Quasi-periodic orbits for space mission design and exploration

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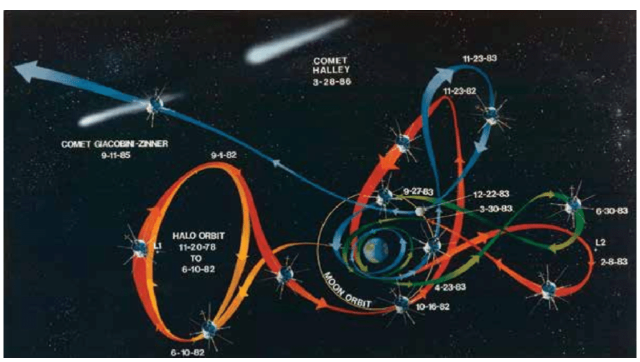
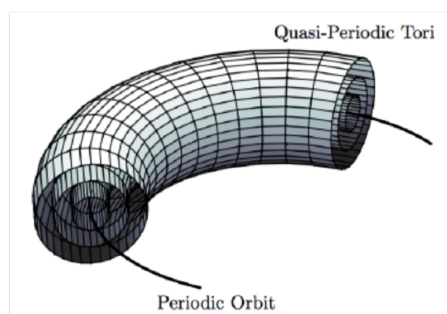
The exploitation of Dynamical Systems Theory to the study of the motion of objects in space has lead to innovative mission designs and substantial propellant savings (a). After several decades of research, however, work in the literature remain focused on families of periodic orbits that do not survive when high-fidelity models of planetary systems are taken into consideration.

In this talk, I will focus on a different class of dynamical structures know as quasi-periodic invariant tori (QPT) that populate the phase space near periodic orbits (b) and remain organized in families even when the dynamical problem is non-autonomous. As a result, quasi-periodic trajectories are better equipped for designing and operating spacecraft missions near complex dynamical environments, such as the vicinity of asteroids and planetary moons. Furthermore, they provide favorable and naturally bounded initial conditions for advanced multi-spacecraft architectures (c) that can unlock new science via scientific measurements of unprecedented temporal and spatial correlation.

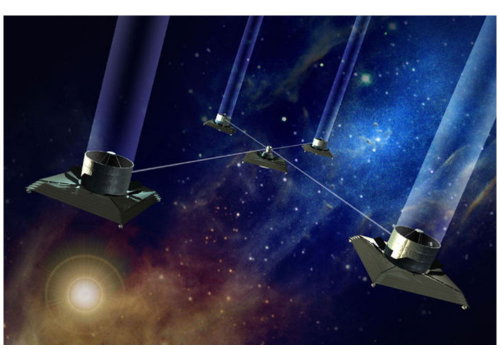
To illustrate these advantages, I will first introduce a numerical continuation procedure that calculates families of quasi-periodic trajectories through the invariant curves of stroboscopic mappings. I will then describe how the proposed methodology can be customized to account for mission-driven constraints and/or problem parameters, and finally tackle the qualitative analysis of two astrodynamics problems: motion near axisymmetric bodies, and motion near small eccentric planetary moons. The dynamical understanding of these problems is a matter of utmost importance for both Earth-bound and deep space exploration missions that rely on flight dynamics to accurately predict the evolution of satellites in space. Examples of how QPT can support these mission developments will be provided within the framework of the Martian Moons eXploration mission (d), an attempt envisaged by JAXA to retrieve pristine samples from the surface of Phobos.



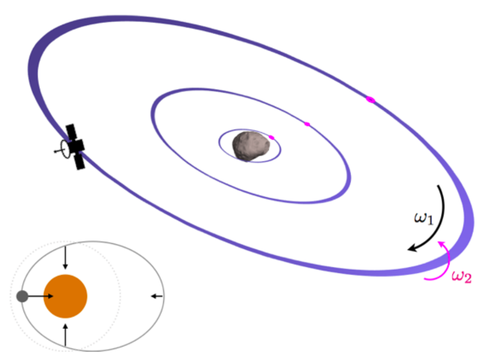
(a) NASA's ISEE-3 trajectory



(b) QPT near periodic orbits



(c) NASA's concept for terrestrial planet finding



(d) MMX trajectories around Phobos