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The effective number of neutrinos: standard and non-standard calculations

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We have performed a new numerical calculation of the decoupling process of neutrinos in the early Universe, including the values of all mixing parameters from a recent analysis, taking into account the full set of differential equations for the neutrino density matrices (equivalent to the occupation numbers for mixed neutrinos). Our results are important for fixing the radiation content of the Universe in the standard case in terms of Neff, recently measured by Planck. We also show to which extent the value of Neff can be enhanced in the presence of non-standard neutrino interactions with electrons, and we have also considered the case of a very low reheating scenario, where the last radiation-dominated phase of the Universe begins at temperatures as low as MeV. The main consequence of such scenarios concerns the production of neutrinos, because they are the known relativistic particles with the largest decoupling temperature. The thermalization of the neutrino background could be incomplete due to the lack of interactions, leading to Neff < 3. We will show the bounds on the reheating temperature both from BBN and from late-time cosmological observables, including the latest results of the Planck satellite.

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