On the Kinematics of Galaxies and Associated QSO Absorption Systems

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1 Introduction

The methods available for studying galaxies directly, both individually and as a class of objects, limit astronomers to certain regions of parameter space. Since most observational techniques are rooted in the collection and analysis of photons, there is always the danger of preferentially studying those objects for which this information is more readily obtained. Such selection effects can dramatically alter the physical picture one deduces. For example, detailed studies of galaxies at optical wavelengths becomes extremely difficult for objects located at distances corresponding to z approx. 1.5-3. Furthermore, certain structures are too diffuse and/or faint to detect from their emission signatures alone, even at relatively low redshifts. For example, for material in the outer regions of the galaxy, where only small amounts of star formation are occuring, it is very difficult to detect the presence of the material from optical images alone despite the advent of ever bigger and better instruments and telescopes. Fortunately, several methods exist that allow astronomers to avoid these observational hurdles. One such method is the use of quasar (QSO) absorption line systems.

2 Background

2.1 History

Spectroscopy of distant quasars has long revealed absorption features arising from material intervening between the quasar and the observer. (see e.g. BGS 1968, SSB 1988, CS 1996, B 1994). Such features include absorption from elements such as Mg, Mn, Ca, Fe, O, C and neutral H. When the systems were first observed, it was unclear what structures were causing the absorption. Several theories were offered to explain the origin of the absorption systems ranging from randomly distributed extra-galactic clouds, inter-cluster gas in distant galaxies, inter-stellar gas from both normal and "dead" intervening galaxies and "local" absorption from the quasar itself (Bahcall and Peebles 1969 and references therin). Most of these analyses were based on computing a probability distribution for producing an absorption system along the line of sight for a particular model. None of the models that attributed the absorption to distant galaxies seemed to sufficiently reproduce the observed features of the QSO spectra of the time. In order to reproduce observation, galactic-absorber models required galaxies to have a much larger disk than what was observed. In 1969, John Bachall and Lyman Spitzer Jr. first proposed that gas within extended halos of galaxies could also reproduce the absorption features in background QSO's. This model increased the galaxy cross section enough to account for the absorption properties observed.

A variety of subsequent spectroscopic studies of absorption line systems have provided evidence that the absorbing gas exhibited similar statistical properties as galaxies thereby supporting the galaxy-as-absorber interpretation (see e.g. Young et. al. 1982; Tytler et. al. 1987; Sargent et. al 1988a, 1988b; Petitjean and Bergeron 1990; Steidel and Sargent, 1992; Bergeron et. all 1994). Other works employed a combination of quasar spectroscopy and imaging of the quasar field in order to look for the luminous components of the proposed extended galactic halos. These studies revealed that luminous galaxies could, in fact, be found near (within $100h^{-1}kpc$) the line of sight to quasars (Bergeron and Boisse, 1991; Steidel, Dickinson and Persson, 1994). These early studies firmly established the idea that gas that gives rise to characteristic signatures in the spectra of background quasars are indeed associated with galaxies along the line of sight. Numerous studies since have been aimed at understanding the detailed structure of the absorption lines in terms of their chemical, kinematic and evolutionary properties and how these relate to different galaxy properties.

2.2 Motivation

Absorption systems yield information about galaxies that cannot be obtained by alternate methods. The material sampled by the QSO sightline could not possibly be seen in optical emission, and can only be seen at these wavelengths with the aid of a cosmological mag-light. The ions that give rise to absorption give us information about the ionization and kinematic conditions along the line of sight. Knowing where the line of sight "goes", respect to the galaxy and the quasar, gives us information about the physical processes at work. For example, the presence of high-ionization gas can place limits on the origin of the ionizing radiation. Whether or not the ionization comes from collisional thermal motions in the gas, or a background radiation field can potentially tell us which portion of a galaxy we are probing. We would also like to get not only structural and thermal information about the gas, but also kinematic information. This information places constraints on the dynamical processes that could potentially give rise to absorption. Since MgII is observed to be a good tracer of neutral hydrogen gas in regions (optically thick to ionizing lyman continuum photons) it is particularly interesting for QSO absorption studies concerning galaxy formation and evolution. When the column density of HI falls below approximately $10^{19} cm^{-2}$, the gas becomes too diffuse to detect. Mg II on the other hand, can be observed at low column densities and, in addition, for these low column densities ($N(HI) = 10^{17} cm^{-1}$) the strength of the Mg II transition is more sensitive to the kinematics of the atoms it probes, and not the column density itself, making it a useful kinematic probe.

The possibility of using these systems as probes of galaxy evolution is, in some respects, more appealing than the use of traditional flux-based indicators for several reasons. First, since absorption line systems are not subject to the same difficulties (i.e. magnitude limits and resulting biases) as traditional galaxy surveys, they can be used to gain information about galactic evolution in regimes where direct observational methods fail. This is evident by the simple fact that long before large telescopes were able to "see" the galaxies associated with the absorption systems, their presence had been clearly established from QSO spectroscopy. Additionally, absorption systems can be studied at all redshifts smaller than the redshifts of background quasars. Since quasars are known to exist in large numbers past z=5 (Fan et. al 2000), this implies that one could potentially study absorption over that entire regime. It is not currently possible to study galaxy evolution uniformly over such a large redshift range with current ground or space based optical/UV techniques.

However, all that does not glitter is not gold in the land of QSO absorption. Before one can make optimal use of these systems, it is essential to understand the relationship between the absorption (which arises from a region usually spatially distinct from the luminous central portions of the galaxy) and the galaxy properties that we can measure directly (such as luminosity, morphology etc.). In addition, it is necessary to get a clear picture of how these relationships vary from epoch to epoch and how they depend upon the relative quasar-galaxy geometry. In this vein, one may combine absorption line data with emission line data and directly compare the properties of the absorbing "clouds" along the line of sight and the luminous material located at some distance away. In 1994 Steidel, Dickinson and Persson presented the statistics for a large sample of 103 absorption systems with identified "host" galaxies. One result of this work was the conclusion that absorbing gas seemed to be distributed symmetrically around the host galaxy. Another result, however, was that the *strength* of the Mg II absorption was not obviously anti-correlated with impact parameter (where "impact parameter" is just the linear separation between the galaxy and the quasar in the plane of the sky) contrary to previous predictions based on smaller samples (Steidel 94, Lanzetta and Bowen 1992). This work clearly demonstrated the need for more information on the structural properties of the galaxy with respect to the absorbing gas.

A variety of models have been proposed in order to explain the observed correlations (or lack thereof) between the galaxy properties and absorption properties. These models each provide different physical pictures for how the absorption arises in the intervening galaxies, and are each dependent on a different parameters. There is a tremendous variety of physical scenarios within the models that make predictions of the gas kinematics with respect to the region in the galaxy in which the gas is confined which can be tested by observation. For example, we expect that gas clouds confined to the disk of the galaxy will display an absorption profile kinematically consistent with the rotation of the disk when sampled tangentially to the cloud motion. On the other hand, a line of sight that doesn't pass through any disk material, but rather, passes through only a spherically symmetric "halo" around the disk, is likely to exhibit a velocity profile that reflects the motions within the halo. These could be random cloud motions, more turbulent motions (such as material that has been ejected from the stellar disk), or perhaps regular halo motion such as clouds "falling-in" to the central gravitational potential of the disk. It is important to understand exactly where in the galaxy the absorption is coming from since the lines trace out different chemical and kinematic conditions. Combined with the galaxy parameters (luminosities, redshifts, morphologies etc.) one can try to understand the implications of this information in terms of the physics of galaxy formation and evolution in regimes where there is currently very little information on these processes.

With this in mind, the aim of my thesis project was to compare the gas kinematics (obtained with QSO spectroscopy) with the motion of the stellar disk of the galaxy (obtained with galaxy spectroscopy) using optical imaging to see the structural properties of the galaxy with respect to the region of absorption.

3 Overview of Method

In order to conduct a direct comparison of the luminous stellar disk with the gaseous material, several data sets are required. One can measure the rotational velocity of a galaxy by examining it's rotation curve. This is just the circular velocity of the galaxy as a function of radius measured from the galaxy's center. Rotation curves are obtained using long slit spectroscopy. The idea here is to out all objects in the field except the galaxy of interest before the light entering the telescope aperture reaches the spectrograph (see figure 1). The light passing through the slit is then dispersed by a diffraction grating, yielding a 2-dimensional spectrogram (see figure 2). The rotation of the galaxy is evidenced by shifts in the emission features with respect to the emission from the center of the galaxy along the spatial axis of the slit (see figure 3). Each of the 5 galaxies studied in this project had a strong OII $\lambda\lambda 3726.2, 3728.9$ emission doublet redshifted into the range $\lambda = 5000 - 6500$ Å(where redshift is defined as $1 + z = \frac{\lambda_{obs}}{\lambda_o}$) for the redshifts of interest. In order to see how the gas relates to the stellar disk, one can then compare high-resolution spectrosopy of the gas with the actual observed rotation curve. Finally, using high resolution imaging, one can determine exactly which portion of the the extended galaxy the absorption line is sampling with respect to the luminous material. This method allows one to simultaneously study the galaxy dynamics and gas kinematics as a function of the structural properties of the galaxy.

4 Observations

4.1 Galaxy Spectroscopy

The long slit spectroscopy for all 5 galaxies studied here were done in March 1999 at the 10m telescope of the W.M. Keck Observatory on Mauna Kea, Hawaii using the Low Resolution Imaging Spectrograph (LRIS) (Oke et. al 1995). The data were obtained using the 600 lines mm^{-1} grating blazed at $7500\AA$ producing a resolution of $1.28\AA\ pixel^{-1}$. The observations consisted of three types of frames: one 2 second calibration image taken of an HgNeArKr arc lamp, two 5 second flat images taken internally by illuminating the slit mask and spectra of the galaxies taken using a slit (either a single long slit or as part of a mask) aligned along the semi-major axis of the absorber. See table below for a summary of observations.

Object	z_{gal}	Date (UT)	λ Range (Å)	Exposure (s)
Q1222+228 Absorber	0.5502	1999 Mar 19	5450-8020	2400
Q1148+3842 Absorber	0.5534	1999 Mar 19	5190-7760	2400
Q1317+2743 Absorber	0.6606	1999 Mar 18	5770-8340	1200
Q0827+2421 Absorber	0.5259	1999 Mar 18	5400-7960	1200
Q1038+0625 Absorber	0.4428	1999 Mar 19	4980-7530	2400

4.2 Quasar Spectroscopy

The spectroscopy of the quasars was done at the other 10m telescope at Keck using the High Resolution Echelle Spectrometer(HIRES) (Vogt et al. 1994). This instrument has much higher spectral resolution than LRIS (R approx. 45,000 corresponding to 6.6 km sec^{-1} for HIRES vs. R approx. 2000 for LRIS) which makes it possible to study the absorbtion in detail. For three of the five systems, the data were collected by Chris Churchill. For the other two systems, the observations consisted of one 3 second Thorium-Argon arc calibration spectrum, flat field frames with combined integration time of 15 seconds, bias frames (taken to measure the dark current of the CCD), and two spectra for each quasar. See table below for summary of observations.

Object	z_{em}	Date (UT)	λ Range (Å)	Exposure (s)
Q1222+228	2.040	1995 Jan 23	3810.5-6304.9	3600
Q1148+3842	1.303	1995 Jan 24	3986.5-6424.5	5400
Q1317+2743	1.022	1995 Jan 23	3810.5-6304.9	3600
Q0827+2421	2.046	1998 Feb 27	3215.7-5605.8	7200
Q1038+0625	1.270	1998 Mar 1	3975.1-6407.8	7200

4.3 Optical Imaging

High resolution images of the field containing the quasar and the absorbing galaxy were taken by the Wide Field/Planetary Camera 2 (WFPC

2) imaging camera aboard the Hubble Space Telescope (HST). Each image is the sum of four individual images with exposure times of about 1000 seconds each. The individual exposures are taken at slightly offset (sub-pixel) postitions with the quasar centered on the CCD chip and then combined using the Variable-Pixel Linear Combination technique (or "drizzling") to form the final frame which has a pixel scale of 0.05 arcseconds $pixel^{-1}$ (Hook and Fruchter 1994). The HST observations are summarized below.

Object	Date (UT)	Exposure (s)
Q1222+228	1997 June 11	5000
Q1148+3842	1995 May 31	4700
Q1317+2743	1995 June 1	4800
Q0827+2421	1995 May 29	4600
Q1038+0625	1995 May 31	4600

5 Data Reduction and Analysis

The LRIS data were reduced using standard image processing techniques with the IRAF data reduction package. Pixel-to-pixel variations in the data were removed by dividing the images by the flat field images. Cosmic rays removal was done with the IRAF task *szap*. Each half of the LRIS 2048x2048 CCD chip has a different value for the gain ($\frac{e-}{DN}$) and so this must be accounted for at the beginning of the reduction process. In order to remove the signal of the night sky from the images, a polynomial function in each wavelength bin was fit to the background sky signature and this function was subtracted from the images. The spatially extended OII emission lines were apparent from the resulting images (see figure 3). Using the IRAF *apextract* task the galaxy spectrum was then extracted from the image at each point along the slit in order to measure red and blue shifts from the emission line corresponding to the center of the galaxy. The known emission lines from the HgNekrAr arc lamp spectrum were used to wavelength calibrate the galaxy spectrum. The arc was extracted in the same position in the image as the galaxy in order to have a solution consistent with the galaxy. The arc lines were then fit with a polynomial and the resulting wavelength solution was applied to the non-background subtracted images (that still contained strong OH emission lines from the night sky) to ensure accuracy of the solution. Once this was complete, the solution was applied to the galaxy, generating a final wavelength-calibrated spectrum at each spatial location along the slit corresponding to the extent of the emission line. The rotation curves were measured using a procedure similar to that detailed in Vogt et. al. 1993. Once the fits to the doublet were obtained for each aperture along the slit, a rotation curve for the galaxy was constructed (see e.g the top graph in figure 5). The center of the galaxy was estimated from the position of the continuum (with respect to the emission feature) and the redshift of this emission line was taken as the systemic redhift for the galaxy.

The HIRES data for both Q0827+2421 and Q1038+0625 was reduced using the Mauna Kea Echelle Extraction (makee) program (developed by Tom Barlow) designed specifically for reducing data obtained with the HIRES spectrograph. This is a highly automated package that produces wavelength calibrated spectra from the arc, flat, bias, and object image frames. The reduction details for the remaining three systems can be found in Churchill 1997. The spectra were divided into sections which correspond to the observable transitions. The MgII $\lambda\lambda$ 2796.352,2803.531 transitions were used for comparison with the galaxy due to the strength of these features in the quasar spectra and the fact that these transitions were present in all spectra. The spectra were then centered at the wavelength corresponding to the transition rest wavelength shifted by the systemic redshift of the galaxy thereby showing the relative motion of the gas (probed by the HIRES spectra) with respect to the galaxy (probed by the LRIS rotation curve).

The HST data were reduced by Alice Shapley prior to the beginning of this work. The images were used in order to determine the inclination angle of the galaxy with respect to the plane of the sky (in order to de-project the 3-D galaxy from the 2-D image) and also to determine exactly which regions the absorption features probe with respect to the galaxy. This was essential in determining how the comparison should be interpreted. Using the IRAF task *ellipse*, elliptical isophotes were fit to each galaxy on the HST image. The fitting was done iteratively until an isophote appeared to fit the shape of the galaxy. Since determining the rotation curve for the galaxy depended upon the shifts of the spectral features as a function of radius, it was necessary to know the inclination angle of the galaxy. A galaxy inclined at 90^o to the plane of the sky appears completely "edge-on" in the image. In this case, the galaxy's motion is exactly perpendicular to the plane of the sky and, hence, the slit and the velocity measured (from the doppler shift of the features corresponding to the outer region) is not affected by inclination. If, however, the galaxy is not edge-on, the inclination of the galaxy must be considered when measuring the line shifts. This is all simply determined as follows:

$$\theta_{incl} = \arccos \frac{a}{b}$$

$$V_{true} = \frac{V_{measured}}{\sin \theta_{incl}}$$

Where b is the semi-major axis of the elliptical isophote fit to the galaxy and a is the semi-minor axis. For the purposes of determining the absolute rotational velocity, one must deproject the velocity from the plane of the sky. Since we don't have any geometric information on the gas, however, the comparisons were done in projection in order to maintain consistency between the two data sets.

6 Results

Figures 5-14 summarize the results of this project. The HST images of the fields are presented in figure 5. Subsequent figures show the comparison between the gas absorption and the galaxy emission and are followed by the images for each quasar galaxy pair. Below I have gone over each galaxy in detail. The next section will be devoted to the interpretation and discussion of the results.

6.1 Q1222+228; $z_{gal} = 0.5502$

While this quasar has been studied previously (see Young, Sargent, Boksenberg; Sargent, Boksenberg, Steidel; Steidel, Sargent; Churchill 97 for details), the absorption system associated with this galaxy has not been analyzed. The systemic redshift of the galaxy is $z = 0.5502$ and is nearly edge-on $\theta_{incl} = 75^o$ as seen from the HST images. The allignment of the slit with respect to the galaxy is shown in figure 1. The rotation curve for the galaxy along with the MgII λ3796.352Å transition arising from the gas is shown in figure 5. The two plots are put on the same scale so deviations can be easily seen. The MgII transition from gas associated with the galaxy is the leftmost trough–the other features on the plot arise from different transitions in gas located at higher redshift. From the comparison, it appears that the velocity of the gas is most consistent with the *systemic* motion of the galaxy, however we must consider the HST information before drawing conclusions. We see that the absorption is not saturated, although the line is definitely real. This galaxy is known to be rather faint ($m_{AB} = 22.82$) and from the HST image an impact parameter $D = 21.4h^{-1}kpc$ (this is the second closest "impact" in the sample) . This impact parameter exceeds the radius of the *luminous* stellar disk by a factor of 3. The MgII profile exhibits a range of velocities slightly offset from the systemic velocity of the galaxy with a width of roughly 40 km sec^{-1}.

6.2 Q1148+3842; $z_{gal} = 0.5537$

This galaxy is found to have a systemic redshift of $z = 0.5537$ and is inclined at $\theta_{incl} = 40^o$ to the plane of the sky. Figure 7 reveals a dynamic picture quite different from the previous case. The absorbing gas kinematics indicate that the line of sight is intersecting several different velocity components. The velocity spread is quite large ($120kmsec^{-1}$) and there appear to be several sub-components to the absorption profile all with relatively small velocity each (about $20kmsec^{-1}$). The galaxy lies at an impact parameter of $D = 12.05h^{-1}kpc$ (4.5 times the luminous stellar disk radius). In this case it is important to keep in mind that while the galaxy is not extremely inclined to the plane of the sky, it is not face-on. This must be considered in the interpretations of the profile. It is remarkable that the absorption profile spans a large range of velocities. In this sense, this case seems to suggest that the line of sight is sampling the rotation of the disk (although it does not rule out absorption from the halo). Given the inclination angle of the galaxy, this is interesting in terms of the physical dimensions of the disk. I will discuss this further in the next section.

6.3 Q1317+2743; $z_{gal} = 0.6611$

The galaxy lies at a redshift of $z = 0.6611$ and is inclined at $\theta_{incl} = 58^o$ to the plane of the sky. From figure 9 it is clear that this is a different situation from both of the previous cases. The impact parameter from the QSO to the galaxy is $D = 57.89h^{-1}kpc$ a factor of 20.6 larger than the luminous stellar disk radius. From the rotation curve/gas kinematics relationship, we see that the absorption is arising at a velocity centered at $180kmsec^{-1}$ with a rather narrow profile. There doesn't appear to be several sub-components as in the previous case. It is quite interesting that the absorption profile looks like an of the galaxy rotation curve. It is known that galaxies at low redshift exhibit rotation curves in which they ramp up in the central regions and then flatten out (Rubin, 1980) at large radii. In fact, this has been one of the primary pieces of observational support for idea that a majority of the baryonic matter in the universe is non-luminous. If we assume that, because the impact parameter is so large, the inclination angle is fairly high, and the profile suggests that we may be seeing the disk rotation out at $57.89h^{-1}kpc$, the line of sight is intercepting a tangential component of the rotational velocity, we can compute an enclosed mass for the system. Using the virial theorem, we know that M_r, the mass enclosed at a radius, r, is simply given by:

$$M_r = \frac{V_c^2 * r}{G}$$

Where G is the gravitational constant and V_c is the circular velocity. Carrying this out, one obtains for the mass enclosed ($H_0 = 70km$ sec^{-1} Mpc^{-1})6.2x10^{11} solar masses. This mass is consistent with the masses we see for galaxies at low redshift, which is notable (since this galaxy is at a redshift of 0.6611!).

6.4 Q1038+0625; $z_{gal} = 0.4428$

The systemic redshift of the galaxy was determined to be $z = 0.4428$ and the disk is inclined at $\theta_{incl} = 60^o$ to the plane of the sky. Here we see a similar *kinematic* situation as in Q1317+2743 in the sense that the material seems to be kinematically related to the outer regions of the disk. The impact parameter to the galaxy is $D = 33.6h^{-1}$ kpc which is 8 times as large as the luminous stellar disk. We see a lot of structure within the profile itself (similar to 1148+3842) suggesting either multiple cloud components moving in the halo, or simply differential rotation resulting from the fact that for an inclined disk, the line of sight samples tangential velocity components from gas moving with the disk rotation. The velocity spread in the profile is nearly $150kmsec^{-1}$ and it is important to note that the kinematic spread in the gas seems most correlated with the outer edge of the rotation curve, and thus the line of sight must not sample the entire velocity range present in the disk.

6.5 Q0827+2421; $z_{gal} = 0.5259$

The last galaxy in the sample, Q0827+2421 was found to have a systemic redshift of $z = 0.5259$ and was inclined at $\theta_{incl} = 69^o$ with respect to the plane of the sky. The galaxy is located at $D = 22.6h^{-1}kpc$, a factor of 8 times the luminous stellar disk. This absorption feature is rather saturated as evidenced by the bottoming out of the line. The velocity spread of the profile is interesting in that it seems to span the entire range of motion that we are seeing in the rotation curve from the disk. The seemingly anomalous feature located at $200 km sec^{-1}$ is seen in the HST image as an accreting satellite and corresponds to the location in the slit where the measurement was made. Since the absorption feature is saturated we know that the velocity spread is dominated by the thermal motions of the gas being probed (characterized by the Doppler "b" parameter.) In this case we see a velocity spread of $300 km sec^{-1}$, consistent with the possibility that we are seeing the large range of motions of rotation within a galactic disk.

7 Discussion

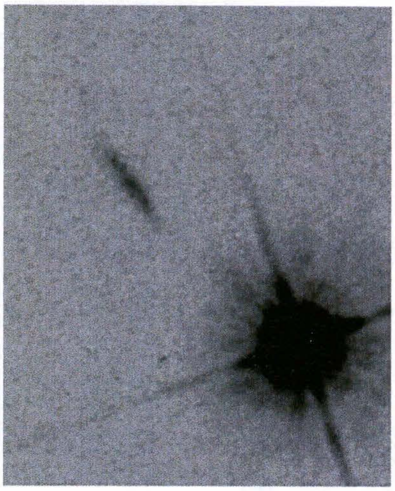
Given that several different models exist that explain the absorption properties of galaxies in distinct physical frameworks, it is interesting to look at the five systems studies in light of some of these models.

In all of the cases observed for this study the gas kinematics were offset (albeit very slightly in the case of 1222+228) from the systemic motion of the galaxy and showed velocity spreads consistent with the line of sight sampling the disk regions of the galaxy. In *all* of the systems observed the region where the kinematics were seen to correlate with the rotation curve corresponded to the region of the rotation curve measured closest to the quasar–closest to the line of sight. In the single case where the gas seemed to be centered at the systemic redshift of the galaxy, it is important to note that the luminosity of the galaxy is the faintest in the entire sample, although no correlations with luminosity were observed.

Galaxy models have been proposed in which the Mg II absorption strength (evidenced by the velocity spread) is inversely proportional to the impact parameter (Lanzetta, 1992; Lanzetta and Bowen 1992). This model has been dubbed the "halo" model, since it suggests that clouds of gas accreting from the halo into the gravitational potential of the galaxy would give rise to absorption and the features of the absorption could be characterized by the impact parameter. This model has been determined as not being quite accurate (SDP, Churchill et. al 1999). These groups observed that no significant correlation between impact parameter and absorption strength could be found. For the largest impact parameter, however, of Q1317+2743, a relatively narrow absorption line was, in fact, observed , the absorption in this case was also observed to be perhaps an extension of the disk rotation at large radii. Given that the galaxy is somewhat edge-on, and the impact parameter is quite large, it is not impossible that this is in fact what is going on. In addition, the weakest absorption was found to arise in an edge-on galaxy with small impact parameter. It therefore seems that the impact parameter alone cannot give us information about the kinematics of the absorbers, although to rule out the halo model would also be inconsistent with observations. Q1317+2743 is a very interesting case because we are able to calculate a mass at $6.2x10^{11}$ solar masses. This is interesting from the evolutionary standpoint in terms of these systems as being interpreted as pre-cursors of present day spirals. The implication is then that the virialized mass is not substantially changing from z=.6611 to the present. Along these lines, this observation seems to confirm previous work done in 1982 by Rubin et. al in which they studied NGC 3067 and concluded (from geometric arguments) that absorption gas located in the disk would be kinematically consistent with their determination of the galaxy's rotation curve. This is by and large what is found in this study–the disk kinematics seem to dominate 4 out of the 5 galaxies studied here.

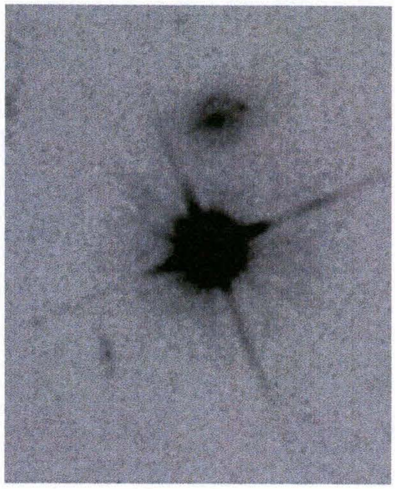
Other modeling work has been done to demonstrate that a halo component (or a disk component) alone could not account for the absorption lines systems (Charlton and Churchill, 1998, Churchil et. al, 1999). In these studies it was shown that, from largely cross-sectional arguments alone, that one had to include disk kinematics in any model of absorption well as halo kinematics. In the systems in this study, we see that randomly moving halo clouds could definitely be contributing to the absorption profiles, however, there seems to be a more systematic trend between the profile and the disk material and that the overal geometry plays an important role. In the case of Q1148+3842 we see a possible evidence that for a disk that is more face on, we see component structure to the profile symmetric about a central component. This is perhaps indicating that the line of sight is going through a thick disk where differential rotation as a function of height in the disk could cause this velocity spread.

With only 5 sight lines, any general claims about Mg II absorbers would be difficult to place on sound statistical footing. Nonetheless, it seems a picture is emerging here which is much more complicated than originally believed. The kinematics of the gas and the disk clearly have some relationship that with more systems could be investigated much more thoroughly. Rather than a simple halo picture of line formation, we are now seeing multiphase and multi-kinematic components. This work provides observational evidence for a non-negligible contribution from galactic disks to absorption. Integrating this information with information about CIV absorption (thought to be associated with halo gas but also kinematically related to Mg II) and other absorption line studies would definitely be avenues to pursue in the future. I, for one, have a lot more thinking to do concerning the nature of these absorbers and their relationship to the galaxy properties.



Q1222+228

D=21.4



Q1148+3842

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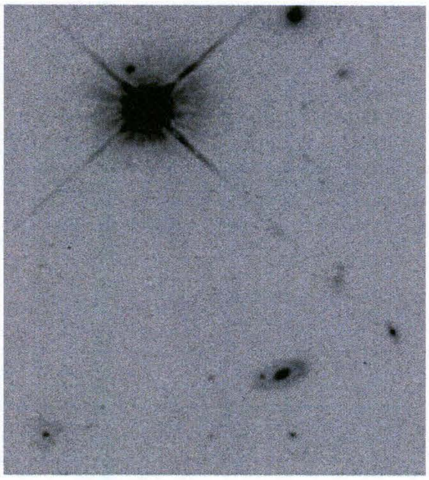
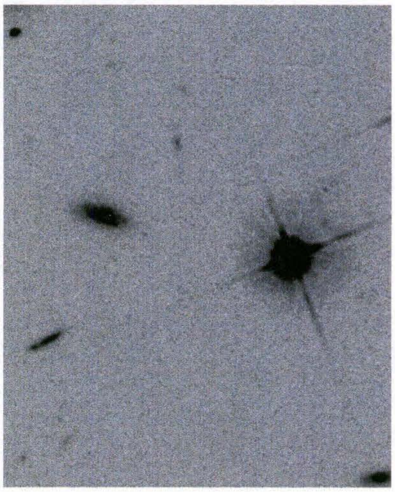


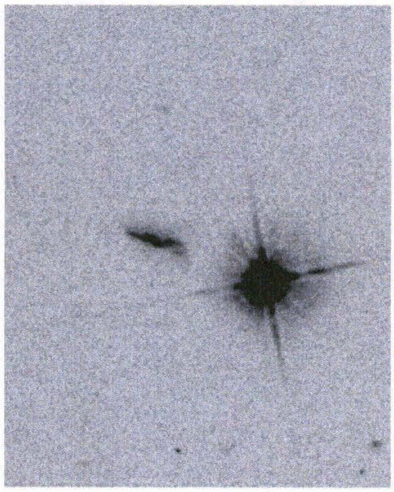
Q1317+2743

D=57.89



Q1038+0625

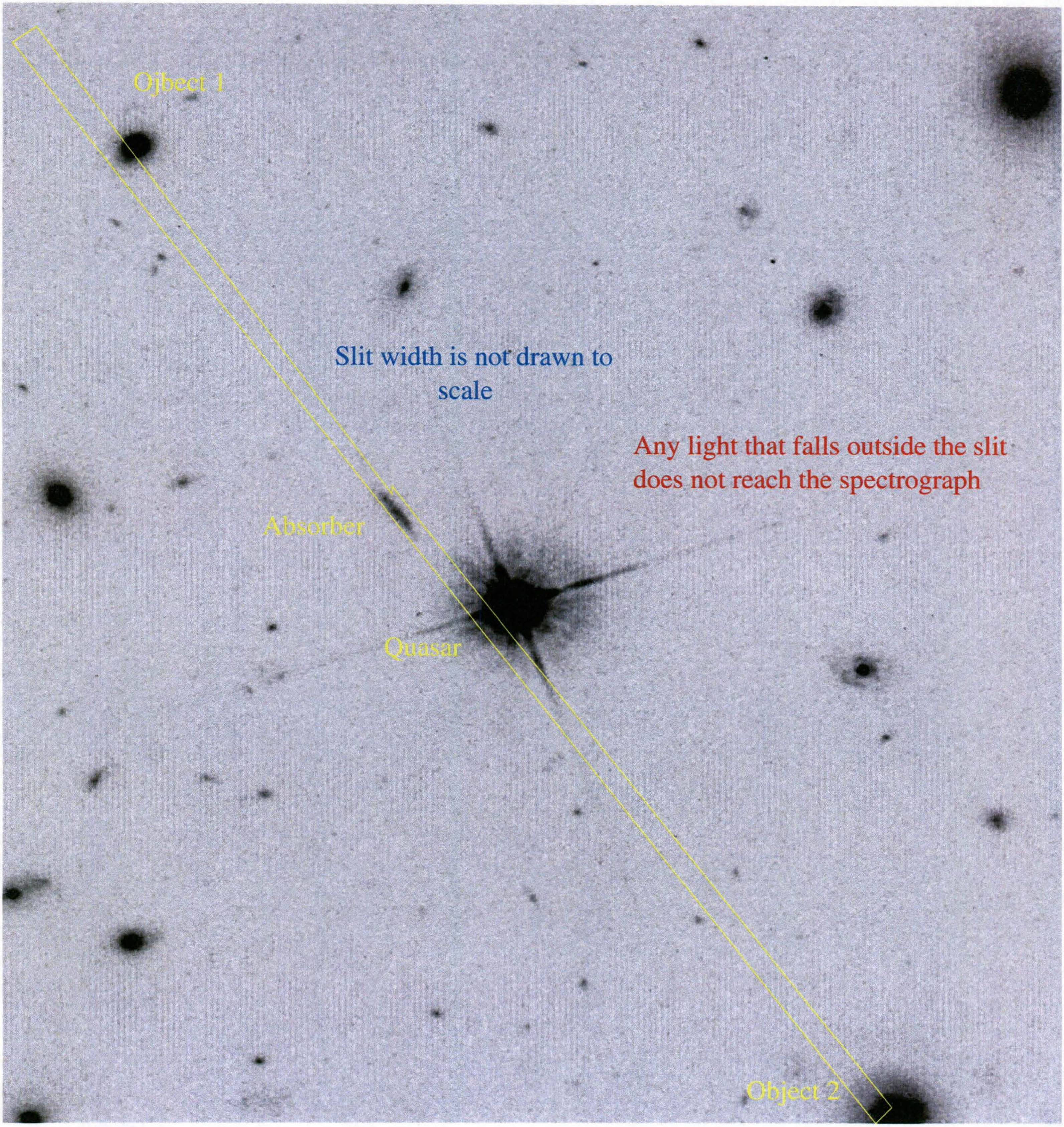
D=33.6

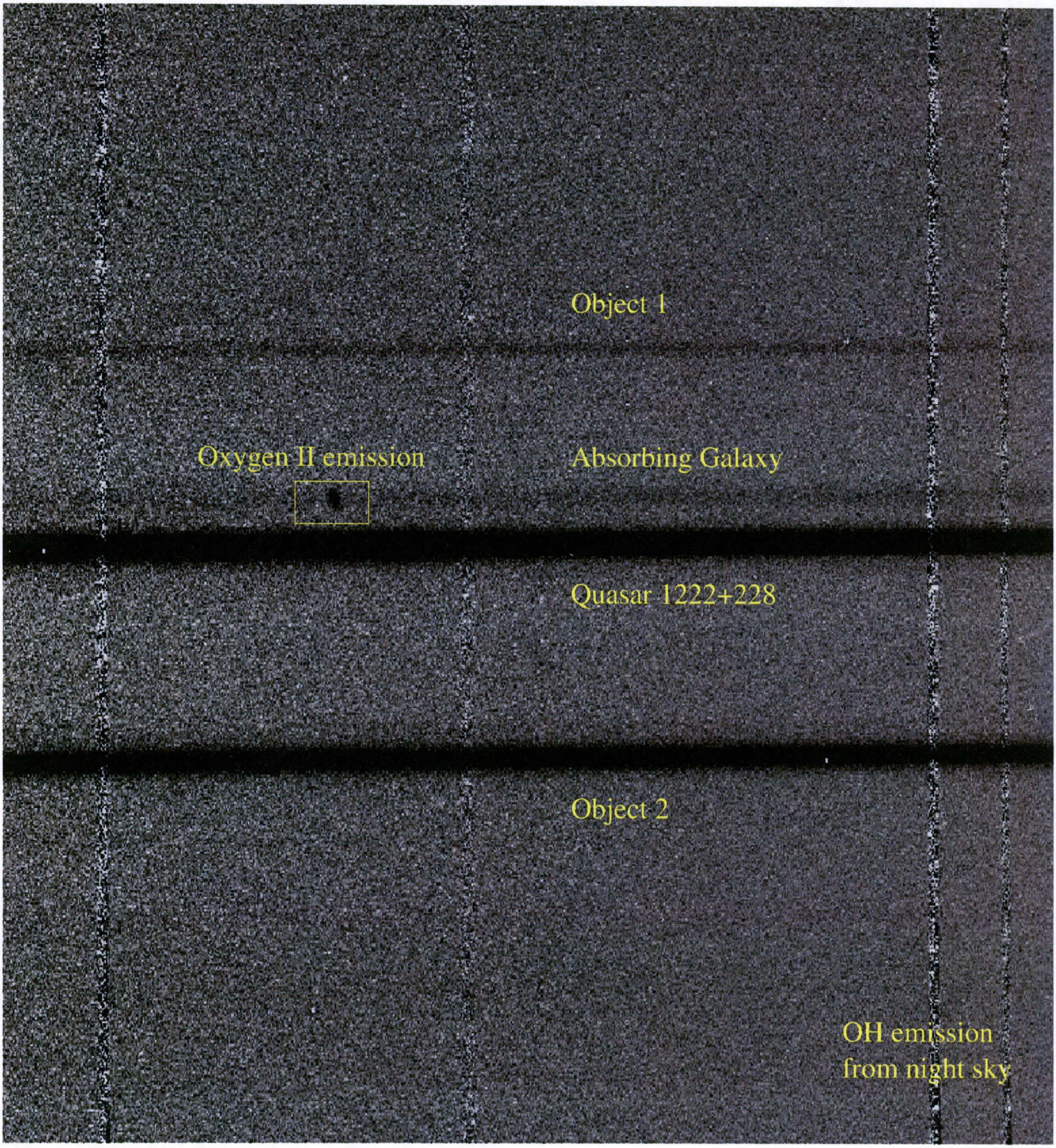


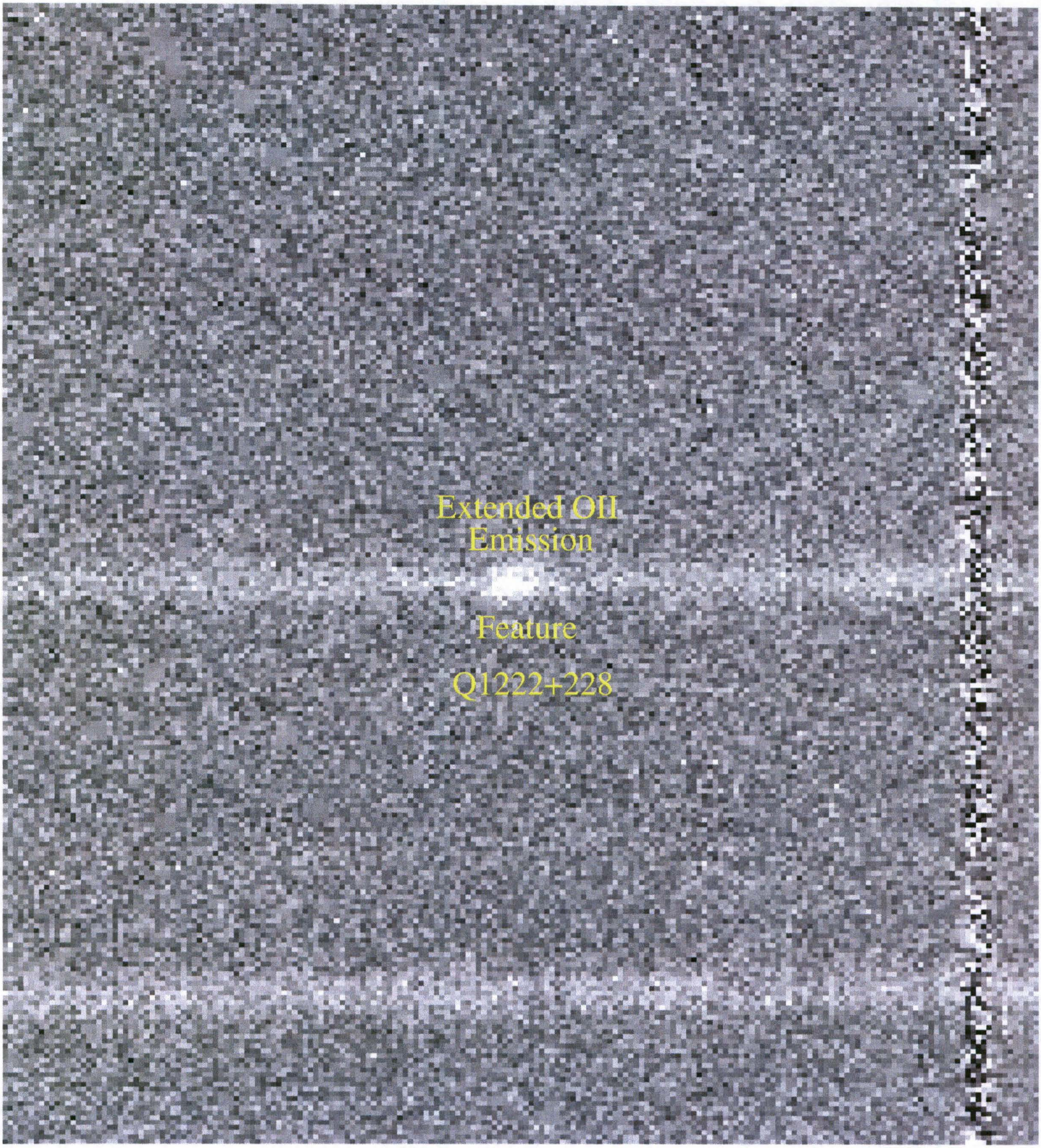
Q0827+2421

D=22.6

D=impact parameter in units of h^{-1} kpc


Ojbect 1
Slit width is not drawn to scale
Any light that falls outside the slit does not reach the spectrograph
Absorber
Quasar
Object 2


Object 1
Oxygen II emission
Absorbing Galaxy
Quasar 1222+228
Object 2
OH emission
from night sky


Extended OII
Emission
Feature
Q1222+228

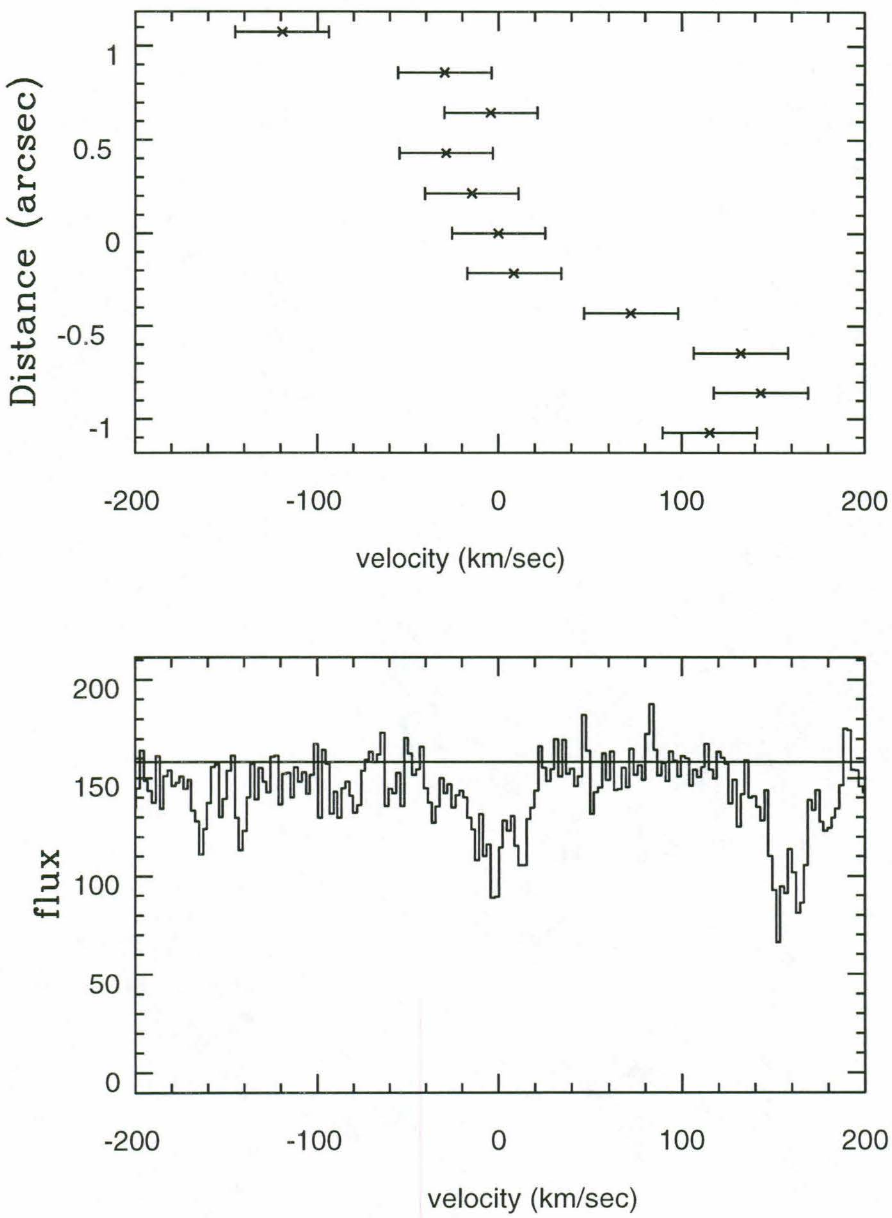
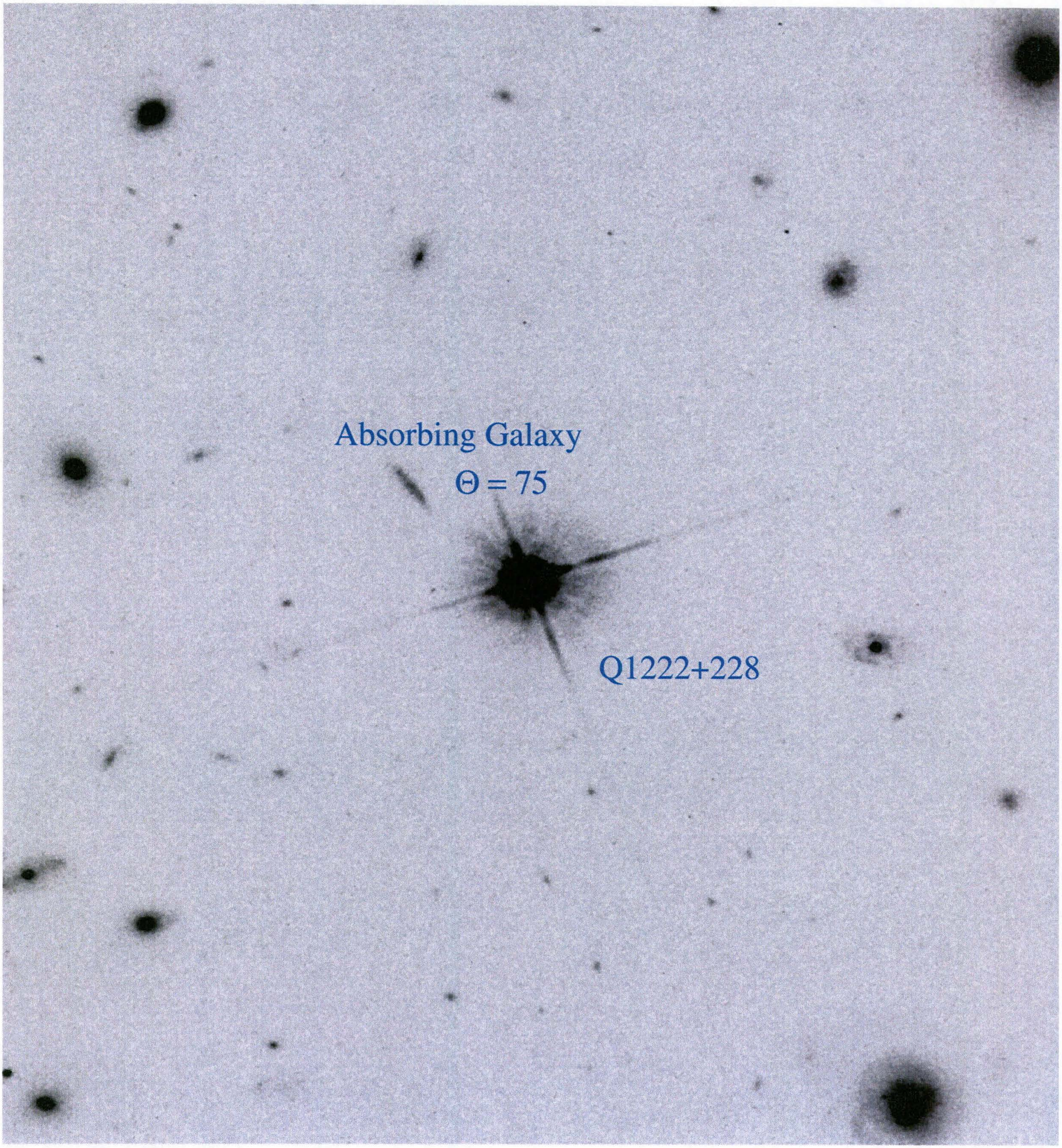


Figure 5: rotation curve for galaxy (upper); HIRES data for gas (lower)
Comparison of Galaxy/Gas kinematics for Q1222+228 absorber


Absorbing Galaxy
Θ = 75
Q1222+228

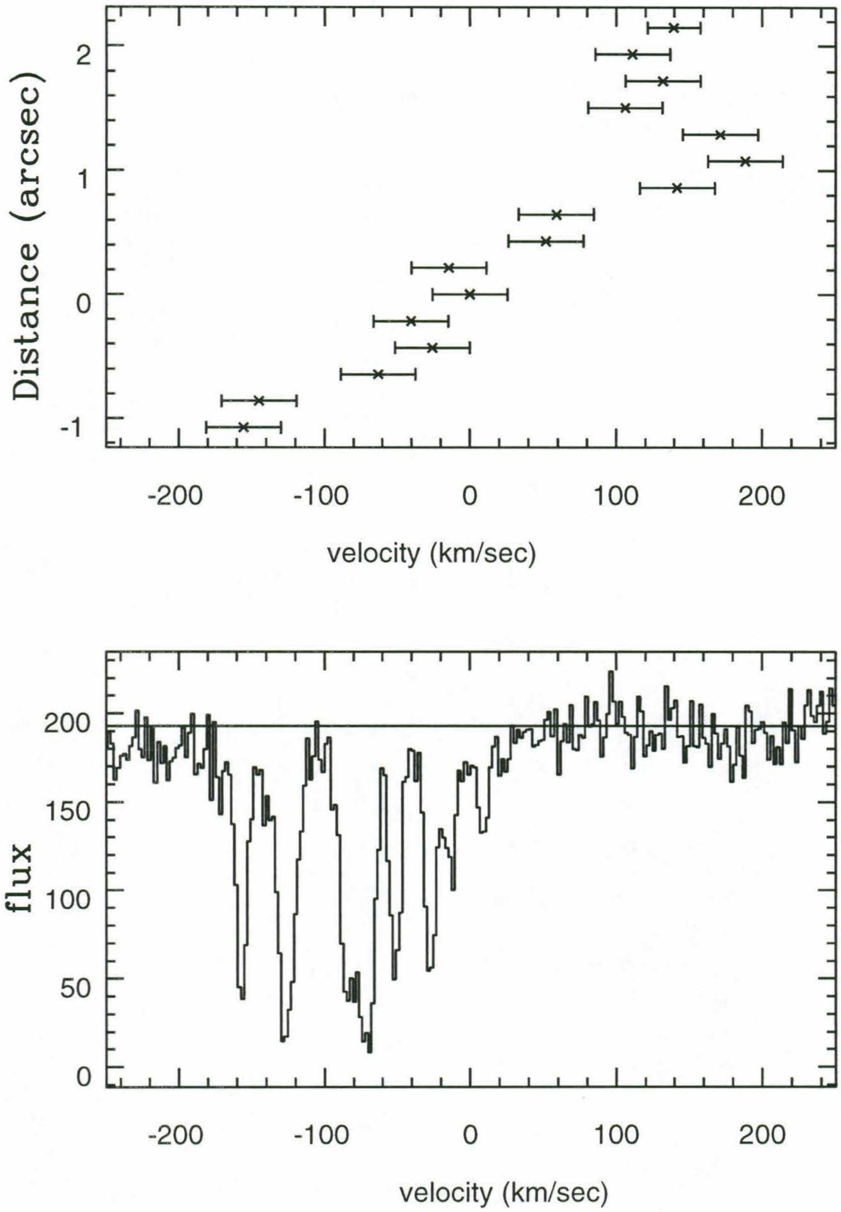
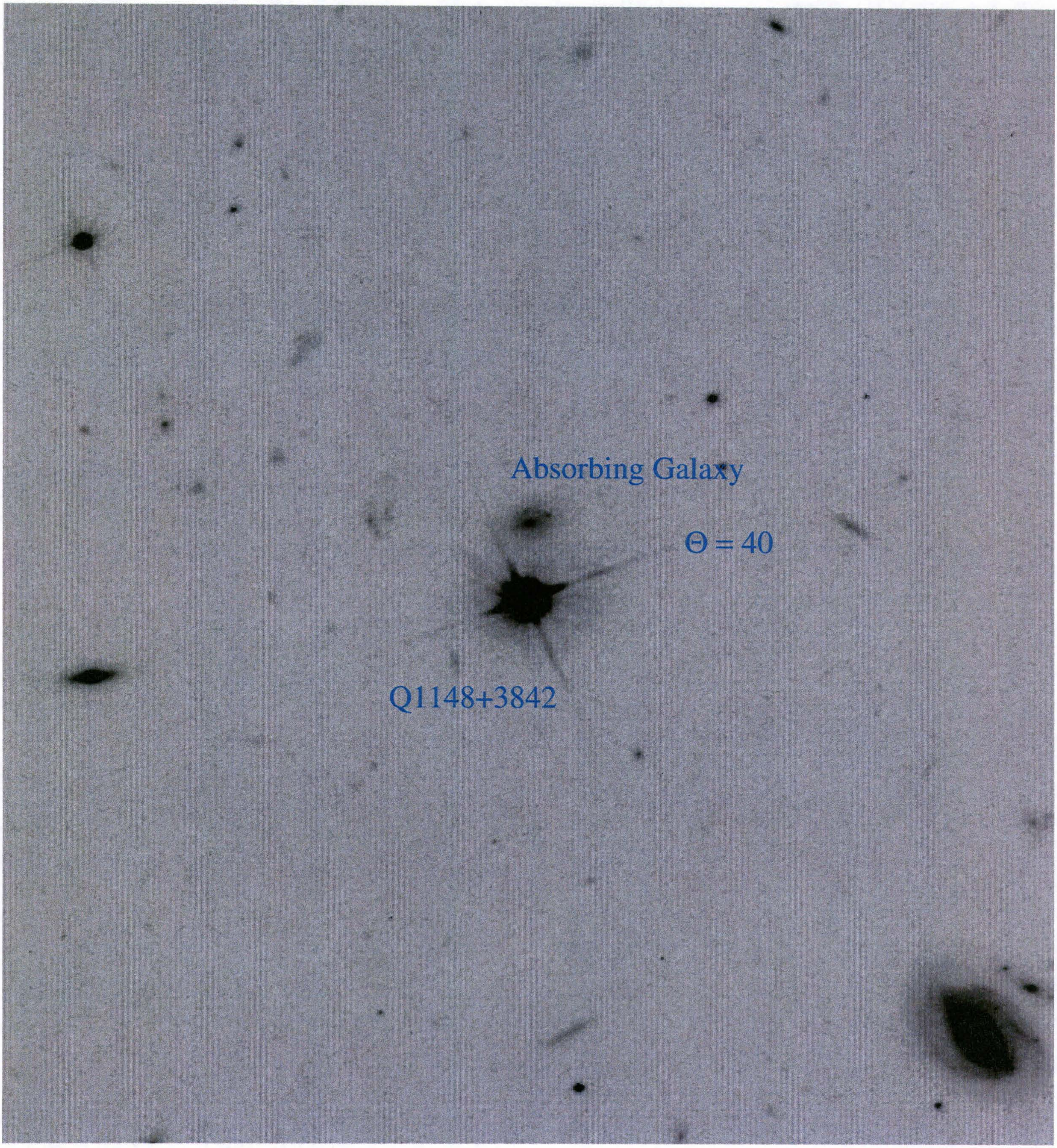


Figure 7: rotation curve for galaxy (upper); HIRES data for gas (lower)
Comparison of Galaxy/Gas kinematics for Q1148+3842 absorber


Absorbing Galaxy
Θ = 40
Q1148+3842

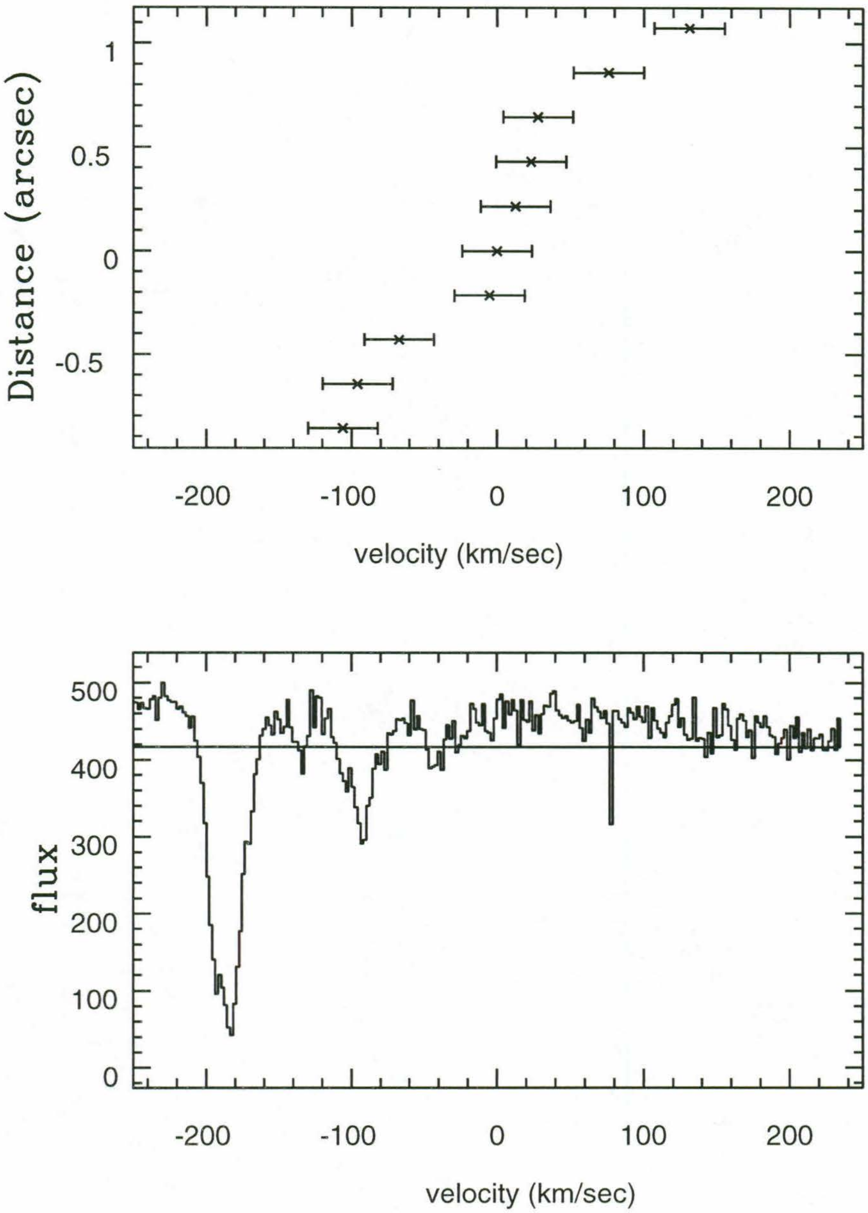
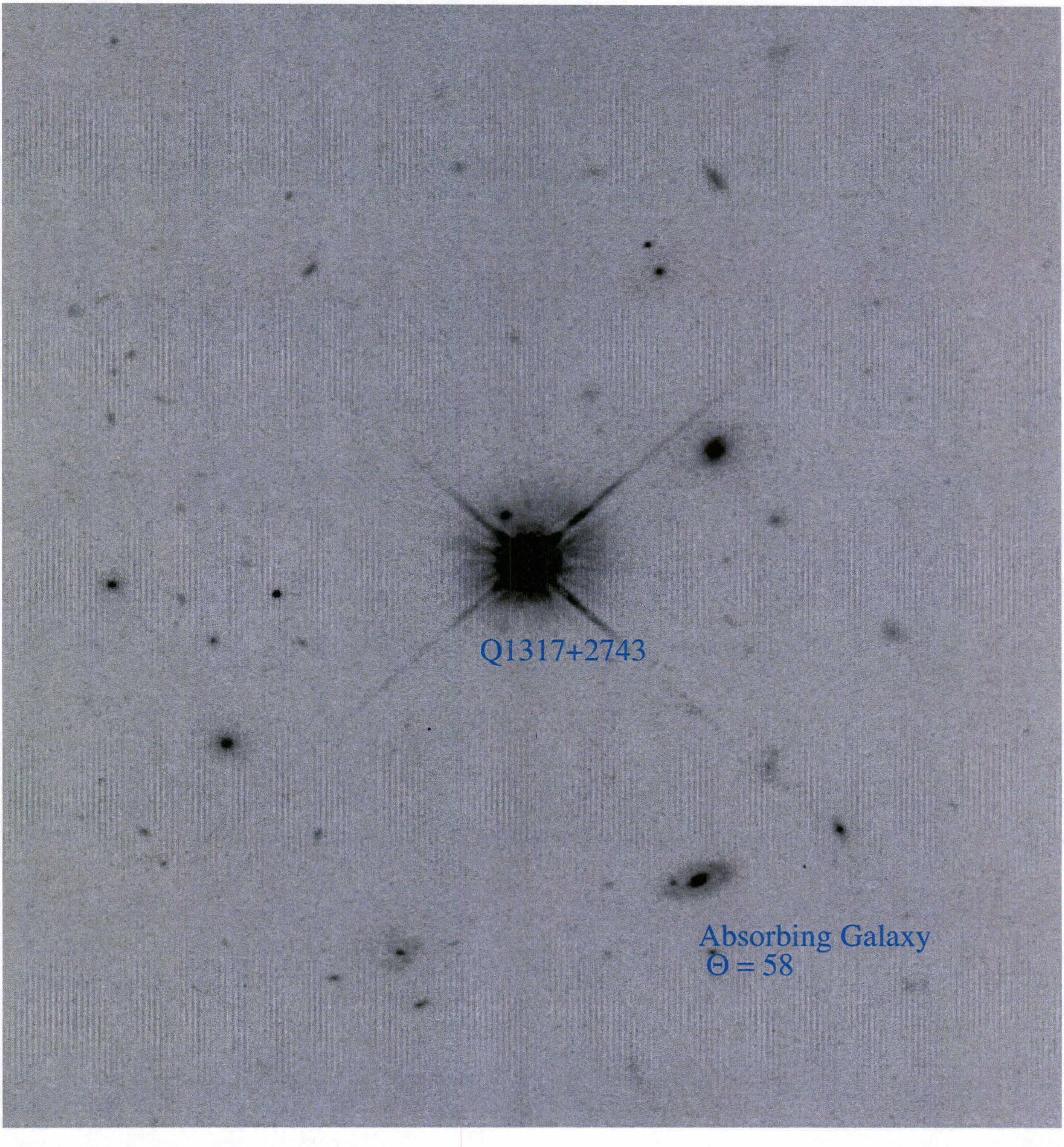


Figure 9: rotation curve for galaxy (upper); HIRES data for gas (lower)
Comparison of Galaxy/Gas kinematics for Q1317+2743 absorber


Q1317+2743
Absorbing Galaxy
Θ = 58

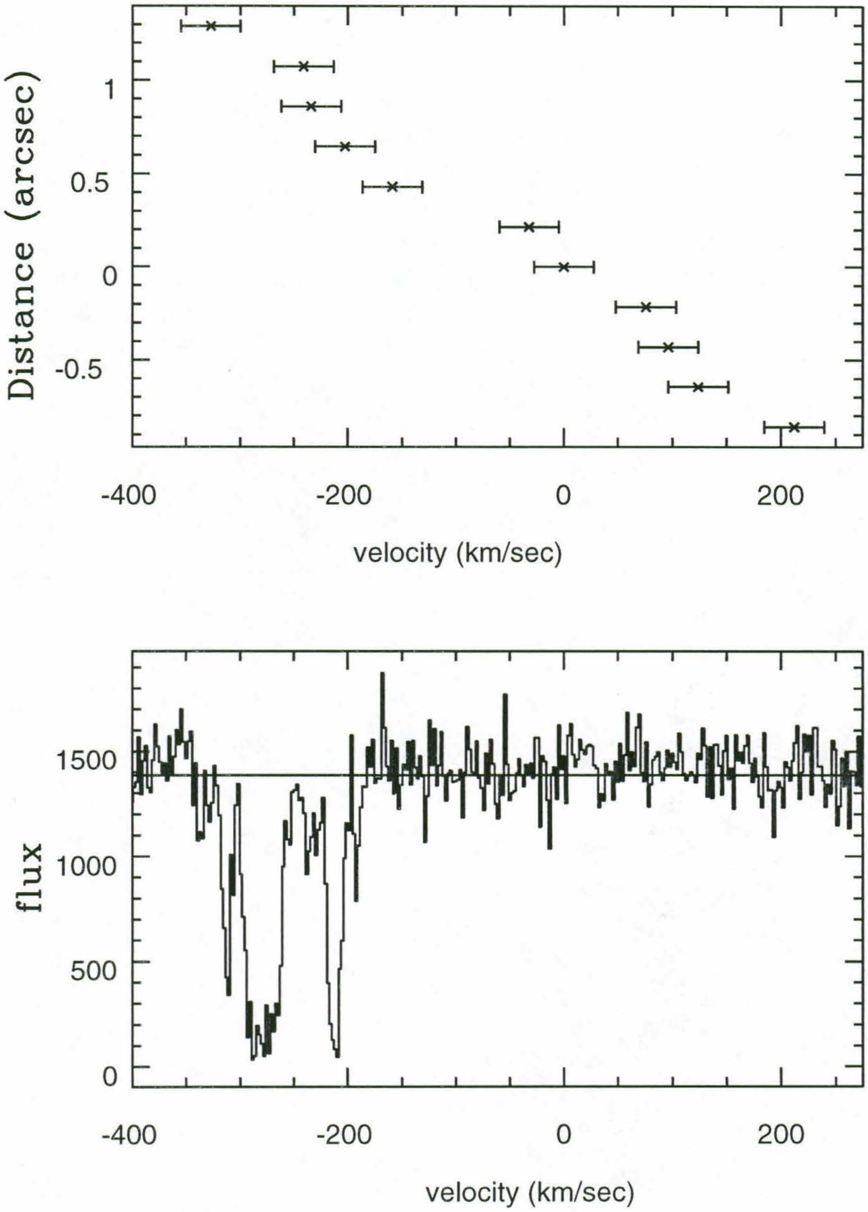
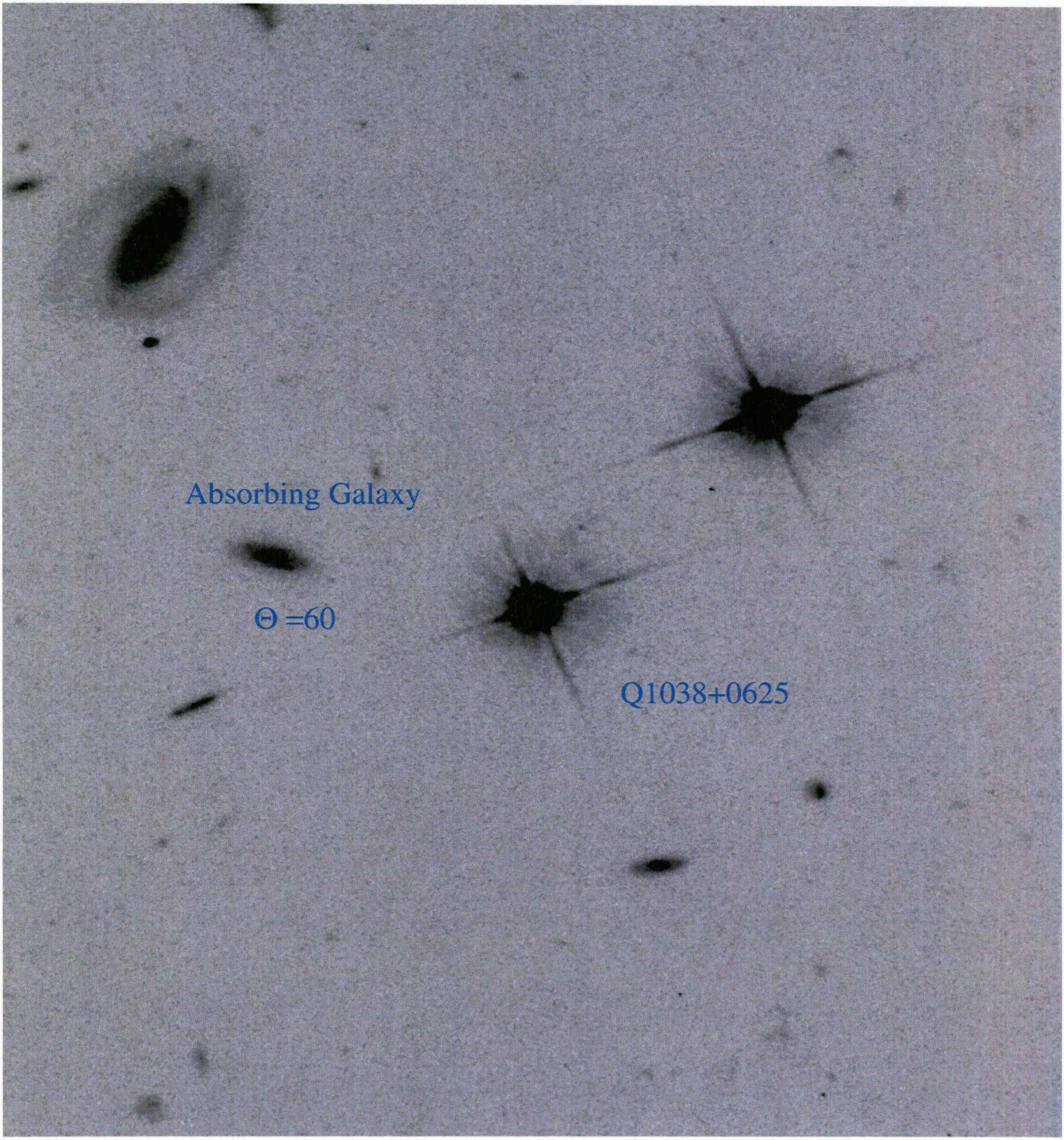


Figure 11: rotation curve for galaxy (upper); HIRES data for gas (lower)
Comparison of Galaxy/Gas kinematics for Q1038+0625 absorber


Absorbing Galaxy
Θ =60
Q1038+0625

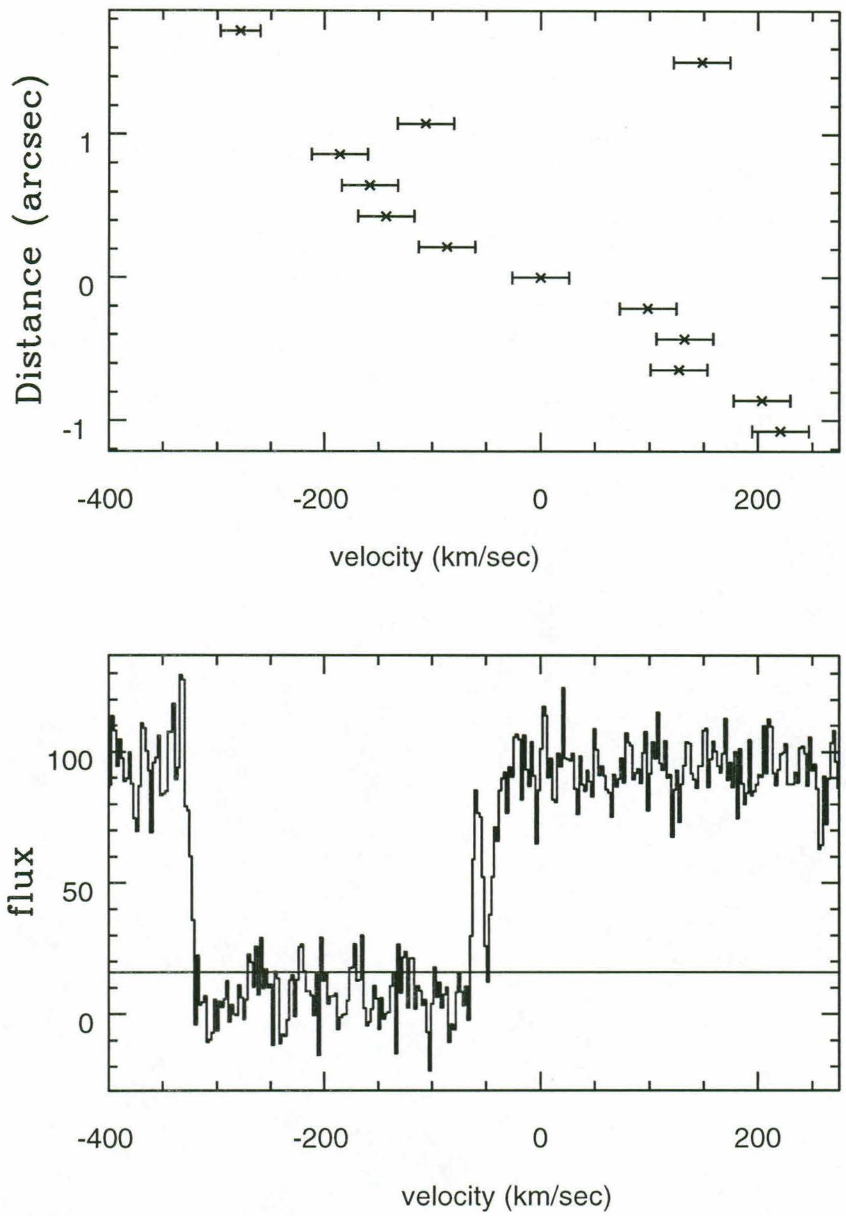
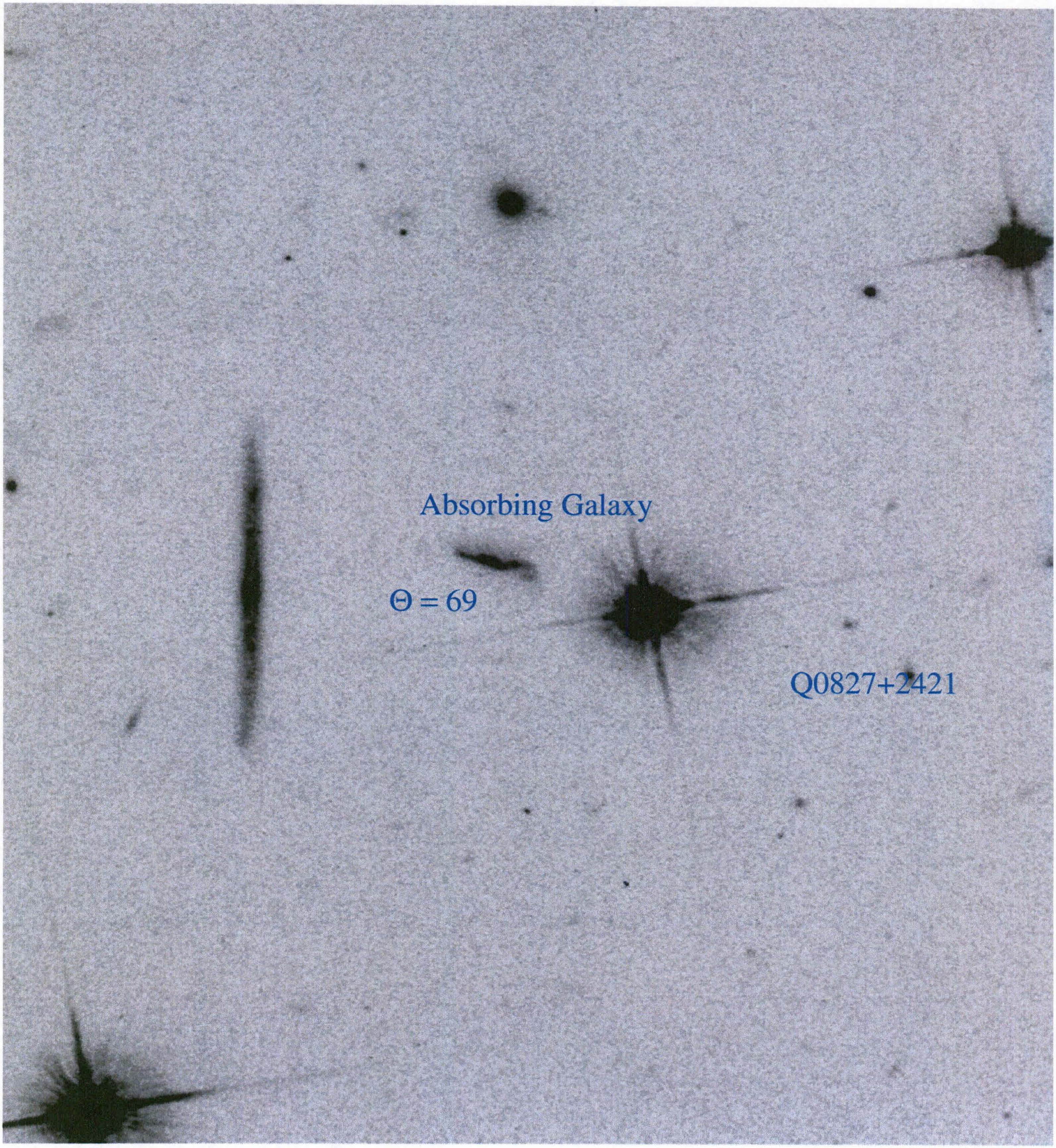


Figure 13: rotation curve for galaxy (upper); HIRES data for gas (lower)
Comparison of Galaxy/Gas kinematics for Q0827+2421 absorber



Absorbing Galaxy
Θ = 69
Q0827+2421

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