67. Sum of neutrino masses

Revised September 2017 by K.A. Olive (University of Minnesota).

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

\[
m_{\text{tot}} = \sum_\nu \left( g_\nu / 2 \right) m_\nu ,
\]

where \( g_\nu \) is the number of spin degrees of freedom for \( \nu \) 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 \( \rho_c \) is the critical energy density of the Universe, and using \( n_\gamma = 412 \) 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-\( \alpha \) 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. 26 of this Review for more details.