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MULTIFREQUENCY OBSERVATIONS OF THE FLARING QUASAR 1156+295

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ABSTRACT

A large outburst in the quasar 1156+295 was discovered in 1981 April as part of our program to obtain simultaneous multifrequency spectra of variable quasars. Ultraviolet observations were coordinated with ground-based observations at radio, infrared, and optical wavelengths. Measurements were made at four epochs starting immediately after the outburst was discovered, when the *B*-magnitude was 14.0, and at intervals of 4 and 60 days and 1 year. The luminosity integrated only over observed wavelength bands was $\sim 3 \times 10^{48}$ ergs s^{-1} on the first epoch of observation. The slope of the IR–UV spectra changes from $\alpha \approx -0.8$ in the IR to $\alpha \approx -1.7$ in the UV ($f_\nu \propto \nu^\alpha$). The general shape of the IR–UV spectrum did not change significantly as the overall flux varied in time. The only significant change in the shape of the overall multifrequency spectrum occurred when a radio outburst was detected about 11 months after the start of the optical flare; at this time the slope at centimeter wavelengths increased significantly. Variability time scales as short as 4×10^4 s were found at optical frequencies. Theoretical considerations suggest that the outburst in early 1981 involved a large increase in the mass of the plasma responsible for the continuum emission of this highly variable quasar. Modeling of the source with a synchrotron self-Compton model suggests that the core of the source has a linear dimension of 0.01 pc, a magnetic field strength in the range 0.1–30 gauss, and a bulk relativistic motion in the quasar rest frame characterized by a Lorentz factor in the range 2–8. These parameters are similar to those we have derived from multifrequency observations of other BL Lac objects and variable quasars.

Subject headings: quasars — radiation mechanisms — radio sources: variable

I. INTRODUCTION

This paper is the second in a series in which we report on a program of simultaneous multifrequency observations of BL Lac objects and optically violent, variable (OVV) quasars. We report here on the OVV quasar 1156+295, known also as 4C 29.45 and Ton 599. The observations are particularly interesting since they were made following a major outburst, and the subsequent time evolution of the source was unusually well documented. Other papers in this series deal with the X-ray bright BL Lac object I Zw 187 and the BL Lac object PKS 0735+178 (Bregman *et al.* 1982, 1983). The general goal of this research program is to develop a deeper understanding of the source of continuum emission from quasars.

The main properties which characterize OVV quasars are (i) large and rapid variability, (ii) large (and variable) optical polarization, (iii) steep optical spectra, and (iv) strong, variable radio emission from compact, relatively flat-spectrum sources. These properties of OVV quasars are shared by BL Lac objects, although the latter may be more extreme (Moore and Stockman 1981) and appear to have less conspicuous small-scale radio structure (Stannard and McIlwrath 1982). The most striking difference, the appearance of emission lines, is much less apparent during major OVV outbursts, when the continuum rises, and the emission lines appear relatively weak (Miller and French 1978). Thus, OVV quasars provide a link between BL Lac objects and normal quasars, and more complete investigations of their properties seem worthwhile.

A major goal of our multifrequency program on BL Lac objects and OVVs is to determine the spectra of these objects over as wide a frequency range as possible. Because of their extreme variability, simultaneous observations are required to obtain a single time-frozen spectrum. A series of such spectra for a single object allows us to document its spectral evolution, and we believe that this kind of information can yield considerable insight into the physical conditions in the regions producing the continuum radiation. The simultaneous multifrequency observations reported here for 1156+295 cover UV, optical, near-IR, and radio wave bands.

The observational information on 1156+295 through 1980 is summarized by Moore and Stockman (1981). Its properties are in accord with those of OVV quasars: a moderately steep optical slope, $\alpha = -0.9$ (Richstone and Schmidt 1980); a characteristic range of B usually fainter than 15th magnitude but with large variations; and a fairly strong radio flux, typically $\gtrsim 1$ Jy, from a compact source $\lesssim 1''$. (Weak secondary structure has recently been detected with the VLA at 1.5 and 4.9 GHz; Perley 1982.) An emission-line redshift of $z = 0.729$ has been determined by Schmidt (1975).

Archival plates show that 1156+295 was generally fainter than $B = 16$ mag during the period 1900–1970. In the second half of the 1970s it showed an enhanced level of emission both in the optical (reaching $B = 14$–15 mag) and at 2.7 GHz. Just prior to our *IUE* run of 1981 April 4–8, the B-magnitude was measured at the Rosemary Hill Observatory, University of Florida. (This is a standard procedure for our program because these variable quasars are often too faint to be observed with *IUE*.) The measurement on 1981 April 3, $B = 13.65 \pm 0.15$, together with values deduced later from earlier plates, indicates that 1156−295 underwent a major outburst in the early part of 1981. The brightest B-magnitude recorded was 13.15 ± 0.13 on 1981 March 13. In this paper we report simultaneous, multifrequency observations of 1156+295 made soon after peak luminosity and later at intervals of 60 days and 1 year. Additional nonsimultaneous observations made at other times are also presented. As soon as the outburst was discovered, other observers were alerted, and many of the results which they obtained are discussed in the accompanying paper by Wills *et al.* (1983, hereafter Paper W).

The outline of the rest of the paper is as follows. In § II we present the observations, and in § III we discuss the most important implications of the multifrequency spectra in the context of theoretical models. Our conclusions are briefly summarized in § IV.

II. OBSERVATIONS

The wavelength bands covered by each group and the dates when the observations were made are given in Table 1. Brief descriptions of each of the observations are given in the following subsections. The numerical values of the measured fluxes are usually not given because in most cases the figures adequately convey the information or because the data are available in Paper W. The investigators are prepared to furnish more details to those interested.

a) Ultraviolet Observations

The ultraviolet spectra were taken with the *International Ultraviolet Explorer* (*IUE*). The observing shifts are listed in Table 2, which also includes the measured B-magnitudes. The data have been analyzed by methods similar to those described by Bregman *et al.* (1982). There is no evidence of any emission or absorption lines. The 1981 data, binned in 50 Å intervals, are shown in Figure 1. Because of technical difficulties, the 1982 short wavelength observation was aborted after 50 minutes; the resulting data give no reliable spectral information, and the mean value from 1200–1900 Å is entered on Figure 6. No reddening corrections have been applied because standard considerations on the amount of galactic material for this line of sight (Heiles 1976;

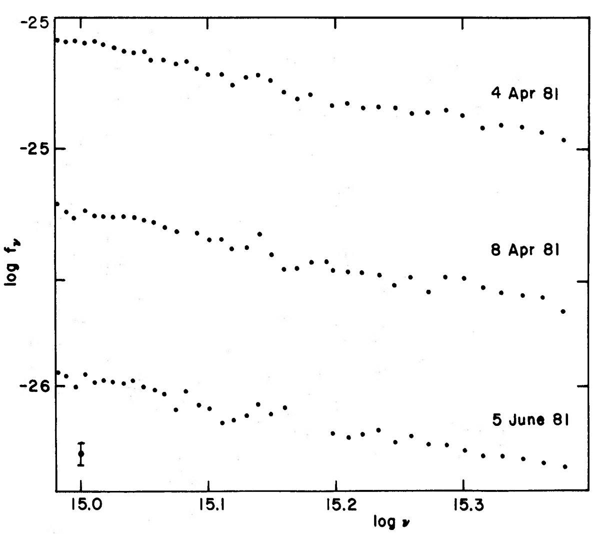

FIG. 1.—*IUE* spectra averaged in 50 Å bins for the three 1981 epochs of simultaneous observations; f_ν in ergs cm^{-2} s^{-1} Hz^{-1} and ν in Hz for all figures. The tick marks on the ordinate axis represent decades, and the error bar in the lower left corner shows an exemplary 10% error, as discussed in the text.

TABLE 1

MULTIFREQUENCY OBSERVATIONS OF 1156+295

Observers	Wavelengths[a]	Date (UT)
Bregman, Glassgold, and Huggins	1200–3200 Å	1981 Apr 4 1981 Apr 8 1981 June 5 1982 Apr 28
Pica, Pollock, Leacock, Smith, and Webb	*B* monitoring[b] *UBVRI*	1981 Apr 3–1982 Jul 1 1981 Apr 4, 5, 7, 9, 10, 25
Wiśniewski	*UBVRI*[b]	1981 Apr 5–10 1981 Apr 15 1981 Jul 4–5 1982 Apr 26 1982 Apr 28 1982 May 3
Jeske and Spinrad	4000–5950 Å (7 Å)	1981 Apr 4 1981 May 31
Henry	4200–7200 Å (8 Å)	1981 Apr 4 1981 Apr 8
Miller	4000–7200 Å (20 Å)	1981 Jun 5
Liebert and Stocke	4500–6800 Å (10 Å)	1981 Apr 5
Impey	*J*, *H*, *K*	1981 Apr 4–8 1981 Apr 30 1981 May 2–4 1982 Apr 28
Rudi	*J*, *H*, *K*, *L*	1981 Jun 1
Neugebauer	*J*, *H*, *K*	1981 Apr 11 1982 Apr 30
Aller, Aller, and Hodge	4.8, 8.0, 14.5 GHz[b]	1980 Jan–1982 Jun (monitoring)
Balonek, Dent, and O'Dea	2.7, 7.9, 15.5, 31.4, 89.6 GHz[b]	1981 Feb–1982 Mar (monitoring)

[a] The resolution of the optical spectrophotometry is given in parentheses just below the usable wavelength range of each spectrum.

[b] Portions of these data are tabulated or plotted in Paper W.

Burstein and Heiles 1978) give $E(B-V) = 0.01 \pm 0.03$. The statistical errors in the points are considerably less than the *IUE* photometric accuracy, which we estimate to be about 10%. The ripples are one manifestation of these errors. They are not real, and invariably occur in exposures of faint objects (Hackney, Hackney, and Kondo 1982).

The data in Figure 1 are composites made from the separate exposures obtained with the short- and long-wavelength cameras (SWP and LWR, respectively). The spectra can be fitted with a power law $f_\nu \propto \nu^\alpha$ with $\alpha_{UV} \sim -2$. From the values given in Table 2, it may be seen that there is no significant change in α_{UV} for the 1981 observations. Visual inspection of Figure 1 suggests

TABLE 2

IUE OBSERVATIONS OF 1156+295

	Date (UT)	Image	Exposure	B(mag)	α_{UV}
10:54	1981 Apr 4	L 10283	60	14.0 ± 0.1	−1.7 ± 0.3
12:03	1981 Apr 4	S 13653	180	...	...
9:52	1981 Apr 8	S 13679	120	14.6 ± 0.1	−1.6 ± 0.3
11:50	1981 Apr 8	L 10312	60	...	...
6:33	1981 Jun 5	L 10785	105	15.6 ± 0.2	−1.7 ± 0.2
8:23	1981 Jun 5	L 14191	327	...	...
11:56	1982 Apr 28	S 16847	50	15.0 ± 0.1	...

that the short-wavelength portion may be flatter than the long during 1981 April, but the photometric uncertainties are too large to be sure.

b) Optical Photometry

The optical photometry results, *B* from Rosemary Hill Observatory (A. J. Pica *et al.*) and *UBVRI* from Mt. Lemmon (W. Z. Wiśniewski), are recorded in Paper W. From these data it was possible to determine the *B*-magnitude to within a few hours of the multifrequency epochs given in Table 2, except for 1981 June 6. In this case we estimated *B* from measurements with the fine error sensor of *IUE*. Although less accurate, this procedure gave values in agreement with other methods on the remaining dates. The important spectral information contained in the *UBVRI* photometry will be discussed in § II*f*). It is available on 1981 April 4 and 1982 April 28, as well as other dates not simultaneous with the *IUE* observations; some of these data are shown in Figures 2 and 3.

c) Optical Spectrophotometry

Optical spectrophotometry is available for all three of the simultaneous multifrequency epochs in 1981 but not for 1982 April. The wavelength ranges in Table 1 define the usable portions of the spectra after noisy sections at the ends were eliminated.

The only emission line which has been detected is Mg II 2800 Å redshifted to $\sim$4835 Å. The data are not good enough to make accurate determinations of the equivalent widths because the continua have risen so high. At the time of our 1981 observations the mean flux in the line was only $\sim$5%–10% of the continuum, and the rough order of magnitude of the equivalent width was 10 Å. This is clearly much less than the equivalent widths reported earlier by Richstone and Schmidt (1980, 109 $\pm$ 9 Å) and in Paper W.

The spectrophotometric results are plotted in Figure 2 together with the UV spectra and broad-band photometric results (discussed below). All of the data in this figure are simultaneous to within a few hours. The UV data have been replotted in terms of the best straight-line fits (slope close to -2). The optical data have been smoothed, typically in 100 or 200 Å bins. They all show a rise near log $\nu = 14.8$ due to Mg II and possibly other lines, such as Fe II multiplets. The 1981 June 5 spectrum from Lick Observatory also shows a turndown in going to lower frequencies which occurs at log $\nu =$ 14.68, or $\sim$3625 Å in the rest frame—not far from the Balmer edge. This bump is reminiscent of the familiar "3000 Å" bump seen in quasars, but it is peculiar that it was not observed in the earlier spectra when the quasar was no more than 5 times more luminous. No change in polarization was observed in the neighborhood of the bump; Miller's observations of the polarization and position angle on 1981 June 5, are independent of wavelength from $\sim$3500–6500 Å; $P = 13.4\% \pm 0.4\%$ and $\theta = 146° \pm 2°$.

d) Infrared Photometry

Most of the 1981 infrared data given in Table 3 were obtained at the 3.8 m United Kingdom Infrared Telescope (UKIRT) on Mauna Kea using a photovoltaic InSB detector and rotating HR polaroid. The photo-

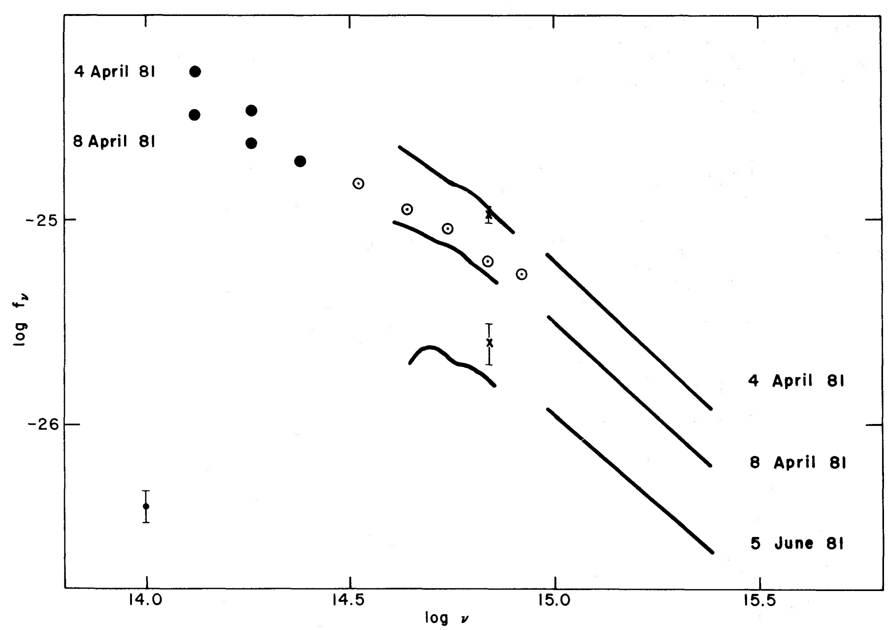

FIG. 2.—Optical spectrophotometry (*solid curves*), optical photometry (*open circles*, Wiśniewski), and infrared photometry (*filled circles*, Impey) for the 1981 simultaneous epochs; the crosses are the *B*-magnitudes. The 10% error bar in the lower left is typical of the uncertainty in the absolute values in the spectrophotometry.

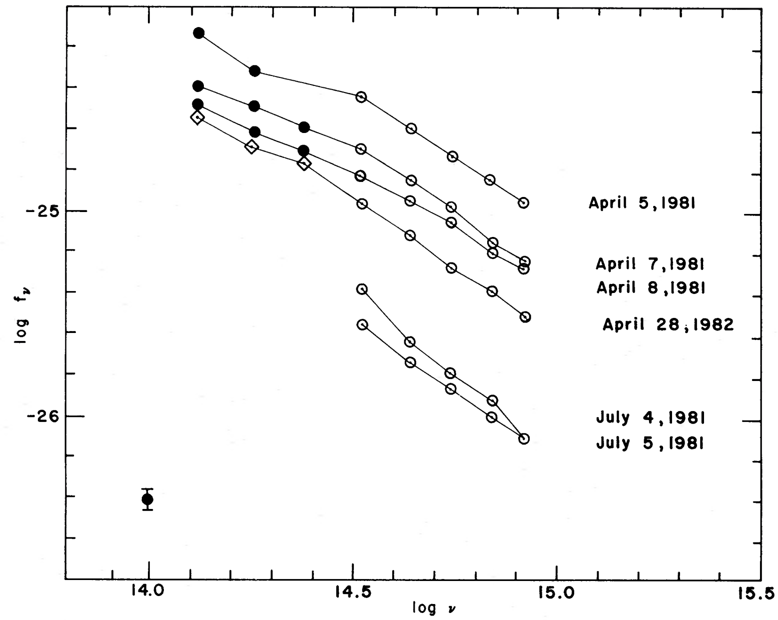

FIG. 3.—Selection of additional multiband photometry; same labeling as in Fig. 2. The solid curve for 1981 April 4 is spectrophotometry by Liebert and Stocke, and the diamond shapes are the data of Neugebauer. The 5% error bar in the lower left is typical of the uncertainty in the absolute values in the infrared photometry.

TABLE 3
INFRARED PHOTOMETRY

Date	Wave Band	Pol. (%)	θ (°)	Magnitude	Flux (mJ)
1981 Apr 4	*K*	11.2 ± 0.7	21.8 ± 1.7	10.22 ± 0.02	54.2 ± 1.1
	H	12.5 ± 2.3	21.5 ± 5.0	11.09 ± 0.02	34.5 ± 0.7
1981 Apr 5	*K*	14.3 ± 0.9	31.6 ± 1.7	9.87 ± 0.02	74.8 ± 1.5
	J	15.3 ± 1.7	22.3 ± 3.0	11.30 ± 0.03	47.7 ± 1.4
1981 Apr 6	*K*	10.0 ± 1.8	13.0 ± 4.9	10.53 ± 0.02	40.7 ± 0.8
	H	10.3 ± 0.9	22.8 ± 2.4	11.35 ± 0.02	27.2 ± 0.5
	J	10.4 ± 1.4	18.7 ± 3.7	12.14 ± 0.03	22.0 ± 0.7
1981 Apr 7	*K*	5.5 ± 0.8	0.5 ± 4.0	10.31 ± 0.02	49.9 ± 1.0
	H	4.7 ± 2.1	165.8 ± 12.0	11.16 ± 0.02	32.4 ± 0.6
	J	3.6 ± 2.1	160.5 ± 16.0	11.98 ± 0.03	25.5 ± 0.8
1981 Apr 8	*K*	8.9 ± 1.6	158.4 ± 4.9	10.76 ± 0.02	32.9 ± 0.7
	H	11.3 ± 1.1	157.4 ± 2.7	11.49 ± 0.02	23.9 ± 0.5
	J	...	...	12.26 ± 0.03	19.7 ± 0.6
1981 Apr 30...........	*K*	8.3 ± 5.4	53.9 ± 18.0	12.21 ± 0.03	8.7 ± 0.3
	H	...	...	13.07 ± 0.03	5.6 ± 0.2
	J	...	...	14.05 ± 0.04	3.8 ± 0.2
1981 May 2	*K*	8.3 ± 2.5	107.7 ± 8.2	11.86 ± 0.03	12.0 ± 0.4
	H	...	...	12.69 ± 0.03	7.9 ± 0.2
	J	...	...	13.60 ± 0.03	5.7 ± 0.2
1981 May 3	*K*	5.6 ± 0.9	161.0 ± 4.4	11.66 ± 0.04	14.4 ± 0.6
	H	...	...	12.46 ± 0.03	9.9 ± 0.3
	J	...	...	13.45 ± 0.03	6.6 ± 0.2
1981 May 4	*K*	11.6 ± 3.0	127.8 ± 7.1	12.09 ± 0.02	9.7 ± 0.2
	H	...	...	12.98 ± 0.03	6.1 ± 0.2
	J	...	...	13.95 ± 0.04	4.2 ± 0.2
1981 Apr 11[a]..........	*J*	...	...	12.46 ± 0.08	15.78 ± 1.16
	H	...	...	11.67 ± 0.08	24.04 ± 1.16
	K	...	...	10.84 ± 0.08	28.54 ± 1.16

[a] The data on 1981 Apr 11 were obtained by G. Neugebauer with the help of B. T. Soifer and K. Mathews; the remainder are the work of C. Impey.

metric and polarimetric observations used star/sky chopping at a rate of 5–7 Hz and were taken through a 10″ aperture. The broad-band filters and their effective wavelengths are J (1.25 μm), H (1.65 μm), K (2.2 μm), and L (3.45 μm). The photometry and polarimetry have been calibrated with a series of instrumental tests. Standard polarized and unpolarized stars were observed, and the instrumental polarization was repeatable between different nights to 0.3% (Serkowski 1974; Dyck and Beichman 1974). The analyzer efficiency (wavelength dependent) and position angle zero point were redetermined during each run. Polarization introduced by the telescope optics is negligible. Linear polarization measurements were made on the assumption of no elliptical component in the incoming radiation; the basis for this is the negative searches for optical circular polarization ($V \leq 0.1\%$) in BL Lac objects (Landstreet and Angel 1972; Nordsieck 1972; Maza 1979).

The photometry was calibrated in absolute units based on the calibration of α Lyr by Oke and Schild (1970) and the model-atmosphere calculation by Schild, Peterson, and Oke (1971); the flux for a 0 mag star is taken to be 1520 Jy at J, 980 Jy at H, 620 Jy at K, and 310 Jy at L. The uncertainties in the primary calibrators are such that the zero point of the absolute flux scale is no more accurate than 5%. Broad-band filter measurements do not uniquely define an energy distribution, so the data have been corrected for the difference between the spectral flux distribution of the quasar and the calibrators. The flat-topped beam profiles and accurate offset guiding on the UKIRT ensure that no errors have been introduced in the photometry by telescope motion. The UKIRT data in Table 3 include the larger of either the statistical error or the error estimated from the repeatability of the measurements on a given night. They do not include a 5% uncertainty in absolute calibration.

Observations at J, H, and K were made in 1981 April and in 1982 April using an InSB detector at the f/72 focus of the 5 m telescope on Palomar Mountain. The photometry was with respect to the standard magnitudes listed by Elias *et al.* (1982). The conversion to absolute fluxes was based on essentially the same values as listed above. The quoted uncertainties include statistical uncertainties plus uncertainties in the absolute calibration values as well as an estimate of systematic uncertainties. The 1981 data are given in the last three rows of Table 3, and the 1982 data are given in Table 4.

e) *Radio Observations*

Radio observations at 4.8, 8.0, and 14.5 GHz were obtained with the 26 m paraboloid of the University of Michigan Radio Astronomy Observatory on a regular basis starting in 1981 February. The data reduction procedures are described by Aller (1970) and Aller, Aller, and Hodge (1981). The University of Massachusetts group made observations at 2.7 GHz starting in 1975 and, from 1981 April, at 7.9 GHz and 15.5 GHz at Haystack Observatory. Also starting in 1981 April, they made observations at 31.4 GHz at the National Radio Astronomy Observatory and at 89.6 GHz with the 36 foot (11 m) telescope on Kitt Peak. The radio data are tabulated in Paper W. They serve to determine the radio-frequency portion of our multifrequency spectra, and they provide an interesting comparison with the time evolution of the IR-optical-UV flare. The relatively high frequency radio fluxes discussed here are part of the flat or increasing portion of the spectrum and are associated with the compact core of 1156+295.

Figure 4 shows the Michigan results available up to the time of writing. Prior to 1981 April the spectra were flat, but they became inverted ($\alpha > 0$) during this month. During the first half of 1981, the spectra were generally oscillatory in time, but in early 1982 a dramatic outburst at centimeter wavelengths occurred. The increases propagate from higher to lower frequencies in accord with an expanding-source type model (van der Laan 1966), but the spectral index $\alpha = 0.5$ at outburst

TABLE 4

1982 Optical and Infrared Photometry

Observer	Date	Wave Band	Flux (mJy)
Pica *et al.* (Rosemary Hill)	1982 Apr 28	B	4.56 ± 0.34
Wiśniewski (Mount Lemmon)	1982 Apr 28	U	3.15
		B	4.16
		V	5.41
		R	7.57
		I	11.0
Impey (UKIRT)	1982 Apr 28	V	5.07 ± 0.25
		R	5.89 ± 0.24
		I	7.98 ± 0.40
	1982 May 1	J	11.0 ± 0.9
		H	15.3 ± 1.2
		K	24.1 ± 1.9
		L	71.9 ± 12
Neugebauer (Palomar)	1982 Apr 30	J	16.8 ± 1.1
		H	20.5 ± 1.3
		K	28.6 ± 1.8

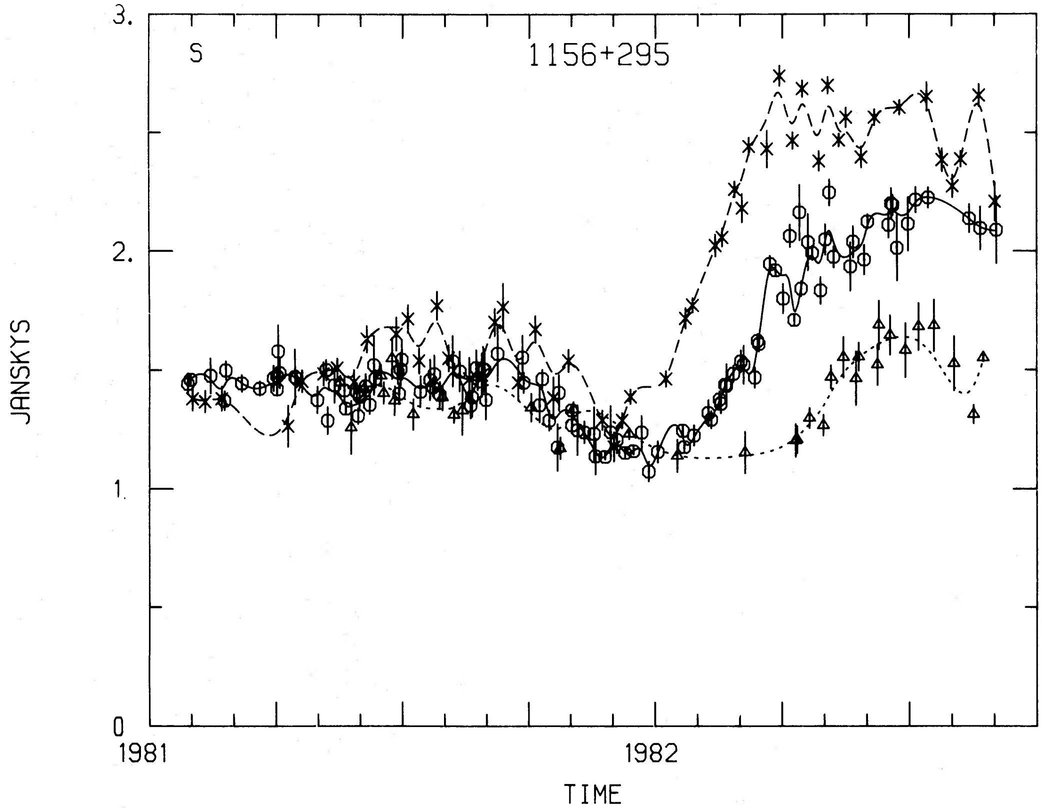

FIG. 4.—Daily averages of the total flux density at 14.5 GHz (*crosses*), 8.0 GHz (*octagons*), and 4.8 GHz (*triangles*). The curves are smoothing cubic splines. Years are labeled at the beginning of each year.

maximum is much smaller than predicted ($\alpha = 2.5$). This behavior is confirmed by the measurements of Dent *et al.* (1979) at 7.9 and 15.5 GHz, and several measurements at 31.4 and 89.6 GHz. Starting about the second quarter of 1982, the 14.5 GHz flux flickers about a roughly constant level; the 8 GHz flux seems to show a similar behavior. Similar effects have been observed in other sources during outbursts, e.g., the BL Lac object OJ 287 (Aller and Ledden 1978). In accord with the discussion of these authors, the flatter than predicted spectrum and the rapid flickering could be explained by a period of prolonged particle injection.

The substantial increases in the radio fluxes from 1981 April to early 1982 may be a time-delayed response to the 1981 IR-optical-UV outburst. Other interpretations are possible, however, in light of the gaps in the measurements prior to 1981 April, and some of these are discussed in Paper W. At the time of writing the radio fluxes at 4.8, 8.0, and 14.5 GHz have all begun to decline.

f) *The Multifrequency Spectra*

Examples of complete simultaneous spectra which include the radio fluxes are shown in Figures 5 and 6 for 1981 April 8 and 1982 April 28. Of all the multifrequency spectra available for 1156+295, the one for 1981 April 8 is most complete. The results define a relatively smooth spectrum from radio to ultraviolet, although there is a large gap from sub-millimeter through infrared wavelengths. The spectrum increases with ν at radio frequencies and turns over somewhere in the far-infrared. Unfortunately, no X-ray measurements have yet been made of 1156+295. The radio data in Figure 5 are not exactly simultaneous with all of the other measurements; they have been obtained by interpolation on the basis that the observed radio fluxes are not changing significantly on a time scale of one week. The slope of the radio spectrum is $\alpha \propto 0.15$ (in $f_\nu \propto \nu^\alpha$). The other 1981 multifrequency spectra are similar to the one in Figure 5: the radio-frequency parts are inverted (with small, positive α), and the IR-optical-UV spectrum is rapidly decreasing, with α decreasing with frequency.

The radio fluxes for the three simultaneous epochs of 1981 differ only slightly on the scale used in Figure 5. Thus the main differences between the three 1981 multifrequency spectra are best seen in Figure 2 covering the IR–UV bands. This figure also illustrates some of the difficulties in obtaining simultaneous multifrequency spectra. All of the data in Figure 2 were obtained within a few hours. The gaps arise because of practical matters such as scheduling difficulties and bad weather. Sometimes the fluxes from different bands do not seem to match smoothly, but the apparent differences between

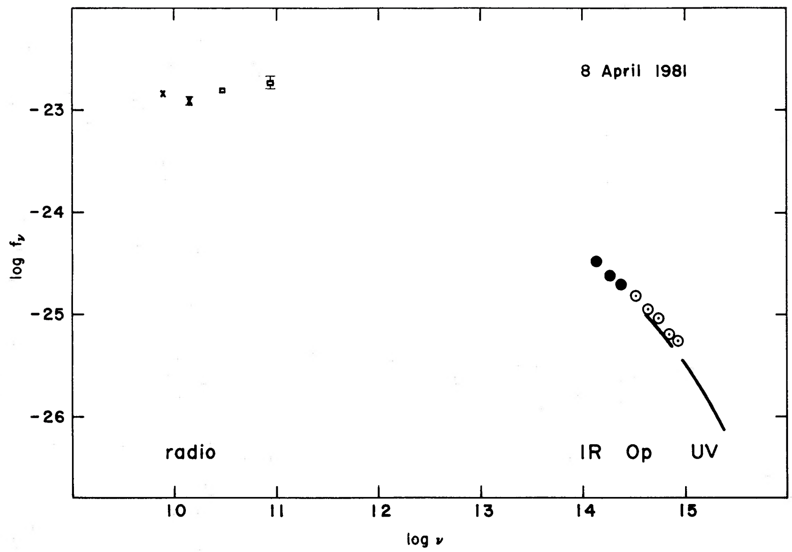

FIG. 5.—Extended multifrequency spectrum for 1981 April 8; same labeling as in Fig. 2, plus radio data from University of Massachusetts (*open squares*) and University of Michigan (*crosses*).

observers in Figure 2 are all within the estimated uncertainties, i.e., ~5% for photometry and 10% for spectrophotometry.

The shape of the 1982 April 28 simultaneous spectrum in Figure 6 is close to that of a year earlier on 1981 April 8. The most important difference is in the radio portion of the spectrum, which steepens more rapidly in the 5–15 GHz range; this is connected with the radio outburst which started toward the end of 1981. Thus the main changes in the spectrum of 1156+295 following the early 1981 flare involve the absolute level of the IR-optical-UV flux, with little change in shape. About 10 months later, the centimeter radio emission underwent a dramatic outburst in which the 5–15 GHz slope increased from ~0.2 to ~0.5 at the peak in mid-1982.

The most complete multifrequency spectrum (1981 April 8) extends one and one-half decades in frequency in covering the near-IR to far-UV wavelength bands; it cannot be fitted well by a single power law. It has been customary to quote spectral indices for spectra covering smaller frequency ranges. We shall do so only for purposes of comparisons and break the IR–UV data into three sub-bands. The results are $\alpha_{K\text{-}I}$(2.2–0.9

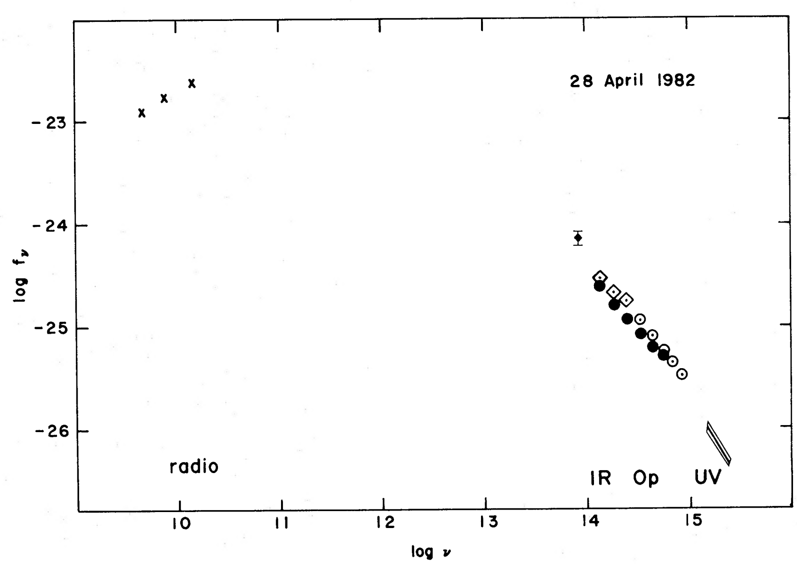

FIG. 6.—Extended multifrequency spectrum for 1982 April 28; same labeling as in Fig. 5 except for additional IR data (*filled diamond*, Neugebauer).

μm) ≈ -0.8 and α(4400–1200 Å) ≈ -1.7; in the visible region from 4000–8000 Å, the spectrum gradually changes slope between the two quoted values.

Inspection of Figure 2 suggests that the optical and UV spectra may have become less steep after the flare. Considering the gaps in coverage, especially in the infrared, and the uncertainties in comparing the different measurements, this result cannot be considered definitive. Additional information on possible spectral changes is available on dates when IR and optical observations were simultaneous but no *IUE* measurements were made. Some of these are shown in Figure 3. Significant day-to-day changes in particular photometric bands are common, as are changes in slope. There seems to be no systematic trend in the 1981 variations. Figure 3 includes 1982 photometry, and again the overall character of the IR-optical spectrum is the same as in 1981. One noteworthy aspect of Impey's IR photometry given in Table 4 is that the slope in early April ($\alpha = -0.98 \pm 0.18$ for 1981 April 5–8) is significantly (2 σ) shallower than in late April ($\alpha = -1.39 \pm 0.08$ for 1981 April 30–May 1). Somewhat later (1981 June 11), however, Rudy's JHKL measurements are well fitted by $\alpha = -1.0 \pm 0.1$.

III. DISCUSSION

In § II we have presented simultaneous observations covering a broad frequency range of the quasar 1156+295 made after the outburst which occurred in early 1981. The most extensive wavelength coverage was achieved on the four epochs listed in Table 2, which are separated by 4 days, $\sim$60 days, and $\sim$1 year. Additional simultaneous measurements at IR and optical wavelengths were made within the first few months after the flare was recognized. Monitoring of the radio continuum continues at several frequencies, as well as *B*-band photometry; and further simultaneous observations are planned. Although these data probably constitute the largest available body of observations on a flaring OVV, significant gaps exist, particularly before the flare. For example, the characteristics of the rise in the light curve and its behavior near maximum are lacking. In the following paragraphs we discuss some of the more important aspects of these results.

a) The Total Luminosity

It is difficult to estimate the total luminosity of 1156+295 without measurements in the wavelength band from 1 mm to 10 μm. On 1981 April 8, the integrated luminosity over just the observed portions of the spectrum was $\sim 1.5 \times 10^{48}$ ergs s^{-1}, using $H_0 = 100$ km s^{-1} Mpc^{-1} and $q_0 = 0$ and assuming isotropic emission. (For the other multifrequency epochs, similar estimates can be obtained by scaling with the measured *B*-magnitudes because the shapes of the IR-optical-UV spectra are similar.) The radio power below 1 mm is slight, and the peak in νf_ν, the power per unit logarithmic interval, occurs near 1.5 μm (or 8700 Å in the rest frame) for the wavelengths observed. The total luminosity may be much larger, depending on the detailed properties of the currently unmeasured flux in the far-infrared. For example, if we conservatively extrapolate the data on 1981 April 8 to obtain a single peak in the flux of 2 Jy at 300 μm, the luminosity is increased by about a factor of 3. In any case, the luminosity estimated on the basis of available measurements on 1981 April 8, 1.5×10^{48} ergs s^{-1}, should be considered as a lower limit.

b) Variability

The major optical flare in early 1981 occurred over a three month interval. This is the time for the object to rise from and fall back to a characteristic level of $B = 15$–16 mag. Similar values have been found in the optical outburts of other OVVs and BL Lac objects—e.g., B 1308+326 in 1977 and 1978 (Puschell *et al.* 1979); 1510−089 in 1948 (Liller and Liller 1975), 3C 279 in 1937 (Eachus and Liller 1975), AO 0235+164 in 1975–1976 (MacLeod, Andrew, and Harvey 1976; Ledden, Aller, and Dent 1976; Rieke *et al.* 1976) and in 1979 (Balonek and Dent 1980; Pollock *et al.* 1979), 0846+51 in 1975 (Arp *et al.* 1979). Of course, the light curves for these events are incomplete, and they differ in important details, but the occurrence of a time scale of a few months in a fair number of objects might be significant. On the other hand, the BL Lac object OJ 287 underwent a much longer outburst from 1969–1973 (Pollock *et al.* 1979; Usher 1979).

The optical flare in 1156+295 was followed about 11 months later by an outburst at radio frequencies which lasted for almost 1 yr. To compare the time scales for the optical (*B*) and radio (14.5 GHz) outbursts, we use the definition $\tau_\nu = f_\nu(\Delta t/\Delta f_\nu)$ to obtain $\tau_B \sim 3 \times 10^6$ s and $\tau_{14.5\ \mathrm{GHz}} = 4 \times 10^7$ s. We observed 1156+295 to vary over many different time intervals—months, weeks, days, and hours. The shortest significant variations of a few percent were found by Wiśniewski and with high-speed photometry (Paper W; Grauer 1982) to occur over intervals of about $\frac{1}{3}$ hr; this corresponds to a time scale $\tau \sim 4 \times 10^4$ s, or to a size of the order of $\frac{1}{2}$ light-day.

The most important spectral change which we have observed for 1156+295 is an increase in the slope of the radio flux in the 5–100 GHz region, associated with the large increase in radio emission starting about 11 months after the start of the IR-optical-UV outburst. By comparison, previously studied flaring quasars show a variety of behavior. For example, the OVV quasar 1308+326 steepened in the IR during both its 1977 and 1978 outbursts, but there was no clear correlation with radio flux changes. The 1975 flare in the BL Lac object AO 0235+164 also provided some evidence for steepening at IR wavelengths, but in this case both the 1975 and 1979 IR-optical outbursts were simultaneous with radio peaks. The behavior of the IR fluxes in these objects is to be contrasted with our measurements for 1156+295, where the IR spectrum at most steepens slightly after the outburst, and with the BL Lac object 0846+51, where the optical spectrum definitely becomes steeper following its 1975 outburst (Arp *et al.* 1979).

The best evidence for an associated optical-radio event is in the BL Lac object OJ 287. During a 3 yr, 3 mag decline from its 1970–1971 outburst, close *UBVRI* monitoring of OJ 287 failed to disclose any systematic color changes, although there were some short-term excursions about the mean color. The optical outburst was reflected in considerable detail by the 2–8 cm flux, with a delay of about 11 months (Smith *et al.* 1975; Pomphrey *et al.* 1976). In 1975 the BL Lac object 0420−01 became active after a period of relative quiescence (Pollock *et al.* 1979). An outburst at 2 cm about 2 yr after an optical flare in 1975 (Dent *et al.* 1979) occurred at about the same time that another optical flare took place. The association between the radio and optical outbursts is unclear for this source.

c) Theoretical Considerations on Variability

The multifrequency spectra enable us to investigate in a general way which properties of the emitting plasma are responsible for the observed brightness changes. For a uniform plasma, the synchrotron flux is proportional to $MB^{1-\alpha}$, where M is the mass, and B is the magnetic field. Moreover, in most evolutionary models of synchrotron emission (Kardashev 1962), the magnetic field rather than the mass is responsible for a change in slope because higher energy electrons have shorter lifetimes. The multifrequency data do show a steepening of slope in the IR–UV spectrum, but there is no evidence for any significant change in the shape of the spectrum with time. We conclude therefore that the mass of the emitting plasma in 1156+295 changed rather than the magnetic field.

d) Application of the Synchrotron Self-Compton Model

In other papers in this series, we calculate the size, magnetic field, and velocity for the optically thin emitting regions of a number of BL Lac objects and OVV quasars. We use a synchrotron self-Compton model (e.g., Jones, O'Dell, and Stein 1974) that requires five observable properties of the multifrequency spectra as input (Bregman *et al.* 1982): the flux and frequency at which the source becomes optically thick (F_t, ν_t); the spectral slope in the optically thin region (α); a measure of the inverse Compton flux (E_{SC}); and the time scale of temporal flux variability. Although we have no information on the inverse Compton flux for 1156+295 without X-ray observations, some quantities depend so weakly on E_{SC} ($r \propto E_{SC}^{0.1}$) that they are well determined as long as E_{SC} falls in the range observed for most quasars. From the data of Ku, Helfand, and Lucy (1980), we estimate this range to be $10^{-1} > E_{SC} > 10^{-6}$. As suggested by the observations, the source first becomes optically thick at 3×10^{11} Hz $< \nu_t < 3 \times 10^{12}$ Hz, $F_t \sim 1$ Jy, the variability size is ~ 1 light-day, and the optically thin slope is approximately -0.8. We then calculate that the radius of the core region is $\sim 10^{-2}$ pc, the magnetic field is in the range 0.1–30 gauss, and the emitting region is moving relativistically with respect to the quasar rest frame with Lorentz factor 2–8.

The magnetic field is large enough and the radiative cooling time of the electrons short enough (less than the variability time scale) to produce a slope change in the IR–UV spectrum consistent with the observations. Finally, these physical properties are similar to what we have calculated elsewhere for several other violently variable quasars and BL Lac objects (Bregman *et al.* 1981, 1982, 1983).

The physical properties of the radio-emitting region may be considerably different from those of the IR–UV core. If the region responsible for the radio emission from 1156+295 is similar to those deduced from very long baseline interferometric data above for other sources (Kellermann and Pauliny-Toth 1981), then its linear extent must be at least 100 times larger and its magnetic field 100 times smaller than for the IR–UV region. It is likely that the radio-emitting region is a large region separate from the IR–UV core, and that these regions are connected in such a way that activity in the core is observed eventually at radio frequencies.

IV. SUMMARY

We have reported here a series of multifrequency observations of the quasar 1156+295 which were made mainly within a year and a half after its outburst in early 1981. So far we have been able to obtain four series of simultaneous measurements of this quasar. With the help of many other observers, especially the authors of Paper W, a substantial body of data has been assembled on a major flare-up of a very variable quasar.

The main optical outburst covered a period of three months at the start of 1981, when the overall luminosity of the quasar rose by a factor of ~ 10 to a peak $\gtrsim 3 \times 10^{48}$ ergs s^{-1}. During this prolonged outburst, the overall shape of the measured multifrequency spectrum did not change in any qualitative sense. Small significant changes were detected in the spectrum at particular wavelength bands, and the shortest measured time scale $\tau = f/(df/dt)$ was found to be 1 light-day. Almost 1 yr after the start of the optical flare, an outburst was detected at centimeter wavelengths. The radio fluxes at 4.5, 8.0, and 14.5 GHz then fluctuated about roughly constant values for almost half a year before declining in the second half of 1982. Although it is tempting to interpret the radio outburst as a delayed response to the optical, there is no compelling observational evidence for this connection. Detailed study of the time variation of 1156+295 did not start until the optical flare was ending.

The multifrequency spectra and their time variation provide important information on the structure of the source of this quasar's continuum emission. For example, we interpret the observed absence of any qualitative change in the IR–UV spectrum to mean that the early 1981 outburst involved a change in the mass of the emitting plasma rather than in the magnetic field. From modeling of the spectra with synchrotron self-Compton theories, we find that the source must be undergoing bulk relativistic motion with a Lorentz factor in the range 2–8. The core of the source has a magnetic field in the range 0.1–30 gauss and a linear size ~ 0.01 pc. This last conclusion is supported by measurements of temporal changes. More restricted ranges in model parameters could be derived if the simultaneous observations were extended to include measurements at X-ray and far-IR wavelengths. We hope to be able to present such results in the future.

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