THE UV VARIABILITY OF THE SEYFERT I GALAXIES III Zw 2 AND MARKARIAN 509

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III Zw 2 and Markarian 509 are classified as classical Seyfert I galaxies based on their broad emission line spectra and strong blue optical continuum[1]. The optical spectra of both galaxies are similar -- Balmer emission with a full-width-zero-intensity of ∿ 150 Å, weak Fe II emission and weak He emission[1]. The redshift of III Zw 2 is Z = 0.091, and its magnitude and colors are V = 15.6, U-B = -0.70 and B-V = 0.52. The redshift of Markarian 509 is Z = 0.034 and it has V ≅ 13.1, U-B = -0.98 and B-V = 0.22.

The two galaxies differ markedly in their radio properties. III Zw 2 is a strong source with a highly variable compact component[2,3] while MK 509 is a very weak source[4,5]. Both galaxies show significant variations in x-rays[6,7] and MK 509 has shown variations at optical wavelengths as well[8]. We have made simultaneous observations in the ultraviolet, optical and infrared in order to examine three fundamental aspects of the origin of the continuum emission: (1) are these thermal and nonthermal components, (2) how large is the emitting region, and (3) does the UV flux originate in the same region responsible for the optical, IR, radio and/or x-ray continuum emission?

The ultraviolet observations were made in the low dispersion mode through the large aperture of IUE. Exposure times for Mk 509 were 40 min in both short and long wavelength cameras; those for III Zw 2 were 3½ hours in the short wavelength camera. Mk 509 was observed in May, August and November of 1979. III Zw 2 was observed in May of 1978 and in May and August of 1979. The average short wavelength spectra are shown in figure 1; more detailed discussions of these spectra will be published later[9,10]. We measured UV fluxes in bandpasses of 70-200Å free of strong emission lines. Simultaneous optical data were obtained with a photon-counting reticon and the 1.5 m Tillinghast Reflector at Mt. Hopkins. Broad band IR photometry was obtained within 10 days of the UV measurements with the CFA InSb system on the 2.1 m at KPNO. We also accumulated all other published optical[11,12,13,14], IR[15,16,17,13] and x-ray[18] photometry. Additional unpublished x-ray[19] and radio[20] data were kindly made available by J. Delvaille and W. Dent and T. Balonek.

Although we do not have sufficient simultaneous coverage to discuss timescales and detailed spectral changes, we have enough information to discuss amplitudes and long term trends. Two ways of characterizing the amplitude of variation are the ratio of the variance (σ) to the mean (μ) and the ratio of the maximum excursion (Max E) to the mean. These yield identical information if the deviations are characterized by a normal distribution; however Max E/μ is much more sensitive to the presence of a long tail in the distribution. It should be pointed out that it would be better to use the median rather than mean for these characterizations provided the median is well defined.

Table 1 gives estimates of σ/μ and Max E/μ derived from all the available data at the frequencies listed. n is the number of observations and $\bar{f}$ is the mean flux density in each band. Figure 2 shows the energy distributions from the x-ray to the radio. We also give an estimate of the observational error for a single observation (σ/μ has been corrected for σ obs) at each frequency. For the UV observations, the error in the observed flux -- calculated by examining the pixel to pixel deviations over our bandpasses -- is comparable to the measured calibration error in IUE[21]: both are ∿ 6%. The other errors are as quoted by the observers.

For III Zw 2, the amplitude of the variations in the UV-O-IR range is less than or of order 15% whereas in the x-ray and high frequency radio the variations exceed 50%. The amplitude of the variations in Mk 509 decreases steadily from the x-ray to the infrared.

Figure 3 shows the behavior of III Zw 2 in the x-ray through radio (high frequency) from May 1978 through Dec. 1979. The simultaneous outburst in the radio and x-rays is apparent, but no such variation is seen in the optical and IR. Although we do not have a UV measurement at the peak of the outburst, the UV data in 1979 follow the optical data well but do not follow the radio data.

For both objects, the overall energy distribution appears to be non-thermal. It has been suggested that the IR continuum in III Zw 2 is due to dust[17,15], however the optical and UC observations of III Zw and 2 and Mk 509 suggest that this is not the case. The Hα/Hβ/Hγ ratios in both objects indicate little reddening for the region of permitted line formation and the equivalent widths of the optical and UV lines do not vary. The IR-UV spectra of III Zw 2 and Mk 509 have the same shape. Both are reasonably well characterized by a powerlaw with an emission feature at 3000 Å (also often seen in quasars[12]). Finally, there is no evidence for the 2200 Å feature in the long wavelength spectrum of Mk 509. If the IR were re-radiated UV, we would expect to see this feature[22].

If the IR is not thermally reradiated UV flux, the low amplitude of variability in UV-IR indicates that the region in which this radiation originates is not the same as that in which the radio and X-rays are produced. The simultaneous appearance of bursts in the radio and X-ray implies that the X-radiation is inverse Compton scattered flux produced in the compact radio component.

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Table 1 (a) III Zw 2 Variability

Band	log ν (Hz)	n	σ/μ	Max E/μ	log $\overline{f}$ (ergs/cm^2/s/Hz)	σ_{obs}
2-6 Kev	18.0	7	0.50	1.66	-28.91	.20
1475 Å	15.31	2	—	—	-26.14	.10
1595 Å	15.27	3	0.12	0.22	-26.12	.10
1830 Å	15.21	3	0.12	0.22	-25.92	.10
3500 Å	14.94	6	0.13	0.46	-25.43	.10
4500 Å	14.83	9	0.15	0.42	-25.39	.05
5500 Å	14.74	8	0.12	0.44	-25.34	.05
7000 Å	14.63	7	0.12	0.44	-25.22	.05
1.25 μ	14.38	14	0.11	0.46	-25.02	.05
1.65 μ	14.26	12	0.13	0.45	-24.88	.05
2.20 μ	14.13	13	0.10	0.38	-24.61	.05
3.5 μ	13.93	4	(0.10)	0.29	-24.42	.10
10.1 μ	13.48	1	—	—	-24.36	.20
90 GHz	11.0	8	0.89	2.78	-22.65	.20
30 Ghz	10.5	8	0.33	0.91	-22.54	.10
15.5 GHz	10.2	21	0.17	0.64	-22.69	.07
7.9 GHz	9.9	11	0.21	0.66	-22.79	.05

Table 1 (b) MK 509 Variability

Band	log ν (Hz)	n	σ/μ	Max E/μ	log $\overline{f}$ (ergs/cm^2/s/Hz)	σ_{obs}
2-10 Kev	18.16	4	(0.27)	(0.74)	-28.67	.15
1430 Å	15.32	3	0.21	0.40	-25.34	.10
1760 Å	15.23	3	0.19	0.35	-25.23	.10
2250 Å	15.12	3	0.16	0.31	-25.11	.10
2660 Å	15.05	3	0.11	0.20	-25.00	.10
3500 Å	14.93	1	—	—	-24.82	.10
4000 Å	14.89	2	—	—	-24.87	.05
4700 Å	14.81	4	0.11	0.25	-24.93	.03
5400 Å	14.75	4	0.06	0.11	-24.90	.03
5900 Å	14.71	4	0.07	0.16	-24.88	.03
7000 Å	14.63	3	0.10	0.23	-24.78	.05
1.25 μ	14.38	3	0.01	0.05	-24.53	.03
1.65 μ	14.26	3	0.01	0.02	-24.36	.03
2.20 μ	14.13	3	0.04	0.07	-24.18	.03
3.5 μ	13.93	4	(0.11)	—	-23.92	.15
10.1 μ	13.48	1	—	—	-23.85	
6 cm	9.70	1	—	—	-25.40	
21 cm	9.15	1	—	—	-24.90	

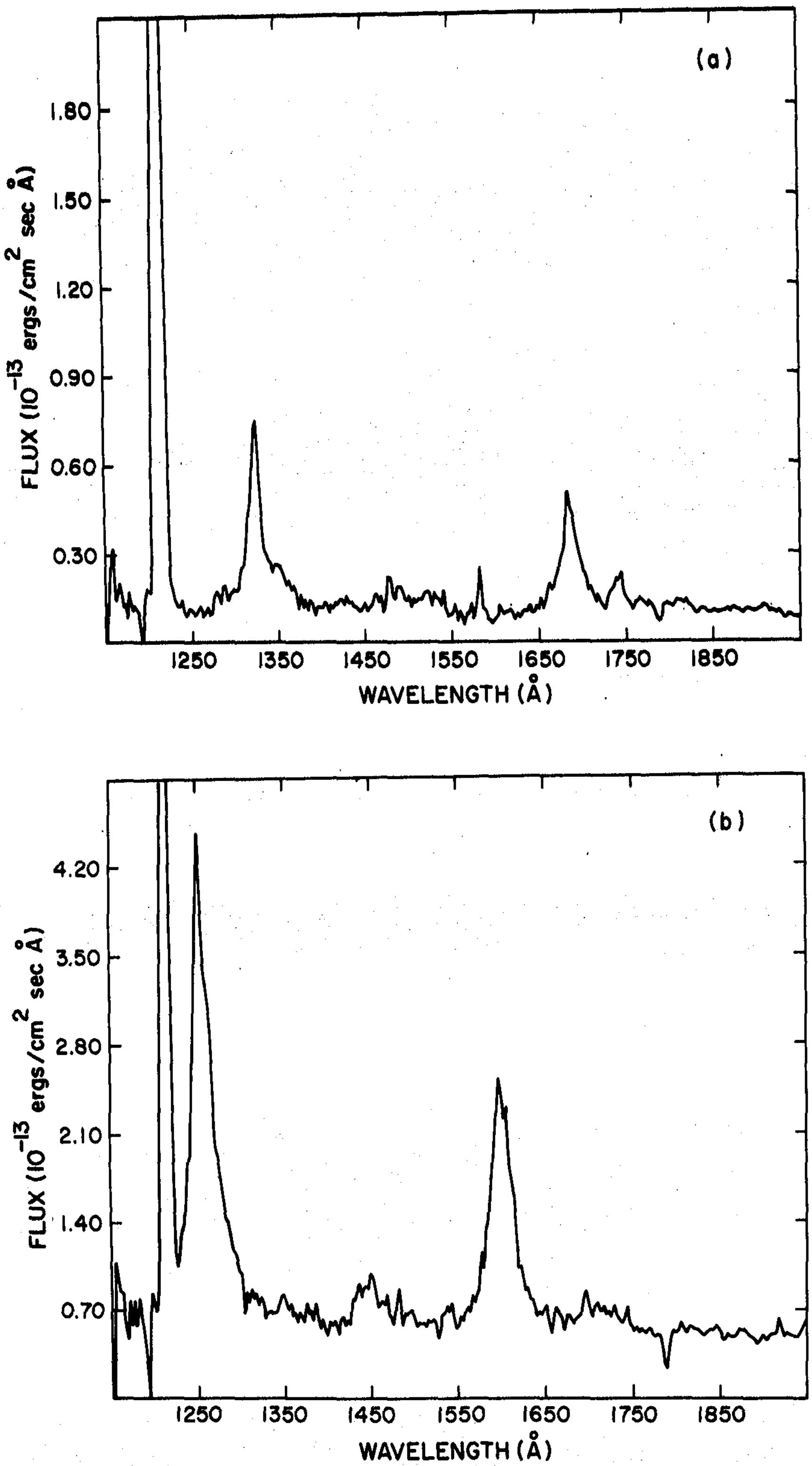

Fig. 1. IUE SWP spectra of (a) III Zw 2, and (b) Mk 509.

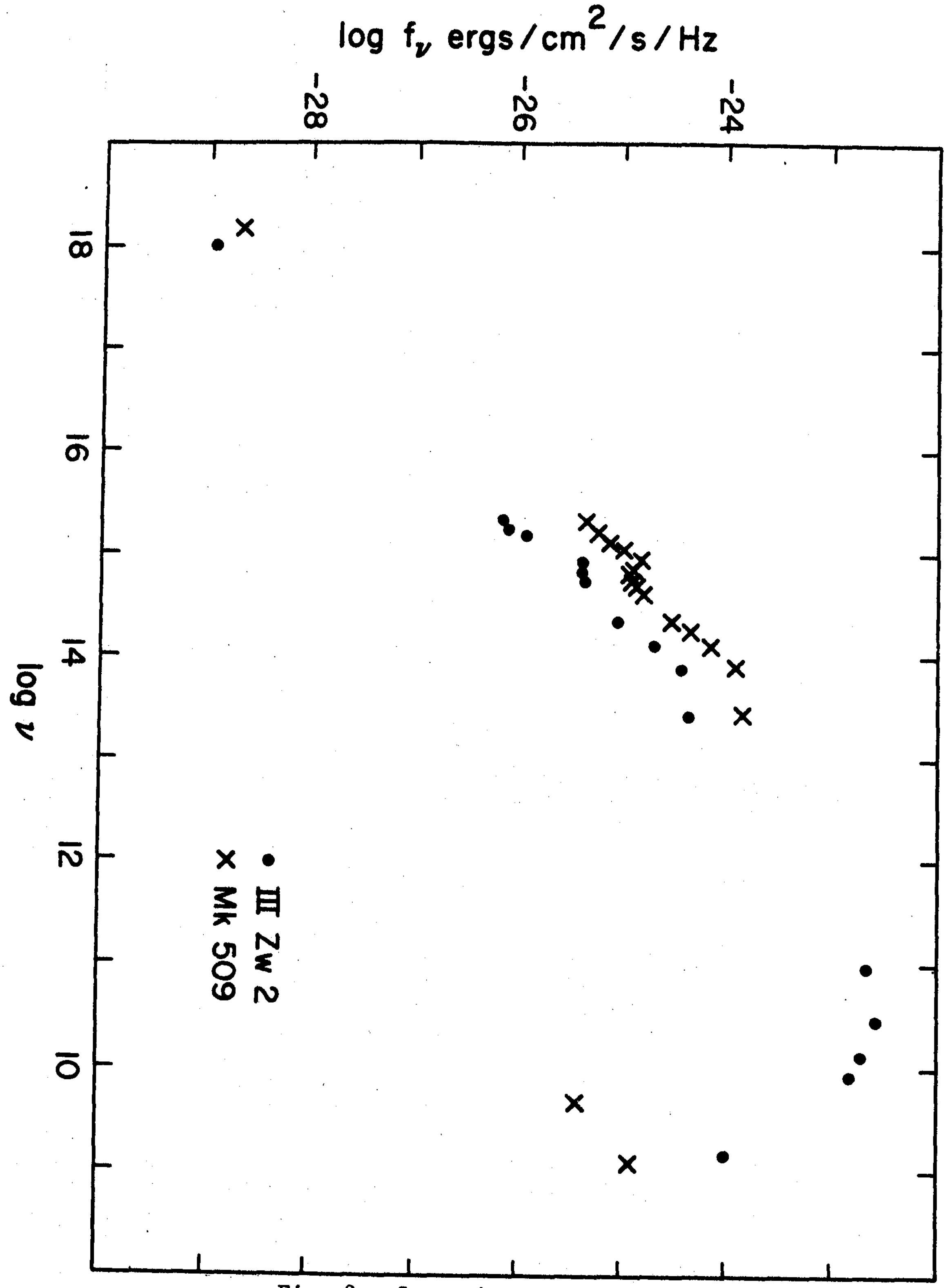

Fig. 2. Composite energy distributions - Radio through X-ray - for III Zw 2 and Mk 509.

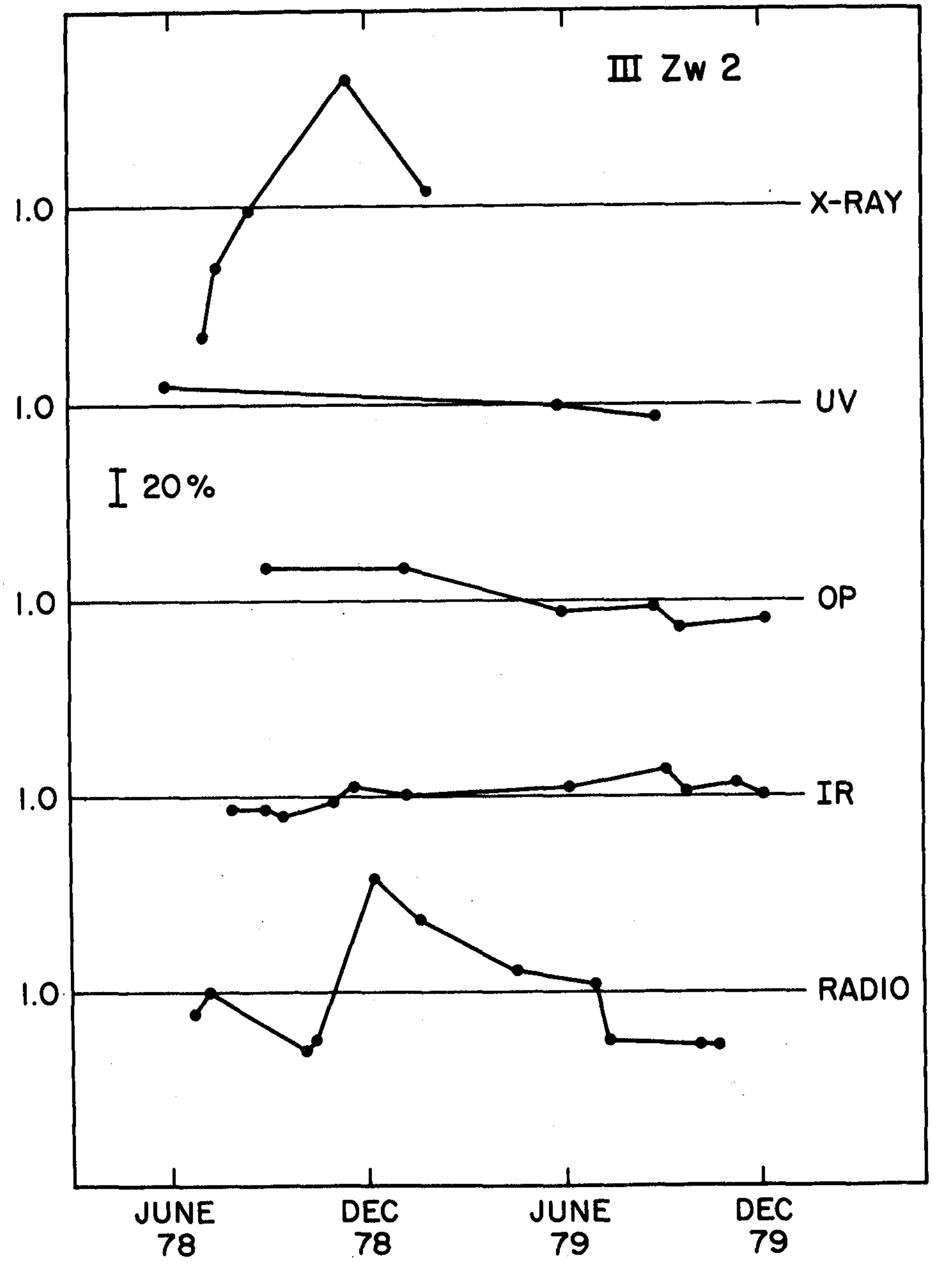

Fig. 3. X-ray, UV, optical, IR, and radio light curves for III Zw 2 plotted as deviations relative to the mean flux. Available data are shown for the time period June 1978 to December 1979. The lines between points are only meant to aid the eye and are not necessarily representative of the true light curve.