Relic neutrino Background from Cosmic-Ray Reservoirs

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Dark Matter and Cosmic Rays, Napoli November 11th 2024

Based on: AGDM, Granelli, Nava, Sala [2405.04568]

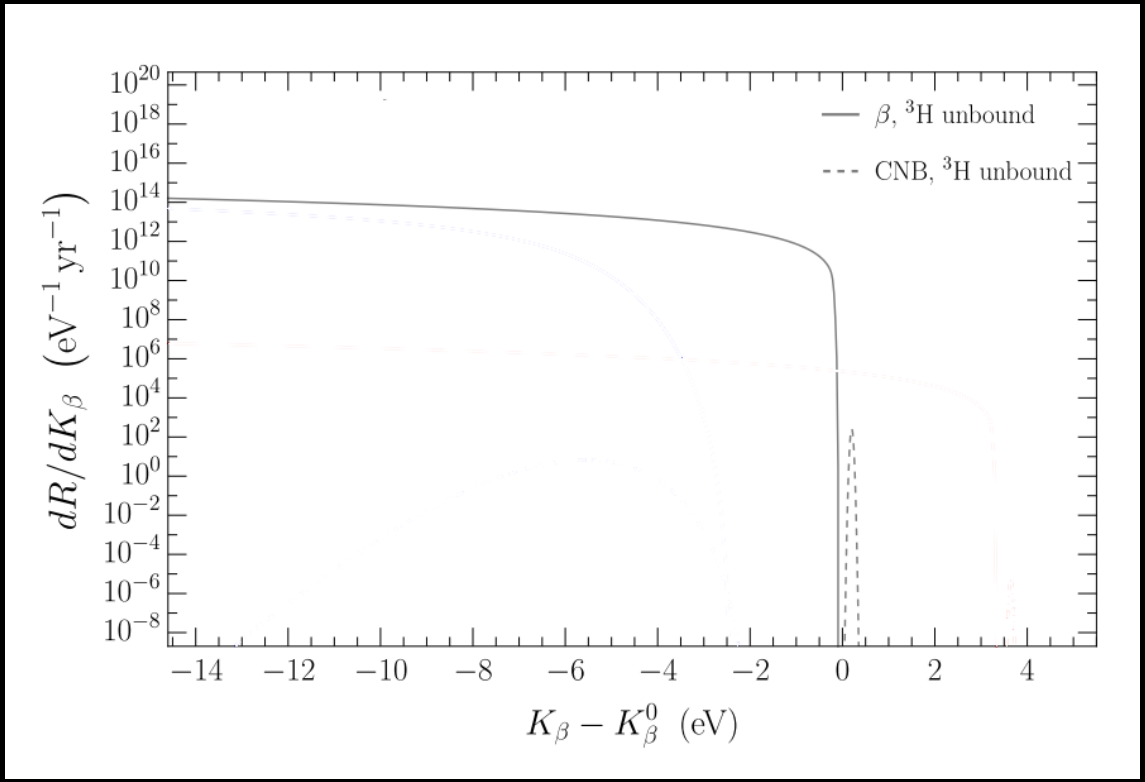
Relic neutrino Background (RνB): status

Not observed yet!

$$\nu_e + {}^3\mathrm{H} \rightarrow {}^3\mathrm{He}^+ + e^-$$

Direct detection via capture on tritium (PTOLEMY)[1,2]:

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



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1. PTOLEMY collaboration 2203.11228
2. Cheipesh, Cheianov, Boyarsky 2101.10069

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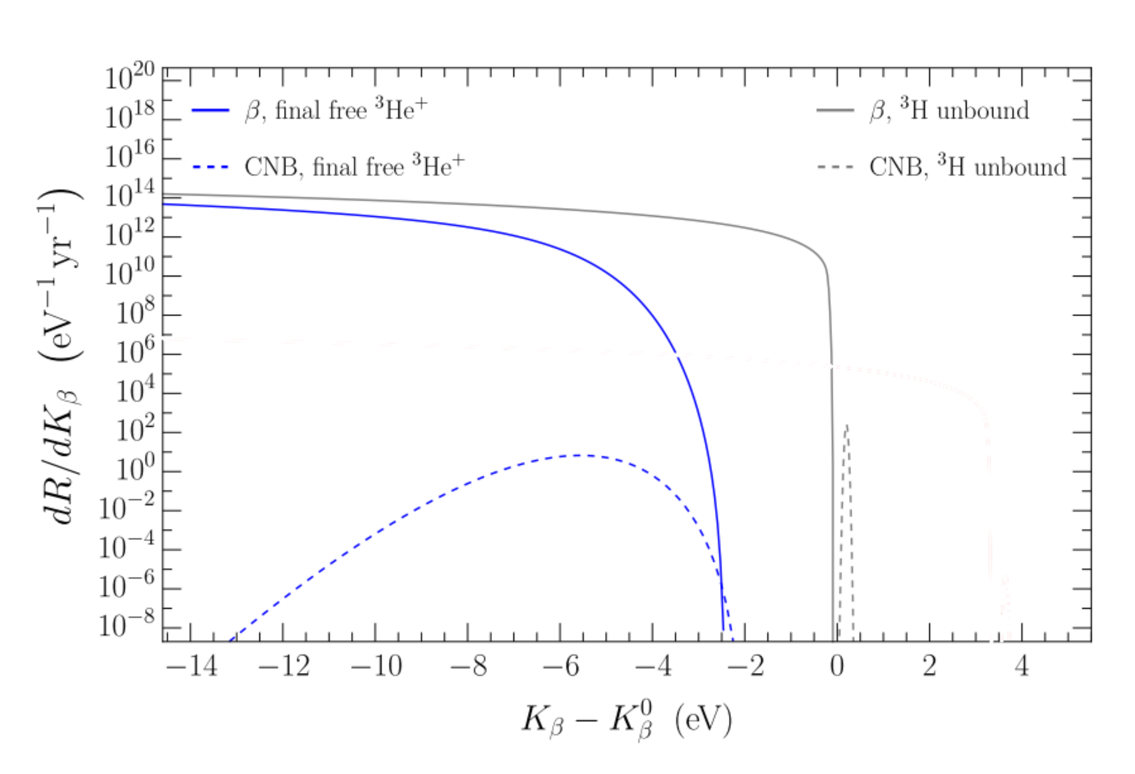

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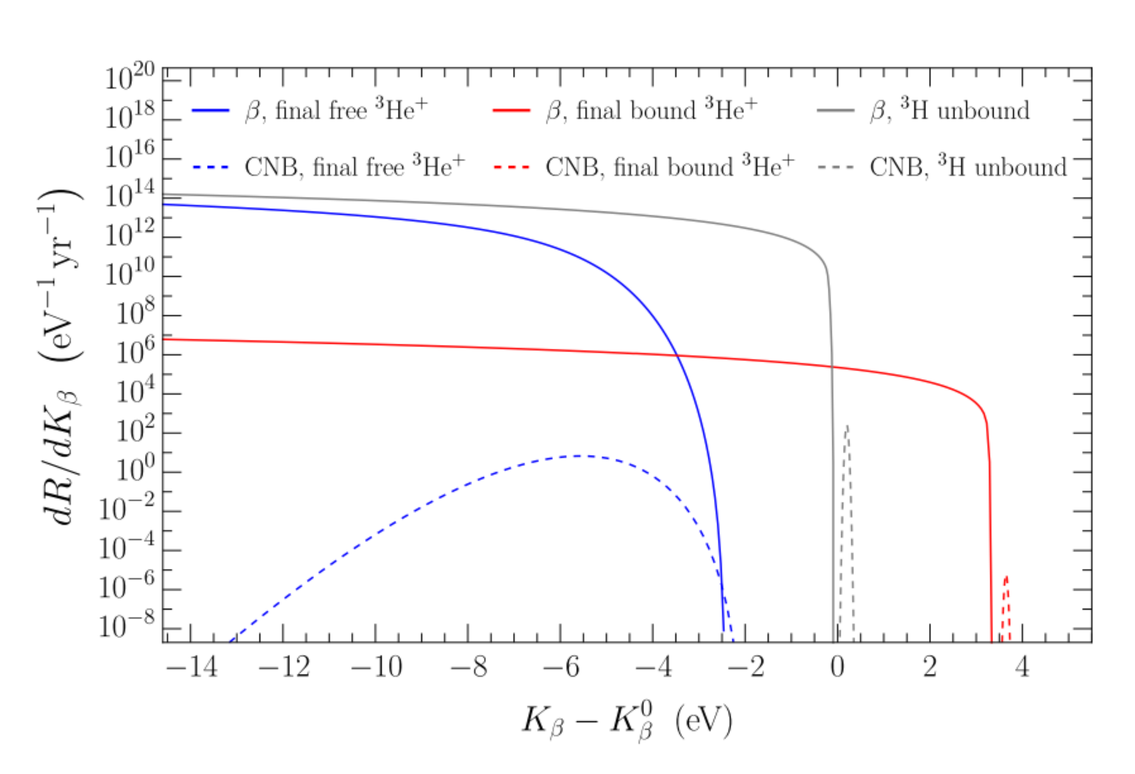

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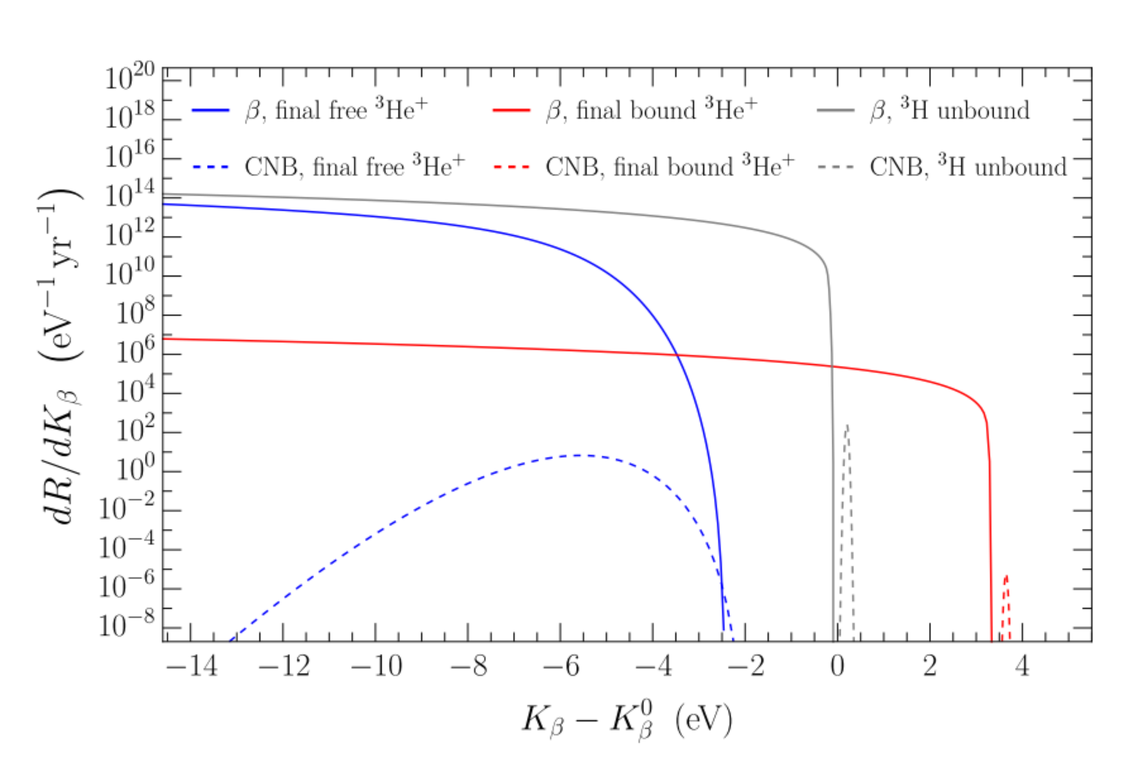

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Needs new tech, problem solved if ~ unbound tritium

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Cosmic rays upscatter the relic neutrinos

$$\sigma(CR - \nu) \propto E_{CR}$$

most upscattered by UHECR! [3]

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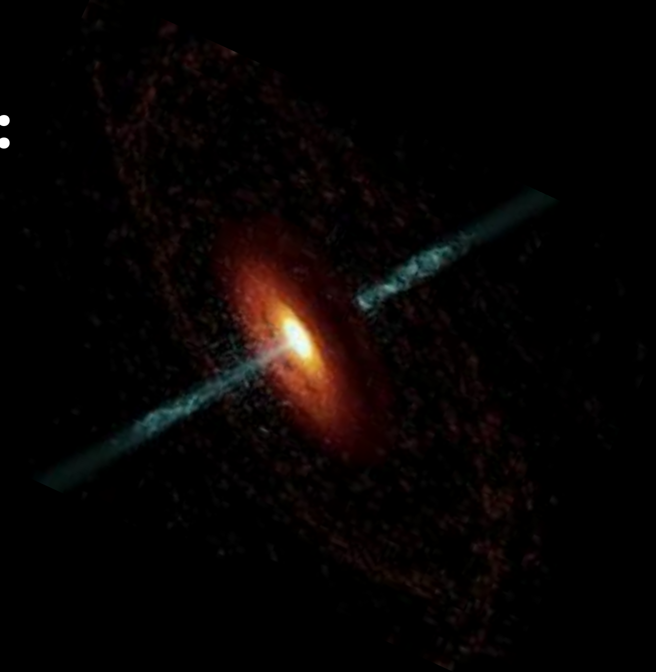

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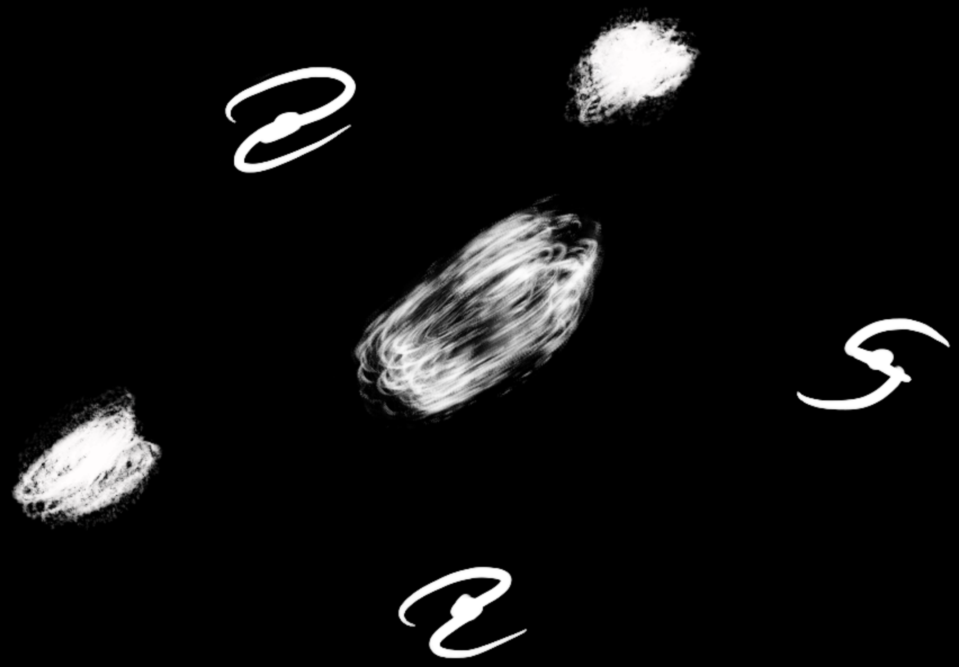
Let’s look at the (possible) source



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Fang, Murase (2017, Nature Phys.) 1704.00015:

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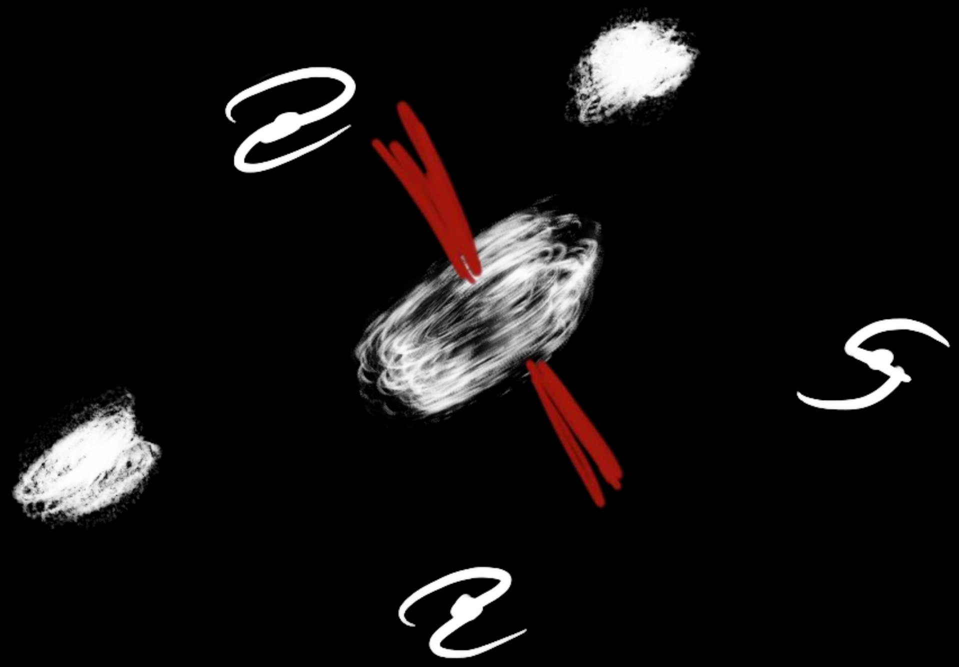

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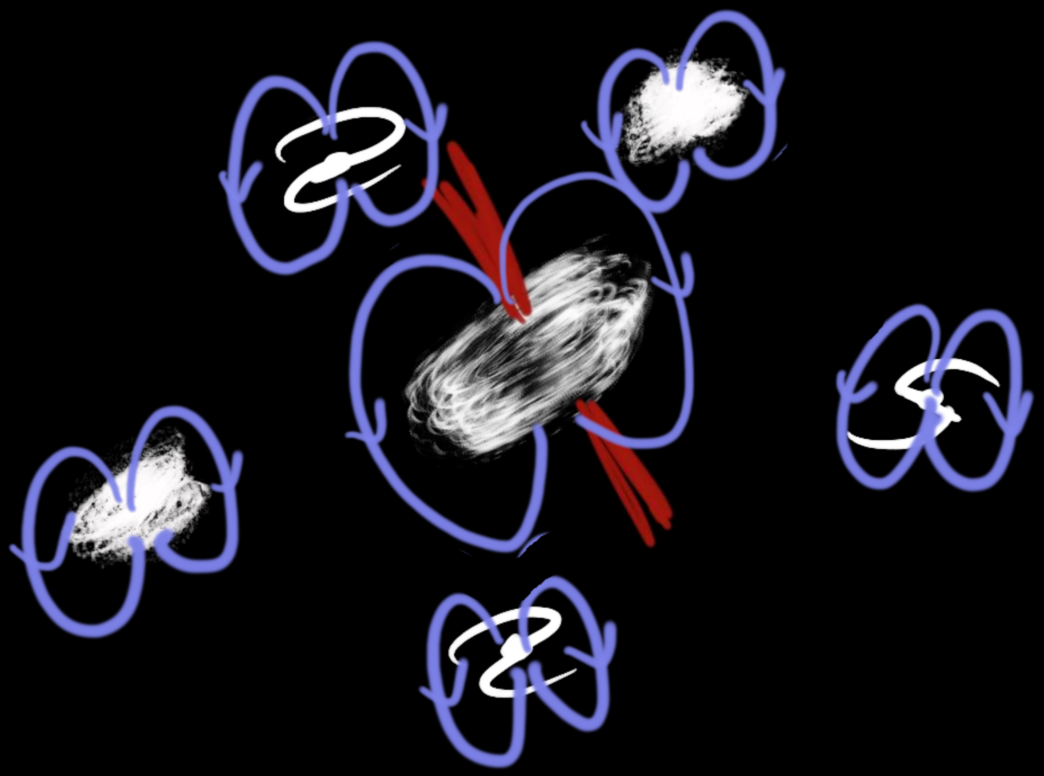

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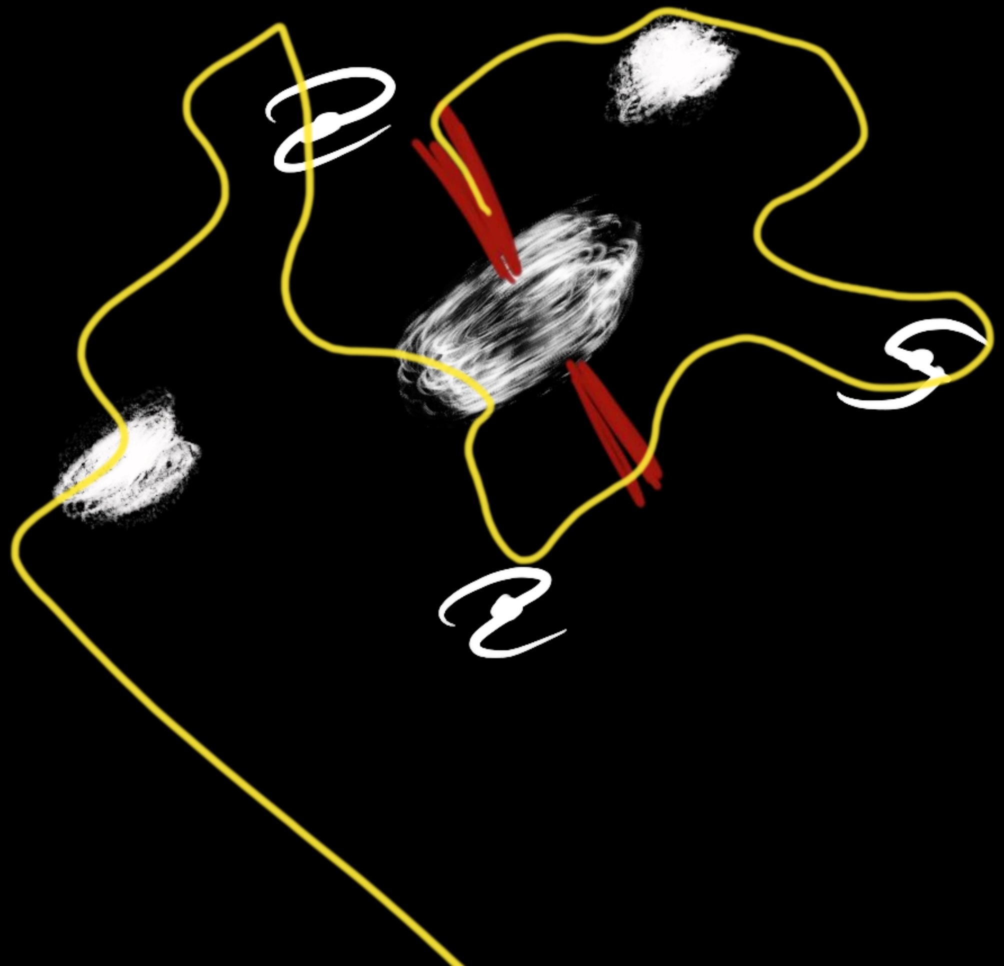

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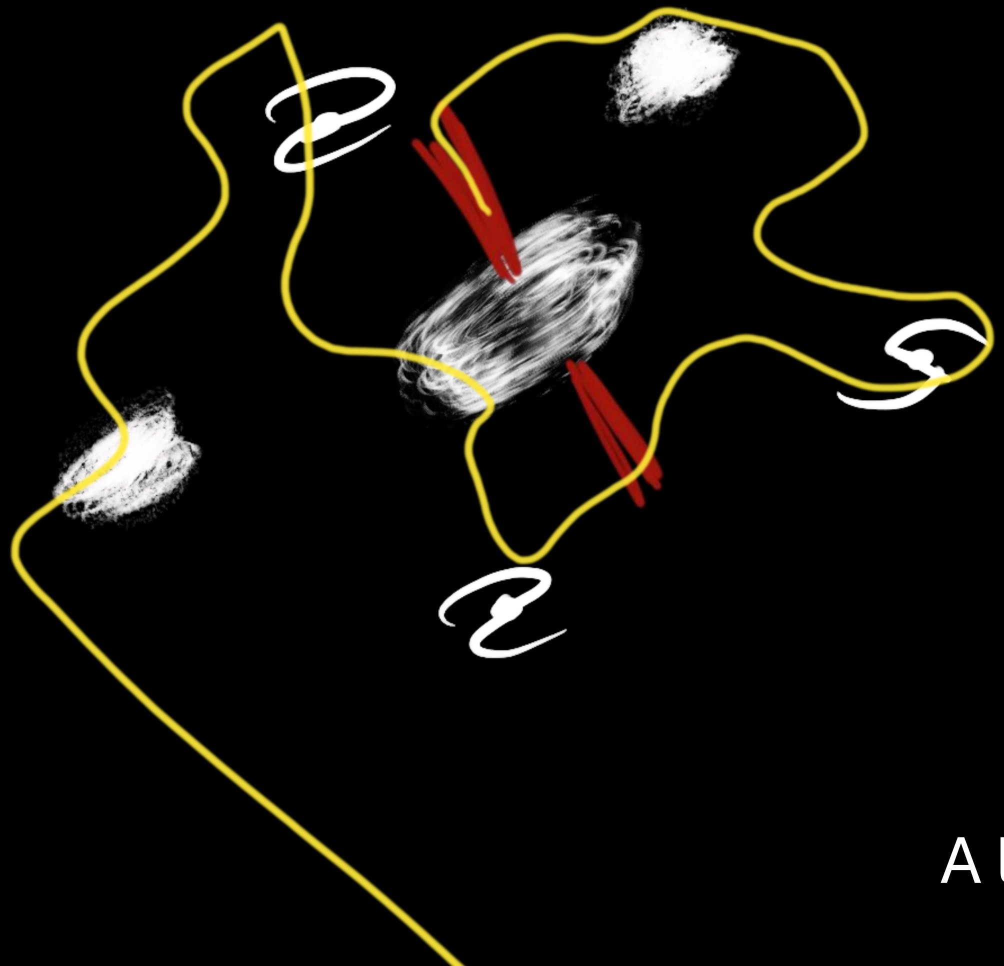

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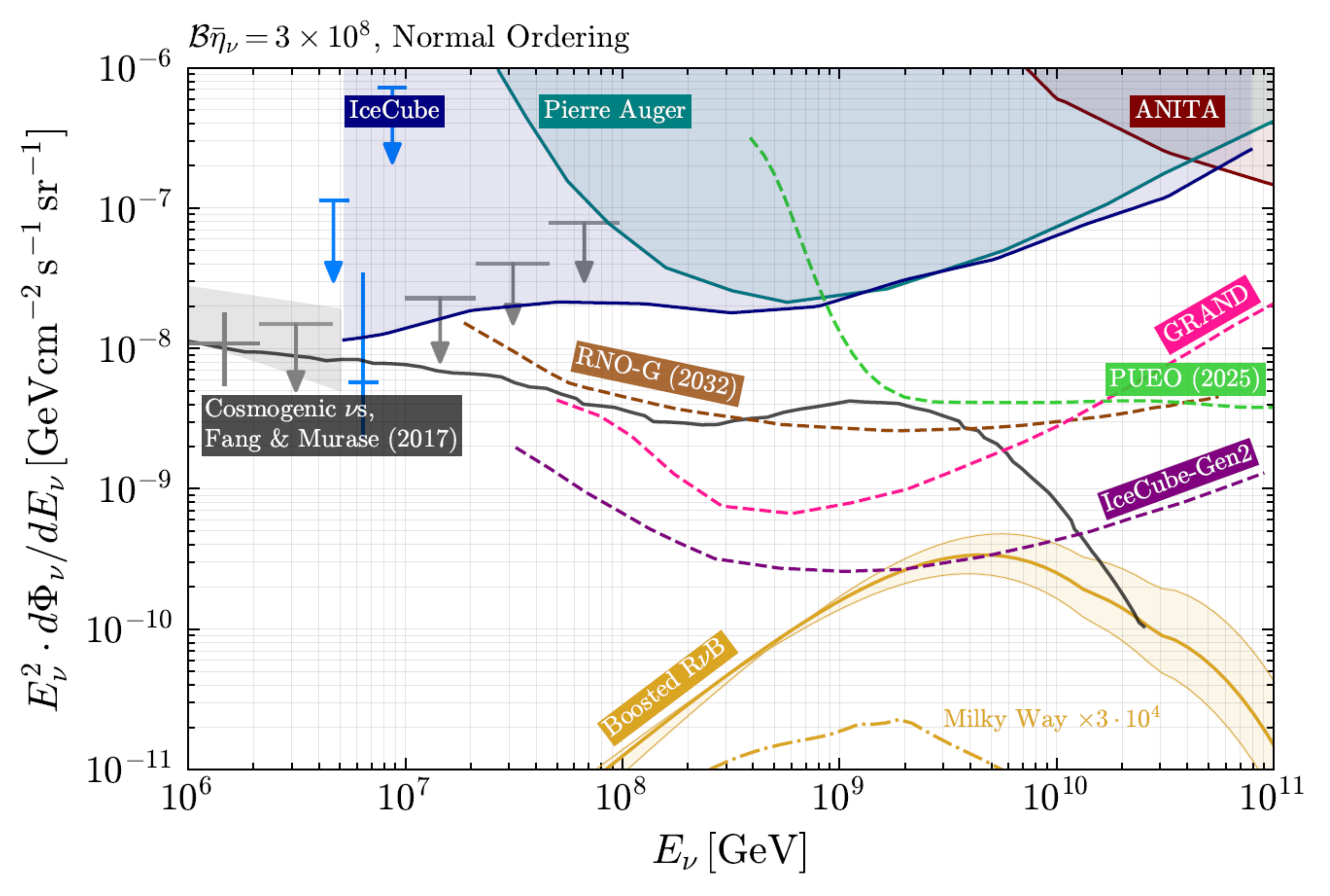
A lot of time to upscatter neutrinos!

Flux from Cosmic Reservoirs

- Improves previous bounds by orders of magnitude[4,5]
- Overdensities only on cluster scale, not diffuse
- Can tell apart from Cosmogenic neutrinos:
  - Spectral shape (DIS is crucial)
  - Flavour composition



4. Ciscar-Monsalvatje, Herrera, Shoemaker 2402.00985
5. Franklin, Martinez-Soler, Perez-Gonzalez, Turner 2404.02202

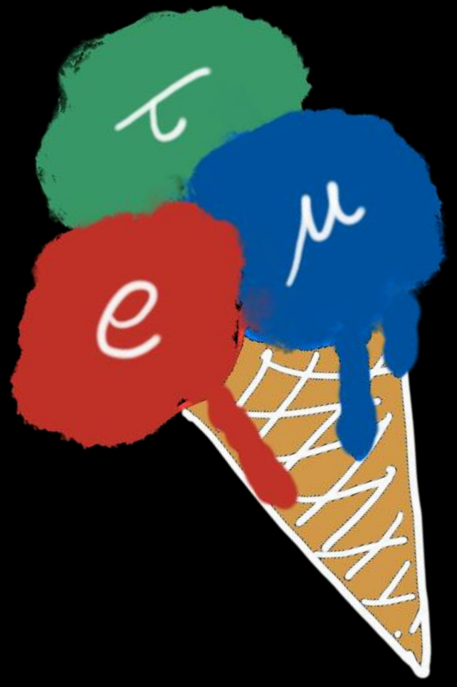
Flavour composition

νs are non-relativistic $\Rightarrow$ σ depends on m_ν

We computed the flux of mass eigenstates ν_i, preserved during propagation

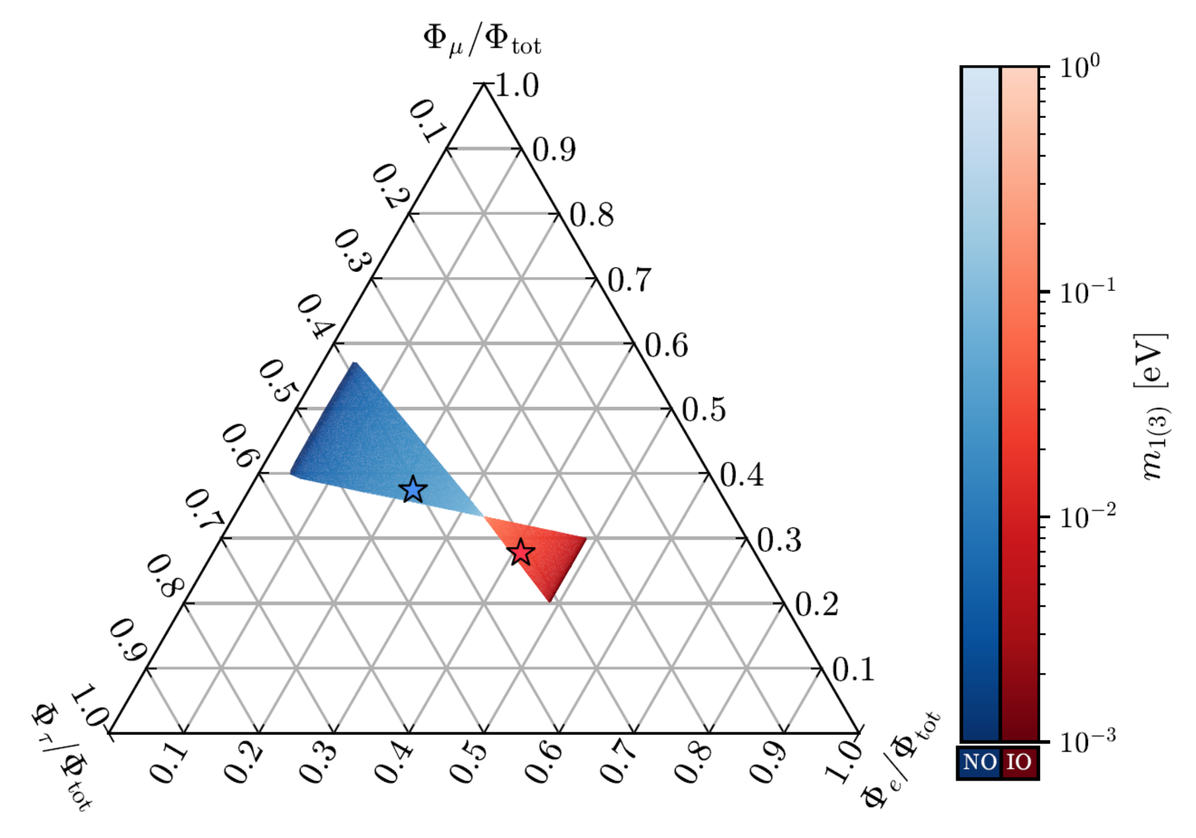
At detection, the flux of flavour eigenstate ν_α is

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



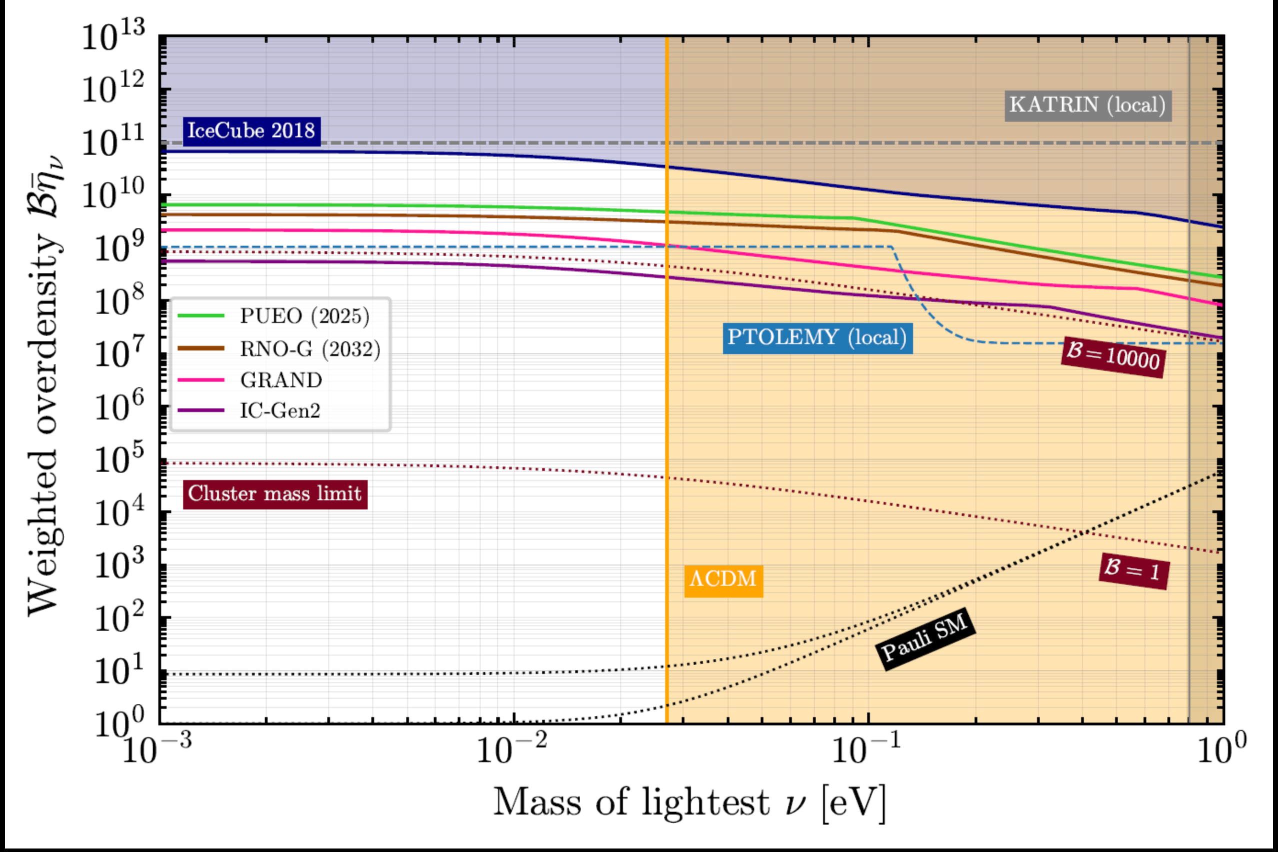
Flavour composition

- Higher neutrino mass: degenerate neutrinos, 1:1:1 flavour ratio
- Lower neutrino mass: the heaviest neutrino(s) dictate the flavour composition
- NO/IO: less/more electron neutrinos



Do these overdensities make sense?

- Limit to overdensity in SM: Pauli blocking, needs BSM
- **Smirnov, Xu 2201.00939** get close with new Yukawa interaction
- Limit on mass of the cluster: alleviated by non-homogeneous distribution



Conclusions

- We implemented a corrected cross section and CR composition and showed this has orders of magnitude impact wrt to the literature
- We set the most stringent bound on η_ν (can be even stronger with correct normalization of CR flux and non homogeneous distribution)
- We provided two ways to disentangle this signal from others (cosmogenic):
  - Energy dependence (correct cross section including DIS is crucial)
  - Flavour composition, which depends on absolute neutrino masses

What else?

- BSM mechanisms that induce neutrino overdensities? ν self-interactions? ν-DM interactions?
- Improved modeling of CR diffusion in the reservoir? Very naive treatment
- Hadronic resonances: the most important region to set the limit is also the most complex and not modeled in our analysis
- Other environments?
- What if the target is not the RvB? Upscattering DM

Thank you for your attention!

Backup slides

Effective distance D_{eff}

A measure of the effective distance traveled by Cosmic Rays through an equivalent homogeneous environment

$$D_{eff} = \mathcal{B} c \tau_{esc}$$

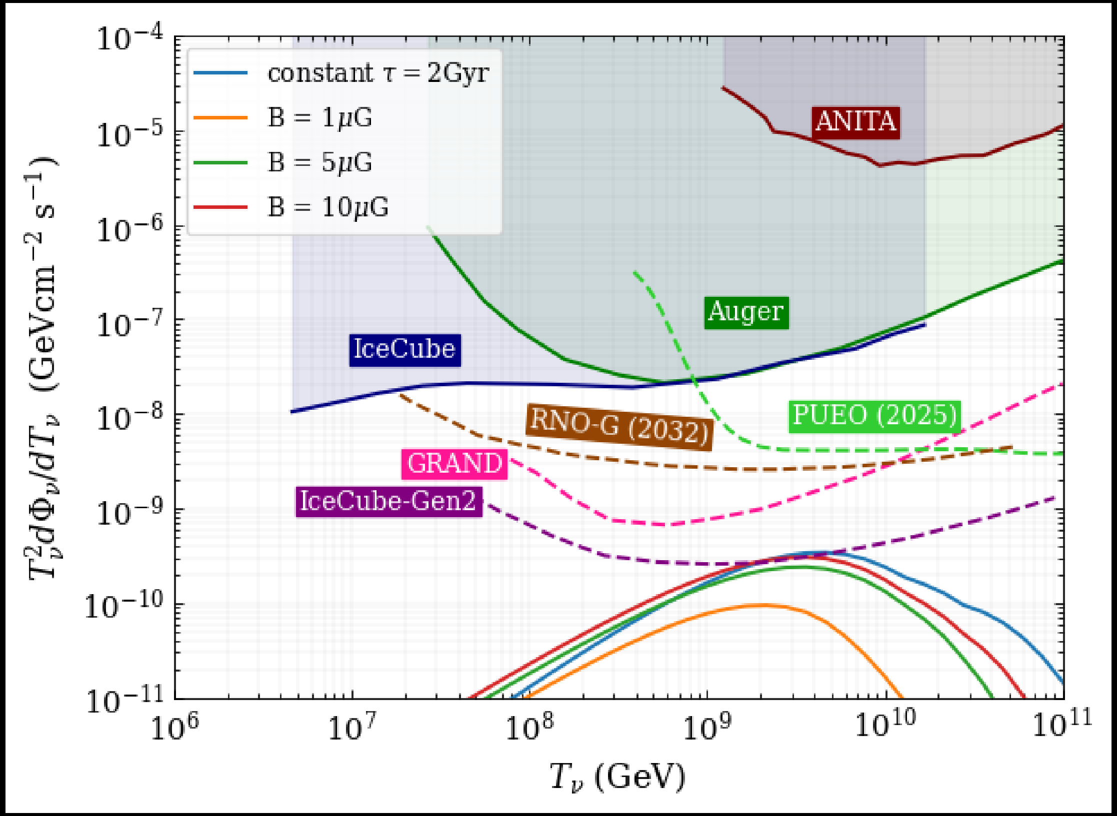
where

$$\mathcal{B} = \int d^3\,\vec{r}\;\; f_{CR}(\vec{r})\,\frac{\eta(\vec{r})}{\bar{\eta}}$$

Energy dependence of τ_{esc}

Trapping time τ_{esc} depends on the energy E of the particle and on the magnetic field B as[6]

$$\tau_{esc} \sim 1\ \text{Gyr} \times \begin{cases} (ZeB/E)^{1/3} & \text{if} \quad ZeB/E < lc \\ (ZeB/E)^{2} & \text{if} \quad ZeB/E > lc \end{cases}$$



6. Condorelli, Biteau, Adam 2309.04380

Pauli blocking

νs with momentum higher than $p_{\mathrm{esc}} = m_\nu v_{\mathrm{esc}}$ are not gravitationally bound to the cluster. There are therefore

$$N = \frac{1}{8}\left(\frac{4\pi}{3} p_{\mathrm{esc}}^3\right)\frac{V}{\pi^3}$$

available states. NFW profile, compute $v_{\mathrm{esc}}(r) = \sqrt{\frac{2GM(<r)}{r}}$, thus $\eta(r)$ and average it.

Allowed overdensity scales as m_ν^3 and as M_{vir}[7]

7. Ringwald, Wong (2004) hep-ph/0408241

Cluster mass limit

NFW:

$$M_{\mathrm{vir}} \propto r_{\mathrm{vir}}^3$$

so average density is (almost) the same for all halos, $\bar{\rho}_{\mathrm{halo}}$

We impose

$$\bar{\eta}_\nu n_\nu^0 \sum_i m_i < \bar{\rho}_{\mathrm{halo}}$$

Cosmic-Rays composition