Extragalactic Gas at Low Redshift
ASP Conference Series, Vol. 254, 2002
John S. Mulchaey & John T. Stocke, eds.

Damped Lyα Absorption from the Nearby Low Surface Brightness Galaxy SBS 1543+593: a Summary

David V. Bowen, Todd M. Tripp and Edward B. Jenkins

Princeton University Observatory, Princeton, NJ 08544

Elias Brinks

Depto. de Astronomía, Apdo. Postal 144, Guanajuato, Gto. 36000, Mexico

Walter Huchtmeier

Max-Plank-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany

Abstract. Ground-based & HST images of the nearby galaxy SBS 1543+593 show it to be a Low Surface Brightness (LSB) galaxy with a central surface brightness of $\mu_B(0) = 23.2$ mag arcsec^{-2} and scale length 0.7 h_{75}^{-1} kpc, values typical for the local LSB galaxy population. The galaxy lies directly in front of the QSO HS 1543+5921 ($z = 0.807$); an HST STIS spectrum of the quasar reveals a damped Lyα (DLyα) line at the redshift of the interloper with an H I column density of $\log N(\mathrm{H\ I}) = 20.35$, as well as several low-ionization metal lines with strengths similar to those found in the Milky Way interstellar medium. 21-cm measurements of the galaxy show it to have a systemic velocity of $v = 2868$ km s^{-1}, and an H I mass of $M_{\mathrm{H\,I}} = 1.3 \times 10^9 M_\odot$. Our data show that LSB galaxies are certainly able to produce the DLyα lines seen at higher redshift, fueling the speculation that LSB galaxies are a major contributor to that population of absorbers. Compared to 21-cm emission limits obtained towards two other $z \sim 0.1$ DLyα systems, it is likely that SBS 1543+593 would not have been detected if at a similar redshift. Hence LSB galaxies similar to SBS 1543+593 can be responsible for DLyα systems at even modest redshifts without being detectable from their 21-cm emission.

1. Introduction

In the course of spectroscopic follow-up observations of quasar candidates in the Hamburg Quasar Survey, a redshift of $z = 0.807$ was measured for the QSO HS 1543+5921. However, Schmidt-plate images showed the object to be very extended, suggesting that the QSO might be centered on a low redshift galaxy. Follow-up observations by Reimers & Hagen (1998, hereafter RH98) found the QSO to be aligned with the foreground galaxy SBS 1543+593, and measurement of an H II region in a spiral arm revealed the galaxy to be at $z = 0.009$.

Although detecting QSOs close to nearby galaxies is not difficult, finding one which shines through the center of a galaxy and which is bright enough to be observed spectroscopically with HST is extremely rare. In this contribution we summarize the results of several programs designed to investigate this QSO-galaxy pair. Full details can be found in Bowen, Tripp, & Jenkins (2001) for imaging and UV-spectroscopy data, and Bowen et al. (2001) for the 21-cm emission measurements, both described herein.

2. Imaging: Galaxy Properties

A 3x300 sec R-band image of the QSO-galaxy pair taken with the ARC 3.5 m telescope at the Apache Point Observatory is shown top of Fig. 1. These data were used to produce a surface brightness profile of the galaxy, shown in Fig. 2. The profile near the center of the galaxy is obviously contaminated by flux from the QSO and a bright nearby star, but the remaining points can be well fit with a standard exponential profile, $\mu_R = \mu_R(0) + 1.086(r/a)$, where $\mu_R(0)$ is the central surface brightness in mag arcsec^{-2}, r is the radius from the galaxy's center, and a is the scale length. The fit to the data in Fig. 2 shows that the galaxy has $\mu_R(0) = 22.6$ mag arcsec^{-2} and a scale length of 7 arcsec, or 0.7 h_{75}^{-1} kpc at the redshift of the galaxy.[1] The total R-band magnitude of the galaxy, $m_R(T)$ can be derived from the fit to the surface brightness profile, $m_R(T) = \mu_R(0) - 2.5\log(2\pi a^2) = 16.3$, in good agreement with a simple integration of the counts which excludes star and QSO. This corresponds to an absolute magnitude of $M_R = -16.0$, or 1/50 L^*_R.

Three HST STIS images were also taken of the QSO-galaxy pair using the CCD detector and no filter. The coadded image represents a total exposure time of 802 sec and is reproduced at the bottom of Fig. 1, with the data smoothed by a boxcar filter of size 3x3 pixels to show the LSB features better. The field of view is $\sim$ 50x50 arcsec and the throughput of the detector is such that the image records photons with wavelengths between 2000 and 11,000 Å, with the sensitivity peaking at 5852 Å. The image shows that SBS 1543+593 is composed of two primary spiral arms. The H II region observed spectroscopically by RH98 is marked, and is seen to break up into several discrete regions. A second galaxy, at the bottom right of the figure, identified by RH98 as a point source, is here easily resolved into a barred spiral. No redshift is measured for this galaxy, but given the small angular size and high surface brightness, it is probably background to SBS 1543+593.

3. STIS spectroscopy: damped Lyα from SBS 1543+593

G140L and G230L HST STIS spectra are shown in Fig. 3, with several emission lines identified. The flux rises sharply to the blue, following a power-law of roughly $F_\lambda \propto \lambda^{-1}$. In Fig. 4 we show a normalized portion of the G140L spectrum. Lyα absorption from SBS 1543+593 is clearly seen at the redshift expected. Strong lines of Si II λ1260, O I λ1302+Si II λ1304, and C II λ1334

---

[1] $h = H_0/75$, where H_0 is the Hubble constant, and $q_0 = 0$ is assumed throughout.

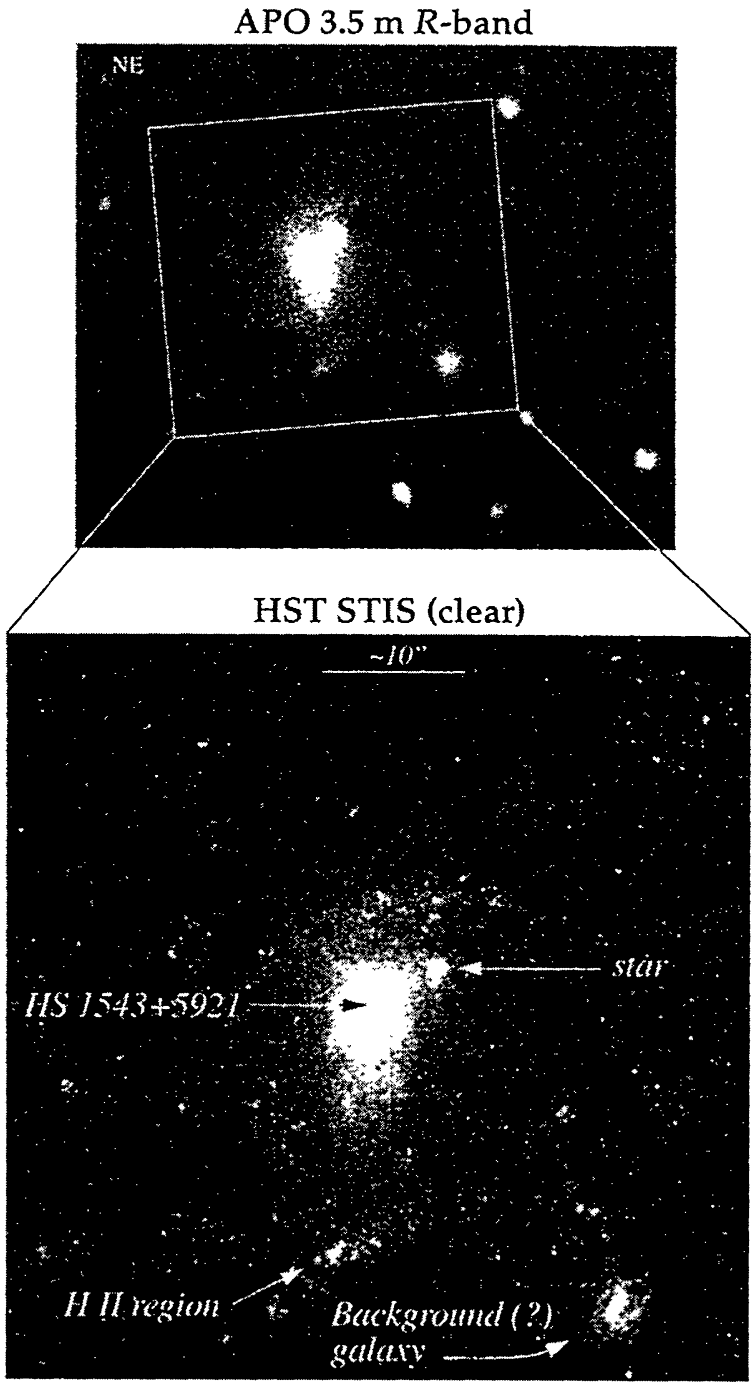

Figure 1. Optical (top) and HST (bottom) images of SBS 1543+593. The optical image comes from the Apache Point Observatory ARC 3.5 m telescope, while the HST image was taken with the STIS CCD and no filter. The H II region whose redshift was measured by RH98 is indicated, along with a foreground star (confirmed spectroscopically by RH98), and a galaxy to the SW which is probably far behind the LSB galaxy.

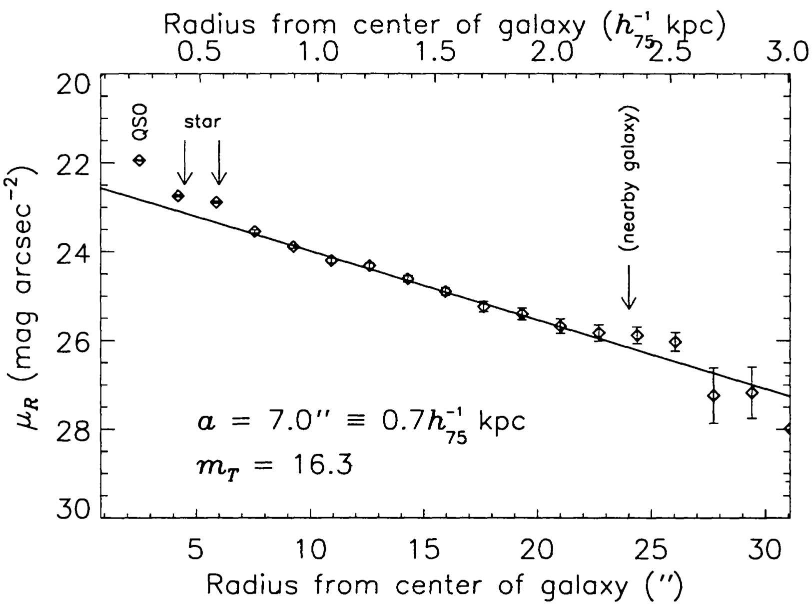

Figure 2. Plot of R-band surface brightness for SBS 1543+593. Positions of contributing features are marked. A theoretical profile of $\mu_R = 22.6 + 1.086(r/7.0)$ is also drawn.

are also detected at strengths similar to Milky Way absorption lines. Although the region blueward of Lyα is confused at this resolution, it is likely that we detect Si II λ1193 from SBS 1543+593 blended with Galactic Si II λ1206.

To model the Lyα lines from the Galaxy and from SBS 1543+593, we convolved theoretical line profiles with the available STIS Line Spread Function calculated at 1200 Å. The H I column density from our own Milky Way is known to be $\log N(\text{H I}) = 20.26$ cm^{-2} from, e.g., the Bell Labs H I Survey (Stark et al. 1992). The signal-to-noise of the Galactic Lyα absorption line is poor, due to the subtraction of intense geocoronal Lyα emission. Hence we fitted theoretical line profiles to both the Lyα absorption lines keeping $\log N(\text{H I})$ fixed for the Milky Way absorption. The resulting fits are shown in Fig. 4. The profile for Milky Way absorption well fits the data, despite using a value of $N(\text{H I})$ known a priori, and for SBS 1543+593 we derive $\log N(\text{H I}) = 20.35$ cm^{-2}.

4. 21-cm emission line measurements

HS 1543+5921 itself does not appear to be radio loud at a 4σ noise level of $\simeq 1.8$ mJy. However, we have detected 21-cm emission from SBS 1543+539 using the 100 m radio telescope at Effelsberg (Fig. 5). The center of the emission is at a heliocentric velocity of 2868±2 km s^{-1} ($cz = 0.0096$). We derive a flux of 3.9 Jy km s^{-1} integrated over a velocity range of 2740−3000 km s^{-1}, which yields an H I mass of $M_{\text{H I}} = 1.3 \times 10^9\, h_{75}^{-2}\, M_\odot$.

An estimate of the dynamical mass for the galaxy gives $M_{\text{dyn}} \geq 2.8 \times 10^9\, h_{75}^{-1}\, M_\odot$, at least of order 50% higher than the gas mass. The H I mass

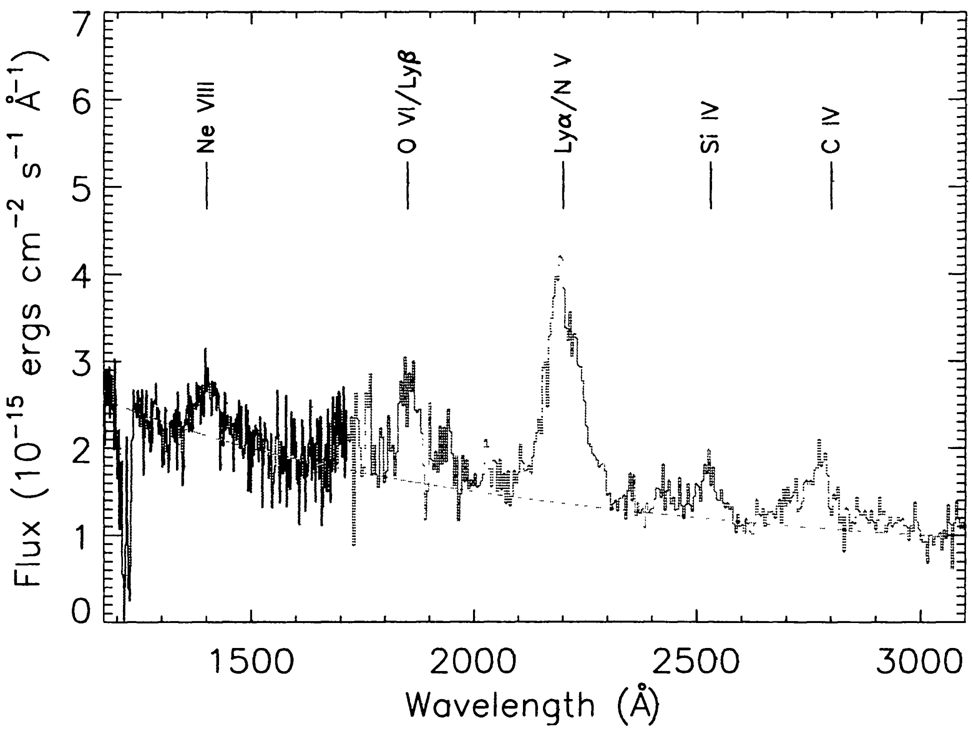

Figure 3. G140L (dark) and G230L (light) STIS spectra of HS 1543+5921 obtained with HST. A power law spectral energy distribution of $F_\lambda \propto \lambda^{-1.0}$ is superimposed.

is about 1/5 that of the Milky Way, and is close to the median value of $M_{\rm H\,I}$ found by de Blok et al. (1996) for a sample of 19 late-type LSB galaxies. The 38 LSB galaxies studied by Karachentsev et al. (2001, and refs. therein) in the magnitude range $-16.2 < M_B < -15.1$ have an average value of $M_{\rm H\,I}/L = 2.6$ with a scatter between 0.3 and 11.8. The value for SBS 1543+593 is obviously well within this range.

5. Discussion

Our data have shown that SBS 1543+593 is an LSB galaxy causing a DLyα system at $z \simeq 0.009$ in the spectrum of HS 1543+5921. This makes it the lowest redshift DLyα system discovered outside of the local group. The identification of DLyα from a *known* LSB is important, for the following reasons. So far, results from ground-based and HST imaging of fields around QSOs known to show $z < 1$ DLyα lines have been surprising, with the detection of a whole variety of galaxy types, including normal early and late-type HSB spirals, and amorphous LSB galaxies, identified as responsible for the absorption (Steidel et al. 1994; Steidel et al. 1995; Lanzetta et al. 1997; Le Brun et al. 1997; Rao & Turnshek 1998; Pettini 2000). This wide variety of absorber types has led to the speculation

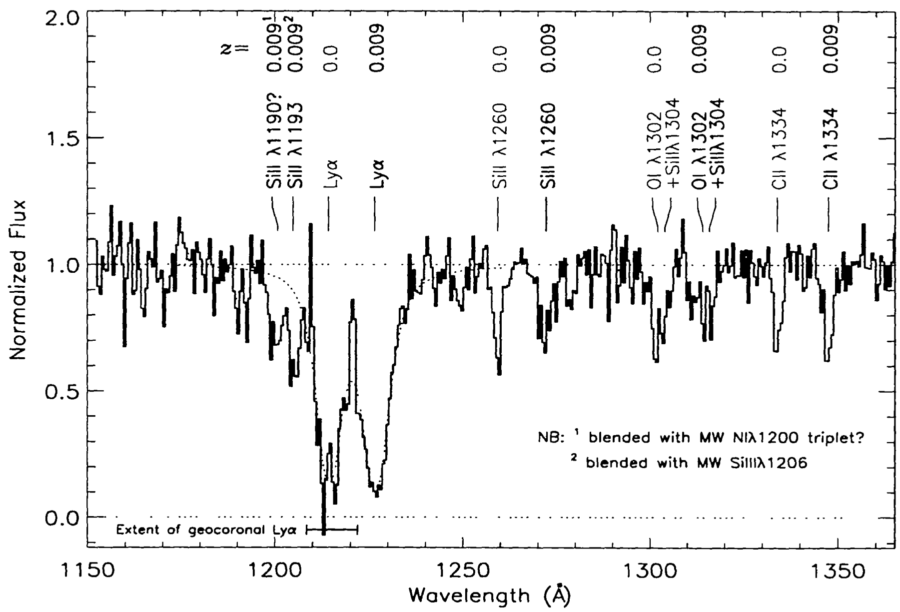

Figure 4. Normalized 2139 sec coadded G140L STIS spectrum of HS 1543+5921. The Lyα lines from our own galaxy and from SBS 1543+593 at $z = 0.009$ are detected, along with several low-ionization species. Redshifts of the lines are shown above their identification. Theoretical Lyα line profiles are overplotted, corresponding to $\log N(\mathrm{H\ I}) = 20.26$ from the Milky Way and 20.35 from SBS 1543+593. Also labeled is the minimum and maximum extent of the geocoronal Lyα emission which was subtracted from the data to produce this spectrum.

that DLyα systems may not simply signal the presence of normal gas-rich spiral galaxies after all, as has been postulated since their discovery (Wolfe 1986). It is important to note, however, that in most cases there exists no redshift information for the purported absorbers. Proximity to the line of sight is no guarantee that an 'identified' object is the absorber, since there are often several absorption systems at redshifts other than that of the DLyα line along the QSO line of sight. If galaxies are responsible for these other systems, then the chance of mis-identification is high (particularly if DLyα systems do not arise in normal galaxies). Hence the detection of a DLyα line from SBS 1543+593 is unique, in that we know unequivocally that the absorber is an LSB galaxy.

It also seems likely that if SBS 1543+593 were moved to a redshift similar to those of the $z < 1$ DLyα systems already studied, it would be extremely difficult to detect in the optical, partly due to its low surface brightness and partly due to its close proximity to the QSO and its small angular size. In fact, in this case, it is more likely that the nearby barred spiral galaxy south-west of the pair, which we take to be background to SBS 1543+593, would be identified as the DLyα absorber if no redshift information were available.

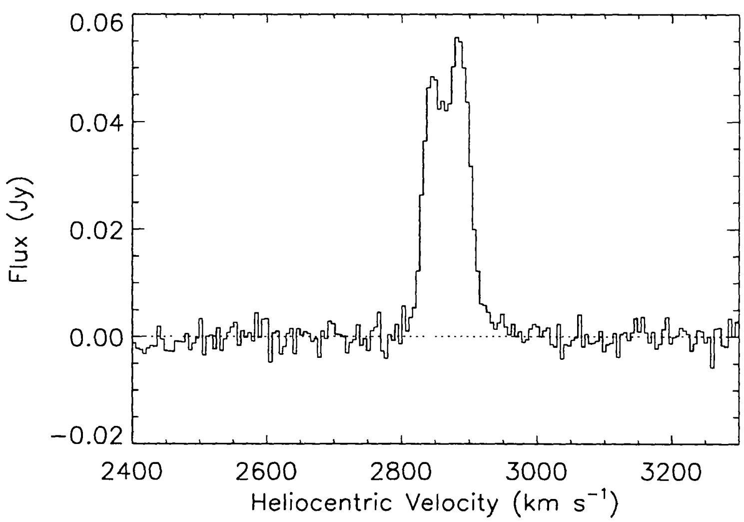

Figure 5. 21-cm emission from SBS 1543+593 obtained with the Effelsberg 100 m radio telescope. The bulk of the emission arises at 2868 km s^{-1}.

Observing the 21-cm emission line however, does not suffer from these difficulties, particularly if the background QSO is not radio-loud, and in principle, picking out emission at the redshift of a DLyα system should be a relatively 'clean' observation. The problem, of course, is that the flux from the low surface brightness of the H I emission can only be detected if the galaxy is at a very low redshift.

Kanekar et al. (2001) failed to detect 21-cm emission from the $z = 0.101$ candidate DLyα absorber towards PKS 0439−433. They set a 3σ limit of $M_{\rm H\,I} < 1.8 \times 10^9 h_{75}^{-2} M_\odot$ for the system assuming a velocity spread equal to their resolution, 30 km s^{-1}; such a limit would be insufficient to detect SBS 1543+593, and hence would not rule out such an LSB galaxy as being responsible for the $z = 0.101$ system. Lane (2000) also searched for 21-cm emission from the 21-cm absorber at $z = 0.0912$ towards B 0738+313, and again failed to detect any flux. Their observations were slightly more sensitive, reaching a 3σ limit of $M_{\rm H\,I} < 6.5 \times 10^8\, h_{75}^{-2}\, M_\odot$ assuming a velocity resolution of 22.5 km s^{-1}. Even here, however, if we re-calculate $M_{\rm H\,I}$ by instead considering the velocity range over which we detect 21-cm emission from SBS 1543+593, some 124 km s^{-1}, this limit would increase to $M_{\rm H\,I} < 3.8 \times 10^9\, h_{75}^{-2}\, M_\odot$. Again, this would be too high a limit to permit detection of SBS 1543+593 at $z = 0.0912$. Using this velocity range for Kanekar et al.'s observations would increase their limit to $M_{\rm H\,I}$ from the absorber towards PKS 0439−433 as well.

Hence the non-detection of 21-cm emission at higher redshifts does not rule out LSB galaxies such as SBS 1543+593—known unequivocally to be a DLyα system— from being responsible for DLyα systems.

Our observations of SBS 1543+593 support the idea that LSB galaxies may contribute significantly to the population of DLyα absorbers, as initially suggested by Impey & Bothun (1989). Although finding a DLyα from an LSB galaxy does not prove that *all* DLyα systems are LSB galaxies, our detection does prove that LSB galaxies can produce such systems.

Perhaps more significant is the detection of this QSO-galaxy pair in the first place. Finding any bright QSO shining through the center of a nearby galaxy is extremely rare, and it is intriguing that an LSB galaxy is the interloper. LSB galaxies are believed to be relatively free of dust, and hence optically thin to the photons of background objects — these may therefore be the best types of galaxies to allow the light of quasars to shine through. This potential selection effect has been a concern for interpreting the copious abundance measurements of high-redshift DLyα systems: if a particular type of galaxy preferentially favors QSO light passing through it, then the derived metallicities are only applicable for that type of galaxy.

The mere existence of this QSO-galaxy pair seems to support these views. Unfortunately, just how common such QSO/LSB-galaxy alignments are at higher redshift will always be difficult to determine, due to the intrinsic faintness of the galaxies, especially if the galaxy is close to the QSO sightline as with this pair.

References

de Blok, W. J. G., McGaugh, S. S. & van der Hulst, J. M. 1996, MNRAS, 283, 18

Bowen, D. V., Tripp, T. M. & Jenkins, E. B. 2001, AJ, 121, 1456

Bowen, D. V., Huchtmeier, W., Brinks, E., Tripp, T. M. & Jenkins, E. B. 2001, A&A, 372, 820

Impey, C. & Bothun, G. 1989, ApJ, 341, 89

Kanekar, N., Chengalur, J. N., Subrahmanyan, R. & Petitjean, P. 2001, A&A, 367, 46

Karachentsev, I. D., Karachentseva, V. E., Huchtmeier, W. K. 2001, A&A, 366, 428

Lane, W. 2000, PhD thesis, Univ. of Groningen

Le Brun, V., Bergeron, J., Boisse, P. & Deharveng, J. M. 1997, A&A, 321, 733

Lanzetta et al. 1997, AJ, 114, 1337

Pettini M., Ellison, S. L., Steidel, C. C., Shapley, A. E. & Bowen, D. V. 2000, ApJ, 532, 65

Rao S. M. & Turnshek, D. A. 1998, ApJ, 500, L115

Reimers, D., & Hagen, H. 1998, A&A, 329, L25 (RH98)

Stark, A. A., Gammie, C. F., Wilson, R. W., Bally, J., Linke, R. A., Heiles, C. & Hurwitz, M. 1992, ApJS, 79, 77

Steidel, C. C., Bowen, D. V., Blades, J. C. & Dickenson, M. 1995, ApJ, 440, L45

Steidel, C. C., Pettini, M., Dickinson, M., & Persson, S. E. 1994, AJ, 108, 2046

Wolfe, A. M., Turnshek, D. A., Smith, H. E. & Cohen, R. D. 1986, ApJS, 61, 249