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On the Correlation Between Abundance and Column Density in DLAs

J. L. Hou*, **R.X. Chang** †
Shanghai Astronomical Observatory, and the Joint Institute for Galaxy and Cosmology, the Chinese Academy of Sciences, Shanghai, China,
E-mail: houjl@shao.ac.cn,crx@shao.ac.cn

L. Barreyre
University Paul Sabatier, Toulouse, France
E-mail: laure.barreyre@hotmail.fr

J. Fu
Shanghai Astronomical Observatory, Shanghai, and the Graduate School of Chinese Academy of Sciences, Beijing, China
E-mail: fujian@shao.ac.cn

We have re-established two kinds of correlations found in Damped Lyman Alpha systems (DLAs) based on the most recent data. One is the anti-correlation between Zn abundance and HI column density. Another is the anti-correlation between [X/Zn] (where X stands for the refractories Fe, Cr and Ni) and Zinc metal column density ([Zn/H]+log(N_{HI})). We have included the sub-DLAs, QSO-DLAs and GRB-DLAs (the DLAs towards long duration GRB afterglow). We find that the anti-correlation between Zn abundance and HI column density still exists, and this anti-correlation also exists for other iron-peak elements. But for alpha elements the large dispersion prevents a clear conclusion. The anti-correlation between abundance ratio [X/Zn] and Zn column density is also valid when we include the lower and higher column density DLA systems for iron-peak elements. This is a certain indication of dust depletion for iron-peak elements in DLAs. There also exists a strong correlation between [Si,S/Fe] abundance ratios and [Zn/Fe]. This is an indication for the nucleosynthesis origin of Zinc, in which Zinc behaves similar to the alpha elements.

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1. Introduction

Damped Lyman α systems (DLAs) are high column density gaseous systems (N>2 10^{20} cm^{-2}), detected through their absorption lines in the optical spectra of quasars (those systems are called QSO-DLAs), up to relatively high redshifts (up to $z \sim 5$). Their study constitutes a powerful means to investigate the properties of distant galaxies (or of their building blocks)[1].

Metal abundance, column density and dust depletion play important roles in understanding the nature of DLAs. One of the important observed properties in DLAs is the anti-correlation between Zn abundance and HI column density [2]. Whether this anti-correlation is caused by observational bias (dust obscuration and detection limitation) or caused by physical reasons is still unclear. Based on the various data compiled from literatures, Hou et al.[3] pointed out a previously unnoticed anti-correlation between the observed abundance ratio [X/Zn] (where Zn is assumed to be undepleted and X stands for the refractories Fe, Cr and Ni) and Zinc metal column density ([Zn/H]+log(N_{HI})) in DLAs. They suggest that this trend is an unambiguous sign of dust depletion, since metal column density is a measure of the amount of dust along the line of sight (see also [4]).

Recently, the anti-correlation between metal and column density has been extended to the sub-DLAs (that is the systems with HI column density between 10^{19} cm^{-2} and 2×10^{20} cm^{-2}) ([5],[6]). On the other hand, observations also show that there exists an anti-correlation between Carbon abundance and linear size in the Lyman alpha forest. It seems that the anti-correlation between metal abundance and HI column density exists from lower HI column density systems to higher systems. Considering that different systems with different column density have totally different optical depth: Lyman-alpha forest are highly ionized clouds, sub-DLAs are partially ionized clouds, DLAs are totally neutral gas, the observed anti-correlation should have special implications for the nature of those systems.

In this presentation, we will show the obtained correlations by including both sub-DLAs and GRB-DLAs (that is the DLAs towards long duration GRB afterglow) by using the most up-to-date data available.

2. Data Sources

All the elemental abundance and column density data are compiled from the most recent literature available. As the GRB-DLAs data are only recently available, the number of observed systems with available abundances is relatively small. For sub-DLAs, upper or lower limits abundances are often given due to the uncertainties on the absorption lines in the spectra. Moreover, different elements are not always consistently detected in all three types of DLAs. We have considered all possible elements in our analysis, which are the alpha elements : O, Al, Mg, Si, S and Ti, and the iron peak elements: Fe, Mn, Ni and Cr. The Zinc is also included and it is traditionally regarded as an iron-peak element, although this remains controversial. We shall discuss the possible nucleosynthesis origin of Zinc based on the abundance pattern in DLAs.

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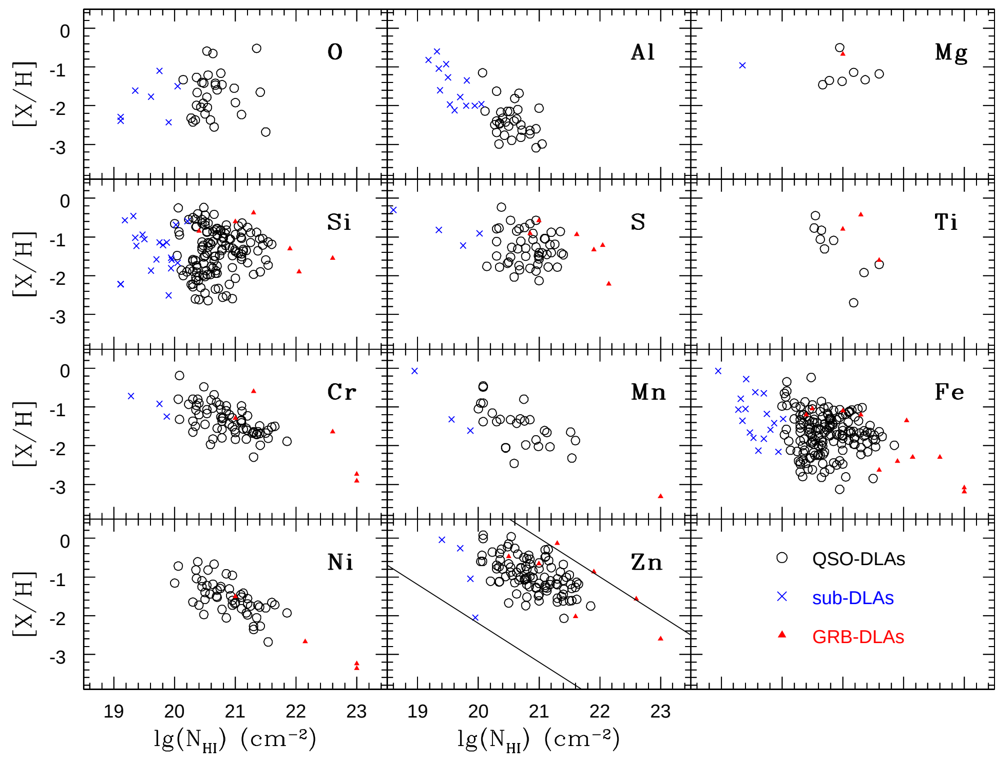

Figure 1: The [X/H] versus HI column density. The blue crossed, black circled and red triangle points represent sub-DLA, QSO-DLAs, and GRB-DLAs, respectively. It is clear that the anti-correlations exist when we include the sub-DLAs and GRB-DLAs for all iron-peak elements and some alpha elements, such as Al.

3. Results

3.1 Abundance vs. HI column density

In Figure 1, it is evident that the anti-correlations for Zn and iron elements (Fe, Cr) still exist even we include lower (sub-DLAs) and higher (GRB-DLAs) HI absorbing systems. But for alpha elements, such as Si, this relationship is not clear due to the large observed dispersion.

3.2 Abundance ratio vs. metal column density

In Figure 2, we plot the abundance ratio [X/Zn] vs. Zinc column density. It is clear that the anti-correlations between abundance ratio and Zn column density exist when we include lower and higher HI column density systems for both alpha and iron-peak elements, but the alpha elements exhibit a shallower slope when compared with the iron-peak elements. This strongly suggests that the iron-peak elements have severe dust depletions in DLAs. The depletions of iron-peak elements become larger when the metallicity increases in the DLA systems. However, among the alpha elements, only S and Si show this correlation; others do not show any correlation due to the small number of data points.

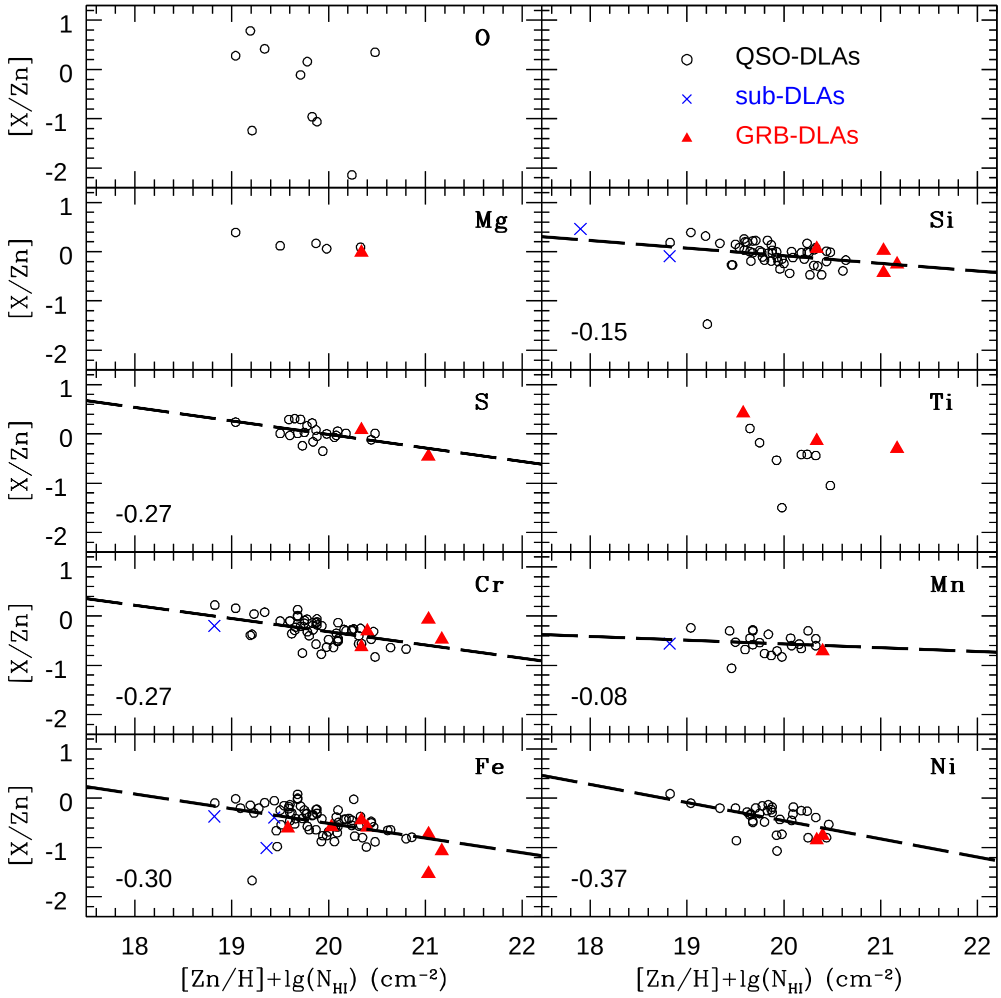

Figure 2: Gas phase abundance ratio [X/Zn] in DLAs plotted as a function of Zinc column density, expressed as [Zn/H]+log(N_{HI}). The symbols are the same as in Figure 1. The anti-correlations are clear for the refractory elements Cr, Fe, Ni (shown by dashed lines, obtained by a least square fit to the data, the slopes are given in the left lower corner in each panel). There also exist anti-correlations for S and Si, but with smaller slopes.

3.3 Nucleosynthesis origin of Zinc

We note that based on observations of Milky Way stars, [Fe/Zn]=0 from [Fe/H]$\sim$ -2 $\sim$ 0. This implies that $\sim$2/3 of Zn are produced at late times by SNIa, exactly as is Fe in the solar vicinity. This assumption introduces a time-delay in the production of the bulk of Zn with respect to the one of other α-elements, such as S, Si, coming from massive stars. On the other hand, recent new observations of metal poor stars show that the [Zn/Fe] show some amount of enhancement like the α-elements. Obviously, the nucleosynthesis of Zn should be carefully scrutinised in future models of massive star nucleosynthesis.

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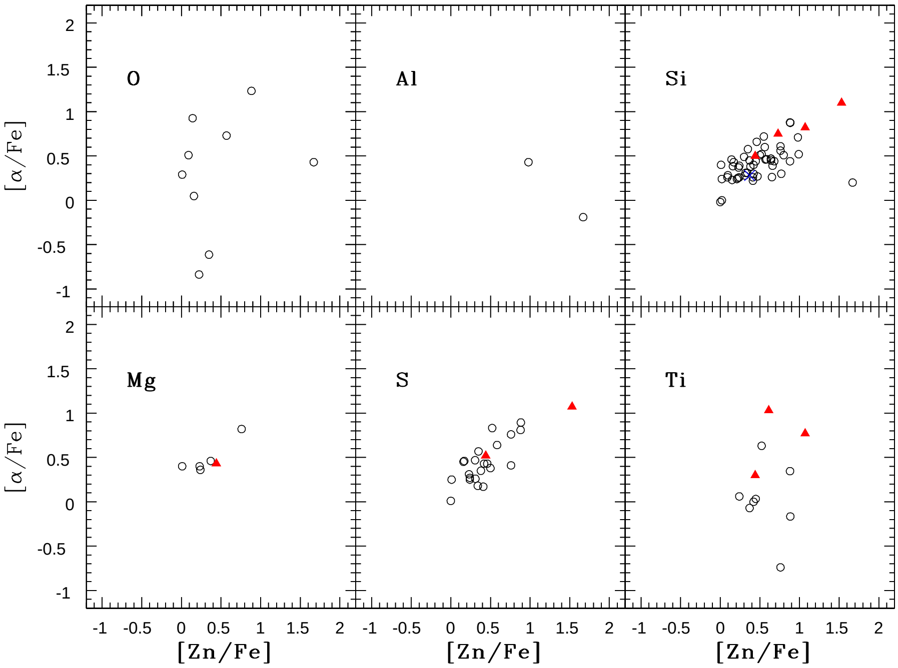

Figure 3: Abundance ratios [α/Fe] plotted against [Zn/Fe]. There is clear correlation between [S,Si/Fe] and [Zn/Fe], which is a strong implication of SNII origin of Zn. The symbols are the same as in Figure 1.

Figure 3 plots [α/Fe] against [Zn/Fe] to to consider the effects of dust depletion in DLAs. It can be seen that [S,Si/Fe] and [Zn/Fe] are clearly correlated. This suggests that Zn could also be produced by SNII like S and Si. It is very likely that Zn is produced by both SNIa and SNII, probably in nearly equal fractions. Therefore, Zn can be considered to behave as an α-element as well as a Fe-peak element.

References

[1] Hou, J.L., Shu, C.G., Shen, S.Y., et al. 2005, *Metallicity and HI Column Density Properties of Damped Ly-alpha Systems, ApJ,* 624, 561

[2] Boissé, P., Le Brun, V., Bergeron, J. & Deharveng, J.M. 1998, *A HST Spectroscopic Study of QSOs with Intermediate Redshift Damped Ly-alpha Systems, A&A,* 333, 841

[3] Hou, J.L., Boissier, S. & Prantzos, N. 2001, *Chemical Evolution and Depletion Pattern in Damped Lyman Alpha Systems, A&A,* 370, 23

[4] Prochaska, J.X. & Wolfe, A.M. 2002, *The UCSD HIRES/KECK I Damped Ly-alpha Abundance Datebase II. The Implications, ApJ,* 566, 68

[5] Khare, P., Kulkarni, V.P., Péroux, C. et al. 2007, *The Nature of Damped Lyman Alpha and sub-Damped Lyman-alpha Absorbers, A&A,* 464, 487

[6] York, D.G., Khare, P., Vandern Berg, D. et al. 2006, *Average Extinction Curves and Relative Abundances for Quasi-Stellar Object Absorption-line Systems at* $1 \leq z_{abs} < 2$*, MNRAS,* 367, 945