# Resonant neutrino self-interactions in cosmology

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## Abstract

Neutrino-neutrino dispersion models have gained popularity as potential solutions for reconciling the discrepancy between local measurements of the Hubble constant ($H_0$) and the model-dependent measurements derived from the cosmic microwave background radiation and other early Universe probes. This work addresses the current state of neutrino self-interactions, with a specific focus on the phenomenology associated with resonant interactions. We compare our results to existing limits on mediator mass, encompassing both extremely light and heavy scalar particles.

## Introduction

Decades of observations have led to a precise estimate of the Universe's expansion rate, but there is a discrepancy between different measurements. This tension is significant and, if it persists, new physics will be needed to explain it. While some models have tried to address this tension at late times, it seems more natural to introduce new physics at early epochs.

One possible model involves nonstandard self-interactions of neutrinos. Neutrinos are advantageous because they have a small number of unknown parameters that are being explored in various environments. The dynamics of these interactions depend heavily on the nature of the mediator particle, particularly its mass.

Previous studies have focused on very light or heavy mediator particles, but the intermediate-mass range has not been thoroughly investigated. Here, we focus on this mass range with resonances, where neutrino scattering peaks at the epoch when acoustic oscillations were shaped. Due to resonance, the interaction rate is enhanced, and similar effects to those observed in other cases could be achieved with a much smaller coupling.

## Comparison with others

- The light mediator case where $m_\varphi \lesssim 10^{-3}$ eV gives a bound of $g_\nu \lesssim 10^{-7}$. Which is one the strongest for light mediators.
- For the heavy mediator, $m_\varphi \gtrsim 10^3$ eV, There is an anomaly of the effective coupling $g_\nu^2/m_\varphi^2$. A bimodality of the posterior is observed where the non-null coupling values can be as high as $\sim 10^{-2}/\text{MeV}^2$.
- While for the resonant case, no anomaly is observed, implying upper bounds as strong as $g_\nu \lesssim 10^{-14}$ (depending on the mediator mass see Figs. on the right).

## Perspectives

- All neutrino self-interaction cases require extra radiation. We need a complete model to add it consistently.
- Currently, we have preliminary results of the bounds now using Full-Shape Galaxy Spectrum data.

## The interaction rate

We model the interaction with a Breit-Wigner like cross section

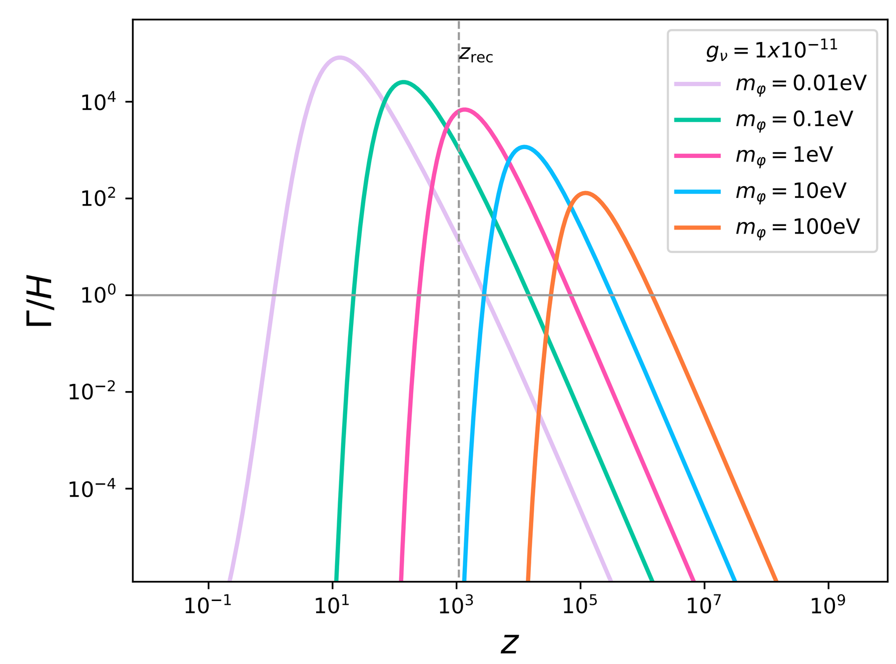
$$\sigma(s) = \frac{g_\nu^4}{4\pi} \frac{s}{[s - m_\varphi^2]^2 + \Gamma_\varphi^2 m_\varphi^2}.$$

Despite it behaving as a Dirac delta function (when the width $\Gamma_\varphi = g_\nu^2 m_\varphi / 4\pi$ is small). In cosmology, the peak of the resonance is smoothed due to the fact that we need to consider all the available energies for the interaction rate

$$\langle \sigma v \rangle = \frac{1}{n_\nu^2} \int \frac{d^3 p_1}{(2\pi)^3} \frac{d^3 p_2}{(2\pi)^3} f(p_1) f(p_2) \sigma(s) v.$$

Then the interaction rate is a numerical function

$$\Gamma = \langle \sigma v \rangle \, n_\nu = \frac{g_\nu^2 \pi^5 m_\varphi^2}{24 \zeta(3) T_\nu} F(m_\varphi^2; T_\nu).$$




The ratio between the interaction rate and the Hubble function dependent on the redshift

## Cosmology perturbations

The evolution of neutrinos in the perturbed Universe is dictated by

$$\dot{\Psi}_0 = -\frac{qk}{\epsilon}\Psi_1 - \dot{\psi}\frac{d\ln f_0}{d\ln q},$$

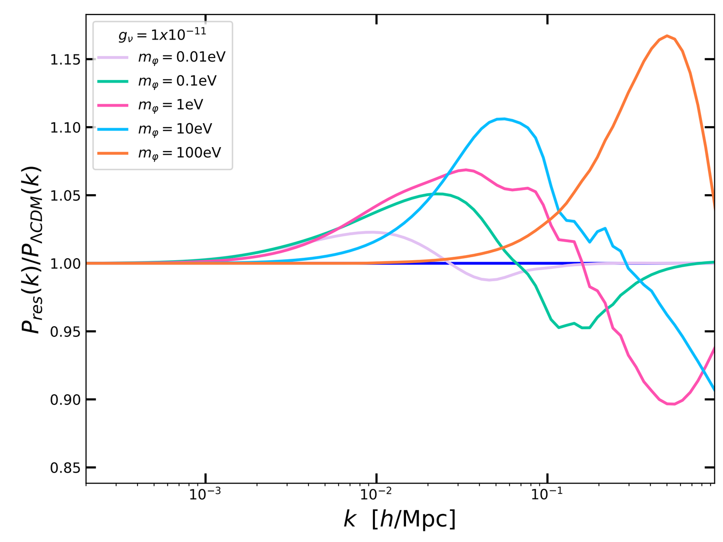
$$\dot{\Psi}_1 = \frac{qk}{3\epsilon}(\Psi_0 - 2\Psi_2) - \frac{\epsilon k}{3q}\psi\frac{d\ln f_0}{d\ln q},$$

$$\dot{\Psi}_2 = \frac{qk}{5\epsilon}(2\Psi_1 - 3\Psi_3) - a\Gamma\Psi_2,$$

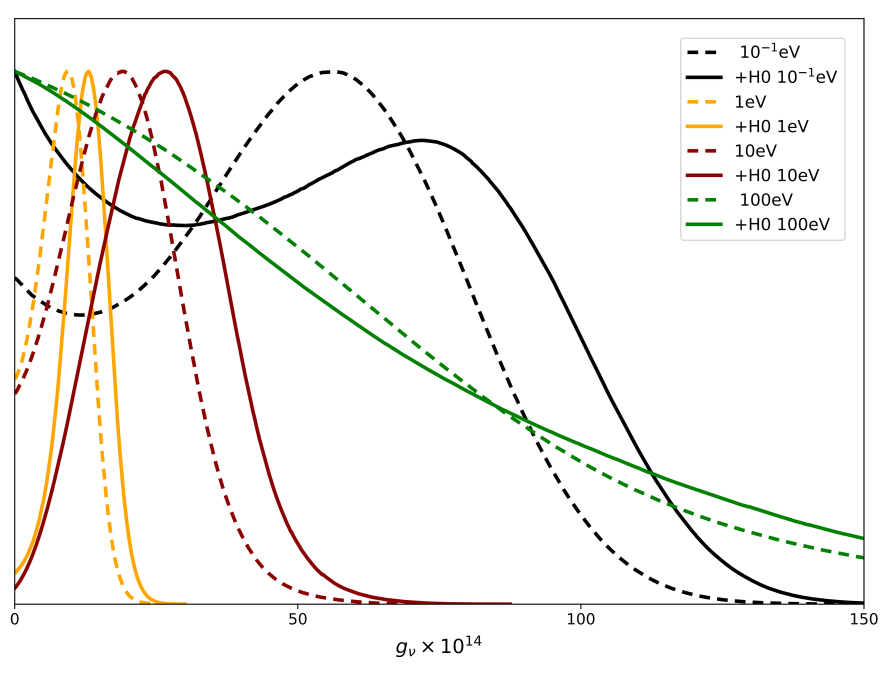
$$\dot{\Psi}_{l\geq 3} = \frac{qk}{(2l+1)\epsilon}\left(l\Psi_{l-1} - (l+1)\Psi_{l+1}\right) - a\Gamma\Psi_l,$$

where $f(x,q,t) = f_0(q(t))(1 + \Psi(x,q,t))$, is the distribution function of neutrinos. As we can see in the system of equations the interaction rate only affects $l \geq 2$. However, all equations are coupled.

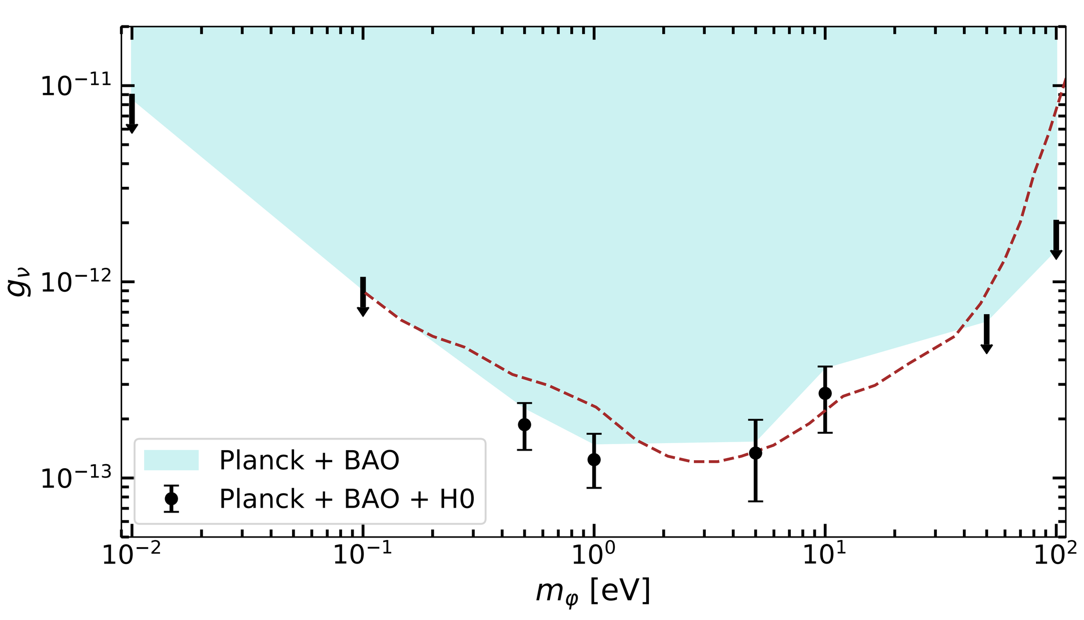
The self-interactions propagate to other species via the gravitational potentials. And eventually, affect both the TPS and MPS. We observe some uniqueness in the self-interaction effect which is highly dependent on the scale (mediator mass), and for some scales, there is an enhancement of the linear spectra:




## Results




Posterior of $g_\nu$: Using Planck+BAO and $+H_0$




Excluded region of the interaction coupling at 95 % C.L.

## References

- Venzor, Garcia-Arroyo, De-Santiago, Pérez-Lorenzana. Phys. Rev. D 108, 043536 (2023).
- Venzor, Garcia-Arroyo, Pérez-Lorenzana, De-Santiago. Phys. Rev. D 105, 123539 (2022).