AROUND THE CLOCK OBSERVATIONS OF THE Q0957+561A,B GRAVITATIONALLY LENSED QUASAR

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ABSTRACT

An observing campaign with 10 participating observatories has undertaken to monitor the optical brightness of the Q0957+561A,B gravitationally lensed quasar for 10 consecutive nights in 2000 January. The resulting A image brightness curve has significant brightness fluctuations and makes a photometric prediction for the B image light curve for a second campaign planned for 2001 March 12–21. The ultimate purpose is to determine the gravitational lens time delay to a fraction of an hour and to seek evidence of rapid microlensing.

Subject headings: gravitational lensing—quasars: individual (Q0957+561A,B)

1. INTRODUCTION

The Q0957 system is the first identified multiply imaged quasar (Walsh, Carswell, & Weymann 1979) and the first to have a measured time delay (Schild & Cholfin 1986). It is also the first in which a microlensing event was detected (Grieger, Kayser, & Refsdal 1988). Subsequent decades have produced refinement of the models that describe the lensing and the many observational parameters required to turn the physical configuration into an important cosmological tool.

Along this path, the biggest surprise was the observation that the system seems to show a rapid microlensing at low amplitude (Schild & Smith 1991; Schild 1996). If confirmed, this would have important implications for the nature of the dark matter, since solar-mass objects in lens galaxy G1 should have a microlensing timescale of 30 yr. It would also have implications for the existence of fine structure in the luminous structure of the source quasar.

Unfortunately, the observational tests for this reported fine structure require high photometric precision and an accurate value for the time delay. Worse, an investigation by Colley & Schild (2000) in which the quasar was intensively observed throughout five nights in 1994 September and again in 1996 January showed that from one observatory one cannot easily measure the time delay to better than a day, because all but the most sophisticated statistics would favor a delay where there is no data overlap between the A and delayed B images, namely, when the time delay is an integer number of days plus a half day. (The Sun is up in either the A or later B data.) Furthermore, because of this, it is virtually impossible to assess whether or not there is microlensing on a timescale of a day or less. But there is good news; the quasar was demonstrated to show brightness fluctuations of the order of 1% in a night.

Therefore, to serve two purposes, a precise determination of the time delay and a detection of rapid microlensing, an observing campaign enlisting 10 observatories undertook continuous monitoring of the quasar images on the nights of 2000 January 20–21. The present manuscript describes the observations and results of the first year of observing; the image A component becomes the prediction for the image B light curve for the coming session in 2001 March 12–21, if there is no microlensing.

2. OBSERVATIONS

To create a continuous brightness record for Q0957+561A,B, observations from northern hemisphere observatories would be required during their winter months. Thus, poor weather would be likely at any site, and some redundancy would be necessary to avoid significant gaps in the data record. We tried to get at least two participating observatories in differing weather zones for any UT hour of the program. Each observatory is presumed to provide about 8 hr of coverage, which allows for substantial overlap in coverage from Eastern Asia to Western Europe, and even into North America, although the Pacific is singly covered by Mount Hopkins (Arizona) and South Korea.

Our list of participating observatories is given in Table 1, where successive columns give the observatory name, telescope aperture, altitude, latitude, and longitude, and the pixel scale of the CCD camera. Observers were instructed to
begin and end the observational session with an R filter, and to do about 15% of the observing through the night at V. The V data have not yet been reduced.

Data were reduced following standard procedures and the precepts of Colley & Schild (2000). With data from many observatories available, a standardized header file and byte order had to be established, and the data were bias-subtracted and flat-fielded with IDL software. Simple aperture photometry, with aperture diameters of 6", was then carried out on all image frames.

Because the plate scales and CCD sizes of the several observatories varied significantly, it was not possible to use exactly the same standards for all data frames. The data frames from Maidanak, for instance, contain only one of the usual standards (star 5 from Schild & Cholfin 1986). Therefore, each of the observatories’ data sets is calibrated independently, by the Honeycutt (1992) method for ensemble photometry.

During the aperture photometry, the FWHM seeing is calculated by using a best-fit Moffat ($\alpha = 2.5$) profile that allows for ellipticity and rotation. Running hourly averages are computed for the image A and B photometry from each observatory. Subtracting this average from the individual photometric measurements from each image gives a deviation as a function of seeing. Seeing is expected to introduce correlated errors in the photometry, slightly more in A than in B (e.g. Colley & Schild 1998). We find exactly that behavior here but to a differing degree from each observatory. A parabola accurately reproduces the behavior of the deviation from the hourly average versus the log of FWHM seeing. A “fixed” version of the photometry can be created by subtracting this behavior out for each photometric datum.

3. DATA COMBINATION AND RESULTS

Our R filter brightness curve is shown in Figure 1, with hourly averages of data from each observatory. Overplotted is the “snake” from the Press, Rybicki, & Hewitt (1992) method to average and interpolate time-series observations. We explicitly use the structure function determined in Colley & Schild (2000) for the interpolation. The resulting curve is useful for our talking and planning purposes, but the original hourly averages with error bars will be used in the final cross-correlation when the second year’s data are available.

In combining data from several observatories, we had to make adjustments, or zero-point shifts, for each observatory. Although the quasar brightness is always measured relative to the standard stars, the standards are all redder than the quasar, and a small correction to the standard Kron-Cousins R filter system is required. Such a correction is required for the Mount Hopkins system as well, and in practice we have determined the correction relative to the Mount Hopkins filter/CCD response.

We have determined the zero-point correction by two methods. In the first, the measured standard-star brightness is averaged for all data frames from a particular observatory, and the average observed brightnesses compared to the standard values plotted as a function of the color of the standards. This gives a standard curve that can be extrapolated to the colors of the quasar images to derive the correction to the observatory’s zero point. This is a normal procedure in transforming photometry to a standard system, and we have employed what is often referred to as first-order transformation coefficients. The amplitude of the correction is ordinarily a few hundredths of a magnitude. For example, the correction for the Mount Hopkins data is 0.04 mag.

![Figure 1: R-band light curve of Q0957+561A,B from 2000 January 20 to 31. At top is the image A brightness record; in the middle is the image B brightness record; and at bottom is a series of line density graphs illustrating when each observatory was contributing data.](image-url)
In a second procedure, a running hourly average of the “fixed” data was computed for each observatory. We then generated the Press et al. (1992) “snake” for all observatories except one, and computed the optimum (in the weighted least-squares sense) offset between the snake and the photometry from the remaining observatory. Rotating through all the various observatories, offsetting, and then iterating quickly produces optimum offsets that minimize the differences in the photometry measured from all of the observatories.

The first and second methods produce similar results, but the first, of course, generates an offset to be applied simultaneously to the A and B image data. The offsets, however, would not necessarily be identical, because the lens galaxy contributes a very red component to the very blue QSO images in very different amounts, A to B. This is troublesome, because one likely culprit for nonzero photometric offsets in the first place is differences in filters and detector responses.

So, in our second, more empirical method, we allowed the image A and image B offsets to be determined independently. The good news is that while the offsets ranged over a tenth of a magnitude, they generally agreed between A and B to better than 1% for all except Wise and Bohyunsan Optical Astronomy Observatory (BOAO) data. Furthermore, the offsets from the transformation coefficients agreed with the second, empirical method with an rms of 6 mmag (again excluding Wise and BOAO). The Wise and BOAO offsets agree more poorly because both of those observatories contributed principally in one night and in both cases showed substantial variation (of the order of a few percent). These larger variations confuse the offset optimization (in a way that is complementary to the problem that a lack of variations confuse time-delay estimates). We have chosen simply to stay with the second method (snake residual minimization) for the simple reason that it is the more straightforward of the two, and we invite those interested in such nuances to consult our full data table.

We then have the problem that we have data of nonuniformity in nonuniform passbands, zero-pointed by nonuniform standard stars, none of which has a spectrum similar to our object, and none of which is even as blue as our object. We found, however, that by examining the colors of the standards, we could generate approximate offsets that agree quite well with completely empirical offsets, and that the offsets themselves are quite consistent between the A and B images at a single observatory. We therefore adopt this empirical method as our best procedure for determining offsets.

We are pleased that our image A brightness curve shows some brightness fluctuations that can be sought in our forthcoming second season of observing. Relative to the simple weighted mean for the entire data record, we found that the \( \chi^2 \) value is greater than 20,000 for 296 degrees of freedom for both A and B images. The nonuniformity of the data makes such a direct calculation asymptotic, so we also computed this \( \chi^2 \) value for the Mount Hopkins data alone, in which we found values of greater than 1000 for 93 degrees of freedom. While this is certainly not a detailed statistical treatment, our previous work (Colley & Schild 1999) showed that our error bars on Mount Hopkins data were quite reliable, and we therefore have confidence that this measurement shows significant departures from constant.

Furthermore, the complex pattern of brightness fluctuations seen around JD \( 2,449,000 \) = 2569–2572 is fairly well defined by observations, and an even larger, although more poorly constrained, drop is evident at 2565.3. This latter feature is well sampled from observations in Korea, but we remain cautious because the drop occurs simultaneously in both images, which seems unlikely. We have checked the data with another software program (IRAF) and find no fault with the reductions. If the feature is real, it gives an important feature to be sought near the beginning of the observational period now being planned. If this feature can be identified on 2001 March 12, determination of a time delay to less than an hour should be possible.

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15 Data tables, both before and after binning, can be found at: http://cfa-www.harvard.edu/~wcolley/Q0957/data/.

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