frontiers in Astronomy and Space Sciences

EDITORIAL
published: 12 June 2019
doi: 10.3389/fspas.2019.00043

Editorial: The Earth–Moon System As a Dynamical Laboratory

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Keywords: cislunar dynamics, Earth–Moon system, libration point orbits, mini-moons, lunar perturbation, asteroid retrieval, Earth–Moon–Sun

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Specialty section:
This article was submitted to Fundamental Astronomy, a section of the journal Frontiers in Astronomy and Space Sciences

Received: 09 May 2019
Accepted: 21 May 2019
Published: 12 June 2019

Citation:
Alessi EM, Masdemont J and Rossi A (2019) Editorial: The Earth–Moon System As a Dynamical Laboratory. Front. Astron. Space Sci. 6:43. doi: 10.3389/fspas.2019.00043

Editorial on the Research Topic

The Earth-Moon System as a Dynamical Laboratory

The aim of this collection is to address the dynamical challenges related to the cislunar space. The Earth–Moon environment can be considered as a laboratory of dynamics, characterized by very peculiar features. On the one hand, we can notice the high ratio between the mass of the Earth and the mass of the Moon, the lunar orbit itself, the proximity to the Sun and the chaotic behavior of the dynamics associated with small bodies (artificial and non). On the other hand, crucial experiments are taking place in the cislunar place. First, it is well-known that there exists a concrete effort to explore the lunar surface with both uncrewed and crewed missions, and to operate a Lunar Gateway. Second, the understanding of the minor bodies population in the solar system cannot overlook a deep knowledge of the minor bodies orbiting in the Earth–Moon system, paying attention in particular to the objects of a few-meters diameter size, whose characterization is still missing. Third, the gravitational attraction of the Moon exhibits a demonstrated influence on high altitude Earth' satellites, which can be crucial in the perspective of limiting the growth of artificial space debris in the long term.

All these aspects are covered within this Research Topic, which includes 1 review, 1 mini review, 1 methods, and 7 original research papers, and it is the result of the collective commitment brought by international experts in celestial mechanics and astrodynamics (both authors and referees). It is worth noticing that they come from different background—mathematics, physics, aerospace engineering- and different generations. The articles of the issue focus on theoretical and numerical developments, but also on the practical use of the given models and tools. In practice, this reflects into the design of space missions but also in the understanding of the motion of natural bodies and their possible exploitation. Moreover, many of the mathematical and operational concepts presented in the Research Topic can be extended to different planet-moon systems.

To study the motion of either a spacecraft or a natural body (in both cases assumed with a negligible mass), the authors consider as a baseline dynamical model either the Circular Restricted Three-Body Problem (CR3BP) (in Biggs et al., Cipriano et al., Lizy-Destrez et al., Jedicke et al., and Sánchez et al.) or the classical theory of perturbations applied to the Kepler problem, assuming as perturbations the Earth's oblateness and the lunar perturbations (in Colombo and Daquin et al.). The role of the Sun is accounted in Biggs et al. and Heiligers in terms of solar radiation pressure (SRP) and in Daquin et al. and Jorba-Cuscó et al. in terms of gravitational perturbation. In Valsecchi, the Hill's model is applied to find orbital solutions for the motion of the Moon itself.

Natural bodies play a central role in the reviews by Jedicke et al. and Sánchez et al. Jedicke et al. focus the analysis on the population of asteroids of a few-meter diameter size, which are temporary-captured in the Earth–Moon system. The authors address the aspects concerning the dynamical definition of these configurations, along with the possible mechanism of capture. Moreover, they explain the challenges associated with the observation of this minor body population, describing also their possible technological and commercial exploitation. This analysis is complemented by the review provided by Sánchez et al., who present the main trajectory designs envisaged so far to retrieve an asteroid either to the Earth–Moon system or to the Sun–Earth system.

The dynamics of artificial objects in the context of the CR3BP is tackled by Cipriano et al., Biggs et al., Lizy-Destrez et al., and Heiligers. Cipriano et al. present the LUMIO (LUnar Meteoroid Impact Observer) mission, which was selected for consideration for future implementation by the European Space Agency under the SysNova Competition entitled "Lunar CubeSats for Exploration." The concept is particularly interesting because it addresses the trajectory design of a Libration Point Orbit (LPO) mission in the Earth–Moon system, but also because it aims at the observation of impacts of meteoroids on the lunar farside, by detecting their impact flashes, and thus complementing the ground-based measures. LPO missions in the Earth–Moon systems are the focus also of the work by Biggs et al. and Lizy-Destrez et al. Biggs et al. show how an Extended State Observer can be used to estimate the SRP perturbation on a halo orbit, together with the possible injection errors. The main purpose is to improve the station-keeping control. Lizy-Destrez et al. face the rendez-vous problem in the CR3BP, which is a fundamental topic for the establishment and the operability of a Lunar Gateway. Finally, Heiligers shows how to compute homoclinic and heteroclinic connections between planar Lyapunov orbits in the CR3BP embedded with a constant SRP acceleration. Such dynamical corridors, opened by an *ad hoc* usage of solar sails, represent new natural transport mechanisms that can be considered in the cislunar space.

Daquin et al. and Colombo are concerned with the long-term effect of the lunisolar gravitational perturbation on Medium Earth Orbits and Highly Elliptical Orbits (HEO), respectively. While Daquin et al. concentrate on the role of chaos and its quantification, Colombo shows how to model accurately the lunisolar perturbations on HEO, and how to exploit effectively the corresponding dynamical maps for real missions.

In the last two articles, Valsecchi and Jorba-Cuscó et al., different dynamical models to work in the Earth–Moon system are proposed. Valsecchi shows the existence of periodic solutions in the Hill's problem, that respect the periodicity of the Saros. He also provides a comparison of the solutions with the NASA Jet Propulsion Laboratory ephemerides of the Moon, obtaining good consistency. A possible extension of this work is to have a simple realistic model where the three gravitational attractions—Sun, Earth, Moon—are considered, and that can be used to more accurately define the dynamical behavior of a small body orbiting in the cislunar space. With an analogous purpose, Jorba-Cuscó et al. analyze the Bicircular Problem and the Quasi-Bicircular Problem and their applicability in the neighborhood of the collinear and triangular points of the original CR3BP.

In conclusion, the Earth–Moon system is the paradigm of how a proper modeling of the dynamics and its understanding leads to an effective exploitation of the environment for scientific purposes. The various methods and applications presented in the Research Topic also show that a key role is played by the synergy that should be found among applied mathematics, space engineering, and planetary science.

AUTHOR CONTRIBUTIONS

All the authors contributed to the editorial and have critically reviewed and approved it.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.