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LETTER

Letter to the Editor

Low deuterium abundance in the $z_{\rm abs}$=3.514 absorber towards APM 08279+5255*

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Abstract. A high-resolution, high signal-to-noise HIRES-Keck spectrum of APM 08279+5255 reveals a feature in the HI Lyα profile of the $z_{\rm abs}$=3.514 absorber at the expected position of the corresponding DI Lyα line. The absorber shows a relatively simple velocity structure, with a major component detected in several metallic lines including CII, CIV, SiII, SiIII and Si IV. Modeling of the hydrogen column density with the minimum number of components yields $\frac{D}{H} \approx 1.5 \times 10^{-5}$. However, a more complex structure for the hydrogen cloud with somewhat ad hoc components would allow a higher $\frac{D}{H}$. The system has a very low metallicity with [Si/H] ≈ -3.5 and [C/H] ≈ -4.0 and is therefore representative of essentially unprocessed material, with a deuterium abundance close to the primordial value. The present analysis favours the low D/H value of $\frac{D}{H}$ =$3.39 \pm 0.25 \times 10^{-5}$ measured towards QSO 1009+2956 and QSO 1937-1009 (Burles & Tytler 1998a, 1998b) as the fiducial value of deuterium at high redshift.

Key words: cosmology: observations – cosmology: early Universe – galaxies: quasars: individual: APM 08279+5255 – nuclear reactions, nucleosynthesis, abundances

1. Introduction

Deuterium, together with ^{3,4}He and ^{7}Li is one of the few elements produced by nuclear reactions in the first minutes after big bang (Wagoner, Fowler & Hoyle 1967), with the difference that for deuterium SBBN is the only significant source. Deuterium yields are the most sensitive to the nuclear density at the nucleosynthesis epoch making deuterium the most sensitive baryometer among the primordial light elements.

Deuterium is measured in the LISM and extrapolation to the primordial value requires a modeling of the Galactic chemical evolution. The intrinsic uncertainties in this extrapolation can be avoided by direct deuterium observations of almost primordial material in the high redshift/unevolved absorption systems (Adams, 1976). This was in fact achieved only recently for a few systems, but with conflicting results and abundances which differ by almost one order of magnitude. At present the number of systems analyzed in detail is evenly distributed between two possibilities. Two systems provide a *high* D/H value at $\approx 2 \times 10^{-4}$ (Songaila et al. 1994, Carswell et al. 1994, Webb et al. 1997) and other two systems a *low* abundance at 3.39 $(\pm 0.25) \times 10^{-5}$ (Burles and Tytler 1998a,1998b).

It has been pointed out that the high deuterium case is always prone to the possibility of a contamination of the deuterium line with an Lyα interloper. For the lower deuterium case either the hydrogen column density may have been overestimated or a special chemical evolution, with large astration of D, may have occurred in these systems. The handful of detections found so far does not allow a choice between the different cases on the basis of simple statistics. The paucity of suitable systems is due to the fact that only a narrow range of HI column densities allows the detection of the DI line. At too low densities the DI line is too weak for detection, whereas at too high densities the line is washed out by the saturation of the HI line. Moreover, a suitable system must have a rather simple velocity structure, ideally a single cloud system, which is obviously rare. Burles & Tytler estimated that only about 1 out of 30 QSO's satisfies these conditions. Here we present a new system which shows these characteristics and a measure of deuterium which supports the case for low primordial deuterium.

2. Observations and analysis

The spectra of APM 08279+5255 have been obtained with the Keck I telescope and the HIRES spectrograph by Ellison et al. (1999) and made available for the astronomical community.[1] An analysis of these spectra with details on the reduction pro-

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[1] ftp://fttp.ast.cam.ac.uk/pub/papers/APM08279

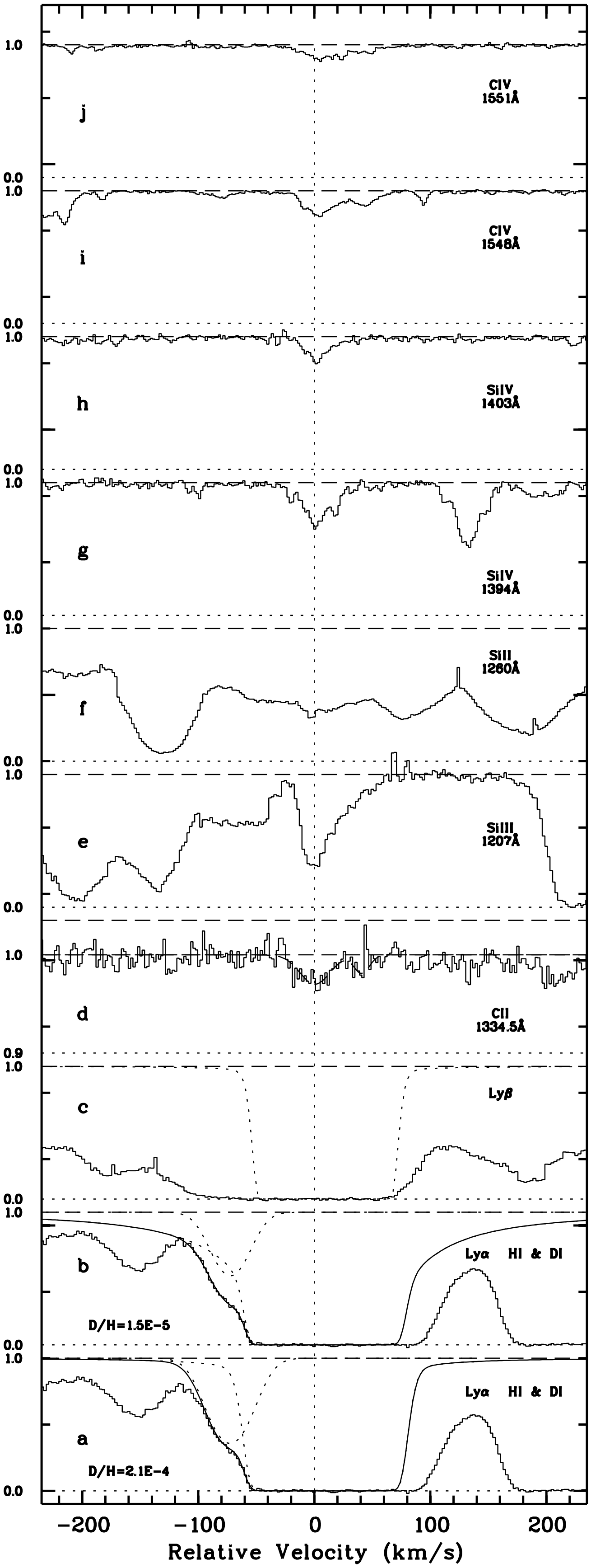

Fig. 1a–j. Absorption system at z_{abs}= 3.51374. See text for details.

Table 1. Column densities.

Element	λ_{lab}(Å)	z_{abs}	log N(X)	b
CII	1334.5323	3.51374	12.24 ± 0.05	17.8 ± 1.8
CII	1334.5323	3.51435	11.85	L
SiII	1260.4221	3.51368	11.67	L
SiIII	1206.500	3.51376	12.77	14.7±0.5
DI	1215.3394	3.51387	13.27 ± 0.08	21.2 ± 2.3
HI	1215.6700	3.51387	18.09 ± 0.03	21.0 ± 0.6

L Linear part of the curve of growth

cedure and a log of observations can be found in the original paper. This QSO is one of the brightest known also by virtue of gravitational lensing magnification. The image of this QSO reveals two components of similar intensity separated by about $0''.4$ (Irwin et al. 1998).

Ellison et al. (1999) describe the absorber at z_{abs}=3.514 and identify the high ionization species of SiIV and CIV associated with the system. A total of five components are resolved in SiIV and two in CIV, with both ions showing a main component at redshift $z_{abs} = 3.5138$.

Our attention was caught by the feature on the blue wing of the Lyα profile of the displayed in Fig. 4 of Ellison et al. , which we suspected to be a D line. In addition we have identified features due to CII 1334.5 Å, SiII 1260.4 Å and SiIII 1206.5 Å(see Fig. 1). The CII and SiII lines are very faint and the detection has been possible thanks to the quality of the HIRES spectrum at this wavelength (S/N $\sim$ 125). The SiII 1193.3 Å absorption may also be present, albeit strongly blended with a lower redshift Lyα absorber. Lyβ falls in the available spectral range but is, unfortunately, severely blended with local Lyα clouds (Fig. 1, panel c).

The CII profile shows a double component with the main absorption occurring at redshift z_{abs}=3.51374, namely the redshift at which the main features of CIV ($z_{abs} = 3.51380$) and SiIV ($z_{abs} = 3.51376$) also occur, as measured by Ellison et al. (1999). A third CII 1334 Å absorption at about +200 km s^{-1} is associated to another Lyα cloud redwards of our system. The CII and SiII ions are better tracers of neutral hydrogen (and deuterium) than higher ionization species in Lyman limit systems (Prochaska, 1999).

To fit the observed profiles we used the `fitlyman` package (Fontana & Ballester 1995) in `MIDAS`. The results for the analysis are reported in Table 1 and the fits are shown in Fig. 1. We model the Lyα absorption profile assuming a dominant component in HI as seen in all the metallic lines. Since the D line affects the blue wing of the absorption profile we restricted the fit to a narrow window ($-125.5, +28.1$ km s^{-1}) which includes only the blue wing. In the fitting procedure the central wavelength, broadening and column density of the single component with the associate D are left as free parameters with the only restriction that z_{abs} must be the same for DI and HI. The best fit (χ^2=0.28) gives a deuterium abundance of $\frac{D}{H}$=$1.5 \pm 0.3_{stat} \times 10^{-5}$. The statistical error follows from the fit and reflects only the data quality; as discussed below, the error budget is dominated by systematics related to the cloud modeling. The column densities, b parameters, $z_{\rm abs}$ and 1σ errors are given in Table 1. The resulting redshift ($z_{\rm abs}$ = 3.51387) is in agreement with the most intense component of the metallic ions, thus supporting the identification of deuterium. Fig. 1, panel b, shows the data and the fitted profile (thin solid line). The dotted lines show the individual synthetic profiles of DI and HI.

Remarkably, the HI and DI broadening velocities are consistent with the b value of the CII 1334 Å absorption of the same system. This suggests that the HI, DI and CII absorptions are actually tracing the same gas, where macroscopic, rather than thermal, motions dominate the line broadening. The broadening for the metal lines is larger than usually seen in blend-free absorbers towards QSOs. An additional source of broadening may be the lensing, since both images of the lens, separated by about $0''.4$ are present in the spectrograph slit ($0''.86$)and recorded simultaneously.

The $\frac{D}{H}$ abundance derived here should be considered as a lower limit since we know from Si IV and C IV that other components might be present. Adding new components to the fit, although of lower column densities, would inevitably slightly lower the H I column density for the major component. Additional components, at slightly higher redshift, are required to reproduce the extra absorption on the red wing of Lyα. In any case this red component is much smaller than the dominant one since its Lyβ is much weaker.

To illustrate how these effects can be important in Fig. 1, panel a, we show a model for the Lyα line with a lower hydrogen column density (log N(HI) = 17.20) and a slightly higher deuterium column density (log N(D I) = 13.52), which corresponds to a ratio of $\frac{D}{H}$=2.1×10^{-4}. This fit has been performed in a smaller window ($-105.3, +28.1$ km s^{-1}) and the χ^2 is 0.35, i.e. comparable to the former case. However the fit fails to reproduce the edge of the blue wing shortwards the deuterium feature, because of a less prominent hydrogen Lyα damping wing. An additional hydrogen cloud with relatively low column density present at this position is required to provide a good fit to the entire absorption. Since this solution requires an ad hoc absorption at the right place we consider the former solution more probable. Unfortunately Lyβ cannot help to further constrain the H I column density. In Fig. 1, panel c, the observed Lyβ is shown together with the synthetic spectrum computed with the parameters derived from Lyα fitting to show that consistency is achieved with the predicted Lyβ sitting in a strongly absorbed region. The blue wing of Lyβ is clearly contaminated by lower redshift Lyα interlopers and carries no useful information on the absorption system. Observations of higher order terms of the Lyman series, if free from blends, will certainly be important to further constrain the H I column density.

3. Discussion

Deuterium measurements in high redshift absorbers of low metallicity provide the best estimate of the primordial deuterium. Relatively high deuterium ($\frac{D}{H} \approx 2\times10^{-4}$) has been measured in the system at redshift $z_{\rm abs}$=3.32 towards QSO Q0014-813 (Songaila et al. 1994, Carswell et al. 1994). However the discovery of a Lyα contaminant led Burles Kirkman and Tytler (1999) to argue against the possibility to measure D/H in this system. A similarly high D/H value has been found by Webb et al. (1997) in the system at $z_{\rm abs}$=0.7 towards QSO 1718+4807 (but see Tytler et al. 1999). Other tentative and somewhat more uncertain detections, all giving high $\frac{D}{H}$ of $\approx 10^{-4}$, have been reported by Carswell et al. (1996) and Wampler et al. (1996). In contrast with the high values of $\frac{D}{H}$, Burles & Tytler(1998a,1998b) found $\frac{D}{H}$ about one order of magnitude lower in two Lyman Limit Systems towards Q1937-1009 and Q1009+2956, respectively. Both systems have similar abundance, with an average of $\frac{D}{H}$ =$3.39(\pm0.25)\times10^{-5}$. Levshakov et al. (1998) derived $\frac{D}{H} \approx 4.1$–4.6×10^{-5} by using the same observational data of Tytler and collaborators by accounting for spatial correlations in the large scale velocity field. A new upper limit of D/H $< 6.7\times10^{-5}$ in the Lyman limit system at $z = 2.799$ towards QSO 0130-4021 has been recently presented by Kirkman et al. (1999).

In this letter we have shown that the feature on the blue wing of the HI Lyα absorption at $z_{\rm abs} = 3.514$ in the spectrum of APM 08279+5255 can be identified with confidence as the DI line of the main component of the absorber. The absorber is an excellent candidate for the deuterium analysis since it shows a relatively simple structure, the appropriate column density and a low metallicity. The [CII/HI] abundance[2] derived for the system is -2.4, and the [SiII/HI] is -1.97 using the solar abundances of Anders and Grevesse (1989) . However ionization corrections are not negligible. From the column densities of Si II, Si III and Si IV, a CLOUDY (Ferland, 1995) photoionization model computed by assuming N(HI) $= 10^{18.1}$ cm^{-2} and a Haardt-Madau spectrum at redshift 3.5 (Haardt & Madau, 1996) provides [Si/H]$= -3.5$ and log U $= -2.0$ (Burles, private communication). Carbon provides a worse fit, but with the optimal solution obtained for [C/H]$= -4.0$, consistent with the typical overenhancement with respect to Si observed in the Pop II Galactic halo stars.

A matter of concern in the analysis of the spectrum is the possible influence of the lensing on the derived abundances (see for instance Rauch et al. 1999). The possibility than only one light path intersects the absorber is ruled out by the fact that the core of the Lyα absorption is at zero intensity level (Fig. 1). The transverse size at $z = 3.514$ depends on the redshift of the lens, which is not known. Candidates are the damped system at $z = 3.07$, and the Mg II systems at $z = 1.81$ and $z = 1.18$ (Irwin et al., 1998). If the lens is the damped system the transverse size is $\simeq 0.99$ kpc h_{50}^{-1} ($\Omega_0 = 1$). This size becomes as small as $\simeq 0.11$ kpc h_{50}^{-1} if the lens is at $z = 1.18$. The widths of metal lines set an upper limit only ≈ 10 km s^{-1} on the velocity difference between the slabs sampled by the two light paths. Therefore a small transverse size, with the lens at $z = 1.18$, is favoured, in agreement with the suggestion of Irwin et al. (1998). Since intrinsically large variations in D/H between different regions

[2] Using the standard definition [X/H]= log (X/H) - log (X/H)$\odot$

are unlikely and we have no evidence of large variations in radial velocities, the D/H abundance analysis should not be affected by the lensing.

Our derived $\frac{D}{H}$ abundance is of 1.5 $\times 10^{-5}$, about a factor of two lower than the value of Burles & Tytler (1998a, 1998b). The case discussed here supports the low deuterium value as the fiducial abundance in high redshift systems. The present value is of lower accuracy of the cases discussed by Burles and Tytler (1998a,1998b) considering possible large systematic errors in the hydrogen column density. Larger values are not completely ruled out and the measure may be considered as a lower limit. Considerations based on the consistency among the various primordial elements also suggest a deuterium value somewhat higher of what is measured here. From BBN calculations performed with the Kawano (1992) code by assuming 3 massless neutrino families, the baryon to photon ratio ($\eta = n_b/n_\gamma$) implied by $\frac{D}{H} = 1.5 \times 10^{-5}$ is of 8.4×10^{-10}. This η implies a helium abundance (in mass) of Y = 0.251 and a lithium abundance of $\frac{^7\mathrm{Li}}{\mathrm{H}} = 8.3 \times 10^{-10}$. Making our D measurement consistent with the Li plateau value of $\simeq 1.7 \times 10^{-10}$ requires a factor of $\simeq 5$ Li depletion in Pop II dwarf stars. This depletion is greater than presently allowed either by observations (Bonifacio & Molaro 1997) or theory (Michaud & Charbonneau 1991). The high value implied for Y is also not compatible with either the determinations of Pagel et al. (1992) or Izotov & Thuan (1998) and there have been no other claims of a primordial He in excess of these values.

Most of the uncertainty in the present measure of $\frac{D}{H}$ is due to the uncertainty in the hydrogen column density, which is constrained only by the Lyα line. Additional observations of the QSO at shorter wavelengths are needed to detect higher members of the Lyman series. These may allow to further constrain the H I column density making possible in the future a more valuable deuterium measurement in the $z_{\rm abs} = 3.514$ absorber.

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