Massive Eclipsing Binaries in the Local Group

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Abstract : We aim to increase the number of hot, massive stars with well-constrained parameters resolved from the study of eclipsing, double-lined systems in the Galaxy and the Large Magellanic Cloud (LMC). The diversity in metallicity will assist in constraining evolutionary models in different environments. Our study is carried out over different spectral regimes and resolutions: intermediate-resolution near-infrared spectroscopy with the VLT for five obscured binaries in the galactic, young, massive Danks clusters and high-resolution optical spectroscopy of nine luminous systems in the LMC. Our analysis so-far has yielded an O-type main-sequence system with components of mass 22-25 $M_{\odot}$ with an accuracy 4% and radii ~9 $R_{\odot}$, accurate to 1%. The dynamically-measured radii have allowed a direct distance measurement to the Danks 1 cluster with a precision of 2%. We aim for a new precise measurement of the distance to the LMC using early-type systems, thus contributing towards the direct calibration of the extragalactic distance scale. In addition, we report systems comprising of OIf-type components, which may provide valuable insight on the physics of the strong winds that characterize the progenitors of Type Ib/c supernovae.

The Danks Galactic clusters

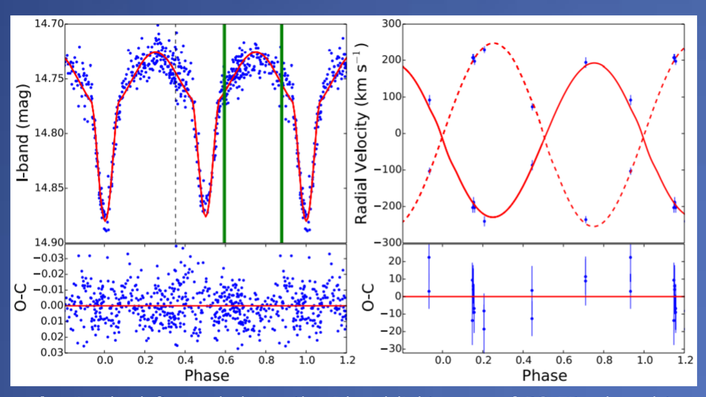

Fig. 1. The left panel shows the *I*-band light curve of D2-EB, phased to the best-fit parameters derived with PHOEBE. Radial velocities were inferred from the fit of the CNO/HeI blend at 2.112 μm. The right panel shows the radial velocity measurements overploted by the modeled curve. The solid line denotes the primary and the dashed line the secondary component.

We present an analysis of *K*-band spectroscopy from VLT/ISAAC with which we determined accurate fundamental parameters of D2-EB, a massive, early-type eclipsing binary in the young cluster Danks 2, which is embedded in the G305 Galactic, star-forming region. The best-fit model to the binary (Fig. 1) was obtained by using the blend of the HeI line and the CNO complex at 2.112 μm for measuring radial velocities. The system was found to contain two O6.5-7 main-sequence components with an age of ~5 Myr. We determined masses and radii of 24.5±0.9 $M_{\odot}$ and 9.2±0.1 $R_{\odot}$ for the primary and 21.7±0.8 $M_{\odot}$ and 8.7±0.1 $R_{\odot}$ for the secondary component with a precision 3.8% for the masses and 1% for the radii. Employing the precise measurements of the radii and multi-band photometry of D2-EB, we determined a distance to the system of d = 3.52±0.08 kpc from a fit to the spectral energy distribution of the system (Fig. 2). Up to now, this is the most well-constrained distance measurement to the Danks clusters and thus to the host complex, with a precision of 2% (Kourniotis et al. 2015)

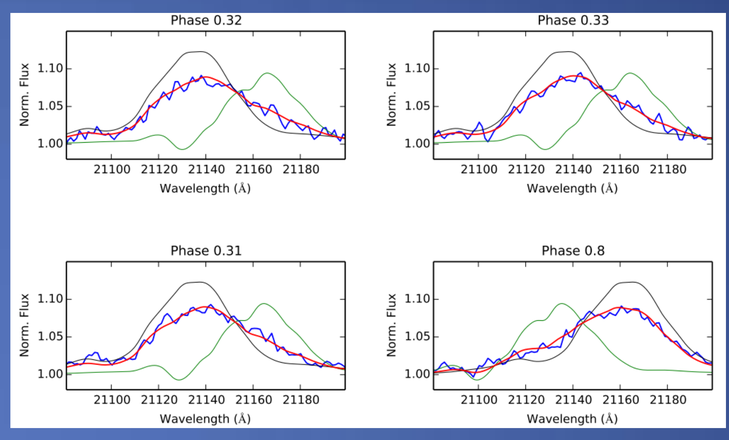

Fig. 3. Preliminary fit of the CNO/HeI blend of a massive early-type binary located in the Danks 1 cluster. The composite spectrum (red) comprises of two models for extreme luminous O-type stars (black and green), which were generated with the CMFGEN atmospheric code for stars characterized by strong wind.

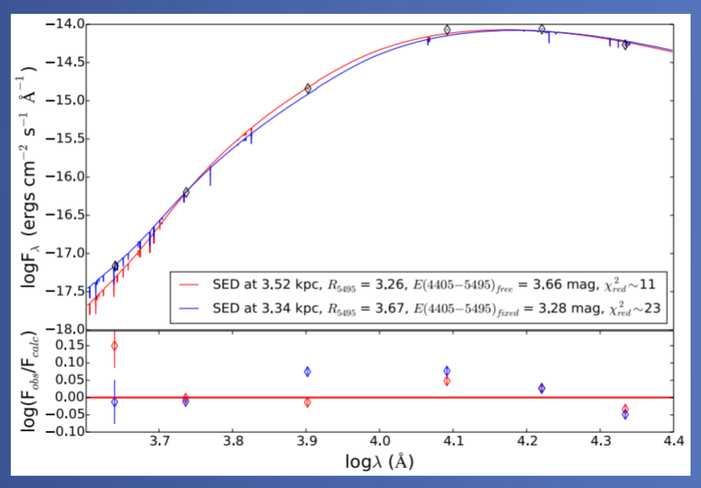

Fig. 2. Fit of the reddened, composite spectral energy distributions using FASTWIND models to the BVIcJHKs photometry of D2-EB, setting the amount of extinction E(4405-5495) as a free parameter (red) and fixed to the value of the observed, band-integrated equivalent E(B-V) (blue).

We further obtained *K*-band spectroscopy of four more obscured, luminous systems in the Danks clusters with VLT/ISAAC, two of which are found to be single-lined binary systems. The third system comprises of B-type components, and the fourth system is eccentric and hosts luminous intermediate O-type stars characterized by strong mass-loss winds. For the study of the latter extreme system, synthetic *K*-band templates were generated with the CMFGEN radiative transfer code (Hillier & Miller 1998), and observations of the CNO/HeI blend were optimally fit using components of OIf+ and OIf spectral type (Fig. 3). Both these types correspond to transition states between O-type and WR stars. The OIf+ component further shows strong emission of H and HeII in a P-Cygni profile. The radial velocity curve along with the I-band light curve of the star were modeled with PHOEBE and are both shown in Fig. 4. Our preliminary analysis yields masses of >60 $M_{\odot}$ for both components. Emission from collisionally ionized plasma is additionally supported by the fact that, the target is found as an X-ray source in the 3XMM database.

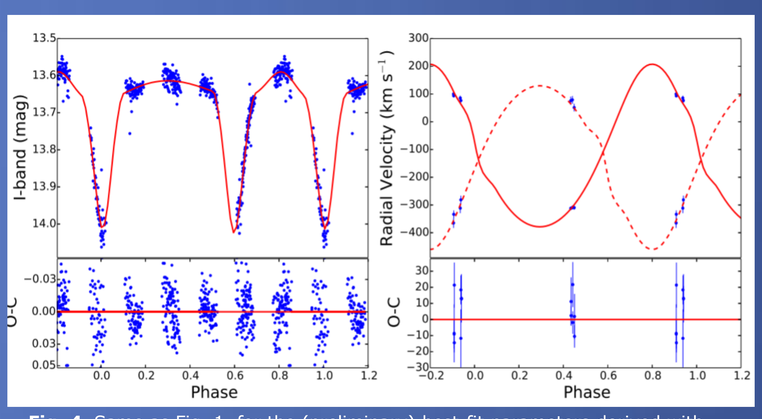

Fig. 4. Same as Fig. 1, for the (preliminary) best-fit parameters derived with PHOEBE of the extreme binary in the Danks 1 cluster.

The LMC

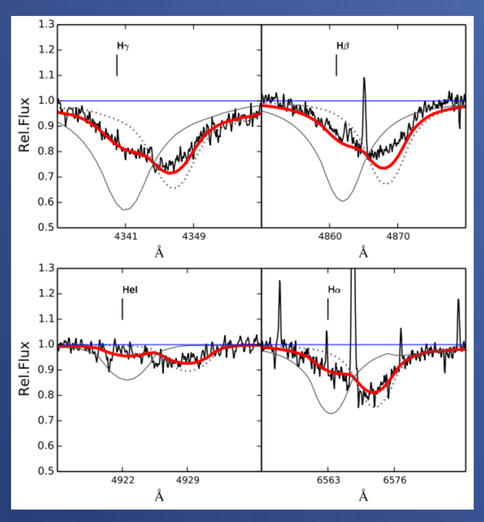

Fig. 7. Fit of hydrogen and helium lines of LMC5. Synthetic TLUSTY models are shown with grey lines for the primary (dashed) and the secondary (solid) component. The composite model is shown with red fitting the observations displayed with black. Emission of hydrogen likely denotes the presence of circum-binary/stellar material.

With the goal of increasing the number of massive systems with well-determined parameters beyond the Milky Way, we undertook spectroscopy of nine early-type binaries in the LMC using high-resolution optical spectroscopy obtained with the echelle spectrograph mounted on the 2.5m Du Pont telescope, the double spectrograph MIKE installed on the 6.5m Magellan II telescope, the HARPS spectrograph installed on the ESO La Silla 3.6m telescope, and the echelle spectrograph HRS mounted on the 11m SALT. Of these, eight luminous eclipsing systems were selected from the ASAS database of massive variables (Szczygiel et al. 2010), whereas the SALT target was reported as an eclipsing binary by Szymanski et al. (2011). By modeling the OGLE light and radial velocity curves with PHOEBE (e.g. Fig. 5), we present **preliminary** stellar parameters for five systems, LMC1, LMC2, LMC3, LMC4, and LMC5, which are listed in Table 1 along with their period and time of the primary eclipse (HJD_0). The modeled radii and the best-fit spectroscopic temperatures yielded luminosities, which are shown on the HR diagram in Fig. 6. By interpolating with MESA isochrones (Choi et al. 2016), we derive ages for the four systems that range from 3 to 34 Myr. Among the remaining four systems, we report a system showing evidence of circum-binary/stellar material (Fig. 7) and a candidate triple system containing a WN component. The aim of the current study is to derive masses with uncertainty below 5%. The precise radii will further allow determination of the distance to the LMC with a dynamical, model-independent method using early-type stars.

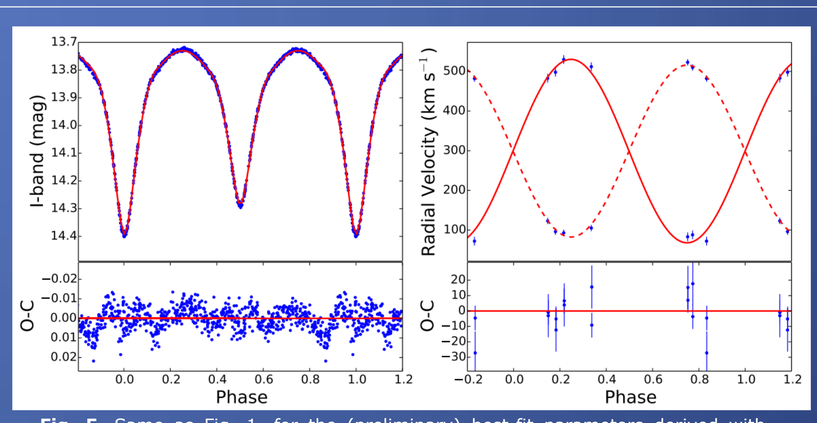

Fig. 5. Same as Fig. 1, for the (preliminary) best-fit parameters derived with PHOEBE of the detached luminous system LMC4.

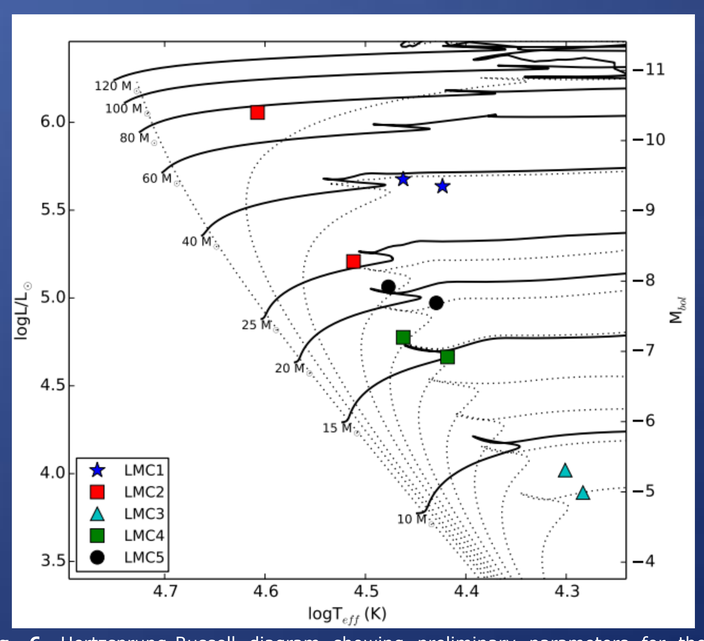

Fig. 6. Hertzsprung-Russell diagram showing preliminary parameters for the components of five massive eclipsing systems in the LMC. Evolutionary tracks and isochrones from 1 to 34 Myr are shown, generated with the MESA stellar evolution package at the metallicity of the LMC.

System	Binary Type	Period (d)	HJD_0 HJD-2450000	M ($M_{\odot}$) prelim.	R ($R_{\odot}$) prelim.	Age (Myr) prelim.
LMC 1	double contact	7.625	5831.85963	41 + 55	27 + 31	5
LMC 2	sec. RLOF	3.702	3585.40869	80 (fix) + 20	22 + 12	3 + 6
LMC 3	detached	3.660	5863.94203	8 + 7.5	9 + 8	34
LMC 4	detached	3.068	5894.87043	15 + 14	10 + 10	10
LMC 5	detached	5.947	3577.32312	21 + 26	13 + 14	8 - 10

Table 1. Preliminary parameters of five luminous eclipsing systems in the LMC.

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