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Searching for places where to test the variations of fundamental constants

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Abstract. It has been realised in the last few years that strong constraints on the time-variations of dimensionless fundamental constants of physics can be derived at any redshift from QSO absorption line systems. Variations of the fine structure constant, α, the proton-to-electron mass ratio, μ, or the combination, $x = \alpha^2 g_{\rm p}/\mu$, where $g_{\rm p}$ is the proton gyromagnetic factor, have been constrained. However, for the latter two constants, the number of lines of sight where these measurements can be performed is limited. In particular the number of known molecular and 21 cm absorbers is small. Our group has started several surveys to search for these systems. Here is a summary of some of the characteristics of these absorbers that can be used to find these systems.

Key words. Galaxies: ISM - quasars: absorption lines - physics: fundamental constants

1. Introduction

Current laboratory constraints exclude any significant time variation of the dimensionless constants of physics in the low-energy regime. However, it is not impossible that these constants could have varied over cosmological time-scales. Savedoff (1956) first pointed out the possibility of using redshifted atomic lines from distant objects to test the evolution of dimensionless physical constants. The idea is to compare the wavelengths of the same transitions measured in the laboratory on earth and in the remote universe. This basic principle has been first applied to QSO absorption lines by Bahcall et al. (1967).

The field has been given tremendous interest recently with the advent of 10 m class telescopes. To make a long story short it is not yet certain that the variation of α claimed by Webb et al. (1999) is confirmed or not because some people have claimed (unreasonably in our opinion) that everybody is wrong (e.g. Srianand et al. 2004, Quast et al. 2004, Levshakov et al. 2005) except Murphy et al. (2003). Future will tell us the truth ! On the other hand, other constants (in particular μ) are till now claimed not to vary at the limit of the experiments (e.g. Ivanchik et al. 2005, Kanekar et al. 2005, Reinhold et al. 2006, King et al. 2008, Wendt & Reimers 2008, Thompson et al. 2009).

Since the amount of observing time required by the study of one absorption system is quite large (typically 10 to 20 hours of 10 m class telescope per quasar), the systems have to be selected carefully. In particular for μ and x, the small number of suitable systems may prevent the development of the field. We therefore have embarqued on several surveys to find these systems. We search for molecular hydrogen at the VLT and 21 cm systems at GMRT.

2. How to find molecules

Molecular hydrogen is not conspicuous in Damped Lyman-α systems at high redshift contrary to what is seen in the Galaxy and, for a long time, only the DLA towards Q 0528−2505 was known to contain H_2 molecules (Levshakov et al. 1985). H_2-bearing DLAs are nevertheless crucial to understand the physical properties of the interstellar medium of high-z galaxies (Hirashita & Ferrara 2005, Srianand et al. 2005, Cui et al. 2005, Noterdaeme et al. 2007).

2.1. VLT/UVES survey for molecular hydrogen

The first systematic search for molecular hydrogen in high-redshift ($z_{\rm abs} > 1.8$) DLAs was carried out using the Ultraviolet and Visual Echelle Spectrograph (UVES) at the Very Large Telescope (VLT, Ledoux et al. 2003, see also Petitjean et al. 2000).

More recently we gathered a total sample of 77 DLAs/strong sub-DLAs, with $\log N(\mathrm{H\,I}) \geq 20$ and $z_{\rm abs} > 1.8$, for which the wavelength range where corresponding H_2 Lyman and/or Werner-band absorption lines are expected to be redshifted is covered by UVES observations of the quasars (Noterdaeme et al. 2008). H_2 is detected in thirteen of the systems with molecular fractions as low as $f \simeq 5 \times 10^{-7}$ up to $f \simeq 0.1$, with $f = 2N(\mathrm{H_2})/(2N(\mathrm{H_2}) + N(\mathrm{H\,I}))$ in the redshift range $1.8 < z_{\rm abs} \leq 4.2$ (see Ledoux et al. 2006). Upper limits are measured for the remaining 64 systems with detection limits of typically $\log N(\mathrm{H_2}) \sim 14.3$, corresponding to $\log f < -5$. We find that about 35% of the DLAs with metallicities relative to solar [X/H] > -1.3 (i.e., 1/20$^{\rm th}$ solar) with X = Zn, S or Si, have molecular fractions $\log f > -4.5$, while H_2 is detected – regardless of the molecular fraction – in ∼ 50% of them. On the contrary, only about 4% of the [X/H] < -1.3 DLAs have $\log f > -4.5$. We show that the presence of H_2 does not strongly depend on the total neutral hydrogen column density, although the probability of finding $\log f > -4.5$ is higher for $\log N(\mathrm{H\,I}) \geq 20.8$ than below this limit (19% and 7% respectively). The overall H_2 detection rate in $\log N(\mathrm{H\,I}) \geq 20$ DLAs is found to be about 16% (10% considering only $\log f > -4.5$ detections) after correcting for a slight bias towards large $N(\mathrm{H\,I})$. There is a strong preference for H_2-bearing DLAs to have significant depletion factors, [X/Fe] > 0.4. In addition, all H_2-bearing DLAs have column densities of iron into dust larger than $\log N(\mathrm{Fe})_{\rm dust} \sim 14.7$, and about 40% of the DLAs above this limit have detected H_2 lines. This demonstrates the importance of dust in governing the detectability of H_2 in DLAs. There is no evolution with redshift of the fraction of H_2-bearing DLAs nor of the molecular fraction in systems with detected H_2 over the redshift range $1.8 < z_{\rm abs} < 4.3$.

2.2. A few characterisitics of the H_2 bearing DLAs

A blind survey like the one described above is useful to derive information on the overall population of DLA systems. When it comes to select systems where H_2 can be detected and thus to increase the detection efficiency, a few characteristics can be used:

(i) There is no strong correlation between the presence of H_2 and the H I column density (Fig. 1) and molecules are seen at any $\log N(\mathrm{H\,I})$.

(ii) There is a definite tendency for molecules to be more frequent at high metallicity (Fig. 2; see also Petitjean et al. 2006). High molecular fractions ($\log f > -4.5$) are found in about 40% of the high-metallicity DLAs ([X/H] ≥ 1/20$^{\rm th}$ solar) whilst only ∼ 5% of the [X/H] < −1.3 DLAs have $\log f > -4.5$.

(iii) Dust is an important ingredient for the formation of H_2 and molecules are predominantly found in dusty systems (Fig. 3; see also Ledoux et al. 2002).

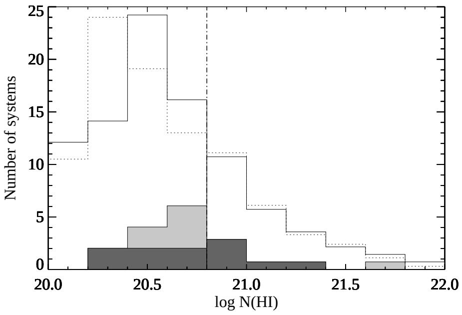

Fig. 1. Total neutral hydrogen column density distributions of DLAs in the overall UVES sample (SH1; solid line), the sub-sample of H_2-bearing systems (SH2; grey), and that of the systems with molecular fraction $\log f > -4.5$ (SH2P; dark grey). The distribution from the SDSS-DR5 DLA sample (Prochaska et al. 2005, Noterdaeme et al. 2009b) is represented with a different scaling (right axis) so that the area of both histograms are the same.

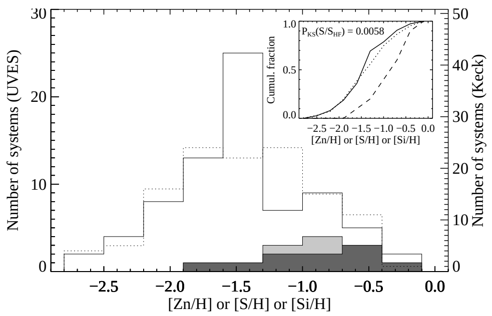

Fig. 2. The metallicity distribution of DLAs in the overall UVES sample (SHI ; solid line) is compared to that from the Keck sample (dotted; Prochaska et al. 2007), adequately scaled (right axis) so that the area of both histograms are the same. The distributions are similar. Distributions from sub-samples SH2 (grey) and SH2P (dark grey) are also shown. It is clear from this and the Kolmogorov-Smirnov test probability (inset) that the distributions from H_2-bearing systems are skewed towards high metallicities.

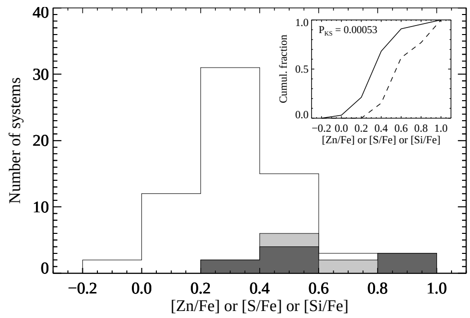

Fig. 3. Distribution of depletion factors from the overall UVES sample (SHI ; solid line), sub-samples SH2 (grey) and SH2P (dark grey). It is clear from these histograms that the distribution of depletion factors for H_2-bearing systems is different from that of the overall sample. This shows clearly that H_2-bearing DLAs are more dusty than the overall DLA population. The probability that the two samples are drawn from the same parent population is indeed very small: $P_{\rm KS}$(SHI/SH2P)$\approx 10^{-3}$.

2.3. Other molecules

Using refined selection criteria it was possible to increase the efficiency of the selection of H_2-bearing systems to about 50%. This gave us the possibility to discover the first CO absorber together with several HD absorbers (Srianand et al. 2008, Noterdaeme et al. 2009a). This opens up the exciting possibility to study astrochemistry at high redshift.

3. 21 cm absorbers

We have also embarked on a large survey to search for 21 cm absorbers at intermediate and high redshifts. For this we first selected strong Mg II systems ($W_{\rm r} > 1$ Å) from the Sloan Digital Sky Survey in the redshift range suitable for a follow-up with the Giant Meterwave

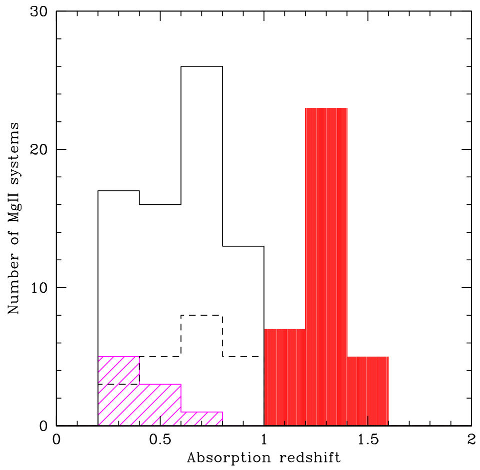

Fig. 4. Redshift distribution of Mg II systems that were searched for 21-cm absorption. The filled histogram is the GMRT sample of 35 Mg II systems presented in Gupta et al. (2009) (33 of these absorption systems have W_r(Mg IIλ2796)> 1Å). The solid line histogram is for the sample of Lane (2000). The distribution for the W_r(Mg IIλ2796)≥ 1Å subset of these systems is given by the dashed line histogram and the hatched histogram corresponds to 21-cm detections among them.

Telescope (GMRT), $1.10 < z_{\rm abs} < 1.45$. We then cross-correlated the ~3000 SDSS systems we found with the FIRST radio survey to select the background sources having at least a $S_{1.4\rm GHz} > 50$ mJy bright component coincident with the optical QSO. There are only 63 sources fulfilling these criteria out of which we observed 35 over ~400 hours of GMRT observing time (Gupta et al. 2009).

We detected 9 new 21 cm absorption systems (Gupta et al. 2007, 2009). This is by far the largest number of 21-cm detections from any single survey. Prior to our survey no intervening 21-cm system was known in the above redshift range and only one system was known in the redshift range $0.7 \le z \le 1.5$ (see Fig. 4). Our GMRT survey thus provides systems in a narrow redshift range where variations of x can be constrained. For this, high resolution and high signal-to-noise ratio observations of the absorbers must be performed to detect the UV absorption lines that will provide the anchor to fix the exact redshift, the variations of x being subsequently constrained by the position of the 21 cm absorption line.

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