# A PROGRAM OF INTERNATIONAL COOPERATIVE INVESTIGATION OF GRAVITATIONAL LENS SYSTEMS

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Since 1997, a program of observations of gravitational lens systems (GLS) with the 1.5-m telescope of the high-altitude Maidanak Observatory has been carried out by joint efforts of seven institutions from five countries. The Q2237+0305, Q0957+561, SBS 1520+530, and other GLS were observed in VRI spectral bands using the TI 800×800, Pictor 416 and ST-7 CCD cameras with the aim to obtain the high-precise estimates of magnitudes and colours of the lensed quasar components at different epochs. The results of photometric image processing are presented. This work was made possible in part by Award No.UP2-302 of the U. S. Civilian Research and Development Foundation for the Independent States of the former Soviet Union (CRDF), and with the kind support of the Maidanak Foundation established in 1998 in Norway. Funding from the Uzbek-Ukrainian program of developing the Maidanak Observatory was also very important, as well as the 98–02–17490 and 1.2.5.5 grants from the Russian Basic Research Foundation. The Maidanak Observatory also participated in the successful Qouc-around-the-Clock program monitoring the Q0957+561 quasar continuously with 8 telescopes around the globe for 10 nights in January 2000.

## INTRODUCTION

Because of bending the light rays from remote quasars in gravitational fields of lensing galaxies situated close to the line of sight, the observer can see various more or less complicated patterns, depending on a particular arrangement of a source, a lens, and an observer with respect to the line of sight.

Very useful astrophysical information about a quasar, a galaxy and a medium between the quasar and the observer can be obtained from observations of GLS. The observable quantities are the brightness of quasar components in different wavelengths and at different epochs, the geometry of the object, and the brightness profile of the lensing galaxy. Since the intrinsic quasar brightness variation can be seen in different lensed images somewhat shifted in time, there exists a possibility to measure the time delays between the lightcurves of individual quasar images and thus, with a good knowledge of the mass distribution of a lensing galaxy, to determine the Hubble parameter. In addition to the brightness variations inherent in quasars, the individual lensed images sometimes change their brightness independently from each other. It happens in microlensing events when an object from the lensing galaxy passes close to the line of sight of the specific lensed image. The analysis of microlensing lightcurves allows to estimate the masses of microlenses and to examine the quasar spatial structure at extremely small angular scales.

## OBSERVATIONS

Most of GLS are faint and compact objects with a rather complicated spatial structure, therefore, their photometry is a difficult task demanding very good seeing conditions. That is why the excellent 1.5-m AZT-22 telescope on Maidanak Mountain known by its superb seeing conditions, high atmosphere transparency and large number of clear nights, was used for observations. The telescope was specially designed for high-resolution imaging and has a perfect optics of almost diffraction quality. The tower and the dome are equipped with a system of forced ventilation.

A professional TI 800×800 Pitt CCD and an amateur Pictor-416 cameras were used for observations in 1995–1998, at the scales of 0.13 arcsec/pixel and 0.16 arcsec/pixel, respectively. The images were usually taken in series, consisting of 5–10 frames, with an exposure of 3–5 minutes for a frame. Since 1999, a new ST-7 CCD camera provided by the Maidanak Foundation has been used. It is sufficiently linear and has rather good parameters, which made possible to increase the accuracy of photometry. About 10 gravitational lens systems were observed in V, R and I spectral bands during 1997-99 with these cameras. A new large professional CCD camera is expected to be installed at the 1.5-m telescope this year. The camera was ordered by the Maidanak Foundation in the laboratory of Copenhagen University, under supervision of Prof. Andersen who had kindly agreed to build it free of charge.

### SBS 1520+530

The SBS 1520+530 system was identified as a gravitationally lensed BAL quasar in 1996 in spectroscopic observations with the 6-m BTA telescope [2]. The spectra of the A and B components separated by approximately $1''\!.5$ are almost identical [2], and give the same redshifts of about 1.855 for both images. The third, much fainter, NW component located at about $2''\!.5$ to the north-west from A, is almost the same in its colour. The fourth star-like object (SE hereafter) which is even fainter and redder than NW has been also discovered at about $4''\!.5$ to the south-east. These two objects are supposedly the foreground stars.

Table 1: VRI magnitudes of SBS 1520+0305 (July 1998)

| Component | V | R | I |
|---|---|---|---|
| A | 17.98 ± 0.02 | 18.02 ± 0.02 | 17.77 ± 0.02 |
| B | 18.72 ± 0.05 | 18.72 ± 0.06 | 18.52 ± 0.04 |
| NW | 19.30 ± 0.08 | 19.24 ± 0.08 | 19.08 ± 0.12 |
| SE | 20.49 ± 0.10 | 19.95 ± 0.10 | 19.02 ± 0.09 |

Crapmton *et al.* [3] reported a discovery of a faint ($19^{m}\!.2$ in H band) object located $0''\!.4$ from the B component. Supposing it is a lensing galaxy, the authors of [3] predicted its R magnitude of about $21^{m}\!.6$.

Our observations in VRI bands made with the TI 800×800 CCD camera on July 18–20, 23, and 28, 1998, on Maidanak are presented in Table 1. Since there were no significant changes in the components brightness from night to night during this time period, the averaged magnitudes are shown in this table. The image of a 17-magnitude star situated $25''$ to the north-east from the object was used for the PSF estimation.

Table 2: Relative magnitudes of SBS 1520+0305 components in R band at different epochs

| Component | 1996, [2] | 1997, [3] | Maidanak, July 1998 | Maidanak, July 1999 | Maidanak, Sept.1999 |
|---|---|---|---|---|---|
| A | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| B | 0.65 | 0.66 | 0.70 | 0.78 | 0.79 |
| NW | 1.17 | 1.25 | 1.22 | 1.16 | 1.17 |
| SE | 3.05 | – | 1.95 | 1.95 | 1.93 |

The photometry of R images taken with the new ST-7 CCD camera in July 1999 (four dates), and in September 1999 (five dates) was also made. Comparing these data with those of previous measurements, [2, 3], the photometric changes in the system can be seen from Table 2 where the relative magnitudes (with respect to the A component) are presented.

### PHOTOMETRY OF Q0957+561 ("FIRST LENS")

This double quasar, which is the first object identified as a gravitational lens system, demonstrates variability in optical and in radio wavelengths and thus is a good candidate for the Hubble constant estimation. The time delay of 417 days in optical wavelengths is now considered to be accurate to better than 1%, giving the value of a Hubble parameter of $63 \pm 12\,\mathrm{km/(s\ Mpc)}$.

In January 2000, the observations of Q0957+561 with the 1.5-m Maidanak telescope were fulfilled in the framework of the International round-the-clock monitoring campaign launched by Prof. Schild. The data containing over 500 Mb were taken on Maidanak during 10 days in January. These have been reduced and can be seen plotted on the project home page:
*http://cfa-www.harvard.edu/~wcolley/Q0957/newsletter000831.html.*
On these plots, the Maidanak (grey) data importantly contribute to the observed continuous brightness curve and show no systematic problems. The second run is expected to start in March 2001.

**VRI PHOTOMETRY OF Q2237+0305**

The Q2237+0305 gravitationally lensed quasar (the Einstein Cross) constitutes one of the most impressive effects of gravitational lensing phenomenon. Four images of a distant quasar are arranged almost symmetrically around the nucleus of a lensing galaxy within a circle of less than $2''$ in diameter.

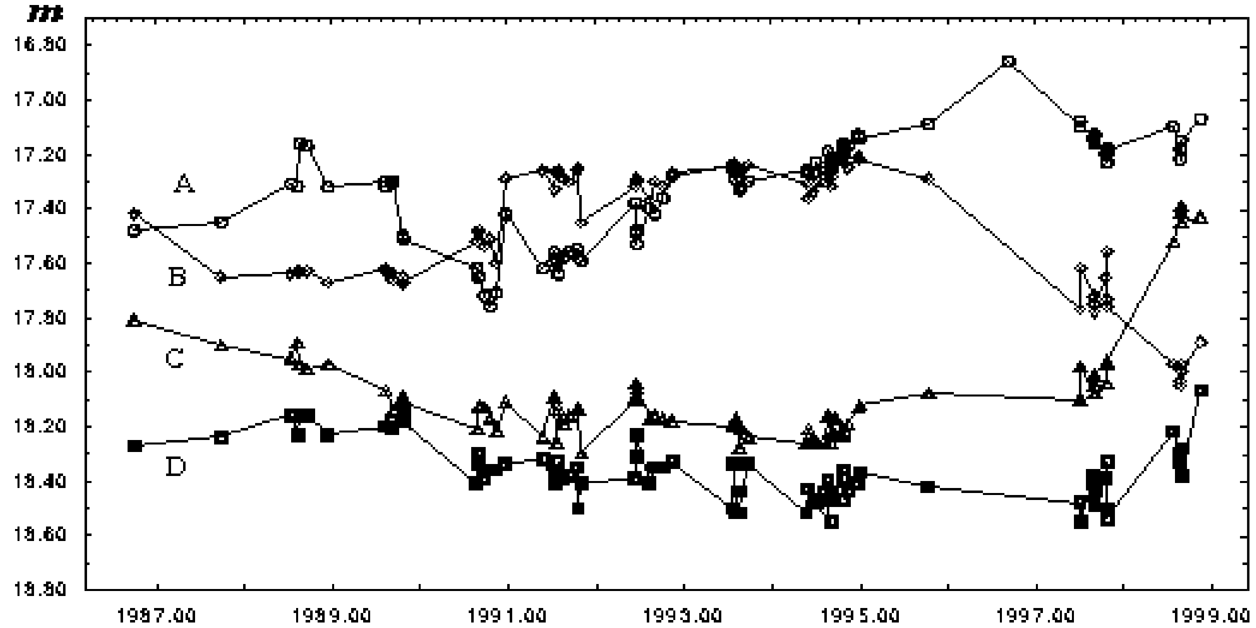


Figure 1: Historic lightcurves of Q2237+0305 components

In this work, the results of Q2237 photometry in the R band for 12 dates during 133 days in 1997, and for 15 dates during 115 days in 1998 are presented, as well as the results of VRI photometry in 1997–1999. In Fig. 1 historic lighcurves of the Einstein Cross components in the R band are presented. The lightcurves, composed of all available data, demonstrate high microlensing activity which is typical for this system. In this picture, the data from 1995 to 1998 were obtained on Maidanak. A noticeable increase of the component C brightness is the most important event of the 1997–98 time period. In 1998 it exceeded B in brightness for the first time since the system discovery, while the latter became 0.8 magnitudes fainter as compared to 1995. Our photometry is in a good agreement with the results of the Einstein Cross monitoring in the V band, presented in [9].

Even the first multicolour photometry of the Q2237+0305 system have shown that the components noticeably differ in their colour [10]. The further observations, in particular [6] and the observations of 1995 from Maidanak [7] demonstrated that the colour of the components might have changed in time. That is why the multicolor observations of Q2237+0305 were continued in 1997, 1998 and 1999 on Maidanak [4].

Below we analyse the relative colours which are less sensitive to the difference in photometric systems and the errors of zero-pointing as compared to the absolute colours, and thus can be used for comparing and a qualitative analysis even for different bases in various observational datasets. The result of such a comparison can be seen from Table 3, where the relative colours of the components calculated from the results of our observations and with the use of the available multicolour photometry of other observers are presented. The table shows that colour variations in the Q2237 system are real and significant, at least for the B and C components. First of all, an obvious reddening of the B component with a decrease of its brightness in 1998 should be noted. At the same time, the C component became more blue in 1998 when a prominent increase of its brightness took place.

Table 3: Variations of relative colours in the Q2237+0305

| Epoch, colour base | A | B | C | D |
|---|---|---|---|---|
| 1987, (g-i), [10] | 0.00 | 0.08 | 0.33 | 0.19 |
| 1990, (U-R), [6] | 0.00 | 0.03 | 0.24 | 0.42 |
| 1995, (V-I), [1] | 0.00 | −0.08 | 0.12 | 0.15 |
| 1995, (V-I), [7] | 0.00 | −0.12 | 0.23 | 0.08 |
| 1997, (V-I), [4] | 0.00 | −0.12 | 0.09 | 0.14 |
| 1998, (V-I), [4] | 0.00 | 0.04 | −0.12 | 0.25 |
| 1999, (V-I), Maidanak | 0.00 | 0.08 | −0.15 | 0.26 |

Unfortunately, the available data don't permit to fulfill a quantitative analysis and to trace, for example, a relationship between the colour and brightness variations. Sometimes a qualitative dependence can be noticed, *e.g.*, when a component increases its brightness often becomes more blue at the same time. There are two explanations of the observed colour variations in GLS: either (1) the value of light extinction by the lensing galaxy matter changes in time or (2) microlensing reveals the fact that the effective size of the quasar is different in various wavelengths. The last explanation were proposed in 1991 by [8]. More precise and detailed lightcurves of the longer duration, taken in several spectral bands are needed to choose between the two explanations.

## CONCLUSIONS

The data presented here shows great potentials of the Maidanak site and the 1.5-m AZT-22 telescope for high spatial resolution photometry of gravitational lens systems. The excellent properties of the Maidanak Mountain have been also confirmed by the recent cooperative seeing investigation, [5], resulting in as small as 0.69 arcsec median FWHM estimation. The new data on the recently discovered SBS 1520+530 system should be especially noted, as well as VRI photometry of the Q2237+0305 which had definitely demonstrated that variations of the components colour are real and significant.

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