New limits on neutrino decay from the Glashow resonance of high-energy cosmic neutrinos

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At a glance

- Neutrino decay beyond the Standard Model may affect high-energy cosmic ν
- IceCube's detection of the first Glashow resonance candidate reveals that ν_1, ν_2 survived the trip over Mpc–Gpc
- Thus, we set new limits on their lifetimes, assuming the inverted ν mass ordering

Neutrino decay

- In the Standard Model (SM), the ν lifetime is » the age of the Universe
- But, beyond the SM, ν could decay faster, by emitting a new (pseudo)scalar ϕ, *e.g.*,

$$\mathcal{L} = g_{ij}\bar{\nu}_i\nu_j\phi + h_{ij}\bar{\nu}_i\gamma_5\nu_j\phi + \text{h.c.}$$

- We focus on the inverted ν mass ordering, with ν_3 lightest and stable, so $\nu_{1,2} \to \nu_3 + \phi$
  - This allows for a powerful test of decay via the Glashow resonance (see below)
- Decay reduces the flux of ν_i (i = 1,2) by

$$e^{-\frac{m_i}{\tau_i}\frac{L}{E}}$$

m_i: mass, L: distance, τ_i: lifetime, E: energy

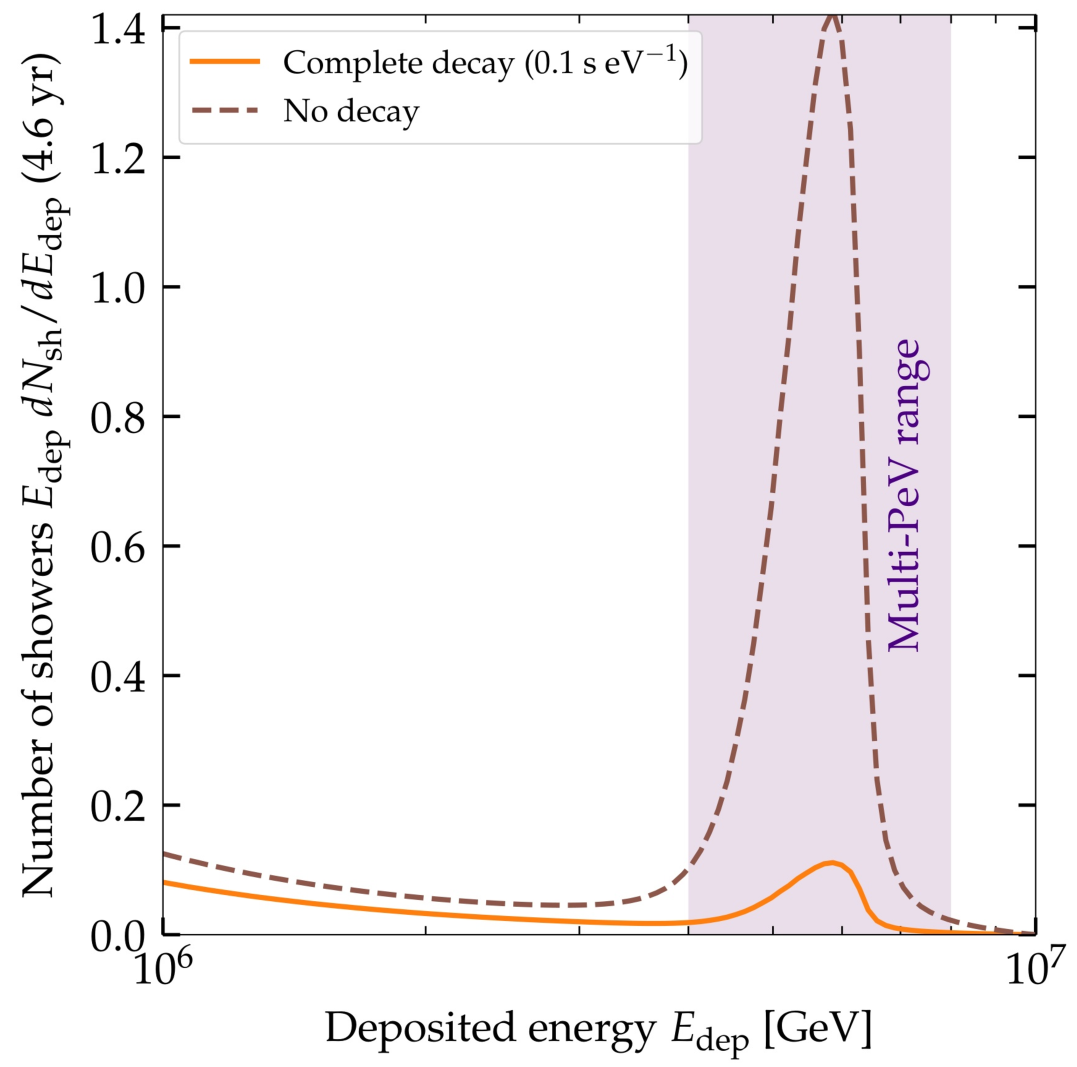
- Cosmic neutrinos are ideal probes, due to their traveling for Mpc-Gpc to Earth

The Glashow resonance

- The Glashow resonance (GR), $\bar{\nu}_e + e \to W$, occurs for $\bar{\nu}_e$ of 6.3 PeV
- The W decays mainly into hadrons, e, τ, which make "shower" events in IceCube
- At 6.3 PeV, the GR cross section is 200× the ν-nucleon (νN) cross section
- IceCube observed the first candidate GR shower in 4.6 years, triggered by cosmic ν
  - Partially contained shower with 6 PeV
  - Most likely ν energy is the GR energy, 6.3 PeV
  - Many early muons, compatible with W decay

Testing for ν decay

- ν_3 has a tiny electron content, < 5%
- If most ν_1, ν_2 decay into ν_3, the few surviving ν_e are unlikely to trigger the GR
- So the GR shower seen by IceCube reveals that ν_1, ν_2 survived the trip to Earth and ...
- ... we place lower limits on their lifetimes



Statistical analysis

- We vary 11 free parameters:
  - ϕ_0: Neutrino flux normalization
  - γ: Spectral index, emitted astrophysical flux $E^{-\gamma}$
  - $f_{e,S}$, $f_{\mu,S}$: ν_e and ν_μ ratios emitted by sources
  - $f_{\bar{\nu}}$: Fraction of $\bar{\nu}$ in the flux
  - θ_{12}, θ_{23}, θ_{13}, δ_{CP}: Mixing parameters
  - $\log_{10}[(\tau_1/m_1)/(\text{s eV}^{-1})]$: Lifetime of ν_1
  - $\log_{10}[(\tau_2/m_2)/(\text{s eV}^{-1})]$: Lifetime of ν_2
- Likelihood:

$$\mathcal{L}\left(\phi_0, \gamma, f_{e,S}, f_{\mu,S}, f_{\bar{\nu}}, \boldsymbol{\theta}, \frac{\tau_1}{m_1}, \frac{\tau_2}{m_2}\right) = \frac{e^{-N_{sh}} N_{sh}^{N_{obs}}}{N_{obs}!}$$

N_{sh}: Expected rate of 4-8 PeV showers (GR+νN)
N_{obs}: Observed rate of 4-8 PeV showers

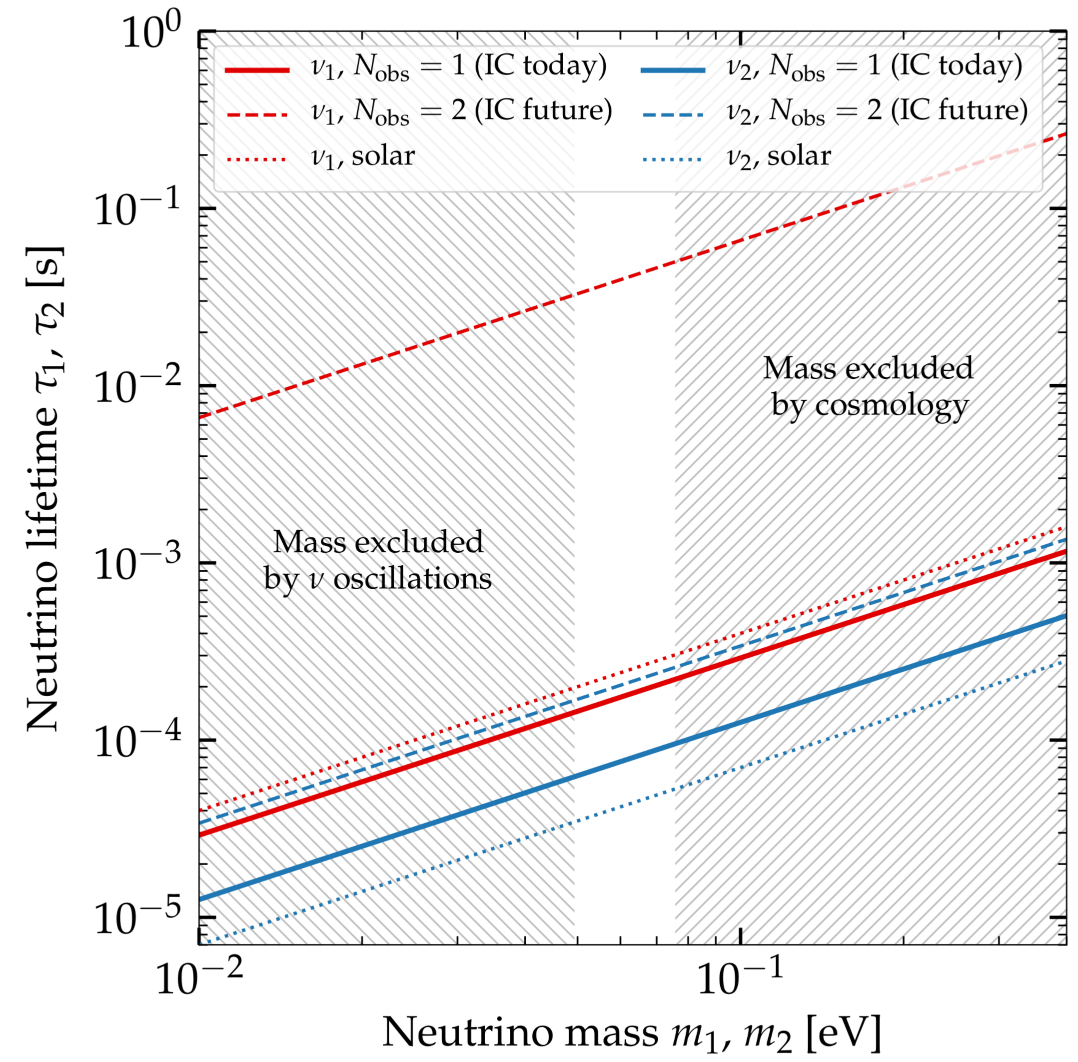
- Bayesian analysis (using MultiNest):
  - Priors on ϕ_0, γ informed by IceCube results
  - Priors on $\boldsymbol{\theta}$ from global oscillation fit (NuFit 4.1)
  - Flat priors on $f_{e,S}$ ([0,1]), $f_{\mu,S}$ ([0,1-$f_{e,S}$]), $f_{\bar{\nu}}$ ([0,1])
  - Flat priors ([-5,15]) on $\log_{10}(\tau_1/m_1)$, $\log_{10}(\tau_2/m_2)$

Lower limits on ν lifetime

- Based on N_{obs} = 1 detected shower in the 4-8 PeV range, we set (90% C.L.)

$$\tau_1/m_1 > 2.91 \times 10^{-3}\ \text{s eV}^{-1}$$
$$\tau_2/m_2 > 1.26 \times 10^{-3}\ \text{s eV}^{-1}$$

  - For ν_1, it roughly matches the limit from solar ν
  - For ν_2, it improves on the limit from solar ν
- The limit for ν_1 is better because it has more electron-flavor content than ν_2
- In the near future, with N_{obs} = 2 showers, the limit for ν_1 will be the best to date
- With N_{obs} = 4 showers (~18 yr of IceCube), the limit for ν_1 will be > 600 s eV^{-1}



- Present-day lower limits on lifetimes imply upper limits on the ϕ coupling:

$$(g_{13}^2 + h_{13}^2)^{1/2} > 4.77 \times 10^{-6}\ (\text{eV}/m_1)$$
$$(g_{23}^2 + h_{23}^2)^{1/2} > 7.24 \times 10^{-6}\ (\text{eV}/m_2)$$

Conclusions

With a single Glashow resonance candidate, we improved the lower limit on the ν_2 lifetime and matched the existing limit on ν_1, under the inverted mass ordering

Selected references: Baerwald, Bustamante, Winter, JCAP 1210, 020 (2012) • Bustamante, Beacom, Murase, PRD 95, 063013 (2017) • Beacom *et al.*, PRL 90, 181301 (2003) • Palomares-Ruiz, Vincent, Mena, PRD 91, 103008 (2015) • Shoemaker & Murase, PRD 93, 085004 (2016) • Lu, UHECR 2018 • Lu, PoS ICRC2019, 945 (2019)

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