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A NEW STUDY OF THE INTERACTING BINARY STAR V356 SGR

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ABSTRACT

In this paper we present new results on V356 Sgr from IUE and Voyager ultraviolet (500-3200 Å) observations obtained in 1986 and 1987, primarily during two total eclipses. The eclipse of 15 Aug 86 was fully covered with IUE low dispersion images and 9 hours of Voyager UVS data. The eclipse of 25 Mar 87 was covered with IUE low dispersion images and 1 high dispersion SWP image. During both eclipses the total strength of the emission lines were found to be invariant. Also, an uneclipsed UV continuum was detected at wavelengths shorter than 1500 Å. The high dispersion SWP spectrum revealed that the emission lines are extremely broad, almost symmetrical emissions with weak, slightly blue shifted absorption components. No evidence of carbon, C I, C II, C III, or C IV, is seen in the emission or absorption spectrum of V356 Sgr in eclipse. Models for this binary system are presented.

Keywords: Interacting Binary Stars, Ultraviolet Emission Lines, CNO Processing, Ultraviolet Spectroscopy

1 INTRODUCTION

V356 Sgr is a massive eclipsing binary with a period of 8.896 days and a total eclipse of 11 hours duration. Both components of the binary are spectroscopically visible in the optical. Eclipse depths in V are 0.87 and 0.39 magnitudes, respectively, for primary and secondary minimum. Period changes suggest a steady, very low rate of mass transfer ($\sim 10^{-7} M_{\odot} \text{ yr}^{-1}$) is occurring within the system. V356 Sgr also has some of the best determined physical dimensions of any interacting binary (Ref. 3). Table 1 lists the physical characteristics of the binary. The binary is moderately reddened, with an E(B-V) as determined from the individual colors of the components and from the 2200 Å feature of 0.23 ± 0.03 magnitudes. The most quoted model for V356 Sgr is that proposed by Wilson and Caldwell (Ref. 6) In this model they propose the existence a thick, opaque non-luminous ring or disk around the B3 star. Ultraviolet emission lines were subsequently discovered in this star by Plavec et al. (Ref. 4). The UV emission lines are amongst the strongest detected in any algol system. Despite this they are detectable only during the total eclipse of the system, the ultraviolet flux from the B3 star overwhelming them at all other times. No optical emission lines, including H α , have ever been reported in the binary. Recent very high S/N H α eclipse observations, contemporaneous with the UV observations, also show *no* evidence of optical emissions

2. OBSERVATIONS

The new IUE and Voyager UVS observations were obtained in 1986 and 1987, with most of the data taken during two total primary (when the B3 star is occulted) eclipses. The eclipse of 15 Aug 86 was covered with 12 SWP and 8 LWP IUE low dispersion images and 9 hours of Voyager UVS data. The eclipse of 25 Mar 87 was covered with 7 SWP and 6 LWP IUE low dispersion images and 1 high dispersion SWP image. No Voyager UVS data was obtained during this March eclipse. Additional IUE SWP and LWP low dispersion images were obtained after the two observed eclipses. Supplemental Voyager UVS data were obtained prior to the eclipse on 15 Aug 86 and in May 87.

3. OPTICAL LIGHT CURVE

The IUE FES was used to obtain an optical light curve for the eclipses in V356 Sgr. The FES light curve suggests two conclusions. 1) The quadratic ephemeris of Hall, Henry, and Murray (Ref. 1), $2433900.766 + 8.896106E + 3.5 \times 10^{-8}E^2$, best fits the data. The significance of the second order term is confirmed. 2) There is suggestive evidence of changes in the shape of the eclipse light curve from the two FES light curves.

4. ULTRAVIOLET LIGHT CURVE

UV light curves were generated from the low dispersion images in three narrow (25 Å, 65 Å, and 250 Å) continuum bands in the UV. These three light curves and the FES light curve were ratioed to the observed flux (appropriately scaled and reddened) of the A3 star 38 Lyn. The 1908 and 2625 Å light curves appear relatively normal. The 1262 Å curve, however, showed a substantial excess over that expected. During the total phase of the eclipse the B3 star can contribute no flux. So this UV excess *cannot* arise in the B3 star. Voyager 500-1200 Å observations produced only a marginal detection of V356 Sgr during eclipse. This suggests that the characteristic temperature of the UV excess is comparable to or slightly cooler than that of the B3 star (~ 16500 K from outside of eclipse UVS observations). Since the source of the flux is (predominantly) uneclipsed by the A2II star it must either arise outside the domain of the B3 star or be of significantly larger radius than the A2 giant. Analysis of the shape of the flux excess argues in favor of the extended region. Figure 1 shows the Voyager and IUE spectra V356 Sgr outside and during the total eclipse. In this figure the eclipse spectrum is compared to the scaled and reddened spectrum of 38 Lyn, an A3 star, and to a synthetic spectrum obtained by combining the scaled and reddened 38 Lyn spectrum with a simulated electron scattering of the system light. This "scattered light" spectrum was obtained by taking the observed maximum spectrum and

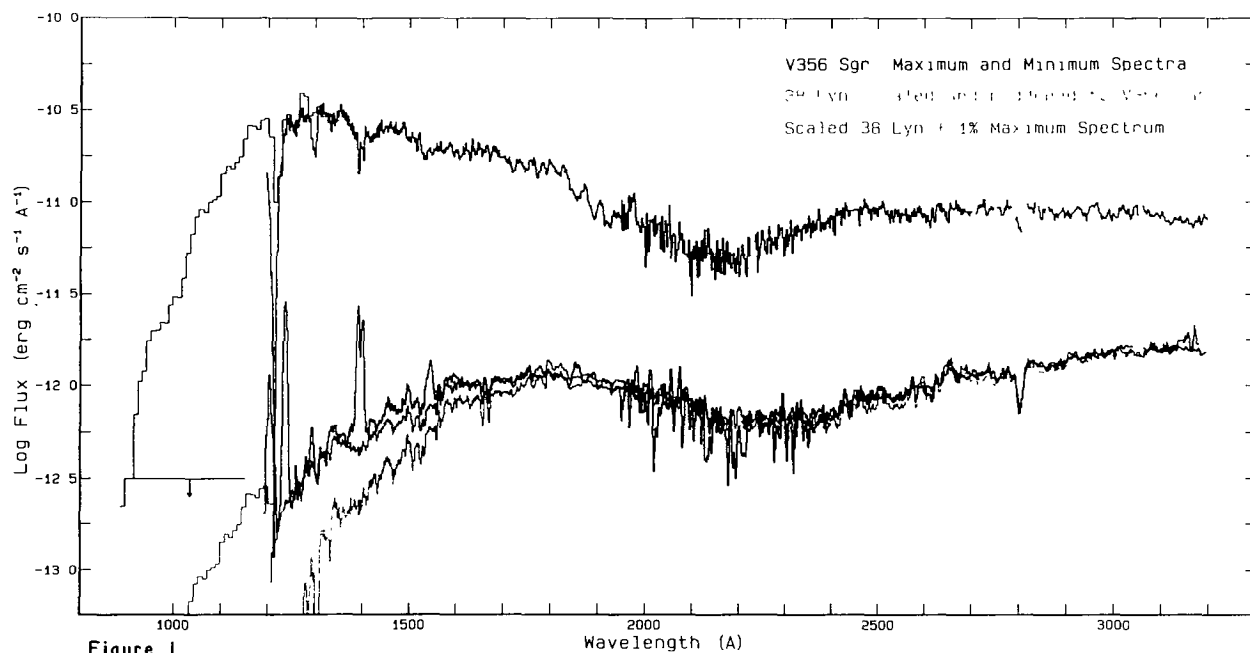


Figure 1

Figure 1. Observed Voyager and IUE spectra of V356 Sgr at maximum and during the total eclipse of the B3V star. An IUE spectrum of a A3 reference star, 38 Lyn, scaled to the visual magnitude of the A2II component in V356 Sgr and reddened by 0.23 magnitudes in B-V is also shown. Also shown is a synthetic spectrum obtained from summing the scaled and reddened 38 Lyn spectrum with one percent (1%) of the observed maximum light V356 Sgr spectrum (Voyager plus IUE) smoothed to simulate electron scattering. Note the surprisingly good agreement between the synthetic spectrum and the observed V356 Sgr primary eclipse spectrum.

Figure 2. Si IV 1400 line strength as a function of phase during the eclipse of 15 Aug., 1986.

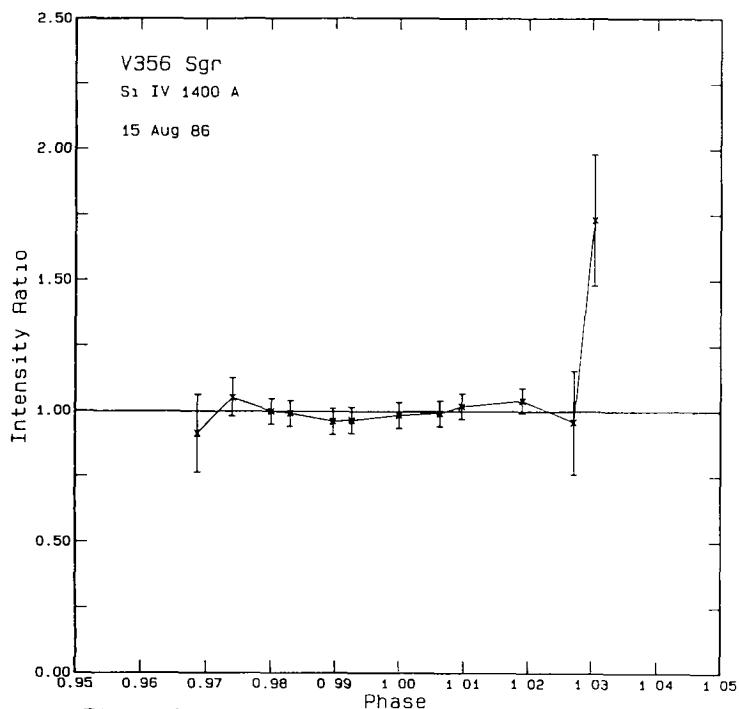


Figure 2

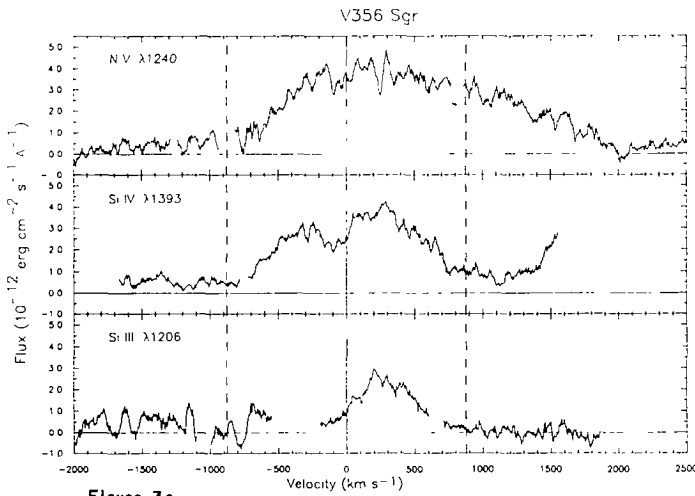


Figure 3a

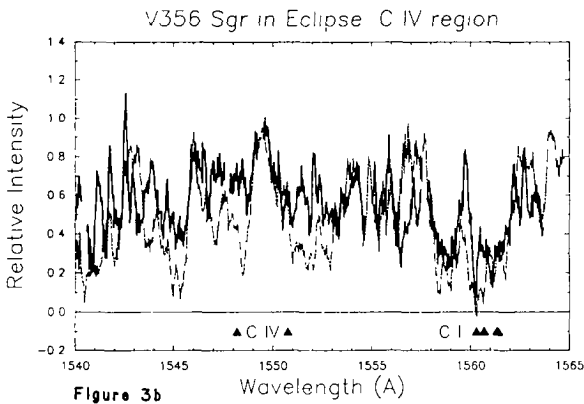


Figure 3b

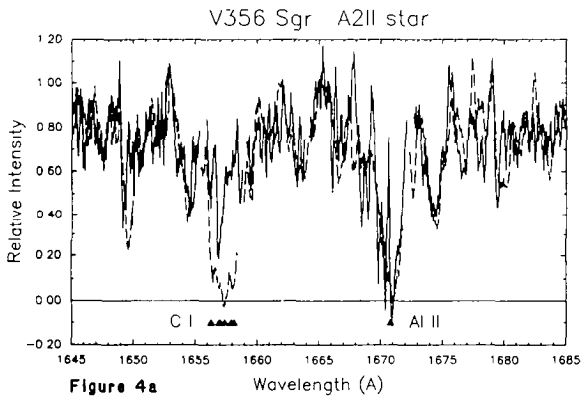


Figure 4a

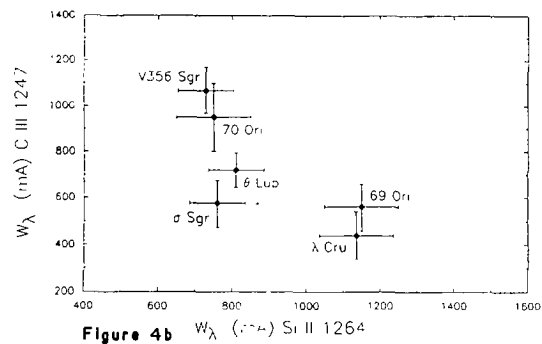


Figure 4b

Figure 3. a) Emission lines of N V $\lambda 1238$ and 1242 (at $+964$ km s^{-1} in this velocity plot), Si IV $\lambda 1393$, and Si III $\lambda 1206$ from the high dispersion SWP image obtained during the eclipse of 25 March, 1987. Dotted lines are drawn at $\pm V_{\text{escape}}$ for the B3 star. b) The C IV $\lambda 1550$ region from the same high dispersion image. Dashed curve is the spectrum of the A2III reference star ζ Sgr. Note the absence of any detectable C IV line. Dotted line is drawn at the expected level of the scattered light shown in Figure 1.

Figure 4. a) Region of the expected strong photospheric C I line in the A2II component in V356 Sgr. The dashed curve is the spectrum of the A2III reference star ζ Sgr. Note the complete absence of a carbon line in the A2II star's atmosphere. The sharp C I line is the interstellar component. b) Photospheric C III $\lambda 1247$ and Si II $\lambda 1264$ equivalent widths for the B3V component in V356 Sgr and five non-binary stars of similar spectral type.

Figure 5. The Al III $\lambda 1860$ region in the eclipse spectrum. The dashed curve is the spectrum of the A2III reference star ζ Sgr. Note the Al III emission and the total absence significant absorption of the A star photospheric light at the central absorption core of the Al III lines.

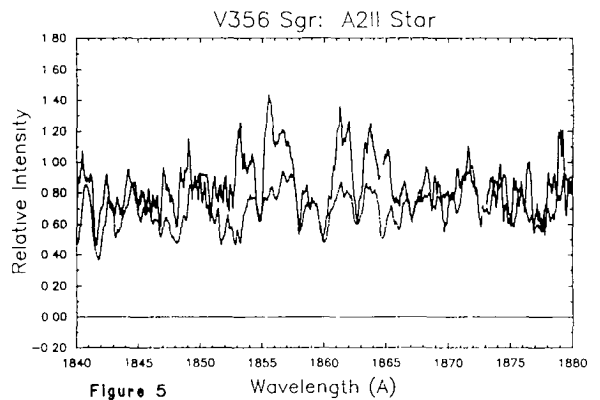


Figure 5

smoothing it with a 20 Å boxcar smoothing function. As can be seen in Figure 1 an excellent fit is obtained to the observed eclipse spectrum by assuming one percent (1%) of the total system light is scattered in the line of sight during eclipse. Thus, the origin of the flux excess appears to be electron scattering from an extended cloud surrounding the system.

5. ULTRAVIOLET EMISSION AND ABSORPTION LINES

Using the data obtained from the low dispersion images it was discovered that the total strength of the UV emission lines was invariant during both eclipses (Figure 2). This suggests that the line formation region is outside the immediate domain of the two stars in the binary and suggests a possible association with the region responsible for the scattered light. The high dispersion SWP spectrum obtained in March, 1987 revealed that the emission lines are extremely broad, FWHM $\sim 1100 \text{ km s}^{-1}$, almost symmetrical emissions with weak, slightly blue shifted absorption components (Figure 3). Also, apparent in the high dispersion IUE image is that the "C IV" emission line reported in previous investigations is *not* the carbon doublet but rather dissolves into numerous weak emissions of, probably, Fe III. No evidence of carbon, C II, C III, or C IV, is seen in the emission spectrum of V356 Sgr during eclipse. Line profile fits to the emission line data suggest that *all* lines can be fit with the same line shape parameters. No evidence supporting a stratified line formation region was found. The strength of the carbon emission lines C II, C III, and C IV in V356 Sgr are at least a factor of \sim twenty weaker than the silicon (Si II, Si III, and Si IV) lines. Similarly, no evidence is found for carbon in the photosphere of the A2II star in V356 Sgr (Figure 4). Inspection of the high dispersion non-eclipse IUE images of V356 Sgr reveal a relatively normal B3/B4 stellar spectrum, including carbon lines. Figure 4 also presents data on the relative strengths of the photospheric C III $\lambda 1247$ and Si II $\lambda 1264$ lines for V356 Sgr and a set of B2.5 to B5 stars with similar rotational velocities. It is quite apparent that the C III line is of at least normal strength, indeed for its spectral type the C III line in V356 Sgr appears somewhat stronger than expected. Thus, we must conclude that the B3V component of V356 Sgr has an essentially normal carbon abundance while the A2II star has no observable carbon. How are these two carbon line observations compatible? Simple arguments (cf. those presented for other binaries in Ref. 2) can show that the secondary (A2II) star has likely lost enough mass to have reached its CNO processed layers. These layers will be virtually devoid of carbon and slightly nitrogen rich (cf. Ref. 2). Thus, a compositional difference is expected to exist between the two components of the binary system.

One final question remains: what is the geometrical distribution of the high ionization gas. Figure 5 shows the Al III emission lines seen superposed on the photosphere of the A2II star. Despite the obviously saturated central absorption of the Al III lines *no* significant absorption of the A star's photospheric light is detected. Thus, the line formation region must be outside our line of sight, i.e. outside the orbital plane. Similar results are obtained for Si III and the scattered light continuum (Figure 3).

6. MODEL

Shu (Ref. 5) has proposed a model for a "magnetically assisted accretion driven" wind for critically rotating pre-main sequence stars. His model can, with little modification, be directly applied to V356 Sgr. Carbon poor material will be transferred to a small accretion disk surrounding the B3 star. Using Shu's arguments, a portion ($\sim 75\%$) of this disk material will be accreted by the B3 star with the remainder being driven away in a wind with a characteristic velocity near the escape velocity of the B3 star and a preferential direction away from the orbital plane. Thus, this model predicts a gas outside the orbital plane with the chemical composition of the secondary but the velocity characteristics of the primary. This work is supported by NASA Grants NAGW-587 and NAG5-441.

7. REFERENCES

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	Table I. V356 Sgr		8.896106
Period (days)			
Spectrum	B3V	A2II	
Mass (M_{\odot})	12.1 \pm 1.1	4.7 \pm 0.6	
Radius (R_{\odot})	6.0 \pm 0.7	14.0 \pm 1.5	
Log g	3.96 \pm 0.10	2.82 \pm 0.10	
V_{escape} (km s^{-1})	877 \pm 65	358 \pm 30	
$V \sin i$ (km s^{-1})	350	90	
V_{sync} (km s^{-1})	33	77	
T_{eff} (K)	16500* \pm 750	8600 \pm 300	
\dot{P}	4 \times 10 $^{-9}$		
M ($M_{\odot} \text{ yr}^{-1}$)	4 \times 10 $^{-7}$		