Living Around Active Stars
Proceedings IAU Symposium No. 328, 2016
D. Nandy, A. Valio & P. Petit, eds.

doi:10.1017/S1743921317004501

Interaction of extra solar planets with their host star

Douglas Silva and Adriana Valio

Center for Radio Astronomy
and Astrophysics Mackenzie (CRAAM),
São Paulo, Brazil
email: douglas93f@gmail.com

Abstract. Transit is the passage of the planet in front of its star. During one of these transits, the planet may occult a spot on the photosphere of the star, causing small variations in its light curve. By detecting the same spot in a later transit, it is possible to estimate the stellar rotation period. The comparison between the rotation period of star at the equator and the planets orbital period showed the existence of resonances between these periods. Two types of mechanisms are proposed in the literature: electromagnetic interaction between the stellar and planetary fields and gravitational interaction. Our results have shown that for planets CoRoT-2b, CoRoT-5b and CoRoT-8b, tidal effects seem to dominate, whereas for planets CoRoT-4b and CoRoT-6b electromagnetic interaction dominates over tidal effects. A distinct characteristic of these last two systems is that the orbital period is larger than the rotation period of the star.

Keywords. resonances: rotation period, orbital period, tidal effects, electromagnetic interac

1. Introduction

According to the website exoplanet.eu there are already more than 3,700 exoplanets discovered orbiting other stars, with more than 2,700 transiting their host star. During the passage of the planet in front of its host star, there is a decrease in the intensity of light from the star. When the planet eclipses the star, it can occult spots causing slight variations perceptible in the star transit light curve.

These small changes detected during planetary transit interpreted as due to the spots were fit using the model developed by Silva (2003). In this way it was possible to obtain the physical characteristics of the spots and by applying this technique to many transist, estimate the rotation profile of the star. Five stars detected by CoRoT satellite have been analyzed and their rotation periods and differential rotation determined. Using the rotation profile, we estimated the period at the stellar equator.

The results showed a resonance between the planetary orbital period and the rotational period of the star, as shown on Table 1. This observed resonance may indicate an interaction between the planet and its host star. Two interaction mechanisms are proposed in the literature. The first type of interaction is the gravitational type, or tidal effect, and the second type of interaction is the magnetic interaction that occurs between the magnetic fields of the host star and planet (Cuntz *et al.* (2000)).

To study the gravitational interaction, we adapted the model of Jackson *et al.* (2008), which studies the evolution of the planet's orbital semi-major axis and eccentricity. The application of this model shows the evolution caused by the tidal effects.

For the magnetic interaction, the models of Lanza (2009) and Lanza (2012) were used, to calculate the energy dissipated by magnetic reconnection between the lines of magnetic fields of both the planet and the star. In Lanza (2012), the authors emphasize the energy release processes in the stellar corona due to changes in helicity.

Table 1. Differential Rotation and Rotation of CoRoT stars

Star	CoRoT -2a	CoRoT -4a	CoRoT -5a	CoRoT -6a	CoRoT -8a	Sol
$P_{rot}(days)$	4.54	8.87	26.63	6.35	21.7	27.6
$P_{rot}(\alpha)(days)$	4.48	8.71	26.49	6.08	21.42	
Diff. Rot.(rd/day)	0.042	0.026	0.103	0.101	0.014	0.050
Relative Diff. Rot. (%)	3.0	3.6	42.9	10.2	4.9	22.1
$P_{equat}(days)$	4.47	8.53	20.52	5.98	20.33	24.7
$P_{orb}(days)$	17.43	9.203	4.038	8.886	6.212	
$P_{equat} : P_{orb}$	2 : 5	1 : 1	1 : 5	3 : 2	1 : 3	

The objective of this study is to better understand planetary systems of solar-type stars orbited by hot Jupiters, and their interaction with one another.

Star-planet interactions

To study the gravitational interaction we used the system of equations described in Jackson *et al.* (2008) to determine the orbital evolution the eccentricity and semi-major axis of the planets:

$$\frac{1}{e}\frac{de}{dt} = -\left[\frac{63}{4}(GM_s^3)^{1/2}\frac{R_p^5}{Q_p' M_p} \pm \frac{171}{16}\left(\frac{G}{M_s}\right)^{1/2}\frac{R_s^5 M_p}{Q_s'}\right] a^{\frac{-13}{2}} \tag{1.1}$$

$$\frac{1}{a}\frac{da}{dt} = -\left[\frac{63}{2}(GM_s^3)^{1/2}\frac{R_p^5}{Q_p' M_p}e^2 \pm \frac{9}{2}\left(\frac{G}{M_s}\right)^{1/2}\frac{R_s^5 M_p}{Q_s'}\right] a^{\frac{-13}{2}} \tag{1.2}$$

where e is the eccentricity, a the semi-major axis, G the constant gravitational, M_S the mass of the star, M_p the planet's mass, $R_s$the radius of the star, R_p the radius of the planet, $Q_p^{'}$ is the planetary dissipation parameter and $Q_s^{'}$ is the stellar dissipation parameter.The $(+)$ sign applies for systems where the orbital period is smaller than the stellar rotation period, whereas the $(-)$.

To obtain the energy dissipated by the system, we used the following equation of Jackson *et al.* (2008)

$$h = \left(\frac{63}{16\pi}\right)\frac{(GM_s)^{3/2}M_s R_p^3}{Q_\prime^p}a^{-15/2}e^2 \tag{1.3}$$

where h is the internal heating per unit surface area of the planet. As the planetary orbit evolves through the coupling of tide, the orbital energy can result in substantial internal heating of the planet caused by tidal effects. The equations were integrated over the estimated age of each planet studied using the Runge-Kutta algorithm. The input data for the model for our planetary systems were taken from Table 1. For the stellar dissipation parameter, we assume $Q_s = 10^{5.5}$ and for terrestrial planets, we used $Q_p = 10^{6.5}$ (Jackson *et al.* (2008)).

For the power dissipated by the magnetic reconnection we used the equation Lanza (2009) described as follows:

$$P_{rec} = \gamma_{rec}\frac{\pi}{\mu}R_p^2 B_{rp}^{4/3} B_{p0}^{2/3} V_{rel} \tag{1.4}$$

where P_{rec} is the power dissipated, $0 < \gamma < 1$ is a factor that depends on the angle between the interacting magnetic field lines, R_p is the radius of the planet, B_{rp} is the coronal field of the star on the stellar equatorial plane at $r = a$ and B_{p0} is the magnetic field strength at the poles of the planets and V_{rel} is the relative velocity between the planet and the stellar coronal field.

https://doi.org/10.1017/S1743921317004501 Published online by Cambridge University Press

Table 2. Dissipated tidal energy of the CoRoT planets

System	a	e	year (10^9)	*Power (W)*
CoRoT 2	0.028	$0,023$	$0,13-0,5$	$1,53\times10^{20}$
CoRoT 4	0.09	$0,09$	$0,7-2,0$	$1,15\times10^{18}$
CoRoT 5	0.04947	$0,09$	$5,5-8,3$	$5,08\times10^{19}$
CoRoT 6	0.0855	$0,11$	$1,0-3,3$	$2,06\times10^{18}$
CoRoT 8	0.063	$0,09$	$2,0-3,0$	$5,47\times10^{18}$

Table 3. Power dissipated magnetic by reconnection and Helicity magnetic

System	a (R_{star})	R_p (m)	$V_{rel}10^5_{km/s}$	$P_{rec}(W)$	$P_{Hel}(W)$
CoRoT 2	6.7	1.2×10^7	1.6	1.52×10^{17}	7.69×10^{17}
CoRoT 4	17.47	8.3×10^7	1.1	4.66×10^{18}	5.97×10^{17}
CoRoT 5	9.877	9.2×10^7	1.4	7.99×10^{18}	9.11×10^{18}
CoRoT 6	17.95	8.1×10^7	0.96	4.094×10^{18}	4.72×10^{17}
CoRoT 8	17..61	1.5×10^7	1.1	1.639×10^{17}	2.035×10^{16}

The magnetic models developed by Lanza (2012) estimated the energy released by changes in helicity of magnetic fields. The model was developed for linear force-free field, asymmetric forces free fields and non-linear fields. In this work, we only adopted the approach of non-linear field as shown below:

$$P_{hel}=\frac{27\pi}{16\mu}\frac{n+1}{n}\lambda^2B_0^{4/3}B_{p0}^{2/3}R_p^2\left(\lambda_2+n^2\right)^{\frac{-1}{3}}V_{rel}\left(\frac{r}{R}\right)^{-(n+11)/3} \tag{1.5}$$

where n is a positive constant, λ^2 is the eigenvalue, r is radius of the star and R radius of the planet. The values used for B_{p0} and B_0 are respectively 100 Gauss and 10 Gauss, $n=5$ and $\lambda^2=0.82343$, the same values adopted by Lanza (2012). These values are intended to maximize power dissipation. The relative velocity was taken as the difference between the orbital velocity of the planet and the rotational velocity of the star

Results

The gravitational and magnetic interactions were modeled for CoRoT 2, CoRoT 4, CoRoT 5, CoRoT 6 and CoRoT 8. To calculated the energy dissipated by tidal effects we used the variation of the orbital parameters obtained by Solving the Equations (1.1) and (1.2).

The values listed on Table 2 were obtained by substituting the present values of the semi-major axis and the eccentricity in Equation (1.3) of this work.

To obtain the values of the power dissipated by magnetic reconnection, listed in Table 3, we used Equation 1.4 of this work, and for the values of power due to the helicity variation, we used Equation 1.5.

Conclusions

Comparison of the results listed on Tables 2 and 3 shows that the power dissipated by gravitational effects is greater than the power lost by magnetic reconnection or helicity

https://doi.org/10.1017/S1743921317004501 Published online by Cambridge University Press

for the CoRoT 2, CoRoT 5 and CoRoT 8 systems. Lanza(2012) also concluded that the power dissipated by magnetic interaction was not sufficient to explain the observations of the stars studied.

However, the power dissipated by magnetic reconnection was greater than the energy dissipated by tidal effect for the CoRoT 4 and CoRoT 6 systems, these systems have planets with an orbital period greater than the period of rotation of the stars, unlike the others.

Therefore the mechanism that dominates, tidal or magnetic effects, depends on the type of star and the individual parameters of the planet and its host star.

References

Silva, A. V. R. 2003, *Bulletin of the Astronomical Society of Brazil*, 23, 15

Lanza, A. F. 2012, *A & A*, 544, A23

Lanza, A. F. 2009, *A & A*, 505, 339

Jackson, B., Greenberg, R., & Barnes, R. 2008, *ApJ*, 681, 1631-1638

Jackson, B., Barnes, R., & Greenberg, R. 2008, *MNRAS*, 391, 237

Cuntz, M., Saar, S. H., & Musielak, Z. E. 2000, *ApJL*, 533, L151

https://doi.org/10.1017/S1743921317004501 Published online by Cambridge University Press