THE TIMESCALES OF THE OPTICAL VARIABILITY OF BLAZARS. I. OQ 530

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ABSTRACT

We have obtained photometric observations of the BL Lacerate object OQ 530 in an effort to study the nature of variations which may be occurring on timescales ranging from years to less than one day. Rapid events have been observed, with changes as rapid as 0.06 mag observed in 20 min. These changes are among the most rapid ever detected for a BL Lacerate object. The variations have been investigated to determine if they are periodic in nature. We find no evidence for any significant periodicities to be present.

I. INTRODUCTION

Historically, rapid variability has been known to be an identifying property of BL Lacertae objects (Strittmatter *et al.* 1974). However, only recently has variability on timescales much less than one day been conclusively demonstrated to be present for the prototype of this class, BL Lacertae (Miller, Carini, and Goodrich 1989). As part of an ongoing program to systematically study a number of BL Lacertae objects and determine if they also exhibit optical variations similar to those observed for BL Lacertae, we have obtained observations of OQ 530. OQ 530 was included in this study because it is known historically to have a range of ~ 5.0 mag (Miller 1978). Subsequent studies (O'Dell *et al.* 1978; Puschell and Steien *et al.* 1980; Worrall *et al.* 1984) confirmed that significant optical variations were present on timescales ranging from a few days to several months. Therefore, OQ 530 was an excellent candidate object to be included in our sample of objects to be investigated for possible variations on these very short timescales.

II. OBSERVATIONS

The high time resolution observations of OQ 530 reported here were obtained with the No. 1 0.9 m telescope at Kitt Peak National Observatory equipped with a direct CCD camera and an autoguider. The observations were made through a V filter with an RCA CCD. Repeated exposures of 90 s were obtained for the star field containing OQ 530 and several calibrated standard stars (Miller *et al.* 1984; Smith *et al.* 1985). These standard stars, located on the same CCD frame as OQ 530, provided comparisons for use in the data-reduction process. The observations were reduced using the method of Howell and Jacoby (1986). Each exposure is processed through an aperture photometry routine which reduces the data as if it were produced by a multistar photometer. Differential magnitudes can then be computed for any pair of stars on the frame. Thus, simultaneous observations of OQ 530, several comparison stars, and the sky background allow one to remove variations which may be due to fluctuations in atmospheric transparency and extinction. The aperture photometry routine used for these observations is the APPHOT routine in IRAF.*

The photoelectric photometry of OQ 530 has been obtained using the 0.9 and 1.3 m telescopes at Kitt Peak National Observatory and the 1.05 m telescope at Lowell Observatory. The photoelectric photometry which was obtained at KPNO utilized either the automated filter photometer or the Mark 2 computer photometer equipped with a 1P21 photomultiplier and standard UBV filters. The observations obtained at Lowell Observatory used the Bowell Two-Channel photometer equipped with S-20 photomultipliers. One channel contains V and R filters, the other channel contains U and B filters. The extinction was determined each night and the transformation to the standard UBV system was made using the standard stars of Landolt (1973).

III. RESULTS

The photometry of OQ 530 covering the period from 1979 to 1989 is summarized in Table I and displayed in Fig. 1. The date the observations were obtained is listed in column 1, the observatory and telescopes are listed in column 2, the V magnitudes are listed in column 3, $B-V$ colors are listed in column 4 and $U-B$ colors are listed in column 5. A total range of 1.37 mag is observed during this 10 year period. The variations appear to be erratic, exhibiting no well-defined long-term trends. Variations of ~ 0.1 mag/day are common and are consistent with the results obtained from the high time resolution CCD photometry obtained for this object.

The results of the rapid timescale observations of OQ 530 obtained 1988 April 1–4 are summarized in Figs. 2–6. All of the observations presented here were obtained with a CCD through a V bandpass filter. The upper panel in each figure displays the differential magnitude between comparison star 2 and OQ 530. The lower panel displays the differential magnitude between comparison star 2 and comparison star 3. The scatter of the differential magnitudes in the lower panel in each case provides an indication of the stability of the standard stars used in reducing these observations and is a measure of the overall observational uncertainty. The most conspicuous feature in Fig. 2 is the ~ 0.3 mag outburst that is

[a)] Guest Observer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc.
[b)] Guest Observer, Lowell Observatory.

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TABLE I. The long-term optical observations of OQ 530.

DATE	OBSERVATORY	V	B-V	U-B
09/12/79	KPNO/0.9m	15.07±0.02	0.64 ±0.05	-0.53 ±0.06
01/17/80	KPNO/0.9m	15.28±0.03	0.59 ±0.05	-0.47 ±0.06
02/23/80	KPNO/1.3m	15.61±0.03	0.53 ±0.04	-0.56 ±0.08
05/13/80	KPNO/0.9m	15.22±0.03	0.61 ±0.05	-0.51 ±0.07
05/15/80	KPNO/0.9m	15.31±0.03	0.62 ±0.05	-0.56 ±0.06
05/19/80	KPNO/0.9m	15.60±0.04	0.55 ±0.06	-0.51 ±0.08
03/29/81	KPNO/1.3m	15.42±0.03	0.63 ±0.04	-0.54 ±0.09
03/30/81	KPNO/1.3m	15.54±0.03	0.59 ±0.05	-0.56 ±0.08
06/06/81	KPNO/0.9m	15.17±0.03	0.59 ±0.04	-0.59 ±0.07
06/07/81	KPNO/0.9m	15.03±0.03	0.55 ±0.04	-0.52 ±0.06
06/10/81	KPNO/0.9m	15.53±0.04	0.60 ±0.06	-0.48 ±0.10
04/18/82	KPNO/1.3m	15.48±0.03	0.62 ±0.05	-0.59 ±0.08
04/20/82	KPNO/1.3m	15.39±0.03	0.60 ±0.05	-0.55 ±0.07
01/23/83	KPNO/0.9m	16.20±0.08	....	....
05/10/83	KPNO/0.9m	15.56±0.03	0.54 ±0.06	-0.63 ±0.08
04/24/85	LOWELL	14.83±0.03	0.48 ±0.05	-0.46 ±0.09
06/20/85	LOWELL	15.48±0.04	0.49 ±0.07	-0.31 ±0.12
05/09/86	LOWELL	15.61±0.05	0.69 ±0.08	....
05/12/86	LOWELL	15.40±0.04	0.56 ±0.07	....
12/13/86	LOWELL	15.36±0.05	0.72 ±0.08	....
06/03/87	LOWELL	15.39±0.04	0.43 ±0.07	-0.32 ±0.07
04/01/88	KPNO/0.9m	15.24±0.02	....	....
04/02/88	KPNO/0.9m	15.20±0.02	....	....
04/03/88	KPNO/0.9m	14.96±0.02	....	....
04/04/88	KPNO/0.9m	15.17±0.02	....	....
09/10/88	LOWELL	15.25±0.04	....	....
09/11/88	LOWELL	15.52±0.04	....	....
03/15/89	KPNO/0.9m	15.46±0.04	....	....
03/17/89	KPNO/0.9m	15.55±0.04	....	....
03/18/89	KPNO/0.9m	15.55±0.02	....	....
05/12/89	KPNO/0.9m	15.43±0.02	....	....
05/13/89	KPNO/0.9m	15.37±0.02	....	....
05/14/89	KPNO/0.9m	15.28±0.02	....	....

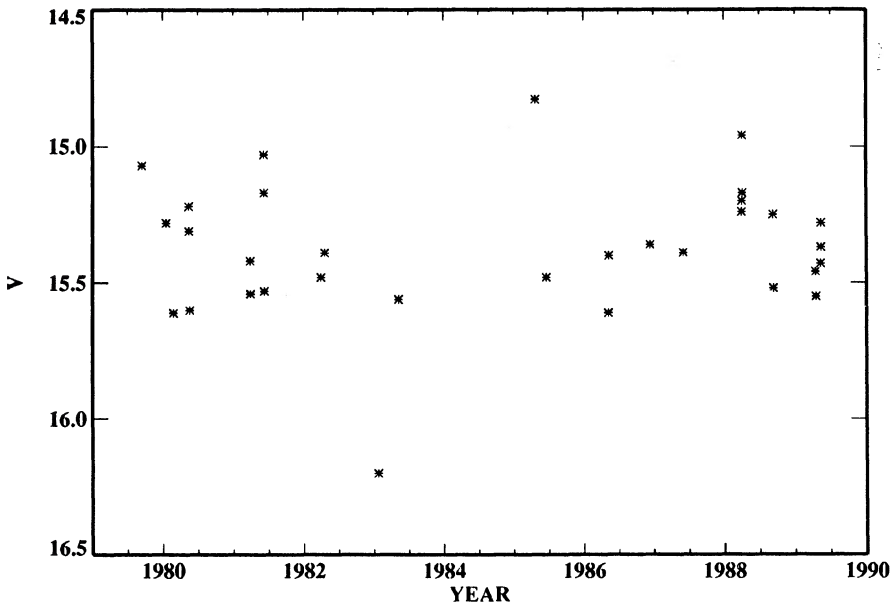

FIG. 1. The *V* observations of OQ 530 for the period 1979–1989.

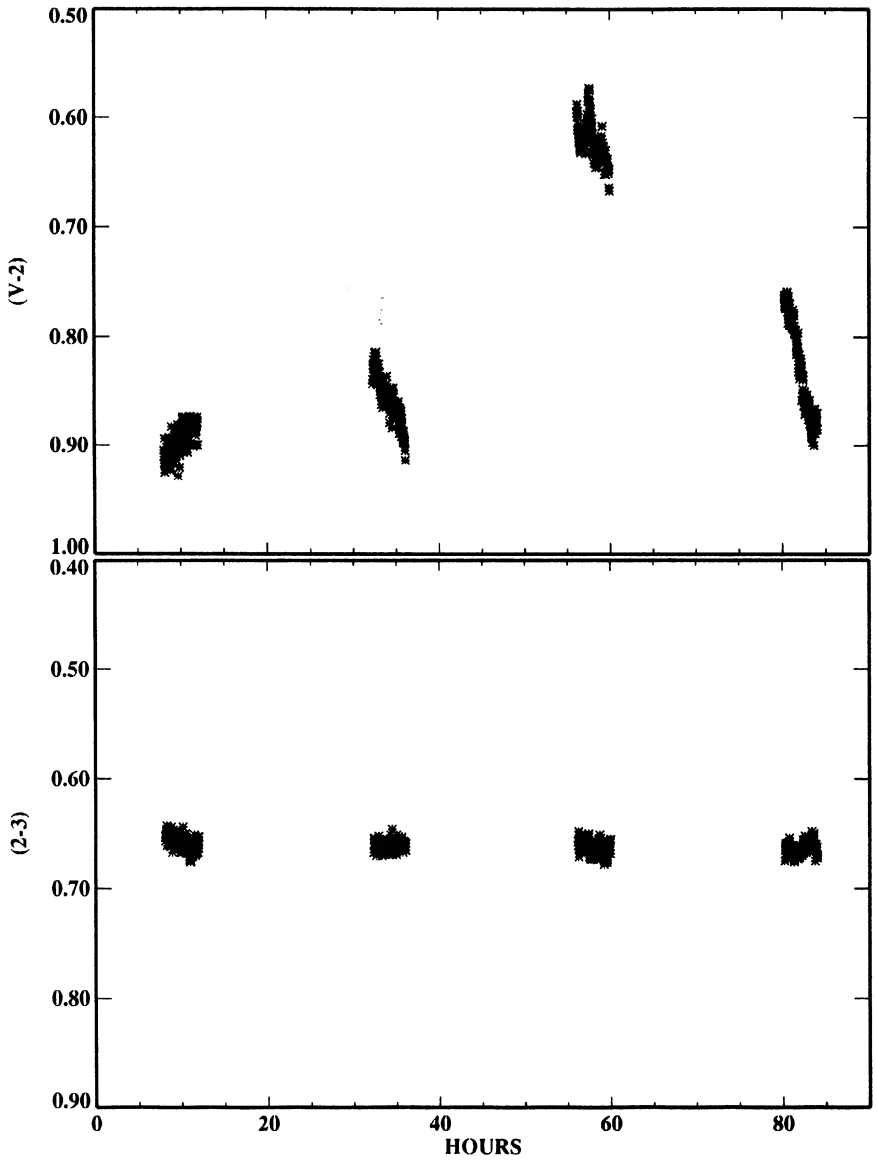

FIG. 2. The observations of OQ 530, obtained through a *V* filter, for the period 1988 April 1–4 are shown in the upper panel. The scatter of the two comparison stars are shown in the lower panel. The zero point of the *x* axis corresponds to 000 hr UT on the night of 1988 April 1.

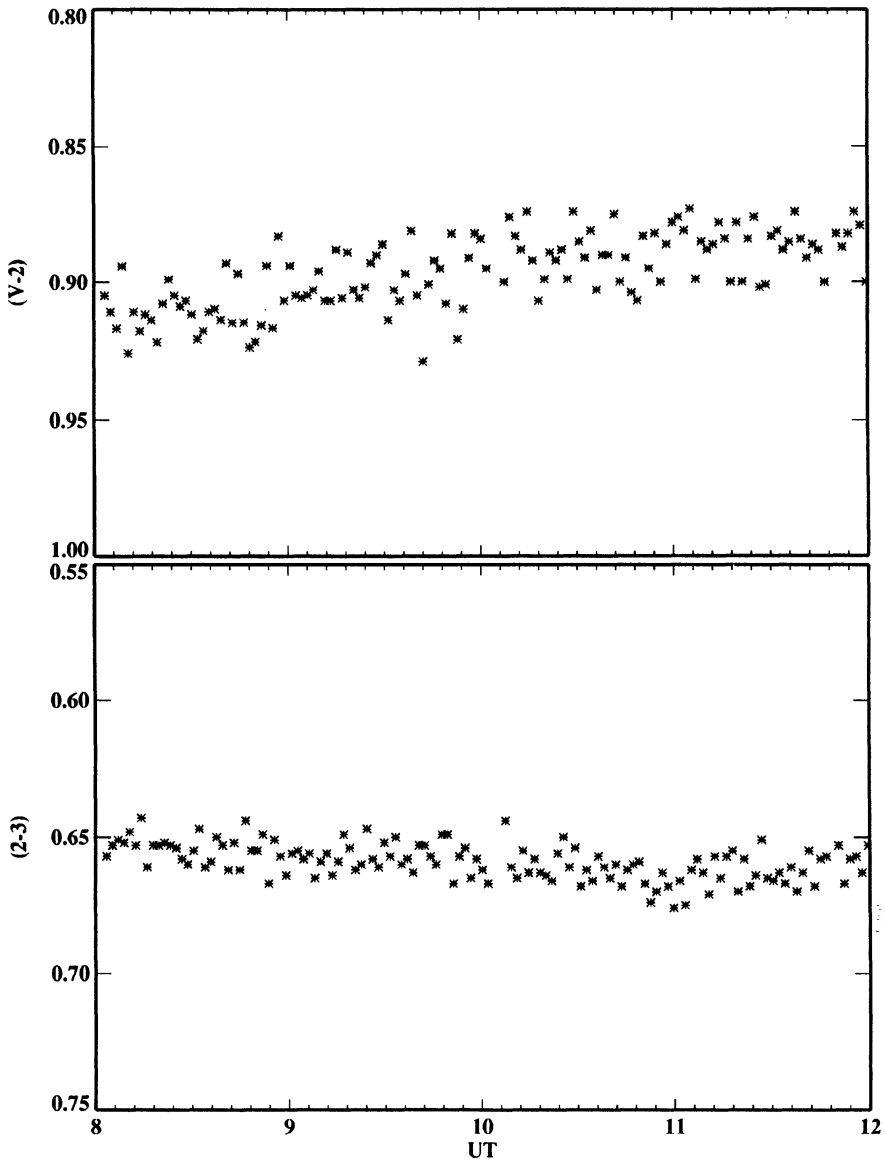

FIG. 3. The observations of OQ 530, obtained through a *V* filter on 1988 April 1, are displayed in the upper panel. The scatter of the two comparison stars is shown in the lower panel.

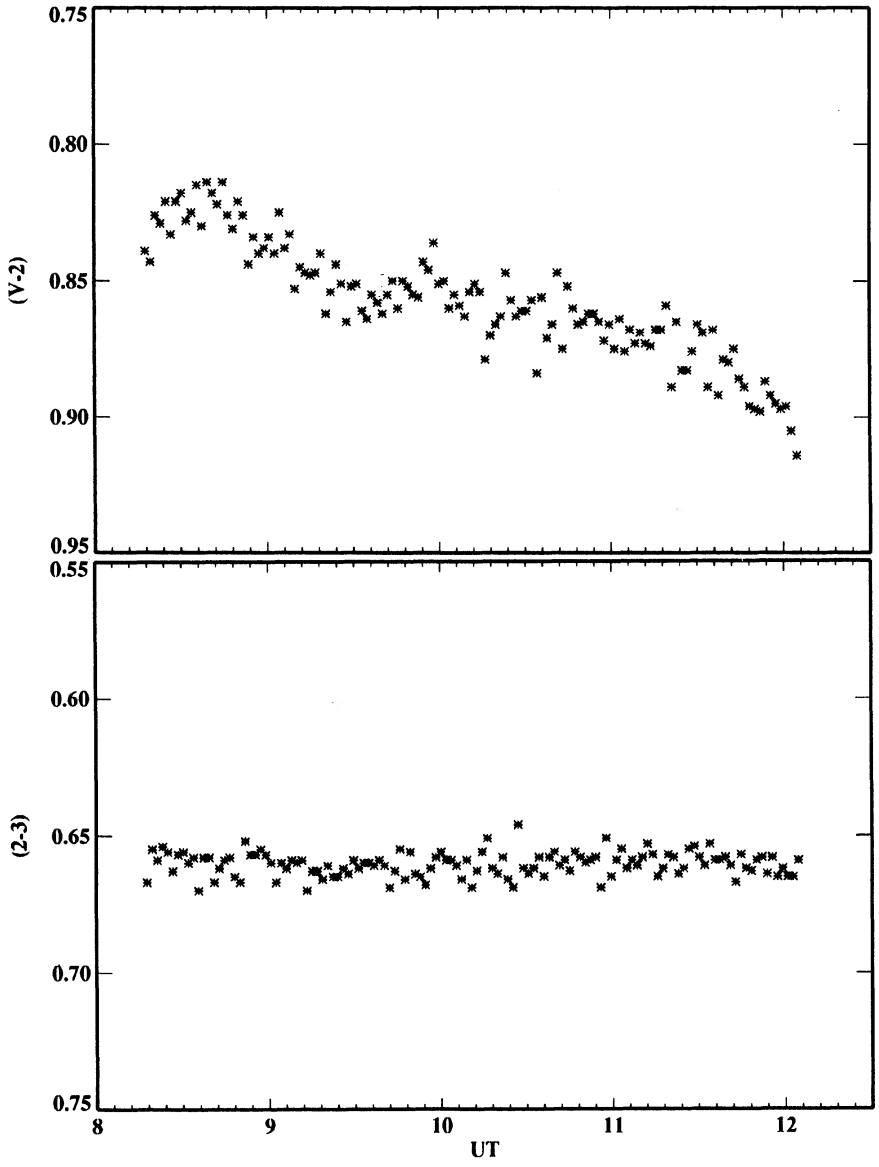

FIG. 4. The observations of OQ 530, obtained through a *V* filter on 1988 April 2, are displayed in the upper panel. The scatter of the two comparison stars is shown in the lower panel.

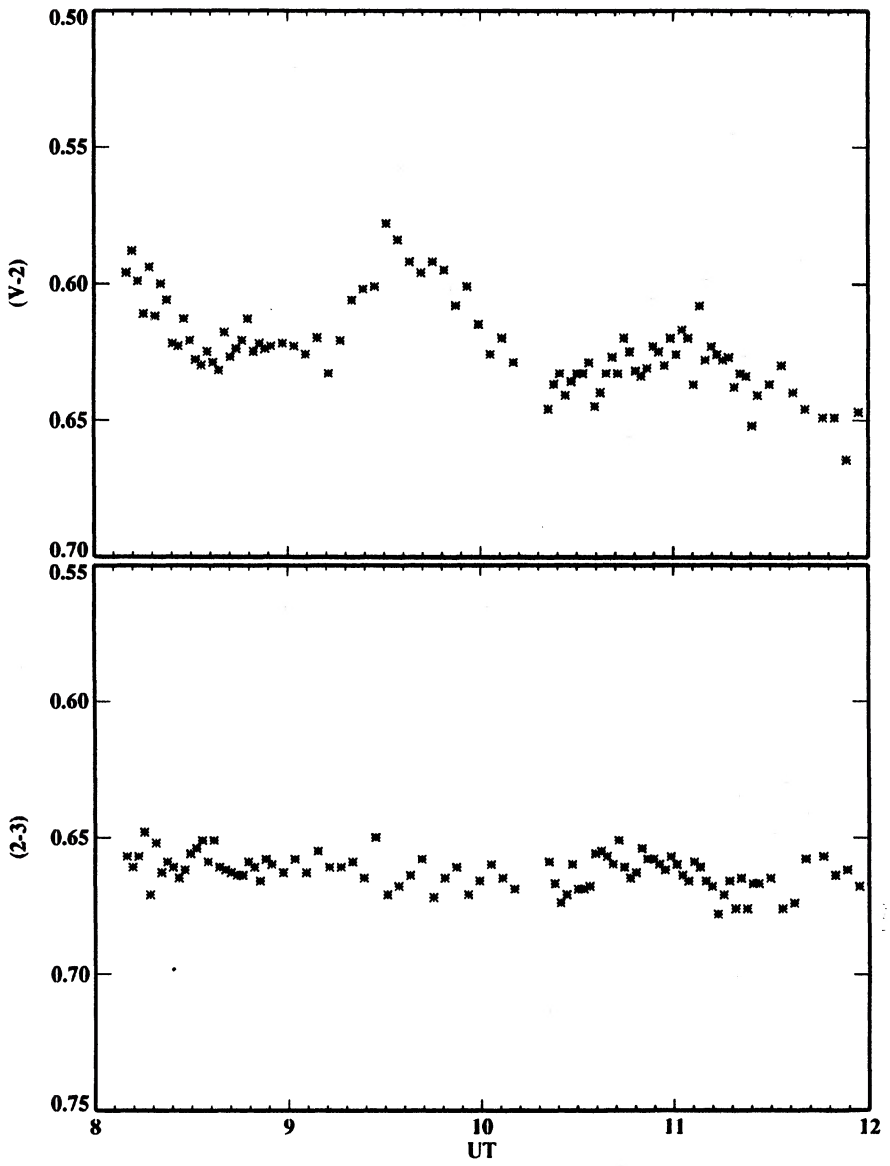

FIG. 5. The observations of OQ 530, obtained through a *V* filter on 1988 April 3, are displayed in the upper panel. The scatter of the two comparison stars is shown in the lower panel.

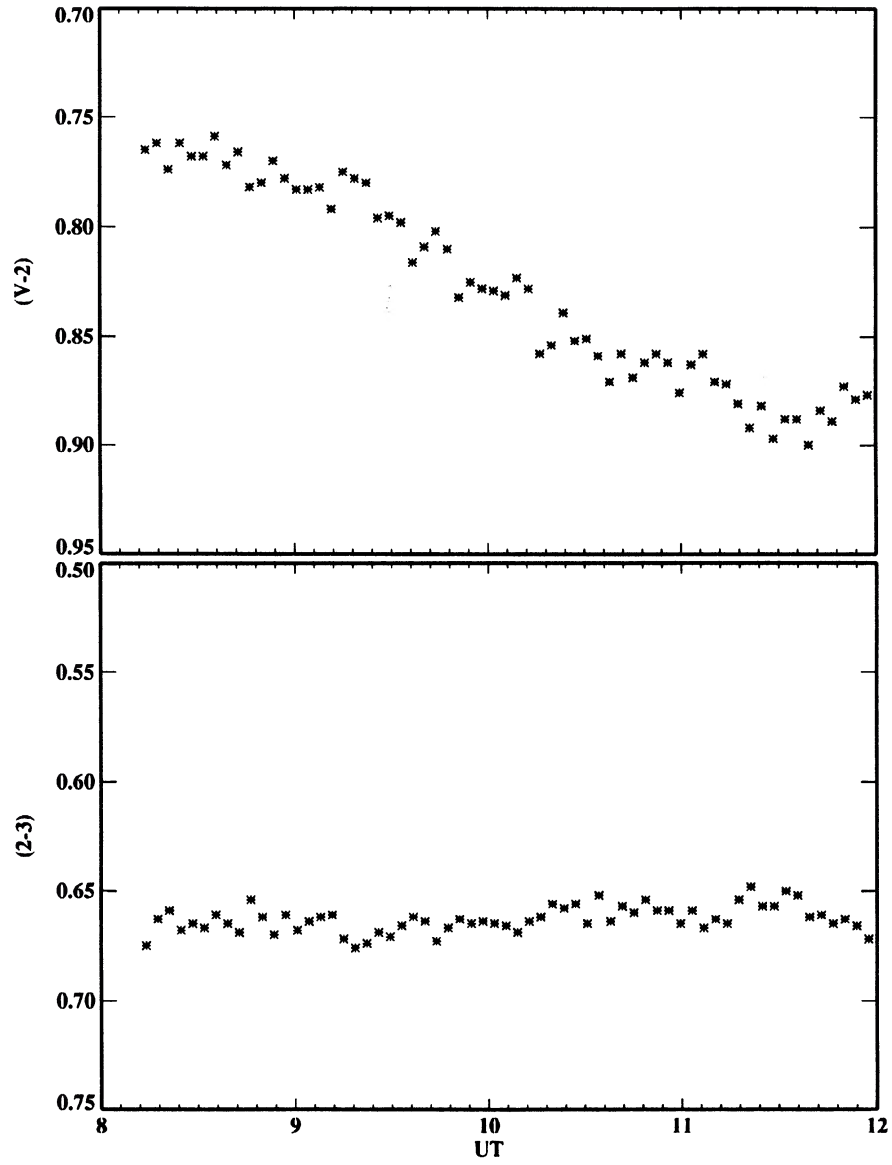

FIG. 6. The observations of OQ 530, obtained through a *V* filter on 1988 April 4, are displayed in the upper panel. The scatter of the two comparison stars is shown in the lower panel.

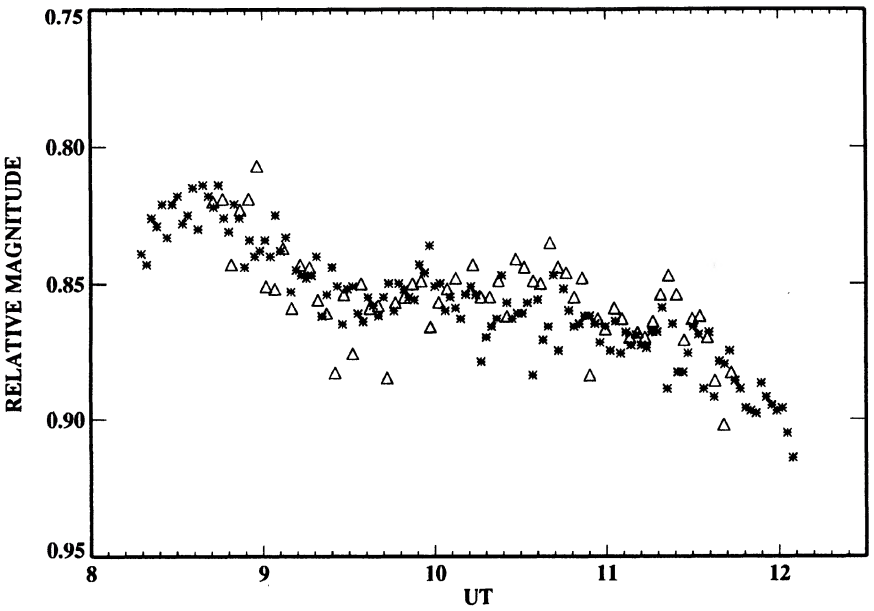

FIG. 7. The observations of OQ 530, obtained simultaneously from Lowell Observatory (asterisks) and Kitt Peak National Observatory (triangles) are displayed. These observations were obtained through a V bandpass filter.

concentrated primarily on the night of April 3, although a major decline from the maximum brightness clearly carries through on the following night of April 4.

Preceding this large outburst, a gradual brightening trend of ~ 0.005 mag/hr was observed on the night of April 1 (Fig. 3). No conspicuous events on timescales of minutes to hours were observed on this night. However, on April 2 (Fig. 4), OQ 530 exhibits quite complicated structure in its variability with a total range of ~ 0.1 mag observed. A local maximum is observed between 0800 UT and 0900 UT. This is followed by a rapid decline of 0.05 mag in less than one hour. A broad shoulder on the light curve follows and continues for approximately three hours. During the final ~ 30 min that the source was observed, another sharp decline of ~ 0.05 mag is observed.

When OQ 530 was observed the night of April 3 (Fig. 5), it was found to be ~ 0.3 mag brighter than when it was last observed on the previous night. The variations were very erratic with a well-defined outburst of amplitude ~ 0.08 mag detected near 1000 UT. The following night, April 4 (Fig. 6), the object was ~ 0.25 mag fainter and was observed undergoing a regular decline of ~ 0.15 mag during the 4 hr it was observed.

On the night of April 2, observations were obtained for OQ 530 simultaneously at Lowell Observatory and Kitt Peak National Observatory. The observations at Lowell Observatory were obtained with a CCD camera attached to the 1.05 m telescope. The data were obtained and reduced in the manner described in Sec. II. Figure 7 shows a plot of both the Kitt Peak (triangles) and Lowell (asterisk) data. We see that the observations match each other nearly perfectly, further supporting the reality of the observed varations.

A power spectrum analysis of the data was undertaken to determine if any periodicities existed in the data. The period analysis was accomplished using the discrete Fourier transform and CLEAN routine of Roberts *et al.* (1987). No evidence for periodicities was detected in these observations of OQ 530.

OQ 530 was near a brightness of $V = 15.0$ during the time these observations were obtained indicating it was moderately bright but not near its historical maximum in brightness. Therefore, the rapid intraday variations which are reported here are likely to be typical of the variability which this object will exhibit on timescales of hours to days.

One may estimate the size of the emitting region for this object from $R \leqslant ct$, assuming no relativistic beaming. The timescale identified from the present observations is the rise time for the event observed between 0900 and 1000 UT on April 3. This event exhibited an increase in brightness of 0.06 mag and the duration of this event is 20 min. If one uses the timescale of this event to define a "characteristic timescale" or doubling time, and one assumes that the radiation is generated in the vicinity of a black hole, e.g., $R \sim 3R_S$ where $R_S = 2G\mathcal{M}/c^2$ is the Schwarzschild radius, then the mass of the supermassive blackhole $\mathcal{M}$ is given by

$$\mathcal{M} \leqslant \frac{c^3 t}{6G}. \quad (1)$$

This leads to an upper limit to the mass of the supermassive black hole of $6 \times 10^8 \mathcal{M}_\odot$.

In summary, we have found rapid, large amplitude variations for the BL Lacertae object OQ 530. These events are consistent with the variations observed in the long-term light curve for this object. These events may be used to place constraints on the size of the source region. In no instance have we found the variations to be periodic in nature.

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