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Observations of Hydrogen Deficient Binary Upsilon Sagittarii[†]

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Abstract. The absolute magnitude M_v of the hydrogen deficient binary υ Sgr has been estimated as -4.8 ± 1.0 from the distribution of the interstellar reddening, polarization and interstellar lines of the surrounding stars. From the ANS observations obtained at the time of the secondary eclipse, it appears that the hotter secondary is surrounded by a disc with colours of a B8–B9 star. The λ 1550 C IV absorption line arising in the stellar wind does not show any change in strength during the secondary minimum. The upper limit to the mass-loss rate from the high temperature wind is estimated as $\leqslant 5 \times 10^{-7} M_\odot \text{yr}^{-1}$ from the 2 cm and 6 cm radio observations.

Key words: stars, chemically peculiar—stars, individual—stars, eclipsing—ultraviolet astronomy—mass loss

1. Introduction

Upsilon Sagittarii is the brightest of the small group of hydrogen deficient binaries, the other known members being KS Per (HD 30353) and possibly LSS 4300 (Drilling 1980). All of them are single-lined spectroscopic binaries consisting of A-type supergiant primaries with optically unseen companions; υ Sgr is probably an eclipsing binary as well (Gaposchkin 1945; Eggen, Kron & Greenstein 1950). The presence of Hα and other emission lines and the infrared excesses with 10 μm emission feature are indicative of extensive mass loss and the presence of circumstellar dust. The observational properties have been summarized by various investigators (Greenstein 1950; Hack, Flora & Santin 1980; Schönberner & Drilling 1983). Further, to explain the Hα absorption components to the emission, Nariai (1967) has presented a model in which the system is surrounded by an expanding tail of gas and dust in which emission and infrared excess occur. Although the presence of a secondary can be inferred from the recent ultraviolet studies (Duvignau, Friedjung & Hack 1979; Hack, Flora & Santin 1980; Hellings *et al.*, 1981; Drilling & Schönberner 1982), the nature of the secondary is not very clear. Hack, Flora & Santin (1980) infer a spectral type of O9 V for the companion from a comparison of IUE spectra of υ Sgr with S2/68 satellite energy distributions of α Cyg and ζ Oph; on the other hand, Drilling & Schönberner (1982)

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find from the low resolution IUE spectra that the line and continuum can be matched by a companion of type B3 Ib which is about 3–5 mag fainter at V relative to the primary ($\sim$ A2 Ia). Furthermore, in order to account for the extreme hydrogen deficiency and high nitrogen abundance Schönberner & Drilling (1983) propose that the primary is a helium star of about 1 $M_{\odot}$ which has undergone extensive mass loss thereby stripping the outer layers, and the secondary has accreted part of the mass and is thus overluminous for its mass ($\leqslant 4\,M_{\odot}$). It was pointed out by Hellings *et al.* (1981) and Hack, Flora & Santin (1980) that the strong spectral features seen in the IUE low resolution spectrum of C IV, N V, Si IV, Si III *etc.*, occur in the stellar wind and thus might not really represent the spectral characteristics of the secondary. Although both υ Sgr and KS Per have similar characteristics, their M_vs seem to be different. The M_v of KS Per has been determined by Danziger, Wallerstein & Böhm-Vitense (1967) as $-3.2 \pm .7$ corresponding to an A2 II star, whereas υ Sgr is usually assumed to be -7 mostly based on the luminosity classification of Ia. As pointed out by Danziger, Wallerstein & Böhm-Vitense (1967), when the lines are greatly enhanced on account of the low opacity, the approximate spectral type cannot be used to infer the effective temperature or absolute magnitude with high accuracy. A further complication arises regarding the secondary if the primary is assumed to have M_v of -7. Kippenhahn & Meyer-Hofmeister (1977) have computed the radii and the location in H–R diagram of mass-accreting main-sequence stars for various accretion rates. Since the present mass of the secondary is expected to be $\leqslant 4\,M_{\odot}$, and not much different from its original mass (according to Schönberner & Drilling 1983), if we assume the primary has $M_v = -7$, then the secondary occupies a very improbable position in the H–R diagram (B3, $M_v \sim -4$) indicating very high mass accretion rates. Greenstein (1940) earlier estimated M_v as -7.6 from kinematics. Because of the large uncertainty in distance estimates based on kinematics, a re-examination of M_v of the primary is warranted.

In this paper we rediscuss the determination of the distance and absolute magnitude of υ Sgr in a similar way as was done for KS Per by Danziger, Wallerstein & Böhm-Vitense with the help of Astronomical Netherlands Satellite (ANS) observations. We further discuss the ANS observations—which include observation at the time of the secondary eclipse—with a view of obtaining some constraints regarding the nature of the companion. In addition, we present optical observations in the Hα region. Finally, we present the observations at 2 and 6 cm done with Very Large Array (VLA) and estimate upper limits for the rate of mass loss from the system.

2. ANS observations

A total of eleven photoelectric observations of υ Sgr have been obtained by ANS (kindly supplied by Dr D. P. Gilra) at 1550 Å (square-response full-width 150 Å and 50 Å), 1800 Å (150 Å), 2200 Å (200 Å), 2500 Å (150 Å), and 3300 Å (100 Å). The entrance aperture had dimensions equivalent to 2.5 × 2.5 arcmin and pointing accuracy was 20 arcsec. The internal accuracy of photoelectric system is supposed to be good to 0.5 to 1 percent. The details of satellite, and method of observations and reductions are given in Wesselius *et al.* (1982). The observations of υ Sgr have been obtained over a period of one year. The individual observations are given in Table 1, with the date of observation, the phase and the magnitude in each wavelength band. The zero magnitude corresponds to 3.64×10^{-9} erg cm^{-2} s^{-1}Å^{-1}. The phase is calculated from

Table 1. ANS observations of υ Sgr.

Date	Phase			Magnitude*			
		3300	2500	2200	1800	1550W	1550N
1974 Oct 13.00	0.6885	4.064	4.886	5.326	5.169	5.353	
1974 Oct 13.62	0.6923	4.054	4.850	5.286	5.080	5.256	
1975 Apr 9.13	0.9753	4.226	5.054	5.494	5.294	5.428	5.634
1975 Apr 10.54	0.9866	4.173	5.042	5.479	5.268	5.472	
		4.171	5.044	5.478	5.265	5.468	
1975 Oct 12.86	0.3354	4.115	4.891	5.366	5.198	5.348	
		4.116	4.893	5.369	5.198	5.349	
		4.115	4.901	5.374	5.194		5.532
		4.116	4.906	5.367	5.191		5.548
1975 Oct 14.02	0.3423	4.129	4.917	5.389	5.248	5.393	
		4.128	4.917	5.388	5.234	5.397	

* 0.0 mag corresponds to 3.64×10^{-9} erg cm^{-2} s^{-1} Å^{-1}.

the ephemeris given by Hack, Flora & Santin (1980) and corresponds to photometric phase.

2.1 *Reddening, Absolute Magnitude and Distance*

We estimate the distance and M_v of υ Sgr based on the distribution of $E(B-V)$, polarization and interstellar lines with distance. The reddening $E(B-V)$ has been variously estimated ranging from 0.1 to 0.3. Using low-resolution IUE observations, Drilling & Schönberner (1982) estimated the reddening $E(B-V)$ as 0.1 by ironing out the 2200 Å depression using Seaton's (1979) interstellar reddening curve. They matched the energy distribution of the star with a combination of F0 Ib and a visually 5.2 mag fainter B3 Ib star (θ Ara). Later, by fitting the energy distribution longward of 2000 Å with a helium star model of $T_{\mathrm{eff}} = 10500$ K, Drilling *et al.* (1984) obtained $E(B-V)$ as 0.12. Earlier, Dyck & Milkey (1972), and Duvignau, Friedjung & Hack (1979), the latter using Copernicus observations, estimated $E(B-V)$ as 0.20.

The ANS observations in Table 1 have been corrected for interstellar reddening using the reddening relations given by Wesselius *et al.* (1980). As can be seen from Fig. 1 these observations normalized to 3300 Å band are not compatible with $E(B-V) = 0.12$. The 2200 Å observation still shows a dip and also the energy distribution does not match the combination of F0 Ib (α Lep or α Car) and a B3 Ib star (θ Ara) which is fainter by 5.2 mag in V. A wide variety of combinations of energy distributions of an A supergiant and a B star can match the ANS observations to roughly equal degree of agreement (or disagreement) although none of the combinations could fit exactly. Fig. 1 also illustrates a combination of an A2 Ia and a B3 Ib star which is fainter by 4.7 mag in V, and an A2Ib star and a B8 V star which is fainter by 3 mag in V, etc. However, $E(B-V)$ of 0.17 to 0.20 seem to be required to explain the 2200 Å observation, and to match with various combinations of ANS energy distributions. We will discuss this aspect further in Section 3. The value of $E(B-V)$ of 0.3 is quite incompatible with these observations. Bohlin & Holm (1984) give correction factors for bringing the ANS fluxes to the IUE flux scale. According to these authors, the IUE fluxes agree with ANS to

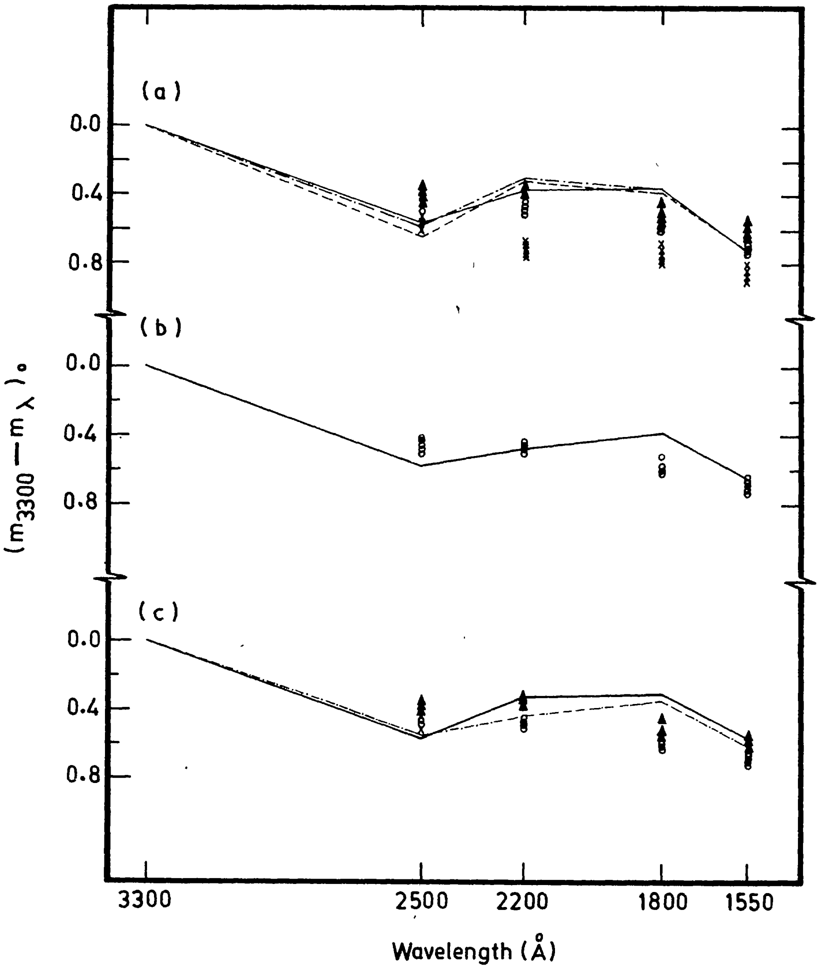

Figure 1. ANS observations of υ Sgr corrected for different values of interstellar reddening. Triangles, open circles and crosses corresponds to $E(B-V) = 0.20$, 0.175 and 0.12 respectively. These observations are fitted to various combinations of standard star energy distributions in a, b, and c. The notation is as follows: (a) Full line: A5 Ib + 5.25 mag visually fainter *B*2 V; dashed line: A2 Ia + 6.2 mag visually fainter O9 V (10 Lac + α Cyg); dot dashed line: A2 Ia + 4.7 mag visually fainter B3 Ib (θ Ara). (b) Full line: A2 Ib + 6.0 mag visually fainter B3 V. (c) Full line: A2 Ia + 3.0 mag visually fainter B8 Ia; dashed line: A2 Ib + 3.0 mag visually fainter B9 V; dot dashed line: A2 Ib + 3.3 mag visually fainter B9 V.

within 2.5 per cent after applying the correction factors. We converted ANS fluxes to the IUE scale and tried to estimate the reddening by ironing out the 2200 Å depression using Seaton's (1979) reddening curve, which again indicates that the reddening might be around $E(B-V) = 0.16$ to 0.20. However, because of the crowding of spectral lines, the lower resolution of ANS observations relative to IUE might give a slightly higher value of $E(B-V)$. Since the reddenings estimated by Drilling *et al.* (1984) using a helium star atmosphere and a normal composition atmosphere (Drilling & Schönberner 1982) do not differ very much, we assume that the uncertainty in the reddening estimate, stemming from hydrogen deficiency is not appreciable. We conclude that $E(B-V)$ value of υ Sgr is between 0.12 and 0.20.

To arrive at the distribution of $E(B-V)$ with distance modulus in the direction of υ Sgr, we have used the B stars (mostly earlier than B5) in the field of less than 6 degrees (most of them within 3 degrees) around the galactic longitude and latitude of υ Sgr. The *UBV* photometry and spectral types, whenever available, have been gathered from various sources and are given in Table 2. Whenever the MK spectral types are not available, the *Q* method and the relation given by Dworetsky, Whitelock & Carnochan (1982) has been used to derive them from the colours. The intrinsic colours and absolute magnitudes for the spectral type have been taken from FitzGerald (1970) and Lesh (1968, 1979) respectively. Fig. 2 shows the correlation of $E(B{-}V)$ with $V_0 - M_v$ (the line shown in the figure is a mean line drawn by visual inspection) and shows that the reddening increases smoothly with distance modulus—at least until $E(B-V) \sim 0.3$—and can be used to estimate M_v. The reddening value of $E(B-V) = 0.12$ to 0.20 leads to $V_0 - M_v = 8.1$ to 10.2. For υ Sgr with $V = 4.61$, using $R\,[\equiv A_v/E(B-V)] = 3.2$ leads to M_v of -3.9 to -6.2.

The observations of polarization and interstellar lines of the stars near υ Sgr taken from literature are given in Table 3. The polarization of υ Sgr appears to be variable (Coyne & Gehrels 1967; Coyne 1977), however, most of the contribution seems to come from the interstellar medium. The $\lambda_{\max}$ of polarization and the position angle are close to that determined for κ Aql. κ Aql has the same galactic latitude as υ Sgr but is 10 degrees away in longitude, and both υ Sgr and κ Aql have the interstellar components of Ca II K (and H) line with the same velocity and roughly equal intensity (Adams 1949, 1943). κ Aql has slightly higher percentage of polarization and also a higher value of $E(B-V)$ (0.28). Thus it appears that υ Sgr is at the same distance as κ Aql, or slightly closer. Assuming the same distance modulus as for κ Aql (Savage & Jenkins 1972) one obtains $M_v = -4.8$ for υ Sgr. The previous estimates of M_v of -7 by McLaughlin (1939) was based on the strengths of the interstellar lines. However, Adams (1943, 1949) has resolved the interstellar Ca II lines and both components have roughly the same intensity as in κ Aql. Moreover, the line strength of Na I lines have been

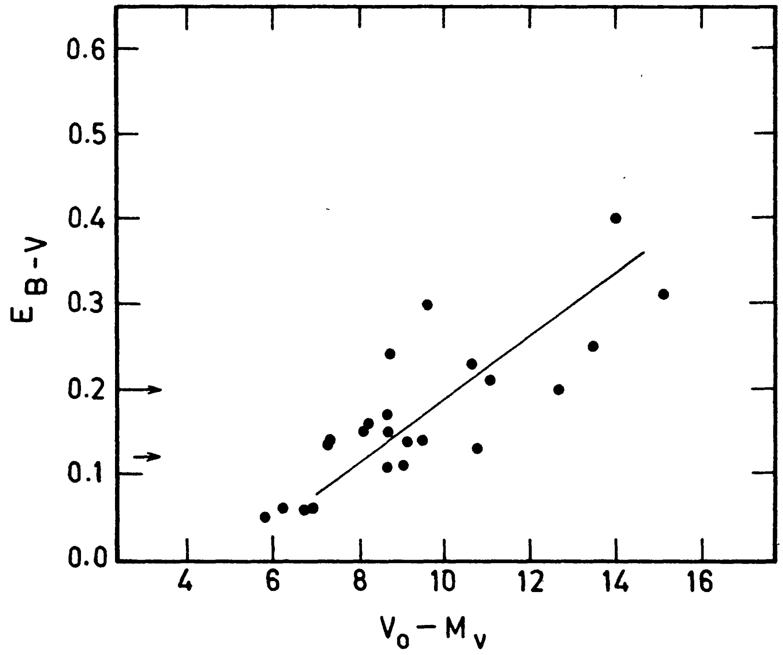

Figure 2. Plot of $E(B-V)$ versus reddening-corrected distance modulus $V_0 - M_v$ for stars around υ Sgr. The arrows on the ordinate denote the two values of $E(B-V)$ for υ Sgr.

Table 2. Photometric parameters of B stars in the field of υ Sgr.

HD/BD	l	b	Spectral Type	V	$B-V$	$U-B$	M_v	$E(B-V)$	V_0-M_v
υ Sgr	21.84	−13.77	—	4.61					
175141	15.46	− 9.63	B8	9.23	0.03	−0.32	−0.4	0.14	9.18
175754	16.39	− 9.91	O8 f	7.01	−0.08	−0.96	−4.4	0.23	10.67
175876	15.30	−10.59	O7	6.92	−0.11	−1.00	−4.8	0.21	11.05
177014	16.76	−11.31	B8.5	9.27	0.19	−0.03	0.0	0.24	8.50
177137	18.4	−10.7	(B6)	8.69	0.04	−0.36	−0.5	0.17	8.65
177517	20.44	−10.16	B9 V	5.97	−0.02		0.0	0.05	5.81
177559	16.94	−11.85	B6 Vn	8.1	0.01	−0.66	−0.5	0.15	8.12
177817	20.04	−10.66	B8 IV	6.03	−0.04	−0.36	−0.4	0.06	6.24
177863	17.75	−11.78	B8 III	6.29	−0.04		−0.6	0.06	6.70
177989	17.81	−11.89	B0 III	9.33	−0.05	−0.89	−5.0	0.25	13.53
178070	21.1	−10.4	(B6)	8.67	0.04	−0.36	−0.5	0.17	8.63
178175	17.35	−12.26	B2 V	5.54	−0.11	−0.78	−2.2	0.13	7.32
178487	25.79	− 8.55	B0 Ia	8.66	0.16	−0.78	−6.6	0.40	13.98
179003	21.5	−11.2	(B8)	9.00	0.02	−0.25	−0.4	0.11	9.05
179407	24.03	−10.4	B0.5 Ia	9.41	−0.09	−0.81	−6.7	0.31	15.12
180110	22.25	−12.01	B5	7.79	0.02	−0.40	−0.9	0.16	8.18
180194	21.6	−12.4	(B5)	9.02	0.00	−0.42	−0.9	0.14	9.47
14°5313	22.97	−10.48	B5	8.28	0.0	−0.45	−0.9	0.15	8.70
180629	20.5	−13.3	(B5)	8.10	−0.05	−0.50	−0.9	0.11	8.65
181613	22.9	−13.3	(B4)	10.08	−0.03	−0.50	−1.1	0.13	10.76
181558	18.74	−15.10	B5 V	6.26	−0.10	−0.51	−0.9	0.06	6.97
183133	23.36	−14.92	B5 V	6.79	−0.03	−0.55	−0.9	0.13	7.27
183761	21.6	−16.5	(O8)	8.92	−0.10	−0.98	−4.4	0.20	12.68
183570	22.7	−15.85	(B6)	7.43	−0.01	−0.45	−0.5	0.14	7.38

Table 3. Polarization and interstellar line strengths of stars near υ Sgr.

HD (name)	l deg	b deg	Spectral type	$E(B-V)$	$V_0 - M_v$	λ_{max}	P_{max} per cent	$\theta(P_{max})$ deg	Interstellar lines* km s^{-1}
176162	22	−8	B5 IV	0.12	6.15	0.58	0.91 0.87	120.2	−11.6 (15), −15.0M
179406 20 Aql	28	−8	B3 V	0.33	5.64	0.51	1.39 1.32	183.7 182.5	−13.6 (10), −24.2 (2), −15.2 M
181615 υ Sgr	22	−13		0.15 ±0.03		0.51	1.004 0.78	168.2 170.7	−11.6 (10), 4.2 (4), −13.1 M
183344 U Aql	31	−12	F5–G3 Ib	0.42	9.4	0.50 0.54	2.72 2.76		
184915 K Aql	32	−13	B0.5 III	0.28	8.8	0.58	1.35 1.39	171.5 170.3	−12.1 (8), 8.2 (4)

* Ca II K line components, the number in parenthesis is the intensity as given by Adams (1949). M refers to the molecular lines.

† The polarization measurements are from Coyne & Gehrels (1967); for other stars they are from Serkowski, Mathewson & Ford (1975).

given by Duvignau, Friedjung & Hack (1979) who also plot the relation of Na I D 1 line equivalent width against the hydrogen column density. This relation yields $N_H \sim 5 \times 10^{20}$ cm^{-2} for an equivalent width of 0.186 Å; however, there is a large amount of scatter in the relation. Using the relation $N_H/E(B-V) = 5.3 \times 10^{21}$ leads to $E(B-V) \sim 0.1$ which is compatible with the $E(B-V)$ estimate given earlier. Further, Hack, Flora & Santin (1980) show that the equivalent widths of other interstellar lines in β Lyr and υ Sgr have about the same value. The distance to β Lyr is only 350 pc (Plavec, Weiland & Dobias 1982). Thus we conclude that M_v of υ Sgr is -4.8 ± 0.8 and roughly the same as that estimated for KS Per of -3.2 ± 0.7 (Danziger, Wallerstein & Böhm-Vitense 1967).

2.2 *The ANS Photometry and the Depth of Secondary Eclipse*

The observations are few and do not cover the complete period. We propose to see how consistent these observations are with the models proposed earlier based on the depth of the secondary eclipse in the ultraviolet (UV). These observations have been phased with the ephemeris of Hack, Flora & Santin (1980). They occur at phases 0.99, 0.98, 0.69, 0.34 and 0.33. These have been plotted in Fig. 3 after normalizing to the averaged flux at phase 0.69 for all the five ANS bands, along with the light curve in the blue region obtained by Eggen, Kron & Greenstein (1949). The coincidence of the minimum of 1947 observations with 1975 ANS observations shows that the period is fairly accurate. The optical observations show that the eclipse is asymmetrical and has a depth of 0.1 mag. As can be seen from the figure and as is anticipated, the depth in UV is higher. Since the ANS observations do not cover the total eclipse to define the shape, we assume the duration of the eclipse to be the same as in blue light in order to extrapolate the eclipse curve from phase 0.99 to phase 0.0 and estimate the depth of the eclipse at phase 0.0. This has been done in two ways with practically the same result for the minimum depth. It is likely that the light is not constant even outside the minima (Cousins 1963). There may even be short-period variations. The ANS observations show that the flux

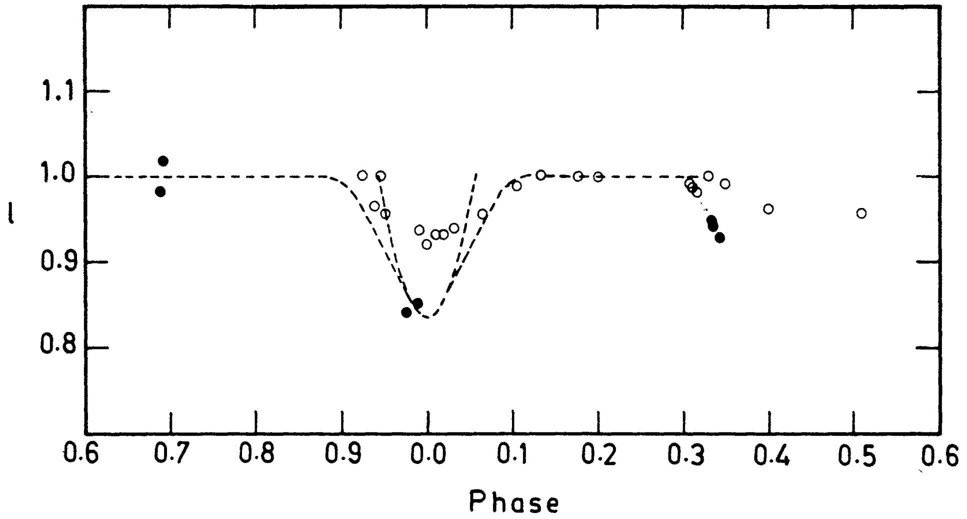

Figure 3. Light curve of υ Sgr. Open circles are the observations of Eggen, Kron & Greenstein (1949) in the blue; the dots are 2200 Å ANS observations.

observed at 0.692 phase differs from that at phase 0.689, particularly at the shorter wavelengths. The depth of the secondary minimum in terms of the light outside eclipse represented by the mean of the fluxes at phase 0.692 and 0.689, and the flux at phase 0.692 separately, are given in Table 4. The eclipse seems to be partial. As can be seen from Table 4, the depth of the eclipse between 2500 Å to 1550 Å is the same or perhaps slightly less at shorter wavelength (*i.e.* 1800 Å and 1550 Å). This behaviour is similar to that reported by Duvignau, Friedjung & Hack (1979). With the assumption that the secondary eclipse is an occultation, the differential depth can give an indication of the luminosity of the secondary. Within the uncertainty of the exact shape of the minimum, the α_0^{oc} is estimated to be 0.96 ± 0.03 for the assumed limb-darkening coefficient of 0.5 (Irwin 1960). Further, assuming α_0^{oc} is the same in all the wavelengths, the luminosity of the secondary [*i.e.* $(1-l)^{oc} = \alpha_0^{oc} L_s$] is estimated. Taking the value of $E(B-V) \simeq 0.2$ and the mean fluxes of phase 0.689 and 0.692 as representing the total light outside the eclipse, the magnitudes in the ANS bands inferred for the secondary are quoted in Table 4. The colours thus determined for the secondary do not correspond to any single spectral type (Wesselius *et al.* 1980, 1982), but vary between B8 to A3 (as the wavelength decreases). This behaviour is similar to that described by Duvignau, Friedjung & Hack (1979) from the energy distribution of S2/68 observations. The UV colours obtained from the secondary eclipse depth certainly do not indicate a spectral type of B3 Ib.

Table 4. The depth of the secondary minimum, and the estimated magnitude of the secondary.

λ	4340	3300	2500	2200	1800	1550
depth*	0.075	0.13	0.16	0.167	0.165	0.165
depth†		0.13	0.182	0.182	0.185	0.195
$M_{\text{secondary}}$		5.30 ±0.10	5.31 ±0.08	5.23 ±0.05	5.33 ±0.10	5.46 ±0.10

* Assuming that the average flux at phase 0.692 and 0.688 represents the light outside the eclipse.

† Assuming that the average flux at phase 0.692 represents the light outside the eclipse.

The inclination of the orbit can be estimated as between 66° to 84.7° depending on the shape of the eclipse. From this, the mass function of 1.677 $M_\odot$ (Hack, Flora & Santin 1980) leads to $m_2^3/(m_1+m_2)^2 = 2.2$ and 1.7 respectively. Further, assuming the mass ratio m_p/m_s to be around 0.3 as proposed by Plavec (1973) and Schönberner & Drilling (1983), one has $m_p \sim 1\ M_\odot$ and m_s about 3 $M_\odot$. This leads to a spectral type of B9, if the secondary obeys the mass-luminosity relation of the main sequence. The estimate of K, the ratio of radii (r_s/r_p) is quite uncertain—it could even be as large as 0.9. Adopting $M_v = -4.8$ and T_{eff} of 10500 K the latter leads to $R_p \sim 29.7\ R_\odot$, $\log L/L_\odot = 4.01$.

3. Spectra in the Hα region

Spectra in the red region were obtained monitoring the Hα profile. A spectrogram obtained in September 1976 with the 1 m telescope at Kavalur at 17 Å mm^{-1} dispersion at phase 0.28, shows an emission feature at 6583.6 Å probably due to [N II], in addition to the Hα and Fe II lines. The profile of Hα appears to be very similar to that quoted by

Greenstein & Merrill (1946). The 6584 Å feature seems to have the same radial velocity as the other emission lines. The other line of [N II], at 6548 Å, could not be detected with certainty. The presence of [N II] lines indicates circumstellar material of low density. Danziger, Wallerstein & Böhm-Vitense (1967) have also detected [N II] 6584 Å in KS Per.

4. VLA observations

The resonance lines due to high temperature gas indicate a considerable mass loss (Hack, Flora & Santin 1980). This is to be expected from stellar evolution as the primary must either have lost or is still losing mass at a high rate. To derive the mass-loss rate from the free-free continuum of the circumstellar material, we observed υ Sgr at 2 and 6 cm with the Very Large Array (VLA) on 1983 December 12. No emission was detected, the upper limits (3σ) to the flux density being 0.9 mJy at 2 cm and 0.3 mJy at 6 cm, and hence only an upper limit of $\dot{M}$ can be derived. Following Wright & Barlow (1975), the mass loss rate $\dot{M}$ of a star with a flux density S_ν at frequency ν can be expressed as

$$\dot{M} = \frac{0.095\mu S\nu^{3/4} D^{3/2} V_\infty}{z\gamma^{1/2} g^{1/2} \nu^{1/2}} \qquad M_\odot\,\mathrm{yr}^{-1}$$

where S_ν is in Jy, ν is in Hz and D the distance is in kpc and V_∞ is the wind terminal velocity in km s^{-1}. μ, z and γ are the mean molecular weight per ion, the rms ionic charge and the mean number of electrons per ion respectively, g is the Gaunt factor at radio frequency obtained from the formula of Spitzer (1962). Taking the abundance ratio H/He as 0.1, and temperature of 10^5 K for the wind as indicated by the lines of C IV, N V, Si IV, we adopt $\mu = 4.1$, $\gamma = 2.0$, $z = 2.0$ and g (6 cm) $= 7.2$. Adopting the distance 0.6 kpc as obtained earlier and $V_\infty = 700$ km s^{-1}, as inferred from the C IV, Si IV lines, from IUE spectra (Hack, Flora & Santin 1980), we obtain an upper limit to the mass-loss rate of about $5.4 \times 10^{-7}\,M_\odot\,\mathrm{yr}^{-1}$. This rate is far too low to account for the evolutionary state of the system. Hence we conclude that the mass loss rate was probably much higher in the past, as the primary was estimated to have lost 5 to 12 $M_\odot$ in its earlier evolution (Schönberner & Drilling 1983).

5. Discussion

The depth of the secondary eclipse in the UV and the energy distribution indicate a spectral type later than B3 Ib for the secondary, contrary to that proposed by Drilling & Schönberner (1982), whose classification is based on the strength of the UV resonance lines. Several explanations for this discrepancy are conceivable.

First we discuss the possibility that the UV secondary minimum is filled in by additional light which becomes observable, at least partially, during the eclipse. This additional source may arise from circumbinary gas clouds with multi-component emission lines in the UV, or it might arise from a disc (or a hot spot) around the B star. The IUE spectra obtained by Hack, Flora & Santin (1980) and Drilling & Schönberner (1982) show that there are no strong emission lines present in the UV spectrum, which fact points to a disc. With the mass ratio $m_p/m_s = 0.3$ (see Section 3) the radii of the

Roche lobes around the primary and secondary are about 38 $R_\odot$ and 70 $R_\odot$, respectively. Within the uncertainties of M_v, the primary just about fills its Roche lobe, and hence mass transfer seems to occur. Blue-shifted absorption components of -300 km s^{-1} around the time of the primary minimum seen occasionally (Bidelman 1949; Nariai 1967) also indicate mass transfer. The presence of absorption components at 0.5 phase (Hα, Al III) has been interpreted (Hack, Flora & Santin 1980) as due to a jet or stream of material from the secondary to the primary. The variability of the spectral features as evidenced from the changes in the profile of Hα (Greenstein & Adams 1947) show similar behaviour to that seen in Algol type systems like U Cep.

Then we have to discuss whether the classification B3 Ib based on UV resonance lines really pertains to the photosphere of the secondary. These lines, through their P-Cygni profiles, manifest that they are formed mostly in the wind material. However, the only true photospheric line may be 1183.7 Å of N III (20), seen in the Copernicus spectrum. It indicates a spectral type of B3 or earlier (Duvignau, Friedjung & Hack 1979); however, this identification is regarded as uncertain. Hence the spectral classification of the secondary remains open. The compromise is a B3 star surrounded by a disc whose colour temperature corresponds to a B8–B9 star, which may come close to a realistic model.

6. Conclusion

The absolute magnitude of the primary seems to be close to M_v of -4.8 ± 1.0 which is similar to the value derived for KS Per of 3.7 ± 0.7 by Danziger, Wallerstein & Böhm-Vitense (1967). From the ANS observations of depth of the secondary eclipse, it appears that the hotter secondary is surrounded by a disc which makes the colours of the secondary similar to a B8–B9 star. The strength of the stellar (or systemic) wind lines of C IV 1550 Å do not change even during the secondary eclipse indicating that the wind is not affected by the orbital motion. The appearance of [N II] 6583 Å indicates a low density envelope. Finally, from radio observations an upper limit to the mass loss rate is estimated as 5×10^{-7} $M_\odot$ yr^{-1}. To understand the system fully a complete phase coverage is needed in the UV as well as in the optical.

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