GPU-assisted search for Jupiter-Ganymede to Jupiter-Europa resonance transfers in a restricted 4-body model

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The phenomenon of mean-motion resonance overlapping is known to be crucial for the generation of large-scale chaos and global instability in celestial systems. This instability in turn can be profitably leveraged for the purposes of low-energy space mission trajectory design. 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) planar circular restricted 3-body problem (PCRTBP) systems; resonance overlapping occurs whenever the manifolds of different resonances intersect in a heteroclinic connection.

In most prior work, including the aforementioned two studies, connections were found between orbits resonant with the same moon; however, both Jupiter and Saturn have multiple moons, each having their own set of mean motion resonances. When designing multi-moon tours of such 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, necessitating the use of at least restricted 4-body models to study the dynamics and possible trajectories for the spacecraft.

In this study, 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. In the 2 DOF PCRTBP model, families of unstable periodic orbits exist at each resonance over a range of energy levels, along with 2D stable/unstable manifolds. However, even the simplest restricted 4-body models are 2.5 DOF Hamiltonian systems; thus, unstable resonant orbits here will be 2D tori with 3D stable/unstable manifolds in a 5D phase space, precluding the use of 2D Poincaré sections for finding heteroclinic connection. Thus, new, more complex methods are used for carrying out this numerical search.

After computing the tori corresponding to Jupiter-Ganymede and Jupiter-Europa resonances, as well as their manifolds, we use GPU-assisted tools inspired by collision detection

algorithms from computer graphics to rapidly find approximate intersections between the resonant orbit manifolds; the methods presented improve significantly upon our previous work (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, which is known to be a key step on the pathway to the libration points and surface of Europa. These results could help inform future missions to the Jovian system.