Light curves and variability of SBS 0909+532A,B

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Abstract: We use R–band optical frames of SBS 0909+532 taken at Calar Alto and Maidanak in 2003. Wise frames are also used to check the reliability of the fluxes of the field stars. We resolve the two components of the double quasar (A and B) and obtain the corresponding light curves, which show a moderate variability. We also measure the time delay of the system from χ^2 and D^2 techniques and 1000 synthetic light curves based on the observed records. Assuming that the quasar emission is observed first in B and later in A (in agreement with basic observations of the system), we obtain $\Delta\tau_{BA} = -\ 45\ ^{+1}_{-11}$ days (95% confidence interval; χ^2) and $\Delta\tau_{BA} = -\ 48\ ^{+7}_{-6}$ days (90% confidence interval; D^2). A by–product of the analysis is a rough estimation of both the Hubble constant (H_0) and the mean surface density of the main deflector ($< \kappa >$). As due to the current poor knowledge of the position of the main lens galaxy, the uncertainties in H_0 and $< \kappa >$ are indeed large. Thus, using the concordance cosmological model, the redshifts of the deflector and the source, basic astrometry of the system and the measured delay, our 1σ contraints are $H_0 = 82 \pm 41$ km s^{-1} Mpc^{-1} (isothermal profile) and $1- < \kappa > = 0.43 \pm 0.21$ ($H_0 = 70$ km s^{-1} Mpc^{-1}). While the constraint on the cosmic expansion rate is very weak in comparison with other lensing and not lensing determinations of this physical quantity, we infer the first measurement of the mean surface density in the lensing elliptical galaxy.

1 Introduction

The system SBS 0909+532 was discovered by Stepanyan et al. (1991). Some years later, a collaboration between the Hamburger Sternwarte and the Harvard–Smithsonian Center for Astrophysics resolved the system into a pair of quasars (A and B) with a direct R–band flux ratio (at the same time of observation) $\Delta m = m_B - m_A = 0.58$ mag and a separation of about 1."1 (Kochanek et al. 1997). From observations with the 4.2 m William Herschel Telescope, a Spanish collaboration got spectra for each component of the system. The data showed that the system consists of two quasars with the same redshift ($z_s = 1.377$) and identical spectral distribution, supporting the gravitational lens interpretation of SBS 0909+532 (Oscoz et al.

1997). Oscoz et al. (1997) detected a Mg II doublet in absorption at the same redshift (z_{abs} = 0.83) in both components, and they suggested that the absorption features were associated with the photometrically unidentified lensing galaxy.

In recent years, Lubin et al. (2000) indicated the possible nature of the main deflector (early–type galaxy) and confirmed its redshift ($z_d = 0.830$). Lehár et al. (2000) discovered the main lens galaxy between the components, which has a large effective radius, with a correspondingly low surface brightness. The colors of the lens are consistent with those of an early–type galaxy at redshift 0.83. This lens galaxy is closer to the brightest component (A), which is not in contradiction with SIS–like lens models, since the farther and fainter component (B) is stronger affected by dust extinction (e.g., Motta et al. 2002). Assuming a singular isothermal ellipsoid (SIE) model, Lehár et al. predicted a time delay $\Delta\tau_{BA}$ in the range [− 10, − 87] days (H_0 = 70 km s^{-1} Mpc^{-1}).

2 Observations, photometry and light curves

We have three different sets of frames for SBS 0909+532 in the R band. The first set of optical frames cover the period between 2003 March 4 and June 2. These observations were made with the 1.52 m Spanish telescope at Calar Alto Observatory (EOCA), Spain. During this first monitoring, exposures were taken every night when clear, what makes a total of 20 observing nights. The second set of observations include frames in February 2003 as well as during April–May and October–November 2003. The total number of nights is 18. In this second program the images were taken with the 1.5 m AZT−22 telescope at Maidanak Observatory (Uzbekistan). Finally, we use frames of SBS 0909+532 in 2003 taken with the Wise Observatory 1 m telescope. In this case, the pixel scale and the bad seeing (FWHM) do not allow to resolve the two components of the lens system, but these images are characterized by wide FOVs. This fact permits to do differential photometry between several pairs of field stars and, thus, to test the reliability of the Calar Alto and Maidanak records (stars).

Due to the small angular separation between the two lensed components (see Introduction), the photometry of the lens system is a difficult task. In general, aperture photometry does not work, so we must look for better approaches. When computing the fluxes of the lens system we use a PSF fitting method. The key idea of this procedure is to obtain the different fluxes we are interested in by using a PSF that comes from a bright star in the field common to all frames. Apart from a PSF star, we also need a reference star to do differential photometry and to obtain relative fluxes $y_A = m_A - m_{ref}$ and $y_B = m_B - m_{ref}$. The good behaviour of the reference star is usually checked by using a control star, so that the fluxes $y_{con} = m_{con} - m_{ref}$ are expected to agree with a constant level. For each night, we take all the available images and obtain the mean values of y_A and y_B. We also compute the standard deviation of the means as errors. Finally, we only consider relative fluxes with uncertainties $\leq$ 40 mmag.

We test different field stars and take the "a" and "b" stars as control and reference objects, respectively (Fig. 1 of Kochanek et al. 1997). It seems that both "a" and "b" are non–variable stars through 2003. Hence, our light curves are $y_A = m_A - m_b$ and $y_B = m_B - m_b$. We show our global R–band light curves of SBS 0909+532A,B in Figure 1. The red squares (Maidanak) and circles (Calar Alto) are the measurements of y_A, whereas the blue squares (Maidanak) and circles (Calar Alto) are the values of $y_B -$ 0.45 mag. We have 31 points for the A component (red symbols) and 26 points for the B one (blue symbols). The top panel of Fig. 1 contains the results in the winter–spring of 2003 and the bottom panel of Fig. 1 includes the results in the autumn of 2003.

Despite we are sure about the faintness of the lens galaxy in our individual frames, we

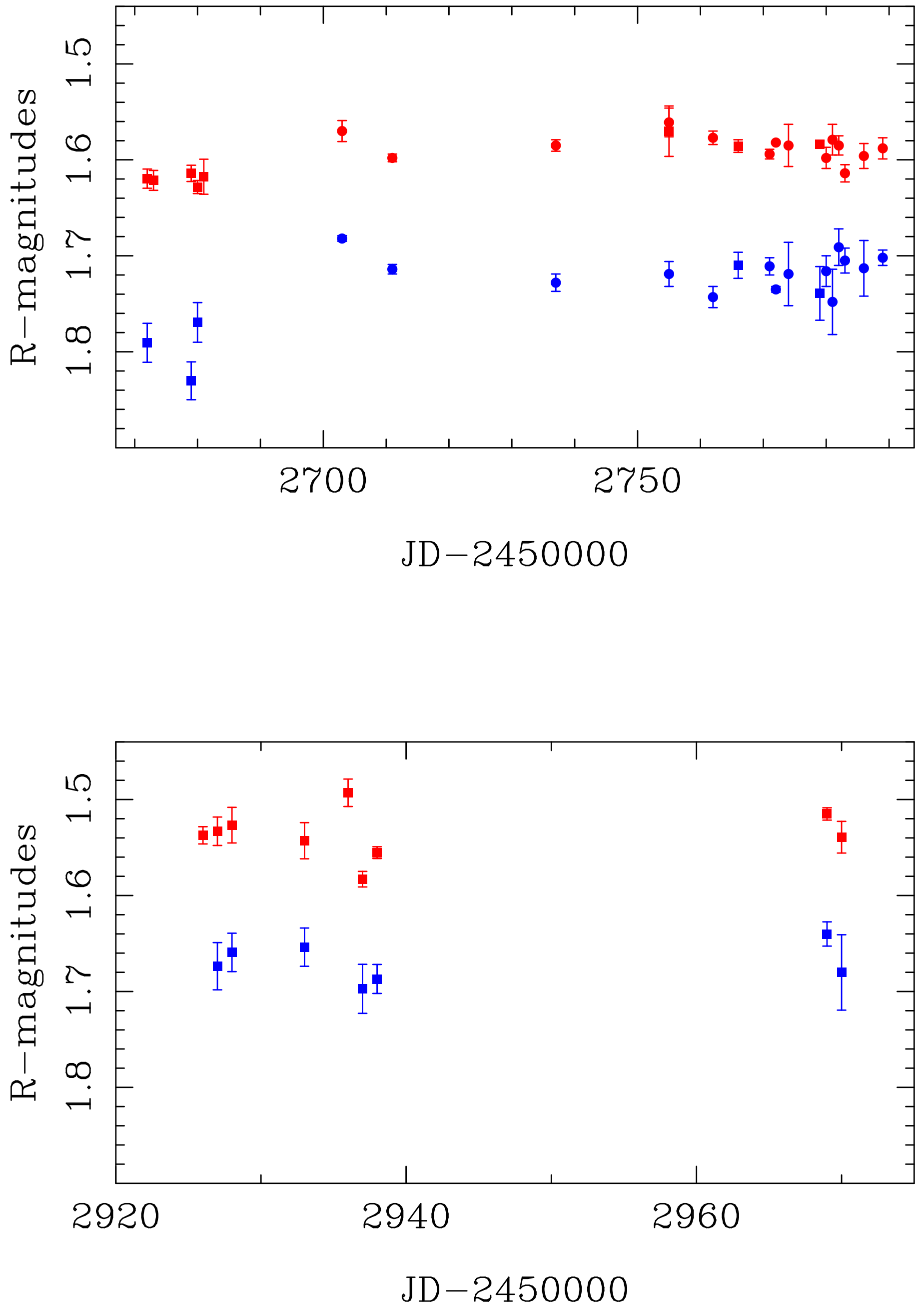

Figure 1: Global R–band fluxes of SBS 0909+532 in 2003. The red squares (Maidanak) and circles (Calar Alto) are the fluxes y_A, whereas the blue squares (Maidanak) and circles (Calar Alto) are the relative fluxes y_B- 0.45 mag. The top panel contains the results in the winter–spring of 2003 and the bottom panel includes the results in the autumn of 2003.

quantitatively check the contamination of the relative fluxes by galaxy light. To do that, we take some of our best Maidanak images (FWHM $\sim$ 1"). First, we combine the selected frames and derive a numerical model of the galaxy from a regularizing algorithm. To produce a more stable reconstruction, the real galaxy profile is assumed to be close to the Sersic profile. After that, the individual frames are fitted to a photometric model that includes the galaxy brightness (Koptelova et al. 2005). Therefore, we are able to infer clean relative fluxes of A and B (without contamination by galaxy light) and to compare them with the contaminated ones (from direct PSF fitting). As a result of the comparison, we report typical (averaged) contaminations of 18.8 mmag and 4 mmag for the A and B components, respectively.

3 Time delay and flux ratio

To calculate the time delay between both components of SBS 0909+532, we use the R–band brightness records corresponding to the winter–spring of the year 2003. The R–band time coverage in the winter–spring of 2003 (about 120 days) is longer than the time coverage in the autumn of 2003 (about 50 days). Thus, we focus on the data from day 2670 to day 2790, i.e., 22 points in the A component and 19 points in the B component (see the top panel of Figure 1).

Once we have the data set, a suitable cross–correlation technique is required. Here we use both the χ^2 minimization (e.g., Kundić et al. 1997) and the minimum dispersion (D^2) method (e.g., Pelt et al. 1996). Assuming that the quasar emission is observed first in B and later in A, or $\Delta\tau_{BA} < 0$ (in agreement with basic observations of the system), we infer a χ^2 measurement $\Delta\tau_{BA} = -\ 45\ ^{+1}_{-11}$ days (95% confidence interval) when doing 1000 *repetitions* of the experiment (synthetic light curves based on the observed records). When we measure the time delay of the system, we simultaneously derive the time–delay–corrected flux ratio (at the same emission time) in the R band. However, this quantity is contaminated by the light of the lens galaxy, and taking into account the weak contaminations of A and B (see the end of the previous section), the totally corrected R–band flux ratio is of 0.575 $\pm$ 0.014 mag. We remark that our final R flux ratio is in total agreement with the rough (uncorrected by the time delay and the contamination by galaxy light) measurement by Kochanek et al. (1997): 0.58 $\pm$ 0.01 mag. To properly determine a flux ratio, one must use clean fluxes at the same emission time, i.e., fluxes at different observation times and without contamination (Goicoechea, Gil–Merino & Ullán 2005). Only for particular cases (e.g., faint lens galaxy, short delay and moderate variability), it may be reasonable to use direct fluxes. From the D^2 technique, we obtain that $\Delta\tau_{BA} = -\ 48\ ^{+7}_{-6}$ days (90% confidence interval), which strengthens the conclusions from the χ^2 method.

4 Conclusions

We present a collaborative programme on the variability of the double quasar SBS 0909+532A,B. The R–band observations of the system and the field stars were made with three modern ground–based telescopes in the year 2003. After doing photometry on the images, we conclude that the "a–b" stars are non–variable sources, and we choose the "b" star as the reference candle. The point–spread function (PSF) fitting method permit to resolve the two components of the quasar and to derive the R light curves of each component. These new R light curves represent the first resolved brightness records of SBS 0909+532A,B. These curves show a moderate variability through 2003, and the observed fluctuations are promising for different kinds of future studies.

To estimate the time delay between the components of SBS 0909+532, we use an 120–day piece of the R-band brightness records as well as χ^2 and D^2 techniques. Assuming that $\Delta\tau_{BA} < 0$, a χ^2 measurement $\Delta\tau_{BA} = -\ 45\ ^{+1}_{-11}$ days (95% confidence interval) is inferred from 1000 *repetitions* of the experiment. We also derive the totally corrected R–band flux ratio: 0.575 $\pm$ 0.014 mag. From the dispersion method, we obtain $\Delta\tau_{BA} = -\ 48\ ^{+7}_{-6}$ days (90% confidence interval). With respect to the time delay, we report a value of about one and a half months (see both χ^2 and D^2 results), so our light curves rule out a delay close to three months. This last delay (around three months) has been favoured in a recent analysis (Saha et al. 2005).

Forty years ago, Refsdal (1964) suggested the possibility of determining the current expansion rate of the Universe (Hubble constant) and the masses of the galaxies from the time delays associated with extragalactic gravitational mirages. More recently, Kochanek (2002) presented a new elegant approach to the subject. For SBS 0909+532, although the redshifts are very accurately known and the time delay is now tightly constrained (or at least there is a first accurate estimation), the inaccurate position of the main lens galaxy does not permit to accurately measure the cosmic expansion rate (H_0) and the mean surface density of the main deflector ($<\kappa>$). In any case, we derive 1σ intervals: $H_0 = 82 \pm 41$ km s^{-1} Mpc^{-1} (isothermal profile) and $1- <\kappa> = 0.43 \pm 0.21$ ($H_0 = 70$ km s^{-1} Mpc^{-1}). These weak constraints suggest the necessity of new accurate astrometry of SBS 0909+532.

Acknowledgements

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