Magellanic Cloud Eclipsing Binaries : Primary Distance Indicators

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Abstract. Our collaboration involves groups in Denmark, the U.S.A. Spain and of course New Zealand. Combining ground-based and satellite (IUE and HST) observations we aim to determine accurate and precise stellar fundamental parameters for the components of Magellanic Cloud Eclipsing Binaries (MCEBs) as well as the distances to these systems and hense the parent galaxies themselves. This poster presents our latest progress.

Required Observational data:

- **Photometric Light Curves**: Yield orbital parameters and relative geometry of system, i.e. e, i, ω, $\mathcal{R}_1/A$, $\mathcal{R}_2/A$, $T_{\mathrm{eff},2}/T_{\mathrm{eff},1}$.
- **Spectroscopic Radial-Velocity Curves**: Yield the masses ($\mathcal{M}_1$ and $\mathcal{M}_2$) and the physical separation (A).
- **Standard System Photometric Indices**: Strömgren $uvby$ photometry will yield $E(B-V)$ – at least for OB-type stars – via the $(b-y)/\mathrm{c}_1$ diagram plus 'visual' fluxes.
- **Ultraviolet spectrophotometry**: Yields absolute temperature scale and interstellar reddening – flux-fitting.

The **distance** (d) is then given by:

- **In theory:** Calculate the total *absolute* luminousity (L) (the sum of the two components) from the component surface areas and the effective temperatures and compare with the *apparent* luminosity (l):

$$d = \sqrt{\frac{L}{l}} \tag{1}$$

- **In practice:** Fitting, via least-squares, the observed HST/FOS UV spectrophotometry to the reddened model flux integrated over the surfaces of the stars.

This distance measurement is then a direct measurement of the distance to the binary system and hence the parent galaxy in which it resides. There are NO intermediate steps, and few *a priori* assumptions. The method relies only on theoretical binary star and atmosphere models and the joint determination of stellar temperatures and interstellar extinction using a 4-parameter uv-visual extinction curve (Fitzpatrick and Massa, 1990).

Figure 1: Spectrophotometry, for eight of the systems listed in Table , obtained with the *Faint Object Spectrograph* onboard the *Hubble Space Telescope*.

HV 2274

HV 2274 is a well detached, double-lined, eclipsing binary in the Large Magellanic Cloud. It is also in an eccentric (i.e. elliptical) orbit. From the analysis of the CCD BVI photometric light curves and HST-GHRS spectroscopic radial-velocity curves (fig. 2), the calibrated CCD Strömgren $uvby$ photometry (fig. 3) which yeilds $E(B-V) = 0.073 \pm 0.014$ and the HST-FOS uv-spectrophotometry (fig. 4) below, we have determined a distance of

$$d_{\mathrm{HV\,2274}} = 49.8 \pm 1.5\,\mathrm{kpc} \equiv (m_V - M_V)_{\mathrm{HV\,2274}} = 18.49 \pm 0.07\,\mathrm{mag} \qquad (2)$$

to HV 2274 and therefore

$$d_{\mathrm{LMC}} = 48.7 \pm 1.5\,\mathrm{kpc} \equiv (m_V - M_V)_{\mathrm{LMC}} = 18.44 \pm 0.07\,\mathrm{mag} \qquad (3)$$

to the center of the Large Magellanic Cloud, assuming HV 2274 lies in the disc of the Large Magellanic Cloud.

Above (fig. 5) is a false colour representation (blue and red correspond to 22 731 and 21 350 K respectively) of the surface temperatures of the two components of HV 2274 showing the well detached nature of the system and the relatively undistorted nature of the components. Below (fig. 6) the the components are plotted on an HR diagram along with theoretical evolution and isochrone tracks (dotted line) demonstrating the xcellent agreement between observation and the theory of stellar evolution (at least for this particular case).

Table 1. MCEBs in the HST/IUE Observing Programme

System	$M_{\rm V}$ (max.) mag.	Sp. Types/ Masses ($\rm M_{\odot}$)	Period (days)	$(m_{\rm V} - M_{\rm V})_0$ mag.	Refs.
SMC-HV 1620	+14.5	O9.5III + O9V ∼21 ∼17	3.63	18.6 ± 0.4	1,2,3
SMC-HV 1761	+15.7	B2V: + B2V: ∼11 ∼11	1.47		4
SMC-HV 1876	+15.2	∼B0: + B0: – –	2.76		5
SMC-HV 2226	+15.3	B0.5IV + B3III 9.3 5.6	1.90	18.64 ± 0.30 18.78 ± 0.15	5,6 7
LMC-HV 982	+14.6	∼O9/B0 + O9/B0 – –	5.34		8,9

Table 1. cont: MCEBs in the HST/IUE Observing Programme

System	$M_{\rm V}$ (max.) mag.	Sp. Types/ Masses ($\rm M_{\odot}$)	Period (days)	$(m_{\rm V} - M_{\rm V})_0$ mag.	Refs.
LMC-HV 2241	+13.5	∼B0III + B2IV: ∼35 20	4.34	18.5 ± 0.4 18.43 ± 0.20	10,2 3,7
LMC-HV 2274	+14.4	B1.5III + B1.5III 12.2 11.4	5.73	18.49 ± 0.07 18.44 ± 0.07[1]	11,12 7
LMC-HV 5936	+15.1	∼B2IV + ∼B2V: – –	2.81		5,13,7 14
LMC-HV 12634	+15.2	B0-1V + B2V: – –	1.19		5,7,15 16,17
LMC-EROS 1044	+15.2	∼B0V + ∼B0V – –	2.73		18,19

Table 2. Data acquired for the HST/IUE Observing Programme MCEBs

System	UV Spectro-Photometry	Standard System Photometry	CCD Light Curves	Spectroscopic RV Curves	Type	Most Urgently Required
SMC-HV1620	HST-FOS IUE-SWP	MJUO-CCD (II)	MJUO-CCD (II) DAV	N&B	SD	Higher accuracy spectra.
SMC-HV1761	HST-FOS IUE-SWP	DK-CCD (II)	MJUO-CCD (I)		D	RV spectra + photometry reduction : analysis.
SMC-HV1876	HST-FOS IUE-SWP		DK-CCD (I) incomplete		SD	RV spectra + photometry (stand. sys. & light curves).
SMC-HV2226	HST-FOS IUE-SWP		DK-CCD (I)	Bell-AAT	SD	Stand. sys. photomemtry.
LMC-HV982	HST-FOS IUE-SWP	DK-CCD MJUO-CCD (II)	DK-CCD (II) MJUO-CCD (II)	DK-NTT (n=??)	D/Ecc	Reduction of NTT spectra and photometry : analysis.
LMC-HV2241	HST-FOS IUE-SWP/LWP	MJUO-CCD (II)	MJUO-CCD (II) DAV	N&B	SD	Higher accuracy spectra.
LMC-HV2274	HST-FOS IUE-SWP/LWP	DK-CCD (II)	MJUO-CCD (I)	HST-GHRS (n=8) DK-NTT (n=15/2)	D/Ecc	Reduction of NTT spectra and photometry : analysis.
LMC-HV5936	HST-FOS IUE-SWP	DK-CCD (II)	DK-CCD (I)	Bell-AAT	SD	$T_{\rm eff}$ calibration, reduction of photometry : analysis.
LMC-HV12634	HST-FOS IUE-SWP	DK-CCD (II)	DK-CCD (I) MJUO-CCD (I)	HST-GHRS (n=2) DK-NTT (n=??)	D	Reduction of NTT spectra and photometry : analysis.
LMC-EROS1044	HST-FOS IUE-SWP	MJUO-CCD (II)	MJUO-CCD (II) EROS		D	RV spectra, stand. sys. photometry.

Table 3. Data acquired for selected other MCEBs

System	UV Spectro-Photometry	Standard System Photometry	CCD Light Curves	Spectroscopic RV Curves	Type	Most Urgently Required
SMC-HV11284		DK-CCD (II)	DK-CCD (II)		D	
LMC-HV12484			MJUO-CCD (I)?	DK-NTT (n=??)	D	Teff calibration (???) + phot' reduction/analysis.
LMC-HV12578		DK-CCD (II)	DK-CCD (II)		D	Teff calibration (???) + phot' reduction/analysis.
LMC-EROS1036	IUE-SWP		EROS		D	RV Spectra + photometry (stan' sys' & light curves).

Figure 1. HST/FOS UV Spectrophotometry

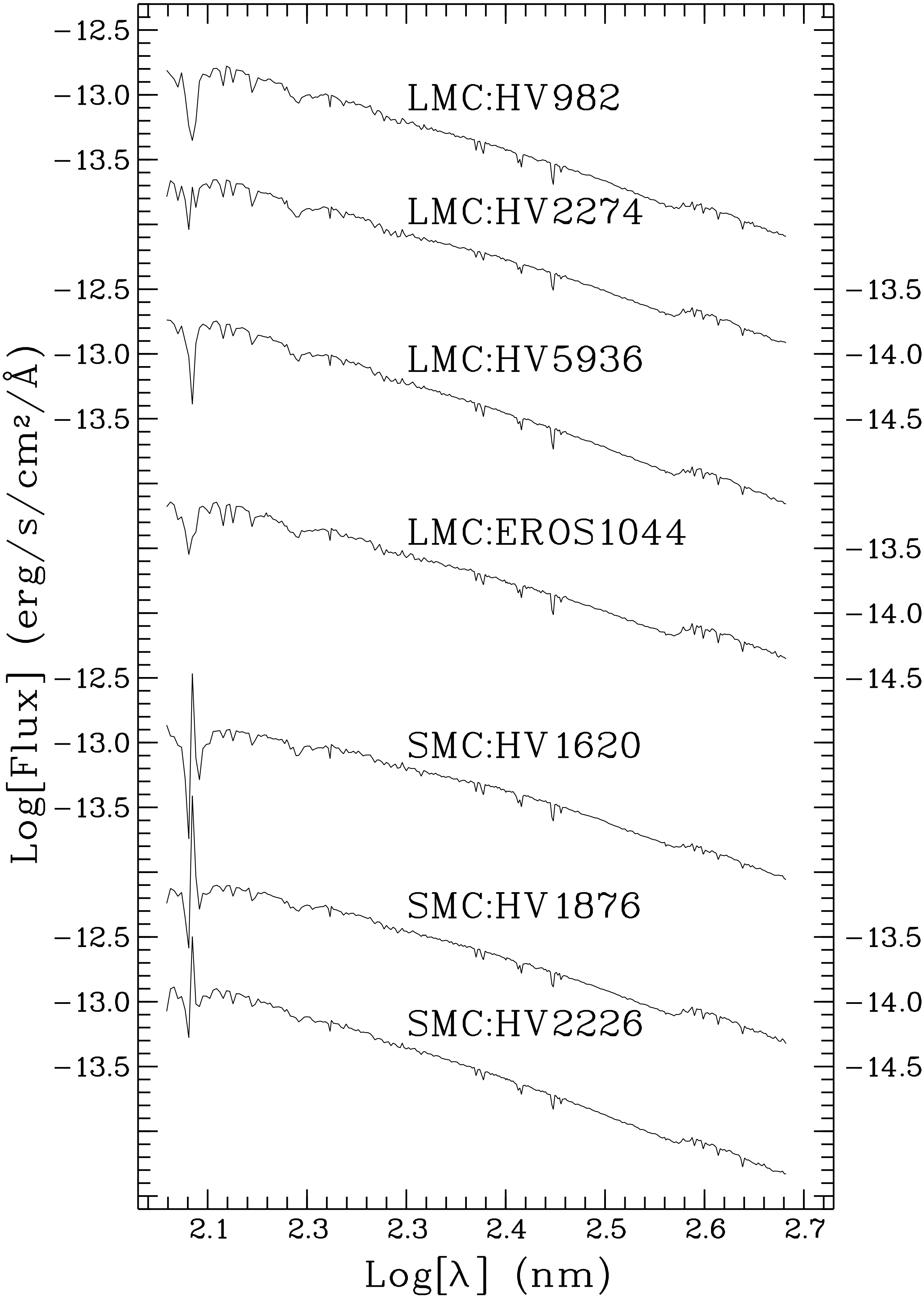

Figure 2. Model light and radial-velocity curve fits for HV 2274.

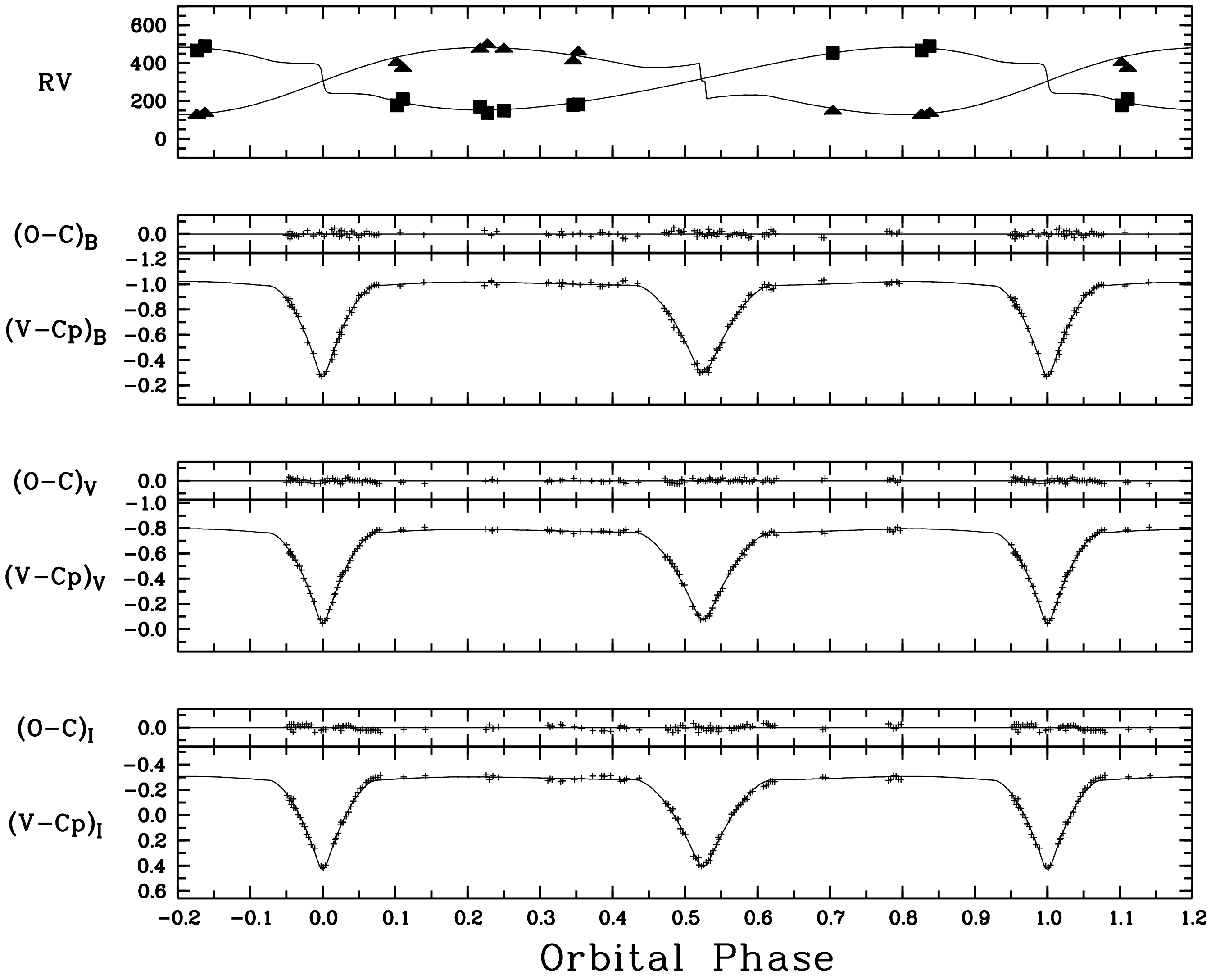

Figure 3. Determination of $E(B-V)$ of HV 2274 in the $(b-y)/\mathrm{c}_1$ diagram.

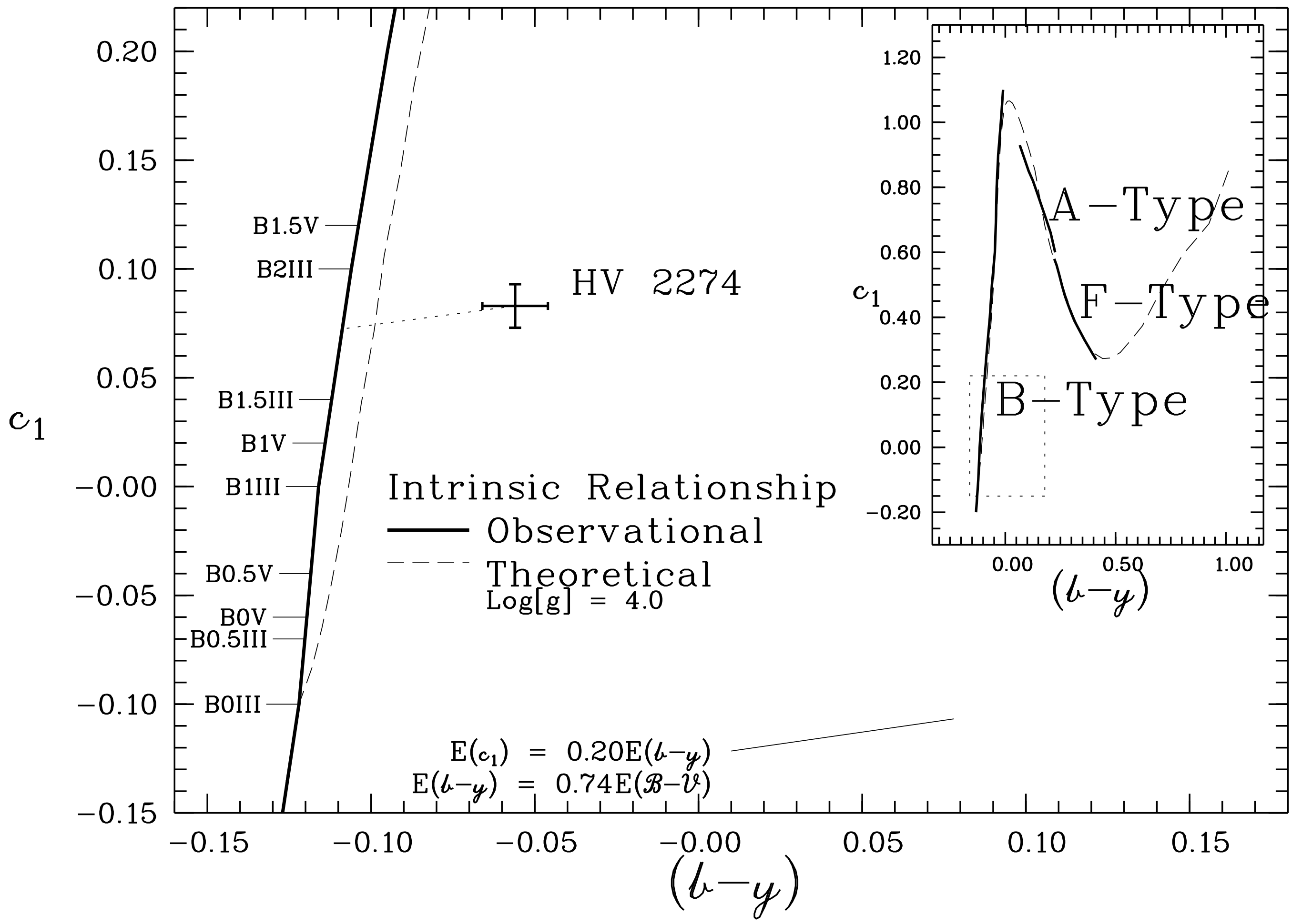

Figure 4. Stellar atmosphere model fit to HST/FOS spectrum for HV 2274.

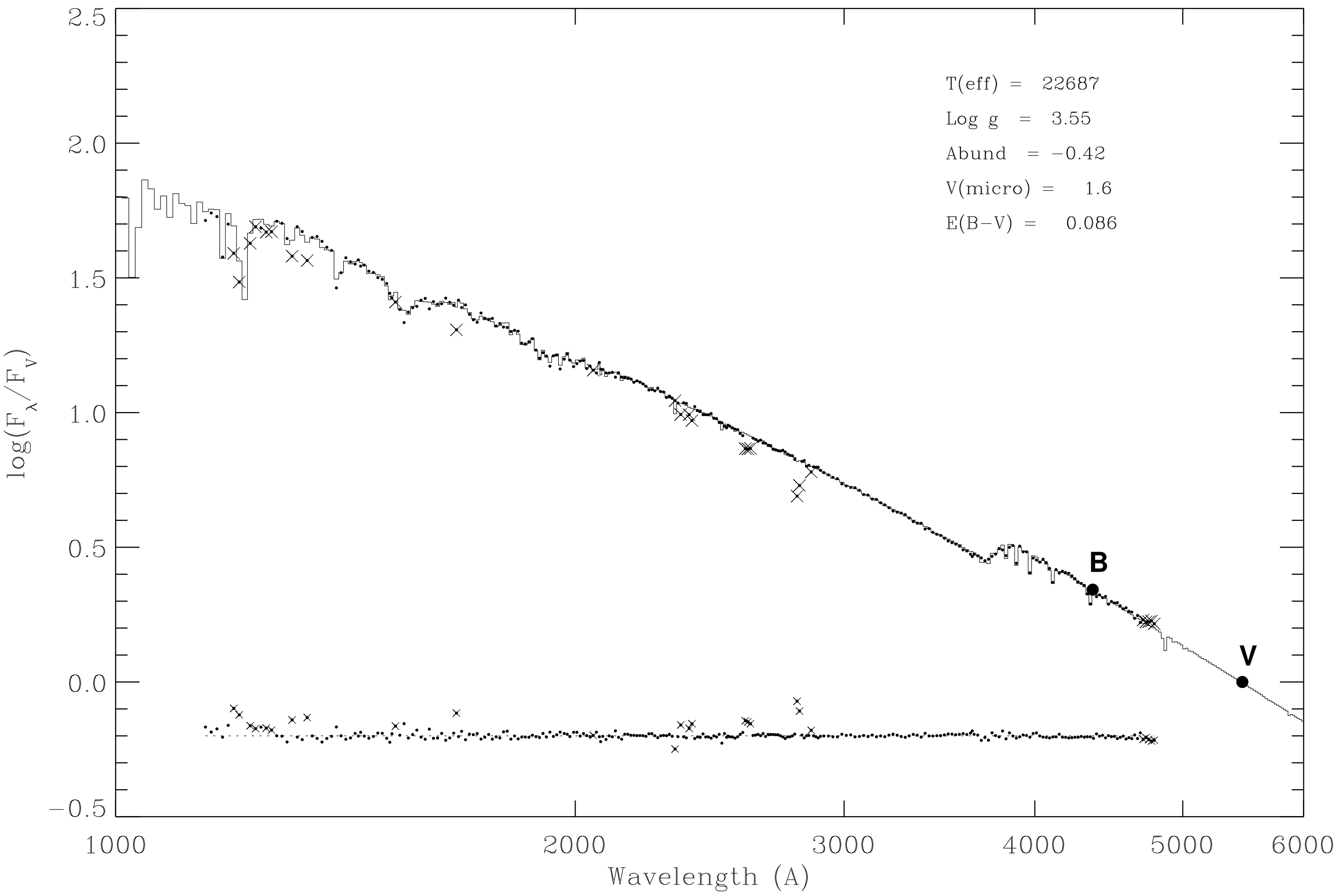

Figure 5. Schematic of surface geometry for HV 2274.

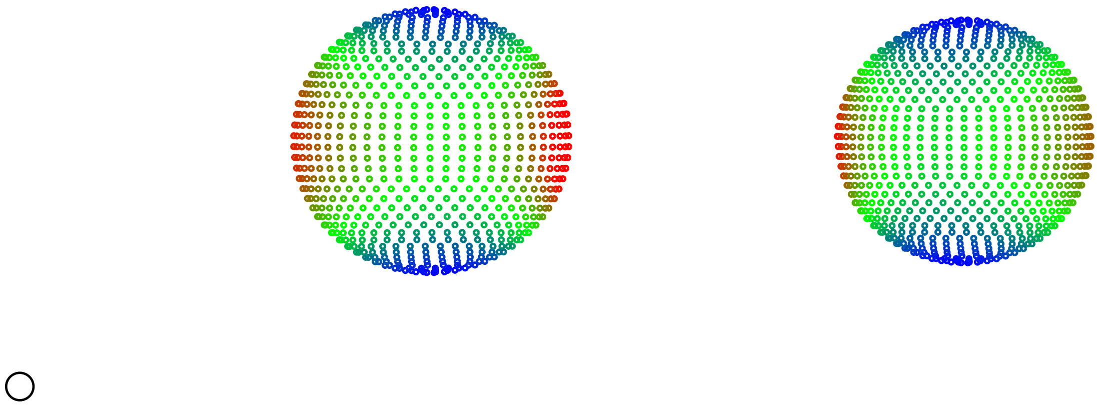

Figure 6. Evolutionary tracks for HV 2274.

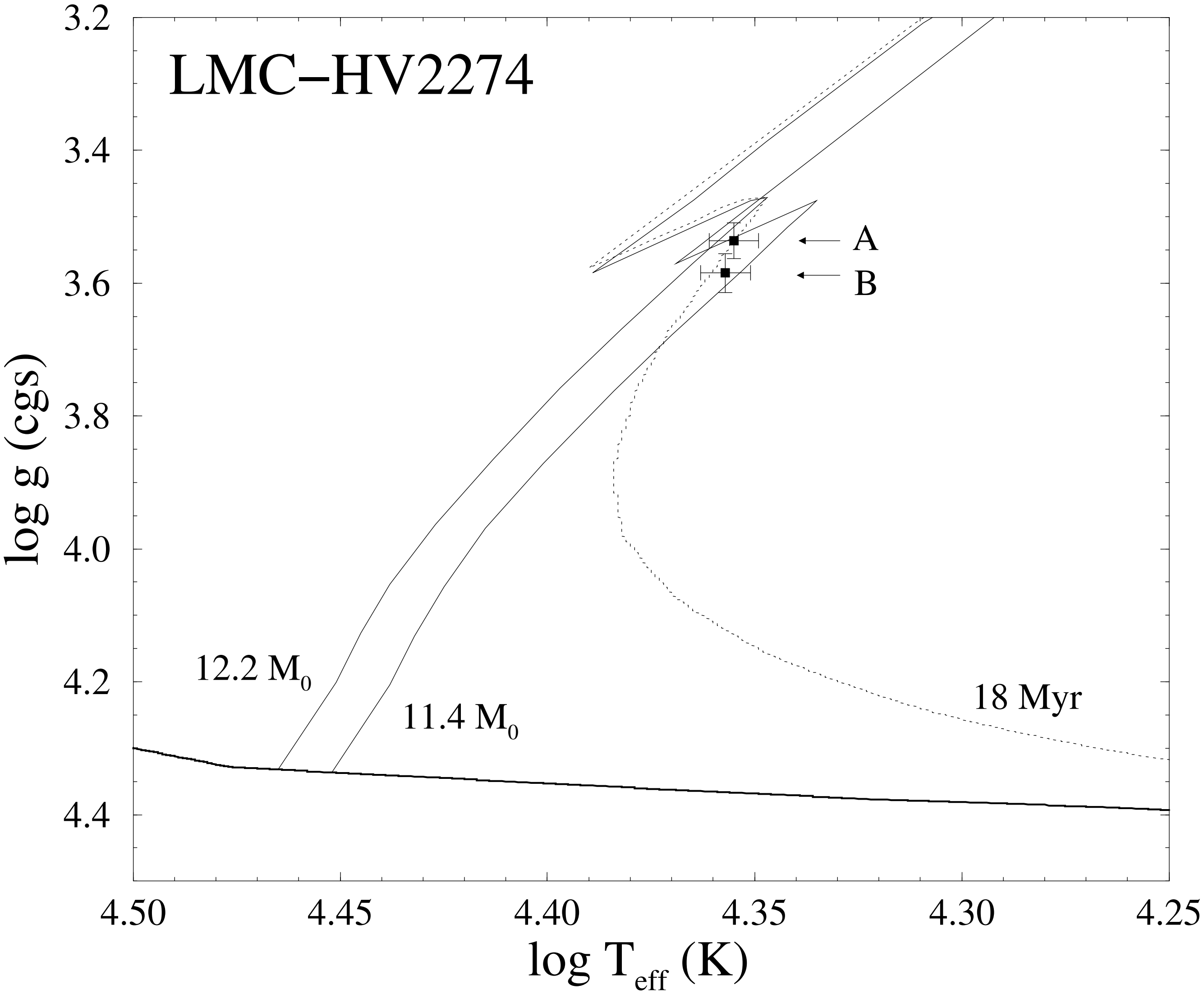

Table 1: Properties of LMC/SMC Eclipsing Binary Stars in the IUE/HST Observing Program.

[1] Distance corrected to the center of the LMC.

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Table 2. Data acquired for the HST/IUE Observing Programme MCEBs

Notes to table 2:

- **HST-FOS**: HUBBLE SPACE TELESCOPE FAINT OBJECT SPECTROGRAPH (Guinan et al., 1998).
- **IUE-SWP**: INTERNATIONAL ULTRAVIOLET EXPLORER SWPLO camera.
- **IUE-SWP/LWP**: INTERNATIONAL ULTRAVIOLET EXPLORER SWPLO and LWPLO cameras.
- **DAV**: UBV photoelectric lightcurves (Davidge 1987, 1988).
- **DK-CCD (I)**: BV CCD photometric lightcurves (Jensen et al., 1988).
- **DK-CCD (II)**: $uvby$ CCD photometry (lightcurves and standard system) (Unpublished).
- **MJUO-CCD (I)**: BVI lightcurves (West et al., 1992; Watson et al., 1992; Tobin et al., 1993; Duncan et al., 1993).
- **MJUO-CCD (II)**: $uvbyVI$ photometry (lightcurves and standard system) (Pritchard 1998a, 1998b).
- **EROS**: $B_E R_E$ CCD photometric lightcurves (Grison et al., 1995).
- **N&B**: Photographic + 1-m telescope (Niemela and Bassino, 1994).
- **Bell-AAT**: CCD + 4-m telescope – AAT (Bell et al., 1991; Bell et al., 1993).
- **DK-NTT**: CCD + 4-m telescope – NTT (Unpublished).
- **HST-GHRS**: HUBBLE SPACE TELESCOPE GODDARD HIGH RESOLUTION SPECTROGRAPH (Guinan et al., 1998).
- **incomplete** phase coverage.
- **Type: D** = detached, **SD** = Semi-detached, **Ecc** = eccentric.

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