The Gas Reservoir for present day Galaxies : Damped Lyα Absorption Systems

J.U. Fynbo and B.Thomsen

Institute of Physics and Astronomy, University of Århus, DK-8000, Denmark

P. Møller

European Southern Observatory, Karl-Schwarzschild-Straße 2, W-8046 Garching bei München, Germany

Abstract. We present results from an ongoing search for galaxy counterparts of a subgroup of Quasar Absorption Line Systems called Damped Lyα Absorbers (DLAs). DLAs have several characteristics that make them essential in the process of understanding how galaxies formed in the early universe and evolved to the galaxies we see today in the local universe. Finally we compare DLAs with recent findings of a population of starforming galaxies at high redshifts, so called Lyman-break galaxies.

1. Introduction

Damped Lyα Absorbers are the objects with highest HI column density of QSO absorption line systems. QSO absorption line systems are intergalactic material or in rare cases even galaxies that lie along the line of sight to background QSOs. In the spectrum of the background QSOs QSO absorption line systems manifest themselves primarily in thousands of Lyα absorption lines on the blue side of the QSO Lyα emission line - the so called Lyα forest. In a simplified picture each Lyα absorption line represents an intersecting intergalactic cloud. Lyα absorption lines at a wavelength close to the QSO Lyα emission line are caused by clouds near the QSO in physical space whereas Lyα absorption lines further towards the blue are less redshifted and hence caused by clouds closer to us along the line of sight (for a recent review see Rauch, 1998).

Damped Lyα Absorbers (DLAs) are QSO absorption line systems are causing damped Lyα absorption. To do that DLAs have neutral hydrogen column densities larger than $2 \times 10^{20} cm^{-2}$, which is comparable to the column density of baryons in normal disk galaxies at the present epoch. A very important result recently found is that most of the baryons that reside in stars in galaxies today, at high redshift were in cold gas in DLAs (Wolfe et al. 1995). In other words, DLAs constitute the gas reservoir out of which present day galaxies formed.

Since DLAs are objects found by the absorption they cause, much information has been collected about metallicity and dust content through the study of line strengths of metal lines associated with the DLAs allthough the interpretation of the data is still subject to debate (Lu et al., 1996, Kulkarni et al., 1997).

Little, however, is known about the sizes and morphologies of the objects. One way to obtain this information is to detect emission from them.

From an observational point of view the main problems in studying emission from DLAs are *(i)* that they are very faint and *(ii)* the presence of a much brighter QSO at a distance of only 0-3 arcsec on the sky. At a redshift of $z = 2$ DLAs produce regions of 15-25Å (the width depending on the HI column density) of saturated absorption in the spectrum of the background QSOs. Hence imaging in a narrow filter with a width corresponding to the width of the damped absorption line will circumvent problem *(ii)*. If the DLA is a Lyα *emitter* it will be relatively easy to detect against the modest sky background in the narrow band filter which circumvents problem *(i)*. Narrow band imaging of DLAs have been pursued in more than a decade (e.g. Lowenthal et al., 1995), but only recently with success. The DLA at $z = 2.81$ towards PKS0528-250 (Møller and Warren, 1993, 1998, Warren and Møller, 1996) and the DLA at $z = 1.934$ towards Q0151+048A (Møller, Warren and Fynbo, 1998, Fynbo, Møller and Warren, 1998a, 1998b) have been detected using the narrow filter technique. In the case of the DLA towards Q0151+048A we detected extended Lyα emission, which allowed us to obtain the rotation curve of the galaxy (Møller, Fynbo and Warren, 1998).

In this paper we report on results from a new narrow band project aimed at the DLA at $z = 1.943$ towards PKS1157+014, and compare results for the DLAs with a sample of high redshift galaxies that are selected in a completely independent way - the Lyman-break galaxies.

2. Observations

PKS1157+014 was observed with the 2.56m Nordic Optical Telescope (NOT) March 28 - 31 1998. Two of the nights were lost to bad weather. We obtained a total integration time of 10 hours in narrow band, and 4000 sec in both I and U. The seeing ranged from 0.6 arcsec in I to 0.9 arcsec in the narrow band. Due to the two nights lost to bad weather we didn't reach the flux-limits we aimed at. With the data obtained we reach a 5σ flux limit of 7.5×10^{-17} erg s^{-1} cm^{-2} in the narrow band and 5σ limiting magnitudes of 25.9 and 25.3 in I(AB) and U(AB) respectively.

3. The field of PKS1157+014

Fig. 1 shows 96×24 arcsec^2 surrounding PKS1157+014 from the combined I-band, U-band and narrow filter frames. As seen the quasar is not present in the narrow band frame due to the strong absorption line. We do not see any significant Lyα emission at or near the position of the quasar from the DLA. We have obtained two more nights on NOT in March 1999, which will allow us to reach a 5σ detection limit of $5 \times 10^{-17} ergs^{-1}$ cm^{-2}, which is sufficiently deep to detect the DLAs we have seen in earlier projects. However, we do detect two candidate emission line galaxies marked by 'S' at signal-to-noise levels between 4 and 5 in the combined narrow-band frame. These very blue and compact emission line galaxies are very similar to the emission line galaxies associated to the DLAs seen in the fields of PKS0528-250 and Q0151+048. In both DLA-fields

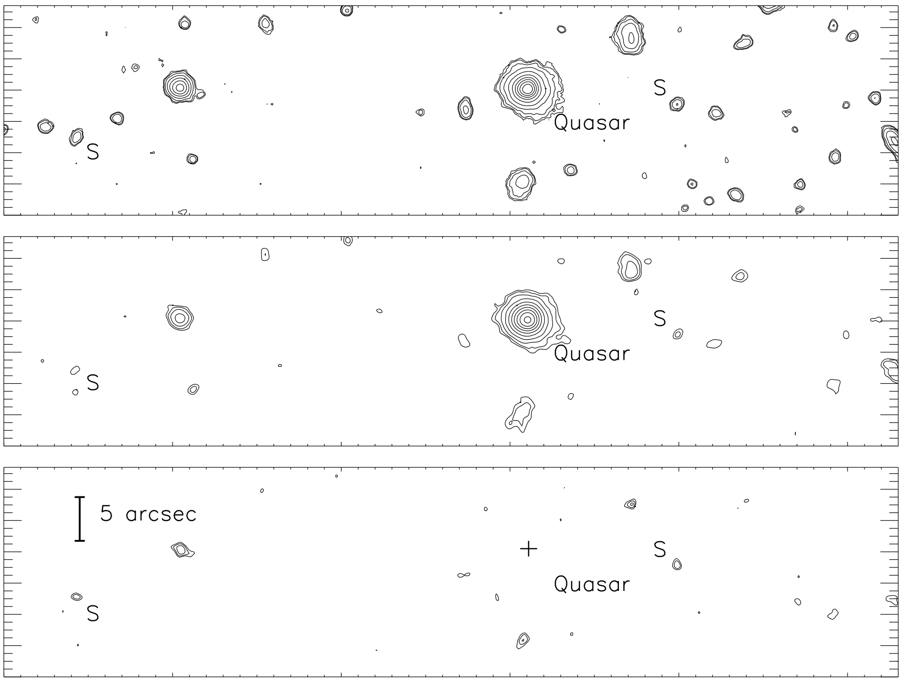

Figure 1. *Top panel :* 96×24 arcsec^2 surrounding PKS1157+014 from 4000sec of integration in the I-band. Marked are the quasar and two candidate emission line galaxies (S). North is to the left and east is down. *Middle and lower panels :* The same field as above, but from 4000sec of integration in the U-band and 10 hours of integration in the narrow filter.

we have studied so far with narrow band imaging we have found one or more galaxy at the redshift of the DLA, indicating that also at high redshift galaxies were members of groups. It is interesting to note how the galaxies seem to be aligned. This is seen in most high redshift groups of Lyα emitting galaxies (see Fig. 6 in Møller and Warren, 1998). This trend is in agreement with N-body simulations of hierarchical structure formation were galaxies predominantly form along filaments (e.g. Evrard et al., 1994).

4. Are Lyman-break galaxies and DLAs the same objects?

In the last few years hundreds of high redshift galaxies have been found using a technique completely independent of QSO absorption lines. This technique is based on the fact that young, starforming galaxies will have a strong spectral break at the lyman limit, which at high redshift is redshifted into the optical window (see Dickinson, 1998, for a recent review). Galaxies found using this method are refered to as Lyman-break galaxies (LBGs). LBGs need to be bright enough for spectroscopical confirmation of their high redshift so they are typically brighter than R(AB)=26. Since DLAs and LBGs are selected completely independently from the population of progenitor galaxies it is very interesting to compare the recent results for the LBGs with results from studies of DLAs. Assuming that DLAs arise in gaseous discs associated with LBGs one way to perform this comparison is to calculate how faint we need to integrate down the extrapolation of the luminosity function of LBGs in order to explain the observed probability for a QSO line of sight to cross a DLA.

Results of this calculation are presented in Fynbo et al., 1998b, and summarised here. At $z = 3$ we find that 70-90% of DLA galaxy counterparts are fainter than R(AB)=26, which is the current limit for spectroscopic confirmation of LBG candidates. Since DLAs contain close to all the gas that make up present day galaxies we conclude that the progenitors of a typical present day galaxy at $z = 3$ were small and faint and that the LBGs only constitute the tip of the iceberg of high redshift galaxies in terms of locating the reservoir of cold gas out of which present day galaxies formed. This is also consistent with the results from semi-analytical modeling of galaxy formation in which LBGs form in very rare high overdensity regions and are the progenitors of present day bright cluster galaxies (e.g. Baugh et al., 1998). Hence when we wish to study properties such as metallicity, dust content and star formation for the population of progenitor galaxies as a whole, the DLAs are more likely representative than LBGs.

References

Baugh C.M., Cole S., Frenk C.S., Lacey C.G., 1998, ApJ, 498, 504

Dickinson M, 1998, in press (astro-ph/980264)

Evrard A.E., Summers F.J., Davis M., 1994, ApJ, 422, 11

Fynbo J.U., Møller P., Warren S.J., 1998a, In: 'Structure and Evolution of the intergalactic Medium from QSO Absorption Line Systems', ed. Petitjean P., Charlot S., (Editions Frontieres), p.408

Fynbo J.U., Møller P., Warren S.J., 1998b, MNRAS, submitted

Kulkarni V.P., Fall S.M., 1997, ApJL, 484, 7

Lowenthal J.L., Hogan G.J., Green R.F., Woodgate B., Caulet A., Brown L., and Bechthold J., 1995, ApJ, 451, 484

Lu L., Sargent W.L.W., Barlow T.A., Churchill C.W., Vogt S.S., 1996, ApJS, 107, 475

Møller P., Warren S.J., 1993, A&A, 270,43

Møller P., Warren S.J., Fynbo J.U., 1998, A&A, 330, 19

Møller P., Warren S.J., 1998, MNRAS, in press (atro-ph/9804205)

Rauch M., 1998, Annual Review of Astronomy and Astrophysics 1998, vol. 36 in press (atro-ph/9806286)

Warren S.J., Møller P., 1996, A&A, 311,25

Møller P., Fynbo J.U., Warren S.J. 1998, in preparation

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