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Constraints on the physical properties of the damped Lyα system of Q0000−2619 at z = 3.054

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Abstract. We present the detection of C II and C II* absorption in the $z = 3.0543$ damped Lyα system toward Q0000−2619. The derived population ratio implies a fine structure excitation temperature between 19.6 and 21.6 K. The upper value sets a strict upper limit on the CMB temperature at this redshift, which is consistent with the predicted value of 11.05 K from standard cosmology. Under the assumptions of an ionization degree ranging from 0 to 10%, a gas kinetic temperature between 100 and 10 000 K and a UV field with a Milky Way spectrum, the density of the absorber is constrained to be between 0.7 and 40 cm^{-3} and the H-ionizing flux between 1 and 80 times the intensity of the Galactic UV field. If the damped Lyα system is assumed to be homogeneous, the implication is that its size in the direction of the line of sight must be between 1 and 100 pc.

Key words: cosmology: cosmic microwave background – galaxies: intergalactic medium – galaxies: quasars: absorption lines – galaxies: quasars: individual: Q0000-2619

1. Introduction

Fine structure transitions observed in the absorption spectra of quasars provide unique information on the temperature of the microwave background at the redshift of the absorber, on the intensity of the UV-field and on the density of the absorbing system (Bahcall & Wolf 1968). The measured excitation temperatures, or upper limits to the excitation temperature, of the fine structure of C I and C II has been used by several authors to constrain the temperature of the Cosmic Microwave Background radiation (CMB) up to a redshift of 4.38 (Lu et al. 1996). The most significant published constraints on the CMB temperature at $z > 0$ are summarized in Fig. 1. The Big Bang cosmological model predicts a simple relationship between the CMB temperature and the redshift z (e.g. Peebles 1993):

$$T_{\rm CMB}(z) = T_{\rm CMB}(0)(1+z) \qquad (1)$$

Alternative anisotropic cosmological models (Phillips 1994) make strong claims for a value of $T_{\rm CMB}$ more than 5 K below the standard prediction at $z = 3$. So far all the measured excitation temperatures and upper limits are consistent with a Friedmann universe.

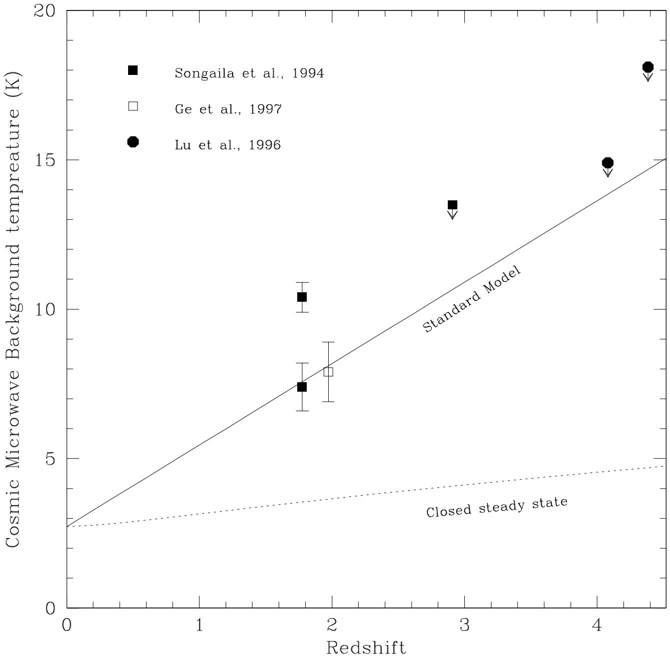

Fig. 1. Upper limits to the CMB temperature at $z > 0$. The predicted relations between the CMB temperature and the redshift, for the Standard Model (the hot Big Bang) and for the Closed Steady State Model (Phillips 1994) are also shown.

The observed excitation temperature (or upper limit) of C I and C II fine structure has also been used to constrain the density of the absorbing systems (Chaffee et al. 1988; Songaila et al. 1994; Ge et al. 1997).

Here we discuss the detection of C II and C II* absorption at $z = 3.0543$ in the spectrum of Q0000−2619 obtained at the NTT. The absorption lines are associated with a damped Lyα system with neutral hydrogen column density of N(H I)= $1.5 \pm 0.5 \times 10^{20}$ cm^{-2} (Savaglio et al. 1994, SOM hereafter). By measuring the equivalent width of the C II multiplet absorption lines we derive strict upper limits on the temperature of the CMB at this redshift and constrain the density of the absorbing systems. In the next section the observations are briefly presented. In Sect. 3 the C II fine structure excita-

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tion temperature, which gives directly the upper limit on the CMB temperature at redshift 3.0543, is derived. In Sect. 4 the relative strengths of the different excitation mechanisms are reviewed. The constraints on the density and the UV field in the $z = 3.0543$ damped Lyα system are derived in Sect. 5 and discussed in Sect. 6.

2. Observations

In October 1990 echelle observations of Q0000$-$2619 at $z = 4.12$ were obtained with the ESO Multi Mode Instrument (EMMI) (D'Odorico 1990) at the ESO NTT telescope. The spectra cover the wavelength range from 4400 Å to 9265 Å with a resolution of 0.2 and 0.3 Å between 4700 and 8450 Å and signal-to-noise ratio S/N= 15–60 per resolution element. The data were reduced and analysed by Savaglio et al. (1997) to which we refer the reader for a detailed description of the observations and data reduction procedure. In the spectrum of Q0000$-$2619, SOM have identified nine metal absorption systems; among these two are known damped systems at redshifts 3.054 and 3.390. Eight of the nine systems have redshift greater than 3. We carefully inspected the spectrum looking for absorption from the C I and C II ground state multiplet. For all systems at redshifts greater than 3, the absorption from the C I ground state multiplet would land redwards of the Lyman-α emission. No absorption from C I is detectable in the spectrum.

C II absorption was detected for both the damped systems at $z = 3.054$ and $z = 3.390$ (SOM). For these systems the C II (λ1334) absorption line lands bluewards of the Lyα emission. The C II at $z = 3.3913$ is heavily blended, while the C II at redshift $z = 3.0543$ is reasonably clean, despite falling in the Lyman forest at $\lambda = 5410.6$. At $\lambda = 5415.4$ we detect a weak absorption line (3.5σ confidence) consistent with absorption from the excited fine-structure level of C II at redshift $z = 3.0543$.

Table 1 summarizes the data on the absorption lines detected for the system at $z = 3.0543$.

3. Excitation temperature

At a redshift of 3.0543, the C II $J = 1/2$ (λ1334.53 Å) and $J = 3/2$ ($\lambda\lambda$1335.66,1335.71 Å) absorption lines land respectively at 5410.54 Å and 5415.17,5415.37 Å. Fig. 2 shows the spectrum of Q0000$-$2619 in the vicinity of the C II multiplet. In this wavelength range the spectral resolution is of 0.2 Å and the S/N per resolution element is about 15.

The multiplet lands in the Lyman forest and in the damping wing of the Lyα absorption of the $z = 3.390$ damped system, at $\sim$ 5337 Å. The C II ground state absorption line is slightly blended. We used a multiple Gaussian fit to deblend the C II line and measured an equivalent width of $W_\lambda = 1.16 \pm 0.02$ Å. The C II* absorption line is detected at 3.5σ. For C II* $W_\lambda = 0.077 \pm 0.02$. The Gaussian fit to the line has a FWHM of 0.29 Å which is consistent with the instrument resolution. The two equivalent widths correspond respectively to $\log(W_\lambda/\lambda) = -3.67$ and -4.85. In both cases a local continuum level corresponding to the damping wing of the Lyα absorption at $z = 3.390$ has been used. The C II absorption line is well fitted by a Gaussian having a FWHM of 53 ± 5 km s^{-1}, which given the instrumental resolution in this range of 11 km s^{-1} corresponds to an intrinsic b parameter of 31 ± 3 km s^{-1}. In Fig. 3 the theoretical curve of growth of C II is plotted for three values of b: 28, 31 and 34 km s^{-1}. The two values of $\log(W_\lambda/\lambda)$ are also shown. The corresponding column density values derived for C II and C II* are summarized in Table 2.

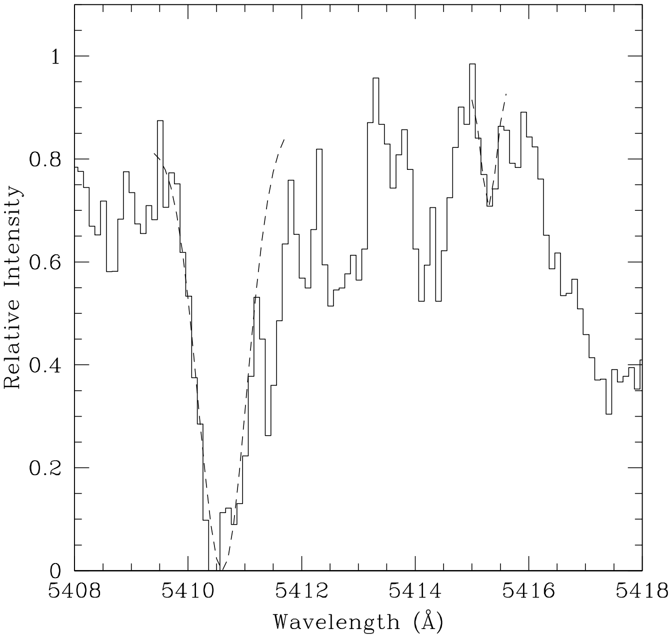

Fig. 2. The spectrum of Q0000$-$2619 in the vicinity of the C II multiplet at $z = 3.0543$ with profile fit to the C II $\lambda1334.53$ and C II* $\lambda\lambda1335.66, 1335.71$ lines. The dashed line is the Gaussian fit to the absorption lines.

Table 1. The damped Lyα system at $z_{\rm abs} = 3.0543$. CII and CII* wavelengths and equivalent widths are from this paper, all the other line measurements and identifications are from SOM.

FWHM[1] (km s^{-1})	$\lambda_{\rm obs}$ (Å)	W_λ (Å)	$\sigma(W_\lambda)$ (Å)	$z_{\rm abs}$	ID
11	~4928	> 30	...	~3.054	Lyα
11	5279.65	1.79	0.17	3.0545	OI(1302)
11	5410.54	1.16	0.02	3.0543	CII(1334)
11	5415.37	0.08	0.02	3.0543	CII*(1335)
11	5650.72	0.57	0.09	3.0544	SiIV(1393)
11	5687.20	0.15	0.08	3.0543	SiIV(1402)
11	6276.49	0.06	0.02	3.0541	CIV(1548)
11	6287.08	0.03	0.02	3.0542	CIV(1550)

[1] Spectral resolution

According to the Boltzmann equation, an excitation temperature $T_{\rm ex}$ can be expressed in terms of the column densities N_1 and N_0 in the excited and the ground-state level:

$$N_1/N_0 = g_1/g_0 \exp(-\Delta T_{10}/T_{\rm ex}) \qquad (2)$$

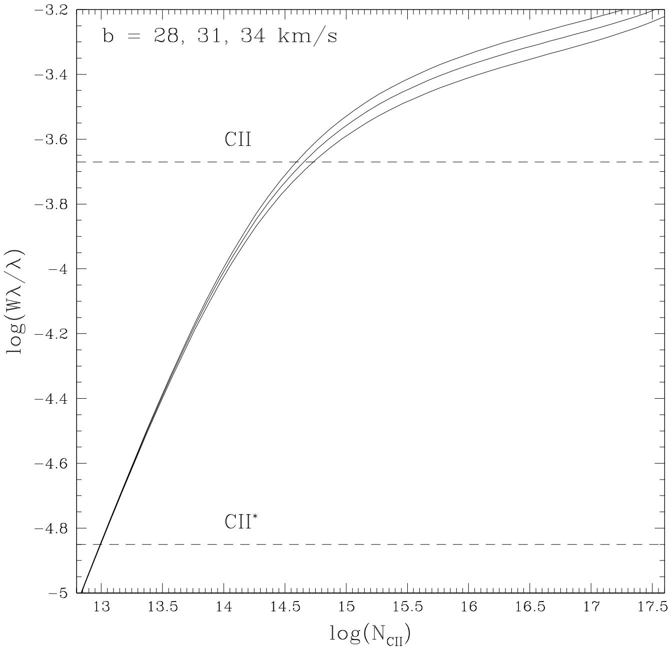

Fig. 3. Theoretical curve of growth for C II, for $b = 28$, 31 and $34\,{\rm km\,s^{-1}}$. The dashed lines are the value of $\log(W_\lambda/\lambda)$ measured for C II and C II*. C II $J = 1/2$ (λ1334.53 Å) and $J = 3/2$ ($\lambda\lambda$1335.66,1335.71 Å) absorption lines have oscillator strength 0.128, 0.013 and 0.115 respectively (Morton 1991).

Table 2. C II fine structure population and excitation temperature.

b(km s^{-1})	28	31	34
N(C II)($\times 10^{14}$ cm^{-2})	5.0 ± 0.3	4.3 ± 0.3	3.5 ± 0.2
N(C II*)($\times 10^{13}$ cm^{-2})	1.0 ± 0.2	1.0 ± 0.2	1.0 ± 0.2
$T_{\rm ex}(K)$	19.6 ± 1.1	20.5 ± 1.2	21.6 ± 1.2

where $k\Delta T_{10}$ is the energy difference between the excited level (1) and the ground level (0). For the fine structure levels $J = 3/2$ and $J = 1/2$ of C II, $\Delta T_{10} = 91.2$ K. The weights g_J are given by $2J + 1$. The derived ratio of column densities, $N_1(J = 3/2)/N_0(J = 1/2)$ corresponds to an excitation temperature of 19.6 K (for $b = 28\,{\rm km\,s^{-1}}$), 20.5 K (for $b = 31\,{\rm km\,s^{-1}}$) and 21.6 K (for $b = 34\,{\rm km\,s^{-1}}$). The excitation temperature of 21.6 K provides a strict upper limit on the temperature of the CMB at the absorber redshift of 3.0543; this upper limit would hold even if the C II* absorption were a spurious effect of the Lyman forest. The CMB temperature at this redshift is predicted to be 11.05 K by the Big Bang model.

The excitation temperature provides a strict upper limit to the CMB temperature as other sources may contribute appreciably to the excitation. In fact, if the C II* absorption is not a spurious effect of the line forest, other mechanisms have to be at play to explain an excitation temperature of at least 19.6 K. The possible excitation mechanisms are reviewed in the next section.

4. Excitation mechanisms

The higher fine-structure states of a ground state multiplet can be populated by (1) particle collisions, (2) direct excitation by infrared photons and (3) indirect excitation by ultraviolet photons.

The equilibrium between the excitation and de-excitation of the C II $J = 1/2 \rightarrow 3/2$ fine structure is described by:

$$N_0\Big(\sum_j \langle\sigma_{01} v\rangle n_j + B_{01} U(\nu_{01}) + \Gamma_{01}\Big) = \qquad (3)$$

$$N_1\Big(A_{10} + \sum_j \langle\sigma_{10} v\rangle n_j + B_{10} U(\nu_{01}) + \Gamma_{10}\Big)$$

Here the collision excitation rate is expressed as $\langle\sigma v\rangle n$, where $\langle\sigma v\rangle$ is the temperature averaged product between the cross-section and the particle velocity and n is the particle density, $j =$ H, e, p. The direct photon excitation rate is expressed as the product between the Einstein probability coefficient for induced transition (B) and the radiation energy density per frequency interval ($U(\nu_{01})$). The UV pumping rate is represented by the coefficient Γ, which includes the UV energy density term. A_{10} is the Einstein probability coefficient for spontaneous transition and for the C II transition $J = 3/2 \rightarrow 1/2$, $A_{10} = 2.29 \times 10^{-6}\,{\rm s^{-1}}$ (Nussbaumer & Storey 1981). For convenience we can divide both sides of Eq. (3) by A_{10} and rewrite:

$$N_0\Big(\sum_j q_{01,j} n_j + b_{01} U(\nu_{01}) + \gamma_{01}\Big) = \qquad (4)$$

$$N_1\Big(1 + \sum_j q_{10,j} n_j + b_{10} U(\nu_{01}) + \gamma_{10}\Big)$$

where $q_{ij,j}$, b_{ij} and γ_{ij} are respectively the collisional excitation rate, the Einstein probability coefficient for induced transition and the UV pumping rate, all divided by A_{10}. In order to establish the importance of the various factors in determining the observed population ratio in the fine structure levels of C II, we need to evaluate the magnitude of each term in this equation.

4.1. Collisional excitation and de–excitation

The particles which may be responsible for collisional excitation are essentially electrons, protons and atomic hydrogen, with different contributions dominating in different temperature and ionization regimes.

The expression for the rate of collisional excitation by electrons is given in Bahcall & Wolf (1968) and, by using the detailed computation of the effective collisional strength given in Hayes & Nussbaumer (1984) and Keenan et al. (1986), one obtains typically $q_{01,e^-} = 0.15\ {\rm cm^3\,s^{-1}}$ for $T_e = 100$ K and $q_{01,e^-} = 0.051\ {\rm cm^3\,s^{-1}}$ for $T_e = 10\,000$ K.

The excitation rates as a function of electron temperature for neutral hydrogen collisions are also given in Keenan et al. (1986) and for $T_e = 100$ K $q_{01,{\rm H}} = 2.8 \times 10^{-4}$ ${\rm cm^3\,s^{-1}}$, for $T_e = 10\,000$ K $q_{01,{\rm H}} = 1.5 \times 10^{-3}\ {\rm cm^3\,s^{-1}}$. The electron collision term will dominate the hydrogen collision term for $n_e \geq 0.002\,n_{\rm H}$ at $T_e = 100$ K and for $n_e \geq 0.03\,n_{\rm H}$ at $T_e = 10\,000$ K. If the plasma is collisionally ionized the electron collision term will be the dominant one for temperature $T > 10\,000$ K, when the fraction of ionized hydrogen becomes significant (Bahcall & Wolf 1968). If the absorbing medium is significantly photoionized and $n_e \geq 0.03\,n_{\rm H}$ the electron collision term will be the dominant term at any kinetic temperature whereas if photoionization is not signficant and $n_e < 0.002\,n_{\rm H}$ hydrogen collisions will dominate.

The C II excitation rate for proton collision becomes comparable to the electron contribution only for temperatures $T_e \geq 10^5$ K (Bahcall & Wolf 1968), but at these temperatures C II is completely destroyed by collisional ionization (Sutherland & Dopita 1993). We will therefore ignore the proton collision contribution.

The collisional de-excitation rate is given by:

$$\langle \sigma_{10,j} v \rangle = \frac{1}{2} \langle \sigma_{01,j} v \rangle \exp(91.2\ {\rm K}/T_e) \qquad (5)$$

As a first approximation, the collisional de-excitation term on the right hand side of Eq. (4) can be omitted if $n_e < 1\,{\rm cm}^{-3}$ or $n_{\rm H} < 10^3\,{\rm cm}^{-3}$.

4.2. Direct IR photon excitation and de–excitation

The photons responsible for directly populating C II fine structure excited levels have a frequency of $\bar{\nu}_{10} = 64.0\,{\rm cm}^{-1}$. Sources of far–infrared photons are the CMB and thermal dust emission. Since the CMB radiation has a Black Body spectrum the direct excitation rate from CMB photons can be expressed as:

$$b_{01} U(\nu_{01}) = 2 \exp(-91.2\ {\rm K}/T_{\rm CMB}) \qquad (6)$$

As we have seen, the Big Bang model predicts the CMB temperature to be 11.05 K at this redshift, moreover the upper limit on the CMB temperature at $z = 4.08$ set by Lu et al. (1996), constrains the CMB temperature empirically. If we assume that the CMB temperature varies monotonically with z:

$$T_{\rm CMB}(z) = T_{\rm CMB}(0)(1+z)^\alpha \qquad (7)$$

then the measure of Lu et al. (1996) gives $\alpha < 1.05$ between $z = 0$ and $z = 4.08$, that is $T_{\rm CMB} < 11.85$ K at $z = 3.0543$. This implies that $b_{01}U(\nu_{01})$ must be lower than $9.1 \times 10^{-4}\ {\rm s}^{-1}$, i.e. only a minor contribution to the derived population ratio in our system, where N_1/N_0 for C II is between 0.02 and 0.03 (Table 2). As a first approximation therefore this term can be neglected and the same is true for $b_{10}U(\nu_{01}) = \frac{1}{2} b_{01} U(\nu_{01})$.

An infrared photon flux with an intensity comparable to the one measured in the Galactic plane (Bennett et al. 1992, Kogut et al. 1996) would correspond to an excitation rate at least 2 orders of magnitude smaller than the one for a CMB photon flux with $T_{\rm CMB} = 10$ K and can be ignored.

4.3. Indirect UV photon excitation and de–excitation

The other important type of photon excitation is UV photon pumping. After the absorption of a photon an atom will usually cascade back through a variety of states, sometimes reaching levels that could not be populated by direct radiative upward transition from the ground state. If m represents all the quantum numbers for one of the upper levels, reached by photon absorption, the transition rate from level 0 to level 1, is given by (Spitzer 1978):

$$\Gamma_{01} = \sum_m B_{0m} U(\nu_{0m}) \epsilon_{m1} \qquad (8)$$

where ϵ_{m1} is the fraction of downward transitions from level m that populate level 1, when the atom first reaches the group of lower levels. For transitions within a multiplet the values of ϵ_{mj} are tabulated (e.g. Allen 1963). To evaluate Γ_{01} we considered all the direct upward transitions from C II ground state $2p^2P^0$, longwards of 900 Å: $^2P^0 \to {}^2P$ ($\lambda\lambda 903, 904$), $^2P^0 \to {}^2S$ ($\lambda\lambda 1037, 1036$), $^2P^0 \to {}^2D$ ($\lambda\lambda 1335, 1334$). For the UV field we adopted the Milky Way spectral energy distribution (SED) given by Black (1987) with a Milky Way intensity at 912 Å of $4.7 \times 10^{-19}{\rm erg\ cm}^{-2}\ {\rm s}^{-1}\ {\rm Hz}^{-1}$ (Mathis et al. 1983), obtaining:

$$\Gamma_{01} = 5.3 \times 10^{-10}\ {\rm s}^{-1}, \qquad (9)$$

that is $\gamma_{01} = 2.3 \times 10^{-41}$. Since the UV pumping de-excitation rate γ_{10} is of the same order of magnitude as γ_{01}, the UV de-excitation term can also be omitted in Eq. (4), for any likely UV flux intensity and SED.

The final shape of the balance equation is:

$$N_1/N_0 = \sum_j q_{01,j} n_j + \gamma_{01} \qquad (10)$$

with the collisional term being dominated by the electrons or hydrogen atoms contribution according to the absorber ionization degree. The UV field can also be expressed in terms of the hydrogen density through the ionization parameter, $U = \phi({\rm H})/n_{\rm H}c$, where $\phi({\rm H})$ is the surface flux of hydrogen-ionizing photons. If we assume a UV flux having the Milky Way SED given in Black (1987), $\gamma_{01} = 0.7 n_{\rm H} U$ and:

$$T_{\rm ex} = \frac{-91.2\ {\rm K}}{\log[0.5(\sum_j q_{01,j} f_j n_{\rm H} + 0.7 n_{\rm H} U)]} \qquad (11)$$

where f_j is the fraction of particle j with respect to the hydrogen density.

5. Results

From the ratio C II/C IV observed in our data at $z = 3.0543$ SOM derived $\log U \geq -3.2$ and assuming solar abundance ratios a consistent fit to the data was obtained with $\log U = -2.8$ and $Z \sim 0.001 Z_\odot$ (SOM). As shown in Table 2, the derived excitation temperature for the levels $J = 3/2$ and $J = 1/2$ of C II for the damped Lyα absorber toward Q0000−2619 at $z = 3.0543$ is between 19.6 and 21.6 K. We can use these values and expression 11 to constrain the density and UV flux at

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[1] Keenan et al. (1986) obtained $\Gamma_{01} = 2.4 \times 10^{-10}{\rm s}^{-1}$ by using the UV intensity field and SED given in Gondhalekar et al. (1980)

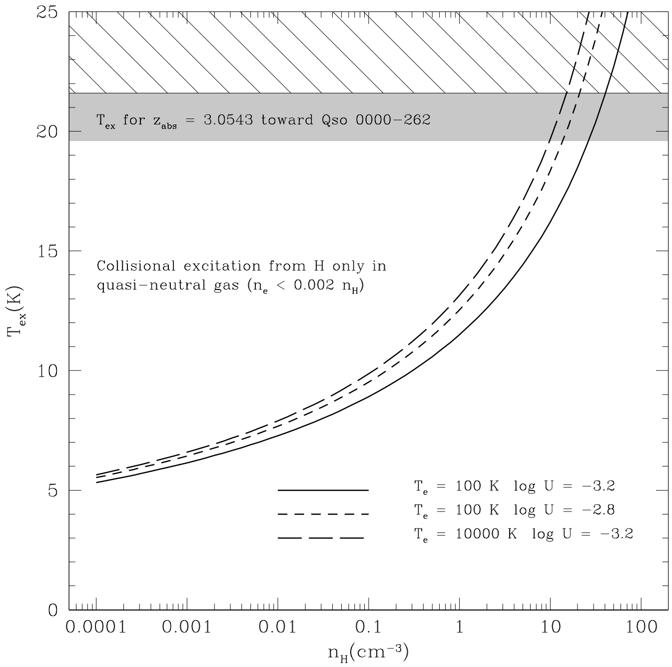

Fig. 4. The fine structure excitation temperature of C II as a function of the absorber density, under the assumption that the absorber is a quasi-neutral gas and collisional excitation is due to atomic hydrogen. The shaded area corresponds to the range of the derived excitation temperature for the damped Lyα absorber at $z = 3.0543$ toward Q0000−2619. The continuous horizontal line gives the upper limit on the excitation temperature and implies that the density of this system must be lower than 40 cm^{-3}.

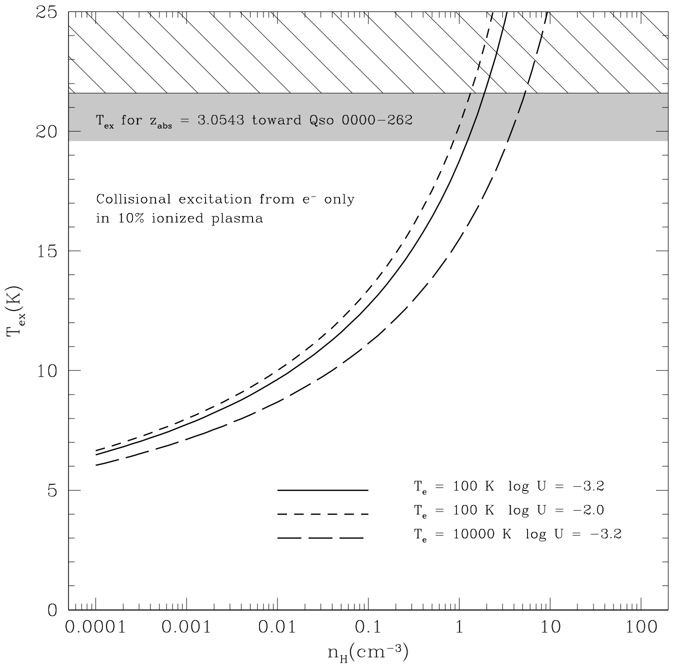

Fig. 5. Fine structure excitation temperature of C II as a function of the absorber density, under the assumption that 10% of the gas is ionized and collisional excitation is due to electrons. The shaded area corresponds to the range of the derived excitation temperature for the damped Lyα absorber at $z = 3.0543$ toward Q0000−2619.

the absorber. However, in order to evaluate Eq. (11), we need to make an assumption about the ionization degree of the gas in the absorber. Since the efficiency of the electron and hydrogen collisional is very different, the collisional excitation term depends critically on the gas ionization degree. To illustrate this we will consider two limiting cases for the absorbing cloud: a quasi-neutral gas, for which $n_e < 0.002\, n_{\rm H}$, and a 10% ionized plasma.

In Fig. 4 the result of Eq. (11) is plotted, in the case of a quasi-neutral gas, where the collisional excitation is due to collisions with atomic hydrogen. The horizontal continuous line gives the upper limit on the excitation temperature. The points where the curves intersect this line correspond to the density values above which the collisional excitation would be such that the excitation temperature would be higher than the measured value. This is a forbidden region. The density of the absorber must thus be lower than 40 cm^{-3}. This is a strict upper limit. Higher values of the ionization parameters would move the intersection point to lower density values. If the C II* absorbing line is a spurious effect of the Lyman forest, then the C II* equivalent width must be lower than the one we measured and the upper limit on the density must be lower; increasing the cloud kinetic temperature also moves the density-limit to lower values. With $\log U = -2.8$ the upper limit on the absorber density is 20 cm^{-3}. The shaded area in the figure corresponds to the interval of the derived excitation temperature for the absorber toward Q0000−2619. The intersection of the long-dashed curve with the lower bound of this area provides a lower limit of 10 $\rm cm^{-3}$ to the density of the system, if the gas is quasi-neutral ($n_{\rm e} < 0.002$ $\rm n_H$).

In Fig. 5, C II fine structure excitation temperature is plotted as a function of the absorber density (like in Fig. 4) this time for the case of a 10% ionized plasma. Electron collisions dominate collisional excitation in this case and because electron collisions are more efficient than atomic collisions, lower gas densities are required to achieve the same level of C II fine structure excitation. From Fig. 5 one derives that with ionization parameter $\log U = -3.2$ the range of possible gas densities is between 1 and 5 $\rm cm^{-3}$. We note however that the exact value of the ionization parameter has little effect on the position of the intersect for the curves in Fig. 5. For any $\log U \leq -2.0$ (thick–dotted line) we obtain that $n_{\rm H}$ must be greater than 0.7 $\rm cm^{-3}$, with the same 10% ionization and temperature range. An ionization parameter of -2.0 at a density of 0.7 $\rm cm^{-3}$ correspond to a UV flux at 912 Å of 20 times the Galactic UV field (if the same SED is assumed).

These simple considerations allow us to constrain the absorber density to the range of $0.7 - 40$ $\rm cm^{-3}$, for a gas kinetic temperature between 100 and 10 000 K and ionization degree between 0 and 10%. An ionization degree between 0 and 100% would imply possible absorber densities in the range $0.1 - 40$ $\rm cm^{-3}$. An ionization parameter $\log U = -3.2$ and the density range $1.0 - 40$ $\rm cm^{-3}$ imply a UV field with H-ionizing photon flux ranging from 2 to 80 times the Galactic H-ionizing flux.

The upper value is a strict upper limit on the intensity of the UV flux in the absorbing system.

6. Discussion

The observed excitation temperature (or upper limit) of C I and C II fine structure has been used to constrain the density of the absorbing systems by several authors and the published values are very similar to the upper limit derived here. Songaila et al. (1994) observed absorption from the first fine-structure level of C I in a cloud belonging to a damped Lyα system at a redshift of 1.776, towards the quasar Q1331+170. They measured an excitation temperature of 7.4 ± 0.8 K, while the CMB temperature at this redshift is predicted to be 7.58 K. From their measure they derive a 1σ upper limit for the cloud density of $n_{\rm H} = 7\,{\rm cm}^{-3}$ for a cloud kinetic temperature of 100 K and of $n_{\rm H} = 4\,{\rm cm}^{-3}$ for a cloud kinetic temperature of 1000 K, given that the CMB is at the predicted temperature. Ge et al. (1997) detected absorption from the ground state and the excited state of C I and C II in the $z = 1.9731$ damped Lyα system of Q0013−004. They measure an excitation temperature of 11.6 ± 1.0 K for C I and of 16.1 ± 1.4 K for C II. They use the C II excitation temperature to constrain the density of the cloud to be $n_{\rm H} = 21.0 \pm 9.6\,{\rm cm}^{-3}$ if the cloud kinetic temperature is of 100 K and $n_{\rm H} = 4.5 \pm 2.0\,{\rm cm}^{-3}$ for a kinetic temperature of 1000 K. With these densities and a photo-ionization parameter $\log U = -3.5$, their estimate of the H-ionizing photon flux ranges between 3.6 and 17 times the Galactic H-ionizing flux. These values are then combined with the measured C I excitation temperature to derive an upper limit of 7.9 ± 1.0 K or 10.6 ± 1.0 K respectively on the temperature of the CMB at this redshift, with the first value as their best guess, based on photo-ionization modeling of the absorbing cloud.

To constrain the density and UV field of the $z = 3.0543$ absorber of Q0000−2619 we have considered a gas kinetic temperature in the range 100−10 000 K. There are not many observational constraints on the gas temperature of damped Lyα systems. Cloud photo-ionization models can reproduce the observational data with the gas temperature ranging from 15 to 10 000 K (Chaffee et al. 1988). However observations of 21 cm absorption line from damped Lyα systems at $z \sim 3$ obtained lower limits on the neutral hydrogen spin temperature of the order of 1000 K (Carilli et al. 1996; Kanekar & Chengalur 1997). This temperature must not be taken as a measure of the gas mean temperature, but as an indication of the presence of warm gas in the absorbing system. The typical spin temperature measured in the Galactic clouds is $T_s \sim 100$ K (Braun & Walterbos 1992). Despite the Galactic cloud spin temperature not being directly comparable with the measure of the spin temperature in a damped Lyα system, a $T_s \geq 1000$ K suggests that for a given total neutral hydrogen column density, the damped Lyα system contains a larger percentage of warm phase gas ($T \sim 8000$ K) than is seen in typical Galactic lines of sight (Carilli et al. 1996).

The constraints on the density of the damped system can be used to estimate its size. In the simplistic hypothesis that the absorber is homogeneous a neutral hydrogen column density of $1.5 \pm 0.5 \times 10^{20}\ {\rm cm}^{-2}$ and a density range of $0.7 - 40\,{\rm cm}^{-3}$ imply that the size of the system along the line of sight is between 1−100 pc. If the filling factor is significantly lower than 1, this estimate is a lower limit. It has been proposed that the DLAs with neutral hydrogen column density N(H I)$\geq 2 \times 10^{20}\ {\rm cm}^{-2}$, are large and massive galactic disks (e.g., Prochaska & Wolfe 1997) with typical sizes of a few kpc. The constraints we derived for this damped system at $z = 3.0543$ indicate that the size of this absorber is of the order of the size of giant hydrogen clouds in our galaxy or of a galactic disk seen face-on. If this is not a galactic disk, at these redshift, systems of this scale could be protogalactic clumps, that is the building blocks of the various type of galaxies (ellipticals, spirals, etc.) that are observed at present epoch (Khersonsky & Turnshek 1996, Haehnelt et al. 1998).

7. Conclusion

In the damped Lyα system at $z = 3.0543$ of Q0000−2619 studied by SOM C II absorption was detected. In this paper we report the detection at 3.5σ of absorption from the excited fine structure level of C II at $z = 3.0543$. From the measure of the equivalent width of the two lines we derived an upper limit of 21.6 K on the fine structure excitation temperature. This value provides a strict upper limit on the temperature of the CMB at $z = 3.0543$, which at this redshift is predicted to be 11.05 K. We then used the derived relative populations of the fine structure levels of C II to set constraints on the absorber density and on the UV field in the absorbing cloud. Assuming an ionization degree ranging from 0 to 10%, a gas kinetic temperature between 100 and 10 000 K and a UV field with a Milky Way spectrum, the density of the absorber is constrained to be between 0.7 and 40 cm^{-3} and the H-ionizing flux between 1×10^7 and $8 \times 10^8\ {\rm cm}^{-2}{\rm s}^{-1}$, that is between 1 and 80 times the intensity of the Galactic UV field. The upper limits hold even if the detected absorption from C II* at $z = 3.0543$ is seriously contaminated by Lyman forest absorption. If the damped Lyα system is assumed to be homogeneous, a density value between 0.7 and 40 cm^{-3} constrains the size of this absorber at $z \sim 3$ to be between 1 and 100 pc in the direction of the line of sight.

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