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The Structure of the Gravitational Lens System B1152+199

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Abstract: We have commenced a program to monitor the gravitational lens B1152+199 with the Australia Telescope Compact Array (ATCA) to search for variability of the lensed components with the goal of measuring the lensing time delay. As part of this program we made a 9 hour full-synthesis observation in June 2000 to derive a 'template' for model-fitting the shorter, multi-epoch, monitoring observations. We report here on the results of this full-synthesis observation and on three additional epochs of monitoring for time variation.

Keywords: gravitational lensing — radio continuum: galaxies

1 Introduction

The unexpected discovery in 1979 of the first gravitational lens, 0957+561 (Walsh, Carswell & Weymann 1979), provided further evidence supporting the General Theory of Relativity and opened the field of gravitational lens studies. Due to the magnification of gravitational lenses, fainter, more distant sources can be observed, and the intervening medium studied. Studies of lensing systems also provide an independent means of estimating the mass of lensing galaxies. In addition, a well characterised lensing system enables H_0 to be estimated (see, e.g., Koopmans et al. 2001). Optical and radio surveys of gravitational lenses are approaching the sensitivity required to confirm or reject the best-fit values for cosmological constants obtained from supernovae and other data (Myers 1999), and each well-determined lens system brings this goal closer to fulfilment. The largest uncertainty in most cases is in the model of the lensing system.

B1152+199 was discovered during VLA observations in 1998 as part of the Cosmic Lens All-Sky Survey (Myers et al. 1999). The lens produces two images of a quasar, separated by $1.56''$, with a flux density ratio at 8.46 GHz, at the epoch 1998.26, of 3.03 ± 0.03. Follow-up optical observations determined the background quasar, at $z = 1.019$, is being lensed by a foreground galaxy at $z = 0.439$ (Myers et al. 1999). A faint, steeper-spectrum radio source was also detected $23''$ from the lensed double, however this appeared to be unrelated (in a lensing sense) to the flat spectrum double. The relatively flat 8 to 15 GHz spectral index, -0.32 ($S \propto \nu^{\alpha}$), makes B1152+199 a strong candidate for time delay studies.

We are undertaking a program of observations of the gravitational lens B1152+199 in order to improve our understanding of the lens system as a step towards the ultimate aim of accurately determining H_0 once the time delay for the system has been measured. In Section 2 we present the results from our full-synthesis observation of the lens system, and the evidence for variability in the source components is assessed in Section 3. In Section 4 the results of preliminary modelling of the lens system are given.

2 Full-Synthesis ATCA Image

We undertook a full-synthesis, polarimetric imaging observation with the ATCA at 6.1 and 8.6 GHz on 24 June 2000 to obtain a 'template' model for use in model-fitting the snapshot observations, following the method successfully employed in determining the delay of the gravitational lens PKS 1830−211 (Lovell et al. 1998). The resulting 8.6 GHz image of the central region is shown in Figure 1, which reveals that the two lensed images of the quasar can be clearly distinguished. The results of model-fitting the two components are given in Table 1. The spectral index between 6.1 and 8.6 GHz, of $\alpha \sim -0.3$ ($S \propto \nu^{\alpha}$) is the same as that found by Myers et al. (1999) between 8 and 15 GHz. These observations do not have the resolution of the VLA A-configuration observations of Myers et al. (1999), however for the purposes of monitoring, the ATCA has the advantage over the VLA of providing regular access to ~6 km baselines throughout the year, yielding the required arcsecond resolution at 8.6 GHz. In contrast, for half the year the VLA has a maximum antenna spacing of 3.6 km or less which is insufficient to resolve the components of the lens.

Polarised flux was detected from the lensed components. The polarisation fraction is preserved in gravitational lensing (e.g. Schneider, Ehlers & Falco 1993). The percentage polarisation of component A is $(2.7 \pm 0.1)\%$ at

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Table 1. Model-fit flux densities and flux density ratios of Components A and B

Epoch	6.08 GHz			8.64 GHz		
	A (mJy)	B (mJy)	Ratio	A (mJy)	B (mJy)	Ratio
24 Jun 2000	53.01 ± 0.05	17.93 ± 0.05	2.96 ± 0.01	47.96 ± 0.05	16.14 ± 0.05	2.98 ± 0.01
02 Sep 2000	54.7 ± 0.3	18.6 ± 0.3	2.94 ± 0.06	47.3 ± 0.3	15.9 ± 0.3	2.98 ± 0.08
15 Sep 2000	55.0 ± 0.3	18.7 ± 0.3	2.94 ± 0.06	47.4 ± 0.3	15.9 ± 0.3	2.98 ± 0.08
27 Sep 2000	54.8 ± 0.3	18.1 ± 0.3	3.03 ± 0.07	47.7 ± 0.3	15.5 ± 0.3	3.08 ± 0.08

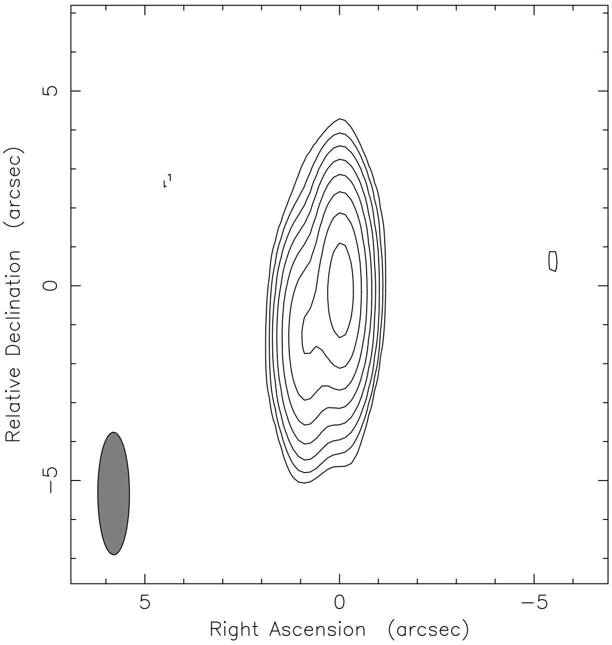

Figure 1 June 2000 ATCA image of B1152+199 at 8.6 GHz. The ATCA image is consistent with the two point-like images of the lensed quasar separated by 1.56″, as discovered by Myers et al. (1999). Polarimetry revealed a high rotation measure towards the weaker component south-east (i.e. to the lower left) of the brighter component at the origin of the figure. The map peak is 48 mJy/beam, and contour levels are −0.25, 0.25, 0.5, 1, 2, 4, 8, 16, and 32 mJy/beam. The beam (FWHM) is 3.2 arcsec × 0.8 arcsec at a position angle of 0.2°.

6.1 GHz and (2.4 ± 0.2)% at 8.6 GHz. For component B the percentage polarisation is (1.9 ± 0.4)% at both frequencies. Combination of the polarimetric data from both frequencies allowed the rotation measures to be estimated (with inherent phase-turn ambiguities). Component A has a rotation measure of ~70 rad/m^2 and component B has a rotation measure of (at least) ~560 rad/m^2. The errors are appreciable, ~100% for component A and ~20% for component B, but it is clear there is a much larger rotation measure towards component B. The implication is that the radiation forming the southern image of the background quasar passes much closer to the center of the foreground lensing galaxy.

This was confirmed by recent $UBVRIz'$ photometry of the system with the 2.56 m Nordic Optical Telescope (NOT) by Toft, Hjorth & Burud (2000), in which both lensed images and the lensing galaxy were detected. The position of the lensing galaxy was found to be almost coincident with the fainter quasar image, component B. Component B suffers heavy extinction, relative to the brighter quasar image, by dust in the lensing galaxy. As component A appears to suffer little extinction, Toft et al. (2000) measured the relative intensity ratios in the different bands to determine the extinction curve of the lensing galaxy.

The other result from our full ATCA synthesis was the detection at 6.1 GHz of a fourth source (‘component D’) in the field, on the opposite side of component C, as shown in Figure 2. The most natural interpretation from the alignment of these components is that C and D are hotspots in low surface brightness radio lobes. Component C has a peak flux density at this frequency of 1.9 mJy/beam, whereas that of component D is 0.3 mJy/beam (with a noise level of ~0.05 mJy/beam). Component D is thus both fainter and further from the center of the galaxy than component C. This is in contrast to expectations from the symmetric relativistic model of Ryle & Longair (1967), in which structural asymmetry is due solely to differences in light travel time. This model predicts that the fainter component would be closer to the core. However, as discussed by Arshakian & Longair (2000), the simple model excludes important environmental asymmetries and (probably less significant) intrinsic jet asymmetries, and a better understanding of such systems can be obtained by adopting an asymmetric relativistic model. We are planning further multi-frequency observations to unambiguously determine the rotation measures to the lensed images and, through higher sensitivity imaging, to study the spectral properties of the two radio lobes in more detail.

Although components C and D appear extended, we examined the corresponding positions on the NOT image to see if there were optical counterparts. To our surprise, there was an I ~ 18 star-like object in the vicinity of component C. Preliminary analysis of follow-up VLT observations, however, reveals that the optical object is offset by several arcseconds from the centroid of the radio emission, and furthermore, that it has a rather red color, typical (within photometric uncertainties) of an M-type star, indicating that the optical object is a foreground star. There was no object visible in the NOT image in the vicinity of component D.

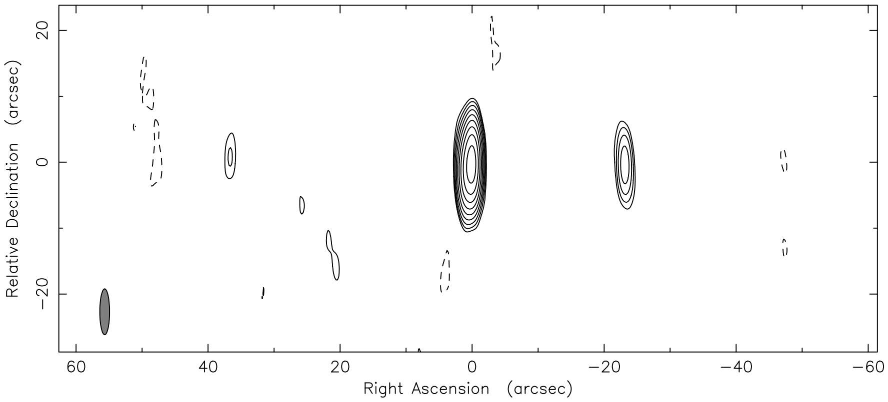

Figure 2 ATCA image of B1152+199 at 6.1 GHz. Component C, first detected by Myers et al. (1999), is to the right of the bright lensed components and component D, discovered in this June 2000 observation, is to the left. Component C was also detected in the 8.6 GHz ATCA observation, but component D was below the sensitivity limit. Contour levels are −0.25, 0.25, 0.5, 1, 2, 4, 8, 16, 32, and 64% of the map peak of 59 mJy/beam. The beam (FWHM) is 7.0 arcsec × 1.5 arcsec at a position angle of 0°.

3 Time Delay Determination

The results from three snapshot observations are presented in Table 1. The quasar has not varied significantly over the three months spanned by these observations. It is interesting, however, to compare these flux densities with those from April 1998 (at 8.46 GHz) of Myers et al. (1999): 52.27 and 17.23 mJy. From the joint ATCA/VLA observations of PKS 0405–385 (Jauncey et al. 2000), we expect absolute calibrations between the arrays to differ by a few percent at most, and not at the observed ∼10% level. The different resolutions are not the cause of the difference: the higher resolution (A-configuration) VLA observations have the *higher* component flux densities. These differences are suggestive of modest source variability over the two year interval between the observations, however no variation in the component flux densities was observed during an intensive monitoring campaign with the VLA in between June and November 1999 (Koopmans, private communication). We are attempting to quantify the differences in amplitude calibrations between the two arrays.

In addition to the component flux densities, we are able to determine fractional polarisations from the snapshot observations although the errors are naturally more appreciable. Variability in fractional polarisation, without necessarily accompanying flux density variation, has been shown to be an alternative method of determining the time delay (Corbett et al. 1996; Biggs et al. 1999).

Experience with the PKS 1830–211 system has emphasised the importance of identifying the starting epochs of flares and decays in the component light-curves, as these enable the time delay to be more tightly constrained (Lovell et al. 1998). Hence we are continuing our ATCA snapshots at 6 km array configurations, and supplementing this with observations in other configurations to monitor the total flux density. We planned initially to monitor the source at both 6.1 and 8.6 GHz, however we now consider it better to monitor solely at 8.6 GHz with twice the original bandwidth, as this increases our sensitivity, gives better angular resolution, and we expect variations to be somewhat more pronounced at the higher frequency.

4 Lens Modelling

As their PSF-subtraction and the deconvolution reductions yielded differing positions for the lensing galaxy, Toft et al. (2000) undertook preliminary modelling of the lens system to see which of the two positions was more plausible. The modelling revealed that the image configuration could not be reproduced using the position of the galaxy derived from the deconvolution, but that the position derived from PSF-subtracted images provided a reasonable fit.

Toft et al. (2000) modelled the lens system assuming a standard dark halo as the dominating lens mass, and derived a time delay of ∼60 days for the lensing system. No attempt was made to quantify the uncertainty in this value due to the degenerate nature of the problem resulting from the lack of observational constraints, with the main uncertainty being the unknown projected position of the lensing galaxy.

We have commenced modelling of this system using the `gravlens` code (Keeton 2001). Use of a Singular Isothermal Sphere with the galaxy position and mass allowed to vary gave acceptable fits to the positions and flux densities of components A and B. The resulting galaxy position was located at a ($\Delta\alpha$, $\Delta\delta$) with respect to component A of (0.69, −0.94), which is only ∼0.15 arcsec from the best-fit position from the Toft et al. (2000) modelling. The derived time delays for this model were 50.4 days for $\Omega = 1.0$, $\Lambda = 0.0$, and 52.6 days for $\Omega = 0.3$, $\Lambda = 0.7$, with an assumed H_0 of 75 km s^{-1} Mpc^{-1}. The lack of additional constraints on the system precludes any meaningful attempt to determine the range of possible delays at this stage.

5 Conclusion

We have commenced a monitoring program to measure the time delay in B1152+199. Initial synthesis observations revealed a high rotation measure in the weaker lensed component indicating the light from this component passes much closer to the centre of the lensing galaxy, which is confirmed by the optical studies of Toft et al. (2000). The full-synthesis observations also resulted in the discovery of a new component, component D, on the opposite side of the lensed images from the component C of Myers et al. (1999). These components are presumably associated with radio lobes from either the background quasar or the foreground galaxy. Monitoring observations with the ATCA between June and September 2000 show no significant variation in flux density, but there is some indication of variability between VLA observations in April 1998 and the start of our ATCA monitoring program. Preliminary modelling predicts a time delay of $\sim$50 days for the system, in agreement with the results of Toft et al. (2000), although further modelling will benefit from additional constraints from more recent HST and VLT observations.

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