SUBARCSEC OPTICAL AND RADIO OBSERVATIONS OF THE GRAVITATIONALLY LENSED SYSTEM B1422+23.1

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Abstract

Optical observations of the multiple-component gravitational lens candidate B1422+23.1 using the 2.5m Nordic Optical Telescope and a MERLIN image at 1658 MHz are presented. The radio image at L-band and B, V, R and I band images with a 0.6 arcsec seeing resolve the components. These observations show that the brightness ratio of the components at optical bands is similar to those at radio bands. This strengthens the case for a gravitational lens hypothesis for the source.

Keywords: *Gravitational lensing quasar, radio map, optical image*

1. Introduction

The study of gravitationally lensed quasars has become an important astrophysical tool. For example, it has been useful in the investigation of the mass function of the lensing galaxies and the determination of important cosmological parameters like Hubble constant (see Morgan et al. 2003). The distinguishing characteristics of gravitationally lensed images include the preservation of fractional polarization and similar broad and narrow-band spectral properties. The lenses are achromatic in the sense that the brightness ratio of the lensed images is independent of observing frequency. In addition, the image configuration and shapes can also put constraints on the lensing hypothesis since mostly elliptical galaxies act as lenses.

B1422+23. 1, a multiple component quasar at a redshift of 3.62 is believed to be a gravitationally lensed system (Patnaik et al. 1992). The radio source has 4 compact components with maximum image separation of 1.3 arcsec. The Three brighter components, A, B, and C have similar polarization properties at 8.4 GHz. The radio spectrum between 5 and 8.4 GHz of A, B and C are similar, but that of D is different; since D is very weak its spectrum was not accurately determined. However, Lawrence et al. (1992) report infrared observations at 2.2μ where, in addition to the three brighter components, emission is detected at the radio position of D. Since the flux density of D at 2.2μ is uncertain, its relation to the other three components believed to be lensed, was unclear. It appeared from relative astrometry that emission had been detected from it. It is, however, necessary to establish the nature of all the four components in this source since it has important implications for the lens models.

In this paper, we present optical images of B 1422+23. 1 at B, V, R and I bands taken with the Nordic Optical telescope (NOT) at La Palma and a new MERLIN radio image at 1658 MHz. These images, which clearly separate the components and detect D in both optical and radio bands, provide strong additional evidence that D is the fourth image of a lensed system, B1422+23.1

2. Optical Observations

B1422+23, 1, was observed with the 2.5m Nordic Optical Telescope (NOT) at La Palma in Spain on the night of 1992 June 30-July 1 (UT) and 1993 April 22-23 (UT) using Stockholm CCD camera.

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The seeing, as measured from stellar images in different frames, was in the range of 0.55 - 0.60 arcsec (see Table 1). The CCD camera has 520 x 520 pixels and each pixel corresponds to 0.2 arcsec, which gives about three pixels per resolution. The integration time at each band was 300 sec. A calibration field, 1641 + 00 (F873 - 8, Stobie et al. 1985) was observed in V, R and I to calibrate the optical magnitudes. The initial data processing flat fielding and sky substraction were done in the STARLINK software package. The rest of the processing was done in NRAO AIPS SOFTWARE package. Figure 1 shows the raw I-band image of B1422+23.1. The image shows an elongated component at the position of components A and B. C and D are clearly resolved. All the images show the same structural characteristics; except in the B-band image, where component B appears to be fainter.

In order to improve the clarity of the images, we used maximum entropy deconvolution in AIPS software package. A bright star in the frame was used to determine the point spread function. The resulting image was restored to the same resolution as in the raw data.

We also restored the deconvolved images with higher resolution (0.4 arcsec) in order to separate A and B. These higher resolution images show the components at similar locations as in the radio maps (see section 2.2). We subtracted four Gaussian components at the radio positions and the residual map is consistent with map noise.

Table 1. Journal of observations. Absolute calibration of the B magnitude is not available

Filter	Obs date	Scan	Magnitude
V	30june92	300s	15.42 ± 0.03
R	30june92	300s	15.59 ± 0.06
I	30june92	300s	15.0 ± 0.1
I	23april93	300s	15.2 ± 0.1
B	23april93	300s	-
1658MHz	09apr93	12hrs	350.4±5mJy

3. Radio Observations

1422+23.1 was observed at 1658MHz on 09 April 1993 with the Jodrell Bank Observatory's MERLIN2 telescope array (Thomasson 1986). This was a 12-hr 'phase-referenced' track consisting of 8mins scans interleaved with 3mins scans on a point source 1424+240. A few scans on 0552+398 and 3C286 were used for amplitude (or flux density) and polarization calibration (see Baars et al 1977). The observations were made in spectral line mode with 15 frequency channels each of 1 MHz bandwidth. The data were processed in the NRAO AIPS package at Jodrell Bank.

The MERLIN map is presented in Fig 3 and has an rms noise level of 0.3mJy/beam. At 1658 MHz all the four components are detected as in the published high frequency maps (Patnaik et al. 1992). The component parameters are shown in Table 2.

Table 2. Component positions and parameters obtained from the MERLIN map at 1658 MHz; spectral indices, α were calculated from the total flux densities and against 5 GHz values in the Patnaink et al. 1992 (spectral index, α is derived in the sense that $S \sim \nu^{-\alpha}$)

Comp	R.A.(1950) h m s	Dec(1950) ° ′ ″	S_{total} mJy	S_{pk} mJy/b	sp index α
A	14 22 21.022	23 09 32.64	135.7	131.2	0.42
B	14 22 20.993	23 09 32.32	137.5	131.5	0.43
C	14 22 20.973	23 09 31.60	73.4	71.0	0.41
D	14 22 21.037	23 09 31.68	3.8	3.8	0.15

3. Results and discussion

Our new very sensitive radio image confirms the four radio components found in earlier observations at 5 GHz and 8.4 GHz made with MERLIN and VLA respectively (Patnaik et al. 1992).

The optical images (Fig.1) indicate the existence of the four components; component D is clearly detected in these images. These images are similar to those of Yee & Ellington (1994) who observed in r and g.

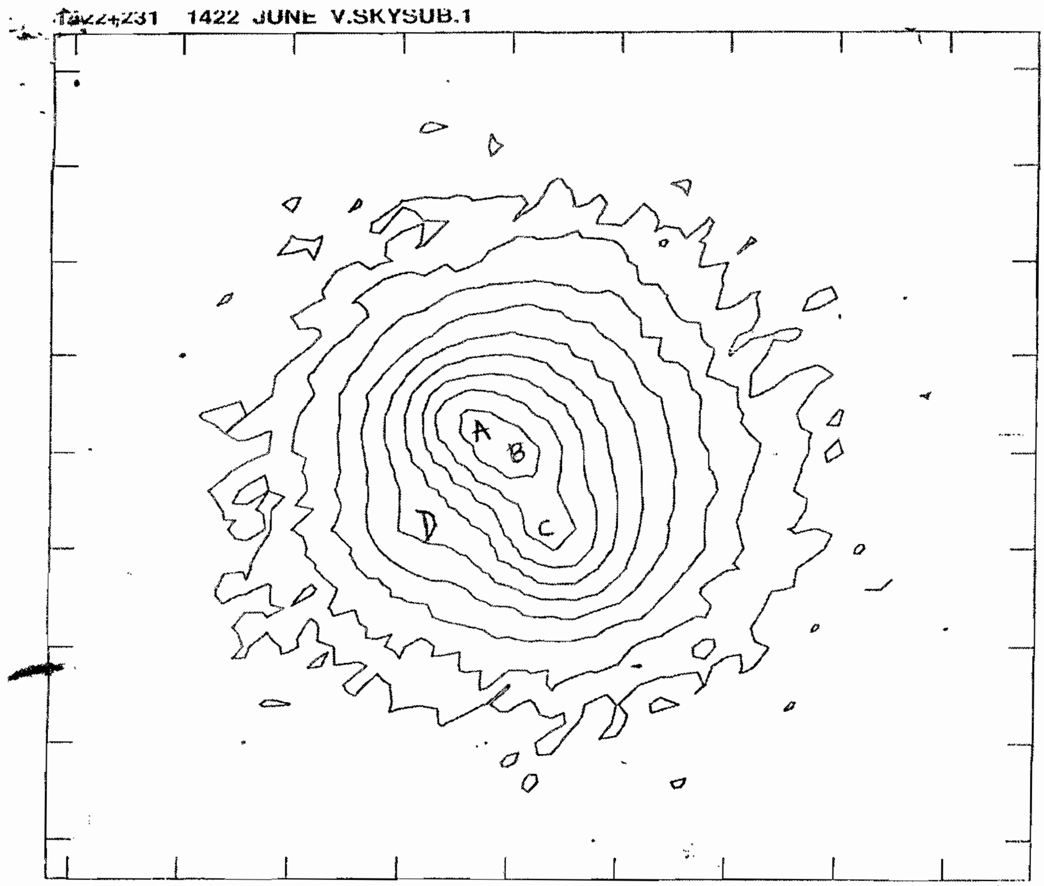

Fig. 1: The V-Band raw image of B1422+23.1 taken with the NOT with 0.55 arcsec seeing

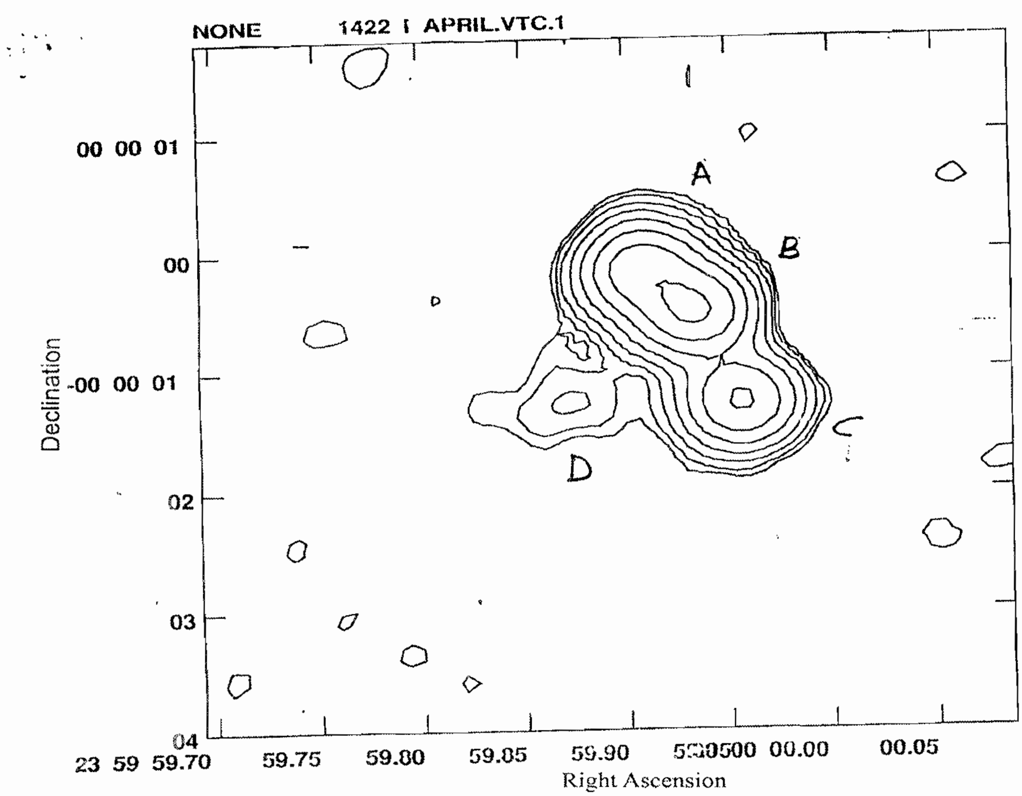

Fig. 2: The I - band deconvolved image of B1422 +23.1 with a resolution of 0.4 arcsec.

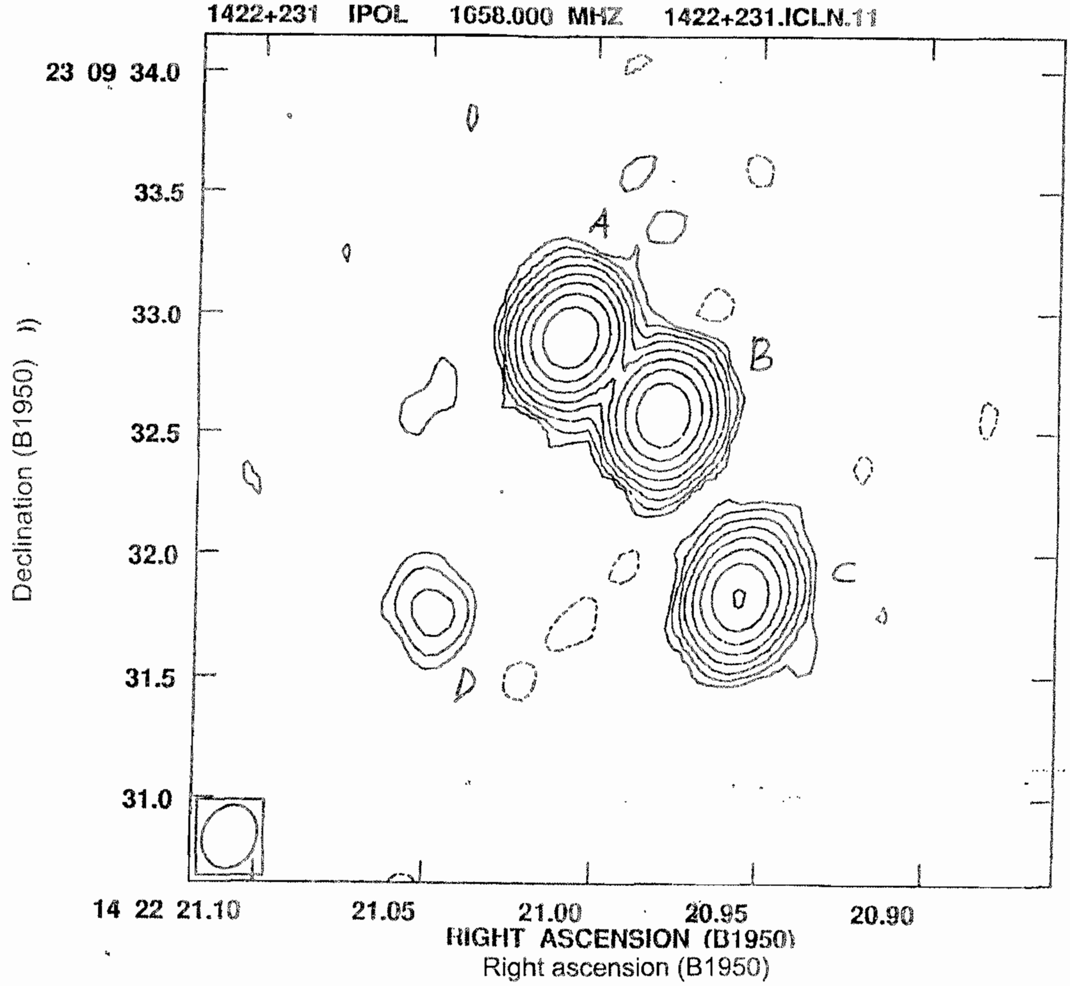

Fig. 3: MERLIN image at 1658MHz; the restoring beam is 173x137 mas (PA 23^0).
The contour levs are 1,1,2,4,8,16,32,64,...mJy/beam; the peak brightness is 131.2 mJy/beam.

The radio images also show the four components with flux densities which confirm the turnover in radio spectrum indicated by Patnaik et al. (1992); no polarization is detected at 1658 MHz. Patnaik et al. (1992) presented strong evidence that the components A, B and C are the product of gravitational lensing. Although D was suggested to be lensed as well, the evidence was not as strong. Since both C and D are well separated images we compare their brightness ratios at various bands to determine the nature of D (see Table 3). This comparison is clearly consistent with the fact that D is a lensed component as C. Some of the other multiple-component gravitational lenses recently observed include 0134-093 (Winn et al. 2002) which has 5 components.

Table 3. The magnitude and flux density ratios are with respect to component A. The I band values refer to June 1992 and April 1993 epochs respectively

	A	B	C	D
B	1.0	1.49	0.61	≤0.025
V	1.0	1.35	0.60	0.028
R	1.0	1.52	0.73	0.037
I	1.0	1.34	0.66	0.04
I	1.0	1.20	0.52	0.027
Radio	1.0	1.01	0.54	0.03

We have looked for the presence of the lensing galaxy in our images. The most probable redshift of a lens for an object at a redshfit of 3.62 is between 0.7 and 1.0. A normal elliptical galaxy at this redshift is expected to be between 21 to 23 magnitude in V. The total magnitude of B1422+23.1 is 15.3 at V. Taking the above brightness ratios for the components, the magnitudes estimated are 16.4, 16.2, 17.0 and 20.1 respectively for A, B, C and D in the V-band. We do not have the required dynamic range or the resolution to detect a 21 to 23 magnitude galaxy which could be really faint. Considering the lens geometries one expects the lens to be located near the weakest component, that is, between D and B, nearer to D. Moreover, one requires high resolution images to avoid the blending of light components. Therefore, this object is clearly a good candidate for more sensitive and higher resolution observations with the Hubble Space Telescope (HST).

The significance of the (June 1992) optical observations include the fact that they constitute about the earliest observations of this lens system. So, they hopefully provide a standard for further monitoring of the lens images for possible variability.

3. Conclusion

We have presented MERLIN images at 1658MHz and optical observations of the multiple component gravitational lens 1422+23.1 made with NOT in B, V, R and I bands. All the four components are detected in our images and the brighter components A, B and C have similar spectral indices. Although the spectral index of component D is different at radio bands, the brightness ratio between this component and component C is similar at both radio and optical bands; which is a strong additional evidence in favour of a lensing hypothesis for all the four components. Our observations, therefore, provide a crucial standard for further monitoring of this source especially at optical bands.

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