

Primordial High Energy Neutrinos

Theoretical & observational constraints and sharp
spectral features

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Motivations.

Early universe SM probes:

- CMB: $z \sim 1100$, observed and well studied
- 21-cm: $z \sim 20$, soon to be observed
- CvB: $z \sim 10^{10}$, challenging detection prospects



→ **Primordial High Energy Neutrinos (PHENU) ?**

Motivations.

PHENUs:

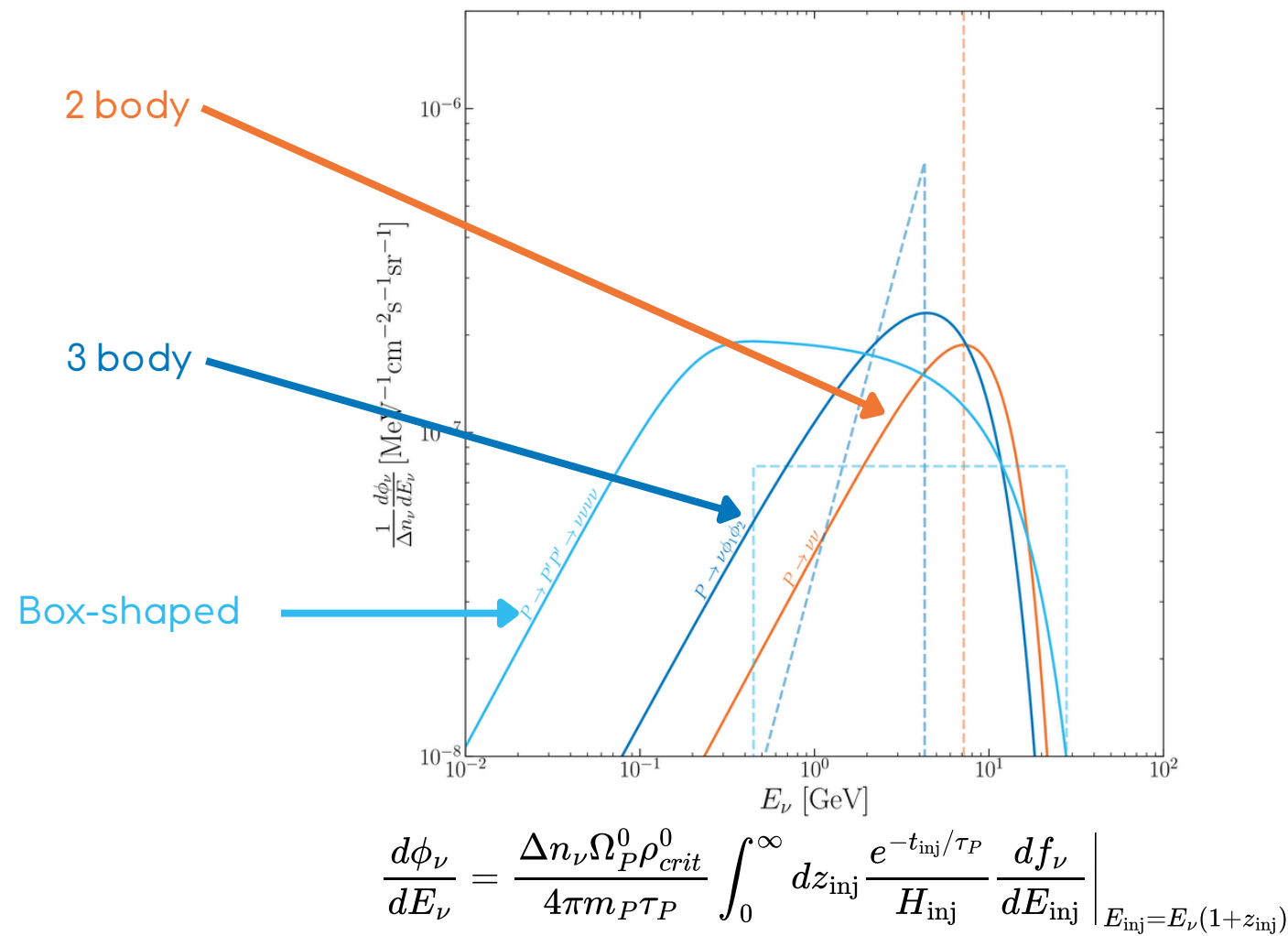
- Simple BSM scenario
- Emitted anywhere after neutrino decoupling ($z \sim 10^{10}$)
- A sharp signal could remain unaffected and observable today



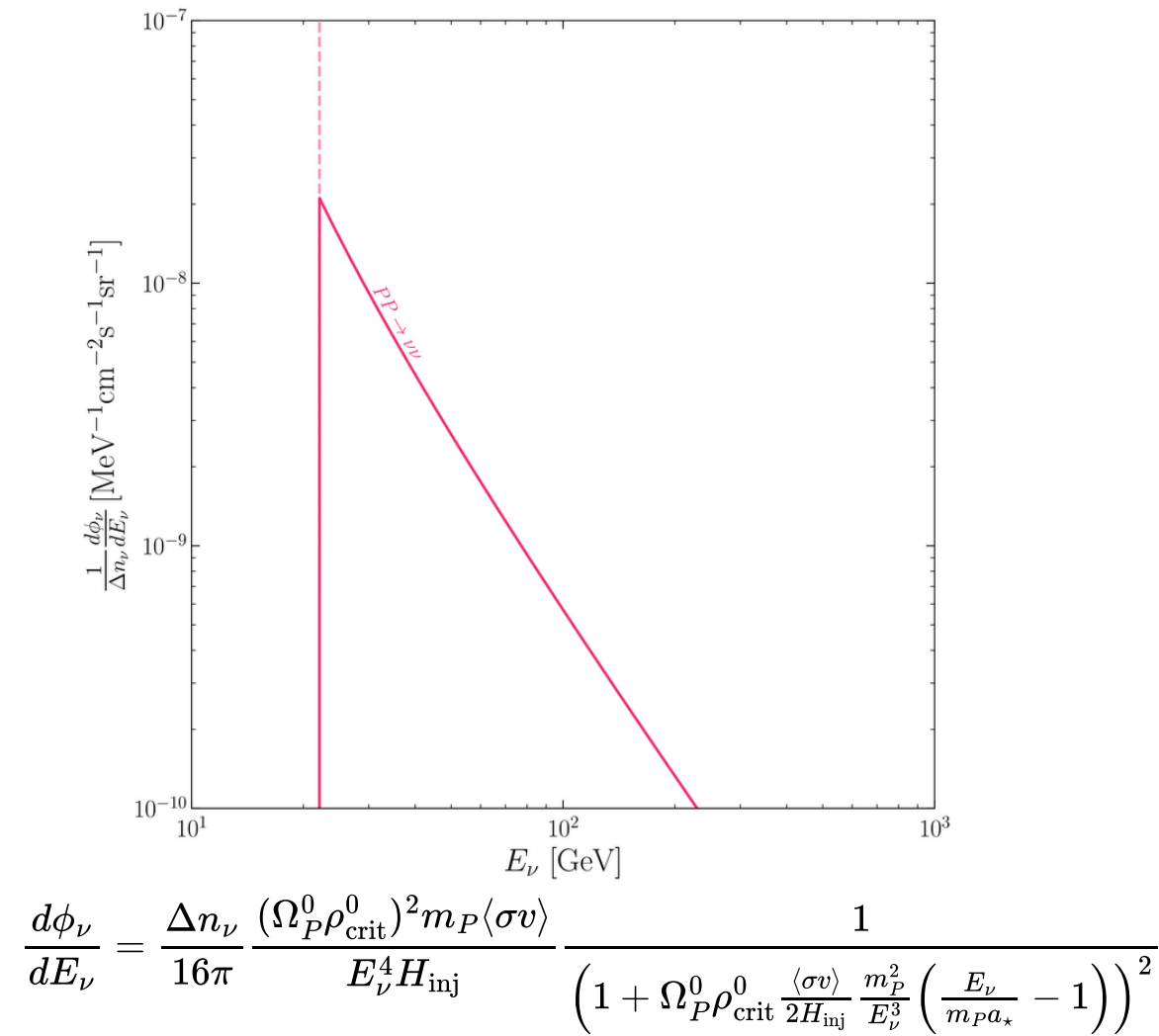
→ **Primordial High Energy Neutrinos (PHENU) !**

Sharp Spectral Features.

Decays



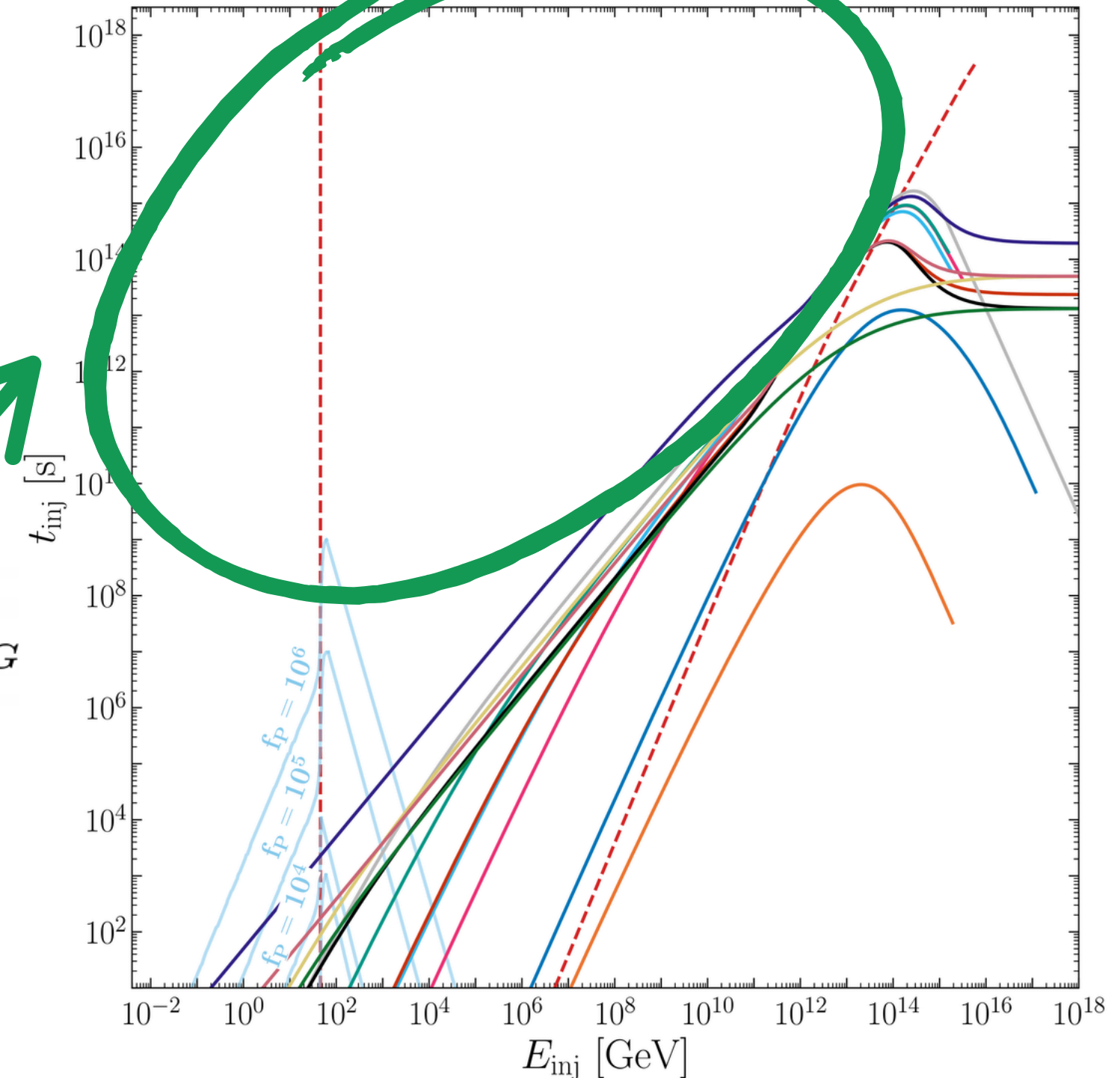
Out of equilibrium annihilation



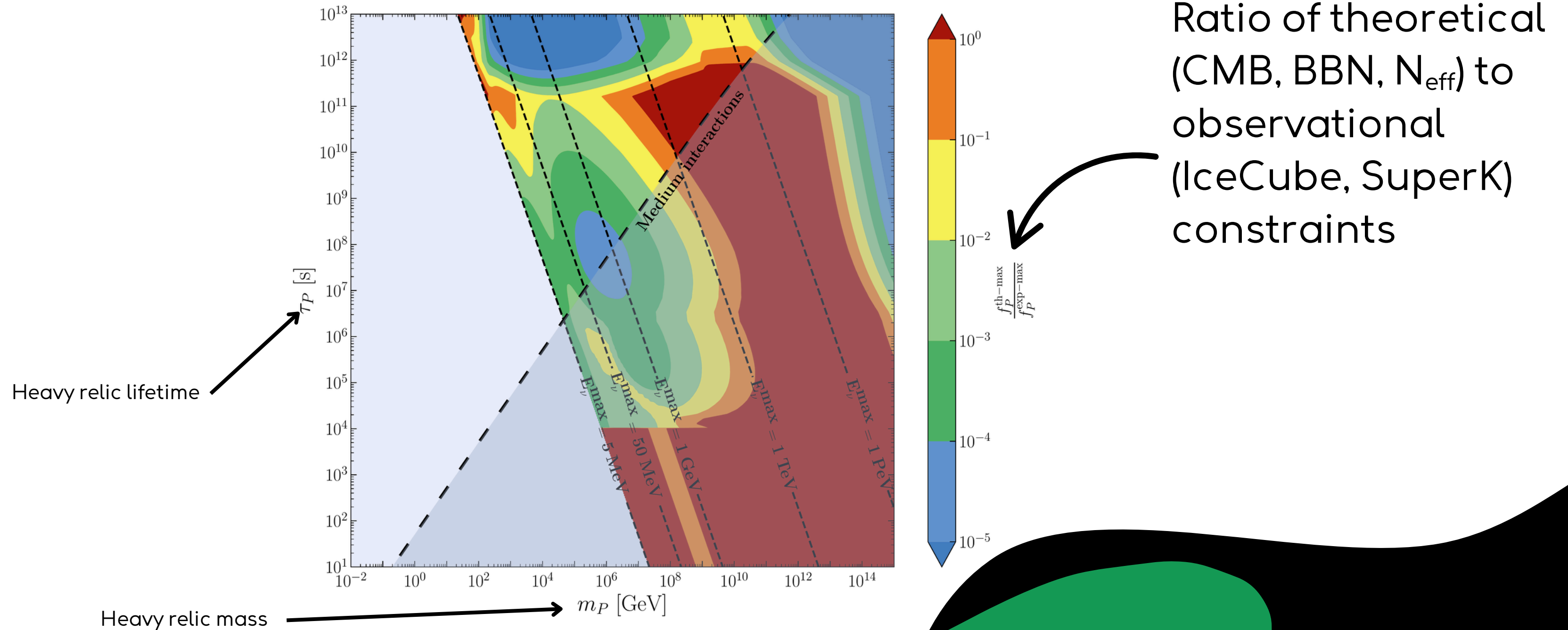
Medium interactions.

Sharp spectral features
mostly unaffected

$$S_\nu(z_e, E_0) = \int_0^{z_e} \frac{dz}{(1+z)H(z)} \langle \sigma v \rangle n_{\nu_{BG}}$$



Results.



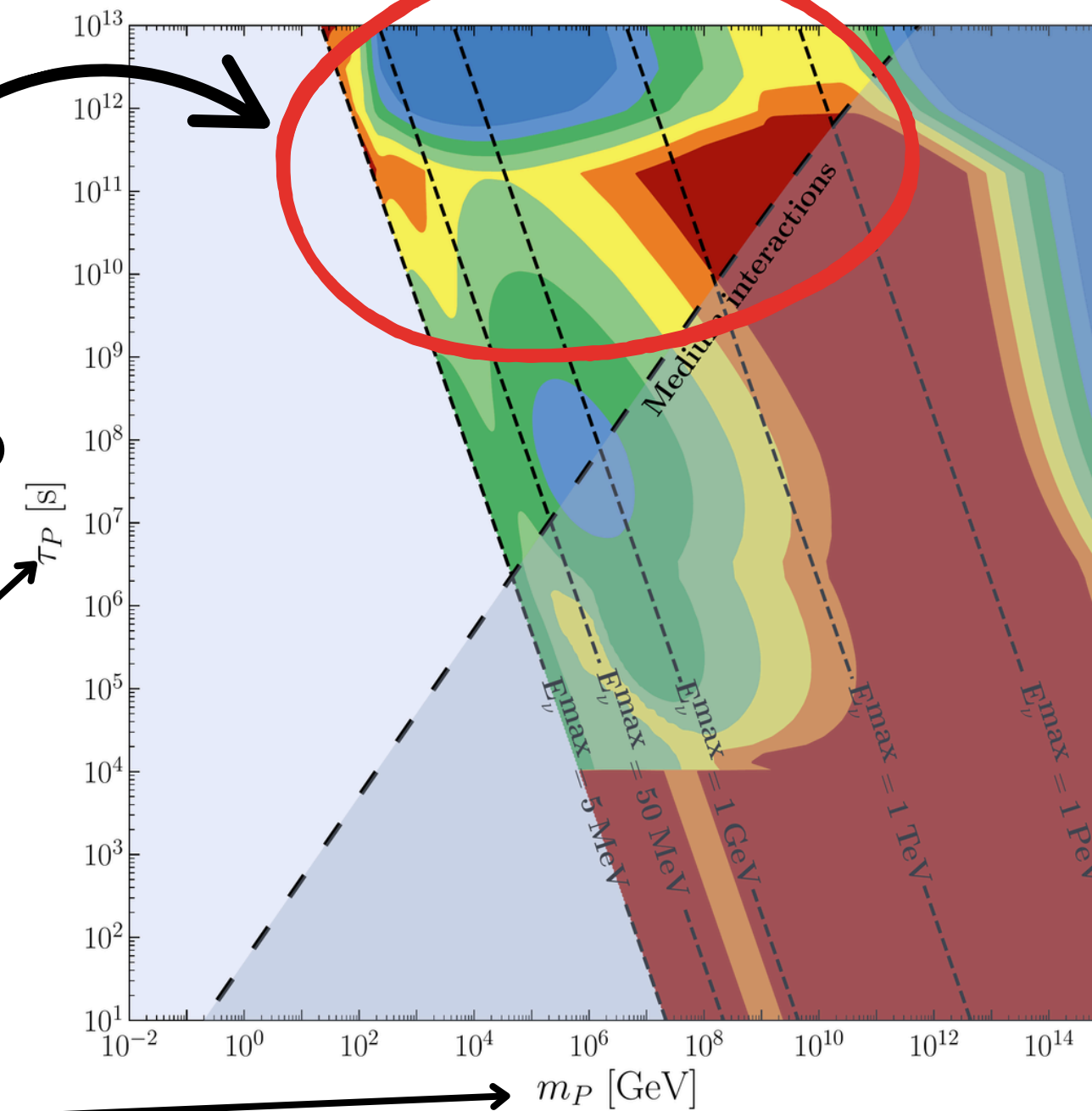
Results.

Potentially observable in existing and future neutrino telescopes

Heavy relic lifetime
 $10^9 \text{ s} \lesssim \tau_P \lesssim 10^{12.5} \text{ s}$

Heavy relic abundance
 $10^{-8} \lesssim f_P \lesssim 10^{-2}$

Heavy relic mass
 $10 \text{ TeV} \lesssim m_P \lesssim 10^{11} \text{ GeV}$



Ratio of theoretical (CMB, BBN, N_{eff}) to observational (IceCube, SuperK) constraints

$$\frac{f_P^{\text{th-max}}}{f_P^{\text{exp-max}}}$$

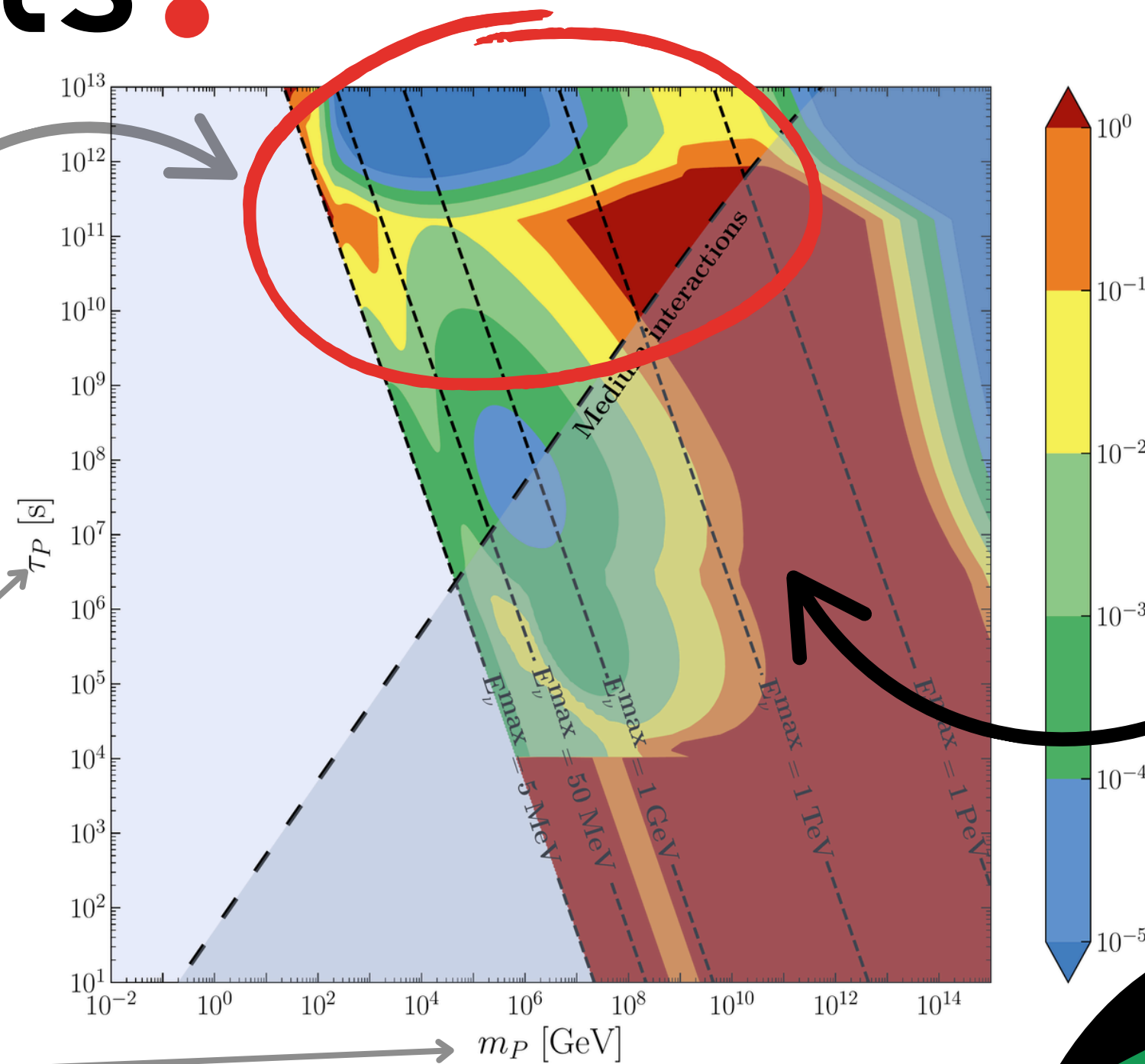
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Ongoing work: distortion of the spectrum using Monte Carlo techniques

Primordial high energy neutrinos (PHENU)

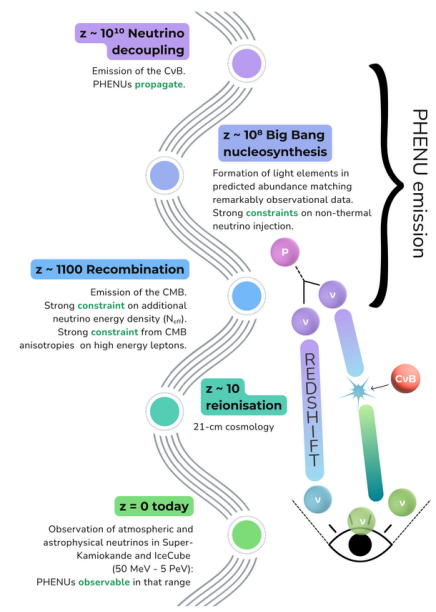


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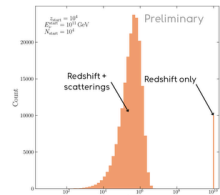
What if high energy neutrinos of primordial origin, with sharp spectral features, could propagate unaffected until today?

Early universe probe

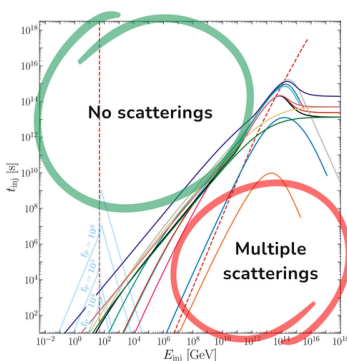


- Very few early universe probes
- PHENU are simple BSM scenarios
- Produced with sharp spectral features from decay/annihilation of a heavy relic P, and propagating to us

- Sharp spectral features are affected by scatterings with the CvB
- We compute the average scattering number along the line-of-sight
- Self-scatterings are negligible



Medium interaction

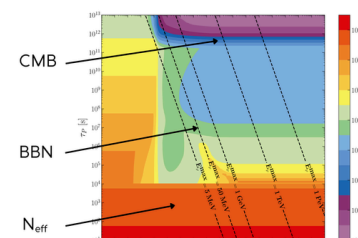


$$S_\nu(E_\nu, z_{inj}) = \int_0^{z_{inj}} \frac{dz}{(1+z)H(z)} \Gamma_\nu(E_\nu, z) = 1$$

Multi-scatter regime needs Monte-Carlo integration.
→ next step: computing distortion of the PHENU spectrum

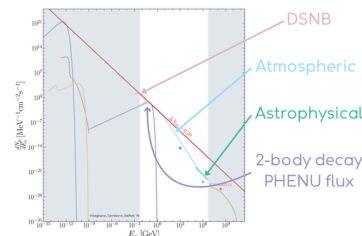
Stay tuned

Constraints



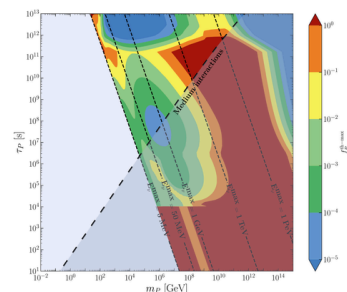
Indirect constraints from CMB (Acharya, Khatri, '19), BBN (Bianco et al. '25), and Neff set an upper bound on the abundance f_p of the heavy relic.

Super-K and IceCube neutrino data bound the relic abundance, requiring PHENU fluxes observed flux.



arXiv:2507.02063

Results



Indirect/direct ratio defines the (-yellow-red) region where PHENUs can be observed today, unaffected by scatterings (unshaded area).

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Thank you for your attention

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