Dark Matter Annihilation to Neutrinos: New Limits and Future Prospects

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Based on hep/ph:1912.09486
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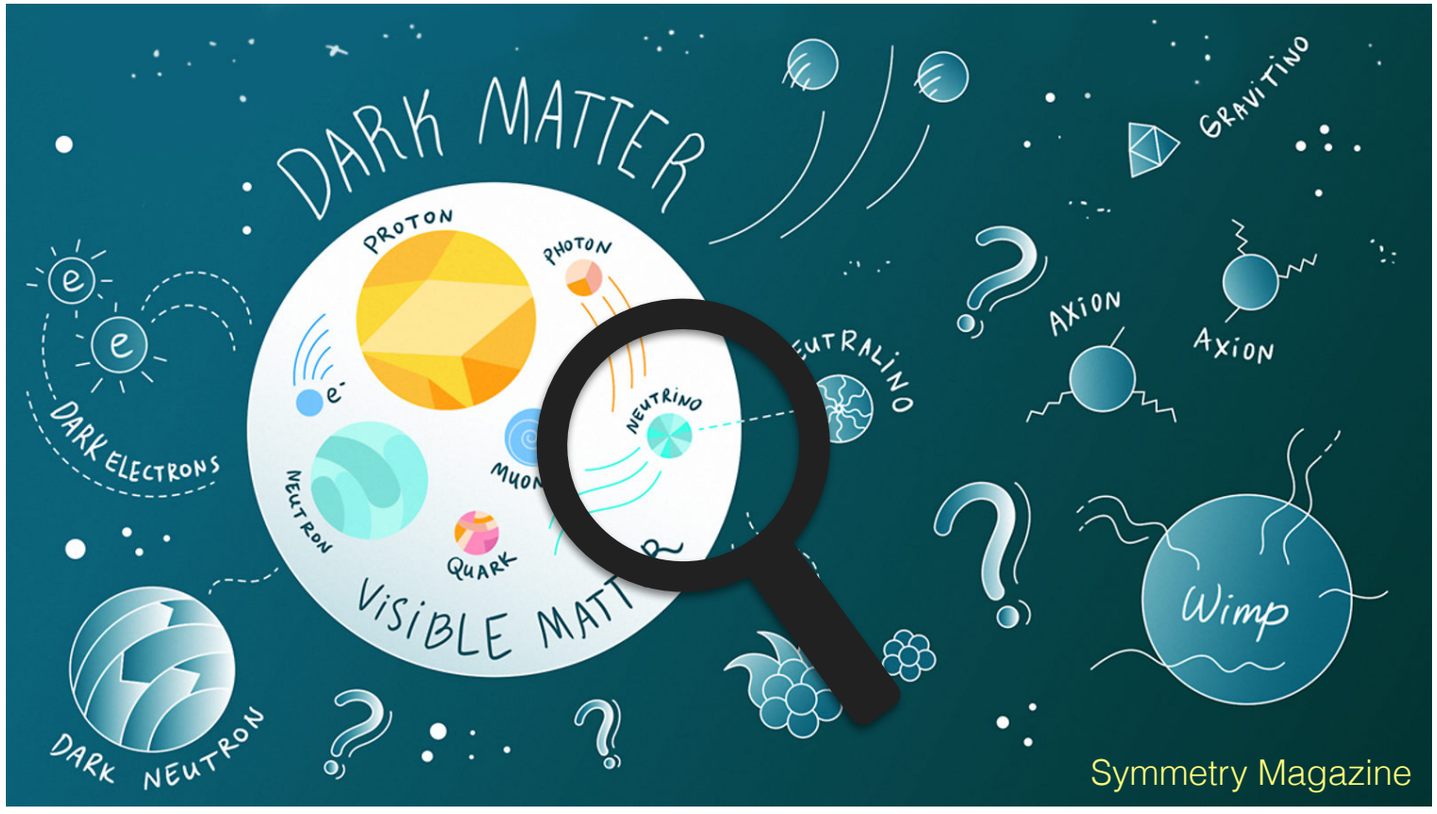
Indirect Search for Dark Matter

- What is dark matter (DM)?
- What SM particles does DM interact with?
- How does it interact?

Thermal production of WIMPs in early Universe implies possible ongoing self-annihilation of DM.



Strongest constraints are in place from the absence of any signal in X-ray & gamma-rays from the Milky Way.

Neutrino portal: *the most invisible channel*, hardest to detect, difficult to rule out!

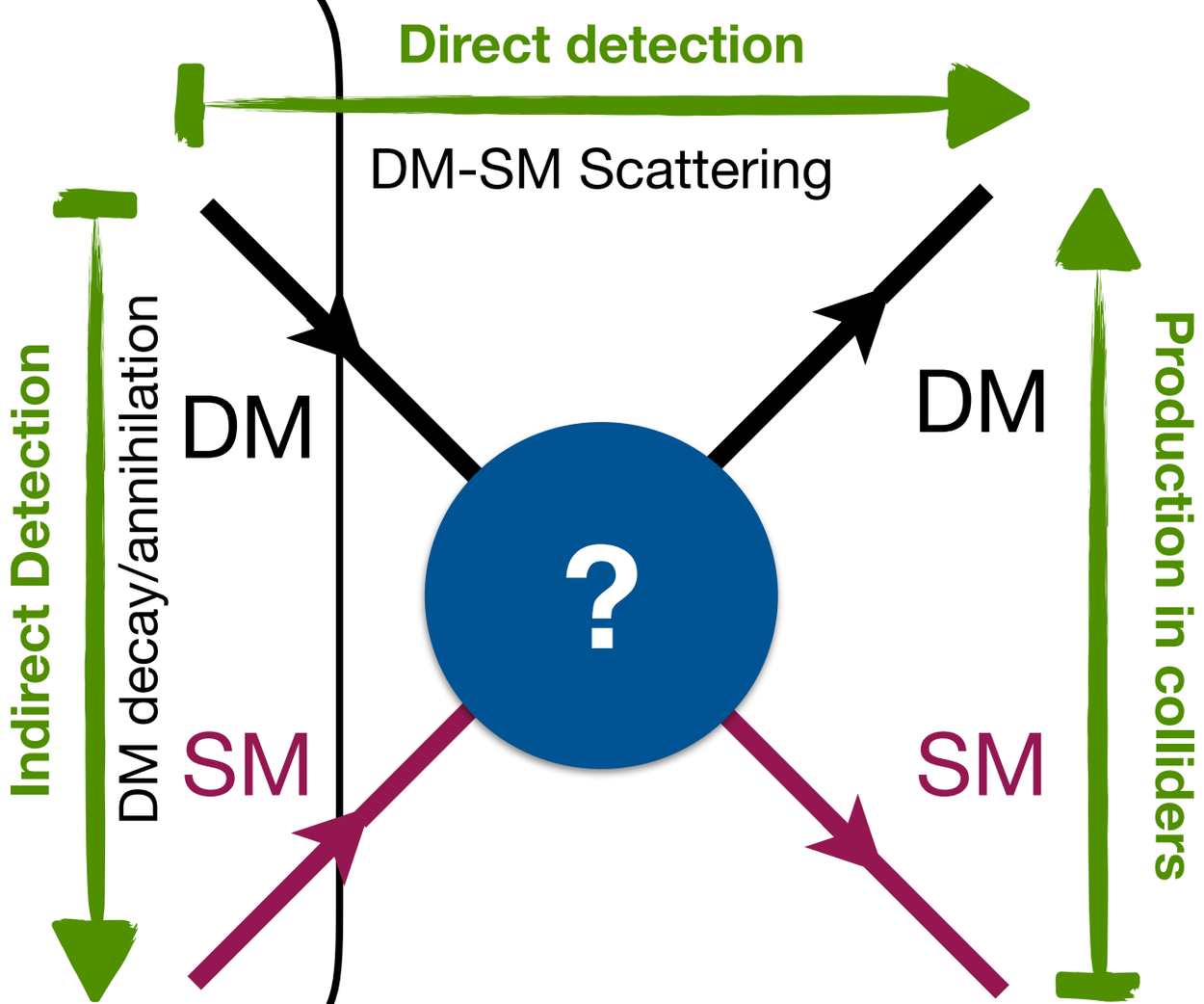
Neutrino portal to Dark Matter

Neutrinos may be the principal portal to the dark sector.

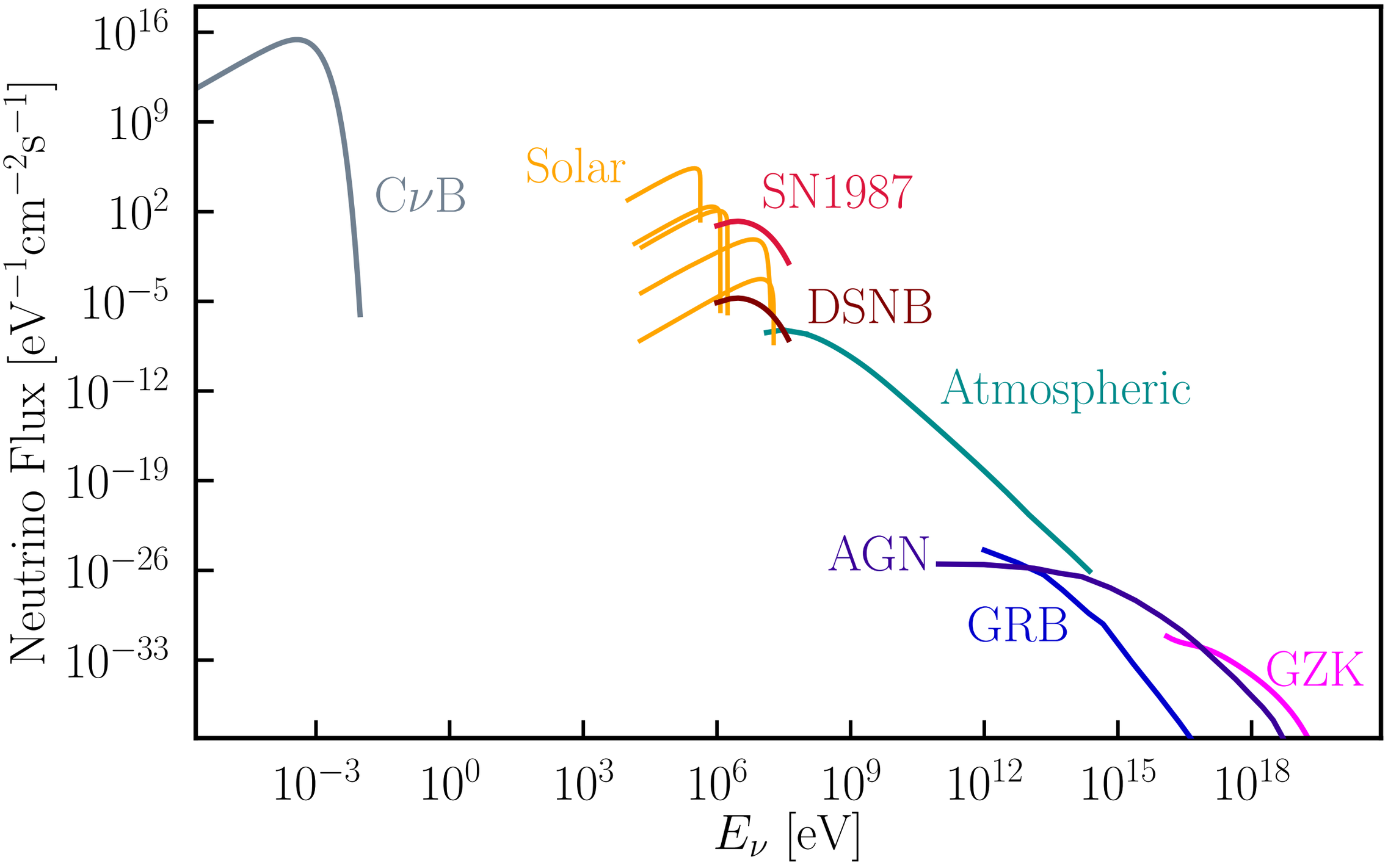
- Motivated by the *scotogenic* models
- Can explain the MiniBoone anomaly

Indirect dark matter signatures in the neutrino sector:

- Features in geo, solar, atmospheric, and cosmic neutrino spectra
- Anisotropies in high-energy neutrinos due to DM-Neutrino interaction.
- Features in the diffuse SN neutrino background.



The Universe in Neutrinos



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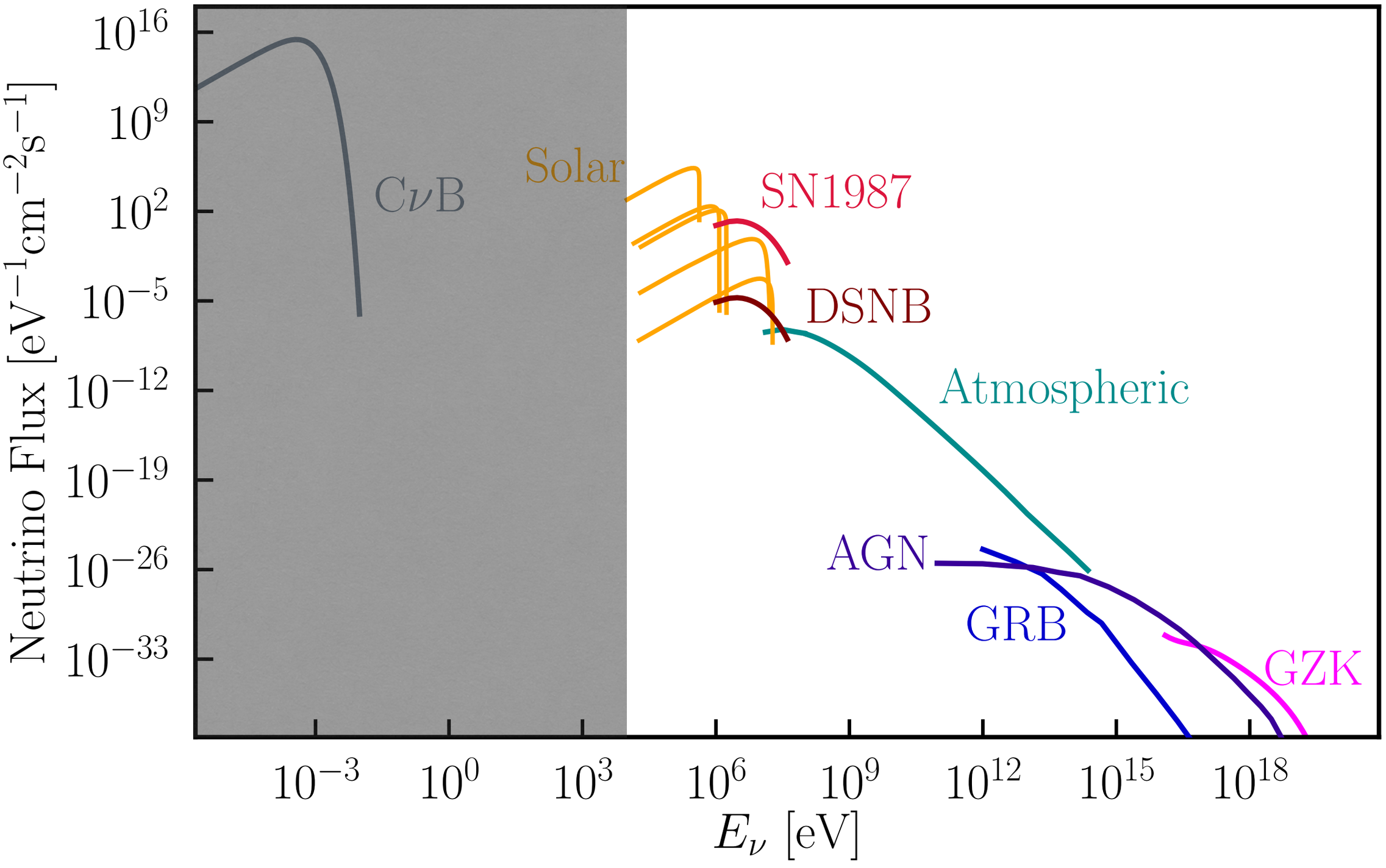

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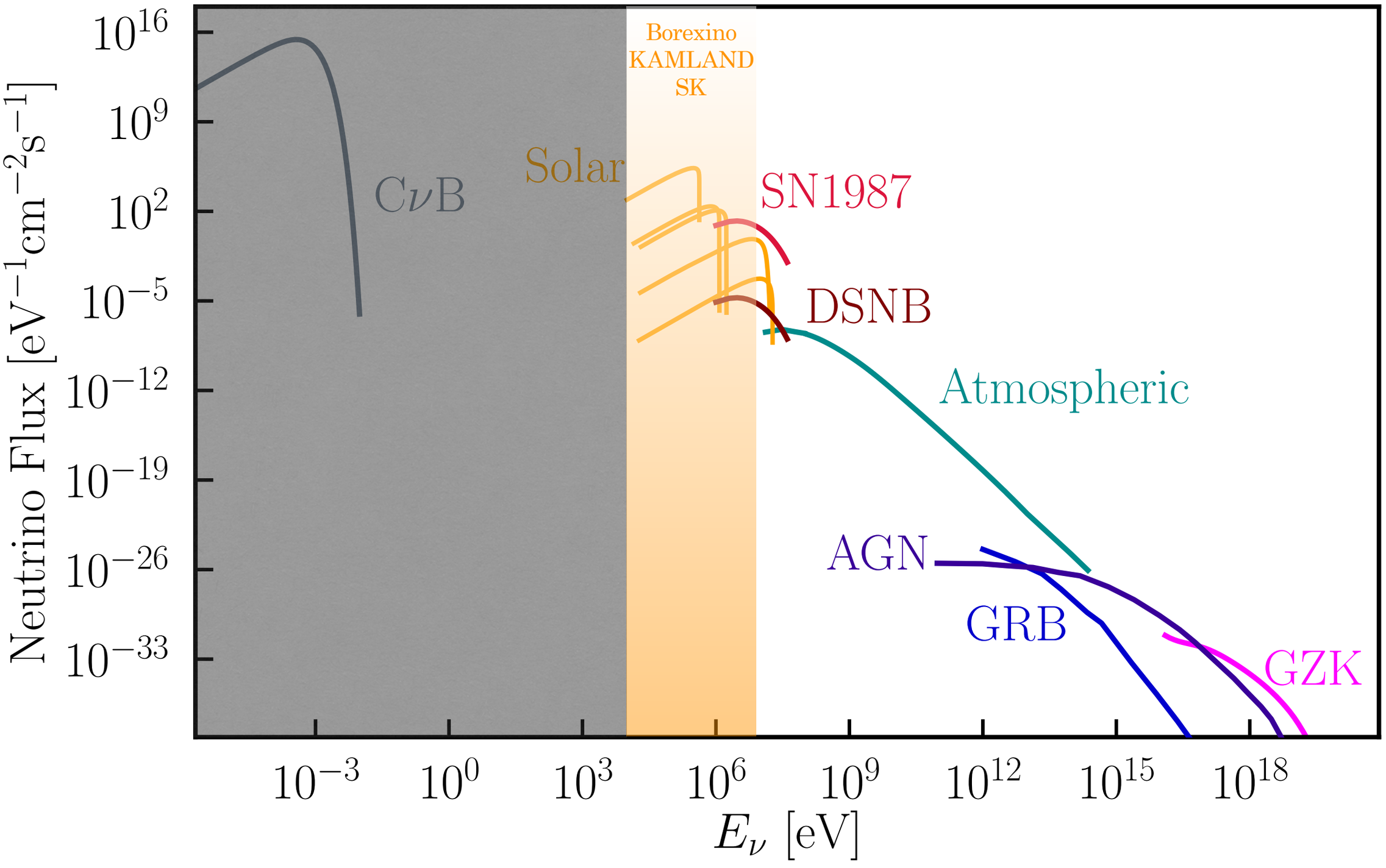

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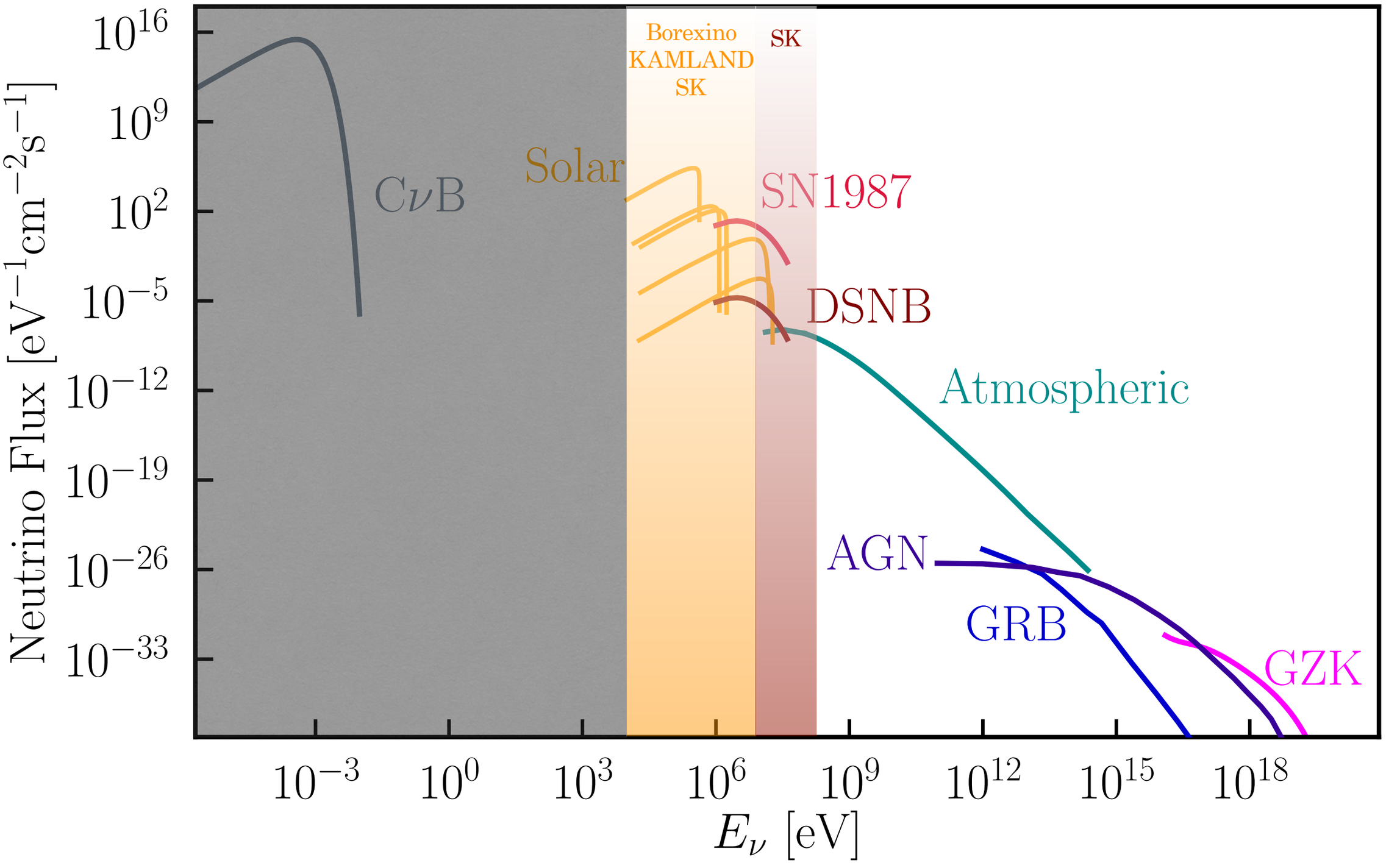

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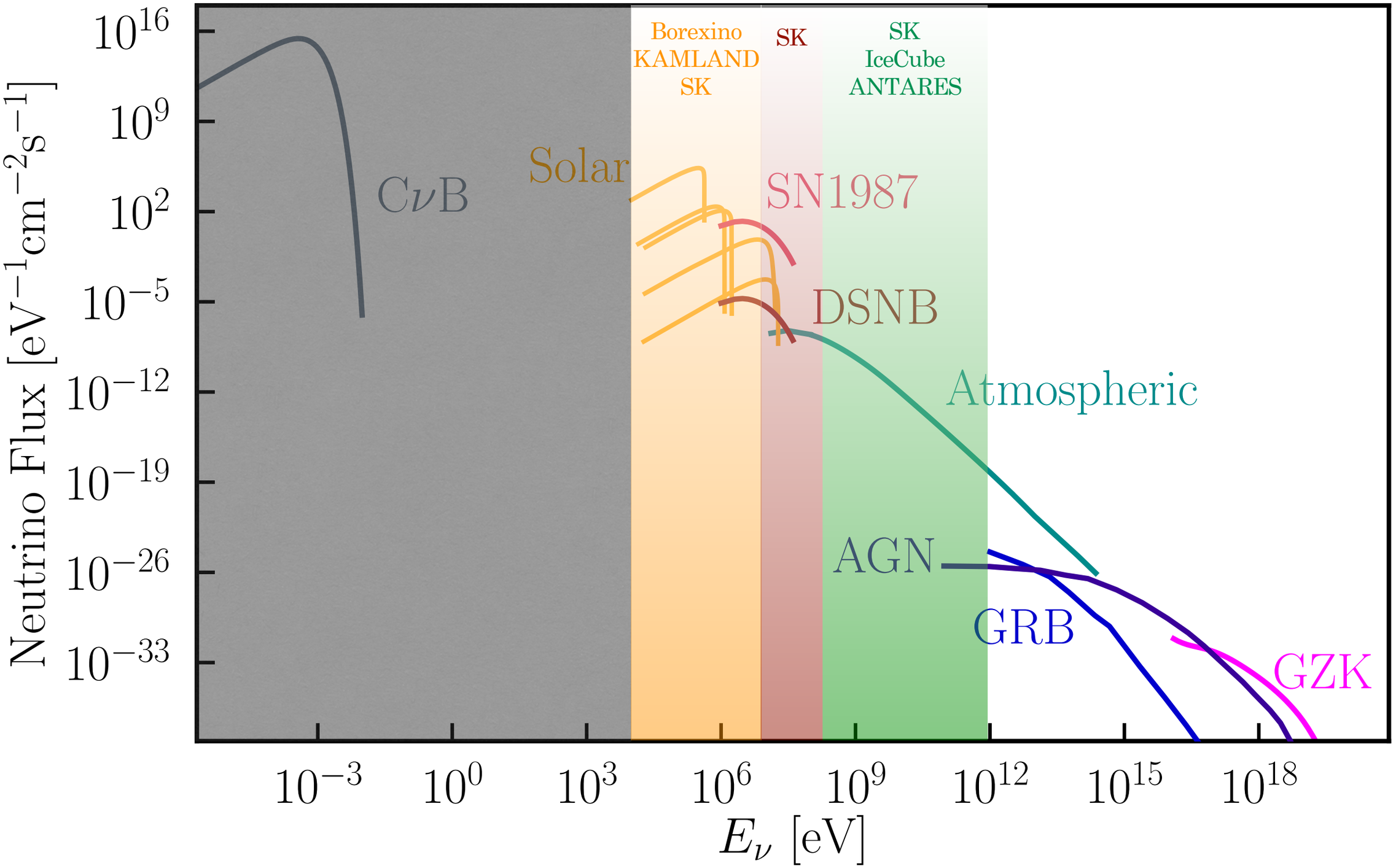

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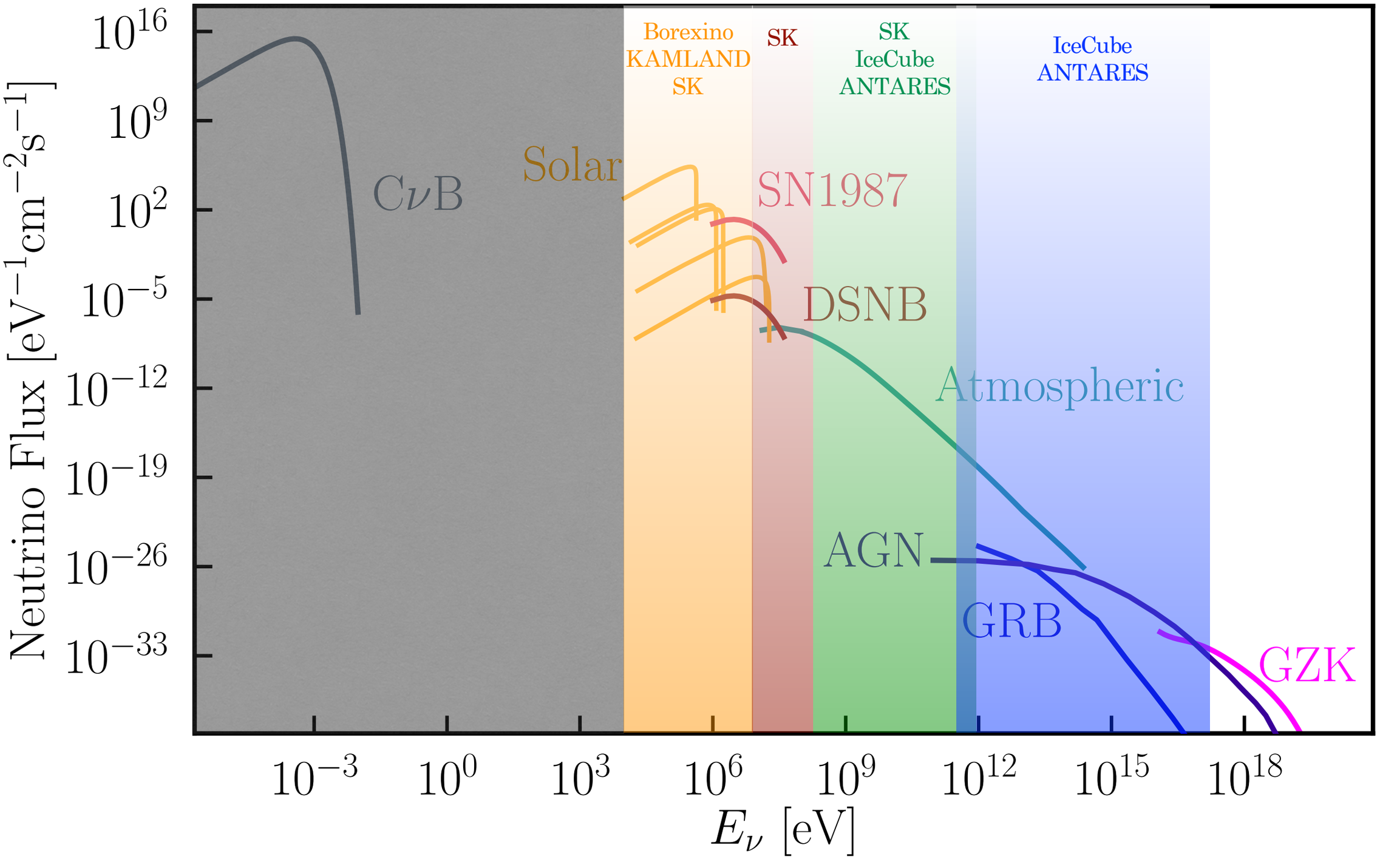

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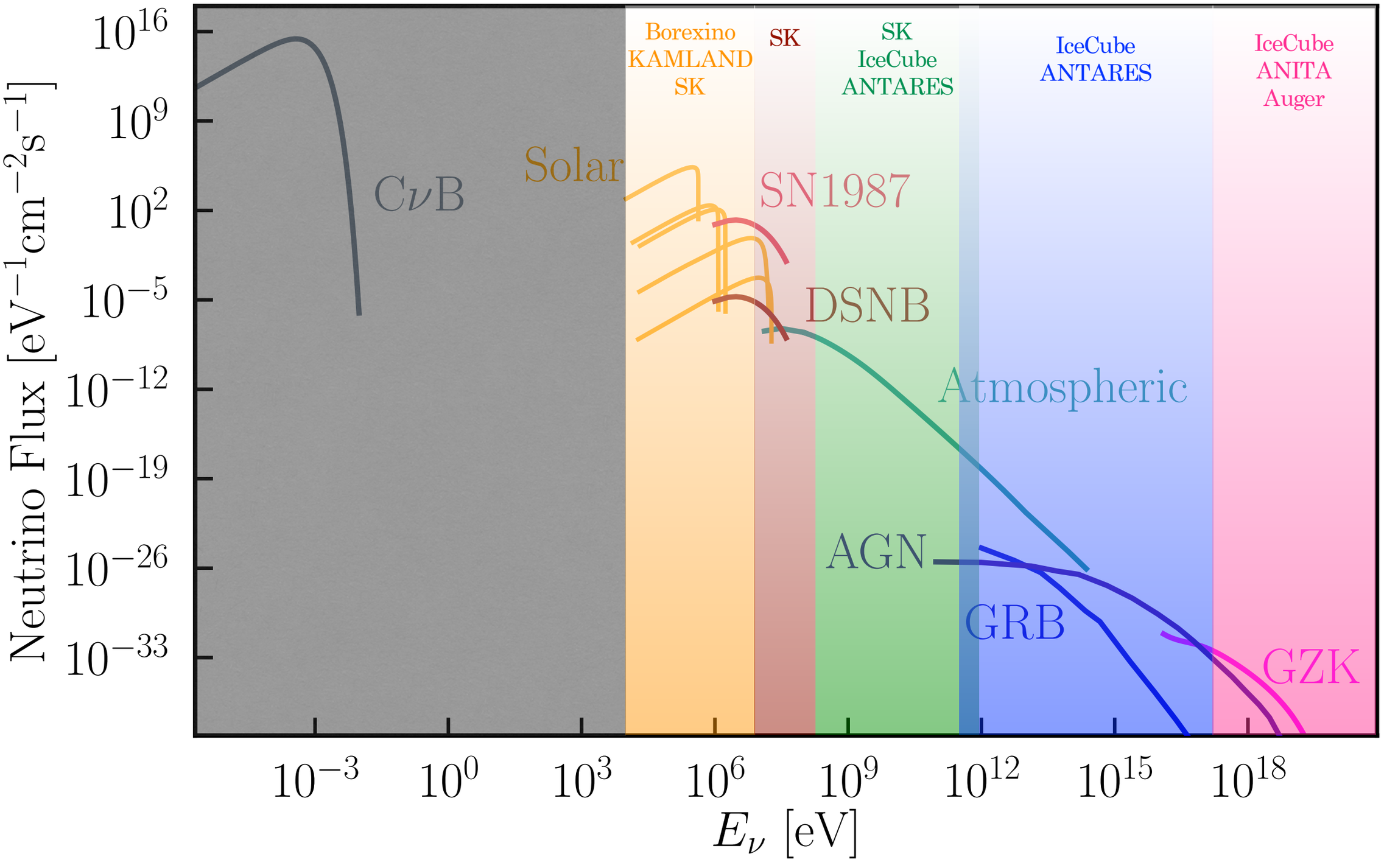

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Galactic component

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thermally averaged DM annihilation cross section

The neutrino production spectrum for direct annihilation of DM to neutrinos

$$\propto \delta(m_\chi - E_\nu)$$

J-facror: 3d integral over the target solid angle in the sky and the line of sight

$$J \equiv \int d\Omega \int_{\text{l.o.s.}} \rho_\chi^2(x) dx,$$

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$$\frac{d\Phi_\nu}{dE} = \frac{c}{4\pi}\frac{\Omega_{DM}^2\rho_{crit}^2\langle\sigma v\rangle}{2m_x^2}\int_0^{z_{up}} dz\frac{\big(1+G(z)\big)(1+z)^3}{H(z)}\frac{dN_\nu(E')}{dE}$$

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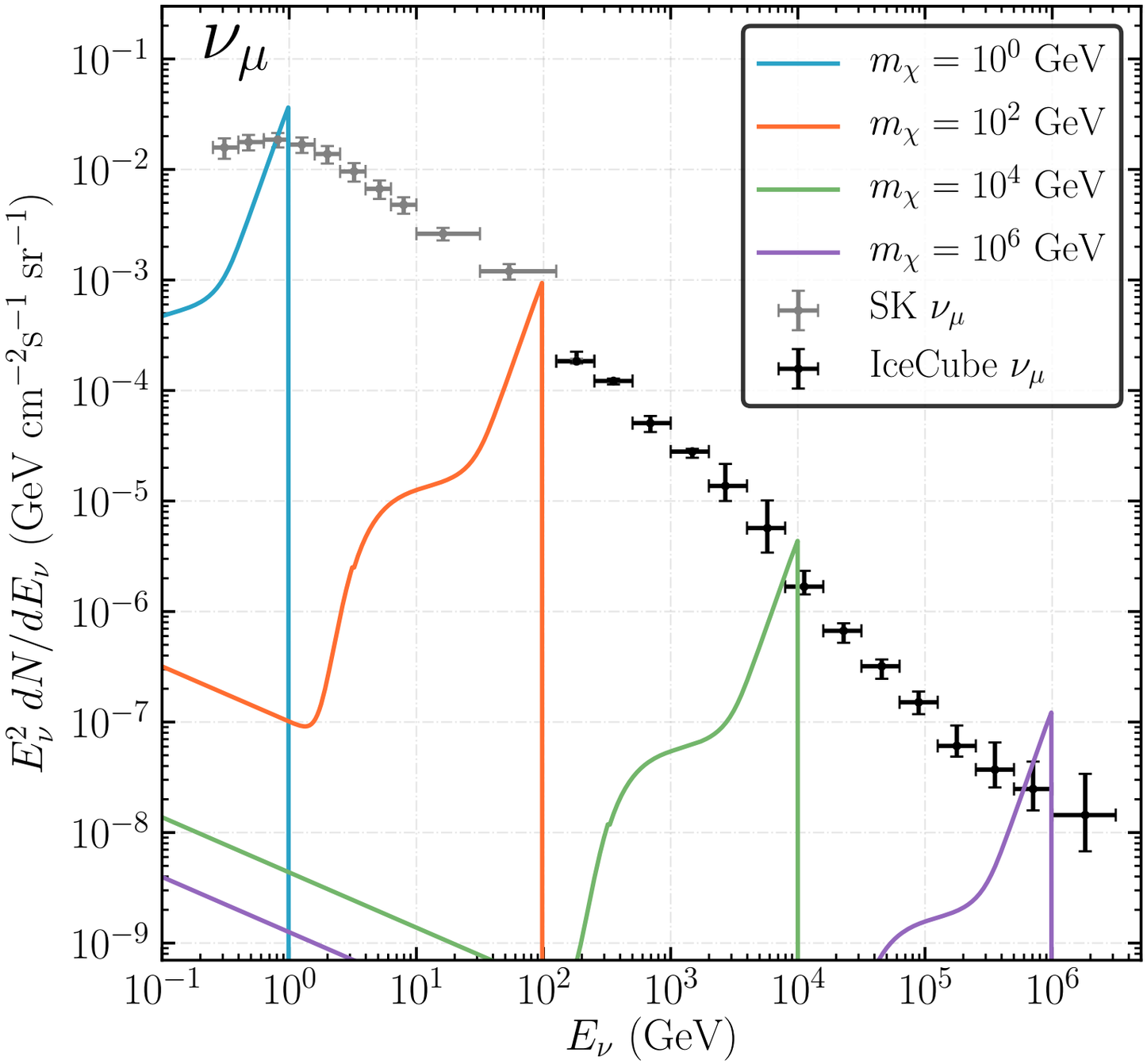
An isotropic neutrino signal is also expected from DM annihilation in every other halo in the universe:

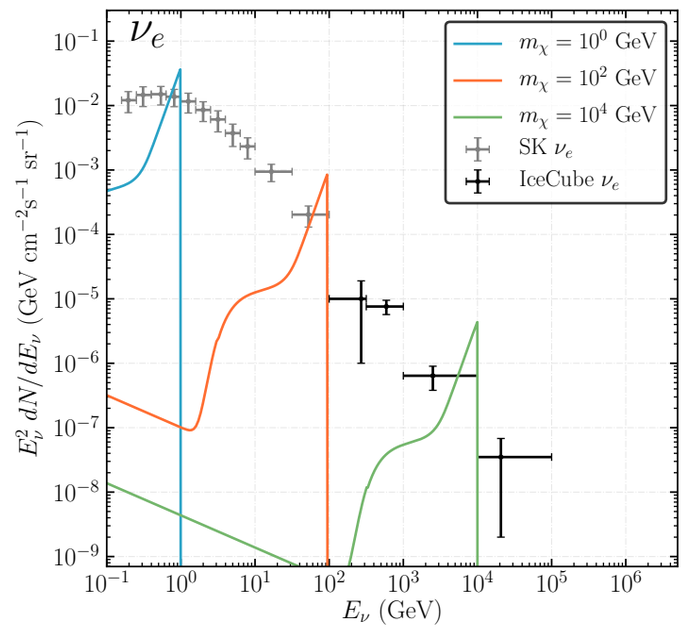
Production spectrum $\frac{2}{3E}\delta\left[z-\left(\frac{m_\chi}{E}-1\right)\right]$

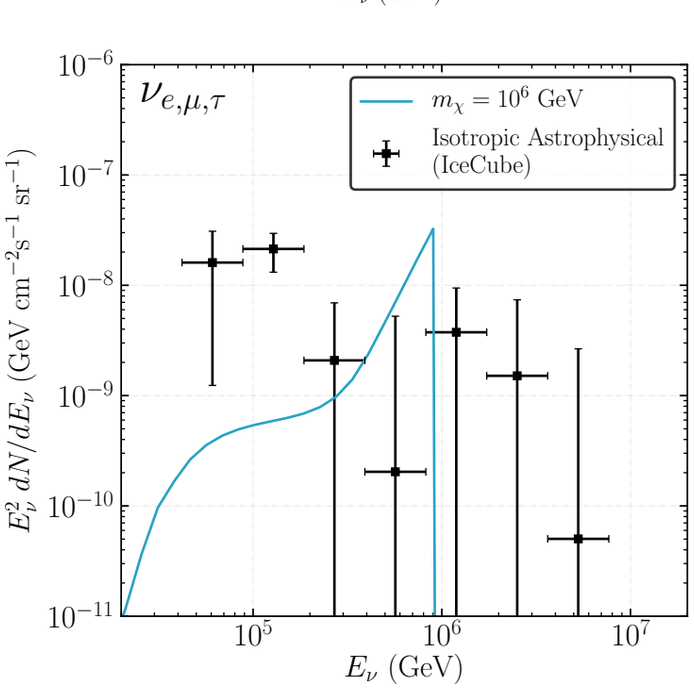
Halo boost

$$\frac{d\Phi_\nu}{dE} = \frac{c}{4\pi}\frac{\Omega_{DM}^2\rho_{crit}^2\langle\sigma v\rangle}{2m_x^2}\int_0^{z_{up}} dz\frac{\left(1+G(z)\right)(1+z)^3}{H(z)}\frac{dN_\nu(E')}{dE}$$

Neutrinos Signal from DM Annihilation





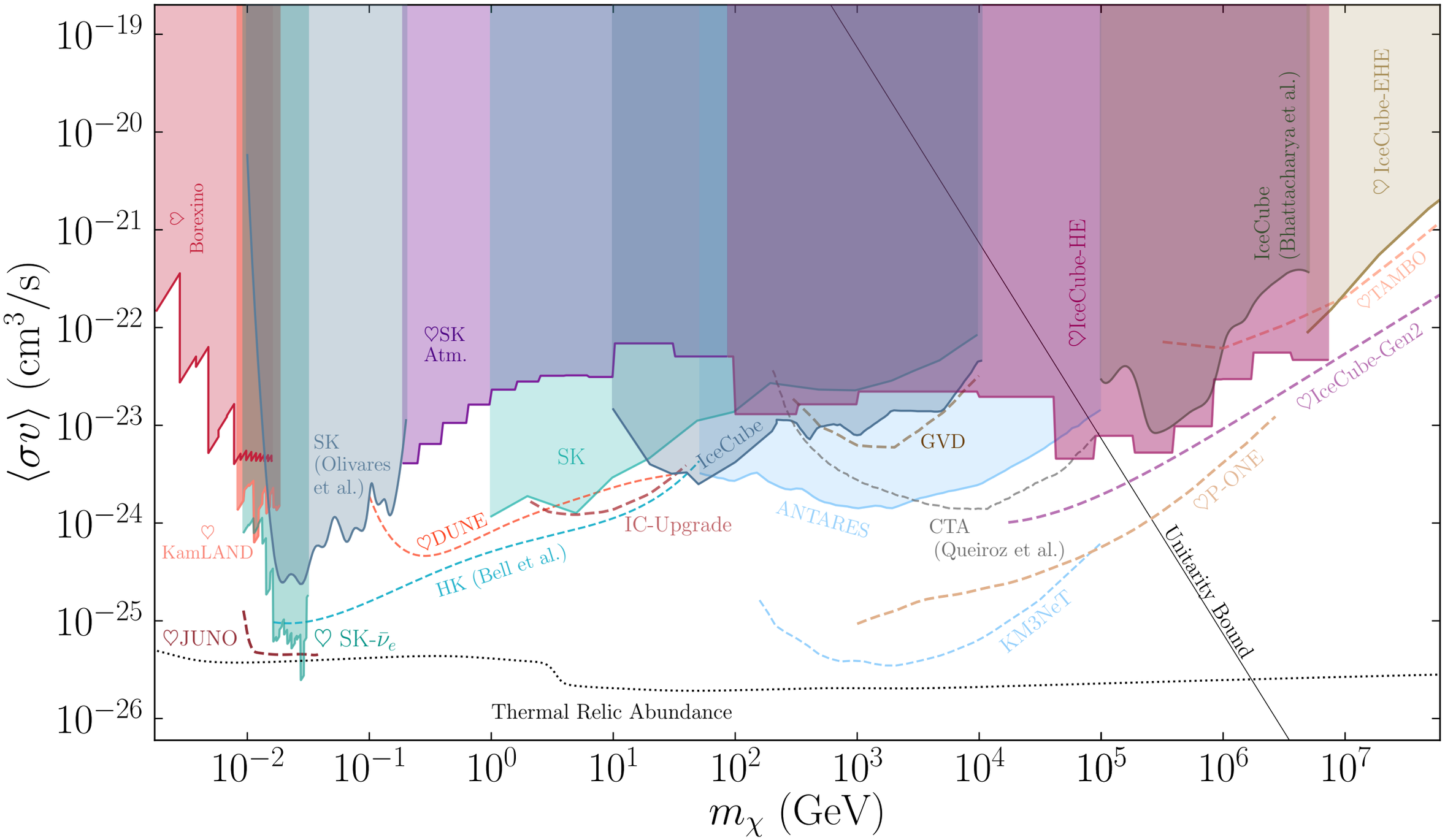


Direct DM annihilation to neutrinos would create spikes in atmospheric and cosmic neutrino flux

Experiments

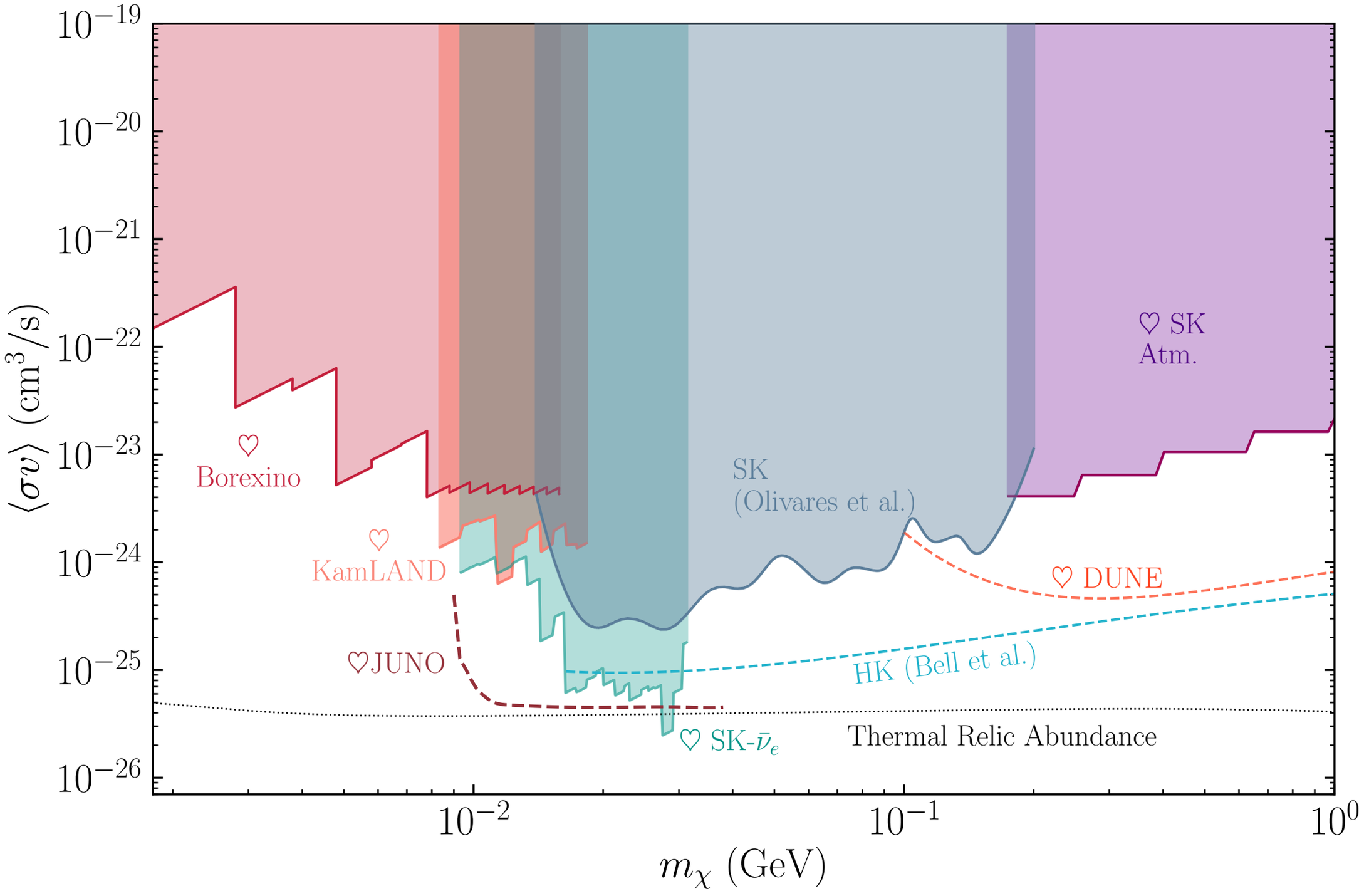
Energy Range	Experiment	Directionality	Detected Flavor
$2.5 - 15$ MeV	Borexino	×	$\bar{\nu}_e$ (IBD)
$8.3 - 18.3$ MeV	KamLAND	✓	$\bar{\nu}_e$ (IBD)
$10 - 100$ MeV	JUNO	✓	$\bar{\nu}_e$ (IBD)
$15 - 10^3$ MeV	SK	×	$\bar{\nu}_e$ (IBD)
$0.1 - 10^4$ GeV	DUNE HK	×	All Flavors
$1 - 10^4$ GeV	SK	✓	ν_μ, $\bar{\nu}_\mu$ (CC)
$20 - 10^4$ GeV	IceCube	✓	All Flavors (NC)
$50 - 10^5$ GeV	ANTARES	✓	ν_μ, $\bar{\nu}_\mu$ (CC)
$0.2 - 100$ TeV	CTA	✓	All Flavors
> 100 PeV	RNO	✓	All Flavors
$10 - 10^4$ GeV	IC-Upgrade	✓	All Flavors
> 10 PeV	IC Gen-2	✓	All Flavors
$10 - 10^4$ TeV	KM3Net	✓	All Flavors
$1 - 100$ PeV	TAMBO	✓	ν_τ, $\bar{\nu}_\tau$ (CC)
> 100 PeV	GRAND	✓	ν_τ, $\bar{\nu}_\tau$ (CC)

Constraining the DM parameter space



Constraining the DM parameter space

- Low Mass



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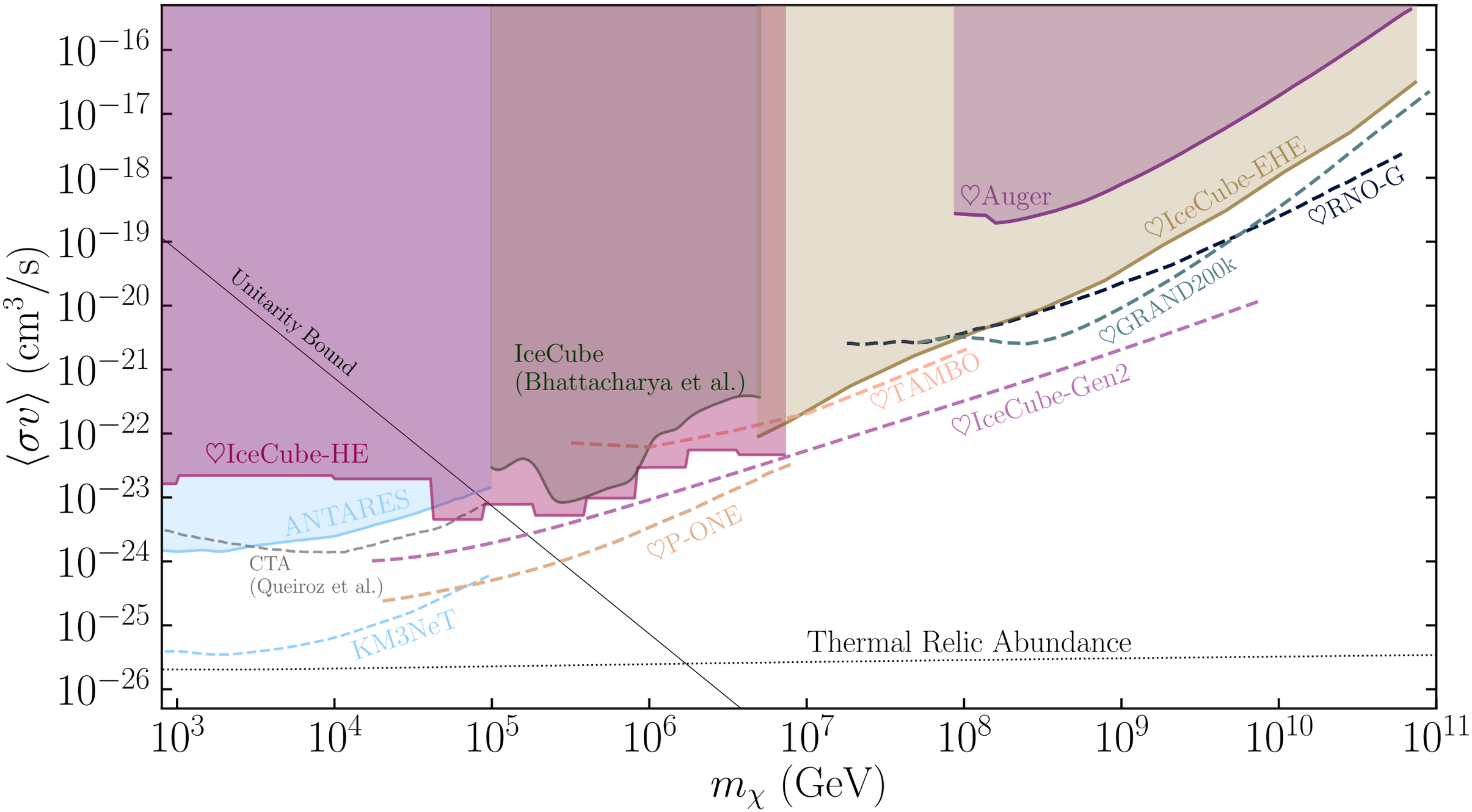
- High Mass (only accessible to neutrinos)



Summary

Neutrinos could present the key portal from Standard Model to the dark sector.

The limits in the neutrino sector are complementary to the ones from photons and charged lepton searches.

Neutrinos offer a unique opportunity to probe for new physics, especially at high energies.

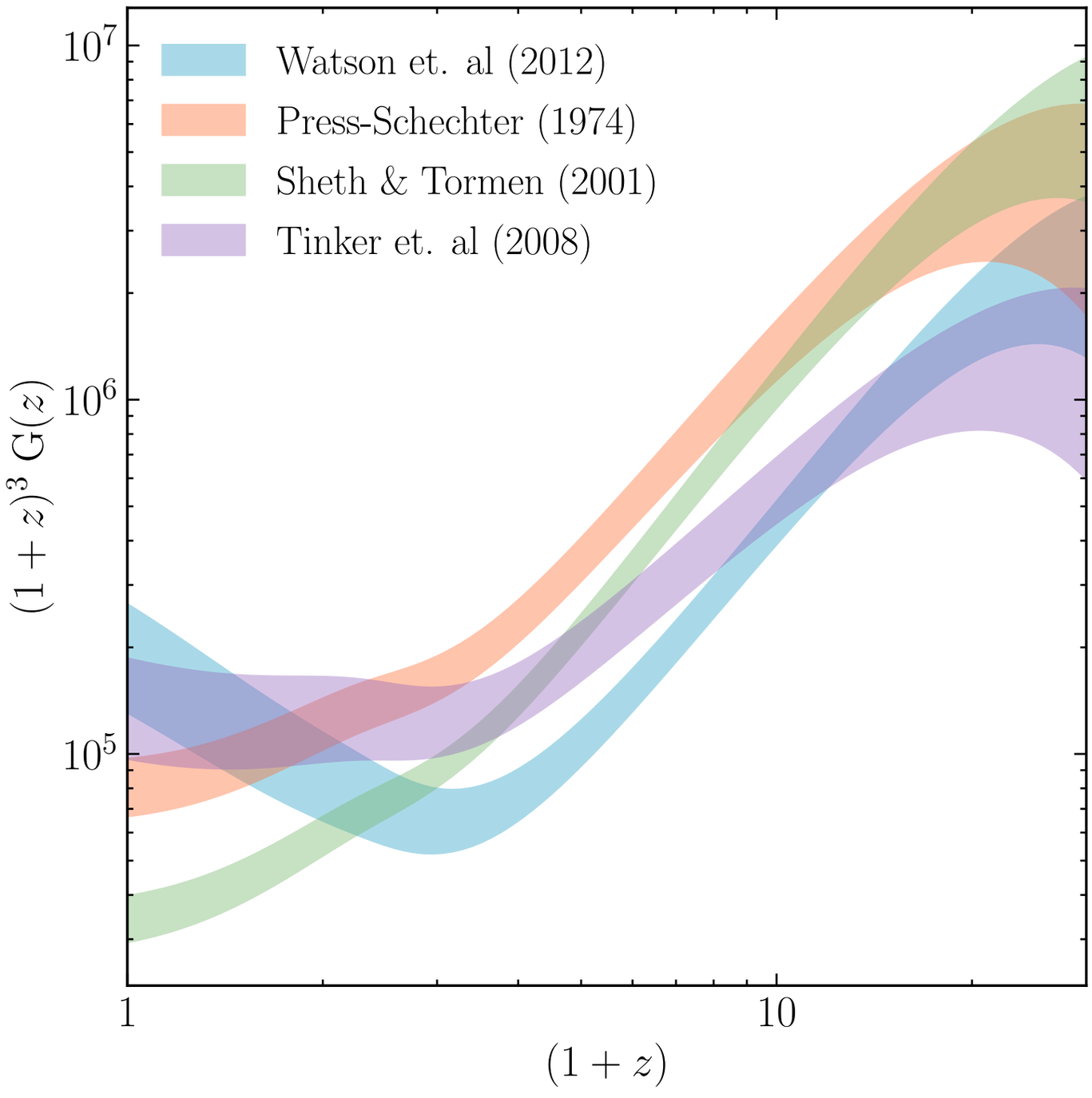
Thanks to the experimental advances in neutrino detections, we are able to obtain a comprehensive set of limits on dark matter annihilation directly to neutrino-antineutrino pairs, for a DM mass range spanning 15 orders of magnitude.

Future neutrino experiments will be closing in on the parameter space of direct dark matter annihilation to neutrinos.

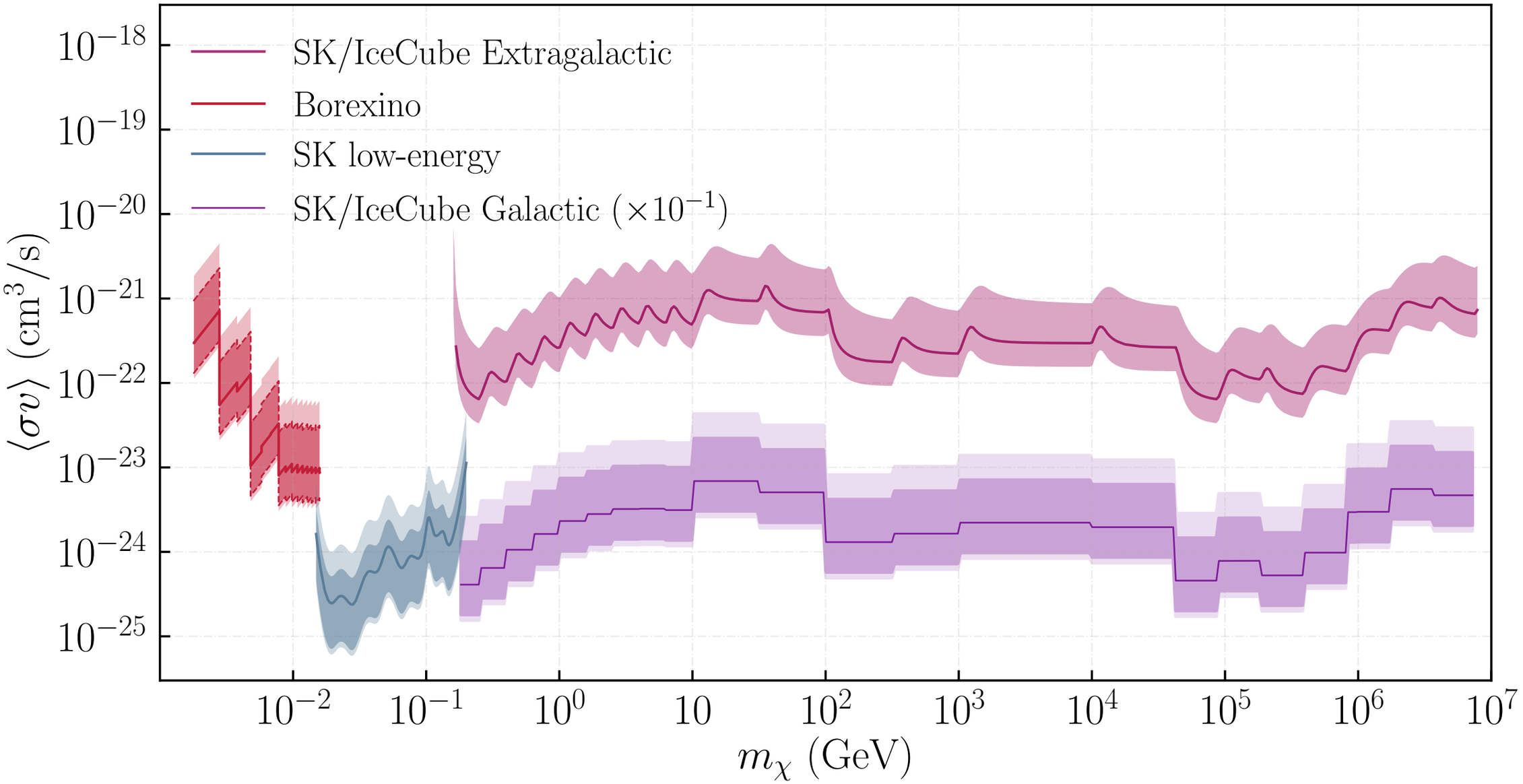
Thanks!

Back up Slides

Halo Parameters



Uncertainties



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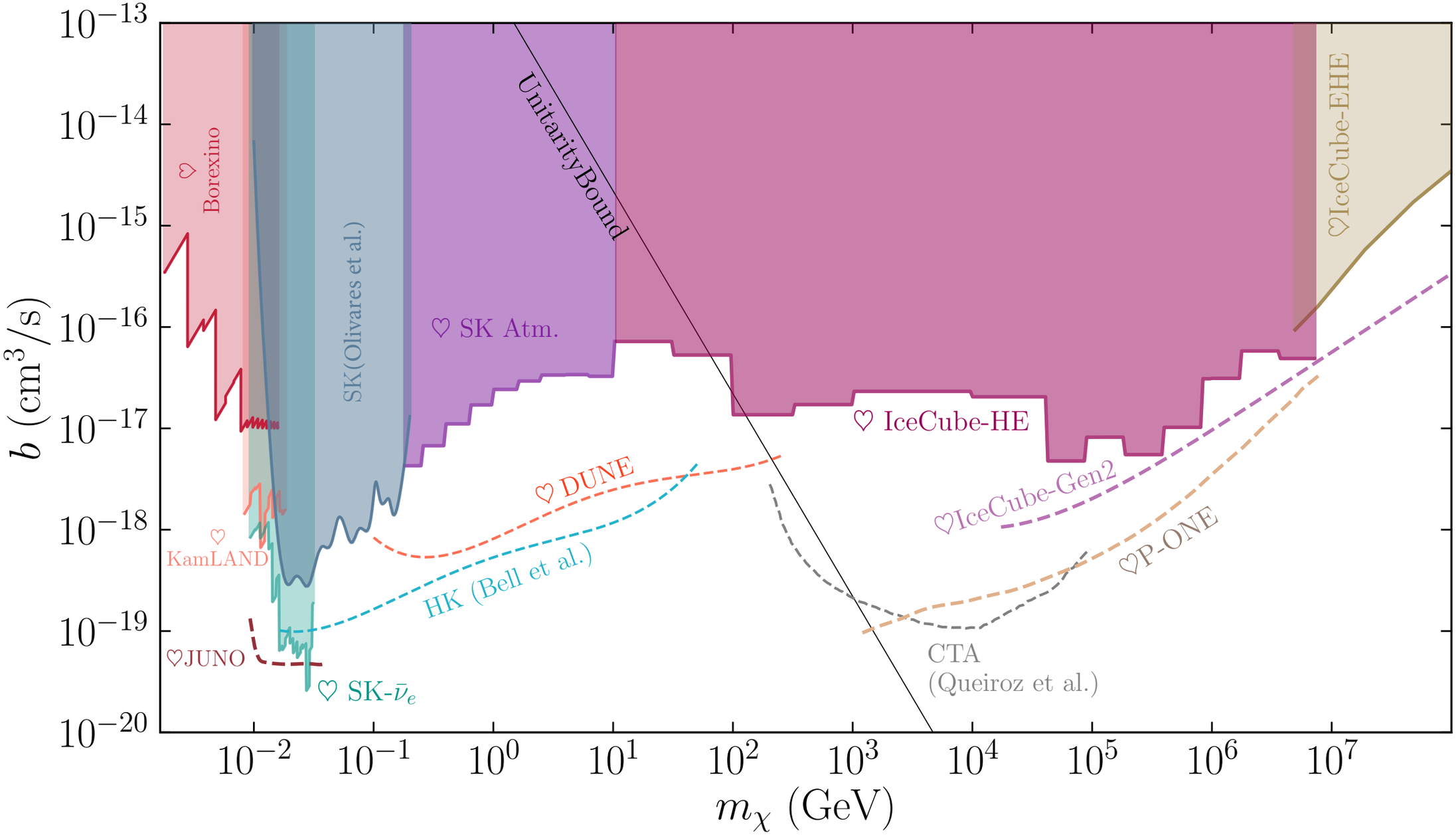
- **p-wave** $< \sigma v >= b(v/c)^2$



Constraining the DM parameter space

- **d-wave** $< \sigma v >= d(v/c)^4$