Sum of Neutrino Masses

Revised August 2021 by K.A. Olive (University of Minnesota).

Neutrinos decouple from thermal equilibrium in the early universe at temperatures $\mathcal{O}(1)$ MeV. The limits on low mass ($m_\nu \lesssim 1$ MeV) neutrinos apply to $m_{\rm tot}$ given by

$$m_{\rm tot} = \sum_\nu m_\nu \ .$$

Stable neutrinos in this mass range decouple from the thermal bath while still relativistic and make a contribution to the total energy density of the Universe which is given by

$$\rho_\nu = m_{\rm tot} n_\nu \simeq m_{\rm tot} (3/11)(3.045/3)^{3/4} n_\gamma \ ,$$

where the factor 3/11 is the ratio of (light) neutrinos to photons and the factor $(3.045/3)^{3/4}$ corrects for the fact that the effective number of neutrinos in the standard model is 3.045 when taking into account e^+e^- annihilation during neutrino decoupling. Writing $\Omega_\nu = \rho_\nu/\rho_c$, where ρ_c is the critical energy density of the Universe, and using $n_\gamma = 410.7 \text{ cm}^{-3}$, we have

$$\Omega_\nu h^2 \simeq m_{\rm tot}/(93 \text{ eV}) \ .$$

While an upper limit to the matter density of $\Omega_m h^2 < 0.12$ would constrain $m_{\rm tot} < 11$ eV, much stronger constraints are obtained from the observations of the CMB, combined with lensing and baryon acoustic oscillations data. These combine to give an upper limit of around 0.12 eV, and may, in the near future, be able to provide a lower bound on the sum of the neutrino masses. The current lower bound of $m_{\rm tot} > 0.06$ eV implies a lower limit of $\Omega_\nu h^2 > 6 \times 10^{-4}$. See our review on "Neutrinos in Cosmology" for more details.