Robotic optical monitoring of a compact lens system: FBQ 0951+2635 in the *i* Sloan filter

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Abstract The quasar FBQ 0951+2635 is gravitationally lensed by an early-type galaxy. The presence of two close quasar images (A and B) is the most notorious consequence of this phenomenon. In this contribution, we describe an experiment on the variability of FBQ 0951+2635 using the Liverpool Robotic Telescope (LQLM programme). Our 100-day monitoring campaign in the *i* Sloan passband allow us to resolve both images and to produce individual light curves. There is no evidence of short-timescale extrinsic (e.g., microlensing) variability in the new records. Moreover, we measure an accurate *i*-band flux ratio (corrected by the time delay, but uncorrected for the galaxy contamination on B): $A/B = 2.74 \pm 0.02$ (1σ), which agrees with the *i*-band ratio of 2.8 ± 0.1 (1σ) from the SDSS frame of the system. At the red end of the optical continuum, the SDSS and LQLM experiments suggest the absence of a substantial extrinsic gradient on a timescale of a few years.

1 Introduction

FBQ 0951+2635 was discovered 10 years ago [7]. This is a double quasar consisting of two components (A and B) at redshift $z_s = 1.246$. It is gravitationally lensed by an early-type galaxy (G) at $z_l = 0.260$ [3]. Optical follow-up of FBQ 0951+2635 has been done in the current decade, e.g., imaging from the Sloan Digital Sky Survey (SDSS) [1] and a 2.5-year monitoring campaign at the Nordic Optical Telescope (NOT) [5]. Most monitoring campaigns focused on the *R* passband, and these efforts allowed to study the time delay and the extrinsic variability [5, 6]. The *R*-band time delay between both components (A and B) is of about two weeks, and there is evidence for *R*-band extrinsic variations, which were attributed to microlensing. Thus, the NOT *R*-band observations indicated the possible existence of a microlensing

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gradient of about 10 mmag/100 days, as well as a Gaussian microlensing event with amplitude of about 50 mmag and lasting about 100 days. Microlensing is caused by collapsed objects in the halo of the lensing galaxy G [2].

We included FBQ 0951+2635 as a key target in our Liverpool Quasar Lens Monitoring (LQLM) programme [4, 8]. A main goal was to study the short-timescale ($\sim$ 100 days) extrinsic variability in one of the reddest optical filters (*i* Sloan passband). We also wanted to check the performance of the 2m Liverpool Telescope in the *i* band when taking modest exposures of a compact lens system (A and B are separated by $1.1''$). The measurement of an accurate flux ratio (A/B) at the red end of the optical continuum was another main goal. In this proceedings, we present the LQLM observations and light curves (Sect. 2). In Sect. 3, we also report on the short-timescale variability and the flux ratio in the *i* band.

2 Observations and light curves

The optical frames of FBQ 0951+2635 were taken with the Liverpool Robotic Telescope (RATCam optical camera) between February 6, 2007, and May 31, 2007. Each nightly observation consisted of five exposures of 100 sec in the *i* band, using a dither cross pattern. Initial pre-processing included bias subtraction, trimming of the overscan regions, flat fielding, removal of unsuitable frames, cosmic rays cleaning, and defringing. Later, all frames in each night ($\leq$ 5) are combined, i.e., they are aligned and then averaged. There are two field stars near the lensed quasar: the bright star S1 and the relatively faint star S3 [5].

Neither our best combined frames in terms of seeing ($FWHM$ for S1) and signal-to-noise ratio (SNR for S3), nor our deep stacked frame (4.4 hours of exposure, $FWHM = 1.17''$, and $SNR = 413$) lead to detection of the lens galaxy (G). Moreover, we obtain meaningless results by using constraints on the relative position and brightness profile of G [5]. We think that a well-structured 2D signal from the very faint galaxy is absent in our frames. Thus, our instrumental photometry pipeline [8] only fits the instrumental fluxes of both components, which are described by stellar-like objects (PSF fitting photometry, using S1 as PSF star). Once the instrumental photometry is done, we obtain calibrated and corrected brightness records of A, B and field stars. The transformation (calibration-correction) pipeline incorporates zero-point, colour and linear inhomogeneity terms. This uses the SDSS photometric system [8]. In order to get accurate records in the *i* band, we exclusively apply the transformation pipeline to the combined frames with $FWHM < 1.5''$ and $SNR > 50$.

In Fig. 1 we display the final light curves of the lensed quasar (A and B components) and the S3 star, using some offsets to join together the three records. The faintest component B (filled triangles) and the reference star S3 (open diamonds) have similar magnitude ($\sim 18.5-18.6$), and the typical error in the S3 fluxes is 17 mmag (see error bars inside open diamonds). The typical uncertainty in the B fluxes is larger than 17 mmag, because B is located within a crowed region. Unfortunately,

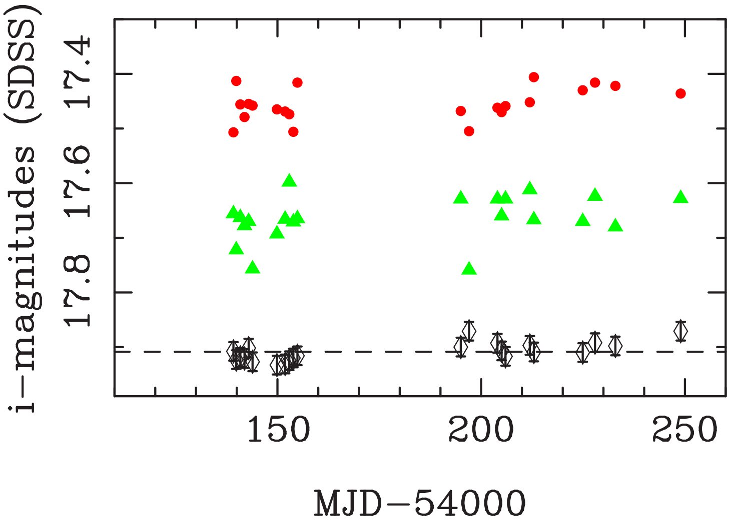

Fig. 1 LQLM light curves of FBQ 0951+2635: A (*filled circles*), B (shifted by − 0.9 mag; *filled triangles*), and S3 (shifted by − 0.6 mag; *open diamonds*).

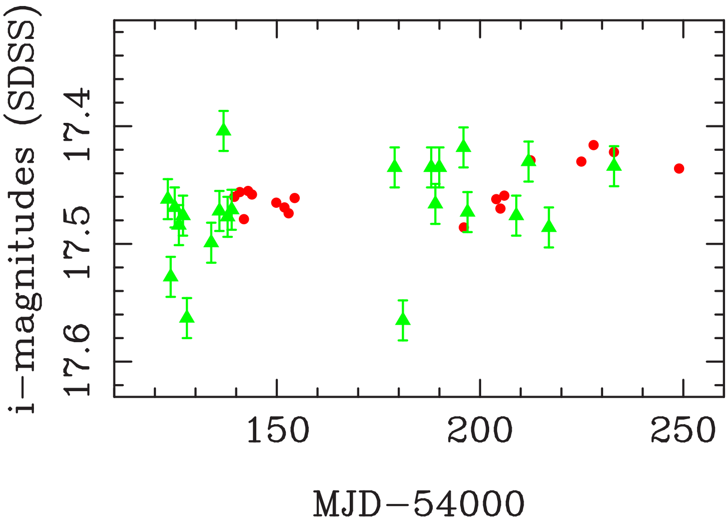

Fig. 2 Comparison between the A master record (*filled circles*) and the time- and magnitude-shifted light curve of B (*filled triangles*). See main text for details.

even using frames with $\langle FWHM \rangle \sim 1.2''$ and $\langle SNR \rangle \sim 80$, it is not possible to achieve 1−2% photometry for B (some deviations between adjacent nights are relatively large). In spite of these difficulties, we draw some interesting astrophysical conclusions in Sect. 3.

3 Variability and flux ratio

Four pairs of adjacent fluxes of A show significant differences (see filled circles in Fig. 1), so they are grouped to obtain a master light curve, i.e., an accurate (smooth) trend that reliably describes the underlaying short-timescale variability. This is depicted in Fig. 2 (filled circles). Before the gap, the quasar has a small level of activity. However, after the gap, there is a 50-mmag event. Previous *R*-band records exhibited similar variability on a timescale of a few months [5]. To gain perspective on the nature of the observed variability (A component), the B light curve is shifted in time (using the time delay of 16 days), and then is compared to the master light curve of A. From a global offset of 1.094 mag, we derive an optimal overlap between both brightness records. The time- and magnitude-shifted light curve of B is also included in Fig. 2 (filled triangles). The typical error in the S3 fluxes is used as a lower limit for the uncertainty in the photometric measurements of B (see Sect. 2). We find a clear agreement between the master curve of A and the adjacent fluxes of B, when these last fluxes are properly shifted in time and magnitude. Thus, there is no evidence of short-timescale extrinsic (e.g., microlensing) variability in our *i*-band experiment.

The new short-term light curves of FBQ 0951+2635 allow us to measure an accurate flux ratio (corrected by the time delay) in the *i* band: $A/B = 2.74 \pm 0.02$ (1σ). The high-quality SDSS frame of FBQ 0951+2635 in the *i* band ($FWHM = 0.75''$ and $SNR = 99$) also leads to a flux ratio $A/B = 2.8 \pm 0.1$ (1σ), in good agreement with the LQLM estimation. We point out that the uncertainty in the SDSS ratio incorporates both photometric and simultaneity errors. This last error is associated with the use of fluxes at the same time of observation, i.e., without time delay correction. As the SDSS frame was taken in December 11, 2004, we do not find any extrinsic gradient on a timescale of a few years. The previous positive detection (gradient in the 1999−2001 period) in the *R* band [6] is plausibly related to a long-timescale microlensing fluctuation, which turned on flat in late 2004 [9].

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