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

II. RESULTS FOR THE SECOND OBSERVING SEASON

WESLEY N. COLLEY,1 RUDOLPH E. SCHILD,2 CRISTINA ABAJAS,3 DAVID ALCALDE,4 ZEKI ASLAN,4,5 ILFAN BIRKMAE,6 VAHRAM CHAVUSHYAN,7 LUIS CHINARRO,3 JEAN-PHILIPPE COURNOYER,8 RICHARD CROVE,9 VLADIMIR DUDINOV,10 ANNA KATHINKA DALLAND EVANS,11 YOUNG-BEOM JEON,12 LUIS J. GOICOECHEA,13 ORHAN GOLBASI,2 IREK KHAMITOV,3 KIETIL KJERNSMO,11 HYUN JU LEE,12 JONGHWAN LEE,12,14 KI WON LEE,15 MYUNG GYOON LEE,12 OMAR LOPEZ-CRUZ,7,16,17 EVENCIO MEDIAVILLA,3 ANTHONY F. J. MOFFAT,8 RAUL MUJICA,7 AURORA ULLAN,13 JOSÉ MUÑOZ,3 ALEXANDER OSCOZ,3 MYEONG-GU PARK,18 NORMAN PURVES,9 OYVIND SAANUM,11 NAIL SAKHBULLIN,6 MIGUEL SERRA-RICART,3 IGOR SINELNIKOV,10 ROLF STABELL,11 ALAN STOCKTON,9 JAN TEUBER,19 ROY THOMPSON,9 HWA-SUNG WOO,18 AND ALEXANDER ZHELEZNYAK10

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ABSTRACT

We report on an observing campaign in 2001 March to monitor the brightness of the later arriving Q0957+561B image in order to compare with the previously published brightness observations of the (first-arriving) A image. The 12 participating observatories provided 3543 image frames, which we have analyzed for brightness fluctuations. From our classical methods for time-delay determination, we find a 417.09 ± 0.07 day time delay, which should be free of effects due to incomplete sampling. During the campaign period, the quasar brightness was relatively constant and only small fluctuations were found; we compare the structure function for the new data with structure function estimates for the 1995–1996 epoch and show that the structure function during our observing interval is unusually depressed. We also examine the data for any evidence of correlated fluctuations at zero lag. We discuss the limits of our ability to measure the cosmological time delay if the quasar’s emitting surface is time resolved, as seems likely.

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

1. INTRODUCTION

An observing campaign to determine the Q0957+561A,B gravitational lens time delay to a fraction of a day has been undertaken by the Quasar Observing Consortium (QuOC), justified by the evidence available that the quasar has brightness fluctuations on timescales of hours and that microlensing on day timescales is observed (Colley & Schild 1999). Our report (Colley et al. 2002, hereafter Paper I) of the brightness fluctuations observed in 2000 January (QuOC 1) in the first-arriving A image becomes a prediction of the pattern of fluctuations expected in 2001 March. In this report we present reductions of CCD images for the determination of the B image brightness record and the determination of a refined value of the time delay.

This time-delay determination comes as a refinement of previous estimates that have gradually converged to a value near 417 days. After some years of uncertainty as to whether the delay was near 415 days or 540 days, new estimates have come from new data sets and reanalysis of extensive older data sets to produce values of 416.3 (Pelt et al. 1998), 417.5 (Kundic et al. 1997), 425 ± 17 (Pijpers 1997), and 417.4 (Colley & Schild 2000). Reanalysis of much of the same data has produced a divergent value of 422 ± 0.6 days (Oscoz et al. 2001), but our present program allows no check on this value because our monitoring was only over a 10 day time interval. Radio brightness monitoring has not had the time sampling, accuracy, or the demonstrated rapid variability to justify participation in this program.

In § 2 we report the new data (QuOC 2) and reductions for the 12 participating observatories, and § 3 contains an analysis for time delay. We found only a low amplitude of brightness fluctuations for the quasar during the monitoring period, and any evidence for rapid microlensing is within the noise of our data. However, a sharpened value of the time delay allows us to reanalyze high-quality data sets from published reports (Colley & Schild 2000), and a determination of the structure function for the rapid
microlensing in that data set will be the subject of a subsequent report.

2. OBSERVATIONS

Our list of participating observatories was shown as Table 1 of Paper I. For the second season three additional observatories joined the collaboration, principally to cover the Pacific region. The 61 cm Mauna Kea reflector was operated from the Institute for Astronomy offices at Hilo, Hawaii. The Mexican 1.5 m Harold Johnson Telescope at OAN (Observatorio Astronómico Nacional) at San Pedro Mártir joined the 2.1 m OAGH (Observatorio Astrofísico Guillermo Haro) telescope in northern Mexico. The Mount Megantic telescope operated jointly by the Université de Montréal and Université Laval, Canada, provided coverage of the North American continent from a different weather zone.

In this section we provide additional remarks about the data reductions and its relationship to the telescope and camera properties. Any changes from the properties noted in Paper I will be given. Our list begins at the international date line and is ordered by increasing longitude. Throughout this section and report, we refer to R-filter images only, and although approximately 10% of our data was taken with a V filter we do not remark on the results for this supplementary reduced data set.

2.1. Bohyunsan Optical Astronomy Observatory (South Korea)

The Bohyunsan Optical Astronomy Observatory (BOAO) produced 180 quasar image frames over five nights, all of uniformly high quality. The BOAO data from our first-year observations are particularly important because they recorded a rapid brightness decline in the A image that will strongly contribute to the present time-delay determination. However, as noted in Paper I, the rapid brightness decline seemed to be recorded in both quasar images, and we were suspicious that it might have been the result of some peculiar instrumental effect, although re-reduction of the data with entirely different software seemed to confirm the reality of the rapid brightness change. Thus, it is reassuring that the BOAO data in the new campaign seem to again be of high quality and contain no bothersome artifacts evident in the reduced data.

2.2. Sobaeksan Optical Astronomy Observatory (South Korea)

The Sobaeksan Optical Astronomy Observatory (SOAO) 61 cm telescope on the top of Mount Sobaek in the middle of South Korea is often differently affected by weather than BOAO and so is of importance to us because of concern about coverage of the vast Pacific region. The telescope lacks an offset guider, however, and some of the images are streaked slightly. Nevertheless, we reduced 236 quasar image frames obtained over five nights, albeit with slightly shorter exposure times. The smaller aperture produces lower signal levels, and the error bars for the data set may be seen to be somewhat larger.

However, the time coverage by the SOAO observatory has been critical to our program, especially as it provided the only coincident coverage of the rapid brightness decline recorded the previous year at BOAO, as noted previously. The relatively large amplitude, approximately 40 mmag (1 mmag = 0.001 mag) over just 5 hr, adds considerable weight to our time-delay determination.

2.3. Maidenak (Uzbekistan)

Since the previous year’s campaign, the Maidenak 1.5 m telescope has been equipped with a new CCD camera having 2048 × 800 pixels and providing an image scale of 0.121 pixel⁻¹. The images are of the highest quality because of a combination of superb optics and consistently excellent seeing.

We did, however, encounter a problem with the new camera. A large diffuse bright spot of only 3% amplitude covers the entire central region of the CCD frame. The spot is apparently caused by light that is diffusely reflected from the region of the CCD detector back to the camera optics and then again reflected back onto the CCD camera. This produces an excess brightness near the center of the CCD frame that the standard flat-fielding procedure interprets as locally more sensitive pixels. So in correcting for the apparently high sensitivity of the central region’s pixels, the flat-fielding procedure also reduces the brightnesses of the central stars in the corrected frame. The point is that flat-fielding assumes that all processes affecting the sky brightness across the image frame, such as pixel-to-pixel sensitivity and vignetting, are multiplicative, and a process that adds brightness causes failures and errors in the flat-fielding process. We corrected the problem by preparing an unsharp mask image from a stack of nighttime image frames and subtracting off the excess brightness from our image frames and flat-field frames before flat-fielding.

The corrected frames have produced an important backbone to our brightness record, because of the consistently high quality and because of the excellent coverage of our monitoring window. The campaign produced 395 image frames over eight nights in our program.

2.4. Tubitak National Observatory (Turkey)

The Tubitak National Observatory (TUG) RTT150 1.5 m Russian-Turkish Joint Telescope was not equipped with an offset guider, and some images are somewhat streaked, but the effect was minimized by taking relatively short exposures. A total of 192 image frames were collected on six nights. We were unable to obtain consistent photometry from the images, and we do not believe that the guiding was the problem. Instead, it appears that a slight nonlinearity in the camera’s response is indicated. For example, on the cloudiest night, although the quasar brightness is referenced to local field stars, our reduced photometry was several percent different from the photometry on strictly clear nights.

We are hopeful that the data will be reducible after some mapping function of the camera response to light is available. For the present we cannot include this otherwise excellent data set in our time-delay determination or in the Figure 1 plot of the brightness curve, at least until we understand better the camera’s slightly nonlinear response to light.

2.5. Nordic Optical Telescope (Canary Islands)

The 2.5 m Nordic Optical Telescope (NOT) is the largest involved in our campaign and was scheduled for four nights, which turned out to have nearly ideal weather, producing a harvest of 755 image frames. These have provided excellent photometry and excellent statistics on the four nights, and
together with the Maidanak results have produced a "backbone" against which we refer other observatories to look for systematic differences.

2.6. Johannes Kepler Telescope (Canary Islands)

The 1 m Johannes Kepler Telescope was scheduled for the last two nights of the formal monitoring period plus two nights beyond, to allow some information about the time delay in case the 424 day delay value championed by Oscoz et al. (2001) turned out to be correct. A total of 147 quasar image frames were analyzed and produced a brightness record compatible with results for the other observatories.

2.7. Instituto de Astrofísica de Canarias 80 cm (Canary Islands)

The Instituto de Astrofísica de Canarias (IAC) 80 cm reflector produced 173 quasar image frames on eight nights of the formal monitoring period and three nights beyond to allow a further check on the longer delay value of 424 days advocated by Oscoz et al. (2001). We have not been able to bring the photometric results into agreement with the reductions for other observatories for reasons that we do not yet understand. Most problematic are the results for JD 2,451,983, where the reduced photometry is 2% brighter for image B than for image A as compared to results for the same night from Maidanak and from NOT. Data from the remaining nights seem not to share this defect, and we are puzzled about its origin. Because the images were precisely registered on the CCD detector by an offset guider, it is possible that a CCD defect has affected the photometry for a single night. We have found that pixel-to-pixel sensitivity variations of the CCD detector of 10% are routinely found, and we suspect that the CCD camera is not operated in correct adjustment. We expect to investigate this anomaly further, but for the present analysis we cannot justify censoring

![Figure 1](image-url)

*Fig. 1.—R-band light curve of Q0957+561A,B from 2001 March 12 to March 21. To facilitate comparison with the first season's data, 417 days have been subtracted from the Julian dates. Top, image A brightness record; middle, image B brightness record; bottom, a series of line density graphs illustrating when each observatory was contributing data.*
2.8. Mont Mégantic (Montreal)

The Mont Mégantic observatory is sited at a very dark mountainous region 250 km east of Montreal, near the US border. It offers a 1.6 m Ritchey-Chretien telescope with an offset guider that has been extensively used in photometric programs to date. Over four nights the observatory contributed 115 data images of excellent quality to our program.

2.9. Mount Hopkins (Arizona)

The Mount Hopkins Observatory has been the mainstay of Q0957 brightness monitoring for over 20 years. Because of scheduling difficulties the 14 nights allocated overlap only three nights with the campaign time interval. The additional 11 nights precede the campaign and allow a check on possible time delays less than the nominal 417 days. Over 12 nights, 375 image frames were reduced for photometry.

2.10. The 1.5 m Harold Johnson Telescope, San Pedro Mártir (Mexico)

A total of 126 images over four nights were reduced for photometry with the 1.5 m Harold Johnson Telescope. The images were of excellent quality. The telescope was scheduled for only the first seven nights of the campaign, with the last three nights covered by a second Mexican telescope.

2.11. The 2.1 m Telescope OAGH, Cananea (Mexico)

From the OAGH in Cananea, Sonora, a total of 84 image frames were obtained over two nights at the end of the monitor period. Very poor (3\%5) seeing was experienced during part of one night. In general, the image quality was not quite as good as the upgraded Harold Johnson 1.5 m telescope, likely a result of a problem with the mercury belt of the mirror support system. Nonetheless, the data reduction procedure seems to have produced excellent results for this telescope.

2.12. The 61 cm Mauna Kea Telescope (Hawaii)

The Hawaiian Mauna Kea 61 cm telescope was operated remotely from the Institute for Astronomy at Hilo and from the University of Hawaii at Honolulu. With clear skies and excellent seeing, a large quantity of data was obtained, but lack of an offset guider caused some trailing of the images. Nevertheless, most of the data could be easily reduced with our robust computer program, and the Hawaiian telescope produced one of our main data sets. Over eight nights 430 useful image frames were obtained.

3. ANALYSIS: DATA REDUCTION AND TIME DELAY

The data from all observatories was analyzed by a single program as described in Colley et al. (2003; Paper I) and in Colley & Schild (1999, 2000). Briefly, all images were debiased and flat-fielded, and the corrected images had the star positions identified by an automatic procedure. Aperture photometry was performed on the two quasar images and several nearby standards, and the quasar brightness was referenced to the standards. Corrections for the aperture cross talk were determined according to the Colley et al. (2003) method: a simple parabolic fit to the magnitude relative to the mean magnitude of the run versus the log of FWHM seeing is made, and that signal is subtracted out. Colley & Schild (1999) showed that a detailed correction involving galaxy subtraction from HST data (Bernstein et al. 1997) and detailed A-B aperture cross-talk corrections yielded a relation to seeing that is well described by this very simple model.

The reduced data are shown in Figure 1, where we plot the photometry obtained in the campaign time frame 2001 March 12–21. Upper and lower plots show the A and B image photometry, and the bottom panel shows as bars the time coverage of each participating observatory and at the bottom the total coverage. The plotted data points show the hourly photometry means obtained by each observatory and an error bar calculated from the photon statistics relevant to the detection (not a standard error relative to the mean).

We are frankly disappointed by the low level of brightness fluctuations shown by the late-arriving B image, which will now be compared with the A image data for the previous year. Note that from simple inspection it may be seen that the amplitude of fluctuations in image B is approximately half the level seen in image A for 2001. Similarly, data for image A in 2000 show fluctuations only half as large as those for image B. Both the 2000 A and 2001 B patterns exhibit less than half the amplitude of the pattern found for fluctuations in 1994–1996 by Colley & Schild (2000). Thus, the quasar has given us an opportunity to demonstrate that accurate photometry and detection of a very low level amplitude of brightness fluctuations could be produced with our methodology, but we would have preferred stronger fluctuations.

The time-delay calculation was undertaken with the “PRH” method (Press, Rybicki, & Hewitt 1992, hereafter PRH), which, despite some controversy, has become a standard utility. The method is based on the notion that the quasar variations exhibit a power-law “structure-function,” which is to say the expected magnitude variance of one point from another on the light curve is a power law in the time separation of the points (i.e., \( V \propto |t_1 - t_2|^{\alpha} \)). This method allows one to address the nonuniform time sampling of the data without direct interpolation. From there, usual second-order Gaussian statistical methods are used to construct a “\( \chi^2 \)” statistic that reduces to the usual \( \chi^2 \) method if no interpolation was necessary.

The method can have problems, particularly if the data records are affected by microlensing (a highly non-Gaussian signal; Press & Rybicki 1997; Thomson & Schild 1997; Schild 1996). The method also has a propensity to favor lags where there is the least data overlap (Colley & Schild 2000), but because our data have an irregular sampling history, this is not expected to be a problem.

Results for the PRH method test are shown in Figure 2, where we plot \( \chi^2 \) as a function of lag between the A and B images. A small valley for 417.1 days is presumed to indicate the best value of the time delay. Toward the left of the plot, the \( \chi^2 \) value declines chiefly because the main feature of the image A light curve ceases to overlap with the image B’s shifted dates.

The agreement of the two quasar brightness curves for a 417.1 day lag is shown in Figure 3, where we plot the image A data (unfilled circles) from 2000 and the image B data (filled circles) from 2001. Error bars are computed as described previously and are calculated from the
fundamental photon statistics, not from the purely empirical departure of individual points from the hourly means. Also shown is the "error snake" that shows the width of the 1 $\sigma$ error interval computed by the PRH method as part of the interpolation scheme. Note that the mean width of this snake is only 5 mmag. A quick glance shows that the true errors seem to be very close to the computed errors, in the sense that more than half of the hourly average points lie within the 1 $\sigma$ snake.

The formal time-delay value calculated for the project is 417.09 ± 0.07 days. Inspection of Figure 3 shows that a weak pattern of fluctuations is seen throughout the campaign period, and a single fluctuation at JD = 2,449,000 = 2564.5 of 30 mmag amplitude predominates. We suspect that the overall pattern and the single large event contribute about equally to the time-delay value. As was noted by Colley et al. in Paper I, the event was seen in the Korean BOAO data from the first season and not entirely believed because the data seemed to show a simultaneous event in the B data for 2000 also. However, reevaluation of the data with a different analysis program (IRAF) seems to show that the feature is real, and its repetition in 2001 makes the case more convincing.

With the data in Figure 3 plotted for the best-fit lag, the plot also becomes a record of microlensing, in the sense that any significant differences between the two brightness records indicates a pattern of fluctuations not intrinsic to the quasar and presumably originating in the lens galaxy. We do not find that the Figure 3 comparison makes a convincing case that any microlensing has been detected at the 5 mmag level. There is an appearance of a peak for JD = 2,449,000 = 2564, and we note that evidence for this peak comes from two observatories (Maidanak and BOAO). We have seen evidence for a peak of similar amplitude and duration in the Q0957B data record for JD 2,449,704 as illustrated in Figure 3 of Colley & Schild (2000). The detection of an event in our microlensing record is only based on three hourly average data points, each having approximately 2 $\sigma$ significance, and we feel obliged to err on the side of conservatism and claim no significant detection.

We do not consider that this proves that rapid microlensing does not exist; our sharpened time delay of 417.1 days allows us to show from previous data records that data from a single observatory can overlap and produce microlensing information. This will be the subject of a further report.

4. THE STRUCTURE FUNCTION

In Figure 4 we show the structure function for the quasar's brightness fluctuations during 2000 January for image A and 2001 March for image B. In Figure 4 the variance plotted as a function of lag is a squared quantity, so the actual brightness fluctuations are the square root of the plotted numbers. Thus, for a lag of 1 day, either image component showed variance of approximately $10^{-5}$, or the mean brightness fluctuation was $0.3 \times 10^{-2}$, or 3 mmag. So on average, the quasar brightness changed by only 3 mmag during any 24 hr time interval.

This level of brightness fluctuation is extraordinarily low for this quasar, as can be seen from comparison with the solid line that shows the fit to the variance measured in 1995 (Colley & Schild 2000, Fig. 5). Thus, we were extremely unlucky that the date chosen for the beginning of our monitoring for reasons of optimum observability turned out to coincide with a period of low quasar activity. This allowed us to demonstrate the ability to reduce data from multiple observatories and measure brightness with high precision, but we would have preferred to find large fluctuations to firmly establish a time delay and a rapid microlensing signature.

Figure 4 qualitatively shows that the quasar's brightness fluctuations may be statistically nonstationary on timescales of 1–10 days, when measured over a few short intervals. Curiously, the lower-than-expected level of fluctuations seen at this timescale does not extend to longer timescales: on timescales of a year, the fluctuations were actually twice as large as measured in 1995 (the data point for year lag is far off scale and not seen on this plot). These departures may correspond to some of the non-Gaussianity sought by Press & Rybicki (1997).

5. THE CORRELATION FOR ZERO LAG

In the course of monitoring Q0957, many groups have noticed a "zero lag" correlation between the A and B images (e.g., Kundic et al. 1995). This zero lag correlation is impossible by all models of gravitational lensing and would require some kind of precisely aligned gravitational wave in the halo of our Galaxy or perhaps a cosmic string. It is presently interpreted as a frame-by-frame correlated error in the photometry.

The Kundic et al. (1995) group endeavored with fair diligence to uncover the source of such an error, examining moon phase, zenith angle, and many other observational states for some correlation with the apparent photometric errors, but they encountered little success. We have also noticed that our data seem, on inspection, to exhibit a similar zero lag correlation, even after our parametric correction for seeing, discussed previously. In particular, the PRH snake, a completely objective interpolation, yields light
curves in which the coincidence of the many shallow peaks and valleys is immediately striking to the eye. We therefore engaged ourselves in a great amount of effort to remove errors that might be correlated with flux, sky background, location on CCD, and time of night, but those efforts have yielded little improvement for most observatories.

We show the effect quantitatively in Figure 5 as the PRH $\chi^2$ (lower $\chi^2$ means higher correlation) for lags in the vicinity of zero lag in the two data sets; the solid curve shows the correlation for the 2001 data, and the dashed curve shows the correlation for 2000. Any correlations would be expected to be quite random in the vicinity of zero lag if the photometry were perfect. However, in both cases there is a $\chi^2$ trough near zero. For 2001, the overall minimum is at precisely zero lag, quite suggestive of a photometric problem. For 2000, the case is more muddled. The trough nearest zero is closer to 0.1 days and is only the sixth lowest trough, while the overall minimum is at around a 1 day lag. While in the 2001 data set, there seems to be compelling evidence of a photometric problem, nothing compelling arises in the 2000 data set, despite identical photometric reduction methods.

Most likely, there is a similar photometric error correlation in both 2000 and 2001, but the true correlation of the light curves adds slight destructive and constructive interference to that signal (respectively). We interpret Figure 5, therefore, as showing a zero lag correlation that is evidence of an as yet uncorrected photometric problem at the few millimagnitude level, residing on top of the true correlation (PRH $\chi^2$) of the A and B light curves.

6. THE POSSIBILITY OF MULTIPLE TIME DELAYS

Our brightness monitoring has produced a time delay of $417.09 \pm 0.07$ days and scant evidence for microlensing. During our monitoring campaign the quasar was experiencing below normal brightness variability, and very possibly the low level of microlensing fluctuations measured is related.

At the time this project was organized, time delays for the gravitational lens system seemed to be converging to a value near 417 days. Analysis of the 17 yr brightness history by Pelt et al. (1998) produced a delay of $416.3 \pm 1.7$ days, and
the Kundic et al. (1997) observation of a large event seemed to make their 417.4 day delay unquestionable, although in hindsight the quoted value was for $g$-filter data, and their $r$-filter data gave 420.3 days. Finally, the extensive monitoring over seven consecutive nights reported in Colley & Schild (1999) seemed to make a convincing case that significant fluctuations were observed and repeated after a time delay of 417.4 days. Their Figure 7 appeared to show ample repeated fluctuations to adequately define the time delay.

At the same time, suspicions of a somewhat longer time delay have arisen. The Pijpers time-delay determination using a long, extensive database gave 425 days, but the error seemed to include the favored shorter value. But then a report by Oscoz et al. (2001) seemed to show a longer delay for the same data sets, utilizing different statistical methods. A new thesis by Ovaldsen (2002; see also Ovaldsen et al. 2002) with rereduction of the original data frames seems to show not only stronger evidence for the 424 day delay, but even a small local anticorrelation bump in the delay curve where the favored 417 day lag should be. Thus, we find it perplexing and frustrating that, with so many nights of overlapping data, it is difficult to find an enduring time delay.

As noted by Pelt et al. (1996), the fine structure filtered out of the brightness record does not give a time-delay value (Pelt et al. 1996, Figs. 10 and 11), even though hundreds of nights of data overlap for any test value of lag near 420 days (Pelt et al. 1996, Fig. 1). If microlensing were not affecting the brightness records, it should be easy to determine the time delay to a fraction of a day.

Faced with the dilemma of two seemingly well-founded, significantly different time delays, we must consider the possibility that the time delay is “multiple” or that it is ill-defined for timescales of less than a week. We believe it is something of a combination of these two; the true gravitational time delay is very well defined, since microlensing only introduces tiny changes in the time-delay surface (Chang & Refsdal 1979). However, the light-curve delay is not so well defined, chiefly because in the presence of microlensing, our ability to measure a precise time delay relies on a source that varies simultaneously over its entire radiating surface, as viewed from Earth.

Brightness records from the last two decades show that the flux ratios of the A and B images are changing at the level of 30% over a timescale of years. This is widely interpreted as an effect of microlensing by stellar-mass objects in the lens galaxy, in which the caustic configurations in the A and B images evolve with time (Schild 1996; Pelt et al. 1998). Hence, different parts of the source are being microlensed at different magnification, and those differences change on the timescale of years.

Therefore, a precisely matched light curve from images A and B, offset by the gravitational time delay (precisely) requires that the entire source varies simultaneously from the viewpoint of the observer. Almost no model for quasar variability accommodates that (Schmidt & Wambsganss...
1998; Refsdal et al. 2000), and we are forced to consider a more realistic scenario.

For the Q0957 radio source quasar the black hole mass would be perhaps $3 \times 10^9 \, M_\odot$, giving a Schwarzschild diameter of $2 \times 10^{15}$ cm. Thus, the diameter of the innermost stable orbit, $6R_S$, is approximately $10^{16}$ cm, or 4 lt-days. For a quasar redshift of 1.4, a proper time of 4 lt-days is observed as 10 days.

With an inner diameter for the accretion disk of order 10 days (our time), a simultaneous event that illuminated the entire inner disk would appear to us to brighten roughly 10 days earlier on the front side compared to the back side. Since the inner edge of the disk presumably demonstrates a significant fraction of the variability seen on the few-week timescale typical of the large events seen in the quasar historically, including those leveraged for time-delay measurements by Kundic et al. (1997), a light-travel time problem could be significant.

Additional outer structure at scales of 100 days (our time) is implied in the Elvis (2000) model. If such structure responds to an event near the center, the light travel time problems are exacerbated.

Thomson & Schild (1997) encountered autocorrelation peaks near 100 proper lt-days, which supports the Elvis (2000) model. Such a model would necessarily present substantial light-travel time signal in the light curve.

Further evidence for the phenomenon comes from a cross-correlation calculation for Q0957 by Schild & Choffin (1986), who showed an FWHM of nearly 100 days; subsequent analyses of the same or comparable data sets by Vanderriest et al. (1989) and PRH gave a similar result. Even the modern calculations by Pelt et al. (1996) shows in their Figure 3 and following figures a 100 day wide correlation curve. Only the more modern calculations for short data sets centered around strong brightness changes give the sharper cross-correlation peaks of programs by Kundic et al. (1997) and Colley & Schild (1999). Thus, quasar structure on observed scales of 100 lt-days (observed) has long been indicated by observations.

Significant results were also gleaned from a statistical analysis of the brightness records by Thomson & Schild (1997), who found two unexpected facts. Their Figure 6 shows that different subsets of the brightness data show different lags, with the lags seeming to persist over approximately 2 yr, just what one would expect if stellar mass microlensing were affecting the light-curve time delay. Furthermore, their Figure 3 seems to show autocorrelation peaks with observed lags near 200 days, suggesting that the quasar has some structure on scales much larger than the one-night sampling of most data (note that for a quasar at $z = 1.4$, the proper scale of the implied quasar structure is 200 days/2.4, or approximately 70 lt-day proper size scale). Weaker structure on smaller scales is further implied by autocorrelation peaks near 20 lt-days (observed).

Thus, we interpret our new time-delay measurement as follows. For the microlensing configuration observed in calendar 2000–2001, the dominant light-curve time delay corresponding to the microlensing alignment then relevant is 417.1 days. Possibly other parts of the quasar were being magnified to produce other lags as well, but their signature is hardly apparent because of the disappointingly low level of quasar activity. Very probably a component of what is commonly called rapid microlensing is actually the result of quasar brightness fluctuations seen magnified by the differ-

7. CONCLUSIONS AND DISCUSSION

We have carried out the first gravitational lens time-delay measurement from data sampled nearly continuously over many days. The measurement of $417.09 \pm 0.07$ is certainly consistent with many previous efforts (e.g., Kundic et al. 1997), but puzzlingly inconsistent with others (e.g., Oscoz et al. 2001). Since there was surprisingly little variation in the brightness of the quasar images compared with previous structure function measurements (Colley & Schild 2000), the time-delay measurement is not as strong as we had hoped. Furthermore, there is little evidence of microlensing on timescales of hours to days.

In recognizing that there are now (again) two credible and competing time delays (around 417 days and around 424 days), both with a wealth of evidence to support them, one must attribute the discrepancy either to a lack of quality data, as was done a decade ago (PRH), or to the possibility that the quasar and lens system form multiple delays that foil our efforts to produce a unique time delay. The former seems increasingly untenable given the level of observational effort poured into this system over the past decade. If the multiple-delay hypothesis is to be examined, careful consideration of more complex quasar models must be undertaken (e.g., Wyithe & Loeb 2002).

As a final comment, we note that one of the most intriguing aspects of this work has been the formation of a large, international collaboration and integration of data from widely varying nations, telescopes, and instruments. As the number of lensed quasars has grown, so has the need for nearly constant monitoring by as many telescopes in as many locations as possible, with some coordination. Our project has proved that a large international collaboration of medium-sized observatories can be coordinated sufficiently to obtain nearly constant monitoring of lensed quasars.

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