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THE TRIPLE RADIO SOURCE 0023+171: A CANDIDATE FOR A DARK GRAVITATIONAL LENS

J. N. HEWITT,[1,2,3,4] E. L. TURNER,[3,4,5] C. R. LAWRENCE,[6] D. P. SCHNEIDER,[6,7] J. E. GUNN,[5,8] C. L. BENNETT,[9] B. F. BURKE,[1] J. H. MAHONEY,[1] G. I. LANGSTON,[1] M. SCHMIDT,[6] J. B. OKE,[6] AND J. G. HOESSEL[3,10]

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ABSTRACT

A composite radio source, with two optical counterparts at $z = 0.946$ separated by 5″, has been detected in a radio-optical gravitational lens survey. The redshifts of the optical counterparts are not significantly different ($\Delta\lambda = 8 \pm 6$, 2 ± 20 Å in the two lines detected in both spectra), and their optical spectra are similar. One interpretation of these measurements is that the images of 0023+171 are gravitationally lensed; another is that the components of 0023+171 are two physically associated radio galaxies or components of a single galaxy. Because the radio morphology is complex and the optical objects are faint ($m_r = 22.8$, 23.4), the existing data cannot exclude either one of these interpretations. The only possible evidence for a lensing object is extremely faint ($m_r > 23.5$) optical emission located approximately 1″ from one of the images. If this multiple source is gravitationally lensed, the combination of the low redshift of the source, the faintness of the source, and the large image separation implies a large mass-to-light ratio for the lensing matter ($\sim 1000\ M_\odot/L_\odot$).

Subject headings: galaxies: individual (0023+171) — galaxies: structure — gravitation — radio sources: galaxies

I. INTRODUCTION

The formation of multiple images of astronomical objects by gravitational lensing was first observed in 1979 with the discovery of the double quasar 0957+561 (Walsh, Carswell, and Weymann 1979). Since then, six other systems that appear, with widely varying degrees of certainty, to be gravitationally lensed have been reported in the literature: 1115+080 (Weymann *et al.* 1980), 2345+007 (Weedman *et al.* 1982), 2016+112 (Lawrence *et al.* 1984), 1635+267 (Djorgovski and Spinrad 1984), 2237+030 (Huchra *et al.* 1985), and 1146+111 (Turner *et al.* 1986). Except for 2237+030, it has proved to be difficult to model the imaging with matter associated in a simple way with galaxies observed near the quasar images. The questions raised by the lens systems already studied, and the possibility of using gravitational lensing as an independent probe of dark matter and as a cosmological tool, make it desirable to find a large sample of gravitational lenses. Consequently, we have begun a systematic search for such systems. The identification of 2016+112 was the first success of this search, and data collected since the discovery of 2016+112, especially at optical wavelengths (Schneider *et al.* 1985, 1986), have further strengthened the case for gravitational lensing in this sytem. We now report the discovery of another multiple radio source, 0023+171, that displays many of the characteristics of a gravitational lens system.

Our method of searching for gravitational lenses is as follows: (1) observe a few thousand sources chosen from the MIT-Green Bank (MG) 5 GHz survey (Bennett *et al.* 1986) with the National Radio Astronomy Observatory (NRAO)[11] Very Large Array (VLA) in the A-configuration at a frequency of 5 GHz (giving a resolution of better than half an arcsecond); (2) select sources with multiple radio components and image them optically; and (3) further select sources with multiple radio-optical counterparts and acquire moderate-resolution spectra of each component. Sources with multiple components at the same redshift and with similar spectra are excellent gravitational lens candidates.

II. OBSERVATIONS

a) Radio Data

The source 0023+171 was observed briefly at 5 GHz with the B-array of the VLA in 1982 October and identified as a gravitational lens candidate. It was reobserved for 13 minutes at 5 GHz with the A-array on 1985 February 13. The map of the radio brightness displayed in Figure 1 was produced from the 1985 data with the NRAO Astronomical Image Processing System software package; phase corrections for each antenna were calculated through self-calibration, and the data were then Fourier transformed and deconvolved. The main lobe of the circular synthesized beam is 0″.3 wide (FWHM). Our experience with VLA snapshot observations leads us to a conservative estimate of the dynamic range (the ratio of the peak brightness to the noise level) of about 30:1. The two brighter components, A and B, are clearly resolved and appear to be opposing radio jets. The third component, C, is unresolved. Table 1 lists the positions, which were not changed by the self-calibration procedure, and peak brightness of the three radio sources. The peaks of components A and B are separated

[1] Department of Physics, Massachusetts Institute of Technology.
[2] Haystack Observatory.
[3] Guest Observer at the Palomar Observatory, California Institute of Technology.
[4] Visiting Astronomer, National Optical Astronomy Observatories.
[5] Princeton University Observatory.
[6] Palomar Observatory, California Institute of Technology.
[7] Institute for Advanced Study.
[8] Visiting Associate, Palomar Observatory, California Institute of Technology.
[9] NASA/Goddard Space Flight Center.
[10] Washburn Observatory, University of Wisconsin-Madison.

[11] The National Radio Astronomy Observatory is operated by Associated Universities, Inc., under contract with the National Science Foundation.

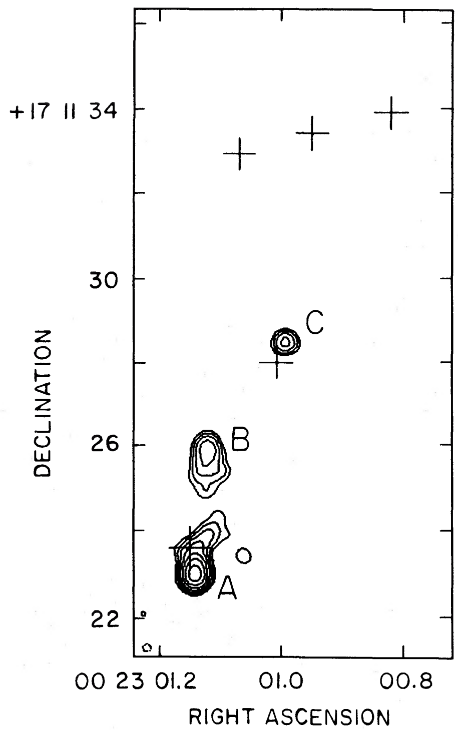

FIG. 1.—Contour plot of VLA snapshot map (A-array, $\nu = 5$ GHz) of 0023+171 showing the three radio components, A, B, and C. Contour levels are −1%, 1%, 2%, 4%, 8%, 16%, 32%, and 64% of the peak brightness of 28 mJy per beam; the beamwidth (FWHP) is $0\farcs3$. Positions of five optical objects, detected in a CCD frame, are indicated with crosses. The size of each cross represents the formal error in the determination of the optical positions with respect to positional standards. The error in the relative positions of the radio and optical components may be as much as a factor of 2 larger.

by $3\farcs0$; the peaks of components A and C are separated by $5\farcs9$. There is some evidence for structure in the A component, suggesting a 60° bend in the jet or, possibly, a fourth faint component. However, the brightness in this region is less than 3% of the peak brightness in the map, and further observations that more fully sample the Fourier components of the brightness distribution are needed to interpret this faint structure.

After subtracting the visibility of 0023+171 from the self-calibrated data, a field of radius 100″ about the phase center was searched for evidence of other radio sources, and none was found. The field of view of the radio observations is limited primarily by the delay beam; i.e., the degree to which the interferometric fringes due to a source far from the phase center of the map can be tracked across the 50 MHz bandwidth of the observations. The combined effects of the delay beam and of the rotation of Earth during the 30 s integration time reduced the sensitivity in the map by, at most, 60% (Thompson 1982), and the limit on the flux density of any source within 100″ of 0023+171 is 1.0 mJy (10 σ).

b) *Optical Data*

As a first step in the optical verification of a gravitational lens candidate, 0023+171 was imaged on 1984 September 18 with the National Optical Astronomy Observatories[12] Kitt Peak 4 m telescope equipped with the prime focus TI2 CCD camera. Four exposures in the *R* band were taken in seeing of $1\farcs3$, for a total of 1920 s integration time; the frames were flattened and averaged, and the resulting image is displayed in Figure 2. On 1984 September 29, 0023+171 was imaged with

[12] The National Optical Astronomy Observatories are operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

TABLE 1

0023+171 POSITIONS, RADIO AND OPTICAL FLUXES, AND SPECTROSCOPY

A. RADIO DATA

Parameter	A	B	C
Right ascension (B1950)[a]	00 23 01.15 ± 0.01	00 23 01.12 ± 0.01	00 23 01.00 ± 0.01
Declination (B1950)[a]	+17 11 23.0 ± 0.2	+17 11 26.0 ± 0.2	+17 11 28.5 ± 0.2
Peak brightness (5 GHz)[b]	28 mJy per beam	4.3 mJy per beam	2.9 mJy per beam

B. OPTICAL DATA

Parameter	AB_{opt}	C_{opt}
Right ascension (B1950)[a]	00 23 01.15 ± 0.05	00 23 01.01 ± 0.5
Declination (B1950)[a]	+17 11 23.6 ± 0.8	+17 11 28.0 ± 0.8
R magnitude	23.12 ± 0.19	21.91 ± 0.12
r magnitude	23.39 ± 0.15	22.80 ± 0.12
i magnitude	23.02 ± 0.15	21.94 ± 0.11
Spectral line wavelengths (Å)		
[Ne V]	6668 ± 11	...
[O II]	7253 ± 2	7246 ± 6
[Ne III]	7530 ± 5	7528 ± 19
Mean weighted redshift	0.9461 ± 0.0005	9.9442 ± 0.0017
Spectral line fluxes[c]:		
[Ne V]	110 ± 30	...
[O II]	1550 ± 70	570 ± 70
[Ne III]	490 ± 60	150 ± 70

[a] Errors quoted are with respect to positional standards.
[b] Referred to the scale of Baars *et al.* 1977; estimated uncertainty is 5%.
[c] Spectral line fluxes are in arbitrary units.

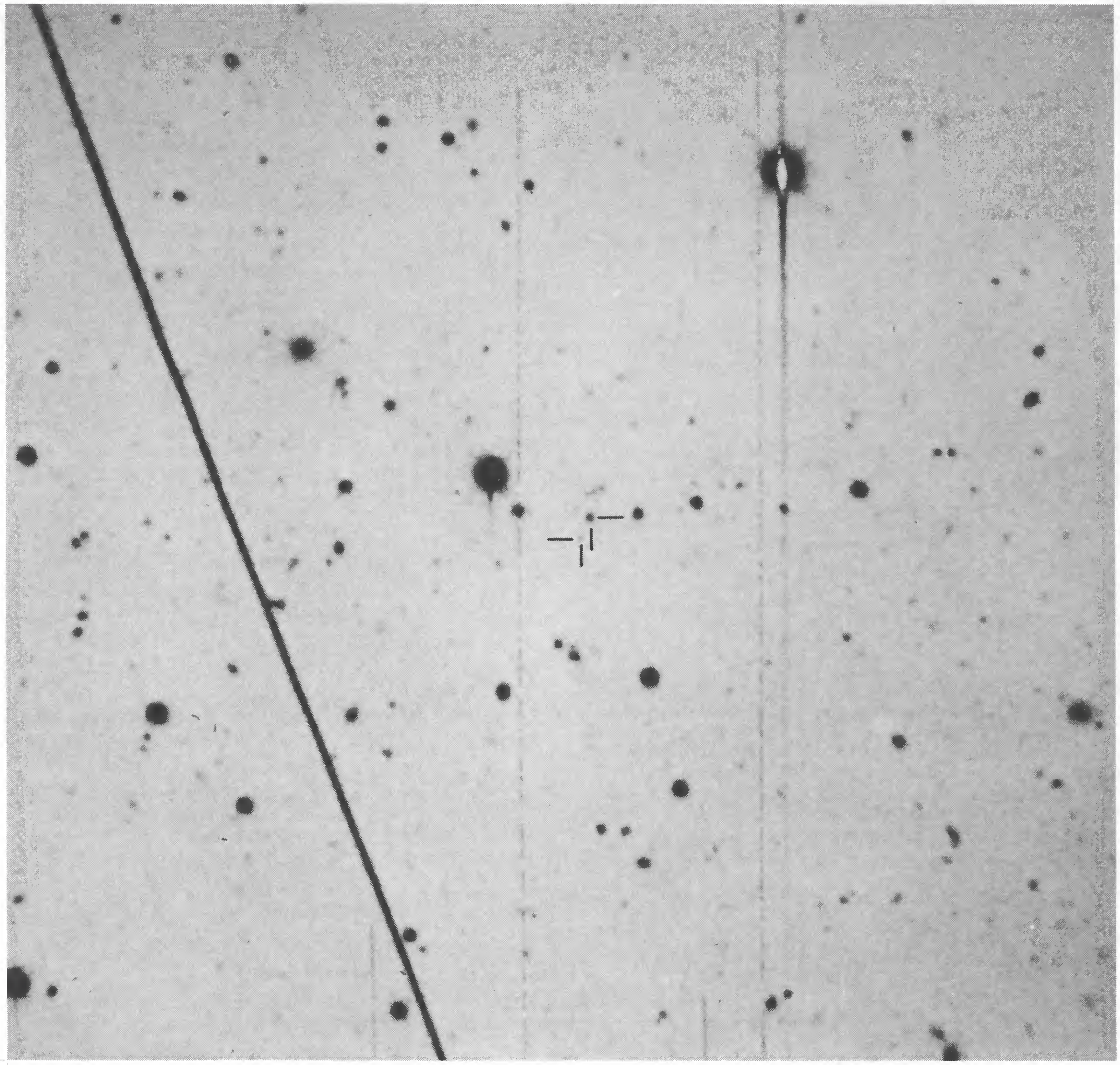

FIG. 2.—*R* band CCD image of the field of 0023 + 171. The two optical objects detected closest to the radio position are marked. North is at the top; east to the left. The field is ~4′ wide. The vertical lines are due to defective columns on the CCD.

the Hale 5 m telescope equipped with the 4-Shooter CCD camera (Gunn *et al.* 1984), and 600 s of data were acquired in the *r* band (Thuan and Gunn 1976) in seeing of 0″.8. On 1985 July 23, 0023 + 171 was imaged in photometric conditions with the 4-Shooter; 150 s of data were acquired in the *r* band in seeing of 1″.0, and 300 s of data were acquired in the *i* band (Wade *et al.* 1979) in seeing of 1″.0 to 1″.3.

Five optical objects within 10″ of the average radio position were detected; a contour plot of the region near the radio objects is presented in Figure 3. The coordinates of the radio components of 0023 + 171 were determined with respect to the VLA calibrator 0007 + 171, for which the position is believed to be known to better than 0″.1 (Perley 1982). Repeated observations of sources at the VLA indicate that radio positions measured with respect to the calibrators in our snapshot program are repeatable at about the 0″.1 level (Lawrence *et al.* 1986*a*). For the optical positions, SAO stars corrected to agree with the AGK3 catalog (Taff and Stansfield 1982) were used as standards, and positions of secondary standards were calculated from measurements of glass copies of the Palomar Observatory Sky Survey plates. Positions of the objects on the CCD frame were referred to the secondary standards, with an error of the fit of 0″.3, and the positions of the faint objects detected in the CCD frame, because of photon noise, are uncertain by 0″.5. Differences of a few tenths of an arcsecond between the radio and optical reference frames have been reported (de Vegt and Gehlich 1982). We estimate the combined error in the difference between the radio and optical positions to be approximately 1″. To this accuracy, two of the optical objects coincide with the radio sources. The brighter object (hereafter called C_{opt}) lies 0″.5 ± 1″.0 from radio source C, and the fainter object (hereafter called AB_{opt}) lies between radio sources A and B. The separation of AB_{opt} and C_{opt} is 4″.8 ± 0″.2. The fitted positions of the five objects are indicated by crosses on the radio map of Figure 1, and the properties of AB_{opt} and C_{opt} are summarized in Table 1. AB_{opt} does not appear resolved, but the lowest contour levels of C_{opt} show possible excess emission to the south. Subtracting a scaled point-spread function from the image leaves an extended object, with *r* magnitude between 23.5 and 24.0, approximately 1″ south of C_{opt}. The faint emis-

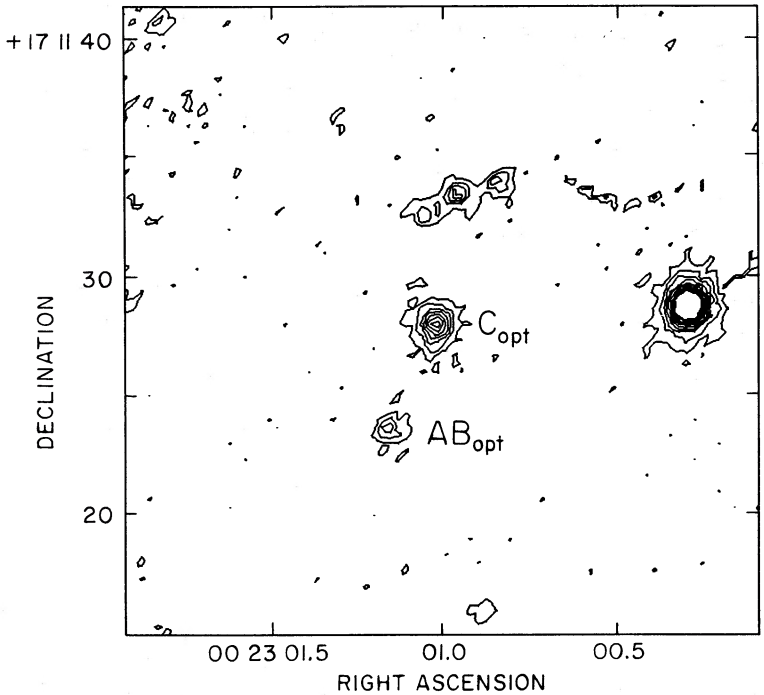

FIG. 3.—Contour plot of an r band CCD image (seeing ~0″.8) in the region near the radio position of 0023+171. The fitted positions of five optical objects near the radio position are marked in Fig. 1.

sion is present in all the CCD frames, and it appears brightest in the i image. However, the structure is not well determined; the data are consistent with either a separate object or the resolution of asymmetric structure in C_{opt}.

Spectra of AB_{opt} and C_{opt} were obtained with the Hale 5 m telescope on 1984 September 29 (6000 s), 1985 January 16 (6000 s), and 1985 July 20 (3000 s) and 21 (7800 s). The detector for all of the observations was an 800 × 800 Texas Instruments CCD; the instruments used were the PFUEI (Gunn and Westphal 1981) in 1984 and 1985 January, and the 4-Shooter (Schneider *et al.* 1986) in 1985 July. The seeing was 1″.0 and 1″.5 during the 1984 September and 1985 January observations, respectively, and ranged from 1″.0 to 1″.8 during the 1985 July observations. The dispersion (6.8 Å per pixel), resolution (25 Å), and slit width (1″.5) were practically identical for the two spectrographs; Figure 4 presents the sum of the spectra of the two objects weighted by their squared continuum signal-to-noise ratios. Two spectral lines are clearly visible in each spectrum, and there appears to be a third weak line in the spectrum of AB_{opt}. The identifications of the lines are summarized in Table 1. The redshift, as determined from the three spectral lines of AB_{opt}, is $z = 0.9461 \pm 0.0005$. The width of the [O II] line in the spectrum of AB_{opt}, as determined by a Gaussian fit, indicates that it is unresolved (FWHM < 25 Å). The signal-to-noise ratio in the weaker lines is insufficient to allow measurement of their widths; they may be unresolved or mariginally resolved. The wavelength differences between the two objects in the [O II] and [Ne III] lines are 8 ± 6 Å and 2 ± 20 Å, respectively. The accuracy of the wavelength determination for the [O II] line is limited by its alignment with the edge of a strong OH band in the night sky spectrum. In addition to the narrow emission lines, there appears to be a slight rise in the continuum of C_{opt} at the position of the redshift Mg II line; however, these spectra of 0023+171 neither confirm nor rule out the existence of a weak Mg II feature in C_{opt}. Finally, the continuum of C_{opt} is stronger than that of AB_{opt}.

III. DISCUSSION

The radio morphology of 0023+171 suggests that it is made up of at least two radio sources which, when considered separately, are not unusual. Source A/B is double and C is a point source, both common structures among radio sources of this flux density (see, for example, Lawrence *et al.* 1986*a*). However, finding two sources separated by a few arcseconds is unusual and prompted our optical studies of 0023+171. The unusual structure does not appear to be due to "missing" any flux with the interferometric measurement of the VLA; the deconvolved flux density is not significantly different from that measured with the Green Bank 300 foot (91 m) telescope, and a snapshot taken with the B-array of the VLA shows no evidence for structure on scales larger than those detected in the A-array map. Single-dish measurements of the flux density of 0023+171 at frequencies of 4755 MHz and 1414 MHz give a spectral index of $\alpha = 0.8$ (in the sense $S \sim \nu^{-\alpha}$; Lawrence *et al.* 1986*a*). The absolute radio luminosity between frequencies ν_1 and ν_2 for an isotropic radiator with a power-law spectrum is given by

$$L_R = \frac{4\pi d_L{}^2 S_{\nu o} \nu_o{}^{\alpha}}{(1-\alpha)(1+z)^{1-\alpha}} (\nu_2{}^{1-\alpha} - \nu_1{}^{1-\alpha}) \text{ ergs s}^{-1} ,$$

where d_L is the luminosity distance to the source, ν_o is the observing frequency, and $S_{\nu o}$ is the flux density measured at the observing frequency. Assuming $H_o = 100h$ km s^{-1} Mpc^{-1}, the absolute radio luminosity of 0023+171 between 10^7 Hz and 10^{11} Hz is $4 \times 10^{43} h^{-2}$ ergs s^{-1} for $q_o = 0$, and $3 \times 10^{43} h^{-2}$ ergs s^{-1} for $q_o = \frac{1}{2}$. Approximately 95% of the flux is due to component A/B. Both A/B and C are strong radio sources, with absolute radio luminosities typical of radio galaxies.

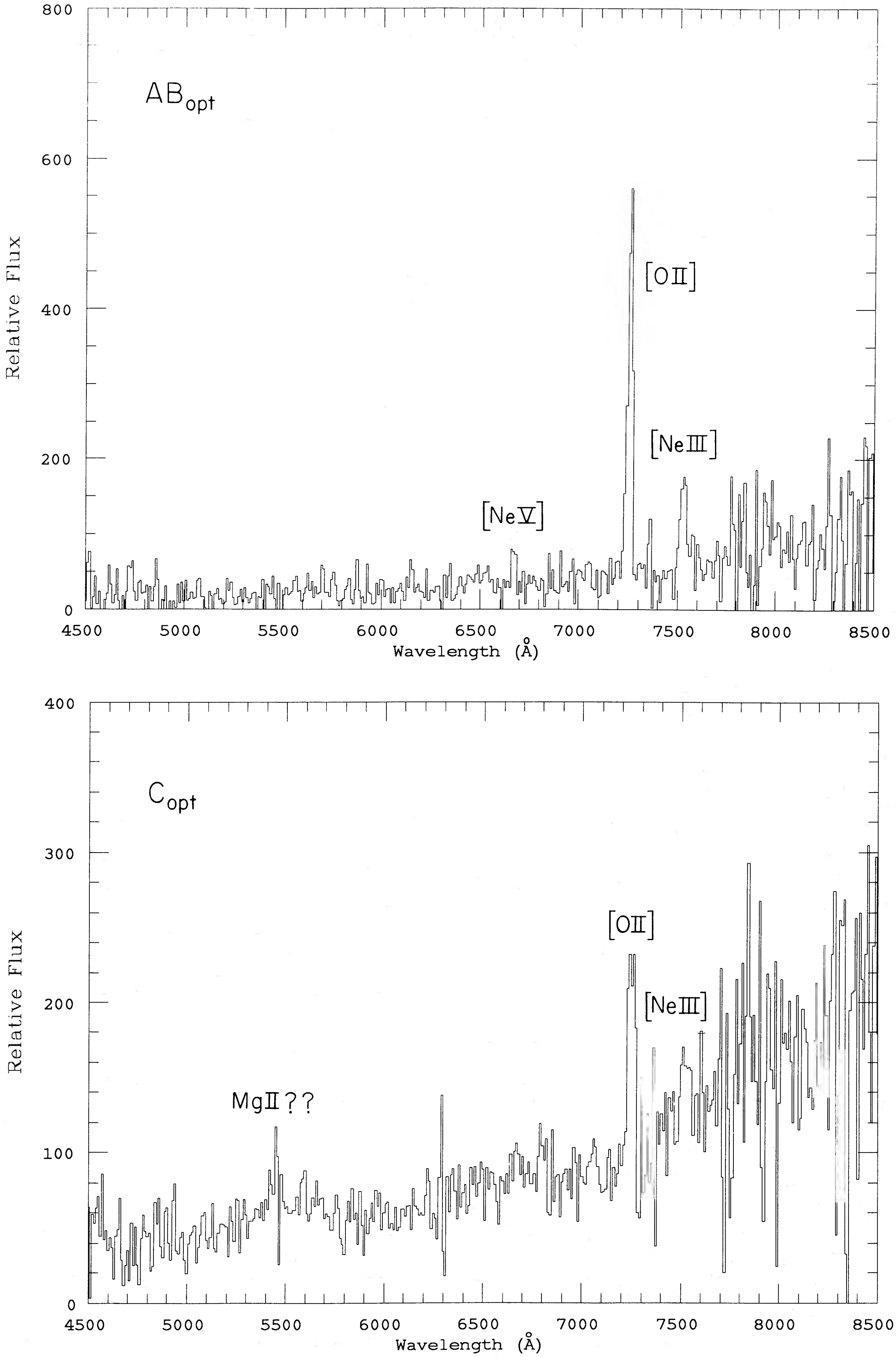

FIG. 4.—Optical spectra of 0023 + 171 AB$_{opt}$ and C$_{opt}$. Nine spectra of each object were combined (for a total of 22,800 s integration time) to produce this figure. Note the difference in vertical scale between the two plots.

The objects, AB_{opt} and C_{opt}, do not appear resolved; however, their faintness precludes any reliable evaluation of their structure. It is difficult to determine the optical luminosities of the sources because their spectral energy distributions are not known. Assuming the spectrum of a giant elliptical galaxy, $H_o = 100$, and $q_o = \frac{1}{2}$, the absolute blue magnitudes are $M_B(AB_{opt}) = -20.4$ and $M_B(C_{opt}) = -21.0$. Assuming a power-law spectrum with index -0.5 gives $M_B(AB_{opt}) = -18.5$ and $M_B(C_{opt}) = -19.7$. In either case, AB_{opt} and C_{opt} are not as bright at optical wavelengths as is typical for radio galaxies.

Given the positional coincidence of the radio and optical components of 0023+171, a natural assumption is that, for each component, the radio and optical emission are physically associated. One then seeks an explanation for the small separation and similar properties of the two optical objects. One interpretation is that we are seeing two gravitationally lensed images of the same object. Another interpretation is that the objects are associated but physically distinct and have similar properties through similar evolution or simply by chance.

a) *Evidence in Support of the Gravitational Lens Interpretation*

The source 0023+171 exhibits the generally recognized characteristics of a gravitationally lensed quasar: two extragalactic objects (both radio sources in this case) at the same redshift, separated by a few arcseconds. The measured velocity difference is consistent with the value of zero expected from a straightforward lens model. The spectra of the optical objects are similar, and the faintness of their optical emission, relative to their radio emission, are unusual and also similar. Two lines are detected in each, at the same wavelengths. A third line is detected in one spectrum, and its absence in the other spectrum is consistent with the emission-line flux ratio of the two objects and the signal-to-noise ratio of the second spectrum. The ratio of the flux in the [O II] line to the flux in the [Ne III] line is 3.2 ± 0.4 for component AB_{opt} and 3.9 ± 1.8 for component C_{opt}, again remarkably similar. In contrast, the ratio of the equivalent widths of the [O II] and [Ne III] lines measured in 11 radio sources by Allington-Smith, Lilly, and Longair (1985) varies over two orders of magnitude. The significance of the radio flux ratio as a test of gravitational lensing is not clear, since one component is resolved and the other is not, but it is of the same order of magnitude as the emission-line flux ratio. Finally, the redshift of the source is plausible. One can estimate the probability that a source at a redshift of $z = 0.946$ would be lensed by a galaxy. Turner, Ostriker, and Gott (1984) have calculated optical depths to lensing based simply on the characteristics (i.e., the mass model) of the lenses and an average over all possible alignments of the source and the lens. For isothermal sphere lenses distributed according to the locally observed galaxy distribution and assuming $q_o = \frac{1}{2}$, the optical depth to lensing of a source at a redshift of $z = 1.0$ is approximately 30% of that for a source at $z = 2.0$. The expected image separation is nearly independent of redshift. If the distribution of redshifts of sources examined for lensing so far is roughly flat, the occurrence of a $z = 0.946$ source in the sample of observed gravitationally lensed quasars is not unlikely.

If 0023+171 is not lensed, the similarity in the emission-line spectra described above must be due simply to similar characteristics of two physically distinct objects. As suggested by Phinney and Blandford (1986), finding two physically distinct objects with the same redshift separated by a few arcseconds may not be unlikely. Extending their analysis to include estimates of the probability that two objects with similar *spectra* (at the same redshift) would be found must reduce the probability of finding by chance a pair like 0023+171. On the other hand, considering the possibility that 0023+171 AB_{opt} and C_{opt} evolved in similar environments would tend to increase the probability of finding a pair like 0023+171 by chance.

b) *Evidence against the Gravitational Lens Interpretation*

Some of 0023+171's properties are not so easily explained by the lensing hypothesis. First, it is clear from the VLA maps that the radio morphology is complex. Components A and B together resemble a classical radio double: two jets emanating from an optical core source. Component C cannot be a simple, undistorted second image of this ordinary radio source since it appears as an unresolved radio component probably coincident with the optical source. This morphology is reminiscent of that of 0957+561, the only other gravitational system to exhibit extended radio emission. For the 0957+561 system, the structure is interpreted as being due to the particular geometry of the lensing: only a small portion of the source plane is multiply imaged, and the jets simply fall outside the critical region (Young *et al.* 1981; Greenfield, Roberts, and Burke 1985). Similarly, in the case of 0023+171, there is structure in the source on the scale of the lens splitting, and any imaging over the full extent of the source can be highly nonuniform. In fact, given the size of the source relative to the area of the sky imaged, it is unlikely that the impact parameter of the source would be such that the entire source would be imaged more than once.

Second, the optical continuum and optical line flux ratios of 0023+171 are different. AB_{opt} has stronger line emission, while C_{opt} has stronger continuum emission. These data could be reconciled with the gravitational lens interpretation if object C is confused, if the continuum and line-emitting regions of the quasar are being magnified differently in the two images, or if sufficient differential variability of the continuum and the line-emitting regions are offset by a time delay between the two images. The presence of faint extended emission offset from the centroid of C_{opt} and the redder continuum of C_{opt} suggest that it may indeed be confused with a faint galaxy, possibly even a lensing galaxy. Both 0957+561 and 2016+112 provide gravitational lens precedents for discordant flux ratios. Before it was recognized that 0957+561B was coincident with a galaxy, the continuum flux ratio was measured to be different from the line flux ratio, especially in the red. The quasars 2016+112 A and B have flux ratios (A/B) of 0.9 in the radio ($\nu = 5$ GHz), 1.2 in the optical continuum (r band; Schneider *et al.* 1985), and 1.6 in the Lyman α line (Schneider *et al.* 1986). For 0023+171, a better understanding of the composite nature of C_{opt} is needed before the different measures of the flux ratio can be reliably compared.

Third, neither the radio nor the optical data provide strong evidence that there is a normal galaxy or cluster of galaxies close enough to the images to act as a lens. A rich cluster or giant elliptical galaxy with $z \leq 0.8$ would have been detected by the optical observations. The only candidate lensing object detected in the direct optical images is the very faint extended object near C_{opt}. As discussed below, if this is a galaxy responsible for the image splitting, an extremely large mass-to-light ratio is required. The three optical objects 10″ north of 0023+171 could provide the concentrated mass required by the splitting, but additional lensing mass would be needed to offset the images. Narayan, Blandford, and Nityananda (1984) have proposed models for gravitational lensing in which images separated by a few arcseconds are the second and third images of a source lensed by a cluster of galaxies. In this scenario, the first image should be on the other side of the cluster, typically a few magnitudes fainter than the second and third images, and no lensing galaxy between the second and third images is required. For 0023+171, the cluster model implies a ~1.5 mJy source an arcminute or so from the A-B-C complex. The absence of any other source in the wide-field radio map does not support this model, though observations with the B or C array of the VLA would be more sensitive to faint sources over a wide field and would provide a more stringent test.

Finally, the detection of a Mg II feature in the spectrum of C_{opt} but not in AB_{opt} would weaken the lensing interpretation. Further observations improving the signal-to-noise ratio of the spectra may determine the significance of the slight rise in the continuum of C_{opt} at 5450 Å. Interpreting such a feature within the context of a gravitational lens model would have to appeal to the possibility that the Mg II line may be emitted from a different region than the forbidden lines.

c) *Implications of the Gravitational Lens Interpretation*

If 0023+171 is indeed a lens system, it is one of the best cases to date for a dark lensing object. Among the six other reported lens systems with image separations on the scale of a few arcseconds, 1635+267 and 2345+007 also show no signs of a lensing galaxy in deep optical searches (Djorgovski and Spinrad 1984; Tyson *et al.* 1986); however, the implied minimum lens mass-to-light ratio is considerably greater for 0023+171 for two reasons. First, the redshift of 0023+171 is smaller than that of any of the proposed lensed objects; this both provides the smallest upper bound for the lens redshift and implies the smallest maximum likelihood lens redshift. Second, the apparent magnitudes of the lensed images in 0023+171 are so faint that they offer little possibility of hiding a normal galaxy lens in their glare. Finally, of course, the observed 5″ splitting in 0023+171 is quite large compared to that expected for lensing by ordinary galaxies (Turner, Ostriker, and Gott 1984).

In the absence of a detailed lensing model for 0023+171, it is not possible to calculate a rigorous lower limit to the lens mass-to-light ratio. Nevertheless, following the line of argument detailed for the lens system 2016+112 by Schneider *et al.* (1986), it is possible to give a crude lower limit by associating the observed splitting with the Einstein ring diameter of a point mass and by treating the lens redshift as a free parameter. Carrying out sucn a calculation assuming $q_o = \frac{1}{2}$ gives

$$M/L \geq 270h \exp_{10} [0.4(R_L - 21.9)] \ M_\odot/L_\odot ,$$

where R_L is the bright limit on the R magnitude of the lensing object. This calculation is based on the conservative assumption that the lensing object's K-correction is identical to that of a giant elliptical galaxy (Schneider, Gunn, and Hoessel 1983); a bluer object would imply a still higher M/L value. This minimum value occurs for an assumed lens redshift of $z_L = 0.76$ and requires a mass of $4.9 \times 10^{12}\ M_\odot$ and a lens absolute magnitude of $M_B \geq -20.1$. If the faint object south of C_{opt} is responsible for the lensing, $R_L = 23.5$ and we find $M/L = 1200h\ M_\odot/L_\odot$, again for $z = 0.76$.

If, instead of assuming the lens to be at the redshift which gives the most conservative M/L limit, it is assumed to be at its *a priori* most probable redshift of $z_L = 0.31$, one obtains instead

$$M/L \geq 1100h \exp_{10} [0.4(R_L - 21.9)] \ M_\odot/L_\odot$$

with a mass of $8.0 \times 10^{11}\ M_\odot$ and absolute magnitude $M_B \geq -16.6$. For the faint object south of C_{opt} we find $M/L = 4800\ M_\odot/L_\odot$. Since R_L is almost certainly fainter than 21.9 (the apparent magnitude of the optically brighter component), z_L is unlikely to happen to be the optimum value for invisibility, and a realistic lens model might well require a factor of 2 or greater more mass than a maximally efficient point mass lens, we conclude that, if 0023+171 is lensed, *the lens M/L value is probably in excess of 1000* $M_\odot/L_\odot$. In addition to the possibility that 0023+171 is not actually a lens system, it might be possible to escape this conclusion by attributing the image splitting to a nearby luminous mass concentration (such as the three objects to the north of the 0023+171 system), with the images offset by matter inhomogeneities along the line of sight.

IV. SUMMARY

In the course of a search for gravitational lenses, radio sources with two optical counterparts at $z = 0.946$ separated by 5″ have been detected. Their redshifts are the same within the measurement error, and their optical spectra show the same emission lines with the same relative intensities. One interpretation of these measurements is that the images of 0023+171 are indeed gravitationally lensed; however, the possibility remains that the components of 0023+171 are distinct, physically associated objects. Probably the strongest evidence in favor of the lensing interpretation is the similarity of the emission-line spectra. In the past, such evidence has been sufficient for classifying a double object as lensed. The discovery of 1146+111, with the large separation of the two "images" (157″), has provided a system, with spectral similarity of the components, that is relatively easily subjected to other tests for gravitational lensing. The failure of such tests to provide further evidence for lensing (Stark *et al.* 1986; Lawrence *et al.* 1986*b*; Tyson and Gullixson 1986) alerts one to the possibility that there may exist pairs of objects with similar spectra that are not lensed. The radio source 0023+171 could, of course, fall into this category, as could the other candidate lens systems for which spectral similarity is the only indication of lensing (1146+111, 1635+267, and 2345+007). However, evidence that 0023+171 is lensed would be strong independent evidence for the existence of dark matter, and attempts to further understand this system seem indicated. More data should be collected to test whether the properties of the components of 0023+171 are consistent with those of gravitationally lensed images over a wide range of frequencies and scale sizes. The theoretical studies that have been used to predict the likely properties of gravitationally lensed images have, by necessity, incorporated many simplifying assumptions. Since these models are now well understood and since lens surveys and accidental discoveries will produce many more candidate lens systems, the theoretical studies should be extended to include more realistic lensing scenarios. Two possibilities that come to mind, particularly in light of the difficulties encountered in interpreting the observations of 0023+171 and some of the other published lens systems, are the inclusion of sources with structure (rather than just point sources) and lenses with realistic mass distributions (rather than just spherically symmetric lenses). With these more realistic theoretical studies, one may be able to say with more con-

fidence how likely it is that 0023+171 is lensed. In the meantime, we can conclude only that 0023+171 may be gravitationally lensed, and that the mass-to-light ratio implied by this interpretation makes it an interesting object worthy of further study.

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C. L. BENNETT: Infrared Astrophysics Branch, Code 697, NASA Goddard Space Flight Center, Greenbelt, MD 20771

B. F. BURKE, G. I. LANGSTON, and J. H. MAHONEY: Room 26-331, Massachusetts Institute of Technology, Cambridge, MA 02139

J. E. GUNN and E. L. TURNER: Princeton University Observatory, Peyton Hall, Princeton, NJ 08544

J. N. HEWITT: Haystack Observatory, Westford, MA 01886

J. G. HOESSEL: Department of Astronomy, University of Wisconsin at Madison, 475 N. Charter St., Madison, WI 53706

C. R. LAWRENCE, M. SCHMIDT, and J. B. OKE: Mail Stop 105-24, California Institute of Technology, Pasadena, CA 91125

D. P. SCHNEIDER: School of Natural Sciences, Institute for Advanced Study, Princeton, NJ 08540