IS THE OPTICALLY UNIDENTIFIED RADIO SOURCE FIRST J121839.7+295325 A DARK LENSC
R. E. Ryan, Jr., S. H. Cohen, R. A. Windhorst, C. R. Keeton, and T. J. Veach
Received 2008 January 30; accepted 2008 July 21

ABSTRACT
We present evidence that the optically unidentified radio source FIRST J121839.7+295325 may be strongly lensing a background galaxy. We estimate the redshift of the assumed gravitational arc, discovered in parallel imaging with HST, from MMT-Blue Channel spectroscopy to be $\zeta_{\text{arc}} = 2.48^{+0.14}_{-0.05}$. We present lens models with an Einstein radius of $R_{E} = 1.3''$ which contains a mass of $M_{\text{dyn}} = 10^{12.0 \pm 0.5} M_{\odot}$, where the uncertainty reflects the range of possible lens redshifts. The putative lens is not detected to $J_{\text{lim}} = 22.0$ mag and $H_{\text{lim}} = 20.7$ mag in our MMT-SWIRC imaging. Using the flux limits from WFPC2 and SWIRC, we estimate that the dynamical mass-to-light ratio of J121839.7+295325 is $M_{\text{dyn}}/L_{B} \approx 10 M_{\odot} L_{\odot}^{-1}$ for $A_{V} = 1$ mag, and this lower limit could be as high as $30 M_{\odot} L_{\odot}^{-1}$ for $A_{V} = 0$ mag. Since the radio source is optically unidentified ($V_{\text{lim}} = 25.5$ mag) and has a radio flux of $S_{1.4 \text{GHz}} = 33$ mJy, it is likely a massive early-type galaxy which hosts a radio-loud AGN at $0.8 \lesssim z_{\text{radio}} \lesssim 1.5$. However, the present data cannot uniquely determine the mass-to-light ratio of the lensing galaxy, and hence the possibility that this system may be a reasonably dark lens is not ruled out.

Subject headings: dark matter — galaxies: individual (FIRST J121839.7+295325) — gravitational lensing

1. INTRODUCTION
In the $\Lambda$-dominated, cold dark matter (CDM) cosmology, massive galaxies form hierarchically inside of dark matter halos (e.g., White & Frenk 1991; Kauffmann et al. 1993). The mass evolution of these CDM halos can place stringent constraints on the cosmological models (e.g., Green et al. 2002), and the most reliable measurements of CDM halo masses are generally derived from modeling gravitationally lensed images. Furthermore, gravitational lensing has become a powerful tool for studying properties of both the lensing objects and the more distant sources. Of particular interest are constraints on the mass profiles (e.g., Koopmans et al. 2006; More et al. 2008) and the mass-to-light ratios (e.g., Keeton et al. 1998; Rusin & Kochanek 2005; Treu et al. 2006) of lens galaxies, and the host galaxies of active galactic nuclei (e.g., Kochanek et al. 2001; Peng et al. 2006). While all of these studies are advancing due to increased numbers of known lensing systems (Ratnatunga et al. 1999; Lehár et al. 2000; Bolton et al. 2006), they are still limited by relatively small sample sizes.

In this work we report the discovery of an optical arc which is $\sim 4.0''$ southwest of the optically unidentified radio source, FIRST J121839.7+295325. This radio source was discovered in the Faint Images of the Radio Sky at Twenty-centimeters (FIRST) with the Very Large Array (VLA; Becker et al. 1995; White et al. 1997) and later detected at 610 MHz (Rengelink et al. 1997) and 74 MHz (Cohen et al. 2004). Its relatively bright flux of $S_{1.4 \text{GHz}} = 33$ mJy suggests that it is at $z_{\text{radio}} \leq 1.5$ (e.g., de Breuck et al. 2001; Waddington et al. 2001). In addition, J121839.7+295325 was undetected in the pure-parallel observations (PropID: 8090, PI: S. Casertano) with the Wide Field and Planetary Camera 2 (WFPC2) on the Hubble Space Telescope (HST) to F606W $\gtrsim 25.5$ mag ($V$ band hereafter; Russell et al. 2008), which indicates it is likely at $z_{\text{radio}} \approx 0.8$ (e.g., Windhorst et al. 1985; Kron et al. 1985; de Breuck et al. 2002; Windhorst 2003). These two independent constraints yield a coarse redshift estimate of $0.8 \lesssim z_{\text{radio}} \lesssim 1.5$. By correlating the WFPC2 archive with the catalog of FIRST sources, Russell et al. (2008) note an arclike feature with $V_{\text{Vega}} = 24.0 \pm 0.1$ mag. Based on the astrometric uncertainties for the HST/WFPC2 and FIRST imaging, they conclude that the likelihood that this arc is the optical identification of the radio source is $L \lesssim 10^{-10}$, following the work of de Ruiter et al. (1977). Since Russell et al. (2008) rule out the possibility that the arc is the optical identification of J121839.7+295325, we investigate the hypothesis that the optical arc is a gravitationally lensed image by the optically unidentified radio source.

This work is organized as follows: § 2 describes our MMT observations, § 3 outlines the lensing analysis, § 4 discusses the lensing interpretation of these observations, and § 5 gives some closing remarks with thoughts toward possible future observations. Unless explicitly stated, all magnitudes are in the AB system (Oke & Gunn 1983). We adopt the following cosmological model: $\Omega_0 = 0.24$, $\Omega_{\Lambda} = 0.76$, and $H_0 = 100 h$ km s$^{-1}$ Mpc$^{-1}$, where $h = 0.73$ (Spergel et al. 2007).

2. THE MMT OBSERVATIONS
2.1. Blue Channel Spectroscopy
While the radio and optical properties provide a broad redshift constraint on the lensing object of $0.8 \lesssim z_{\text{radio}} \lesssim 1.5$, little is known about the optical arc. Therefore, we observed the putative gravitational arc on 2007 May 18 with the blue-channel spectrograph on the 6.5 m MMT, and obtained $4 \times 2400$ and $1 \times 1200$ s exposures. For these observations, our $1'' \times 180''$ slit tracked through the sky at the parallactic angle, as the object varied in air mass of $\text{sec} z \lesssim 1.17$, which was very closely aligned with the position angle of the arc seen in the left panel of Figure 2. With the 500 grooves mm$^{-1}$ grating, the spectral resolution was 3.6 Å with a dispersion of 1.2 Å pixel$^{-1}$. We observed Feige 34 throughout the night to determine the spatial point-spread function (PSF) and to serve as the spectrophotometric flux standard star.
Since there is no natural way to interpret the arc and knot as a circular lens that produces such a long arc (compared with the radius of curvature) would produce a prominent counterarc as a circular lens that produces such a long arc (compared with the radius of curvature) would produce a prominent counterarc as a lensed image, although it has little visible signal-to-noise per pixel. Therefore, we rebinned the one-dimensional spectrum to a usable level, we resampled the one-dimensional spectrum to the relevant HyperZ fitted parameters.

The two-dimensional spectra were reduced by standard algorithms using custom routines in IDL. The CCD read noise, gain, and dark rate were consistent with the K-band flux (e.g., Bolzonella et al. 2000), we can only make statistical inferences: the Balmer/4000 excitations: the Balmer/4000 relative probability, which indicates two possible redshift solutions, a weak spectral break is identifiable at \( \lambda = 8500 \) Å.

Since a weak spectral break is readily apparent at \( z \sim 4300 \) Å with no other noticeable spectral features, we determine the redshift from the photometric signal-to-noise ratio. The one-dimensional spectrum was extracted from a given frame using the observed PSF as weights in both axes. Finally, the wavelength solution for each frame was determined from an HgNeAr comparison lamp, which was observed at the corresponding position on the sky.

Despite the long integration time (3 hr) on the arc, the total signal-to-noise ratio per pixel is relatively low. Therefore, we rebinned the calibrated, sky-subtracted, and stacked spectrum to \( \Delta \lambda = 125 \) Å for \( \lambda < 5400 \) Å and \( \Delta \lambda = 375 \) Å for \( \lambda > 5400 \) Å. At this resolution, a weak spectral break is identifiable at \( \lambda \sim 4300 \) Å, however we cannot conclusively determine whether it is the Lyman break \( \lambda_{\text{LyC}} = 1216 \) Å or the Balmer/4000 break. Therefore, to determine the most likely redshift with its associated uncertainty and relative probability, we computed a spectrophotometric redshift (e.g., Ryan et al. 2007) with the redshift code, HyperZ (Bolzonella et al. 2000). We did not include the \( V \)-band flux in the fit, since the MMT slit did not fully encompass the arc.

In Figure 1, we show the observed spectrum as filled points with the best-fit template as a solid line. In the inset, we show the relative probability, which indicates two possible redshift solutions: the Balmer/4000 break at \( z \sim 0.13 \) or the Lyman break at \( z \sim 2.5 \). If the arclike object is at \( z \sim 0.13 \), then it is likely an unrelated foreground galaxy to J121839.7+295325 with \( M_V = -14 \) mag. However, if it is at the higher redshift, then the observed arc morphology in the \( HST^7 \) WFPC2 imaging suggests that J121839.7+295325 may be gravitationally lensing a background source. Without a flux measurement blueward of the blue channel spectrum (\( \lambda_{\text{obs}} \leq 3800 \) Å) to break this redshift degeneracy (e.g., Bolzonella et al. 2000), we can only make statistical inferences regarding the redshift of the arc and the physical interpretations of the system. From the inset in Figure 1, the integrated probabilities of the two peaks are 13% and 87% for the Balmer/4000 Å and Lyman breaks, respectively. Since the Lyman break redshift is \( \sim 6.7 \) times more likely, we will further develop the lensing hypothesis. The best-fit template found by HyperZ has an age of \( t = 11.5 \) Myr, instantaneous burst with \( M_V = 1.2 \) mag, which is similar to the Lyman break galaxies at \( z < 3.5 \) (Papovich et al. 2001). Therefore the most likely redshift of arc is \( z = 2.48^{+0.14}_{-0.05} \), which we derive from \( \chi^2(z) = \min [\chi^2(z)] \) and \( \Delta \chi^2(z) = 1 \).

### 2.2. SWIRC Infrared Imaging

We observed J121839.7+295325 with the SAO Wide-field InfraRed Camera (SWIRC) on 2008 March 19 and obtained 80 × 120 and 245 × 30 s dithered images in the \( J \)- and \( H \)-bands, respectively. These data were reduced by standard algorithms with a similar suite of IDL routines used for the blue-channel reductions. The seeing was relatively constant through the night at \( \sim 0.8'' \) and \( \sim 0.6'' \) in the \( J \)- and \( H \)-bands, respectively. The sky image per object frame was created using SExtractor (Bertin & Arnouts 1996). In the 5.12'' x 5.12'' field of view, each object frame contained three stars from the Two Micron All Sky Survey (2MASS) point source catalog (Cutri et al. 2003; Skrutskie et al. 2006), which we used to calibrate the astrometry of each frame and to determine the flux zero point, with the (\( m_{\text{AB}} - m_{\text{AB}} \)) magnitude conversions of Rudnick et al. (2001). The astrometrically corrected, sky-subtracted images were averaged together with a 1 σ clip into stacked science frames.

We disregard a small portion of the SWIRC field-of-view owing to appreciable cosmetic defects. Therefore, the stacked images each contain \( \sim 100 \) objects and yield number counts which are consistent with the \( J \)-band galaxy counts of the Chandra Deep Field and Hubble Deep Field, South (Saracco et al. 2001 see their Fig. 2). Based on a power-law fit to our observed counts, we estimate the 3 σ, 50% completeness limits are \( J_{50\%} = 21.0 \) mag and \( H_{50\%} = 19.6 \) mag. The assumed lensing galaxies is not detected in either of these bandpasses, which may suggest that J121839.7+295325 is indeed a rather dark object.

To estimate our detection limits in the infrared imaging, we determine the limit corresponding to a 3 σ fluctuation at the position of the radio source. For a circular aperture with a radius of 3 × FWHM, these limits are \( J_{\text{lim}} = 22.0 \) mag and \( H_{\text{lim}} = 20.7 \) mag and are used below to derive the limits on the mass-to-light ratios.

### 3. THE GRAVITATIONAL LENS MODEL

If we are to interpret this system in the context of gravitational lensing, we must investigate whether lensing can provide a sensible explanation of the optical arc. The morphology of the arc immediately implies that the lensing galaxy cannot be circular: a circular lens that produces such a long arc (compared with the radius of curvature) would produce a prominent counterarc as well. In contrast, an elongated galaxy can produce a single long arc either as a highly distorted single image, or as a merged triplet of images. That leaves the question of how to interpret the compact, high surface brightness knot just off the east end of the arc. Since there is no natural way to interpret the arc and knot as lensed images of single source, the knot is either a lensed image of a second source, or an unrelated foreground object. We attempted to model the knot as a lensed image, although it has little...
**Fig. 2.**—Gravitational lens model. We show the HST WFPC2 observations with the radio position indicated by the tick marks (left panel) and the 1σ astrometric uncertainties, the model reconstruction (middle panel), and the source plane configuration (right panel). We show the critical curves and the caustics on the model and source plane, respectively. We model the source plane as two Gaussians and minimize the $\chi^2$ between the WFPC2 imaging and the lens model to determine their positions, fluxes, and sizes.

**Fig. 3.**—Lens properties. **Top panel:** The total mass enclosed by the Einstein radius of $R_E = 1.3''$. **Middle and bottom panels:** The limits on the dynamical mass-to-light ratio in the rest-frame B-band ($M_{\text{dyn}}/L_B$) derived from the $V_{\text{lim}} = 25.5$ mag (blue), $J_{\text{lim}} = 22.0$ mag (green), and $H_{\text{lim}} = 20.7$ mag (red) observed flux limits for $A_V = 0$ mag. We show the range of most probable lens redshift with the shaded region (see § 1).
impact on the results since the observed image merely determines the properties of the assumed second source.

We did not make a prior assumption about whether the arc is a single image or merged triplet. Instead, we merely postulated that there are two sources behind an elongated lens galaxy. We treated the sources as circular Gaussians for simplicity, fitting for their positions, sizes, and fluxes. We treated the lens galaxy as an isothermal ellipsoid, fitting for its position, Einstein radius, ellipticity, and position angle. For a given set of model parameters, we used the software package lensmodel (Keeton 2001) to find the images of the two sources, which we compared to the observed arc and knot on a pixel-by-pixel basis to compute the $\chi^2$ goodness-of-fit. We used a downhill simplex method to search the parameter space, with an inner loop to optimize the source parameters for a fixed lens galaxy, and an outer loop to optimize the galaxy parameters as well. In the best-fit model, the lens has an Einstein radius of $R_E = 1.3''$ and ellipticity of $e = 0.5$, the two sources are separated by $\Delta \theta = 0.6''$, and the reduced $\chi^2$ is $\chi^2/\nu = 0.94$. In Figure 2 we show the HST WFPC2 image (left), the lens model (middle), and the reconstructed source plane (right). The mass enclosed within the Einstein radius slowly varies with the lens redshift between $M_{dyn} = 10^{12.5} \pm 0.5 M_\odot$ (see Fig. 3, top panel), which is a relatively large mass to have been undetected in the HST WFPC2 and MMT-SWIRC imaging.

There are three additional points to make regarding the lens models. (1) In successful models, the arc is a single highly distorted image of a source lying just outside a cusp caustic in the source plane. We did not impose this as an assumption, it emerged naturally from the modeling. (2) The present model does not explain the variation in surface brightness along the arc, because we used a simple Gaussian source simply to reproduce the shape of the arc. If the arc is indeed singly-imaged, then the surface brightness variation along the arc merely represents the intrinsic variations of the source. (3) Our model predicts a compact, faint torted image of a source lying just outside a cusp caustic in the source plane ($z \gg 1$). We did not make a prior assumption about whether the arc is singly-imaged, then the surface brightness variation along the arc emerges as a constraint to the lens models.

Since J121839.7+295325 is undetected in the HST and MMT imaging, we can only determine a lower limit on its mass-to-light ratio. We must convert the above detection limits ($L_{lim}$ and $H_{lim}$) to the luminosity in a fixed bandpass to determine a mass-to-light ratio, which is independent of redshift. To facilitate direct comparisons with other galaxies, we opt to $k$-correct our limiting apparent magnitudes to the rest-frame $B$-band absolute magnitudes. These conversions require assuming a template spectral energy distribution (SED) for the undetected lensing galaxy (e.g., Hogg et al. 2002). To highlight two extreme possibilities, we show the range of the dynamical mass-to-light ratio consistent with the $V$-band (blue), $J$-band (green), and $H$-band (red) imaging as derived from the E (middle) and Im (bottom) templates (Cohen et al. 1980) in Figure 3. The shaded region shows the likely lens redshift, as discussed in $\S$ 1. If a stellar component to J121839.7+295325 exists, then we expect it likely has an early-type based on its radio flux (e.g., Windhorst et al. 1985). Therefore, to be compatible with the observations, J121839.7+295325 likely has $M_{dyn}/L_B \gtrsim 30 M_\odot L^{-1}_\odot$, and could be as dark as $M_{dyn}/L_B \gtrsim 150 M_\odot L^{-1}_\odot$ for the late-type SED. These limits will slightly decrease/brighten by including dust obscuration, since some fraction of the stellar light may be extincted and increase the maximum luminosity, for fixed flux limits. However, even with a modest amount of extinction ($A_V = 1.0$ mag), the intrinsic mass-to-light ratio would still be $M_{dyn}/L_B \gtrsim 10 M_\odot L^{-1}_\odot$ (for the early-type template). Nevertheless, the WFPC2 $V$-band observations generally provide the strongest constraint, owing to the relatively shallow SWIRC observations.

4. DISCUSSION

The HST WFPC2 imaging suggests that J121839.7+295325 is gravitationally lensing a background object. Our blue channel spectroscopy supports this hypothesis by placing the optical arc is likely at high redshift ($z_{arc} = 2.48^{+0.03}_{-0.02}$). Given the flux limits from HST WFPC2 and MMT-SWIRC ($V_{lim} = 25.5$ mag, $J_{lim} = 22.0$ mag, and $H_{lim} = 20.7$ mag), we find the lensing object may be rather dark, with a $B$-band mass-to-light ratio of $M_{dyn}/L_B \gtrsim 30 M_\odot L^{-1}_\odot$. From the K20 survey, di Serego Alighieri et al. (2005) find a dynamical mass-to-light ratio of $M_{dyn}/L_B \lesssim 2 M_\odot L^{-1}_\odot$ for their sample of 18 early-type galaxies at $z \approx 1$. Their upper limit can be extended to $M_{dyn}/L_B \approx 8 M_\odot L^{-1}_\odot$ by including a sample of 28 galaxies from the Coma Cluster (Gutiérrez et al. 2004). This mass-to-light ratio is roughly consistent with the $z \approx 0.5$ early-type galaxies of van der Marel & van Dokkum (2007) which have $2.5 \lesssim M_{dyn}/L_B \lesssim 6.8 M_\odot L^{-1}_\odot$. By comparing to a series of $z \approx 0$ studies, they find the mass-to-light ratio of early-type galaxies evolves as $\Delta \log (M_{dyn}/L)/\Delta z = -0.457 \pm 0.046$ (random) $\pm 0.78$ (systematic), since the low-redshift ellipticals have $M_{dyn}/L_B \lesssim 15 M_\odot L^{-1}_\odot$ (Padmanabhan et al. 2004). Therefore, if our lower limits derived in $\S$ 3 are correct, then J121839.7+295325 may be a relatively dark galaxy, whose total mass is dominated by dark matter. While there are solid statistical arguments that such objects should exist (Press & Schechter 1974; Blanton et al. 2001), they are currently confirmed examples. Since direct optical observations of these extreme mass-to-light objects will be nearly impossible, they will likely manifest themselves as “dark lenses” (Rusin 2002).

The most common suggestions of dark lensing have arisen from wide-separation quasar pairs (WSQPs), quasars with nearly identical optical spectra separated by $3'' \leq \Delta \theta \leq 10''$, with no identifiable lensing source. Detailed analyses of the spectra of these quasars, from the radio to the X-rays, have revealed that all known WSQPs are simply binary quasars (Hawkins et al. 1997; Muñoz et al. 1998; Mortlock et al. 1999; Peng et al. 1999; Morgan et al. 2000; Green et al. 2002). In addition, the Cosmic Shear survey with HST (Pizzka et al. 2001) has identified a number of gravitational lenses. In one particular field, Miralles et al. (2002) suggested that the conspicuous tangential alignment of galaxies with arc-like morphologies and no obvious overdensity of foreground galaxies may be a dark lens. However, Erben et al. (2003) ruled out this hypothesis by demonstrating the colors of these galaxies are inconsistent with high-redshift lensed objects.

Since J121839.7+295325 remains unidentified in the optical and near-infrared, it is a good candidate for a dark lens. However, the bright radio emission of $S_{1.4 GHz} = 33$ mJy suggests that the lens object likely contains an active galactic nucleus (e.g., Windhorst et al. 1985). If a baryonic counterpart to this radio source exists, then it likely corresponds to a massive and perhaps extincted galaxy, which would make it similar to the distant red galaxies (DRGs; Förster Schreiber 2004) or the extremely red objects (EROs; Franx et al. 2003). If we assume the optical/infrared color of $(R - K) \gtrsim 5.5$ mag typical of an ERO, then J121839.7+295325 must have $K \approx 20$ mag and a stellar mass of $M_* \lesssim 10^{10} M_\odot$ (Conselice et al. 2008 based on their Fig. 7). In this case, our lens models imply that J121839.7+295325 would have a dynamical-to-stellar mass ratio of $M_{dyn}/M_* \gtrsim 100$, which is significantly higher than the $z \approx 2$ star-forming galaxies with $M_{dyn}/M_* \approx 2$ (Erb et al. 2006).
5. CONCLUSION

The HST WFPC2 and MMT data suggest that J121839.7+295325 is an extremely dark galaxy worthy of follow-up observations to confirm or exclude this hypothesis. In particular, with deeper optical spectroscopy of the arc, our redshift analysis can be verified. Moreover, observations blueward of the blue channel spectroscopy will break the redshift degeneracy of $z \approx 0.15$ and $z \approx 2.5$. Owing to the necessary wavelength ($\lambda_{\text{obs}} \lesssim 3800 \, \text{Å}$) and flux limit (AB $\gtrsim 26$ mag), these observations could be conducted with the ultraviolet channel of the Wide Field Camera 3 (WFC3) for HST. Since the radio source has not been optically identified, its redshift may only be very coarsely constrained. The majority of millijansky radio sources have early-type morphologies and colors at $0.8 \lesssim z \lesssim 1.5$ (e.g., Windhorst et al. 1985; Russell et al. 2008), consequently its Balmer/4000$^\text{A}$ break will occur at $7000 \lesssim \lambda_{\text{obs}} \lesssim 1 \, \mu\text{m}$. Furthermore, J121839.7+295325 is undetected to faint flux-levels, and may require a rather deep (AB $\gtrsim 25$ mag) imaging campaign. Therefore, medium-band or grism observations in the infrared mode with WFC3 would better constrain the lens redshift. Should such observations support our proposed lensing scenario, this system could be among the most distant known gravitational lenses (Kochanek et al. 2007), a dusty ERO with $M_z \lesssim 10^{10} \, M_\odot$, or a genuine dark lens, which would be a unique confirmation of the $\Lambda$CDM paradigm.

We acknowledge support from NASA grant HSTAR-10974.01A (to R. E. R.), HST AR-08357.01A (to R. A. W.) awarded by STScI, which is operated by AURA for NASA under contract NAS 5-26555, and NASA JWST grant NAG5-12460 (to R. A. W.). We thank Warren Brown, Jacob Russell, Rolf Jansen, Alejandra Milone, and Nimish Hathi for helpful discussions and guidance. We are particularly grateful for the excellent comments and suggestions of the anonymous referee.

REFERENCES

Becker, R. H., White, R. L., & Helfand, D. J. 1995, ApJ, 450, 559
Bertin, E., & Arnouts, S. 1996, A&AS, 117, 393
Blanton, M. R., et al. 2001, AJ, 121, 2358
Bolton, A. S., Burles, S., Koopmans, L. V. E., Treu, T., & Moustakas, L. A. 2006, ApJ, 638, 703
Bolzonella, M., Miralles, J.-M., & Pelló, R. 2000, A&A, 363, 476
Bruzual, G., & Charlot, S. 2003, MNRAS, 344, 1000
Cohen, A. S., Röttgering, H. J. A., Jarvis, M. J., Kassim, N. E., & Lazio, T. J. W. 2004, ApJS, 150, 417
Coleman, G. D., Wu, C.-C., & Weedman, D. W. 1980, ApJS, 43, 393
Conselice, C. J., Bundy, K., Vivian, U., Eisenhardt, P., Lotz, J., & Newman, J. 2008, MNRAS, 383, 1366
Côté, R. M., et al. 2003, 2MASS All-Sky Catalog of Point Sources (Pasadena: IPAC/Caltech)
de Breuck, C., van Breugel, W., Stanford, S. A., Röttgering, H., Miley, G., & Stern, D. 2002, AJ, 123, 637
de Breuck, C., et al. 2001, AJ, 121, 1241
de Ruiter, H. R., Willis, A. G., & Arp, H. C. 1977, A&AS, 28, 211
di Serego Alighieri, S., et al. 2005, A&A, 442, 125
Erb, D. K., Steidel, C. C., Shapley, A. E., Pettini, M., Reddy, N. A., & Adelberger, K. L. 2006, ApJ, 646, 107
Erben, T., et al. 2003, A&A, 410, 45
Förster Schreiber, N. M., et al. 2004, ApJ, 616, 40
Franx, M., et al. 2003, AJ, 587, 179
Green, P. J., et al. 2002, ApJ, 571, 721
Gutiérrez, C. M., et al. 2004, ApJ, 602, 664
Hawkins, M. R. S., Clements, D., Fried, J. W., Heavens, A. F., Veron, P., Minty, E. M., & van der Werf, P. 1997, MNRAS, 291, 811
Hogg, D. W., Baldry, I. K., Blanton, M. R., & Eisenstein, D. J. 2002, preprint (astro-ph/0210394)
Kauffmann, G., White, S. D. M., & Guiderdoni, B. 1993, MNRAS, 264, 201
Keeton, C. R. 2001, preprint (astro-ph/0102340)
Kochanek, C. S., Falco, E. E., Impey, C., Lehár, J., McLeod, B., & Rix, H.-W. 2007, Castles Survey (Cambridge: Castles), http://www.cfa.harvard.edu/castles/
Krienke, C. M., et al. 2008, ApJ, 649, 599
Kron, R. G., Koo, D. C., & Windhorst, R. A. 1985, A&AS, 146, 38