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Using weak Mg II lines to chart Low Surface Brightness Galaxies

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Abstract. We report the detection, based on HST and Keck data, of two peculiar absorbers in the Lyα forest of the quasar PKS 0454+039. These clouds, at redshifts $z = 0.6248$ and 0.9315 respectively, display both Mg II and Fe II absorption lines in addition to the Lyα line. Based upon photoionization models, these are inferred to be photoionized by the intergalactic UV background, and to have H I column densities in the range $15.8 \leq N(\text{H I}) \leq 16.8$. Furthermore, if one supposes that the relative abundances of heavy elements is similar to that of depleted clouds of our galaxy, the abundances of these two absorbers are greater than the solar value, which is a unique case for absorbers which are not associated to the quasar. We tentatively suggest that these absorbers may select giant low surface brightness galaxies.

1. Introduction

Quasars, beside the interest of their internal mechanisms, are unique tools for the study of the gaseous content of the Universe. In fact, any single gaseous cloud (down to a surface density of a few 10^{12} cm^{-2}) placed on the sightline to one of these bright and distant point sources can leave an imprit, in the form of one or several absorption lines, on the spectrum of the latter.

Absorption line systems (a system is a set of several lines of different ionization states of different elements) are classified following their content in neutral hydrogen :

- The so-called Damped Lyα systems (DLAS), because their Lyα line is located on the damped part of the curve of growth, are characteristic of large neutral hydrogen column densities ($N(\text{H I}) \geq 2\ 10^{21}$ cm^{-2}). Their similarity with Galactic clouds in term of physical conditions (ionization degree, temperature ...), led people to associate them to distant spiral galaxies (Wolfe et al. 1986). In fact, they were recently confirmed, thanks to HST imaging and spectroscopy, to be associated with galaxies of any type (Le Brun et al. 1997),
- The Mg II systems display less neutral hydrogen than DLAS, even if they are still optically thick ($N(\text{H I}) \geq 10^{17}$ cm^{-2}). The gas of these clouds is

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of low ionization level, and they have been shown to be associated with large ($R \sim 90h_{50}^{-1}$ kpc) gaseous halos of bright field galaxies (Bergeron & Boissé 1991, Steidel 1995).

- At last, the absorbers of the Lyα forest outnumber the other classes by several decades, each system displaying only the Lyα line (at least with an average spectroscopic set-up), N(H I) being in the range $10^{12} - 10^{16.5}$. Photoionization models show that the gas of these clouds is highly ionized, with some of them displaying ionic lines from C IV, N V or O VI. The abundances are quite low : $Z \simeq 10^{-3} - 10^{-2} Z_{\odot}$. These clouds could trace both the external parts of the galactic halos and the intergalactic gas spread along the large scale structure of the galaxy distribution (Le Brun & Bergeron 1998).

In this paper, we present the complete study of two absorbers of a new kind, the "weak Mg II absorbers". Section 2 presents the state-of-art about these absorbers and Sect. 3 the peculiar sightline to the quasar PKS 0454+039, with all data we obtained on it. At last, Sect. 4 presents our discussion and conclusions about these objects.

2. The weak Mg II absorbers

The Mg II systems were extensively studied in the 80's thanks to systematic spectroscopic surveys of several tens of quasars at signal to noise ratio about 10, with limiting rest equivalent width of about 0.3 Å. The most complete of those was published in 1992 (Steidel & Sargent). These surveys have shown that the number density, either in value or in evolution with redshift, was fully compatible with these absorbers being linked with field galaxies. This hypothesis was confirmed in the same time by the the first identifications of absorbing galaxies (Bergeron & Boissé 1991). It is only with the advent of the Keck Telescope that Churchill et al. (1998) could initiate a survey for "weak" Mg II absorbers, that is with rest equivalent width down to 0.02 Å. The survey was made with HIRES (Vogt et al. 1994), all details are given in Churchill et al. (1998). As can be seen on Fig 1, the weak Mg II absorber outnumber the strong ones by a factor of 2 to 3, and there is no lower cutoff in the distribution of the rest equivalent width down to 0.02 Å. Also, the evolution of the number density of weak absorbers show that it is compatible with a non evolving (in number) population (Fig. 2). If these absorbers are of the same nature as the strong ones, by comparing the density of absorbers and of galaxies, it requires galaxies to be surrounded by halos of radius $R \sim 120h_{50}^{-1}$ kpc. However, this value can be lowered if a fraction of the weak absorbers is perhaps of different origin for example Low Surface Brightness (LSB) galaxies.

3. The sightline to PKS 0454+039 : data and analysis

To ascertain the nature of weak Mg II absorbers, we have focused on the sightline toward the quasar PKS 0454+039. This object is part of the Keck/HIRES survey, and a high resolution ($R \sim 45,000$) high signal to noise ratio (~ 50) has

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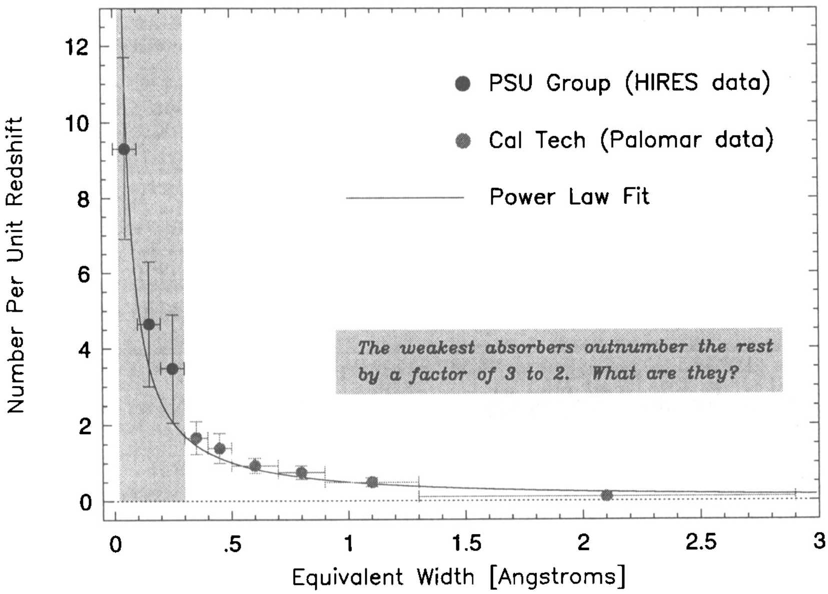

Figure 1. Rest equivalent width distribution of the weak Mg II absorbers (in the shadened zone) as compared to strong ones (on the right of the diagram)

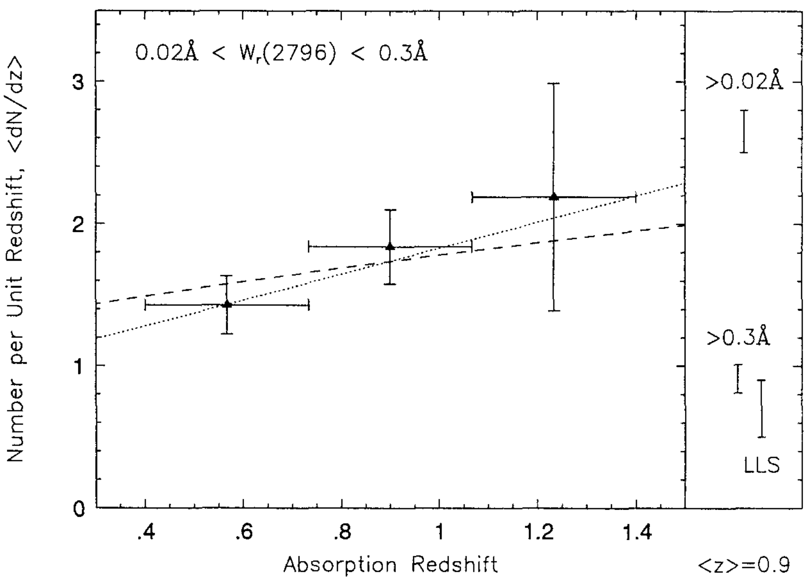

Figure 2. Redshift evolution of the weak Mg II absorbers population.

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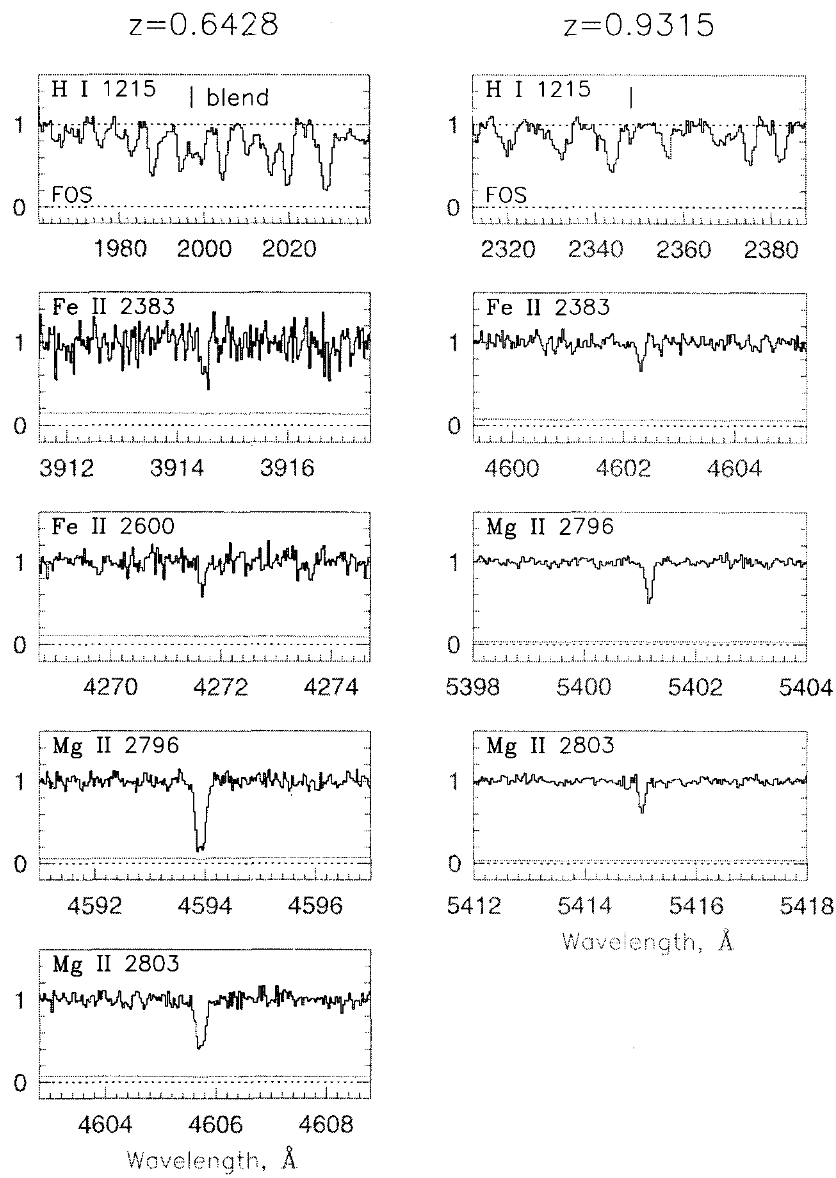

Figure 3. FOS/HST (top panel) and Keck/HIRES (lower panels) spectra of the two absorbers. Note the very different wavelength scales between the optical and UV spectra

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been obtained in the visible domain. Beside of this, the HST/FOS UV spectrum has been extensively studied by Boissé et al. (1998) for the characterization of the $z = 0.8596$ DLAS present in front of the quasar. The spectral resolution is $R \simeq 1300$, and the signal to noise ratio is about 10. The limiting equivalent width for a 3σ detection is about 0.3 Å. At last, we have obtained deep CFHT and HST/WFPC2 R band images of the field surrounding this quasar (Le Brun et al. 1997).

The analysis of the HIRES spectrum shows that two faint Mg II absorbers are present at redshifts $z = 0.6248$ and $z = 0.9315$, together with Fe II lines at the same redshift derived from Fig. 3 displays both the Lyα line, as present in the HST/FOS spectrum (top panels), and the metal lines (lower panels). As can be seen, the Lyα lines are very faint, and were not even included in the 3σ limited sample of absorption lines listed in Boissé et al. (1998). Their rest equivalent width are 0.33 and 0.15 Å respectively.

We have thereafter tried to use the standard analysis methods to derive the physical properties of the gas. However, since, even at the HIRES resolution, the Mg II and Fe II lines are barely resolved, we have used Monte Carlo simulations to determine the best values for the column densities and dispersion parameters, using the doublet ratio. We obtain that, for both systems, $N(\text{Fe II}) \sim N(\text{Mg II}) \sim 10^{12.5}$, while the b parameter are 5 and 2 km s^{-1} for the $z = 0.6428$ and 0.9315 systems respectively.

Unfortunately, the FOS spectrum is of poorer quality, and a Voigt profile fitting was impossible, so that we could not derive directly the properties of the H I gas. We have therefore proceeded in several steps that are summarized below (see Churchill & Le Brun 1998 for a detailed description of this work):

1. We have introduced the turbulence parameter, $f = b_{\text{turb}}/b_{\text{tot}}$, which can have values between 0 and 1. If $f = 0$, the gas is thermally excited, and the b parameter for different elements scales as the square root of the mass ratio. On the contrary, if $f = 1$, the gas is fully collisionally ionized, and all the lines of all elements have the same b value. Of course, all intermediate situations are possible. The variation of $b(\text{H I})$ as a function of the f value is shown on Fig. 4 for the two systems.

2. From this range of possible variations for the b parameter, we thus can derive, using the curve of growth analysis, the range of possible values for the neutral hydrogen column densities : it covers nearly 3 decades from $\sim 10^{14}$ to $\sim 10^{17}$ cm^{-2}.

3. The latter result makes it impossible to derive any hints on the physical states of these absorbers just from the data. We thus have used CLOUDY (Ferland 1996), to make some simulations of the absorbing gas. For each value of $N(\text{H I})$ between 10^{14} and 10^{17}, by step of 0.5 in log, we have run CLOUDY in 'optimized' mode, so that the simulation converges toward the observed values of $N(\text{Fe II})$ and $N(\text{Mg II})$. The other inputs are i) the UV ionizing external radiation field : it could either have a galactic-shaped spectrum, or an intergalactic UV background shape, as given by Haardt & Madau (1996), and ii) the abundance pattern, that is the relative abundances of heavy elements : solar, H II region, that is including depletion by dust, or enhanced abundances of α elements. The output of CLOUDY

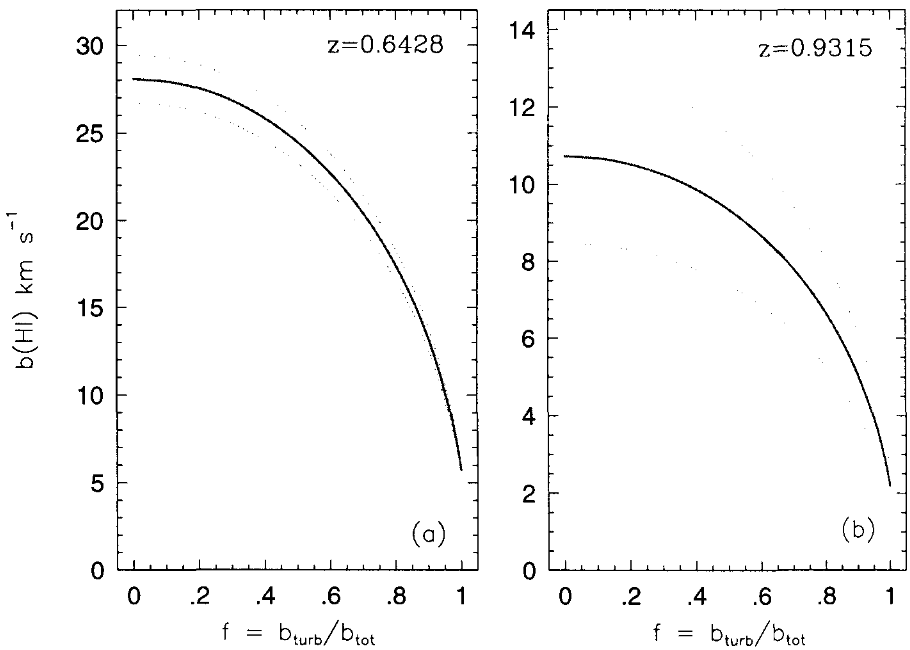

Figure 4. Variation of the H I broadening value as a function of the turbulence parameter for the two absorbers

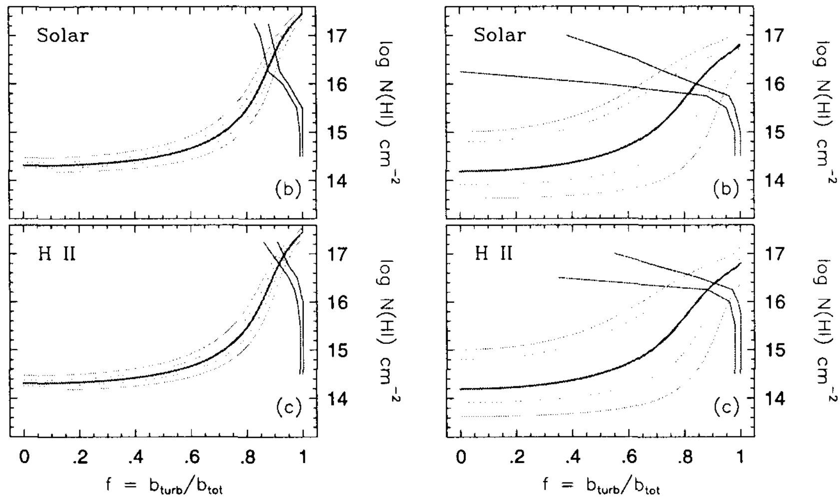

Figure 5. Properties of the two absorbers ($z = 0.6428$ on the left, $z = 0.9315$ on the right). Thick solid lines give the value of N(H I) derived from observed b_{tot}(Mg II) and W_r(H I). Thin curves give the uncertainties from the measurements. The curves that originate in the lower-right corner and rise upwards and then to the left are the allowed locus of f for a cloud model of a given N(H I)

is the full physical state of the gas, including temperature, from which we could derive the f parameter value. Thereafter, we only had to compare the output of the simulation to the observational constraints to get the possible values of N(H I).

4. Discussion and conclusions

These simulations allowed us to eliminate some hypothesis : the α-enhanced abundance pattern fails to produce coherent models, as well as the galactic-shaped ionizing flux, which requires unrealistic spatial densities of stars to reproduce the physical quantities of the gas. Thus, Fig. 5 displays the domain that is allowed in the $f - N$(H I) plane for the two absorbers : it is the intersection of the band coming from lower-left to upper right, which displays the range allowed by data (with the errors), and the band going from lower-right to upper-right, which reflects the uncertainties in the Fe II and Mg II column densities. As can be seen, only a small domain is allowed for each absorber, which covers less than a decade in N(H I).

As a result of this, we can now get estimates of the metallicity of these clouds, which are surprisingly high : the $z = 0.6428$ absorber has abundances $Z \geq 0.2Z_\odot$ if the abundance pattern is solar, and $Z \geq 1.6Z_\odot$ if the gas has abundances similar to the Galactic H II regions, i.e with depletion on dust grains.

For the $z = 0.9315$ absorber, the abundances are above the solar value, whatever the abundance pattern.

Their very high abundances make these absorbers very peculiar, and in any case different from the strong Mg II absorbers, which have metallicities $Z \sim 0.01 Z_{\odot}$, and at least a part of the weak Mg II absorbers thus seems not to originate in field galaxy halos. Furthermore, we have searched the deep CFHT and HST images of the field around the quasar, and there is no galaxy close enough to the sightline that could give rise to these absorption systems, when one takes into account the galaxies that are likely to host the four already know "normal" metallic absorption systems.

There is however a class of galaxies which present the same characteristics as our absorbers : The Giant Low Surface Brightness Galaxies. Their abundances, as measured in H II regions, are above the solar value (McGaugh 1994, Pickering & Impey 1995), and the H I gas velocity dispersion is quite low, in the range $10 - 30$ km s^{-1}, thus similar to the value derived in our absorbers. These two similarities, which can not be found in any other class of galaxies, leads us to suggest that a least a fraction of the weak Mg II absorbers is due to these giant LSBGs. The spatial densities of absorbers and galaxies cannot be compared yet, since the samples of both are to small to derive useful statistics.

The immediate follow-up of this work should go in two direction : first, more detailed UV spectroscopy is necessary, to derive better constraints on both the Lyα profile and other ions absorption lines (C IV, O III, O VI, ...), and also by more imaging and spectroscopy in the field, to try to identify the absorbing galaxies, or companions of them. These developments will need large aperture space and ground-based telescopes.

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