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# TRANSFERS BETWEEN JUPITER-GANYMEDE AND JUPITER-EUROPA RESONANT TORI IN A CONCENTRIC CIRCULAR RESTRICTED 4-BODY MODEL

**Abstract**

In the planar circular restricted 3-body problem (PCRTBP), at each mean motion resonance, families of stable and unstable resonant periodic orbits exist over a range of energy levels. Of these, the unstable resonant orbits possess attached stable and unstable invariant manifolds. Owing to the Chirikov resonance-overlap criterion, it is the intersection of manifolds from different resonances that enables large scale natural transport across the system phase space. Indeed, prior studies have used the stable and unstable manifolds of resonant periodic orbits for mission design in the Jupiter-Europa (Anderson and Lo, 2011) and Saturn-Titan (Vaquero, 2013) PCRTBP systems.

A common feature of the previous research into mean motion resonances has been that the search for connections was done between different resonant orbits, but for all orbits resonant with the same moon. However, when designing multi-moon tours of planetary systems, it is necessary to transition from orbits resonant with one moon to those resonant with a different moon. And in the region where this transition must occur, the gravitational influence of both moons plays an important role, motivating the use of restricted 4-body models to study the dynamics and possible trajectories for the spacecraft.

In this paper, we investigate transfer options between Jupiter-Ganymede and Jupiter-Europa resonances using the concentric circular restricted 4-body problem to model the Jupiter-Europa-Ganymede system. As this is a periodically forced PCRTBP model, unstable resonant periodic orbits from the PCRTBP persist mostly as unstable quasi-periodic orbits (tori) in the forced system. Due to the presence of an extra forcing phase angle, the phase space as well as the resonant tori and their manifolds are of higher dimension than the corresponding objects in the PCRTBP; this makes the search for manifold intersections and close encounters much more complex than the unforced PCRTBP.

We first briefly review our previously developed results on efficient computation of tori as well as Fourier-Taylor parameterizations of their stable/unstable manifolds (Kumar et al, 2022). We then describe our methodology for using GPUs and the manifold parameterizations for finding intersections or near-intersections of torus manifolds, improving upon our previous algorithms (Kumar et al, 2021). We demonstrate a variety of low-cost transfer options from various Jupiter-Ganymede resonances to the 3:4 Jupiter-Europa resonance, and investigate the existence of zero-cost, fully ballistic transitions between them as well. These results could help inform future missions to the Jovian system.