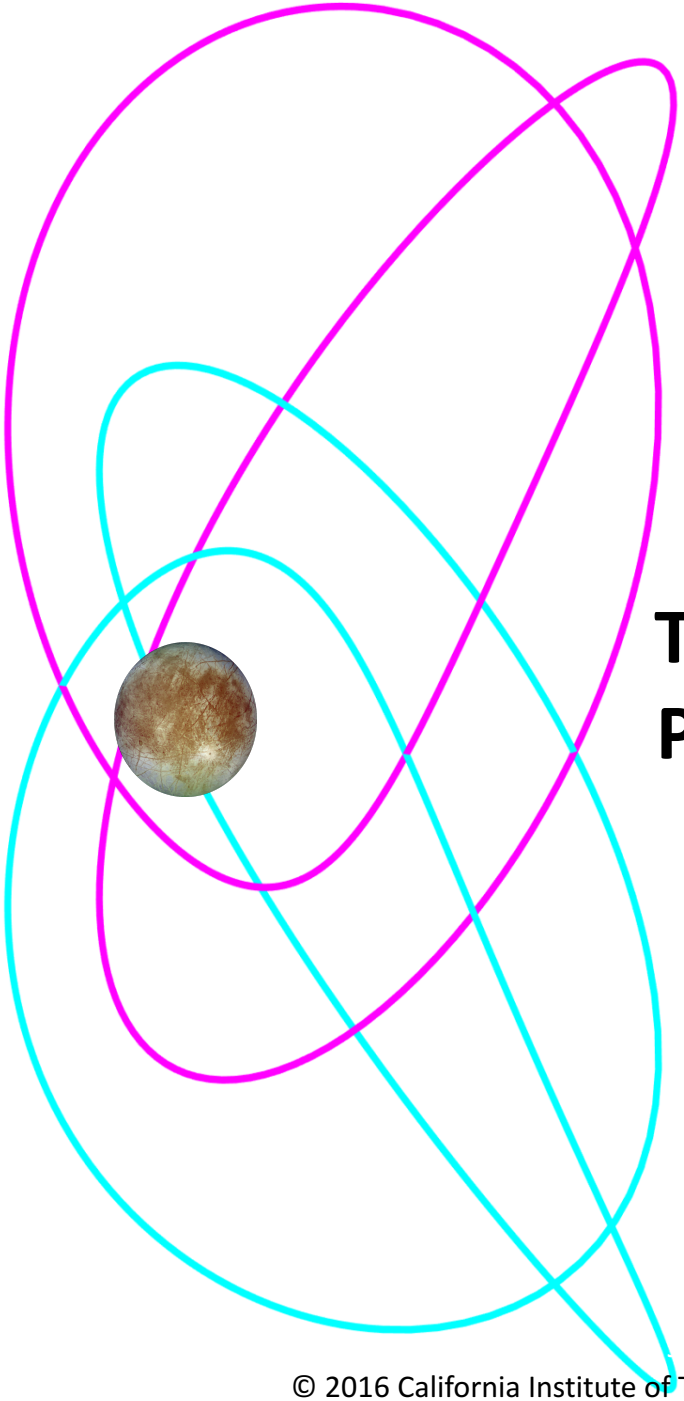

Poincare

A Multi-Body, Multi-System Trajectory Design Tool in MONTE Part 1: The Science Orbit Catalog

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MONTE U Seminar October 26th 2016

Jet Propulsion Laboratory
California Institute of Technology

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A Multi-Body Multi-System Trajectory Design Tool in MONTE

What Poincare is

- Trajectory design tool based on a catalog of three-body science orbits and a differential corrector to compute connecting transfer arcs between orbits in multi-body systems
- Poincare attempts to offer a unified approach, i.e., an "all-in-one" integrated search within one interface and setup in MONTE
- MONTE Tier-2 code with complete set of unit tests and formal documentation
- Poincare consists of two major modules delivered in two phases:
  - *Science Orbit Design Tool* to facilitate rapid and well-informed decisions regarding the selection of periodic orbits for a particular mission and enable the simultaneous study of various orbit alternatives
  - *Reference Trajectory Design Tool* to calculate optimal transfers from a departure orbit to a science orbit via dynamical systems structures resulting in an end-to-end reference trajectory
- Focused on low energy trajectories
- Simple, modular design, easy to maintain, update, and expand

Phase I: The Orbital Catalog

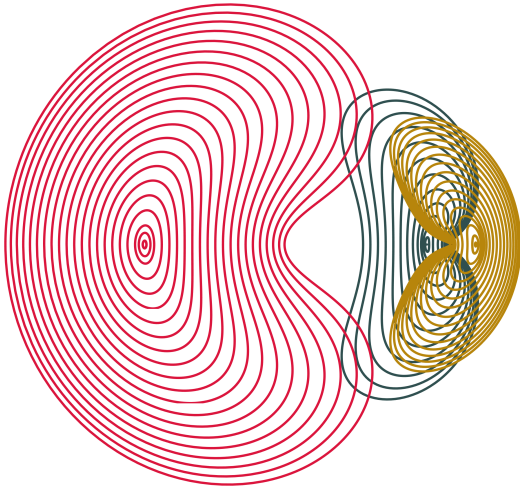
Libration Point Orbits	P2-Centered Orbits	Resonant Orbits	3B Systems	Stored Parameters
L_1, L_2, L_3 Lyapunov	Distant Retrograde Orbits	1:1 resonance	Sun-Earth	primary/secondary body
L_1, L_2, L_3 Halo	Distant Prograde Orbits	1:2 resonance	Earth-Moon	gravitational constant mu
L_1, L_2, L_3 Vertical	Low Prograde Orbits	1:3 resonance	Saturn-Titan	initial state
L_1, L_2, L_3 Axial		1:4 resonance	Jupiter-Europa	period
L_4, L_5 Short Period		2:1 resonance		jacobi constant
L_4, L_5 Long Period		2:3 resonance		eigenvalues
L_4, L_5 Vertical		3:1 resonance		stability index $\nu = \frac{1}{2}\left(\lambda_{max} + \frac{1}{\lambda_{max}}\right)$
L_4, L_5 Axial		3:2 resonance		
Butterfly		3:4 resonance		number of patch points
Dragonfly		4:1 resonance		diff corrector constraints
		4:3 resonance		propagation error and tol

How orbital families are calculated

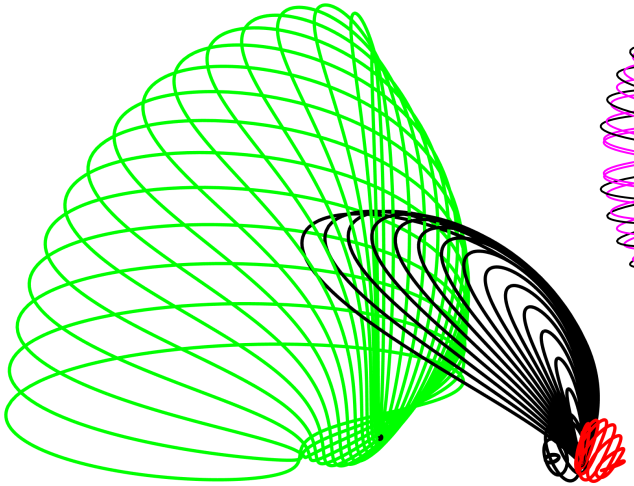
- Multiple shooting differential corrections algorithm based on a <u>generalized constraint and free variable method</u> within pseudo-arclength continuation scheme
- One algorithm for all orbits – easy to implement and maintain
- A priori information (direction of growth, symmetry, number of crossings) not needed
- 36 families per three-body system, over 650,000 orbits currently stored in catalog
- ‘New’ families of periodic orbits already found; easy to add future families to catalog

Libration Point Orbits

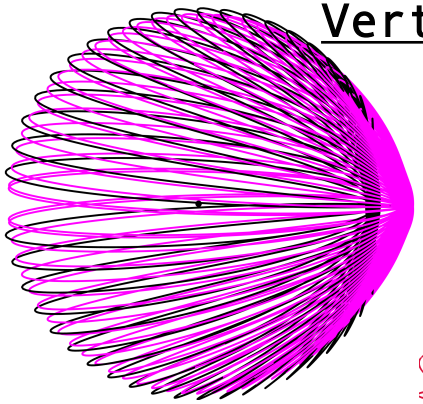
Lyapunov



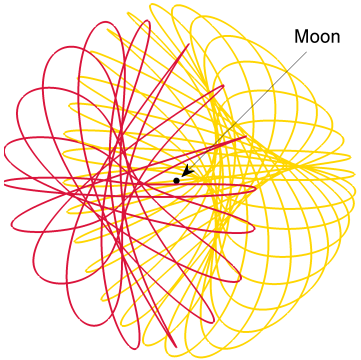
Halo



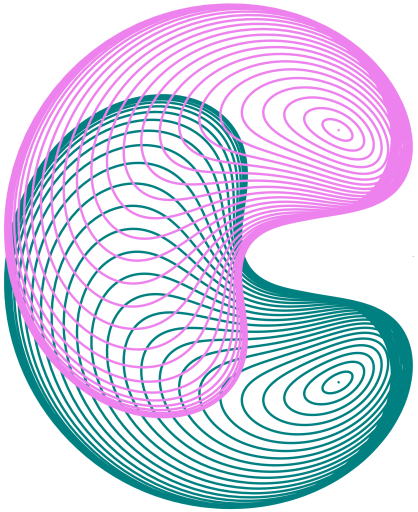
Vertical



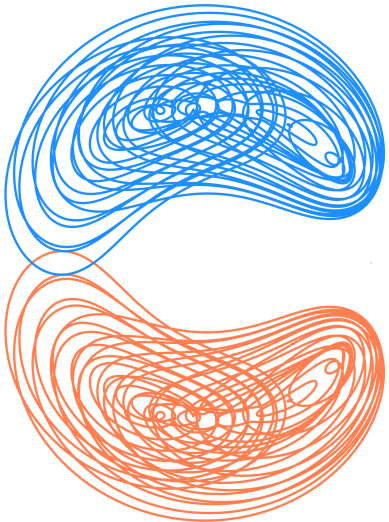
Axial



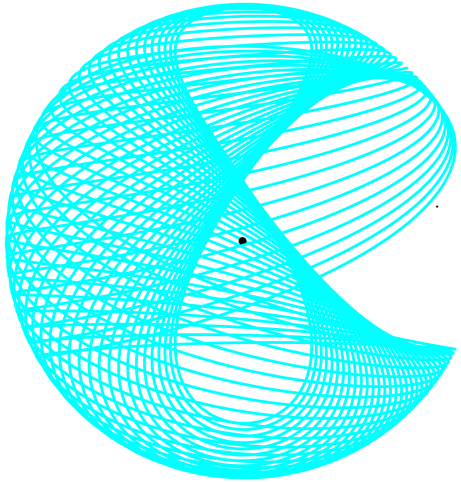
Short Period



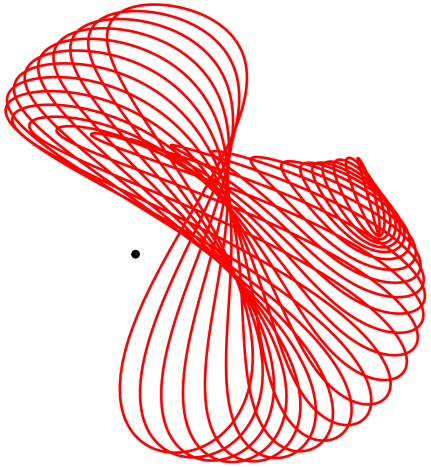
Long Period



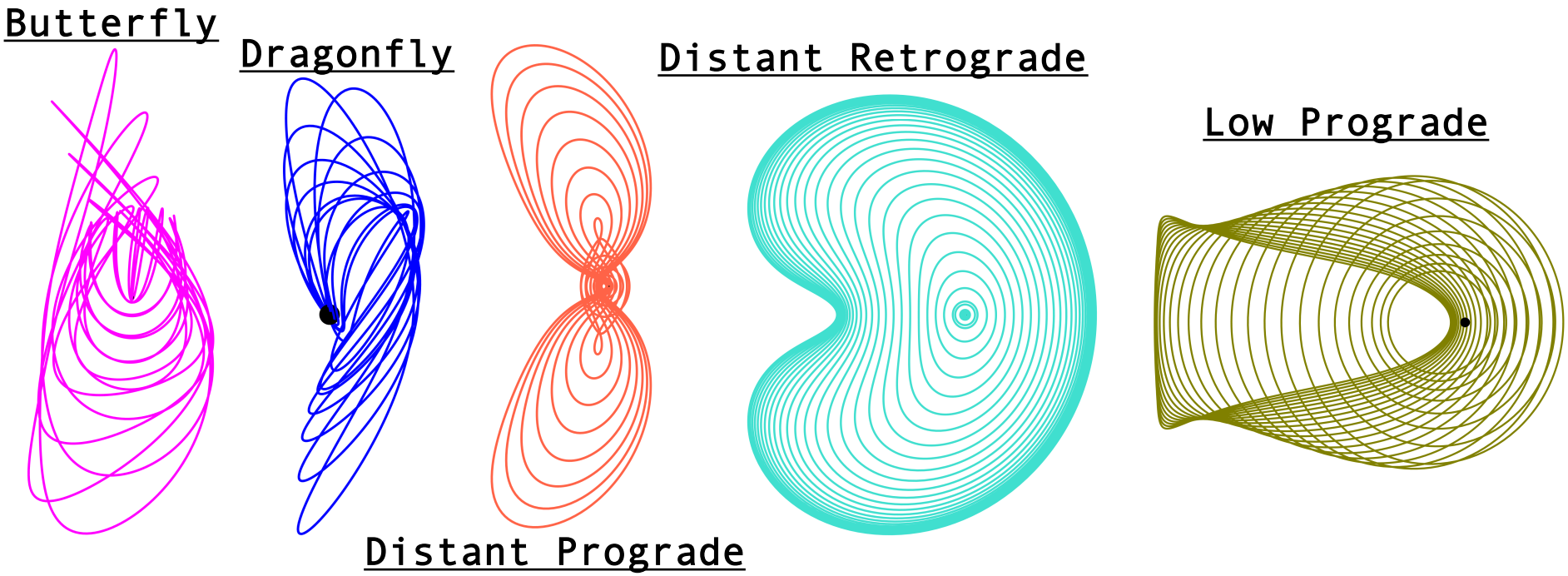
Triangular Vertical



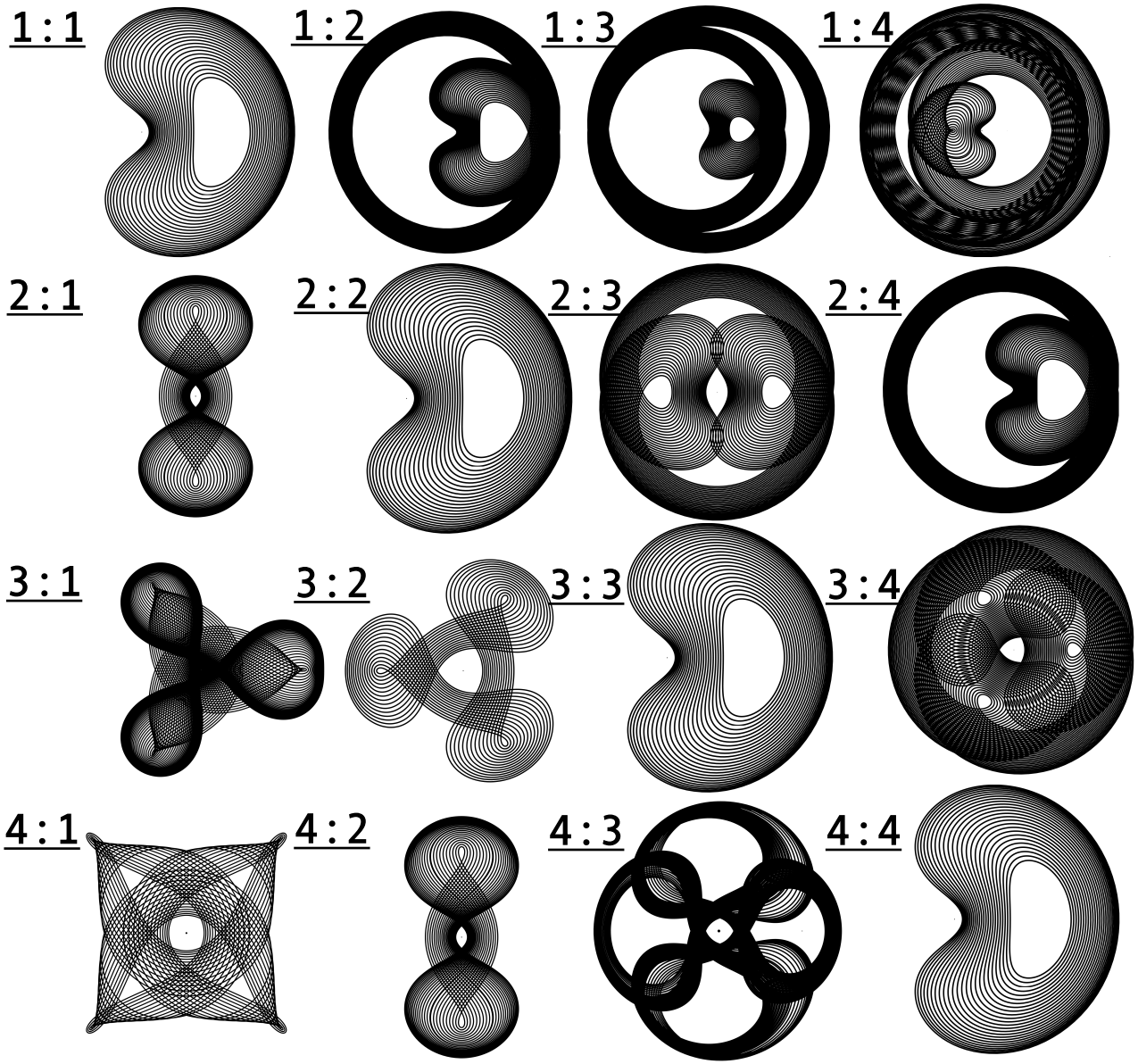
Triangular Axial



Libration Point Orbits & P2-Centered Orbits

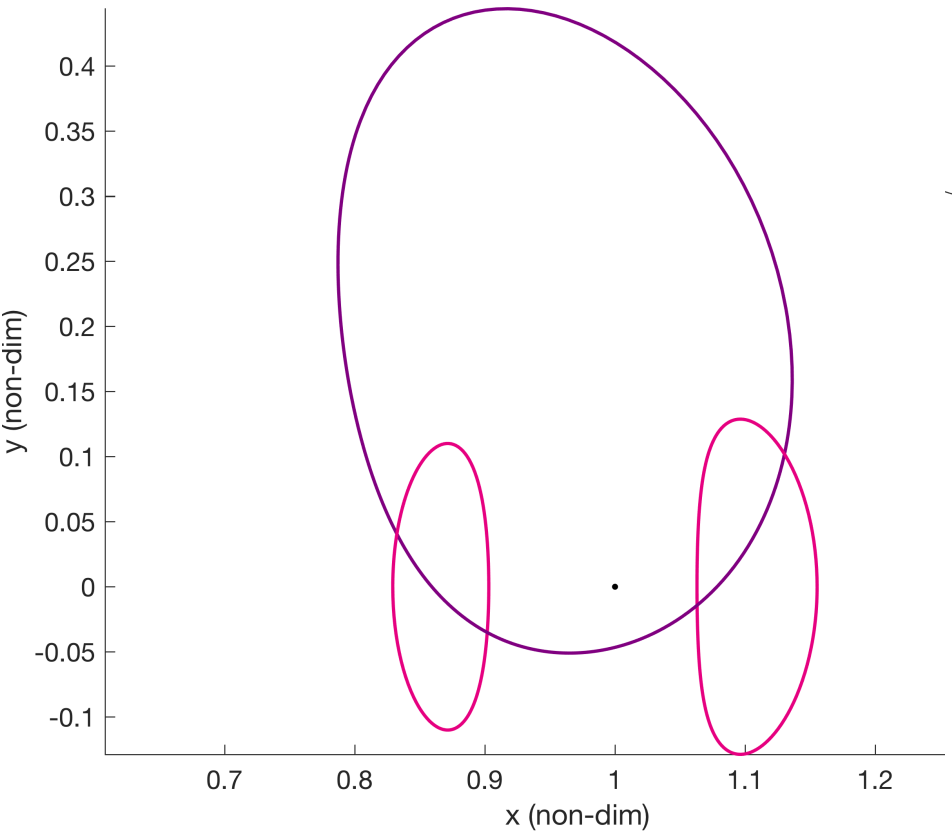


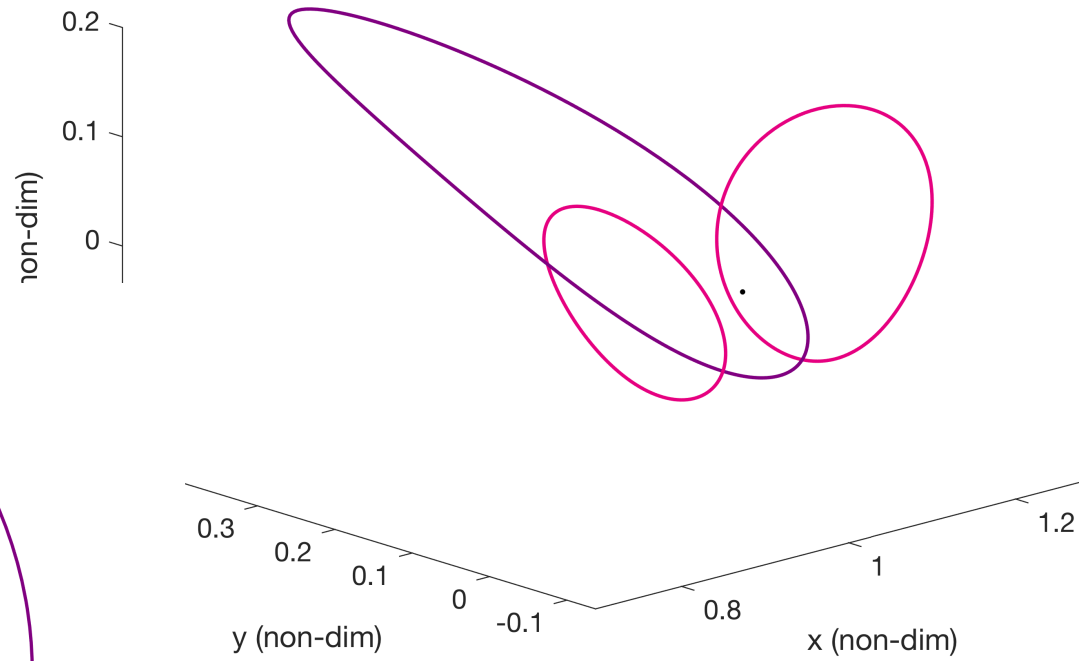
Three-Body Resonant Orbits



"New" Orbits?

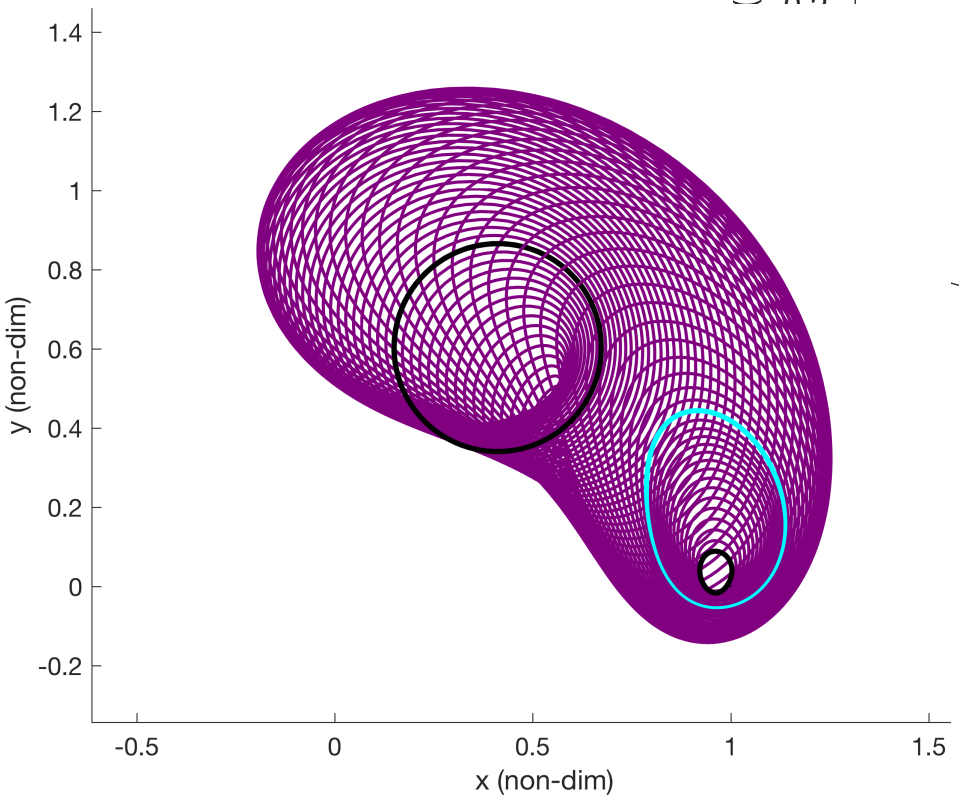
Polesitter?

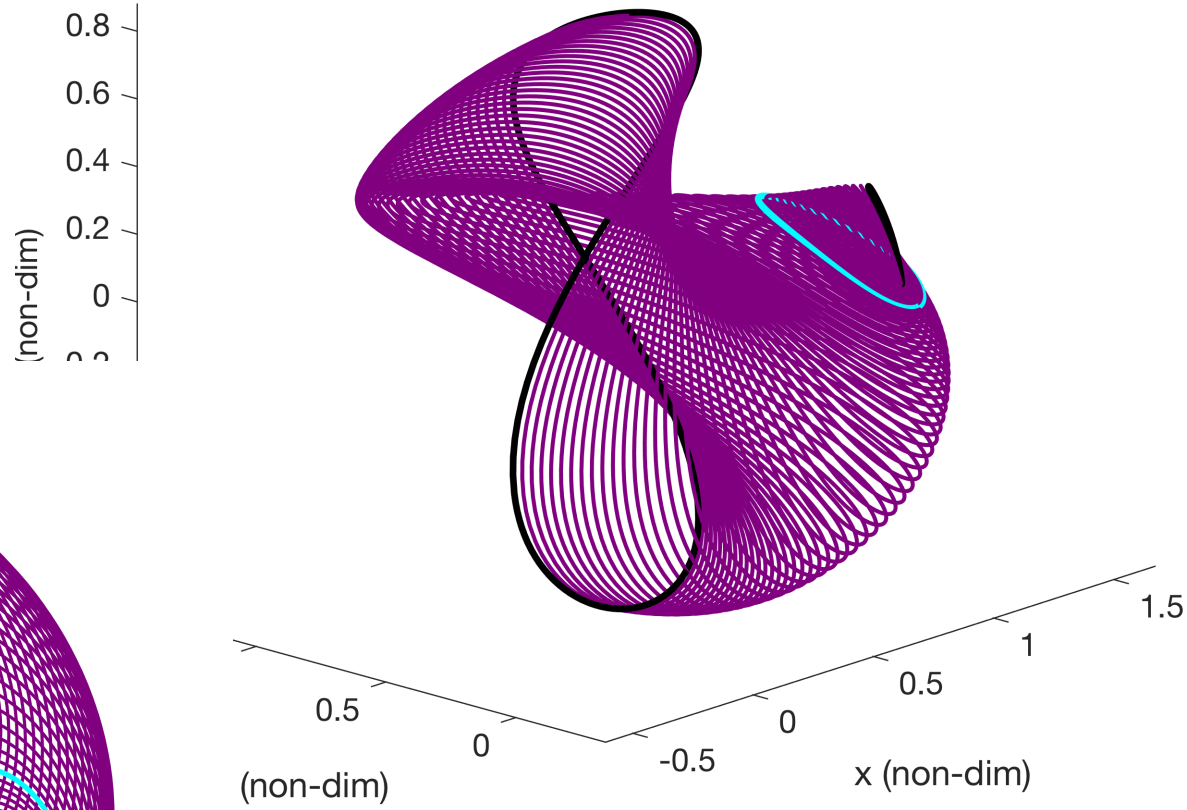




"New" Orbits?

L5 Axial Orbits!

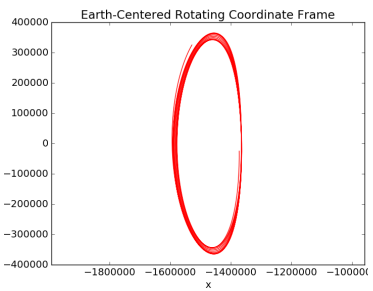


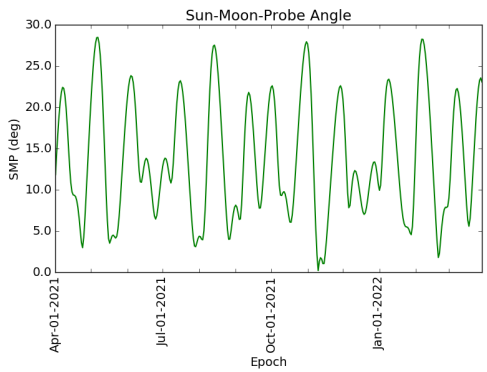


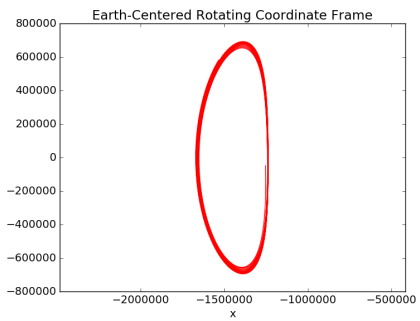
Poincare -- Current State

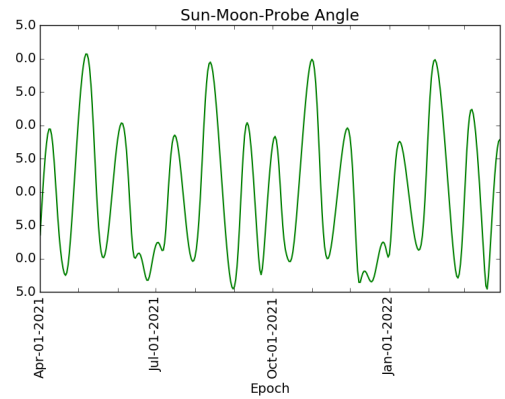
What Poincaré can do <u>today</u>

- Provides three independent python packages to:
  - set up a three-body universe in MONTE → `import cr3bp`
  - access and search for orbits in catalog → `import db_creation`
  - easy state propagator interface → `import SimplePropagator`
- Visualize and save trajectory in a boa, then utilize full MONTE capabilities
- For example, ideal for NEOCam science orbit trade-off studies









- Database is open and easy to add new families as needed
- Could be open to the community in the future (similar to JPL Horizons)
- We provide a python interface to access the catalog but it can be accessed from other platforms

Available Functions in CR3BP class

Function	Description
makeCR3BP	Creates an object of type CR3BP given the names of the primary and secondary. Values of mu and L* are optional.
makeCR3BP_FromSecondaryState	Creates an object of type CR3BP given the state of the secondary with respect to the primary. SecondaryState defines a circular orbit around the primary. It also creates a gravity model associated with a SC. The name of the SC can be specified or a default name will be used.
makeCircularFromCartesian	Creates a state for the secondary (centered at the primary) that defines circular orbit. The state is defined with the same position vector but with a velocity vector that defines a circular orbit. If L* is specified, the position vector is scaled such that its magnitude is equal to L*.
makeCircularFromOrbitalElements	Creates a state for the secondary centered at the primary that defines a circular orbit by computing osculating orbital elements for that epoch and setting the eccentricity to zero.
makeDimensional	Converts a non-dim state (assumed to be defined in rotating frame coordinates centered at the barycenter of the CR3BP system) into a MONTE state. An epoch can be assigned to the state.
makeNonDimensional	Converts a MONTE state defined in any frame and center into a non-dim state centered at the barycenter in the rotating frame of the cr3bp system.
JacobiConstant	Computes the Jacobi constant value associated with a state.
l1	Solves quintic polynomial and returns L1 state in nondimensional coordinates.
l2	Solves quintic polynomial and returns L2 state in nondimensional coordinates.
l3	Solves quintic polynomial and returns L3 state in nondimensional coordinates.
l4	Solves quintic polynomial and returns L4 state in nondimensional coordinates.
l5	Solves quintic polynomial and returns L5 state in nondimensional coordinates.

Demo

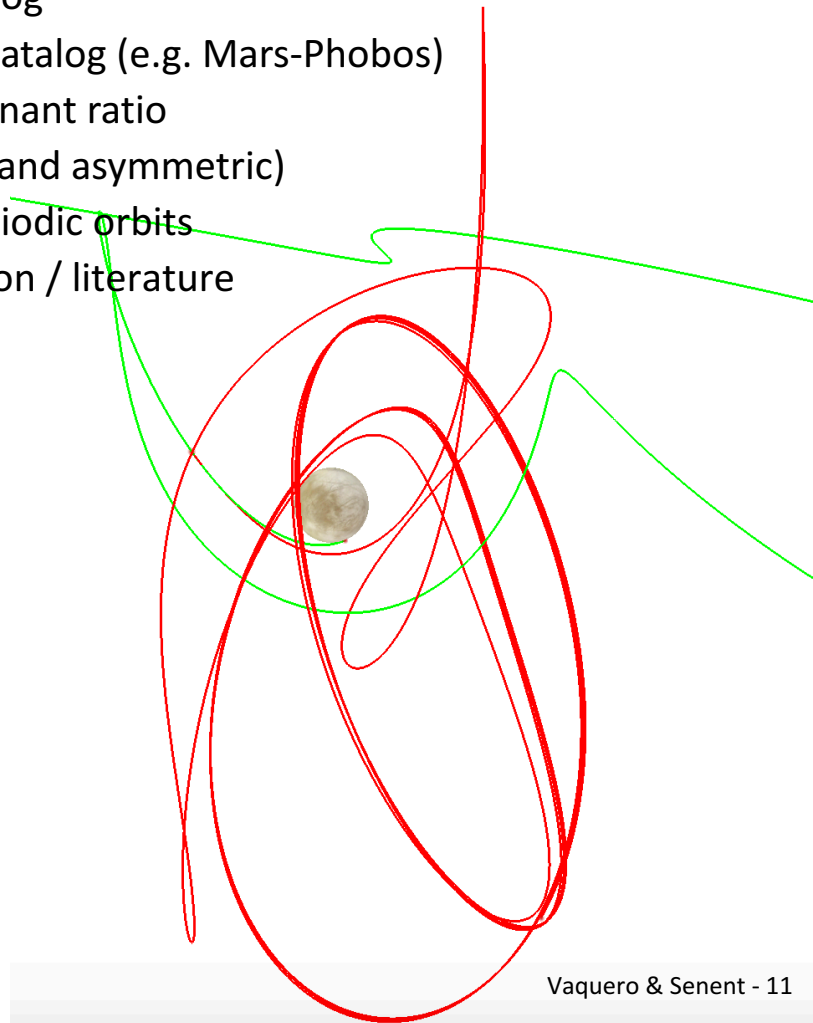
Poincare – Next Steps

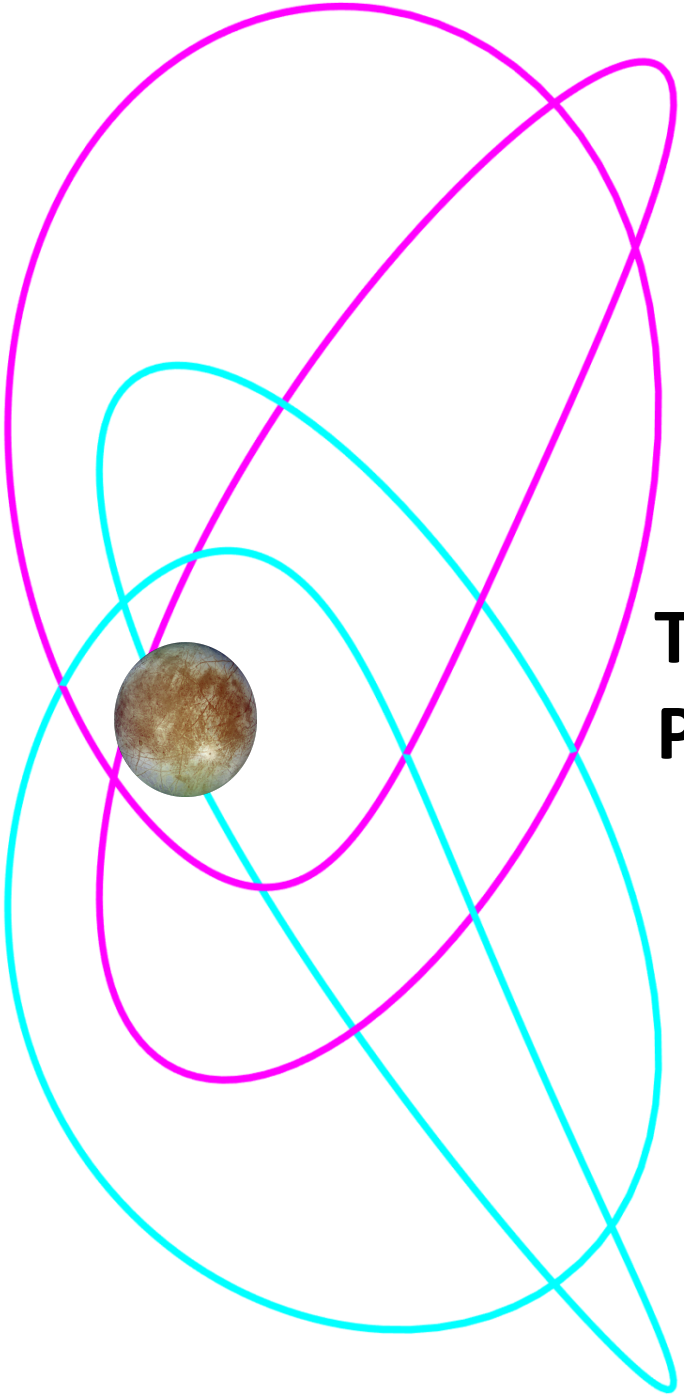
What is next

- Continue generating families of periodic orbits for the catalog
  - Expand number of three-body systems available in catalog (e.g. Mars-Phobos)
  - Expand families of 2D resonant orbits up to 6:7 resonant ratio
  - Generate families of 3D resonant orbits (symmetric and asymmetric)
  - Continue literature survey for known families of periodic orbits
  - Incorporate any other families available in our section / literature

- Continue development and testing of differential corrector

- Investigate ways of generating transfers between orbits
  - conic arcs
  - invariant manifolds





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Part 1: The Science Orbit Catalog

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