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HIGH METALLICITY AND MOLECULAR HYDROGEN IN DAMPED LYMAN-ALPHA SYSTEMS

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Abstract. A systematic search for molecular hydrogen (H_2) in damped Lyman-α systems (DLAs) at high redshift, $z_{\rm abs} > 1.8$, was recently carried out with UVES at the ESO Very Large Telescope (Ledoux et al. 2003). The output of this survey suggested that high metallicity is a good criterion for the presence of H_2 in DLAs. We systematically observed with UVES DLAs with the highest metallicities and constructed a new sample of 18 high redshift DLAs/sub-DLAs with N(H I) $> 10^{19.5}$ cm^{-2} and metallicities $-1.3 \leq$ [X/H] < -0.3, with X=Zn, S or Si. We found two new H_2-bearing DLAs toward the quasars Q 2343+125 and Q 2348−011. We show that the fraction of DLAs with large molecular fractions, $\log f > -4$ (with $f = 2N({\rm H_2})/(2N({\rm H_2}) + N({\rm H\,I}))$), is as large as 50% for [X/H] > -0.7, when it is only $\sim$ 15% in the overall sample ($-2.5 <$ [X/H] < -0.3). This demonstrates that high metallicity is an important factor for the presence of molecular hydrogen in the diffuse neutral gas of high-redshift galaxies.

1 Introduction

High-redshift damped Lyman-α systems (DLAs) detected in absorption against QSO spectra are characterized by large neutral hydrogen column densities, $N({\rm H\,I}) \geq 2 \times 10^{20}$ cm^{-2}, similar to what is measured through local spiral disks (Wolfe et al. 1986). DLA galaxies are believed to be the reservoir of neutral gas in the Universe (e.g. Prochaska et al. 2005). A major step forward in understanding the nature of DLAs through their molecular content has recently been made via the unique high-resolution and blue-sensitivity capabilities of UVES at the VLT. In the course of the first large and systematic survey for H_2 at high redshift, we have searched for H_2 in DLAs down to a detection limit of typically $N({\rm H_2}) = 2 \times 10^{14}$ cm^{-2} (e.g. Ledoux et al. 2003). The result of this survey is that H_2 is detected in $\sim$15% of the systems, and that H_2 is usually found in the systems having the highest metallicities. To investigate this possible dependence with metallicity further, we have searched for H_2 in a representative sample of high-metallicity DLAs.

2 Sample

We have selected from the literature all $z_{\rm abs} > 1.8$ DLAs and sub-DLAs (with $\log N({\rm H\,I}) > 19.5$) with previously measured metallicities larger than [X/H] $= -1.3$ and accessible to the Ultraviolet and Visible Echelle Spectrograph (UVES), mounted on the ESO VLT-UT2 8.2 m telescope on Cerro Paranal, Chile. We ended up with a sample of 18 DLAs/sub-DLAs. The H_2 content of ten of these systems had already been published (Srianand & Petitjean 2001, Petitjean et al. 2002, Ledoux et al. 2002, 2003, 2006b, Srianand et al. 2005, Heinmüller et al. 2006). Five of the eight remaining systems had data in the UVES archive and new observations of four quasars (Q 2343+125 (re-observation), Q 2348−011, Q 0216+080 and Q 2206−199) were performed with UVES.

We report two new detections of H_2 in DLAs from our new observations in the $z_{\rm abs} = 2.431$ and the $z_{\rm abs} = 2.426$ DLAs toward, respectively, Q 2343+125 and Q 2348−011 (see also Petitjean et al. 2006). The first system has the lowest molecular fraction ever measured in a DLA system ($\log f \sim -6.4$), with H_2 detected in the first two rotational levels (J = 0 and J = 1 only). The latter, in turn, has one of the highest molecular fractions ($\log f \sim -1.7$) with H_2 rotational levels detected at least up to J = 5.

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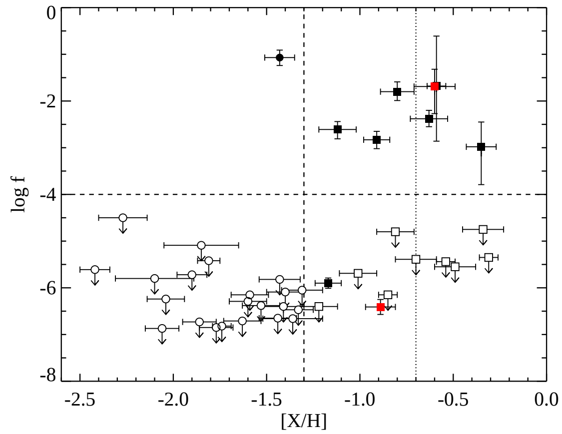

Fig. 1. Molecular fraction, $f = 2N(\mathrm{H_2})/(2N(\mathrm{H_2})+N(\mathrm{H\,I}))$, as a function of metallicity, [X/H], with X = Zn, S or Si. One can see that the probability of detecting H_2 is correlated with the metallicity of DLAs. The new sample is characterized by $[\mathrm{X/H}] \geq -1.3$ (vertical dashed line), with a median metallicity of $[\mathrm{X/H}] = -0.7$ (vertical dotted line). The rest of the sample (with $[\mathrm{X/H}] < -1.3$, circles) is from Ledoux et al. (2003). Filled symbols are detections, while open ones stand for upper limits at $3\,\sigma$. Red squares are the two new detections. The fraction of systems with $\log f > -4$ is of the order of 5% for systems with metallicity $[\mathrm{X/H}] < -1.3$; about 30% for $-1.3 \leq [\mathrm{X/H}] \leq -0.7$ and 50% for $[\mathrm{X/H}] > -0.7$.

3 Results

Molecular hydrogen is found in ~15% of the global population of DLAs. There is no H_2 detection down to $\log f \sim -5$ for $[\mathrm{X/H}] < -1.5$ while $\log f > -3.5$ for about 40% of the systems with $[\mathrm{X/H}] \geq -1.3$ (see Fig. 1). This clearly demonstrates that the presence of molecular hydrogen is strongly correlated with the metallicity. A first interpretation comes from the correlation between metallicity and depletion of metals onto dust grains (Ledoux et al. 2003), that implies larger dust content in high-metallicity DLAs and therefore larger H_2 formation rate. Presence of dust also implies larger UV absorption that prevents H_2 from dissociating. More generally, Ledoux et al. (2006a) have suggested a possible correlation between mass and metallicity in DLAs, and massive DLA galaxies could have enhanced star-formation activity that is expected to be correlated with the molecular fraction (Hirashita & Ferrara 2005). In any case, selecting H_2-bearing DLAs is crucial for understanding the physical conditions in the neutral gas at high redshift. Thanks to the relative population of H_2 rotational levels, one can indeed derive ambient UV fluxes, kinetic temperatures and particle densities using fine-structure levels of neutral carbon, that is generally detected in DLAs were H_2 is observed (see, e.g., Srianand et al. 2005). Detailed analysis and determination of physical conditions in H_2-bearing DLAs, in particular in the $z_{\mathrm{abs}} = 2.426$ DLA toward Q 2348−011, will be done in forthcoming papers.

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