CCD PHOTOMETRY OF QSO 0957+561 A & B FOR THE PERIOD 1987–1992 USING LA PALMA ARCHIVE

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Abstract. We present the results of CCD photometry of the first gravitational lens system QSO 0957+561, obtained on the base of La Palma archive. Using cross-correlation analysis we have found the time delay between A and B quasar images to be 430 $\pm$ 15 days. Our photometry of QSO 0957+561 A & B gives additional independent confirmation of the recent results on the time delay about 425 days.

1. Introduction

Gravitational lensing gives us one more opportunity for the Hubble parameter H_0 estimation (Refsdal, 1964). We can determine H_0 via measuring the time delay between the quasar images, building a mass model for the lens and assuming a cosmological model (e.g. Kayser and Refsdal, 1983). The gravitational lens system mostly used for this purpose is QSO 0957+561 (e.g. Grogin and Narayan, 1996).

In this paper we determine the time delay for QSO 0957+561 using La Palma archive for the period 1987–1992.

2. Data Reduction

The data used have been achieved by GEC (mainly), RCA and EEV CCD chips at La Palma observatory (JKT telescope). They include object frames, zero exposure frames and flat fields in B and V bands. The object frames were processed in the usual way: mean overscan bias level subtracting, trimming, master zero exposure frame subtracting, dividing by the normalized master flat field and cosmic rays and bad pixels removing using ESO MIDAS astronomical package. We meas-

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TABLE I

Adopted weight-mean B and V magnitudes of stars 3 and 4.

star	B	V
3	14.79 ± 0.02	14.30 ± 0.03
4	14.89 ± 0.02	14.36 ± 0.03

ured the objects of interest through an aperture with a constant radius of $2''$ using DAOPHOT II under MIDAS (Stetson, 1987).

For each frame the quasar images' magnitudes were obtained as weight-average over the magnitudes derived with respect to stars 3 and 4 (Table I; we adopt the comparison stars notation given by Keel, 1982). The magnitudes of the comparison stars 3 and 4 were obtained as weight-average over the magnitudes quoted by Keel (1982) and Vanderriest *et al.* (1989). We measured star 5, suspected to be variable (Schild and Thomson, 1995), in the same way.

Multiple B and V magnitudes for a given night were weight-averaged to get the nightly mean for each band. We used 47 CCD frames in B band and 48 – in V band and have got out of them 31 points in B band and 36 – in V band for both images A and B. There are 26 common dates in both B and V bands. We reduced our B magnitudes to V band and then combined the data – we got the weight-mean V magnitude for each night. These combined V light curves were used to calculate the cross-correlation function. Our combined V light curves were transformed to the system of the published ones in R band (Shild and Thomson, 1995) for comparison. The obtained light curves together with the published ones are presented in Figure 1.

3. Results

We compared our combined and transformed light curves with the published ones and we found a very good correlation with them and an absence of any significant difference for the overlapping parts (see Figure 1). There is only systematic shift connected with the difference in the colour system. The night-to-night variability found is about or less than the standard deviation of our estimates – 1–3%. As an additional control for accuracy of our measurements we present the light curve of star 5, which despite the suspicion of Schild and Thomson (1995), did not show any significant variability in the period.

In this paper we used the cross-correlation method MCCF introduced by Oknyanskij (1994). We applied this method to find the time delay between the variation in A and B images. Using combined V light curves we found the time delay between

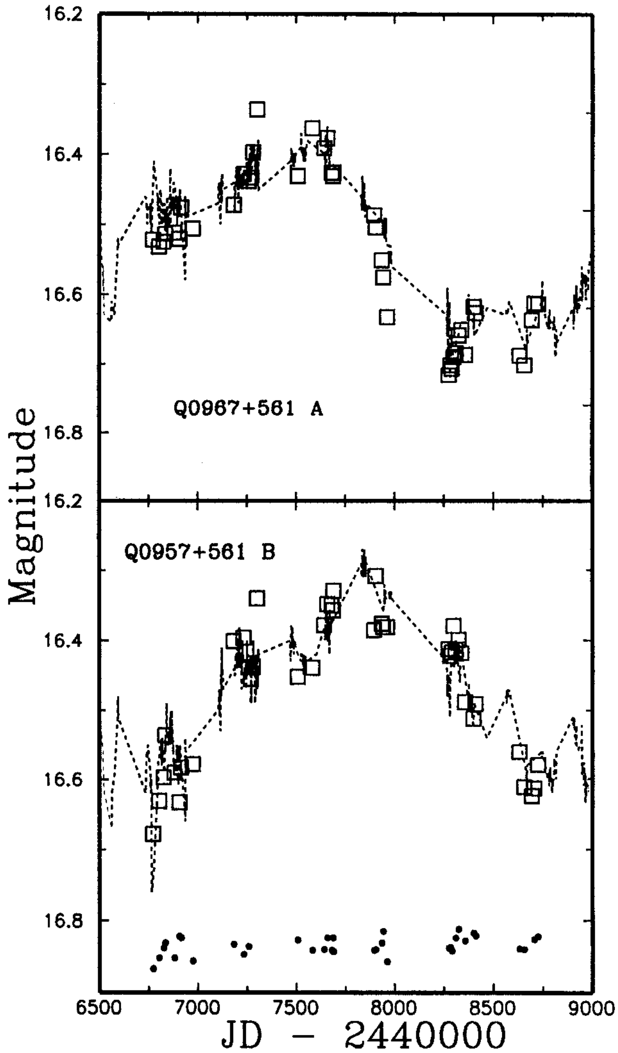

Figure 1. Combined and transformed to R band V light curves (boxes) of QSO 0957+561 A & B for the period 1987–1992 together with the published light curves (dashed line) for the same period. Points represent V light curve of star 5 transformed to R and shifted by +2.1 mag.

the variations in the images A and B to be 430 ± 15 days. The error was established through Monte Carlo simulations.

Cross-correlation of the published data for the same period has not shown as sharp peak as for our data. Moreover, we do not see any clear preferable result in the interval 400–500 days. The local maximum which can be noted near 406 days is rather a fluctuation only. Cross-correlation curves are presented in Figure 2.

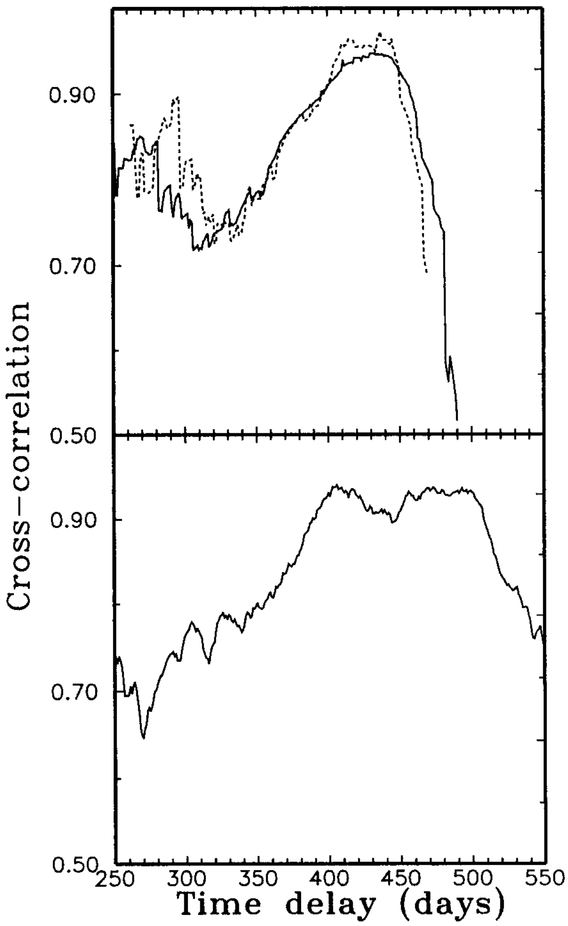

Figure 2. MCCF function for our data (upper panel) and for the published data (lower panel); for the dashed line MAX = 15 days, and for the thick solid line MAX = 30 days. MAX is the maximal possible distance between an interpolated point and the nearest to it real one (Oknyanskij, 1994). MCCF peak is sharper for our data rather than for the published data.

4. Discussion and Conclusion

Time delay determination for QSO 0957+561 has long and didactic history (see, for example, Oknyanskij, 1996). After about 10 years of controversy on the time delay, recent studies confirm delay of 400–440 days (see, for example, the discussion in Goicoechea *et al.*, 1998). Accounting for the errors quoted one can see that our result is in good agreement with this interval, as well as with the most recent results of 417 $\pm$ 3 days (Kundić *et al.*, 1997), 404 $\pm$ 26 days (Schild and Thomson, 1997) and 425 $\pm$ 17 days (Pijpers, 1997). Meanwhile, we have to note that our result obtained from independent data set definitely confirms that the time delay should be rather close to 425 days than to 525 days. However, we cannot formally reject the possibility the time delay to be in 500–600 days interval based only on our data since the spacing of the data does not give us this opportunity.

Using the SPLS and FGS models of Grogin and Narayan (1996), the velocity dispersion of 288 ± 9 km s^{-1} (Tonry and Franx, 1999) and our value of the time delay of 430 ± 15 days, we obtain $H_0 = 68 \pm 7$ km s^{-1} Mpc^{-1} using the SPLS model, and $H_0 = 70 \pm 7$ km s^{-1} Mpc^{-1} using the FGS model. The values of H_0 obtained from the analysis of the gravitational lens system QSO 0957+561 are in good agreement (within the errors quoted) with the results obtained from other gravitational lens systems (see Koopmans and Fassnacht, 1999). We should note that the last consideration of realistic models for the gravitational lens system QSO 0957+561 (Bernstein and Fischer, 1999) makes our estimations of the error about 10% for H_0 value rather too optimistic. As it was found by Bernstein and Fischer (1999) (despite the accuracy of the time delay measurement) the real error for estimations of H_0 is not less than 30%.

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