National Aeronautics and Space Administration

Low Energy Capture into High Inclination Orbits for Ocean Worlds Missions

Principal Investigator: Martin W. Lo (392M)
Professor Sigrid Close, Jared Blanchard (Stanford University)
Program: Strategic University Research Partnership

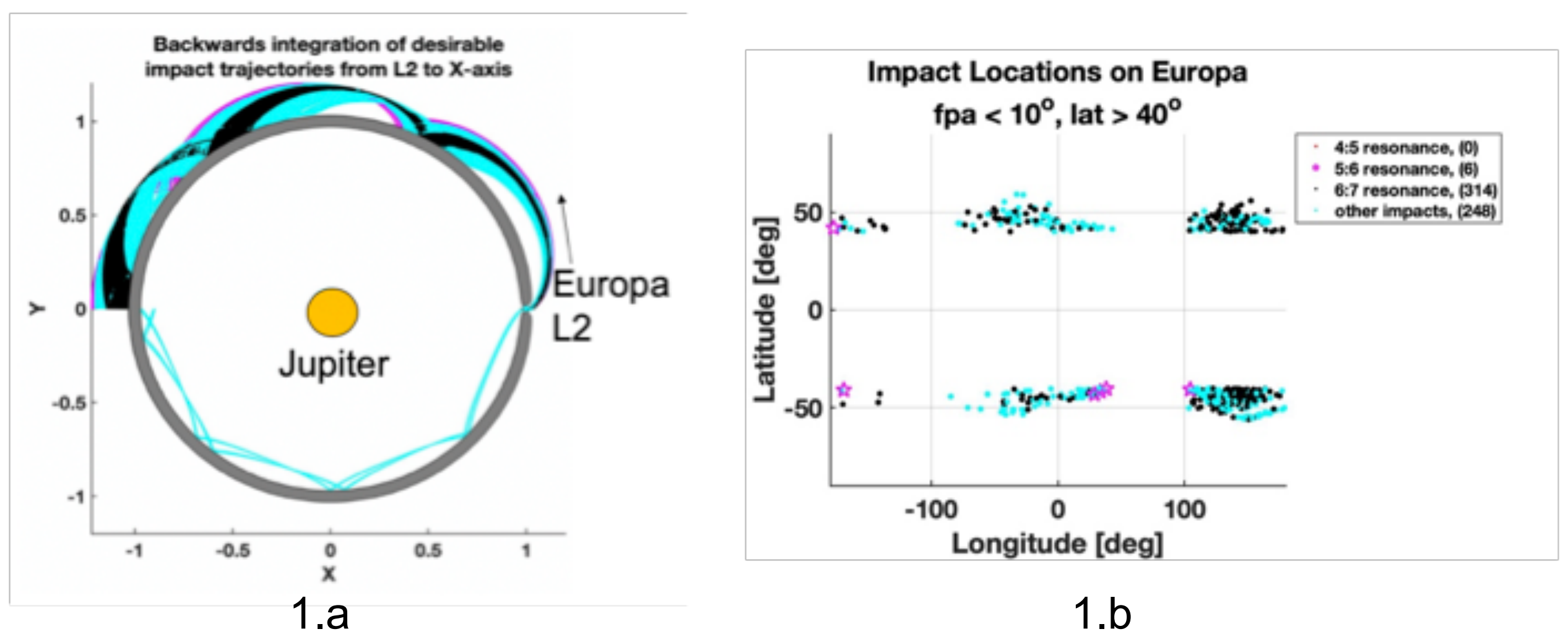
Project Objective:

Verify the existence of and determine the trajectories of resonant orbits that intersect with Europa at high latitudes with shallow flight path angles. During our study of Europa Lander concepts, we found it very hard to reach high latitudes above 60 deg latitude. This study is to investigate which resonances (orbits around Jupiter) are able to reach high latitudes and what makes it so difficult.

Benefits to NASA and JPL (or significance of results):

The results of this research achieved the stated objective by identifying trajectories that impact Europa at high latitudes, with low flight path angles, from a 5:6 resonant orbit. The research produced significant insights into the properties of 3D resonant periodic orbits and their manifolds, as well as a deeper understanding of the reachability of certain longitudes on Europa in the planar case. Orbits with high inclination around Jupiter tended to be more stable. The high inclination of the orbit removes it from the influence of Europa. Where as orbits with inclination near 0 have close encounters with Europa. They are then able to be captured and land on Europa with various inclinations around Europa. We do not yet understand what controls the inclination of the captured approach orbit. This is probably controlled by the passage thru the L2 libration orbits and their invariant manifolds.

This work will inform JPL mission designers on possible tour designs to the moons of the Water Worlds. Upcoming missions such as Europa Clipper will benefit directly as the simulations were done with the Europa-Jupiter system in mind.



1.a 1.b

Fig. (1.a) Trajectories integrate backwards from Europa L2 at the left all the way to the right 180° around Jupiter to the negative X-axis to determine the resonance of the orbit. (1.b) The Impact locations on Europa with FPA ≤ 10°, and landing site Latitude ≥ 40°. Points are colored by resonance. Magenta stars came from 5:6 resonant orbits, which are the most useful to mission designers. Note the scarcity of these orbits.

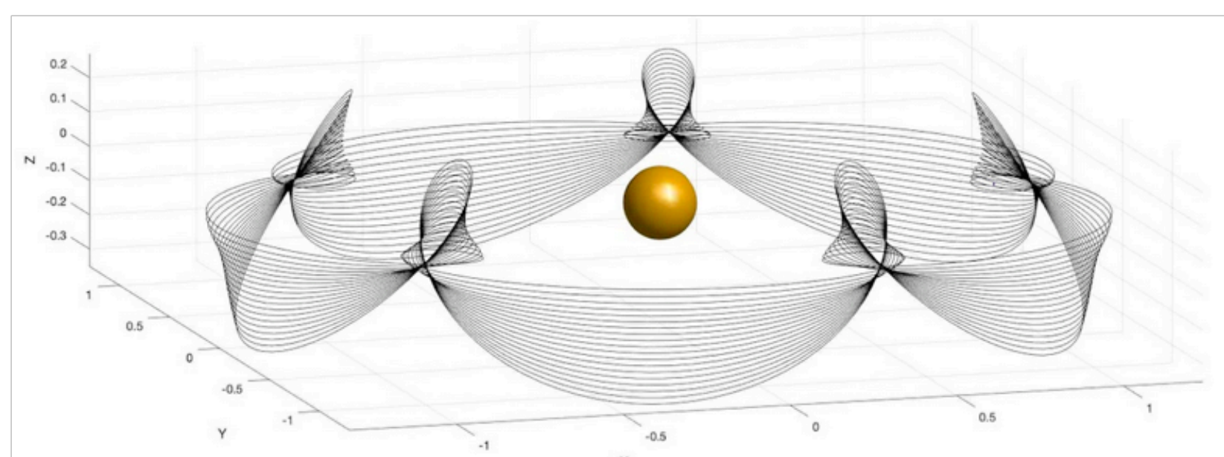


Figure 4. The family of 3D 5:6 resonant orbits are technically unstable and low energy, but their stability indices was very low, near 1. Hence they were unsuitable for approach to Europa. Their manifolds take much too long to approach Europa.

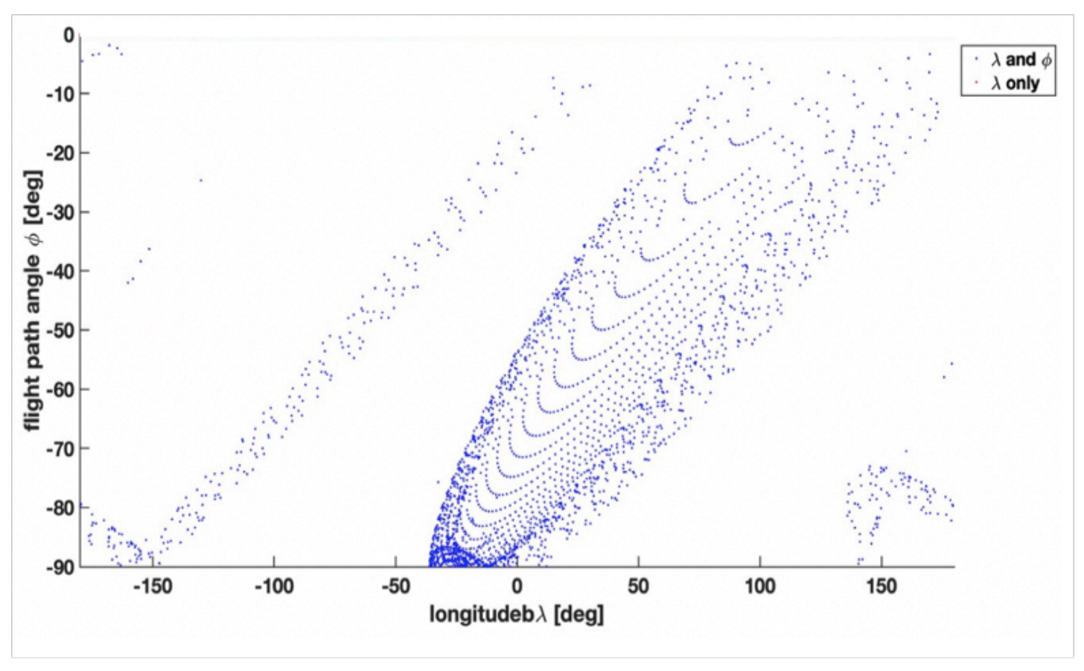


Figure 5. Distribution of impact points on Europa longitude and Flight Path Angle distribution. The pattern in the plot is due to the grid pattern of the initial location of the orbits.

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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

FY18/19 Approach & Results:

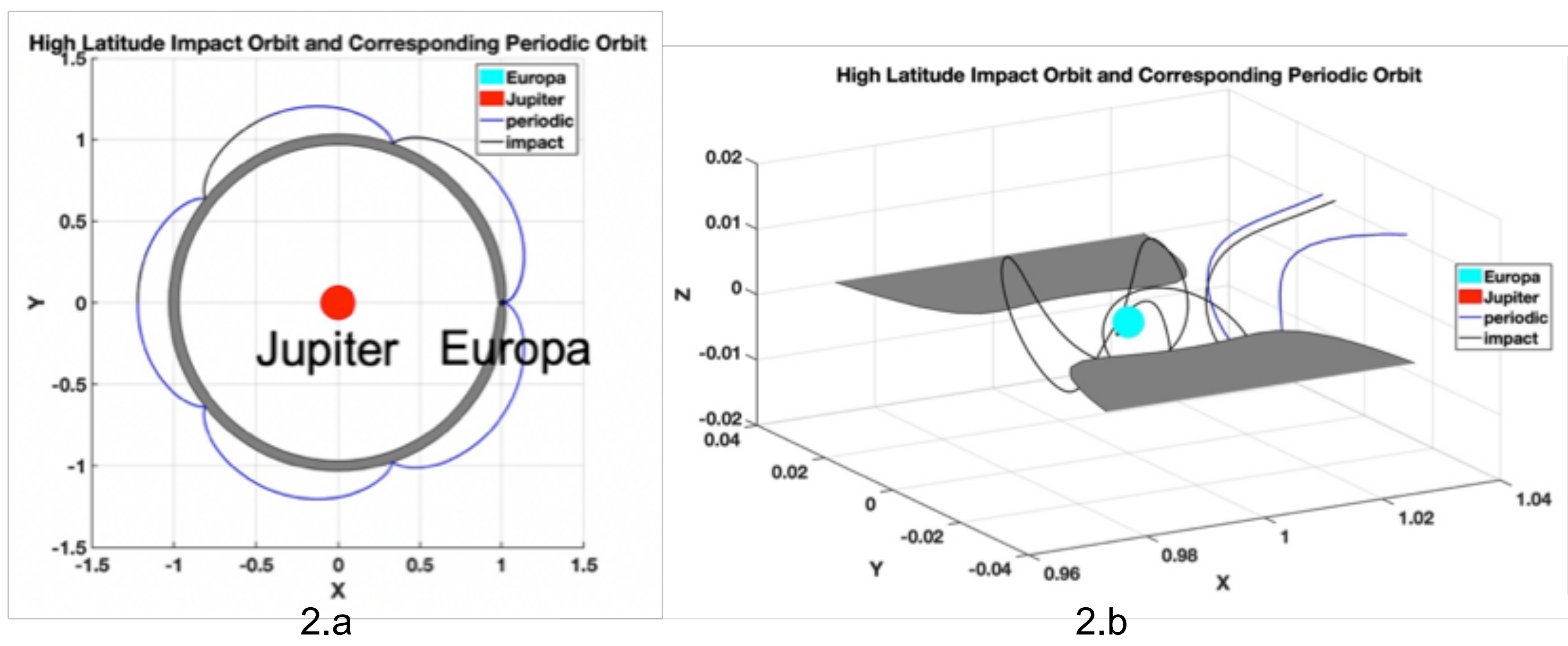
A database of initial conditions in the circular restricted three-body problem positioned at the L2 disc of the Jupiter-Europa system was created for Europa Lander concept studies by B. Anderson et al. [1]. We parsed this database to find a set of orbits that approached Europa from outside the L2 gateway and impacted Europa. We then propagated backwards the few that impacted at high latitudes with shallow flight path angles to see what type of resonant orbit they most closely approximated. We found that, of a million initial conditions at Jacobi constant C = 3.003, only 6 impacts came from 5:6 resonant orbits, which are the most useful to mission designers. Figure 1.a shows the backwards integrated trajectories. Figure 1.b shows the frequency, type, and impact locations of these trajectories were produced. The resonances are shown by different colors. Of most interest are the 5:6 resonances which are the magenta stars. There were very few of them.

We investigated the landing trajectories the came from the 5:6 resonance as shown in Figure 2.a. Using the backwards integrated trajectory as starting point, we differentially corrected and found the corresponding 5:6 resonant orbit. The plot of the two orbits in Figure 2.a are virtually indistinguishable at this scale. Figure 2.b is a blow up near Europa to show how they differ. One can see that the resonant orbit approaches the L2 region where chaotic trajectories live. In Figure 3, we present the invariant manifolds of the 5:6 resonant orbit. The hot colors refer to the unstable manifolds, the cool colors refer to the stable manifolds. The two hot colors refer to the two branches of the unstable manifolds. Similarly for the stable manifolds. In this case, the 5:6 resonant orbit has an inclination of 0.6 deg and it is highly unstable.

To better understand the behavior of 3D resonant orbits, we computed and analyzed a family of 3D 5:6 orbits shown in Figure 4. We used some of the planar orbital data from Vaquero 2010, as starting point for computing the family. It turns out, resonant orbits with high inclination, while still can be unstable, their instability is very weak. It is so weak that the invariant manifold tends to cling to the resonant orbit and may take hundreds or thousands of years to escape the periodic orbit. Hence these are not useful for mission purposes. The useful 3D resonant orbits with high instability that we examined, had very low inclinations of around 0.6 degrees. When they reach Europa, they are able to reach high latitudes in some cases.

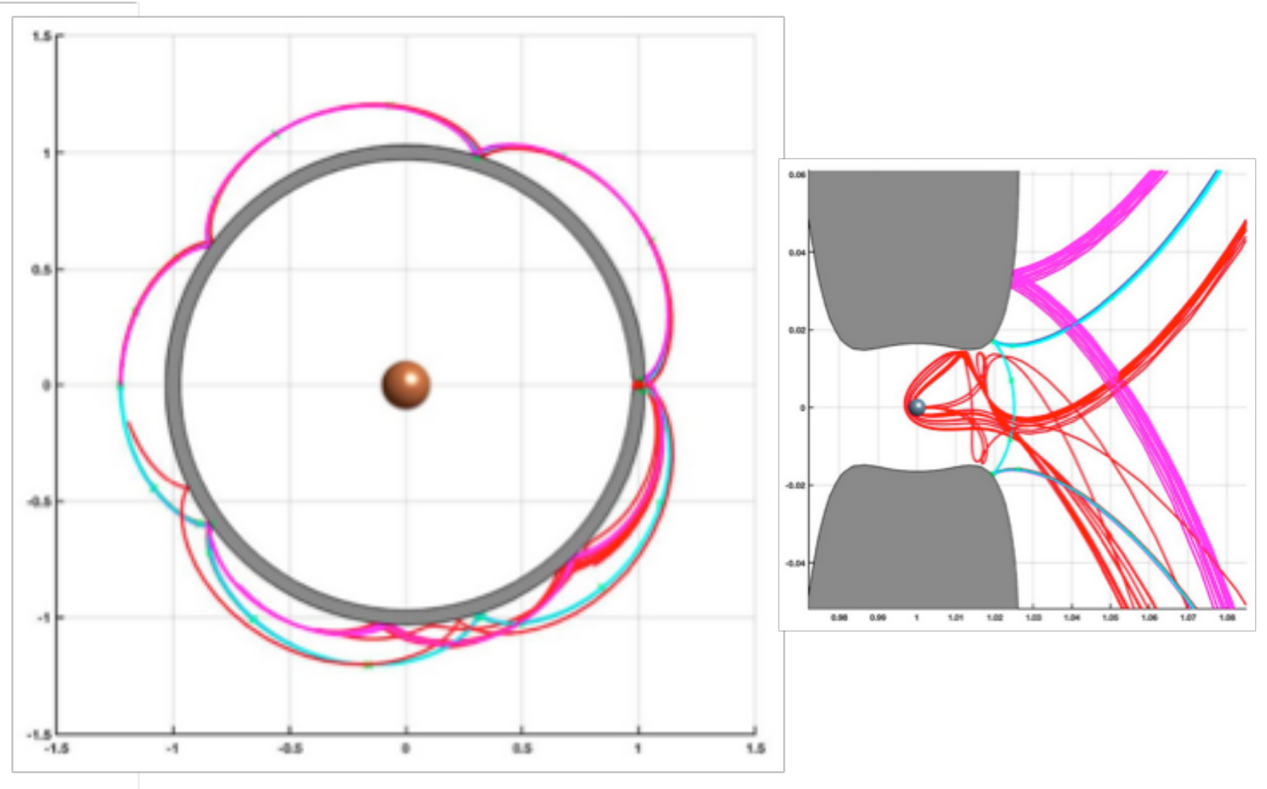
With respect to the high inclination resonant orbits, if we were able to rotate the orbits slightly so that the resonant orbits would approach Europa closely when the orbit is near the orbital plane of Europa, this close encounter should create instability and permit low energy capture. This requires the computation of resonant orbits which as not symmetric with respect to the XZ-plane. This is something we do not know how to compute at the moment and should be investigated in the near future.

We also began a study on the longitudinal distribution of the landing sites as a function of the orbital flight path angle. For this work, we analyzed only the planar trajectories to gain insight before looking at the 3D orbits. Figure 5 shows the distribution for a fixed energy level (Jacobi constant). The curved patterns in the plot are from the grid pattern of the initial orbit data. We do not yet understand the gap patterns in the longitudes of the landing sites as a function of the FPA, but there is clearly a pattern. This is work to be completed in the future.



2.a 2.b

Figure (2.a) High latitude impact orbit (black) and corresponding 5:6 periodic orbit (blue) closely follow one another, indistinguishable in this plot. (2.b} Blow up of the 2 orbits in 2.a near Europa (cyan) showing how the black orbit impacts Europa, and the blue periodic orbit approaches L2 and then departs Europa.



3.a 3.b

Fig. (3.a) The invariant manifolds of the 5:6 resonant orbit is integrated and winds around the orbit. The hot colors are the unstable manifolds, the cool colors are the stable manifolds. (3.b) Blow up of the region around Europa's L1 and L2 and the manifolds.

Acknowledgements:

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PI/Task Mgr. Contact Information:

626-429-9310, Martin.W.Lo@jpl.nasa.gov

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