Searching for the dark baryons

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Baryons constitute about 4% of our universe, as shown both by Primordial Nucleosynthesis (that allows to probe the universe at redshift $z \simeq 10^9$), by the analysis of the CMB data (that probes the universe at $z \simeq 10^3$) and by the Lymann-α lines in the Quasar spectra due to galaxies at $z \simeq 1-2$. However, nowadays, most of those baryons are missing since we know that about 10% of them are in stars (i.e. in the visible part of galaxies), the hot gas in galaxies and galaxy clusters accounts for another $20-30\%$ of baryons, but it is unknown in which form the remaining $60-70\%$ of all baryons are hidden. This is called the missing baryon problem. A possibility is that these baryons are contained in the so-called cosmic filaments in the form of a warm-hot intergalactic medium. However, it is unlikely that all the missing baryons are confined in the cosmic filaments and, actually, there are several reasons to believe that a non-negligible amount of these hidden baryons are in galactic halos (for more details on this issue see [1]). Evidences for this conclusions come, for example, from the evolution of spiral galaxies along the Hubble sequence, the necessity of a replinishment of the galactic disk with new gas to account for the absence of a stop in the star formation process, the presence of High Velocity Clouds and Intermediate velocity clouds up to a galactocentric distance of about 50 kpc, and so on. One possible way of searching for the missing baryons is through gravitational microlensing towards the Magellanic Clouds and through pixel-lensing observations towards the Andromeda galaxy (see [2,3]).

A possible innovative way to search for the dark baryons in galactic halos makes use of the CMB data. A recent analysis of the WMAP data acquired during 7 years of sky observations have been used to study the region of the sky around the Andromeda galaxy (M31) and have allowed us to conclude that a sizeable temperature asymmetry does exist towards both the M31 disk and the halo [4]. It appears, in particular, that the halo temperature asymmetry is most likely induced by the Doppler shift due to rotation of the M31 halo about the rotation axis and arises from either the presence of cold gas clouds in the M31 halo (in this respect see [5,6]) or the kinematical Sunyaev-Zeldovich effect due to the Inverse Compton scattering of energetic electrons on CMB photons that get more or less energy depending on the side of the galaxy in which they are scattered (see [8]).

In the Figure we show, for the M31 halo, the 1σ (green lines), 2σ (brown lines), and 3σ (red lines) excess temperature contrast (in mk/pixel) curves in the W band along with the mean profile (pink line close to zero) for 500 simulated CMB sky maps. In red, the observed temperature contrast profile in the M 31 disk (with 1σ errors) is given. The statistical analysis shows that there is a probability below 1% that the temperature asymmetry towards the M31 halo is due to a random fluctuation of the CMB signal. In particular, the temperature asymmetry profile in the W band is beyond the 2σ curve beyond about 40 kpc and beyond the 3σ curve in the region between about 60 and 120 kpc from the galactic center, thus showing that the effect is very likely to be real. We mention that a size of about 120 kpc corresponds to the typical size inferred for the dark matter halos around massive galaxies such as M31. We also note that the CMB maps have been correctly simulated by assuming $\Delta T(\hat{n}) = \Delta T_{CMB}(\hat{n}) \otimes B(\hat{n}) + N(\hat{n})$, where ΔT_{CMB} is a realization of the Gaussian CMB field, $N(\hat{n})$ is the pixel noise and $B(\hat{n})$ is the

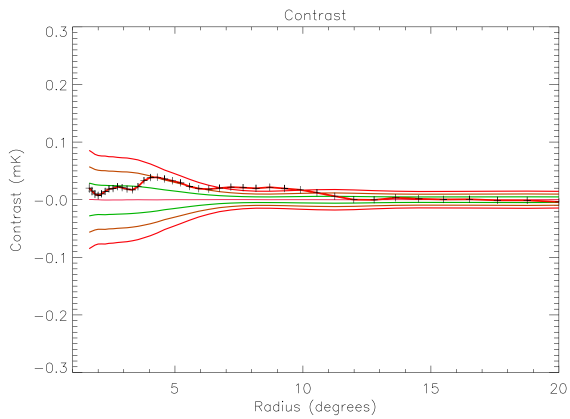

Figure 1. The 1σ (green lines), 2σ (brown lines), and 3σ (red lines) excess temperature contrast (in mk/pixel) curves in the W band along with the mean profile (pink line close to zero) for 500 simulated CMB sky maps. In red, the observed temperature contrast profile in the M31 halo (with 1σ errors) is given. The WMAP maps with the Galactic disk contribution modeled and removed (foreground-reduced maps) are used here.

proper beam of the experiment. Using the synfast routine of HEALPix with the best-fit power spectrum constrained with BAO and H_0, as given by the WMAP Collaboration, 500 realizations of the CMB sky were made. The maps have been then convolved with the WMAP beams for W, V, and Q bands, respectively, taking into account the convolution with the beam function of the experiment and randomly extracting the noise value from a normal distribution with $\sigma = \sigma_0/\sqrt{N_{obs}}$.

Finally, we emphasize that the methodology of using CMB data to probe both the disk and the halo of M31, even if with the limitation of the presently available data, may suggest a novel way of approaching this problem especially in view of the high accuracy CMB measurements with the Planck satellite.

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