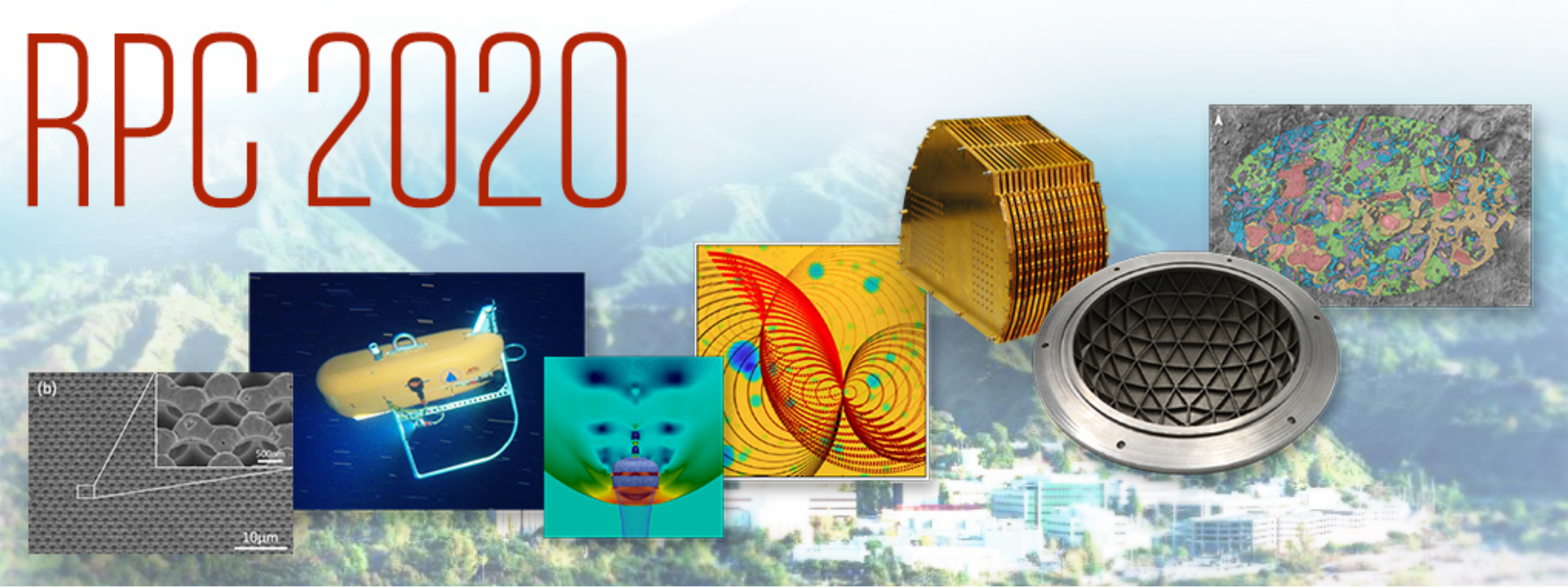

Virtual Research Presentation Conference

Low Energy Resonant Trajectories For Polar & High Latitude Landers to Ocean Worlds

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Program: Spontaneous Concept

RPC 191

Jet Propulsion Laboratory
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Tutorial Introduction: Swiss Cheese Plots

Abstract

Recent studies for lander missions to the Water Worlds showed that it is difficult to reach high latitude sites following a tour using resonant orbits. For this project, we want to land at the South Pole of Enceladus, but first with a stop at a Near-Rectilinear Halo Orbit (NRHO). Poincare Map is a standard tool to study resonances for the planar Circular Restricted 3 Body Problem (CR3BP). But our problem is for the spatial (3D) CR3BP. By a clever choice of velocities tangent to the landing site, integrating backwards from the landing sites, we were able to generate a 2D Poincare Map using 3D orbital data. Since the periapsis of orbits around Enceladus has the same velocity tangency condition, we discovered it is possible to generate a Poincare Map using NRHO periapsis as our “landing site”. The Poincare Map revealed all of the resonant orbits that can land at the South Pole, or the NRHO periapsis. We refer to these Modified Poincare Maps as Swiss Cheese Plots. Figure 1 is a map of the resonant orbits that reaches the NRHO periapsis. This method can be used to design flybys, capture orbits, and landing trajectories to all planets and moons.

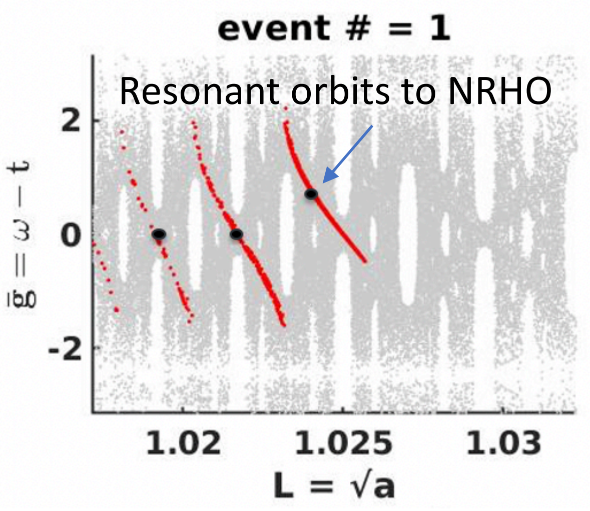


Figure 1.
Modified Poincare Map, Swiss Cheese Plot.

Problem Description

a) Water Worlds require lander missions. Tour design for landing is very different from flyby missions. Tour design to land on high latitudes proved to be difficult. For Europa, it was hard to reach sites above 40 deg latitude (north & south). But the poles often contain the most interesting science and potential for water and life.

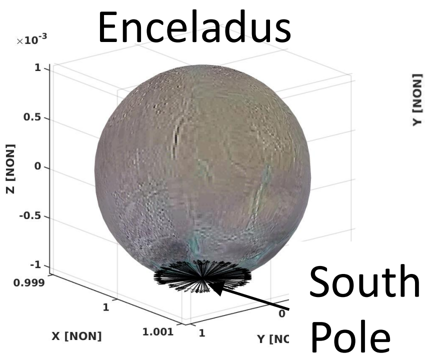
b) Current tour design capability is highly developed for flyby missions, not as highly developed for lander missions. Landing on the Water Worlds requires a tour of the satellite system in order to reach the destination moon. Hence the landing trajectory has to be a resonant trajectory using low energy trajectory for the approach and landing. This requires nonlinear trajectories in the 3 body problem. Conic approximation used for typical tour design is inadequate to solve this problem. Using nonlinear dynamical system methods, we were able to solve this problem with the Swiss Cheese Plot.

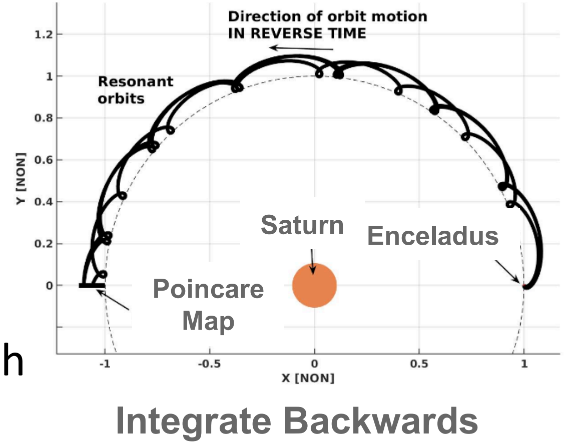
c) This is important to NASA since NASA missions are now focused on landing on moons, from the Earth’s Moon to the Water Worlds. The Swiss Cheese Plot method we discovered provides a form of Nonlinear Pork Chop Plot for mission designers to quickly select and design resonant landing trajectories to the planets and moons. In the case of the Enceladus mission concept, this technique works for periapsis and apoapsis of orbits. Hence it can be extended to the design of flyby mission and capture orbits as we have shown for an NRHO.

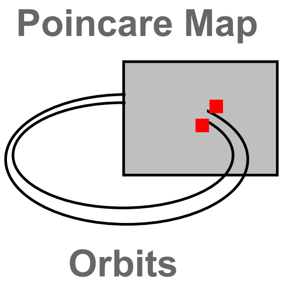
Methodology

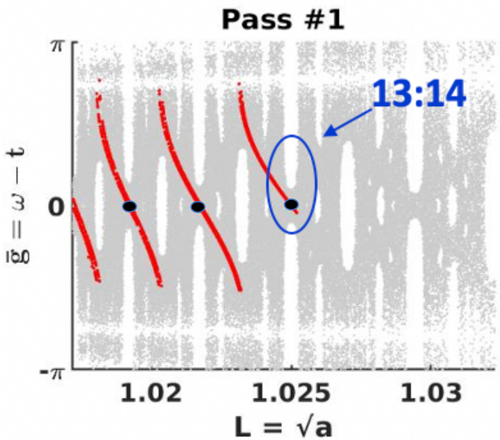
a) The Poincare Map is used to find resonant orbits in planar 2D 3 body problems. We devised a new Modified Poincare Map for the 3D 3 body problems. Given any landing site on a moon or planet, this allowed us to quickly find all of the resonant orbits that can land at that site.

b) For the Enceladus mission concept, we start at the South Pole, define velocities tangent to the pole at the same energy, integrate backwards to generate a Poincare Map. The red dots is the Poincare Map. It indicated the 13:14 resonant orbit can land at the South Pole. This can be done in a small disc around the pole to study trajectories landing nearby the pole. This can be done at any point on the Moon to produce a global map of landing sites reachable by resonant orbits.







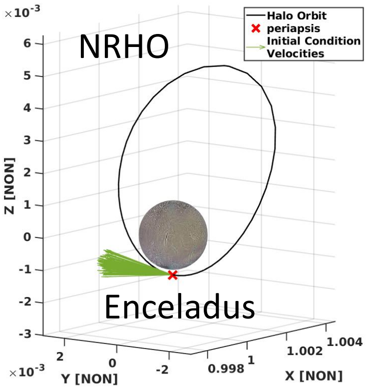


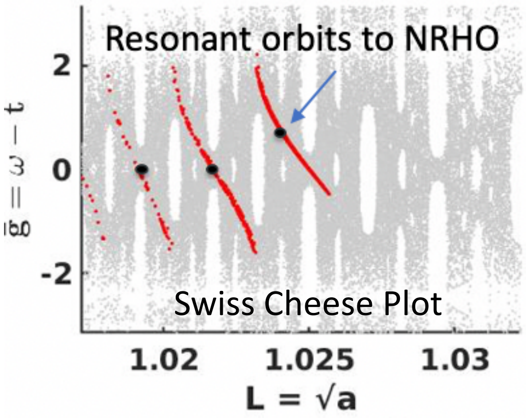
Results

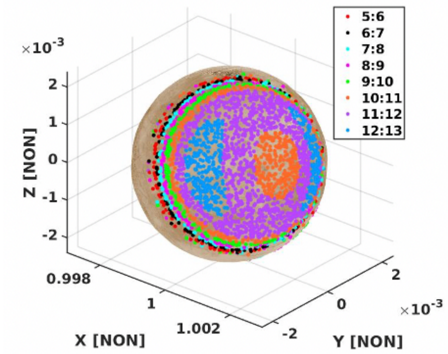
a) We solved the problem for finding resonant trajectories to land at Enceladus' South Pole. Our solutions is more general that the original problem. We found resonant orbits that can insert into NRHO at Enceladus. Moreover, we are able to produce a map of all resonant orbit's landings on a moon. The example shown below is for Europa.

b) This provides a global mission design tool for landings, flybys, capture orbits using nonlinear resonant trajectories in the 3 body problem. The global solution maps will enable machine learning techniques for mission design.

c) Future Work: Analyze flybys and capture orbits using the Swiss Cheese Plot. Extend this to 4 body problem needed for Earth's Moon. Produce GPU tools to compute the Swiss Cheese Plot, apply this to machine learning to automate mission design.







Publications and References

Publications

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[B] Lo, Martin, Damon Landau, Brian Anderson, Ryan Burns, “NTR 51765, Using Poincare Map To Find Resonant Trajectories To Flyby, Capture Into Orbit Around, Or Land On Secondary Bodies (Planets and Moons) In the Three Body Problem”, 9/25/2020.

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[1] J. T. Blanchard, B. D. Anderson, M. W. Lo, and S. Close, “Low energy capture into high inclination orbits for ocean worlds missions,” *AAS/AIAA Astrodynamics Specialist Conference*, 2020.