The Lidov-Kozai Effect – Applications in Exoplanet Research and Dynamical Astronomy

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Springer

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Cover illustration: An exoplanet seen from its moon (artist's impression). Credit: IAU/L. Calçada

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Preface

> Up to now, it nearly makes me laugh and cry of rapture when I recall this result.
>
> Vladimir Beletsky, *Six Dozens (Memoirs)*

The Lidov-Kozai effect (LKE), as any other basic astrophysical phenomena, has several "faces", or manifestations. The most familiar face, granted in Wikipedia, is the phenomenon of coupled periodic variations (which can be very large) of the inclination and eccentricity of an orbiting body, which (the variations) may take place in the presence of an inclined-enough perturber.

A face, less familiar to the general audience, but physically the generic one, is the so-called phenomenon of *ω-libration*; i.e., libration of the *argument of pericenter* of an orbiting body, when an inclined-enough perturber is present. In fact, the ω-libration is at the core of the LKE: it is just a large-amplitude ω-libration that entails the mentioned coupled variations in inclination and eccentricity.

Another concept, frequently present in the modern astrophysical literature, is the LKE as a valuable tool to explain various merger events. Indeed, if it is "necessary to merge" any gravitating binary (say a binary consisting of two ordinary stars, or black holes, or asteroids, or a star and a "hot Jupiter," or a planet and an artificial satellite, etc.) into a single object, the LKE is commonly the first one in the queue of possible explaining mechanisms that come to mind of an astrophysicist. This is just because it is rapid and no dissipation is needed—only the presence of a perturber. This third face revealed itself already in the pioneering works of Lidov (who outlined a condition for a merger of a satellite with the Earth, in particular the Moon with the Earth), and since then it has been becoming only more and more attractive for researchers.

To date, the LKE, in all of these faces, has been verified to be important in the dynamics of a lot of kinds of astrophysical objects. Historically the applications started with satellites and asteroids; now they comprise comets, trans-Neptunian objects, exoplanets, multiple stars, and many others. Perhaps, of most interest for the astronomical and astrophysical community at present is its relevance for many exoplanetary systems.

Recent years witnessed major advancements in the theory of LKE. In particular, another face of the LKE emerged: the so-called *flip* (orbit turnover) phenomenon.

It would be no exaggeration to say that at present the Lidov-Kozai effect becomes one of the most studied astrophysical effects; this is manifested, in particular, in a sharp rise of citations of the pioneer articles of Lidov and Kozai during recent years (see Fig. 1).

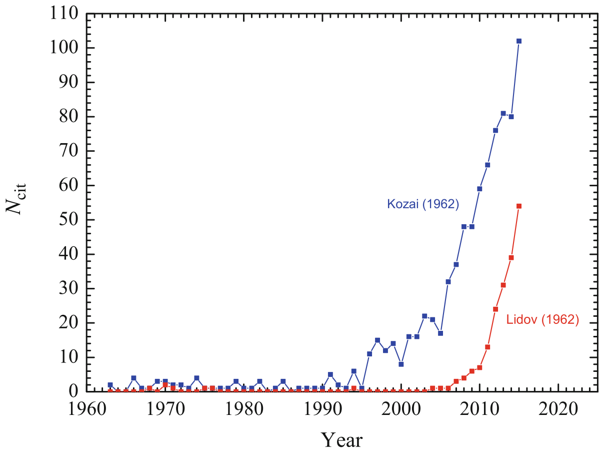

Fig. 1 The per-year number of citations of the pioneer articles of Lidov and Kozai, as a function of time, up to year 2015 inclusive (The citation data of the NASA ADS database have been used to construct the diagram)

The topics, covered in this book, include: historical background for appearance of works by Lidov and Kozai in the beginning of the 1960s (*Luna*-3, etc.); modern secular theories and integrable approximations in celestial mechanics; an overview of classical works on the Lidov-Kozai effect; modern advancements and generalizations in the Lidov-Kozai theory, in particular in the framework of noncircular and nonrestricted problems; the Lidov-Kozai mechanism explaining the observed orbital configurations of irregular satellites, explaining comets-sungrazers, and explaining the observed dynamical patterns in the asteroid and Kuiper belts; the role of the Lidov-Kozai mechanism (in particular the Lidov-Kozai migration) in sculpting exoplanetary systems; applications in stellar dynamics, such as scenarios for formation of close binary stars; and explanations for highly eccentric stellar orbits in the Galactic center.

The initial aim of this book was to provide the most full coverage of the effect's theory and applications. However, due to a large amount of the published and newly appearing advancements, it is practically impossible to fulfill this aim in detail. Therefore, apart from the provided bibliography, for further reading on the subject, I would recommend the material on the Lidov-Kozai effect in asteroidal dynamics, presented in Sects. 8.2 and 11.2.2 of the book *Modern Celestial Mechanics* by A. Morbidelli (2002), and the material on the LKE in exoplanetary dynamics presented in Sects. 7 and 8 of the review "The Long-Term Dynamical Evolution of Planetary Systems" by M. B. Davies et al. (2014).

The presented book is self-contained: only basic knowledge in mathematics and mechanics is required for understanding the material, if read from the beginning. I hope that the book can be helpful for a researcher working in astrophysics, celestial mechanics, stellar dynamics, theoretical mechanics, and space mission design, at any level (researcher, graduate student, undergraduate student), depending on the interests of the reader.

I am most grateful to Vladislav Sidorenko, Konstantin Kholshevnikov, Mikhail Vashkovyak, and Alessandro Morbidelli for valuable remarks and comments. I am especially thankful to Vladislav Sidorenko for providing rare bibliographic materials on the subject.

Saint Petersburg, Russia Ivan I. Shevchenko
2016

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