THE ASTROPHYSICAL JOURNAL, **274**:62–85, 1983 November 1

THE QSO 1156+295: A MULTIFREQUENCY STUDY OF RECENT ACTIVITY

BEVERLEY J. WILLS,[1] J. T. POLLOCK,[2,3] H. D. ALLER,[4] M. F. ALLER,[4] T. J. BALONEK,[5,6,7] R. E. BARVAINIS,[5] R. P. BINZEL,[8] F. H. CHAFFEE, JR.,[9] W. A. DENT,[5,7] J. N. DOUGLAS,[1] C. FANTI,[10] D. B. GARRETT,[1] L. GREGORINI,[10] RICHARD B. C. HENRY,[11] R. E. HILL,[12] R. HOWARD,[13] N. JESKE,[14] S. O. KEPLER,[8] R. J. LEACOCK,[3] F. MANTOVANI,[10] C. P. O'DEA,[5,15] L. PADRIELLI,[10] P. PERLEY,[15] A. J. PICA,[3,16] J. J. PUSCHELL,[17] N. SANDULEAK,[12] G. A. SHIELDS,[8] A. G. SMITH,[3] T. X. THUAN,[18,19] C. M. WADE,[15] A. J. WASILEWSKI,[12] J. R. WEBB,[3] D. WILLS,[1] and W. Z. WIŚNIEWSKI[20]

Received 1982 November 8; accepted 1983 March 31

ABSTRACT

A 5 mag optical outburst in the QSO 1156+295 occurred in the spring of 1981. The peak luminosity was among the highest observed in QSOs. A very large radio outburst was observed 6–12 months later and propagated from high frequencies (90 GHz) to low (1.4 GHz). Here we investigate the object's behavior before, during, and after the outbursts using flux density and polarization measurements and spectrophotometric data. The observations at optical, IR, and radio frequencies cover a factor of 10^7 in frequency.

Before 1976 the object appears to have been relatively inactive. The recent activity at radio and optical frequencies seems to have been building up since sometime between 1976 and 1979, and at the time of writing (1982 October) the object is still active. At the peak brightness (1981 March), optical flickering on half-hour time scales was observed, and at the peak of the radio outburst, variations on time scales of less than a few days were found at centimeter wavelengths. There were also large and rapid variations in optical linear polarization, with the degree of polarization as large as 29%; only small variations in polarization were observed at centimeter wavelengths, where the degree of polarization was small (<4%). No optical absorption was seen (>100 mÅ equivalent width) to the blue of the Mg II λ2798 emission line near maximum light. When 1156+295 was bright, the optical spectrum was essentially featureless like that of a BL Lac object; when faint, the emission-line spectrum appeared to be that of a normal QSO.

We compare our radio data with simple models for the evolution of the spectrum and discuss the energetics of the radio-IR-optical events in terms of a magnetic accretion disk model proposed by Shields and Wheeler. The model appears consistent with the data if the viscosity parameter $\alpha \lesssim 10^{-4}$.

Subject headings: infrared: sources — polarization — quasars — radio sources: variable — spectrophotometry

I. INTRODUCTION

The blue object Ton 599 (Iriarte and Chavira 1957) is the optical counterpart of the radio source 4C 29.45, alias B2 1156+295 and CTD 77 (Wills 1966; Olsen 1970; Grueff and Vigotti 1972). Spectroscopy by Burbidge (1968) confirmed Wills's original identification, and later observations by Schmidt (1975) also showed strong, broad emission near 4835 Å—Mg II λ2798 at a redshift $z = 0.729$. A good-quality spectrogram obtained by Lynds and Wills (1968) covering 3200–6000 Å showed no strong features—the first, but then unrecognized, hint

[1] University of Texas Radio Astronomy Observatory and Department of Astronomy, University of Texas at Austin.
[2] Department of Physics and Astronomy, Appalachian State University, North Carolina.
[3] Department of Astronomy, University of Florida, Gainesville.
[4] Radio Astronomy Observatory, University of Michigan.
[5] Department of Physics and Astronomy, University of Massachusetts, Amherst.
[6] Department of Physics and Astronomy, University of New Mexico, Albuquerque.
[7] Visiting Astronomer at the National Radio Astronomy Observatory, which is operated by Associated Universities, Inc., under contract to the National Science Foundation.
[8] McDonald Observatory and Department of Astronomy, University of Texas at Austin.
[9] Mount Hopkins Observatory, Smithsonian Institution.
[10] Istituto di Radioastronomia del CNR Istituto di Fisica "A. Righi," Università di Bologna.
[11] Department of Astronomy, University of Michigan.
[12] Warner and Swasey Observatory, Case Western Reserve University.
[13] National Radio Astronomy Observatory, Tucson.
[14] Astronomy Department, University of California, Berkeley.
[15] National Radio Astronomy Observatory, Socorro, New Mexico.
[16] Now at Department of Physical Sciences, Salisbury State College, Maryland.
[17] Center for Astrophysics and Space Sciences, University of California, San Diego.
[18] Department of Astronomy, University of Virginia.
[19] Visiting Astronomer at the Kitt Peak National Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under contract to the National Science Foundation.
[20] Lunar and Planetary Laboratory, University of Arizona.

of the large-amplitude variability of the optical continuum. Kesteven, Bridle, and Brandie (1976), in a survey for variable sources, showed 1156+295 to be variable at 11 cm. Before the recent outbursts, very long baseline interferometric (VLBI) observations at 13 cm (W. D. Cotton, private communication) showed 80% of the flux within 2 milli-arcsec (mas), and Very Large Array (VLA) observations (Perley 1982) showed an unresolved core including 98% of the total flux. Indirect evidence that the object is an OVV (optically violent variable) came from observations of strong and variable optical linear polarization (Stockman 1978).

No study of the variability of the optical continuum brightness was made until 1156+295 was included in a list of BL Lac objects and OVV QSOs for simultaneous multifrequency observations by Glassgold *et al.* (1983) (accompanying paper). A sample of these objects is observed about a week in advance of each *International Ultraviolet Explorer* (*IUE*) observing date in order to select the brightest. Thus was the outburst discovered at the University of Florida's Rosemary Hill Observatory on 1981 April 3.

The maximum observed range (in ΔB) is 5 mag, comparable to the largest outbursts observed in other QSOs and BL Lacertae objects, e.g., greater than 6.7 mag in 3C 279 (Eachus and Liller 1975), 5.2 mag in AO 0235+164 (Rieke *et al.* 1976), and 5.4 mag in PKS 1510−08 (Liller and Liller 1975). At maximum, 1156+295 ranks in the top 10 most luminous known QSOs ($M_B = -28.7$).[21] Such outbursts are rare, and the energy released is so large that the properties of the outburst may be directly related to the mechanism of conversion of (for example) gravitational to electromagnetic radiation and to the ultimate power source of QSOs (including BL Lac objects). We have therefore followed the recent behavior of 1156+295 in some detail at optical and radio wavelengths and have attempted to compare this with past behavior.

Photometric observations are presented in § II for the outburst(s) of 1981 and 1982, including high time resolution photometry showing variations on time scales of weeks to ~half an hour. Data have been gleaned from early plate material, showing that the object may have been quite bright at the beginning of this century but was quite faint and probably inactive between about 1950 and the beginning of recent activity in 1977–1979. Some results of optical linear polarization are discussed. Section III presents spectrophotometric results. Broad-band spectra show very little change in spectral shape during changes in continuum brightness. High-resolution spectra (0.1 Å FWHM) show no evidence for the Mg II λ2798 absorption sometimes seen in OVVs and other QSOs. The radio flux density variations at several frequencies are documented and discussed in § IV and compared with the optical light curve. In § V we discuss models for 1156+295 including variability time scales, and we compare the observed energy output with a magnetic accretion disk model proposed by Shields and Wheeler (1976). Finally, the results are summarized in § VI, and the different sizes of active and inactive regions of 1156+295 are compared.

[21] We assume that the entire redshift is due to expansion of a universe with $H_0 = 100\ h_0$ km s^{-1} Mpc^{-1} and $q_0 = 1$.

II. OPTICAL PHOTOMETRY

Some of the broad-band photometry reported here, including that from archival photographic material, was reduced using the B-magnitude sequence established at Rosemary Hill Observatory. This sequence was calibrated by photographic transfer using the photoelectric sequence in the field of ON 231 (Wing 1973). Figure 1 gives a finding chart for 1156+295 and the reference stars of the magnitude sequence, and Table 1 lists the adopted magnitudes of these stars. Photoelectric photometry indicates that star 10 is variable and so should not be used as a standard. Dumortier (1976) has also set up a sequence based on Wing's photoelectric standards. The agreement for seven stars in common is good, and the average difference is 0.06 mag. Photoelectric photometry (by R. P. B., using the instrument described in § II*c*) for star 11, as well as for an additional reference star (21), is given as a note to Table 1. For completeness we have appended to Table 1 the *UBV* measurements of three very bright nearby standard stars (Epps 1972).

a) *The 1981–1982 Outburst(s)*

Figure 2 shows a plot of all known broad-band photometry from the beginning of 1981. These data are also given in Table 2, where notes on the individual measurements give their source and other information. Observations made on the same night by the same observer have been averaged; these measurements were consistent within the expected uncertainties.

Fortunately, eight observations were made in the two months prior to the detection of the outburst, and six of these define the rise of the light curve. The data of Figure 2 and Table 2 show that even in early January the object was very much brighter than its faintest recorded level (~18.2 mag). The light curve may be quite similar to those for outbursts in other OVVs such as 3C 279 (Eachus and Liller 1975) and PKS 1510−08 (Liller and Liller 1975). In general, during fading from outbursts of large amplitude and short duration (a few months or less), several smaller outbursts are seen. Often the flux remains fairly constant at the peak, perhaps for a few weeks. In 1156+295 at least two smaller outbursts were seen at JD 2,444,699 and 2,444,726, lasting 4 or 5 days. The magnitude remained at $B \sim 14.7$ between JD 2,444,703 and 2,444,709. Just before the object was lost in the daytime sky in 1981 September it was especially bright ($B \sim 14.1$), but by the beginning of the next observing season (1981 December) $B \sim 17$, near its quiescent level. Since then it has been very active, fluctuating between $B \sim 14.5$ and 16.5.

b) *The Historical Light Curve*

All the measurements of optical brightness that we could find, covering the period before 1981, are given

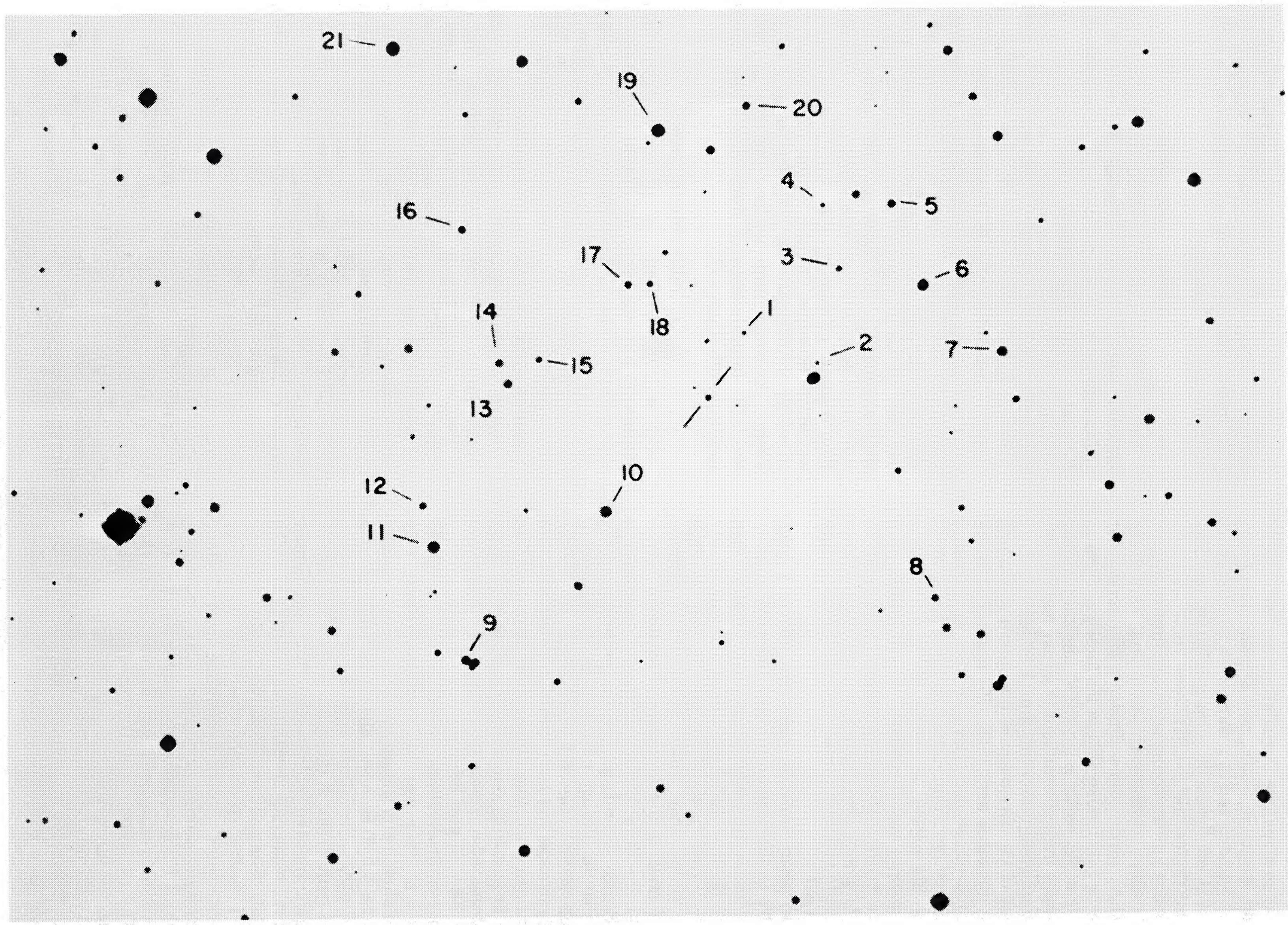

FIG. 1.—Finding chart for 1156+295 and the stars of the Rosemary Hill Observatory magnitude sequence given in Table 1. This chart, 35′ × 25′, is an enlargement from the National Geographic Society–Palomar Observatory Sky Survey O-print. North is at the top and east to the left. (© 1960 National Geographic Society–Palomar Sky Survey. Reproduced by permission of the California Institute of Technology.)

TABLE 1

PHOTOMETRY OF REFERENCE STARS

A. ROSEMARY HILL OBSERVATORY COMPARISON SEQUENCE FOR 1156+295

Star No.	B	Star No.	B
1	18.02	11	13.44[a]
2	18.32	12	16.45
3	18.14	13	15.82
4	17.89	14	16.19
5	16.00	15	16.92
6	15.26	16	16.12
7	16.02	17	18.04
8	17.59	18	17.28
9	15.48	19	13.16
10	variable	20	16.05
		21[a]	...

B. PHOTOMETRY BY EPPS 1972

BD	SAO	R.A. (1950)	Decl.	V	$U-B$	$B-V$
+29°2245	82097	$11^h58^m.2$	29°28′	8.36	0.07	0.59
+30°2205	82072	11 54.9	29 33	9.18	1.69	1.38
+30°2208	62776	11 55.7	30 03	10.16	0.06	0.57

[a] R. P. B. measures $B = 13.72 \pm 0.01$ and 12.21 ± 0.01 for stars 11 and 21, respectively. These photoelectric magnitudes are based on well-observed Landolt standards (Landolt 1973), in the B system of Johnson and Morgan, and were both measured on UT 1982 February 27 (2.1 m telescope) and UT 1982 March 20 (0.91 m telescope) at McDonald Observatory. Excellent agreement between the two measurements suggests that these stars are unlikely to be variable.

in Table 3, together with references to the original sources of data. For all direct photographic data, except the Rosemary Hill Observatory data, where iris photometry was used, and the Dumortier data, magnitudes were derived by visual interpolation using the Rosemary Hill B-magnitude sequence. Upper limits are not included in the table but are discussed below.

The main source of historical data is the plate material in the Harvard photographic collection, which was searched (by J. T. P.) to study the previous behavior of the light curve. Because of the relatively bright peak magnitude recorded during 1981 ($B \sim 13$), all plates, including those of the small patrol cameras, were examined. Over 500 plates containing the region were included, 264 of which had a plate limit of $B > 15$. The plate coverage from 1926 to 1951 is excellent, with an average of 8.5 and a minimum of 2 plates per year, reaching fainter than $B \sim 15$. For the period from 1927 to 1941 the average was 12 plates per year. The object was seen rarely, and even then it was fainter than $B \sim 16$.

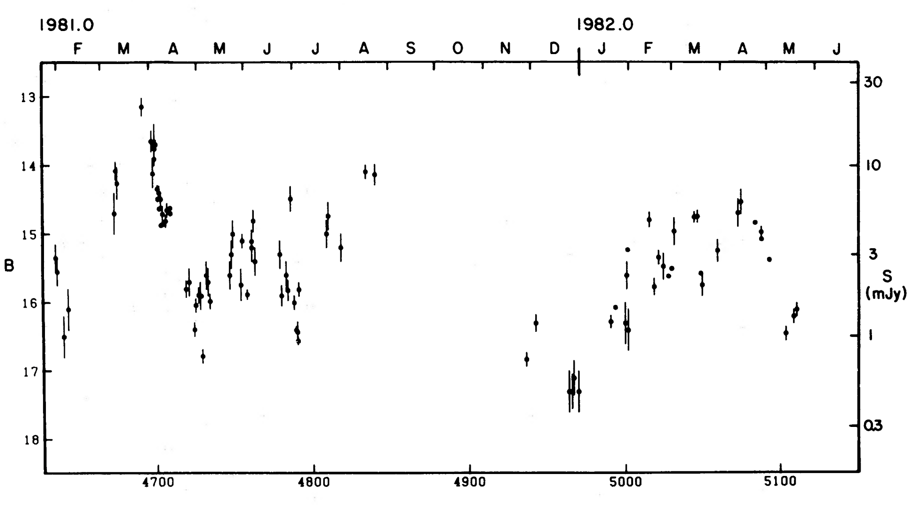

FIG. 2.—The light curve of 1156+295 during 1981–1982 (data in Table 2). Error bars are ±1 standard deviation.

TABLE 2

1981–1982 OPTICAL LIGHT CURVE FOR 1156+295

UT Date	JD 2,440,000+	B	rms Error	Note
1981:				
Jan 31	4635.758	15.35	0.20	1
Feb 1	4636.785	15.55	0.20	1
Feb 5	4640.708	16.50	0.30	2
Feb 8	4643.708	16.10	0.30	2
Mar 10	4673.708	14.70	0.30	2
Mar 11	4674.757	14.08	0.13	3
Mar 12	4675.770	14.26	0.23	3
Mar 28	4691.672	13.15	0.13	3
Apr 3	4697.663	13.65	0.15	4
Apr 4	4698.623	14.12	0.2	
Apr 4	4698.708	13.99	0.10	5
Apr 5	4699.592	13.91	0.05	4
Apr 5	4699.708	13.70	0.30	2
Apr 5	4699.801	13.76	0.03	6
Apr 6	4700.541	13.70	0.07	4
Apr 7	4701.648	14.34	0.05	4
Apr 7	4701.670	14.49	0.03	6
Apr 8	4702.547	14.40	0.10	4
Apr 8	4702.708	14.63	0.03	6
Apr 9	4703.648	14.49	0.10	4
Apr 9	4703.740	14.87	0.03	6
Apr 10	4704.743	14.71	0.12	4
Apr 10	4704.753	14.86	0.03	6
Apr 12	4706.867	14.81	0.09	4
Apr 13	4707.648	14.65	0.10	4
Apr 15	4709.736	14.62	0.03	6
Apr 15	4709.837	14.70	0.03	6
Apr 25	4719.569	15.80	0.12	4
Apr 27	4721.639	15.70	0.20	1
Apr 30	4724.723	16.39	0.10	4
May 1	4725.627	16.04	0.10	4
May 3	4727.637	15.89	0.11	4
May 4	4728.5	15.9	0.2	7
May 5	4729.708	16.78	0.10	8
May 8	4732.634	15.60	0.20	1
May 9	4733.632	15.70	0.20	1
May 10	4734.758	15.98	0.11	4
May 23	4747.585	15.60	0.20	1
May 24	4748.600	15.30	0.20	1
May 25	4749.621	15.00	0.20	1
May 30	4754.621	15.74	0.23	4
May 31	4755.621	15.1	0.1	9
Jun 3	4758.647	15.88	0.07	4
Jun 6	4761.591	15.20	0.20	1
Jun 6	4761.660	15.11	0.17	4
Jun 7	4762.749	14.81	0.16	4
Jun 8	4763.718	15.40	0.20	1
Jun 24	4779.608	15.30	0.20	1
Jun 25	4780.621	15.90	0.15	4
Jun 28	4783.604	15.60	0.20	1
Jun 29	4784.640	15.82	0.15	4
Jul 1	4786.632	14.49	0.18	4
Jul 3	4788.598	16.00	0.10	4
Jul 4	4789.800	16.40	0.05	6
Jul 5	4790.616	16.43	0.15	4
Jul 5	4790.800	16.56	0.05	6
Jul 6	4791.607	15.81	0.10	4
Jul 24	4809.589	15.00	0.20	1
Jul 25	4810.602	14.74	0.20	4
Aug 12	4828.588	15.20	0.20	1
Aug 18	4834.557	14.10	0.10	4
Aug 24	4840.550	14.14	0.15	4
Nov 28	4936.870	16.83	0.10	4
Dec 4	4942.927	16.30	0.12	4
Dec 25	4964	17.3	0.3	7
Dec 27	4966	17.3	0.25	7
Dec 28	4967	17.10	0.25	7
Dec 31	4970	17.3	0.3	7
1982:				
Jan 21	4990.781	16.28	0.09	4
Jan 24	4993.7	16.49	0.03	6
Jan 30	5000	16.3	0.3	7
Jan 31	5001	15.6	0.2	7
Feb 1	5001.7	15.78	0.03	6
Feb 1	5002	16.4	0.3	7
Feb 15	5015.703	14.79	0.11	4
Feb 18	5018.760	15.77	0.12	4
Feb 21	5021.699	15.34	0.10	4
Feb 24	5024.653	15.47	0.19	4
Feb 27	5027.917	15.61	0.01	10
Mar 1	5029.958	15.50	0.01	10
Mar 3	5031.819	14.96	0.20	4
Mar 16	5044.694	14.75	0.08	4
Mar 18	5046.650	14.74	0.09	4
Mar 20	5048.819	15.57	0.01	10
Mar 21	5049.760	15.74	0.16	4
Mar 31	5059.767	15.24	0.16	4
Apr 13	5072.651	14.69	0.20	4
Apr 15	5074.668	14.53	0.18	4
Apr 24	5083.752	14.83	0.03	6
Apr 28	5087.720	14.97	0.08	4
Apr 28	5087.730	15.07	0.02	6
May 3	5092.753	15.37	0.03	6
May 14	5103.5	16.45	0.10	4
May 19	5108.5	16.2	0.1	4
May 21	5110.5	16.1	0.1	4

NOTES.—(1) Maria Mitchell Observatory *B* plates. Eye estimates were made using the Rosemary Hill *B* sequence. In general the field was too near the edge of the plates, making the images too comatic for accurate iris photometry.

(2) Sanduleak, Wasilewski, and Hill. Using a series of deep, nitrogen-baked IIIa-J objective prism plates taken with the Burrell Schmidt telescope at the Kitt Peak Station of Warner and Swasey Observatory. These magnitude estimates were made by visually intercomparing the image density of the spectrum of Ton 599 with nearby stars. The apparent *B*-magnitudes of these comparison stars were then derived from image diameter measurements made on PSS print O-1379, which was calibrated using the SA 56 photoelectric sequence provided by Priser 1974.

(3) Harvard Archives *B* plates, reduced by iris photometry using the Rosemary Hill sequence.

(4) Rosemary Hill Observatory *B* plates, reduced by iris photometry.

(5) McDonald Observatory IDS (R. G. Kron).

(6) Photoelectric photometry (W. Z. W.), LPL, Mount Lemmon.

(7) Magnitudes derived from polarimeter count rates (see § II*d*).

(8) McDonald Observatory IDS (B. J. W., D. W.).

(9) Magnitudes derived from spectrophotometry (see Table 7).

(10) McDonald Observatory photoelectric photometry (R. P. B.) (see Table 1, note *a*).

TABLE 3

PRE-1981 MAGNITUDES FOR 1156+295

UT Date	JD 2,400,000+	B	Note
1907 May 6	17702	18.0 ± 0.2	1
1927 Feb 5	24917	16.7 ± 0.2	1
1927 Mar 4	24944	16.7 ± 0.2	1
1928 Feb 14	25291	16.5 ± 0.2	1
1930 Apr 2	26069	16.2 ± 0.2	1
1931 Jan 13	26355	16.0 ± 0.2	1
1948 Apr 28	32670	16.5 ± 0.2	1
1948 May 2	32674	16.0 ± 0.2	1
1955 Apr 12	35210	17.2 ± 0.15	2
1956 Mar 4	35537	16.5 ± 0.2	3
1974 Jan 24	42072	17.40 ± 0.05	4
1975 Jan 15	42428	14.3 ± 0.2	1
1975 Jan 18	42431	17.5 ± 0.25	5
1975 Apr 5	42507.510	18.23 ± 0.08	6
1975 Apr 6	42509.458	18.06 ± 0.15	6
1976 Jan 27	42804.599	17.99 ± 0.07	6
1976 May 26	42925.388	17.87 ± 0.09	6
1977 Apr 11	43245	18.0 ± 0.1	7
1978 Feb 10	43550	18.7 ± 0.35	8
1978 Mar 14	43582	16.7 ± 0.35	8
1978 May 29	43658	17.9 ± 0.35	8
1978 Nov 27	43840	17.2 ± 0.35	8
1979 Jan 23	43897	17.7 ± 0.35	8
1979 Apr 2	43966	17.0 ± 0.35	8
1979 Apr 18	43982	16.2 ± 0.2	9
1979 Apr 3	43967	16.1 ± 0.2	9
1979 May 2	43996	15.4 ± 0.2	9
1979 May 22	44016	15.5 ± 0.2	9
1979 May 21	44015	16.2 ± 0.1	7
1979 May 31	44025	15.0 ± 0.2	9
1979 Jun 12	44037	15.6 ± 0.2	9
1980 Jan 26	44265	16.8 ± 0.3	10
1980 Feb 8	44278	16.9 ± 0.1	7
1980 Mar 13	44312	16.8 ± 0.3	10
1980 Apr 11	44341	16.9 ± 0.35	8
1980 Apr 12	44342	16.7 ± 0.35	8
1980 May 4	44364	16.7 ± 0.3	10
1980 May 4	44364	16.1 ± 0.2	9
1980 May 5	44365	16.1 ± 0.2	9
1980 May 9	44368.626	17.36 ± 0.12	11
1980 Jun 4	44394.619	17.33 ± 0.15	11
1980 Jun 11	44402	15.3 ± 0.2	9

NOTES.—This table gives data for detections, but there are upper limits from the Harvard plate collection between 1926 and 1951, and from 1968 (see text).

(1) Harvard Archives.

(2) National Geographic Society–Palomar Observatory Sky Survey. Note that this estimate may be too bright by about 0.1 owing to the UV excess of the QSO relative to the red colors of most comparison stars, because of the significant UV sensitivity of the O emulsion.

(3) Iriarte and Chavira 1957. Dr. Iriarte has reestimated the magnitude using the Rosemary Hill magnitude sequence.

(4) B derived from Oke multichannel spectrometer data (Richstone and Schmidt 1980).

(5) Eye estimate from a 5′ diameter image-tube plate. Star 1 ($B = 18.0$) was the only standard available for comparison. The plate was a $U-B$ double exposure taken at the 2.1 m telescope to search for QSO pairs (Wills and Wills 1977). The image was definitely not brighter than on the PSS O-plate.

(6) Dumortier 1976.

(7) Values from spectrophotometry ("G," Table 6).

(8) These magnitudes are derived from $B = m + 0.5$, where m is the magnitude given by Moore 1981. The observations are described by Moore and Stockman 1981.

(9) Maria Mitchell Observatory.

(10) Sanduleak, Wasilewski, and Hill—objective prism. See Table 2, note 2.

(11) Rosemary Hill Observatory.

Single plates from 1934, 1941, and 1947 had plate limits of $B \sim 18.2$, yet the object was not visible. No Harvard data are available from 1952 through 1967, and the only data in this period are from the Tonantzintla blue star catalog (Iriarte and Chavira 1957) and the National Geographic Society–Palomar Observatory Sky Survey (PSS). Note that 1156+295 was probably quite bright in 1967 March (± one month), since lines easily detected by Burbidge (1968) and Schmidt (1975) were not seen on the higher quality spectrogram obtained by Lynds and Wills (1968). Here we are assuming that the continuum flux increased greatly, but the line flux did not. This is consistent with observations of this and other QSOs (see § III). The Harvard Damon patrol plates are available from 1968, but in general they are no deeper than ~ 15 mag. Only one of 33 Damon plates taken before 1981 recorded an image of 1156+295—in 1975 January at $B \sim 14.2$. This value should be compared with $B \sim 17.5$ estimated from an image-tube plate taken three days later and two measurements of $B \sim 18.1$ in 1975 April by Dumortier (1976). This 3 mag change over 3 days is the most rapid large-amplitude change ever observed, and since it is based on a single magnitude measurement just brighter than the plate limit ($B \sim 15$), the reality of the change is questionable. This year also marked the beginning of a factor of 2 increase in the 2.7 GHz flux density (see § IV).

Subject to large uncertainties due to sparse photometric coverage, we conclude from data obtained since the beginning of the century (see Table 3 and the above discussion) that 1156+295 has been much more active in the last 3 years (1979–1982) than in the past, especially compared with the 25 years between 1926 and 1951.

c) *High-Speed Photometry*

Photometric variability on time scales of hours, in *UBVRI*, has been studied (by W. Z. W.) with the Lunar and Planetary Laboratory (LPL), University of Arizona, 1.5 m telescope on Mount Lemmon. These results are shown in Table 4. There is marginal evidence for variations over several hours.

Much higher time resolution data were obtained on UT 1981 April 9 at the university of Texas's McDonald Observatory (S. O. K.). These observations were made in unfiltered light with a high-speed, two-channel photometer (Nather 1973) with a blue-sensitive photomultiplier (RCA 8850 with a bi-alkali photocathode). The integration time used was 10 s, but the data shown in Figure 3 are five-point averages. Corrections have been made for dark noise and sky background, and for atmospheric extinction using mean (seasonal) extinction coefficients appropriate for McDonald Observatory. The light curve shows good evidence for ~ 0.07 mag flickering on about half-hour time scales. Note the extremely steady

TABLE 4

PHOTOMETRY

A. UNIVERSITY OF ARIZONA, LPL, MOUNT LEMMON (W. Z. W.)

UT Date	UT Time	V	$U-B$	$B-V$	$V-R$	$R-I$	α
1981 Apr 5	0440	13.27	−0.68	0.50	0.61	0.55	
1981 Apr 5	0500	13.28	−0.66	0.46	0.65	0.54	
1981 Apr 5	0630	13.27	−0.65	0.45	0.59	0.63	
1981 Apr 5	0645	13.32	−0.72	0.44	0.66	0.57	
1981 Apr 5	0700	13.32	−0.67	0.46	0.67	0.56	
1981 Apr 5	0715	13.33	−0.66	0.43	0.63	0.61	−1.47 ± 0.03
1981 Apr 5	0750	13.35	−0.64	0.40	0.66	0.57	
1981 Apr 5	0820	13.37	−0.62	0.41	0.64	0.61	
1981 Apr 5	0910	13.36	−0.58	0.40	0.68	0.58	
1981 Apr 5	0940	13.34	−0.63	0.42	0.70	0.55	
1981 Apr 7	0405	13.89	−0.70	0.60	0.58	0.61	−1.58 ± 0.08
1981 Apr 8	...	14.05	−0.80	0.58	0.47	0.56	−1.30 ± 0.11
1981 Apr 9	0545	14.36	−0.71	0.51	...	...	...
1981 Apr 10	0605	14.44	−0.52	0.42	...	...	...
1981 Apr 10	...	14.41	−0.50	0.39	...	...	...
1981 Apr 15	0540	14.12	−0.53	0.50	0.68	0.57	−1.66 ± 0.03
1981 Apr 15	0805	14.32	−0.59	0.38	0.70	0.73	
1981 Jul 4	...	15.90	−0.56	0.50	0.60	0.88	−1.89 ± 0.07
1981 Jul 5	...	16.09	−0.60	0.47	0.55	0.70	−1.50 ± 0.07
1982 Jan 24	...	16.07	−0.56	0.42	0.77	0.69	−1.77 ± 0.05
1982 Feb 1	...	15.23	−0.54	0.55	0.72	0.57	−1.78 ± 0.07
1982 Apr 24	0603	14.36	−0.56	0.47	0.64	0.62	−1.61 ± 0.03
1982 Apr 28	0353	14.60	−0.64	0.43	0.65	0.59	
1982 Apr 28	0432	14.60	−0.64	0.47	0.61	0.63	
1982 Apr 28	0531	14.65	−0.63	0.46	0.64	0.65	−1.53 ± 0.02
1982 Apr 28	0617	14.64	−0.64	0.47	0.62	0.68	
1982 Apr 28	0656	14.62	−0.58	0.42	0.61	0.63	
1982 May 3	0606	14.89	−0.73	0.48	0.72	0.59	−1.57 ± 0.09

B. INFRARED TELESCOPE FACILITY (J. J. P.)

UT Date	J	H	K	α
1982 Mar 25	13.32 ± 0.03	12.46 ± 0.01	11.52 ± 0.03	−1.25 ± 0.02

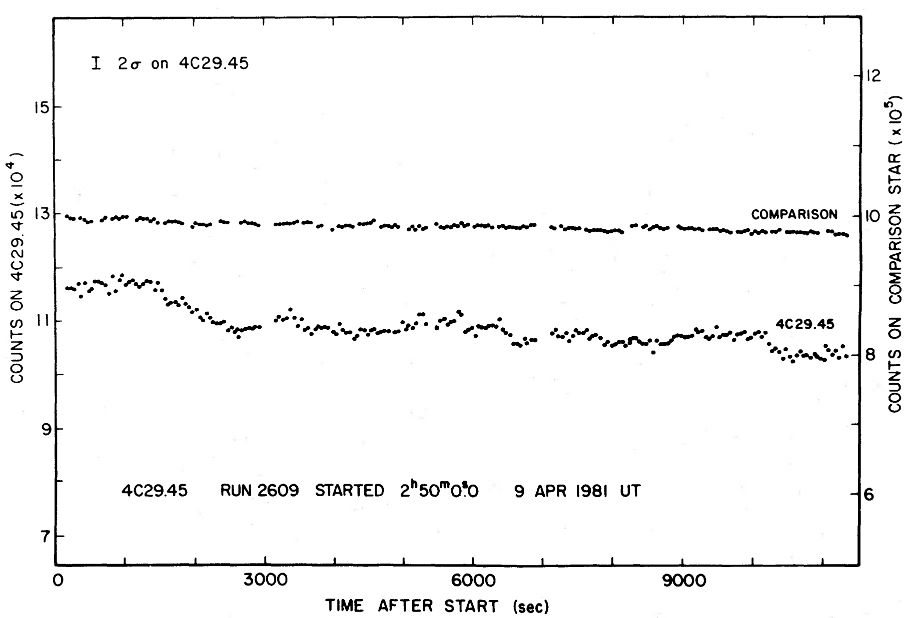

FIG. 3.—High time resolution photometry of 1156+295. Each point is the result of 50 s integration. A 2 σ error bar shows the uncertainty due to photon counting statistics.

count rate from the comparison star, monitored simultaneously using the same power supply.

Similar observations with this same equipment were made by R. P. B. on UT 1982 February 27, and no variations greater than 0.02 mag were seen; however, the observation was only 1 hr long. Short time scale variations have been seen before in other objects, the largest recorded rates of change perhaps being 0.6 mag over 30 minutes in BL Lac (Kinman 1978) and changes of 0.3 mag per hour in the OVV 3C 454.3 (Angione 1971). In the past some doubt has been cast on the reality of observed flickering because subsequent observations of the same object showed none. In BL Lac, Racine (1970) reported 0.1 mag variations over a few hours and 0.03 mag over times as short as 2 minutes; Véron (1975) found no variations over 1–5 minute time scales, but her uncertainties, $\sigma \sim 0.03$ mag, were too large to exclude the existence of Racine's 2 minute fluctuations. Kiplinger (1974) placed very stringent limits on periodic variations in OJ 287 even though variations of 0.007 mag over about 20 minute time scales had been reported by Visvanathan and Elliot (1973) and Frohlich, Goldsmith, and Weistrop (1974). Despite the difficulties in assessing the reality of some reported variations, the present and some previous results suggest that the intrinsic character of (high speed) variations in individual BL Lac objects and OVVs may be different at different times.

d) *Optical Linear Polarization*

Optical linear polarization was measured at the University of Texas's McDonald Observatory 2.1 m telescope (M. Breger, B. J. W., and D. W.) using the instrument described by Breger (1979). These results and previous, published measurements collected in Table 5 show a high degree of variability. Note the change of about 30° from night to night and the high degree of linear polarization (28.5%) on 1981 January 31. Such large values have sometimes been observed in BL Lac objects but, until now, not in the QSOs.

Moore and Stockman (1981) find no wavelength dependence of optical polarization (1978 March 14), and they find circular polarization of less than 0.5% (1980 April), both results typical of OVV QSOs.

III. BROAD-BAND SPECTRA AND SPECTROPHOTOMETRY

Over 30 spectra of 1156+295 have been obtained during 1981. Table 6 gives an observing log, including observers, instrumental parameters, and weather conditions. The spectra are shown in chronological order and identified by a date and letter in Figure 4, which shows log F_λ versus log λ on displaced ordinate scales. The logarithmic scales have the advantage that the slope is proportional to the spectral index; also, the equivalent widths of lines are proportional to their area. Similarly, the noise in this representation is a measure of the ratio of noise to signal. The height of a line of constant intensity, for calibrated spectra, is indicated by the length of the vertical bar to the right of the scan.

In general, the flux calibration accuracy of spectrophotometry with large apertures in good seeing (and no clouds) is 5%–10% (absolute) with similar relative accuracy in the wavelength dependence of flux. With

TABLE 5

OPTICAL LINEAR POLARIZATION

UT Date	JD 2,440,000+	p (%)	P.A. (deg)	V	Note
1978 Feb 10	3550	9.2 ± 1.2	24 ± 4	18.2 ± 0.35	1
1978 Mar 14	3582	4.8 ± 0.3	119 ± 2	16.2 ± 0.35	1
1978 May 29	3658	0.9 ± 0.6	...	17.4 ± 0.35	1
1978 Nov 27	3840	8.7 ± 0.4	93 ± 1	16.7 ± 0.35	1
1979 Jan 23	3897	3.6 ± 0.6	3 ± 4	17.2 ± 0.35	1
1979 Apr 2	3966	7.6 ± 0.5	122 ± 2	16.5 ± 0.35	1
1980 Apr 11	4341	14.4 ± 0.4	65 ± 1	16.4 ± 0.35	1
1980 Apr 12	4342	9.9 ± 0.5	68 ± 1	16.2 ± 0.35	1
1981 May 4	4729	6.3 ± 0.3	127 ± 1.5	15.5 ± 0.2	2, 4
1981 Dec 25	4964	9.2 ± 0.3	4 ± 1	16.9 ± 0.3	3, 4
1981 Dec 27	4967	12.2 ± 0.4	17 ± 1	16.90 ± 0.25	3, 4
1981 Dec 28	4968	10.0 ± 0.3	14 ± 1	16.70 ± 0.25	3, 4
1981 Dec 31	4970	7.1 ± 0.25	177 ± 1	16.9 ± 0.3	3, 4
1982 Jan 30	5000	18.7 ± 1.0	30 ± 1	15.9 ± 0.3	3, 4
1982 Jan 31	5001	28.5 ± 1.0	0 ± 1	15.2 ± 0.2	3, 4
1982 Feb 1	5002	14.0 ± 0.5	159 ± 1	16.0 ± 0.3	3, 4

NOTES.—For infrared polarimetry, see the companion paper by Glassgold *et al.* (1983).

(1) Stockman 1978, Moore 1981, Moore and Stockman 1981.

(2) M. Breger: 2.1 m telescope, McDonald Observatory.

(3) B. J. W. and D. W.: 2.1 m telescope, McDonald Observatory.

(4) All these magnitude estimates were determined from the polarimeter count rate through an unfiltered bandpass 3200–9000 Å (or to beyond 9000 Å for 1981 December measurements), together with an estimate of system response, known to about 10%. Some observations were made in conditions of cloud and/or poor seeing, so they are not very reliable.

TABLE 6

SPECTROPHOTOMETRY LOG

UT Date	Seeing (″)	Slit (″)	FWHM (Å)	Sky	Instrument	Observer(s)[a]
1977 Apr 11	1–2	2.7 × 4.0	8	clear	Lick ITS	G
1979 May 21	2–3	2.7 × 4.0	8	clear	Lick ITS	G
1979 May 21	2–3	2.7 × 4.0	8	clear	Lick ITS	G
1980 Feb 8	3–4	10.0 × 10.0	10	clear	Lick ITS	G
1980 Dec 11	3–4	2.7 × 4.0	8	cloud	Lick ITS	G
1981 Mar 6...........	2–3	3.0 × 3.5	8	thin cloud	McDonald IDS	W
1981 Apr 4	...	...	8	clear?	McDonald IDS	K
1981 Apr 4	...	4 dia	7	clear	Lick ITS	J
1981 Apr 4	2.5	8 dia	8–10	clear	U. Mich	H
1981 Apr 5	(3)	3.5 dia	10	clear	Steward	L
1981 Apr 5	2.5	8 dia	8–10	clear	U. Mich	H
1981 Apr 6	2.5	8 dia	4–5	cloud	U. Mich	H
1981 Apr 7	2.5	8 dia	4–5	clear	U. Mich	H
1981 Apr 8	2.5	8 dia	8–10	clear	U. Mich	H
1981 Apr 9	2	6 dia	8.5	clear	K.P. IIDS	T
1981 Apr 10	2	6 dia	8.5	cloud?	K.P. IIDS	T
1981 Apr 10	2	6 dia	8.5	clear	K.P. IIDS	T
1981 Apr 12	...	...	...	?	McDonald CRS	U
1981 May 5...........	2–3	5.0 × 6.5	8	clear	McDonald IDS	W
1981 May 31	...	4 dia	7	clear	Lick ITS	J
1981 May 31	...	3.0 × 3.5	8	cloud	McDonald IDS	W
1981 Jun 3............	2	5.0 × 6.5	8	clear	McDonald IDS	W
1981 Jul 1	1	3.0 × 3.5	8	thin cloud	McDonald IDS	W
1981 Jul 3	2	5.0 × 6.5	8	clear	McDonald IDS	W

[a] Observers are: G = S. A. Grandi; W = D. Wills and B. J. Wills; K = R. G. Kron, A. Jankowitz, and D. Hamilton; J = N. Jeske; H = R. B. C. Henry; L = J. W. Liebert and J. T. Stocke; T = T. X. Thuan; U = A. K. Uomoto and B. J. Wills.

smaller apertures the absolute flux is usually good to 10%–20%. We believe some features in some spectra of Figure 4 are not real, because of differences in spectra obtained on the same or adjacent nights, or differences between simultaneous spectra from a dual-aperture spectrograph. Such features are the bump between 4050 and 5100 Å in the spectrum of 1981 April 4 "J," the bump near 4050 Å (spectrum "K" on the same night), and narrower features present in the "H" spectra of 1981 April 4, 6, and 7. In most spectra, no attempt has been made to remove, by calibration, the deep A and B atmospheric absorption bands near 7600 and 6870 Å.

In Table 7 we show "broad-band" *UBVRI* magnitudes and spectral indices derived from the spectrophotometry with the approximate calibration accuracy given in the second column. These may be compared with the *UBVRI* photometry by W. Z. W. and the derived spectral indices already given in Table 4. Note that there is good agreement between the spectrophotometric values and the photographic and photoelectric photometry where data exist on the same night. Except for the spectra on 1977 April and 1974 January 24 where the continuum is lowest, there is only marginal evidence for significant changes in spectral index with time, with $\alpha = -1.58 \pm 0.05$ from U to I bands. (This value corresponds to $U-B = -0.61 \pm 0.02$, $B-V = 0.41 \pm 0.03$, $V-R = 0.60 \pm 0.03$, and $R-I = 0.58 \pm 0.03$.) However, the *JHK* photometry in 1982 spring (Table 4, J. J. P.) indicates that the spectrum is flatter in the far-IR, with $\alpha = -1.25 \pm 0.02$ (1982 March 25). The 1981 spring far-IR spectra may have been even flatter (Glassgold *et al.* 1983). For the low continuum spectra the magnitudes no longer measure continuum shape but are affected more strongly by the presence of emission lines.

Changes in the ionizing continuum may be expected to affect the physical conditions in the line-emitting region, so we have looked for changes in the Mg II line at 4830 Å, both in strength and profile. We have formed a composite from the spectra in which this line is most clearly present (Fig. 5) and have scaled the height of this profile, fitting it by least squares to the other spectra. The resulting intensity and equivalent width measurements are given in Table 8. We find no evidence for changes; however, it will be important to search for future changes in the line spectrum as these may reflect the delayed response of the line-emitting region to the enhanced continuum flux, caused by geometrical and other factors. From an observational point of view, it would be better to measure the lines more accurately when the continuum is fainter.

When the continuum is faint ($B \sim 18$), the line spectrum looks like that of a normal QSO, and the equivalent width of Mg II (38 Å in the rest frame, including the Fe II wings) is within the range observed for much less active QSOs (25–60 Å). The FWHM (full width at half-maximum intensity) for Mg II, 4500 km s^{-1}, is typical for a QSO with predominantly compact radio structure (Wills 1982).

Evidence for ejection of material from this or previous periods of activity may be found from a search for

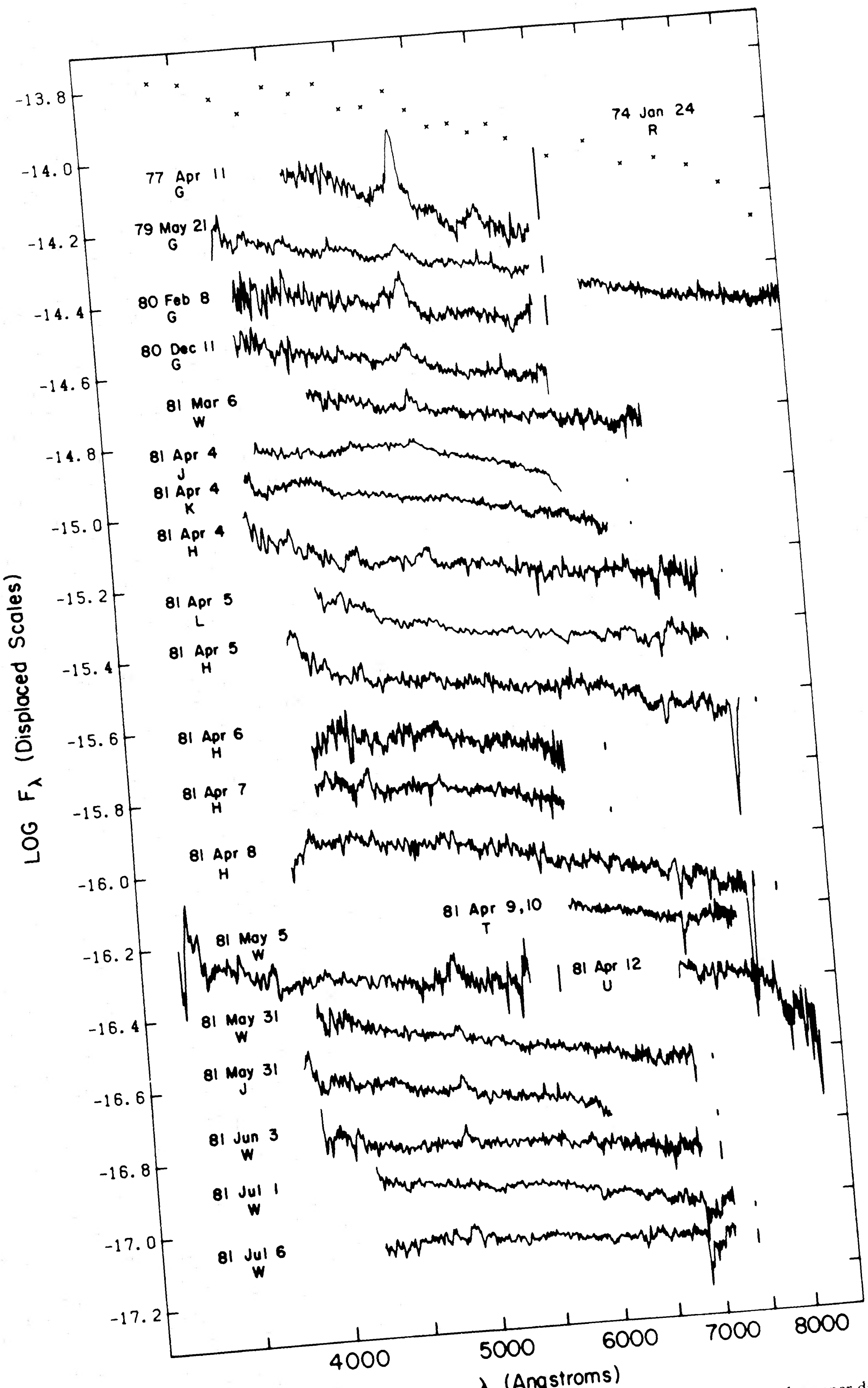

FIG. 4.—Spectrophotometry of 1156+295 between 1974 and mid-1981. The 1974 spectrum is Oke multichannel scanner data by Richstone and Schmidt (1980). Details of the other spectra are given in Table 6 and in the text. The date of observation and the observer(s) are indicated to the left of the scan. Log F_λ is given as a function of log λ, on displaced ordinate scales. Equal areas represent equal equivalent widths, or line intensity relative to the continuum. Where absolute flux densities were obtained, the height of the vertical bar to the right of the scan indicates the height of a line of constant intensity.

TABLE 7

"BROAD-BAND" MAGNITUDES AND COLORS DERIVED FROM SPECTROPHOTOMETRY

UT Date	Acc.[a]	U	B	V	R	I	$U-B$	$B-V$	$V-R$	$R-I$
1974 Jan 24	0.05	16.85	17.40	17.17	16.73	15.95	−0.55	0.23	0.44	0.78
1977 Apr 11	0.2	17.5	18.0	17.8	...	...	−0.50	0.19	...	...
1979 May 21	0.2	15.7	16.3	15.9	15.5	15.3	−0.62	0.38	0.48	0.17:
1980 Feb 8	0.1	16.3	16.9	16.5	...	...	−0.63	0.38	...	...
1980 Dec 11	...	...	...	...	...	...	−0.65	0.37	...	...
1981 Mar 6	...	...	...	...	...	...	...	0.39	0.61:	...
1981 Apr 4	?	...	14.1	13.7	...	...	...	0.39	...	...
1981 Apr 4	0.1	13.3	13.8	13.4	...	...	−0.49:	0.36	...	...
1981 Apr 4	0.1	...	13.8	13.4	12.8	...	...	0.45	0.64	...
1981 Apr 5	0.15	...	13.5	13.2	12.5	...	...	0.32	0.68	...
1981 Apr 5	0.15	...	13.8	13.4	12.8	...	...	0.42	0.58	...
1981 Apr 6	...	...	...	...	...	...	...	0.47	...	...
1981 Apr 7	0.2	...	14.4	13.9	...	...	...	0.45	...	...
1981 Apr 8	0.1	...	14.7	14.2	13.7	...	...	0.42	0.53	...
1981 Apr 9	0.15	...	...	...	14.2	...	...	...	...	...
1981 Apr 10	0.12	...	...	...	14.0	...	...	...	...	...
1981 Apr 12	?	...	...	...	14.1	>14.7:	...	...	...	>0.6:
1981 May 5	0.1	16.3	16.9	16.4	...	...	−0.58	0.54	...	...
1981 May 31	...	...	...	...	...	...	...	0.40	0.59	...
1981 May 31	0.1	14.5	15.1	14.7	...	...	−0.61	0.38	...	...
1981 Jun 3	0.2	...	16.6	16.1	...	...	...	0.52	...	...
1981 Jul 1	...	...	...	...	...	...	...	0.49	0.57	...
1981 Jul 6	0.1	...	16.2	15.6	...	...	...	0.59	...	...

[a] This is the estimated rms uncertainty.

absorption lines, blueshifted with respect to the QSO rest frame. With this in mind F. H. C. obtained a 2 hr integration on 1156+295 on UT 1981 April 10, with the Smithsonian Astrophysical Observatory's echelle spectrograph (Chaffee 1974) and image stacker (Chaffee and Latham 1982) on the Multiple Mirror Telescope (MMT), giving a resolution of 6 km s^{-1} and covering up to 2000 km s^{-1} from the peak of the Mg II emission line (Fig. 6). No sharp absorption lines with $W_\lambda \gtrsim 100$ mÅ are present in the data.

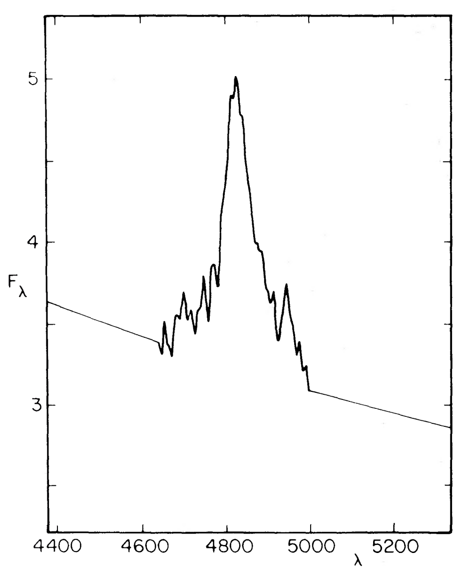

FIG. 5.—A smoothed composite profile of the Mg II λ2798 emission line.

IV. OBSERVATIONS AT RADIO FREQUENCIES

Table 9 collects flux densities measured at many frequencies and epochs; some are taken from the literature, often supplemented by information kindly supplied by various authors. Also included are unpublished measurements, some historical, others made specifically for the study of variability in 1156+295, and more specifically because of the 1981 spring optical activity. Flux densities are arranged in order of increasing frequency, and in chronological order within each frequency. Nearby frequencies are included together. Where more than one measurement from the same reference/observatory occur sequentially, the reference is given next to only the first entry. Both the UT and Julian Date are given, and where these are not known accurately, or where the measurements were taken over

TABLE 8

THE Mg II λ2798 EMISSION LINE

UT Date	W_λ (Å)[a]	I (10^{-14} ergs cm^{-2} s^{-1})[a]
1977 Apr 11	63 ± 4	2.01 ± 0.18
1979 May 21	14 ± 1	2.30 ± 0.20
1980 Feb 8	29 ± 2	2.71 ± 0.23
1980 Dec 11	17 ± 2	...
1981 Mar 6	12 ± 2	2.14 ± 0.35:
1981 May 5	22 ± 3	2.25 ± 0.33
1981 May 31	6 ± 2	2.17:
1981 Jun 3	8 ± 2	1.08 ± 0.27
1981 Jul 6	7 ± 2	1.51 ± 0.39

[a] Equivalent widths and intensities in the observer's frame. Weighted mean intensity: $2.08 \pm 0.10 \times 10^{-14}$ ergs cm^{-2} s^{-1}; 1981 only: $1.67 \pm 0.20 \times 10^{-14}$; 1977: $2.01 \pm 0.18 \times 10^{-14}$.

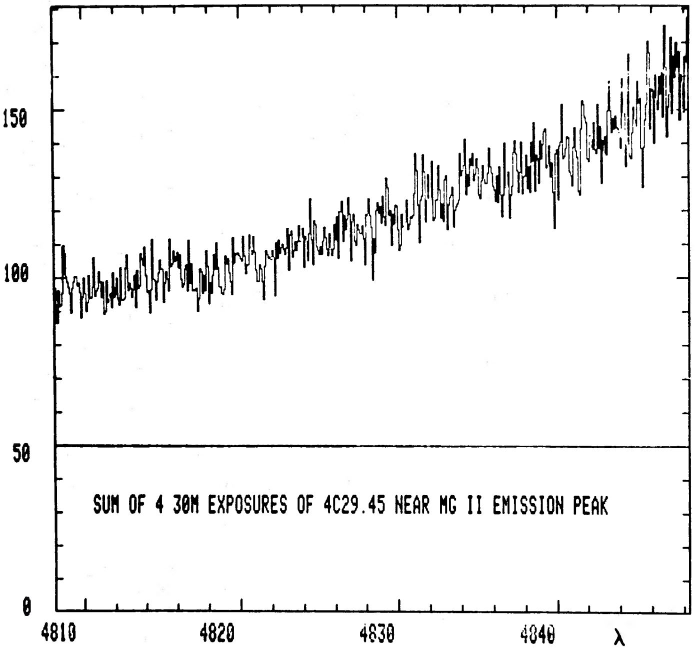

FIG. 6.—A high-resolution scan (0.10 Å ~ 6 km s^{-1}) near the peak of the Mg II λ2798 emission line at 4838 Å. The horizontal line gives the approximate zero level after correcting for instrumental dark counts.

a period of time, the Julian Date is followed by a colon. The numbers in the final column refer to notes at the end of the table. The flux densities given in the table are taken directly from the original references, but the notes indicate those few cases where flux densities have been scaled before plotting.

The variations of flux density with time, at several frequencies, are shown in Figures 7 and 8. Usually monthly averages have been plotted at 4.8, 8, and 14.5 GHz although more closely spaced data are shown in cases where the flux density changed significantly between successive measurements. At 408 MHz, despite the fact that we have attempted to plot data on a consistent flux density scale, those data from different observatories—Arecibo (Spangler and Cotton 1981), Bologna (Fanti *et al.* 1981), and the University of Texas Radio Astronomy Observatory (UTRAO)—appear to differ systematically by as much as 10%. Although this is probably within the combined calibration uncertainties, it cautions against comparing measurements from different observatories at these low frequencies. Although the general trends agree well for 14.5 GHz (University of Michigan) and 15.0 GHz (VLA) flux densities, the latter are systematically smaller because of a scale difference, and so have been plotted separately (see Table 9, note 15).

The long-term trends, since 1969, are best illustrated by the data at 2.7 and 8.0 GHz in Figure 7, where they are compared with the optical light curve (*B*-magnitudes). The variation of 2.7 GHz polarized flux density and position angle are also shown in this figure. Note that polarization data with significance less than 2.8 σ are indicated by dashed vertical lines. Figure 8 shows radio variability since 1980, on an expanded time scale, at 0.4, 1.4, 2.7, 8.0, 14.5, 15.0, and 22 GHz, and at optical frequencies. The data are more sparse at earlier times and at other frequencies and so have not been plotted.

Between 1969.0 and 1975, the 2.7 GHz flux density is relatively low (~1.15 Jy) with small (±0.1 Jy) variations (Fig. 7). Isolated flux density measurements at 1.4, 5.0, 8.0, and 10.6 GHz (Table 9 and Fig. 8) are also lowest over this time period. The radio spectrum at this time (about 1972.5, JD 2,441,500) is almost a power law ($S_\nu \propto \nu^{-0.4}$) below 1 GHz, flattening only slightly at higher frequencies, suggesting the predominance of a transparent radio source (Fig. 9*a*). By 1976 2.7 GHz flux densities increased, with maxima in 1977 July (1.7 Jy) and 1979 October (2.1 Jy). Superposition of the 2.7 GHz data on the data at 1.4, 8, and 14.5 GHz shows identical flux density changes, within the observational uncertainties—at least until the beginning of 1980. This is a particularly strong constraint on the character of the variations at 8 GHz, where the light curve is sampled quite frequently, but not at 1.4 GHz. The 0.4 GHz curve is *not* simply related to the variations at the higher frequencies. A possible interpretation is that maxima at 0.4 GHz in late 1978 (Fanti *et al.* 1981 and Table 9) and late 1980 correspond to the maxima observed at 2.7 GHz in 1977 and 1979. Spectra for the epochs 1977.2 and 1980.1 (approximately) are compared with the 1972 spectrum in Figure 9*a*. Regardless of admitted uncertainties in deriving the interpolated spectrum of 1980.1, it is obvious that there must be multiple outbursts or quasi-continuous particle injection or acceleration in a region of not very large optical depth at centimeter wavelengths.

TABLE 9

RADIO FLUX DENSITIES

Frequency GHz	UT Date year-mo-dy	J.D. 2440000+	Flux Density Jy		Reference	Note
0.178	c.1962		2.8	0.14	Pilkington and Scott 1965	0
0.318	1970?		2.88	0.19	Condon and Jauncey 1974	1
0.408			2.79	0.24	U.Bologna B2 Radio Survey	2
0.408	1972.5	1499:	2.4	0.2	U.Manchester, Jodrell Bank	3
0.365	1973 11	2002:	3.2	0.2	U.Texas Radio Astronomy Obs.	4
0.408	1975 7 18	2612	2.30	0.10	Fanti et al. 1981	5
0.408	1975 9 19	2675	2.52	0.13		5
0.408	1975 12 19	2766	2.61	0.10		5
0.408	1976 10 13	3065	2.66	0.10		5
0.408	1976 10 29	3081	2.65	0.09		5
0.430	1976 11	3098:	2.68	0.10	Spangler and Cotton 1981	6
0.435	1976 12	3128:	2.28	0.15		6
0.408	1977 3 8	3211	2.76	0.08	Fanti et al. 1981	5
0.408	1977 4 13	3247	2.50	0.08		5
0.408	1977 6 19	3314	2.56	0.09		5
0.365	1977 7	3340:	3.3	0.1	U.Texas Radio Astronomy Obs.	4
0.430	1977 7	3340:	2.39	0.08	Spangler and Cotton 1981	6
0.408	1977 7 19	3344	2.52	0.10	Fanti et al. 1981	5
0.408	1977 9 15	3402	2.52	0.13		5
0.408	1977 10 29	3446	2.40	0.08		5
0.408	1977 11 24	3472	2.47	0.08		5
0.408	1977 12 20	3498	2.50	0.08		5
0.430	1978 1	3524:	2.48	0.08	Spangler and Cotton 1981	6
0.408	1978 1 27	3536	2.50	0.09	Fanti et al. 1981	5
0.408	1978 2 28	3568	2.60	0.12		5
0.408	1978 4 1	3600	2.52	0.05		5
0.408	1978 4 21	3620	2.51	0.08		5
0.408	1978 5 24	3653	2.80	0.08		5
0.408	1978 7 17	3707	2.70	0.08		5
0.430	1978 9	3767	2.49	0.08	Spangler and Cotton 1981	6
0.408	1978 10 11	3793	2.85	0.06	Fanti et al. 1981	5
0.408	1978 11 21	3834	2.58	0.07		5
0.408	1979 1 13	3887	2.47	0.07		5
0.408	1979 3 1	3934	2.45	0.08		5
0.365	1979 8	4101:	3.1	0.1	U.Texas Radio Astronomy Obs.	4
0.408	1980 1 23	4262	2.69	0.10	U.Bologna Radio Observatory	5
0.408	1980 4 14	4344	2.76	0.05		5
0.408	1980 5 21	4381	2.59	0.09		5
0.408	1980 6 17	4408	2.61	0.08		5
0.408	1980 8 3	4455	2.75	0.06		5
0.408	1980 9 3	4486	2.66	0.15		5
0.408	1980 10 5	4518	2.80	0.11		5
0.408	1980 11 1	4545	2.93	0.07		5
0.408	1980 12 9	4583	2.89	0.06		5
0.365	1980 12	4589:	3.3	0.2	U.Texas Radio Astronomy Obs.	4
0.408	1981 2 2	4638	2.65	0.07	U.Bologna Radio Observatory	5
0.408	1981 3 2	4666	2.62	0.06		5
0.408	1981 4 12	4707	2.89	0.06		5
0.408	1981 5 11	4736	2.85	0.07		5
0.408	1981 6 22	4778	3.07	0.07		5
0.408	1981 7 22	4808	2.74	0.07		5
0.408	1981 9 28	4876	2.58	0.07		5
0.408	1981 11 2	4911	2.69	0.06		5
0.408	1981 12 0	4939	2.66	0.06		5
0.430	1982 3 13	5042	4.9	0.5	M.M.Davis, Arecibo	7
0.612	1969/70 3				P=3.1±0.7%,θ=6±8,Conway et al.'72	8
0.968	1972.3	1428:	1.68	0.08	P=1.8±0.2%,θ=30±3,Haves et al.'74	
1.417	1966 6	-710:	1.98	0.10	Olsen 1967	
1.400	1968 Spring	-62	1.61	0.06	M.M.Davis,NRAO	9
1.415	1970 Feb/Mar	646	1.39	0.06	Bridle et al. 1972	
1.42	1974 6 8	2207	1.48	0.05	Witzel et al. 1979	
1.400	1976 12	3128:	1.53	0.05	Spangler and Cotton 1981	6
1.400	1977 2	3189:	1.49	0.05		6
1.400	1977 4	3249:	1.54	0.05		6
1.400	1978 2	3554:	1.56	0.05		6
1.400	1978 2	3554:	1.61	0.05		6
1.400	1978 2	3554:	1.57	0.05		6
1.400	1978 5	3644:	1.51	0.05		6
1.400	1978 5	3644:	1.48	0.05		6
1.400	1978 5	3644:	1.52	0.05		6
1.465	1980 2 23	4293	2.00	0.03	VLA calibrator list (R.Perley)	
1.465	1981 2 19	4655	1.88	0.06	P=2.5±0.1%,θ=90±3, Perley(1982)	10
1.465	1981 4 4	4699	2.00	0.01	VLA Wade and P.Perley	11
1.465	1981 4 16	4711	2.09	0.01		11
1.465	1981 4 26	4721	2.03	0.01		11
1.465	1981 5 9	4734	1.893	0.010		11
1.465	1981 6 4	4760	1.968	0.011		11
1.465	1981 6 11	4767	1.977	0.015		11
1.465	1981 6 19	4775	1.998	0.009		11
1.465	1981 7 9	4795	1.998	0.014		11
1.465	1981 8 6	4823	1.821	0.013		11
1.465	1981 8 13	4830	1.856	0.014		11
1.465	1981 9 18	4866	1.941	0.014		11
1.465	1981 10 19	4897	1.877	0.006		11
1.465	1981 11 19	4928	1.823	0.008		11
1.400	1982 3 13	5042	2.32	0.15	M.M.Davis, Arecibo	7
1.465	1982 4 29	5089	1.7	0.17	VLA	11
1.465	1982 5 20	5110	1.9	0.19	VLA	11
2.695	1969 3	296:	1.22	0.09	Macdonald and Miley 1971	
2.695	1969 6	388:	1.30	0.05	Adgie(1974),baseline=1300 λ	
2.695	1969 8	449:	1.24	0.05	'' = 700 λ	
2.695	1970 5	722:	1.02	0.05	'' =5800 λ	
2.695	1970 5	722:	1.13	0.02	M.M.Davis, NRAO	12
2.695	1971 4	1057:	1.12	0.05	Adgie(1974),baseline=2300 λ	
2.695	1971 12	1301:	1.15	0.04	P=4.2±0.3%, θ=143 ± 2	13
2.7	1972 9 7	1568	1.17	0.03	Kesteven,Bridle and Brandie 1976	
2.7	1973 1 19	1702	1.28	0.02	'' '' ''	
2.7	1973 4 11	1784	1.24	0.02	'' '' ''	
2.7	1973 8 24	1919	1.09	0.02	'' '' ''	
2.7	1973 11 3	1990	1.10	0.02	'' '' ''	
2.7	1974 2 3	2082	1.10	0.02	'' '' ''	
2.7	1974 6 18	2217	1.10	0.02	'' '' ''	
2.7	1975 11 18	2735	1.34	0.04	Balonek,O'Dea and Dent,NRAO 91-m.	14
2.695	1976 1 18-31	2803	1.23	0.07	Potash and Wardle 1979	
2.7	1976 2 24	2833	1.31	0.02	P=1.6±0.4%,θ=138± 7,Balonek et al	14
2.7	1976 8 28	3019	1.44	0.07	P=1.4±1.1%,θ=152±22, '' ''	14
2.7	1976 12 4	3117	1.44	0.01	P=2.8±0.3%,θ=138± 3, '' ''	14
2.7	1977 4 5	3239	1.58	0.05	P=2.4±0.6%,θ=144± 7, '' ''	14
2.7	1977 7 19	3344	1.65	0.02	P=1.7±0.2%,θ=129± 4, '' ''	14
2.7	1977 11 21	3469	1.49	0.04	P=1.9±0.8%,θ=123±13, '' ''	14
2.7	1978 5 1	3630	1.41	0.01	P=2.7±0.4%,θ=106± 4, '' ''	14
2.7	1978 9 10	3762	1.47	0.06	P=1.5±0.8%,θ=116±15, '' ''	14
2.7	1978 12 10	3853	1.67	0.05	P=1.4±0.5%,θ=121±10, '' ''	14
2.7	1979 5 12	4006	1.75	0.02	P=1.2±0.2%,θ=137 ± 5, '' ''	14
2.7	1979 10 21	4168	2.08	0.03	P=1.1±0.7%,θ=176 ±17, '' ''	14
2.7	1980 4 6	4336	1.99	0.04	P=0.9±0.5%,θ=148 ±17, '' ''	14
2.7	1980 8 7	4459	1.84	0.05	P=0.9±0.3%,θ=119 ±10, '' ''	14
2.7	1980 12 13	4587	1.91	0.03	P=1.8±0.4%,θ=125 ± 6, '' ''	14
2.7	1981 2 6	4642	1.89	0.03	P=1.5±0.3%,θ=127 ± 6, '' ''	14
2.7	1981 4 29	4724	1.84	0.02	P=1.4±0.3%,θ=124 ± 5, '' ''	14
5.0	1970 4	692:	0.89	0.03	Pauliny-Toth and Kellermann 1972	
5.0	1973 2-4	1757:	1.15	0.02	Fanti et al. 1975	
4.885	1980 2 23	4293	1.75	0.03	VLA calibrator list (R.Perley)	
4.885	1980 11 19	4563	1.56	0.05	P=2.8±0.1,θ=120±3, Perley(1982)	
4.885	1981 4 4	4699	1.47	0.01	VLA	11
4.885	1981 4 16	4711	1.50	0.01		11
4.885	1981 4 26	4721	1.52	0.01		11
4.885	1981 5 9	4734	1.473	0.017		11
4.80	1981 5 16	4740.5	1.45	0.03	U.Michigan	15
4.80	1981 5 24	4748.6	1.26	0.11		15
4.80	1981 6 3	4758.5	1.42	0.04		15
4.885	1981 6 4	4760	1.413	0.019	VLA	11
4.885	1981 6 11	4767	1.389	0.009		11
4.80	1981 6 15	4770.5	1.48	0.05	U.Michigan	15
4.80	1981 6 17	4772.5	1.40	0.05		15
4.885	1981 6 19	4775	1.397	0.018	VLA	11
4.80	1981 6 23	4776.5	1.55	0.09	U.Michigan	15
4.80	1981 6 25	4778.5	1.37	0.06		15
4.885	1981 6 30	4786	1.350	0.019	VLA	11
4.80	1981 7 8	4794.4	1.31	0.07	U.Michigan	15
4.885	1981 7 9	4795	1.361	0.024	VLA	11
4.80	1981 7 29	4815.4	1.38	0.05	U.Michigan	15
4.885	1981 8 6	4823	1.387	0.025	VLA	11
4.80	1981 8 7	4824.3	1.31	0.04	U.Michigan	15
4.885	1981 8 13	4830	1.392	0.017	VLA	11
4.80	1981 8 13	4830.3	1.33	0.10	U.Michigan	15
4.80	1981 8 24	4841.3	1.47	0.06		15
4.80	1981 9 1	4849.3	1.32	0.04		15
4.80	1981 9 2	4850.3	1.18	0.07		15
4.885	1981 9 18	4866	1.395	0.003	VLA	11
4.80	1981 9 25	4873.3	1.44	0.04	U.Michigan	15
4.80	1981 10 2	4880.2	1.34	0.06		15
4.80	1981 10 12	4890.2	1.32	0.13		15
4.885	1981 10 19	4897	1.299	0.015	VLA	11
4.80	1981 10 23	4901.1	1.17	0.05	U.Michigan	15
4.80	1981 11 2	4911.2	1.33	0.03		15
4.885	1981 11 19	4928	1.258	0.004	VLA	11
4.80	1981 12 12	4951.2	1.23	0.02	U.Michigan	15

TABLE 9—*Continued*

Frequency GHz	UT Date year-mo-dy	J.D. 2440000+	Flux Density Jy		Reference	Note
4.80	1982 1 16	4985.9	1.14	0.07		15
4.80	1982 1 30	4999.8	1.18	0.17		15
4.80	1982 3 4	5032.8	1.15	0.09		15
4.830	1982 3 13	5042	1.31	0.07	M.M.Davis, Arecibo	7
4.80	1982 4 10	5069.7	1.20	0.07	U.Michigan	15
4.80	1982 4 11	5070.7	1.21	0.06		15
4.80	1982 4 20	5079.6	1.30	0.04		15
4.885	1982 4 29	5089	1.5	0.15	VLA	11
4.80	1982 4 30	5090	1.27	0.04	U.Michigan	15
4.80	1982 5 5	5095	1.47	0.05		15
4.80	1982 5 14	5104	1.55	0.09		15
4.885	1982 5 20	5110	1.6	0.16	VLA	11
4.80	1982 5 23	5113	1.46	0.11	U.Michigan	15
4.80	1982 5 25	5115	1.55	0.06		15
8.085	1971 12	1301:	0.84	0.04	P=3.8±0.6%, θ=155± 5	13
8.085	1976 1 18-31	2803:	0.97	0.06	Potash and Wardle 1979	
8.00	1977 5 25	3288.6	1.15	0.20	U.Michigan	15
8.00	1977 5 29	3292.6	1.40	0.02		15
7.850	1977 10 5	3422	1.14	0.13	Spangler and Cotton 1981	16
7.850	1978 8 3	3724	1.30	0.10		16
7.850	1978 11 16	3829	1.48	0.10		16
7.850	1979 2 12	3917	1.62	0.08		16
8.00	1980 1 24	4262.9	1.84	0.02	U.Michigan	15
8.00	1980 2 23	4292.8	1.84	0.06		15
8.00	1980 2 24	4293.8	1.71	0.26		15
8.00	1980 3 27	4325.7	1.59	0.11		15
8.00	1980 4 30	4359.6	1.59	0.02		15
8.00	1980 5 1	4360.6	1.62	0.02		15
8.00	1980 5 13	4372.5	1.56	0.03		15
8.00	1980 6 7	4398.4	1.67	0.03		15
8.00	1980 6 8	4399.4	1.55	0.06		15
8.00	1980 6 9	4400.5	1.62	0.04		15
8.00	1980 6 19	4410.4	1.56	0.04		15
8.00	1980 6 24	4415.4	2.16	0.34		15
8.00	1980 6 26	4416.5	1.60	0.03		15
8.00	1980 7 5	4426.4	1.63	0.06		15
8.00	1980 8 1	4453.3	1.73	0.10		15
8.00	1980 8 3	4455.3	1.69	0.05		15
8.00	1980 8 5	4457.3	1.57	0.06		15
8.00	1980 8 10	4462.3	1.63	0.05		15
8.00	1980 9 1	4484.2	1.64	0.03		15
8.00	1980 9 2	4485.2	1.60	0.08		15
8.00	1980 9 3	4486.2	1.59	0.04		15
8.00	1980 9 11	4494.2	1.31	0.12		15
8.00	1980 9 17	4500.2	1.63	0.06		15
8.00	1980 9 26	4509.2	1.57	0.05		15
8.00	1980 9 28	4511.2	1.55	0.05		15
8.00	1980 10 4	4517.1	1.51	0.04		15
8.00	1980 10 5	4518.1	1.43	0.06		15
8.00	1980 10 13	4526.2	1.40	0.07		15
8.00	1980 10 16	4529.1	1.51	0.10		15
8.00	1980 10 21	4534.1	1.60	0.04		15
8.00	1980 10 26	4539.1	1.55	0.10		15
8.00	1980 10 28	4541.1	1.38	0.05		15
8.00	1980 11 1	4545.1	1.49	0.04		15
8.00	1980 11 2	4546.1	1.46	0.04		15
8.00	1980 11 4	4548.1	1.64	0.07		15
8.00	1980 11 5	4549.1	1.49	0.08		15
8.00	1980 11 11	4555.1	1.73	0.11		15
8.00	1980 11 12	4556.1	1.56	0.10		15
8.00	1980 11 19	4563.0	1.59	0.04		15
8.00	1980 11 30	4574.0	1.86	0.17		15
8.00	1980 12 10	4584.0	1.52	0.03		15
8.00	1980 12 16	4589.9	1.55	0.04		15
8.00	1980 12 24	4597.9	1.57	0.04		15
8.00	1981 1 13	4617.8	1.62	0.04		15
8.00	1981 1 14	4618.8	1.91	0.12		15
8.00	1981 1 28	4632.9	1.44	0.04		15
8.00	1981 1 30	4634.8	1.46	0.02		15
8.00	1981 2 14	4649.8	1.48	0.07		15
8.00	1981 2 24	4659.7	1.37	0.04		15
8.00	1981 2 25	4660.7	1.50	0.04		15
8.00	1981 3 6	4669.1	1.44	0.04		15
8.00	1981 3 19	4682.7	1.42	0.03		15
8.00	1981 3 29	4692.7	1.46	0.05		15
8.00	1981 4 1	4695.7	1.47	0.04		15
8.00	1981 4 1	4695.7	1.42	0.03		15
8.00	1981 4 2	4696.7	1.58	0.11		15
8.00	1981 4 3	4697.7	1.49	0.06		15
8.00	1981 4 14	4708.6	1.47	0.12		15
8.00	1981 4 15	4709.6	1.46	0.03		15
8.00	1981 4 30	4724.6	1.37	0.06		15
8.00	1981 5 6	4730.6	1.50	0.04		15
8.00	1981 5 7	4731.5	1.29	0.06		15
8.00	1981 5 12	4736.5	1.44	0.07		15
8.00	1981 5 19	4743.5	1.42	0.06		15
8.00	1981 5 20	4744.5	1.34	0.03		15
8.00	1981 5 28	4752.5	1.41	0.04		15
8.00	1981 5 29	4753.5	1.31	0.03		15
8.00	1981 5 30	4754.5	1.39	0.05		15
8.00	1981 6 4	4759.5	1.43	0.05		15
8.00	1981 6 7	4762.5	1.35	0.04		15
8.00	1981 6 10	4765.6	1.52	0.12		15
8.00	1981 6 11	4766.5	1.46	0.04		15
8.00	1981 6 17	4772.5	1.02	0.21		15
8.00	1981 6 27	4780.4	1.49	0.05		15
8.00	1981 6 28	4781.4	1.40	0.04		15
7.9	1981 6 28	4784	1.60	0.13	Balonek and Dent, Haystack 37-m.	14
8.00	1981 6 29	4782.4	1.50	0.07	U.Michigan	15
8.00	1981 6 30	4783.4	1.54	0.08		15
8.00	1981 7 6	4792.4	1.59	0.29		15
8.00	1981 7 13	4799.4	1.41	0.07		15
7.9	1981 7 20	4806	1.58	0.11	Balonek and Dent, Haystack 37-m.	14
8.00	1981 7 20	4806.4	1.46	0.09	U.Michigan	15
8.00	1981 7 22	4808.4	1.43	0.04		15
8.00	1981 7 23	4809.4	1.48	0.08		15
8.00	1981 7 27	4813.3	1.40	0.06		15
8.00	1981 7 30	4816.4	1.24	0.17		15
8.00	1981 8 6	4823.3	1.54	0.11		15
7.9	1981 8 7	4824	1.42	0.17	Balonek and Dent, Haystack 37-m.	14
8.00	1981 8 8	4825.3	1.43	0.22	U.Michigan	15
8.00	1981 8 10	4827.3	1.30	0.14		15
8.00	1981 8 11	4828.3	1.49	0.08		15
8.00	1981 8 19	4836.3	1.35	0.05		15
8.00	1981 8 20	4837.3	1.39	0.08		15
8.00	1981 8 23	4840.3	1.51	0.08		15
8.00	1981 8 28	4845.3	1.50	0.10		15
8.00	1981 8 29	4846.3	1.50	0.09		15
8.00	1981 8 30	4847.3	1.37	0.08		15
7.9	1981 9 5	4853	1.65	0.10	Balonek and Dent, Haystack 37-m.	14
8.00	1981 9 8	4856.3	1.57	0.12	U.Michigan	15
8.00	1981 9 9	4857.3	1.41	0.14		15
8.00	1981 9 26	4874.2	1.55	0.09		15
8.00	1981 9 27	4875.2	1.45	0.04		15
8.00	1981 10 8	4886.2	1.35	0.07		15
8.00	1981 10 10	4888.1	1.46	0.04		15
8.00	1981 10 15	4893.2	1.29	0.04		15
8.00	1981 10 21	4899.1	1.17	0.10		15
8.00	1981 10 22	4900.1	1.40	0.07		15
8.00	1981 10 27	4905.2	1.73	0.46		15
7.9	1981 10 31	4909	1.24	0.13	Balonek and Dent, Haystack 37-m.	14
8.00	1981 11 1	4910.1	1.33	0.02	U.Michigan	15
8.00	1981 11 1	4910.1	1.27	0.03		15
8.00	1981 11 5	4914.2	1.25	0.11		15
8.00	1981 11 10	4919.0	1.24	0.05		15
7.9	1981 11 11	4920	1.18	0.08	Balonek and Dent, Haystack 37-m.	14
8.00	1981 11 17	4926.2	1.23	0.11	U.Michigan	15
8.00	1981 11 18	4927.1	1.14	0.08		15
8.00	1981 11 25	4933.5	1.13	0.01		15
8.00	1981 11 29	4937.5	1.24	0.11		15
8.00	1981 12 3	4941.5	1.21	0.06		15
8.00	1981 12 9	4947.4	1.15	0.02		15
8.00	1981 12 15	4953.5	1.16	0.01		15
8.00	1981 12 21	4959.8	1.24	0.07		15
8.00	1981 12 26	4964.8	1.07	0.04		15
8.00	1982 1 2	4972.0	1.16	0.05		15
8.00	1982 1 20	4989.8	1.24	0.02		15
8.00	1982 1 21	4990.8	1.18	0.02		15
8.00	1982 1 28	4997.8	1.23	0.04		15
8.00	1982 2 8	5008.8	1.32	0.05		15
8.00	1982 2 10	5010.8	1.29	0.04		15
8.00	1982 2 16	5016.8	1.38	0.03		15
8.00	1982 2 17	5017.8	1.36	0.04		15
8.00	1982 2 20	5020.8	1.44	0.03		15
8.00	1982 2 21	5021.9	1.43	0.09		15
8.00	1982 2 26	5026.7	1.48	0.03		15

TABLE 9—*Continued*

Frequency GHz	UT Date year-mo-dy	J.D. 2440000+	Flux Density Jy		Reference	Note
8.00	1982 3 1	5029.8	1.53	0.05		15
8.00	1982 3 3	5031.8	1.52	0.08		15
8.00	1982 3 11	5039.8	1.47	0.04		15
8.00	1982 3 13	5041.7	1.62	0.03		15
8.00	1982 3 14	5042.7	1.61	0.03		15
8.00	1982 3 22	5050.8	1.94	0.03		15
8.00	1982 3 26	5054.7	1.92	0.03		15
8.00	1982 4 1	5060.8	1.80	0.06		15
8.00	1982 4 6	5065.6	2.06	0.05		15
8.00	1982 4 9	5068.7	1.71	0.02		15
8.00	1982 4 14	5073.6	1.84	0 03		15
8.00	1982 4 19	5078.7	2.04	0.12		15
8.00	1982 4 22	5081.6	1.99	0.03		15
8.00	1982 4 28	5087.7	1.83	0.06		15
8.00	1982 5 1	5091	2.05	0.06		15
8.00	1982 5 4	5094	2.24	0.06		15
8.00	1982 5 7	5097	1.97	0.05		15
8.00	1982 5 19	5109	1.93	0.10		15
8.00	1982 5 21	5111	2.04	0.07		15
8.00	1982 5 23	5113	1.73	0.19		15
8.00	1982 5 29	5119	1.96	0.06		15
8.00	1982 6 1	5122	2.12	0.03		15
10.7	1970 12	936:	0.80	0.03	Kellermann and Pauliny-Toth 1973	
10.695	1972	1469:	0.96	0.04	Pauliny-Toth,Preuss and Witzel	17
10.600	1977 1	3159:	1.14	0.03	Simard-Normandin and Kronberg 1978	
10.650	1981 4 14	4709	1.39	0.04	Pearson OVRO 40-m.	18
10.650	1981 4 15	4710	1.42	0.04	'' '' ''	18
10.650	1981 4 15	4710	1.43	0.04	'' '' ''	18
15.5	1977 7 26	3351	1.12	0.11	Spangler and Cotton 1981	16
15.5	1977 10 5	3422	1.25	0.18		16
15.5	1978 1 23	3532	1.00	0.08		16
15.5	1978 8 3	3724	1.36	0.18		16
15.5	1978 11 16	3829	1.34	0.12		16
15.5	1979 2 12	3917	1.50	0.08		16
14.5	1980 6 5	4396.5	1.59	0.13	U.Michigan	15
14.5	1980 6 11	4402.5	1.62	0.06		15
14.5	1980 6 21	4412.4	1.64	0.08		15
14.5	1980 6 22	4413.4	1.69	0.05		15
14.5	1980 6 28	4419.4	1.62	0.07		15
14.5	1980 7 24	4445.3	1.52	0.05		15
14.5	1980 8 7	4459.3	1.57	0.06		15
14.5	1980 8 13	4465.3	1.44	0.06		15
14.5	1980 8 23	4475.2	1.57	0.09		15
14.5	1980 9 6	4489.2	1.49	0.12		15
14.5	1980 9 15	4498.2	1.61	0.06		15
14.5	1980 9 20	4503.2	1.42	0.09		15
14.5	1980 9 30	4513.1	1.20	0.07		15
14.5	1980 10 12	4525.1	1.61	0.07		15
14.5	1980 10 22	4535.1	1.60	0.07		15
14.5	1980 10 30	4543.1	1.64	0.05		15
14.5	1981 2 1	4636.8	1.38	0.05		15
14.5	1981 2 10	4645.8	1.37	0.05		15
14.5	1981 2 22	4657.7	1.?8	0.05		15
15.035	1981 4 4	4699	1.35	0.01	VLA Wade and P.Perley	11
14.5	1981 4 9	4703.6	1.26	0.09	U.Michigan	15
14.5	1981 4 19	4713.6	1.45	0.05		15
15.5	1981 4 19	4714	1.36	0.09	Balonek and Dent, Haystack 37-m.	14
15.035	1981 4 26	4721	1.37	0.01	VLA	11
14.5	1981 4 28	4722.6	1.33	0.30	U.Michigan	15
14.5	1981 5 4	4728.6	1.48	0.05		15
15.5	1981 5 5	4730	1.42	0.08	Balonek and Dent	14
15.035	1981 5 9	4734	1.55	0.14	VLA	11
14.5	1981 5 14	4738.5	1.51	0.04	U.Michigan	15
14.5	1981 5 26	4750.5	1.45	0.05		15
14.5	1981 6 5	4760.4	1.63	0.06		15
15.035	1981 6 4	4760	1.34	0.07	VLA	11
15.035	1981 6 11	4767	1.40	0.02		11
15.5	1981 6 14	4770	1.67	0.09	Balonek and Dent	14
15.035	1981 6 19	4775	1.43	0.04	VLA	11
14.5	1981 6 26	4779.4	1.65	0.07	U.Michigan	15
15.035	1981 6 30	4786	1.53	0.06	VLA	11
14.5	1981 7 3	4789.4	1.67	0.16	U.Michigan	15
14.5	1981 7 4	4790.4	1.72	0.06		15
15.035	1981 7 9	4795	1.45	0.04	VLA	11
14.5	1981 7 12	4798.3	1.54	0.05	U.Michigan	15
14.5	1981 7 25	4811.3	1.77	0.06		15
15.5	1981 8 1	4818	1.47	0.09	Balonek and Dent	14
14.5	1981 8 3	4820.3	1.55	0.06	U.Michigan	15
15.035	1981 8 6	4823	1.42	0.03	VLA	11
15.035	1981 8 13	4830	1.52	0.04		11
14.5	1981 8 18	4835.3	1.46	0.09	U.Michigan	15
14.5	1981 8 27	4844.3	1.48	0.09		15
15.5	1981 8 31	4848	1.88	0.09	Balonek and Dent	14
14.5	1981 9 6	4854.3	1.70	0.06	U.Michigan	15
14.5	1981 9 12	4860.2	1.76	0.10		15
15.035	1981 9 18	4866	1.43	0.04	VLA	11
14.5	1981 9 23	4871.2	1.45	0.07	U.Michigan	15
14.5	1981 10 5	4883.1	1.67	0.06		15
15.5	1981 10 14	4892	1.49	0.09	Balonek and Dent	14
14.5	1981 10 18	4896.2	1.38	0.09	U.Michigan	15
15.035	1981 10 19	4897	1.33	0.03	VLA	11
14.5	1981 10 29	4907.1	1.54	0.05	U.Michigan	15
15.035	1981 11 19	4928	1.11	0.02	VLA	11
14.5	1981 11 23	4931.5	1.29	0.04	U.Michigan	15
14.5	1981 12 1	4939.5	1.18	0.06		15
14.5	1981 12 7	4945.5	1.29	0.03		15
14.5	1981 12 13	4951.5	1.39	0.03		15
15.5	1981 12 19	4958	1.35	0.11	Balonek and Dent	14
14.50	1982 1 8	4977.9	1.46	0.03	U.Michigan	15
14.50	1982 1 22	4991.8	1.72	0.04		15
14.50	1982 1 27	4996.9	1.77	0.03		15
14.50	1982 2 13	5013.8	2.02	0.05		15
14.50	1982 2 18	5018.8	2.06	0.04		15
15.5	1982 2 23	5024	2.44	0.09	Balonek and Dent	14
14.50	1982 2 27	5027.8	2.26	0.03	U.Michigan	15
14.50	1982 3 2	5030.9	2.18	0.06		15
14.50	1982 3 7	5035.7	2.44	0.04		15
14.50	1982 3 20	5048.7	2.43	0.08		15
14.50	1982 3 29	5057.7	2.74	0.04		15
14.50	1982 4 8	5067.7	2.47	0.04		15
14.50	1982 4 15	5074.7	2.68	0.04		15
14.50	1982 4 27	5086.6	2.38	0.04		15
15.035	1982 4 29	5089	3.3	0.33	VLA	11
14.50	1982 5 3	5093	2.70	0.04	U.Michigan	15
14.50	1982 5 11	5101	2.47	0.03		15
14.50	1982 5 16	5106	2.56	0.04		15
15.035	1982 5 20	5110	3.1	0.31	VLA	11
14.50	1982 5 27	5117	2.39	0.05	U.Michigan	15
14.50	1982 6 6	5127	2.56	0.03		15
22.485	1981 4 4	4699	1.58	0.03	VLA Wade and P.Perley	11
22.485	1981 4 16	4711	1.47	0.03		11
22.485	1981 4 26	4721	1.50	0.02		11
22.485	1981 5 9	4734	1.60	0.14		11
22.485	1981 6 4	4760	1.65	0.04		11
22.485	1981 6 11	4767	1.44	0.08		11
22.485	1981 6 19	4775	1.32	0.18		11
22.485	1981 6 30	4786	1.60	0.08		11
22.485	1981 7 9	4795	1.51	0.24		11
22.485	1981 8 6	4823	1.06	0.11		11
22.485	1981 8 13	4830	1.47	0.17		11
22.485	1981 9 18	4866	1.65	0.05		11
22.485	1981 10 19	4897	1.54	0.08		11
22.485	1981 11 19	4928	1.29	0.04		11
22.485	1982 4 29	5089	4.3	0.43		11
22.485	1982 5 20	5110	3.9	0.39		11
31.4	1981 4 14	4709	1.50	0.15	Dent and Balonek, NRAO 11-m.	20
31.4	1981 7 17	4803	1.95	0.16	'' '' ''	20
87.6	1981 4 4	4699	1.85	0.27	Blitz and Mathieu, NRAO 11-m.	21
89.6	1981 4 16	4711	1.94	0.30	Dent and Balonek, NRAO 11-m.	20
89.6	1981 4 19	4714	2.10	0.24	Puschell, NRAO 11-m.	21
89.6	1981 4 20	4715	1.86	0.30	'' ''	21
86.	1981 5 2	4727	1.48	0.24	Wannier and Scoville, NRAO 11-m.	21
91.	1981 5 24	4750	1.84	0.10	R.Howard, NRAO 11-m.	21
87.3	1981 12 5	4944	2.91	0.27	Balonek and Dent, FCRAO 14-m.	19
90.99	1982 1 31	5001	3.1	0.2	Howard, NRAO 11-m.	21
87.6	1982 2 7	5008	2.53	0.31	Dent,Kinzel,Kenney and Balonek	19
87	1982 2 22	5023	3.21	0.30	P=6.0±2.8%,θ=41±13, R.Barvainis	19
87	1982 2 23	5024	2.93	0.33	P=7.0±2.2%,θ=62± 9, ''	19
90.0	1982 3 6	5035	2.7	0.2	B.L.Ulich, NRAO 11-m.	22
87	1982 3 23	5052	3.50	0.19	P=7.8±2.3%,θ=57± 8, R.Barvainis	19
87	1982 4 4	5064	2.39	0.22	P=0.0±3.0% ''	19
87	1982 4 11	5071	2.50	0.16	''	19
87	1982 5 6	5096	2.73	0.48	P=8.5±1.8%,θ=80± 6 ''	19
87	1982 5 16	5106	2.35	0.31	''	19
87	1982 6 3	5124	2.07	0.38	''	19
87	1982 6 10	5131	2.22	0.22	P=0.0±2.3% ''	19
90	1982 6 15	5136	2.8	0.3	R.Howard, preliminary NRAO 11-m.	

The decline in flux density from the 1980 maximum occurs sooner and/or more rapidly for the higher frequencies (comparing data at 1.4, 2.7, 5, 8, and 15 GHz). A double outburst occurred about 1981.6, almost simultaneously at all except the low frequencies. This event is indicated by the thin vertical line in Figure 8. The composite spectra before, during, and after this event are shown in Figure 9*b*. Note the general decline at lower frequencies (< 1 GHz), the temporary increase near 10 GHz, and, in the spectrum of late 1981, the hint of impending activity suggested by the 90 GHz flux density.

The most prominent feature of the radio light curve is the very large outburst beginning at 90 GHz in 1981 fall and continuing at centimeter wavelengths in 1982 spring. The spectrum of 1982.3 is shown in Figure 9*b*. The spectrum of this large outburst (obtained by subtracting the observed 1981.9 from the 1982.3 spectrum) is $S_\nu \propto \nu^{1.5}$ in the optically thick region. If we use a simple adiabatically expanding cloud model, then for frequencies at which the source is optically thick, $S_\nu(\text{outburst}) \propto (t - t_0)^3$ (van der Laan 1971), and we can use the observed increase of flux density with time to derive t_0, the epoch of the start of an assumed instantaneous expansion. The observations at 8 GHz and 15 GHz are consistent with $t_0 =$ JD 2,444,870 (1981 September, within a few weeks). The cubic fit to the data is shown in Figure 10. We derive the maximum flux density and time of maximum at various frequencies as shown in Table 10. Note (Fig. 10 and Table 10) that the simple model predicts the outburst at higher frequencies to be too strong relative to that at lower frequencies; also, the predicted time delay between the outburst at different frequencies is probably too large compared with that observed. The assumption of $\tau \gg 1$ is probably not correct, as a result of either inhomogeneous emitting regions or relativistic expansion or both; so t_0 as derived would be too early. However, a very much later t_0 would be excluded by the 90 GHz

Notes to Table 9

(1) Condon and Jauncey 1974. This flux density should be increased by 1.16 to put it on the Wyllie 1969 scale but reduced by 1.11 (for $\alpha = -0.4$) to compare with the 408 MHz data.

(2) The flux density from the Bologna Survey has been multiplied by 1.13 to match the Wyllie 1969 scale.

(3) This observation, obtained by the Jodrell Bank Mk I–Mk III interferometer (7″ lobe), was communicated by D. Stannard. For the purposes of plotting only, in Fig. 8 the flux density has been increased by 1.13 to match the Wyllie 1969 scale.

(4) These 365 MHz UTRAO flux densities have been reduced (D. B. G.) using the flux densities of the nearby sources 4C 25.35 and 4C 25.39, on the Wills 1973 scale. Only the plotted data have been multiplied by 0.94 to correct for the difference in frequency (assuming $S_\nu \propto \nu^{-0.4}$) and to change the flux density scale, so that they may be compared with the bulk of the 408 MHz data obtained by Fanti *et al.* 1979, 1981, which is on the Wyllie 1969 scale.

(5) Bologna 408 MHz flux densities are within 5% of the Wyllie 1969 scale (Fanti *et al.* 1981). Further information is given in the latter reference. Data after 1979 have not been previously published.

(6) 430, 435, 1400 MHz. The observations and data reduction have been described by Spangler and Cotton 1981, who give statistical summaries of the flux densities. Individual flux densities were communicated by S. R. Spangler and are on the scale defined by Kellermann, Pauliny-Toth, and Williams 1969. For comparison with 408 MHz flux densities plotted in Fig. 8, the 430 MHz values have been increased by 1.13 to correct for the difference in frequency (assuming $\alpha = -0.5$) and to match the Wyllie 1969 flux density scale. No scaling has been applied to the 1400 MHz flux densities, since differences in scales are smaller than other uncertainties at these frequencies.

(7) Measured by M. M. Davies on 1982 Mar 13, using the Arecibo 304 m telescope. 430 MHz: $S(1156+295)/S(3C\ 268.2) = 0.74 \pm 0.01$. This error includes noise but not confusion uncertainties, which are very important at this frequency. However, comparisons with future relative measurements with the same telescope should be possible to accuracies of 1%–2%. We have taken $S(3C\ 268.2) = 4.7 \pm 0.5$ Jy (not plotted). 1400 MHz: The flux density ratio to that of 3C 268.2 is 1.55 ± 0.4. The table entry assumes 1.48 ± 0.08 Jy for 3C 268.2 (Wills 1973 scale, which is similar to others at this frequency). 4830 MHz: The flux density ratio to that of 3C 277.3 is 1.01 ± 0.04. The tabular value assumes the flux density of 3C 277.3 is 1.30 ± 0.04 (Wills 1973 scale, similar to others at this frequency).

(8) Observations were made in either 1969 March or 1970 March.

(9) For observing and reduction techniques, see Bridle *et al.* 1972.

(10) The uncertainty in θ due to ionospheric Faraday rotation is less than 20° (R. Perley, private communication).

(11) Very Large Array (VLA) flux densities are all on the scale defined by Baars *et al.* 1977. Observations and reductions are by C. M. W. and P. P. All data are preliminary. The 22.5 GHz data in particular are subject to appreciable atmospheric effects. The scale at 15 GHz is similar to that used at this frequency for flux densities by other observers in this paper.

(12) Observation with the National Radio Astronomy Observatory (NRAO) Green Bank interferometer, with a spacing of 100 m.

(13) Wardle and Kronberg 1974.

(14) 2.7 GHz observations were made (T. J. B., C. P. O., W. A. D.) with the NRAO 91 m antenna (Kapitzky 1976). 7.9 and 15.5 GHz observations were made (T. J. B., W. A. D.) with the Haystack Observatory 37 m antenna (Dent and Kapitzky 1976; Dent, Kapitzky, and Kojoian 1974). The flux density scale uses DR 21 and 3C 274 as primary calibration sources, as described in the above references.

(15) The Michigan flux density scale is based upon measurements of Cas A using the spectra defined by Baars *et al.* 1977. On the scale used by Michigan at 4.8, 8.0, and 14.5 GHz, the flux densities are 71.4, 49.1, and 30.8 Jy, respectively, for Virgo A and 7.39, 5.54, and 3.90 Jy, respectively, for 3C 286. At 4.8 and 8.0 GHz these values are within 2%–3% of the Baars *et al.* scale (as defined by the Baars *et al.* spectra of Vir A and 3C 286), but at 14.5 GHz the values are 7%–10% higher. The University of Michigan data plotted in Figs. 7 and 8 have not been rescaled. The observing and reduction procedures have been described by Aller 1970 and Aller, Aller, and Hodge 1981.

(16) 7.850, 15.5 GHz. The observations and data reductions have been described by Spangler and Cotton 1981, and individual flux densities were communicated by Cotton. No flux density scaling was necessary, since the scales defined by Baars *et al.* 1977, Dent and Kapitzky 1976, and Dent, Kapitzky, and Kojoian 1974 agree to ~1%.

(17) Previously unpublished observations with the Bonn 100 m telescope.

(18) Observation with the Owens Valley Radio Observatory 40 m telescope.

(19) Observations with the Five College Radio Astronomy Observatory 45 m telescope (Balonek 1982), on the same flux density scale as in note 20.

(20) Measurements near 31 and 90 GHz using the 11 m NRAO telescope on Kitt Peak. For observing and reduction techniques see Dent and Hobbs 1973 and Hobbs and Dent 1977.

(21) Measurements near 90 GHz using the 11 m NRAO telescope on Kitt Peak. Flux density calibration is referred to planetary temperatures adopted at NRAO Kitt Peak (Ulich 1974; Ulich, private communication; see also Hobbs and Dent 1977).

(22) This drift scan measurement at 90 GHz may be low because of uncertain antenna pointing.

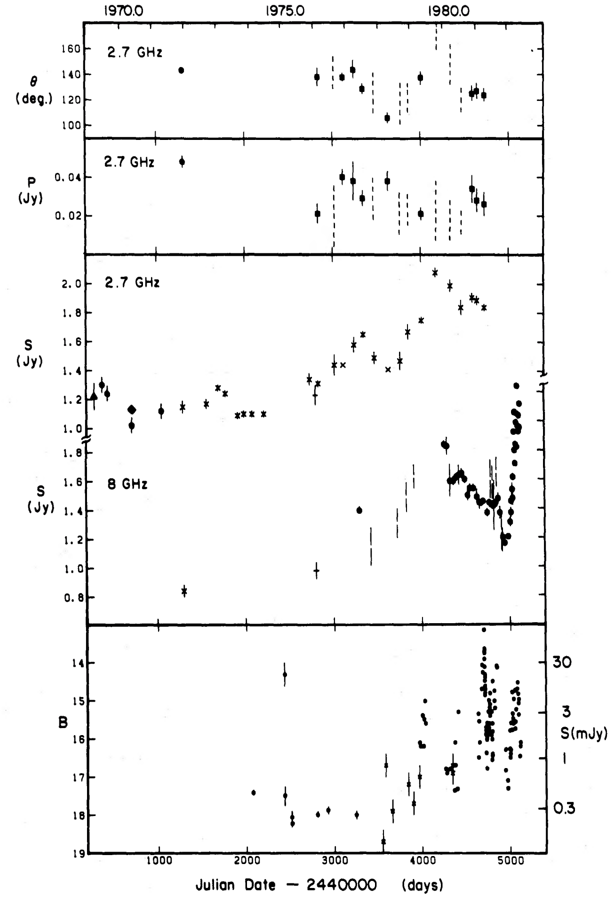

FIG. 7.—Flux density and polarization at 2.7 GHz and flux density at 8 GHz compared with optical (~4400 Å) magnitudes as a function of time. The radio data and references are given in Table 9, which also includes data at other frequencies and earlier epochs. Different symbols distinguish data from different observers (see Table 9). The optical data, for these and earlier epochs, are given in Tables 2 and 3, and upper limits to optical flux densities are discussed in the text. Error bars represent ±1 standard deviation. Error bars have been omitted from the 1980 data (but see Figs. 2 and 9). Note that polarization data with significance less than 2.8 σ are plotted with dashed error bars.

data. If acceleration of the synchrotron emitting particles is not essentially quasi-simultaneous, then t_0 has no meaning. The assumption of $t_0 \sim$ JD 2,444,690 (that is, the beginning of the radio expansion coinciding with the time of maximum of the largest optical outburst) is *not* consistent with the radio data and the simple expanding cloud model. If our derived t_0 is meaningful and if indeed we are justified in associating the largest optical outburst with the largest radio outburst, then the difference between the time of the optical continuum outburst and t_0, about 180 days, may place important constraints on the QSO geometry. It will be important to test whether or not the continuing optical activity shows corresponding behavior at radio wavelengths. (Is the smaller optical outburst near JD 2,444,000 [1979 May] similarly related to the radio maximum near JD 2,444,200 [1979 December]?)

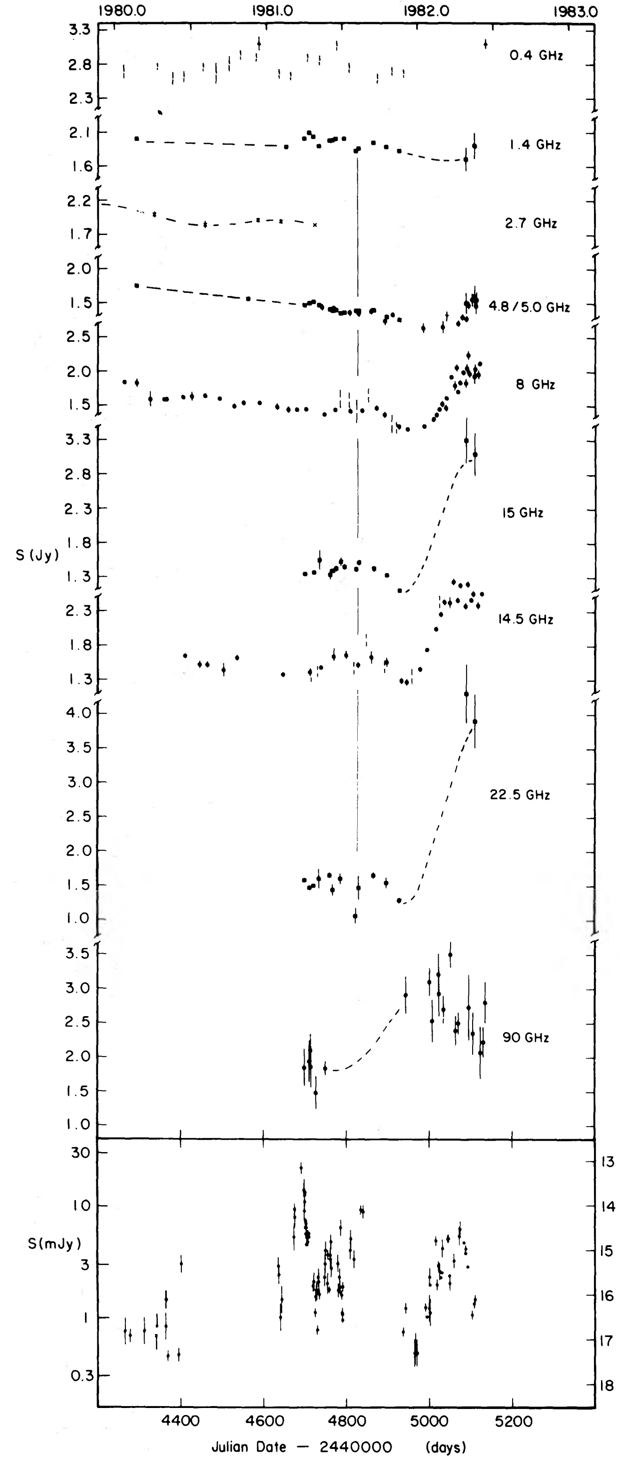

FIG. 8.—Flux density vs. epoch during 1980 through mid-1982 for various radio frequencies compared with optical data. Note that the optical flux densities are plotted on a logarithmic scale. The radio flux densities are all on the same linear scale. Error bars are ±1 standard deviation. The dashed lines simply connect data points of the same frequency. The data and references are given in detail in Table 9. The thin vertical line is discussed in the text. The two filled symbols at 0.408 MHz are derived from UTRAO data.

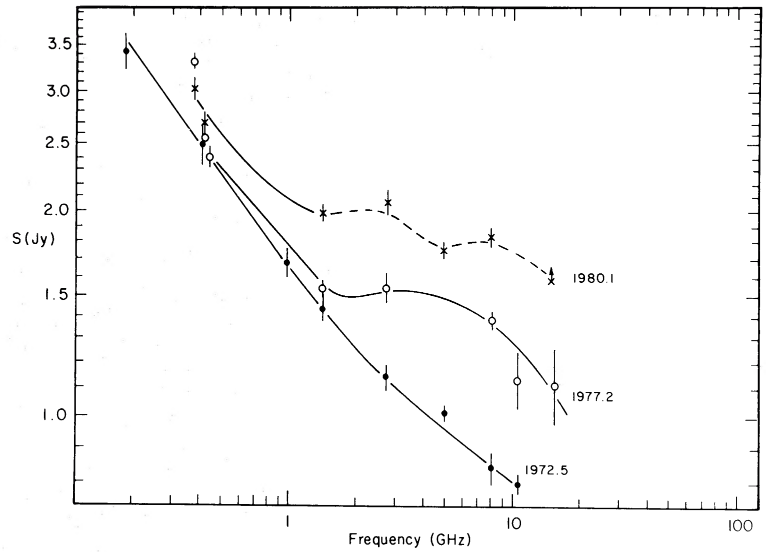

FIG. 9*a*

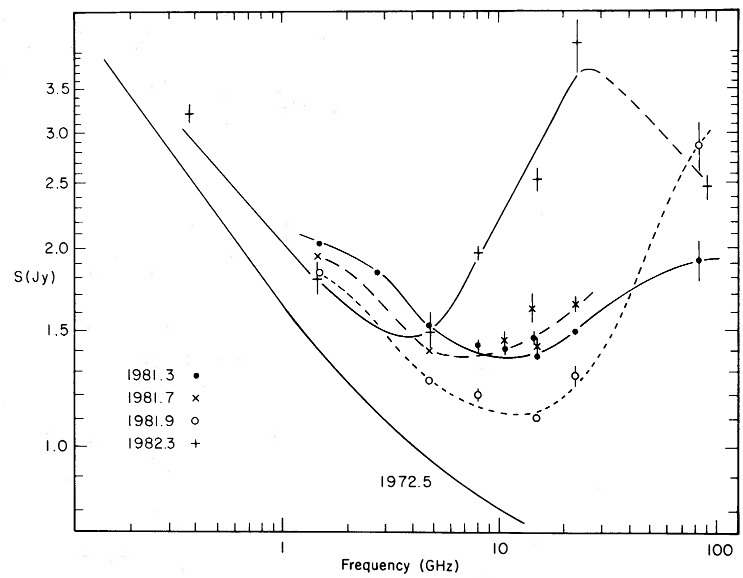

FIG. 9*b*

FIG. 9.—Radio spectra for the epochs (*a*) 1972.5, 1977.2, and 1980.1 and (*b*) 1981.3, 1981.7, 1981.9, and 1982.3. Error bars are 1 (estimated) standard deviation.

TABLE 10

A MODEL RADIO OUTBURST

ν (GHz)	S_{max} (Jy)	t_{max}[a] JD 2,440,000+	t_{max}[a] Year	$(t - t_0)$ (days)
0.4	0.04	5926	1984.7	1056
1.4	0.14	5452	1983.4	582
5.0	0.5	5187	1982.6	317
8.0	0.9	5124	1982.4	254
15.0	1.7	5058	1982.24	188
22.5	2.6	5024	1982.15	154
90.0	11.5	4950	1981.9	80

[a] t_0 = JD 2,444,870.

That the outburst is not simply the result of a single adiabatically expanding cloud is also seen in the rapid fluctuations ($\sim 10\%$ over $\lesssim$ a few days) at the maximum of the 1982 spring outburst at 8 and 15 GHz, suggesting that the outburst may be the superposition of many events involving rapid particle acceleration and decay. (It is tempting to try to correlate these variations at different frequencies, but the time resolution of the data is insufficient.) This "flickering" has been noted in other sources during outbursts (e.g., Aller and Ledden 1978). It is interesting to note that the flickering appears to be less during the rise, perhaps owing to the fact that the region is optically thick then, hiding from view the more active depths of the cloud. MacLeod *et al.* (1971) have noted spikes at the peak of an outburst in BL Lac, with

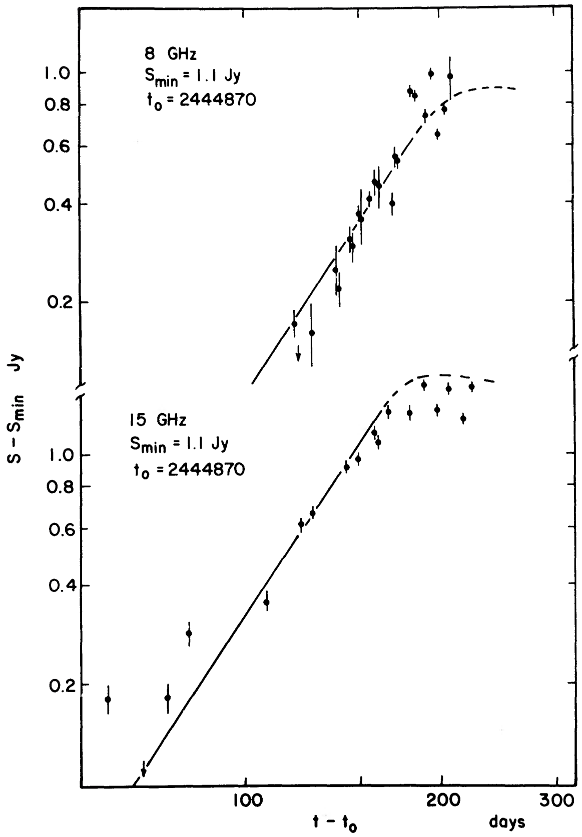

FIG. 10.—The fit of a simple van der Laan expanding cloud model to the rise in flux density of the largest radio outburst. The data shown are University of Michigan 8 and 15 GHz flux densities. Errors (± 1 standard deviation) do not include the uncertainty in S_{min}, which will be more important for small log ($S - S_{min}$). Characteristics of the model at these and other frequencies are given in Table 10.

amplitude 1–2 Jy and time scale less than 7–20 days, with the curve at 4.5 cm lagging behind that at 2.8 cm by less than 1 day. Andrew, Harvey, and Medd (1971) note for OJ 287 at 4.5 cm "there is some suggestion . . . that the start of the series of short-lived (< days) outbursts coincided with the maxima in the longer term event."

Although it seems very likely that the very large outburst in 1982 spring at centimeter wavelengths is related to the largest optical flare in 1981 spring, a stronger case can be made for a more general association of the increase in activity at optical and radio wavelengths over the last 3–4 yr based on the preceding relatively long (> 6–9 yr) period of inactivity. Convincing evidence for a direct association of radio and optical outbursts is rare. The best examples are two outbursts in AO 0235+164, because they were almost simultaneous at radio and optical frequencies (MacLeod, Andrew, and Harvey 1976; Ledden, Aller, and Dent 1976; Rieke *et al.* 1976; Pica, Smith, and Pollock 1980; Balonek and Dent 1980). In OJ 287 (Pomphrey *et al.* 1976), the radio activity lagged behind the optical by about 2 yr.

The maximum luminosity in the radio outburst alone is $\gtrsim 10^{45}\ h_0^{-2}$ ergs s^{-1}, up to 90 GHz. Here we have assumed isotropic emission. For the light-travel times of weeks observed in this radio source, brightness temperatures of greater than 3.10^{14} K are implied. Assuming incoherent, isotropic electron synchrotron radiation, then to avoid catastrophic inverse Compton losses, the Doppler factor, δ, for expansion or relativistic motion of the emitting cloud must be greater than 5 (see Burbidge, Jones, and O'Dell 1974). An observer of a relativistically expanding cloud would see both optically thick and optically thin regions simultaneously, and this is qualitatively consistent with the departures of the data from the simple expanding cloud model discussed above (i.e., an outburst spectrum flatter than $\alpha = 2.5$ in the optically thick region and a less rapid increase in flux near the peak of the outburst; see van der Laan 1971).

Radio polarization data are given in Figure 7 and Table 9, and a summary of the University of Michigan polarization data is given in Table 11. The data of the early 1970s show a systematic increase of polarization position angle with increasing frequency, and degrees of polarization of 2%–4% (see Table 9). The 2.7 and 8 GHz data of 1971 have larger position angles compared with the recent values of $\sim 124°$. There is some evidence for smaller position angles at 1.4 GHz in 1982 spring—i.e., during the rise in flux density—compared with those of a year before.

Since it has been noted that polarization position angles at radio and optical frequencies are sometimes very similar for individual BL Lac objects (e.g., Rudnick *et al.* 1978), it is of interest to compare the available data for 1156+295. Although there seem to be much more rapid changes of polarization in the optical, both in degree and position angle, it is tempting to speculate that there may be some significance in the $\pi/2$ difference between the median optical P.A. ($\sim 15°$) and that at high radio frequencies ($\sim 110°$), and the occasional near alignment (see Fig. 11). If real, this effect may be related to the roughly $\pi/2$ changes in radio position angle noted by O'Dea, Dent, and Balonek (1983) and others.

Perley (1982) has measured an unresolved core for 1156+295, using the VLA at 1.4 and 5 GHz (half-power beamwidths 0".80 and 0".25, respectively). In addition he finds, at 5 GHz, a component 1".9 away in P.A. 340°, having a peak flux density $\sim 1.4\%$ that of the core and connected to it by a bridge. At 1.4 GHz a halo surrounds the core, with peak brightness 4.8% that of the core. At much higher resolution, W. D. Cotton (private communication) reports a model derived from 1978

TABLE 11

AVERAGE RADIO POLARIZATION: UNIVERSITY OF MICHIGAN DATA

ν (GHz)	1981 May–Jul p (%)	1981 May–Jul P.A. (deg)	1982 Jan–Apr p (%)	1982 Jan–Apr P.A. (deg)
4.8	2.4 ± 0.4	103 ± 5	3.6 ± 0.3	103 ± 2
8.0	2.5 ± 0.6	129 ± 7	2.1 ± 0.4	113 ± 5
14.5	4.9 ± 1.5	120 ± 9	1.9 ± 0.4	84 ± 6

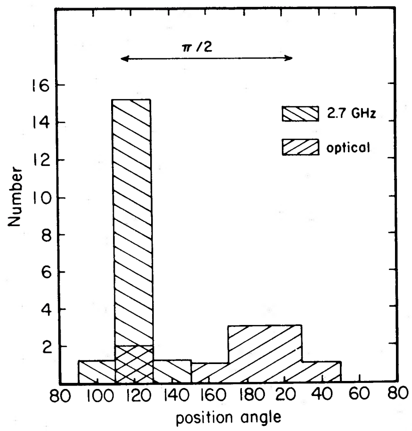

FIG. 11.—A comparison of 2.7 GHz and optical polarization position angles. The radio data are given in Table 9 and the optical data in Table 5. Both cover a period of several years.

December VLBI observations at 13 cm (Haystack, Green Bank, OVRO, and Goldstone). The source was resolved and appeared to be a circular Gaussian with half-width ($1/e$) of 1.06 ± 0.06 milli-arcsec, with a flux density 1.35 ± 0.03 Jy—that is, about 80% of the total flux at that time. Unfortunately, no VLBI observations have been made during the times of greatest activity.

V. DISCUSSION

a) Optical Variability Time Scales

The photometry shows that there are several characteristic (rest frame) time scales[22] in the optical variations, ranging from $\gtrsim 1$ yr for the very large amplitude variations (the present activity beginning about JD 2,443,500, $\sim$1978.0) to about 1000 s for changes of a few percent. Intermediate time scales of a few days and $\sim$1 month also seem to be present. The longer time scale activity could be interpreted as the superposition of smaller flares of duration $\lesssim$several days. If there are many spatially and temporally separated flares emitting isotropically, an upper limit to the diameters of these regions is given by (Terrell 1967):

$$D \lesssim \frac{4c}{\pi}\frac{\Delta T}{1+z}\frac{\bar{L}}{\Delta L} \quad \text{with} \quad \Delta L \sim \bar{L}\,, \tag{1}$$

or

$$D \lesssim 4c\bar{L}/[(1+z)dL/dt]\,, \tag{2}$$

where ΔT is the overall time scale of a variation of total amplitude ΔL, and $\bar{L}$ is the average flare luminosity over this time interval, and dL/dt is an observed instantaneous rate of change. From the high-speed photometry, the most rapid change (Fig. 3) gives $D < 4 \times 10^{13}$ cm. From the most rapid change in the light curve of Figure 2 (near JD 2,444,700) we derive $D < 8 \times 10^{15}$ cm. If our assumptions about the geometry are wrong, and instead the small-scale fluctuations are from the same region of space as the largest flares, then $\Delta L < \bar{L}$, and the upper limits would be several times larger.

If the small flares are not independent of each other but, as suggested below, are triggered by an instability that propagates through an accretion disk, the entire unstable region (the whole disk?) may be characterized by a size less than 10^{17} cm.

The above discussion applied to the variations observed in other active sources leads to similar size limits (Pollock 1982).

b) Energetics and a Comparison with Model Predictions[23]

Figure 12 shows the details of the largest optical outburst between JD 2,444,640 and 2,444,729. Luminosity, with a constant background subtracted and normalized to a maximum of 1, is given as a function of rest frame (proper) time. This maximum luminosity corrected to a rest frame wavelength of 2500 Å (e.g., Richstone and Schmidt 1980) is $L_{max} = 2.26 \times 10^{32}\, h_0^{-2}$ ergs s^{-1} Hz^{-1} (assuming isotropic emission and nonrelativistic motion).

The spectrum of 1156+295 at the peak of the optical outburst ($\sim$1982.3) has been derived between 1.8×10^8 and 2.5×10^{15} Hz. The spectrum at radio wavelengths is shown in Figure 9*b*. In the infrared, optical, and ultraviolet we have used the spectrum for 1981 April 8 given by Glassgold *et al.* (1983), scaled to match the maximum observed *B*-magnitude. This is justified by their important result that the overall spectra show little change in shape with change in brightness. Over a more limited wavelength range, our broad-band photometry in the IR and visual, and our spectrophotometry, support this result, at least in 1981 spring. Between 90 GHz and optical *K* band we have assumed a power-law interpolation, with $\alpha = -0.41$. This interpolation is roughly consistent with the data but is not the only possible interpretation.

Integrating under this spectrum, we obtain the bolometric luminosity at the peak of the optical outburst, $P_{max} = 2.9 \times 10^{47}\, h_0^{-2}$ ergs s^{-1}, with most of the energy emitted in the IR and optical. The value of P_{max} is insensitive to the choice of wavelength limits; the photon energies are small where the spectrum is flat ($\alpha \sim 0$ below 10^{11} Hz), and $\alpha \sim -2.0$ in the UV. Uncertainty of the spectrum shape in the far-IR (10^{11}–10^{14} Hz) is unlikely to change P_{max} by more than 50%. The largest uncertainties are unknown contributions at frequencies $\gtrsim 10^{16}$ Hz.

We have also estimated the total energy emitted during the large outburst shown in Figure 12, $E_{burst} = 2.1 \times 10^{53}\, h_0^{-2}$ ergs. Pollock (1982) finds the total

[22] If relativistic motions are present, as seems likely from the arguments concerning the high radio brightness temperature, time scales in the emitting frame for the outburst(s) (at radio to UV wavelengths) should be increased by the Doppler factor, δ.

[23] The deduced luminosities of the outburst(s) may be considerably reduced if relativistic motions are present (see footnote 22). However, much of the energy released during the outburst will then be in kinetic energy, and its origin must still be explained, so we have ignored the relativistic corrections.

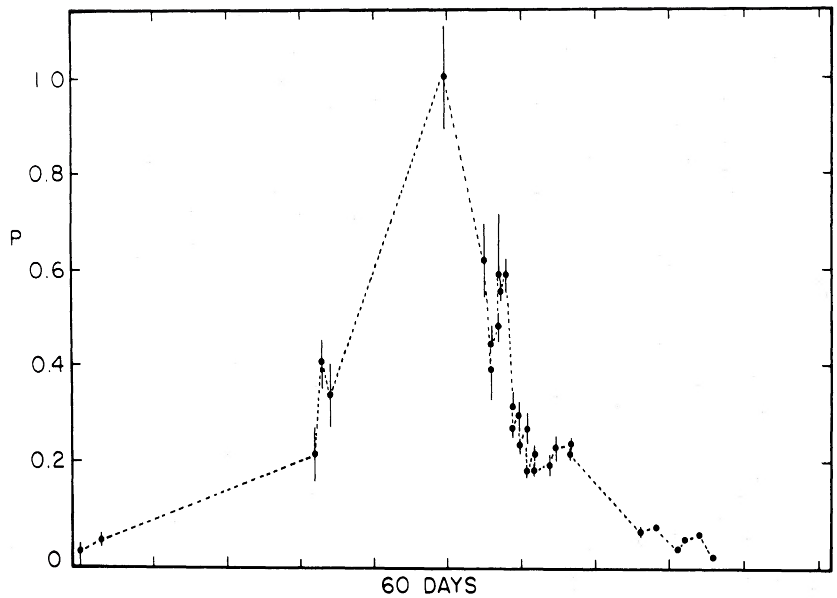

FIG. 12.—Detail of the largest optical outburst, with background subtracted and normalized to the peak luminosity. The time scale is that in the rest frame of 1156+295 ($z = 0.729$).

energies in large outbursts in other objects to be similar or larger ($7 \times 10^{53}\ h_0^{-2}$ ergs for 1308+326 in 1977 to $3 \times 10^{55}\ h_0^{-2}$ ergs for AO 0235+164 in 1975 November).

We estimate the "quiescent" luminosity to be $P_q \sim 3 \times 10^{45}\ h_0^{-2}$ ergs s^{-1}. This is consistent with the Mg II line luminosity ($\sim 10^{43}\ h_0^{-2}$ ergs s^{-1}) and typical line and UV continuum intensity ratios.

One simple model for the energetics of the flare is infall of matter onto a black hole. Assuming 0.3 conversion efficiency (Thorne 1974), the above $E_{\rm burst}$ is equivalent to 0.8 $M_\odot$. However, it is not clear how this energy would appear as synchrotron radiation and be consistent with the observed high degrees of linear polarization and the rapid polarization variability. Shields and Wheeler (1976) suggest a possible model for the creation of plasmoids containing magnetic fields and ultrarelativistic electrons, involving accretion disks around black holes.

In this model, the disk magnetic field is amplified by accretion and differential rotation of the disk, storing magnetic energy ($E_{\rm burst}$) over the time interval between bursts ($\tau_{\rm twixt} \sim 10^8$ s for 1156+295). An instability somehow results in sudden release of this energy by particle acceleration and ejection of magnetic fields on a time scale $\lesssim \tau_{\rm burst} \sim 3 \times 10^6$ s, the duration of the outburst. Shock waves from an initial, localized flare propagate across the disk, triggering further flares which we identify with the fluctuations on time scales $\lesssim$few days. In the following, the reader should refer to Shields and Wheeler (1976) for further details, assumptions of the model, and further explanations of the symbols used.

We now check the consistency of this model with our observations. In order that the quiescent luminosity not exceed the Eddington limit, $L_q \lesssim L_{\rm Edd} \sim 1.3 \times 10^{38}$ $(M/M_\odot)$ ergs s^{-1}. Thus the black hole mass $M \gtrsim 3 \times 10^7\ M_\odot$. Rather arbitrarily, we choose $M \sim 10^8\ M_\odot$. We derive the steady state accretion rate from L_q, identified with the maximum power liberated at the inner edge of the disk ($0.3\dot{M}c^2$), and find $\dot{M} \sim 0.4\ M_\odot$ yr^{-1}. The model gives the energy stored $E_{\rm store}(<r)$ within a radius r:

$$E_{\rm store}(<r) \approx \frac{2 \times 10^{50}}{\alpha} \frac{\dot{M}}{(M_\odot/{\rm yr})} \left(\frac{M}{10^8\ M_\odot}\right)^{1/2} \times \left(\frac{r}{10^{14}\ {\rm cm}}\right)^{1/2} \text{ ergs},$$

where we have assumed magnetic viscosity to dominate over turbulent viscosity, and α is the viscosity parameter in the "α" disk model, and the power dissipation as a function of r is

$$P(r) \sim \frac{GM\dot{M}}{r} \sim 10^{46} \frac{M}{10^8\ M_\odot} \frac{\dot{M}}{1\ M_\odot/{\rm yr}} r_{14}^{-1} \text{ ergs s}^{-1} .$$

For the storage model we require $E_{\rm store}(>r) \geq E_{\rm burst}$ for some acceptable r, and $P(r) \geq P_{\rm store}$ is required in order to explain the frequency of outbursts (see Shields and Wheeler 1976). Thus $P(r) > P_{\rm store} \sim E_{\rm burst}/\tau_{\rm twixt} \sim 2.1 \times 10^{45}\ h_0^{-2}$ ergs s^{-1} leads to storage within $r = 1.6 \times 10^{14}\ h_0^{-2}$ cm ($\sim$5 light-hours in the observer's frame; compare this with the Schwarzschild radius of the black hole, 3×10^{13} cm), and the requirement $E_{\rm store} > E_{\rm burst}$ leads to $\alpha < 4.8 \times 10^{-4}$. In order to check whether this is possible, we calculate a *lower limit* to α from the requirement that the time it takes material to spiral inward from r should be $\sim 10^8$ yr (estimated typical QSO lifetime). Following Shields and Wheeler's calculations, we derive $\alpha > 6.10^{-5}$, and thus we conclude that the model for the outburst is energetically consistent with magnetic field amplification and storage in a differentially rotating accretion disk around a $10^8\ M_\odot$ black hole.

Physically, the foregoing constraints can be summarized as follows. The burst energy divided by the time interval between bursts gives a power comparable to the quiescent power, so that the energy for the bursts must be produced at high efficiency deep in the potential of the black hole. In order to have enough mass in the disk at this small radius to store the burst energy, the viscosity must be very low so that the material only gradually spirals inward.

VI. SUMMARY

During 1969 to 1976, the QSO 1156+295 ($z = 0.729$) appears to have been quite inactive at optical wavelengths ($B \sim 17$–18 mag) and at radio wavelengths ($S_\nu \propto \nu^{-0.4}$). By 1979 it had shown unmistakable increases in radio and optical flux densities, culminating, after a few minor oscillations, in enormous outbursts in the optical ($B = 13.1$ in 1981 spring) and, less than six months later, at 3 mm and, a year later, at centimeter wavelengths (an increase of a factor of 3 in flux density at 1.3 cm). At maximum, $M_B \sim -29$, within 1 mag of the most luminous known QSOs during outburst (3C 279, PKS 1510−08, and 2134+004). During the most active periods in the optical, 5%–7% optical fluctuations on time scales of $\sim \frac{1}{2}$ hr were observed, and at the peak of the radio outburst, ~ 10% variations on time scales less than several days were observed at centimeter wavelengths.

In the optical there are large and rapid changes of linear polarization with $p = 1\%$–29%. By contrast, the degree of polarization at centimeter wavelengths is small (2%–4%) with a narrow range of position angles.

The evolution of the radio spectrum and the derived brightness temperatures suggest that the source is only partially optically thick at the highest (radio) frequencies. This, together with the rapid variations observed at the peak of the large radio outburst, suggests that the simple expanding cloud model is unlikely to apply. However, we can use this model to set limits on the time at which most of a radio cloud began to expand—most likely, 5–6 months (in the observer's frame) after the major optical outburst.

When 1156+295 is faint, the optical spectrum is that of a typical QSO. When bright, the spectrum is essentially featureless, and there is very little change in spectral shape with optical brightness, at least between IR and UV observed wavelengths (see also Glassgold *et al.* 1983). The entire continuum from radio to observed UV wavelengths is consistent with a common emission mechanism, being flat at radio wavelengths and becoming increasingly steep in the observed UV.

We find that the total energy released in the large optical flare is consistent with its having been stored as magnetic energy in an accretion disk during the long quiescent period, if the radius within which this energy is stored is about 2×10^{14} cm, and the disk is one in which magnetic dominates over turbulent viscosity, with $\alpha \lesssim 5 \times 10^{-4}$. This is independent of whether the disk is self-gravitating or of small mass compared with the central massive object (black hole). The small flares may be triggered by an instability that propagates through the whole accretion disk.

It is interesting to compare the sizes of various regions, active and inactive:

1. Energy may be stored in an accretion disk within 2×10^{14} cm, or ~ 0.06 light-days.
2. Optical variability suggests continuum sizes $\lesssim 0.03$ pc, or 36 light-days.
3. The difference in time between the peak of the largest optical flare and the estimated time for the beginning of the expansion of a radio cloud leads to size estimates of $\sim$ light-months.
4. VLBI in 1978 December gives 80% of the flux within 2 milli-arcsec, or ~ 20 lt-yr.
5. A typical size of the optical emission-line region for a QSO of this (quiescent) luminosity is ~ 20–150 lt-yr.
6. Radio structure extends about 2″ from the core, or $\sim 2 \times 10^4$ lt-yr.
7. There is no evidence for optical absorption lines from low-excitation material far removed from the emission-line region.

Optical and radio flux density monitoring continues on a regular basis. Sporadic observations of the optical and UV spectra and optical polarization will be made as time and weather permit. It would help the understanding of this and other similar sources, if good time coverage for photometric observations[24] could be ensured, and if further VLBI and other observations could be made, so we hope that other observers will be interested in following the activity of this QSO.

The following people kindly provided new data, further information on already published data, or somehow contributed by helping to obtain data: R. L. Adgie (Royal Radar Establishment, England), L. Blitz and R. D. Mathieu (University of Maryland), M. Breger (University of Texas), W. D. Cotton and S. R. Spangler (NRAO), M. M. Davis (Arecibo Observatory), S. A. Grandi (University of California, Los Angeles), E. P. Belserene (Maria Mitchell Observatory), B. Iriarte (Instituto Nacionale de Astrofisica Optica y Electronica, Mexico), W. Kinzel and J. Kenney (University of Massachusetts), R. G. Kron and D. Hamilton (Yerkes Observatory), J. W. Liebert and J. T. Stocke (Steward Observatory), R. L. Moore (Caltech), E. T. Olsen (JPL), T. J. Pearson (Owens Valley Radio Observatory), R. A. Perley (National Radio Astronomy Observatory, Socorro), D. O. Richstone (University of Michigan), M. Schmidt (Caltech), H. E. Smith (University of California, San Diego), D. Stannard (Jodrell Bank), B. L. Ulich (Mount Hopkins Observatory), A. K. Uomoto (University of Michigan), E. J. Wadiak (University of Virginia), P. G. Wannier (Caltech), J. F. C. Wardle (Brandeis University), and A. Witzel

[24] Optical observers should note the Rosemary Hill Observatory photographic comparison sequence given in Table 1 and Fig. 1.

(Max-Planck Institut für Radioastronomie, Bonn). We thank A. E. Glassgold, J. N. Bregman, and P. J. Huggins (New York University), who have kept us informed of their work published in the accompanying paper (Glassgold *et al.* 1983), J. C. Wheeler for discussions about accretion disks, and the referee for many helpful comments.

Radio astronomy at the Haystack Observatory of the North East Radio Observatory Corporation is supported by the NSF. The Five College Radio Astronomy Observatory (FCRAO) is operated with support from the NSF under grant AST 81-214-81 and with the permission of the Metropolitan District Commission, Commonwealth of Massachusetts. The University of Florida program has been supported by a series of grants from NSF; the current grant is AST 8203926. The research at the University of Texas was supported by NSF grants AST 81-01205 (J. N. D. and D. B. G.), AST 79-01182 (D. W. and B. J. W.) and AST 81-08691 (S. O. K.). We acknowledge support through various other grants, both NSF and NASA.

REFERENCES

Adgie, R. L. 1974, *A.J.*, **79**, 846.
Aller, H. D. 1970, *Ap. J.*, **161**, 1.
Aller, H. D., Aller, M. F., and Hodge, P. E. 1981, *A.J.*, **86**, 325.
Aller, H. D., and Ledden, J. E. 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: University of Pittsburgh Press), p. 53.
Andrew, B. H., Harvey, G. A., and Medd, W. J. 1971, *Ap. Letters*, **9**, 151.
Angione, R. J. 1971, *A.J.*, **76**, 25.
Baars, J. W. M., Genzel, R., Pauliny-Toth, I. I. K., and Witzel, A. 1977, *Astr. Ap.*, **61**, 99.
Balonek, T. J. 1982, Ph.D. thesis, University of Massachusetts.
Balonek, T. J., and Dent, W. A. 1980, *Ap. J. (Letters)*, **240**, L3.
Breger, M. 1979, *Ap. J.*, **233**, 97.
Bridle, A. H., Davis, M. M., Fomalont, E. B., and Lequeux, J. 1972, *A.J.*, **77**, 405.
Burbidge, E. M. 1968, *Ap. J. (Letters)*, **154**, L109.
Burbidge, G. R., Jones, T. W., and O'Dell, S. L. 1974, *Ap. J.*, **193**, 43.
Chaffee, F. H. 1974, *Ap. J.*, **189**, 427.
Chaffee, F. H., and Latham, D. W. 1982, *Pub. A.S.P.*, **94**, 386.
Condon, J. J., and Jauncey, D. L. 1974, *A.J.*, **79**, 1220.
Conway, R. G., Gilbert, J. A., Kronberg, P. P., and Strom, R. G. 1972, *M.N.R.A.S.*, **157**, 443.
Dent, W. A., and Hobbs, R. W. 1973, *A.J.*, **78**, 163.
Dent, W. A., and Kapitzky, J. E. 1976, *A.J.*, **81**, 1053.
Dent, W. A., Kapitzky, J. E., and Kojoian, G. 1974, *A.J.*, **79**, 1232.
Dumortier, B. 1976, Ph.D. thesis, University of Paris.
Eachus, L. J., and Liller, W. 1975, *Ap. J. (Letters)*, **200**, L61.
Epps, E. A. 1972, *Royal Obs. Bull.*, No. 176, p. 127.
Fanti, C., Fanti, R., Ficarra, A., Formiggini, L., Giovannini, G., Lari, C., and Padrielli, L. 1975, *Astr. Ap.*, **19**, 143.
Fanti, C., Fanti, R., Ficarra, A., Mantovani, F., Padrielli, L., and Weiler, K. W. 1981, *Astr. Ap. Suppl.*, **45**, 61.
Fanti, R., Ficarra, A., Mantovani, F., Padrielli, L., and Weiler, K. W. 1979, *Astr. Ap. Suppl.*, **36**, 359.
Frohlich, A., Goldsmith, S., and Weistrop, D. 1974, *M.N.R.A.S.*, **168**, 417.
Glassgold, A. E., *et al.* 1983, *Ap. J.*, **274**, 101.
Grueff, G., and Vigotti, M. 1972, *Astr. Ap. Suppl.*, **6**, 1.
Haves, P., Conway, R. G., and Stannard, D. 1974, *M.N.R.A.S.*, **169**, 117.
Hobbs, R. W., and Dent, W. A. 1977, *A.J.*, **82**, 257.
Iriarte, B., and Chavira, E. 1957, *Bol. Obs. Tonantzintla y Tacubaya*, **2**, 3.
Kapitzky, J. E. 1976, Ph.D. thesis, University of Massachusetts.
Kellermann, K. I., and Pauliny-Toth, I. I. K. 1973, *A.J.*, **78**, 828.
Kellermann, K. I., Pauliny-Toth, I. I. K., and Williams, P. J. S. 1969, *Ap. J.*, **157**, 1.
Kesteven, M. J. L., Bridle, A. H., and Brandie, G. W. 1976, *A.J.*, **81**, 919.
Kinman, T. D. 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: University of Pittsburgh Press), p. 82.
Kiplinger, A. L. 1974, *Ap. J. (Letters)*, **191**, L109.
Landolt, A. U. 1973, *A.J.*, **78**, 959.
Ledden, J. E., Aller, H. D., and Dent, W. A. 1976, *Nature*, **260**, 752.
Liller, M. H., and Liller, W. 1975, *Ap. J. (Letters)*, **199**, L133.
Lynds, C. R., and Wills, D. 1968, *Ap. J. (Letters)*, **153**, L23.
Macdonald, G. H., and Miley, G. K. 1971, *Ap. J.*, **164**, 237.
MacLeod, J. M., Andrew, B. H., and Harvey, G. A. 1976, *Nature*, **260**, 751.
MacLeod, J. M., Andrew, B. H., Medd, W. J., and Olsen, E. T. 1971, *Ap. Letters*, **9**, 19.
Moore, R. L. 1981, Ph.D. thesis, University of Arizona.
Moore, R. L., and Stockman, H. S. 1981, *Ap. J.*, **243**, 60.
Nather, R. E. 1973, *Vistas Astr.*, **15**, 91.
O'Dea, C. P., Dent, W. A., and Balonek, T. J. 1983, *Ap. J. (Letters)*, **266**, L1.
Olsen, E. T. 1967, *A.J.*, **72**, 738.
———. 1970, *A.J.*, **75**, 764.
Pauliny-Toth, I. I. K., and Kellermann, K. I. 1972, *A.J.*, **77**, 797.
Perley, R. A. 1982, *A.J.*, **87**, 859.
Pica, A. J., Smith, A. G., and Pollock, J. T. 1980, *Ap. J.*, **236**, 84.
Pilkington, J. D. H., and Scott, P. F. 1965, *Mem. R.A.S.*, **69**, 183.
Pollock, J. 1982, Ph.D. thesis, University of Florida, Gainesville.
Pomphrey, R. B., Smith, A. G., Leacock, R. J., Olsson, C. N., Scott, R. L., Pollock, J. T., Edwards, P., and Dent, W. A. 1976, *A.J.*, **81**, 489.
Potash, R. I., and Wardle, J. F. C. 1979, *A.J.*, **84**, 707.
Priser, J. B. 1974, *Pub. US Naval Obs. 2d Ser.*, Vol. **20**.
Racine, R. 1970, *Ap. J. (Letters)*, **159**, L99.
Richstone, D. O., and Schmidt, M. 1980, *Ap. J.*, **235**, 361.
Rieke, G. H., Grasdalen, G. L., Kinman, T. D., Hintzen, P., Wills, B. J., and Wills, D. 1976, *Nature*, **260**, 754.
Rudnick, L., Owen, F. N., Jones, T. W., Puschell, J. J., and Stein, W. A. 1978, *Ap. J. (Letters)*, **225**, L5.
Schmidt, M. 1975, *Ap. J.*, **195**, 253.
Shields, G. A., and Wheeler, J. C. 1976, *Ap. Letters*, **17**, 69.
Simard-Normandin, M., and Kronberg, P. P. 1978, *A.J.*, **83**, 1374.
Spangler, S. R., and Cotton, W. D. 1981, *A.J.*, **86**, 730.
Stockman, H. S. 1978, in *Pittsburgh Conference on BL Lac Objects*, ed. A. M. Wolfe (Pittsburgh: University of Pittsburgh Press), p. 149.
Terrell, J. 1967, *Ap. J.*, **147**, 827.
Thorne, K. S. 1974, *Ap. J.*, **191**, 507.
Ulich, B. L. 1974, *Icarus*, **21**, 254.
van der Laan, H. 1971, *Nuclei of Galaxies, Pontificiae Academiae Scientiarum Scripta Varia*, **35**, 245.
Véron, M. P. 1975, *Astr. Ap.*, **41**, 423.
Visvanathan, N., and Elliot, J. L. 1973, *Ap. J.*, **179**, 721.
Wardle, J. F. C., and Kronberg, P. P. 1974, *Ap. J.*, **194**, 249.
Wills, B. J. 1973, *Ap. J.*, **180**, 335.
———. 1982, in *IAU Symposium 97, Extragalactic Radio Sources*, ed. D. S. Heeschen and C. M. Wade (Dordrecht: Reidel), p. 373.
Wills, B. J., and Wills, D. 1977, in *IAU Symposium 74, Radio Astronomy and Cosmology*, ed. D. L. Jauncey (Dordrecht: Reidel), p. 96.
Wills, D. 1966, *Observatory*, **86**, 245.
Wing, R. F. 1973, *A.J.*, **78**, 684.
Witzel, A., Schmidt, J., Pauliny-Toth, I. I. K., and Nauber, U. 1979, *A.J.*, **84**, 942.
Wyllie, D. V. 1969, *M.N.R.A.S.*, **142**, 229.

Note added in proof.—A. G. S. reports that 1156+295 remained at $B = 16.5$ during 1982 May and June. At the end of 1982 November (the beginning of the 1982–1983 observing season), $B = 15.0$, fading to $B = 17.3$ by 1983 mid-February. A rapid flare to $B = 14.9$ was observed in March, fading to 18.0 by mid-May. During 1983 June and July, $B = 17.6$–17.9.

H. D. Aller and M. F. Aller: Department of Astronomy, Dennison Building, University of Michigan, Ann Arbor, MI 48109

T. J. Balonek: Hopkins Observatory, Department of Physics and Astronomy, Williams College, Williamstown, MA 01267

R. E. Barvainis and W. A. Dent: Department of Physics and Astronomy, GRC 517G, University of Massachusetts, Amherst, MA 01003

R. P. Binzel, J. N. Douglas, D. B. Garrett, S. O. Kepler, G. A. Shields, B. J. Wills, and D. Wills: Department of Astronomy, RLM 15.308, University of Texas, Austin, TX 78712

F. H. Chaffee: Mount Hopkins Observatory, c/o Steward Observatory 228, University of Arizona, Tucson, AZ 85721

C. Fanti, L. Gregorini, F. Mantovani, and L. Padrielli: Istituto di Radioastronomia del CNR Istituto di Fisica "A. Righi," Università di Bologna, Italy

R. B. C. Henry: Department of Physics, University of Delaware, Newark, DE 19711

R. E. Hill, N. Sanduleak, and A. J. Wasilewski: Warner and Swasey Observatory, Case Western Reserve University, 1975 Taylor Rd., East Cleveland, OH 44112

R. Howard: National Radio Astronomy Observatory, Suite 100, N. Forbes Blvd., Tucson, AZ 85705

N. Jeske: Astronomy Department, University of California, Berkeley, CA 94720

R. J. Leacock, A. G. Smith, and J. R. Webb: Department of Astronomy, University of Florida, Gainesville, FL 32611

C. P. O'Dea: National Radio Astronomy Observatory, Edgemont Road, Charlottesville, VA 22901

P. Perley and C. M. Wade: National Radio Astronomy Observatory, P.O. Box 0, Socorro, NM 87801

A. J. Pica: Department of Physical Sciences, Salisbury State College, Salisbury, MD 21801

J. T. Pollock: Department of Physics and Astronomy, Appalachian State University, Boone, NC 28608

J. J. Puschell: Center for Astrophysics and Space Sciences, University of California, San Diego, La Jolla, CA 92093

T. X. Thuan: Department of Astronomy, University of Virginia, P.O. Box 3818, University Station, Charlottesville, VA 22903

W. Z. Wiśniewski: Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721