Galaxy morphology – halo gas connections

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Abstract. We studied a sample of 38 intermediate redshift MgII absorption-selected galaxies using (1) Keck/HIRES and VLT/UVES quasar spectra to measure the halo gas kinematics from MgII absorption profiles and (2) *HST*/WFPC–2 images to study the absorbing galaxy morphologies. We have searched for correlations between quantified gas absorption properties, and host galaxy impact parameters, inclinations, position angles, and quantified morphological parameters. We report a 3.2 σ correlation between asymmetric perturbations in the host galaxy morphology and the MgII absorption equivalent width. We suggest that this correlation may indicate a connection between past merging and/or interaction events in MgII absorption-selected galaxies and the velocity dispersion and quantity of gas surrounding these galaxies.

1. Introduction

Our knowledge of the galaxy–halo environment is slowing being painted by the study of the interstellar medium in both emission and absorption. Understanding the distribution and kinematics of extra–planar and extended halo gas, compared to that of the host galaxy, can provide constraints on formation and evolutionary models.

Diffuse ionised gas (DIGs), usually observed in NII and Hα emission, has been studied in edge–on disk galaxies. Lynds & Sandage (1963) found filaments in M82 that flow away from the plane of the disk. Rand (2000) showed that DIGs extend out to 13 kpc above the plane of NGC 5775. The gas is decreasing in rotational velocity with height above the plane and may have no rotation above several kpcs.

In 21–cm emission, Swaters *et al.* (1997) finds gas extending out to at least 5 kpc above the galaxy plane of NGC 891 that rotates 25 to 100 km s^{-1} more slowly than the disk gas. Models are consistent with a halo that is lagging behind the disk rotation. Fraternali *et al.* (2002, 2004) also found halo gas with slower rotation than the disk gas in several galaxies. This so–called "anomalous gas" displays a radial inward flow toward the centre of the galaxy. They may be observing the infalling stage of galactic fountains. They also detect "forbidden gas" that moves contrary to disk rotation and does not fit well in the classical fountain picture. Vertical motions and "holes" in the HI distribution have been seen in M31 (Brinks & Bajaja 1986) and in the dwarf irregular HoII (Puche *et al.* 1992). These holes might be produced by the expansion of large bubbles around stellar associations via strong outflowing winds and/or supernovae. It is clear that the disk–halo interface is dynamically and kinematically complex.

The study of halo gas in emission has several observational challenges. Halo gas is intrinsically faint which limits studies to the local Universe and the present epoch. Furthermore, only the highest column density regions of inner halos can be studied. An additional complication is the distinction between halo and disk emission for various

galaxy orientations. On the other hand, observing halo gas in absorption allows one to probe both the inner and outer halos to much lower column densities at all redshifts. Absorption selected galaxies are chosen by gas cross section only and not by *a priori* knowledge of galaxy morphology, orientation, and surface brightness.

Absorption studies primarily use the Mg II $\lambda\lambda 2796, 2803$ doublet as a tracer of halo gas. Since the early 1990s, the association of Mg II absorption with normal, bright, field galaxies has been well established (e.g. Bergeron & Boissé 1991; Steidel *et al.* 1994).

2. Galaxy orientations and morphologies

We have examined the detailed connections between halo gas and galaxies using HIRES and UVES quasar spectra to study the Mg II absorption kinematics and *HST*/WFPC–2 images of the quasar fields to measure the host galaxy properties. All galaxies in our sample are spectroscopically confirmed to have the same redshift as the Mg II absorption.

In Fig. 1, we present 36 of 38 galaxies in our current sample having redshifts between $0.3 < z < 1$. Each galaxy "postage stamp" is $5'' \times 5''$ with the quasar oriented downward. The range of impact parameters are $7 \leqslant D \leqslant 80 \ h^{-1}$ kpc. Note that the galaxies exhibit a wide range of orientations with respect to the quasar line of sight. Also, there are a wide variety of galaxy morphologies. Some of the galaxies appear slightly perturbed and/or have bright H II regions. Others have minor satellites or major companions. Three of the Mg II absorbers are associated with double galaxies that could be in the process merging or being harassed.

We modelled the morphology and orientations of the galaxies using GIM2D (Simard *et al.* 2002). The models comprise of a smooth disk and bulge component from which we quantify disk inclinations, disk position angles, disk scale lengths, bulge position angles, bulge effective radii, bulge–to–total ratios, galaxy half–light radii, and morphological asymmetries. An example model and the model residual are shown in the upper panels of Fig. 2. We used Voigt profile fitting to model the HIRES and VLT spectra (Churchill & Vogt 2001; Churchill *et al.* 2003). The fits to the spectra provide the number of clouds in an absorption system and their associated column densities, Doppler parameters, and velocities. Directly from the spectra we also measured the equivalent width, velocity spread, and velocity asymmetry of the absorbing gas.

To examine halo geometry, we tested for correlations between galaxy orientation and absorption properties for a subsample having a rest–frame equivalent width $W(2796)$ less than 1.4 Å. This cutoff limits our subsample to "classical" systems and is designed to eliminate DLAs and wind driven systems (see Churchill *et al.* 2000; Bond *et al.* 2001b). The orientation of a galaxy is the combined projection of the galaxy's inclination i and the position angle ϕ. The position angle is defined as the primary angle between the galaxy major axis and the quasar line of sight. We find there are no statistically significant correlations between galaxy orientation parameters and Mg II absorption properties. In particular, if the gas is distributed in a disk geometry then $\cos\phi\cos i$ should correlate with $W(2796)$. As shown in the bottom–left panel of Fig. 2, the distribution is consistent with being random.

The GIM2D model residual image of the example galaxy, shown at the top–right panel of Fig. 2, displays a spiral barred structure along with an extend tidal tail on one side. Without modelling the galaxy these underlying features would go unnoticed. To quantify these asymmetries we used two different methods. One method computes the asymmetries on the residual image (Schade *et al.* 2002) and the other is computed directly from the science image (Abraham *et al.* 1994, 1996). We find a 3.2 σ correlation using the Abraham *et al.* method and a 2.7 σ correlation using the Schade *et al.* method between
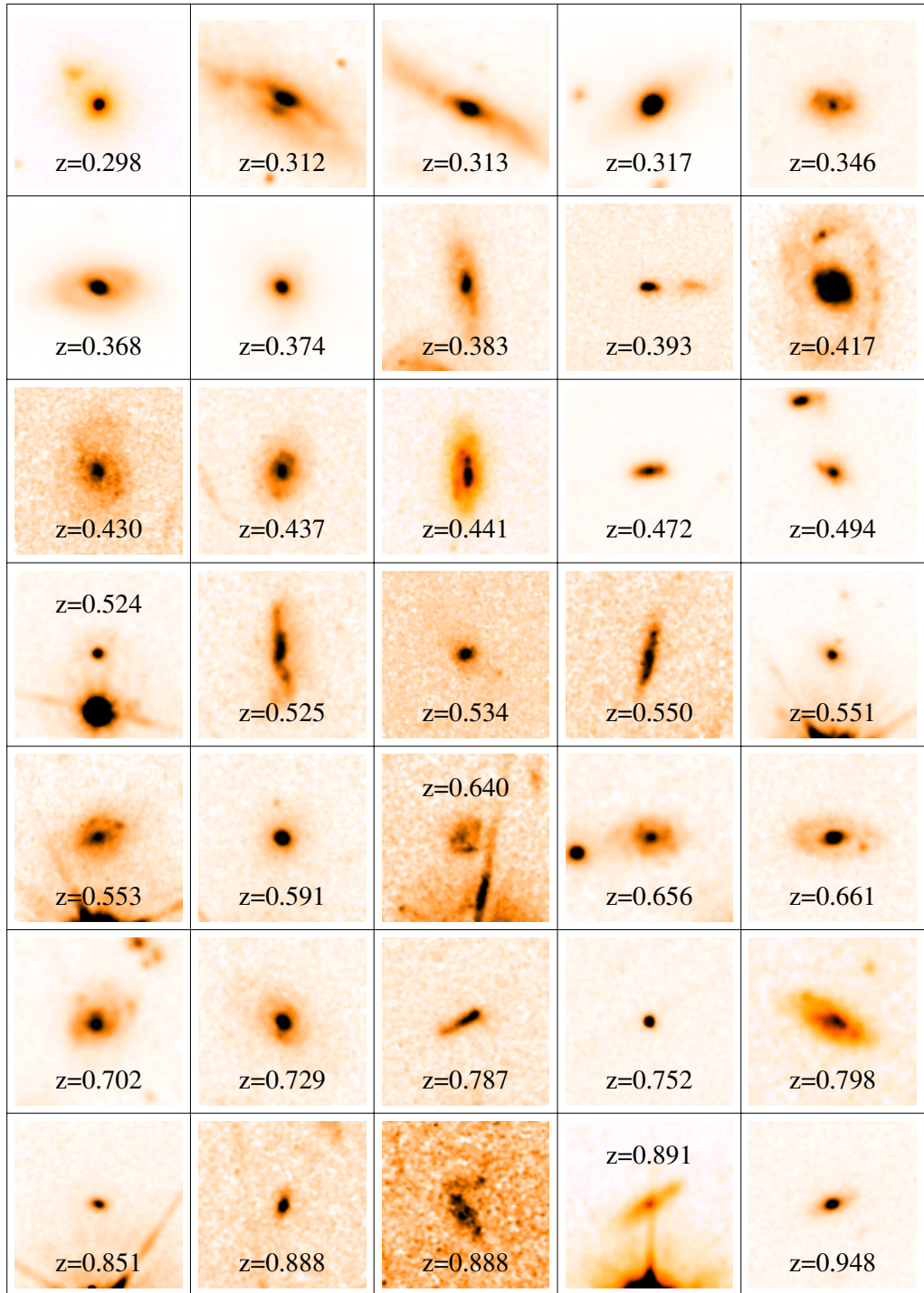
Figure 1. *HST*/WFPC–2 images of 36 spectroscopically confirmed MgII absorbing galaxies. The "postage stamps" are $5'' \times 5''$ and are orientated such that the quasar is down. Displaying the galaxies in this fashion allows one to see the variety of galaxy orientations with respect to the quasar line of sight.
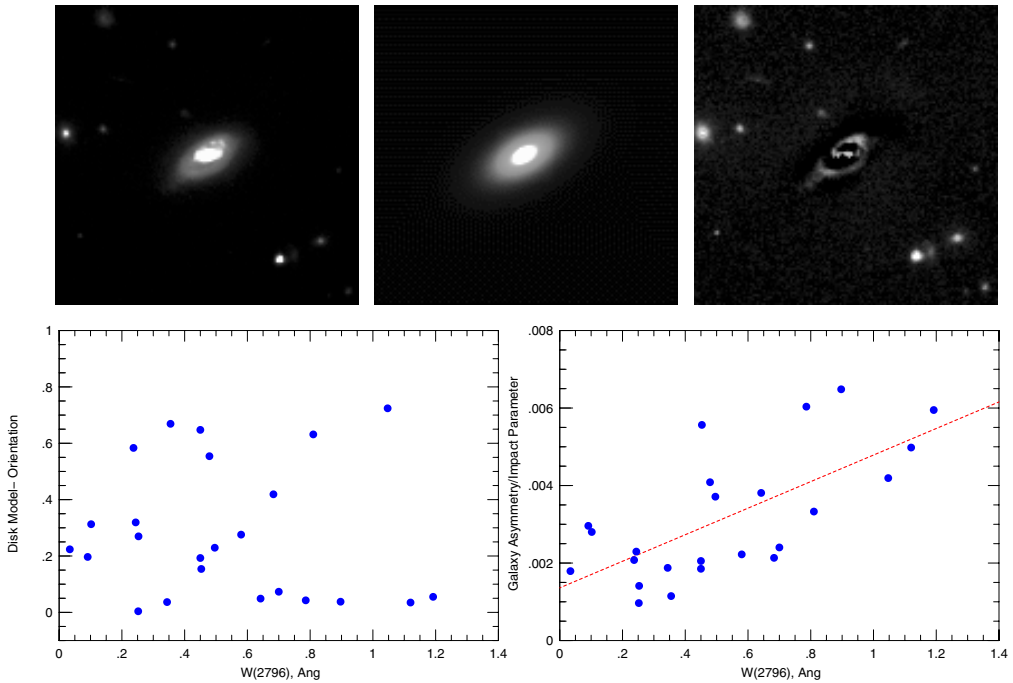
Figure 2. — (top–left) *HST* image of an absorbing galaxy. — (top–middle) Smooth galaxy model produced with GIM2D. — (top–right) Model residual image. — (bottom–left) Disk model galaxy orientation plotted against rest–frame MgII $\lambda2796$ equivalent width. — (bottom–right) Asymmetries in galaxy morphologies normalised to the impact parameter plotted against MgII $\lambda2796$ equivalent width.

$W(2796)$ and galaxy morphological asymmetry normalised by the impact parameter. The correlation is shown in the bottom–right panel of Fig. 2, where the dashed line is a maximum likelihood fit. In the near future, we will be conducting a multivariate analysis to further explore the nature of correlations between galaxy and absorption properties (e.g. Churchill *et al.* 2000).

3. Interpretations

The lack of correlations with galaxy orientation implies that gaseous halos are not necessarily disk–like or spherical, or that the distribution of gas could be patchy and have a less than unity covering factor (also see Churchill *et al.* 2005, this volume). The 3.2 σ correlation suggests that a galaxy with strong perturbations could produce a similar absorption strength at a large galactocentric distance as a galaxy with mild perturbations at a smaller galactocentric distance. It is possible that strong star formation, winds, or tidal stripping could lead to the development of both morphological perturbations in the galaxy and an increase in the halo gas cross section. Galaxies that are more symmetric may not produce as significant MgII absorption since there is a lacking or inadequate mechanism for repopulating the halo gas. This would explain why some bright galaxies close to the quasar produce very weak to no absorption (see Churchill *et al.* 2005, this volume).

To help understand these results and to see if there may be sample selection effects, we will employ more advanced models (i.e. lagging halos, fountains, infall). Furthermore,
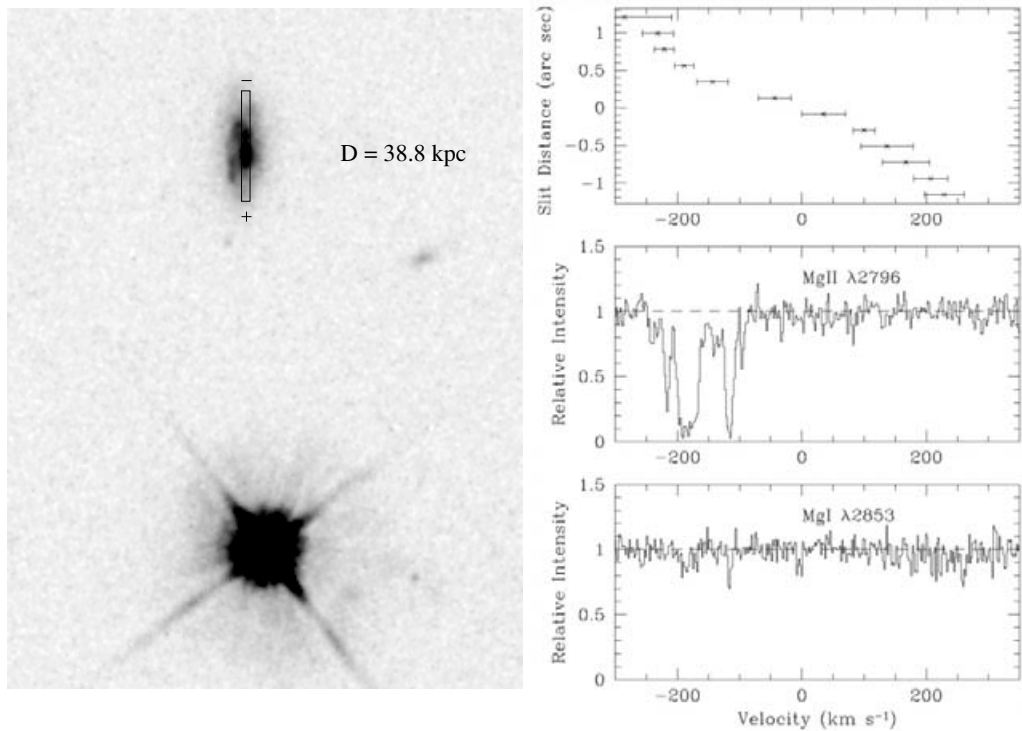
Figure 3. — (left) *HST*/WFPC–2 F702W images of Q1038+064. The slit position used for the galaxy spectroscopy is indicated; the relative spatial position along the slit is indicated with "+" and "−". The projected distance D is 38.8 h^{-1} kpc. — (right) Galaxy rotation curve (top) as a function of slit position with the MgII kinematics of the observed MgII $\lambda2796$ (middle) and MgI $\lambda2853$ absorption profiles (bottom) from the HIRES spectrum of the quasar.

a full census of absorbers and non–absorbers is central to a deeper interpretation of our results.

4. Future of kinematic studies

In order to further analyse the galaxy–halo kinematic connection it is necessary that we obtain spectra of the galaxies. We can then place the halo absorption features in the same velocity frame as the galaxy. The velocity field between the galaxy and the halo will tell us how they are kinematically related so that we can differentiate between competing halo models.

A prime example of such a study was by Steidel *et al.* (2002), who presented the kinematic properties of halo gas for a sample of five edge–on galaxies. In Fig. 3 (left panel) we present the *HST* image of the Q1038+064 field with an absorber at $z = 0.4415$. Long slit spectroscopy was obtained to get the kinematics of the gas in the disk (upper–right panel). A HIRES spectrum of the quasar was obtained for kinematic information of the halo gas (lower–right panels). The halo gas kinematics is probed at 38.8 h^{-1} kpc away from the disk. Absorption between -250 and -150 km s^{-1} shows halo gas kinematics similar to that in the disk. Additional absorption between -150 and -75 km s^{-1} is suggestive of slower rotation with respect to the disk, similar to that mentioned by Fraternali *et al.* (2001, 2002, 2004). Thus, in this galaxy probing out to distances far beyond the plane, one finds that the halo gas is aware of the kinematics of the disk.

In four of their five cases, Steidel *et al.* (2002) found disk–like halo kinematics consistent with a rotating and/or lagging halo. Another study of an edge–on galaxy (Ellison *et al.* 2003) found Mg II absorption with velocities inconsistent with the galaxy rotation. This "forbidden" gas may actually be caused by superbubbles (see Bond *et al.* 2001a).

Over all, only a half dozen galaxies have been studied in great detail by comparing the kinematics of the absorbing gas and the galaxy kinematics. However, these galaxies were all edge–on disk galaxies. We are carrying out an in-depth study, similar to that mentioned above, for our sample of 38 galaxies having a wide range of morphologies and line–of–sight orientations. Here, we have reported an orientation and morphology analysis, in absence of galaxy spectra. Our results hint that there are some relationships between the halo and the host galaxy when looking at the distance normalised galaxy perturbations. Obtaining the galaxy spectra will allow us to perform a full halo model analysis which is much needed in order to understand the nature of galactic halos.

Acknowledgements

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