1986ApJ...300..209S

THE ASTROPHYSICAL JOURNAL, 300:209–215, 1986 January 1

CCD CAMERA BRIGHTNESS MONITORING OF Q0957+561A, B

RUDOLPH E. SCHILD
Center for Astrophysics

AND

BRYAN CHOLFIN
Newton, Massachusetts

Received 1984 December 26; accepted 1985 July 8

ABSTRACT

We present results of continued monitoring of the twin QSO 0957+561 with data obtained with a CCD camera from 1983 February through 1984 March. The 0.2 mag increase previously reported to have occurred from 1982 January through 1983 January in the A component was seen to occur during 1983 January through 1984 January in the B component. From an autocorrelation of the CCD data, we determine the time of arrival difference to be $\Delta t = 1.03 \pm 0.1$ yr; the A image precedes the B image. A sharp decline in brightness of the A component between 1984 January and 1984 March allows us to make a prediction for the same months of 1985, when the B component should fade by 0.2 mag.

We also present data from 123 observations made on seven nights with 11 minute time resolution, with which we look for brightness fluctuations on a time scale of days or hours. The two components seem to have been relatively quiescent at the time of our observations; we find only marginal evidence for nightly brightness fluctuations and no evidence for fluctuations on a time scale of hours.

Subject headings: gravitation — photometry — quasars

I. INTRODUCTION

As soon as the gravitational lens nature of the twin QSO 0957+561 (TwQSO) was discovered (Walsh, Carswell, and Weymann 1979; Young *et al.* 1980), it was realized that accurate modeling of the gravitational lens, including effects of the cluster of galaxies, would be improved by accurate knowledge of the light travel time difference Δt between the A (northern) and B (southern) components. Because the QSO is at cosmological distance, it is possible that study of Δt contains information on important cosmological constants. Early monitoring of the brightness of the two components was undertaken by Keel (1982), using photography; by Vanderreist *et al.* (1982), by electronography; and by Schild and Weekes (1984, hereafter SW), from CCD photometry. Florentin-Nielsen (1984) reports photographic monitoring observations from the Brorfelde Schmidt telescope.

All the above mentioned monitoring studies showed that both the TwQSO components are variable on a time scale of months, as is typical of QSOs. Vanderriest *et al.* further noted that the TwQSO appeared to vary by a few hundredths of a magnitude on a time scale of days. This observation was confirmed by SW, who further noted that the brightness appeared to change on a time scale of hours.

Given such short-term variability and the prediction that the time delay Δt should be ~ 5 yr (Young *et al.* 1981), our observing strategy for the 1983–1984 observing season was to monitor the source with 10 minute exposures to investigate the following questions:

i) How accurate is a single CCD brightness measurement?

ii) What is the shortest time scale for detectable intrinsic TwQSO brightness fluctuations?

iii) Are larger amplitude or shorter time scale fluctuations observed in B than in A, possibly indicative of minilensing?

II. OBSERVATIONS AND REDUCTIONS

The TwQSO was observed in 123 exposures of 10 minute duration each on two nights in 1983 February and five nights in 1983 December/1984 January. Because ~ 1 minute is needed to read one exposure and initiate the next, our time between observation midpoints is nearly 11 minutes. The RCA CCD thinned blue detector was used at the 61 cm telescope on the Fred L. Whipple (formerly Mount Hopkins) Observatory with a *J* filter sensitive to the blue-green spectral region. Although previous optical monitoring with a CCD (SW) was done in the red because of poor blue sensitivity of early detectors, we have chosen to extend our observations in the blue-green to reduce our sensitivity to the underlying galaxy G1, which has an extended image. The TwQSO was observed on a single *F*(red) data frame on each night of observation to ensure that our knowledge of the *J*/*F* brightness ratio was sufficient to allow comparison with the older data. Many nights of observation were not of photometric quality because of the observed presence of cirrus clouds. Because our reduction procedure involves determining the ratio of the TwQSO A and B components to field stars, the presence of light clouds should not affect our results.

Data were reduced by standard techniques. A zero exposure data frame, the average of four or more taken throughout the night, was subtracted and the corrected data frame was flat field–corrected with flat field frames exposed to a white painted spot on the surface of the closed telescope dome. A standard field in M67 (Schild 1983) was imaged on the four nights considered photometric, and absolute photometry on the Gunn system bands *g* and *r* was determined for the five field stars listed in Table 1 as local standards. A CCD image of the TwQSO field showing the standard stars is shown as Figure 1.

For all the processed data frames, the brightnesses of the five field stars were summed in a circular aperture of $2''.92$ radius.

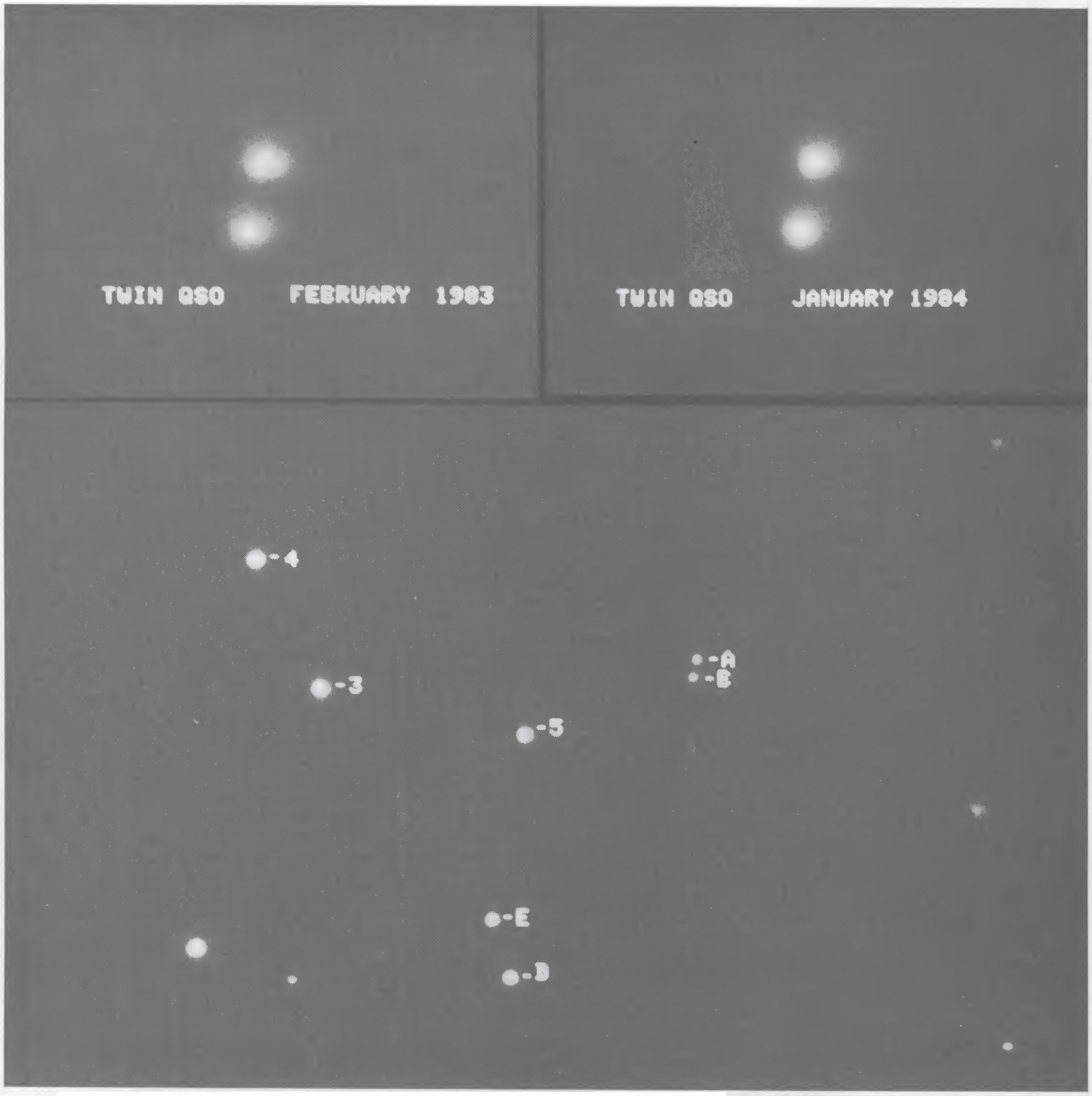

FIG. 1.—CCD image from a 10 minute exposure in the blue-green to show the identifications of the field stars

The image center was computed from a calculation of the first moment of the light distribution, with the location of the brightest pixel taken as the trial center. This procedure works extremely well; the star centers determined gave separations between stars with an rms deviation averaging 0.013 pixels. Because a measurement of the separation between two stars contains errors in the position of each star, the rms scatter of the determination of a single star position is presumably 0.013/1.4 or 0.009 pixels. This scatter is only $0\farcs0068$ for our focal plane scale of $0\farcs73$ pixel^{-1}. This result suggests that the CCD camera and relatively straightforward software can provide star positions of high accuracy over the small field of the detector. Further computing experiments show that an error of 1 pixel ($0\farcs731$) in the trial center of the star position causes an rms error in the position centroid of only $0\farcs007$. For an isolated star image, the resulting error in the photometry is only 0.002 mag. These results show that our centroiding and photometry algorithms should not be the causes of any substantial errors in photometry.

Reduction of the TwQSO images is complicated by the fact that the two images are not isolated, and light from one image can scatter into the image of the other. Furthermore, light from the underlying galaxy G1 image must make a contribution to the measured brightness of component B. It is not clear whether the best photometric accuracy is achieved by summing counts in a circular aperture, which has the advantages of simplicity and relative insensitivity to guiding errors, or by fitting a profile to the images. The latter procedure has the disadvantage that image asymmetries due to guiding errors may introduce artifacts of many kinds, particularly in the presence of the underlying galaxy G1, and we have not attempted an image fitting procedure.

TABLE 1

FIELD STANDARD MAGNITUDES ON GUNN PHOTOMETRIC SYSTEM

Star	g[a]	r[a]
3	14.35	14.33
4	14.40	14.37
5	15.00	14.57
D	15.33	15.11
E	15.66	15.36

[a] Magnitudes at Gunn g and r have an rms deviation of 0.03 mag.

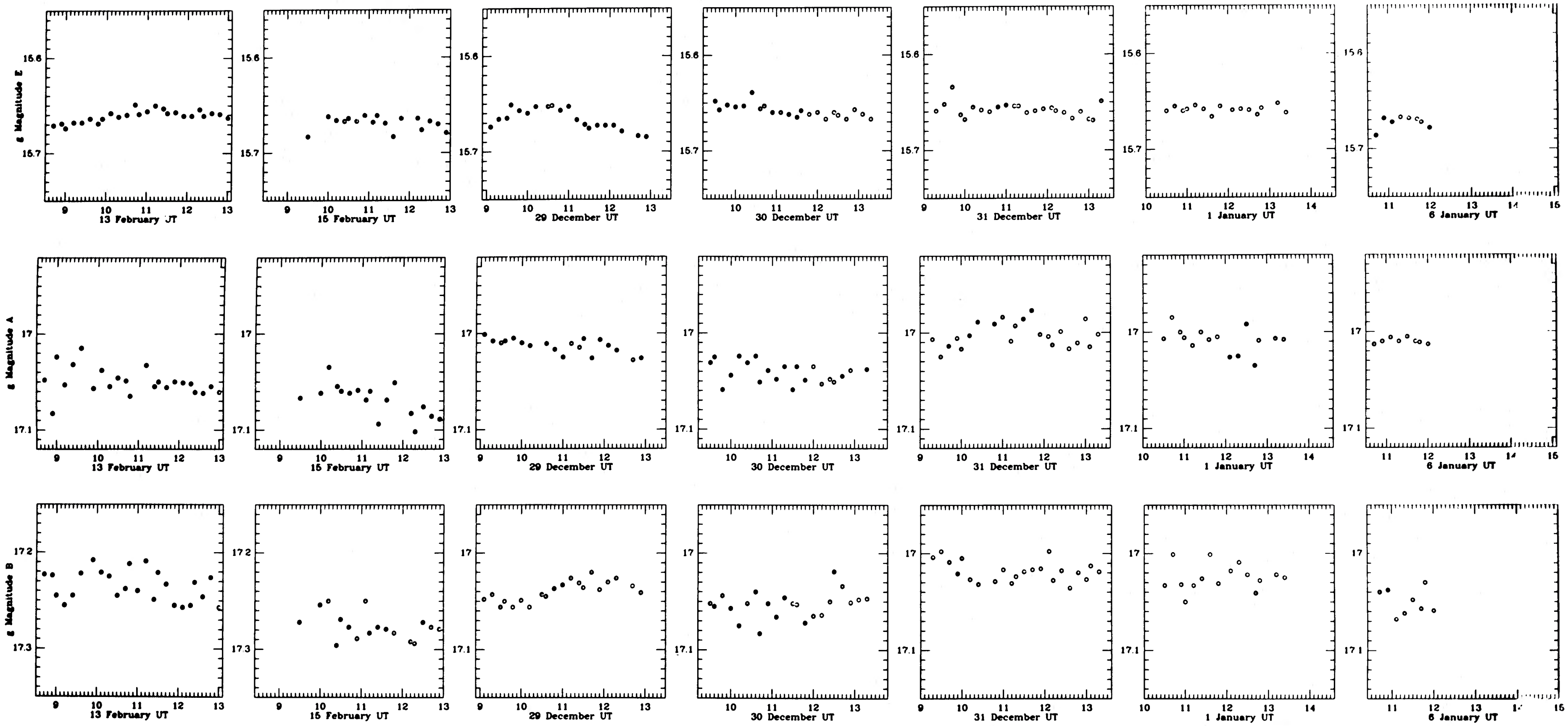

FIG. 2.—CCD brightness monitoring for (*top*) field star E, and for TwQSO components (*middle*) A and (*bottom*) B. Note that the first two panels for component B have a different zero point that the rest of its data, because component B increased in brightness by 0.2 mag between 1983 February and December.

As a check on our ability to make brightness measurements with the CCD camera over an extended period of observations, we have examined the CCD brightness measurements of one of our field standards, star E. This star was chosen because it is the faintest and also similar in color to the TwQSO. For each CCD data frame, the ratio of the E count to the sum for four additional field stars identified in Figure 1 was computed. The brightnesses of the five field stars were determined from comparison to M67 on photometric nights. The results for star E are shown in Figure 2, where the brightness ratio is given as a g magnitude on the Gunn photometric system.

The data for star E have an rms deviation from their nightly means of 0.005 mag. The seven nightly means have an rms deviation of 0.006 mag from the mean of the nightly means. From this we infer that the CCD camera is capable of making precision brightness measurements, and we discuss in detail many sources of error in the Appendix. For our present purposes, it is important to note that somewhat larger errors may be expected for the TwQSO component brightness measurements because of (1) lower signal-to-noise ratio of the A and B measurements, or (2) overlapping of the A and B images, especially on nights of bad seeing.

Because 78,000 net electrons were observed in each TwQSO image component (somewhat less if clouds were present), and since sky determination errors can be expected to average out in averaging each night's data and should not cause errors as large as 1% (Appendix), we do not believe that (1) can account for the observed variability to be discussed below. As also discussed in the Appendix, we have rejected data taken on one night and on part of another to eliminate effects at the 1% (=0.01 mag) level from (2).

We have thus attempted to keep our CCD errors from any one source below the 1% level. The results of our brightness monitoring are shown in Figure 2. The mean of the rms deviations of our brightness measurements from their nightly means are 0.011 mag for component A and 0.013 for component B.

The most interesting results on TwQSO variability found on our data in Figure 2 are:

i) Component B increased in brightness by 0.2 mag between 1983 February 13–15 and December 29. Note the change in zero point in Figure 2 between February and December for component B. The A component increased by 5% during the same period.

ii) Component B appears to have changed in brightness by 0.045 mag (=4.5%) between 1983 February 13 and 15. During the same time interval, the A component changed 0.02 mag or less. The rms deviations of the A and B components averaged 0.015 mag on these nights.

iii) Component B appears to have decreased by 0.03 mag between 1984 January 1 and 6. The rms deviations were only 0.014 and 0.005 mag. Component A and star E were apparently constant during the interval.

iv) Over the nights 1983 December 29 to 1984 January 6, the A component appears to have been constant in brightness with an rms deviation of its nightly means of only 0.005 mag, except that on the night of December 30 it was fainter by 0.03 mag.

Results (ii), (iii), and (iv) suggest that both component have brightness fluctuations of several percent amplitude on a time scale of a day or less. Other evidence for brightness fluctuations on a time scale of days comes from SW, Vanderreist *et al.* (1982), and our own more recent brightness monitoring. We do not feel that our results indicate significant fluctuations on a time scale of hours, although we note that both components appear to have been relatively quiescent at the time of our CCD monitoring. The fluctuations are presumed to be intrinsic to the QSO itself, since Young (1981) has shown that brightness fluctuations due to minilensing are likely to have a time scale of years. The existence of fluctuations on a day or less time scale suggests that Δt can ultimately be determined with an accuracy of 1:1000. One-day time scale brightness fluctuations of 10% amplitude have been reported for 3C 271 by Oke (1976*b*) and for 3C 279 and 3C 466 by Oke (1967*a*). Grauer (1984) has reported brightness fluctuations for the optically violent QSO 4C 29.45 on a time scale of 30 minutes, and Matilsky, Shrader, and Tananbaum (1982) have reported significant X-ray brightness fluctuations in 200 s.

III. THE ARRIVAL TIME DELAY Δt

The historical CCD data extending back to the year of discovery of the TwQSO have been summarized in SW. Their Figure 1 shows that image component A, which is expected to arrive first, was constant at the 0.05 mag level from 1979 December until 1981 December, when it began a year-long increase of 0.2 mag. This increase provided a signature to watch for in the B image. Our new data, listed in Table 2, show that the B component increased in brightness by 0.2 mag beginning in 1982 December and ending by 1983 December. During the same time, the A component was relatively constant in brightness, but between 1984 January and April, the A component faded by 0.2 mag. Thus we determine the time delay Δt to be 1 yr and we predict that in 1984 December the B component will be at $R_J = 16.4$ and that it will fade by 1985 April. The history of TwQSO brightness begun by SW is shown as Figure 3. A careful superposition of the curves with eye fit indicates a most probable value of $\Delta t = 1.0 \pm 0.1$ yr. Florentin-Nielsen (1984) determined $\Delta t = 1.55 \pm 0.1$ yr from photographic photometry obtained with the Brorfelde Schmidt telescope.

To help distinguish between our best-fit value of 1.0 ± 0.1 and the Florentin-Nielsen (1984) value of $\Delta t = 1.55 \pm 0.1$, we have computed the cross-correlation of the CCD data. The results, shown in Figure 4, show cross-correlation peaks for 0.47, 1.03, and 1.81 yr.

TABLE 2

TwQSO NIGHTLY MEAN MAGNITUDES

Date	R_J(A)	R_J(B + G1)	R_J(B)[a]	n[b]
1983 Feb 13	16.51	16.51	16.73	23
1983 Feb 15	16.53	16.57	16.81	17
1983 May 6	16.50	16.47	16.68	2
1983 May 18	16.51	16.48	16.70	1
1983 Dec 5	16.45	16.42	16.62	1
1983 Dec 6	16.48	16.41	16.61	2
1983 Dec 29	16.48	16.40	16.60	19
1983 Dec 30	16.50	16.42	16.62	21
1983 Dec 31	16.47	16.37	16.56	22
1984 Jan 1	16.47	16.39	16.59	16
1984 Jan 6	16.47	16.41	16.61	6
1984 Mar 31	16.66	16.39	16.59	2

[a] This is the magnitude of TwQSO component B corrected for the brightness of underlying galaxy G1. The magnitude for G1 was taken from SW as $R_J = 18.34$. All R_J magnitudes are transformations to the standard Johnson 1966 system.

[b] Number of observations.

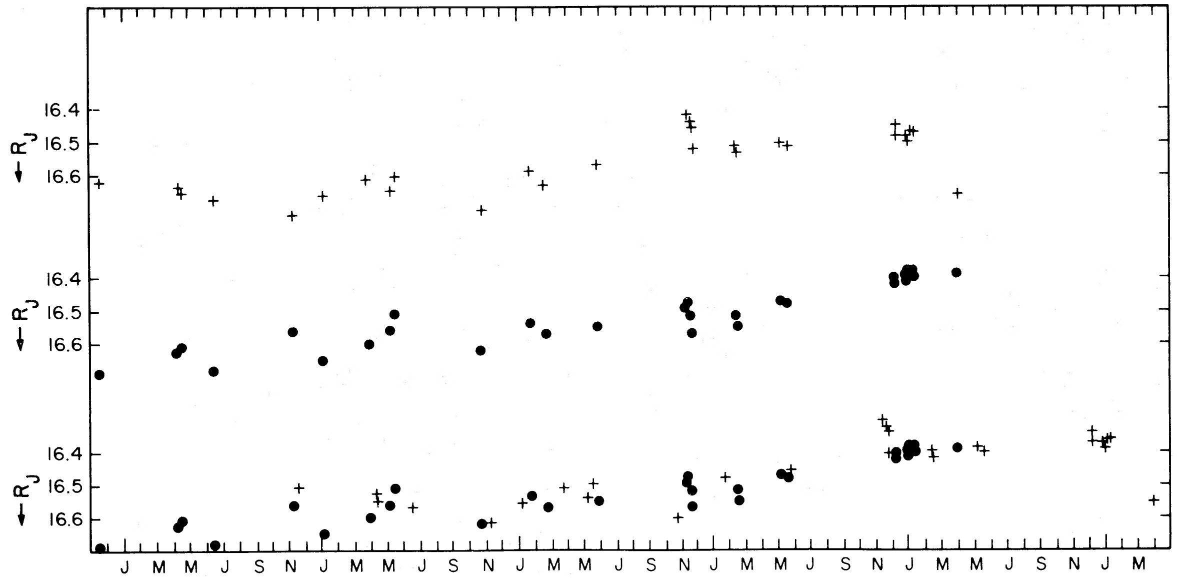

FIG. 3.—CCD brightness monitoring of TwQSO components A and B, including data from SW and results from the present investigation. In the lower panel, we show data for both components phased with $\Delta t = 1.03$ yr. Data for TwQSO component A are shown as plusses and data for component B are shown as circles.

The cross-correlation peak for 0.47 years appears to be spurious because although some features line up, there are cases where inadmissably large errors would result. In particular, the observation of Component A on 1980 November 9 is 0.14 mag too faint to match up with the component B results of 1981 April/May. Also, our latest results for component B (not included in Table 2) for 1984 October/November disagree with results for Component A in spring of 1984.

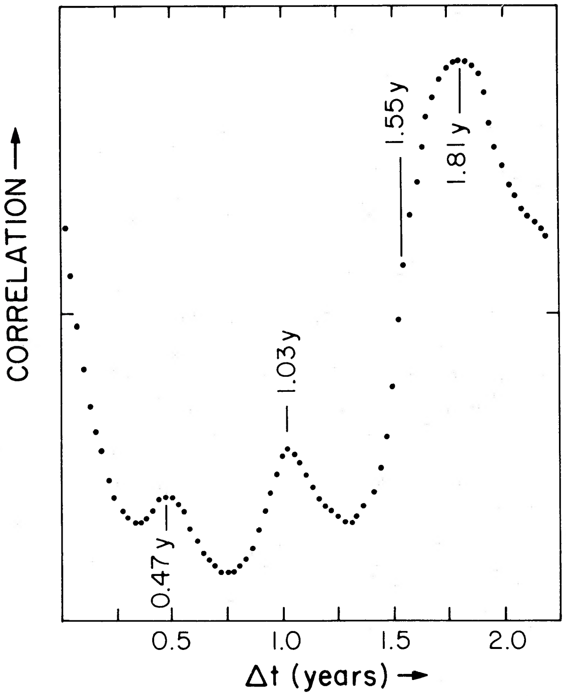

FIG. 4.—Cross-correlation (linear scale) of the light curves of the A and B components, offset by intervals up to $2\frac{1}{4}$ yr. Several cross-correlation peaks found are discussed in the text.

In a similar way, we rule out the 1.81 yr peak. The 1.81 yr peak has a spuriously high plateau because the cross-correlation is biased by the interval 1982 November to 1984 January when the A component was significantly brighter. Observations of component B on 1982 January 23 differ from the phased 1980 April 9–14 component A data by 0.10 mag, and a less serious discrepancy for the 1983 February 13–15 B component is also found.

No cross-correlation peak is found for the Florentin-Nielsen (1984) value of $\Delta t = 1.55 \pm 0.1$. We believe that the best value is given by our cross-correlation peak of $\Delta t = 1.03$ yr. For this value, the cross-correlation peak is sharpest, and we find no inconsistencies where data for the phase-shifted measurements indicate inadmissably large errors.

If we take the time delay as $\Delta t = 1.03 \pm 0.1$ yr, we can determine the brightness ratio of the two components. This brightness ratio is the ratio of the magnifications of the lens for the two beams, but the observed ratio must be corrected for the brightness of underlying galaxy G1. We determine from a best eye fit that for observations phased together with $\Delta t = 1.03$ yr, $\Delta m = 0.11 \pm 0.02$ mag in the sense that component B + G1 is brighter than A. We adopt a magnitude $R_J = 18.3 \pm 0.1$ from SW for G1. During the interval 1980 January to 1982 January, the A component had a mean magnitude of $R_J = 16.67$, and component B + G1 was $R_J = 16.56$. The subtraction of G1 makes the component magnitude $R_J = 16.80$ for component B. The observed magnification ratio is therefore A/B = 1.13 ± 0.02. Young *et al.* determined that A/B = 1.30 from a single observation; if the emission lines did not change during the time $\Delta t = 1.03$ yr so that the instantaneous value is equal to the value which would be measured from phased observations, then the emission line ratio differs significantly from the continuum brightness ratio. Our value of the continuum ratio is more likely to be the result not only of lensing by the mean gravitational field of the lensing galaxy and cluster but also to include effects of minilensing by individual stars in the lens galaxy (Young 1981). We plan to monitor the strengths of the emission lines of the A and B components so we can phase them with our $\Delta t = 1.03$ yr and determine thereby the ratio of the magnifications of the mean fields of the lens galaxy and cluster. Comparison with our ratio for the continuum image magnifications will give us information about effects of minilensing.

IV. SUMMARY

1. Our CCD brightness monitoring procedure appears to be capable of measuring isolated stars of 15th–16th mag with an accuracy of 0.005 mag rms.

2. For the TwQSO components, our rms scatter is 0.01 mag per observation, provided observations are made on nights with 2″ seeing or better.

3. Both the TwQSO components appear to show brightness fluctuations of a few percent on a day's time scale.

4. The time delay Δt between arrival of the A and B image appears to be 1.03 ± 0.1 yr. This needs verification from an event predicted to occur in 1985 January–March.

Note Added 1985 June 12.—Our continued monitoring during the 1984–1985 observing season gave these results on 30 nights: the A component leveled off at the faint level of $R = 16.54$, and the B component showed the brightness reduction predicted by observations of A a year earlier. In particular, component B faded by 0.1 mag between 1985 January 15 and April 10. These observations rather strongly constrain Δt to be in the interval $0.83 \leq \Delta t \leq 1.23$ yr. We believe that our previous determination from cross-correlation, $\Delta t = 1.03 \pm 0.1$ yr, is the correct value.

Observations from the recent 1984–1985 observing season also provide rather strong constraint against the cross-correlation peak of $\Delta t = 0.47$ yr, but only slight additional constraint on the longer $\Delta t = 1.81$ yr cross-correlation peak.

The continued development of CCD camera systems at CfA is under the direction of Dr. J. Geary, whom we thank for advice and support. We thank Mr. R. Burg, Dr. S. Kent, and Dr. M. Kurtz for contributing observations of the TwQSO.

APPENDIX

ERRORS IN CCD PHOTOMETRY OF TwQSO

Our technique of monitoring the brightness of the TwQSO 0957+561 A, B eliminates one principal source of error: extinction. Because the five standard stars and the TwQSO components are observed simultaneously, extinction changes in time, including variations in extinction because of clouds, should be canceled by our method of referencing our photometry to field star standards.

Counting statistics show that sufficient numbers of photons have been detected to provide photometry accurate to 1% or better. Our 10 minute exposure gives 78,000 detected photons, and approximately half that number are from the night sky for our standard 5″.84 diameter aperture.

We list all of the sources for errors in photometry, and discuss them in turn below: (1) extinction, clouds, etc.; (2) image enlargement due to "seeing" and guiding errors; (3) CCD registration effects; (4) flat fielding errors; (5) sky determination errors; (6) influence of galaxy G1; (7) overlapping of images.

1. Extinction.—To test whether time or spatial variations in extinction can affect our results, we have reduced data for star E separately and we have examined the results in two ways. Our star E photometry was processed by determining the ratio of digital counts in our standard 5″.84 diameter aperture centered on star E to the counts for stars D, 3, 4, and 5. The results are shown in Figure 2, where it can be seen that systematic effects are below the 1% level. For star brightness ratio data, we have determined the rms deviations from the nightly means. The mean rms deviation for all the nights shown in Figure 2 is 0.005 mag. Similarly, the rms deviation of the nightly means from our adopted mean of means is 0.006 mag. Thus we conclude that night-to-night extinction changes, changes in extinction during a night, and spatial variations in extinction due to structured clouds, are unimportant at the 1% level.

2. Seeing effects.—These cause errors in two ways. Because of image spreading due to atmospheric seeing, the amount of light in a fixed aperture depends on the image profile, especially the extended outer portion. This is expected to change during a night and from night to night. For typical observing conditions, 91% of the detected photons are contained in our measuring aperture. Because the seeing profile is expected to be the same for our five comparison stars, we expect seeing to be compensated for in our use of local standards. Our mean error of star E data includes errors from seeing for isolated stars, and our discussion of (1) shows that such seeing effects are adequately compensated for in our data reduction procedures.

Seeing affects our results for the TwQSO in a more complicated way, because light of component A can be scattered into the aperture of component B. This is an aspect of overlapping of star images, discussed in (7) below.

3. Effects of image registration on the CCD detector.—These can also be inferred to be unimportant on the basis of our results for star E. The effect being considered here results from the fact that the CCD detector has microscopic lines of reduced sensitivity at the spaces where the pixels join together. If the brightest portion of a star image falls on a local area of lower sensitivity, the detected CCD signal will be somewhat lower.

Because the offset guider on the 24 inch (61 cm) telescope has a small amount of flexure, in the course of a 4 hr observation session the CCD image of star E drifts approximately 3 pixels. The fact that the measured brightness of star E remains constant at the 1% level ensures that registration errors are not important.

4. Flat fielding residual errors.—These result from incorrect subtraction of the offset determined from a 0 s exposure CCD data frame, or from temporal changes in the sensitivity of our CCD detector. Such effects could result from small changes in the temperature of our read amplifier or of the surfaces of our detector. The net result would be errors in our corrections for the detector's response to uniform illumination. Tests for such nonuniformities over the past 3 yr of operation of the RCA CCD detector have shown that residual errors after flat fielding are less than 0.3%, so they would not be expected to have any result on photometry at the 1% level. The fact that data for star E show constancy at the 1% level demonstrates that residual flat fielding errors are not important.

5. *Sky determination errors.*—In our procedure to measure the brightness of the TwQSO components, we determine the sum of CCD counts in a circle of 5".84 diameter. The measured brightness includes the counts of the sky background (and foreground). Since the sky has a blue-green magnitude of approximately 21 mag arcsec^{-2}, the sky brightness in our 5".84 diameter aperture is approximately 17.4 mag and is thus comparable to an image component of the TwQSO. Because it should be possible to determine the sky brightness to an accuracy of 1%, it should be possible to make satisfactory correction for the subtracted background sky. Note that since star E and all the other field standards are much brighter than the TwQSO components, our satisfactorily low rms for the star E photometry does not imply anything about our TwQSO results.

To obtain an upper limit on the effect of our sky determination errors, we have examined our measured sky brightnesses for all the data frames on a photometric night. After subtracting a slow drift in sky brightness, we determined that the rms deviation of our sky brightness measurements was 1% of the mean sky brightness. Thus an upper limit to the error of our sky determination is 1% of the sky value, or 0.4% of the brightness of a QSO image component. If the sky brightness itself fluctuates, our sky brightness error estimate is an overestimate of the true error. We conclude that in any case, sky brightness determination does not significantly affect our results.

6. *Influence of galaxy G1.*—Galaxy G1 is 1" north of the TwQSO B image, so the measuring aperture for the northern A image records a small amount of light from the underlying galaxy. We have used Stockton's (1980) values for the observed galaxy parameters, $r_c = 0''.24$ and $r_t/r_c = 2.5$, to determine from a direct integration that the light in aperture A (the aperture centered on the TwQSO A component) is approximately 17% of the light in aperture B. The brightness in aperture A has been determined by SW, but their results are on the *BVRI* system, and our monitoring is on the Gunn *gr* system. In transforming between systems we must take special precautions because the rest frame 4000 Å spectrum break in G1 occurs at 5560 Å for a redshift of 0.39. This is in the middle of the *V* band. To minimize sensitivity to $B-V$, we modify the transformation equations in Kent (1984) to

$$g = B - 0.19 - 0.59(B-V) .$$

From this transformation and the galaxy G1 photometry in SW, we determine $g = 20.23$ in aperture B. Thus for our typical TwQSO component magnitude of $g = 17.0$, galaxy G1 contribute 5% of the light in aperture B and 0.8% of the light in aperture A.

Because of seeing changes during a night or from night to night, the off-center G1 image will enlarge in a slightly different way than the stellar images of the TwQSO A and B components. Because we did not use nights with seeing worse than 2", and because galaxy G1 contributes such a small fraction to our A and B images, we believe that the underlying galaxy does not cause effects in our data at the 1% level or more.

7. *Overlapping of images.*—Because of diffraction of light in the telescope optics and light scattering by dust on mirror surfaces and in the atmosphere, the image of each QSO component has faint extensions which reach as far as the other component. We can determine directly the amount of this image enlargement from analysis of images of the isolated field stars on our CCD data frames. From our study of images of star 3, we find that for the 8.2 pixel separation of our apertures, light from a TwQSO component scattered into the aperture that measures the other component is 1% of the measured intensity in conditions of good seeing. When seeing had deteriorated to 2" or worse, the scattered component increased to 2%–5%, and we attempted to determine a correction based on the measured scattering from the image of star 3. We found, however, that the data corrected for this effect appeared to have artifacts introduced by the correction, possibly in part because of complications introduced by the existence of galaxy G1, and we have therefore not included any data for which the seeing is 2" or more.

REFERENCES

Florentin-Nielsen, R. 1984, *Astr. Ap.*, **138**, L19.
Grauer, A. 1984, *Ap. J.*, **277**, 77.
Johnson, H. L. 1966, *Ann. Rev. Astr. Ap.*, **4**, 193.
Keel, W. 1982, *Ap. J.*, **255**, 20.
Kent, S. 1984, *Pub. A.S.P.*, **97**, 165.
Matilsky, T., Shrader, C., and Tananbaum, H. 1982, *Ap. J.* (*Letters*), **258**, L1.
Oke, J. B. 1967*a*, *Ap. J.*, **147**, 901.
———. 1967*b*, *Ap. J.* (*Letters*), **150**, L5.
Schild, R. 1983, *Pub. A.S.P.*, **95**, 1021.
Schild, R., and Weekes, T. 1984, *Ap. J.*, **277**, 481 (SW).
Stockton, A. 1980, *Ap. J.* (*Letters*), **242**, L141.
Vanderriest, C., Biyaoui, A., Felenbok, P., Lelievre, G., Schneider, J., and Wlerick, G. 1982, *Astr. Ap.*, **110**, L11.
Walsh, D., Carswell, R. F., and Weymann, R. J. 1979, *Nature*, **279**, 381.
Young, P. J. 1981, *Ap. J.*, **244**, 756.
Young, P. J., Gunn, J. E., Kristian, J., Oke, J. B., and Westphal, J. A. 1980, *Ap. J.*, **241**, 507.
———. 1981, *Ap. J.*, **244**, 736.

BRYAN CHOLFIN: 25 Clements Road, Newton, MA 02158

RUDOLPH E. SCHILD: Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138