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# The BANANA Survey: Spin-Orbit Alignment in Binary Stars

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**Abstract.** Binaries are not always neatly aligned. Previous observations of the  $\text{DI Herculis}$  system showed that the spin axes of both stars are highly inclined with respect to one another and the orbital axis. Here, we report on our ongoing survey to measure relative orientations of spin-axes in a number of eclipsing binary systems.

These observations will hopefully lead to new insights into star and planet formation, as different formation scenarios predict different degrees of alignment and different dependencies on the system parameters. Measurements of spin-orbit angles in close binary systems will also create a basis for comparison for similar measurements involving close-in planets.

**Keywords.** techniques: spectroscopic, binaries: eclipsing, stars: rotation

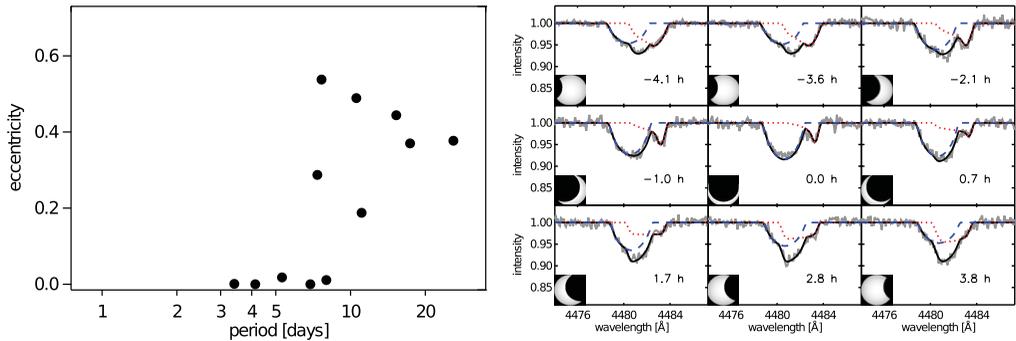
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## 1. Introduction

While many stars form in binary systems, binary formation is still not well understood. This is particularly true for close binary systems with orbital periods of a few days. If the orbital characteristics of these systems would not have changed since pre-main-sequence then the stars would have formed from one entity, as during the pre-main-sequence phase their sizes were bigger. As fission seems unlikely (Tohline 2002), the orbit probably shrunk and therefore the angular momentum of these systems must have undergone a complex history. One part of the angular momentum distribution which is seldom probed is the stellar spin.

Close binaries and star-planet systems might be expected to have well-aligned orbital and spin angular momenta, since all of the components trace back to the same portion of a molecular cloud. However, good alignment is not guaranteed. Disks around young stars might become warped during the last stage of accretion. This warp could torque the orbit by a large angle while maintaining the orientation of the spins (Tremaine 1991). More generally, star formation may be a chaotic process, with accretion from different directions at different times (Bate 2010).

There are also processes that could alter the stellar and orbital spin directions after their formation. A third body orbiting a close pair on a highly inclined orbit can introduce large oscillations in the orbital inclination and eccentricity of the close pair (Kozai 1962). Tidal dissipation during the high-eccentricity phases can cause the system to free itself of these “Kozai oscillations” and become stuck in a high-obliquity state (Fabrycky & Tremaine 2007). However, if dissipation is sufficiently strong then the system will evolve into the double-synchronous state, characterized by spin-orbit alignment (e.g. Hut 1981). Therefore, whether a close binary or a star-planet system is well-aligned or misaligned depends on its particular history of formation and evolution. Even though this issue is



**Figure 1.** The left panel shows the orbital period and eccentricity of our current sample in the BANANA project. The nine panels on the right show spectra obtained during primary eclipse in the DI Herculis systems. Each panel shows the Mg II lines (4481 Å) of the two stars. The gray line represents the data, the dashed (blue) line the model for the foreground secondary, the (dotted) red line the model for the eclipsed primary and the black line the combined model. Each panel has an inset illustration showing the uncovered part of the primary. The time from mid eclipse is also given. If the primary spin would have been aligned then at mid-eclipse the primary absorption line should be near symmetric, which is not the case.

important for a complete understanding of star formation, there has been very little observational input.

For these reasons, we are conducting measurements of the relative orientations of the rotational and orbital axes in close binary star systems, most of which harbor early-type stars. Our name for this undertaking is the BANANA project, an acronym chosen to remind us that binaries are not always neatly aligned (Albrecht *et al.* 2009, 2011).

Our aims and measurement approach are similar to the efforts undertaken in the exoplanet community (see e.g. Albrecht, these proceedings), but there is one difference in the analysis method. When observing double-lined binaries during eclipses to measure the Rossiter-McLaughlin effect (Rossiter 1924, McLaughlin 1924), the light from the occulting foreground object cannot be ignored. We, therefore, cannot simply measure the center of lines during eclipses, but have to model the spectra of both stars and compare these to the observations. See Albrecht *et al.* (2007) for details.

The left panel in Fig. 1 shows the orbital periods and eccentricities of the systems in our program. The right panels show observations of an eclipse of the primary star in the DI Herculis system, in which rotation is strongly misaligned with the orbital spin (Albrecht *et al.* 2009).

In our current sample, we find evidence for aligned systems and evidence for spin-orbit misalignment. Furthermore, we find that stellar obliquity seems not to be a simple function of orbital distance or eccentricity.

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