Mem. S.A.It. Suppl. Vol. 3, 261

Memorie della
Supplementi

Sub-DLAs Abundances: Implications for the Cosmological Evolution of Metals

C. Péroux[1], M. Dessauges-Zavadsky[2], T.S. Kim[2,3], S. D'Odorico[2] and R.G. McMahon[3]

[1] Osservatorio Astronomico di Trieste, Italy. e-mail: peroux@ts.astro.it
[2] European Southern Observatory, Garching-bei-München, Germany
[3] Institute of Astronomy, Cambridge, UK

Abstract. Damped Lyα Systems (DLAs), with N(HI) $> 2 \times 10^{20}$ cm^{-2}, observed in the spectra of quasars have allowed to quantify the chemical content of the Universe over cosmological scales. Such studies can be extended to lower column densities, in the sub-DLA range ($10^{19} <$ N(HI) $< 2 \times 10^{20}$ cm^{-2}), which are systems believed to contain a large fraction of neutral hydrogen at $z > 3.5$. We use a homogeneous sample of sub-DLAs constructed from ESO UVES archives to determine the chemical abundance and ionization fraction of this class of quasar absorbers, and compare the results with a compilation of abundances from more than 70 DLAs taken from the literature. As previously reported, the individual metallicities traced by [Fe/H] of these systems evolve mildly with redshift. We also compute the HI column density weighted mean abundance which is believed to be an indicator of the Universe's metallicity. Our study suggests a slightly stronger evolution of this quantity in the sub-DLA range. Observational arguments support the hypothesis that the evolution we probe in the sub-DLA range is *not* due to their lower dust content. Therefore these systems might be associated with a different class of objects which better trace the overall chemical evolution of the Universe.

Key words. cosmology: observations - galaxy: evolution - quasar: absorbers

1. Introduction

In addition to traditional emission studies, absorption systems along the line-of-sight to distant quasars provide a completely independent probe of galaxy evolution. The highest column density Damped Lyα systems (hereafter DLAs) have N(HI) $> 2 \times 10^{20}$ atoms cm^{-2}. The reason why damped systems are a cosmologically important population is that they contain most of the neutral gas in the Universe at $z > 1$ (Lanzetta et al. 1991; Wolfe et al. 1995; Storrie-Lombardi et al. 1996). Since the metal content of these systems can be determined with rather high precision up to high redshift, they are a powerful tool to study the stellar and chemical evolution of

Send offprint requests to: C. Péroux
Correspondence to: peroux@ts.astro.it

galaxies. In particular, a way to trace the metallicity of the Universe is provided by estimating the ratio of the total metal content to the total gas content measured in these systems (Pettini et al. 1997; Pei, Fall & Hauser 1999). Using such techniques, Prochaska & Wolfe (2002) find that the hydrogen column density weighted [Fe/H] metallicities have similar values from $1.5 < z < 3.5$. The results are in disagreement with expectations since models of cosmic chemical evolution (e.g. Fall & Pei 1995) predict evolution of global metallicity with cosmic time.

In a recent study, Péroux et al. (2003a) have shown that sub-DLAs, defined as systems with $10^{19} <$ N(HI) $< 2 \times 10^{20}$ atoms cm^{-2}, are to play a major role, especially towards higher redshifts. The authors postulate that at $z > 3.5$, 45% of the neutral gas mass is in sub-DLAs. These predictions are based on an extrapolation of the quasar absorber column density distribution, $f(N)$, derive from Péroux et al. (2001) data sample, to lower column densities assuming the distribution can be fitted by a gamma function. Following similar line of thoughts as for DLAs, these results suggest that sub-DLAs metallicities should be studied in details in order to obtain a complete picture of the redshift evolution of the Universe's metallicity. For this purpose, we have constructed a homogeneous sample of sub-DLAs based on high-resolution quasar spectra from the ESO UVES/VLT archives (Dessauges-Zavadsky et al. 2003, hereafter Paper I) and analyse several of their properties (Péroux et al. 2003b, hereafter Paper II). We briefly summarise here the main findings of our study concerning abundances.

2. Metallicity Evolution

2.1. Metallicity of Individual Systems

[Fe/H]: Using photionization modelling based on the CLOUDY package, we find that the ionization correction on the Fe II column density is within the observational errors (Paper I). Therefore the abundance measurements of the sub-DLAs can be directly compared with the one of the DLAs gathered from various sources in the literature. We use the abundance ratios with respect to solar values defined in the usual manner($[X/H] = \log[N(X)/N(H)]_{DLA} - \log[N(X)/N(H)]_{\odot}$) and presented in Paper I. As previously reported (e.g. Prochaska & Wolfe 2002; Dessauges-Zavadsky et al. 2001), there are evidences for a mild evolution of the individual [Fe/H] in DLAs. The analysis suggests a stronger correlation of the [Fe/H] in sub-DLAs although the significance of test is weakened by low number statistics. The effect is predominant at $z < 2$ and most of the evolution observed lies in this redshift range. The evolution with redshift of the [Fe/H] ratio might be more pronounced for sub-DLAs than for DLAs. This difference, if confirmed by a larger sample of data, suggests that the detection of DLAs is more biased by dust at low redshift or that the sub-DLAs are associated to a class of galaxies which traces better the overall chemical evolution of the Universe.

[Zn/H]: The well-known draw back of using Fe II for abundance determination is the fact that this element is sensitive to depletion onto dust grains (Pettini et al. 1997). An alternative to overcome the dust depletion issue is provided by Zn, an element known to be only mildly depleted. In our sample of sub-DLAs, most of the Zn II lines are weak or undetected and thus we can only provide upper limits. In addition, the ionization correction in sub-DLAs is important for Zn II and thus the interpretation of the abundances are more complicated. However, the slope in the Zn II DLA sub-set, a tracer of true metallicity evolution, is not as steep as in the Fe II sub-DLA sub-set. This suggests that the evolution we probe in these latter absorbers is *not* due to the hidden effect of dust.

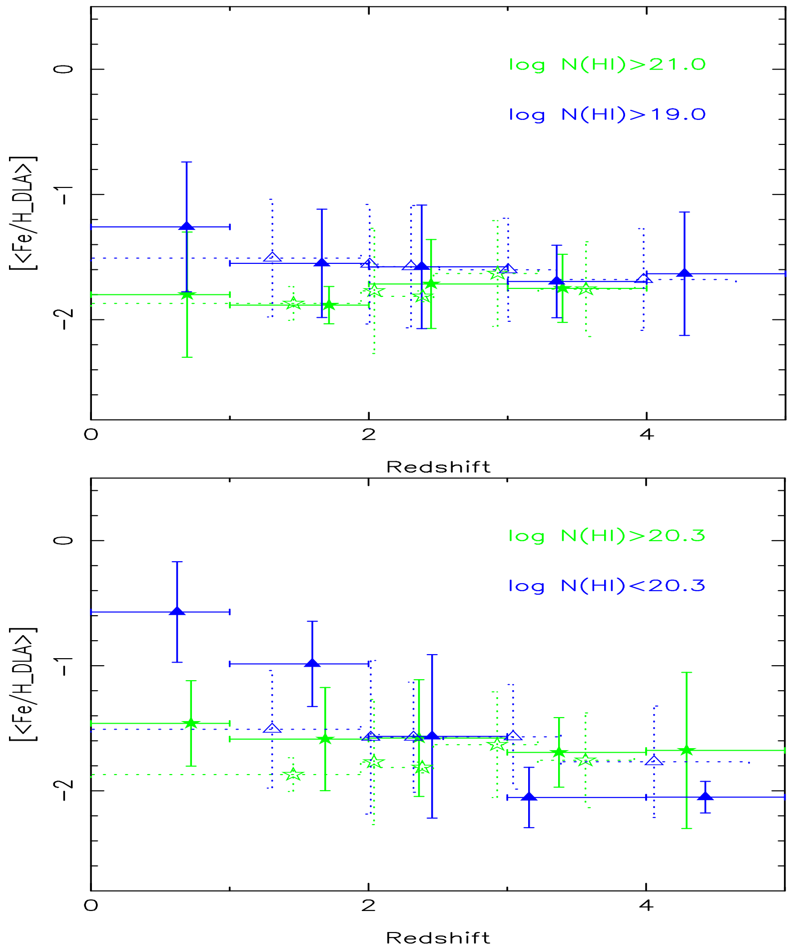

Fig. 1. HI column density weighted mean metallicities for various sub-sets of quasar absorbers. The dotted bins are for constant HI intervals and the solid bins are for constant redshift intervals. The evolution of $[\langle \mathrm{Fe/H_{DLA}} \rangle]$ is clearly more pronounced for sub-DLAs than for DLAs, but this result is not apparent when all absorbers with N(HI) $> 10^{19.0}$ atoms $\mathrm{cm^{-2}}$ are considered.

2.2. Weighted Mean Metallicity

Figure 1 presents the column density weighted mean Fe II abundances of n systems in redshift bins of $\Delta z = 1$ (solid bins) and in constant HI interval (dashed bins), for various sub-samples of quasar absorbers. Although more advanced statistical methods have been recently suggested (Kulkarni & Fall 2002), we choose to follow the prescription from Pettini et al. (1997):

$$[\langle \mathrm{Fe/H_{DLA}} \rangle] = \log \langle (\mathrm{Fe/H})_{\mathrm{DLA}} \rangle - \log\,(\mathrm{Fe/H})_{\odot} \quad (1)$$

Figure 1 presents the results of these calculations for different sub-set of quasar absorbers (see Paper II). The top panel includes all quasar absorbers (DLAs + sub-DLAs) as well as systems with N(HI) $> 10^{21.0}$ atoms $\mathrm{cm^{-2}}$. The bottom panel shows DLA and sub-DLAs separately. We note that the evolution of $[\langle Fe/H_{DLA}\rangle]$ is clearly more pronounced for sub-DLAs than for DLAs, but this result is not apparent when all absorbers with N(HI) $> 10^{19.0}$ atoms cm^{-2} are considered. Indeed, in our sample the number of DLAs (72) is much larger than the number of sub-DLAs (17). On the contrary, in the Universe we expect the number of sub-DLAs to be up to 3 times (at $z \sim 4$) the number of DLAs (Péroux et al. 2002). Since high column density systems dominate the HI weighted mean metallicity, it will be important to increase the sub-DLA sample size to better probe $[\langle Fe/H_{DLA}\rangle]$. Nevertheless, these results show that the HI column density weighted mean metallicity Fe II of sub-DLAs *do* evolve with redshift more markedly than for the DLA population. The dotted bins correspond to constant HI intervals and therefore present similar number of systems. They also present an increase of metallicity with decreasing redshift, showing that this result is not an artifact of the low number of sub-DLAs known at $z < 2$. Starting from a metallicity 1/100 solar at $z \sim 4.5$, the sub-DLAs evolve up to a metallicity 1/3 solar at $z \sim 0.5$. The ionization correction cannot explain the evolution observed since we have shown in Paper I that for [Fe II/HI], it *does not* exceed 0.2 dex. These results again reinforce the hypothesis where sub-DLAs better trace the global metallicity evolution and therefore should be included in the quasar absorber's metallicity determination to obtain a complete picture of their abundances.

3. Conclusion

We have constructed and fully analysed a homogeneous sample of 12 sub-DLAs. We study the chemical content of these absorbers in conjunction with DLAs from the literature. The metallicity of absorbers as traced by [Fe/H] shows a slightly more pronounced slope for sub-DLAs than for DLAs. We find that the evolution of $[\langle Fe/H_{DLA}\rangle]$ might also be stronger for sub-DLAs than for DLAs. The question thus remains open whether the two classes of objects have similar chemical evolution histories or whether there are objects with different ages and star formation histories but in a similar stage of chemical evolution.

Acknowledgements. CP is supported by a Marie Curie Fellowship. CP thanks the organisers of the meeting.

References

Dessauges-Zavadsky, M., D'Odorico, S., McMahon, R.G., & Péroux, C., 2001, "17^{th} IAP Astrophysics Colloquium", Ed. Ferlte, Lemoine, Desert & Raban.

Dessauges-Zavadsky, M., Péroux, C., Kim, T.S., D'Odorico, S., & McMahon, R.G., MNRAS, 2003, *submitted*, [Paper I].

Kulkarni, V. P. & Fall, S. M., 2002, ApJ, 580, 732.

Lanzetta, K., McMahon, R.G., Wolfe, A., Turnshek, D., Hazard, C. & Lu, L., 1991, ApJS, 77, 1.

Pei, Y.C, Fall, M.S. & Hauser, M.G., 1999, ApJ, 522, 604.

Péroux, C., Storrie-Lombardi, L., McMahon, R., Irwin, M. & Hook, I., 2001, AJ, *121*, 1799.

Péroux, C., Irwin, M., McMahon, R.G., & Storrie-Lombardi, L.J., 2002, "Chemical Enrichment of Intracluster and Intergalactic Medium", ASP Conference Proceedings, Vol. 253, Ed R. Fusco-Femiano & F. Matteucci.

Péroux, C., McMahon, R., Storrie-Lombardi, L. & Irwin, M., 2003a, MNRAS, *submitted*, astro-ph/0107045.

Péroux, C., Dessauges-Zavadsky, M., D'Odorico, S., Kim, T.S., & McMahon, R.G., MNRAS, 2003b, *submitted*, [Paper II].

Pettini, M., Smith, L.J., King, D.L. & Hunstead, R.W., 1997, ApJ, 486, 665.

Prochaska, J.X. & Wolfe, A.M., 2002, ApJ, 566, 68.

Storrie-Lombardi, L., McMahon, R. & Irwin, M., 1996, MNRAS, 283, L79.

Wolfe, A., Lanzetta, K. M., Foltz, C. B. & Chaffee, F. H., 1995, ApJ, 454, 698.