A&A 372, 820–823 (2001)
DOI: 10.1051/0004-6361:20010592

Astronomy & Astrophysics

21-cm H I emission from the Damped Lyman-α absorber SBS 1543+593

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Received 13 March 2001 / Accepted 24 April 2001

Abstract. We detect 21-cm emission from the Low Surface Brightness (LSB) galaxy SBS 1543+593, which gives rise to a Damped-Lyα (DLyα) absorption line in the spectrum of the background QSO HS 1543+5921 ($z_e = 0.807$). We obtain an accurate measure of the velocity of the H I gas in the LSB galaxy, $v = 2868$ km s^{-1}, and derive a mass of $M_{\rm H\,I} = 1.3 \times 10^9\ M_\odot$. We compare $M_{\rm H\,I}$ with limits obtained towards two other $z \sim 0.1$ DLyα systems, and show that SBS 1543+593 would not have been detected. 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.

Key words. galaxies: individual: SBS 1543+593 — radio lines: ISM — quasars: absorption lines

1. Introduction

In a recent paper, Kanekar et al. (2001) reported an attempt to detect 21-cm emission from the candidate $z = 0.101$ Damped Lyα (DLyα) absorber towards PKS 0349−433. At these low redshifts, such a search is entirely warranted, since normal gas-rich late-type galaxies should be detectable from their 21-cm emission if responsible for the absorption. As the authors themselves pointed out, such observations are necessary to establish whether DLyα systems have anomalously high H I content, irrespective of their optical luminosity or physical morphology. Significantly, Kanekar et al. failed to detect any emission from the candidate DLyα system. Since their detection limits were sufficient to find any normal high-mass spiral galaxy, they concluded that a low-mass galaxy might well be the absorber.

Such a conclusion is consistent with results from ground-based and Hubble Space Telescope images of fields around QSOs known to show $z < 1$ DLyα systems. A wide variety of galaxy types have been identified as possibly responsible for the absorption, including normal early- and late-type high surface brightness (HSB) spirals, and amorphous low surface brightness (LSB) galaxies (Steidel et al. 1991; Steidel et al. 1993; Lanzetta et al. 1997; Le Brun et al. 1997; Rao & Turnshek 1998; Pettini et al. 2000; Turnshek et al. 2001; Cohen 2001). This wide variety of absorber types has led to the suggestion that DLyα systems may not arise from normal gas-rich HSB spiral galaxies alone, as has been assumed since they were first detected (Wolfe et al. 1986).

We recently discovered (Bowen et al. 2001, hereafter Paper I) that the nearby LSB galaxy SBS 1543+593 gives rise to a DLyα system in the spectrum of the background QSO HS 1543+5921 ($z_e = 0.807$). The line of sight to the QSO passes within 2.4″ ($\equiv$ $0.3h_{75}^{-1}$ kpc) from the center of the galaxy[1], and an H I column density of N(H I)= 20.35 dex is measured along the sightline to the quasar. The galaxy has a central surface brightness of $\mu_B(0) = 23.2$ mag arcsec^{-2} and an absolute magnitude of $M_R = -16.5$. The redshift of the galaxy, $z = 0.009$, was measured by Reimers & Hagen (1998) (who discovered the pairing of QSO and galaxy) from an isolated H II region in a southern spiral arm; no other estimate of the galaxy's systemic redshift is available.

In this paper, we present the detection of 21-cm emission from SBS 1543+593, allowing us to determine more accurately the systemic velocity of the galaxy, as well as its H I mass. We compare the latter quantity with that derived by Kanekar et al. (2001), as well as a limit obtained by Lane (2000) for a second low-z DLyα absorber, and show that SBS 1543+593 would not have been detected in either survey. 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.

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[1] $h_{75} = H_0/75$ km s^{-1} Mpc^{-1}, where H_0 is the Hubble constant, and $q_0 = 0.0$ is assumed throughout this paper.

2. Observations and results

We initially checked to see if HS 1543+5921 was radio-loud, in the hope of using the background source to search for 21-cm absorption from the foreground galaxy. Using the NVSS database (Condon et al. 1998) we found no coinciding radio emission above a 4σ noise level of about 1.8 mJy. An unrelated 32 mJy flux density source, unresolved at the resolution of the NVSS survey (typically 45″), lies 2′ to the southeast of the expected position of the QSO.

21-cm line emission observations were made 22nd January 2001, using the 100 m radio telescope at Effelsberg, which has a half power beam width of 9.3′. The "total power mode" was applied, i.e., a reference field was observed 5 min earlier in Right Ascension and later subtracted from the on-source observation in order to reduce instrumental effects. 15 mins were spent on-source, and 15 mins off-source. The two channel 21-cm receiver (with a system noise of 30 K) was followed by a 1024 channel autocorrelator split into four banks of 256 channels each. A total bandwidth of 6.25 MHz yielded a channel separation of 5.2 km s^{-1} and a velocity resolution of 6.3 km s^{-1}. A second order polynomial was applied as a baseline correction. The rms error was determined to be 2.1 mJy per channel.

The 21-cm emission detected from SBS 1543+539 is shown as a function of heliocentric velocity in Fig. 1. The center of the emission measured from the FWHM of the profile is 2868 ± 2 km s^{-1} (cz = 0.0096) and shows the classic double-horn peaks, with maxima at 2843.5 and 2884.0 km s^{-1}. Such profile shapes are well understood to arise from the disks of spiral galaxies with flat rotation curves and exponential gas distributions (Giovanelli & Haynes 1988). We also note though that the profile resembles those studied by Matthews et al. (1998) for a sample of extreme late-type spirals, whose single-dish emission line profiles are "filled in" between the rotation peaks, perhaps due to the rotation curves of the galaxies rising more slowly than those of typical spiral galaxies. SBS 1543+539 may have a similar characteristic, which can be tested with more extensive two-dimensional 21-cm H I mapping. The velocity of the 21-cm emission agrees reasonably well with the value of 2700 km s^{-1} (with no quoted error) measured by Reimers & Hagen (1998). Their value was derived, essentially, from measuring the velocity of Hα and [O III] emission lines in low signal-to-noise data with a resolution of ∼18 Å, or ∼800−1300 km s^{-1}.

Comparing the redshift of SBS 1543+593 with the metal absorption lines detected in Paper I is not so straightforward. The HST spectra in which the lines were observed were recorded with the STIS G140L grating and the 52 × 0.5 aperture, for which there is considerable uncertainty in the zero point of the wavelength calibration. This can in principle be corrected by comparing the velocities of Galactic low-ionization metal lines with the velocity of H I emission along the line of sight. Unfortunately, the low resolution of the G140L (200−300 km s^{-1}) and the low signal-to-noise of the data make the precise velocity of the Galactic absorption hard to determine. Further, inspection of the 21-cm emission along the sightline [taken from the Leiden/Dwingeloo 21-cm survey (Hartmann & Burton 1997)] shows that besides the bulk of the emission around 0 km s^{-1}, there are strong peaks from Galactic High Velocity Clouds at $v \sim -140$ and −70 km s^{-1}. Our final estimate of the absorber's velocity is ∼3050 km s^{-1}, apparently in poor agreement with the 21-cm emission. Nevertheless, the error in this number is large, ∼100–200 km s^{-1}, and higher resolution UV observations are clearly needed to better tie down the redshift of the absorbing gas before considering a real discrepancy between the bulk of the 21-cm gas and the absorbing material.

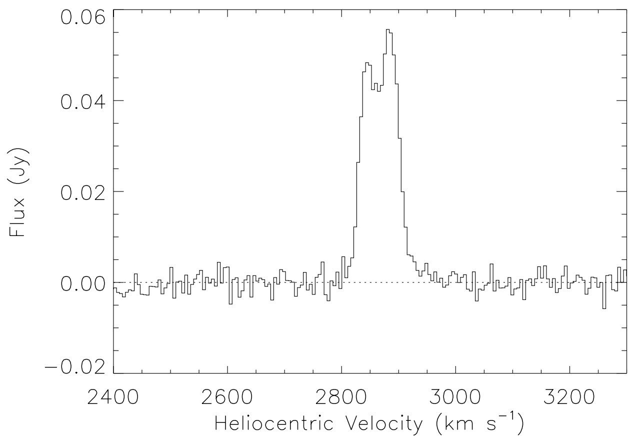

Fig. 1. 21-cm emission from SBS 1543+593. The bulk of the emission arises at 2868 km s^{-1}, with two peaks arising from the rotating, inclined disk at 2843.5 and 2884.0 km s^{-1}.

We calculate the total mass of the H I gas in the usual manner:

$$M_{\rm H\,I} = 2.36 \times 10^5 D({\rm Mpc})^2 \int S({\rm Jy})\,{\rm d}v({\rm km\,s^{-1}})\ M_\odot,$$

where D is the luminosity distance to the galaxy, taken to be 38 Mpc for the adopted cosmology, and S is the 21-cm flux, which is integrated over the observed velocity range of the profile. For SBS 1543+593 we derive a flux of 3.9 Jy km s^{-1} over a velocity range of 2740−3000 km s^{-1}, which gives

$$M_{\rm H\,I} = 1.3 \times 10^9\ h_{75}^{-2}\ M_\odot\ .$$

The statistical error on the flux is 0.048 Jy km s^{-1}, but this is likely an underestimate of the true error, since systematic errors also contribute. Experience with similar datasets suggests an error of ∼10% is more realistic, which would lead to an uncertainty of $\sim 1 \times 10^8\ M_\odot$ in the H I mass of SBS 1543+593.

The width of the H I profile displayed in Fig. 1 corresponds to a lower limit to the dynamical mass of

$$M_{\rm dyn} = 0.76 \times 2.33 \times 10^5 (\delta V)^2\, R\, M_\odot$$

where δV is the half width at zero intensity and R the radius of the galaxy (see, e.g., van Moorsel 1982). In Paper I we were able to trace the R-band light of SBS 1543+593 out to a radius of $\sim 30''$, or 4.1 h_{75}^{-1} kpc. Taking this value to be R, and using $\delta V = 62$ km s^{-1}, we find:

$$M_{\rm dyn} \geq 2.8 \times 10^9\, h_{75}^{-1}\, M_\odot.$$

This is a lower limit because the rotational velocity has not been corrected for the (unknown) inclination. Although measuring the inclination is difficult (see Paper I), the galaxy is clearly far from being edge-on, so $M_{\rm dyn}$ is a conservative limit. Nevertheless, the dynamical mass is at least of order 50% higher than the gas mass.

In Paper I we estimated the R-band magnitude of the galaxy to be $R = 16.3$. We can correct to a B-band magnitude by adopting the correction found by de Blok et al. (1996) for their sample of LSB galaxies, and derive $B = R + 0.78 = 17.1$. This allows us to calculate the usual mass-to-light ratio of the galaxy, M/L, where L is derived from the B-band luminosity. Since the absolute magnitude of SBS 1543+593 is $M_B = -15.8$, then its total luminosity is $L/L_\odot \sim 3 \times 10^8$, which gives

$$M_{\rm H\,I}/L \sim 4.$$

In this case, the error in calculating $M_{\rm H\,I}/L$ is likely dominated by the value of L rather than $M_{\rm H\,I}$, since contamination of the galaxy's light from the QSO and close-by star may cause L to be overestimated (see Paper I).

3. Conclusions

The H I mass derived for SBS 1543+593 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. Assuming $R - I \approx 0$, it appears that the LSB galaxy is gas-rich compared to other LSB galaxies studied by de Blok et al., although there are few galaxies at such low total luminosities in their sample. The value of $M_{\rm H\,I}/L \sim 4$ for SBS 1543+593 is correspondingly high, since the typical value for galaxies in de Blok et al.'s sample was $\leq$1. On the other hand, 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.

With the derived $M_{\rm H\,I}$, we can consider how easily SBS 1543+593 would be identified as the origin of a DLyα system if at higher redshift. It is complicated to calculate precisely whether a particular set of *optical* observations would reveal SBS 1543+593 much beyond its redshift of 0.0096. For example, the success in adequately subtracting the QSO profile to reveal overlying galaxies depends on the signal-to-noise of the data, and the size and stability of the seeing during the observations. Similarly, an image's ability to record LSB features depends on the detector's physical characteristics (particularly its spatial scale), and the proximity of the galaxy to the QSO itself. 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 the emission at the redshift of the 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 low redshift. Hence searches for 21-cm emission from DLyα absorbers are confined to the very lowest redshift systems known.

Kanekar et al. (2001) failed to detect 21-cm emission from the $z = 0.101$ candidate DLyα absorber towards PKS 0439−433. The absorber is a "candidate" because the Lyα absorption line has not yet been observed in the ultraviolet, although the strength of low-ionization lines in the system suggest the H I column density should be high, N(H I) $\sim 10^{20}$ cm^{-2} (Petitjean et al. 1996). Kanekar et al. 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.

It is relatively straightforward to calculate the redshift out to which a galaxy like SBS 1543+593 *could* be detected given our observational set-up. We would measure a 3σ flux of 1 Jy km s^{-1} over 20 channels from a galaxy with $M_{\rm H\,I} = 1.3 \times 10^9\, h_{75}^{-2}\, M_\odot$ at a distance of 94 Mpc, or $z = 0.023$ for $H_0 = 75$ km s^{-1} Mpc^{-1}. In actuality, we could extend this limit by observing at lower resolution: rebinning by a factor of 4 (20 km s^{-1} per channel) and assuming that the error in the flux would be reduced by a factor of two would enable us to detect SBS 1543+593 at the 3σ level at a distance of 136 Mpc, or $z = 0.034$.

As noted in Paper I, the detection of a DLyα system from SBS 1543+593 does not prove that *all* DLyα systems arise in LSB galaxies. Nevertheless, as evidence accumulates to show that at least some DLyα absorbers must be dwarf or LSB galaxies, our data demonstrates that the non-detection of 21-cm emission towards higher redshift systems is entirely consistent with the H I mass of one particular LSB galaxy – SBS 1543+593 – known unequivocally to be a DLyα system.

Acknowledgements. We thank the referee, Véronique Cayatte for helpful comments. Support for this work was provided in part from NASA through grant NAS5-30110.

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