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Author: Prof. Josep J. Masdemont
Universitat Politecnica de Catalunya (UPC), Spain

KEYNOTE: BREAKWELL LECTURE - LIBRATION POINT ORBITS: A BRIEF JOURNEY THROUGH FUNDAMENTAL DYNAMICS AND APPLICATIONS

Abstract

Libration points, also known as Lagrange points, are positions in a two-body system where the gravitational forces and the centrifugal force balance, allowing a small third object to remain stationary relative to the two larger bodies. First identified by Joseph-Louis Lagrange in 1772 in the context of the restricted three-body problem, these points represent a key milestone in the understanding of celestial mechanics.

Libration point orbits (LPO's), such as halo orbits and Lyapunov orbits, became of practical interest during the second half of the 20th century, particularly with the rise of space exploration. Their first notable application was in the planning of missions like the International Sun–Earth Explorer-3 (ISEE-3) in 1978, which was positioned near the Earth–Sun L1 point. Since then, LPOs have been used extensively for scientific and observational missions. The James Webb Space Telescope, for example, operates around the Earth–Sun L2 point to benefit from thermal and observational stability and the planned Lunar Gateway, which envisions a crewed outpost in a Near-Rectilinear Halo Orbit around the Moon.

Beyond their role in hosting space stations and observatories, the invariant manifolds associated with LPOs offer dynamical pathways in phase space that can be exploited for low-energy transfers. These structures enable efficient interplanetary trajectories and mission designs, minimizing propellant for transfers and station keeping purposes.

The mathematical richness of the problem, involving nonlinear dynamics and chaos theory, makes it a fertile ground for the development of advanced analytical and computational tools in astrodynamics.

In this lecture, we will explore the fundamental dynamical concepts associated with libration points and LPOs, including Lyapunov, halo, and various types of quasi-periodic orbits. We will summarize techniques to present practical representations and the overall structure of these orbit families as well as their transition within broader multi-body dynamical systems.

Particular emphasis will be placed on the geometrical interpretation of phase-space structures, such as invariant manifolds. We will address the associated computational challenges and highlight how these manifolds are essential for designing efficient station-keeping strategies, even with solar sail propulsion. Additionally, we will examine how their intersections enable transfer mechanisms between libration point orbits, creating low-energy pathways that exploit chaotic heteroclinic connections.

Finally, we will consider how these concepts extend to more general astronomical settings, illustrating the universality and richness of libration point dynamics in celestial mechanics.