

64. Sum of Neutrino Masses

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The limits on low mass ($m_\nu \lesssim 1$ MeV) neutrinos apply to m_{tot} given by

$$m_{\text{tot}} = \sum_{\nu} (g_\nu/2) m_\nu ,$$

where g_ν is the number of spin degrees of freedom for ν plus $\bar{\nu}$: $g_\nu = 4$ for neutrinos with Dirac masses; $g_\nu = 2$ for Majorana neutrinos. Stable neutrinos in this mass range make a contribution to the total energy density of the Universe which is given by

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

where the factor 3/11 is the ratio of (light) neutrinos to photons. Writing $\Omega_\nu = \rho_\nu / \rho_c$, where ρ_c is the critical energy density of the Universe, and using $n_\gamma = 412 \text{ cm}^{-3}$, we have

$$\Omega_\nu h^2 = m_{\text{tot}} / (94 \text{ eV}) .$$

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 0.2 eV, and may, in the near future, be able to provide a lower bound on the sum of the neutrino masses. See Sec. 25 of this *Review* for more details.