IUE OBSERVATIONS OF WZ SAGITTAE IN OUTBURST

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The International Ultraviolet Explorer was used to obtain spectra at both 7 Å and 0.2 Å resolution of the recurrent nova WZ Sagittae during its 1978 outburst. The first spectra were obtained on 1978 Dec 1.8 UT, approximately 0.7 days after discovery. The decay from outburst was followed until 1979 Jan 1, after which it was too near the Sun to be observed. A post-outburst spectrum was obtained on 1979 July 11. In this paper, preliminary results from the analysis of the low resolution spectra are discussed. These observations will be used to support the similarity between WZ Sge and dwarf novae and to test accretion disk models.

The images were processed in the standard manner (Boggess et al. 1978). There may be some photometric error in the 1978 Dec spectra in the wavelength range from 1150 Å to 2000 Å. An incorrect Intensity Transfer Function (ITF) was used to process IUE short wavelength spectra between 1978 April 22 and 1979 July 7. The nature of the ITF problem is such that spectra which were underexposed or which had high radiation-induced backgrounds might have photometric errors of 20% or more. Well exposed spectra of sources with temperatures of 15000 °K or more will have lower errors. WZ Sge was sufficiently bright in the UV that the exposure times were 200 seconds or less. As a result the background is low and most of the spectra are well exposed so that we expect the ITF error to be minor for these calibrated spectra. In any event, the largest errors would appear in the 1500 to 2000 Å region.

Throughout the outburst period there were few changes in the identity of the strong lines which appeared in the spectrum. N V 1240 Å, Si III 1300 Å, C II 1335 Å, Si IV 1400 Å, C IV 1550 Å, He II 1640 Å, and Al III 1855 Å persisted throughout the outburst. An illustration showing the spectra of WZ Sge at several times in the outburst period is given in the review paper by Sparks et al. (1979). The N V, C IV, and He II lines appeared as doubled emission lines in the earliest spectra. The C IV and N V emission lines strenghtened relative to the continuum as the visual magnitude faded from 8.0 to 10.5 and then weakened as the visual magnitude fell further. A strong absorption line of Si II 1265 Å

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appeared after the first spectrum and persisted throughout the rest. By the time the post-outburst spectrum was obtained a broad Lyman α absorption line had appeared. At no stage did the spectrum of WZ Sge resemble that of Nova Cygni 1978 which evolved from an F or G type spectrum through a stage with strong chromospheric emission lines and eventually to a stage with high excitation forbidden lines and an undetectable continuum.

The continuum radiation of WZ Sge declined simultaneously at both visible and ultraviolet wavelengths. This is illustrated in Fig. 5 of Sparks et al. Which shows magnitudes derived from the IUE's Fine Error Sensor and from a 50 Å band about 1450 Å which contains no strong lines. The UV flux even reproduces a 1.5 mag dip in the visual light curve centered on 1979 Jan 1. There clearly is no phase lag between the visual and ultraviolet spectra such as seen for FH Serpentis (Code 1972) and for Nova Cygni 1978 (Sparks et al.). This behavior is similar to the apparent behavior of the dwarf nova SS Cygni (Holm and Gallagher 1974; Heap et al. 1978).

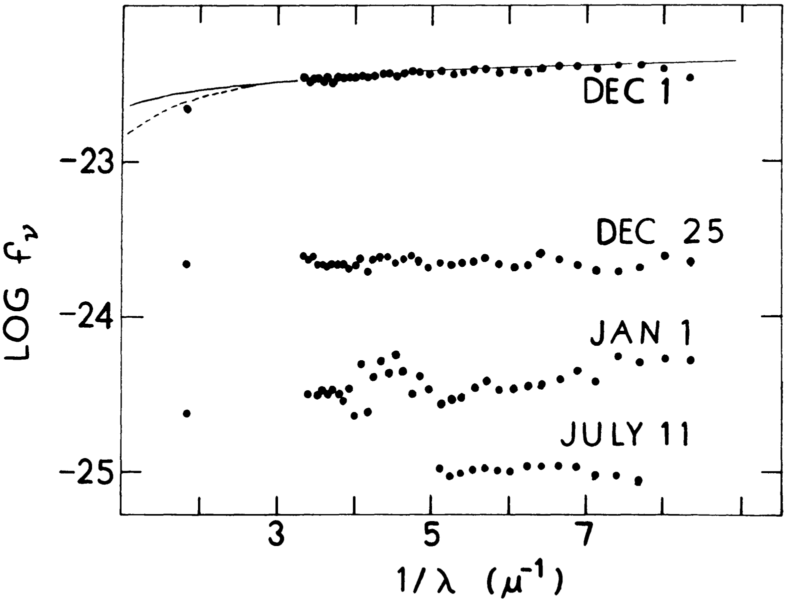

Fig. 1. The spectral energy distribution of WZ Sagittae

The ultraviolet energy distribution of WZ Sge on several occasions during and after outburst are shown in Figure 1. The data were averaged in 50 Å bins. There is little change in the overall energy distribution even though the luminosity fell by a factor of 400 between 1978 Dec 1 and 1979 July 11. This supports the conclusion that the visual and UV fluxes declined simultaneously.

The absence of an interstellar absorption feature at 4.6 μm^{-1} in Figure 1 implies that the extinction is low. Analysis using the method of Holm and Cassinelli (1977) shows that $E(B-V) \leq 0.025$. The upper limit on the color excess can be used to derive an upper limit on the distance. Unfortunately, UBV colors have been measured for few stars in the direction of WZ Sge. The Photoelectric Catalogue (Blanco et al. 1968) gives A type stars, HD 191083 and BD+16 4120B, at a distance of about 300 pc (if main sequence) and having color excesses of 0.1 and 0.05 respectively. The implication from these stars is that WZ Sge is nearer than 300 pc. This estimate is in agreement with the estimate of 65 pc by Krzeminski and Kraft (1964) from a spectroscopic analysis which assumes the source of the visual light is the white dwarf and with the estimate of 83 pc by van Maanen (1926) from a trigonometric parallax. Although there are weakness in the groundbased data supporting the distance limit, the evidence suggests that the luminosity of WZ Sge at maximum light is, to an order of magnitude, similar to that for dwarf novae and much below that of classical novae.

Since the interstellar extinction is negligible, the observed energy distribution can be compared directly with models. We have used both stellar atmosphere models and model accretion disks. The Kurucz et al. (1974) line blanketed models give good agreement between the Dec 1 observations and a 20000 °K atmosphere and between the Dec 25 observation and a 16000 °K atmosphere. If the distance is 100 pc, the photosphere radius is 0.46 $R_\odot$ and 0.17 $R_\odot$ respectively on the two dates. It is probably fortuitous but interesting that the radius on Dec 1 is identical to the semi-major axis of the orbit derived by Robinson et al. (1978). We also considered accretion disk models because Robinson et al. (1978) find that at minimum an accretion disk accounts for most of the visual light. All the disk models of Herter et al. (1978) increase too steeply into the ultraviolet. A possible explanation of this disagreement between observation and theory, suggested by Herter et al. themselves, is that the disk is truncated at too small a radius. A simpler steady-state disk model (Lynden-Bell 1969) predicts a power law spectrum, $\nu^{1/3}$ over a limited range of frequency. This power law spectrum is illustrated in Figure 1 by a solid line. There is surprisingly good agreement with the Dec 1 observed spectrum. The agreement is not as good with later observations in December, but there is a region of agreement with July 11 observation. Note that the dashed line in Figure 1 represents a modification of the power law spectrum which results from truncating the disk at a radius which does contribute a significant amount of radiation in the visual region.

The equations of Lynden-Bell (1969) can be solved formally to show that

$$R_{disk}/R_{*} \gg 1.3\ (\dot{M}_{max}/\dot{M}_{min})^{0.25}\ \nu_{max}/\nu_{min}$$

where R_{disk} is the outer radius of the disk at maximum, R_* is the radius of the white dwarf, $\dot{M}_{max}$ and $\dot{M}_{min}$ are mass transfer rate at maximum and minimum respectively, ν_{max} is the lowest frequency at maximum light at which the power law spectrum is a good fit, and ν_{min} is the highest frequency at minimum light at which the power law is good. From the 1978 Dec 1 and 1979 July 11 observations, this equation gives $R_{disk}/R_{*} >> 70$. If this analysis is correct, the result implies that the mass of the white dwarf must be larger than estimated by Robinson et al. (1978) so that the stellar radius drops below 0.01 solar radii and the semi-major axis is increased above 0.5 solar radii. It should be noted that the data on which this conclusion is based may include photometric errors as discussed above. We shall re-evaluate this result when spectra can be corrected for the error.

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DISCUSSION FOLLOWING HOLM, WU, SPARKS, SCHIFFER AND BOGGESS

Piirola: We observed the linear polarization of Nova Cygni 1978 in the UBV bands. The polarization increased from ∿1.5% to ∿1.9% between October 1 and 11. Also position angle was changed somewhat. This correlates with the infrared observations which show that a dust-formation phase was started between October 7 and 15.

Pringle: I would like to caution taking the formal value obtained for the outer radius of the disc. I have a feeling that this value should be taken rather as an upper limit since there are a number of effects that can help to deter the turn down of the theoretical disc spectrum at long wavelengths--for example if the outer regions of the disc become optically thin or if there is any reprocessing of the inner disc radiation by the counterparts of the disc or by the companion star.

Whelan: The disc atmospheres of Herter et al. are cut off at hot outer temperatures ($T \sim 20000K$) so they have a small value of R_{out}/R_{in}. That is why those models do not fit your data where you found $R_{out}/R_{in} \sim 100$. The black body Lynden-Bell model is good and the atmosphere models of Mayo et al. have larger values of R_{out}/R_{in} and go to cooler ($T \sim 5000K$) outer radii. Observationally we know that there are cool regions of the disc because we see low ionization potential neutral or once ionized species.