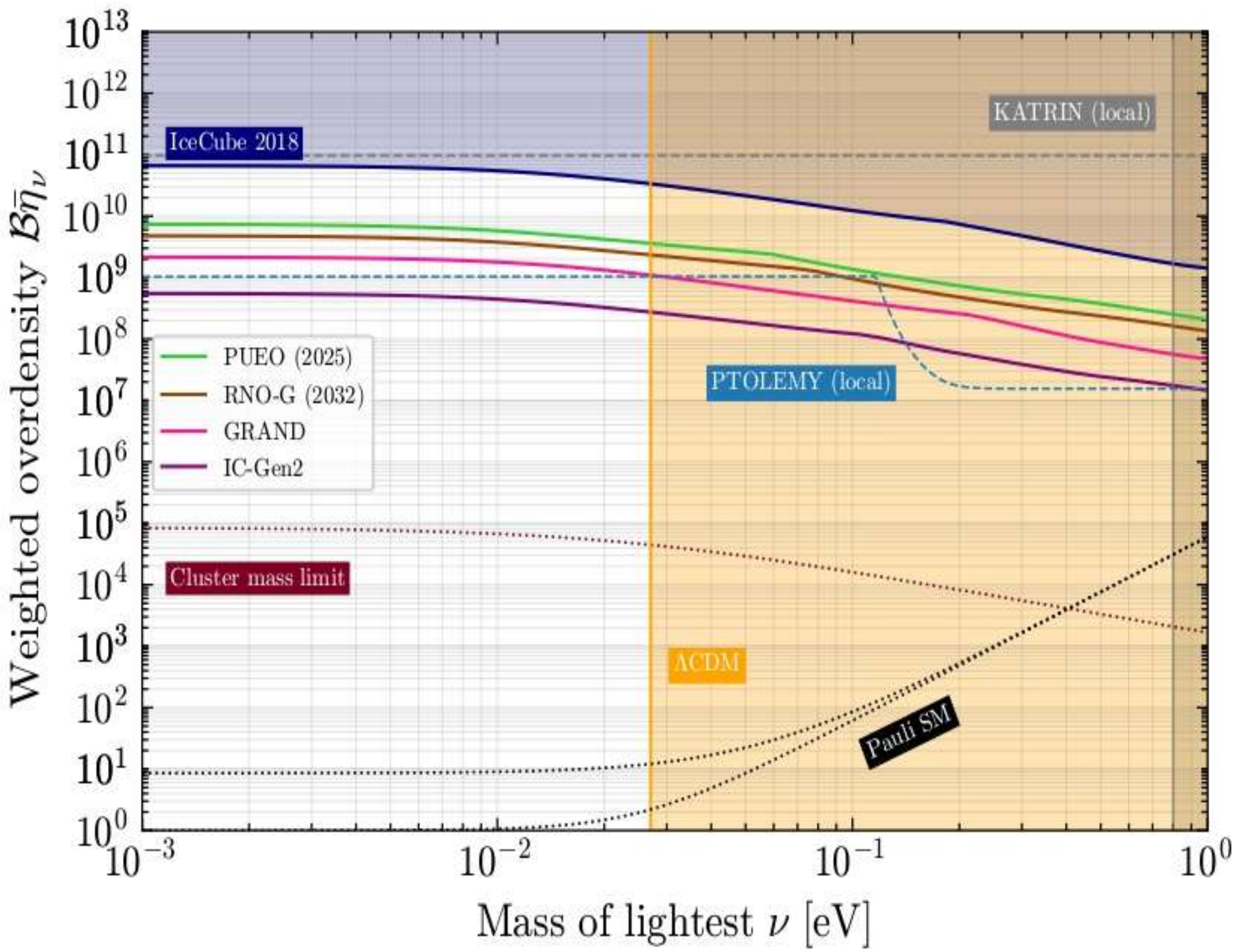


Limits on the overdensity

- With pure SM: no way to detect boosted CνB
  1)Pauli Blocking
  2)Cluster mass limit

- Smirnov, Xu: 2201.00939, Yukawa interaction, they obtain $\eta_\nu{}^{BSM} \sim 10^7$

- Cluster mass bounds can be alleviated with non-homogeneous distribution (Model building needed)



Flavor Composition at Earth

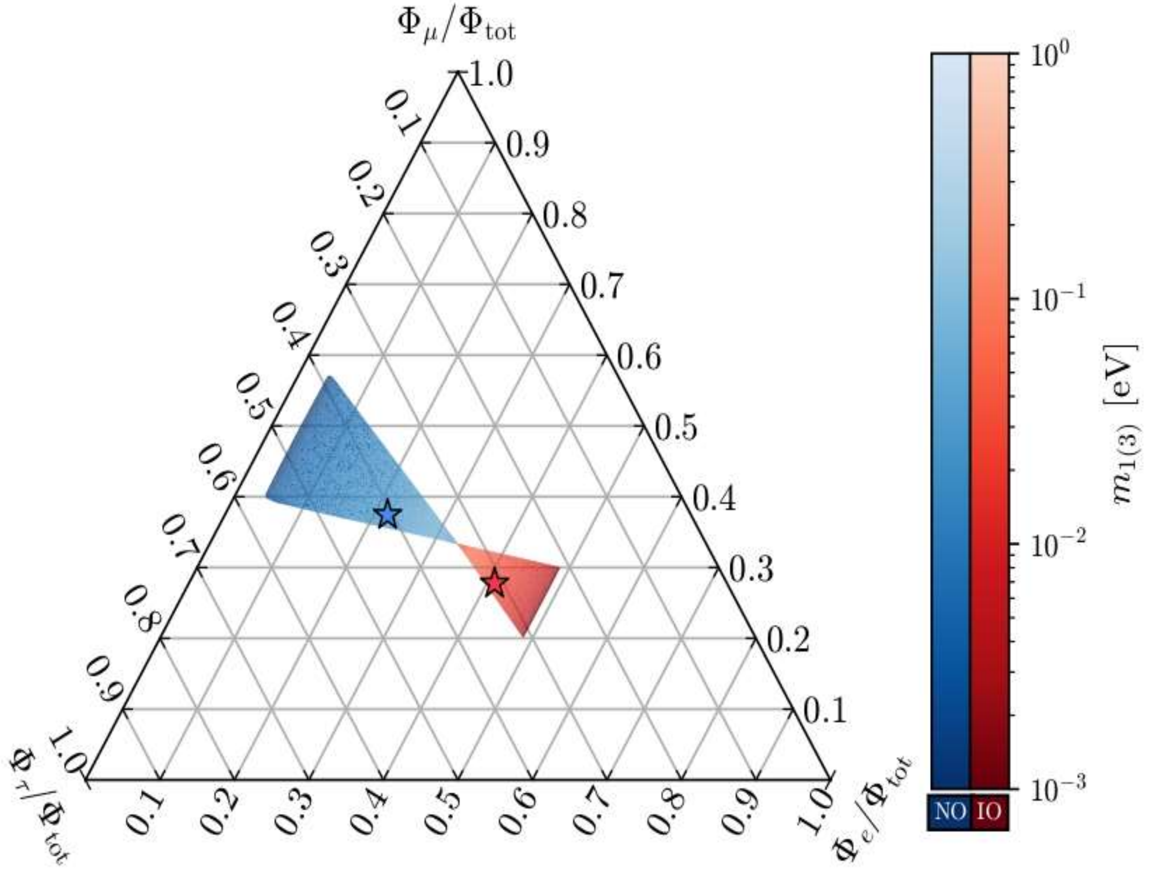
Relic neutrinos produced as FLAVOR eigenstates by weak interactions but by now they lost coherence:

They are now present as MASS eigenstates

At detection the flux in the flavor α is given by

$$\frac{d\Phi_\alpha}{dE_\nu} = \Sigma_i |U_{\alpha i}|^2 \frac{d\Phi_i}{dE_\nu}$$

- Degenerate neutrinos, 1:1:1 flavor ratio
- Low lightest neutrino: flavor composition controlled by the PMNS matrix and mass splittings
- NO/IO->less/more electron neutrinos



Conclusions

- We improved on 2402.0098, using a more complete $\nu + N$ cross section and mixed CR composition, impact about 1 order of magnitude

- We set strong bounds, $\eta_\nu < 10^8$ on the scale of galaxy clusters (They could be even stronger with non constant CR,ν distribution)

- We propose two ways to disentangle our signal from cosmogenic neutrinos: Energy dependence, Flavour composition

Final remark: Such large overdensity still requires unavoidably a BSM origin

Thank you for your attention!

Backup Slides

Bound on η_ν from cluster mass limits

Expect galaxy cluster profile to be approximately NFW

$$M_{vir} = \frac{4\pi}{3} \Delta_{vir}\, \rho_{m_0} {R_{vir}}^3$$

From the dissipationless spherical top-hat collapse Δ_{vir}~200 (NFW1996), therefore

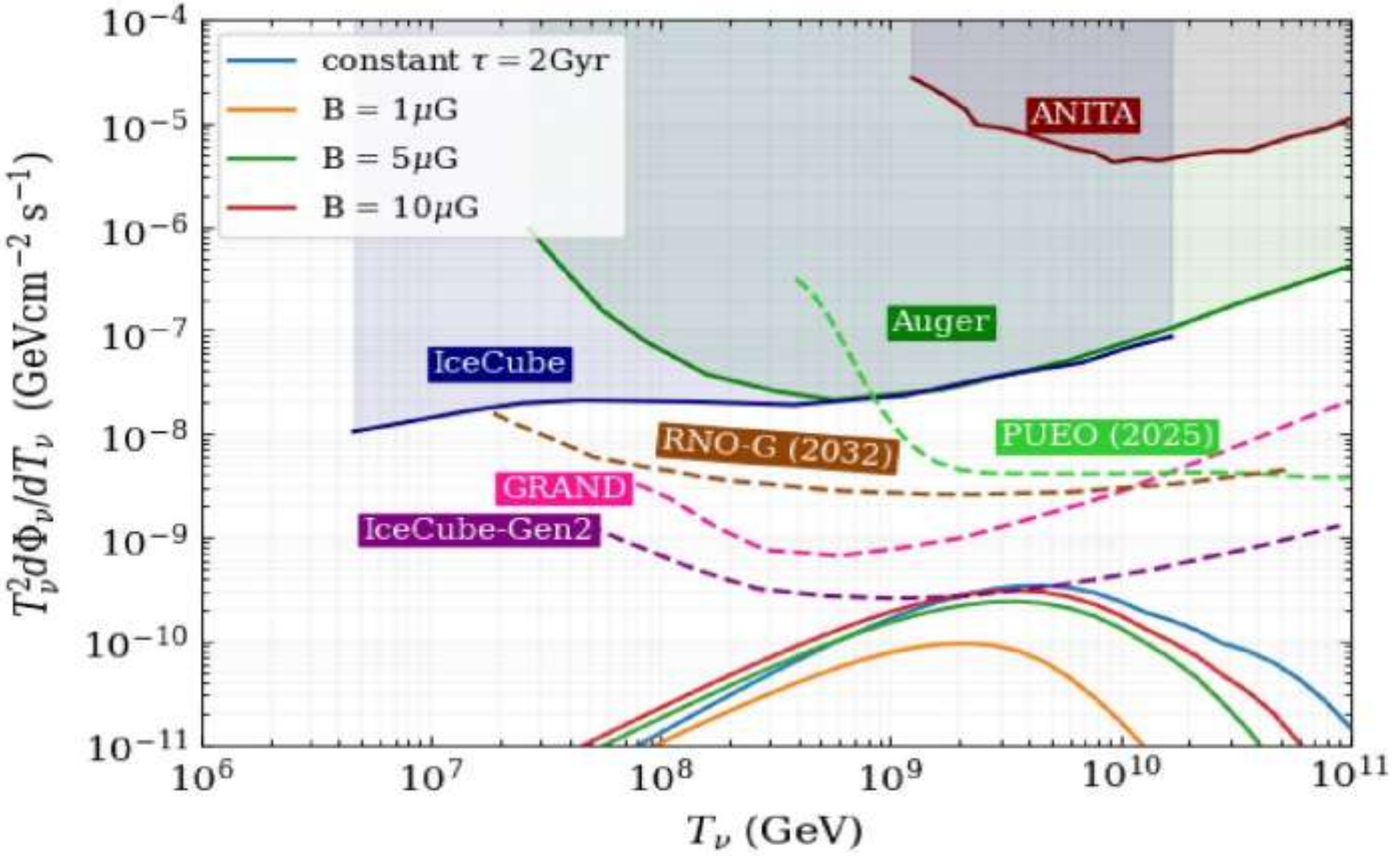
$$M_{vir} \propto \bar{\rho}_{halo}\, {R_{vir}}^3,\ \text{with } \bar{\rho}_{halo} \sim 200\ \rho_c$$

We finally impose

$$\eta_\nu\ n_{\nu_0} \Sigma_i\ m_i < \bar{\rho}_{halo}$$

Energy and B dependence of τ_{esc} in Clusters

- We assumed a fixed τ_{esc}=2 Gyr, indeed it depends on UHECR energy (Condorelli, Biteau, Adam 2309.04380)
- Lower flux at high energy due to faster escape but O(1) effect



Inverted Hierarchy scenario