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# On the Kozai resonance in planetary systems

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## Abstract

In the framework of the Kozai problem, we investigate the influence of an eccentric giant planet on the dynamics of an Earth-mass companion on inclined orbit. Using the classical octupole Hamiltonian expansion, we show that the Kozai equilibria play a major role in the dynamics of an inner body on quasi-circular orbit: while its variation in eccentricity is limited for mutual inclination of the orbital planes smaller than $\sim 40°$, it becomes large and chaotic for higher mutual inclination. We also pay special attention to a region around $35°$ of mutual inclination consisting of particularly low-eccentricity orbits of the small body and therefore of particular interest for the research of life in extrasolar systems.

## 1. Introduction

A well-known secular resonance of the restricted three-body problem is the Lidov-Kozai mechanism ([8, 3]). As shown in [3], a highly inclined asteroid perturbated by Jupiter (assumed on a circular orbit) periodically exchanges its eccentricity and inclination.

These last years, this work founds many applications in planetary and stellar dynamics, especially in the studies of binary systems. Concerning planetary systems, some analytical studies have highlighted that highly non-coplanar systems can be long-term stable. While the spatial resolution of systems detected by radial velocity method is currently not possible, a first observational confirmation [9] has estimated the mutual inclination of the orbital planes of planets $c$ and $d$ of the Upsilon Andromedae system to $30°$. When the orbits are highly non-coplanar (i.e. mutual inclination $> 40°$), the Kozai resonance may act as a secular phase-protection mechanism (e.g. [10, 4]) such that the system remains stable, even though both orbits may suffer large-scale variations both in eccentricity and inclination; in other words, the variations can be large but occur in a coherent fashion, dictated by the resonance condition, such that close approaches do not occur. Libert & Tsiganis [5] have shown that a good fraction of the detected multi-planetary systems have physical/orbital characteristics consistent with a stable Kozai-resonant state, if their (unknown) mutual inclination is $\sim 45 - 60°$. Moreover, in their formation scenario of highly non-coplanar systems [6], some Kozai-resonant systems have resulted from the dynamical disruption of a triply resonant configuration on initially nearly coplanar orbits.

Since many extrasolar massive planets have been discovered with significant eccentricity, the present work aims to extend the original study of Kozai by considering the influence of an eccentric orbit of the giant perturber on the dynamics of an Earth-mass companion on an inclined orbit.

## 2. Analytical model and Results

Our analytical study of the secular perturbations relies on the classical octupole Hamiltonian expansion (third-order theory in the ratio of the semi-major axes), as third-order terms are needed to consider the secular variations of the outer perturber and potential secular resonances between the arguments of the pericentre and/or longitudes of the node of both bodies. Short-period averaging and node reduction (by adoption of the Laplace plane reference frame) reduce the problem to two degrees of freedom. The 4D dynamics is analysed through representative planes which identify the main equilibria of the problem.

Our study shows that an inner small planet on a quasi-circular orbit attracted by a giant companion on an elliptic orbit behaves secularly in a quite similar way as in the circular problem studied in [3]: small variation of its eccentricity when the mutual inclination of the orbital planes is smaller than $\sim 40°$, on the contrary to the large chaotic variation observed for higher mutual inclination. Let us note that further investigations have shown that, for mutual inclinations between $40°$ and $140°$, the influence of the octupole terms on these Kozai-Lidov cycles generates extremely high eccentricities and retrograde orbits ("orbit flipping", see [2, 11]).

Our study also shows that the dynamical region around $35^\circ$ of mutual inclination, detected numerically in the stability study of [1] and consisting of long-time stable orbits with quasi-null eccentricity variation of the small planet, may be regarded as a secular resonance of the problem. It corresponds to a commensurability of the precession rates of the arguments of the pericentre of both planets in the Laplace plane reference frame (see [7] for more detail). This region is of particular interest for the research of life in extrasolar systems, as the tiny eccentricity variation of the planet assures a constant distance between the planet and the host star, whatever the eccentricity of its giant companion.

Our results also apply to binary star systems where a planet is revolving around one of the two stars.


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## References


[1] Funk B., Libert A.-S., Süli Á., Pilat-Lohinger E.: On the influence of the Kozai mechanism in habitable zones of extrasolar planetary systems, A&A, 526, id.A98, 2011.

[2] Katz B., Dong S., Malhotra R., 2011: Long-Term Cycling of Kozai-Lidov Cycles: Extreme Eccentricities and Inclinations Excited by a Distant Eccentric Perturber, Phys. Rev. Lett., 107, id. 181101, 2011.

[3] Kozai Y.: Secular perturbations of asteroids with high inclination and eccentricity, ApJ, 67, 591-598, 1962.

[4] Libert, A.-S., Henrard, J.: Exoplanetary systems: The role of an equilibrium at high mutual inclination in shaping the global behavior of the 3-D secular planetary three-body problem, Icarus, 191, 469-485, 2007.

[5] Libert, A.-S., Tsiganis, K.: Kozai resonance in extrasolar systems, A&A, 493, 677-686, 2009.

[6] Libert, A.-S., Tsiganis, K.: Formation of '3D' multiplanet systems by dynamical disruption of multiple-resonance configurations, MNRAS, 412, 2353-2360, 2011.

[7] Libert, A.-S., Delsate, N.: Interesting dynamics at high mutual inclination in the framework of the Kozai problem with an eccentric perturber, MNRAS, 422, 2725-2736, 2012.

[8] Lidov M. L.: The evolution of orbits of artificial satellites of planets under the action of gravitational perturbations of external bodies, Planet. Space Sci., 9, 719-759, 1962.

[9] McArthur, B.E., Benedict, G.F., Barnes, R., Martioli, E., Korzennik, S., Nelan, Ed., Butler, R.P.: New observational constraints on the $\upsilon$ Andromedae system with data from the Hubble Space Telescope and Hobby-Eberly Telescope, ApJ, 715, 1203-1220, 2010.

[10] Michtchenko, T. A., Ferraz-Mello, S., Beaugé, C.: Modeling the 3-D secular planetary three-body problem. Discussion on the outer $\upsilon$ Andromedae planetary system, Icarus, 181, 555-571, 2006.

[11] Naoz S., Farr W. M., Lithwick Y., Rasio F. A., Teyssandier J.: Hot Jupiters from secular planet-planet interactions, Nature, 473, 187-189, 2011.