**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.

\[
\begin{align*}
\ddot{x} - 2\dot{y} &= \frac{\partial U}{\partial x}, & \ddot{y} + 2\dot{x} &= \frac{\partial U}{\partial y}, & \ddot{z} &= \frac{\partial U}{\partial z},\\
U &= \frac{1}{2} (x^2 + y^2) + \frac{1 - \mu}{r} + \frac{\mu}{d}, & C_f &= 2U - v^2.
\end{align*}
\]

**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.

**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.