The damped Ly α system toward Q0913+072: looking at an early epoch in Galaxy Formation

---

Peter Erni[*]
Institut für Astrophysik und Extraterrestrische Forschung, Auf dem Hügel 71, 53121 Bonn, Germany
E-mail: `perni@astro.uni-bonn.de`

Philipp Richter
Institut für Astrophysik und Extraterrestrische Forschung, Auf dem Hügel 71, 53121 Bonn, Germany

Cédric Ledoux
European Southern Observatory, Alonso de Córdova 3107, Casilla 19001, Vitacura, Santiago, Chile

We present a detailed analysis of chemical abundances in a damped Lyman α absorber at z_{abs} = 2.618 toward the quasar Q0913+072 (z_{em} = 2.785) using public UVES/VLT high resolution data. The total hydrogen column density is log N(H I)=20.39. We find a very low overall metallicity where the detected species include H I, O I, C II, Fe II, Al II, and Si II. Upper limits can be given for Fe III, Si III, Al III, Mg II, S II, S III, N I, N II, N III, C IV, Si IV, and molecular hydrogen. The system is very deficient in carbon ([C/H]=$-$2.91), nitrogen ([N/H]≤ -3.69) and oxygen ([O/H]=$-$2.47), representing one of the few DLA systems where the CNO-elements can be measured accurately. Direct measurements of O I and upper limits for N I, as well as N II and N III, imply [N/O]$\lesssim -1.22$. Thus, we are looking at a chemically juvenile DLA system, possibly only enriched by the first generation of stars. Plotting the [N/Si] versus [N/H] ratios supports the idea of a common nitrogen ground floor for DLAs at [N/Si]≈ -1.5, indicating a primary nitrogen production by Pop III stars, due to the explosion as Type II Supernovae.

Baryons in Dark Matter Halos
5-9 October 2004
Novigrad, Croatia

---

[*] Speaker.

Published by SISSA http://pos.sissa.it/

1. Introduction

Quasar absorption-line (QAL) systems are an important tool to learn more about the intergalactic medium (IGM). They allow us to trace the chemical evolution of the early Universe, sample a variety of environments and can provide information about the chemically young Universe, only enriched by the first few generations of stars (Pettini et al. 2000b [1]). Damped Lyman α absorbers (DLA), QAL systems with high neutral hydrogen column densities (N(HI) $\geq 10^{20}\mathrm{cm}^{-2}$), are most suitable for the study of the chemical evolution at high redshift. DLAs dominate the neutral gas content of the Universe at $z > 1$, due to their wealth on neutral hydrogen (Rao & Turnshek 2000 [2]). Further, while the observable baryonic content of today's galaxies is concentrated in stars, in the past, it must have been in the form of gas. The very good accordance with the estimated baryonic mass density for DLAs (Ω_{DLA}) at $z \approx 2$ and the baryonic mass density in today's stars (Storrie-Lombardi & Wolfe 2000 [3]) makes DLAs prime candidates to be the progenitors of present-day galaxies. The here investigated DLA system is characterized by a very low overall metallicity. Whether this is due to a retarded star formation or a discontinuity after the first starburst is not clear. Nevertheless, the presence of the most important elements in combination with high resolution data provides us with a unique insight into the very first stage of metal enrichement history in a protogalactic structure.

2. UVES/VLT Observation and Data Analysis

The quasar Q0913+072 was observed by the VLT UV-Visual Echelle Spectrograph (UVES), providing a high-resolution ($\mathrm{R} \sim 45,000$) spectrum. The raw data were reduced using the UVES data pipeline implemented in the ESO-MIDAS software package. The signal-to-noise ratio in the whole spectrum ($\sim 3,500$Å $- 10,200$Å) is generally very high and gains a maximum of ~ 150 per resolution element for $\lambda \lesssim 4000$Å. These data are public and can be found in the UVES database of ESO's Science Archive Facility[1]. The data were analyzed with the program FITLYMAN (Fontana & Ballester 1995 [4]) in the ESO-MIDAS software package, using a χ^2 minimization algorithm for Voigt-profile fitting. Simultaneous fitting procedures and the high resolution spectrum allow us to determine the column density N and the doppler parameter b= $\sqrt{\mathrm{b}_{\mathrm{therm}} + \mathrm{b}_{\mathrm{turb}}}$, which in our case is dominated by the turbulent term, with high accuracy.

3. Metal Abundance Measurements

The outcome of a single-component simultaneous fit for Ly α, Ly β and Ly γ is a neutral hydrogen column density of $\log \mathrm{N(H\,I)} = 20.39$. Fitting the low-ionization lines we can resolve two dominant and three satellite components at -1.3, $+10.7$ and $+113.6$, $+151.5$, $+181.29\,\mathrm{km\,s^{-1}}$, respectively, using a velocity rest frame at $z = 2.6183$ (see Fig. 1). Because of the high hydrogen column density the Ly α absorption is so broad that the five different components are superposed in one big Lyman trough, which makes it impossible to determine the hydrogen column density for each of the five previously mentioned components. When fixing the centers of the two dominant components we obtain column densities of $\log \mathrm{N(H\,I)} = 19.52$ and $\log \mathrm{N(H\,I)} = 20.32$, respectively.

---

[1] http://archive.eso.org

Species v_{rad}	logN(X) -1.32 km s^{-1}	[X/H]	logN(X) 10.7 km s^{-1}	[X/H]	logN(X) 113.6 km s^{-1}	logN(X) 151.5 km s^{-1}	logN(X) 181.3 km s^{-1}	logN(X)$_{A+B}$	[(X$_{A+B}$)/X$_{tot}$]
O I	14.06	−2.15	14.46	−2.55			13.10	14.61	−2.47
C II	13.40	−2.64	13.88	−2.96	12.92	13.20	13.23	14.00	−2.91
Fe II	12.55	−2.47	12.95	−2.87	≤12.20	≤12.00	≤11.00	13.10	−2.79
Fe III	≤12.83	≤ −2.19	≤13.16	≤ −2.66	≤13.40	≤12.90	≤12.80	≤13.33	≤ −2.56
Si II	12.72	−2.36	13.19	−2.69	≤12.10	≤12.20	≤12.30	13.32	−2.63
Si III	≤12.30	≤ −2.78	≤12.60	≤ −3.28	≤12.74	≤13.12	≤13.38	≤12.78	≤-3.17
Al II	11.30	−2.71	11.96	−2.85	10.70	11.30	11.50	12.05	−2.83
Al III	≤10.50	≤ −3.51	≤11.00	≤ −3.81	≤11.30	≤11.50	≤11.70	≤11.12	≤ −3.76
Mg II	≤13.62	≤ −1.48	≤13.72	≤ −2.18	≤14.81	≤12.71	≤14.89	≤13.97	≤ −2.00
S II	≤14.08	≤ −0.64	≤13.86	≤ −1.66				≤14.28	≤ −1.31
S III	≤12.44	≤ −2.28	≤13.43	≤ −2.09				≤13.47	≤ −2.12
N I	≤12.16	≤ −3.31	≤12.48	≤ −3.79				≤12.65	≤ −3.69
N II							≤12.50		
N III							≤13.42		

Table 1: Summary of the logarithmic column densities and metal abundances with the common notation $[X/H]=\log(X/H)-\log(X/H)_{\odot}$. We derive a very low overall metallicity and a relatively uniform metall abundance in all components.

We measure the following metal abundance in the two most dominant components (−1.3 and +10.7 km s^{-1}): $[C/H]_A = -2.64$ and $[C/H]_B = -2.96$ or $[C_{A+B}/H_{tot}] = -2.91$, $[O/H]_A = -2.15$ and $[O/H]_B = -2.55$ or $[O_{A+B}/H_{tot}] = -2.47$. We also detect week absorptions in this two components at a $2-3\sigma$ limit of N I, restricting the nitrogen column density to the upper limits $[N/H] \le -3.31$ and $[N/H] \le -3.79$ or $[N_{A+B}/H_{tot}] \le -3.69$. A complete summary of all the detected species and upper limits is shown in Table 1.

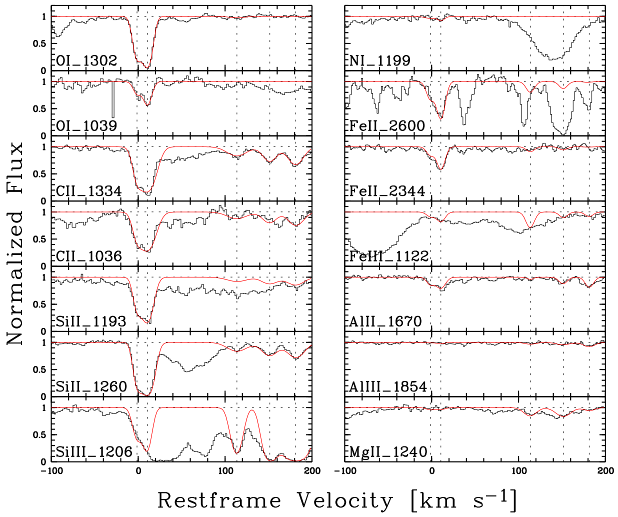

Figure 1: For the low-ionization lines we can resolve two dominant and three satellite components at −1.3, +10.7 and +113.6, +151.5, +181.29 km s^{-1}, respectively, using a velocity rest frame at $z = 2.6183$.

4. Results and Discussion

The redshift of $z_{abs} = 2.618$ corresponds to a lookback time of "only" 2.3 Gyr [2] but does not allow any conclusion on the chemical evolution of the system itself. In fact, the chemical enrichment in this system must have started with some delay compared to other DLAs. It is the remarkable

---

[2] using $H_0 = 71^{+4}_{-3}$km s^{-1}, $\Omega_m = 0.27 \pm 0.04$ and $\Omega_{tot} = 1$

overall metal deficiency, especially in nitrogen, which implies a juvenile system, making this DLA system so interesting. Further, comparing with a database of 66 DLAs (Centurión et al. 2002 [5] and Lanfranchi et al. 2003 [6]) the abundances in [S/H], [Si/H], [Fe/H], [S/H] and [N/H] are among the lowest ever measured.

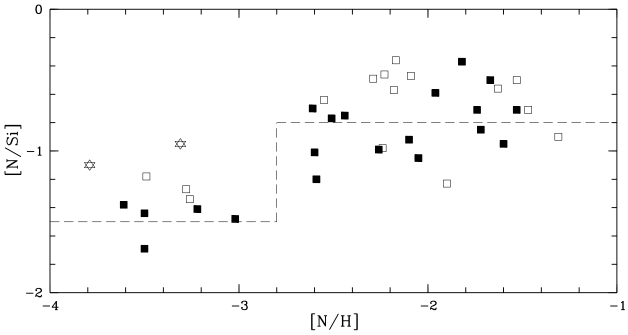

Figure 2: [N/Si] ratio versus nitrogen abundance for 39 DLAs. Open symbols are upper/lower limits, filled symbols measured abundances and stars the A and B component of the here presented DLA system.

Nitrogen is thought to be produced in intermediate mass stars with a mass range of 4−8$M_{\odot}$ which undergo hot bottom burning in the AGB phase. Thus, nitrogen is restored into the ISM with a delay which depends on the lifetime of the stellar progenitors which is significantly lager than that of SNe II. According to Henry et al. (2000) [7] the bulk of nitrogen production occurs after ∼250−300 Myr. The two plateaus in a [N/Si] versus [N/H] plot (Fig. 2) are believed to be due to a bimodal distribution (Prochaska et al. 2002 [8]), a primary and a secondary phase of nitrogen production. The α-enrichment depends critically on the star formation rate (SFR) and it is clear that different DLAs have different star formation histories. This means that they can reach the same amount of α-enrichment at different times. On the other hand, nitrogen production depends more critically on the lifetime of its progenitors rather than on the SFR. Thus, plotting the [N/Si] versus the nitrogen enrichment is close to a true temporal evolution (Molaro et al. 2004 [9]). It might be subject to later investigations if these two plateaus represent a primary and secondary nitrogen production and whether they allow to determine the nature of the very first enrichment processes (possibly SNe II), or provide information on the first star burst, the time delay for SNe Ia to appear, and to state restrictions on progenitor masses for SNe II.

5. References

[1] Pettini, M., Ellison, S.L., Steidel, C.C. Shapley, A.E., Bowen, D.V. 2000b, ApJ, 532, 65
[2] Rao, S., Turnshek, D.A. 2000, ApJS, 130, 1
[3] Storrie-Lombardi, L.J., Wolfe A.M. 2000, ApJ, 543, 552
[4] Fontana, A.,& Ballester, P. 1995, ESO Messenger, 80,37
[5] Centurión, M., Molaro, P., Vladilo, G. 2003, A&A 403, 55
[6] Lanfranchi, G.A., Friaça, A.C.S. 2003, Non. Not. R. Astron. Soc. 334, 481
[7] Henry, R.B.C., Edmunds, M.G. and Köppen, J. 2000, ApJ, 541, 660
[8] Prochaska, J., Henry, R.B.C., O'Meara, J.M. 2002, PASP, 114, 993
[9] Molaro, P., M. Centurión, M., D'Odorico, V. 2004, Carnegie Obs. Astroph. Ser., Vol. 4