Abstract: The emerging structure of the neutrino mass matrix, when combined with the primordial element abundances, places the most stringent constraint on the flavor asymmetries in the cosmological neutrino background and therefore its energy density. I review the mechanism of synchronized neutrino oscillations in the an early universe with degenerate (asymmetric) neutrino and antineutrino densities and the implications of refined measurements of neutrino parameters.

The Cosmological Energy Density of Neutrinos from Oscillation Measurements

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I INTRODUCTION

The dawn of the era of precision cosmology has come with the observations of anisotropies in the cosmic microwave background (CMB) with the Wilkinson Microwave Anisotropy Probe (WMAP) over the whole sky to better than fundamental uncertainty over a wide range in anisotropy scale [1]. Combined with the three-dimensional galaxy distribution of the Sloan Digital Sky Survey [2], a consistent picture has emerged for the standard concordance cosmology: a universe dominated by dark matter and dark energy with structure growing from nearly scale-invariant adiabatic Gaussian density perturbations. In the simplest models, WMAP and SDSS measure the cosmological matter density to nearly 10% [3].

Given the success of the standard concordance cosmology, it is tempting to assume that the density of all cosmological matter and radiation components of the universe are known to great precision. However, the neutrino density, often simply assumed to be fixed to its standard model value, is actually only known to factors of its own magnitude when using the WMAP data alone [4].

One can hope to do better with primordial nucleosynthesis. During primordial nucleosynthesis, the nucleon beta-equilibrium weak interaction rates are sensitive to the electron neutrino and antineutrino densities. The cosmic expansion rate depends on the overall neutrino density, which sets when nuclear reactions freeze-out. These two effects can compensate each other and can produce primordial element abundances for deuterium, helium and lithium that are consistent with their observed abundances, as long as the nucleon density is increased to allow the nuclear rates to keep up with the required increased expansion rate [5]. The non-zero neutrino chemical potentials (or degeneracy parameters) of this model led to its description as degenerate big bang nucleosynthesis (DBBN). Since the nucleon (baryon) density is independently constrained by the CMB, the magnitude of deviations from non-zero neutrino chemical potentials was appreciably constrained from the original DBBN models, but still allowed neutrino densities over twice that of the standard value [6].

With the emergence of the mass and mixing spectrum of the active neutrino flavors, we included single-heavy neutrino densities in the above and accounted for the effect on the neutrino mass matrix 

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