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The distance to the Small Magellanic Cloud from eclipsing binaries

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Abstract. A preliminary distance etimate to SMC 108.1.14904, a long-period eclipsing binary in the Small Magellanic Cloud, is presented. The binary system contains two bright, non-active G-type giants. Its orbital period is 185 days and the orbit is circular. Using surface brightness calibration, we obtain a distance modulus to the system of $(m - M) = 19.02 \pm 0.04$ (statistical) ± 0.05 (systematic) mag, where the systematic error is dominated by uncertainties in the surface brightness calibration. This is a second eclipsing binary in the SMC analysed by our team.

Keywords. binaries: eclipsing, galaxies: distances and redshifts, galaxies: individual (Small Magellanic Cloud)

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1. Introduction

Determination of distances to eclipsing binary stars is an important component of the international Araucaria project, devoted to establishing the zero-point calibration to some important standard candles (Pietrzyński & Gieren 2002). One of our tasks is to precisely measure the distance to the Large Magellanic Cloud (LMC), and also to its neighbour, the Small Magellanic Cloud (SMC). Therefore, we selected 20 late-type eclipsing binaries in the LMC and eight in the SMC. Pietrzyński *et al.* (this volume) presented results regarding the LMC's eclipsing binaries; here, we focus on the SMC.

Fig. 1 presents the position of our target in the body of the SMC. All binaries contain photometrically non-variable (at least at the 0.01 mag level) G- or K-type giants which are well-detached. We already analysed one of these eclipsing binary stars (Graczyk *et al.* 2012). The main objective of this subproject is an independent comparison of the distance to the LMC obtained from similar eclipsing binaries, and calibration of some distance indicators at lower metallicities. Here we briefly report on our analysis of the second system, SMC 108.1.14904.

2. Procedure to obtain the distance

To determine the distance to a particular eclipsing binary we employed the following procedure:

• The V- and I-band light curves are collected from the OGLE project (Udalski *et al.* 1997);

- High-resolution spectra are obtained to sample an orbit;
- J- and K-band near-infrared photometry is secured outside eclipses;
- The Broadening Function (Rucinski 1992) and TODCOR (Mazeh & Zucker 1994) formalisms are used to obtain the radial velocities of both components;
- Extinction is estimated from the Haschke *et al.* (2011) reddening maps;
- From the preliminary light-curve solution and derredened individual $(V-K)$ colours, approximate temperatures of both components are calculated;
- Simultaneous analysis of radial velocities and light curves using the 2007 version of the Wilson–Devinney code (Wilson & Devinney 1971; van Hamme & Wilson 2007; hereafter WD) is undertaken;
- Updated $(V-K)$ colours and the absolute dimensions of the components are used to calculate the distance to the binary using the empirical surface brightness calibration for $(V-K)$;
- New temperatures are calculated based on the updated $(V-K)$ indices; and
- The last three steps are repeated until full consistency of the model parameters is obtained.

3. Absolute dimensions and the distance to the system

Based on simultaneous analysis of the radial velocities and light curves, we derived a set of fundamental physical parameters for the system and its components. WD fits to both the V- and I-band light curves were of high quality and did not exhibit any systematic deviations (see Fig. 2). From the solution we infer that both components are of equal mass, with the primary star being the smaller, hotter and less luminous of the two. Note that the primary lies just outside of the red boundary of the Cepheid instability strip in the SMC and, in agreement with theoretical expectations, we could not detect any signs of significant pulsations in this star.

Table 1 presents the astrophysical parameters of the system. The distance was derived using di Benedetto's (2005) infrared calibration of the V-band surface brightness relation. The resulting distance modulus is $(m-M) = 19.02 \pm 0.04$ (statistical) ± 0.05 (systematic) mag. The primary source of statistical uncertainties is owing to the reddening uncertainty, while the systematic error is dominated by the uncertainties in di Benedetto's relation. The difference in distance moduli between both components is very small. This

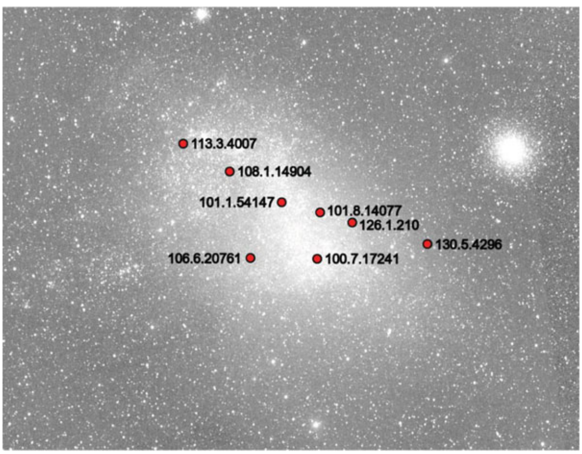

Figure 1. Eight late-type eclipsing binary stars in the SMC selected for distance measurements.

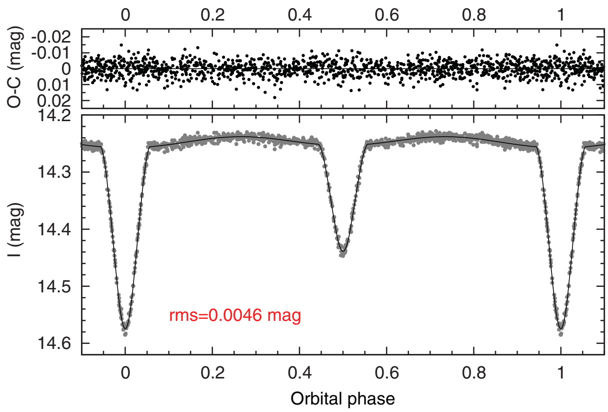

Figure 2. I-band light-curve solution to the SMC 108.1.14904 system. The rms of the residuals is at the level of the intrinsic photometric noise.

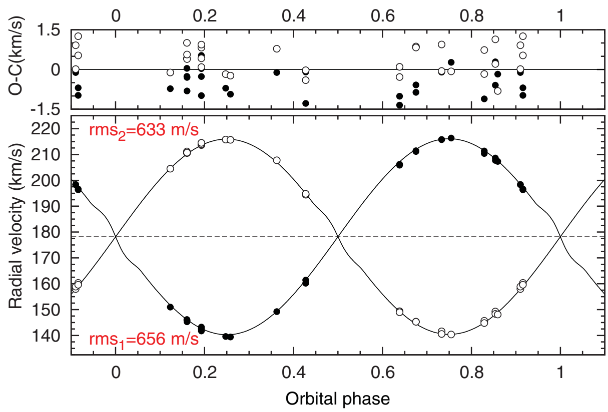

Figure 3. Radial-velocity solution to both components. The radial velocities of the primary (solid bullets) are blueshifted by -0.7 km s^{-1} with respect to the secondary's velocities.

Table 1. Basic astrophysical parameters of the SMC 108.1.14904 system.

Parameter	Primary star		Secondary star
Spectral type	G2 II		G8 II
Distance modulus (mag)	19.021		19.019
Orbital period (days)		185.1	
Semimajor axis ($R_\odot$)		282.7	
Orbital inclination (deg)		78.8	
Systemic velocity (km s^{-1})	177.8		178.5
Radius ($R_\odot$)	47.3		63.8
Mass ($M_\odot$)	4.42		4.43
Temperature, $T_{\rm eff}$ (K)	5470		4855
Observed V magnitude	15.93		15.99
Observed $(V-K)$ colour (mag)	1.85		2.39
Extinction, $E(B-V)$ (mag)		0.051	

serves as an independent check of the model's consistency. The main approach to improving this distance determination would need to obtain better temperature and reddening estimates from analysis of disentangled spectra and also secure more near-infrared K-band photometry.

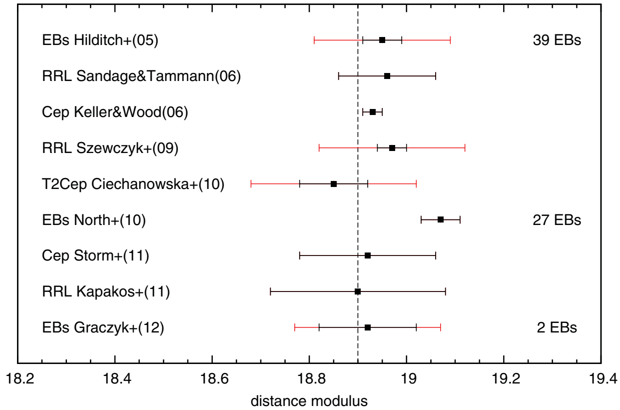

Figure 4. Recent distance measurements to the SMC. The 'standard' distance modulus to the SMC, $(m - M)_0 = 18.90$ mag, is also highlighted. The inner error bars denote statistical errors and outer error bars represent the systematic uncertainties. EBs: Eclipsing binaries.

4. Concluding remarks

The distance modulus to a second late-type eclipsing binary star, SMC 113.3.4007, was reported by Graczyk *et al.* (2012), i.e., $(m - M) = 18.83$ mag. Combining both results, we obtain a mean distance modulus of 18.92 mag. Both stars lie in the north-eastern quadrant of the SMC, so that this result is not fully representative of the whole galaxy since there is a distance gradient across its visible disk, with the north-eastern part being closer than the centre. Fig. 4 gives a summary of recent distance measurements to the SMC using different methods. After approximate subtraction of the systematic uncertainties in common among all methods (e.g., photometric zero points, foreground reddening), the mean weighted distance modulus to the SMC from all determinations is 18.95 mag, with a reduced $\chi^2 = 0.69$. This suggests that sociological phenomena may affect the clustering of the results.

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