The Cosmological Hydrogen Recombination Spectrum

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Abstract: We present accurate results for the spectral distortions of the Cosmic Microwave Background (CMB) arising during the epoch of cosmological hydrogen recombination within the standard cosmological (concordance) model for frequencies in the range 100 MHz – 3500 GHz. We followed the evolution of the populations of the hydrogen levels including electron states up to principle quantum number n=100. All the angular momentum sub-states were treated individually, resulting in a total of 5050 hydrogen levels. We also included the main collisional processes.

Introduction

The study of the Cosmic Microwave Background (CMB) provides one of the most powerful tools to test cosmological models and to determine the parameters describing the Universe. However, until now the main efforts have been concentrated on the temperature and polarization angular fluctuations, certainly with great success.

The CMB photons which are detected today were essentially last scattered towards us during the epoch of cosmological recombination, where the temperature of the Universe had become sufficiently low to permit the formation of neutral atoms [1, 2]. During this time there was a net generation of photons, which introduces distortions to the CMB blackbody spectrum. In this work we computed these distortions due to the recombination of hydrogen including the main physical processes.

Except for the far Wien tail of the CMB, these distortions are very small (see Fig. 1). However, a measurement of these tiny deviations from a pure blackbody would provide another independent way to determine some of the key cosmological parameters, such as the baryon density or the total matter content.

The Cosmological hydrogen recombination spectrum

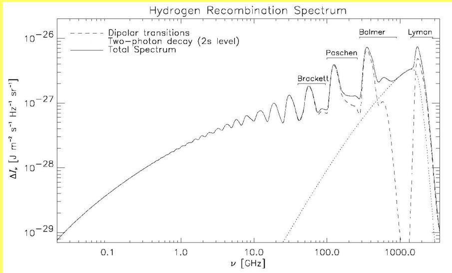

Fig. 1: The cosmological hydrogen recombination spectrum for n_{max}= 100, following all sub-states and including collisions. Also the contribution from the 2s two-photon decay is shown.

The cosmological hydrogen recombination spectrum (Fig. 1) shows a characteristic oscillatory behavior at high frequencies, which cannot be mimicked by foregrounds or other astronomical sources and therefore may allow its extraction in the future. At frequencies below ~1GHz the distortion reaches the level of DI/I ~ 10^{-7}, but it is very small (DI/I < 10^{-8}) in the range 10GHz-500GHz.

The addition of more shells should slightly increase the emission at frequencies <100MHz. However, one expects that free-free will become important below ~80MHz and that it will erase any emission below ~1MHz.

Effect of collisions and *l*-splitting

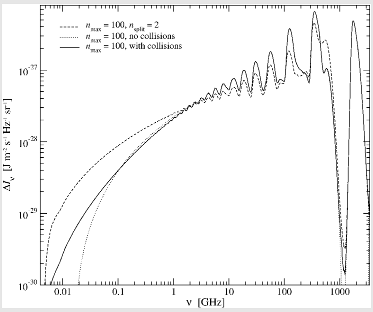

Fig. 2: Effect of collisions and *l*-splitting on the hydrogen recombination spectrum.

In Fig. 2 one can see that collisions only affect the distortions at low frequencies (< 2GHz), while the Lyman, Balmer, Paschen and Brackett transitions remain unchanged. For the curve with n_{split}=2 we only followed the evolution of the total populations of the shells for n>2 (no "*l*-splitting"). Collisions are *not* strong enough to justify this approximation, because the spectrum in the whole range is strongly altered.

Convergence for different numbers of shells

In Fig. 3 the dependence of the recombination spectrum on the total number of included shells is illustrated.

For n_{max}=100 the spectrum seems converged on a level of better than ~1% for frequencies above 1GHz and ~10-20% below 1GHz.

Inclusion of more shells would slightly increase the emission below ~1GHz. Below ~80MHz free-free absorption will become important and below 1MHz one does not expect any signatures form hydrogen recombination.

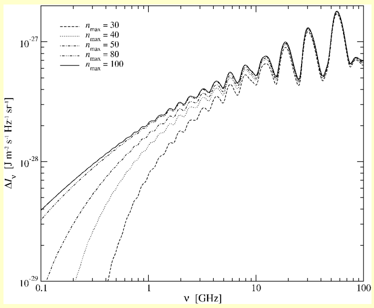

Fig. 3: The hydrogen recombination spectrum at low frequencies for different n_{max}.

Conclusions

We have obtained accurate results for the cosmological hydrogen recombination spectrum in the frequency range from 100MHz to 3500GHz (see Fig.1 and Fig. 3). As our calculations show, collisions are not frequent enough to establish statistical equilibrium within the shells above n=2 and that the resulting spectrum is significantly different when only following the total populations of the shells for n>2 (see Fig. 2). Furthermore there is no "pre-recombination" emission as discussed in [3, 6].

References

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