Abstract

This document is presented as partial fulfilment of the requirements for the degree Doctor of Philosophy. It summarizes the work on preliminary studies, simulations, hardware, software design, development, data acquisition, reduction and analysis in the context of non-keplerian effects in eclipsing binary stars. The conducted work covers the broad set of aspects involved in the research of the topics ranging from instruments building, commissioning, through simulations of effects predicted by theory in close to real conditions, to the creation of a custom pipeline for spectroscopic data, planning, executing and analysis of data form observing campaigns. This dissertation consists of abstracts in English and Polish, a detailed synopsis in English and four appendices that are peer-reviewed publications published in journals from the Journal Citation Reports (JCR) as required by the Polish Law. The list of all author's publications is presented on page 5.

Preliminary studies started with the selection of the non-keplerian effects which can benefit most from the development of new hardware and software solutions. First selected effect was based on, relatively distant, third body influence on the inner binary component. The technique of precise photometric observations of eclipsing stars was selected as the measurement method with eclipses timing measurements utilizing the light-time effect (LTE). The author created a numerical, geometrical model of the binary system and accompanying tools for large-scale simulations (hundred thousands of systems), data analysis. The simulations concentrated on establishing detection limits for circumbinary planets, i.e the so called p-type planets. Satellite missions Kepler and CoRoT, as well as potential limits for ground based photometric observations were taken as case studies. The relations binding the planet discovery space with the physical parameters of the binaries and the geometrical parameters of their light curves were evaluated. White and red noise influence on the expected results was tested and the sensitivity of the technique established. Among the important results of the research are also suggestions for the best targets and observing strategies for detection of circumbinary planets via light time effect and eclipses timing. These results have influenced the selection of targets and of hte observing strategy in the Solaris Project. The work was published as *Detecting circumbinary planets using eclipse timing of binary stars – numerical simulations* in the Monthly

Notices of the Royal Astronomical Society in 2010 and is presented as Appendix A.

Various non-keplerian effects influence radial velocity (RV) curves. With precision of measurements reaching $2ms^{-1}$, tidal and rotational distortion of the components of a binary star become visible. Relativistic effects and orbital precession cannot be neglected. The author extended the model of a binary star created in the previous study and added RV-specific effects to the system model, further optimizing the tools for high-performance computations and large datasets analysis. The authors investigated the connection between the tidal distortion of the shape of the stars and the best-fitting orbital eccentricity, the possibility of deriving orbital inclination of a non-eclipsing binary star by exploiting relativistic effects and the circumstances in which the orbital precession can be detected. The majority of synthetic close binaries the authors examined required corrections for the studied effects. The results give an insight into the expected non-keplerian distortions of precise RV measurements of binary stars, their scale and probability of occurrence based on the Yonsei–Yale stellar models. This work was published as *Non-Keplerian effects in precision radial velocity measurements of double-line spectroscopic binary stars: numerical simulations* in the Monthly Notices of the Royal Astronomical Society in 2013 and is presented as Appendix B.

The research on the detection of non-keplerian effects also involved the work on the establishment of a network of robotic telescopes dedicated to photometric measurements of eclipsing binary stars, the Solaris Project. The project was funded in late 2010. The design, installation and commissioning took place between 2011 and 2014 and involved 10 installation visits to sites in the Southern Hemisphere. The author spent 403 days in the observatory sites and took part in designing and erecting four Solaris observatories: Solaris-1 and Solaris-2 in the South African Astronomical Observatory, South Africa, Solaris-3 in Siding Spring Observatory in Australia and Solaris-4 in Complejo Astronómico El Leoncito in Argentina. All four systems are autonomous and operate without human supervision and are designed to be a state-of-the-art tool for astrophysics. The author had a leading role in the design and deployment of IT infrastructure for the sensors and the whole network, including the necessary hardware drivers, supporting tools, database design and development, and the first version of the data reduction and analysis pipeline. During the construction phase the author was responsible for the technical aspects of the installation, among others: logistics, planning and support in construction, dome erection, equipment installation and setup, optical collimation and system integration. The author acquired, reduced and analysed initial set of data that demonstrated the quality and performance of individual observatories and the system as a whole and supported the acquisition and analysis of the commissioning dataset. The dataset includes exoplanetary transit modelling (Wasp-4b, Wasp-64b and Wasp-98b) for benchmarking purposes, PG1336-018, an eclipsing binary with a pulsator to study high-cadence performance and J024946-3825.6, a low-mass binary system for which a complete model is provided for the first time. This work was published as *Project Solaris, a Global Network of Autonomous Observatories: Design, Commissioning, and First Science Results* in Publications of The Astronomical Society of the Pacific in 2017 and is presented as Appendix C.

The final aspect of the research was the creation of the Torun Rossiter–McLaughlin effect survey where the author conducted observations, reduced and analysed data from selected subset of eclipsing binaries to measure their spin-orbit alignment with spectroscopic and photometric data. The work included the preparation and execution of an observing campaign on various instruments, design and development of software capable of modelling spectra and light curve of the binary during the eclipse on the basis of analytical equations. With five measured spin-orbit angles, the survey increased significantly (from 9 to 14) the number of stars for which the angle has been measured. Research contributes to the open question whether the orbital elements reflect the properties of the protostellar cloud or result from post-formation dynamical evolution. The developed software with continued observations have the potential to contribute significantly to our knowledge of the source of misaligned spin orbits in binary systems. Photometric and spectroscopic study continues. This work was published as *Tracking spin-axis orbital alignment in selected binary systems: the Torun Rossiter–McLaughlin effect survey* in the Monthly Notices of the Royal Astronomical Society in 2018 and is presented as Appendix D.