CNP research day

Diffuse Boosted Cosmic Neutrino Background

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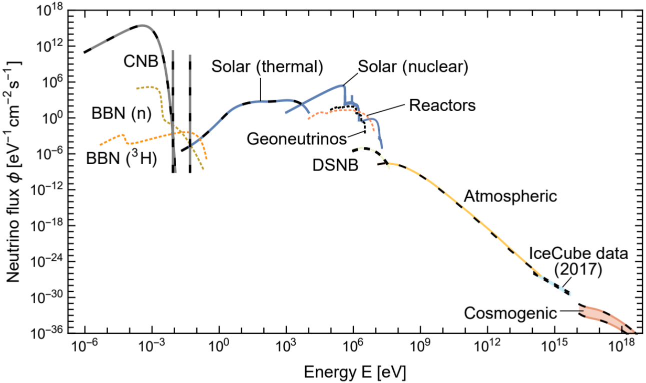
arXiv:2405.14946

Motivation

Figure: Vitagliano, Tamborra, and Raffelt 2020



Motivation

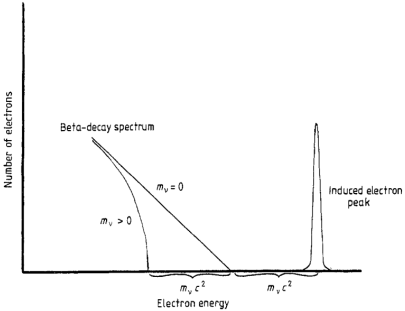
- CνB (relic neutrinos) decoupled from matter at the early universe ($\sim$ 1 second old).
- As the universe expanded, it further cooled down ($\sim 1.95K$).

CνB is extremely difficult to detect due to its low energy!

Previous work

- **'overdensity'**
- **KATRIN** placed an upper limit on neutrino overdensity Aker et al. 2022: 10^{11}

Figure: Irvine and Humphreys 1983



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

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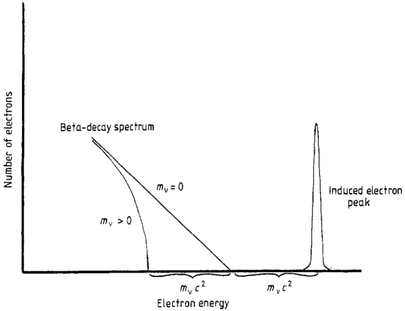

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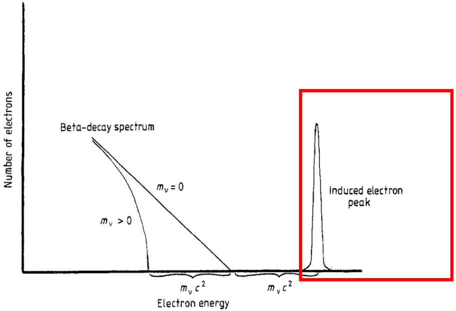

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Motivation

Is it possible for CνB to be boosted to higher energies?

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YES!

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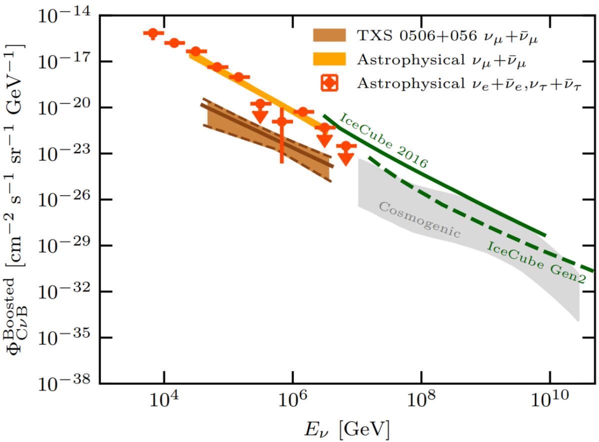
YES!

Cosmic rays scattering off relic neutrinos $\rightarrow$ boost!

Previous work



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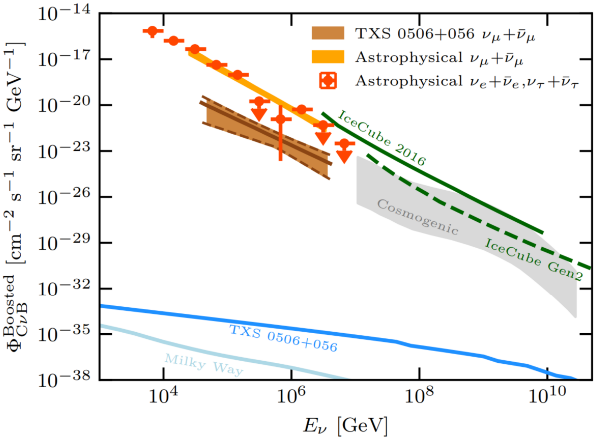
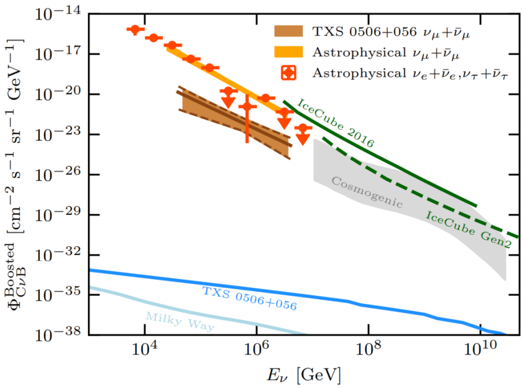


Previous work

Milky Way $\rightarrow \sim 10^{13}$

TXS 0506+056 $\rightarrow \sim 10^{10}$

Figure: Císcar-Monsalvatje, Herrera, and Shoemaker 2024



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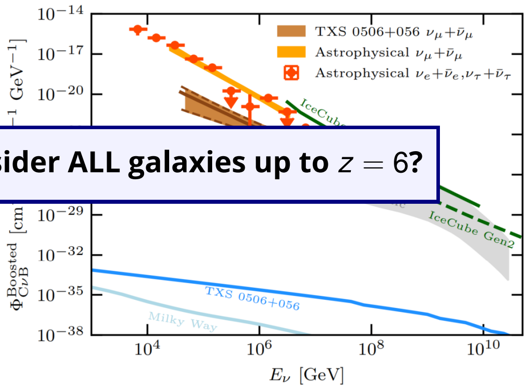
Milky Way $\rightarrow \sim 10^{13}$

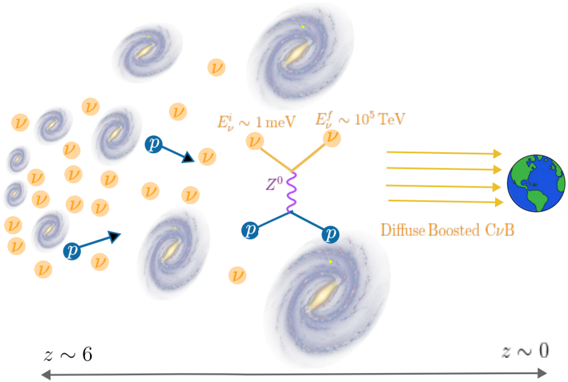
TXS 0506+056 $\rightarrow$



What if we consider ALL galaxies up to $z = 6$?

Schematic plot

Figure: Herrera, Horiuchi, and Qi 2024



Double integral

$$\frac{d\phi_\nu}{dT_\nu} = \int_{z_{\min}}^{z_{\max}} dz \frac{c}{H_0} \frac{1}{\sqrt{(1+z)^3\Omega_m + \Omega_\Lambda}} f_i(z) n_v (1+z)^3 \int_0^\infty dT_p \sigma_{p\nu}(T_p) \frac{d\phi_p}{dT_p} \frac{1}{T_\nu^{\max}(T_p)} \Theta\left[T_\nu^{\max}(T_p) - T_\nu(1+z)\right]$$

Assumptions

CR composition

consider only protons

scattering process

consider only neutral current interactions

Double integral

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Cosmological terms

Double integral

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proton-neutrino scattering cross section

Double integral

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Cosmic Ray spectrum in the Milky Way

Double integral

$$\frac{d\phi_\nu}{dT_\nu} = \int_{z_{\min}}^{z_{\max}} dz \frac{c}{H_0} \frac{1}{\sqrt{(1+z)^3\Omega_m + \Omega_\Lambda}} f_i(z) n_v (1+z)^3 \int_0^\infty dT_p \sigma_{p\nu}(T_p) \frac{d\phi_p}{dT_p} \frac{1}{T_\nu^{\max}(T_p)} \Theta \left[T_\nu^{\max}(T_p) - T_\nu(1+z)\right]$$

maximal energy transferred to a neutrino in one scattering

Double integral

$$\frac{d\phi_\nu}{dT_\nu} = \int_{z_{\min}}^{z_{\max}} dz \frac{c}{H_0} \frac{1}{\sqrt{(1+z)^3\Omega_m + \Omega_\Lambda}} f_i(z) n_v (1+z)^3 \int_0^\infty dT_p \sigma_{p\nu}(T_p) \frac{d\phi_p}{dT_p} \frac{1}{T_\nu^{\max}(T_p)} \Theta\left[T_\nu^{\max}(T_p) - T_\nu(1+z)\right]$$

redshift evolution of Cosmic Ray flux

Go to detailed explanation

Double integral

$$\frac{d\phi_\nu}{dT_\nu} = \int_{z_{\min}}^{z_{\max}} dz \frac{c}{H_0} \frac{1}{\sqrt{(1+z)^3\Omega_m + \Omega_\Lambda}} f_i(z) n_\nu (1+z)^3 \int_0^\infty dT_p \sigma_{p\nu}(T_p) \frac{d\phi_p}{dT_p} \frac{1}{T_\nu^{\max}(T_p)} \Theta\left[T_\nu^{\max}(T_p) - T_\nu(1+z)\right]$$

neutrino density at redshift z

Check the results!

Redshift evolution of CR

Return to other terms

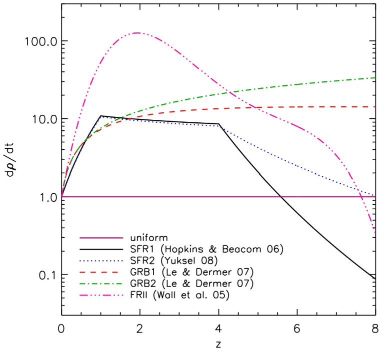
Redshift evolution of Cosmic Ray flux

$$f_i(z) = \frac{N_i(z)}{N_i(z_{min})}$$

$N_i(z)$: distribution of:

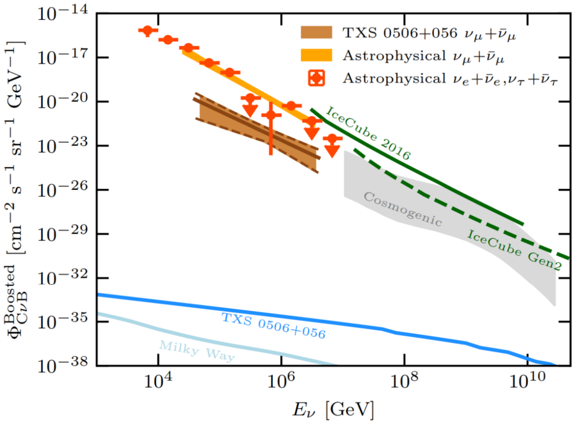
- SFR
- GRB
- QSO

Figure: Kotera, Allard, and Olinto 2010



Result

Figure: Císcar-Monsalvatje, Herrera, and Shoemaker 2024



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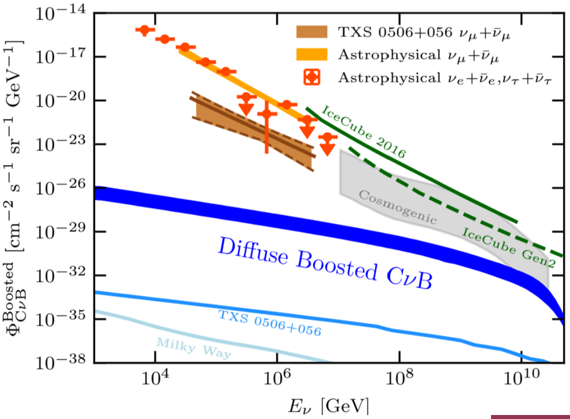
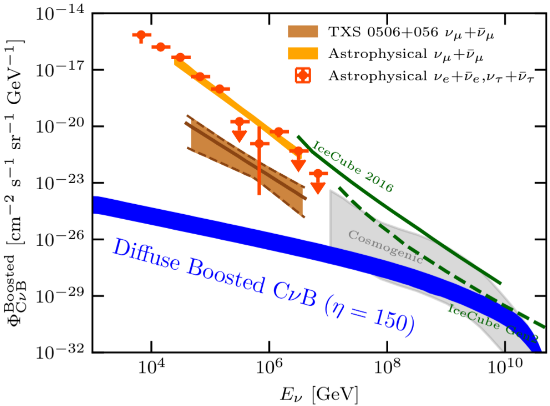


Result - incorporating overdensity

Figure: Herrera, Horiuchi, and Qi 2024



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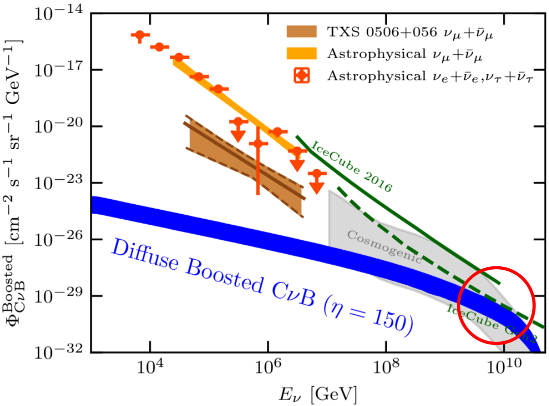

Conclusion and Outlook

Boosted flux

Relic neutrino flux is remarkably boosted.

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With a sensitivity increasing of only $\sim$ **150** compared to IceCube Gen2, we have a hope to directly detect $C\nu B$.

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Outlook

Further improvement is possible by taking into account:

- heavy nuclei
- deep inelastic regime
- charged current interaction $\rightarrow$ a program in progress with Shunsaku Horiuchi, Ian Shoemaker, Gonzalo Herrela.

Questions?

References I

- Aker, M et al. (2022). “New constraint on the local relic neutrino background overdensity with the first KATRIN data runs”. In: *Physical Review Letters* 129.1, p. 011806.
- Císcar-Monsalvatje, Mar, Gonzalo Herrera, and Ian M Shoemaker (2024). “Upper limits on the cosmic neutrino background from cosmic rays”. In: *Physical Review D* 110.6, p. 063036.
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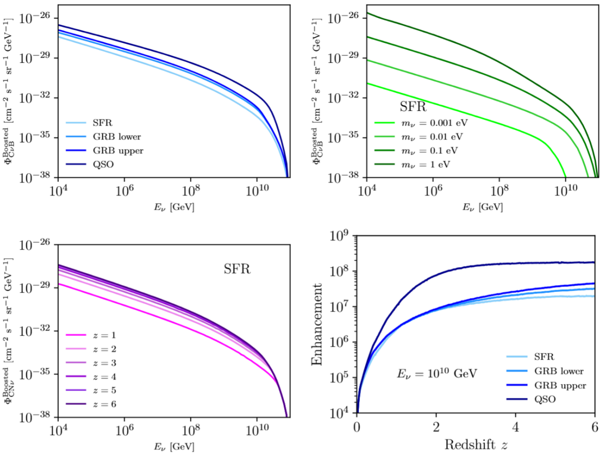
- Irvine, JM and R Humphreys (1983). “Neutrino masses and the cosmic-neutrino background”. In: *Journal of Physics G: Nuclear Physics* 9.7, p. 847.
- Kotera, Kumiko, Denis Allard, and Angela V Olinto (2010). “Cosmogenic neutrinos: parameter space and detectabilty from PeV to ZeV”. In: *Journal of Cosmology and Astroparticle Physics* 2010.10, p. 013.

References II

Vitagliano, Edoardo, Irene Tamborra, and Georg Raffelt (2020). “Grand unified neutrino spectrum at Earth: Sources and spectral components”. In: *Reviews of Modern Physics* 92.4, p. 045006.

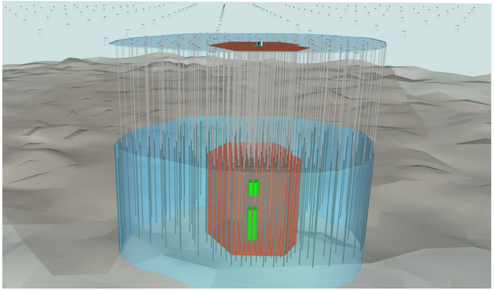
More Results



IceCube Gen2

- next-generation South Pole neutrino observatory
- ”A core detector will be the IceCube-Gen2 optical array, with a size eight times larger than the current IceCube and optimized to detect neutrinos with energies ranging from hundreds of TeV to tens or even a few hundreds of PeV.”

Figure: https://icecube-gen2.wisc.edu/about/icecube-gen2/



A 3D rendering of the planned IceCube-Gen2 extension. IceCube-Gen2 encompasses three new arrays—in-ice optical, surface, and extensive radio—that expand the capabilities of the current IceCube Neutrino Observatory. Image credit: IceCube Collaboration