Enabling and Enhancing Planetary Exploration via Trajectory Design

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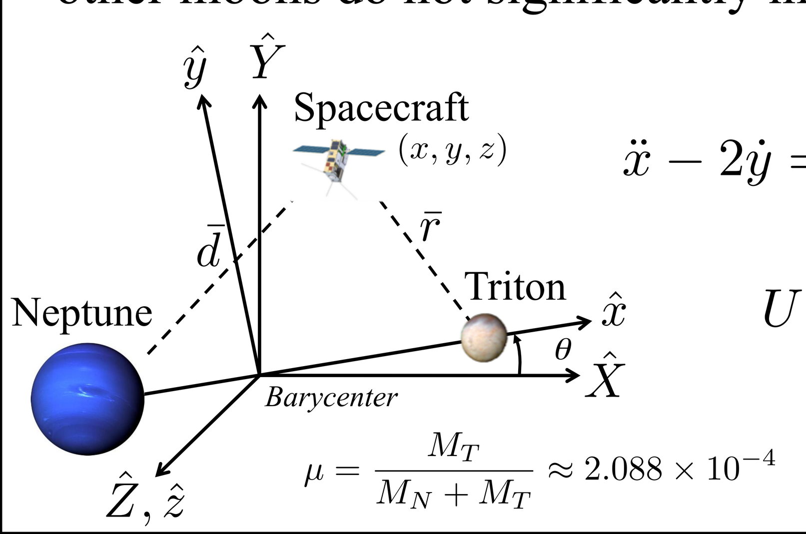
Motivation and Overview

- Planetary exploration necessitates design of robust, feasible trajectories for individual spacecraft and/or secondary payloads
- Outer planetary systems consist of multiple bodies, significantly influencing the motion of a spacecraft
- Chaotic gravitational dynamics in multi-body systems are efficiently studied using dynamical systems theory
- Trajectory design strategies can be leveraged to:
  - Enhance scientific return through mission orbit selection, reduced propellant requirements, lifetime extension
  - Identify feasible low-cost transfers subject to constraints or hardware limitations, or analyze natural satellite transit
  - Support concept development and design space exploration
  - Enable secondary payloads to enhance mission objectives
- Consider Neptune-Triton-spacecraft three-body problem

Circular Restricted Three-Body Problem

Employ approximate dynamical model to identify dominant motions for rapid, informed trajectory design

Assume Neptune, Triton are point masses on circular orbits, other moons do not significantly influence spacecraft motion



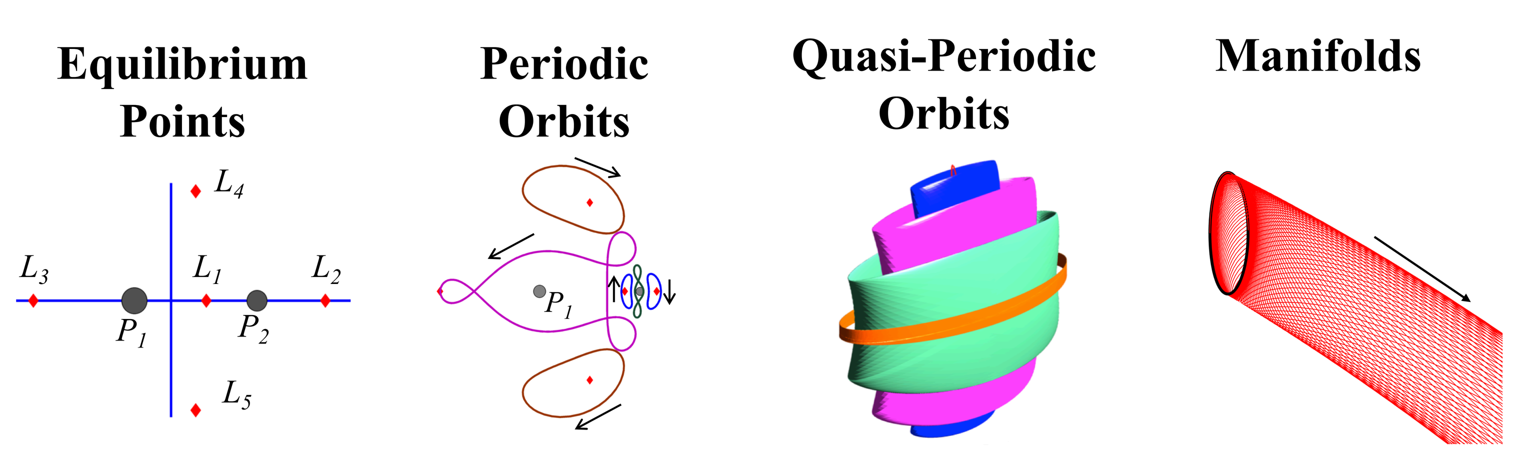
$$\ddot{x} - 2\dot{y} = \frac{\partial U}{\partial x} \qquad \ddot{y} + 2\dot{x} = \frac{\partial U}{\partial y} \qquad \ddot{z} = \frac{\partial U}{\partial z}$$

$$U = \frac{1}{2}(x^2 + y^2) + \frac{1-\mu}{r} + \frac{\mu}{d}$$

$$C_J = 2U - v^2$$

Fundamental Dynamical Structures

Dynamical systems techniques support computation of structures that guide the flow in multi-body systems

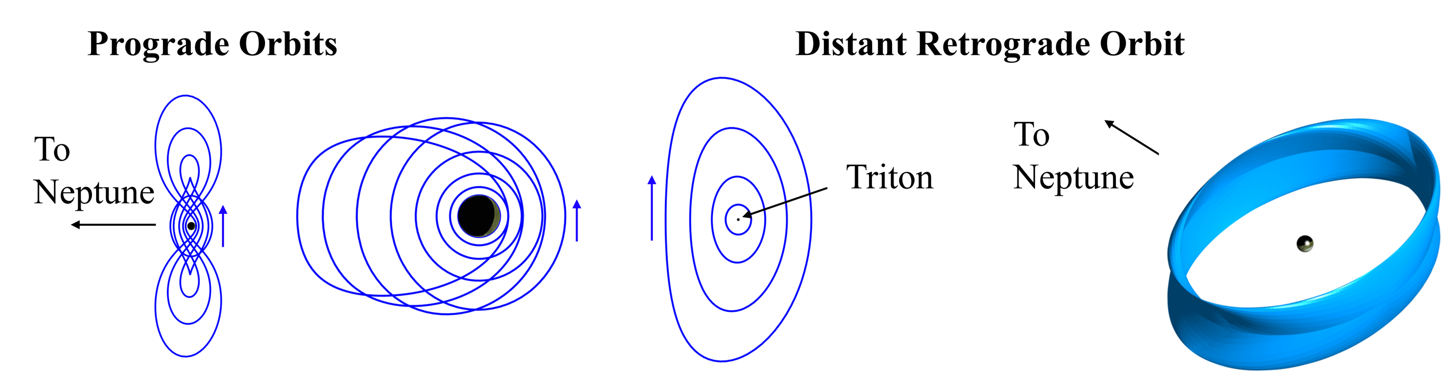


Orbits in Neptune-Triton System

- Bounded motions support identification of mission orbits to achieve scientific objectives subject to mission constraints, design system tours and identify robust low-cost transfers
- Approximately retained in higher-fidelity models

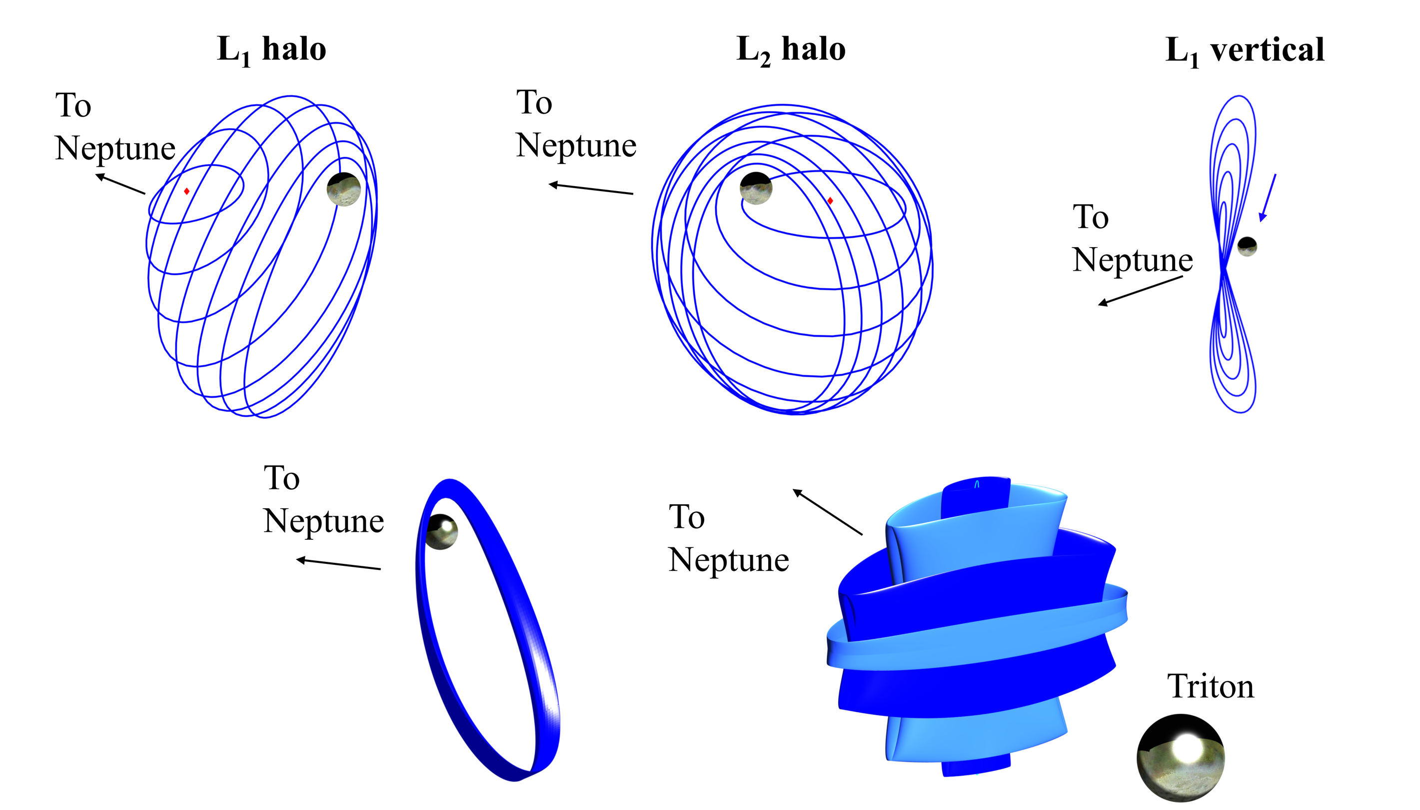
Triton-Centered Orbits

Support extended observations, measurements of Triton



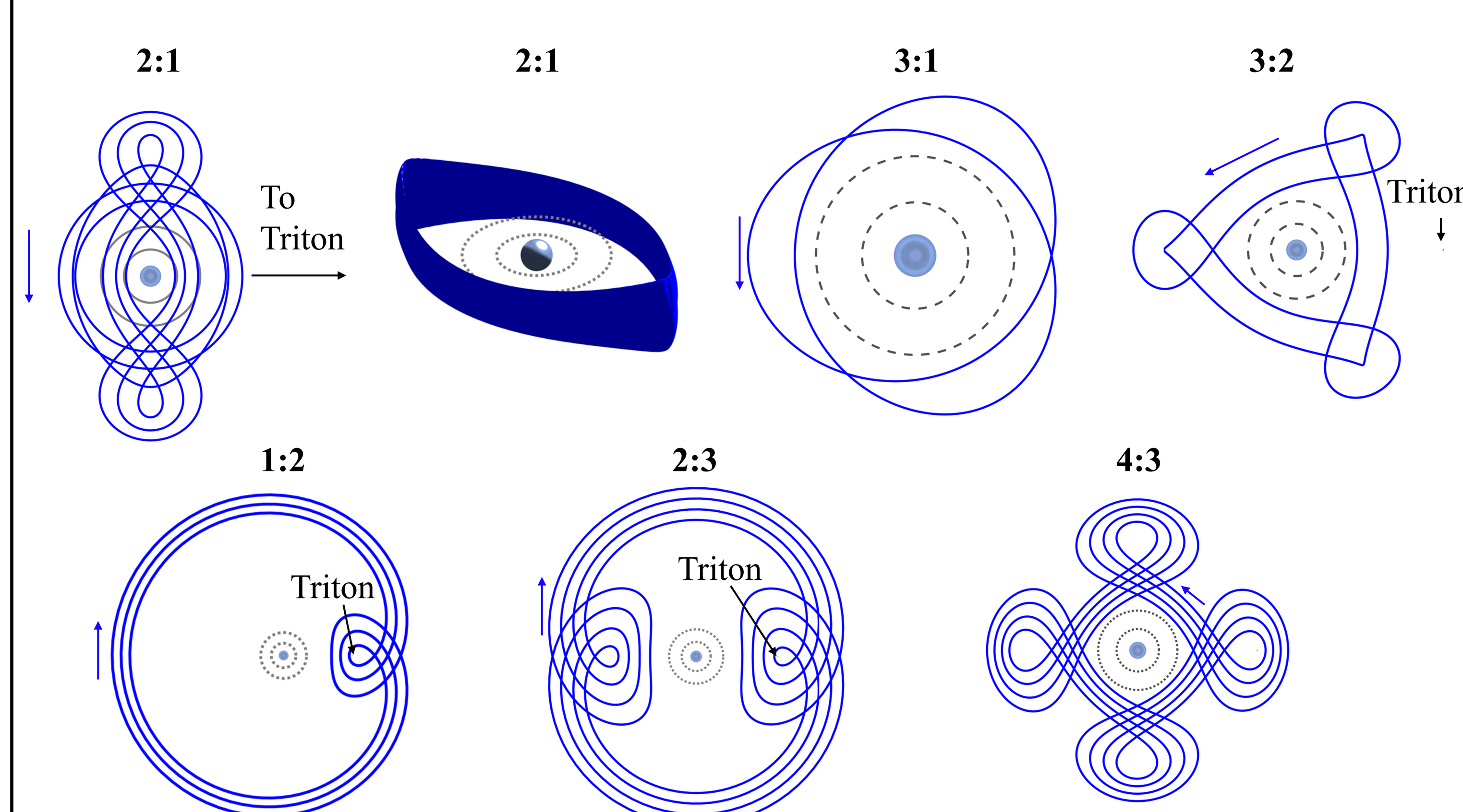
Libration Point Orbits

Fixed relative configuration in system, useful stability properties, can offer view of Triton's poles



Resonant Orbits

Enable tours and measurements within system

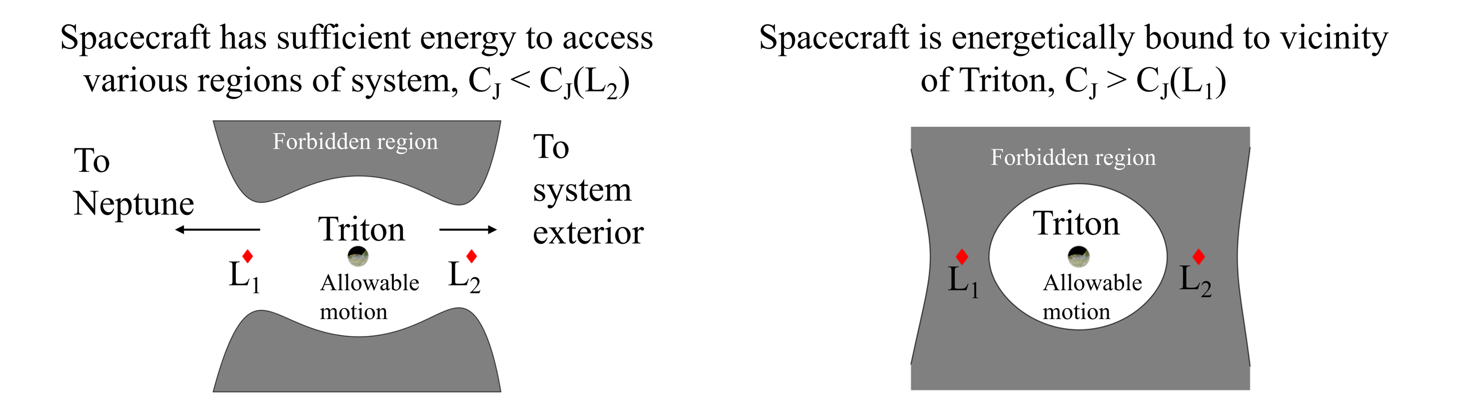


Valuable Insights During Trajectory Design

Dynamical systems approach supplies useful insight during concept development and mission planning

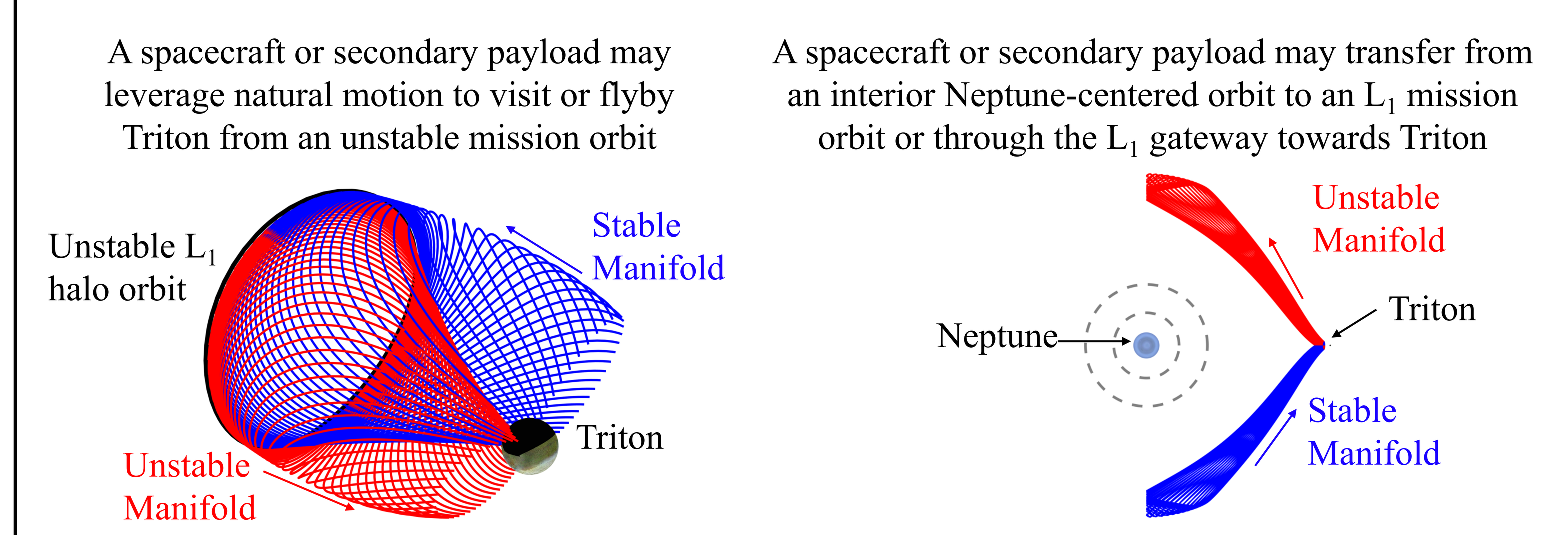
Itinerary Planning

Constant of motion and zero velocity curves in autonomous approximation provides preliminary assessment of regions of accessibility, minimal maneuver requirements



Transit Pathways

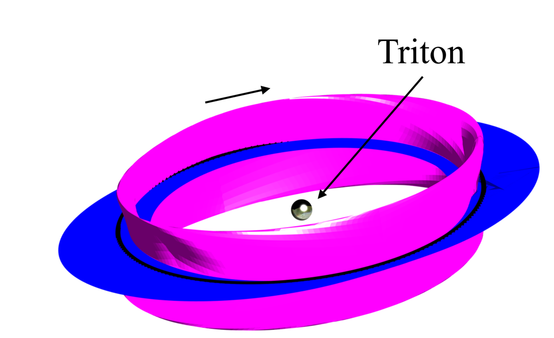
Manifolds of unstable orbits guide transit within system, support robust and low-cost transfer design



Orbit Maintenance and Accessibility

Orbit stability enables prediction of station-keeping needs and guides preliminary assessment of reachability of regions in support of achieving various scientific objectives

Orbits with only oscillatory modes produce families of quasi-periodic orbits and do not possess natural stable or unstable manifolds. May require less station-keeping, but will require maneuvers for orbit insertion



Persistence in Higher-Fidelity Models

Analysis in autonomous dynamical model provides rapid and useful insight into trajectories that are approximately retained in higher-fidelity models, capturing point-mass ephemeris gravity of various bodies, oblateness, higher-order gravitational models etc.