THE NATURE OF V861 SCO (=HD 152667)

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ABSTRACT

The physical parameters of the components of V861 Sco are derived from light-curve analysis and published spectroscopy. Good agreement with evolutionary models is obtained. The stellar wind is investigated using IUE data; the results include no large phase dependence of the mass loss rate and insensitivity of the velocity of the wind (measured with respect to interstellar lines) to changes in the photospheric velocity, even near the base of the wind. However, small random changes in velocity near the base of the wind are amplified to larger changes further out.

1. INTRODUCTION

Interest in V861 Sco was aroused by the suggestion of Polidan et al. (1978, 1979) that the system contains a black hole. Although this now seems unlikely (White and Pravdo 1979, Armstrong et al. 1980) the system remains worthy of investigation because of its high mass loss rate and because of the scarcity of binary systems containing early-type stars with mass ratios M_1/M_2 as large as 3.

2. LIGHT-CURVE SYNTHESIS

G. Hill's LIGHT code (Hill 1979) has been used to solve for the system parameters (assuming, of course, a normal two star model) using the B photometry of Cousins and Lagerwey (1969). For the primary (B0Ia) an effective temperature of 25000 K was adopted, together with the assumption that it fills its Roche lobe. Radiative gravity darkening (β=0.25) was adopted for both components, and solutions generated for a grid of mass ratios. Initial estimates for free parameters were adopted from fits using Wood's WINK code (Wood 1971) with Walker's (1972) values as a starting point. LIGHT was used in passband mode with theoretical limb darkening and model atmosphere fluxes (c.f. Hill 1979).

C. Chiosi and R. Stalio (eds.), Effects of Mass Loss on Stellar Evolution, 481–486.

The adopted parameters are given in Table 1 (the quoted errors do not allow for uncertainties in the mass ratio), and the resulting light-curve shown in Figure 1. The r.m.s. residual of the model from the data is $0^{m}.02$, which appears to be congruent with the observational errors. The absolute dimensions of the system are based on $a_1 \sin i = 9.4 \pm 0.3) \times 10^6$ km and f(M) = 0.50±0.05 (Walker 1971, Hutchings 1979, Wolff and Beichman 1979). The characteristics of the secondary correspond to a spectral type of ~B2V.

TABLE 1. PARAMETERS OF V861 SCO

$T_1^* = 25000$	$T_2^* = 15170 \pm 1170$
$(R_1^*/\mathrm{sepn.}) = 0.4475$	$(R_2^*/\mathrm{sepn}) = 0.1553 \pm 0.0065$
$\beta_1 = \beta_2 = 0.25$	$i = 75^{\circ}.4 \pm 1^{\circ}.4$
$M_1/M_2 = 3.0$	
$R_1 = 26.3 \pm 0.9\ R_{\odot}$	$R_2 = 8.6 \pm 0.5\ R_{\odot}$
$M_1 = 25.8 \pm 2.7\ M_{\odot}$	$M_2 = 8.6 \pm 0.9\ M_{\odot}$
$\log(L_1/L_{\odot}) = 5.37 \pm 0.07$	$\log(L_2/L_{\odot}) = 3.55 \pm 0.33$

*Polar values

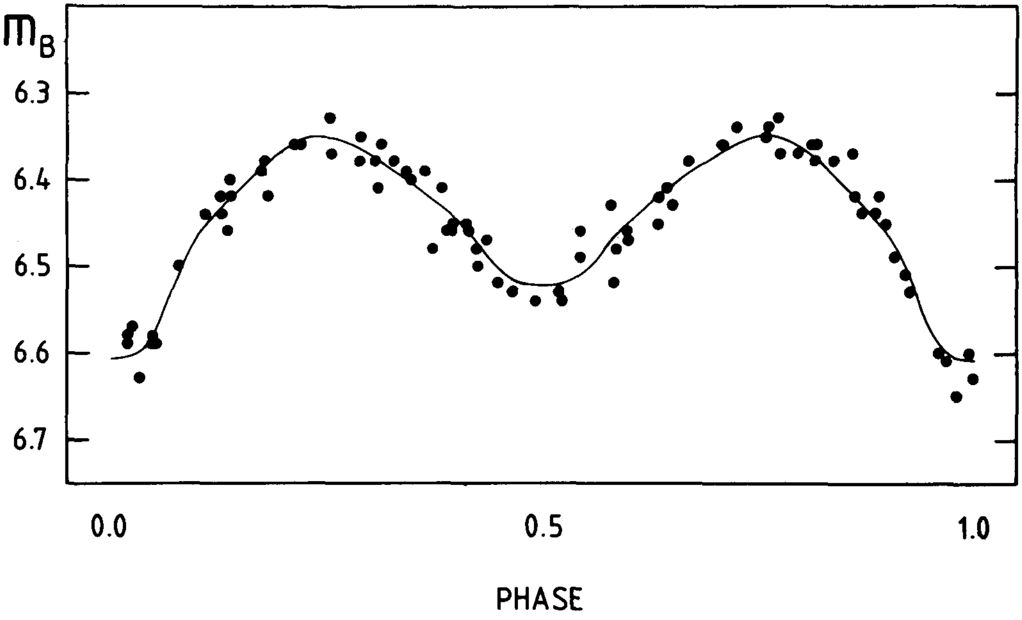

FIGURE 1. Light-curve of V861 Sco. Dots: observations of Cousins and Lagerwey (1969). Solid line: model fit.

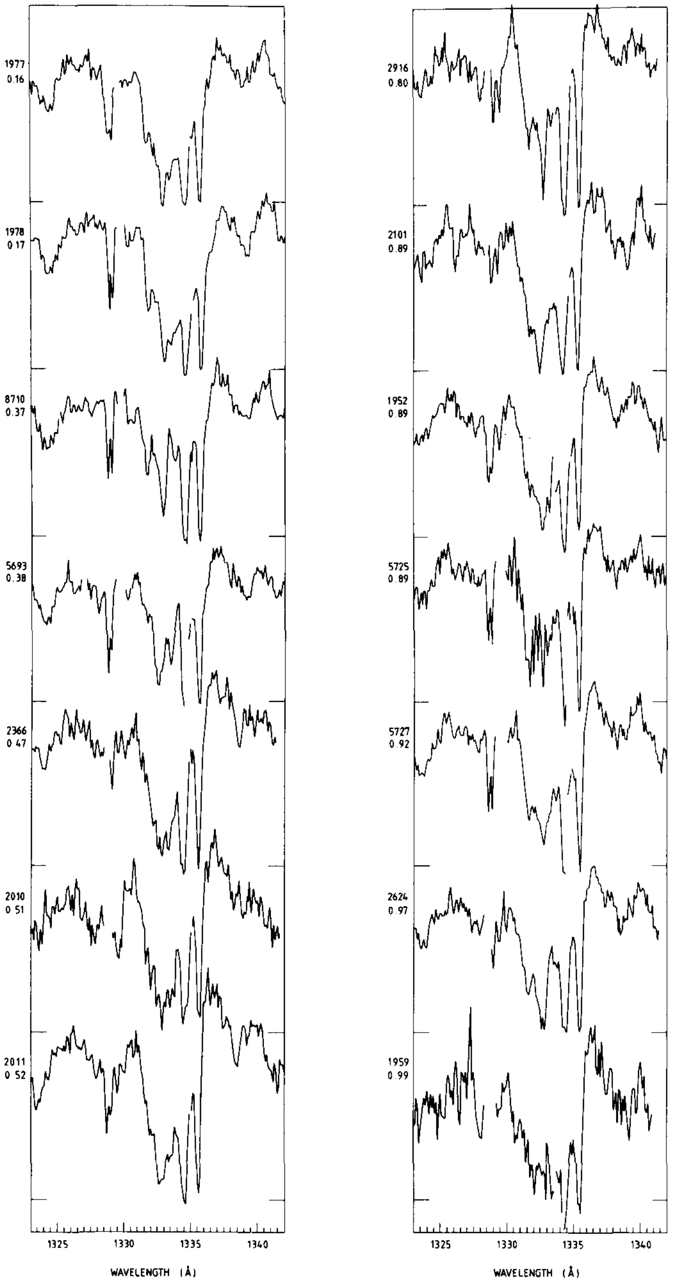

FIGURE 2. IUE observations of C II. Labels give the image number and the phase.

3. STELLAR WIND AND MASS LOSS

Massey et al. (1979) have reported phase dependent variations in the emission profile of Hα which they found repeated well from orbit to orbit (although Howarth et al. 1980 give an example of Hα in absorption). While they were unable to account for the variations in details, they attributed them to gas streams in the system.

We have a large body of high resolution IUE data (14 SWP, 7 LWR images) which we can use to look for further evidence of gas streaming. SWP spectra affected by the ITF error have been corrected using an algorithm provided by J. Settle (Settle and Sandford 1980), and all spectra have been re-extracted from the GPHOT image using STAK and TRAK (Giddings and Settle 1980). Figure 2 shows a montage of observations of the C II resonance lines ordered by orbital phase (other lines are saturated and thus less suitable for this purpose). As can be seen there are no obvious phase dependent variations, except possibly a decrease in optical depth around phase 0.37, although changes in profiles do occur on longer time scales.

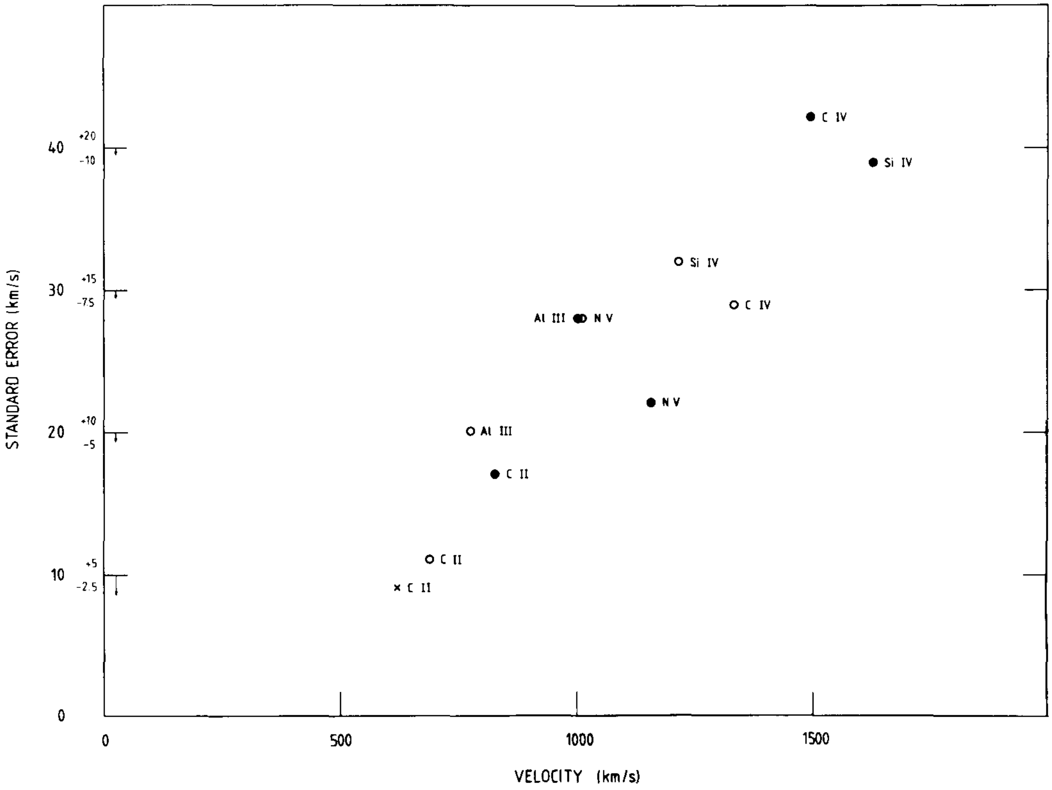

FIGURE 3. Plot of σ_v against v (see text for details). Open circles mark ½ blue edge velocities, filled circles blue edge velocities, x the -620 km/s dip.

An interesting result that has emerged from measurements of the IUE spectra is that ions occuring at high velocities in the wind show greater velocity variability than those formed lower in the wind. This is shown in Figure 3, where the standard error of the mean observed velocity is plotted against the mean observed velocity; a clear correlation emerges. This result appears to be a consequence of changes in the velocity law rather than in the ionisation balance; for example, the data suggest that the C II and C IV edge velocities vary in the same sense. The variations in edge velocity are not detectably phase dependent, and imply that small changes in velocity near the base of the wind are translated into much larger variations as the material moves out.

Note that no correction for underlying orbital motion has been applied to the observed velocities. In particular, careful measurement of the -620 km/s sharp dip observed in the C II resonance lines (Figure 2), perhaps due to a velocity plateau in the wind, shows the observed velocity scatter to be characterised by an s.d. of only 6^{+6}_{-4} (96% confidence interval) km/s after allowance for measuring errors. This contrasts with the photospheric velocity amplitude of $\sim$170 km/s (Wolff and Beichman 1979).

The rate of mass loss via the stellar wind of the primary may be estimated from the infrared excess or from the UV resonance lines. From IR data Wolff and Beichman (1979) found $\dot{M} = -5 \times 10^{-6}\ M_\odot$/yr, while Tanzi et al. (1979) and Howarth et al. (1980) obtained $\dot{M} = -1 \times 10^{-6}\ M_\odot$/yr. From UV data Howarth et al found $\dot{M} < -1.5 \times 10^{-6}\ M_\odot$/yr; Hutchings and Dupree (1980) give $\dot{M} = -9 \times 10^{-6}\ M_\odot$/yr. The semi-empirical relationship of Chiosi (1980), used with the parameters of Table 1, predicts $\dot{M} = -1.0 \times 10^{-5} M_\odot$/yr, while that of Andriesse gives $-4.8 \times 10^{-6}\ M_\odot$/yr.

4. EVOLUTIONARY STATUS

De Loore et al. (1977) have published theoretical loci of constant N in the mass-luminosity plane for hydrogen shell burning stars, where N parameterises the mass loss rate:

$$N = -\dot{M}\, c^2/L$$

We find for the primary of V861 Sco N=300, in common with other binary systems (Vanbeveren and de Loore 1980). Then using the theoretical HR diagram of de Loore et al. (1978) we find that the primary is indeed hydrogen shell burning. The evolutionary mass of the primary is 23±1 $M_\odot$ (having arisen from a $\sim$48 $M_\odot$ ZAMS progenitor), in good agreement with the observed mass. The radius is fully consistent with Roche lobe filling and the results of the light-curve analysis.

The bolometric magnitude of the secondary is -4.1±0.8, below the limit for rapid mass loss (e.g. Snow and Morton 1976), so we use Stothers' (1972) conservative M-L diagram to obtain 8±2 $M_\odot$ as the evolutionary mass of the secondary (which is on the main sequence). Agreement with the observed mass is again satisfactory.

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