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SUBARCSECOND OPTICAL IMAGES OF THE RADIO GRAVITATIONAL LENS B1152+199[1]

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ABSTRACT

We present *R*-band observations of the Cosmic Lens All-Sky Survey gravitational lens system B1152+199, obtained with the active optics system at the Telescopio Nazionale Galileo. Owing to the very good spatial resolution of the images (0″.6), the optical counterpart of the two quasar components and the lens galaxy have been clearly identified. Contrary to previous estimates, the new location derived for the lens is in excellent agreement with the lensing interpretation for the system. We estimate a time delay of about 30 h^{-1} days.

Subject headings: gravitational lensing — quasars: individual (B1152+199)

On-line material: color figure

1. INTRODUCTION

The gravitational lens system B1152+199 (Myers et al. 1999) was discovered in the Cosmic Lens All-Sky Survey (CLASS). In radio images, B1152+199 is a two-component system with a separation of 1″.6 and a flux ratio of ~0.33. Keck II LRIS spectra yielded a source redshift of $z_s = 1.0189 \pm 0.0004$ and, for the putative lens galaxy, a redshift of $z_l = 0.4386 \pm 0.0008$ (Myers et al. 1999). However, only one component was detected in the first optical observations. The undetected component was assumed to be greatly weakened by the effect of dust extinction. This fact renders B1152+199 very interesting for the study of the extinction law in the extragalactic domain. This study, based mainly on complex modeling (e.g., Gordon, Calzetti, & Witt 1997), is very limited at present (see, e.g., Pitman, Clayton, & Gordon 2000). Gravitational lenses allow a more direct derivation of the extinction law from the comparison between two differently reddened images of the same quasar (Nadeau et al. 1991; Malhotra, Rhoads, & Turner 1997; McLeod et al. 1998; Falco et al. 1999; Kochanek et al. 2000). In addition, this gravitational lensing system also seems to be very well suited to utilizing the time delay to estimate the Hubble constant (Myers et al. 1999). However, high spatial resolution images are required for any of these studies.

Recently, Toft, Hjorth, & Burud (2000) studied the extinction curve of the lens galaxy of B1152+199. They used optical images taken with the Nordic Optical Telescope (seeing ~1″) to infer the locations of the two compact components and the lens galaxy via a deconvolution algorithm. However, they did not reproduce the two-component configuration when the galaxy is at the position found in the deconvolved images.

In this Letter, we present new photometric observations of B1152+199 of very high spatial resolution (0″.6) that allow clear identification of the lens galaxy at a position that is in excellent agreement with currently used lens models. In § 2 we describe the observations and the data analysis. In § 3 we discuss the implication for the lensing interpretation of the newly derived galaxy position and summarize the main conclusions.

2. OBSERVATIONS AND DATA ANALYSIS

On 2000 March 29, we obtained *R*-band images with the 3.5 m Italian National Telescope Galileo (TNG) at the Canary Islands in La Palma, Spain. The detector was OIG, an optical camera equipped with a mosaic of two thinned and back-illuminated EEV 42-80 CCDs with 2048 × 4096 pixels^2 each. The pixel scale is 0″.144 (binned 2 × 2), the gain 1.6e^- ADU^{-1}, and the readout noise ~4e^- pixel^{-1}. The good weather conditions along with the active optics of the telescope provided an excellent seeing of 0″.6. We acquired five consecutive images, with exposure time of 120 s for the first one and 300 s for the following four. A final combined image with an equivalent exposure time of 22 minutes was obtained.

We used five stars, observed in the same CCD frame as the object, as point-source functions (PSFs) to perform the PSF photometry. We used a model with two pointlike sources for the quasar components and a de Vaucouleurs or exponential disk for the lens galaxy. The parameterized model had 14 parameters: positions and fluxes for the two quasar components (they were assumed to be unresolved) and the lens galaxy; effective radius $R_{\rm eff}$ (scale radius), ellipticity ϵ, and position angle for a de Vaucouleurs profile (exponential disk) to describe the galaxy morphology; sky background; and a Gaussian blur to improve the PSF match. The model, convolved with the PSF, was fitted to the image by adjusting its parameters to minimize the sum of the squared residuals using Powell's algorithm (as described in Lehár et al. 2000 and McLeod et al. 1998). The brightest star, located ~13″ southwest of the system, was the best PSF, but it was not saturated in only the shortest exposure. We focus our analysis on this shortest exposure, but we use all the PSFs and the combined image to estimate the error in our fits.

Despite the high brightness contrast and the small separation between the three components, given the superb seeing conditions, with our fits we found the two quasar components, with a relative separation in excellent agreement with the Very Large Array radio observations (Myers et al. 1999); the lens

[1] Based on observations made with the Italian Telescopio Nazionale Galileo operated on the island of La Palma by the Centro Galileo Galilei of the Consorzio Nazionale per l'Astronomia e l'Astrofisica at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias.

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TABLE 1
B1152+199: Relative Positions and R-Band Magnitude Ratios

ID	$\Delta\alpha$ (arcsec)	$\Delta\delta$ (arcsec)	Δm
A	$\equiv 0$	$\equiv 0$	$\equiv 0$
B	0.95 ± 0.02	-1.24 ± 0.02	4.1 ± 0.2
G	0.50 ± 0.05	-0.98 ± 0.05	3.5 ± 0.2

galaxy was found to be located $0''.52 \pm 0''.05$ away from the fainter quasar. The relative positions and magnitudes are listed in Table 1. As expected from such faint objects, we could not distinguish between a de Vaucouleurs or an exponential disk profile because both yielded almost identical fits and pattern residuals. The best parameters found for a de Vaucouleurs (exponential disk) profile were $R_{\rm eff} = 0''.5 \pm 0''.1$ ($0''.2 \pm 0''.1$), $\epsilon = 0.6 \pm 0.1$ (0.4 ± 0.1), and P.A. $= 40° \pm 20°$ ($30° \pm 20°$). However, given the low signal-to-noise ratio of the galaxy, a deep *Hubble Space Telescope* (*HST*) image is needed for a better description of the galaxy morphology. We show in Figure 1 the image of B1152+199 and the different components after subtracting our quasar and/or galaxy model. In the residual image, we can also see an extended feature close to the lens galaxy in the southwest direction. A possible interpretation is that it corresponds to a neighbor galaxy; however, the residual is too faint to reach a qualitatively significant conclusion, and it might be an artifact of our fit. The residuals around the brightest quasar component are due to an imperfect PSF subtraction. Because the peak residuals were less than 2% of the peak intensity of the source, they do not significantly affect our photometry.

The difference of 4 mag between the two quasar components is in good agreement with the photometry performed by Toft et al. (2000), confirming the high extinction of the system by dust in the lens galaxy reported by these authors. However, we find a different lens galaxy position, whose implications for the lensing interpretation are analyzed in the next section.

3. DISCUSSION AND CONCLUSIONS

Double-lensed quasars usually have an insufficient number of constraints to perform a detailed study of their mass distribution, and they are typically well fitted by several standard models. Lens models with more general mass distributions (see,

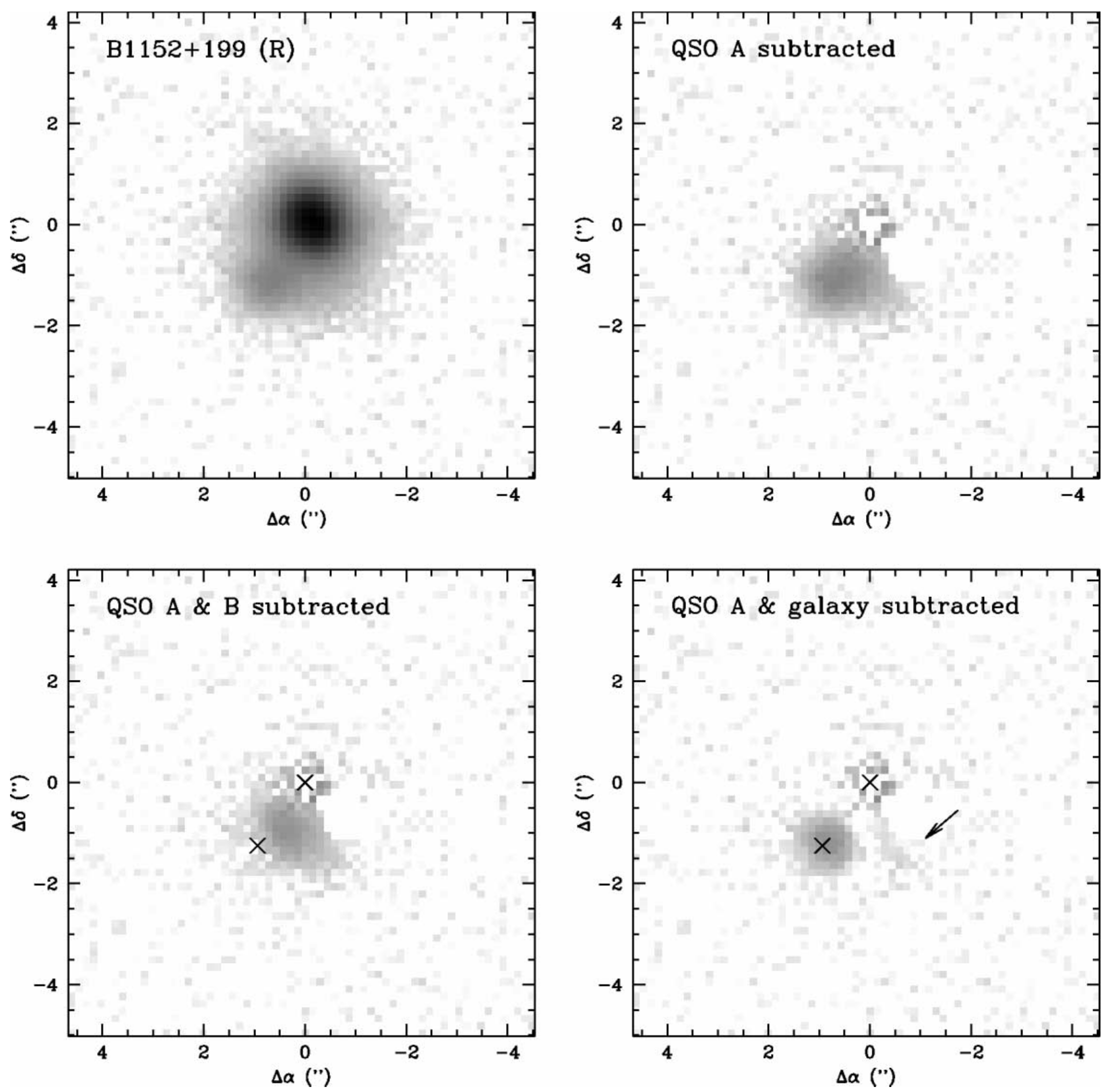

Fig. 1.—R-band image of B1152+199. *Top left panel*: Original image. *Top right panel*: Quasar A (brighter) has been subtracted. *Bottom left panel*: Quasars A and B (fainter) have been subtracted. *Bottom right panel*: Quasar A and galaxy have been subtracted. Crosses mark the locations of the radio quasar images. The arrow points at the extended feature commented on in the text. [*See the electronic edition of the Journal for a color version of this figure.*]

TABLE 2
B1152+199 Lens Models

Model	$\Delta\alpha$ (arcsec)	$\Delta\delta$ (arcsec)	b (arcsec)	ϵ ($1 - b/a$)	θ_ϵ (deg)	γ (shear)	θ_γ (deg)	$h\Delta t$[1] (days)	χ^2
SIS+γ	0.50 ± 0.05	−0.98 ± 0.05	0.83 ± 0.02	…	…	0.11 ± 0.03	−77 ± 6	30 ± 3	0
SIE	0.50 ± 0.05	−0.98 ± 0.05	0.81 ± 0.02	0.29 ± 0.07	−76 ± 6	…	…	32 ± 4	0

[1] The time delay is given in days for a flat ($\Omega_0 = 0.3$) cosmology and $H_0 = 100\ h$ Km s^{-1} Mpc^{-1}.

e.g., Muñoz, Kochanek, & Keeton 2001) are not suitable because they are underconstrained. With the current data, we fit only a singular isothermal ellipsoid (SIE) and its equivalent singular isothermal sphere (SIS) plus an external shear (SIE+γ) model. To constrain the lens model, we use the radio data for the quasars (Myers et al. 1999). The radio flux ratio is 0.33, and we assume a conservative minimum flux uncertainty of 10% per component due to the possibility of quasar variability or microlensing. The relative radio position for the quasars is ($\Delta\alpha = 0''.935 \pm 0''.005$, $\Delta\delta = -1''.248 \pm 0''.005$). We also add as a constraint our new measurement of the galaxy position (see Table 1). Both lens models fit ($\chi^2 = 0$) the current data, providing further evidence that with the new galaxy position, the system can be naturally explained as a gravitational lens system. Table 2 lists the best parameters for the lens models and their error bars. The predicted time delay is $32 \pm 4\ h^{-1}$ ($30 \pm 3\ h^{-1}$) days for the SIE (SIS+γ) model in a flat $\Omega_0 =$ 0.3 cosmology.

We summarize as follows:

1. The excellent seeing conditions (FWHM = $0''.6$) of our R-band images provided a clear optical identification of the radio lens B1152+199 discovered in the CLASS survey. Despite the high extinction (~3 mag in the R-band), we detected the two quasar components with a relative position in excellent agreement with the observed radio position (Myers et al. 1999). After the quasar subtraction, the lens galaxy was clearly detected. However, given the faintness of the galaxy ($m_R \sim 20$ mag) and its proximity to the fainter quasar, *HST* images are needed to obtain a better description of the properties of the lens galaxy.

2. The new estimate of the galaxy position, nearer the fainter quasar component than estimated by Toft et al. (2000), is in good agreement with both the extremely high extinction detected in this system (Toft et al. 2000) and the lensing interpretation. An SIE (or SIS+γ) lens model provided a perfect fit of the system with a time delay of $32 \pm 4\ h^{-1}$ days.

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Note added in proof.—Recently, Rusin et al. (MNRAS, in press [2002]) submitted for publication a paper on B1152+199 describing *HST V* and *I* imaging of this system. Their results are thus based on higher resolution data than ours, but they are in excellent agreement with our conclusions.