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THE RECENT OPTICAL VARIABILITY OF 3C 446

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ABSTRACT

Photometry of 3C 446 has revealed large amplitude, rapid optical variations on time scales ranging from months to as short as hours. Significant color variations were found to accompany these variations, such that the colors became redder as the source brightened. These results were compared and found to agree well with a recent model suggested by Marscher.

Subject headings: photometry — quasars

I. INTRODUCTION

The optically violently variable (OVV) quasar 3C 446 has been known to exhibit large amplitude variations in its brightness (Sandage, Westphal, and Strittmatter 1966) and a highly polarized flux (Kinman, Lamla, and Wirtanen 1966; Visvanathan 1973; Stockman and Angel 1978) for many years. 3C 446 has had three major outbursts ($V \leq 16.0$ mag) in the past 15 years; one in 1966, (Sandage 1966), one in 1974 (McGimsey *et al.* 1975), and one beginning in 1977 and continuing to the present (Pollock *et al.* 1979). Sandage *et al.* have pointed out that the colors of 3C 446 became significantly redder during the large outburst observed in 1966. They concluded that the color variations were due to the continuum slope becoming steeper, and the associated colors therefore becoming somewhat redder during the outburst. They also pointed out that the emission lines remained essentially constant in absolute intensity during the outburst, with the contrast between the discrete features in the spectrum and the continuum being greatly reduced. Observations by Oke (1967) support these conclusions. However, Miller and French (1978) have reported detecting no significant change in the spectral index of the continuum of 3C 446 when comparing the unpublished spectral energy distributions obtained by Wampler between 1966–1969 with those they obtained in 1977. They find that the continuum can be fitted with a power law with a spectral index $\alpha = -2.04 \pm 0.1$. The purpose of the present paper is to report the observation of significant optical variations and color variations for 3C 446 which occurred on time scales ranging from months to hours.

II. OBSERVATIONS AND DATA REDUCTION

The photoelectric photometry was obtained at Kitt Peak National Observatory from 1978 September through 1980 May. The observations were made using either the 0.9 m telescope or the 1.3 m telescope. A single-channel photometer with a standard three-color (UBV) filter set was used with a refrigerated 1P21 photomultiplier and pulse-counting system for the observations which were made with the 0.9 m telescope. The Mark 2 computer photometer equipped with a 1P21 photomultiplier and standard UBV filters was used for the observations made with the 1.3 m telescope. The extinction was determined each night, and the transformation to the standard UBV system was made using the equatorial standard stars of Landolt (1973). Standard stars numbered "5" and "6" from the photoelectric sequences of Angione (1971) were observed immediately before and after each observation of 3C 446. The standard error for each observation of 3C 446 was ≤ 0.01 mag in the V and B bands and ≤ 0.02 mag in the U band.

III. RESULTS

The results of the observations are presented in Table 1. In columns 1 and 2 are the date and time (UT) at which each observation was made; column 3, the telescope with which the observations were made; column 4, V magnitude of 3C 446; column 5, $B-V$ color index; column 6, $U-B$ color index; column 7, $B-V$ spectral index; and column 8, $U-B$ spectral index.

The observations of 3C 446 on 1978 September 24–26 and 1979 September 11–12 indicated that the source has $B-V$ colors and $U-B$ colors similar to those observed for this source by Sandage *et al.* during the outburst of 1966 (i.e., $B-V \approx 0.55$ and $U-B \approx -0.51$). The source was quite bright at the time these observations were made and well above the minimum baseline level of $V \approx 18.0$–19.0 mag. Modest changes in brightness were observed ($\Delta V \approx 0.05$ mag) on adjacent days, but no large-scale color variations were found to accompany these changes.

However, the optical variations observed on 1979 November 11–14 are quite different in nature from those observed earlier. Rapid, large amplitude ($\Delta V \approx 0.25$ mag) variations are observed on adjacent days. The colors of 3C 446 are considerably redder than those previously reported and vary significantly from one night to the next. The source appears to become significantly redder as it brightened from $V = 16.04$ mag with $B-V = 0.69$ and

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TABLE 1

OBSERVATIONS OF 3C 446

Date	UT	Telescope (m)	V	$B-V$	$U-B$	α_{B-V}	α_{U-B}
1978 Sept. 24	0516	1.3	15.58	0.54	−0.52	1.82	1.74
1978 Sept. 25	0458	1.3	15.60	0.56	−0.51	1.90	1.79
1978 Sept. 26	0547	1.3	15.65	0.53	−0.53	1.78	1.69
1979 Sept. 11	0413	0.9	15.92	0.51	−0.57	1.69	1.51
1979 Sept. 12	0441	0.9	15.94	0.52	−0.56	1.73	1.56
1979 Nov. 11	0329	1.3	15.76	0.71	−0.26	2.52	2.93
1979 Nov. 12	0312	1.3	16.04	0.69	−0.27	2.44	2.89
1979 Nov. 13	0410	1.3	15.80	0.73	−0.21	2.60	3.16
1979 Nov. 14	0216	1.3	15.56	0.76	−0.17	2.73	3.34
1979 Nov. 14	0303	1.3	15.50	0.78	−0.16	2.81	3.39
1979 Nov. 14	0348	1.3	15.48	0.78	−0.14	2.81	3.48
1979 Nov. 14	0432	1.3	15.43	0.77	−0.16	2.77	3.39
1980 May 15	1049	0.9	15.22	0.49	−0.51	1.61	1.79

$U-B = -0.27$ on 1979 November 12, to $V_{\text{average}} = 15.49$ with $(B-V)_{\text{average}} = 0.77$ and $(U-B)_{\text{average}} = -0.16$ on 1979 November 14. In addition, on the night of 1979 November 14, significant optical variations in the V band were detected on time scales of less than 1 hour (see Fig. 1), with the source brightening 0.13 mag over a time period of a little over 2 hours ($\Delta t = 02^{h}16^{m}$). The shortest significant variation was $\Delta V = 0.05$ mag, which occurred between UT = 0348 and UT = 0432 on 1979 November 14. This variation allows one to estimate the size of the emitting region based on light-travel-time arguments, assuming no relativistic effects, to be $d = 2.6 \times 10^{-5}$ pc. However, for a source which is varying as violently as 3C 446 was during the time it was observed in 1979 November, the assumption that there is no relativistic motion of material in the source region is not likely to be very realistic.

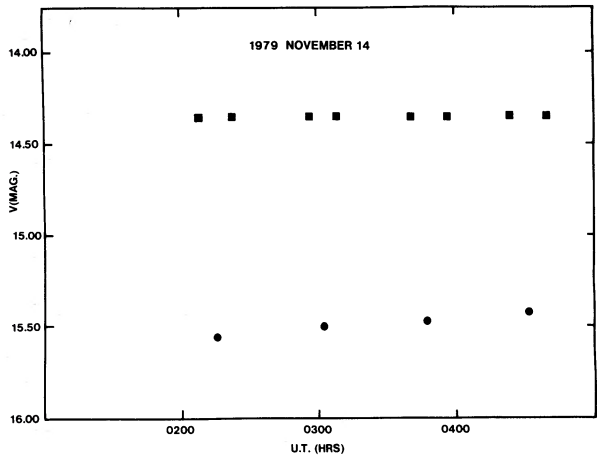

FIG. 1.—The light curve for 3C 446 on 1979 November 14. The *filled circles* are the observations of 3C 446, and the *filled squares* are the observations of the standard star. The brightening of 3C 446 is clearly present, while no variation is detected for the standard star. This was one of two standard stars observed before and after each observation of 3C 446.

If one assumes that the spectrum during this outburst resembles that of a BL Lacertae object (as has been suggested from observations by Miller and French 1978 and Sandage *et al.*), then one can determine the spectral index of the continuum from the broad-band observations, since the discrete features in the spectrum will make only a small contribution relative to the continuum. The spectral indices were calculated from the broad-band colors observed 1979 November 14 using the equations relating the color indices and spectral indices of the nonthermal continuum (Kinman 1976):

$$\alpha_{B-V} = 4.13[(B-V) - 0.1],$$

$$\alpha_{U-B} = 4.58[(U-B) + 0.9],$$

where $F(\nu) \propto \nu^{-\alpha}$. The mean spectral indices were $\alpha_{B-V} = 2.78$ and $\alpha_{U-B} = 3.40$, which are considerably redder than those found by Miller and French (1978). Thus, the outburst which was observed 1979 November 11–14 may be significantly different in nature from those observed earlier.

The steepening of the spectrum as the object brightens does not agree with the predictions of "composite" models (e.g., Sandage 1973) in which a variable blue nonthermal source is thought to exist in the nucleus of an elliptical galaxy. These models predict that the source should appear bluer as it brightens. However, no evidence, either from spectra or direct plates, suggests the existence of nebulosity associated with this source. Thus "composite" models would not be expected to be applicable in this instance.

Marscher (1980) has proposed a model for optical variations observed in quasars and active galactic nuclei in which enhanced regions of synchrotron emission are produced by radiative thermal instabilities in relativistic flows. The violent optical variations observed 1979 November 11–14 for 3C 446 suggest that the motion of particles in the source region is likely to be relativistic. Marscher's model predicts that as the luminosity of the source increases, the nonthermal continuum should become steeper. This is what has been observed for 3C

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446, not only during the recent outburst, but also during the outburst observed by Sandage *et al.* in 1966.

Marscher's model predicts flux variations and the formation of knots in relativistic flows which are thought to occur in quasars and active galactic nuclei. The model predicts that the knots can be responsible for the apparent superluminal motions observed in compact radio sources. Thus, VLBI observations of 3C 446 during any radio events which may be related to this optical outburst would be important in order to test this model.

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