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# EVIDENCE FOR RAPID OPTICAL VARIATIONS OF THE QUASI-STELLAR RADIO SOURCE 4C 29.45[1]

ALBERT D. GRAUER[2]
Department of Physics and Astronomy, University of Arkansas at Little Rock;[3] and
Department of Physics and Astronomy, Louisiana State University
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## ABSTRACT

Four separate high-speed photometry runs were made on 4C 29.45 during an optical outburst. They indicate rapid brightness variations on the order of $0^{d}.02$ or less.

Evidence for rapid optical variations is presented along with estimates of the degrees of certainty which exist.

Further studies of objects of this type are required before a definitive model can be adopted. Several viable theoretical descriptions of a quasar involve a very massive black hole surrounded by an accretion disk. These theories can explain the short time variability reported here with a realistic choice of model parameters.
*Subject headings:* quasars

## I. INTRODUCTION

The object 4C 29.45 (1156+295, TON 599, CTD 77, OM 295, B2) is a quasi-stellar radio source located at $\alpha = 11^{h}56^{m}58^{s}.1$ and $\delta = 29°31'24''.0$ (1950). It was listed as TON 599 by Iriarte and Chavira (1957) who estimated its magnitude as 15.6. Burbidge (1968) identified one very strong broad emission at 4837 Å as Mg II ($\lambda = 2798$ Å) giving $z = 0.729$. Olsen (1970) estimated $m = 17$ from the Palomar Sky Survey and provides a finding map. Grueff and Vigotti (1972) contributed similar information. Schmidt (1975) found the 1909 Å line of C III at 3299 Å, confirming Burbidge's value for $z$. Stockman (1978) classified this object as an optically violent variable (OVV) QSO because its linear polarization was quite different on the two occasions he observed it. Richstone and Schmidt (1980) have identified a number of spectral properties for 4C 29.45. Hewitt and Burbidge (1980) include it in their optical catalog of quasi-stellar objects. Recently it has undergone a violent optical outburst. The observations presented here were made at the time the object's rapid decline in brightness changed slope quite dramatically (Pollock 1981; Wills 1983).

The recent paper which presented evidence for very rapid X-ray variability in 1525+227 (Matilsky, Shrader, and Tananbaum 1982) along with the reported rapid variability of 3C 273 at 1 mm (Sherwood *et al.* 1983) has encouraged the publication of these observations.

## II. OBSERVATIONS

High-speed photometry of 4C 29.45 with a time resolution of 2 s through a Johnson $B$ filter was obtained on the nights of 1981 April 8, 9, and 10 (UT). The No. 2, 91 cm reflector at Kitt Peak National Observatory was used with the University of Arkansas at Little Rock two-star photometer. A description of the photometer and the reduction techniques has been published (Grauer and Bond 1981). A comparison star $\Delta\alpha = 40^{s}$ east and $\Delta\delta = 9'47''$ north relative to 4C 29.45 was measured simultaneously with it. The comparison star's extra-atmospheric instrumental $B$ magnitudes for the three nights respectively were $-9.376$, $-9.380$, and $-9.382$. These values were obtained by applying a mean extinction coefficient to each 2 s comparison star integration and using these values to obtain the average for each night. No zero point corrections were applied. There was no indication of any short-term variations in the comparison star's magnitude as the three nights were photometric. Guiding was done continuously, and errors in it are not the source of the variations observed.

Both 4C 29.45 and the comparison star were observed simultaneously through standard $B$ filters of the $UBV$ system. The QSO was observed with channel one and the comparison with channel two. The telescope was moved off the two stars occasionally to measure the sky background in each channel and then again to measure the comparison in channel one. The interpolated sky measurements were subtracted from the appropriate data channel. The effects of extinction were removed by dividing the QSO data points by the smoothed comparison star observations. The gain ratio between the two channels was obtained repeatedly from the comparison star channel two, sky (both channels), comparison star channel one, and comparison star channel two observing sequences. These values are listed on the graphs at the times they were obtained. The gain ratio was thus measured 19 times on the three nights with an average value of $-0.866$ mag and a standard deviation of 0.006 mag. Single-channel $\Delta$ magnitudes were obtained from the QSO channel one, sky channel one, comparison star channel one, and QSO channel one observing sequences (60 s averages were employed). These single-channel points are plotted as filled circles on the graphs. 4C 29.45 ($V = 14.41$, $B-V = +0.39$, $U-B = -0.50$) and the comparison star ($V = 11.96$, $B-V = +0.27$, $U-B = +0.10$) were placed on

[1] Louisiana State University Observatory Contribution No. 181.

[2] Visiting Astronomer, Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[3] Academic year address.

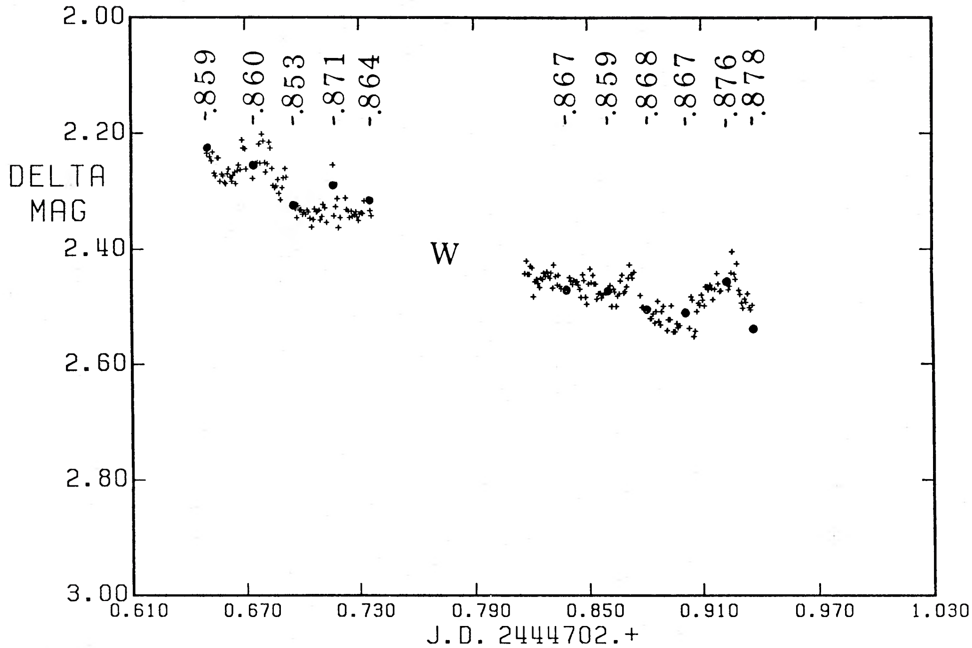


FIG. 1.—Data for 1981 April 8; the original 2 s integrations have been summed into 60 s bins. The difference in $B$ magnitude between 4C 29.45 and the comparison star are plotted vs. heliocentric Julian Date. The crosses are the dual-channel data points, the filled circles are the single-channel data points, and the W is a point taken by Wiśniewski (1981).

the *UBV* system by observing them along with 16 standard stars (standard deviations in magnitudes $V = 0.008$, $B-V = 0.009$, $U-B = 0.033$). The standards employed are those of Landolt (1973). The QSO was observed at 5:17 UT on 1981 April 10.

In Figures 1–3 the differences in $B$ magnitude between 4C 29.45 and the comparison star are plotted versus heliocentric Julian Date. The original 2 s integrations have been summed into 60 s bins. The crosses are the dual-channel points, and the filled circles are the single channel points. In order to obtain the actual $B$ magnitude of 4C 29.45, the $B$ magnitude of the comparison star, 12.23, must be added to the delta magnitude scale. The points marked W are single observations made by Wiśniewski (1981) using a 1.5 m reflector on Mount Lemmon.

Figure 1 presents the data of 1981 April 8. The gap in the

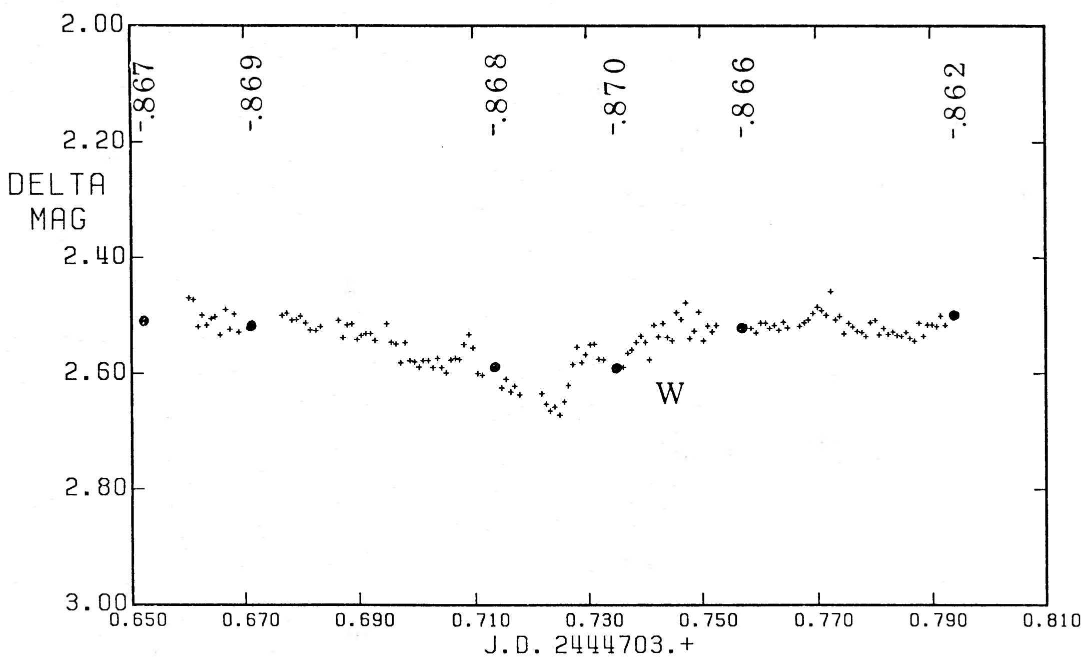


FIG. 2.—Data for 1981 April 9; same display as Fig. 1

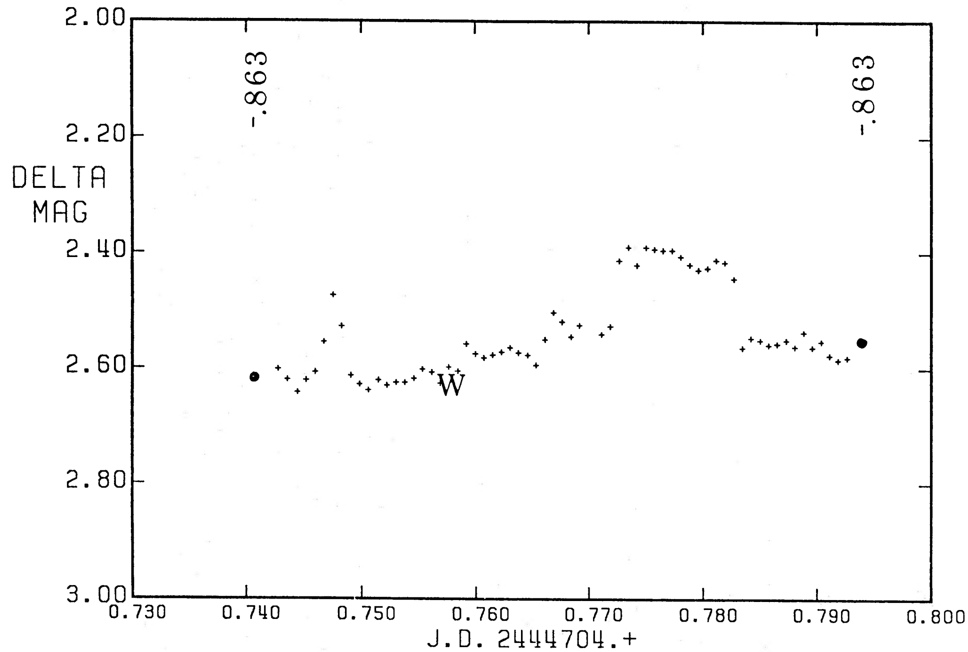


FIG. 3.—Data for 1981 April 10; same display as Fig. 1

data occurred because the author obtained a time of minimum of PG 1413+01 during that time period. PG 1413+01 normally has a $B$ magnitude of 16.7 and drops to nearly the sky background during eclipse. During the 7.1 hr ($0^{\rm d}.3$) spanned by the observations of 4C 29.45, it declined in brightness from a $B$ magnitude of 14.46 to 14.77, a change of 0.31 mag. This is 39 times the standard deviation in the gain ratio measurements taken during the night. This trend is undoubtedly real. Near the end of the data on this night the QSO brightened from a $B$ magnitude of 14.75 to 14.70 in 29 minutes ($0^{\rm d}.02$). The QSO then dropped to a $B$ magnitude of 14.77, 22 minutes later. This rapid change, be it a flicker or a transient oscillation, is 8 times the standard deviation in the gain ratio determinations. It appears to be a real effect. Other lower amplitude variations, suggestive of transient oscillations, are superposed on the steady decline.

In Figure 2, the data of 1981 April 9 indicates some structure superposed on a slight decline. The single-channel data points outline a shallow dip of 0.09 mag. This change is 30 times the standard deviation in the gain ratio measurements taken that night and appears to be real. The sharp dip, near the center of this observing run, followed by a rapid increase (between the single channel data points) could have been caused by a 2 $\sigma$ decrease followed by a 2 $\sigma$ increase in the sky in channel one. This scenario does not seem likely based on the behavior of the sky readings on this and the other nights.

Figure 3 shows several discontinuous jumps in the brightness of 4C 29.45 observed on 1981 April 10. The observed rapid changes (0.19 mag) in the QSO seem difficult to explain either in terms of its behavior or in terms of observational errors. These changes were 32 times the standard deviation of the 19 gain ratio measurements taken on the three nights. Changes in atmospheric extinction cannot be the source of these discontinuities as the comparison star was constant. Tracking could not have caused them, as guiding was done repeatedly on the comparison star and the size of the diaphragm used with it ($22''.6$) was slightly smaller than that used with the variable ($25''.5$). The physical alignment of the two channels was checked and found constant during the course of these observations. The sky was measured before, during, and after this observing session with nothing unusual found in these readings. The observed jumps were nearly instantaneous and represent a 0.19 mag increase in brightness. They could have been caused by doubling the dark counts in the photomultiplier tube from 109 $s^{-1}$ to 226 $s^{-1}$. However, measurements of the dark counts at the beginning of the night (106 $s^{-1}$, $\sigma = 7$ $s^{-1}$) and at the end of the night (111 $s^{-1}$, $\sigma = 7$ $s^{-1}$), the 19 gain ratio measurements taken on the three nights, and the *UBV* observations made on this night do not indicate an unstable tube. Jumps like this were not observed on any other star on any other night with this tube. Subsequent testing of it at KPNO did not reveal any changes in dark counts or sensitivity of this magnitude. The data of 1981 April 10 are presented in this way rather than being rejected out of hand as being physically impossible since they were carefully obtained and the real nature of QSOs is not known.

The nights of April 9 and 10 were searched for evidence of high-frequency oscillations in the range of 0.25–0.005 Hz. None greater than the noise in the power spectrum (0.3%) appeared.

Variations in the values obtained for the sky background or changes in the high voltage power supplies to the photomultiplier tubes large enough to have caused the QSO to appear to vary as it did would have shown up in larger than observed excursions in the gain ratio determinations.

Figures 4 and 5 are included to demonstrate the stability of the two-star photometer. The data were taken and plotted

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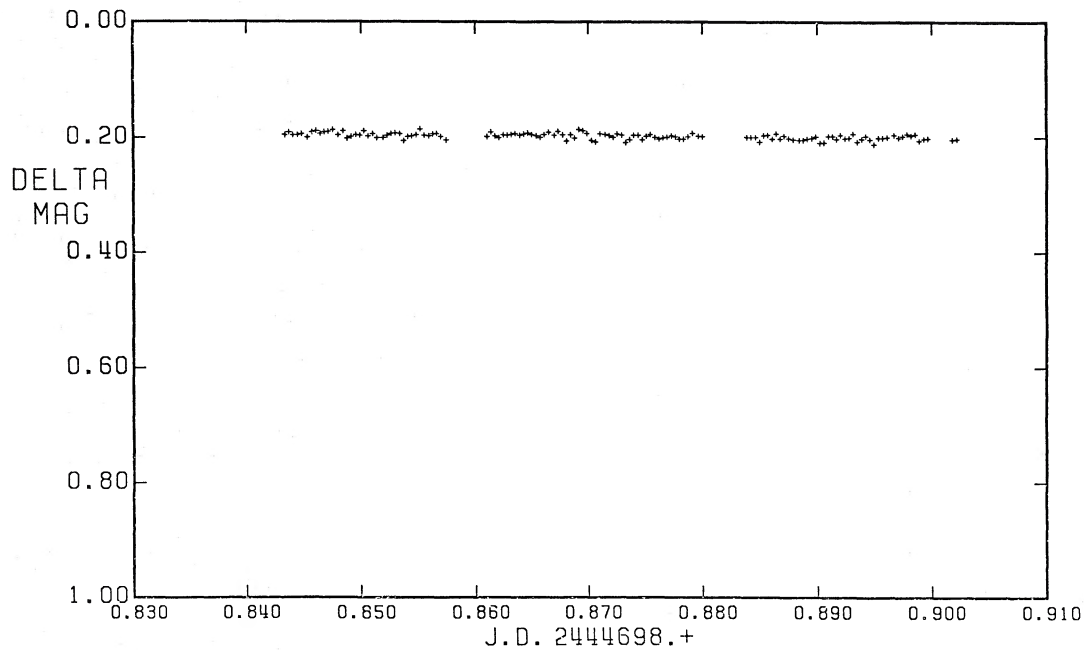


FIG. 4.—Data for 1981 April 4 taken with the two-star photometer on the central star of the planetary nebula Abell 36. The difference in *B* magnitude between the central star and a nearby comparison star is plotted vs. heliocentric Julian Date. The original 5 s integrations have been summed into 60 s bins.

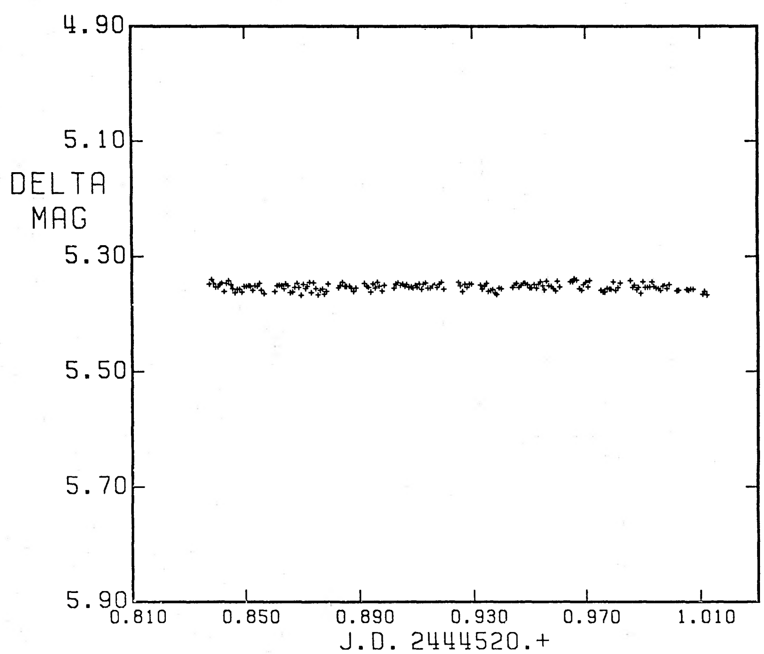


FIG. 5.—Data for 1980 October 8 taken with the two-star photometer on the central star of the planetary nebula M1-2. The difference in *B* magnitude between the central star and a nearby comparison star is plotted vs. heliocentric Julian Date. The original 5 s integrations have been summed into 60 s bins.

using exactly the same techniques which were employed for the 4C 29.45 observations. Abell 36 ($B = 11.15$) and M1-2 ($B = 14.04$) are both central stars of a planetary nebula. These examples are intended to demonstrate that the two-star photometer is well behaved for stars of magnitude similar to that of 4C 29.45. In both cases the original 5 s integrations have been summed into 60 s bins.

### III. DISCUSSION

The object 4C 29.45 was observed to vary substantially on a time scale of $0\overset{d}{.}02$ or less which implies that the emitting region is on the order of 30 light-minutes.

Accretion of material into a massive central black hole surrounded by an accretion disk provides an attractive quasar model (Rees 1977; Paczyński 1978). Inspired by reports that quasi-periodic oscillations may have been observed in 3C 273 and 3C 345 (Kellermann and Pauliny-Toth 1968), Vila (1979) investigated vertical modes of oscillation in a disk system. These theories are consistent with a $10^7 M_\odot$ black hole surrounded by an accretion disk 30 light-minutes in radius and a mass of 0.1 that of the central black hole. Variations on the order of $0\overset{d}{.}02$ or less can then be interpreted as pulsations in the disk. Detailed theoretical analysis will not be fruitful until further data are obtained.

Observers should take every opportunity to collect high-time resolution data on the OVV type QSOs during erruptions.

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ALBERT D. GRAUER: Operations Support Division, Kitt Peak National Observatory, Tucson, AZ 85726-6732