Bounds on secret neutrino interactions from high-energy astrophysical neutrinos

Or

What do high-energy astrophysical neutrinos tell us about new neutrino-neutrino interactions?

Based on: arXiv:2001.04994

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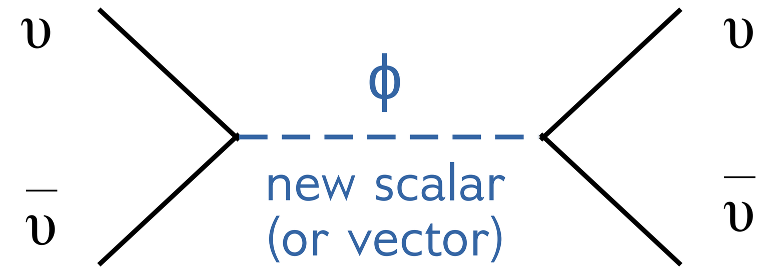
At a glance

- Via new, *secret* υυ interactions (υSI), TeV–PeV astrophysical υ could resonantly scatter off the relic υ background
- This would introduce characteristic features in the astrophysical υ spectrum
- We find no evidence of these features in 6 years of public IceCube data
- We set competitive upper limits on the υSI strength for mediators of 1–100 MeV

Secret neutrino interactions

- υSI occur via a new mediator that couples mainly to neutrinos
- Mediator mass M & coupling g not fixed
- υSI may solve open problems, *e.g.*, υ mass, cosmology tensions, *etc.*
- TeV–PeV astrophysical υ may scatter resonantly off meV relic neutrinos:



- The s-channel cross section dominates:

$$\sigma_{\nu\nu}(E) = \frac{g^4}{16\pi}\frac{s}{(s-M^2)^2 + M^2\Gamma^2}$$

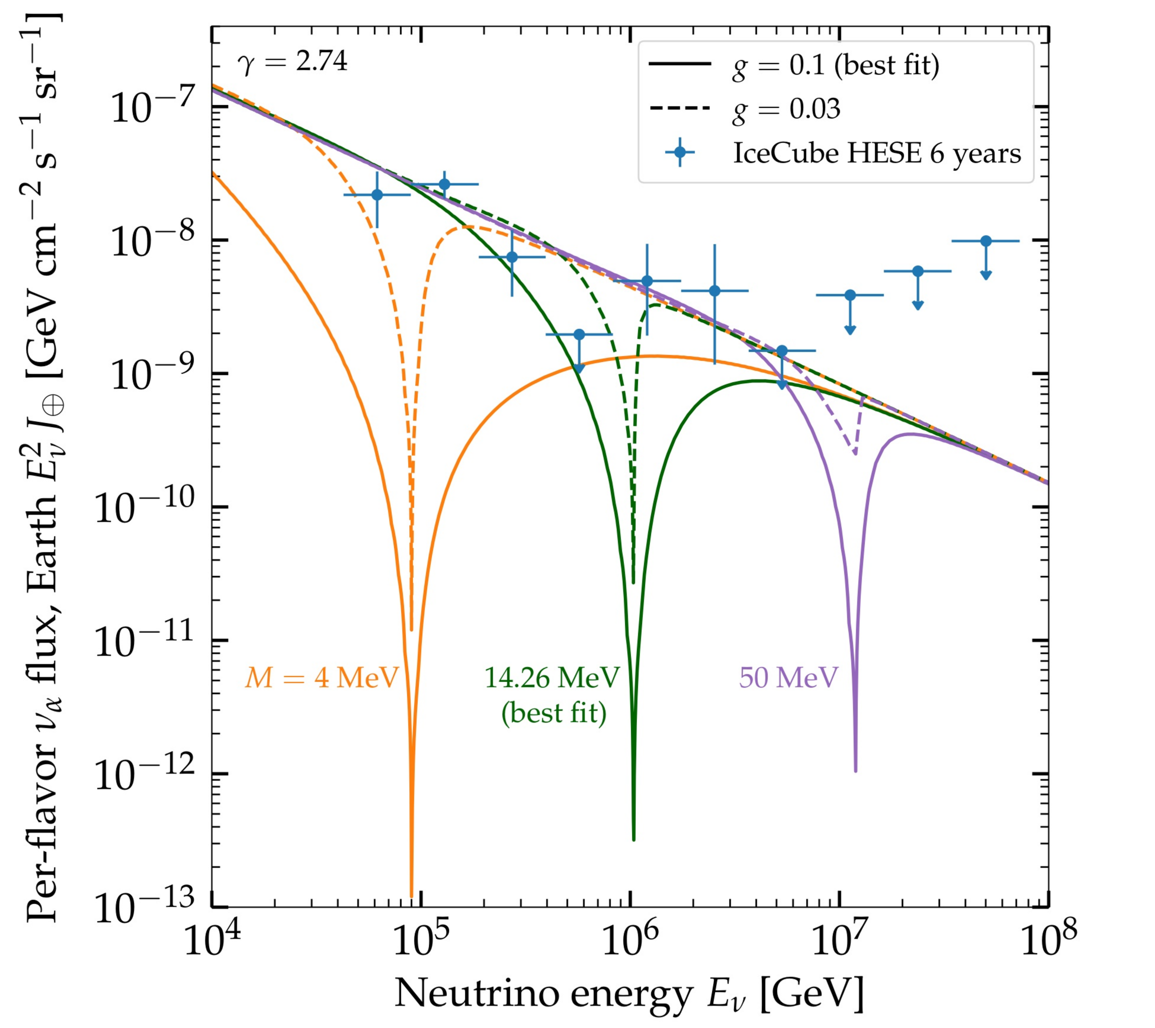
  - Center-of-mass energy: $s^{1/2} = (2Em_\upsilon)^{1/2}$
  - Decay width: $\Gamma = g^2 M / (4\pi)$
  - Resonance energy: $E_{res} = M^2/(2m_\upsilon)$

High-energy astrophysical ν

- We use 6 years of public IceCube High Energy Starting Events (HESE)
- 80 events with energies of 18 TeV–2 PeV:
  - 58 showers (mostly ν_e and ν_τ)
  - 22 tracks (mostly ν_μ)
- There is a gap in events from 300 TeV to 1 PeV that will drive our υSI results

νSI during propagation

- Astrophysical υ travel Mpc–Gpc to Earth
- Their undergoing υSI off relic υ induces:
  - Spectral dip around E_{res} (important)
  - Pile-up at lower energies (negligible)
- We are sensitive to E_{res}~TeV–PeV, *i.e.*, to mediator masses of M = 1–100 MeV
- The larger g is, the wider the dip



Statistical analysis

- Six free parameters:
  - M: Mediator mass
  - g: Coupling strength
  - γ: Spectral index, emitted astrophysical flux $E^{-\gamma}$
  - N_{ast}: Number of astrophysical neutrinos
  - N_{atm}: Number of atmospheric neutrinos
  - N_μ: Number of atmospheric muons
- Likelihood:

$$\mathcal{L} = e^{-N_{ast}-N_{atm}-N_\mu}\prod_{i=1}^{80}\mathcal{L}_i(M, g, \gamma, N_{ast}, N_{atm}, N_\mu)$$

- Partial likelihood of the i-th event:

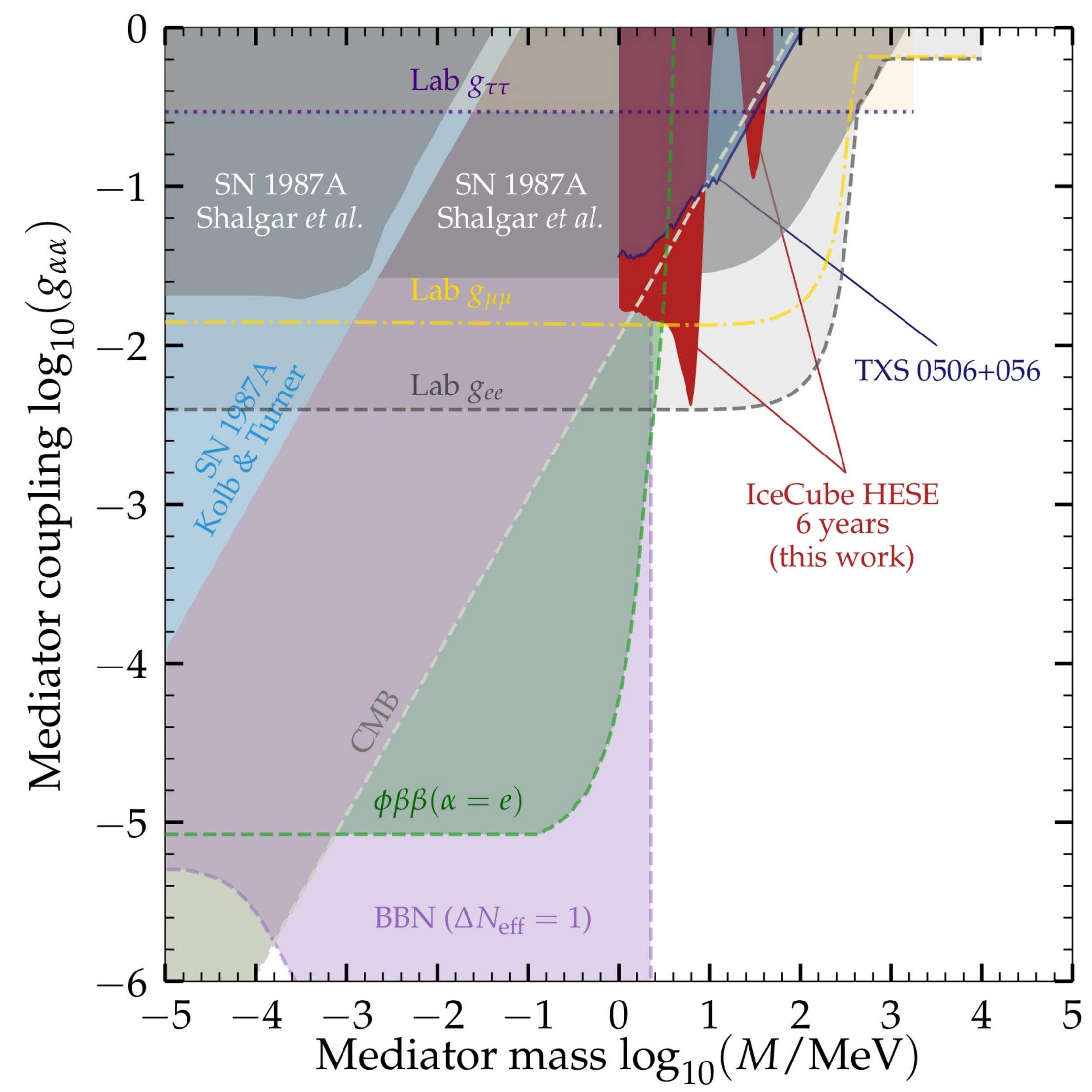
$$\mathcal{L}_i = N_{ast}\mathcal{P}_{i,ast}(M,g,\gamma) + N_{atm}\mathcal{P}_{i,atm} + N_\mu\mathcal{P}_{i,\mu}$$

  Compares chances of it being an astrophysical υ, atmospheric υ, or atmospheric muon
- Bayesian analysis (using MultiNest):
  - Flat priors for $\log_{10}(M/\text{MeV})$, $\log_{10}(g)$, γ, N_{ast}
  - Priors on N_{atm}, N_μ informed by IceCube results

Upper limits on νSI

- The posterior is maximum at

  $M = 14.26^{+2.61}_{-2.21}$ MeV , $g = 0.1$
- The best fit comes from the υSI spectral dip fitting the 300 TeV–1 PeV HESE gap
- The evidence in favor of υSI is not statistically significant
- Bayes factor: $\ln B = 2.48$ (~2.7σ)
- Thus, we place upper limits on g as a function of M:



- The limits above were obtained assuming a υ mass of m_υ = 0.1 eV
  - Smaller m_υ would shift the limits to lower values of M
- Preliminary 7.5-year HESE results contain events with 300 TeV–1 PeV
  - If confirmed, this would strengthen the upper limits on υSI

Conclusions

High-energy astrophysical neutrinos place competitive limits on υSI with mediator masses of 1–100 MeV

Selected references: IceCube Collab., Public Data Access (icecube.wisc.edu/science/data) • Kopper (IceCube), PoS ICRC2017, 981 (2018) • Ng & Beacom, PRD 90, 065035 (2014) • Kamada & Yu, PRD 92, 113004 (2015) • Murase & Shoemaker, PRL 123, 241102 (2019)

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