

The HI properties and environment of Lyman- α absorbers

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Abstract. We present results from two projects in which we have used the HI 21cm emission line as a tracer of gas-rich galaxy populations in the vicinity of Lyman- α absorbers. In the first case, we examine the HI environment of SBS 1543+593, the nearest damped Lyman- α absorber. We use a VLA map of the region around this LSB galaxy which itself shows an extended HI disk to identify 3 gas-rich neighbours within 185 kpc. While it is not clear whether we should expect local damped Lyman- α systems to reside in such gas-rich regions, we would expect this kind of environment to be more prevalent at higher redshifts where less of the gas is in the dense inner regions of galaxies or has been consumed by star formation. This local galaxy is the only system in which we can study the gaseous environment in this kind of detail. In the second case, we examine the HI environment surrounding 16 Lyman- α forest absorbers along 4 QSO sight-lines. We do not detect any gas-rich galaxies at the absorber positions indicating that, at least down to our sensitivity limits, these absorption lines do not seem to be associated with galaxy halos. For half of the Lyman- α absorption systems there is a galaxy within 500 kpc, but for the other half there is not. In two cases there is no galaxy within 2 Mpc of the Lyman- α absorption systems indicating that absorbers do, in some cases, reside in voids.

1. Introduction

Lyman- α absorbers of all varieties are over-densities in the gas distribution in the Universe. The highest over-densities are the damped absorbers which trace the gas in galaxies and protogalaxies through cosmic time. At the low column density end ($N_{HI} < 10^{17} \text{ cm}^{-2}$), the Lyman- α forest traces the smaller over-densities in the gas.

Our understanding of the formation and evolution of galaxies is closely tied to our understanding of their environment. The HI environment of galaxies is particularly important as it represents the primordial material that can fall into galaxies and the processed gas that has been ejected. In addition, HI provides an important complement to optical observations of galaxies since many of the systems detected at 21 cm are missed in optical surveys (particularly the spectroscopic surveys that allow for a redshift determination) because they are low surface brightness (LSB) systems.

I discuss two very different projects in which we use 21 cm HI observations to survey the environments of Lyman- α absorbers. In the first case we look at the environment of the nearest damped Lyman- α (DLA) system, SBS 1543+593, and in the second case we look at the environment surrounding 16 low redshift Lyman- α forest absorbers.

2. The HI environment of SBS 1543+593

As the closest DLA system outside of The Local Group, SBS 1543+593 gives us a rare opportunity to study one of these systems in great detail. We use HI observations made with the Very Large Array (VLA) in C-array (E. Brinks, PI; D. Bowen and T. Tripp collaborators) to study the gas distribution in and around SBS 1543+593.

We use standard AIPS data reduction techniques and create a map with a $15'' \times 14''$ CLEAN beam. We use these data to derive the HI parameters for SBS 1543+593 and its neighbours and to make the HI contour map shown in Fig. 1. We measure an HI mass of $1.2 \times 10^9 M_{\odot}$ for SBS 1543+593, consistent with the values measured by Chengalur & Kanekar (2002) and Bowen *et al.* (2001). In addition, the HI distribution shown in Fig. 1 is consistent with the map of Chengalur & Kanekar (2002) including the HI hole in the central region of the galaxy, a dense HI ring, and HI spurs to the North and South of the galaxy's centre. However, there are several interesting features of this galaxy when the optical and HI maps are compared. Fig. 1 shows that the HI disk is much larger than the optical extent. In fact, the optical extent of the galaxy corresponds with the dense ring seen in the 21 cm emission map. We identify a spur of HI emission off the NNW end of the ring that corresponds to a faint optical extension while a spur of HI emission to the SSE of the ring also has corresponding faint optical emission.

In surveying the region immediately surrounding SBS 1543+593, we identify 3 gas-rich galaxies. Two of the galaxies were not previously catalogued while the third is MCG+10-22-038 which, while previously known, did not have a previously measured redshift. These galaxies reside 183 kpc (MCG+10-22-038), 161 kpc, and 123 kpc from SBS 1543+593 and have HI masses of $3.7 \times 10^8 M_{\odot}$, $2.2 \times 10^8 M_{\odot}$, and $6.1 \times 10^8 M_{\odot}$ respectively.

For the small detection volume of this study covered by the VLA map, a very conservative estimate of the average galaxy density would predict 8.6×10^{-3} galaxies down to $\log(M_{HI}/M_{\odot}) = 8.07$ in the field using the HI mass function from Rosenberg & Schneider (2002). Since this region is clearly not an unbiased position in the field since it was centred around a known galaxy and galaxies tend to cluster, a higher than average galaxy density should not be surprising. However, the detection of 3 galaxies in the immediate vicinity of SBS 1543+593 does indicate a significant over-density that might not be expected near a LSB galaxy since they tend to be less clustered than their higher surface brightness counterparts on large scales (Mo *et al.* 1994). However, clustering around low surface brightness galaxies on scales less than 0.5 Mpc is highly variable with 20% of systems having 3 or more near neighbours (Bothun *et al.* 1993). At least two of the three systems that we detect near SBS 1543+593 probably would not have been included in the Bothun *et al.* (1993) study so it is not clear how often LSBs have neighbours like these dwarf galaxies.

Fig. 1 shows that SBS 1543+593 has an HI disk that is extended well beyond the optical radius of the galaxy. The large extent of the HI disk is surprising given the high density of the galaxy's environment. Nevertheless, the HI distribution in SBS 1543+593 shows evidence for spurs in the outer part of its disk and the HI distributions of the neighbours also show disturbed morphologies possibly indicative of tidal disruption.

Fig. 2 shows the distribution of galaxies from the ZCAT catalogue, which includes data from the CfA survey as well as from several other galaxy surveys, (<http://cfa-www.harvard.edu/huchra/zcat/>) in the region surrounding SBS 1543+593 (small filled circles). The dashed line in the figure indicates the line of sight to the QSO HS 1543+5921 in which the damped Lyman- α absorption from SBS 1543+593 was identified. The points indicate that these new galaxies (large filled circles) are closer to SBS1543+593 (triangle) than any of the previously known galaxies. The presence of such a large reservoir of

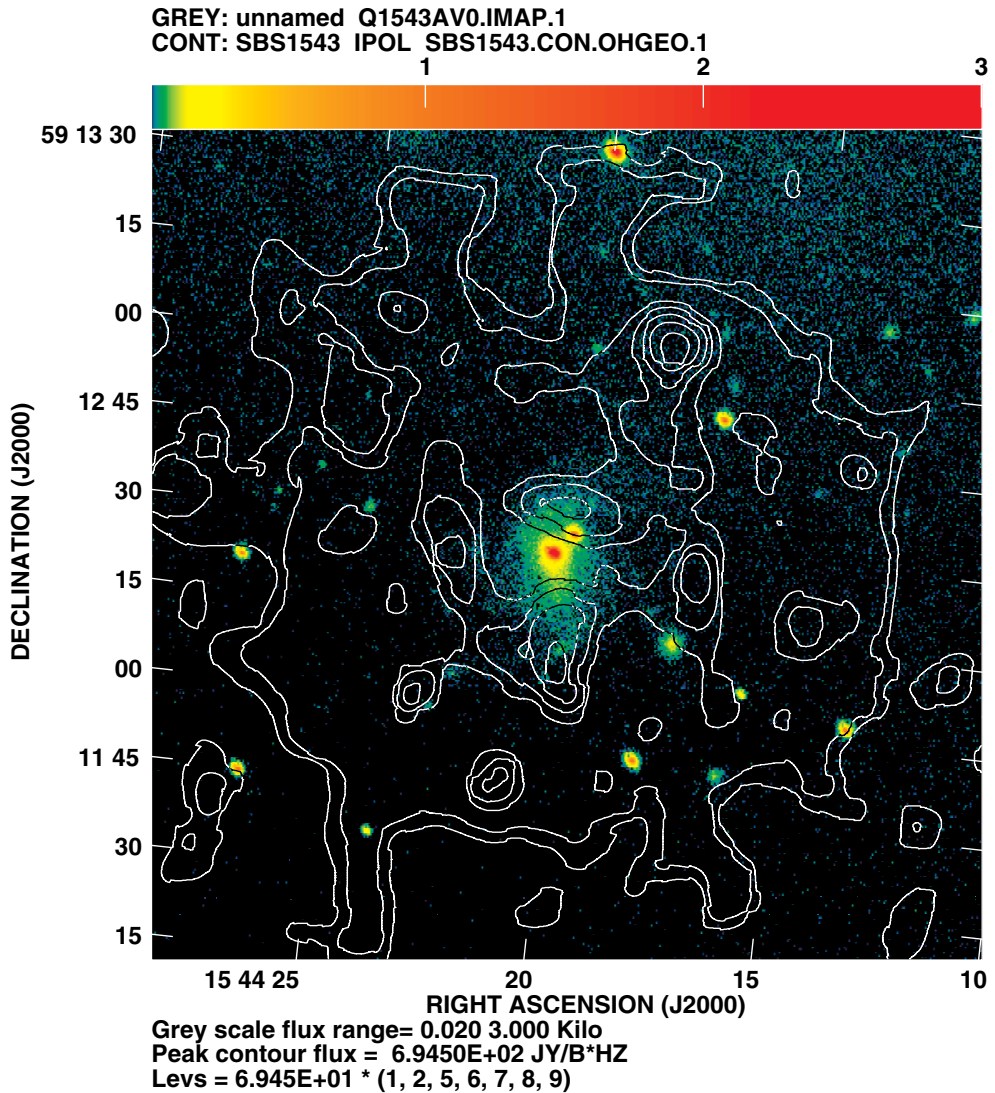


Figure 1. An optical R-band image of SBS 1543+593 overlaid with HI contours from the VLA map. The lowest level contour represents $3 \times 10^{20} \text{ cm}^{-2}$ column density. Note the large extent of the HI disk well beyond the optical LSB galaxy. The optical galaxy corresponds to the dense central ring of gas in this system. Spurs off the North and South sides of the disk may be a result of tidal interactions with the neighbouring galaxies.

primordial HI in the disk of SBS 1543+593 and in the neighbouring dwarf galaxies seems to indicate that this is a very young region. One would expect the tidal fields that are distorting the HI distribution in all of these galaxies to trigger substantial star formation but there is no evidence for this optically.

The neighbours to SBS 1543+593 range in HI diameter at a column density of $2 \times 10^{20} \text{ cm}^{-2}$ from 7 – 15 kpc as compared with the 27 kpc diameter of SBS 1543+593. Clearly the cross-sections of these galaxies are much less significant than that of the DLA. However, one might expect these HI-rich dwarfs to be more common at higher redshift where the multiple DLAs are observed. While SBS 1543+593 is a single system that can not be used

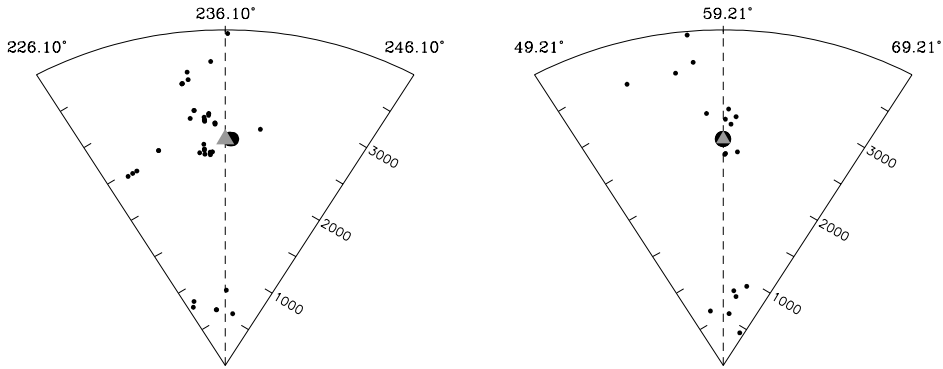


Figure 2. The large-scale distribution of galaxies around DLA SBS 1543+593, which is shown as the gray triangle. The large filled circles represent the HI detections from the VLA maps, and the smaller filled circles represent galaxies compiled in ZCAT (<http://cfa-www.harvard.edu/~huchra/zcat/>) which includes the CfA redshift survey and other galaxy survey information.

to predict the environments of other DLAs, we must factor into our interpretation that higher redshift systems may reside in equally dense or denser HI environments where we would not be able to detect the gas-rich neighbours.

3. The HI Environment of Lyman- α forest absorbers

Lyman- α forest absorbers are the lowest column density systems and therefore provide a tracer of the smallest over-densities in the HI distribution. These systems have given rise to tremendous debate about their nature and their association with galaxies. Some groups have suggested that these absorbers are associated with LSB galaxies (Impey & Bothun 1997) while others argue that they trace the extended halos of high surface brightness galaxies (Lin *et al.* 2000; Lanzetta *et al.* 1995) or that they trace filaments of primordial material that are correlated with galaxies because they are over-densities in the same large scale structures (Davé *et al.* 1999; Stocke *et al.* 2001).

We have used HI 21cm observations from Arecibo, Parkes, and the Australia Telescope Compact Array to search for gas-rich galaxies along the sight-lines to 48 nearby Lyman- α absorbers (collaborators M. Putman, E. Ryan-Weber, J. Stocke). Here we will restrict our discussion to the Arecibo HI observations around 16 low redshift ($cz < 12750 \text{ km s}^{-1}$) absorbers which span a range in column density $12.81 < \log N_{HI} < 14.09 \text{ cm}^{-2}$ (Penton *et al.* 2004, 2000) assuming $b = 25 \text{ km s}^{-1}$.

The Arecibo observations cover a $31.2' \times 31.2'$ field around each of the 4 QSO sight-lines that were observed (PG 1211+143, PG 1116+215, Mrk 335, and Ton 1542). The rms noise in the data cubes after Hanning smoothing was $\sim 0.0015 - 0.002 \text{ Jy/beam}$. In these fields we detect 8 new gas-rich galaxies (we call any galaxy with no previously known redshift a “new” system even if they were previously catalogued) with HI masses ranging from $1.4 \times 10^8 M_{\odot}$ to $4.6 \times 10^9 M_{\odot}$ and we re-detect 3 large spiral galaxies (IC 3061, NGC 4529, and CGCG 126-027).

We do not detect any galaxies in the immediate vicinity of the absorption sight-lines. The nearest HI-rich galaxy is 95 kpc from the absorber, implying that at least to the sensitivity limits of this survey, the halos of gas-rich dwarf and LSB galaxies are not responsible for Lyman- α forest absorption unless their gaseous halos are extremely large relative to their luminosity. Fig. 3 shows the large scale galaxy distributions around

each of these QSO sight-lines. The Xs mark the positions of the Lyman- α absorbers, the triangles mark the positions of previously known galaxies that were re-detected, the large filled circles mark the positions of the newly detected gas-rich galaxies, and the smaller filled circles mark the positions of galaxies identified in ZCAT (<http://cfa-www.harvard.edu/~huchra/zcat/>). This figure shows that most of the Lyman- α forest absorbers fall along the large scale structures defined in the optical and 21 cm galaxy distributions. However, while 8 of the 16 absorbers are within 500 kpc of a galaxy, there are 2 Lyman- α absorbers in the sample that are more than 2 Mpc from the nearest identified galaxy, clearly putting them in voids.

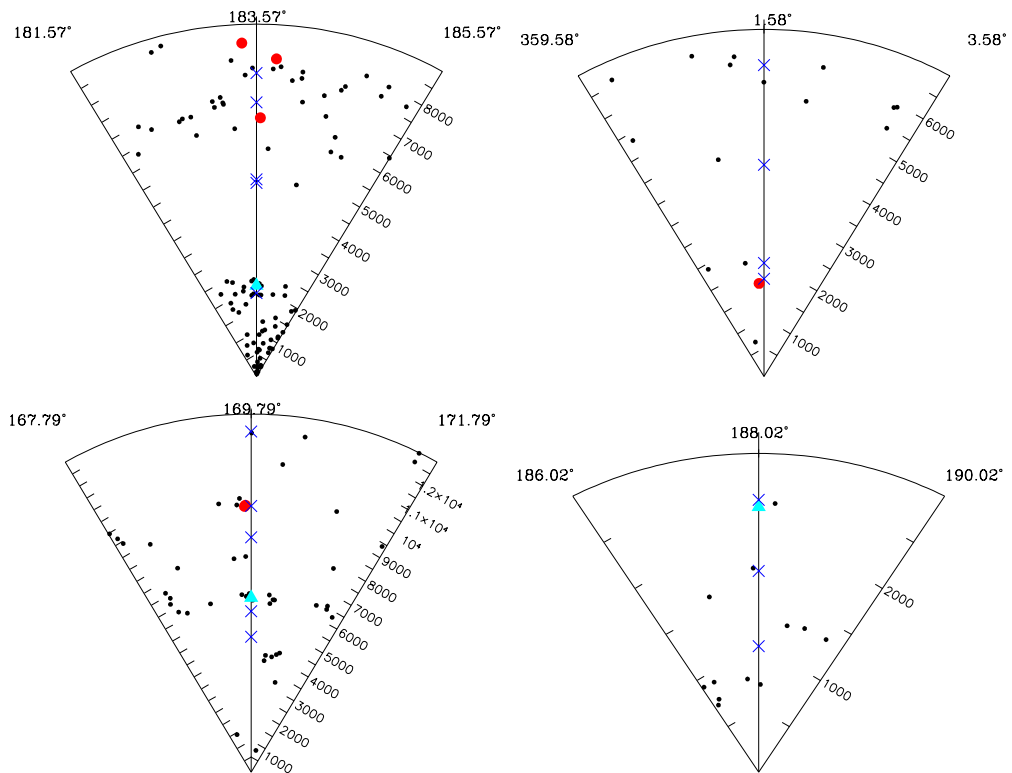


Figure 3. The large scale distribution of galaxies around PG1211 and Mrk 335 (top), and PG1116 and Ton 1542 (bottom). The Xs mark the positions of the Lyman- α absorbers along these sight-lines, the triangles are the locations of bright spiral galaxies that we detect at 21 cm but were previously known. The large circles are new detections of gas-rich galaxies in this survey. Some of them were previously known, but none had previously catalogued redshifts. The small filled circles are the galaxies listed in the ZCAT survey consisting of the CfA redshift data and other galaxy catalogues that have been included (<http://cfa-www.harvard.edu/~huchra/zcat/>).

4. Summary and conclusions

HI observations allow for the detection of faint LSB companions to Lyman- α absorbers of all sorts. These observations provide an excellent probe of the small scale HI environment of these absorbers that is only traceable in the local Universe. As shown in these studies, there are many gas-rich dwarf and LSB galaxies in the local Universe that have gone undetected in optical spectroscopic surveys.

The nearest DLA has been studied in detail (Bowen *et al.* 2001; Bowen *et al.* 2001; Chengalur & Kanekar 2002), yet it was not previously known that it resides in a very gas-rich environment with several close companions. Nevertheless this appears to be a very young region resembling those that should be more prevalent in the higher redshift Universe. This region shows that without the ability to detect these low luminosity, gas-rich systems at higher redshift we may be missing significant clues to understanding the nature of the regions in which DLAs reside.

Despite a deep search for galaxies along the lines of sight to 16 Lyman- α absorbers, we only detected 11 gas-rich galaxies all of which were > 95 kpc from the absorber. While many of these absorbers follow the large scale structure traced by galaxies in the region, there are some that appear to reside in voids at least 2 Mpc from the nearest known galaxy. Given the lack of detection of any galaxy within 95 kpc of these absorbers it appears that the absorption does not arise in the halos of dwarf or low surface brightness galaxies missed in optical surveys.

Acknowledgements

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