Cosmic Magnetic Fields: From Planets, to Stars and Galaxies
Proceedings IAU Symposium No. 259, 2008
K.G. Strassmeier, A.G. Kosovichev & J.E Beckman, eds.

doi:10.1017/S1743921309030646

Magnetic and tidal interactions in spin evolution of exoplanets

Irina N. Kitiashvili

Center for Turbulence Research, Stanford University, Stanford, CA 94305, USA
email: irinasun@stanford.edu

Abstract. The axis-rotational evolution of exoplanets on close orbits strongly depends on their magnetic and tidal interactions with the parent stars. Impulsive perturbations from a star created by periodical activity may accumulate with time and lead to significant long-term perturbations of the planet spin evolution. I consider the spin evolution for different conditions of gravitational, magnetic and tidal perturbations, orbit eccentricity and different angles between the planetary orbit plane and the reference frame of a parent star. In this report I present a summary of analytical and numerical calculations of the spin evolution, and discuss the problem of the star-planet magnetic interaction.

Keywords. Exoplanets – stars: planetary systems – stars: rotation – magnetic field

---

It is known that planetary rotation is determined by orientation of the angular momentum, L. In the case of perturbed rotation of a celestial body, the angular momentum changes its position in space relative to the evolving orbit. For planets moving at close-in orbits in addition to gravitational and tidal perturbations, magnetic field of the parent star and its activity may have significant influence (Shkolnik *et al.*, 2003).

In this report I present results of modeling the spin evolution of a dynamically symmetrical exoplanet (with equal principle moments of inertia, $A = B$) under the action of gravitational, magnetic and tidal perturbations for different values eccentricity, and propose possible scenarios for different types of exoplanet. For this study, I analyze the following system of evolutionary equations derived for the case when the angular spin velocity of a planet is significantly higher than its angular orbital velocity (Beletskii, 1981; Beletsky & Khentov 1995):

$$
\begin{aligned}
\frac{d\rho}{dt} &= \frac{1}{L\sin\rho}\left(\frac{\partial U}{\partial\psi}\cos\rho - \frac{\partial U}{\partial\Sigma}\right) + \frac{M_1}{L} - K_\Omega \sin i \cos\Sigma, \\
\frac{d\Sigma}{dt} &= \frac{1}{L\sin\rho}\frac{\partial U}{\partial\rho} + \frac{M_2}{L\sin\rho} + K_\Omega\left(\sin i \cot\rho \sin\Sigma - \cos i\right), \\
\frac{dL}{dt} &= \frac{\partial U}{\partial\psi} + M_3, \\
\frac{d\vartheta}{dt} &= \frac{1}{L\sin\vartheta}\left(\cos\vartheta\frac{\partial U}{\partial\psi} - \frac{\partial U}{\partial\phi}\right) + \frac{M_2\cos\psi - M_1\sin\psi}{L}, \\
\frac{d\psi}{dt} &= \frac{L}{A} - \frac{1}{L}\left(\frac{\partial U}{\partial\vartheta}\cot\vartheta + \frac{\partial U}{\partial\rho}\cot\rho\right) - \frac{M_1\cos\psi + M_2\sin\psi}{L}\cot\vartheta \\
&\quad - \frac{M_2}{L}\cot\rho - K_\Omega\frac{\sin i}{\sin\rho}\sin\Sigma, \\
\frac{d\phi}{dt} &= L\cos\vartheta\left(\frac{1}{C} - \frac{1}{A}\right) + \frac{1}{L\sin\vartheta}\frac{\partial U}{\partial\vartheta} + \frac{M_1\cos\psi + M_2\sin\psi}{L\sin\vartheta},
\end{aligned}
$$

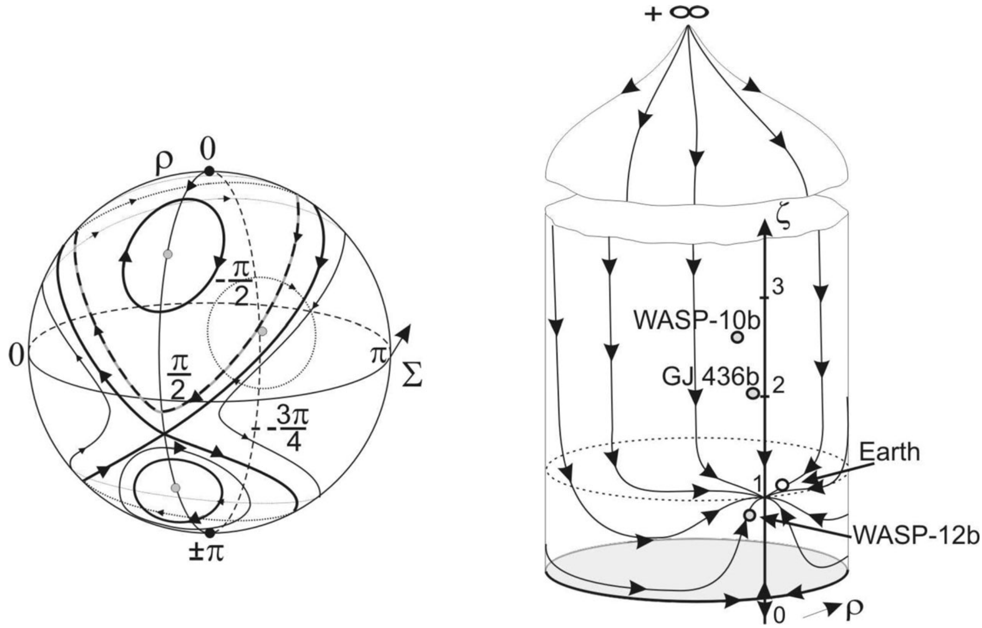

Figure 1. Left: Phase portraits in $\rho - \Sigma$ coordinates on a sphere, which show evolutionary treks of the spin angular momentum, $\vec{L}$, of several dynamically symmetrical planets under the action of gravitational and magnetic perturbations. Dashed curve shows an example of the regime when the planet spin can change sign, i.e. from direct rotation to reverse. Right: Phase portraits of $\vec{L}$ on a cylinder for ρ and $\zeta = L \cdot P/B$ coordinates (where P is the period of rotation, and B is the principle moment of inertia), including tidal perturbations and the orbital evolution. For comparison, locations of the Earth and three exoplanets with weak elliptical orbit are indicated.

where U is the potential force function of gravitational and magnetic perturbations, angles ρ, Σ describe the orientation of spin momentum $\vec{L}$ in the orbital reference frame; ψ, ϕ and ϑ are the Euler's angles, M_i are projections of the tidal perturbation forces on components of the vector $\vec{L}$; A and C are the principle moments of inertia of the planet.

The equations are investigated by using qualitative and numerical methods for dynamical systems (Kitiashvili & Gusev, 2008). Figure 1 shows different scenarios of the spin evolution under gravitational and magnetic perturbations (left panel) and a case, when tidal perturbations are essential (right panel). The results show that the joint action of gravitational and magnetic perturbations can lead to regimes, when the direct rotation of planets can change to the reverse rotation (Kitiashvili & Gusev, 2008). In addition, I have obtained estimates of the principal moment of inertia of some hot Jupiter planets, and their dynamical flattening under the action of tidal forces from the parent stars (Kitiashvili, 2008). For the close-in planets, when the tidal interaction is essential the results reproduce the flip-flop effect obtained earlier by Beletsky (1981) and determine possible states of the spin evolution of extra-solar planets.

References

Beletskii, V. V. 1981, *Celestial Mechanics* 23, 371

Beletsky, V. V. & Khentov, A. A. 1995, *Resonance rotation of celestial bodies* (Nizhnii Novgorod, Nizhegorodskii gumanitarnii centr, in Russian)

Kitiashvili, I. 2008, Proc of IAU Symposium 249, CUP, p. 197

Kitiashvili, I. N. & Gusev, A. 2008, *Cel. Mech. & Dyn. Astronomy* 100, 2, 121

Shkolnik, E., Walker, G., & Bohlender, D. A. 2003, *ApJ* 597, 1092