A damped Ly$\alpha$ candidate at $z \sim 0.1$ toward Q 0439–433

Patrick Petitjean$^{1,2}$, Bertrand Théodore$^3$, Alain Smette$^4$, and Yannick Lespine$^1$

$^1$Institut d’Astrophysique de Paris - CNRS, 98bis Boulevard Arago, F-75014 Paris, France
$^2$UA CNRS 173- DAEC, Observatoire de Paris-Meudon, F-92195 Meudon Principal Cedex, France
$^3$Servide d’Aéronomie du CNRS, BP 3, F-91371 Verrières-le-Buisson Cedex, France
$^4$Kapteyn Astronomical Institute, Postbus 800, NL-9700 AV Groningen, The Netherlands

Abstract. We report on the detection of a $z_{\text{gal}} = 0.101$ galaxy projected on the sky at 4.2 arcsec (or $5.2 \times 10^{-1}$ kpc for $q_0 = 0.5$) from the quasar Q 0439–433 ($z_{\text{em}} = 0.594$). The HST spectrum of the quasar shows strong Mg II, Fe II, Si II, Al II and C IV absorption lines at the same redshift as the galaxy. The equivalent width ratios of the low ionization lines indicate that this system is probably damped with a neutral hydrogen column density of $N(\text{HI}) \sim 10^{20}$ cm$^{-2}$. The C IV doublet presents a complex structure, and in particular a satellite with a velocity $v = 1100$ km s$^{-1}$ relative to the galaxy. Additional HST and redshifted 21cm observations of this QSO-galaxy pair would offer an ideal opportunity to study the morphology of a damped absorber and the kinematics of the halo of a low-redshift galaxy.

Key words: Galaxies: ISM, quasars:absorption lines, quasars:individual:Q 0439-433, Galaxies: halo, of the same order of magnitude as the cosmological density of stars at present epochs (Wolfe 1996). Moreover they present a metallicity $Z \sim 1/10 Z_\odot$ (Pettini et al. 1994), while strong metal line systems have been demonstrated to be associated with galaxies at low and intermediate $z$ (e.g. Bergeron & Boissé 1991). The detailed study of low-$z$ DLA systems is thus crucial as information can be gathered both on the absorbing gas via optical and UV spectroscopy (kinematics, ionization state) and the associated galaxy (impact parameter, morphology, star formation activity). However very few DLA systems are known at low-$z$ (Lanzetta et al. 1995, Rao et al. 1995). Moreover identifying the galaxy associated with low-$z$ DLA systems is not easy as it often lies very close to the quasar (Steidel et al. 1994). Indeed, using HST high spatial resolution images of the field of seven quasars whose spectra present DLA lines at intermediate redshifts ($0.4 \lesssim z \lesssim 1$), Le Brun et al. (1996) show that, in all cases, at least one galaxy candidate is present within 4 arcsec from the quasar, the closest being at $\sim 0.75$ arcsec. There is no dominant morphological type in their sample: three candidates are spiral galaxies, three are compact objects and two are amorphous low surface brightness galaxies.

Here, we report on the detection of a galaxy projected at 4.2 arcsec (or $5.2 \times 10^{-1}$ kpc for $q_0 = 0.5$ at $z = 0.101$) from the quasar Q 0459–433. The galaxy has the same redshift as a strong Fe II-Mg II-C IV metal line system detected in HST-FOS spectra.

1. Introduction

QSO absorption line systems probe the baryonic matter over most of the history of the Universe ($0 < z \lesssim 5$). The so-called damped Ly$\alpha$ (hereafter DLA) systems are characterized by a very large H I column density ($N(\text{HI}) \gtrsim 2 \times 10^{20}$ cm$^{-2}$), similar to the one usually seen in local spiral disks. Such systems at large redshift ($z \sim 2$–3) are thought to be produced by proto-galactic disks. The main argument in favor of this conclusion is that the cosmological density of gas associated with these systems is

Send offprint requests to: P. Petitjean

* Based on observations collected at the European Southern Observatory, La Silla, Chile

** Based on observations obtained with the NASA/ESA Hubble Space Telescope by the Space Telescope Institute, which is operated by AURA, Inc., under NASA contract NAS 5-26555

2. Observations

B, V, R and I broad-band images of the rich field around Q 0439–433 and spectra of the QSO and galaxy were obtained on 20 and 22 February 1996, with EMMI mounted on the NTT. Fig. 1 shows the B-band image after flat-fielding and flux-calibration. The scale is given by a tick mark of size 10 arcsec. The quasar is marked with an arrow; a galaxy is seen 4.2 arcsec north of it. B, V, R and I magnitudes for the quasar and the galaxy are 17.21, 16.84, 16.75, 16.44 and 18.76, 17.74, 17.24, 16.74 respec-
Fig. 1. B-band image taken with EMMI on the NTT. North is at the top, East on the left. The quasar is marked. The scale is given by a tick mark of size 10 arcsec.

Fig. 2. Portion of the spectrum of the galaxy taken with EMMI on the NTT. An emission line clearly appears at $\lambda$5353.08 on top of a broad absorption feature and is identified as $\text{H}\beta$ at $z_{\text{abs}} = 0.1012$.

Spectroscopic observations of Q 0439–433, yet unpublished, were accessed from the HST archive. The observations were made using the Faint Object Spectrograph with the G190H grating (over the wavelength range 1600–2300 Å, for a resolution of 1.35 Å FWHM) and with the G270H grating (over the wavelength range 2250–3250 Å, for a resolution of 1.92 Å FWHM). The data were calibrated using the standard pipeline reduction techniques. The zero point of the wavelength scale was determined requiring that Galactic interstellar absorptions occur at rest. We concentrate on the $z_{\text{abs}} = 0.101$ system. Table 1 gives the characteristics of the lines detected in this system (observed wavelengths and equivalent widths, errors from the adjacent noise, identifications and corresponding redshifts). Fig. 4 shows portions of the spectrum with the lines of interest.

Fig. 3. Images J (left) and K' (right) taken with IRAC2 at the ESO 2.2 m.
3. Results

3.1. A galaxy at $z = 0.3848$

During the spectroscopic observation, the long-slit was oriented north-south and happened to intercept a faint object located 25.8 arcsec north of the quasar (see Fig. 1). The spectrum presents an emission line at $\lambda 5161.3$. The identification with $[\text{O ii}] \lambda 3727$ gives a redshift of $z_{\text{gal}} = 0.3848$. There is no absorption line in the HST data at this redshift with a $3\sigma$ observed equivalent width limit of 0.3 Å. The projected distance between the object and the line of sight to the quasar is $324 h^{-1}_{100} \text{kpc}$ ($q_0 = 0.5$). This large distance is consistent with the idea that the metal line systems at intermediate redshift arise in galaxy halos with radius of the order of $35 h^{-1}_{100} \text{kpc}$ (e.g. Bergeron & Boissé 1991, Steidel 1993).

### Table 1. Absorption lines in the quasar spectrum belonging to the $z_{\text{abs}} = 0.101$ system

| N. | $\lambda_{\text{obs}}$ (Å) | $w_{\text{obs}}$ (Å) | $\sigma_{\text{obs}}$ (Å) | Identification | $z_{\text{abs}}$ |
|----|--------------------------|----------------------|--------------------------|---------------|----------------|
| 1  | 1680.75                  | 0.71                 | 0.14                     | SiII1526      | 0.10000       |
| 2  | 1704.91                  | 1.40                 | 0.14                     | CIV1548       | 0.10122       |
| 3  | 1707.40                  | 0.90                 | 0.14                     | CIV1550       | 0.10100       |
| 4  | 1710.85                  | 0.70                 | 0.14                     | CIV1548       | 0.10506       |
| 5  | 1713.70                  | 0.50                 | 0.14                     | CIV1550       | 0.10506       |
| 6  | 1838.77                  | 1.25                 | 0.12                     | AlII1670b     |               |
| 7  | 2229.60: ZnII12026b      |                      |                          |               |
| 8  | 2581.19                  | 0.60                 | 0.10                     | FeII2344      | 0.10109       |
| 9  | 2614.05                  | 0.22                 | 0.10                     | FeII2374      | 0.10000       |
| 10 | 2623.51                  | 0.98                 | 0.10                     | FeII2382      | 0.10104       |
| 11 | 2847.89                  | 0.94                 | 0.10                     | FeII2586      | 0.10009       |
| 12 | 2862.87                  | 1.07                 | 0.10                     | FeII2600      | 0.10103       |
| 13 | 3078.92                  | 1.64                 | 0.10                     | MgII2796      | 0.10105       |
| 14 | 3086.64                  | 1.39                 | 0.10                     | MgII2803      | 0.10008       |
| 15 | 3140.89                  | 0.29                 | 0.10                     | MgII2852      | 0.10105       |
| (NTT) 4333.74: | 0.39 | 0.15 | CaII3934 | 0.10139 |

$a$ 1σ detection limit

$b$ Blended

### Table 2. Column densities ($\text{cm}^{-2}$) in the $z_{\text{abs}} = 0.101$ system

| Velocity$^a$ | C iv | Si ii | Fe ii | Mg ii | Mg i | Zn ii |
|--------------|------|-------|-------|-------|------|-------|
| -16          | 14.7 | 15.5: | 14.7  | 14.8  | 12.6 | 13.0: |
| 136          | 13.8 | 13.8  | 13.6  | 14.3  | 12.0 | <12.5 |
| 1100         | 14.4 |       |       |       |      |       |

$^a$ relative to $z = 0.1010$ in km s$^{-1}$

Fig. 4. Portions of the G190H and G270H HST spectra. Lines marked with a G symbol correspond to galactic absorptions. Absorption lines from the $z \sim 0.101$ system are numbered as in Table 1. The dotted line is a fit to the lines described in the text and with column densities given in Table 2.
3.2. The absorption system and the associated galaxy at $z_{\text{abs}} = 0.101$

Strong Fe ii and Mg ii lines are present in the HST spectrum with very good redshift agreement. The mean redshift is $z_{\text{abs}} = 0.1010$. It is apparent from Fig. 4 that the lines are blends of several components. Given the limited resolution of the spectra, it is only possible to perform a rough decomposition. We obtain however a good overall fit with two components with Doppler parameters $b = 15 \text{ km s}^{-1}$, separated by 150 km s$^{-1}$. The derived column densities are given in Table 2.

The ratio $w$(Fe ii $\lambda\lambda 2382)/w$(Mg ii $\lambda\lambda 2796) \sim 0.6$ indicates that the system is certainly of fairly high H i column density ($N$(H i) $> 10^{19}$ cm$^{-2}$, Bergeron & Stasińska 1986). The detection of a strong Mg $\lambda 2852$ absorption line (rest equivalent width $w_r = 0.26$ Å) further supports this conclusion. Indeed the Fe ii, Mg ii and Mg i equivalent widths are very similar to those observed in the 21 cm absorber ($N$(H i) $\sim 3 \times 10^{20}$ cm$^{-2}$) at $z_{\text{abs}} = 0.395$ towards Q 1229–021 (Lanzetta & Bowen 1992). There is an absorption feature at $\lambda 2229.6$ which we would normally not attribute to Zn ii $\lambda 2026$ at $z = 0.101$ because the wavelength discrepancy (120 km s$^{-1}$) is slightly larger than the resolution. However the feature has a red wing that could be due to Zn ii, in which case we find log $N$(Zn ii) $\sim 13.3$. There is an absorption feature at $\lambda 3333.74$ in the NTT spectrum that could be identified with Ca ii $\lambda 3934$ at $z_{\text{abs}} = 0.10139$. The associated Ca ii $\lambda 3969$ is below our detection limit of $w_{\text{abs}} = 0.15$ Å (1 σ). The non-detection of Ca ii in a strong Mg ii system would not be surprising however. Bowen et al. (1991) have shown that the distribution of the calcium-absorbing gas is quite inhomogeneous in present-day galaxies even at very small impact parameters ($\rho < 5 h^{-1}_{100} \text{ kpc}$).

There is a strong C iv system coincident in redshift with the low ionization lines. The C iv and Mg ii doublets are spread over $\sim 150$ km s$^{-1}$. However the velocity distribution of the gas is different in C iv and Mg ii (Doppler parameters of 60 km s$^{-1}$, we used to fit the C iv lines) as often observed in DLA systems where Mg ii and C iv are thought to probe galactic disks and haloes respectively (e.g. Turnshek et al. 1989). The low ionization lines have equivalent width typical of the absorption lines produced by the Milky Way gas in the spectra of extra-galactic objects (Savage et al. 1993). However the C iv lines are much stronger in the present system. Moreover there is an additional C iv system redshifted relative to the galaxy by about 1100 km s$^{-1}$. Its origin is unclear but could be due to a companion. Several candidates are present in the field within 35 arcsec (or $45h_{100}^{-1}$ kpc, see Fig. 1). High resolution imaging of the field with HST is needed to investigate the morphology of the galaxy. Indeed, although a faint spiral feature can be seen in the K’-band and optical images, the morphology of the galaxy is unclear. The colours however are indicative of a spiral galaxy.

4. Conclusion

It seems likely that the $z_{\text{abs}} = 0.101$ Mg ii-Fe ii-C iv absorption system detected in the spectrum of Q 0439-433 is a damped Ly$\alpha$ system of moderate column density ($N$(H i) $\sim (2.3 \pm 0.8) \times 10^{20}$ cm$^{-2}$) (Wilkes et al. 1992) with a Galactic contribution of $(1.3 \pm 0.1) \times 10^{20}$ cm$^{-2}$ (Lockman & Savage 1995). This is consistent with the above estimate of the H i column density. Q 0439–433 is a flat-spectrum radio-source with a flux of 0.3 Jy at 2.7 GHz (Peterson & Bolton 1972); it is then possible to carry out a detailed study of the kinematics through the 21 cm absorption line that is sensitive to gas with low spin temperature; on the other hand, HST+STIS spectra should provide an accurate determination of the total H i column density, and in turn may lead to evaluate the H i spin temperature. This QSO-galaxy pair is an ideal case to study the morphology of a damped absorber and the kinematics of the halo of a low-redshift galaxy.

Acknowledgements. AS thanks financial support under grant no. 781-73-058 from ASTRON which is funded by the NWO.

References

Bergeron J., Boissé, P., 1991, A&A 243, 344
Bergeron J., Stasińska G., 1986, A&A 169, 1
Bowen D.V., Pettini M., Penston M.V., Blades C., 1991, MN- RAS 249, 145
Lanzetta K.M., Bowen D.V., 1992, ApJ 391, 48
Lanzetta K.M., Wolfe A.M., Turnshek D.A., 1995, ApJ 440, 435
Le Brun V., Bergeron J., Boissé P., Deharveng J.M., 1996, A&A (submitted)
Lockman F.J., Savage B.D. 1995, ApJS 97, 1
Moorwood A., Finger G., Bierichel P., et al., 1992, The Messenger 68, 61
Peterson B.A., Bolton J.G. 1972, Astrophys. Letters 10, 105
Pettini M., Smith L.J., Hunstead R.W., King D.L., 1994, ApJ 426, 79
Rao S.M., Turnshek D.A., Briggs F.H., 1995, ApJ 449, 488
Savage B.D., Lu L., Bahcall J.N., et al., 1993, ApJ 413, 116
Steidel C.C., 1993, J.M. Shull and H.A. Thronson Jr. (eds) Proc. of the Third Téton Summer School, The Environment and Evolution of Galaxies, Kluwer, Dordrecht, p. 263
Steidel C.C., Pettini M., Dickinson M., Persson S.E., 1994, AJ 108, 2046
Turnshek D.A., Wolfe A.M., Lanzetta K.M., et al., 1989, ApJ 344, 567
Wilkes B.J., Elvis M., Fiore F., et al., 1992, ApJL 393, L1
Wolfè A.M., 1996, in ‘QSO absorption lines’, G. Meylan (Ed.), Springer, Garching, p.13

This article was processed by the author using Springer-Verlag L\'\TeX\ A\&A style file L-\AA\ version 3.