

N93-26766

Probing the Extent and Content of Low Ionization Gas in Galaxies: QSO Absorption and HI Emission

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The small projected separations of some QSOs and low-redshift galaxies provide unique opportunities to study the extent and content of gas in galaxies through observation of absorption in the QSO spectra. Observations of these systems provide valuable information on the connection between the absorbing gas and the galaxy, as well as detailed information on the morphology and environment of the galaxy itself. While there is direct evidence that galaxies can produce the intervening-type QSO absorption lines, over the past decade, the study of such "QSO-galaxy pairs" (at low redshift) has been considered unsuccessful because new detections of absorption were seldom made (Bothun, Margon, & Balick 1984, *PASP*, 96, 583; Morton, York, & Jenkins 1986, *ApJ*, 302, 272; Bowen, Pettini, Penston, & Blades 1991, *MNRAS*, 249, 145). A fundamental problem concerning the relation between these low-redshift systems and those seen at moderate to high redshift remains unresolved. Direct and indirect measures of galaxy absorption cross sections at moderate to high redshifts ($z \gtrsim 0.5$) are much larger than the optical and HI sizes of local galaxies. However, direct comparison of the low and moderate to high redshift systems is difficult since different ions are observed in different redshift regimes.

Observations are presented here for a new sample of QSO-galaxy pairs. We have observed 9 new QSOs which shine through nearby galaxies (on the sky-plane) to search for Ca II absorption in the QSO spectra at the foreground galaxy redshifts. These new pairs were selected to have QSO-galaxy impact parameters, b , less than $20 \text{ h}^{-1} \text{ kpc}$ and less than 3.0 isophotal galaxy radii measured at 25 B-mag per square arcsec and spiral galaxies, only. This strict separation criterion was chosen to fill a crucial gap of impact parameters, $10 \lesssim b \lesssim 20 \text{ h}^{-1} \text{ kpc}$, left from previous studies of Ca II absorption in QSO-galaxy pairs (Bothun *et al.* 1984, Morton *et al.* 1986, Bowen *et al.* 1991). In conjunction with this optical spectroscopic data, we have obtained deep optical images and HI 21 cm spectral line maps of the galaxies to explore any global morphological trends which may significantly contribute to (or reduce) the cross sections of the galaxies and to quantify the Ca II absorption cross sections in terms of the HI column densities.

Observations

Optical spectroscopic observations of the background QSOs were obtained using the Lick 3-m and KPNO and CTIO 4-m telescopes at resolutions ranging from 0.8 to 3.0 \AA . These spectra were reduced in a standard manner. As most of the QSOs in this sample are moderately faint, a large number of individual spectra were obtained for each object; these were weighted and co-added to optimize the signal to noise in the resulting spectra. An automated line finding routine was used to locate all the narrow absorption lines in these final spectra in a unbiased manner; we adopted a 5σ equivalent width threshold for the detection of lines. This routine was also used to determine the observed equivalent width limits in cases where no galaxian absorption lines were detected. The identified lines were then individually measured to insure accurate determination of the values. Column densities and limits for the observed QSO-galaxy pair absorption systems were determined using curves of growth. However since many of the observed lines are saturated and are likely to consist of multiple, unresolved velocity components, these column densities are representative of the absorption system strengths but should be interpreted with caution.

HI 21 cm emission maps of a sub-sample of the pairs described above were obtained with the VLA in the D and C array configurations. The sub-sample was chosen based on the beam versus galaxy sizes for a given array configuration; it includes examples of both detections and non-detections of optical absorption lines. These data were calibrated and mapped in a standard

manner with some special steps taken in cases of severe interference and strong continuum source subtraction. The HI column densities at the QSO positions were determined by interpolating the spatial pixels of the spectral line cube and generating a one-dimensional spectrum at the precise background source position. Moment maps were also generated for the galaxies using a combination of velocity, flux and interactive blanking to reduce noise contributions.

Results

Of the nine new pairs, we have detected 4 new Ca II galaxian absorption systems and have possible detections in 2 additional objects. In the cases of possible systems and non-detections, the observed equivalent width limits are in the range 90 to 140 mÅ (3σ). These data are discussed here in conjunction with a "complete" compilation of all the QSO-galaxy pairs observed to date which have impact parameters less than $22 \text{ h}^{-1} \text{ kpc}$. Two additional objects with larger impact parameters are also considered here since the QSOs show galaxian absorption systems; the many non-detections with $b \gtrsim 22 \text{ h}^{-1} \text{ kpc}$ are analyzed in previous studies (Bothun *et al.* 1984, Morton *et al.* 1986, Bowen *et al.* 1991) and are not considered further here.

Considering both the new sample and the existing QSO-galaxy pair absorption systems, a number of conclusions can be reached. We see no correlation between the Ca II K-line strength with impact parameter measured in either kpc or isophotal radii. This is unlike the correlation of Mg II absorption line strengths with impact parameters seen in moderate redshift QSO absorption systems (Lanzetta & Bowen 1990, ApJ, 357, 321). The existence of 2 Ca II absorption systems with unusually large impact parameters ($b \simeq 45$ & $60 \text{ h}^{-1} \text{ kpc}$) indicates that there is no absolute maximum galaxy cross section for producing detectable Ca II absorption. Since non-detections are also seen over the entire range of b with 10 non-detections between 0 and $20 \text{ h}^{-1} \text{ kpc}$ (4 of these between 0 and $5 \text{ h}^{-1} \text{ kpc}$), there is no minimum impact parameter below which Ca II absorption is always detected.

The HI column densities at the QSO positions are also not correlated with b as measured in $\text{h}^{-1} \text{ kpc}$. The HI column densities are correlated with the optical extent of the galaxies; this is consistent with the Bosma (1981, AJ, 86, 1825) results but is somewhat misleading for the individual data points considered here. The spatial distribution of HI emission in many of the pairs shown here are highly non-uniform with respect to the optical extent in the QSO vicinity.

The measured Ca II line strengths are correlated with the HI column densities; this correlation is independent of the impact parameter. For high quality optical data with an equivalent width limit of 100 mÅ, Ca II absorption should be detectable for HI column densities greater than $10^{19.5} \text{ cm}^{-2}$. This is unlike the Mg II QSO-absorption selected sample which showed no correlation between the optical absorption properties and 21 cm optical depths (Briggs & Wolfe 1983, ApJ, 268, 76).

Of the 9 detections of QSO-galaxy pair absorption systems, most of the galaxies are tidally disrupted or in some way morphologically unusual. Many show a great deal of evidence for induced star formation. Some are classic starburst galaxies, and most are bright *IRAS* sources. The absorption non-detection galaxies with both HI and optical imaging data do not show the unusual morphological nature obviously evident in the detection-pairs. Ca II absorption appears to be a good tracer of large HI column densities. However, the large HI column densities seen in these systems do not imply disk-gas; tidal interactions and active star formation can have a very dramatic effect on the distribution of gas in in these galaxies. Finally, these data are not necessarily representative of all high redshift QSO absorption systems, but they probably form some subset of them.

This work has been supported in part by NASA, contract NAS 5-29293 and grant NAG 5-1630.