**Asteroid Impact**

**Technological Challenges**

- Low-thrust propulsion systems offer innovative options
- Electric propulsion offers much greater efficiency
- Allows for greater velocity change with a reduced mass cost
- Key component for long duration missions with frequent thrusting

**Optimal trajectory design is complicated**

- Highly nonlinear and chaotic dynamics requires intuition by designer
- Using low-thrust propulsion adds additional difficulties in accurately capturing the small perturbations

**Astromody trajectory design typically uses direct optimal control**

- Large nonlinear programming problem inherently approximates the true optimal solution
- High dimensionality of the solution makes it extremely computationally intensive

**Gravitational Modeling**

- Asteroids are extended bodies - not point masses
- Gravity is the key force in orbital mechanics
- An accurate representation of gravity is critical to accurate and realistic analysis

**Spherical Harmonic approach is popular but not ideal**

- Model is only valid outside of circumscribing sphere
- Composed of an infinite series - always results in an approximation
- Model will diverge when close to the surface and is not ideal for landing missions

**Polyhedron Gravitational model used to represent the asteroid**

- Gravity is a function of the shape model
- Globally valid and closed-form analytical solution for gravity
- Exact potential assumes a constant density assumption
- Accuracy is only dependent on the shape

**Optimal Control is used to calculate the reachability set**

- Thruster represents a current electric propulsion ≈ 600 mN
- Combining multiple iterations of the reachability computation allows for general transfers
- Combining four iterations of the reachability set
- Each iteration of the reachability set enlarges the achievable states
- We choose a direction on the reachability set which lies closest to the target

**Reachability on the Poincaré section**

- Poincaré map is a useful tool in the analysis of dynamical systems
- Enables visualization of complicated systems - intrinsic structure becomes visible to the engineer
- Rather than considering the entire state (6D position and velocity) we simply investigate the intersections with a lower dimensional space
- This reduces the complexity of analyzing the dynamics and allows for visualization of highly complex dynamic interactions

**A periodic orbit on the Poincaré map is identified by fixed points \( x_i \)**

- Using the low-thrust propulsion system of the spacecraft we can enlarge the space that is achievable

**Reachability Set - the set of states which are attainable subject to the constraints of the system**

- The thruster of the spacecraft is used to design a transfer trajectory by repeatedly maximizing the reachability set
- Thruster allows us to depart from the fixed orbit and intersect at a new state \( x_i \)

**Reachability Set is computed on the Poincaré section and provides additional insight**

- Spacecraft can only move to areas inside of the reachable set

**Conclusions**

- Demonstrate a transfer around an asteroid using multiple reachability sets
- Each reachable set moves the spacecraft towards the target
- Alleviates the need for selecting accurate initial guesses
- Automatically gain insight into the feasible region of motion for the spacecraft
- Future work will extend this principle to landing trajectories on asteroids
- Irregular shape of asteroids requires innovative techniques for controlling both position and orientation
- Nonlinear control allows for the exploitation of the coupled dynamics
- Complex dynamics requires accurate integration schemes - Variational Integrators
- Successful extension of previous work in the circular restricted three-body problem