ABSOLUTE DIMENSIONS AND DISTANCE MODULUS FOR HV 2226 IN THE SMC

S.A. BELL

Department of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland.

G. HILL

Dominion Astrophysical Observatory, Herzberg Institute of Astrophysics, National Research Council of Canada, 5071 West Saanich Road, R.R. No. 5, Victoria, B. C., Canada, V8X 4M6.

R.W. HILDITCH

Department of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland.

J.V. CLAUSEN

Copenhagen University Observatory, Brorfeldevej 23, DK–4340, Tølløse, Denmark.

A.P. REYNOLDS

Department of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews, Fife, KY16 9SS, Scotland.

and

A. GIMÉNEZ

Laboratorio de Astrofísica Espacial y Física Fundamental, Instituto Nacional de Técnica Aerospacial, Apdo. 50727–28080 Madrid, Spain.

Abstract. Absolute dimensions and the distance modulus have been established for the early-type eclipsing binary HV 2226 in the SMC. Analyses of the new radial velocities reported here, and CCD light curves published by Jensen *et al.* (1988) yield component masses of 9.3 ± 0.7 and 5.6 ± 0.5 $M_\odot$, respectively. The radii are 5.6 ± 0.2 and 5.3 ± 0.2 $R_\odot$ with the secondary component filling its Roche lobe which implies that HV 2226 must have evolved through a case A mass-transfer process. A distance modulus of $(m_V - M_V)_0 = 18\overset{m}{.}6 \pm 0\overset{m}{.}3$ is derived, marginally lower than the adopted mean of $18\overset{m}{.}9$ for the SMC. The position of HV 2226, however, indicates that it is in fact situated in the near side of the SMC. In the present case, the accuracy of this estimate is limited mainly by the uncertainties of ≈ 2000 K in the effective temperatures. We point out that distance moduli with uncertainties of $\pm 0\overset{m}{.}15$ can be achieved from accurate radial velocities, light curves and colour indices of eclipsing binaries; such systems in the SMC and LMC are therefore promising distance indicators and work on further selected candidates is in progress.

Key words: stars – SMC – binaries: spectroscopic – binaries: eclipsing – stars: masses of – stars: luminosities of

1. Spectroscopy and Radial Velocities

The spectroscopic observations were obtained in the interval 1989 October 12–15 by GH and APR with the 3.9-m Anglo-Australian Telescope and the RGO spectrograph at the Cassegrain focus. The 25-cm camera and 1200B grating provided a reciprocal dispersion of 33 Å mm^{-1} over the wavelength range $\lambda\lambda$4000–4400 Å and spectra were recorded on a GEC CCD detector with a pixel size of 22 μm. The

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integration times for HV 2226 were typically 1800 s (1% of the orbital period) allowing data to be obtained on the best night of good seeing ($\approx 1''$) and clear sky at a signal-to-noise of $\approx$ 25–30.

Preliminary data reductions were made using the STARLINK package FIGARO. The spectra were linearized, rectified and finally log-linearized using REDUCE (Hill, Fisher & Poeckert 1982) in preparation for the cross-correlation analysis with VCROSS (Hill 1982). The cross-correlation functions (ccfs) were obtained by defining windows across the spectra which omitted the broad Hγ and Hδ lines. The adopted templates were of spectral type O9 III (10 Lac), B1 Ib (HR 1203) and B2.5 V (η Lyr) with typical signal-to-noise $\simeq$ 250 and accurately known radial velocities. The spectra of HV 2226 were smoothed using a three-point smoothing routine and then cross-correlated against the template spectra. The resulting peaks were measured using double-Gaussian profiles fitted by least squares to the ccfs at the double-lined phases. The derived velocities depend upon the lines of He I, O II and Si II visible in this spectral range.

After the final solution of the light curve was completed, corrections to the individual velocities, and therefore the values of K_1, K_2 and V_0, were calculated with LIGHT2 (G. Hill private communication) to take account of the effects of mutual irradiation of the components and their non-spherical shapes. It is pleasing to note that the derived systemic velocity of $168 \pm 6\,\mathrm{km\,s^{-1}}$ is close to the mean radial velocity of the SMC system and the minimum masses have uncertainties of less than 10%.

2. Colour Indices and Equivalent Widths

Strömgren and Johnson photometry obtained at various phases in the orbital cycle in conjunction with the adoption of a mean $E_{(B-V)}$ for the SMC of $0\overset{\mathrm{m}}{.}04$ suggest a primary component temperature of approximately 28000 K.

The six spectra obtained on the best night at first quadrature, and the three spectra obtained at second quadrature, were co-added to form two higher signal-to-noise spectra of sufficient quality for spectrophotometric analysis with VLINE (Hill & Fisher 1986). Gaussian profiles were fitted to the He I λ4026 line of both components on the first-quadrature summation, and to the blended profile of Hγ on both summations to determine equivalent widths (EW), and hence an estimate of effective temperatures and spectral types for both components. The procedure is an iterative process since the result influences the final selection of radial-velocity templates, and the adopted temperature of the primary component for the light-curve solution. The light-curve solution provides an accurate brightness ratio between the two components which is needed to evaluate the separate equivalent widths of Hγ for the two stars from the blended profile. Only one iteration was required.

From the Hγ EW vs. spectral-type relationship of Balona & Crampton (1974), and the results of the light-curve solution for log g and hence luminosity class, we estimate the primary component to be of spectral type B0.5 IV and the secondary component to be B3 III with a range of $\pm$ 0.5 subclasses. From both the tabulations of Popper (1980) and Böhm-Vitense (1981), these suggest temperatures of 28000 ± 2000 K for the primary component and 19000 ± 2000 K for that of the

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secondary.

The EWs of $\lambda 4026$, after correction for the fact that they are measured relative to the combined continuum, may be compared with the published EWs of $\lambda 4026$ as a function of spectral type by Norris (1971), and a large, unpublished data base from G. Hill (private communication). These indicate spectral types of about B0.5–B1 for the primary component and about B3 for the secondary component, and certainly concur with the results from $H\gamma$. The spectral types of the two stars lie on each side of the maximum in He I line strengths at B2. We conclude, in conjunction with the photometric data, that a best estimate for the primary component temperature is 28000 ± 2000 K; the temperature of the secondary component is then derived from the light-curve solution, and the above value of 19000 ± 2000 K proves to be a fair estimate of the final adopted value.

3. Light Curve Analysis

The differential V light curve presented by Jensen *et al.* (1988) is evocative of a detached system and the analysis of both the V light curves started with this assumption. Two light-curve synthesis codes, LIGHT2, an enhanced version of LIGHT (Hill 1979), and the 1983 version of the Wilson-Devinney code (Wilson & Devinney 1971; Wilson 1979; R.E. Wilson private communication) were employed independently. All the solutions using both codes showed small systematic departures around the ingress to and egress from both minima, although the eclipses themselves are fitted extremely well. The solution for $q = 0.60$ suggests that the system is in a semi-detached configuration with the secondary component filling its Roche lobe. Subsequent solutions employed this system configuration and consequently the secondary component radius was fixed by the spectroscopically-derived mass ratio instead of being a free parameter. It is pleasing to note the excellent agreement between the two codes. This solution shows that about 80% of the light of the primary component is eclipsed at primary minimum and about 96% of the light of the secondary component is eclipsed at secondary minimum. The primary component fills approximately 89% of its Roche lobe.

4. Discussion

Models using the techniques described by Claret & Giménez (1989) have been computed for stars with masses similar to those of the components of HV 2226 adopting the chemical composition of the SMC *i.e.* (X = 0.716, Z = 0.004). Further models have been attempted which employ convective overshooting ($\alpha_c = 0.25$) both with and without mass loss. For stars of this mass range, the effects of mass loss are negligible and no difference can be seen between models using mass loss parameterisations and those neglecting mass loss. The age estimate for the primary component using models involving convective overshooting is 2.2×10^7 yr while models using "standard" physics predict 1.95×10^7 yr. The evolutionary status of the system precludes any attempt to estimate the age of the secondary component.

The derived distance modulus for the system of $18^{\mathrm{m}}\!.6 \pm 0^{\mathrm{m}}\!.3$ is in remarkable agreement with several recent determinations involving the study of Cepheids and

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RR Lyrae variables (*c.f.* Westerlund 1990). If we adopt $E_{(b-y)} = 0.0$, rather than the mean $E_{(B-V)} = 0.04$ for the SMC, then the distance modulus is revised by $+0\overset{m}{.}12$. The location of HV 2226 in the SMC would appear to be on the near (SE) side according to the study of SMC geometry by Caldwell & Coulson (1986). The error in the distance modulus is due principally to the difficulty in assigning an effective temperature to the primary component and hence the cautious error estimate of 2000 K, although the effect of a change in the temperature of the primary component is partially compensated for by the corresponding change in the bolometric correction. Clearly, more *uvbyβ* photometry and spectral classification work is required which could reduce the uncertainty in the primary component temperature to about 1000 K. If more accurate spectroscopic elements are available, errors of about 2% in the absolute dimensions can be obtained, and a precision of $\approx \pm 0\overset{m}{.}15$ in the distance modulus is to be expected. The astrophysical data for HV 2226 are given in Table I and a full discussion of this analysis is given by Bell *et al.* (1991).

TABLE I
Astrophysical data for HV 2226.

Absolute dimensions	Primary	Secondary
$M\,(M_\odot)$	9.3 ± 0.7	5.6 ± 0.5
$R\,(R_\odot)$	5.6 ± 0.2	5.3 ± 0.2
$log\,g$ (cgs)	3.91 ± 0.05	3.73 ± 0.05
$T_{eff}(K)$	28000 ± 2000	19400 ± 2000
$log\,L/L_\odot$	4.23 ± 0.13	3.55 ± 0.18
M_{bol}	$-5\overset{m}{.}9 \pm 0\overset{m}{.}3$	$-4\overset{m}{.}2 \pm 0\overset{m}{.}5$
B.C.	$-2\overset{m}{.}8$	$-2\overset{m}{.}0$
M_V	$-3\overset{m}{.}1 \pm 0\overset{m}{.}3$	$-2\overset{m}{.}2 \pm 0\overset{m}{.}5$
$E_{(B-V)}$	$+0\overset{m}{.}04$	
Distance modulus	$18\overset{m}{.}64 \pm 0\overset{m}{.}27$	

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