

Four-colour photometry of eclipsing binaries

XXXVI. Light curves of the O7V+O9V system V 3903 Sagittarii^{*,**}

L.P.R. Vaz^{1,6}, N.C.S. Cunha^{1,2}, J. Andersen³, J.V. Clausen³, J.M. Garcia^{4,5}, A. Giménez^{2,5}, B.W. Casey⁶, and S. de Koff^{7,8}

¹ Departamento de Física, ICEX, UFMG, C.P. 702, 30161-970 Belo Horizonte, MG, Brazil

² Laboratorio de Astrofísica Espacial y Física Fundamental, INTA, Apdo. 50727, 28080 Madrid, Spain

³ Astronomical Observatory, NBIfAFG, Juliane Maries Vej 30, DK-2100 Copenhagen, Denmark

⁴ Departamento de Física, E.U.I.T. Industriales, UPM, Ronda de Valencia 3, E-28012 Madrid, Spain

⁵ Instituto de Astrofísica de Andalucía, Apdo. 3004, E-18080 Granada, Spain

⁶ Department of Astronomy, University of Wisconsin, wadison, Wisconsin 53706, U.S.A.

⁷ Sterrewacht Leiden, Leiden University, Niels Bohrweg 2, 2333 CA Leiden, The Netherlands

⁸ Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, U.S.A.

Received May 22; accepted July 11, 1997

Abstract. Complete *uvby* light curves of the young detached double-lined massive O-type eclipsing binary V 3903 Sagittarii, obtained from 1989 to 1994, are presented. The observations were obtained at two different sites and a discussion of the characteristics of both data sets is included.

Key words: binaries: eclipsing: spectroscopic — stars: individual: V 3903 Sgr — stars: early-type

attainment of high precision differential photometry, as a good candidate for absolute dimension determinations. Strong proximity effects are present in the light curves, which show shallow but well defined and unequal minima, the primary minimum having a depth of 0^m18, 0^m02 deeper than the secondary one in the *y* band.

V 3903 Sgr is one of the rare massive systems with components still on the main sequence. Amongst these, only EM Car (Andersen & Clausen 1989) and Y Cyg (Simon et al. 1994; Hill & Holmgren 1995) have masses $> 17 M_{\odot}$ determined, together with the radii, to the accuracy desirable for tests of evolutionary models: 1 – 2%. However, both EM Car and Y Cyg have nearly equal mass components, what makes difficult the control of theoretical evolutionary tracks. It turned out that V 3903 Sgr is the system with the most massive primary, with the largest mass difference between the components, and the one closest to the theoretical ZAMS (Vaz et al. 1997) amongst those with the highest reliable absolute dimensions known to date.

In this paper we present the first accurate and complete light curves of V 3903 Sgr. Medium- (18 Å/mm) and high- (6 Å/mm) dispersion CCD coudé spectra have also been obtained. A study based on these data, including times of minimum and a period analysis, (published separately, Vaz et al. 1997) yields precise absolute dimensions ($M_A = 27.27 \pm 0.55$, $R_A = 8.088 \pm 0.088$; $M_B = 19.01 \pm 0.44$, $R_B = 6.125 \pm 0.060$, solar units) and concludes that the system is a member of the Lagoon Nebula complex, very close to the young open cluster NGC 6530, and with an age between 1.7 and 2.5 10^6 years.

1. Introduction

The southern, reasonably bright and massive early type (O7V + O9V, $V = 7^m3$, $P = 1^d74$, circular orbit) detached eclipsing binary V 3903 Sgr (see Table 1) was discovered as eclipsing by Cunha et al. (1990), after reports of variations in the brightness of the system by Cousins (1973) and Clariá (1976). The system is also a double lined spectroscopic binary (Conti & Alschuler 1971; Niemela & Morisson 1988; Vaz et al. 1993, 1997). Therefore, V 3903 Sgr was included in our program for

Send offprint requests to: L.P.P. Vaz at address 1

* Based on observations done with the ZEISS 60 cm telescope at the Pico dos Dias Observatory (PDO), National Laboratory of Astrophysics, LNA-CNPq, Brasópolis, MG, Brazil, and with the Danish 50 cm Telescope (SAT) at the European Southern Observatory (ESO), La Silla, Chile.

** The Tables 2, 3 and 4, presented in this paper will be only available 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>

2. Observations

The photoelectric observations were collected at two sites, with different telescopes and equipment: the ZEISS 60 cm telescope of PDO-LNA-CNPq with a single-channel TEXAS photometer and the Danish 50 cm telescope (SAT) at ESO with a 6-channel photometer. Although the *wby* photometric system was used in all runs, it is natural to expect differences between the two sets of data, caused by differences in the equipment (e.g. filter transmission) and in the site properties (altitude and humidity).

2.1. The PDO measurements

During 35 nights (10 from Jun. 16 to Aug. 17, 1989, 9 from Jul. 30 to Aug. 15, 1990, 16 from May 23 to Jun. 18, 1991) V 3903 Sgr was observed at PDO (LNA-CNPq, Brasópolis, Brazil), with the 60 cm telescope and a single-channel photometer equipped with a photon counting system. A slightly elliptical diaphragm with 39'' major axis was used (Cunha 1990). No other star was detected inside this diaphragm with an image intensifier placed at the eyepiece, despite the richness of the field close to V 3903 Sgr.

Extinction corrections were based on the nightly coefficients from the four comparison stars and other constant stars. When needed, linear or quadratic corrections were applied for eventual instrumental drifts, since the temperature of the cooled photomultiplier was kept 30°C below the (variable) ambient temperature and/or for variations in the atmosphere transparency during the night. The dead time of the RCA 8850 tube (spectral response 116, RCA Photomultiplier Tubes Catalogue, 1971) was accounted for in the reduction procedure.

HD 165 999, HD 164 681, HD 164 584 (7 Sgr) and HD 167 666, all close (maximum projected distance in the sky of 4.9) to V 3903 Sgr, were used as comparison stars and observed alternately between the measurements of V 3903 Sgr. All four stars were found to be constant within the observational accuracy throughout the observing periods. The observations of C_2 , C_3 and C_4 were transformed to C_1 by means of the constant difference of magnitude between them and C_1 obtained from all nights. For completeness we repeat here Table 1 from Vaz et al. (1997), with information for V 3903 Sgr and the comparison stars.

The light curves V 3903 Sgr – HD 165 999 in the instrumental system u (478 points), v (532), b (544), y (537), are shown in Fig. 1 and are accessible in electronic form at the CDS as Table 2. Typical rms errors of one magnitude difference between the comparison stars were found to be: 0^m009 (Δu), 0^m006 (Δv), 0^m005 (Δb , Δy). Most of the phases were covered at least twice.

2.2. The ESO measurements

V 3903 Sgr was also observed, during 32 nights (3 from May 04 to 17, 1990, 3 from Apr. 12 to 25, 1991, Jun. 06 and

Table 1. Catalogue data and standard *wby* β indices for V 3903 Sgr and the comparison stars. The indices for V 3903 Sgr are for phases 0^h75 (*wby*) and 0^h22 (β)

	V 3903 Sgr	C_1	C_2	C_3	C_4
HR	–	–	–	6 724	6 835
HD	165 921	165 999	164 681	164 584	167 666
SAO	186 366	186 375	186 160	186 163	186 594
DM	–24° 13 962	–23° 13 991	–26° 12 724	–24° 13 793	–28° 13 407
Sp	O7V+O9V	A5III	A4V	F5II	A4III
α_{1950}	18 ^h 06 ^m 14 ^s	18 ^h 06 ^m 33 ^s	18 ^h 00 ^m 17 ^s	17 ^h 59 ^m 47 ^s	18 ^h 14 ^m 13 ^s
δ_{1950}	–23° 59' 52''	–23° 34' 40''	–26° 19' 18''	–24° 17' 01''	–28° 40' 17''
l	6 ^o .9	7 ^o .3	4 ^o .3	6 ^o .0	3 ^o .7
b	–2 ^o .1	–2 ^o .0	–2 ^o .1	–1 ^o .0	–5 ^o .9
V	7.306 ±6	7.683 ±8	7.340 ±10	5.408 ±9	6.198 ±6
$b-y$	0.183 ±2	0.170 ±4	0.071 ±4	0.336 ±6	0.114 ±5
m_1	–0.009 ±5	0.142 ±2	0.122 ±7	0.140 ±4	0.162 ±9
c_1	–0.109 ±9	1.096 ±9	1.038 ±9	1.030 ±11	1.145 ±13
β	2.584 ±2	2.869 ±4	2.879 ±6	2.709 ±6	2.852 ±3

18, 1993 and 24 from Jun. 06 to Aug. 09 1994), with the 50 cm Strömgren Automatic Telescope at ESO, La Silla, Chile. The instrument was equipped with the six-channel spectrograph-photometer (four channels for simultaneous *wby* photometry and two channels for simultaneous measurements of H_β narrow and wide filters) and the photon counting system described by Nielsen et al. (1987). In the measurements taken from 1990 to 1993 a circular diaphragm of 13'' diameter was used, but in 1994 observations a 17'' diameter diaphragm was used.

The comparison stars used in the PDO observations, (Table 1), were adopted, and they were constant within the observational accuracy throughout the observing period. Each night several variables were observed, and the nightly extinction corrections were based on coefficients determined from all the comparison stars. As happened in the reduction of PDO measurements, linear or quadratic corrections for instrumental drift and/or changes in sky transparency during the night were applied when needed. The dead times of the six EMI 9789QA uncooled photomultipliers, which have S11 spectral response, were accounted for in the reduction procedure.

Typical rms errors of one magnitude difference between the comparison stars in the ESO measurements were found to be: 0^m006 (Δu), 0^m003 (Δv , Δb , Δy). Most of the phases were covered at least twice. The light curves are shown in Fig. 3 of Vaz et al. (1997) and the observations are available in electronic form at the CDS, as Tables 3 and 4. Table 3 contains 180 magnitude differences V 3903 Sgr – HD 165 999 in the instrumental system for 1990, 1991 and 1993, obtained with the diaphragm of 13'' diameter, and Table 4 contains the 1994 observations

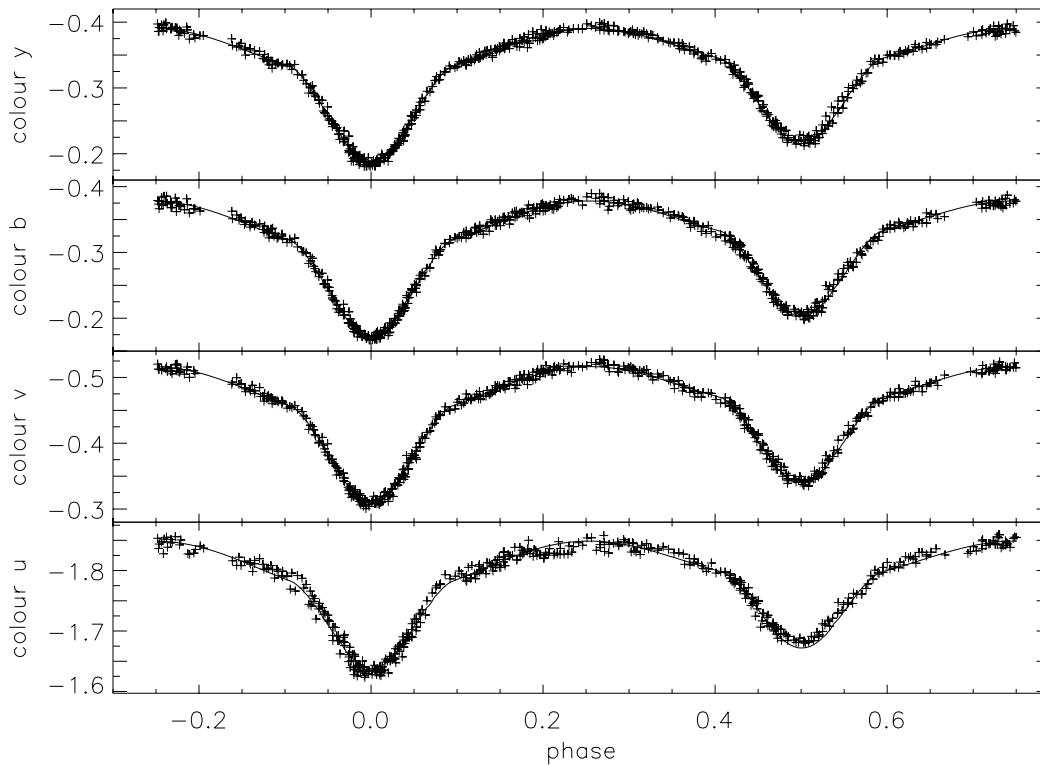


Fig. 1. *uvby* magnitude differences V 3903 Sgr–HD 165999 obtained at PDO, with the theoretical light curves (Vaz et al. 1997)

(507 points, instrumental system), which were obtained with a diaphragm of $17''$ diameter.

3. Comparison of observations obtained in different sites and using different diaphragms

Even though different sites, instruments, photometers and diaphragms were used in these observations, these data match very well with each other, especially for the colours *y* and *b*, for which no discrepancy is noticed between the observations of Tables 2, 3 and 4. The *v* magnitude differences obtained at PDO (instrumental system) lay systematically fainter than those obtained at ESO by $\approx 0^m.013$, and the PDO *u* measurements are systematically fainter than the ESO ones by $\approx 0^m.025$ (again in the instrumental system). The PDO observations were obtained with a single-channel photometer and each filter was measured at a time, while the SAT observations were obtained simultaneously measuring the four colours each time. Despite this difference, the reduction procedures are essentially equal and could not account for these discrepancies.

One reason for such differences could be the fact that the photometers are essentially different: not only the sets of filters are different, but the PDO photometer is filter defined, while the SAT one has, besides the filters, a grat-

ing and a slit in the light path, defining the bandwidth of the measurements (a spectrograph-photometer).

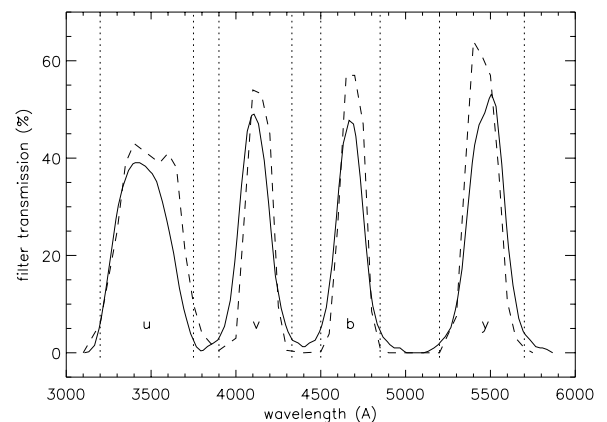


Fig. 2. Transmission curves for the *uvby* filters used at PDO (dashed line) and at ESO (continuous line). The slit limits of the SAT photometer are also shown as vertical dotted lines

In fact, the *u* filter transmission curve for the PDO instrument is $\approx 15\%$ broader in the “red” end than that for

the filter used in SAT photometer. In Fig. 2 we show the transmission functions for the filters of both the PDO and SAT photometers. The most striking difference happens for the u filter. Considering that C_1 (Table 1) is cooler than V 3903 Sgr, there will be an excess of u light, proceeding from the variable in the PDO measurements in comparison with the SAT ones. This could explain the artificial third light (1.4%) found for the PDO u light curve in Vaz et al. (1997, no third light was found necessary for all the SAT light curves and the PDO vby ones). On the other hand, it is difficult to use the same argument to explain the fact that the PDO u light curve be systematically fainter than the SAT one. This happens in the instrumental system only; the light curves transformed to the standard system do agree in both sets for all four colours, showing that the transformations of Table 5 do eliminate the problem. However, in order to keep errors in the geometrical parameters as small as possible, we avoid the transformation to the standard system and analyse the light curves only in the instrumental system.

A red leak in the PDO u filter could also be the reason for these problems, but we do not have any information about the existence of such a leak. Another possible explanation for such discrepancies might be the different altitudes of the 2 sites: while PDO is at 1 800 m in a very humid region, La Silla is located at 2 400 m above sea level in a much drier climate. This would have stronger effect for the shorter wavelengths.

V 3903 Sgr illuminates the bright nebulae IC 4685 (Hirshfeld & Sinnott 1982, 1985), and it is surprising the negligible effect of using different diaphragms in ESO observations (Tables 3 and 4) on the light curves. As the region is rich of bright nebulae, measurements (especially with SAT, which has automatic pointing, but also manually with the PDO telescope) of the sky background were taken careful and consistently in the same relative positions and after every observation of both variable and the four comparison stars. This indicates that the background contributions, at the places selected for its measurements, are fairly constant in counts per unit area, the only explanation for the excellent agreement between the data obtained with SAT using the different diaphragms.

Coefficients for transformation to the standard $uvby$ system are given in Table 5 for the data obtained in the two sites and in the different runs. The differences discussed above are reflected in the coefficients of Table 5.

Further discussion of these observations, including times of minima, some observations in $H\beta$, and a spectroscopic study will be published as part of a detailed photometric analysis of V 3903 Sgr, based on these $uvby$ light curves and β index measurements (Vaz et al. 1997).

Acknowledgements. We acknowledge grants from the Danish Natural Science Research Council, the Danish Board for Astronomical Research, the American National Science

Table 5. Transformation coefficients; Δ indicates the differences in the instrumental system (Tables 2, 3 and 4) and δ the transformed values in the standard system

$\delta(b - y) =$	$D \Delta(b - y)$	
$\delta m_1 =$	$F \Delta m_1$	$+ J \delta(b - y)$
$\delta c_1 =$	$H \Delta c_1$	$+ I \delta(b - y)$
$\delta V =$	Δy	$+ B \delta(b - y)$
For data obtained at PDO-LNA-CNPq (Table 2):		
$B =$	0.026 ± 0.010	$H = 1.050 \pm 0.013$
$D =$	0.996 ± 0.008	$I = 0.016 \pm 0.037$
$F =$	1.047 ± 0.072	$J = 0.043 \pm 0.031$
For data obtained at SAT-ESO 1990 to 1993 (Table 3):		
$B =$	0.061 ± 0.032	$H = 1.015 \pm 0.008$
$D =$	1.022 ± 0.008	$I = 0.103 \pm 0.017$
$F =$	0.954 ± 0.074	$J = 0.019 \pm 0.015$
For data obtained at SAT-ESO 1994 (Table 4):		
$B =$	0.034 ± 0.015	$H = 1.014 \pm 0.010$
$D =$	1.022 ± 0.010	$I = 0.143 \pm 0.008$
$F =$	0.950 ± 0.022	$J = 0.000 \pm 0.008$

Foundation (AST94-1715), the Wisconsin Alumni Research Foundation, the Wisconsin Space Grant Consortium, the ESO traveling fund, and from the Brazilian institutions CNPq, FAPEMIG, FINEP, CAPES. Support was also received through the programme of cultural, educational, and scientific cooperation between Spain and Denmark. LPV gratefully acknowledges the hospitality received at the Dept. of Astronomy, Univ. of Wisconsin, Madison, from Aug. 93 to Oct. 94. This research has made use of the Simbad database, operated at CDS, Strasbourg, France.

References

- Andersen J., Clausen J.V., 1989, A&A 213, 183
 Clariá J.J., 1976, IBVS 1106
 Cousins A.W.J., 1973, Mon. Notes Astron. Soc. S. Afr. 32, 11
 Conti P.S., Alschuler W.R., 1971, ApJ 170, 325
 Cunha N.C.S., 1990, M. Sci. Dissertation, Physics Dept., Federal University of Minas Gerais, Brazil
 Cunha N.C.S., Vaz L.P.R., Pôssa C.M.M., Helt B.E., Clausen J.V., 1990, IBVS 3436
 Hill G., Holmgren D.E., 1995, A&A 297, 127
 Hirshfeld A., Sinnott R.W., 1982, Sky Catalogue 2000.0, Vol. 1. Cambridge Univ. Press and Sky Publishing Co.
 Hirshfeld A., Sinnott R.W., 1985, Sky Catalogue 2000.0, Vol. 2. Cambridge Univ. Press and Sky Publishing Co.
 Nielsen R.F., Nørregaard P., Olsen E.H., 1987, ESO Messenger 50, 45
 Niemela V., Morrison N.D., 1988, PASP 100, 1436
 Simon K.P., Sturm E., Fiedler A., 1994, A&A 292, 507
 Vaz L.P.R., Cunha N.C.S., Vieira E.F., Myrrha M.L.M., 1993, ASP Conf. Ser. 40, 371
 Vaz L.P.R., Cunha N.C.S., Vieira E.F., Myrrha M.L.M., 1997, A&A 327, 1094