IUE ULTRAVIOLET SPECTRA OF V SAGITTAE

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V Sge is a short period, double-line spectroscopic and eclipsing close binary which is also intrinsically variable through a range of at most 3 mag in visual and photographic light. Almost all modern insight is founded upon the interpretation by Herbig, et al. (1965), who developed the evidence for the binary nature of the star, evaluated the nearly 0.5 day Keplerian period, studied the short-term Doppler and intensity variations of the spectrum, and obtained a limiting representation of the intrinsically noisy ultraviolet light curve. The orbital plane view of the binary, as developed by these authors, shows patchy distributions of O IIIfl and O VI emissions and mass loss from the system as a whole.

In view of the facts that (a) the Herbig, et al. study predates modern modelling of cataclysmic binaries as summarized, e.g., by Robinson (1976) and (b) numerous cataclysmic variables have periods up to several thousand days, it seemed useful to re-examine the evidence for cyclical eruptions for V Sge. The light curves by Campbell (1912, 1918, 1938), Jacchia (1931), Ryves (1932), the timings of maximum light by Gaposchkin (1952), and numerous remarks in the recent J.R.A.S. Canada attributed to AAVSO observers have all been scrutinized anew. There are obvious seasonal selection effects in these estimates and measures and, when these effects are removed, an outburst cycle length between 1.2 and 1.8 years is very strongly suggested over the interval from 1904 to 1976. Such an outburst cycle length is characteristic of dwarf novae. Superposed upon this variability are much higher frequency outbursts and declines and these in turn are inflected by the Keplerian eclipse modulation.

Until recently, it has been difficult to determine if the Keplerian period is constant. Partly, this is due to the intrinsic variability of the minima; even photoelectric determinations show noise which is surprisingly large. By now, however, almost 21000 cycles of photometric

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history exist and all of these minima, faced against the ephemeris by Herbig, et al., lead to an improved ephemeris:

$$\text{Hel. Pr. Min.} = 2437889.9136 + 0.5142180E - (0.86 \times 10^{-10})E^2. \quad (1)$$

This fit to the residuals is significantly better than is either linear improvements to the period and epoch or a cubic in E. There can be no doubt that the period has been decreasing. If the period diminution be associated only with the systemic mass loss seen spectrographically and if the mass loss were isotropic, $\Delta\mathfrak{M} \simeq 8.2 \times 10^{-10}\mathfrak{M}$, where $\mathfrak{M}$ is counted in units of the solar mass. For a systemic mass $\simeq 3\odot$, the mass loss would be of the order of $9 \times 10^{-8} \odot$/yr.

In 1978 V Sge was observed on the IUE program PG2SS, originally conceived by S. Sobieski. The star is so faint and the Keplerian period so short that only low dispersion spectra (R ≈ 6Å) could be obtained. In all, 9 SWP (1150 Å < λ < 1950 Å) and 9 LWR (1850 Å < λ < 3300 Å) images were obtained, but two spectra are unusually noisy and three of the LWR spectra are saturated through part of the dispersion. Exposure times ranged from 9 to 40 minutes. The spectra are equally divided between large and small aperture exposures, and conversion of the fluxes from small to large aperture data is based upon the assumption that no significant changes occur over intervals as short as 10 and as long as 36 minutes. The maxima of the eclipsing light curve are sampled by 8 spectra, secondary minimum by 2 spectra, and primary minimum by only 8 spectra.

Representative spectra are shown in Fig. 1 and 2. As can be

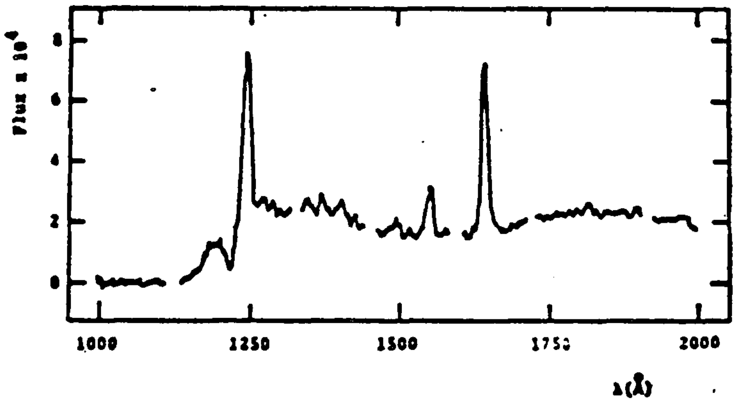

Fig. 1 - Background-subtracted, natural system spectrum of V Sge, 1150 Å < λ < 1950 Å.

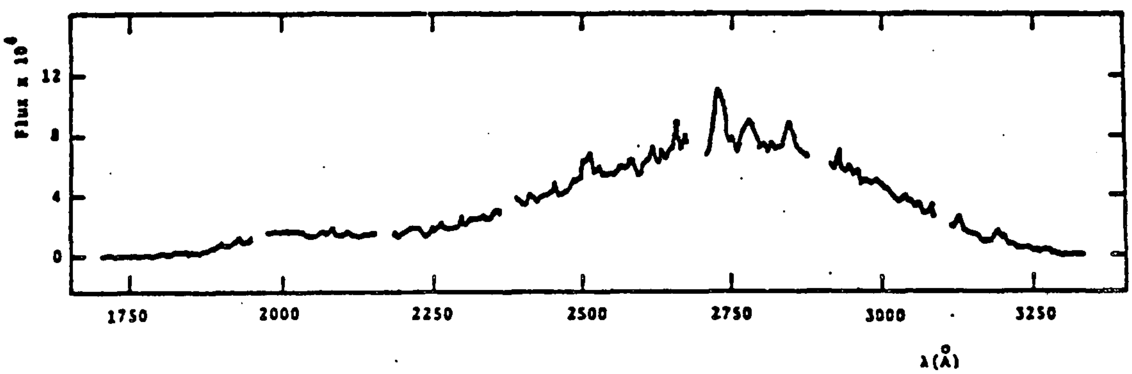

Fig. 2 - Background-subtracted, natural system spectrum of V Sge, 1850 Å < λ < 3300 Å.

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seen, the appearance of the spectra is dominated by emission features. The only absorption which can be detected is Lα and its profile is sometimes cut up by geocoronal emission, the strength of which depends upon the exposure time and chosen aperture. The spectral resolution is so low that the observed wavelength of the Lα absorption cannot be tested against the expansion velocities observed by Herbig, et al. for the weak Balmer absorption reversals. As nearly as can be measured, the equivalent width of the Lα absorption is ≈8Å, but this is likely a lower limit since stellar He II λ1215 and Lα could also be in emission for this star.

As nearly as possible, a smooth free-hand continuum was drawn on each spectrum taking account of the noise level and the emission features. At intervals of 50Å these smoothed continuum levels were corrected for the cathode responses and the familiar interstellar absorption dip near 2200 Å was evident. The reddening law given by Jamar, et al. (1976) was assumed and sample values of E(B-V) were tested in order to remove the interstellar dip and to avoid a spurious bump. A value of E(B-V) = 0.20 was found. This may be compared to the value of 0.40, associated with a distance of 2.75 kpc, chosen by Herbig, et al. to be the best compromise from determinations by UBV photometry, the absence of galaxies in this field, and the strength of the interstellar K-line. Correction for a value as large as 0.40 introduces a bump into the ultraviolet spectrum. On the other hand, Fitzgerald (1968) finds $0.0 < E(B-V) < 0.1$ out to a distance of 1.5 kpc in the field of V Sge. A value of E(B-V) this low, however, leaves an absorption dip near λ2200. A distance of ≈2 kpc is suggested as the best determination consistent with the IUE spectra.

The spectra were obtained over an interval of 179 days. The FES monitor on board the spacecraft provides V magnitudes (to ±0.1 mag), and these were compiled in phase by ephemeris (1). These V observations do not yield a phase-locked eclipsing light curve of the kind obtained by Herbig, et al., and this must be due, in part, to the intrinsic variability over such a long period of time. Fluxes at 6 wavelengths (3 each from the SWP and LWR spectra) apparently free of line emission have been phased by ephemeris (1). These also do not show the familiar eclipsing-type light curve although phase coverage is far from dense. It is clear, therefore, that the intrinsic variability, known from ground-based observing, also occurs in the satellite UV interval.

The calibrated, reddening-corrected fluxes were then studied in order to derive a temperature. This entailed piecing together SWP and LWR spectra obtained over an interval as long as $0^{d}.08 = 0.16P$. If variability has occurred over time scales shorter than this interval, it will have been ignored in the piecing together of the SWP and LWR spectra. Several possibilities were investigated. (1) The masses and radii given by Herbig, et al. could suggest non-degenerate stars. Therefore, H-rich atmospheres from Carbon and Gingerich (1969) were tested against the IUE continuum fluxes. For temperatures as low as are suggested by the masses and radii, no fit whatever could be obtained to the slope of the IUE fluxes. (2) For H-rich model atmospheres hotter than the masses and radii would suggest, failure was also conspicuous. (3) Considerably greater success was attained with white dwarf model atmospheres privately provided by H. L. Shipman. For $\lambda > 1250$, spectra SWP 2218 and 2234 and LWR 1993 and 2012, obtained within an interval of 2 days, were adequately represented by: $T_e = 17000K$, $\log g = 8$, $n(He) = 1$, solar n(metals). There is, however, somewhat too much stellar flux for $\lambda < 1200$. (4) Since the IUE fluxes do not clearly show the primary eclipse, it might be surmised that all stellar atmospheres are inappropriate. For instance, a black body at $T_e \simeq 22000K$ can represent most of the satellite spectrum satisfactorily, but predicts too much flux for $\lambda < 1200$. (5) Since the outburst cycle length is not incompatible with that for dwarf novae as a class, a thick, systemic disk may be considered to be associated with a thermal bremsstrahlung λ^{-2} dependence. With a nominal unit Gaunt factor, $T \simeq 3 \times 10^5K$ approximates part of the IUE continuum, but also predicts too much flux for $\lambda < 1500$. Thus, it is likely that the continuum is composite and variable, as other spectra show, and a unique temperature assignment should not be expected.

Fig. 1 and 2 show the richness of the emission line spectra. Table I enumerates the ions and observed and rest wavelengths which have been tentatively identified.

TABLE I. Tentative Identifications for Emission Lines for V Sagittae

No.	λ	Ion, λ_o	No.	λ	Ion, λ_o
1	1175-1190	C III 1174,76; N III 1183,85; N IV 1188; Si III 1158-1207	19	2385	He II 2385
			20	2450	O IV 2449,50
			21	2510	He II 2511; O IV 2509
2	1242	N V 1239,43; C III 1247	22	2527	C IV 2524,30
3	1272	N IV 1272,73,74	23	2616	C III 2615,17
4	1288	Si III 1280-1313	24	2655	Si III 2656
5	1342	O IV 1339,43,44	25	2672	O III 2675
6	1371	O V 1371	26	2733	He II 2733
7	1400	Si IV 1394,1403	27	2781	O IV 2781,82,87; O V 2781,87,90
8	1424	C III 1426,27,28,29			
9	1495	Si III 1496-1506	28	2850	O III 2846,49,57,58, 61,62,63,64
10	1545	C IV 1548,51			
11	1642	He II 1640	29	2960	O III 2960
12	1719	N IV 1719	30	2984	N V 2981; O III 2984
13	2065	N III 2064,68	31	3020	O III 3018,23
14	2081	N III 2080; N IV 2081	32	3043	O III 3043,47
15	2215	He II 2215	33	3059	O III 3059; O IV 3063
16	2252	He II 2253	34	3128	O III 3122, 3133
17	2297	He II 2306; C III 2297	35	3200	He II 3203
18	2355	Ne IV 2351-2363			

Due to cathode reseaux and to saturation effects for the longer exposures, not all lines are seen on all spectra. However, these effects alone cannot account for the intrinsic variability in strength of many emission features. Fig. 1 and 2, in fact, show that not all identified lines actually appear on these two samples even though they are convincingly present on most of the spectra. This behavior is consistent with the intrinsic variability noted by Herbig, et al. Additionally,

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there are 3 emissions seen on most spectra which cannot be identified at this time: λλ 1815, 2582, and 2930. For all these emission lines, there seem to be velocity variations, but these are probably spurious effects due to the variability in strength.

The ground-based spectra clearly show some emissions to be double and others likely to be single. The study of the IUE lines has been inhibited by the low spectral resolution which leaves unclear the possible duplicity of many of these lines and progress has been very slow. At the present, one may only conjecture that the several ionization stages could lead to the evaluation of temperature and density gradients in the line-forming volume.

An evolutionary interpretation for V Sge continues to be obscure but some progress may eventually emerge if two assumptions are admitted: (a) the errors associated with the masses and radii given by Herbig, et al. are $\approx 0.5\odot$, and (b)the large object is the cool one. If these propositions are accepted, one can envision the large object to be an early A, near-main sequence star with perhaps $T_e \approx 10^4$ K. Interpreting the companion object only as a white dwarf is unsatisfactory, for the IUE spectra may then be affected by the A-type star, and this is not observed. A more likely possibility would consider a thick, hot disk embedding a white dwarf. A disk temperature, $17000\text{K} < T < 3\text{x}10^5$ K, would be sufficiently high and the disk dimensions, limited by the Roche lobe, sufficiently large so that this structure dominated the IUE spectra. Interest in this configuration would rest largely in having a relatively hot, non-degenerate binary member rather than the familiar G- or K-type dwarf or subgiant. It could then be conjectured that V Sge is now in a second stage of fast mass exchange and this could be consistent with the secular period shortening.

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