Constraints on Ω_{baryon} from Measurements of the ^{3}He Abundance

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Abstract:

Measuring the abundances of ^{2}H, ^{3}He, ^{4}He, and ^{7}Li can be used to constrain Ω_{baryon} (Ω_b) through comparison to Big Bang nucleosynthesis (BBN) predictions. The two main factors that affect nucleosynthesis in the Hot Big Bang model are the number of massless neutrinos and the density of baryons. The main factor that determines the production of heavier nuclei is the ratio of protons to neutrons at the time when the temperature has decreased enough for nuclei to form. In order for the "freeze out" of neutrinos to occur at the correct time to produce the observed abundance of ^{4}He/H there have to be three massless neutrinos (corresponding to electrons, taus, and muons), which was confirmed by the LEP experiment at CERN. Knowing the number of massless neutrinos defines the cosmology for the early universe and leaves the baryon density as the main factor to affect the abundances of light nuclei created during BBN. BBN predicts that predominately ^{4}He nuclei will be formed, but there will also be minute amounts of stable ^{2}H, ^{3}He, and ^{7}Li nuclei produced.

Although ^{4}He is the most abundant, and would be easiest to measure, the predictions for ^{4}He abundance are the least dependent on Ω_b of all the light nuclei. Deuterium and ^{3}He are the next most abundant and both have relatively strong dependences on Ω_b, which makes them good indicators of Ω_b. In particular, ^{3}He provides a good consistency check for the measurements of Ω_b obtained from deuterium observations. Bania et al. (2002) measured the 8.665GHz spin flip transition of $^3He^+$ in 60 HII regions and 6 planetary nebulae (PNe) to determine the ^{3}He abundance. Because it is necessary to know the ionization and density structure in order to obtain the ^{3}He abundance from the $^3He^+$ column density, only 21 'simple' sources were used to trace the abundance of ^{3}He in the galaxy. Interestingly, they do not find a gradient of ^{3}He/H abundance with metallicity or galactic radius, which is predicted by stellar evolution models. The "plateau" of ^{3}He/H abundance of $1.9\pm0.6 \times 10^{-5}$ is adopted, which gives an upper limit to the baryon density of $\Omega_b h^2 > 0.009\pm0.014$. Bania et al. (2002) also report the primordial ^{3}He abundance of $1.1\pm0.2 \times 10^{-5}$ (or $\Omega_b h^2 = 0.02\pm0.007$) based on measurements of ^{3}He for one outer galaxy HII region S209 based on 133 hours of observation over 15 years. The ^{3}He abundance has also been measured using observations of the local interstellar medium by Gloeckler & Geiss (1996) using the Solar Wind Ion Composition Spectrometer (SWICS) on the spacecraft Ulysses. By measuring the ratio of $^3He^+/^4He^+$ and assuming that ^{4}He/H~0.1, the ^{3}He abundance was measured to be $2.2\pm0.7 \times 10^{-5}$. Not only are the constraints on Ω_b from both of these studies consistent, but they are also in the agreement with the results from the seven year WMAP data release, which constrains the baryon density to be $\Omega_b h^2 = 0.02258\pm0.057$ (Larson et al. 2010).