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A SPIRAL GALAXY AT $z = 0.366$ WHICH OVERLAPS THE IMAGE OF THE QUASAR 4C 39.47

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ABSTRACT

Direct CCD images in broad-band R and I have been obtained of the radio quasar 1632+391 [4C 39.46, z(emission) = 1.080] as part of an imaging survey of quasars at intermediate redshifts. A large, faint galaxy (FWHM = 4″, $R = 19.7$) was identified which clearly overlaps the quasar's image. This galaxy is centered 4″.2 east of the quasar, corresponding to 28 kpc at the galaxy's redshift ($H = 50$, $q = 0$). Detailed fits to the galaxy's luminosity profile demonstrated that it is a disk-dominated late-type spiral with an absolute B magnitude, −21.6, comparable to those of nearby Sc I galaxies such as M101. Low-dispersion spectroscopy of the galaxy yielded a redshift of $z = 0.3662$, based on Ca II H and K absorption and weak [O II] 3727 emission. The galaxy morphology and line emission imply the presence of appreciable interstellar gas in the superposed galaxy. High-dispersion, high signal-to-noise spectroscopy of the quasar would therefore provide an opportunity to study the interstellar medium in an identified galaxy at high redshift. A search for 21 cm absorption due to the galaxy would also be of great interest. Given the large apparent size of the galaxy, more detailed morphological study would be possible using observations from the Hubble Space Telescope.

Subject headings: galaxies: general — galaxies: interstellar matter — galaxies: redshifts — quasars

I. INTRODUCTION

During the past decade, observers have identified at least five instances of absorption systems in quasar spectra due to intervening clouds in low-redshift galaxies (Bowen *et al.* 1987, and references therein). It therefore has been widely assumed that the high-redshift heavy element absorption systems seen in many quasar spectra are due to similar absorption in the halos and disks of intervening galaxies at larger redshifts. This interpretation has been greatly strengthened by recent detection of such galaxies near the lines of sight to approximately 10 quasars showing Mg II absorption (Bergeron 1988; Miller, Goodrich, and Stephens 1987).

Interpretation of intervening absorption systems is complicated by changes with redshift in both line accessibility and the degree of ionization typically seen. Bergeron and Boisse (1984) noted that high-redshift absorption systems in QSOs tend to be highly ionized, "with a predominance of C IV and Si IV over C II and Si II," while *IUE* observations have demonstrated that absorption systems in the Galactic halo show much lower ionization states, a difference first described by Wolfe (1983). More recently, Danly, Blades, and Norman (1987) found that the ionization states and the kinematics of metal line systems in QSOs cannot be reproduced by absorption in the halo and disk of the Milky Way, no matter what line of sight is chosen (see Caulet 1989 for an alternative viewpoint).

Also, Blades *et al.* (1987) present evidence that, in absorption systems of intermediate redshift, Ca II is depleted compared to Mg II. They noted that if such Ca II depletion is common, low-redshift absorption systems ($z < 0.1$) identified from strong Ca II absorption will not be directly comparable, statistically, with intermediate-redshift and high-redshift systems (see also Briggs *et al.* 1985). Furthermore, Bowen *et al.* (1987) presented evidence that the absorbing gas in low-redshift galaxies may be highly clumped. They detected no Ca II absorption in Mrk 205 due to NGC 4319, which is centered only 8 kpc from the line of sight to the QSO, even though, in at least five other QSOs, investigators have detected Ca II absorption from low-redshift galaxies 16–28 kpc from the QSO's line of sight ($H = 50$ km s^{-1} Mpc^{-1}, $q = 0$ is assumed throughout this *Letter*).

Because of these considerations, unbiased optical identification of galaxies at intermediate to large redshifts superposed on higher redshift QSOs is particularly important, to determine the absorption characteristics of intermediate-redshift galaxies which have *not* been preferentially chosen for their strong absorption.

II. OBSERVATIONS

As part of an imaging survey of radio-loud QSOs with intermediate redshifts ($0.9 < z < 1.5$; Hintzen, Romanishin, and Valdes 1988), direct observations of the 1632+391 field in Mould R and I filters were obtained on 1987 May 3, using a TI

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800 × 800 CCD at prime focus on the KPNO 4 m telescope. The integrations totalled 640 s in each filter. After bias subtraction, division by normalized flat fields, and removal of fringing in the I band, the images were analyzed using the FOCAS object detection and photometry software (Valdes 1982). The photometric zero points were set to the Cousins system using observations of M92 (Christian *et al.* 1985).

Our 3.9 arcmin^2 I-band image of the 1632+391 field is reproduced in Figure 1 (Plate L1). The faintest objects visible have total magnitudes $I = 22.6$–22.8. For the quasar, which is identified by tick marks at the borders, we derived FWHM = 0''.9, $R = 17.99$, and $(R-I) = +0.27$. For the large galaxy 4''.2 east of the quasar, we find FWHM = 4'' (in both R and I), $R = 19.66$, and $(R-I) = +0.61$, where the flux has been measured to the limit of detection at a radius of 4''.5. It is evident from both Figure 1 and the FOCAS detection isophotes that the outer regions of the galaxy overlap the quasar image.

Spectra of the QSO and overlapping galaxy have been obtained using the Multiple Mirror Telescope (MTT) and MMT Spectrograph. A 10 minute integration on the QSO followed by a 1 hr integration centered on the position of the galaxy were obtained on 1988 May 10 (UT) using the blue channel of the spectrograph equipped with an intensified photon-counting Reticon detector. The observations were obtained through 2'' × 3'' apertures and covered the wavelength range from 3200 to 7400 Å at 12 Å resolution (FWHM). These observations resulted in a good spectrum of the QSO (peak $S/N = 12$) which confirmed the presence of C III] 1909 and Mg II 2796 emission at $z = 1.080$ but provided only a weak continuum detection for the adjacent galaxy. Long-slit observations were obtained on 1988 May 26 (UT), using the recently completed red channel of the spectrograph with TI 800 × 800 detector. Two 30 minute integrations were obtained through a 1''.5 × 3'' long slit, yielding spectral coverage extending from 4200 Å to 7100 Å at about 10 Å resolution. The slit was aligned to obtain spectra of the QSO and the galaxy simultaneously. The resulting spectrum of the QSO, reproduced in Figure 2*a*, has strong Mg II emission at a heliocentric redshift of $z = 1.080$. The spectrum of the adjacent galaxy, reproduced in Figure 2*b*, shows apparent Ca II H and K absorption and probable [O II] 3727 emission at heliocentric redshift $z = 0.3662 \pm 0.0007$, where the error quoted is the rms dispersion of the measurements for the three lines. All three features appear in both integrations.

Spectra were also obtained in 1988 June using the Cryogenic Camera at the KPNO 4 m. Exposures totalling 30 minutes were obtained covering 5300–6800 Å with resolution near 15 Å, using a 2''.5 slit. These data show apparent Ca II lines at $z = 0.366$ in the foreground galaxy, confirming the MMT measurements; [O II] 3727 Å is in a region of the spectrum dominated by defocused QSO light and is thus not seen. In the quasar spectra, both MMT and KPNO, Ca II K absorption at $z = 0.366$ has an equivalent width no greater than 0.7 Å in the galaxy's rest frame.

III. DISCUSSION

The excellent seeing in our direct observations allowed a reasonably secure morphological classification for the intervening galaxy, based on its luminosity profile. The first step in analyzing the galaxy image was to subtract off the image of the quasar, using nearby stars to generate a point-spread function. The galaxy image has an axial ratio of 0.8, and its profile can be traced to at least a radius of 4''.5. The observed R profile is shown in Figure 3. This profile, and the very similar I profile, were analyzed and fitted to a variety of standard galaxies using the image modeling program developed by W. R. (see Smith *et al.* 1986 for details). The best model galaxy fit in both R and I is a pure exponential disk (the equivalent of a very late spiral) with a disk scale length of 1''.3 ± 0''.15 (9 ± 1 kpc). This fit is shown as a solid line in Figure 3. (The profile changes slope at radius 3''.6, so the fitting was done only within that radius. Such a falloff below an extrapolated disk is a common feature of the profiles of nearby spiral galaxies.) The fit is marginally improved by the addition of an unresolved component with a luminosity of a few percent of the disk luminosity. This component probably represents the bulge of the galaxy. Even an Sb spiral model, with bulge luminosity 23% of the disk luminosity, gives an unacceptable fit. To demonstrate the reliability of our classification, we show in Figure 3 the profile for an E galaxy (*short dashes*), with size scale appropriate to the galaxy luminosity, and the "best-fit" Sb spiral (*long dashes*). Both models give unacceptable profile shapes and are formally excluded at an extremely high level of confidence.

Thus, the luminosity profile shows that the galaxy is a disk-dominated, late-type spiral. Additional support for this conclusion comes from the color: the expected $(R-I)$ color of an Scd spiral at $z = 0.37$ is 0.55, close to the observed 0.61, while an E galaxy would have $(R-I) = 0.85$ (Romanishin 1989). Assuming the K-correction and intrinsic color for an Scd galaxy, the galaxy has $M(B) = -21.6$, similar to nearby giant Sc I galaxies such as M101 and NGC 4321.

The 1632+391 system therefore provides an excellent opportunity to study the gaseous components of a spiral galaxy at $z = 0.3662$ via its absorption superposed on the quasar spectrum. The 4''.2 separation observed implies that the center of the superposed galaxy lies only 28 kpc from the line of sight to the QSO ($H = 50$ km s^{-1} Mpc^{-1}, $q = 0$), comparable to the offset seen in 4C 55.27 (Miller, Goodrich, and Stephens 1987) and less than half the offset seen in PKS 2128−12 (Bergeron 1986). Both of the latter QSOs show strong Mg II absorption at $z = 0.4$–0.5. While high-dispersion, high S/N data are needed for a definitive search for and study of such systems, we have used our low-dispersion spectra in a preliminary search of the spectrum of 1632+391 for evidence of intervening absorption from the galaxy at $z = 0.3662$.

From the MMT red channel data we found that Ca II H and K each have rest frame equivalent widths $W < 0.7$ Å, a result confirmed by the subsequent KPNO 4 m spectra. From the MMT blue channel data, Mg II 2796 Å and 2803 Å each have $W < 1.1$ Å (3 σ upper limits). The Ca II upper limits are too high to detect H and K absorption typical of the Galactic halo (80–400 mÅ; Morton and Blades 1986) or even most known cases of H and K absorption due to low-redshift disk galaxies ($W = 0.3$–0.9 Å; Bowen *et al.* 1987). The intermediate-redshift Ca II absorption systems ($0.3 < z$[absorption] < 1.0) identified in quasars to data tend to be weaker yet, with 0.1 Å $< W <$ 0.4 Å for the Ca II K line (Blades *et al.* 1987, Table 2). On the other hand, our Mg II upper limits are comparable to typical equivalent widths in known absorption line systems in QSOs: The rest frame equivalent widths of the Mg II 2796 Å lines in systems listed in Table 3 of Bergeron and Boisse (1984) range from 0.2 Å to 4.7 Å, with a mean of 1.2 Å. These absorption systems have redshifts ranging from 0.4 to 1.8. Given the brightness of 1632+391, spectroscopy at much higher dispersion is quite feasible and the *a priori* identification of the superposed galaxy renders such spectroscopy particularly

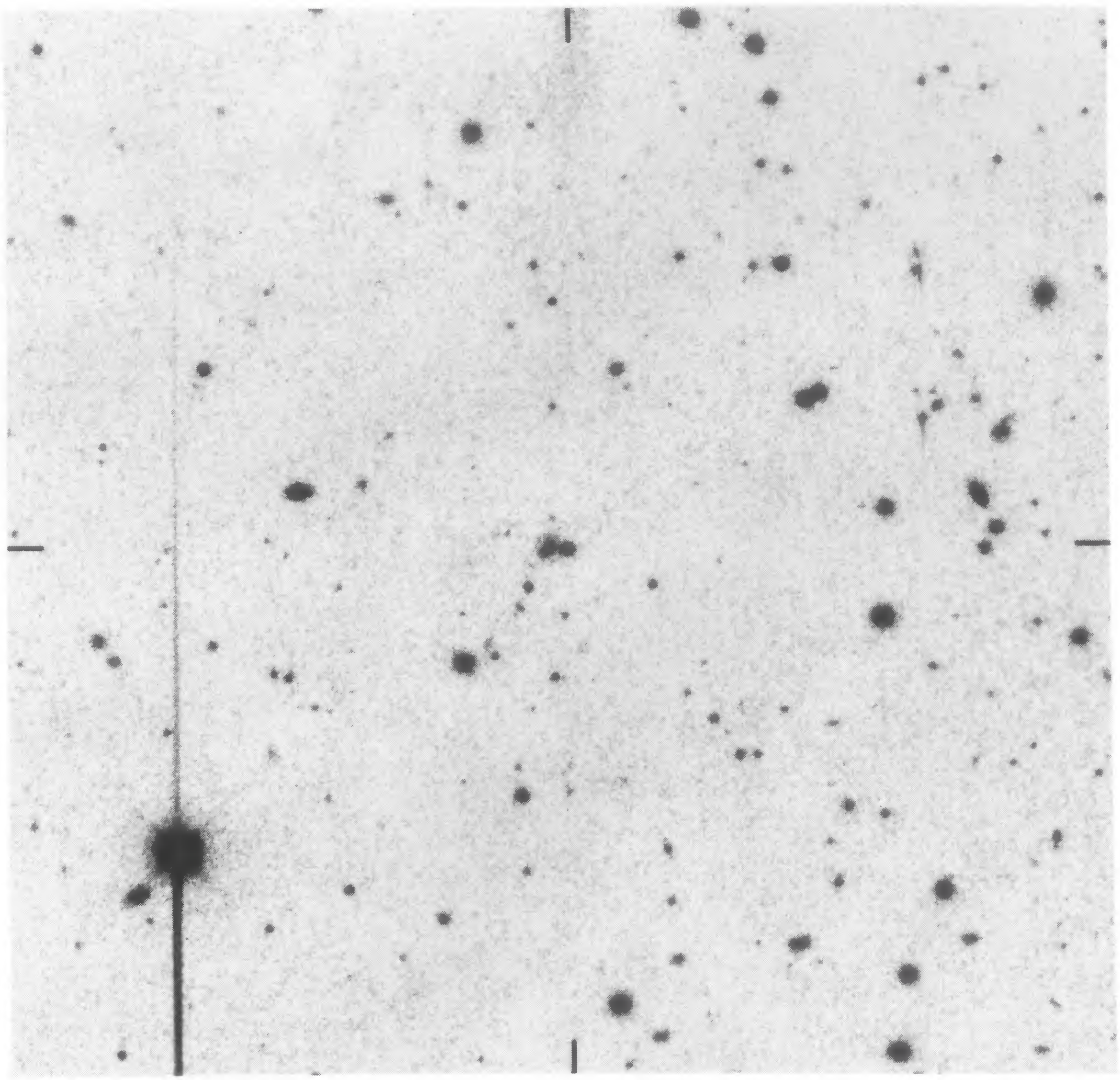

FIG. 1.—The 1632+391 field in the *I* passband. This 640 s integration with a TI 800 × 800 CCD was obtained at the prime focus of the KPNO 4 m telescope in 0".9 seeing. The area shown is 3.9 arcmin^2. East is to the left, north is to the top, and the QSO is identified by tick marks in the margin. The faintest objects definitely detected have total magnitudes $I = 22.6$–22.8.

HINTZEN *et al.* (*see* **337**, L6)

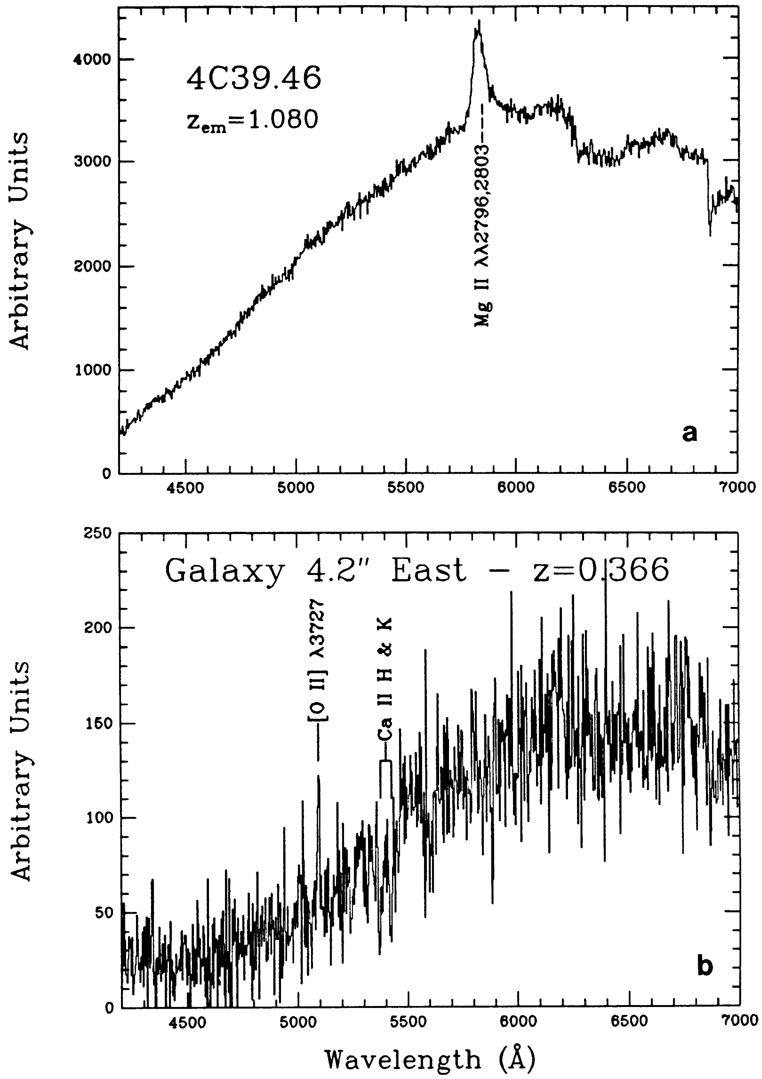

FIG. 2.—Spectra of the quasar and the overlapping galaxy, from observations with the red channel of the MMT spectrograph at 10 Å resolution. (*a*) The spectrum of the QSO. (*b*) The spectrum of the overlapping foreground spiral galaxy.

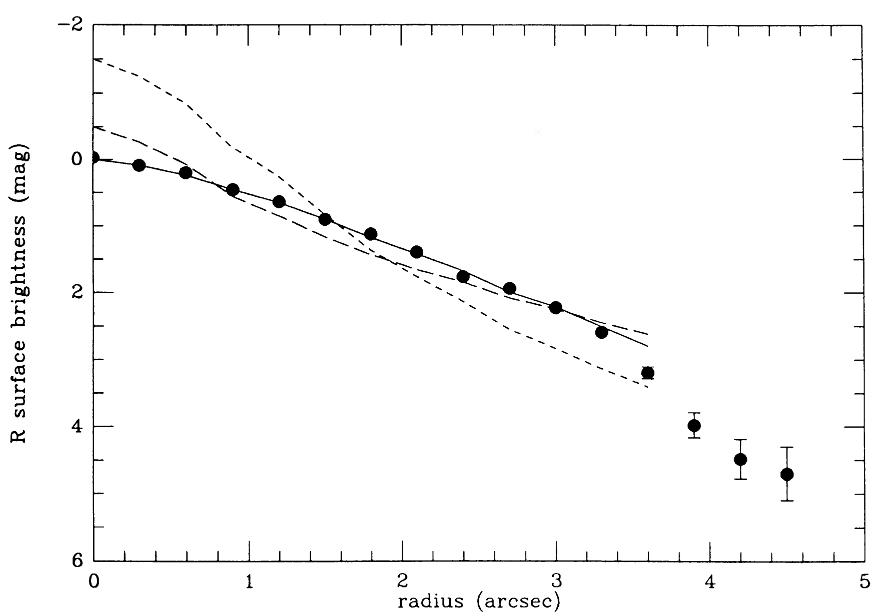

FIG. 3.—The observed luminosity profile derived from our direct *R* imaging for the foreground galaxy overlapping 1632+391 is plotted as filled circles. Error bars are plotted when they are larger than the circles. The solid line is the best-fit disk galaxy (Scd), with a scale length of 1".3. The short-dashed line is the profile for an E galaxy, and the long-dashed line is the profile for an Sb galaxy.

important. Both Mg II 2796, 2803 Å and Ca II H and K absorption from the galaxy would appear in the visible. Since the QSO is a strong radio point source (Potash and Wardle 1979), a search for 21 cm absorption from the spiral galaxy should also prove fruitful. The comparatively large angular size of the galaxy also provides the opportunity for more detailed morphological studies using the Hubble Space Telescope.

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