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Radiative electron capture —A tool to detect He^{++} in space

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Abstract. Large clouds of totally ionised helium and hydrogen might exist in the intergalactic space, invisible for the usual optical observations. These clouds, bombarded with medium energy electrons, should generate photon radiation in the X-ray region. The radiation is associated with the Radiative Electron Capture, REC, by He^{++} ions and should be observable with space born detectors. The photon spectra calculated for a range of temperatures of the electron spectra as well as several column densities of the plasma clouds are discussed.

PACS. 25.40.Lw Radiative capture – 98.62.Ra Intergalactic matter; quasar absorption and emission-line systems; Lyman forest

1 Introduction

One of the most intriguing questions of to-day astrophysics is the mass balance of the Universe. The observed baryonic mass is only about $4 \pm 1\%$ of the total mass.

The nature of the "cold dark matter" [$(29 \pm 4)\%$] and of the "dark energy" [$(67 \pm 6)\%$], *i.e.* of the unobserved missing mass is largely unknown [1]. Various hypotheses are being put forward, such as, *e.g.*, the SUSY particles or the disappearance of massive particles in extra dimensions [2].

Fascinating as this discussion is, it requires precise book-keeping of the known, ordinary baryonic matter spread throughout the Universe. A possible contribution to this baryonic component, which has so far been largely neglected, may be due to the diffuse clouds of completely ionized hydrogen and helium in the intergalactic medium, IGM. This matter, presumably of primordial origin, escapes observation by the usual optical methods.

Clouds of neutral hydrogen have been detected in the earth-bound observatories as the so-called "Lyman forest" in the quasar's absorption spectra in a large range of z. The $^2H/^1H > 4 \times 10^{-5}$ isotope ratios have been determined. The column densities of about $5 \times 10^{17}\,cm^{-2}$ been deduced for the neutral ^1H [3]. Much larger quantities of the hydrogen plasma are presumably associated with these clouds.

The first evidence of the existence of the helium plasma clouds stems from the observation of the red shifted 304 Å absorption line in the light of the quasar Q0302-003 [4,5,6]. This line is characteristic for absorption by singly ionized helium, He^+. No lines expected for the neutral He ($\lambda_0 = 584$ Å) have been seen. These facts can be considered as an indirect evidence of the existence of substantial amounts of completely ionized hydrogen and helium plasma scattered in the IGM. The total mass of the baryonic matter distributed there may be far from insignificant.

Besides contributing to the total mass of the baryonic matter the clouds of the primordial hydrogen and helium in the IGM carry precious information relevant for the theories of Big-Bang nucleosynthesis (BBN) and for the cosmic chemical evolution. Information of this kind might be particularly valuable in the light of the recent high-precision measurements of the Cosmic Microwave Background —CMB [7].

The principle of the observation is illustrated in fig. 1. The He^+ clouds situated between a quasar and the observer display various red shifts. The corresponding z-values are a measure of the distances. To quote [4] "the intergalactic space appears to be peppered with tenuous clouds of possibly primordial gas that have not yet condensed into galaxies".

The observation of the He^+ line, combined with the non-observation of the neutral He lines, are not sufficient to determine the total amount of gas or gas-plasma in the clouds. They give some model dependent limits. To quote [4] further, they show "the tip of the iceberg in terms of the total baryonic mass present". It is thus obvious that any independent observable shedding light on the hidden part of this mass would be of considerable value. One such observable could be the photon spectrum in the X-ray region due to the radiative capture of fast electrons by the He^{++} ions. The present work describes the principle of such observation. The experiment verifying the

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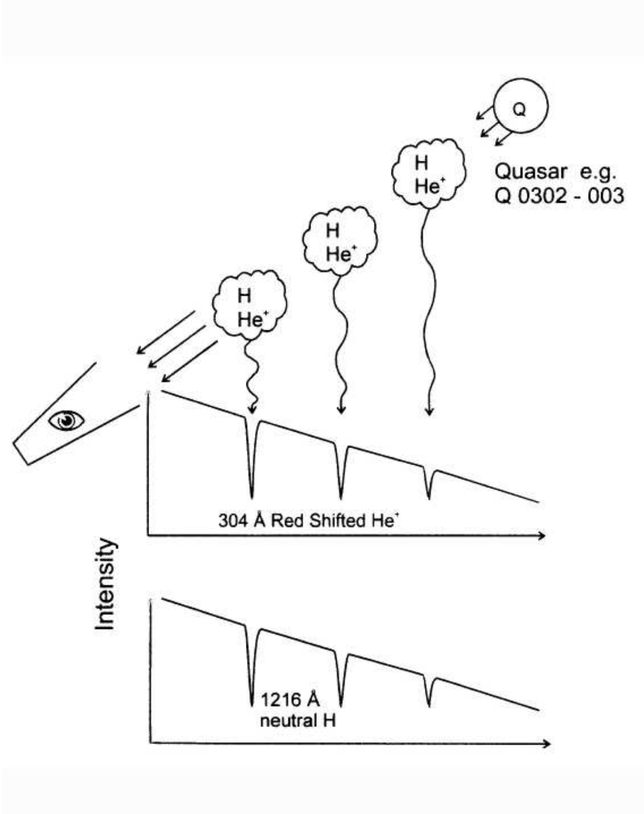

Fig. 1. The white spectrum light from a distant quasar is absorbed in clouds of ionised gas. The absorption lines are red-shifted depending on the distance of the clouds, giving rise to the "Lyman-α forest".

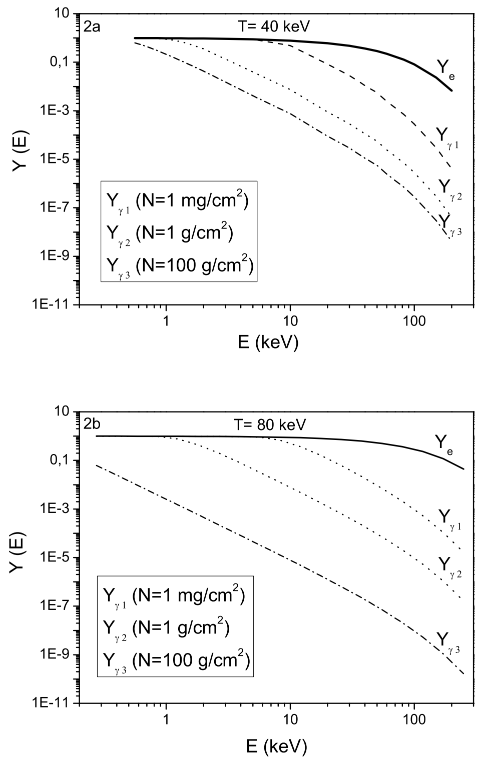

Fig. 2. The REC photon spectra due to the electron capture in the plasma clouds for electrons with $T = 40\,\mathrm{keV}$ (top) and $T = 80\,\mathrm{keV}$ (bottom) and for the column densities varying between $1\,\mathrm{mg/cm^2}$ and $100\,\mathrm{g/cm^2}$ (or between 1.5×10^{21} and 1.5×10^{26} atoms/cm^2).

theoretical cross-sections for the radiative capture process in the difficult to reach relativistic region is described separately [8].

2 Expected photon spectra due to Radiative Electron Capture in the plasma clouds

A general description of the Radiative Electron Capture process for fast relativistic electrons can be found, *e.g.*, in [9] (see also [10,11,12]).

The process corresponds to the time reversed photoelectric effect for atoms in partly ionized states:

$$Z^{q^+} + \hbar\nu \Longrightarrow Z^{(q+1)^+} + e^-, \tag{1}$$

where Z is the atomic number and q is the charge of the ion.

In the case of He^{++} ions the inverse effect occurs for singly ionized helium, He^+. The cross-section for the REC effect, σ_{REC}, depends strongly on the atomic number of the capturing ion Z as well as on the velocity of the electrons, v_e.

Crudely

$$\sigma_{REC} \sim \frac{Z^{4.5}}{v^5}. \tag{2}$$

The plasma clouds in the IGM are subject to continuous bombardment by fluxes of photons and fast electrons. The electron energy spectra are characterized by a power law with temperatures, T, ranging typically between few tens and few hundreds keV (*e.g.*, [13]).

The plasma clouds at sufficient column density are opaque to these electron fluxes, especially so at low electron energies. Due to the REC effect they convert the electron spectra to photon spectra of practically the same energy, cross-section weighted at each energy value:

$$Y_\gamma(E_\gamma) = Y_e(E_e)\left(1 - e^{-N\sigma_{REC}}\right), \tag{3}$$

where $E\gamma = E_e$, $Y_e(E_e)$ is the number of electrons of energy E_e and N is the column number density of the cloud. The column number density is defined as the total number of particles per cm^2 in the column of the length equal the size of the cloud at a given section.

Figure 2 shows the photon spectra calculated for several temperatures and column densities. The background spectra of electrons, indicated schematically in fig. 2, are taken from the BATSE catalogue [13]. The REC spectra are calculated under the assumption of a spherical plasma cloud bombarded isotropically from all directions. This averages out the otherwise strongly anisotropic REC emission.

Only some educated guesses can be made about the N (plasma) values for He^{++} and H^+. The range of the values used in fig. 2 reflects in an exaggerated way the uncertainties in these estimates.

The relative contribution of H^{++} and H^{+} to the REC spectra can be obtained from the estimate

$$[N(\mathrm{He}) + N(\mathrm{He}^{+}) + N(\mathrm{He}^{++})] \approx 0.08[N(\mathrm{H}) + N(\mathrm{H}^{+})]$$

and from the approximate relationship $\sigma_{REC}(\mathrm{He}) \approx 2^{4.5}\sigma_{REC}(\mathrm{H})$ for any given E_e (see formula (2)).

Hence helium and hydrogen contribute about 2/3 and 1/3 to the total photon spectrum, respectively.

3 Summary and conclusions

It is shown that helium + hydrogen plasma clouds in the IGM can act as effective converters of electron-to-photon spectra in the observationally attractive energy range of a few to a few hundred keV.

This offers a possibility of obtaining an observational, quantitative information on the completely ionized hydrogen and helium plasma clouds in the Inter-Galactic Medium.

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