From Interacting Binaries to Exoplanets: Essential Modeling Tools
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New Insights into the Dynamics of Planets in P-Type Motion Around Binaries

Barbara Funk, Siegfried Eggl, Markus Gyergyovits, Richard Schwarz and Elke Pilat-Lohinger

Institute for Astronomy, University of Vienna
Türkenschanzstrasse 17, A-1180 Vienna, Austria
email: funk@astro.univie.ac.at

Abstract. Up to now, more than 500 extra-solar planets have been discovered. Many of these extrasolar systems consist of one star and only one giant planet. However, recently more and more different types of systems have become known, including also extrasolar planets in binaries. In our study, we will concentrate on such systems, since a large percentage of all G-M stars are expected to be part of binary or multiple stellar systems. Therefore, these kinds of systems are worthy of investigation in detail. In particular, we will concentrate on planets in P-Type motion, where the planet orbits around both stars. During the last few years, four such systems (NN Ser, HW Vir, HU Aqr and DP Leo) have been discovered. In our study, we performed dynamical studies for three multi-planetary systems in binaries (NN Ser, HW Vir, HU Aqr), and compared simulated eclipse timing variations (ETV) to current observational data.

Keywords. celestial mechanics, methods: n-body simulations, eclipses, binaries: eclipsing

1. Introduction, model, and methods

This work is dedicated to planets and planetary systems in P-Type motion, where we investigated the dynamical stability of three multi-planetary systems. The initial conditions used can be found in Beuermann *et al.* (2010) for the system NN Ser, in Qian *et al.* (2011) for the system HU Aqr, and in Lee *et al.* (2009) for the system HW Vir. In all cases, the motion of the planets were considered in the framework of purely Newtonian forces and all the celestial bodies involved were regarded as point masses. As the dynamical model for all investigations, we used the full n-body problem, consisting of two stars and two planets. In order to study the dynamical evolution of the different systems, we applied the Lie-Series Integration Method (see e.g. Eggl & Dvorak 2010) and checked these results with a Gauss-Radau integration method (see e.g. Everhart 1974) - both were in good agreement. All calculations were done for an integration time of 500,000 years.

Since all four planetary systems were discovered via eclipse timing variation measurements (ETV, perturbations of the stellar eclipse timing, caused by an unseen planet), we investigated also ETV curves.

2. Dynamical study

The two systems HW Vir and HU Aqr turned out to be unstable after a short time for the given initial conditions. Hence, we integrated best case scenarios, with the most favorable initial conditions, that were compatible with the given error bars. These best cases also lead to unstable motion. In a second step, we investigated the influence of relative orbital inclination, where the two stars define the plane (i = 0) and the planets are inclined to this plane. We changed the inclination of both planets (i = 0° - 50°,

Δi = 10°) and calculated the corresponding mass ($m' = m \cdot sin(i)$). Again, for the systems HU Aqr and HW Vir, none of these configurations lead to stable motion of the planets. Nevertheless, up to now, not the whole possible parameter space has been tested, hence stable motion may be found for some specific initial conditions, which we will investigate in the future.

For the binary system NN Ser, the authors give two possible planetary configurations. In the first case (marked with (2a) in Beuermann *et al.* 2010), the system turned out to be stable just for some specific initial conditions (the eccentric orbit needs to have a mean anomaly (M) between ≈ 120° and 310°). The second configuration (marked with (2b) in Beuermann *et al.* 2010), turned out to be less sensitive to the initial conditions, but again here the mean anomaly plays an important role for the long-term stability.
In a second step, we investigated the influence of relative orbital inclination for M = 0, which corresponds to a worst case scenario. Even for this worst case, we could find stable configurations (up to an integration time of 500,000 years) up to relatively high inclinations (i = 40°) of the two planets. So, we can conclude that at least the system NN Ser could be long-term stable. A detailed description of the whole work including all results can be found in Eggl *et al.* (2011).

3. Eclipse timing variations (ETV)

Since some of the proposed planetary systems seemed to be unstable, we investigated whether a detection with the ETV method is possible at all. Thus, we integrated the given systems and measured the ETV signal caused by circumbinary planets. The first results showed that short term variations in the binary's period are minimal. Yet, the long term effects caused by the binary's motion around the system's center of mass combined with a finite light travel time indeed produce measurable signals.

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