Star-Planet Tidal and Magnetic Interactions

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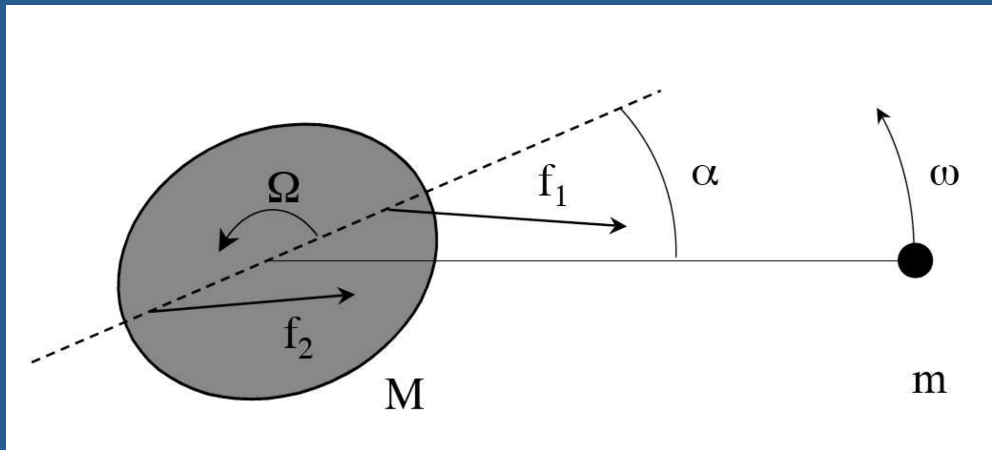
Star-planet interactions

- Stars interact with their close-in planets through gravitation, radiation, and magnetic fields;

- Tides on stars and planets are produced by their gravitational interaction (see, e.g., Zahn, 2008; Mathis et al. 2013) ;



(Zahn 2008)

Tides in star-planet systems

- Tides tend to:
  - circularize the orbit;
  - synchronize the rotation of the two bodies with the orbital period; and
  - align their spins with the orbital angular momentum;

- The timescale to reach such a final, minimum energy state, depends on the strength of the tidal torques acting on the two bodies (e.g., Zahn 2008).

Orbital decay

- When the star rotates with a period longer than the planetary orbit, tides produce an orbital decay;

- The timescale for the engulfment of the planet is:

$$\tau_a = -\frac{2}{13}\frac{a}{\dot{a}} = \frac{4}{121}\frac{M_*}{M_p}\left(\frac{a}{R_*}\right)^5 \frac{Q'_*}{n}$$
$$\approx 0.020 Q'_* \frac{M_*}{M_p}\left(\frac{\bar{\rho}}{\bar{\rho}_\odot}\right)^{5/3}\left(\frac{P}{1\ \mathrm{day}}\right)^{13/3}\ \mathrm{yr}.$$

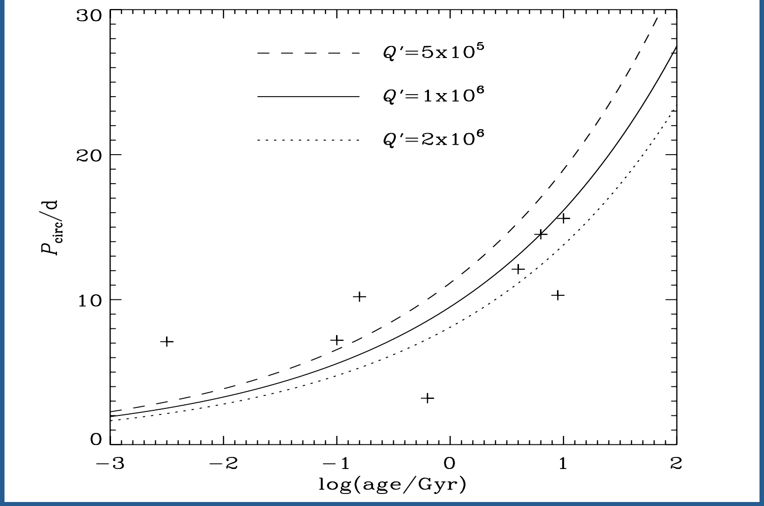
(Ogilvie & Lin 2007)

The ***modified tidal quality factor*** Q'_* parametrizes the efficiency of the dissipation of the kinetic energy of the tides inside the star; the larger Q'_*, the smaller the dissipation. For simplicity, we assume Q' independent of the tidal frequency.

The tidal quality factor

- Theoretical estimates of Q'_* are uncertain by 2-3 orders of magnitudes (e.g., Ogilvie & Lin 2007; Mathis et al. 2013);

- It can be calibrated by observing synchronization and circularization in close binary systems belonging to clusters of different ages; this gives: $Q'_* \approx 10^6$.



(Ogilvie & Lin 2007)

Very Hot Jupiters (VHJs)

- With $Q'_* \approx 10^6$ the orbital decay timescale for a planet with a mass comparable with that of Jupiter and $P_{orb} \approx 1.5$ d around a Sun-like star is only ≈ 50 Myr;

- Conversely, the estimated age of its host star is generally of the order of a few Gyr;

- Are those systems caught in a very special, short-lived phase of their evolution ? Or is the calibration of tidal interaction derived from close binaries not applicable to those systems ?

Observational tests

- We can approach these questions by:

  - studying the tidal evolution of individual sistems (e.g. Carone & Patzold 2004; Lanza et al. 2011);

  - analysing a statistically significant sample of VHJ systems, e.g., along the lines of Jackson et al. (2009) or Hansen (2010, 2012);

- However, PLATO will allow us to put a lower limit on the ***present value*** of Q'_* in individual systems through an accurate timing of their transits;

- For instance, in the case of Kepler-17, Bonomo & Lanza (2012) estimate a TTV of 8 s in ten yrs, if $Q'_* \approx 10^6$; relying on previous Kepler timing, PLATO can measure such a TTV and put a direct constraint on Q'_* in this system.

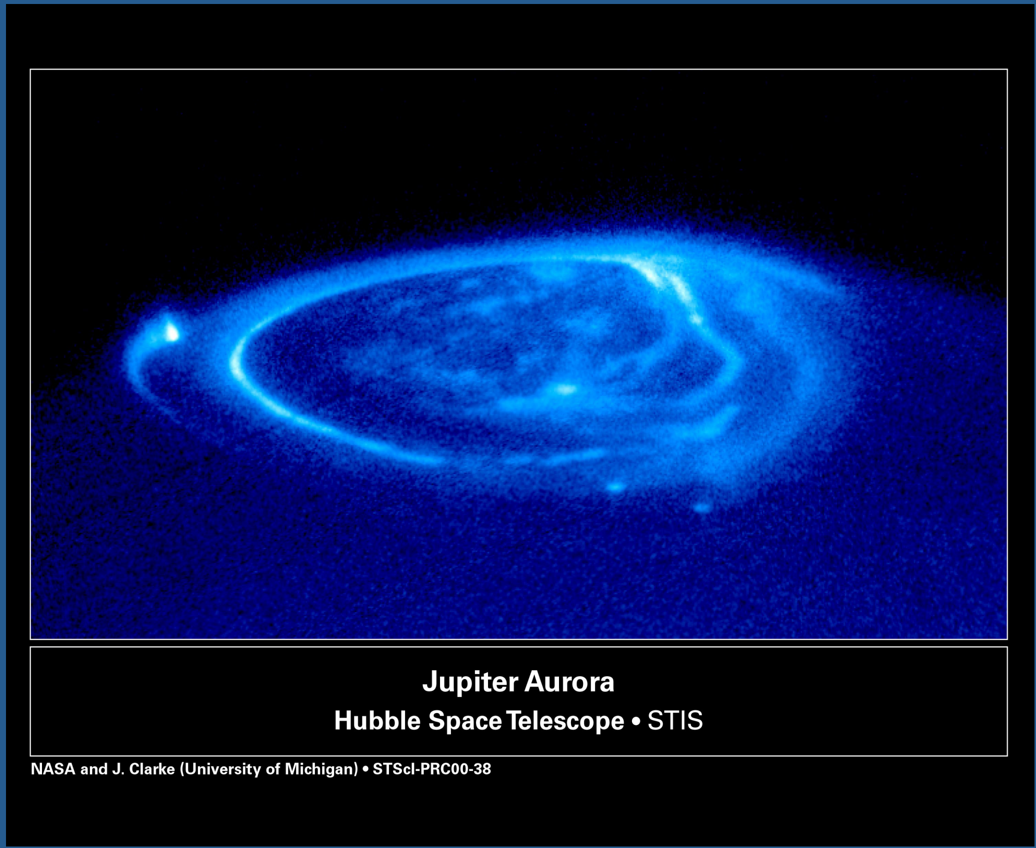
Star-Planet Magnetic Interaction (SPMI)

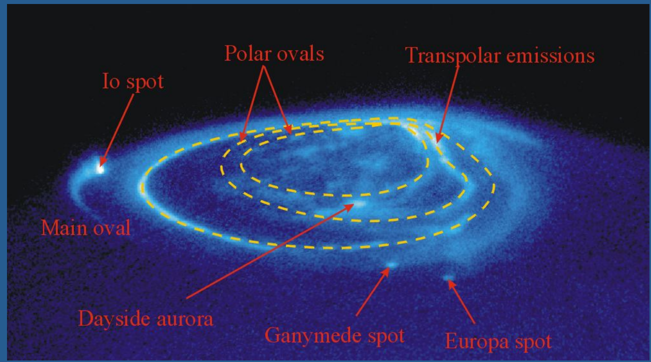
- Close-in planets ($a < 0.15$ AU) can also interact with the magnetic fields of their host stars (see the talk by Rim Fares on magnetic fields of planet-hosting stars);

- An interaction is expected also for a planet that have no intrinsic magnetic field (cf. e.g., Saur et al. 2013);

- The power released in the interaction between the stellar coronal field and a magnetized planet can play a relevant role in planetary evaporation for $a < 0.10$ AU (Lanza 2013).

A scaled version in the Solar System: Jupiter-Io interaction





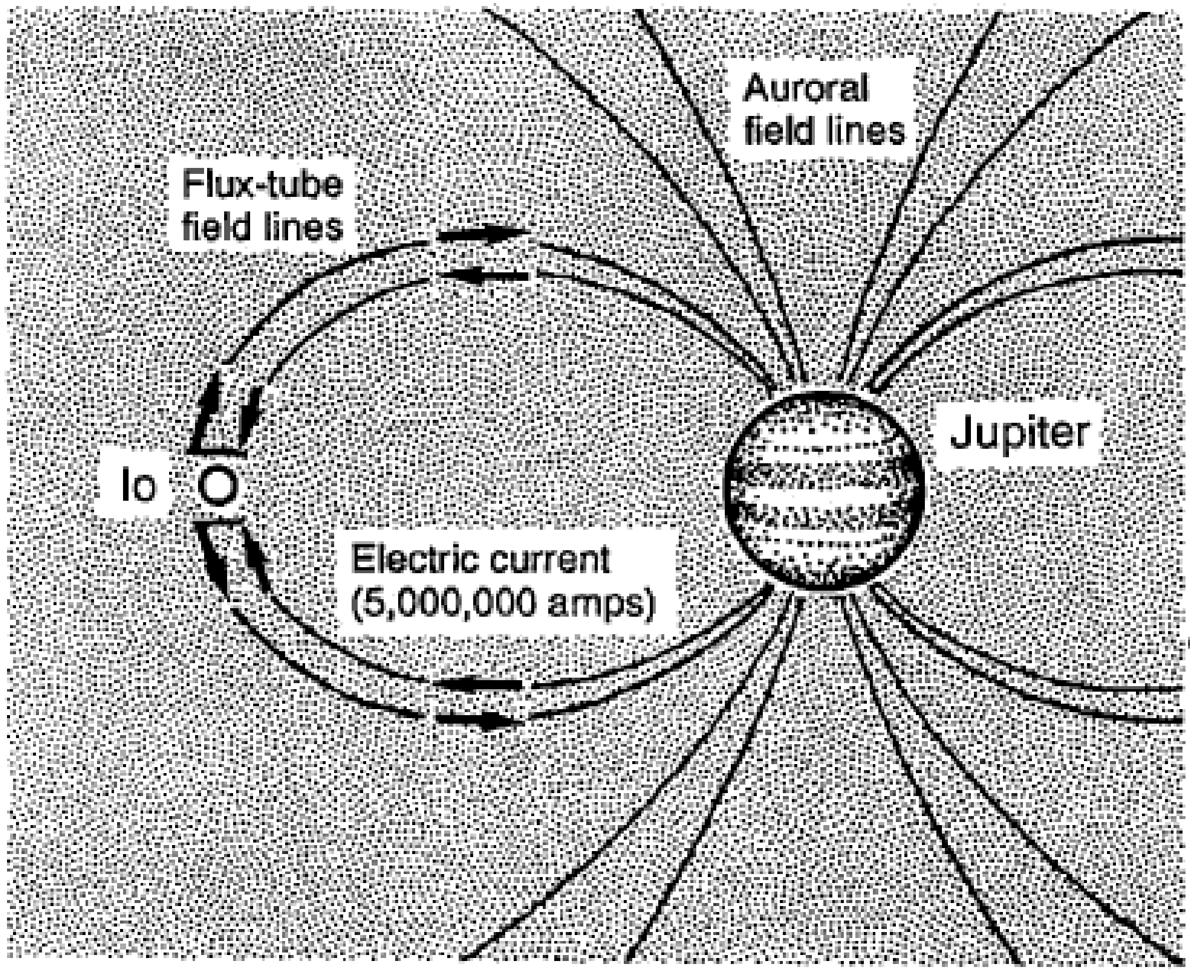
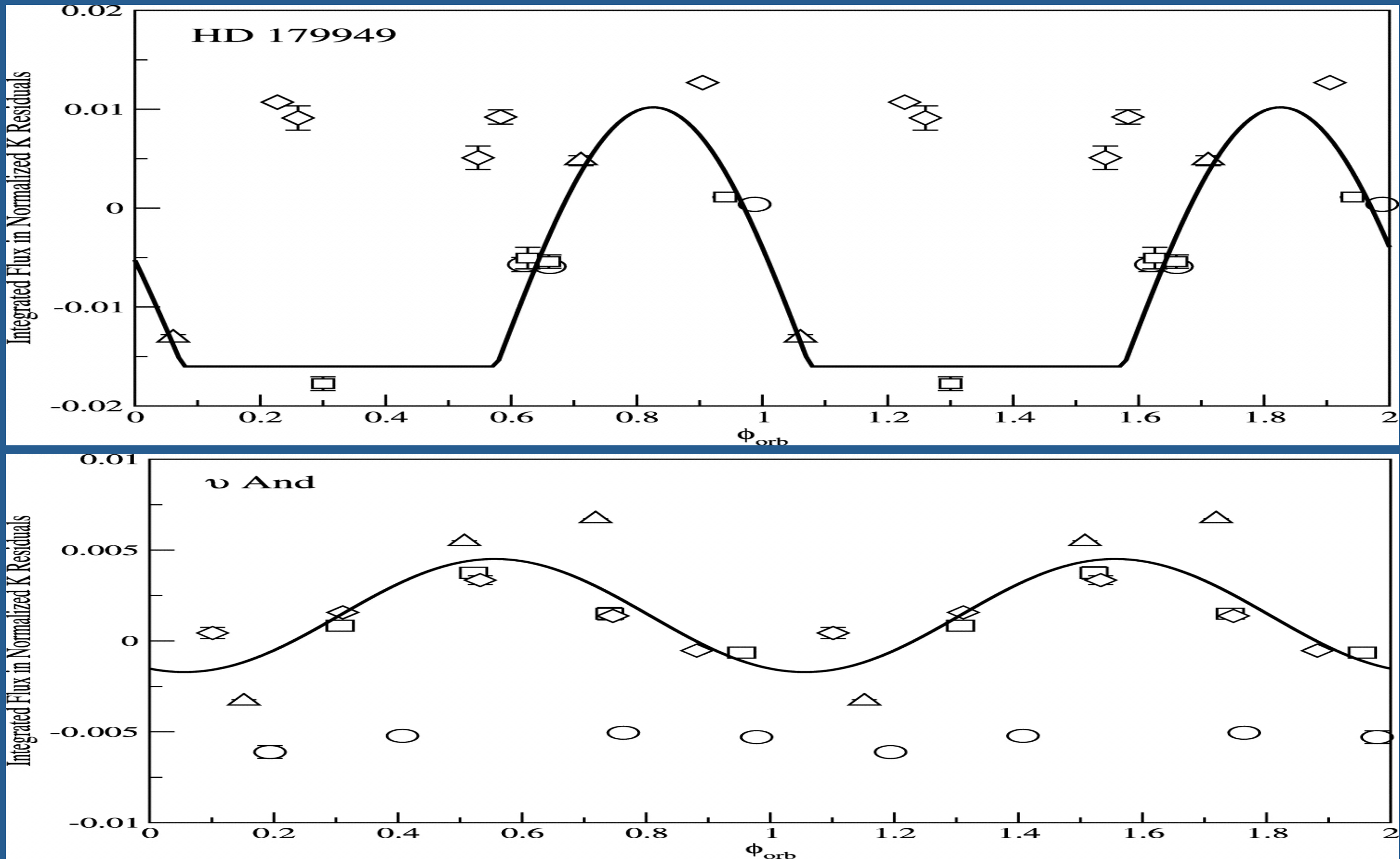


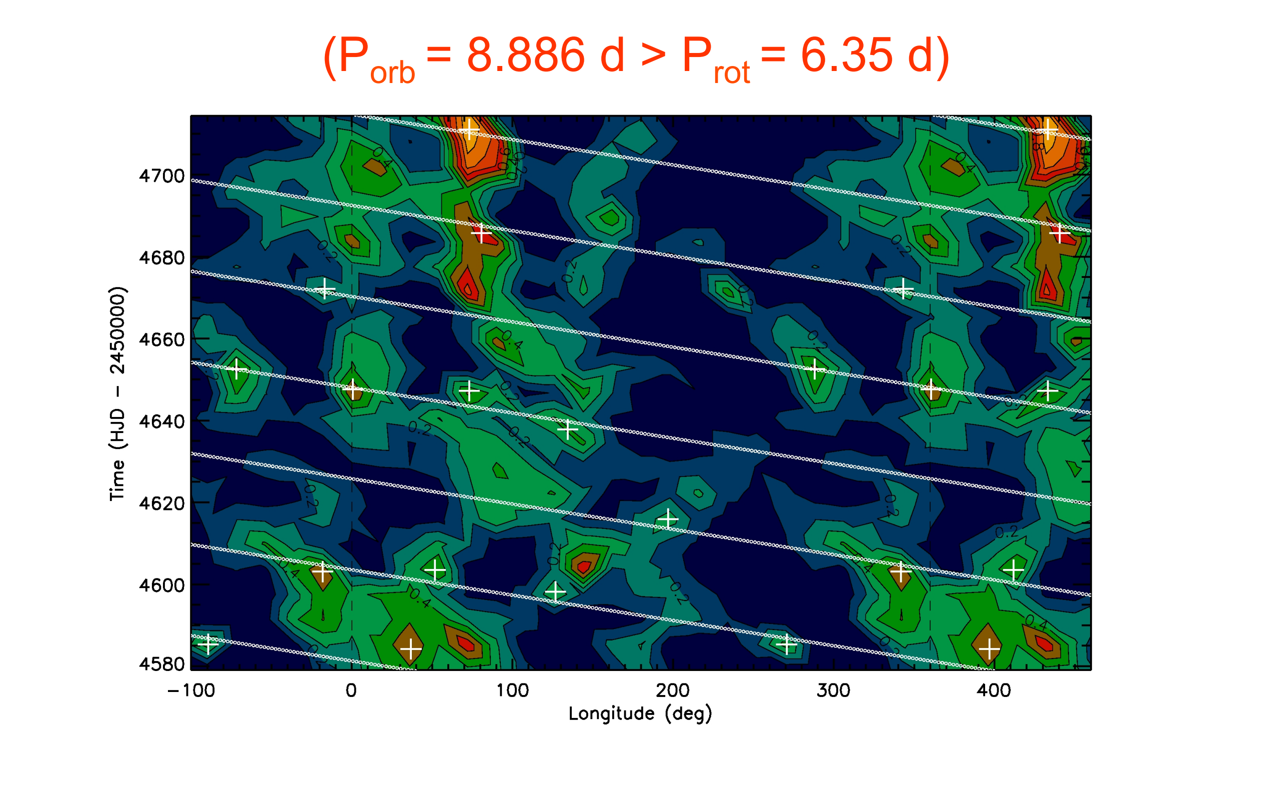
Fig. 2. The electrical circuit model of the Io-Jupiter interaction. A few million amperes of electrical current flows through the circuit in the direction indicated by the arrows [after Goldreich and Lynden-Bell, 1969]. Note that the scale is distorted for clarity; the circuit path in Jupiter's ionosphere is of order 0.001 R_J long.

SPMI in the chromospheres of HD 179949 and υ And



Different symbols refer to different epochs (Shkolnik et al. 2005; 2001 Aug: circles, 2002 Jul: squares; 2002 August: triangles; 2003 Sept: diamonds)

Possible star-planet interaction in CoRoT-6 as revealed by photospheric starspots



The straight lines mark a longitude at -200º from the subplanetary longitude; the crosses mark the active regions possibly associated with that active longitude. The probability of a chance association is less than 1 percent (Lanza et al. 2011).

Star-planet interactions and gyrochronology

- Late-type stars experience a braking of rotation during their main-sequence lifetime due to a magnetized wind;

- For a given spectral type, the rotation period depends on age (e.g., Barnes 2003, 2007; Bouvier 2008);

- Measuring the rotation period through the rotational modulation of PLATO light curves, we can estimate stellar ages with an accuracy up to 15-20 percent (e.g., Epstein & Pinsonneault 2012);

- However, there are indications that stars with close-in planets (HJs) do not follow the standard gyrochronology relationship; this can be due to:
  - Tidal spin-up by the planet (e.g., Pont 2009; Brown et al. 2011; Bolmont et al. 2012);
  - Reduced efficiency of the magnetized wind owing to predominantly closed coronal structures produced by the magnetic interaction with planet's field (Lanza 2010; Cohen et al. 2010).

Conclusions

- The measurement of TTV with PLATO promises to directly constrain the *present* tidal quality factor in VHJ systems, specifically by a combination with Kepler data to reach a time baseline of the order of a decade;

- PLATO high-precision photometry can be used to study stellar photospheric activity and rotation allowing us:

  – To assess the role of tidal and magnetic interactions in the rotational evolution of stars with close-in planets; this is fundamental to applying gyrochronology to planet-hosting stars;

  – To look for evidence of stellar active longitudes phased to the orbital motion of close-in planets (Lanza 2008, 2011).

Thank you for your attention