SDSS J092455.87+021924.9: AN INTERESTING GRAVITATIONALLY LENSED QUASAR FROM THE SLOAN DIGITAL SKY SURVEY

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ABSTRACT

We report the discovery of a new gravitationally lensed quasar from the Sloan Digital Sky Survey, SDSS J092455.87+021924.9 (SDSS J0924+0219). This object was selected from among known SDSS quasars by an algorithm that was designed to select another known SDSS lensed quasar (SDSS J1226−0006A,B). Five separate components, three of which are unresolved, are identified in photometric follow-up observations obtained with the Magellan Consortium’s 6.5 m Walter Baade Telescope at Las Campanas Observatory. Two of the unresolved components (designated A and B) are confirmed to be quasars with \( z = 1.524 \); the velocity difference is less than 100 km s\(^{-1}\) according to spectra taken with the W. M. Keck Observatory’s Keck II Telescope at Mauna Kea, Hawaii. A third stellar component, designated C, has the colors of a quasar with redshift similar to components A and B. The maximum separation of the point sources is 1.78′. The other two sources, designated G and D, are resolved. Component G appears to be the best candidate for the lensing galaxy. Although component D is near the expected position of the fourth lensed component in a four-image lens system, its properties are not consistent with being the image of a quasar at \( z \approx 1.5 \). Nevertheless, the identical redshifts of components A and B and the presence of component C strongly suggest that this object is a gravitational lens. Our observations support the idea that a foreground object reddens the fourth lensed component and that another unmodeled effect (such as micro- or millilensing) demagnifies it, but we cannot rule out the possibility that SDSS J0924+0219 is an example of the relatively rare class of “three-component” lens systems.

Key words: gravitational lensing — quasars: individual (SDSS J092455.87+021924.9)

1. INTRODUCTION

If the rate of gravitational lenses among known quasars is roughly 0.1% of all quasars (Turner, Ostriker, & Gott 1984), then the expected number of new gravitationally

See http://www.sdss.org.
(Refsdal 1964). Finding new lensed quasars in a large, homogeneous survey, such as the SDSS will contribute greatly to the statistics of lensed quasars and the determination of their time delays. To date the SDSS has yielded one new two-image lensed quasar, SDSS J1226−0006A,B (Inada et al. 2003), and here we report on the second lensed-quasar system discovered among the SDSS quasars.

To maximize the likelihood of discovering additional lens systems, we studied the SDSS parameters of previously known lensed quasars. In particular, we studied the parameters of SDSS J1226−0006, and using these parameters, we developed an algorithm to select SDSS J1226−like objects from the SDSS database. This algorithm should be sensitive to lensed quasars with separations on the order of 1.0−2.5. By applying this algorithm to the approximately 10,000 SDSS quasars discovered prior to 2001 December 1, we identified five lensed-quasar candidates. By definition one of them is SDSS J1226−0006. Another candidate is SDSS J0924+0219 (R.A. = 09°24′55.87″, decl. = +02°19′24.9″, J2000), which is identified in the SDSS database as a z = 1.524 quasar. We obtained photometric follow-up observations of SDSS J0924+0219 using the Magellan Consortium’s Walter Baade 6.5 m (WB 6.5 m) telescope at Las Campanas Observatory under good seeing conditions (0.55′′−0.75′′). Additional spectroscopic observations of the components that were resolved by the WB 6.5 m images were obtained with the Keck II telescope at the W. M. Keck Observatory on Mauna Kea in <1′′ seeing. Observations of the other three candidates from this sample have been taken with the WB 6.5 m telescope and indicate that these systems are also likely to be lensed quasars; they will be discussed in future papers.

Section 2 of this paper briefly describes the new algorithm that led to the discovery of SDSS J0924+0219. Section 3 describes the follow-up observations and their results. In §4 we discuss some of the interesting aspects of this system. Finally, we present a summary in §5.

2. METHOD OF SELECTING LENSED QUASARS FROM THE SDSS QUASAR CATALOG

We now describe the manner in which SDSS J0924+0219 was selected as a gravitational lens candidate on the basis of the object parameters in the SDSS object catalog (Lupton et al. 2001). First, we selected objects that were confirmed to be quasars in the SDSS spectroscopic survey (see Richards et al. 2002 for details of the SDSS quasar target selection algorithm). We rejected quasars whose redshifts are less than 0.6 since many low-redshift quasars are extended objects (Schneider et al. 2002), making it hard to distinguish them from unresolved lensed quasars. Next, we restricted our lensed-quasar candidate sample using some SDSS catalog parameters, specifically the galaxy profile fitting likelihood. As the SDSS data are passed through the data reduction pipelines, each extended object is fitted with a set of possible galaxy profiles (Lupton et al. 2001) and labeled with the likelihood that each profile explains the data. These likelihoods are useful for searching for extended quasars, so we optimized our search criteria to use these values, based on our study of the first SDSS lensed quasar, SDSS J1226−0006.

This algorithm targets lensed quasars whose separations are approximately 1.0−2.5, because we empirically confirmed that lensed quasars whose separations are less than 1.0 do not have large “extended” parameters in the SDSS object catalog; we cannot distinguish these small-separation lensed quasars from single, unresolved quasars. For lensed quasars that have separations of more than 2.5, each lensed component should appear as a separate entity in the SDSS catalog. As a result of applying this algorithm to the approximately 10,000 SDSS quasars (in ~1100 deg²), we selected five lensed-quasar candidates. One of these five candidates is the first SDSS lensed quasar, SDSS J1226−0006, and another of these cases is SDSS J0924+0219. If the total lensing rate is roughly 0.1% of all quasars, then on the order of 10 lensed quasars are expected from the approximately 10,000 SDSS quasars that were known at the start of this work. About half of the lensed quasars should have 1.0−2.5 separations (Chiba & Yoshii 1999); therefore, the results of this algorithm are consistent with the theoretical estimate. Whether or not this selection algorithm is the optimal way to select moderate-separation lens candidates from the SDSS imaging data remains to be seen, since it could be biased toward lens systems like SDSS J1226−0006. However, the successful discovery of two lensed quasars suggests that it is a reasonable method to use for our initial lens search.

3. DATA ANALYSIS

3.1. Follow-up Observations

Photometric follow-up observations of SDSS J0924+0219 were obtained using the WB 6.5 m telescope. The data were taken on 2001 December 15 with u, g, r, and i filters, using the Magellan Instant Camera (MagIC, a 2048 × 2048 CCD camera); seeing was 0.55′′−0.75′′ FWHM, pixel size was 0.069′′, and exposure time was 300 s in each band. Each CCD frame was bias subtracted and flat-field corrected.

Additional spectroscopic data were taken on 2002 January 12 with the Keck II Echellette Spectrograph and Imager (ESI; Sutin 1997), using the MIT−LL 2048 × 4096 CCD camera and a 175 line mm⁻¹ grating. We used the echellette mode with a resolution of 11.4 km s⁻¹ pixel⁻¹, a spatial resolution scale of 0.153 pixel⁻¹, and a spectral range covering 3900–11000 Å. The exposure time was 1200 s. The slit direction was set so that two of the three components (components A and B, see below) were on the slit at the same time. The two components are separated by 1787 and the seeing was less than 1.0 FWHM; the two components are clearly distinct in the two-dimensional ESI image. The two spectra were extracted separately using the usual method of summing the flux in a window around each object and subtracting sky from neighboring windows on either side of the trace. The only difference from a single spectrum extraction was that we were careful to exclude the other object from the sky windows. There was no need (and no attempt) to fit the two spectra simultaneously because we cannot see any overlap along the slit in the two-dimensional ESI image. However, flux of component D (see below) actually affects the component A spectrum (with a slit width of 1.0′). We could not see it in the two-dimensional ESI image because component D is close to component A and is more than 2 mag fainter. The estimated contaminations are 6.0% of the flux of component A in the g band (4000−5500 Å), 6.8% in the r band (5500−7000 Å), and 7.4% in the i band (7000−8500 Å). We used a single slit position...
that included components A and B, which puts component G (see below) slightly off to one side. Since component D is much fainter (about 2 mag fainter than component A), it is not noticeable in the spectrum.

3.2. Photometry

The SDSS images (sky and bias subtracted and flat-field corrected) are shown in all bands in Figure 1. The total magnitudes of the five components, with statistical errors, are $u^* = 18.68 \pm 0.02$, $g^* = 18.43 \pm 0.01$, $r^* = 18.34 \pm 0.01$, $i^* = 18.09 \pm 0.01$, and $z^* = 17.98 \pm 0.03$.

In Figure 2 we show the full follow-up MagIC $r$ image, including nearby stars (a, b, and c) as well as SDSS J0924+0219. Figure 3 (top) shows the $u$, $g$, $r$, and $i$ images of SDSS J0924+0219 before the point-spread functions (PSFs) have been subtracted (hereafter original images) and the images of each band after the PSFs have been subtracted (bottom). We subtracted PSFs using stars from the original images in all bands. We used star a for the $u$ image, star b for the $r$ and $i$ images, and star c for the $g$ image. The “peak” flux and the center coordinates of stars a, b, and c and components A, B, and C were calculated by a single Gaussian fit (these results agree with the results obtained by the IMEXAMINE task in IRAF). We named the three stellar components “A,” “B,” and “C” according to their magnitudes, the center extended object component G, and the unknown component that remains after subtracting PSFs was named component D. The flux ratios between components A and B are $u = 0.47$, $g = 0.44$, $r = 0.43$, and $i = 0.43$, and those between components A and C are $u = 0.44$, $g = 0.43$, $r = 0.41$, and $i = 0.40$. Compared with the original images, both components G and D are much more prominent in the PSF-subtracted images (except for $u$). We show the reduced $\chi^2$ from the PSF subtraction in Table 1. The reduced $\chi^2$ of the $g$, $r$, and $i$ images of components A and C are large because component A has contamination from components G and D and component C has contamination from component G. We cannot see components D and G in the $u$ PSF-subtracted image. This fact suggests that component D is not a quasar but rather a galaxy. We give our estimated magnitudes and colors of the three stellar components and components G and D in Table 2. We used stars a, b, and c as the photometric standard stars using their SDSS catalog magnitudes and positions.

3.3. Spectra

Spectra of components A and B taken with ESI on Keck II are shown in Figure 4. Al iii, Si iii], C iii], and Mg ii emission lines are seen clearly; both components are quasars.

**Table 1**

| Object  | $u$  | $g$  | $r$  | $i$  |
|---------|-----|-----|-----|-----|
| Component A | 3.52 | 43.4 | 34.2 | 64.1 |
| Component B | 2.32 | 5.45 | 5.10 | 19.0 |
| Component C | 6.11 | 12.9 | 32.5 | 39.0 |
Fig. 2.—MagIC $r$ image of SDSS J0924+0219 with nearby stars. This CCD has four readout quadrants, which appear as four separate images in this figure.

| Object | Component | $u$    | $g$    | $r$    | $i$    | $u-g$ | $g-r$ | $r-i$ |
|--------|-----------|--------|--------|--------|--------|--------|--------|--------|
| A      | A         | 19.66 ±0.02 | 19.46 ±0.01 | 18.97 ±0.02 | 18.87 ±0.02 | 0.20    | 0.49    | 0.10    |
| B      | B         | 20.49 ±0.05 | 20.34 ±0.04 | 19.89 ±0.04 | 19.79 ±0.03 | 0.15    | 0.45    | 0.10    |
| C      | C         | 20.55 ±0.05 | 20.38 ±0.05 | 19.94 ±0.04 | 19.91 ±0.03 | 0.17    | 0.44    | 0.03    |
| D$^a$  | D$^a$     | >22.30     | 22.45 ±0.12 | 21.82 ±0.06 | 21.61 ±0.05 | ... 0.63 | 0.21    |
| G$^a$  | G$^a$     | >22.30     | 22.73 ±0.13 | 21.25 ±0.05 | 20.78 ±0.05 | ... 1.48 | 0.47    |
| Star   | a         | 20.80 ±0.01 | 18.06 ±0.01 | 16.68 ±0.02 | 16.03 ±0.01 | 2.74    | 1.38    | 0.65    |
|        | b         | 20.72 ±0.09 | 18.13 ±0.01 | 16.72 ±0.02 | 15.68 ±0.01 | 2.59    | 1.41    | 1.04    |
|        | c         | 23.15 ±0.06 | 21.01 ±0.04 | 19.47 ±0.02 | 18.57 ±0.02 | 2.14    | 1.54    | 0.90    |

Notes.—We used stars a, b, and c as photometric standard stars. The errors of components A, B, C, D, and G do not include the photometric uncertainties of these standards. The magnitude of component D is estimated using the flux integrated in the 20 kpc (corresponding to 50 pixels or about 3$''$7 for $z = 0.4$, assuming $\Omega = 0.3$, $\Omega_\Lambda = 0.7$, and $H_0 = 70$ km s$^{-1}$ Mpc$^{-1}$) diameter regions centered on each component location, after subtracting the other components. Components A, B, C, G, and D are identified in Fig. 3.  
$^a$ Components G and D are not observed in the PSF-subtracted $u$ image.  
$^b$ The upper limits of $u$ of components D and G are estimated by integrating the flux in the regions expected by the PSF-subtracted $i$ image after subtracting PSFs.
The velocity difference between the two is less than 100 km s\(^{-1}\), calculated using the Mg \(\text{II}\) emission lines, and the widths of their emission lines are in good agreement. We do not have a spectrum of component C, but its colors indicate that it is also a quasar. A photometric redshift can be computed for component C following Richards et al. (2001), assuming an \(i-z\) color of \(-0.025\). The resulting photometric redshift is \(1.33 \pm 0.20\), which is consistent with the redshifts of components A and B, \(z = 1.524\). The redshifts and emission-line widths are summarized in Table 3.

### 3.4. Astrometry

We calculated the celestial coordinates of components A, B, and C on the basis of the SDSS celestial coordinates of the three stars (Fig. 2, stars \(a, b, and c\)) common to the MagIC \(r\) image and the SDSS data. The separation between components was calculated as follows: between A and B, \(1.78 \pm 0.04\), between B and C, \(1.50 \pm 0.03\), and between A and C, \(1.14 \pm 0.04\). We also calculated the celestial coordinates of components G and D after subtracting PSFs. The results are summarized in Table 4.

### 4. DISCUSSION

SDSS J0924+0219 is certainly a lensed quasar because of its morphology (there is a galaxy between three quasars that are almost the same color) and the small differences in velocity and line widths between components A and B. However, even though there are no emission-line profile differences between components A and B, the ratio of the spectra of the two quasars is not constant with \(\lambda\); it steadily decreases from 0.7 at 4000 Å to 0.2 at 9000 Å, as shown in Figure 5. The flux of component D affects the spectrum of component A, but the estimated contaminations are not large (see § 3.1), and it would not dramatically change the spectrum of component A.

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Fig. 3.—Top: Original MagIC images of SDSS J0924+0219. Bottom: PSF-subtracted images. The open squares in the bottom panels represent the measured centers of components A, B, and C. We can clearly see the three stellar components (A–C) in all original images. We can also see the central extended object (G) and component D (at the upper left of component G) in the \(i\) original image (we can see them more clearly in the PSF-subtracted image). The central extended object (G) and the unknown fifth component (D) are at the upper left of component G in the \(i, r,\) and \(g\) PSF-subtracted image. However, no other components appear in the PSF-subtracted images. The magnitudes of component D are estimated to be about \(i = 21.6, r = 21.8,\) and \(g = 22.5\), and those of component G are estimated to be about \(i = 20.8, r = 21.3,\) and \(g = 22.7\). The pixel size of these images is \(0.069\), the seeing was less than \(0.75\), and the exposure time was 300 s.

Fig. 4.—Spectra of SDSS J0924+0219 components A and B taken with ESI on Keck II. Both components have Al \(\text{III}\), Si \(\text{III}\), C \(\text{III}\), and Mg \(\text{II}\) emission lines at \(z = 1.524\). There are some bad columns around 4500 and 4900 Å.
A. The difference in the flux density ratio between the two components indicates that the two quasars might not be from the same physical source. It is possible that the slit used for the Keck spectroscopic observation was not precisely aligned along the line between components A and B; combined with differential refraction, this could have produced a spectroscopic flux density ratio different from the photometric flux ratio. However, this cannot be the full explanation, since it cannot explain why the spectroscopic flux ratio is not smooth (Fig. 5).

Another possible cause for the differences in the spectra of these two components is that continuum variations of the source quasar combined with the differential time delay causes the wavelength dependence in the flux density ratio. Continuum variations are often seen in quasars (Trèvese, Kron, & Bunone 2001), and differences in flux ratios between lensed-component continua are seen in some cataloged lensed-quasar systems, e.g., HE 1104–1805 (Wisotzki et al. 1995) and FBQ 0951+2635 (Schechter et al. 1998). 22

Here we investigate whether the large differences between the photometric flux ratios (see § 3.2) and the spectroscopic flux density ratio could be caused by the continuum variations combined with the differential time delay. We estimate the time delay between components A and B using the SIS model, 23

\[ c\Delta t = (1 + z_l) \frac{D_A D_t}{D_{ls}} \alpha_E (\theta_+ - \theta_-) \]  

(Peacock 1999), where \( D_A, D_t, \) and \( D_{ls} \) are the angular size distances from observer to the source quasar, from observer to the lensing galaxy, and from the lensing galaxy to the source quasar, respectively, \( \alpha_E \) is the Einstein radius in arcseconds, and \( z_l \) is the redshift of the lensing galaxy. The observed separations from the center of the lensing galaxy are represented as \( \theta_+ \) and \( \theta_- \). We assume that \( z_l = 0.4 \), and the velocity dispersion of the lensing galaxy is 230 \( \text{km s}^{-1} \) (see below), and we adopt \( H_0 = 70 \text{ km s}^{-1} \) \text{Mpc}^{-1}, \( \Omega_m = 0.3 \), and \( \Omega_\Lambda = 0.7 \). Using these parameters, we determined a

\[ 22 \text{ Differential extinctions might also cause the differences in the flux ratios between the components of these two known lenses (Falco et al. 1999).} \]

\[ 23 \text{ We applied our SIS model to B1600+434, whose time delay is known to be about 50 days (Koopmans et al. 2000). Our calculation gave 35 days for this lensed quasar—in rough agreement with the observation.} \]

![Flux ratio between components A and B of SDSS J0924+0219. Although the flux ratio is not constant, the variations could be explained by the continuum variations combined with the differential time delay of each component and/or microlensing. There are some bad columns around 4500 and 4900 A.](image)

**TABLE 3**

| Element          | \( \lambda_{\text{obs}} \) (Å) | FWHM (Å) | Redshift |
|------------------|-------------------------------|----------|----------|
| Al \( \text{iii} \) (1857.40) | 4684.75 | 38.9 | 1.5222 ± 0.003 |
| Si \( \text{iii} \) (1892.03) | 4775.94 | 36.0 | 1.5242 ± 0.002 |
| C \( \text{iii} \) (1908.73) | 4815.97 | 48.5 | 1.5231 ± 0.001 |
| Mg \( \text{ii} \) (2798.75) | 7063.51 | 61.2 | 1.5238 ± 0.001 |

**TABLE 4**

**Astrometry for SDSS J0924+0219 and Nearby Stars**

| Object | R.A. (J2000) | Decl. (J2000) | AR.A. \(^a\) (J2000) | DDecl. \(^a\) (arcsec) |
|--------|-------------|--------------|----------------------|----------------------|
| Component |
| A       | 09 24 55.8293 | +02 19 25.365 | +0.0108 | +0.847 |
| B       | 09 24 55.8327 | +02 19 25.365 | +0.0142 | -0.944 |
| C       | 09 24 55.7659 | +02 19 24.691 | -0.0549 | +0.182 |
| D       | 09 24 55.8653 | +02 19 24.897 | +0.0468 | +0.388 |
| G       | 09 24 55.8185 | +02 19 24.509 | 0.0000 | 0.000 |
| Star |
| a       | 09 24 57.7258 | +02 18 44.566 | +1.9464 | -38.882 |
| b       | 09 24 55.1770 | +02 20 25.660 | -0.6024 | +62.212 |
| c       | 09 24 51.6797 | +02 20 19.861 | -3.9824 | +56.413 |

Notes.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds. Astrometry is from Fig. 3, based on the SDSS coordinates of stars a, b, and c. The errors of components A, B, C, D, and G (not including the absolute errors of stars a, b, and c) are 0.018, 0.042, 0.046, 0.123, and 0.083 pixel per coordinate (0”0012, 0”0029, 0”0032, 0”0085, and 0”0059 per coordinate), respectively.

\(^a\) Position relative to component G.
time delay of about 15 days. Quasars generally do not experience large variations, such as shown in Figures 4 or 5, in less than 15 days, and therefore, there is a significant possibility that additional phenomena cause the differences between the two components of SDSS J0924+0219.

One such effect might be microlensing. We do not see clear evidence of microlensing in either spectra (Fig. 4), but microlensing should be universal in quadruple-lens systems (Witt, Mao, & Schechter 1995); therefore, it is natural that one of the microlensing events happen to both components or to one of the two components causing a difference between them. If we suppose the same situation as that of Q2237+0305 (Huchra et al. 1985) the microlensing optical depth (Schmidt, Webster, & Lewis 1998) supports this fact. Furthermore, if there is another object that darkens component D or if component D is a second lensing galaxy (see discussion below), it might have an effect on the observed spectrum of component A; i.e., the reddening of component A could be larger than that of component B. However, this extinction should be time invariant (effectively), and therefore, we should see the same extinction in the photometric flux ratios, but we do not. Confirming spectra and direct imaging are needed to determine whether the differences between the spectroscopic and direct imaging flux ratios are real or an observational artifact.

Although the SIS model with an external shear (Kochanek 1991) predicts the existence of a lensed component whose amplification is as bright as the brightest of the other three lensed components, there are no stellar components except components A, B, and C that appear in all of the images (Fig. 3). Using the positions of components A–C and of lensing galaxy G (which of course might not be the only lensing galaxy) we can fit the SIS model with an external shear, with a projected potential of

$$\psi(r, \phi) = \alpha_E r + \frac{\gamma}{2} r^2 \cos(2\phi - 2\phi_\psi),$$

where $\alpha_E$ is the Einstein radius of the SIS model in arcseconds, $r$ and $\phi$ are the radial and angular components, respectively, of the angular position on the sky, and $\phi_\psi$ is the position angle of the shear, measured east of north. Fitting this model to the positions (but not the fluxes) of components A–C, we get $\alpha_E = 0^\prime 0850$, $\gamma = 0.065$, and $\phi_\psi = 173^\circ 65$, with a source position ($\Delta R.A., \Delta Decl.$) = ($0^\prime 025, -0^\prime 004$) relative to component G. This value of $\alpha_E$ corresponds to a velocity dispersion of 230 km s$^{-1}$ with the estimated redshift of the lensing galaxy (see the final paragraph of this section). The observed positions of components A–C, the observed position of component D, and the predicted positions of the lensed components are given in Table 5 below. With six constraints and five free parameters, it is no surprise that we obtain small residuals ($<0^\prime 04$) from the observed positions of components A–C. Although the flux ratios of observed components were not taken as constraints, the predicted flux ratios between components A and B and between components A and C are in agreement with the observations. The predicted position of the fourth lensed component (hereafter, component D) is shown in Figure 6. Figure 6a shows the image plane of this model, and Figure 6b shows the enlarged part of the PSF-subtracted $i$ image of Figure 3 with the measured positions of components A–C, component D, and the predicted position of component D’. Component D is separated by only about 0$^\prime$15 from the predicted position of component D’ (Fig. 6a, filled circle, and Fig. 6b, open circle). Also, the predicted position of component D’ is within the region occupied by component D (Fig. 6b).

These results suggest it is possible either that component D is (1) really the “missing” fourth lensed component or (2) the predicted fourth lensed component (D’) mixed with a foreground object that is obscuring the light from component D’. According to Schechter & Wambsganss (2002), microlensing causes the demagnifying (or vanishing) of the fourth lensed image at the “saddle point.” The difference between the expected magnitude and the observed magnitude is large ($\Delta m = m_{\text{predicted}} - m_{\text{observed}} = -2.7$), but this is marginally consistent with Figure 3 of Schechter & Wambsganss (2002). Furthermore, some reports in the literature indicate that millilensing and/or microlensing produce anomalous flux ratios of four-image gravitationally lensed systems (Subramanian, Chitre, & Narasimha 1985; Madau 2001; Keeton 2003; Kochanek & Dalal 2003). The second case is also likely. If there is a foreground dusty galaxy superposed on component D’, it could be obscuring and reddening the light from component D’. This might also explain why component D is bluer than component G; component D may have some contribution from component D’, which is expected to be relatively blue. The reduced $\chi^2$ of component D from the PSF subtraction in the $i$ image is 20.91, and it is comparable with the other stellar components (Table 1); therefore, there is a possibility that component D includes a stellar component. In addition to reddening by the foreground object, the demagnifying

### Table 5

| Component | Observed | Predicted |
|-----------|----------|-----------|
|           | $\Delta R.A.$ (arcsec) | $\Delta Decl.$ (arcsec) | Ratio ($X/A$) | $\Delta R.A.$ (arcsec) | $\Delta Decl.$ (arcsec) | Ratio ($X/A$) |
| A          | +0.162   | +0.847    | 1.00       | +0.1688   | +0.8446    | 1.00       |
| B          | +0.213   | -0.944    | 0.44       | +0.2209   | -0.9289    | 0.38       |
| C          | -0.789   | +0.182    | 0.42       | -0.7548   | +0.1868    | 0.41       |
| D          | +0.702   | +0.388    | 0.09       | ...       | ...        | ...        |
| D’         | ...      | ...       | ...        | +0.6532   | +0.4962    | 0.85       |

**Note:** Positions are relative to component G.

1 Mean ratio of all observed bands.

2 $X$ represents each component: A, B, C, D, and D’.

3 Predicted fourth lensed component.
an external shear restricted only by the positions of the other three lensed components. The observed position of component D is separated by about 0\" in the right panel correspond to the filled symbols in the left panel. The predicted position of component D was calculated using the SIS model with an external shear restricted only by the positions of the other three lensed components. The observed position of component D is separated by only about 0\" from the predicted position of component D', and the predicted position of component D is within the contours of component D. Component D, however, is too red to be a quasar (Table 2). Both panels are 3\" × 3\" and centered on the position of component G.

Two additional minor possibilities exist: (1) that component D is a second lensing galaxy and contributes significantly to the lensing potential, which would change the lensing model such that the predicted position of component D' is incorrect, and (2) that this lensing system has a very interesting lensing potential that produces only three lensed components. According to Keeton, Kochanek, & Seljak (1997), Kassiola & Kovner (1993), and Wallington & Narayan (1993) there are some cases in which nonsingular lensing potentials with large shears, large ellipticities, or large core radii produce only three lensed components. However, SDSS J0924+0219 cannot be explained by these standard lensing models, such as nonsingular lensing potentials with large shears, because components of a "standard" three-component lensing system are expected to be on the same side of the lensing galaxy in the nonsingular lens models (Kassiola & Kovner 1993; Wallington & Narayan 1993), while the three components of SDSS J0924+0219 are not on the same side of the presumed lensing galaxy (component G). Spectroscopy of image D is just one way for the question to be resolved. Higher resolution imaging, say with HST, may resolve it without any need for spectra.

According to Fukugita, Shimasaku, & Ichikawa (1995), a typical elliptical galaxy at 0.2 < z < 0.5 has 1.3 < g−r < 1.8 and 0.5 < r−i < 1.0, which are close to the estimated colors of component G (see Table 2). The estimated colors and the spherical appearance of component G, therefore, indicate that it may be an elliptical galaxy at 0.2 < z < 0.5. This would be the primary lensing galaxy of this lensing system. If the redshift of the lensing galaxy is 0.4, the 1\" separation of components A and B requires the velocity dispersion of the lensing galaxy to be about 230 km s\(^{-1}\) in the SIS model, while the Faber-Jackson law predicts 225 km s\(^{-1}\) from the i magnitude of this galaxy (i = 20.8). Here we assume that \(M_i = -21.3\), \(\sigma_i = 225\) km s\(^{-1}\) (Blanton et al. 2001; Kochanek 1996), \(\Omega_M = 0.3\), \(\Omega_{\Lambda} = 0.7\), \(H_0 = 70\) km s\(^{-1}\) Mpc\(^{-1}\), and the K corrections of i are 0.2 for a z = 0.2 elliptical galaxy and 0.4 for a z = 0.4 elliptical galaxy (Inada 2001). This result favors a redshift of 0.4 for the lensing galaxy and a velocity dispersion of about 230 km s\(^{-1}\).

5. SUMMARY AND CONCLUSIONS

Using a selection algorithm tuned to recover a previously discovered lensed quasar (SDSS J1226–0006), we have identified several additional lensed-quasar candidates from the SDSS data. Using follow-up observations with the Walter Baade 6.5 m and the Keck II telescopes, we confirmed that one of them, SDSS J0924+0219, is a lensed quasar. The redshift of the source quasar is z = 1.524. The maximum separation is 1\". The velocity difference between components A and B is very small, less than 100 km s\(^{-1}\). We can see the lensing galaxy directly in the original Magic i image, and we can see it more clearly in the PSF-subtracted images. The estimated colors and the magnitudes of the lensing galaxy are consistent with those of a typical elliptical galaxy at z = 0.4 with a velocity dispersion of 230 km s\(^{-1}\). We can see only a faint red component near the predicted position of the fourth lensed image (using the SIS model with an external shear). We consider that this faint red component is a fourth lensed component darkened and...
reddened by foreground objects and microlensing. To settle the issue of what causes the lack of the fourth quasar component, we need to obtain deeper and higher resolution images and more sensitive faint-object spectroscopy of component D.

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