

Solar Constraints on Heavy Neutral Leptons with Tau Neutrino Mixing

Vedran Brdar

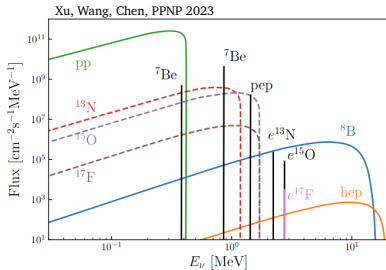
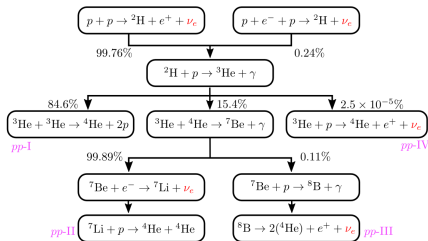
Oklahoma State University



TACOS 2026,
College Station, October 2026

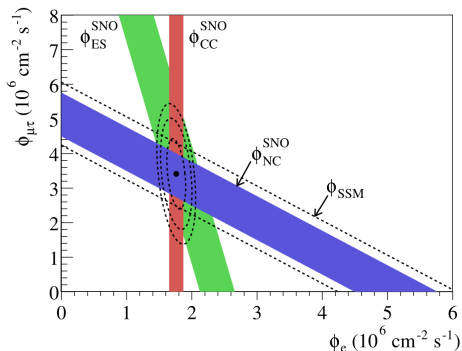
Solar Neutrinos

- Sun produces electron neutrinos: $4p \rightarrow 2e^- + {}^4\text{He} + 2\nu_e$

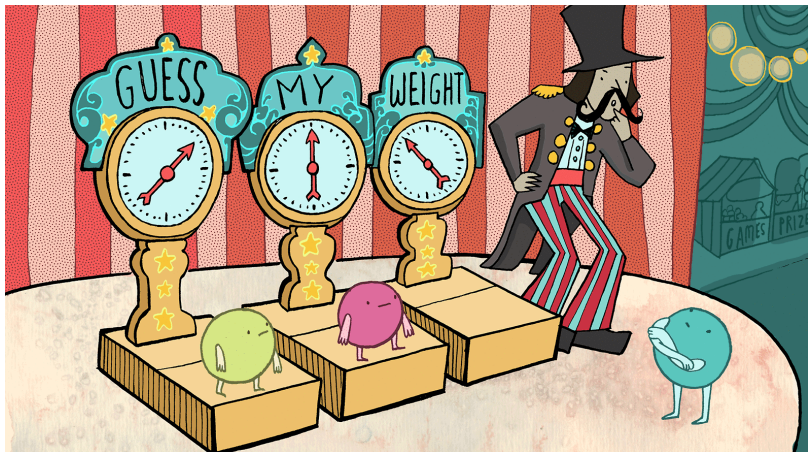


The Solar Neutrino Problem and Its Solution

- First detection of solar neutrinos at the Homestake experiment in 1967
- Observed number of solar ν_e events was ~ 3 times smaller than expected
- Electron neutrinos produced in the Sun oscillate into muon and tau neutrinos as they travel to Earth (SNO experiment)



Neutrinos Have Mass



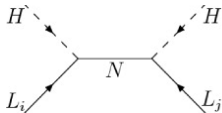
$$P_{\alpha\beta} = \sin^2 2\theta \sin^2\left(\frac{\Delta m^2 L}{4E}\right)$$

Heavy Neutral Leptons (HNLs)

Type-I Seesaw



Minkowski, Mohapatra, Senjanović,
Gell-Mann, Ramond, Slansky, Yanagida



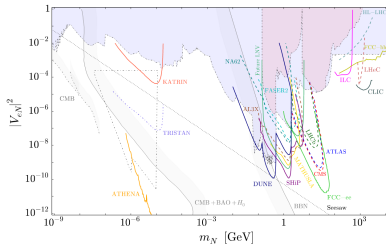
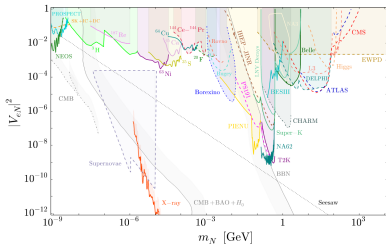
$$\mathcal{M} = \begin{pmatrix} 0 & M_D \\ M_D & M_R \end{pmatrix}$$

$$m_\nu = -M_D \mathbf{M}_R^{-1} M_D^T$$

$$\theta = M_D / M_R$$

$$\mathcal{L} \supset \frac{1}{2} \bar{N}^c M_R N + \bar{L} Y_\nu \tilde{H} N + \text{h.c.}$$

Bolton et al., JHEP 2020



HNLs Mixed with Solar Electron Neutrinos

Letter | Published: 26 February 1981

Constraints on heavy neutrinos

Doug Toussaint & Frank Wilczek

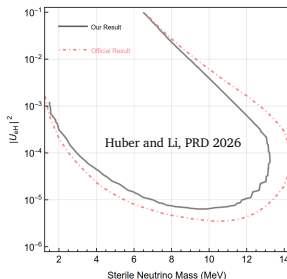
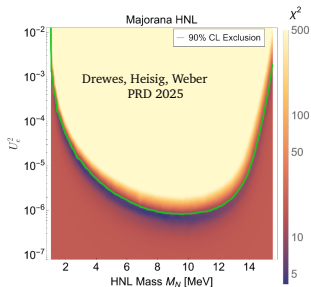
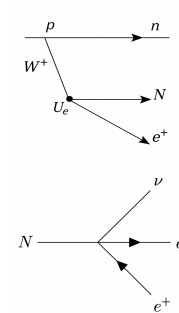
Nature **289**, 777–778 (1981) | [Cite this article](#)

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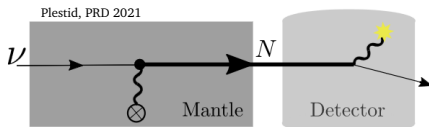
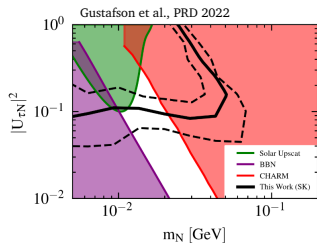
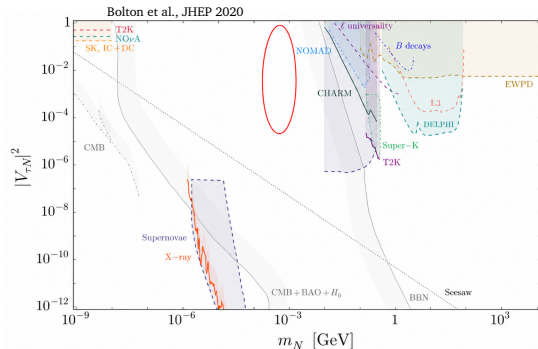
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Abstract

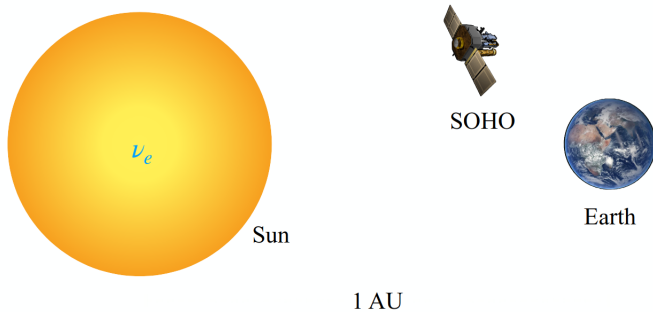
If a heavy neutrino of mass $1.1 \text{ MeV} < m < 14 \text{ MeV}$ participates in the weak charged current coupling for the electron, then it can be produced in the Sun and decay in flight into an electron, a positron and a light neutrino. It is shown here that existing experimental bounds on low-energy interplanetary positrons severely constrain the heavy neutrino–electron coupling. Accelerator experiments severely constrain the coupling of still heavier neutrinos.



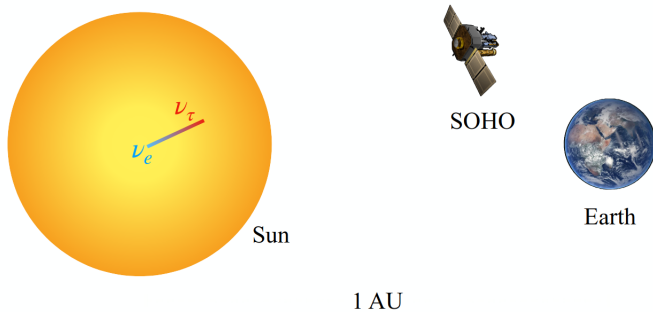
What About HNLs Mixed with Tau Neutrinos?



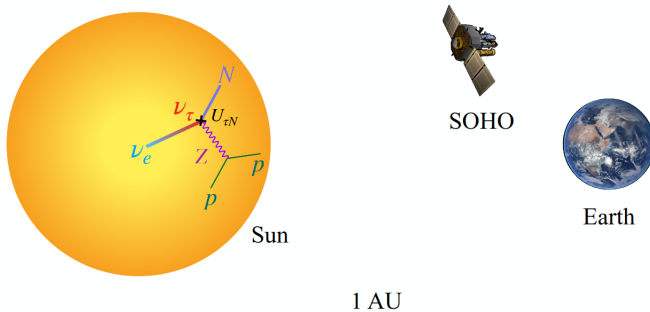
Probing HNLs with Tau-Neutrino Mixing Using Solar Neutrinos



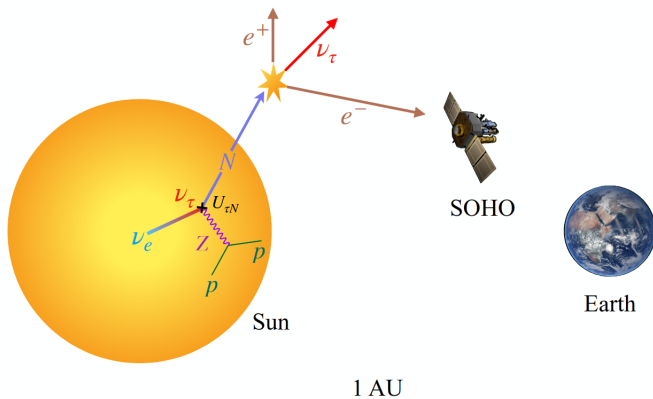
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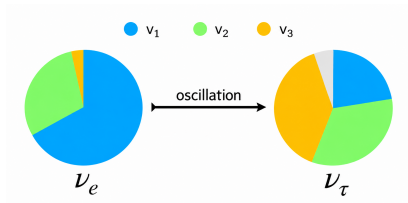
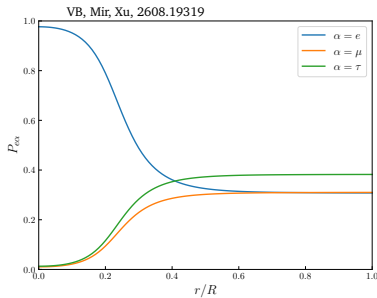
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Probing HNLs with Tau-Neutrino Mixing Using Solar Neutrinos



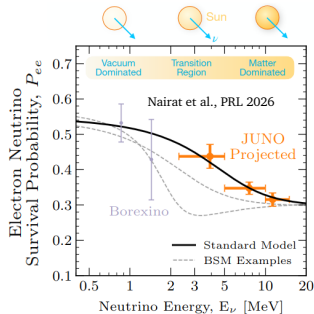
$\nu_e \rightarrow \nu_\tau$ Transition in the Sun



■ we consider ^8B and hep neutrinos

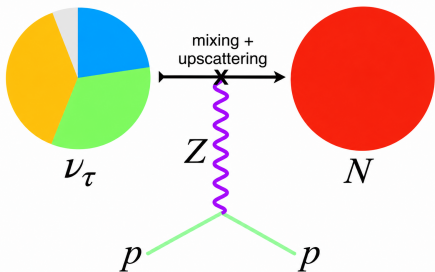
■ adiabatic approximation:

$$P_{e\tau}(r) = \sum_{i=1}^3 |U_{ei}^{(m)}(0)|^2 |U_{\tau i}^{(m)}(r)|^2$$

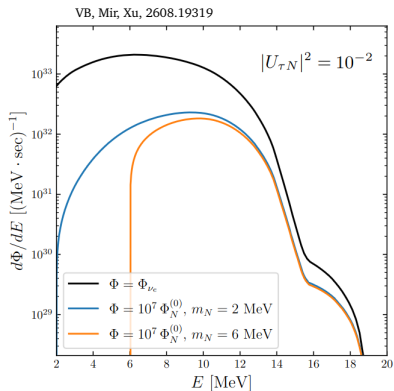


$$\nu_\tau \rightarrow \text{HNL}$$

■ $\nu_\tau p \rightarrow N p$



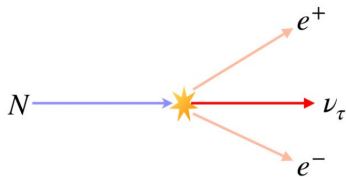
$$\frac{d\Phi_N^{(0)}}{dE_N} = \sum_X \int \frac{d\Phi_{\nu_e}}{dE_\nu} P_{e\tau} n_X \frac{d\sigma_X}{dE_N} dE_\nu dr$$



HNL Decay

$$\frac{d\Phi_N}{dE_N} = \frac{d\Phi_N^{(0)}}{dE_N} e^{-r/R_D}$$

$$R_D = \tau_N v_N (1 - v_N^2)^{-1/2}$$



- Given their relatively long lifetimes for $\mathcal{O}(10)$ MeV masses ($\tau_N \propto m_N^{-5}$) HNLs produced in the Sun typically decay in the heliosphere
- The propagation of $e^\pm$ produced from solar HNL decay is strongly influenced by the magnetic field in the heliosphere
- This is typically described using an effective framework based on transport equations that incorporate spatial diffusion

$e^\pm$ Flux

$$\frac{\partial \psi}{\partial t} = \nabla \cdot (\mathbf{D} \cdot \nabla \psi) + q$$

ψ = number density of e^- (e^+)
per unit energy

diffusion tensor

source term of e^- (e^+)
from HNLs

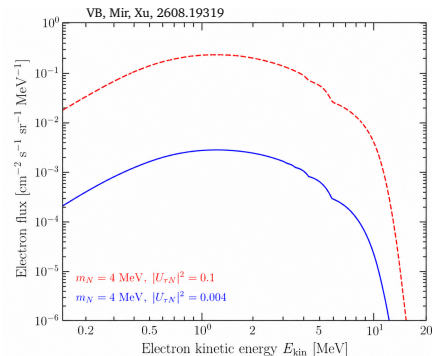
$$q(r, E_e) = \frac{2}{4\pi r^2} \int dE_N \frac{1}{v_N} \frac{d\Phi_N}{dE_N} \left(\frac{d\Gamma_{N \rightarrow e^+ e^- \nu_\tau}^{\text{flight}}}{dE_e} \right)$$

differential decay rate of
boosted HNL with energy E_N

$e^\pm$ Flux

- Over sufficiently long timescales $d\psi/dt = 0$
- Assuming isotropic diffusion, the diffusion term simplifies to $\nabla \cdot (\mathbf{D} \cdot \nabla \psi) = D \nabla^2 \psi$, where D is the scalar diffusion coefficient

$$\psi(E_e) = \frac{\xi(E_e)}{D r} \left[e^{-\frac{R_\odot}{R_D}} - e^{-\frac{r}{R_D}} + \frac{r}{R_D} \Gamma \left(0, \frac{r}{R_D} \right) \right] \quad q \approx \xi(E_e) e^{-r/R_D} / (R_D r^2)$$

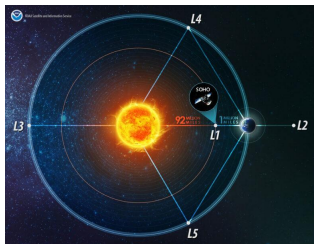


SOHO (Solar and Heliospheric Observatory)

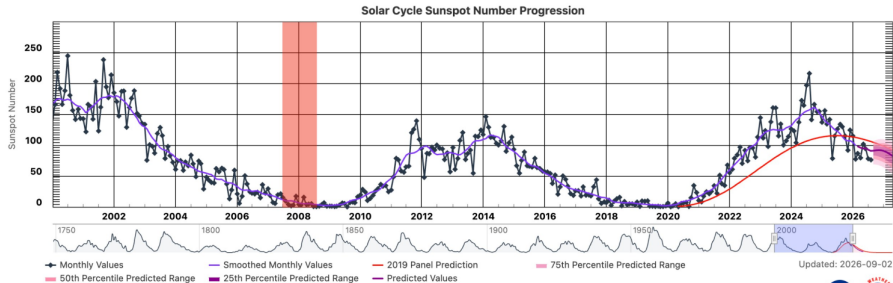


- The EPHIN detector onboard SOHO measures the $e^{\pm}$ spectrum

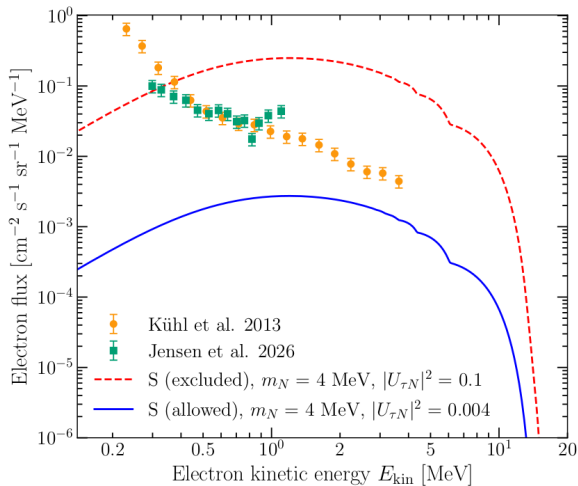
SOHO



- Solar activity declines over each solar cycle, reaching a period known as the **Quiet Sun**
- Reduced solar-wind background during this period facilitates searches for $e^\pm$ from **HNL decays**
- SOHO collected MeV e^- data over a 13-month period from June 2007 to July 2008
- This measurement is dominated by **Jovian e^-**

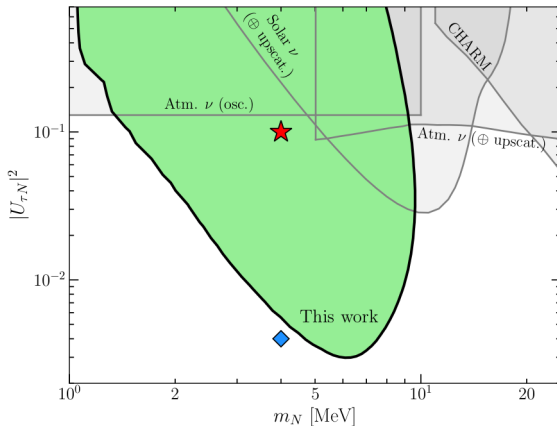


$e^\pm$ Flux and SOHO Data



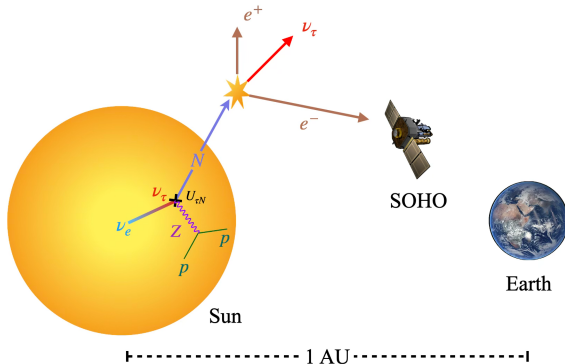
Constraints

- 90% CL constraints in the parameter space of the HNL mass and the HNL mixing with tau neutrino:



- The derived results improve upon all of the existing limits by more than an order of magnitude in $|U_{\tau N}|^2$ for $m_N \sim 5$ MeV

Summary



- This mechanism probes τ -flavored HNLs with masses up to $\mathcal{O}(10)$ MeV
- $e^\pm$ from HNL decays can be detected by space-based solar observatories and we employ data collected by SOHO
- We derive new constraints on the τ -flavored HNL parameter space, reaching below $|U_{\tau N}|^2 \sim 10^{-2}$ at $m_N \sim 5$ MeV and surpassing all previously derived terrestrial constraints in the 1–10 MeV range