Spacecraft Dynamics for Outer Planet Moons Missions: Challenges of Searching for Life at Icy Worlds

Finding life beyond the Earth within our solar system is an age old quest. The icy moons of the outer planets are among the leading candidate search sites due to the abundance of water and internal heat sources driven by strong tides. In many observed cases, water transports to the surface and beyond via cracks in the dynamically shifting ice crust. Planetary scientists and other life hunters have long dreamed of sending in-situ robots to these exotic locations. While NASA has successfully executed and is currently planning flyby missions to icy world moons, orbiters and landing missions have not yet made it past the proposal stage. In this talk, we will discuss the challenges of designing such missions, primarily from a spacecraft dynamics perspective. Multiple phases of the mission will be discussed including the heliocentric planetary tour phase, the planetary capture and moon tour phases, the moon science orbit phase and optional landing excursions. The icy world moons lie deep in the gravity well of their gas giants parents. Exploration with current technology, therefore requires the extensive use of gravity assists in lieu of large propulsive maneuvers. The design space is extraordinarily large, as typical decade-long itineraries include hundreds of gravity assists and thousands of revolutions, while traversing every level of the sun-planet-moon solar system hierarchy. The open dynamical questions include which body to flyby and when, and where should the precious reserve of propellant be expelled. Intense radiation and perturbations due to third-body and non-spherical gravity make for a hostile environment near the planetary moons. Such constraints require hard limitations on radiation exposure and careful exploitation of the flow and equilibria of the natural dynamical system. Several recent and ongoing advances in the design of such missions will be discussed, including new algorithms to assess reachability, to solve the pathfinding combinatorial optimization problem, to locally optimize promising solutions in high fidelity, to find long-life science orbits, to solve and archive databases of periodic orbits, to identify feasible landing options, and to automate the whole process.