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# Four-colour photometry of eclipsing binaries

## XXXVIII. Light curves of the triple system V906 Scorpii⋆,⋆⋆

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**Abstract.** Complete *uvby* light curves of the detached triple-lined late B-type eclipsing binary V906 Scorpii, secured from 1987 to 1991, are presented. A detailed photometric analysis based on these observations and on new spectroscopic material yields accurate masses and radii (errors $\lesssim$2%) for the components, confirms that the system is a member of NGC 6475 (Messier 7), and is published separately (Alencar et al. 1997).

**Key words:** stars: binaries: eclipsing — stars: individual: V906 Sco

### 1. Introduction

The southern, bright and massive late B-type (B9V + B9V, $V = 6\overset{\mathrm{m}}{.}0$, $P = 2\overset{\mathrm{d}}{.}79$, eccentric orbit) detached eclipsing binary V906 Sco (see Table 1) was discovered as eclipsing by Koelbloed (1959), in a photometric study of M7. The system is also a triple–lined spectroscopic binary (Lacy & Evans 1979; Alencar et al. 1997). Moderate proximity effects are present in the light curves, which show well defined and unequal minima, the primary minimum having a depth of $0\overset{\mathrm{m}}{.}21$, $0\overset{\mathrm{m}}{.}02$ deeper than the secondary one in the colour $y$.

The eclipsing components have different masses, and are well inside their Roche–lobes, with the secondary (the star closest to the observer during the primary minimum) being more massive, larger, but cooler than the primary. V906 Sco is one of the rare systems with components still on the main sequence, presenting different masses and with the more massive component very close to the terminal age main sequence (TAMS, Alencar et al. 1997). This, together with the fact that V906 Sco is a member of the open cluster NGC 6475, makes the system very important for the control of modern models of stellar evolution.

**Table 1.** Data for V906 Sco and the comparison stars

| | V906Sco | Comp.1 | Comp.2 | Comp.3 |
|---|---|---|---|---|
| HD | 162724 | 162631 | 162817 | 161390 |
| SAO | 209428 | 209422 | 209446 | 209246 |
| $\alpha_{1950}$ | $17^{\mathrm{h}}\ 50^{\mathrm{m}}\ 35^{\mathrm{s}}$ | $17^{\mathrm{h}}\ 50^{\mathrm{m}}\ 15^{\mathrm{s}}$ | $17^{\mathrm{h}}\ 51^{\mathrm{m}}\ 08^{\mathrm{s}}$ | $17^{\mathrm{h}}\ 43^{\mathrm{m}}\ 41^{\mathrm{s}}$ |
| $\delta_{1950}$ | $-34^{\circ}\ 44'\ 35''$ | $-34^{\circ}\ 51'\ 20''$ | $-34^{\circ}\ 27'\ 28''$ | $-38^{\circ}\ 05'\ 37''$ |
| Sp.type | B9V | A0 | A0 | B9 |
| $V(0\overset{\mathrm{p}}{.}25)$ | 5.96 ±1 | 7.40 ±1 | 6.12 ±1 | 6.43 ±1 |
| $b-y$ | 0.032 ±3 | 0.044 ±3 | 0.063 ±2 | −0.002 ±1 |
| $m_1$ | 0.100 ±3 | 0.126 ±4 | 0.094 ±2 | 136 ±2 |
| $c_1$ | 0.972 ±3 | 1.023 ±5 | 1.183 ±2 | 0.878 ±7 |
| $\beta(0\overset{\mathrm{p}}{.}239)$ | 2.801 ±3 | 2.861 ±4 | 2.811 ±3 | 2.843 ±4 |

Here we present the first accurate and complete light curves of V906 Sco. Medium– (18 Å/mm) and high–

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⋆ Based on observations done with the Danish 50 cm Telescope (SAT) at the European Southern Observatory (ESO), La Silla, Chile.

⋆⋆ Table 2 presented in this paper will only be accessible in electronic form at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsweb.u-strasbg.fr/Abstract.html

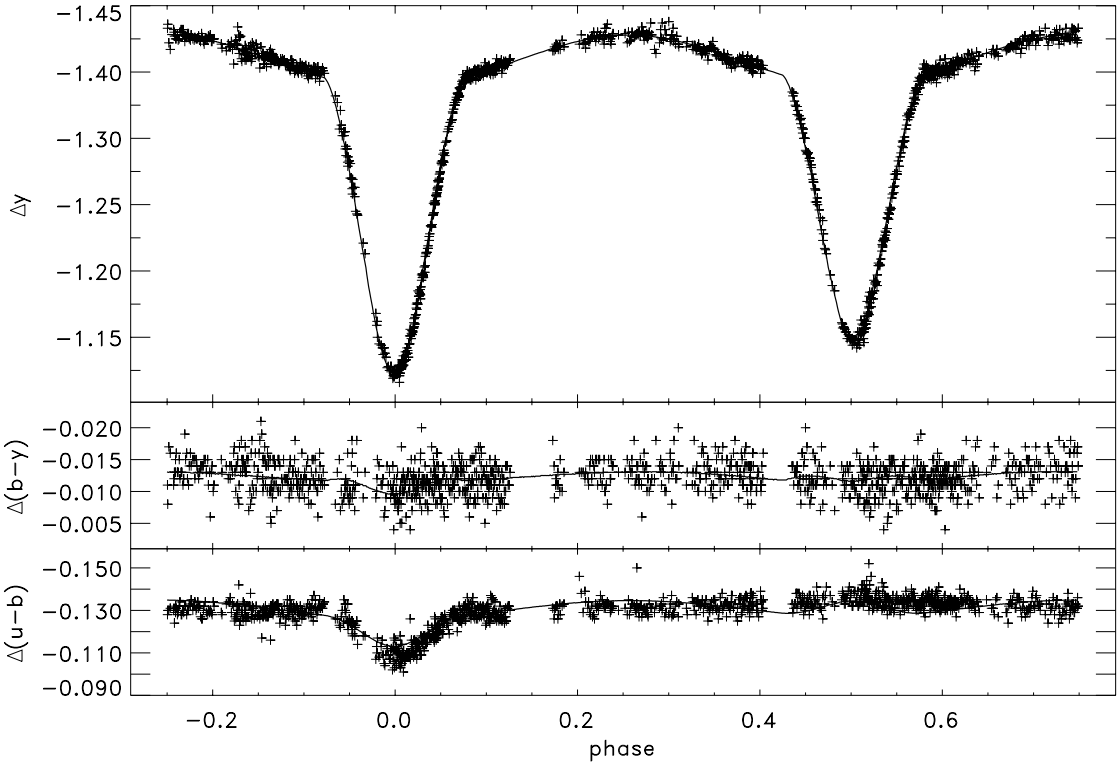


**Fig. 1.** $y$ magnitude differences and $b-y$ and $u-b$ colour index differences V906 Sco−HD 162 631 obtained at ESO, with the theoretical light curves (Alencar et al. 1997)

(6 Å/mm) dispersion CCD coudé spectra have also been secured. These data and a study of V906 Sco based on them (published separately, Alencar et al. 1997) yield precise absolute dimensions ($M_{\rm A} = 3.253 \pm 0.069\ M_\odot$, $R_{\rm A} = 3.515 \pm 0.039\ R_\odot$; $M_{\rm B} = 3.378 \pm 0.071\ M_\odot$, $R_{\rm B} = 4.617 \pm 0.034\ R_\odot$) and confirm that the system is a member of Messier 7 (NGC 6475), with an age of $(2.4 \pm 0.3) \times 10^8$ years. The eclipsing components constitute a visual pair with the third companion, and the slightly eccentric eclipsing orbit probably presents apsidal motion (Alencar et al. 1997).

## 2. Observations

The Strömgren *uvby* system was used in all photometric measurements. During 60 nights (9 nights from Mar. 15 to 29, 1987, 24 from Feb. 30 to Mar. 31, 1988, 14 from Apr. 1 to May 8, 1989, 3 from May 6 to 16, 1990 and 10 from Apr. 4 to 30, 1991) V906 Sco was observed at ESO (La Silla, Chile), with the 50 cm Strömgren Automatic Telescope (SAT) equipped with the six–channel spectrograph–photometer (four channels for simultaneous *uvby* photometry and two channels for simultaneous measurements of $H_\beta$ narrow and wide filters) and photon counting system described by Nielsen et al. (1987). In the measurements a circular diaphram of 13″ diameter was used. Apart from the third component of this triple system, detected spectroscopically, no other stars were detected inside this diaphragm, despite the richness of the field close to V906 Sco (which is approximately in the central projected region of M7). The system has been reported (Van den Bos 1931) to constitute a visual pair; this could not be discerned during our observations, due to the close proximity of V906 Sco and its companion.

Extinction corrections were based on the nightly coefficients from the three comparison stars and other constant stars. When needed, linear or quadratic corrections were applied for correcting for eventual instrumental drifts (uncooled photomultipliers), and/or for variations in the atmosphere transparency during the night. The dead times of the six EMI 9789QA, S11, selected for low dark counts, were accounted for in the reduction procedure.

HD 162 631, HD 162 817 (HR 6 668) and HD 161 390 (HR 6 613) were used as comparison stars and observed alternately between the measurements of V906 Sco. The first two stars are located very close to V906 Sco (maximum projected distance in the sky of 0.°3) while the last one is a bit more distant (3.°8) from the system. All three stars were found to be constant within the observational accuracy throughout the observing periods. The observations of HD 162 817 and HD 161 390 were transformed to $C_1$ (HD 162 631) by means of the constant difference of magnitude between them and $C_1$ obtained from all nights. For the sake of completeness we repeat here Table 1 from

Alencar et al. (1997), with information for V906 Sco and comparison stars.

Typical rms errors of one magnitude difference between the comparison stars in the measurements were found to be: $0\overset{m}{.}005$ for $\sigma(\Delta u)$, $0\overset{m}{.}003$ for ($\Delta v$, $\Delta b$ and $\Delta y$). Most of the phases were covered at least twice. The observations are available in electronic form at the CDS, as Table 2, containing 1117 magnitude differences V906 Sco − HD 162 631 in the instrumental system. Figure 1 shows the observed light curves ($y$, $b-y$ and $u-b$), together with the theoretical solution obtained by Alencar et al. (1997).

The coefficients for transformation to the standard *uvby* system obtained by us agree very well with those determined by Olsen (1993), which are more accurate and based on observations from 1985, 1986 and 1987. Those coefficients should, then, be adopted. They are repeated in Table 3 for convenient use, together with the transformation equations.

**Table 3.** Transformation coefficients from Olsen(1993); $\Delta$ indicates a difference in the instrumental system (directly from Table 2) and $\delta$ a transformed value in the standard system

| | | | |
|---|---|---|---|
| $\Delta(b-y)=$ | | $D\ \delta(b-y)$ | |
| $\delta m_1$ | $=$ | $F\ \Delta m_1$ | $+\ J\ \delta(b-y)$ |
| $\delta c_1$ | $=$ | $H\ \Delta c_1$ | $+\ I\ \delta(b-y)$ |
| $\delta V$ | $=$ | $\delta y$ | $+\ B\ \delta(b-y)$ |

For data obtained at SAT–ESO 1985 to 1991 (Table 2):

| | | | |
|---|---|---|---|
| $B$ | $= 0.021 \pm 0.003$ | $H$ | $= 1.014 \pm 0.003$ |
| $D$ | $= 1.019 \pm 0.003$ | $I$ | $= 0.109 \pm 0.005$ |
| $F$ | $= 0.975 \pm 0.022$ | $J$ | $= 0.011 \pm 0.005$ |

Further discussion of these observations, including a study of times of minima (which makes evident the existence of apsidal motion), some observations in H$\beta$, and a spectroscopic study based on new spectroscopic observations will be published as part of a detailed photometric analysis of V906 Sco, based on these *uvby* light curves and $\beta$ index measurements (Alencar et al. 1997).

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