Trajectory Design Methods to Enable Exploration of Pluto and its Moons

(Spontaneous R&TD)

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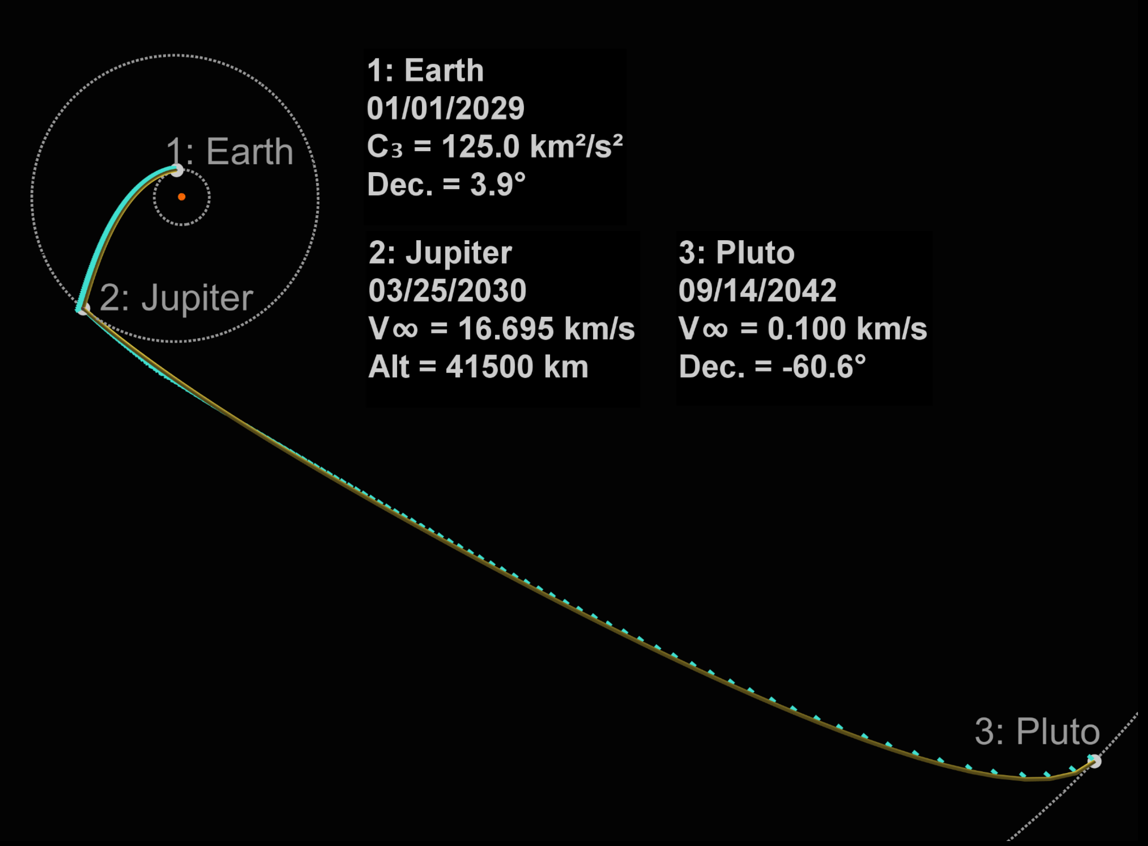
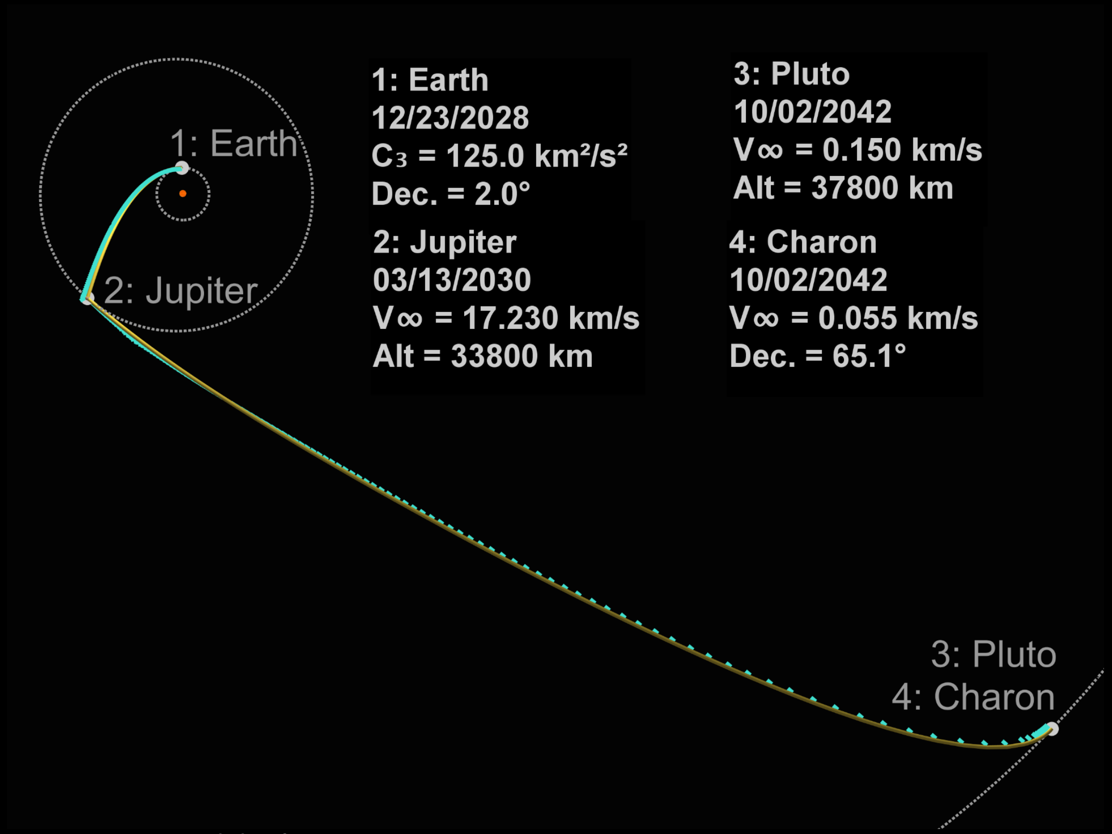
Motivations

- The New Horizons spacecraft made a brief flyby of Pluto on July 14, 2015 followed by an encounter with a KBO on January 1, 2019.
- Although the science return added significantly to our knowledge of outer solar system objects, a more detailed and comprehensive study of Trans-Neptunian Objects (TNO) and Kuiper Belt Objects (KBO) requires extended proximity operations not achievable by a flyby mission like New Horizons.
- The recently demonstrated *Kilopower* fission power system (technology being developed by NASA's Space Technology Mission Directorate for a surface power version of *Kilopower*,) is potentially capable to provide up to 10,000 Watts.
- We were interested in testing *Kilopower* system for our problem.

Mission Description, Requirements, Design Procedure

- MISSION TO PLUTO’S SYSTEM FOR AN ORBITER AND PLUTO’S MOONS TOUR
- **LAUNCH VEHICLE**: SLS BLOCK 1B
- **LAUNCH DATE** : LATE 2020’S
- **PROPULSION SYSTEM**: NUCLEAR ELECTRIC KNOWN AS *KILOPOWER (CAPABLE OF GENERATING 10,000 WATTS)*
- **ENGINE**: 1X NEXT ISP
- Mission design procedure will be explained within the next few slides.





Broad search of gravity assist trajectories to Pluto

- Patched-conics in Star
- Search flyby combos, launch years, flight times (Earth-Jupiter-Pluto, late 2020's, max tof = 13 yr)

- Initial trajectory to Pluto center
  - Solar gravity only
- Launch SLS 4610kg, arrive 2500 kg
- 10 kW NEP, 1x NEXT thruster
- Low speed arrival to set up capture phase

- Add Charon capture
  - Charon pos + Pluto V_∞ specify Charon V_∞
  - Charon V_∞ + B-plane angle specify Charon periapsis vector
  - Conic initial guess

- Minimize arrival energy of end-to-end trajectory
  - Sun, Pluto, and Charon gravity
  - Charon phase free to decouple from Pluto date
  - Capture date the re-adjusted in multiples of Charon's period (6.4 d) to re-enforce phase and reduce flight time

Optimize rendezvous with Pluto

- Initial guess from Star output
- Patched-conics in *ZoSo low thrust model*

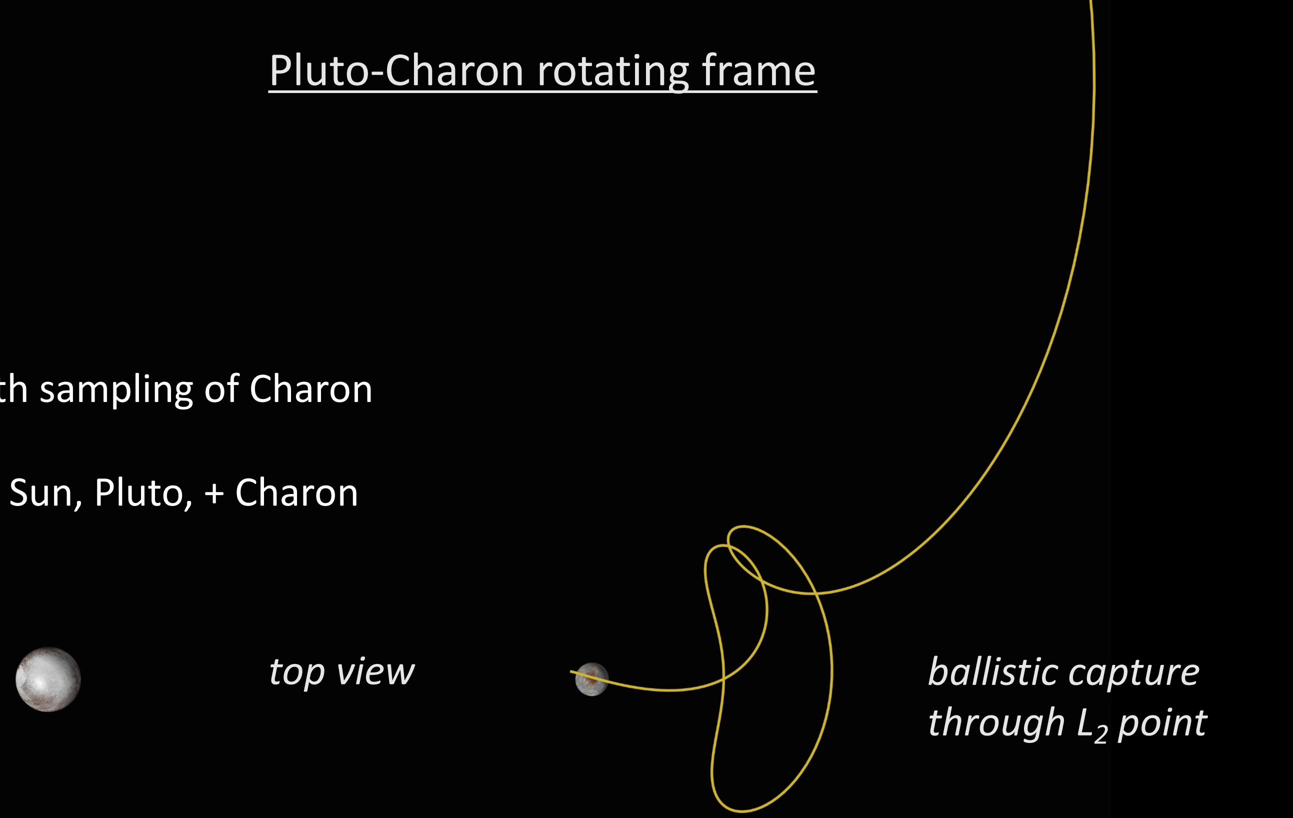
  Max final mass / min flight time

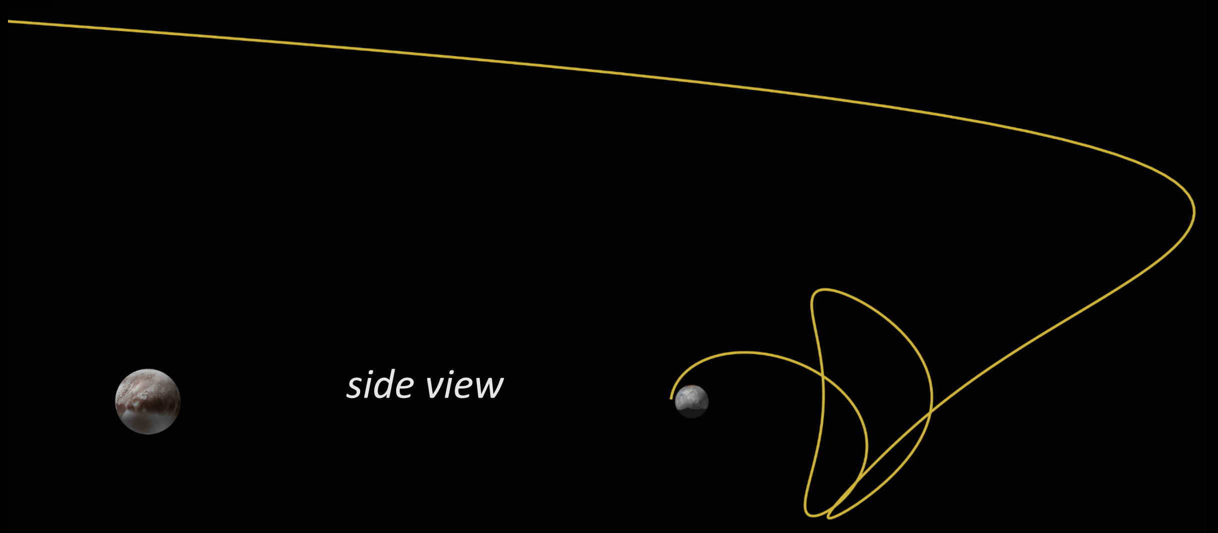
Add Charon capture at Pluto

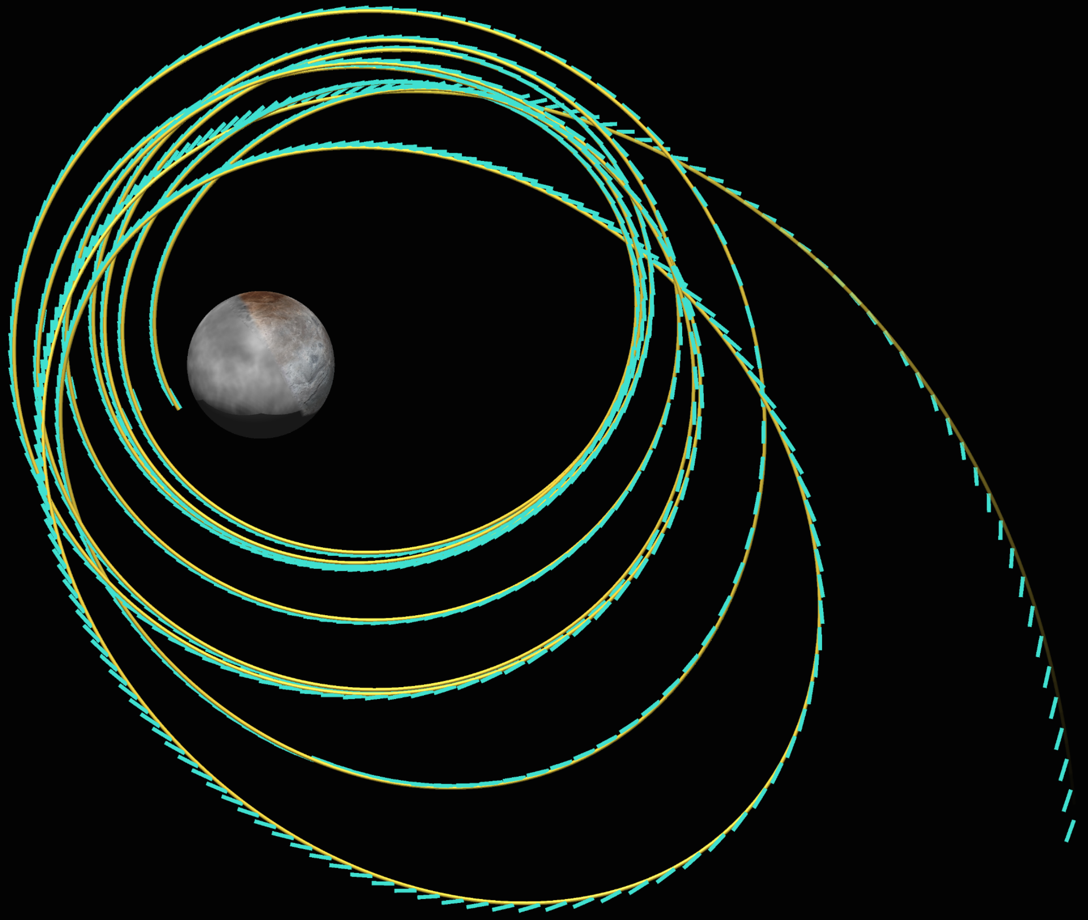
- Conic initial guess from Pluto V_∞ with sampling of Charon phase and B-plane angle
- Minimize energy w.r.t. Charon using Sun, Pluto, + Charon gravity in *ZoSo multi-body model*

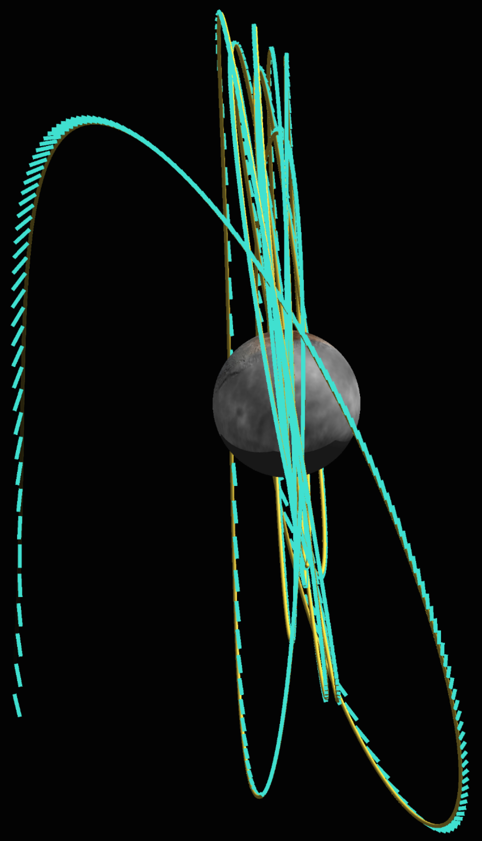
- View above ecliptic frame
- Pluto-Charon Barycenter
- 30-day coast enforced prior to Charon periapsis

Pluto-Charon rotating frame



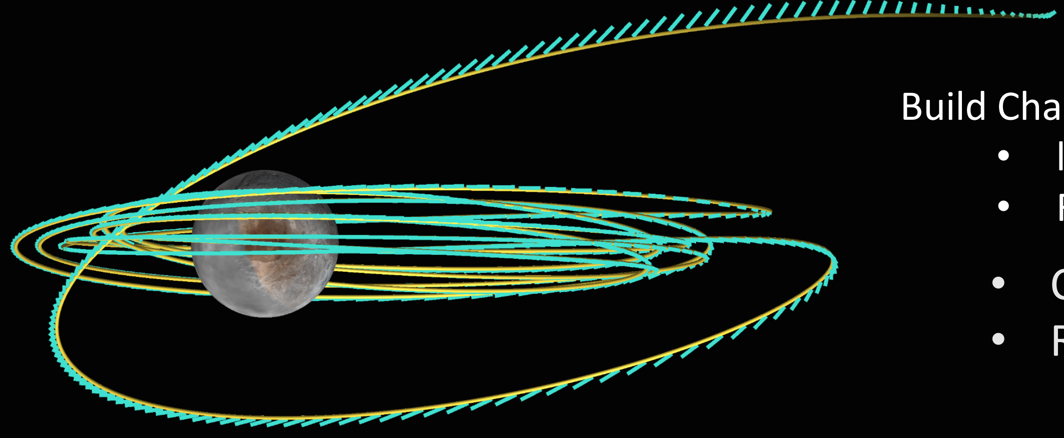






Polar spiral in Inertial frame

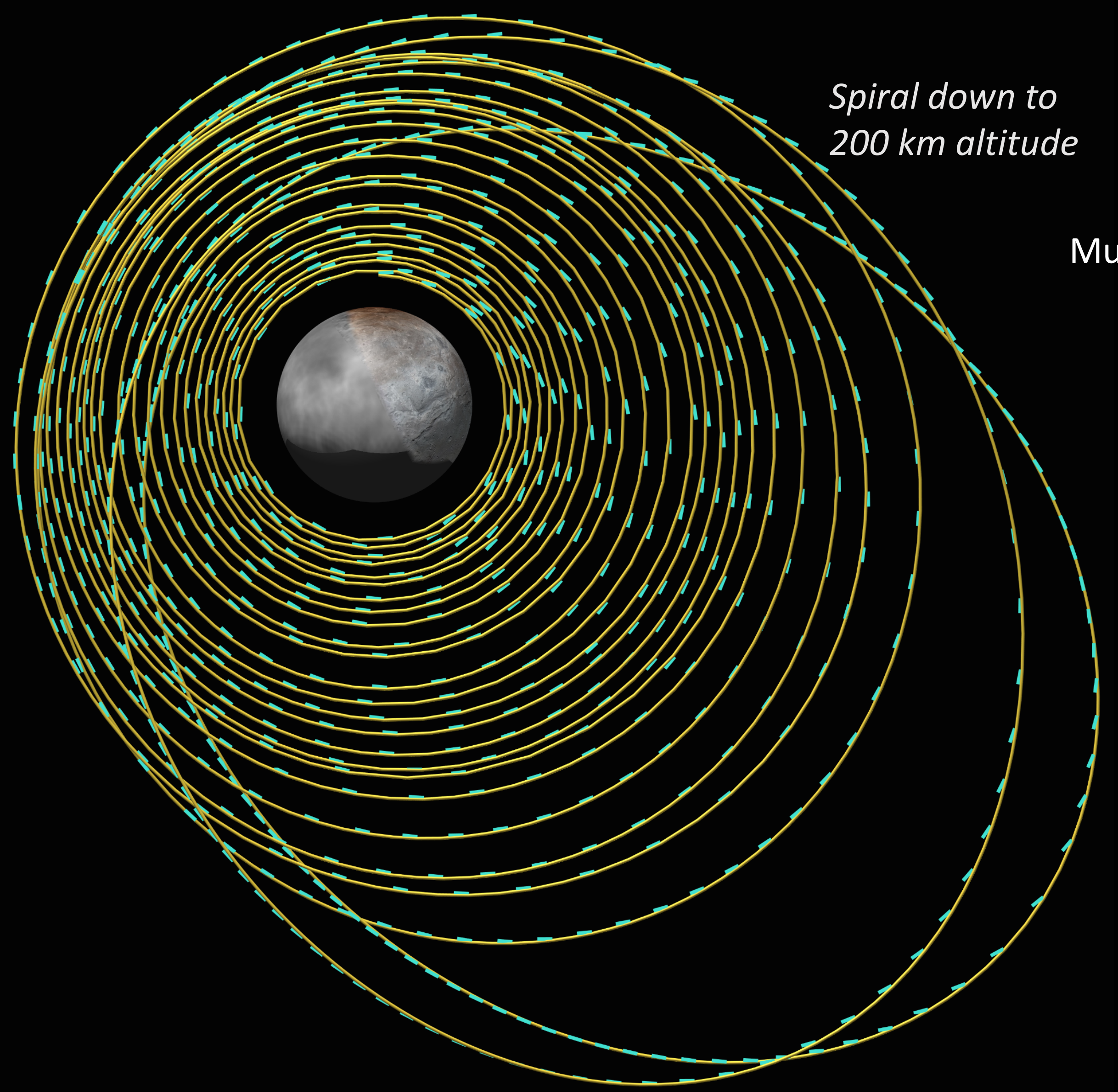
rotating frame



Build Charon-capture spiral by adding conic orbits and reoptimize

- low-thrust, multi-body, and gravity harmonics
- Repeat until Charon dominates dynamics

- Conic orbits are added one (or more) at a time
- Reoptimize in full model to minimize orbital period

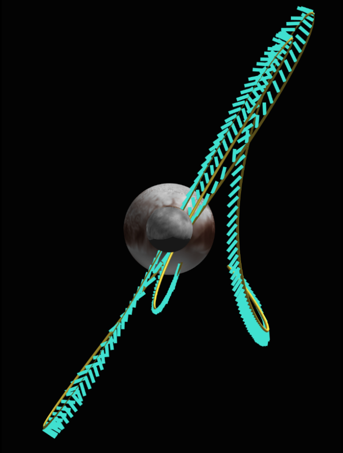


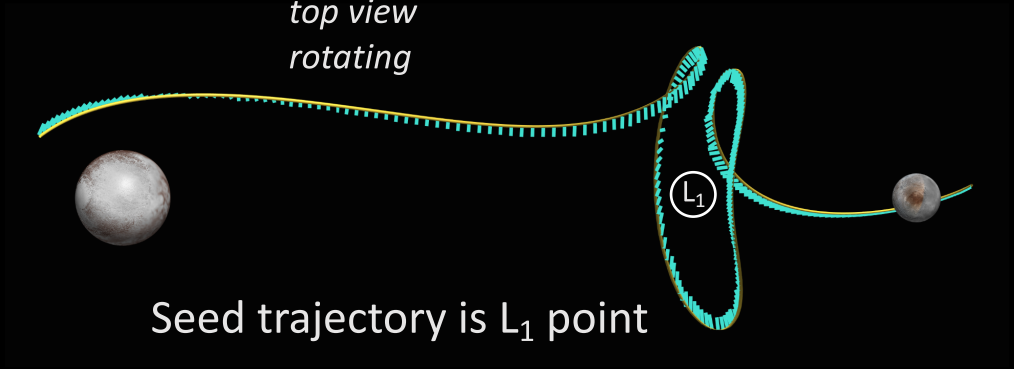
Multi-rev spiral to target science orbit

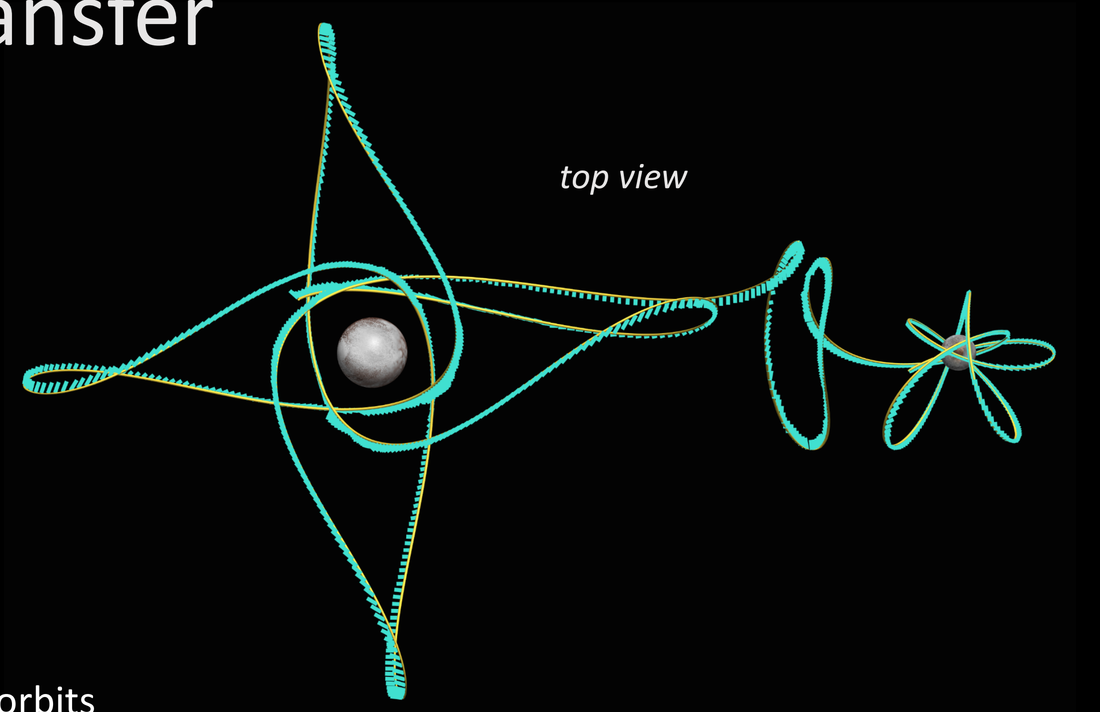
- Orbital averaging in *ZoSo spiral model*
- Minimize target mismatch then minimize flight time with constrained target

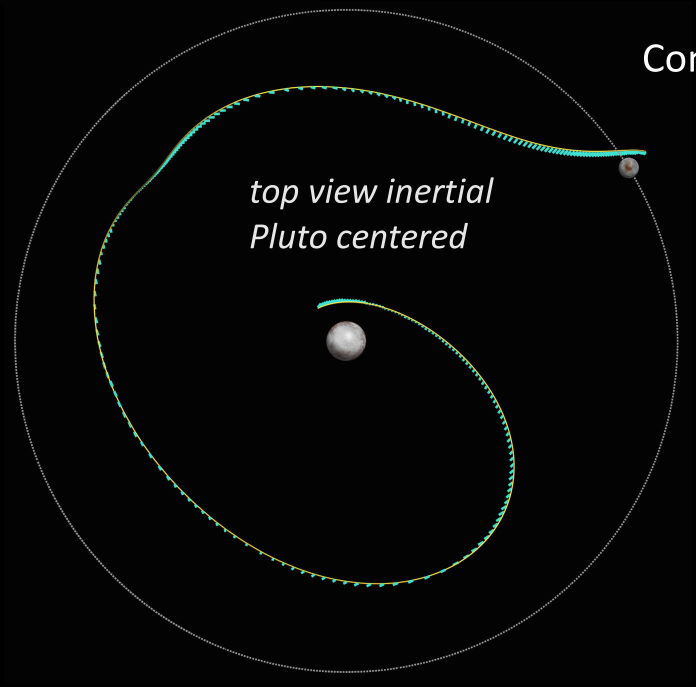
- Inner spiral modeled with averaged dynamics
- Time is “warped” to mimic multiple orbits per time step

Charon to Pluto Transfer



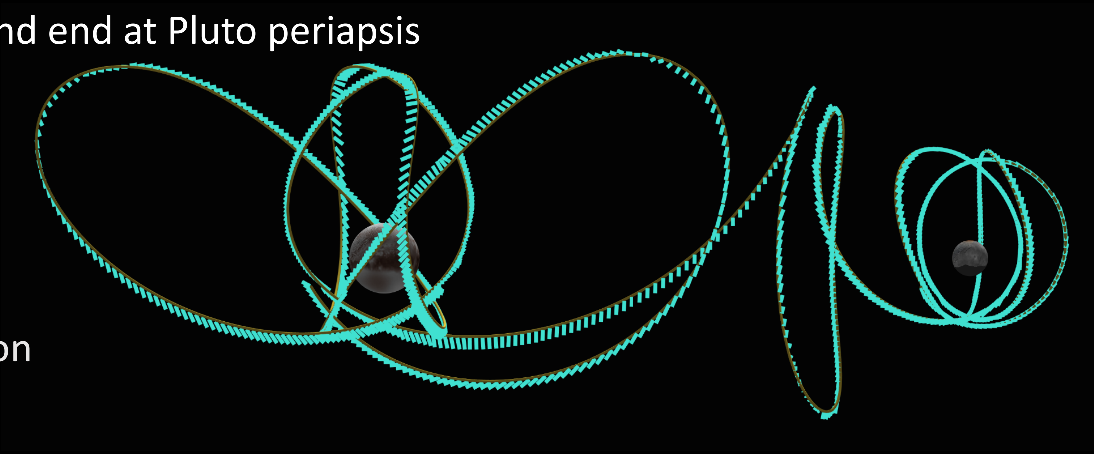




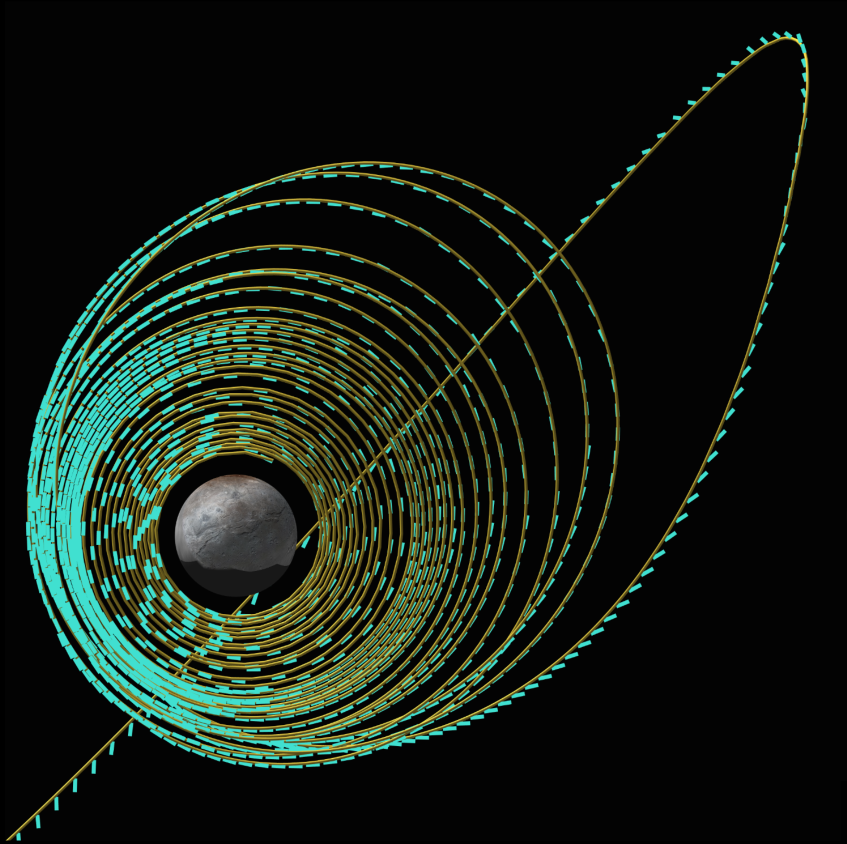


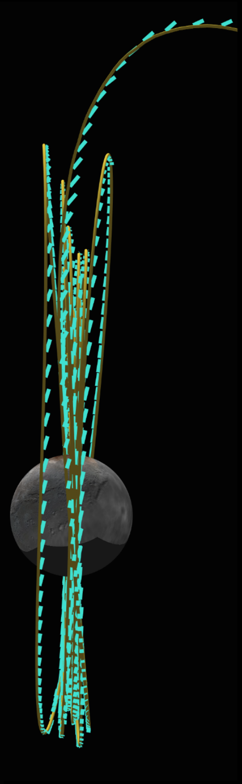
Connect Charon to Pluto

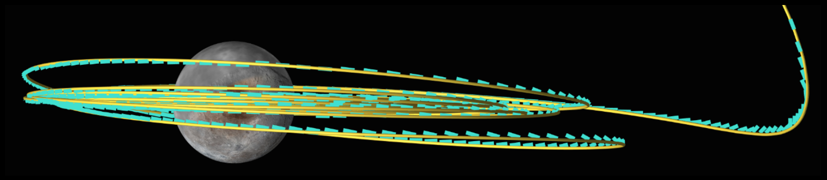
- Initial guess is L_1 point for 1+ Charon orbits
- Minimize sum of C3 (energy) w.r.t. Charon and Pluto with keep out radius
- Constrain begin at Charon periapsis and end at Pluto periapsis



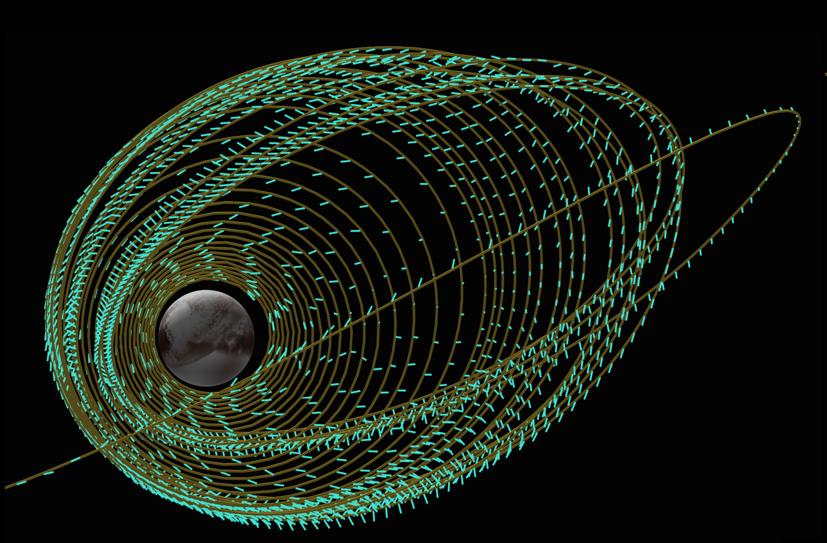
- Begin at L1 point and minimize energy beginning at Charon periapsis and ending at Pluto periapsis
- Add orbits on both ends to build Charon escape and Pluto capture

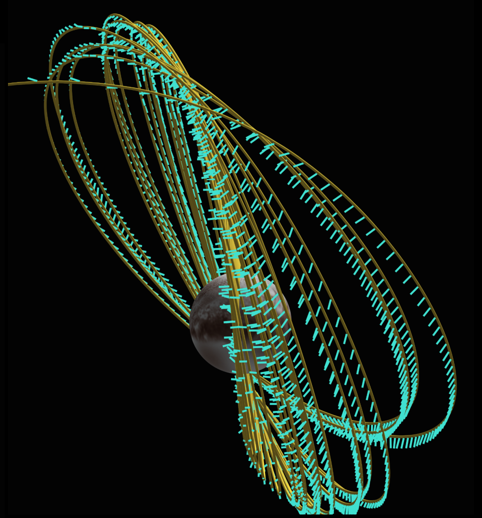


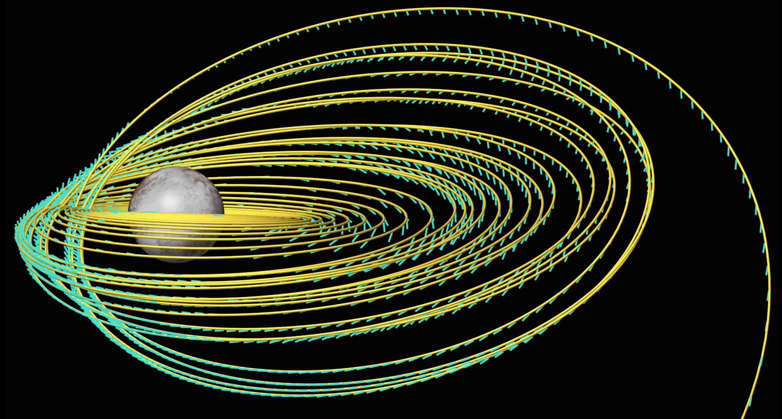




Charon escape spiral







Pluto capture spiral

Multi-rev spiral to target science orbits

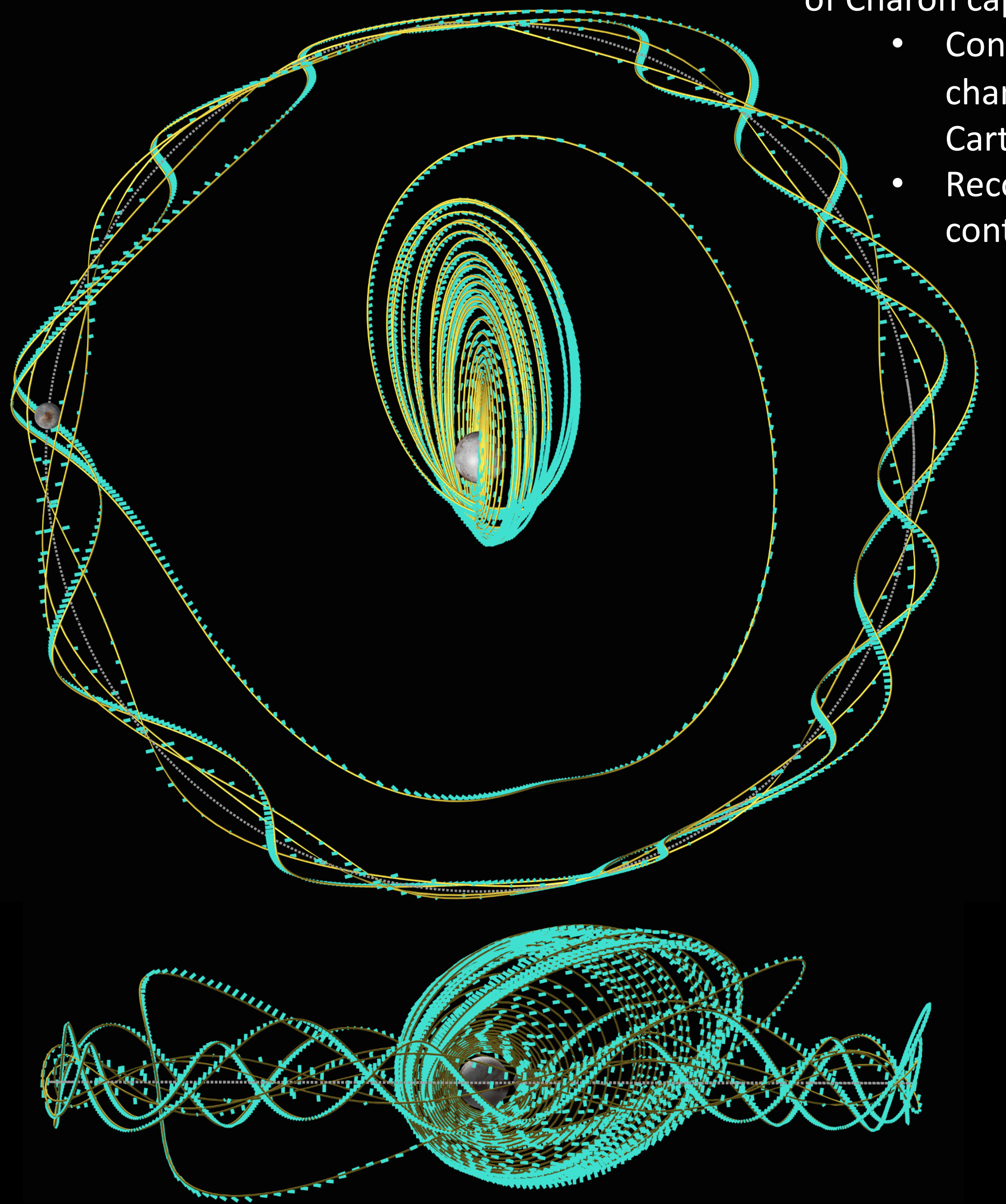
- Orbital averaging in *ZoSo spiral model*
- Minimize target mismatch then minimize flight time with constrained target
- Build Pluto first then optimize Charon escape backwards to science orbit

- Inner spirals modeled with averaged dynamics
- Time is “warped” to mimic multiple orbits per time step

Adjust begin of escape to match end of Charon capture from Step 6

- Convert to rotating frame, change time, rotate back to Cartesian
- Reconverge to enforce continuity at science orbit

Pluto centered inertial



Charon centered inertial