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## Limits on Neutrino-Neutrino Scattering in the Early Universe

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In the standard model neutrinos are assumed to have streamed across the Universe since they last scattered at the weak decoupling epoch when the temperature of the standard-model plasma was  $\sim$ MeV. The shear stress of free-streaming neutrinos imprints itself gravitationally on the Cosmic Microwave Background (CMB) and makes the CMB a sensitive probe of neutrino scattering. Yet, the presence of nonstandard physics in the neutrino sector may alter this standard chronology and delay neutrino free-streaming until a much later epoch. We use observations of the CMB to constrain the strength of neutrino self-interactions  $G_{\text{eff}}$  and put limits on new physics in the neutrino sector from the early Universe. Recent measurements of the CMB at large multipoles made by the Planck satellite and high- $l$  experiments are critical for probing this physics. Within the context of conventional  $\Lambda$ CDM parameters cosmological data are compatible with  $G_{\text{eff}} < 1/(56 \text{ MeV})^2$  and neutrino free-streaming might be delayed until their temperature has cooled to as low as  $\sim 25 \text{ eV}$ . Intriguingly, we also find an alternative cosmology compatible with cosmological data in which neutrinos scatter off each other until  $z \sim 10^4$  with a preferred interaction strength in a narrow region around  $G_{\text{eff}} = 1/(10 \text{ MeV})^2$ . This distinct self-interacting neutrino cosmology is characterized by somewhat lower values of both the scalar spectral index and the amplitude of primordial fluctuations. While we phrase our discussion here in terms of a specific scenario in which a late onset of neutrino free-streaming could occur, our constraints on the neutrino visibility function are very general.

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