

Sum of Neutrino Masses

Revised September 2019 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_{tot} given by

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

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

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

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

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

While an upper limit to the matter density of $\Omega_m h^2 < 0.12$ would constrain $m_{\text{tot}} < 11$ eV, much stronger constraints are obtained from a combination of observations of the CMB, the amplitude of density fluctuations on smaller scales from the clustering of galaxies and the Lyman- α forest, baryon acoustic oscillations, and new Hubble parameter data. These combine to give an upper limit of around 0.15 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 $m_{\text{tot}} > 0.06$ eV implies a lower limit of $\Omega_\nu h^2 > 6 \times 10^{-4}$. See our review on "Neutrinos in Cosmology" for more details.