Evolution and Dynamics of Tight Triple Systems

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Tight Triple Systems have stars in a hierarchical configuration with a third star orbiting the inner binary with a period of fewer than 1000 days. Such systems are important for understanding the formation and evolution of stars in multiple systems. Having a detached eclipsing binary (DEB) as one of its components allows us to obtain precise stellar and orbital parameters of these systems. We discuss the process to obtain accurate parameters of these systems using high-resolution spectroscopy, radial velocity measurements, and precise space-based photometry. This enables us to have a 3D geometrical picture as well as the metallicity, age, and evolutionary status of these systems.

1 Introduction

Hierarchical triple systems have the third star at a greater distance compared to the inner binary separation. Most of these systems have long outer periods and therefore their dynamics can have timescales of decades or centuries. Meanwhile, a subset of these triples, called Tight Triple Systems (TTS) have an outer orbit period of fewer than 1000 days (Hajdu et al. 2017) and hence their dynamics can be observed in timescales of years. Detached eclipsing binaries (DEBs) are the source of the most accurate (<1%) stellar parameters which are robust and independent of different models and methods (Maxted et al. 2020; Korth et al. 2021). Therefore, TTS with DEB would serve as an ideal system to extract accurate stellar parameters. Our study probes a sample of 20-25 TTS (Fig.1) which are spectroscopically double-lined (SB2) or triple-lined (SB3) systems. The systems were extracted from literature, the spectra database of the *CRÈME* project (P.I.: K.G. Hełminiak) and the photometric eclipse timing campaign of the *Solaris* project (P.I.: M. Konacki).

2 Methodology

We obtained TESS and/or Kepler observations for our targets from the the Mikulski Archive for Space Telescopes (MAST). PHOEBE2.3 (Conroy et al. 2020) eclipsing binary modelling code was used for the light curve modelling. The new version of code offers advantages of modelling stellar spots (Fig.1: *left*). The errors of the parameters were calculated using MCMC sampling through the code. The radial velocities were extracted from spectra taken from the *CRÈME* project. We used the TODCOR algorithm to extract radial velocities which were modelled with the V2FIT code (Konacki et al. 2010). The centre-of-mass velocity of the inner-binary (Fig. 1: *right*) was then modelled along with with the tertiary radial velocity (if

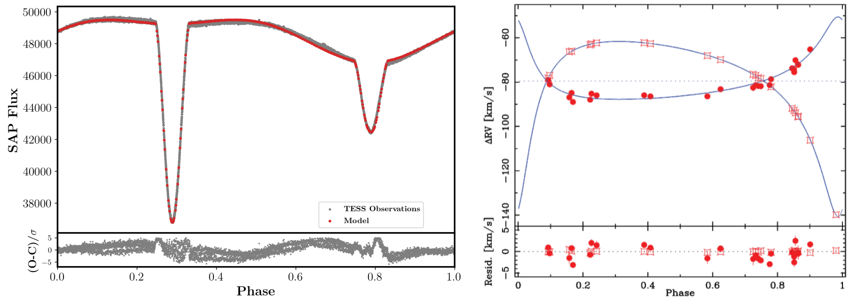

Fig. 1: *Left*: Phase-folded TESS light curve (grey) with best-fit PHOEBE2.3 model (red) for BD+44 5528 (SB3 system). *Right*: Phase-folded radial velocities of centre-of-mass of the binary (filled circles) and the tertiary (hollow boxes). Best fit V2FIT model is in blue.

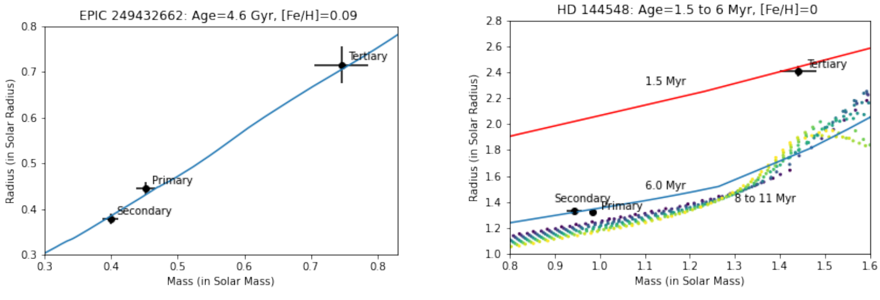

Fig. 2: *Left*: MESA isochrone in comparison to the parameters obtained for system EPIC 249432662 obtained by Borkovits et al. (2019). All the three stars are of the same age and metallicity, hence form a "clean" system. *Right*: Parameters of HD 144548 obtained by Alonso et al. (2015) against different MESA isochrones. The binary stars and tertiary disagree on age given they have the same metallicity. The shaded space corresponds to the age estimate of the OB association in Upper Scorpius to which the system belongs.

any). The total mass of the inner binary was used to get the mass estimate of the tertiary.

3 Evolution and Dynamics

The measurements of mass and radius give us an opportunity to test evolution scenarios for triple stars. Usually, for TTS we see no interactions between the stars themselves (unless their orbits are very dynamic). This would mean that all three stars in a TTS will evolve separately. Therefore we expect similar metallicity and age for the three stars in this "clean" system (Fig.2: left). Assuming a "clean" system, we can estimate a range for the radius of the tertiary from the mass-radius relation obtained from the isochrone fitting using the binary. But sometimes this "clean" system assumption fails and all the three stars do not follow the same isochrone (Fig.2: *right*). This calls for additional probe by independent estimates of metallicity and other relevant stellar parameters (e.g. from spectral analysis of disentangled spectra).

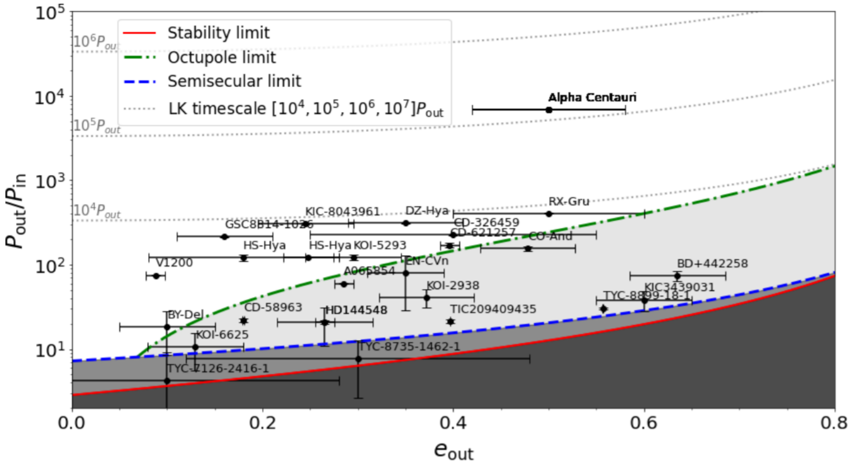

Fig. 3: The plot is a visualisation of parameter space of different dynamical regimes in a triple system, based on Toonen et al. (2020), where e_{out} is outer orbit eccentricity and period ratio of outer and inner orbits is $P_{\text{out}}/P_{\text{in}}$. The proposed systems are over-plotted to this configuration. Alpha Centauri triple system is plotted as a reference.

In TTS, higher-order dynamics are much more significant than wide hierarchical triples. Following the treatment in Toonen et al. (2020), we use the masses of the three stars and the orbital parameters to predict the possible dynamical interactions in TTS. We found that most of the systems lie in the octuple regime (Fig. 3) , in which the inner-binary can undergo inclination flips. Three systems are seen to lie in the semi-secular region and are prone to stellar collisions. But the errors on the positions are too high to be conclusive and hence more observations are needed.

4 Conclusion

Triple systems are now easier to probe with DEBs using high-precision photometry and high-resolution spectroscopy. The accurate parameters of these systems enable us to test scenarios of triple-star evolution and are good checkpoints for future models of multiple star evolution. The accurate mass distributions and orbital architectures provide a platform to test and improve various theories of multiple star formation.

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