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SIMULTANEOUS OBSERVATIONS OF THE BL LACERTAE OBJECT I Zw 187

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ABSTRACT

Two sets of simultaneous spectra separated by 10 months were obtained for the X-ray–bright BL Lac object I Zw 187. The spectra consist of data obtained with radio, infrared, optical, ultraviolet, and X-ray telescopes. Repeated observations (nonsimultaneous) were made in several of these observing bands in order to detect flux variations. After contamination by galactic light is removed from the observations, the BL Lac component has a weak 3000 Å bump superposed upon an infrared-optical-ultraviolet spectrum of slope 0.9. The X-ray data fall on or close to an extrapolation of this power law; this result is consistent with the continuum from infrared through X-ray emission arising from a single synchrotron source. Optical and X-ray fluxes are observed to vary by no more than a factor of 3, and the shortest time scales of variability in these bands are comparable, about 1 week. No flux variations have been detected in the flat radio spectrum. Within the context of a synchrotron self–Compton model, the size of the optically thin region is $\sim 10^{16}$ cm, and the magnetic field is $\gtrsim 10^2$ *G*.
Subject headings: BL Lacertae objects — infrared: sources — radiation mechanisms — radio sources: galaxies — ultraviolet: spectra — X-rays: sources

I. INTRODUCTION

A clear understanding of the physical conditions in the continuum-emitting region is a primary goal of quasar research. Accurate spectra covering as wide a frequency range as possible are crucial to achieving this goal, but, unfortunately, they are difficult to obtain. Not only do broad-band observations of quasars, BL Lac objects, and active galactic nuclei require the use of many different telescope facilities, they exhibit irregular flux variations that require simultaneous measurements. This is the first in a series of papers which report and analyze nearly simultaneous spectra of BL Lac objects and optically violent variable quasars (OVVs).

There are two main reasons for obtaining simultaneous spectra. First, simultaneous spectra represent fundamental data which allow one to identify accurately the shape and position of spectral features that occur over several observing regions (e.g., the structure of low-frequency and high-frequency turnovers and the broad 3000 Å bump). Second, these data, when interpreted in terms of theoretical models, yield such properties as the size of the emitting region, its magnetic field, and the motion of the emitting plasma.

The BL Lac object reported on in this paper, I Zw 187 (I Zw 1727+502) is well suited for this analysis because it is sufficiently bright at all frequencies between radio and X-ray bands for accurate measurements to be made. Zwicky (1966) first drew attention to this compact galaxy by publishing a featureless spectrum. Photoelectric spectrophotometric observations (Oke *et al.* 1967) indicated that a nonthermal component was present which diluted the galactic spectrum. Sargent (1970) also recorded a featureless spectrum, but eventually Oke (1978) was able to detect weak galactic absorption lines from which he derived a redshift of

0.0554. Miller (1981) has also detected absorption lines at a redshift of 0.0546.

Observations obtained during the past 15 years reveal that I Zw 187 displays many properties that are typical of BL Lac objects. Temporal flux variations, possibly implying slope variations, have been observed in the nonthermal spectrum. Using photoelectric observations, no optical flux variations have been seen on the time scale of 1–3 days (Oke *et al.* 1967; Kinman 1980), but Oke *et al.* found a 0.5 mag change in the blue part of the spectrum for observations separated by 50 days while Sandage (1967) found $\Delta U \approx 0.5$ for observations separated by a month. Photographic monitoring has shown that flux variations of approximately 0.6 mag (B) occur over a 2 week period, and that the greatest range in B is 0.9 mag (Pica *et al.* 1980). In additon to flux variations, I Zw 187 displays optical polarization which varies between 4 and 6% (Kinman 1976).

Analysis of the optical data is complicated by the contamination of the spectrum by a large elliptical galaxy with about $M_v \approx -21.8$ ($H = 50$ km s^{-1} Mpc^{-1}; Oke 1978; Kinman 1978; Weistrop *et al.* 1981). When the underlying galactic component is removed from the composite spectra, the nonthermal component has a power-law slope between $\alpha = 1.6$ (Oke) and $\alpha = 0.80$–0.93 (Kinman 1978).

Although I Zw 187 has not been studied extensively at radio frequencies, it does possess a nearly flat radio spectrum with a flux density between 0.15 and 0.22 Jy in the frequency range from 1.4 to 8 GHz (Altschuler and Wardle 1975; LeSuéren, Biraud, and Lauqué 1972; Weiler and Johnson 1980); no flux variations are evident. VLBI measurements show that most of the radio emission at 5 GHz originates in a region larger than 1.2 milli-arcseconds ($\sim$ 1 pc; Weiler and Johnson).

In addition to optical and radio properties that are rather ordinary for a BL Lac object, I Zw 187 has one truly striking property—it is an extremely bright X-ray source. It was one of the few BL Lac objects detected with the *HEAO* A-1 experiment (Chubb 1978) and, of all BL Lac objects observed with the *Einstein* Observatory, I Zw 187 has the largest ratio of X-ray to optical luminosity (Ku 1982). Here we report on a series of observations which enable us to investigate the origin of the X-ray emission. Spectra that include data from the radio through the X-ray region were obtained at two different epochs. These spectra, along with monitoring studies at various frequency regions, are analyzed to calculate the properties of the emitting region.

II. THE OBSERVATIONS

I Zw 187 was observed in 1979 October and 1980 August in several different frequency regimes. The list of observers and the dates of observation are given in Table 1. The different observations are discussed in detail as a function of decreasing frequency.

TABLE 1

MULTIFREQUENCY OBSERVATIONS OF I ZW 187

Observers	Date (UT) (year/month/day)	Region	Observing Band	Raw Data	log ν	log F_ν
Ku	79/10/18.2	X-ray (IPC)	0.5–4.5 keV	0.642 ct/s	17.56	-28.96 ± 0.12
	80/8/10.2		0.5–4.5 keV	0.496 ct/s	17.56	-29.00 ± 0.12
Bregman, Glassgold, and Huggins	79/10/18.2	UV (*IUE*)	1250–1350 Å	2.59 (−15)[1]	15.36	-26.74 ± 0.04
			1350–1450 Å	1.82 (−15)	15.33	-26.84 ± 0.06
			1450–1550 Å	2.48 (−15)	15.30	-26.65 ± 0.07
			1550–1650 Å	1.93 (−15)	15.27	-26.70 ± 0.08
			1650–1750 Å	1.92 (−15)	15.25	-26.65 ± 0.05
			1750–1850 Å	2.00 (−15)	15.22	-26.59 ± 0.04
			1850–1950 Å	1.57 (−15)	15.20	-26.64 ± 0.03
	80/8/10.3	UV	1250–1350 Å	2.88 (−15)	15.36	-26.70 ± 0.04
			1350–1450 Å	2.69 (−15)	15.33	-26.67 ± 0.04
			1450–1550 Å	2.33 (−15)	15.30	-26.68 ± 0.05
			1550–1650 Å	2.49 (−15)	15.27	-26.59 ± 0.04
			1650–1750 Å	2.08 (−15)	15.25	-26.62 ± 0.03
			1750–1850 Å	2.10 (−15)	15.22	-26.57 ± 0.02
			1850–1950 Å	1.86 (−15)	15.20	-26.57 ± 0.02
			2300–2600 Å	1.38 (−15)	15.09	-26.48 ± 0.05
			2600–2900 Å	1.42 (−15)	15.04	-26.38 ± 0.05
			2900–3200 Å	1.40 (−15)	14.99	-26.31 ± 0.05
Pollock, Pica, Smith, and Webb	79/10/13	Optical	B	16.74 ± 0.11	14.83	-26.17 ± 0.05
	80/8/13		U	16.36 ± 0.09	14.92	-26.27 ± 0.02
			U	16.29 ± 0.04	14.92	
			B	16.74 ± 0.13	14.83	-26.23 ± 0.05
			B	16.94 ± 0.12	14.83	
			V	16.24 ± 0.10	14.74	-26.20 ± 0.05
Rudy and LeVan	79/10/18.2	IR	J	13.99 ± 0.25	14.38	-25.87 ± 0.10
			H	13.21 ± 0.10	14.26	-25.69 ± 0.05
			K	12.72 ± 0.10	14.12	-25.56 ± 0.05

TABLE 1.—(*Continued*)

Observers	Date (UT) (year/month/day)	Region	Observing band	Raw Data	log υ	log F_{υ}
Neugebauer	80/8/10	IR	r	16.23 ± 0.03	14.66	−26.15 ± 0.05
			J	14.24 ± 0.05	14.38	−25.81 ± 0.03
			H	13.53 ± 0.05	14.26	−25.71 ± 0.03
			K	13.03 ± 0.05	14.12	−25.62 ± 0.03
Williams and Brand	80/8/12	IR	J	14.11 ± 0.05	14.38	−25.89 ± 0.03
			H	13.32 ± 0.05	14.26	−25.71 ± 0.03
			K	12.86 ± 0.05	14.12	−25.62 ± 0.03
	80/8/19		K	12.86 ± 0.05	14.12	−25.62 ± 0.03
Balonek and Dent	79/10/26	Radio	89.6 GHz	0.14 ± 0.08[2]	10.95	$-23.85 \pm^{0.20}_{0.37}$
	79/10/23		31.4 GHz	0.19 ± 0.05	10.50	−23.72 ± 0.07
	79/11/10		15.5 GHz	0.30 ± 0.07	10.19	−23.52 ± 0.10
	80/3/27		15.5 GHz	0.15 ± 0.09	10.19	$-23.82 \pm^{0.20}_{0.40}$
	80/4/20		15.5 GHz	0.29 ± 0.08	10.19	$-23.54 \pm^{0.11}_{0.14}$
	80/8/6		15.5 GHz	0.24 ± 0.07	10.19	$-23.62 \pm^{0.11}_{0.15}$
	79/11/20		7.9 GHz	0.11 ± 0.06	9.90	$-23.96 \pm^{0.19}_{0.34}$
	80/7/21		7.9 GHz	0.18 ± 0.11	9.90	$-23.74 \pm^{0.21}_{0.41}$
Aller, Aller, and Hodge	79/9/4		14.5 GHz	0.36 ± 0.13	10.16	
	79/10/8		14.5 GHz	0.08 ± 0.11	10.16	$-23.80 \pm^{0.14}_{0.20}$[3]
	79/10/22		14.5 GHz	0.14 ± 0.11	10.16	
	79/8/11		8.0 GHz	0.36 ± 0.08	9.90	
	79/10/5		8.0 GHz	0.27 ± 0.03	9.90	−23.59 ± 0.03[4]
	79/10/18		8.0 GHz	0.22 ± 0.02	9.90	
	79/11/1		8.0 GHz	0.25 ± 0.05	9.90	
	80/8/7		14.5 GHz	0.28 ± 0.14	10.16	
	80/8/13		14.5 GHz	0.20 ± 0.06	10.16	
	80/8/23		14.5 GHz	0.25 ± 0.04	10.16	−23.61 ± 0.03[5]
	80/8/25		14.5 GHz	0.29 ± 0.05	10.16	
	80/8/28		14.5 GHz	0.19 ± 0.08	10.16	
	80/8/2		8.0 GHz	0.20 ± 0.03	9.90	
	80/8/3		8.0 GHz	0.21 ± 0.14	9.90	
	80/8/10		8.0 GHz	0.22 ± 0.04	9.90	
	80/8/11		8.0 GHz	0.28 ± 0.05	9.90	−23.62 ± 0.02[6]
	80/8/15		8.0 GHz	0.24 ± 0.02	9.90	
	80/8/30		8.0 GHz	0.24 ± 0.02	9.90	
	80/9/1		8.0 GHz	0.28 ± 0.03	9.90	
	80/8/22		4.8 GHz	0.21 ± 0.03	9.68	−23.68 ± 0.06

[1] The ultraviolet raw data is given in units of ergs $\text{cm}^{-2}\ \text{s}^{-1}$ Å.
[2] All raw radio fluxes are given in units of Jy.
[3] The measurement taken by Balonek and Dent on 1979 November 10 at 15.5 GHz was included when computing this average flux value.
[4] The measurement taken by Balonek and Dent on 1979 November 20 at 7.9 GHz was included when computing this average flux value.
[5] The measurement taken by Balonek and Dent on 1980 August 6 at 15.5 GHz was included when computing this average flux value.
[6] The measurement taken by Balonek and Dent on 1970 July 21 at 7.9 GHz was included when computing this average flux value.

a) *X-Ray Measurements*

X-ray data were obtained by the Columbia Astrophysics Laboratory with the Imaging Proportional Counter on the *Einstein* Observatory during the dates chosen for simultaneous observations. I Zw 187 was also the subject of a monitoring program designed to detect temporal flux variation.

There is an apparent decrease in flux between 1979 October 18.2 and 1980 August 10.2. However, the 1979 October measurement was made before the gain on the IPC was stabilized, so systematic errors may be the cause of the difference in counting rates. The monochromatic fluxes listed in Table 1 (which were derived from a spectral fitting procedure) are within 10% of the values obtained by imposing upon the data spectral slopes of 1.0 and 1.5 and a column density of neutral hydrogen of $3.25 \times 10^{20}\ \text{cm}^{-2}$ (estimated from Tolbert 1972). The integrated fluxes (0.5–4.5 keV) are 1.11×10^{-11} ergs $\text{cm}^{-2}\ \text{s}^{-1}$ (1979 October) and 9.8×10^{-12} ergs $\text{cm}^{-2}\ \text{s}^{-1}$ (1980 August; measurements have a 30% uncertainty). The slopes are 1.0 (1979 October) and 2.4 (1980 August), but the uncertainty in the slopes is 0.5, so this difference in slopes may not be significant.

Between 1980 April 1 and April 14, 18 exposures were made in order to identify the shortest time scale of variability. No significant changes over a time scale of hours were observed. The day-to-day fluctuations, if not due to instrumental effects, are consistent with a variability time scale similar to that found in the optical data (5 days). The greatest range in the X-ray count rate was slightly more than a factor of 2 between 1980 March and August (1.14–0.49 counts s^{-1}); the gain on the IPC was constant during this time.

b) *Ultraviolet Observations*

Ultraviolet spectra were taken with the *International Ultraviolet Explorer* (*IUE*) during the US1 shifts on the dates listed in Table 1. Although the exposures were approximately 5 hours for the short-wavelength camera and 2 hours for the long-wavelength camera, the spectra are weak. In reducing the data, saturated pixels, hits, and reseaux were removed from the line-by-line spectra. Five lines centered on the signal maximum define the signal and the adjacent five lines on either side define the background. After the background was filtered (11 point median filter) and smoothed (5 point running average), it was subtracted from the signal (the signal was not filtered or smoothed). Because of the weakness of the signal, the spectra are presented in 100 Å averages in the 1250–1950 Å region (short-wavelength camera) and in 300 Å averages in the 2300–3200 Å region (long-wavelength camera). The 1 σ errors in these averages are calculated in the usual way, assuming a normal distribution of data points about the mean. These errors may be larger than the true errors. An analysis of several *IUE* low-dispersion spectra indicates that, in addition to random errors due to photon statistics, there are systematic instrumental errors that do not form a normal distribution (to be discussed in detail in a future work). Because of the peculiar distribution of these systematic errors, the regular method of calculating the standard deviation of the mean yields a value that is too large. We estimate that the real uncertainty in the ultraviolet flux measurement listed in Table 1 is about 0.025 in log F_ν.

The reddening that was calculated, $E(B-V) = 0.025$ (after Burstein and Heiles 1978), is quite close to the reddening of several nearby objects listed by these authors. The extinction correction was made using the method described by Seaton (1980), and these data are presented in Table 1.

A power-law spectrum provides an extremely good fit to the data. The resulting spectral slopes are $\alpha = 1.00 \pm 0.07$ (1980 August) and $\alpha = 1.05 \pm 0.37$ (1979 October; due to the limited frequency range and poor quality of the spectra, the error in α is quite large). Determining the spectral slope from ultraviolet data has the important advantage that contamination by the galactic spectrum is negligible.

The difference in flux and spectral slope between the two short-wavelength spectra is not significant. The photometric uncertainty of well-exposed spectra may be as much as 10–15% in 100 Å bins, and peculiarities in the intensity transfer function at low-exposure levels may create additional errors (Holm 1980).

No emission lines are evident in these spectra.

c) *Optical and Infrared Observations*

An underlying galaxy appears on deep plates of I Zw 187 (Zwicky 1966). This galaxy contributes to the observed flux at optical and infrared frequencies, and its influence must be removed from the data. Several workers have estimated the brightness of the underlying galaxy. Oke (1978) determined that the galaxy, within an 8″ circular diaphragm, has a flux $F_\nu = 6.8 \times 10^{-27}$ ergs s^{-1} cm^{-2} Hz ($\lambda = 4326$ Å), with a 30% uncertainty. The spectral energy distributions for giant elliptical galaxies (Schild and Oke 1971; Whitford 1971) were used along with Oke's data to calculate $V(8'') = 16.97$ and $B(8'') = 18.06$, with uncertainties of 0.2–0.3 mag in each value. Weistrop *et al.* (1981) analyzed the brightness distribution of I Zw 187 and found that $V(8'') = 16.74 \pm 0.11$ and $B - V = 0.81 \pm 0.16$. Here, we adopt a value of $V(8'') = 16.85$, which is intermediate between the two determinations. Dr. T. Kinman has kindly given us his photoelectric *UBV* data of I Zw 187 (Kinman 1978, 1980) for which he has accurately measured I Zw 187 as a function of diaphragm size from 4″ to 30″ diameters. After applying the appropriate brightness corrections for seeing effects, we have determined V as a function of radius consistent with $V(8'') = 16.85$. The B magnitude at 8″ is determined less accurately than $V(8'')$ by Oke (1978) and Weistrop *et al.* because the BL Lac component contributes relatively more flux there. Therefore, we determined B and U for the galaxy by demanding that $B - V$ and $U - B$ be roughly constant as a function of radius; the color gradient effect (Strom *et al.* 1976) should be unimportant here. The results of our analysis are presented in Table 2 and are consistent with Kinman's (1978) original values (determined by a different analysis), as well as with an estimate of $V(8'')$ by Miller (1981). This radial brightness distribution is indistinguishable from those of some elliptical galaxies of comparable brightness in the rich clusters A426 (Perseus) and A2199 (K. M. and S. E. Strom 1978; S. E. and K. M. Strom 1978); it grows less rapidly than the standard growth curve for a giant elliptical (Sandage 1972).

The *UBV* data were obtained by measuring the brightness of photographic images with a 6″ fixed aperture rather than a variable aperture in the iris photometer (as was used in Pica *et al.* 1980). The use of a fixed aperture

TABLE 2

MAGNITUDES AND COLORS OF GALAXY COMPONENT OF I Zw 187

Aperture Size (″)	V	B	U	$B-V$	$U-V$	$U-B$
4	17.54	18.98[a]	...	1.44	...	...
6	16.95	18.02	18.17[a]	1.07	1.22[a]	0.15[a]
8	16.85	17.88	18.28	1.03	1.43	0.40
11	16.62	17.63	18.07	1.01	1.45	0.44
14	16.54	17.61	18.02	1.07	1.48	0.41
20	16.39	17.47	17.97	1.08	1.58	0.50
30	16.26	17.31	17.72	1.05	1.46	0.41
Average......	...	...	...	1.05	1.48	0.43

[a] Error in these measurements is 0.2 mag or greater.

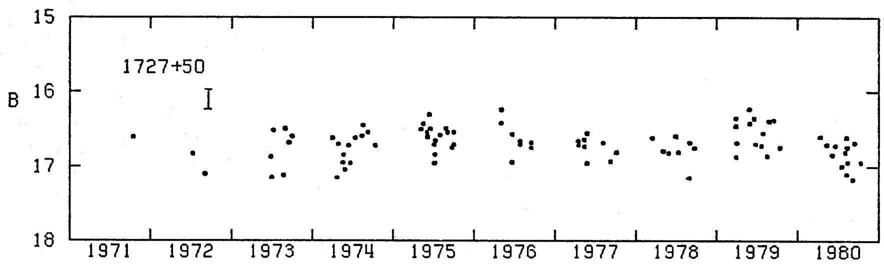

FIG. 1.—Optical monitoring of I Zw 187 (B mag) shows that its flux varies rapidly but is confined to a narrow range of about 0.85 mag. These photographic measurements were reduced with a fixed 6″ aperture iris photometer.

assures that the galaxy's contribution is constant from plate to plate; the 1979 October and 1980 August data, as well as data from other dates, were reduced by this alternative method and are presented in Figure 1. The data in Figure 1 are generally fainter by 0.1–0.2 mag than those presented in Pica *et al.* Substantial flux variations (0.6 mag) are seen in observations separated by 8–22 days. The most rapid variation, $\Delta B = 0.95$ in 8 days (5 σ effect, galaxy contribution removed), yields a variability time scale (Fdt/dF) of about 6 days, similar to the X-ray result. For the 1979 October and 1980 August measurements, the galaxy's contribution was removed and the data were dereddened (final values in Table 1 and Figures 2 and 3).

For the measurement taken at 0.655 μm ($r = 16.22$ corresponds to $F_\nu = 1.41 \pm 0.05 \times 10^{-26}$ ergs cm^{-2} s^{-1} Hz^{-1}; 5″ diaphragm), the galaxy contributes about 50% of the light (calculated from Whitford 1971, and Schild and Oke 1971). The deconvolved and dereddened flux of the BL Lac component is given in Table 1 and Figure 3.

Infrared data were obtained by three observers using photometers of different entrance apertures. In order to remove the galactic contribution properly, $V - J$, $V - H$, and $V - K$ colors for the galaxy are required. Because we have two sets of infrared data obtained through different apertures during one epoch, $V - K$ can be calculated directly, obviating the need to estimate it from typical galactic parameters. To calculate K, H, and $V - K$, we assume that $V - K$ for the galaxy is independent of diaphragm size and that $H - K = 0.21$ is a fair representation of this infrared color (Frogel *et al.* 1978); a mean value of K (or H) is then calculated. To find J, which is dominated by the galaxy more than H or K, we assume that the infrared color $J - H = 0.69$ is appropriate (Frogel *et al.*). The results of this method follow: galactic

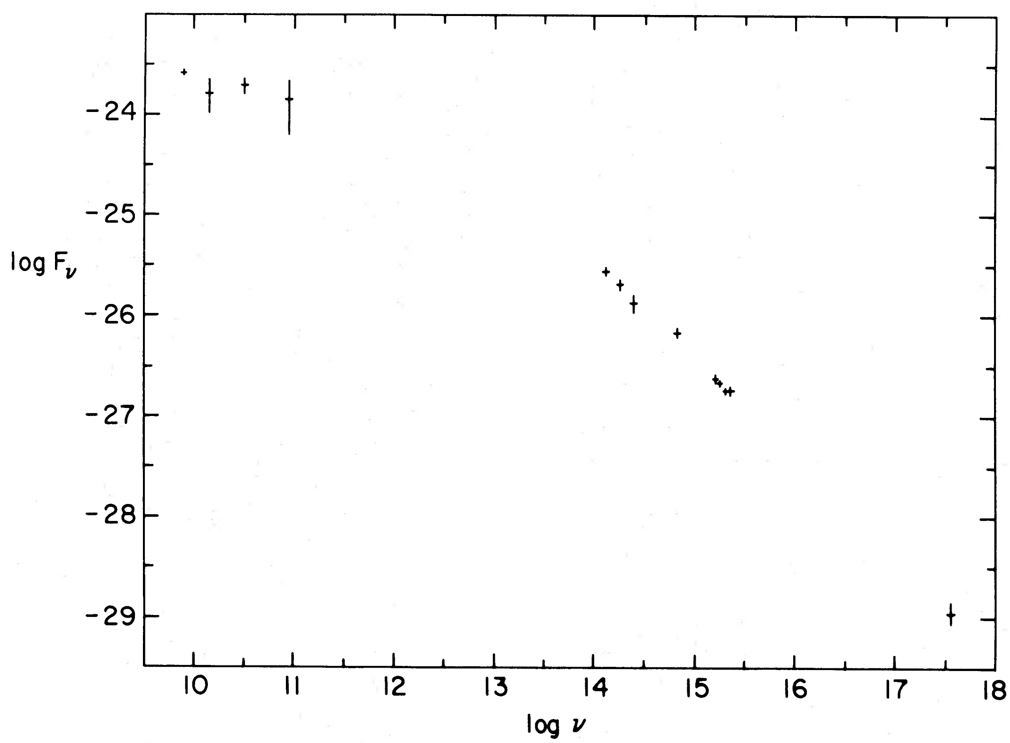

FIG. 2.—This nearly simultaneous spectrum of I Zw 187 was taken in 1979 October. The infrared-ultraviolet continuum connects smoothly with the X-ray measurement.

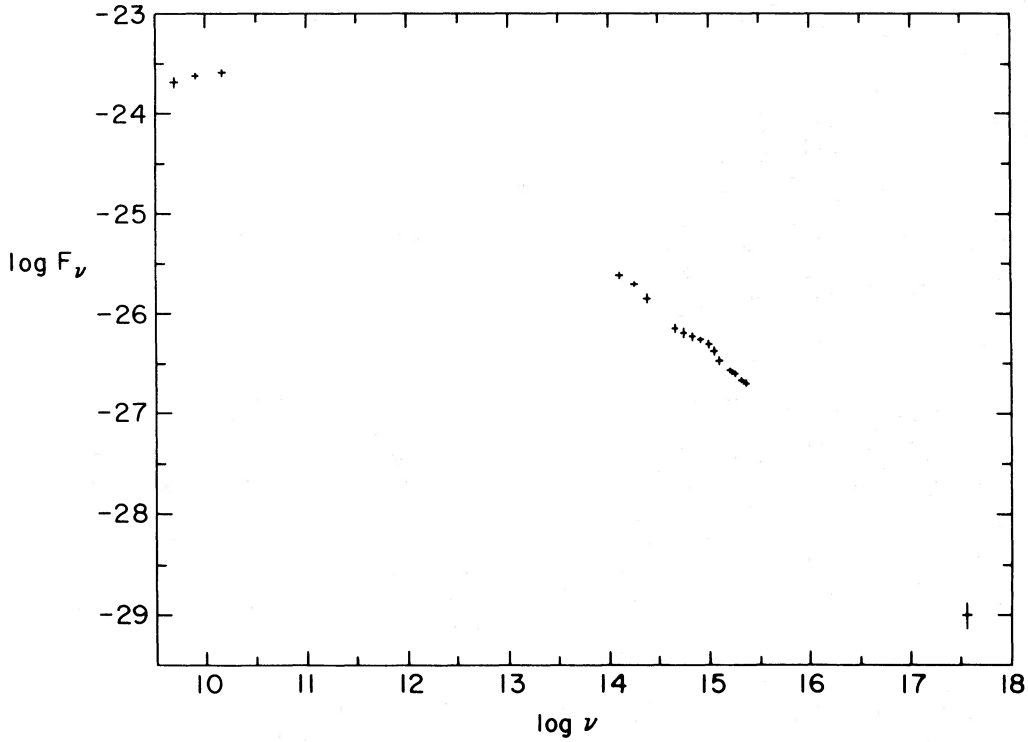

FIG. 3.—This nearly simultaneous spectrum of I Zw 187 was taken in 1980 August. Note the weak 3000 Å bump (log $\nu \approx 15$)

magnitudes within the 17″ diaphragm used by Rudy and LeVan are $J = 14.38$, $H = 13.69$, and $K = 13.48$; galactic magnitudes within a 10″ diaphragm used by Williams and Brand are $J = 14.60$, $H = 13.91$, and $K = 13.70$, and galactic magnitudes within the 5″ diaphragm used by Neugebauer are $J = 15.00$, $H = 14.31$, and $K = 14.10$. The galactic contribution to the total flux is between 50–70% in the 17″ diaphragm, 46–64% in the 10″ diaphragm, and 37–50% in the 5″ diaphragm. Of these three observing bands, the smallest galactic contribution occurs at 2.2 μm (K). The deconvolved, dereddened infrared data are presented in Table 1.

The infrared-optical spectra for the two epochs are, to within the errors, identical. The power-law fits to the dereddened, deconvolved data are characterized by slopes $\alpha = 0.85 \pm 0.10$ (1979 October) and $\alpha = 0.87 \pm 0.04$ (1980 August). These slopes are not only indistinguishable from each other, but are also indistinguishable from the ultraviolet power-law slopes. When a single ultraviolet-optical-infrared slope for each epoch is calculated, we find that $\alpha = 0.97 \pm 0.04$ (1979 October) and $\alpha = 0.88 \pm 0.02$ (1980 August). The formal difference between these values, a 2 σ effect, is probably insignificant. These slopes are similar to the values 0.93–0.80 determined by Kinman (1978) for data taken during 1977 June 11–13 and 1977 October 15 but differ from the value of 1.6 determined by Oke (1978) for data taken on 1976 May 22–23. We are not certain whether this last difference is real or whether it reflects the uncertainty inherent in Oke's deconvolution of the BL Lac galaxy spectrum.

d) *Radio Observations*

Radio measurements in the GHz region were obtained with the 26 m paraboloid of the University of Michigan Radio Astronomy Observatory at 8 GHz and 14.5 GHz during both epochs; data reduction procedures are described in Aller (1970) and Aller, Aller, and Hodge (1981). The second epoch measurements, which are considerably more accurate than the first epoch, indicate that the spectrum is relatively flat. No flux difference is found between the two epochs.

Millimeter wave measurements were obtained at 10 mm and 3 mm during 1979 October with the National Radio Astronomy Observatory 11 m telescope at Kitt Peak National Observatory. These data indicate that the radio spectrum remains flat into the millimeter region, a property typical of BL Lac objects. Additional 7.9 GHz and 15.5 GHz data, obtained at Haystack Observatory, are consistent with the 8.0 GHz and 14.5 GHz data taken at the University of Michigan Radio Astronomy Observatory.

III. DISCUSSION

Sufficient data now exist to permit us to examine the nature of flux variations in several frequency regions. Unlike most BL Lac objects, which show optical variations of 2–5 visual magnitudes, I Zw 187 has not varied by more than $\Delta B = 0.85 \pm 0.11$ during the past 7 years (Fig. 1; $\Delta B = 1.25 \pm 0.13$ with the galaxy removed). Similarly, no dramatic flux variations are found in the radio, infrared, or X-ray regions. X-ray measurements indicate flux variations of a factor of 2 (2.3 ± 0.3), which is similar to the range of optical variations (1.25 mag corresponds to a flux variation of 3.1). Consistent with this trend, no dramatic flux variations appear in the infrared data taken at Palomar Observatory between 1967 and 1980. Radio observations taken between 1972 and 1980 show no evidence at all for variation (1.4–8 GHz; LeSquéren, Biraud, and Lauqué 1972; Altschuler and Wardle 1975; Weiler and Johnson 1980; this work). To summarize, I Zw 187 has not yet displayed radio variability, and it appears to be less variable than most BL Lac objects in the infrared, optical, and X-ray regions.

Simultaneous observations are especially useful in revealing broad-band spectral features. We find evidence for a 3000 Å bump in the spectrum of 1980 August. If real, this is the first detection of the 3000 Å bump in a BL Lac object. It would suggest that this feature, which is frequently observed in QSO spectra (e.g., Neugebauer *et al.* 1979) is not associated with the emission line gas. Additional observations that allow a more thorough investigation of this feature in I Zw 187 will be presented in a future work (Bregman *et al.* 1982). A second peculiarity in the spectra, and one which is well substantiated, is the shallowness of the spectra. The infrared through ultraviolet slope of 0.88 (1980 August) is smaller than the average value for BL Lacs (Stein, O'Dell, and Strittmatter 1976), and the optical to X-ray slope of 1.0 is the smallest of any BL Lac object observed with the *Einstein* Observatory (the mean optical to X-ray slope for BL Lacs is 1.31 ± 0.05; Ku 1982).

The near equality of the infrared-ultraviolet slope and the optical–X-ray slope may have a simple explanation—we suggest that the infrared, optical, ultraviolet, and X-ray emission have a common origin in this object. When the power-law spectra defined by the infrared through ultraviolet data are extrapolated to higher energies, they pass slightly above the X-ray data point (1980 August); the difference between the extrapolated line and the X-ray data (0.38 dex) is a 3 σ effect. In the 1979 October spectrum, the extrapolated power law for infrared through ultraviolet data passes through the X-ray data point (less than a 1 σ difference). It is therefore reasonable to suggest that the X-rays are just a higher frequency part of the same power-law spectrum responsible for the infrared, optical, and ultraviolet emission. Because the optical polarization argues for a synchrotron origin for this continuous emission, the soft X-rays have a synchrotron rather than an inverse Compton origin. Using nonsimultaneous observations, Weistrop *et al.* (1981) arrive at a similar conclusion.

Our observations of the continuous spectrum provide strong evidence that the lack of strong emission lines is not caused by the lack of ionizing photons. According to current models of the emission line region (Kwan and Krolick 1981; Weisheit, Shields, and Tarter 1981), X-rays are an important source of ionization. The observed soft X-ray flux alone provides enough ionizing radiation to produce, at least, high-excitation emission lines. If the ultraviolet spectrum retains its power-law form at energies above a rydberg, sufficient ionizing radiation exists to produce emission lines at all levels of excitation. Therefore, the failure to detect lines implies that there is an insufficient amount of emitting gas rather than an insufficient number of ionizing photons.

By applying a theoretical model of the continuum emission to the data, one can determine the size, magnetic field strength, and other properties of the emitting region. The model used here is a modified version of the synchrotron self–Compton model of Jones, O'Dell, and Stein (1974*a*, *b*). Briefly, the emitting region is homogeneous so it is characterized by single values for the magnetic field and particle density. The only modification of the stationary model which we include here is that the emitting region may have a bulk velocity with respect to the rest frame of I Zw 187 directed toward or away from the observer; beaming effects can be included.

The five observables that uniquely define this model are: (1) the power-law slope of synchrotron radiation; (2) the frequency υ_b and (3) flux F_b at which the synchrotron radiation becomes optically thick; (4) a measure of the amount of inverse Compton radiation ($E_\upsilon{}^{sc}$); and (5) the flux variability time scale (Fdt/dF).

The power-law slope is defined by the infrared through ultraviolet data ($\alpha = 0.9$). The X-ray data, which are probably not due to inverse Compton radiation, yield an upper limit to the inverse Compton contribution ($E_\upsilon{}^{sc} < 1$). The quantities υ_b and F_b are not observed directly, but the simultaneous spectra define their allowed ranges. If the rising infrared-ultraviolet power-law slope turns over and becomes flatter (presumably because of self-absorption), then the turnover point defines υ_b and F_b. In practice, one finds these quantities by extrapolating the radio spectra until they intersect the extrapolated infrared-ultraviolet power-law. Using this method, $\upsilon_b \approx 4\text{–}10 \times 10^{11}$ Hz and $F_b \approx 0.2\text{–}0.4$ Jy. The time scale for flux variation, about 5 days (§§ II*a* and II*c*), enables one to include the effects of source motion on the model. Because we suggested that $E_\upsilon{}^{sc} < 1$, one formally calculates lower limits to the magnetic field $B(G)$, size s(pc), and the motion of the emitting region with respect to the local cosmological rest frame (Lorentz factor γ; Table 3). However, these quantities are so weakly dependent upon $E_\upsilon{}^{sc}$ (e.g., $s \propto E_\upsilon{}^{sc-0.1}$) that these lower limits to s and γ are good estimates of their values as long as $E_\upsilon{}^{sc}$ falls in the range found for other QSOs and BL Lac objects. For X-ray–detected quasars (e.g., survey of Ku, Helfand, and Lucy 1980), $E_\upsilon{}^{sc} > 10^{-5}$ and typically $E_\upsilon{}^{sc} \approx 10^{-3}$ if the

TABLE 3

PROPERTIES OF THE NONTHERMAL CONTINUUM EMITTING REGION

$E_\upsilon{}^{sc}$	log F_b	log υ_b	θ (mas)	s (pc)	$B(G)$	γ
1.0	−23.4	11.6	5.0 (−3)	4.4 (−3)	8.9 (1)	1.001
1.0 (−3)	−23.4	11.6	8.6 (−3)	5.8 (−3)	1.1 (3)	1.053
1.0	−23.7	12.0	2.0 (−3)	2.8 (−3)	6.1 (2)	1.080
1.0 (−3)	−23.7	12.0	3.5 (−3)	3.7 (−3)	7.4 (3)	1.007

X-rays arise from the inverse Compton process (models in which $E_\nu^{sc} = 10^{-3}$ are presented in Table 3).

From this analysis, we find that the size of the emitting region is approximately a light-week ($\sim 10^{16}$ cm) and that there is no significant relativistic motion of the emitting region ($\gamma \approx 1$). The magnetic field is equal to or greater than 10^2 *G*, a value substantially larger than the milligauss fields found in earlier analysis of quasar data (Jones, O'Dell, and Stein 1974*b*). A calculation of the energy density of the magnetic field indicates that it is comparable to or greater than the energy density of emitting particles. Because the radio emission, which occurs at frequencies lower than the turnover frequency, does not behave like a self-absorbed source, we suggest that the emission originates in a "tapered" source (i.e., a density gradient in the source causes it to remain luminous but appear larger at lower frequencies). This interpretation is consistent with the VLBI size (> 1.2 milli-arcsec; 5 GHz) being larger than the theoretical size of the optically thin emitting region.

IV. CONCLUSIONS

Simultaneous radio, infrared, optical, ultraviolet, and X-ray observations of I Zw 187 were made during 1979 October and 1980 August. Additional nonsimultaneous data have been accumulated in these observing regions during the past 15 years. We find that:

1. I Zw 187 is less variable than most BL Lac objects at infrared, optical, and X-ray frequencies; it has not been observed to vary in the GHz range.

2. Nonsimultaneous observations show that the range of flux variations and the shortest time scale for variation are approximately the same in the X-ray and optical observing bands.

3. The infrared-optical-ultraviolet spectrum is characterized by a power law of slope 0.9, and the X-ray data fall close to an extrapolation of this power law. This result is consistent with the infrared, optical, ultraviolet, and X-ray emission all having a common origin, probably the synchrotron process.

4. There is a broad, weak bump in the continuum at about 3000 Å, the first indication that this feature may exist in BL Lac objects.

5. The nearly flat radio spectrum and the infrared-optical-ultraviolet spectrum would intersect in the 4–10 $\times 10^{11}$ Hz range. The point of intersection may be a measure of the frequency at which the source becomes optically thick to synchrotron radiation.

6. When the simultaneous spectra are analyzed in terms of a synchrotron self–Compton model, we find that the size of the optically thin emitting region is approximately 10^{16} cm, that the magnetic field is equal to or greater than 10^2 *G*, and that there is no significant bulk motion of the emitting region.

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