LOCAL GALAXIES AS DAMPED LY-α ANALOGS

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Abstract We calculate in detail the expected properties of low redshift DLAs under the assumption that they arise in the gaseous disks of galaxies like those in the $z \approx 0$ population. A sample of 355 nearby galaxies is analysed, for which high quality H$\text{I}$ 21-cm emission line maps are available as part of an extensive survey with the Westerbork telescope (WHISP). We find that expected luminosities, impact parameters between quasars and DLA host galaxies, and metal abundances are in good agreement with the observed properties of DLAs and DLA galaxies. The measured redshift number density of $z = 0$ gas above the DLA limit is $dN/dz = 0.045 \pm 0.006$, which compared to higher $z$ measurements implies that there is no evolution in the comoving density of DLAs along a line of sight between $z \sim 1.5$ and $z = 0$, and a decrease of only a factor of two from $z \sim 4$ to the present time. We conclude that the local galaxy population can explain all properties of low redshift DLAs.

Keywords: galaxies: ISM; (galaxies:) quasars: absorption lines; galaxies: evolution

1. Introduction

The range of H$\text{I}$ column densities typically seen in routine 21-cm emission line observations of the neutral gas disks in nearby galaxies is very similar to those that characterise the Damped Lyman-α Systems or DLAs with $N_{\text{HI}} > 2 \times 10^{20} \text{ cm}^{-2}$. An attractive experiment would therefore be to map the H$\text{I}$ gas of DLA absorbing systems in 21-cm emission, and measure the DLAs’ total gas mass, the extent of the gas disks and their dynamics. This would provide a direct observational link between DLAs and local galaxies,
but unfortunately such studies are impossible with present technology (see e.g., Kanekar et al. 2001). The transition probability of the hyperfine splitting that causes the 21-cm line is extremely small, resulting in a weak line that can only be observed in emission in the very local ($z < 0.2$) universe, with present technology. On the other hand, the identification of DLAs as absorbers in background QSO spectra is, to first order, not distance dependent because the detection efficiency depends mostly on the brightness of the background source, not on the redshift of the absorber itself. In fact, the lowest redshift ($z < 1.7$) Lyman-α absorbers cannot be observed from the ground because the Earth’s atmosphere is opaque to the UV wavelength range in which these are to be found. Furthermore, due to the expansion of the universe the redshift number density of DLAs decreases rapidly toward lower redshifts. Consequently, there are not many DLAs known whose 21-cm emission would be within the reach of present-day radio telescopes.

So, we are left with a wealth of information on the cold gas properties in local galaxies, which has been collected over the last half century, and several hundreds DLA absorption profiles at intermediate and high redshift, but little possibility to bridge these two sets of information. Obviously, most observers resort to the optical wavelengths to study DLAs but attempts to directly image their host galaxies have been notably unsuccessful (see e.g., Warren et al. 2001 and Møller et al. 2002 for reviews). A few positive identifications do exist, mostly the result of HST imaging.

Although the absolute number of DLAs at low $z$ is small, the success rate for finding low-$z$ host galaxies is better for obvious reasons: the host galaxies are expected to be brighter and the separation on the sky between the bright QSO and the DLA galaxy is likely larger. Early surveys for low-$z$ DLA host galaxies consisted of broad band imaging and lacked spectroscopic follow-up (e.g., Le Brun et al.1997). Later studies aimed at measuring redshifts to determine the association of optically identified galaxies with DLAs, either spectroscopically (e.g., Rao et al. 2003), or using photometric redshifts (Chen & Lanzetta 2003). All together, there are now $\sim 20$ DLA galaxies known at $z < 1$. The galaxies span a wide range in galaxy properties, ranging from inconspicuous LSB dwarfs to giant spirals and even early type galaxies. Obviously, it is not just the luminous, high surface brightness spiral galaxies that contribute to the $\text{H}\text{i}$ cross section above the DLA threshold. As explained above, we cannot study these galaxies in the 21-cm line on a case-by-case basis, but we can do a study of a statistical nature to see if the properties of DLAs and DLA galaxies agree with our knowledge of $\text{H}\text{i}$ in the local universe.
2. **140,000 “DLAs” at $z = 0$**

Blind 21-cm emission line surveys in the local universe with single dish radio telescopes such as Parkes or Arecibo have resulted in an accurate measurement of $\Omega_{\text{HI}}(z = 0)$, which can be used as a reference point for higher redshift DLA studies. $\Omega_{\text{HI}}$ is simply calculated by integrating over the H\textsc{i} mass function of galaxies, which is measured with surveys such as HIPASS (Zwaan et al. 2005a). However, due to the large beam widths of the singe dish instruments, these surveys at best only barely resolve the detected galaxies and are therefore not very useful in constraining the column density distribution function of $z \approx 0$ H\textsc{i}. Hence, for this purpose we use the high resolution 21-cm maps of a large sample of local galaxies that have been observed with the Westerbork Synthesis Radio Telescope. This sample is known as WHISP (van der Hulst et al. 2001) and consists of 355 galaxies spanning a large range in H\textsc{i} mass and optical luminosity. The total number of independent column density measurements above the DLA limit is $\sim 140,000$, which implies that the data volume of our present study is the equivalent of $\sim 140,000$ DLAs at $z = 0$!

Each galaxy in the sample is weighted according to the H\textsc{i} mass function. We can now calculate the column density distribution function $f(N_{\text{HI}})$,

$$f(N_{\text{HI}}) = \frac{c}{H_0} \int \Phi(M_{\text{HI}}) \Sigma(N_{\text{HI}}, M_{\text{HI}}) dM_{\text{HI}} dN_{\text{HI}},$$

where $\Sigma(N_{\text{HI}}, M_{\text{HI}})$ is the area function that describes for galaxies with H\textsc{i} mass $M_{\text{HI}}$ the area in Mpc$^{-2}$ corresponding to a column density in the range $N_{\text{HI}}$ to $N_{\text{HI}} + dN_{\text{HI}}$, and $\Phi(M_{\text{HI}})$ is the H\textsc{i} mass function. $c/H_0$ converts the number of systems per Mpc to that per unit redshift.

Figure 1 shows the resulting $f(N_{\text{HI}})$ on the left, and the derived H\textsc{i} mass density per decade of $N_{\text{HI}}$ on the right. For comparison with higher redshift observations, we also plot the results from two other studies. The Péroux (2005) measurements of $f(N_{\text{HI}})$ below the DLA limit are the result of their new UVES survey for “sub-DLAs”. The intermediate redshift points from Rao et al. (2005) are based on Mg$\text{\textsc{ii}}$-selected DLA systems. The surprising result from this figure is that there appears to be only very mild evolution in the intersection cross section of H\textsc{i} from redshift $z \sim 5$ to the present. From this figure we can determine the redshift number density of $\log N_{\text{HI}} > 20.3$ gas and find that $dN/dz = 0.045 \pm 0.006$, in good agreement with earlier measurements at $z = 0$. Compared to the most recent measurements of $dN/dz$ at intermediate and high $z$, this implies that the comoving number density (or the “space density times cross section”) of DLAs does not evolve after $z \sim 1.5$. In other words, the local galaxy population explains the incidence rate of low and intermediate $z$ DLAs and there is no need for a population of hidden very low surface brightness (LSB) galaxies or isolated H\textsc{i} clouds (dark galaxies).
The right hand panel shows that at $z = 0$ most of the H\textsc{i} atoms are in column densities around $N_{\text{HI}} = 10^{21}$ cm$^{-2}$. This also seems to be the case at higher redshifts, although the distribution might flatten somewhat. The one point that clearly deviates is the highest $N_{\text{HI}}$ point from Rao et al. (2005) at log $N_{\text{HI}} = 21.65$. The figure very clearly demonstrates that this point dominates the $\Omega_{\text{HI}}$ measurement at intermediate redshifts. It is therefore important to understand whether the Mg $\text{ii}$-based results really indicate that high column densities (log $N_{\text{HI}} \sim 21.65$) are rare at high and low redshift, but much more ubiquitous at intermediate redshifts, or whether the Mg $\text{ii}$ selection introduces currently unidentified biases.

### 3. Expected properties of low-$z$ DLAs

Now that we have accurate cross section measurement of all galaxies in our sample, and know what the space density of our galaxies is, we can calculate the cross-section weighted probability distribution functions of various galaxy parameters. Figure 2 shows two examples. The left panel shows the $B$-band absolute magnitude distribution of cross-section selected galaxies above four different H\textsc{i} column density cut-offs. 87\% of the DLA cross-section appears to be in galaxies that are fainter than $L_{\ast}$, and 45\% is in galaxies with $L < L_{\ast}/10$. These numbers agree very well with the luminosity distribution of $z < 1$ DLA host galaxies. Taking into account the non-detections of DLA host galaxies and assuming that these are $\ll L_{\ast}$, we find that 80\% of the $z < 1$ DLA galaxies are...
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Figure 2. Left: The expected distribution of $B$-band absolute magnitudes of $z = 0$ high H\textsc{i} column density systems. The lines plus errorbars show the product of cross sectional area and space density, which translates to the number of expected absorbers per Mpc per magnitude. The right axis shows the corresponding number of absorbers per unit redshift $dN/dz$. The different lines correspond to different column density limits, as indicated by the labels. The thick line corresponds to the classical DLA limit of $\log N_{\text{HI}} > 20.3$. Right: The probability distribution of oxygen abundance $[O/H]$ of H\textsc{i} absorbers. The solid lines refer to the approach of assuming fixed $[O/H]$ gradients and the the dashed lines refer to varying gradients (see text).

sub-$L_\ast$. The median absolute magnitude of a $z = 0$ DLA galaxy is expected to be $M_B = -18.1$ ($\sim L_\ast/7$). The conclusion to draw from this is that we should not be surprised to find that identifying DLA host galaxies is difficult. Most of them (some 87\%) are expected to be sub-$L_\ast$ and many are dwarfs.

Using similar techniques, we find that the expected median impact parameter of $\log N_{\text{HI}} > 20.3$ systems is 7.8 kpc, whereas the median impact parameter of identified $z < 1$ DLA galaxies is 8.3 kpc. Assuming no evolution in the properties of galaxies’ gas disks, these numbers imply that 37\% of the impact parameters are expected to be less than $1''$ for systems at $z = 0.5$. This illustrates that very high spatial resolution imaging programs are required to successfully identify a typical DLA galaxy at intermediate redshifts.

The right panel in Figure 2 shows the probability distribution of oxygen abundance in $z = 0$ DLAs. We constructed this diagram by assigning to every H\textsc{i} pixel in our 21-cm maps an oxygen abundance, based on the assumption that the galaxies in our sample follow the local metallicity–luminosity ($Z - L$) relation (e.g. Garnett 2002), and that each disk shows an abundance gradient of $[O/H]$ of $-0.09$ dex kpc$^{-1}$ (e.g., Ferguson et al. 1998) along the major axis. The solid lines correspond to these assumptions, the dotted lines are for varying metallicity gradients in disks of different absolute brightness. The main conclusion is that the metallicity distribution for H\textsc{i} column densities $\log N_{\text{HI}} > 20.3$ peaks around $[O/H]=-1$ to $-0.7$, much lower than the mean
value of an $L_*$ galaxy of [O/H] ≈ 0. The reason for this being that 1) much of the DLA cross section is in sub-$L_*$ galaxies, which mostly have sub-solar metallicities, and 2) for the more luminous, larger galaxies, the highest interception probability is at larger impact parameters from the centre, where the metallicity is lower. Interestingly, this number is very close to the $z = 0$ extrapolations of metallicity measurements in DLAs at higher $z$ from Prochaska et al. (2003) and Kulkarni et al. (2005). For the mean mass-weighted metallicity of $\text{H}_\text{i}$ gas with $\log N_{\text{HI}} > 20.3$ at $z = 0$ we find the value of $\log Z = -0.35 \pm 0.2$, also consistent with the $z = 0$ extrapolation of $N_{\text{HI}}$-weighted metallicities in DLAs, although we note this extrapolation has large uncertainties given the poor statistics from DLAs at $z < 1.5$. These results are in good agreement with the hypothesis that DLAs arise in the $\text{H}_\text{i}$ disks of galaxies.

4. Conclusions

The local galaxy population can explain the incidence rate and metallicities of DLAs, the luminosities of their host galaxies, and the impact parameters between centres of host galaxies and the background QSOs.

This work is presented in much more detail in a forthcoming paper (Zwaan et al. 2005b).

References

Chen, H. & Lanzetta, K. M. 2003, ApJ, 597, 706
Ferguson A. M. N., Gallagher J. S., Wyse R. F. G., 1998, AJ, 116, 673
Garnett D. R., 2002, ApJ, 581, 1019
Kanekar N., Chengalur J. N., Subrahmanyan R., Petitjean P., 2001, A&A, 367, 46
Kulkarni V. P., Fall S. M., Lauroesch J. T., York D. G., Welty D. E., Khare P., Truran J. W., 2005, ApJ, 618, 68
Le Brun, V., Bergeron, J., Boisse, P., & Deharveng, J. M. 1997, A&A, 321, 733
Møller, P., Warren, S. J., Fall, S. M., Fynbo, J. U., & Jakobsen, P. 2002, ApJ, 574, 51
Møller P., Fynbo J. P. U., Fall S. M., 2004, A&A, 422, L33
Péroux, C., Dessauges-Zavadsky, M., D’Odorico, S., Kim, T., & McMahon, R. G. 2005, MNRAS, in press
Prochaska J. X., Gawiser E., Wolfe A. M., Djorgovski S. G., 2003, ApJ, 595, L9
Rao, S. M., Nestor, D. B., Turnshek, D. A., Lane, W. M., Monier, E. M., & Bergeron, J. 2003, ApJ, 595, 94
Rao, S. M. 2005, astro-ph/0505479
van der Hulst J. M., van Albada T. S., Sancisi R., 2001, ASP Conf. Ser. 240: Gas and Galaxy Evolution, 240, 451
Warren S. J., Møller P., Fall S. M., Jakobsen P., 2001, MNRAS, 326, 759
Zwaan, M. A., et al. 2005a, MNRAS, 359, L30
Zwaan, M. A., van der Hulst, J. M., Briggs, F. H., Verheijen, M. A. W., Ryan-Weber, E. V., 2005b, MNRAS, submitted