Low Redshift Lyman α absorbers and their Connection with Galaxies

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Abstract. We review the ongoing debate about the relationship between low redshift Lyman α absorbers and luminous galaxies. In particular, we discuss the difficulty of 'assigning' a particular absorber to a particular galaxy, and consider methods of circumventing this problem. We also provide a status report on an ongoing project collecting more data to address this issue, and show some results for a close together pair of QSOs providing two adjacent lines of sight through the inter-galactic medium.

1. Introduction

Because the analysis of the new data taken for this project is not complete, we will use the first part of this contribution to explain and (we hope) clarify the ongoing debate about the relationship between low redshift Lyman α absorbers and galaxies. In the second part of the contribution, we will give a status report on the new data analysis.

A simplified version of the two sides of the debate might be that either (a) all low redshift Lyman α absorbers are part of physically-distinct luminous-galaxy halos, or (b) that they are all part of the filamentary structure seen in recent SPH/Mesh structure formation models, and are only related to galaxies by the fact that they both are following the underlying dark matter distribution. Both of these positions have been vigorously defended in the literature, and at this conference. Proponents of (a) include: Lanzetta et al. (1995); Lanzetta, Webb & Barcons (1996); Barcons et al. (1998); Chen et al. (1998); Ortiz-Gil et al. (1999); Chen, Lanzetta and Fernández-Soto (2000); and Linder (2000). Proponents of (b) include: Morris et al. (1991); Morris et al. (1993); Mo & Morris (1994); Morris & van den Bergh (1994); Weymann et al. (1995); Dinshaw et al. (1995); Stocke et al. (1995); Rauch, Weymann & Morris (1996); Shull, Stocke & Penton (1996); van Gorkom et al. (1996); Bowen, Blades &

Pettini (1996); Dinshaw et al. (1997); Jannuzi et al. (1998); Impey, Petry & Flint (1999); Penton, Shull & Stocke (2000); and Penton, Stocke & Shull (2000). Finally to complete the reference list, some of the SPH/mesh models which include mention of the Lyman α absorbers are: Hernquist et al. (1996); Cen et al. (1998); Davé et al. (1999); Cen & Ostriker (1999); and Davé & Tripp (2001).

   Before embarking on a discussion of which hypothesis is correct, it should be emphasized that even if one believes that one can obtain a clear answer (either (a) or (b) above), that the answer must be a function of column density. At column densities $N_H > 10^{21}$ cm^{-2}, one is probing a thickness of material comparable to our own galaxy's disk, and hence something almost certainly part of a galaxy, at least at low redshift. At column densities $N_H \sim 10^{12}$ cm^{-2}, one is getting close to the expected neutral hydrogen content of fluctuations within voids, and must expect a much more heterogeneous set of causes for the absorption.

2.   Philosophy

In order to frame the above debate, it is useful first to list what the observables are. In some sense, any question that cannot be addressed using these observables is uninteresting.
Measurable Absorber Properties:

- redshift

- x,y on sky

- absorption line properties such as Equivalent Width (EW), doppler b parameter, column density, and deviations from a Voigt profile

Measurable Galaxy Properties:

- redshift

- impact parameter and velocity difference to the absorber

- luminosity

- color

- morphology

- environment (in relation to other galaxies)

- galaxy spectral properties such as emission lines and stellar absorption features

   Now let us try to pose a question that might allow us to choose between hypotheses (a) and (b) above, by using the above observables. How about: "What fraction of observed Lyman α absorbers are physically part of the halo of a galaxy? (As a function of absorber column density.)"

Unfortunately, this seemingly simple query begs many questions. Is Voigt fitting to find absorbers in the first place meaningful (e.g. what about velocity cusps where there is no density enhancement)? In addition, we clearly need a lot more detail on what 'physically part of' means. One possibility might be: "bound to, and within some small physical separation from, a galaxy". Even if this is sufficient, we still have to worry about galaxy clustering and hierarchy. Any galaxy halo will contain substructure, for example, the Milky Way and the Large and Small Magellanic Clouds. To which galaxy in that system do we give the Magellanic stream? Also, if there are High Velocity Clouds in the Local Group barycentre (another topic hotly debated at the workshop), should we give those to the Milky Way or to Andromeda?

Two final concerns undermining the validity of the question posed above are (a) that any galaxy sample outside of the Local Group will only contain the top end of the luminosity function. One can almost never be sure there isn't some smaller closer galaxy to any given Lyman α absorber. And (b), H_0 is very small (even if it is 100 km/s/Mpc), so a small uncertainty in velocity, or any real peculiar velocity along the Line of Sight (LOS), corresponds to huge distances, if mistaken for Hubble flow.

How can we modify this question to avoid some of these complications? A new version might be: "Does a given model produce statistical relationships between 'absorbers' and 'galaxies' that match the observations?". Tragically, this version still begs a fair number of questions. For example: can we match 'absorbers' in the models with 'absorbers' in the observations? For SPH and Mesh/Grid models we probably can. For the model proposing that "All absorbers are part of a smooth halo around bright galaxies", we might be able to. An even trickier issue is whether we can match 'galaxies' in the models with real galaxies in the observations. For SPH and Mesh/Grid models, the answer is a definite 'maybe'. At the moment one needs either semi-analytic add-ons, or some column density cut which may well not correspond to galaxies. For the "all absorbers ..." model at least, this matching is straightforward.

As a final piece of philosophy to complete this navel-gazing exercise, what do we do if both of the models match the currently observed statistical relationships (such as that between log EW and log Impact Parameter)? Clearly, we then need to go to higher order statistics, such as residual log (EW) vs. log (galaxy luminosity) or the evolution of any log EW vs. log Impact Parameter relationship with redshift. This approach is being followed by several groups, including ourselves. The other answer is the perpetual cry from observational astronomers: "We need more data". This leads into the next section describing a program in progress to obtain more data.

3. New Analysis status report

An observing program at the Canada France Hawaii Telescope (CFHT) and the WIYN telescope was started back in 1995. Currently the data in hand (i.e. reduced but not fully analyzed) are:
WIYN Hydra Spectroscopy

- 50-150 galaxies per field, Generally z<0.4

- 23 QSO LOS

CFHT MOS Spectroscopy

- 40-50 galaxies per mask

- 26 masks in 15 QSO LOS

The basic approach for the CFHT part of the project is itemized below:

1. Choose QSOs with UV spectroscopy from the HST QSO absorption line Key Project, giving a Lyman absorber line list.

2. At the CFHT, image the field and do aperture photometry on the galaxies to generate galaxy list over a 10 arcmin diameter region.

3. Design and cut masks for spectroscopy, ranking the choice of galaxies by their magnitudes. As usual with the CFHT MOS, this was done in real time at the telescope during the same run that the images were taken.

4. Take low resolution spectra of ∼50 galaxies at a time to get their redshifts, accurate to <100 km/s.

5. Design and perform statistical tests to check the models

In order to illustrate some of the problems discussed in the section 2, we show below the pie diagram for the line of sight towards the quasar pair Q0107-025A and B. The two quasars lie off the RHS of the figure at z∼1. The dotted lines indicate the LOS to the two quasars. The filled triangles indicate absorbers with EW>0.5A, open triangles, absorbers weaker than that. Filled circles are galaxies within 500 kpc (h=0.5, Ω=1) of the QSO LOS, open circles are galaxies further from the LOS.

A number of interesting associations (and lack of associations) can be seen in the figure:

- Starting simply, there is a pleasing match between a bright galaxy at z=0.2262, projected between the two QSOs on the sky (separation about 200 kpc from each LOS), and absorption seen in both LOS. Velocity differences of 480 and 240 km s^{-1} are measured between the galaxy and the absorbers. One of the absorbers has a high enough column density that CIV is also detected.

- Possibly more surprisingly, there is a good match between a galaxy at z=0.1145 and absorption in both QSO LOS. The galaxy is 450 kpc from both LOS, and has a velocity difference of 400 and 480 km s^{-1} from the two absorbers.

- A complex situation is seen at z=0.2, where there is a plethora of candidate galaxies for association with an absorber seen in one QSO LOS but not the other. Three galaxies have measured redshifts within 25 km s^{-1} of the absorber, while several others are within 500 km s^{-1}. There is also what
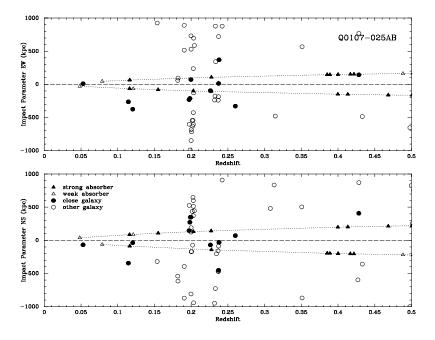
Figure 1.   Pie-diagrams for the galaxies and absorbers in the LOS to the QSO pair Q0107-025A,B.

seems to be an interacting pair of galaxies at a distance of 720 kpc and a velocity difference of 670 km s^{-1} from the same absorber.These might be considered good candidates if we think tidal tails are a potential source of Lyman α absorption.

- At a redshift of 0.2366, there are 6 galaxies all within a velocity range of 300 km s^{-1} of each other and within a Mpc of the QSO LOS, which show no absorption in either LOS. The picture emerging does seem to be more like 'weather in space' rather than well organized spherical halos.

- Finally, we note that we have not yet identified the galaxy causing the Lyman limit absorption in the LOS to Q0107-025B (with corresponding absorption also in the LOS to Q0107-025A). Even our rather crude imaging taken through the CFHT MOS would have spotted a luminous (L*) galaxy on top of the QSO, so it seems likely that any galaxy (should it exist) which one might want to associate with this absorber will turn out to be a dwarf.

The purpose of the above (rather subjective) analysis of two close together pencil beams through space is to illustrate the difficulty in being confident of any assignment of a unique galaxy to a unique absorber. While single LOS may allow one to hope for a tidy universe with large coherent spheres of gas surrounding luminous and easily surveyed galaxies, there are already many indications that the true situation is much more complex, and therefore also more interesting.

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