Probing Galaxies through Quasar Absorption Lines
Proceedings IAU Colloquium No. 199, 2005
P. R. Williams, C. Shu, and B. Ménard, eds.

doi:10.1017/S1743921305003030

A damped Lyα system along two lines of sight at $z = 0.93$

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Abstract. HE0512−3329 is a gravitationally-lensed double QSO with damped Lyα systems observed at $z = 0.931$ in front of both QSO images (DLA A and B). We have obtained spatially resolved HST STIS and optical VLT UVES spectra of both QSOs in order to study differences in the metal abundances across the lines of sight. We detect substantial differences, of roughly 0.5 dex, in both [Mn/H] and [Fe/H], on a transverse scale of 5 h^{-1} kpc. Differential dust depletion appears as the most plausible explanation.

1. Measurements

Fig. 1 shows the UVES spectra of A (left panels) and B on a velocity scale relative to $z = 0.9313$. The only non-saturated transitions available in the A spectrum are Mn II $\lambda 2576, 2594$, Fe II $\lambda 2586$, and probably Mg I $\lambda 2852$. In Lopez *et al.* (2005) [Paper I] we assess the non-saturation character of the 2586 line. For DLA A we get $\log N(\text{Mn II}) = 12.58 \pm 0.05$ ([Mn/H] $= -1.44 \pm 0.09$ dex), $\log N(\text{Fe II}) = 14.47 \pm 0.06 \pm 0.04$ ([Fe/H] $= -1.52 \pm 0.11$ dex), so [Mn/Fe] $= 0.08 \pm 0.07$. The only non-saturated transitions available in the B spectrum are Mn II $\lambda 2576, 2594$. We obtain $\log N(\text{Mn II}) = 13.02 \pm 0.01 \pm 0.04$ ([Mn/H] $= -0.98 \pm 0.09$ dex). The two Fe II transitions in the UVES spectrum are saturated, but from further analysis in Paper I we conclude that the excess metallicity in B might be in line with that for Mn II, so that [Mn/Fe](A) $\approx$ [Mn/Fe](B).

The H I column density comes from Lyα as observed in the STIS spectra. Voigt profile fits yielded $\log N(\text{H I}) = 20.49$ (A) and 20.47 ± 0.08 dex (B).

2. Consequences

There are currently only 5 measurements of metallicity in DLAs at $z < 1$ (Prochaska *et al.* 2003). The $z = 0.9313$ DLA in HE0512−3329 adds an important value to the overall sample at an epoch for which models of chemical evolution can distinguish different kinds of galaxy morphologies. The metallicity derived for DLA A, [Fe/H] $= -1.52$, is representative of the $z \approx 1$ sample, and the data on Mn and Fe abundances either in A or B are consistent with a low-metallicity and dusty absorber.

Because the galaxy hosting the $z = 0.9313$ absorbers is also the likely lensing galaxy, DLA A and B then probe the ISM on two opposite sides and the impact parameters cannot be much larger than 2.5 h^{-1} kpc. These small distances are counter-examples to the claim that lines-of-sight close to DLA galaxies are missing from DLA samples due to dust obscuration.

2.1. *Two damped Lyα systems, one redshift*

The present data on HE0512−3329 are consistent with transverse differences in *both* [Mn/H] and [Fe/H] at $z = 0.9313$. For Mn, this gradient amounts to 0.46 ± 0.13 dex (fit and systematic errors) on a spatial scale of $\sim 5\ h^{-1}$ kpc and with sight-line A passing though the more metal-deficient gas-phase. Our analysis shows that a similar gradient is present also in [Fe/H], although the observational uncertainties are larger. Interestingly, [Mn/Fe](A) $\approx$ [Mn/Fe](B), which, if not greatly affected by dust —see below— suggests chemical uniformity across the lines of sight at much larger distances than probed before (e.g. Churchill *et al.* 2003) and in accordance with uniformity along the lines of sight (Lopez *et al.* 2002; Prochaska 2003).

2.2. *Dust*

The [Mn/Fe] ratio in DLA A is among the highest at all redshifts (Ledoux *et al.* 2002), and the only explanation for this high value is significant dust depletion in DLA A. We have not been able to accurately quantify [Mn/Fe] in DLA B, but the present data are consistent with a similar ratio as in DLA A. Although this Solar ratio *might* be taken as evidence for dust also in B, the cosmic scatter of [Mn/Fe] at [Fe/H] = −1 is larger and there are some examples of high [Mn/Fe] even at low [Zn/Fe].

2.3. *Gradient in metallicity?*

A real metallicity gradient appears at a first glance as an attractive explanation for the transverse differences in [M/H]. In nearby spirals metallicity gradients as a function of galactocentric radius are found in the range −0.04 to −0.20 dex kpc^{-1} (e.g. Vila-Costas & Edmunds 1992). However, arguments from the lens-system geometry show that the absorbing regions must lie more or less equidistant from the galaxy centre, so a simple model of varying metallicity with radius cannot explain the differences observed at similar impact parameters. This is consistent with the similar H 1 in DLA A and B.

2.4. *Differential dust depletion/reddening*

Alternatively, differential dust depletion offers a plausible explanation of the abundance differences. The abundance pattern of DLA A closely resembles that of the Galactic Warm Halo, with Mn and Fe depleted by a factor of 3–4. In consequence, the different Fe and Mn abundances can be explained by lines of sight crossing Warm Halo-like regions that are subject to distinct dust depletion factors, with DLA B being less dusty.

In this scenario, the observed differences of [M/H] in HE0512−3329, where M are refractory elements, become a different and direct confirmation for the hypothesis of dust-depletion in DLAs. Moreover, we would expect differential reddening between QSO A and B. The STIS spectra (Wucknitz *et al.* 2003) in fact show that extinction along the line of sight to QSO A is greater. As a rough estimate, $\log N(\mathrm{H\,1}) = 20.5$ dex leads to an expected colour-excess of $E(B-V) = 0.06$ if dust is present. With an SMC type extinction curve we get $E(1250-V)/E(B-V) = 14$, which gives $A(\lambda_{\mathrm{obs}} = 2400\text{Å}) = 0.84$ mag or an extinction factor of 2.2. This agrees with the $f_{\mathrm{A}}/f_{\mathrm{B}}$ ratio from the STIS spectra plus an additional contribution due to micro-lensing.

https://doi.org/10.1017/S1743921305003030 Published online by Cambridge University Press

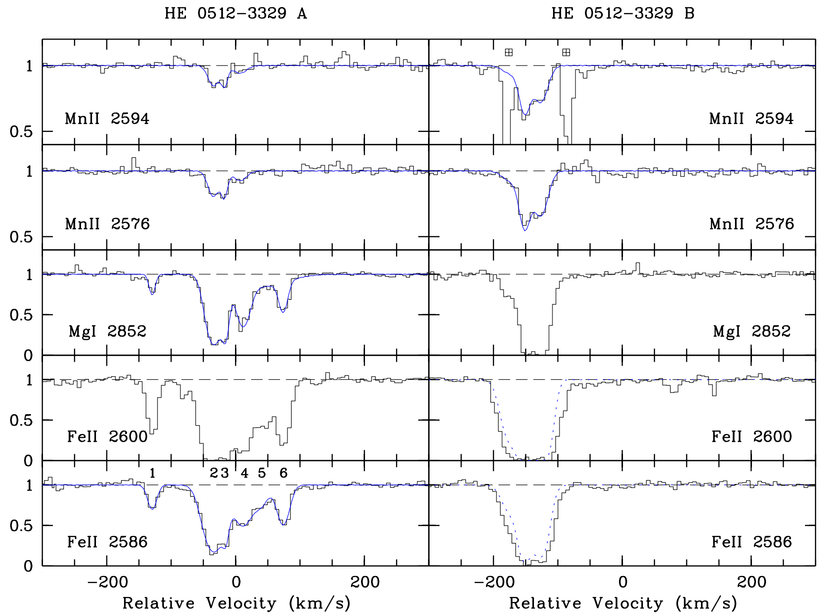

Figure 1. Absorption lines observed in the UVES spectra of DLA A (left panels) and B at FWHM = 9.7 km s^{-1}. The zero-point velocity corresponds to $z = 0.9313$.

2.5. *Implications for [M/H] vs. z*

Regardless of the extent to which dust-depletion is acting differentially to alter [Fe/H], one key consequence of the sight-line differences in HE0512−3329 is their connection to the cosmic spread in [M/H]. The present sample of metallicity measurements at all redshifts is distributed within [Fe/H] = 0-3 dex, a consequence of a mild but readily noticeable evolution of metals over a Hubble time. However, even sub-samples within narrow redshift bins show a large scatter of more than 1 dex in non dust-depleted abundances; different star formation histories must contribute to the inhomogeneity. In the overall context this would mean that the “patchiness” of star formation in a given galaxy dominates which type of DLA we observe; furthermore, this stochastic ingredient could be more marked at higher redshifts, where mixing has had less time to occur. In conclusion, part of the cosmic scatter must be due to these local effects which probably cannot be studied comprehensively. Observations of non-refractory elements in DLA A and B will offer important new clues to this problem. SL acknowledges support from FONDECYT grant N^{o}1030491.

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