Massive Eclipsing Binaries Observed by BRITE

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Massive detached eclipsing binary systems constitute excellent testbeds for upper main sequence stellar structure and evolution models. We present results of the analysis of several detached eclipsing binaries observed by the BRITE-Constellation, focusing on the most eccentric binary system with massive components known so far – N Sco.

1 Introduction

Massive stars play an important role in cosmic history, as their evolution affects the chemical composition of galaxies. Even if modern theoretical models are advanced, internal structure and evolution of massive stars is still not sufficiently described. Rotation, treatment of convection or internal mixing, are among those problems that are still not satisfactorily understood. They can be studied using e.g. massive pulsating stars or binary systems with massive components.

Precise determination of fundamental stellar parameters, like mass, radius, and effective temperature, is at the core of testing theoretical stellar evolution models. Detached eclipsing binaries (DEBs) of SB2 type belong to a sparse group of objects for which direct determination of masses and radii with the precision of 3% or better (Clausen et al., 2008) is possible. This precision enables sensitive testing of the predictions of stellar evolution models. As was discussed in our previous paper (Ratajczak & Pigulski, 2017), there is a distinct lack of well-characterized massive stars. If such stars are components of detached eclipsing binary systems, they constitute excellent testbeds for upper main-sequence stellar structure and evolution models.

2 BRITE observations of massive eclipsing binaries

BRITE-Constellation (Weiss et al., 2014; Pablo et al., 2016) is a network of five nanosatellites aiming to study stellar structure and evolution of the brightest stars (vast majority of $V < 5$ mag). About a dozen detached eclipsing binaries with massive components have been observed by BRITE, among which the most attractive are δ Sco, LS CMa, and N Sco. In this work, we present preliminary results of our studies on an intriguing example of a detached eclipsing binary system with massive components – N Sco.

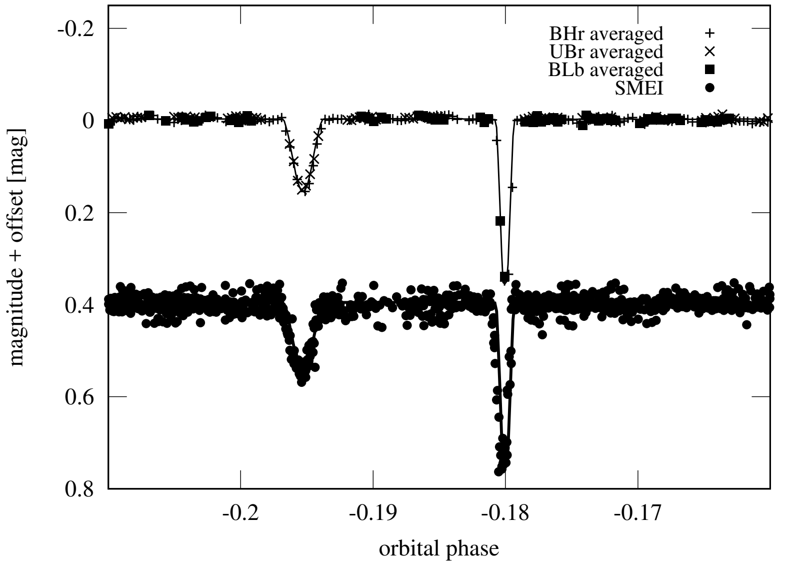

Fig. 1: Light curve of N Sco zoomed on the phases of eclipses. The upper light curve represents BRITE data; the lower – SMEI measurements.

3 N Sco

N Sco (HD 148703, B2III-IV, $V = 4.23$ mag) is a variable star, but it has never before been reported to be an eclipsing binary. It was classified as a constant brightness star based on Hipparcos data (van Leeuwen, 2007), but its radial velocity variations were detected by Moore (1911).

3.1 Photometry

BRITE photometry has revealed the eclipsing nature of N Sco. The observations were carried out by three satellites – BRITE-Heweliusz (BHr; equipped with a red filter), BRITE-Lem (BLb; blue filter), and UniBRITE (UBr; red filter). Altogether $\sim$ 100 000 individual data points were collected. Two eclipses were detected in the BHr data, BLb covered the phase of the deeper eclipse, while UBr detected the shallower one. The time between eclipses amounts to $\sim$ 3.5 d, but it was not possible to determine the orbital period, as the BRITE data coverage (160 d) was not sufficient.

Both eclipses were confirmed in the photometry from the Solar Mass Ejection Imager (Jackson et al., 2004, SMEI) carried out between 2003 and 2010. The SMEI photometry allowed us to determine the orbital period of the system (P=223.88 d) and furthermore suggested a high value of the eccentricity of the system.

Averaged BRITE (one measurement per satellite orbit) and SMEI light curves of N Sco are presented on Fig.1.

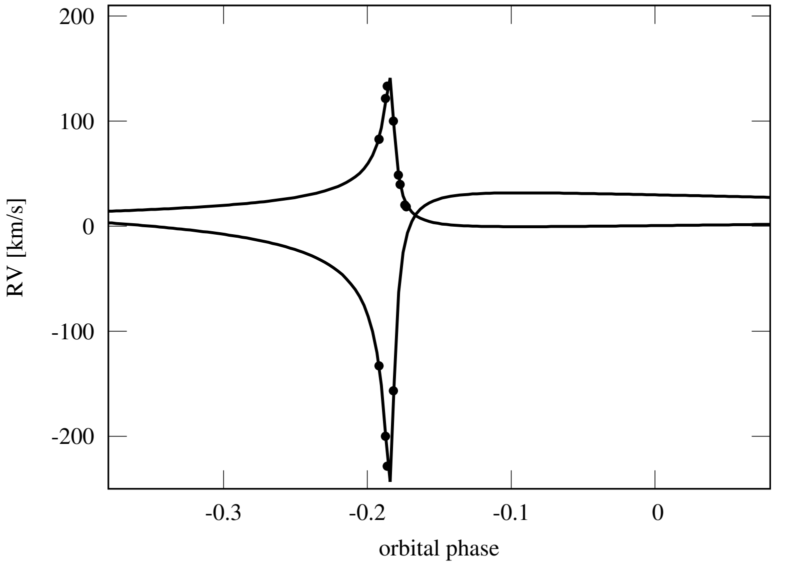

Fig. 2: Radial velocity measurements for the N Sco components based on SALT/HRS spectra with its best-fit orbital solution.

3.2 Spectroscopy

Knowing the coming dates of the periastron passage and keeping in mind that the system components' lines will be firmly separated during that time, we applied for and were awarded DDT time on SALT/HRS (Buckley et al., 2006). The observations were carried out in high resolution mode (R $\sim$ 70 000) in order to detect lines from the secondary component. The spectra were taken twice per night over 5 consecutive nights, between June 11 and 15, 2017 with a SNR of $\sim$ 200. HRS data were reduced with the PySALT (Crawford et al., 2010) and MIDAS (Kniazev et al., 2016) software.

In the first approach, the calculation of radial velocities (RVs) of both components was unsuccessful, as the lines from the secondary component were not detected due to its relatively high rotational velocity. After the investigation of the selected spectral lines, we realized that RVs can be calculated using the region with only one He I line – 6678.2 Å, as the other useful helium lines were blended.

The radial velocity curve based on SALT/HRS data is presented in Fig.2.

3.3 Modelling

To obtain the initial orbital solution we used a procedure that fits a double-Keplerian orbit to RVs of both components. Next, the PHOEBE software (Prša & Zwitter, 2005) was used to model light curves from various filters (BRITE red, BRITE blue, SMEI) and determine fundamental parameters of stars based on both photometric and spectroscopic data. The determination of the absolute values of the parameters and their uncertainties is still ongoing. We report preliminary results, which yielded components masses of 7.5 and 3.9 $M_{\odot}$, and radii of 3.7 and 2.1 $R_{\odot}$, respectively. The

Table 1: Initial orbital solution of N Sco

parameter	value
T_0 [HJD]	2453257.8
P [d]	223.877
e	0.93
ω [deg]	24
i [deg]	88
a [$R_\odot$]	349
K_1 [$\mathrm{km\,s^{-1}}$]	74
K_2 [$\mathrm{km\,s^{-1}}$]	136

estimated effective temperatures are T_1 ~19 000 K and T_2 ~12 800 K. The initial orbital solution is presented in Table 1. It should be noted that the reference phase is defined as in PHOEBE, which for eccentric orbits means that orbital phase is equal to zero does not coincide with minima.

4 Conclusions

Due to its high eccentricity ($e = 0.93$), N Sco appears to be an intriguing system. In order to check how special it is, we cross-correlated two catalogues: the 9th Catalogue of Spectroscopic Binary Orbits (Pourbaix et al., 2004, SB9) and the General Catalogue of Variable Stars, choosing only eclipsing systems (Samus et al., 2017, GCVS). The results are presented in Fig. 3 and indicate that N Sco belongs to a group of the most eccentric eclipsing binaries. There is one binary system, whose eccentricity is higher ($e = 0.96$) – V772 Her (Reglero et al., 1991), but it consists of two low-mass stars (1.1 and 0.6 $M_\odot$). This means that N Sco is the most eccentric eclipsing binary among systems with massive components.

Acknowledgements. Based on data collected by the BRITE Constellation satellite mission, designed, built, launched, operated and supported by the Austrian Research Promotion Agency (FFG), the University of Vienna, the Technical University of Graz, the Canadian Space Agency (CSA), the University of Toronto Institute for Aerospace Studies (UTIAS), the Foundation for Polish Science & Technology (FNiTP MNiSW), and National Science Centre (NCN). All the spectroscopic observations reported in this paper were obtained with the Southern African Large Telescope (SALT). M.R. and A.P. acknowledge support provided by the NCN through grants 2015/16/S/ST9/00461 and 2016/21/B/ST9/01126, respectively.

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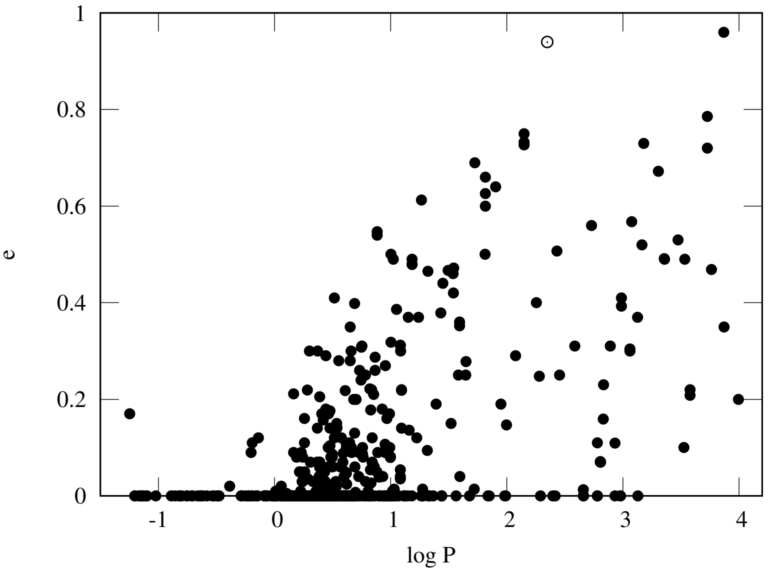

Fig. 3: Period – eccentricity relation for eclipsing binary systems from the SB9 and GCVS catalogues. N Sco is marked with an open circle.

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