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Cosmology

Pre-class reading 4

Recombination of electrons and protons to hydrogen atoms in the cosmological context is dominated by the two-photon decay of the from the metastable 2S level to the ground state. The ionization fraction (ne/nb) drops from approximately unity at z>2000 to a freeze out value of ~0.002 at z<200.

Decoupling of matter and radiation occurs shortly after the number density of free electrons has suddenly decreased due to recombination at z~1100 and T_dec ~0.26eV. Physically, this happens when the Thomson-scattering rate drops below the expansion rate of the Universe.

1a) The temperature of radiation at z_rec ~1300 is T_rec ~0.3eV which is less than the hydrogen ionization potential of 13.6eV. This is a consequence of the high entropy per baryon (small value of eta- baryon fraction). Since there are many times more photons than baryons, there can still be sufficient photons with energy > 13.6 eV in the Wein's tail of the blackbody spectrum to keep the majority of hydrogen atoms ionized, even when the temperature has dropped below the ionization value.

1b) The CMB photons are emitted when the Universe was highly opaque- making the spectrum a blackbody. Even though these photons were scattered many times between the epoch of emission and the epoch at the last scattering surface, the high entropy content of the Universe can keep the gas particles at the same temperature as that of the photons. In this case, there is no net energy transfer between the photons and the electrons ensuring the radiation field remains a blackbody.