National Aeronautics and Space Administration

Global Map Of Resonant Flyby And Capture Orbits To Automate 3 Body Tour Design

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OBJECTIVES

In our previous research, we discovered a method called the Swiss Cheese Plot to find resonant orbits to land on any point on the moons of the Water Worlds. Once a landing trajectory is found, we discovered that there are large sets of trajectories converge to the landing site, acting like a funnel. For this research, we wanted to understand dynamically how the invariant funnel is created.

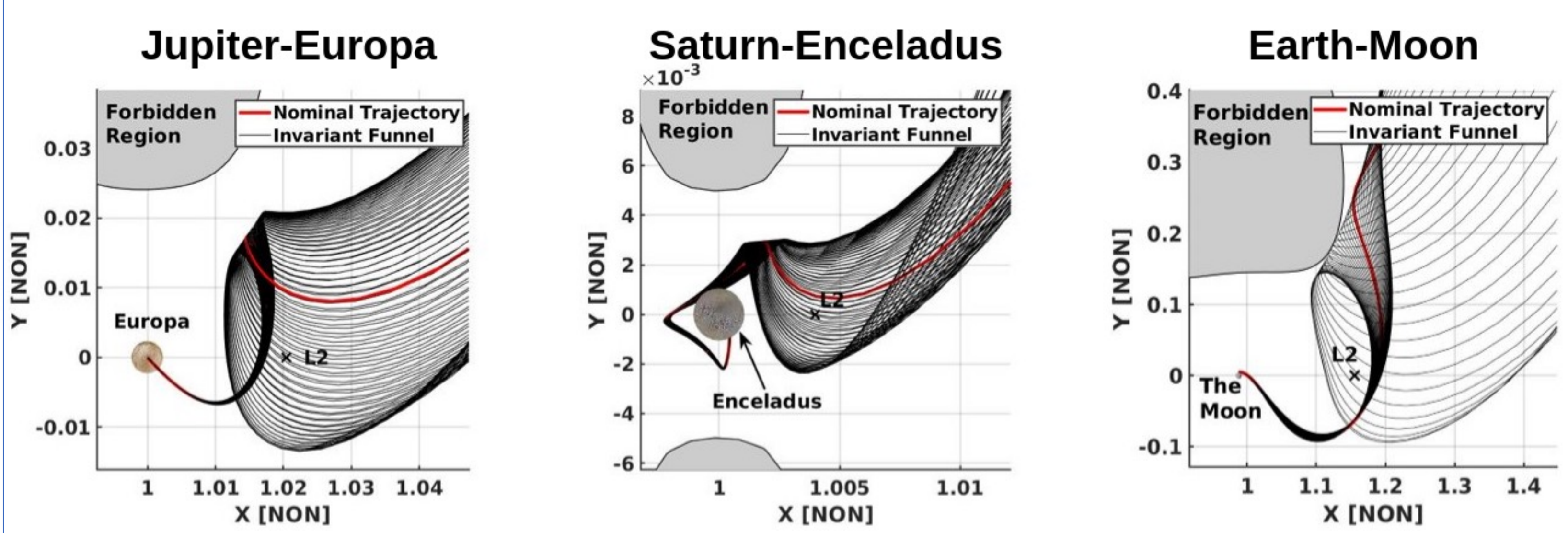

Figure 1: Funnels to landing sites in the Jupiter-Europa, Saturn-Enceladus, and Earth-Moon systems.

BACKGROUND

- Pork Chop Plot important tool for interplanetary missions
- Tours of outer planets' moons require resonant flybys and capture orbits controlled by the 3-Body Problem
- Circular Restricted 3-Body Problem (CR3BP)
- Pork Chop Plot no longer valid in CR3BP
- New global maps needed to speed up tour design for missions to Water Worlds like Europa or Enceladus
- Swiss Cheese Plot shows all resonant landing orbits to single spot on the moons of the Outer Planets.
- Can be extended to flybys between L1 and L2
- Invariant funnels surround these resonant landing orbits in all CR3BP systems
- Large databases needed for machine learning algorithms to automate tour design

APPROACH AND RESULTS

Swiss Cheese Plot

1) Choose landing site
2) Sample landing velocity directions
3) Integrate backwards to XZ plane
4) Compute Poincaré map
5) Pick from desired resonance

Resonant Encounter Map

1) Begin with nominal landing state
2) Generate initial conditions
3) Integrate backwards
4) Compute resonance, $\frac{p}{q} = L^{-3} + \epsilon$
5) Plot resonance on surface

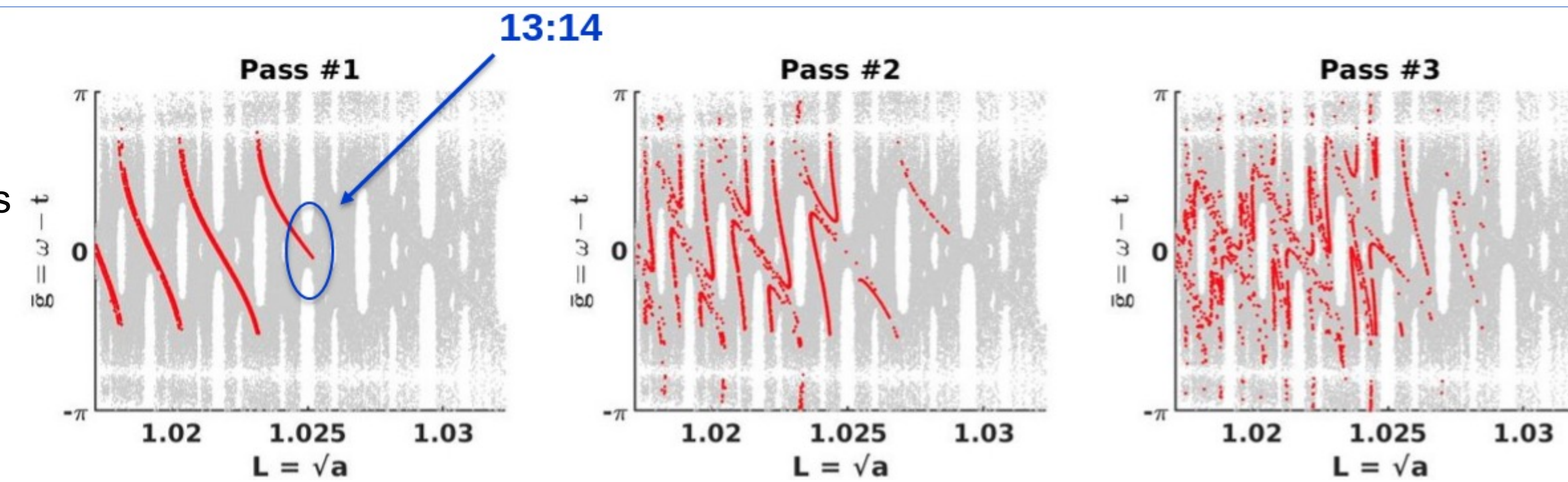

Figure 2: The Swiss Cheese Plot (grey) is generated by allowing particles to complete multiple revolutions about the primary body. With each pass (red), the chaotic dynamics cause the trajectories to spread out more and more, until the gaps corresponding to stable resonant orbits become apparent. These gaps are reminiscent of holes in Swiss Cheese. Trajectories with desired resonance characteristic are chosen directly.

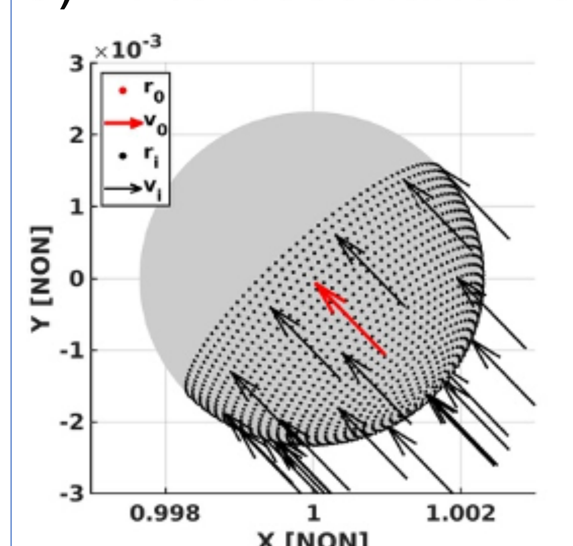

Figure 3: The hemisphere of initial conditions for the resonant encounter map share the Jacobi constant and have parallel velocities.

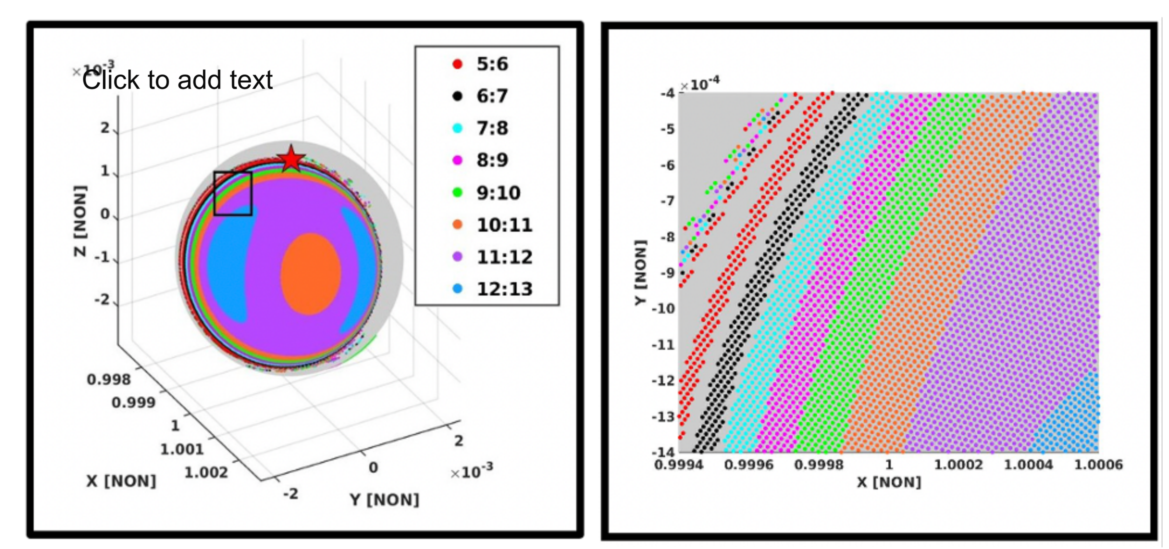

Figure 4: The resonant encounter map is generated by plotting the resonance of each initial condition. The annular regions that share a resonance are called resonant rings. If the initial conditions for a funnel all lie within a resonant ring, it will be well-behaved.

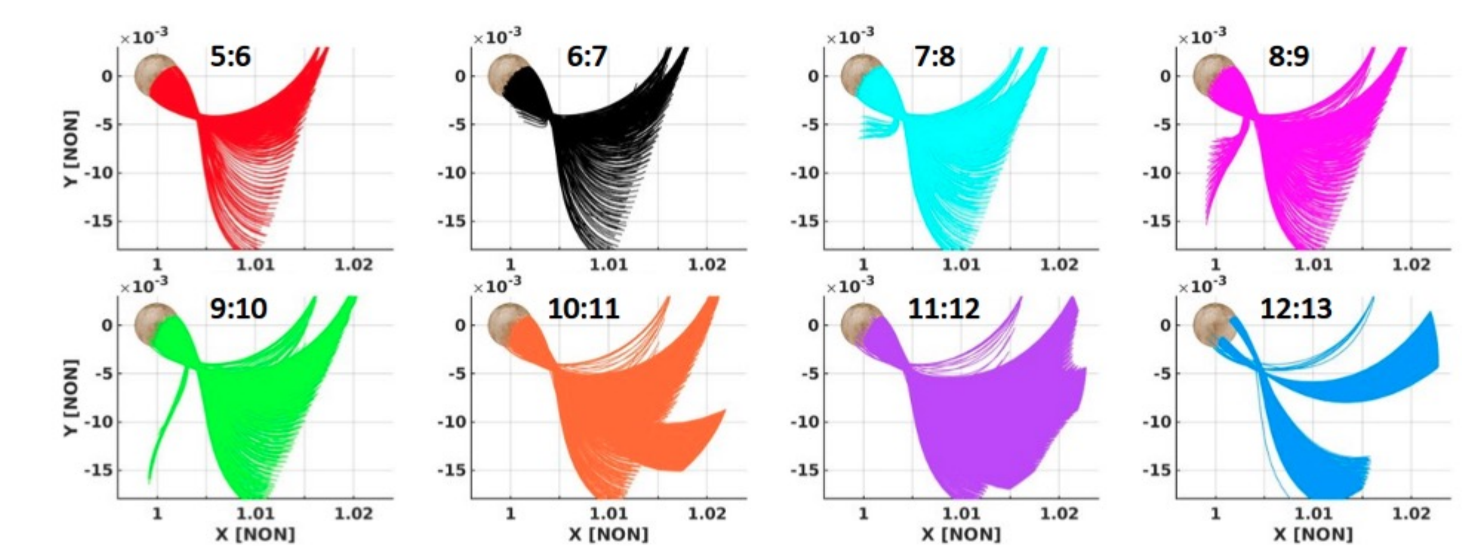

Figure 5: When backward integrating the resonant rings, we notice a region of convergence, called the focus. This can be explained by related them to hyperbolic trajectories in the 2-body problem. However, the branches of trajectories that don't follow the main group is a product of 3-body dynamics.

SIGNIFICANCE/BENEFITS TO JPL AND NASA

- Swiss Cheese Plot simplifies high latitude landing problem for Ocean Worlds like Europa, Enceladus, or Titan
- Invariant funnels may be useful in control algorithms by creating large target regions that can save fuel during navigation
- Resonant encounter map provides mission designers with a quick look at potential resonant trajectories in compact form

PUBLICATIONS

J. T. Blanchard, M. W. Lo, D. Landau, B. D. Anderson, and S. Close, “New tools for tour design: swiss cheese plot, invariant funnel, and resonant encounter map,” AAS 26-605 in *AAS/AIAA Astrodynamics Specialist Conference*, 2021

REFERENCES

J. T. Blanchard, M. Lo, D. Landau, B. Anderson, “Invariant Funnels For Resonant Landing Orbits”, AAS 21-221, 2021.

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