EPSC Abstracts
Vol. 8, EPSC2013-576, 2013
European Planetary Science Congress 2013

Tidal, dynamical and spin evolution of the Kepler 62 planetary system

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Abstract

Due to observational bias, the observed planetary systems are usually close-in and therefore likely to be subjected to tides. About 23% of the Kepler mission's planetary candidates are found in multiple systems close to their host stars. In these systems, the innermost planets' orbits are simultaneously perturbed by star-planet tidal interactions and by planet-planet gravitational forces [1].

We developed a code to study the tidal and dynamical evolution of multiple planet systems and we present here a study of the Kepler-62 system [2]. This recently discovered system hosts 5 planets. As two of these planets are in the insolation habitable zone, it is interesting to study their orbital evolution as well as their spin states. These quantities are important data for climate modeling.

We find that this system is unstable when the simulations are run without tides and General Relativity. However if we assuming a certain dissipation for the planets, we find it stable for at least ten million years. In this case, we also find that the obliquities of the three inner planets are greatly influenced by tides, while the obliquities of the two outer planets oscillate around their initial value. We explored the parameter space of the different planets dissipation and different initial obliquities.

1. Introduction

Tidal evolution in multiple planet systems has been studied in many works [1, 3]. However, these studies are mostly analytical, or they are limited to small eccentricities and coplanar systems. Using the example of the newly discovered Kepler-62 system, we present here the long-term orbital evolution and spin evolution of non-coplanar planetary systems perturbed by tides and planet-planet gravitational forces.

To perform this study, we used a new code which takes into account the evolution of the radius and spin of the central object (be it a star or brown dwarf [4]). It also includes a rigorous treatment of tidal forces [5] and planet-planet gravitational interactions using a symplectic N-body algorithm [6].

This code can be used to investigate the case of synthetic planet systems around all kind of evolving bodies, and also known exoplanet system. Here, we use this code to investigate the tidal and dynamical evolution of the system Kepler-62. We consider that the host star does not evolve – i.e., we keep its radius constant.

2. Model description

To compute the tidal interactions we use the tidal force derived in ref [7], which is a 3D generalization of Hut's force [5]. We consider that the star and the planets are deformable, so we take into account the tidal bulges raised by the star on each planet, and the tidal bulges each planet raises on the star. We consider that the bulges the planets raise on the star are independent and we neglect the tidal interactions between planets.

The resulting tidal force on each planet is implemented in the Mercury code as well as the General Relativity force [8]. The code also computes the spin state evolution of the star and of the planets.

The details of the code and its validation will be found in Bolmont et al. (2013b) – soon to be submitted. A coplanar version of this code was used for the study of the 55 Cnc system [9].

3. Tidal evolution of Kepler-62

The system Kepler-62 is a five planet system orbiting a $0.69M_{\odot}$ star. We used the characteristics of this planetary system given by Borucki et al. (2013) [2] as initial conditions for our code. We made several parameters vary such as the dissipation factor of planets.

We find that the stability of the system depends on the dissipation factors of the planets. The system is found unstable when we consider no tides and no General Relativity. Planet c goes through a series of close encounters with planet d and is ejected from the system.

However, with average dissipation factors, the system is stable over 10^7 yr. Some other configurations lead to destabilization. For example, increasing the dissipation of the inner planet or the dissipation of the star lead to the ejection of planet c.

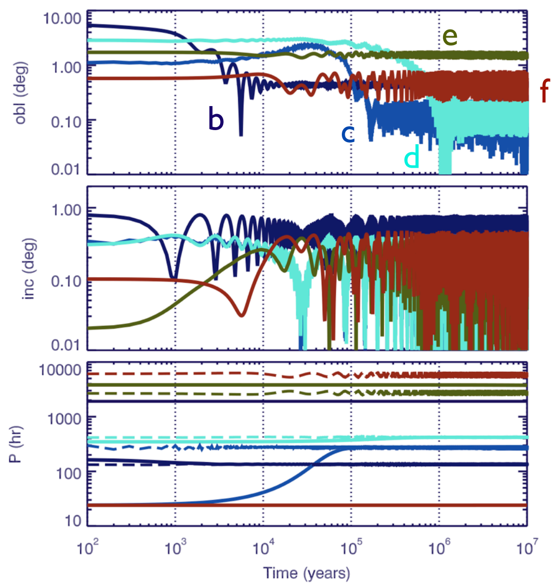

Figure 1: Tidal evolution of the five planets of the system Kepler-62. Top panel: evolution of the planets' obliquities. Middle panel: evolution of their inclination. Bottom panel: evolution of their rotation period (full line). The pseudo-synchronization period is plotted in dashed line.

Figure 1 shows the evolution of the obliquities of the planet, their inclination and their rotation period. The initial values of these parameters were chosen randomly. We can see that planets b, c and d reach pseudo-synchronization within a few 10^5 yr.

The obliquity of planets b and d decrease with time to values below 1°, while the obliquities of f and e remain to their initial level. Planet c experiences a small increase of its obliquity during the pre-pseudo-synchronization period before decreasing. When the planet has a high rotation rate, the effect of the planetary tide can induce an increase of obliquity.

4. Summary and Conclusions

Tides can influence the stability of multiple planetary systems. We showed here the dynamical evolution of the system Kepler-62 and that this system requires the action of tides to be stable over 10^7 yr.

We also showed a possible evolution of the obliquities of the different planets. Planets f and e, which are in the insolation habitable zone are likely to keep their initial obliquity and experience small oscillations around this obliquity. This can have some importance for the climate modeling of those two planets.

Acknowledgements

We thank the CNRS's PNP program for funding.

References

[1] Mardling, R. A.: Long-term tidal evolution of short-period planets with companions. MNRAS, 382, 1768-1790, 2007.

[2] Borucki, W. J., and 64 colleagues: Kepler-62: A five-planet system with planets of 1.4 and 1.6 Earth radii in the Habitable Zone. ArXiv e-prints arXiv:1304.7387, 2013.

[3] Laskar, J., Boué, G., Correia: Tidal dissipation in multi-planet systems and constraints on orbit fitting. A&A, 538, A105, 2012.

[4] Chabrier, G., Baraffe, I., Allard, F., Hauschildt, P.: Evolutionary Models for Very Low-Mass Stars and Brown Dwarfs with Dusty Atmospheres. ApJ, 542, 464-472, 2000.

[5] Hut, P.: Tidal evolution in close binary systems. A&A, 99, 126-140, 1981.

[6] Chambers, J. E.: A hybrid symplectic integrator that permits close encounters between massive bodies. MNRAS, 304, 793-799, 1999.

[7] Leconte, J., Chabrier, G., Baraffe, I., Levrard, B.: Is tidal heating sufficient to explain bloated exoplanets? Consistent calculations accounting for finite initial eccentricity. A&A, 516, A64, 2010.

[8] Kidder, L. E.: Coalescing binary systems of compact objects to (post)$^{5/2}$-Newtonian order. V. Spin effects., Physical Review, D 52, 821-847, 1995.

[9] Bolmont, E., Selsis, F., Raymond, S. N., Leconte, J., Hersant, F., Maurin, A.-S., Pericaud, J.: Tidal dissipation and eccentricity pumping: Implications for the depth of the secondary eclipse of 55 Cnc e.ArXiv e-prints, arXiv:1304.0459, 2013.