Time delay measurements at the NOT

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Abstract.
With the aim of measuring time delays for a sample of gravitationally lensed QSOs we are conducting a long-term photometric monitoring project at the Nordic Optical Telescope (NOT). We present photometric light curves with preliminary time delays and deep high-resolution images obtained using the MCS image deconvolution algorithm.

1. Introduction

We are carrying out a photometric monitoring programme of gravitationally lensed QSOs with the main aim of measuring time delays between the lensed QSO components for as many systems as possible. The images are combined using the MCS algorithm to study properties of the lensing galaxies, such as their light distribution and positions relative to the QSO images. We will give a short description of two of our targets and present their preliminary light curves.

2. Observations and data reduction

The observations are obtained once a week at the 2.56-m NOT situated at La Palma, Canary Islands. The seeing typically ranges from $0\farcs7$ to $1\farcs3$. A pipeline

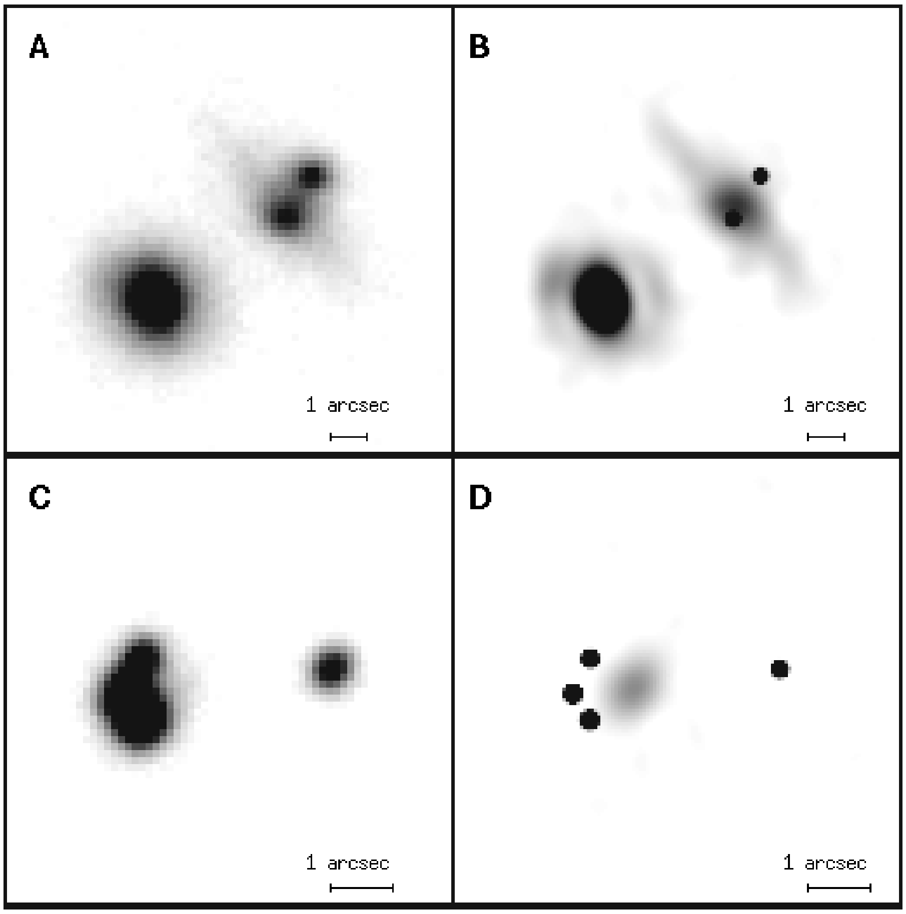

Figure 1. *A*: Stack of several I band frames of B 1600+434 from NOT. *B*: Deconvolved image with FWHM = 0.″38. *C*: Stack of I band frames of RX J0911.4+0551 from NOT. *D*: The deconvolved image with FWHM = 0.″2. North is up and East to the left in all the images.

has been developed for automatic data preprocessing so that all frames are bias, flat field, and fringe corrected in exactly the same way. The photometry is systematically performed with the MCS deconvolution algorithm (Magain et al. 1998). This method is particularly well suited for a monitoring dataset because of its ability to simultaneously deconvolve many dithered images of the same object (e.g., Courbin et al. 1998). In this procedure the total S/N in all the frames obtained at different epochs is used to determine the light distribution of the extended sources and the positions of the point sources (QSOs), since these parameters must be the same for all the frames. The intensities of the point sources are however allowed to vary from image to image, thus producing the light curve.

3. B 1600+434

The doubly imaged radio QSO B 1600+434 (Jackson et al. 1995) at $z = 1.59$ is lensed by an edge-on spiral galaxy (Jaunsen & Hjorth 1997) at $z = 0.41$. The angular separation between the two lensed QSO components is 1.″4. Fig. 1 shows the sum of all our individual frames and the deconvolved image obtained. Time delay observations and detailed modeling can constrain the mass distribution in the depicted edge-on disk galaxy. Unfortunately, the system is faint

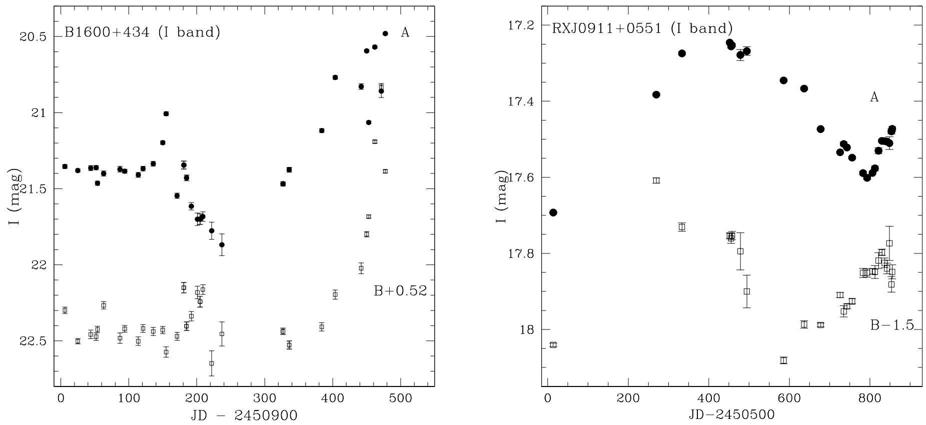

Figure 2. *Left*: I band light curve for B 1600+434. The plotted value for B is I(mag)+0.52 mag. *Right*: I band light curve for RX J0911.4+0551. A represent the integrated flux of the three A components, B is I(mag)−1.5 mag. The error bars indicate the photon noise.

in the optical ($I \sim 21$). Moreover, the B component lies on top of the lensing galaxy and is heavily obscured by dust extinction. Hence, a light curve of the B component must be obtained at very red wavelengths and the photometric accuracy is strongly limited by photon noise. However, the system is highly variable as suggested by Jaunsen & Hjorth (1997). Our I-band light curve of B 1600+434 is presented in Fig. 1. Detailed modeling of the system by Maller et al. (1999) predicts a time delay of 44 ± 5 days, A being the leading component ($H_0 = 60$ km s^{-1} Mpc^{-1}, $\Omega = 0.3$, $\Lambda = 0$). Our light curves are consistent with this value.

4. RX J0911.4+0551

The ROSAT source RX J0911.4+0551 ($z = 2.80$) was detected as a gravitational lens candidate by Bade et al. (1997). It is a quadruply lensed QSO with a maximum separation of $3\farcs1$ (see Fig. 1). External shear from at least one, and probably two, galaxy clusters must be included in the lens potential in order to reproduce the observed geometry of the system. The redshift of the lens galaxy(ies) is not yet known but an estimate of $z \approx 0.7$ is found from multicolour photometry of one of the cluster candidates (Burud et al. 1998). Detailed modeling of the system predicts that the B component is leading, and that the A components are delayed 200 ± 5 days assuming $z = 0.7$ for the lens plane and a $H_0 = 60$ km s^{-1} Mpc^{-1}, $\Omega = 0.3$, $\Lambda = 0$ universe (Kneib, personal communication). In Fig. 2 we show the I-band light curve of the integrated flux from the three A components and the B component offset by 1.5 magnitudes. No time delay estimate can be unambiguously determined from the present dataset. The A light curve appears tilted compared to the B light curve. One possible explanation of this could be long time scale variations due to microlensing in one of the A components, as is seen in Q0957+561 (Schild et al. 1991). Modeling this, in a first approximation, as a linear variation of A would make the curves consistent with a time delay of 200 days. The microlensing interpretation needs to be confirmed by multicolour photometry during the same time interval, and photometry of each of the three individual A components.

5. Conclusions and future work

We have presented preliminary results from our ongoing photometric monitoring of lensed QSOs at the NOT. All the data are reduced with our automatic pipeline, and the photometry is systematically performed with the MCS deconvolution. A few preliminary time delays have already been measured, and variability has been detected in additional lensed QSOs. We will continue our weekly observations in order to refine our preliminary time delays and to measure new time delays for several selected variable systems.

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