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Spin-orbit angles: A probe to evolution

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Abstract. We will present our campaign to estimate the projected spin-orbit angle for transiting hot Jupiters, obtained via observations of the Rossiter-McLaughlin effect. Combining our results to those of other teams we show what the current distribution in projected spin-orbit angle is, quickly reminding what interpretation we make of it. Finally we will show early results from a campaign that we initiated, surveying the Rossiter-McLaughlin effect on transiting SB1 intended to provide a comparison sample to the transiting planet's results.

Keywords. planetary systems: formation, binaries: eclipsing, techniques: spectroscopic

1. Context

Prior to the discovery of the first extrasolar planet found by Mayor & Queloz (1995), it was usually expected that giant planets would not be found much closer to their parent star than Jupiter is. This discovery called for a migrating mechanism to carry a gas giant from its birth location to the currently observed one. Lin *et al.* (1996) using work from Goldreich & Tremaine (1980) presented the idea that planets ought to migrate via exchange of angular momentum with the protoplanetary disc. An alternative explanation was proposed by Rasio & Ford (1996) whereby in an unstable multiplanetary system, planets would gradually scatter each others, some arriving on close-in orbits.

The discovery of 51 Peg b and the other hot Jupiters altered the generally accepted view of well ordered, hierarchical systems such as our own towards more diverse systems. Indeed, with masses ranging over several orders of magnitude, very different radii, large eccentricities and a curious period distribution, planets have demonstrated an enormous variety in their observed parameters.

More recently a new observable appeared: the projected spin-orbit angle β (also called λ) which is obtained via the Rossiter-McLaughlin effect. First theorised by Holt (1893) as a way to determine stellar rotation, it was observed by Rossiter (1924) and McLaughlin (1924) on eclipsing binaries. It was first observed for a planet by Queloz *et al.* (2000) for HD 209458b and on an increasing number of transiting hot Jupiters since, most systems appearing aligned with their star (see Josh Winn's contribution and citations within).

2. The HARPS Rossiter-McLaughlin survey

The WASP consortium has two instruments located in La Palma, Canary Islands, Spain, and in Sutherland, South Africa. The aim is to discovery transiting planets (see contribution by Andrew Collier Cameron). WASP produces candidates which are then confirmed on the 193cm at OHP, the NOT at La Palma, and by the CORALIE spectrograph on the 1.2m Swiss Euler Telescope at La Silla, Chile. After confirming some of those candidates as being planets we used the HARPS spectrograph, mounted on the ESO 3.6m, also at La Silla, to refine the orbits but also to get high signal to noise and high cadence observations during the transits of the WASP planets.

Our first batch of 8 observations was published in three papers: Gillon *et al.* (2009), Queloz *et al.* (2010) and Triaud *et al.* (2010). On these eight we found that four of our targets were retrograde: WASP-2b, 8b, 15b and 17b (see Fig. 1), an unusually large number compared to other results in the literature. We attempted a statistical analysis of all the Rossiter-McLaughlin effect known then: 26, trying to see which of the published theoretical predictions could be compared to the observations (see Triaud *et al.* (2010)).

On the cumulative distribution of projected spin orbit angles, compared with predictions by Fabrycky & Tremaine (2007) and by Nagasawa *et al.* (2008), the two predictions displaying the largest range of angles, we see that predictions by Nagasawa *et al.* (2008) fit the best (Fig. 2). These authors used the Kozai mechanism caused by an outer binary with tidal friction to produce their results while Nagasawa *et al.* (2008) used planet-planet scattering, initiating Kozai cycles, and tidal friction. Both used dynamical events followed by tidal friction.

We concluded that standard disc migration, not expected to produce large angles, could not alone produce the observations, that another mechanism ought to be present, the Kozai mechanism fitting best the observations.

These results depended on an assumption: that the probability for a planet to have a certain β appeared independent of other parameters for all planets, that we had only one distribution. Winn *et al.* (2010) showed it was not so by plotting the projected spin-orbit angle in function of the effective temperature of the star (see Josh Winn's contribution).

3. New results

Since, we continued observing with HARPS, while other colleagues continued their observations. Combining announcements made during the conference and those that we have in stock we can confirm what Winn *et al.* (2010) had remarked: planets around stars colder than 6250 K tend to be more aligned than planets around hotter stars. In fact the combined observations show a large lack of aligned systems for planets around

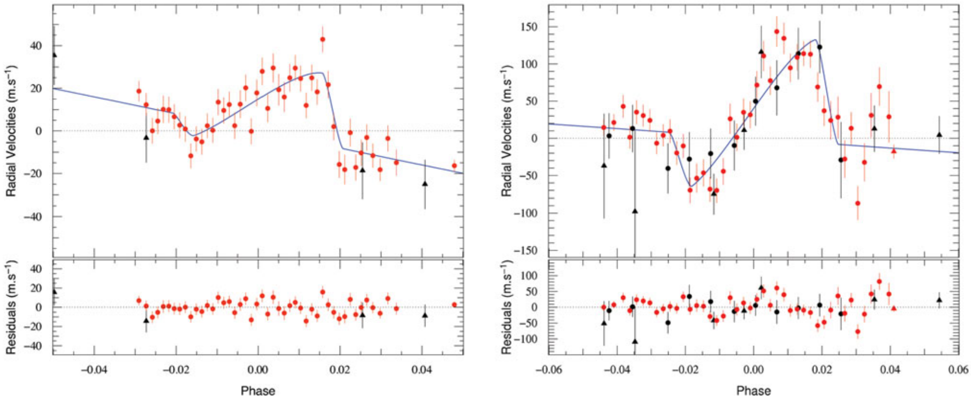

Figure 1. The R-M effect for WASP-15b and WASP-17b and residuals as appearing in Triaud *et al.* (2010). Circles are HARPS observations, triangles are CORALIE observations.

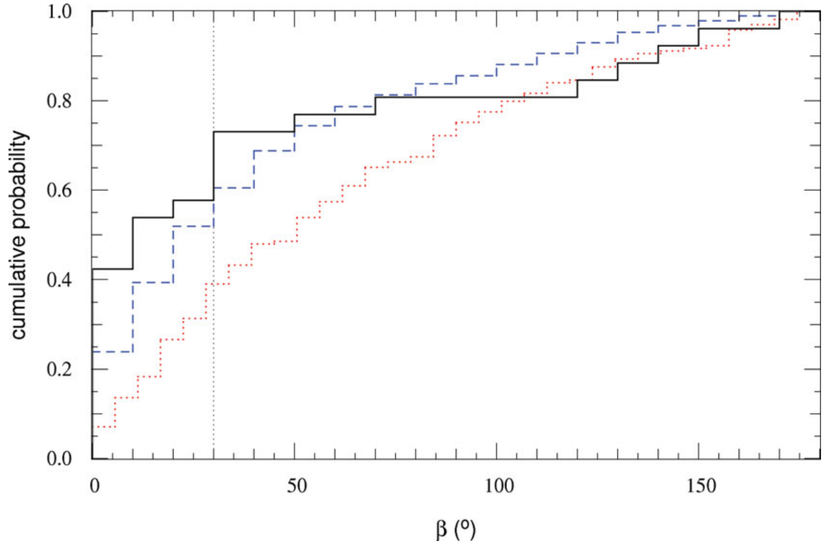

Figure 2. Cumulative distribution of observations (plain). Theoretical predictions by Fabrycky & Tremaine (2007) (dashed). Theoretical predictions by Nagasawa *et al.* (2008) (dotted).

hotter stars compared to those around colder one (Figure 3). Schlaufman (2010) using another method, independently comes to similar conclusions.

From explanations given in Winn *et al.* (2010) 6250 K is the temperature at which the stellar outer convective envelope disappears. Planets around stars colder than this

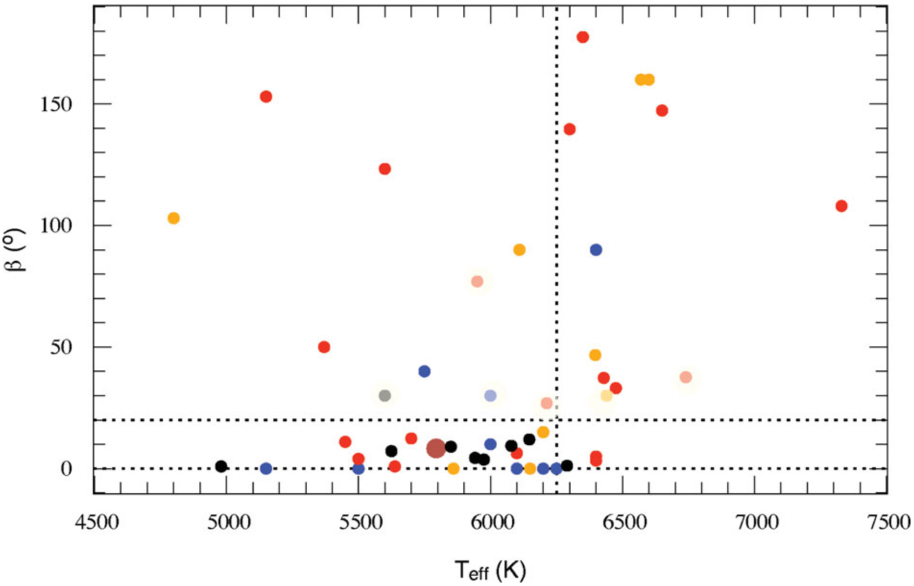

Figure 3. Projected Spin-Orbit angle versus stellar effective temperature. Symbols: observations including refereed and non refereed results. Faded symbols: observations which can be doubted. Those are: TReS-1b because of its large error bar, CoRoT-1b, 3b and 11b and Kepler-8b because notably of the bad sampling due to the faintness of those targets. One of our new observations also suffer from some systematic effect. Numbers likely to change.

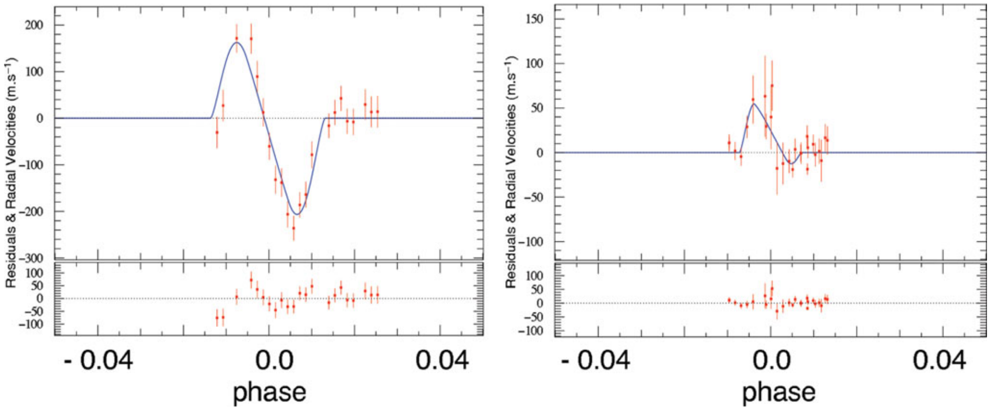

Figure 4. Rossiter-McLaughlin effect for two transiting M dwarfs. On left, the M-dwarf transits a 6600 K star, on a 8.1 day, eccentric period. On right, the M-dwarf is around a 5300 K star, on a nearly circular 6.8 day period. While the first is clearly aligned, the second is 3σ away from $\beta = 0$. Triaud *et al.* in prep.

would realign the convective envelope and therefore would appear aligned; planets around hotter stars retain their original spin-orbit angle. An analysis of the angle of those planets could then be used and compared to theory.

Among our new results we confirm that WASP-7b, observed with the CORALIE spectrograph, is severely misaligned with a quasi polar orbit, but do not confirm the detection of the Rossiter-McLaughlin on WASP-16b (Josh Winn's contribution) where our HARPS results show no deviation from the Keplerian orbit.

4. Comparison sample with Low Mass Binaries

In its search for planets, the WASP consortium found a plethora of transiting M-Dwarfs. These objects, interesting in their own right also provide a good opportunity to have a comparison sample. We now know planets can be aligned and can be misaligned. What about stars? Very few quantitative measurements exist in the literature; only one binary system is known to be misaligned Albrecht *et al.* (2009). We have embarked in a survey to measure the spin-orbit angle for these low mass binary stars, behaving in transit on a first approximation as a planet would: a small dark disc on a bright surface. Being SB1, the radial velocities are extracted exactly like in the planet case. We observe therefore the Rossiter-McLaughlin effect. This is the first survey of its kind. We show here two examples from our observations with CORALIE in figure 4.

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