Astron. Astrophys. 321, 129–133 (1997)

ASTRONOMY AND ASTROPHYSICS

The absorbers towards Q0836+113*

N. Benítez[1,2], **E. Martínez-González**[1], **J.L. Sanz**[1], **A. Aguirre**[3], **and M. Alises**[3]

[1] IFCA, CSIC-UC, Fac. de Ciencias, Avda. Los Castros s/n, E-39005 Santander, Spain
[2] Dpto. de Física Moderna, UC, Fac. de Ciencias, Avda. Los Castros s/n, E-39005 Santander, Spain
[3] Centro Astronómico Hispano-Alemán, Calar Alto, Almería, Spain

Received 2 June 1996 / Accepted 2 October 1996

Abstract. We have performed $RIJHK_S$ imaging of the field around the z = 2.67 quasar Q0836+113, which presents several metal line and a damped Lyα absorption systems in its spectrum. The images reveal the existence of a red K_S = 18.9 object $\approx 11''$ from the quasar. On the basis of the empirical relationships between absorption radius and luminosity we conclude that this object may be the CIV absorber at $z = 1.82$. This could be the first detection of a high redshift galaxy causing high-ionisation absorption. After carefully subtracting the QSO, we do not detect, up to a 3σ limiting magnitude for extended objects of K_S = 20.8, the damped Lyα absorber apparently detected as a Lyα emitter at z = 2.47. This imposes an upper limit on its Hα emission comparable to the results obtained spectroscopically by Hu et al. (1993). It is also suggested, that object "SW" from Wolfe et al. (1992) could be the galaxy responsible for the claimed MgII absorption at z = 0.37.

Key words: galaxies: evolution – galaxies: halos – quasars: individual: Q0836+113 – quasars: absorption lines

1. Introduction

The absorption line systems found in the spectra of distant quasars have proved to be very useful in order to find and study 'normal' high redshift galaxies, not flagged by the prominent emission of an AGN. Several authors have followed this strategy, performing broad band imaging and follow up spectroscopy of objects in quasar fields or with narrow band filters. The success of absorber identifications up to $z \lesssim 1$ has been very high: MgII systems are associated to galaxies which are identified in practically all the cases (Bergeron & Boisse 1991, Steidel et al. 1994, Steidel 1995) and Lyα-clouds are also identified with galaxies in a high fraction ($\simeq$ 50%) by Lanzetta et al. (1995) .

In this paper we report the results of deep near-IR and optical imaging of the field of the z = 2.67 quasar Q0836+113, which presents several low and high ionisation absorption systems and a damped Lyα system in its spectrum.

2. Observations and photometry

Optical R and I observations were carried out at the 2.6m Nordic Optical Telescope (NOT) at La Palma on the nights of 1995 March 3, 4 and 5. The detector was the Thomson 1024^2 IAC camera with a pixel scale of $0.14''$/pixel. The field was centered on the quasar and we took 3 frames of 2700 seconds each in R and 5 frames of 1800 seconds in I. The images were reduced with dome and sky flats using IRAF tasks and calibrated with standard stars. We estimate the zero-point calibration errors to be $\pm$0.06 in R and $\pm$0.08 in I. The FWHM of the final co-added images is $1.8''$ and $0.9''$ for R and I respectively.

The near IR observations were performed at the 3.5m Telescope at Calar Alto with the camera MAGIC on the nights of 1995 March 17, 19 and 21. MAGIC uses a 256 $\times$ 256 NICMOS3 HgCdTe detector array with $0.33''$/pixel. Due to a telescope pointing error the field is not centered on the QSO, but displaced to the SW. 18 frames of 100 seconds and 9 of 290 seconds were taken on H and J respectively and 81 frames of 60 seconds in the K_S band. The images have been reduced in the standard way for near IR observations. After subtracting dark frames, a flat field for each frame was formed by median combining the closest frames with a sigma-clipping algorithm. The final, averaged K_S image, has a $0.8''$ seeing, and the H and J images have seeings of $1.5''$. The frames were calibrated with standard stars from Elias et al. (1982). The zero-point uncertainties are 3% for K_S and 10% for J and H.

We have selected as possible candidates for the absorbers the objects detected in the K_S image, which is the deepest and the one with best seeing. We used the package PISA (Draper & Eaton 1992) with a 3σ detection limit and carefully checked all detections by eye, removing spurious objects on the outer parts of the image, which are less exposed. Afterwards we performed aperture photometry centered on these detections in the R, I and K_S bands using three apertures for each object: $1.5\sigma_{psf}$, $3\sigma_{psf}$ and $6\sigma_{psf}$, where σ_{psf} is the σ of the point spread function for each image. We classified the objects into two classes: stellar and

Send offprint requests to: N. Benítez

* Based on observations made with the Nordic Optical Telescope

Table 1. Coordinates, distance from Q0836+113 and $RIJHK_S$ magnitudes

Object	X(")	Y(")	Radius(")	R	I	J	H	K_S
QSO	0.	0	0	19.426 ± 0.002	19.105 ± 0.007	18.69 ± 0.05	18.17 ± 0.15	17.59 ± 0.02
C	-0.83	3.41	3.51	22.37 ± 0.16	22.60 ± 0.15	> 21.4	> 20.2	20.11 ± 0.22
SW	4.26	-5.19	6.71	23.39 ± 0.19	23.10 ± 0.21	> 21.4	> 20	20.35 ± 0.19
S	0.72	-10.64	10.66	23.63 ± 0.23	22.73 ± 0.14	21.10 ± 0.20	19.74 ± 0.20	18.91 ± 0.08

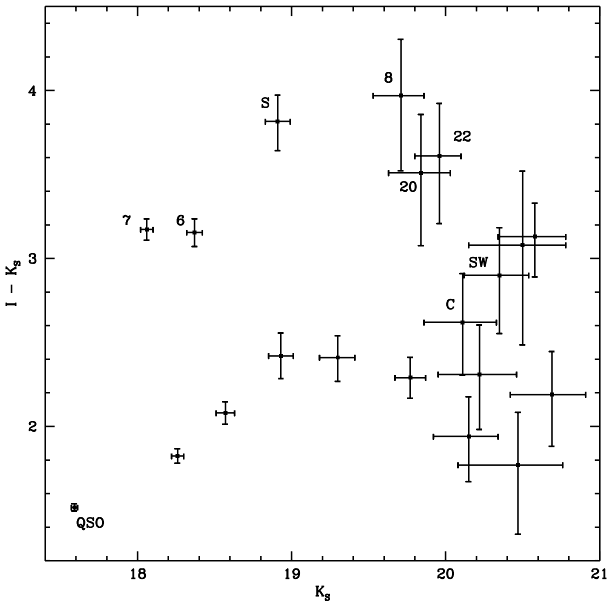

Fig. 1. $I - K_S$ vs. K_S plot for all the objects detected in our field at a higher than 3σ level. The error bars include both the intrinsic photometric error and the rms of the corrections.

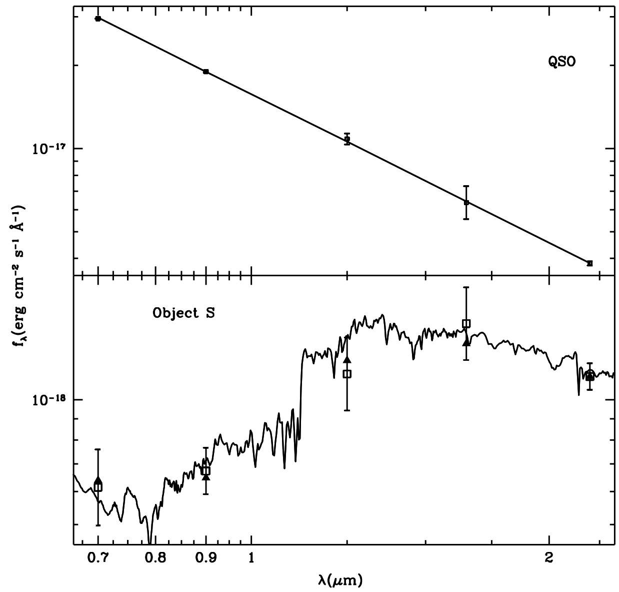

Fig. 2. Spectral distributions, inferred from broad band colours, of the QSO (above) and object S (below). A fit to a $F_\nu \propto \nu^\alpha$ distribution for the QSO and to a model galaxy at z=1.82 corresponding to object S are shown (see details in the main text).

extended. Extended objects have on average, after quadratically subtracting the seeing, an angular extension of $\approx 1''$. For each object we took the magnitude given by the largest aperture for which the intrinsic photometric error was less than 0.3 mag and, if needed, corrected to a $6\sigma_{psf}$ aperture with the average of the corrections for the brighter objects of each class. The $6\sigma_{psf}$ radii correspond to aperture diameters of $8.8''$ in R, $4.6''$ in I and $4''$ in K_S. In Fig. 1 we have plotted $I - K_S$ colors as a function of K_S for the objects detected in our K_S frame. The J and H images are not so deep as the other ones and only overlap with them in the central part containing the QSO. The results of the $RIJHK_S$ photometry of the QSO and the closest objects are presented in Table 1. We have also plotted in Fig. 2 the spectral distributions, inferred from broad band colours, of the QSO and object S. In order to check the photometry we fitted a $F_\nu \propto \nu^\alpha$ distribution to the QSO spectra and obtained $\alpha = -0.21$, close to the median slope of the QSOs observed by Neugebauer et al. 1987. The fit is overplotted in Fig. 2.

3. Results and discussion

Turnshek et al. (1989) reported the presence of four absorption line systems in the spectra of Q0836+113: two MgII systems, one at $z = 0.37$ and the other at $z = 0.79$; a CIV system at $z = 1.82$ which has no low-ionisation associated absorption and a damped Lyα (DLA) system at $z = 2.47$. It should be pointed out that the MgII at $z = 0.37$ lies in the Lyα forest and thus there is a chance of misidentification. We have examined the best available data (Hunstead et al. 1990), kindly provided by M. Pettini, and could not confirm nor rule out definitively the reality of this absorption.

Hunstead et al. (1990) claimed the detection of a Lyα emission spike at the bottom of the DLA absorption line. This result generated considerable controversy: neither Wolfe et al. (1992) nor Lowenthal et al. (1995) have found traces of Lyα emission from the DLA absorber in their spectroscopic observations, although Pettini et al. (1995) apparently have confirmed the detection. Besides, Wolfe et al. (1992) reported the discovery of a faint extended Lyα emission a few arcsec to the NE of the QSO which has not been confirmed, neither spectroscopically nor through direct imaging by Lowenthal et al.(1995). In Figs.

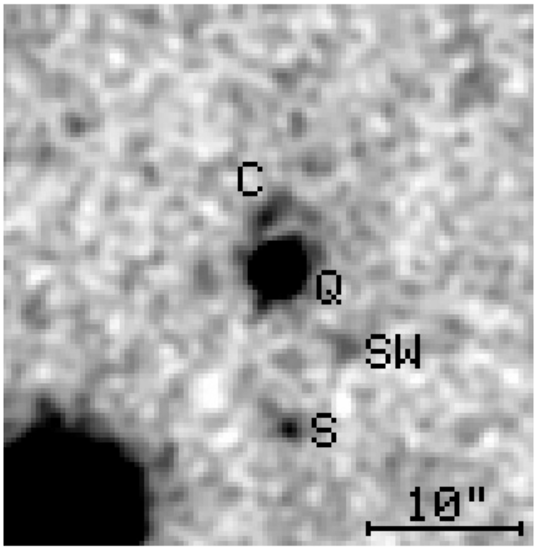

Fig. 3a. I-band image of a $\approx$ 36 $\times$ 36 arcsec^2 field centered on Q0836+113. The image has been convolved with the seeing. North is up and East to the left. The pixels have a scale of 0.33$''$/pixel.

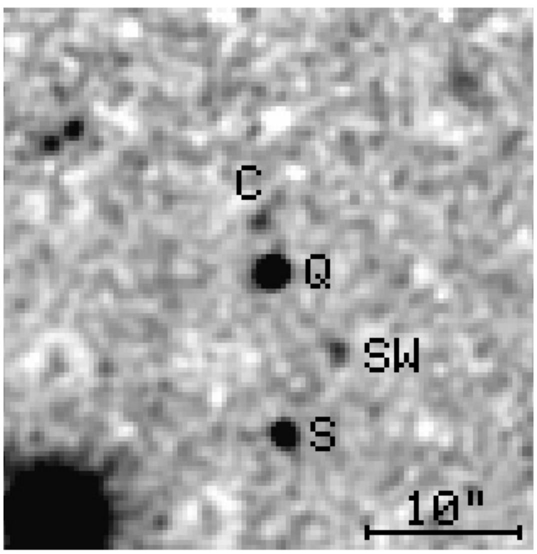

Fig. 3b. The same as Fig. 3a, but in the K_S band.

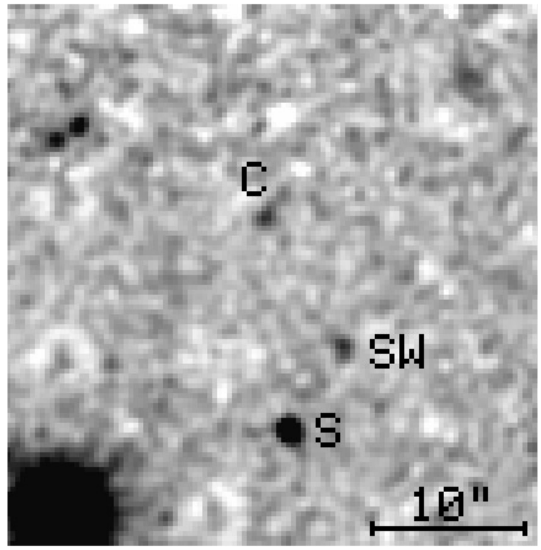

Fig. 3c. The same as Fig. 3b, but after subtracting the QSO using the star at the lower left corner of the field.

3a and 3b we present I and K_S images of a $\approx$ 36 $\times$ 36 arcsec^2 field centered on Q0836+113. In order to check for the existence of possible objects which could be hidden by the quasar, we scaled a nearby, bright but non saturated star, and subtracted it from the quasar in the K_S frame. The result can be seen in Fig. 3c. No object is detected at the position indicated by Wolfe et al. (1992) for the Lyα emitting object up to a 3σ detection limit (for extended objects in an 4$''$aperture) of K_S = 20.8. This apparent magnitude limit cannot be translated to rest-frame luminosity without big uncertainties, but for comparison we would have marginally detected in our image object B2 from Francis et al. (1996) which has z = 2.38 and a Lyα flux similar to that reported by Wolfe et al. (1992) for their detection. It is also noteworthy that we can impose upper limits on the possible redshifted Hα emission from the DLA ($\lambda \approx 2.27\mu$m) as it is contained within the K_S band (2.00 − 2.32μm). Our 3σ detection is K_S = 21.75 arcsec^{-2}, corresponding to a 3σ detection flux of $f_{K_S} \approx 2.7 \times 10^{-16}$ ergs cm^2 s^{-1} arcsec^{-2}, which compares well with the 2σ upper limit of $\leq 2.4 \times 10^{-16}$ ergs cm^2 s^{-1} obtained by Hu et al. (1993) spectroscopically for the Hα emission of this quasar.

In order to find out how the objects detected in the frame are related to the QSO absorption systems, we shall use the results of Steidel and collaborators (Steidel 1995, Steidel et al. 1994) who have identified the galaxies producing $z \leq 1$ MgII absorption in a sample of quasars. They have established that if a galaxy is brighter than $M_K = -22$ (H$_o$=50 km s^{-1} Mpc^{-1}, q_o=0.05) and falls within the distance

$$R_{abs}(L_K) = 38h^{-1}(L_K/L_K^*)^{0.15}\ \mathrm{kpc}$$

from a QSO sight line, it will produce detectable MgII absorption, independently of its morphological type. In Fig. 4 we have drawn R_{abs} as a function of K apparent magnitude for the redshifts z = 0.368, z = 0.788 and z = 1.822. We have used the cosmological parameters (q_o=0.05, H$_o$=50 km s^{-1} Mpc^{-1}) and the K-corrections corresponding to a type Sb-Sc galaxy. We have also plotted the objects which are within a radius of 20$''$ from the QSO. Below we discuss the individual results regarding the most interesting objects in the field.

3.1. Object C

Wolfe et al. (1992) reported the detection of object C nearly superposed with the claimed NE Lyα emission. This galaxy has been identified as the MgII absorber at z = 0.788 (Lowenthal et al. 1995). In Fig. 3 object C can be clearly distinguished, 3.5$''$ from the QSO and at a PA of $\approx$ 7.5 deg. We resolve it partially and find it to be quite elongated, with an ellipticity e = 0.28. It has a bright nucleus closer to the QSO, and a very faint tail

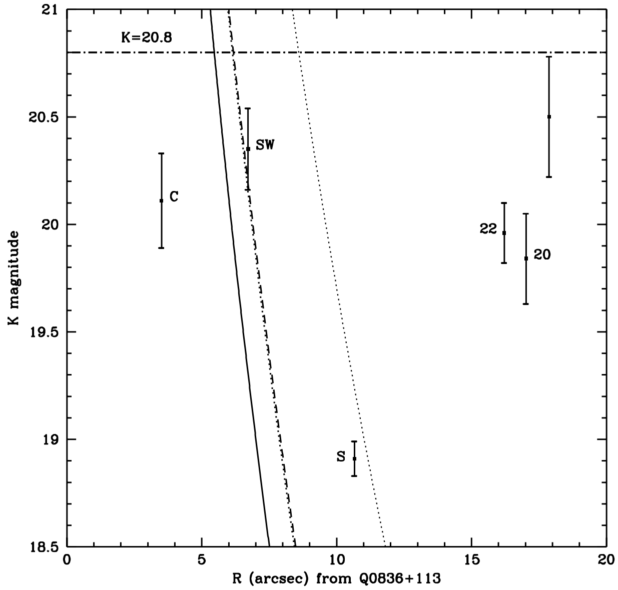

Fig. 4. Steidel et al. (1994) relationship shown for several redshifts. The filled squared points represent the distance from the QSO and the apparent K magnitude of the objects detected within a 20″ radius from the QSO. The thick lines show the low-ionisation absorption radius as a function of the K apparent magnitude for several redshifts. The short-dashed line corresponds to z = 0.368, the continuous line to z = 0.788 and the dotted line to z = 1.82. The thin dotted line corresponds to the maximal radius of high-ionisation absorption at z = 1.82 (see text)

extending NW can be guessed. As could be expected, object C is well within the line corresponding to z = 0.788 MgII absorption in Fig. 4.

3.2. Object SW

Wolfe and collaborators also detected the point-like object SW, at $\approx 7''$ in the SW direction from the QSO which we can also distinguish in Fig 3. In Fig. 4 we see that, excluding object C, only the position of object SW is consistent, within the error bars, with being the MgII absorber at z = 0.368. This tentative identification should be confirmed spectroscopically, since this galaxy has not been detected in Fabry-Perot maps tuned to [OII]3727 at z = 0.37 (Caulet 1991) and Wolfe et al. (1992) report that it apparently presents a relative excess of emission in a narrow band filter tuned to Lyα at the redshift of the DLA system. Besides, the galaxy itself is rather faint for z = 0.368, as its $K = 20.35 \pm 0.2$ corresponds to $L_K \approx 0.03 L_K^*$, which is below the luminosity at which Steidel and coworkers suggest that the luminosity/cross-section scaling relation must break down, $L_K \approx 0.05 L_K^*$. On the other hand, our detection limit of K_S = 20.8 corresponds to an absolute magnitude of $M_K \approx -20.6$, and therefore the galaxy responsible for the absorption should be in our frame unless it is even fainter, $L_K \approx 0.02 L_K^*$. In any case, we must keep in mind that the existence of the MgII absorption at z = 0.37 is still uncertain, and thus it could be that there is no absorber galaxy at all.

3.3. Object S

We can clearly see in our frames an object $10.6''$ to the south of the QSO which was not mentioned in Wolfe et al. (1992) and Lowenthal et al. (1995), and which we call object S. It has a K_S magnitude of 18.9 ± 0.06 and is detected in all our broad-band images. It is red ($R - K_S$=4.7), partially resolved (FWHM$\approx 1''$) and slightly elongated in the NE direction. From Fig. 4 it is clear that object S is not close enough to the QSO to be a MgII absorber at any of the considered redshifts. As we explain below, the analysis of the optical-near IR colours of object S agree with this result and makes very unlikely that this object is a companion to these MgII absorbers. In Dickinson (1995) and Aragón-Salamanca et al. (1993) we can find the $I - K$, K color-magnitude relationship for Cl 1603+4313, a cluster of galaxies at z = 0.895. Object S, with $I - K$ = 3.8 is $\approx$0.6 magnitudes redder than the red envelope of this cluster. Assuming that this color is not caused by dust-absorption, it indicates that object S has $z > 1$.

Could object S be the CIV absorber at z=1.82?. For illustration, we have plotted over the observed spectral distribution in Fig. 2b a model spectrum at z = 1.82 obtained with the Bruzual & Charlot (1993) code. The model galaxy is formed by a burst of star formation involving most of the galaxy mass at z = 7 and undergoes another burst of star formation at z = 1.82. The squares represent the empirical fluxes through each of the filters with their errors, the continuous line is the model spectrum and the triangles are the fluxes that we would measure after convolving this spectrum with the response of the filters. The galaxy spectrum is normalized to coincide with our data in the $K-$band. We see that the colors of object S are consistent with z = 1.82. At this redshift, object S would be rather luminous $L_K \approx 4.5 L_K^*$ and at a distance of $\approx$ 127 kpc (H$_o$=50 km s^{-1} Mpc^{-1}, q_o=0.05) from the quasar position.

In contrast with the growing number of galaxies known to be responsible for low-ionisation absorptions, so far there has not been any single identification of a high ionisation, 'CIV-only' system. Maybe due to this shortage of observational data there are several theoretical models which try to explain the origin of this type of absorption. Stengler-Larrea et al. (1996) have determined that strong CIV systems, with column density greater than log$N > 14.2 \pm 0.2$ also present low ionisation CII associated absorption. This favours a simple model for the absorber galaxies very similar to the one described in Steidel (1993), where the difference between low and high ionization systems basically relates to impact parameter. Stengler-Larrea et al. (1996) estimate that the outer halo responsible for the high-ionisation absorption has a radius $R_{out} \sim 1.4 R_{in}$, where R_{in} is the radius of the inner low-ionisation sphere. From the Steidel et al. (1994) law, if object S were at z=1.82, it would have a low-ionisation absorption radius of $\approx 8''$ and thus a maximal high-ionization halo radius of $\approx 11''$, which is consistent with the QSO spectrum presenting CIV but not low-ionisation absorptions at z=1.82 (see Fig. 4). This would be the first detection of a high-ionisation absorber and could help to clarify the controversy about their origin.

Aragón-Salamanca et al. (1994) have imaged fields around CIV absorption systems at redshift $z \sim 1.6$ in the near-IR, and claim the detection of several candidates for the absorber galaxies at distances $r < 6''$. They would not have considered object S as a candidate because of its rather large impact parameter. However, they have selected multiple CIV systems, which seem to be the high redshift counterparts of the relatively well known MgII systems as they nearly always present low ionisation associated absorption. In fact, all the CIV systems of Aragón-Salamanca et al. (1994) present MgII or CII absorption when the corresponding part of the spectrum is observed, which explains why they have smaller impact parameters.

Another possibility is that object S is a companion to the DLA system. However, if we place object S at z = 2.467, it would become uncomfortably bright, for nearly all the possible combinations of galaxy types and cosmologies.

3.4. Other objects

A close examination of Fig. 3a reveals the existence of some faint objects close to the QSO. These objects are not seen in the K_S band image, and they are not detected at a meaningful signal-to-noise in the I band, so we assume that most of them are probably noise, excepting maybe the wisp to the SE of the QSO, which can also be seen in Fig. 4 of Lowenthal et al. 1995, a frame obtained with a narrow band filter tuned to [OII]λ 3727 at z=0.788.

It is noteworthy (see Fig. 1) that objects 20 and 22, which are the close pair of objects at the upper left of Fig. 3, and object 8 which is at $\approx 50''$ from the QSO present $I-K$ colours similar to object S and could be members of a group at its redshift. Objects 7 and 6 are also remarkable: they are bright, quite compact but non stellar and have the colours expected for the red envelope at z = 0.788, so they may be companions to object C, from which they are at a distance of $\approx 50''$. In any case, spectroscopy, and deeper and wider multiband imaging are clearly needed in order to firmly establish the possible existence of groups at these redshifts.

4. Conclusions

We have performed deep near IR and optical imaging of the field around Q0836+113 with the aim of detecting the absorption systems present in its spectra and obtained the following results:
– The images reveal the existence of a red object $\approx 11''$ south from the QSO, which could be the CIV absorber at z = 1.82. If this is confirmed, it would be the first detection of a CIV system which has no low ionization absorption and would contribute to clarify the controversy regarding the origin of these absorptions.
– After carefully subtracting the QSO, we do not detect, up to a 3σ limiting magnitude of K_S = 20.8 the galaxy responsible for the DLA absorption system which has been claimed to be detected as a Lyα emitter at z = 2.467
– We propose that object SW may be the galaxy causing the MgII absorption at redshift z = 0.368 on the basis of the Steidel et al. (1994) relationship between absorption radius and K absolute magnitude for intermediate redshift MgII absorbers.
– There are several red objects in the field which could be companions to the CIV absorber and to the z = 0.788 MgII absorber.

Acknowledgements. The 3.5m telescope is operated by the Max-Planck-Institut für Astronomie at the Centro Astronómico Hispano-Alemán in Calar Alto (Almería, Spain). The Nordic Optical Telescope is operated on the island of La Palma by the Nordic Optical Telescope Scientific Association in the Spanish Observatorio del Roque de Los Muchachos of the Instituto de Astrofísica de Canarias. We thank Chuck Steidel, Mark Dickinson, Max Pettini and Ignacio Ferreras for their help and for useful comments. NB, EMG and JLS acknowledge financial support from the Spanish DGICYT, project PB92-0741. NB acknowledges a Spanish M.E.C. Ph.D. scholarship.

References

Aragón-Salamanca, A., Ellis, R., Couch, W.J., Carter, D. 1993, MNRAS, 262, 764
Aragón-Salamanca, A., Ellis, R., Schwartzenberg, J.-M., Bergeron, J.A. 1994, ApJ, 421, 27
Bergeron, J., Boisse, P. 1991, A&A, 243, 344
Bruzual, G.A., Charlot, S., 1993, ApJ, 405, 538
Caulet, A. 1991, quoted in Wolfe et al. 1992 as 'private communication'.
Draper, P.W., Eaton, N. 1992, Starlink Project User Note 109.5, Rutherford Appleton Laboratory
Dickinson, M. 1995, To appear in Fresh Views on Elliptical Galaxies, ASP Conference Series, eds. A. Buzzoni, A.Renzini and A. Serrano
Elias, J.H., Frogel, J.A., Mathews, K., Neugebauer, G. 1982, AJ 87, 1029
Francis, P.J., Woodgate, B.E., Warren, S.J. et al. 1996, to appear in ApJ
Hunstead, R.W., Pettini, M., Fletcher, A. B. 1990, ApJ, 356, 23
Hu, E.M., Songaila, A., Cowie, L.L., Hodapp, K.-W., 1993 ApJLett, 419, L13
Lanzetta, K.M., Bowen, D.B., Tytler, D., Webb, J.K. 1995, ApJ, 442, 538
Lowenthal, J.D., Hogan, C.J., Green, R.F. et al. 1995, ApJ, 451, 484
Neugebauer, G., Green, R.F., Matthews, K., et al. 1987, ApJS, 63, 615
Pettini, M., King, D.L., Smith, L.J., Hunstead, R.W. 1995, in QSO Absorption Lines, proc. of the ESO Workshop held at Garching, Germany, ed. G. Meylan, (Springer-Verlag), 55
Steidel, C.C. 1993, in The Environment and Evolution of Galaxies, proc. of the 3rd Teton Astronomy Conference, eds. J.M. Shull and H.A. Thronson, (Dordrecht: Kluwer), 263
Steidel, C.C. 1995, in QSO Absorption Lines, proc. of the ESO Workshop held at Garching, Germany, ed. G. Meylan, (Springer-Verlag), 139
Steidel, C.C., Dickinson, M. and Persson, S.E. 1994, ApJLett, 437, L75
Stengler-Larrea, E.A., Boksenberg, A., González-Solares, E.A. 1996, to appear in MNRAS
Turnshek, D.A., Wolfe, A.M., Lanzetta, K.M. et al. 1989, ApJ, 344, 567
Wolfe, A.M., Turnshek, D.A., Lanzetta, K.M., Oke, J.B. 1992, ApJ, 385, 151

Note added in proff: Object S is also visible in the K band image of 0836+113 published in Aragón-Salamanca et al. 1996, MNRAS, 281, 945.