Radiation Exposure for Jupiter: Europa Resonance Trajectory Optimization

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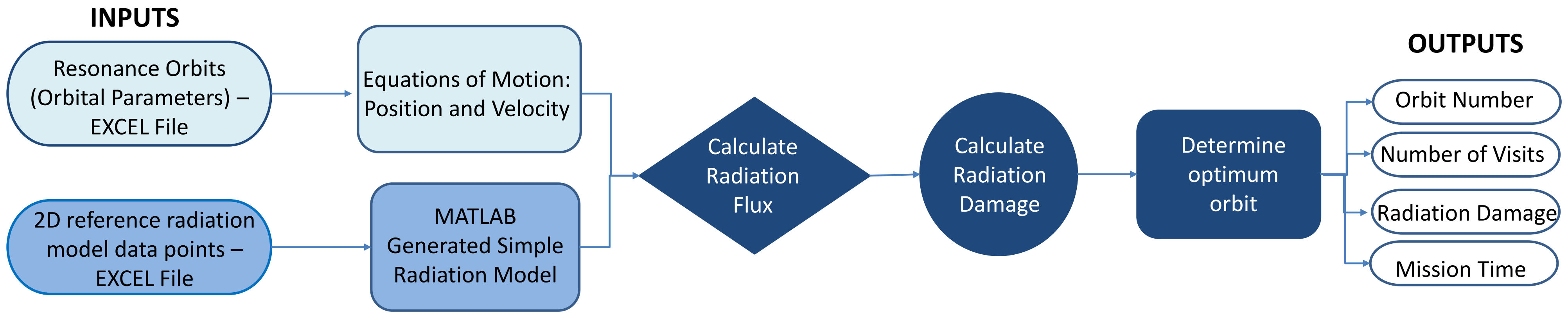
Introduction/Motivation or Background

Radiation mitigation is one of the major challenges in space mission design. Missions to high radiation environments significantly affect the design of the optimal trajectories. Radiation can not be avoided when traveling at high speeds in deep space. Harmful space radiation consists of protons and high-energy nuclei which have hazardous biological impacts and effects on electrical components. All missions to high radiation areas have to account for this radiation damage. Current ways of prolonging the life of a satellite are using materials such as aluminum as a barrier or creating a trajectory that avoids most of the harmful radiation environment. However, these materials still don't provide an adequate amount of shielding, and the orbits are often costly to maneuver into and do not provide long visit times around the planet or the moon to obtain detailed data. Space exploration is substantially dependent on the improvement of radiation shielding techniques especially when it comes to sending humans into space. Europa is one of Jupiter's moons which is located in the high radiation environment of Jupiter. Europa is a new exploration destination due to the observed ocean under its icy surface [1,2,6].

The purpose of this project is to analysis the optimization of orbits based on radiation effects. The approach for this research began with developing a set of resonance orbits for a spacecraft relative to Jupiter's moon Europa. A database of these orbits was then combined with a radiation model of Jupiter. The effective radiation level and exposure time are then calculated and recorded for each orbit. The final optimization process scores the orbit based on specific requirements. The key results for this project is a database of orbits and a search algorithm to optimize orbits around Jupiter's radiation field. This optimization process is based on radiation level and life expectancy of the spacecraft.

Key Approach:

This research was conducted in two main parts: a survey of different materials under high radiation conditions and analysis of test scenarios of optimal trajectory design under these radiation shielding materials. This part of the research is focused on mission design in the high radiation environment around Jupiter with a focus on missions around Europa. There are three major sections in this part of the research: the collection of test resonance orbits, radiation model, and optimization. Figure 1 shows a diagram of the algorithm.


INPUTS

Resonance Orbits (Orbital Parameters) – EXCEL File

2D reference radiation model data points – EXCEL File

Equations of Motion: Position and Velocity

MATLAB Generated Simple Radiation Model

Calculate Radiation Flux

Calculate Radiation Damage

Determine optimum orbit

OUTPUTS

Orbit Number

Number of Visits

Radiation Damage

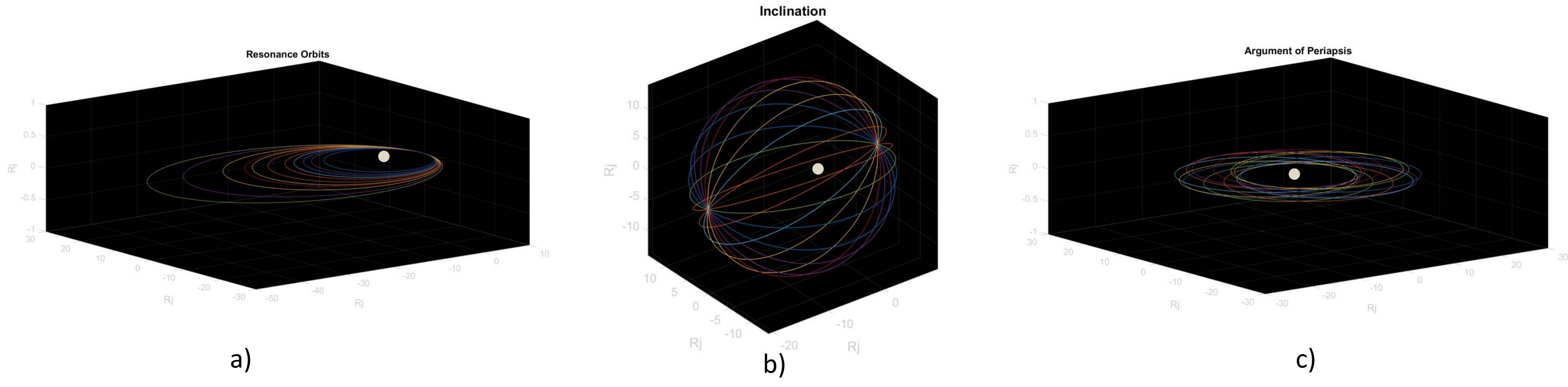
Mission Time

Figure 1: Orbit Analysis and Optimization Algorithm

Resonance Orbits:

The test orbits for this research was based on Europa's orbit. Europa has an orbit around Jupiter that is roughly circular with a mean radius of 67,099 km from the center of Jupiter and a period of 85 hours. This information was then used to calculate the resonance orbits of a satellite. The resonance used are based on research papers and typical mission resonances used. A resonance orbit is defined by two orbiting bodies that have a regular orbital period that can be related by a ratio of small integers. For this research, it means that for a 1:3 resonance orbit, for one orbit of the satellite Europa experiences three orbits. This research used 12 different resonances: 1:1, 1:2, 1:3, 1:4, 1:5, 2:3, 2:5, 3:4, 3:5, 3:7, 4:5, and 5:6 [3,4].

The next step was finding all orbital elements for each resonance orbit. Orbital elements are the parameters required to specifically identify each orbit individually. These elements are based on a classical two-body system and use a Kepler orbit. The orbital elements consist of 6 parameters: angular momentum (h, km^2/s), eccentricity (e), right ascension of the ascending node (Ω, radians), inclination (i, radians), argument of periapsis (ω, radians), and true anomaly (θ, radians) [7]. Each resonance orbit was rotated about the major axis by varying the inclination from 0 to 180 degrees in increments of 18 degrees and varying the argument of periapsis from 0 to 360 degrees in increments of 30 degrees. This was done to obtain a complete set of test orbits since Jupiter's radiation environment is not symmetric or uniform. These orbit variation can be seen below in Figure 2.



a) b) c)

Figure 2: a) 12 resonance orbits, b) 1:2 resonance orbit rotated based on inclination parameter, c) 1:2 resonance orbit rotated based on argument of periapsis parameter.

Radiation Model:

The radiation model around Jupiter was approximated based on Galileo Mission and observations conducted at VLA radio telescope facility in New Mexico. MATLAB was used to provide a simple radiation model to interpolate data using reference stationary images of radiation map around Jupiter, seen in Figure 3 [5]. The reference points were taken in a 2D coordinate system from this image along with the radiation flux associated with the points. The simple radiation model generated in MATLAB can be seen in Figure 4.

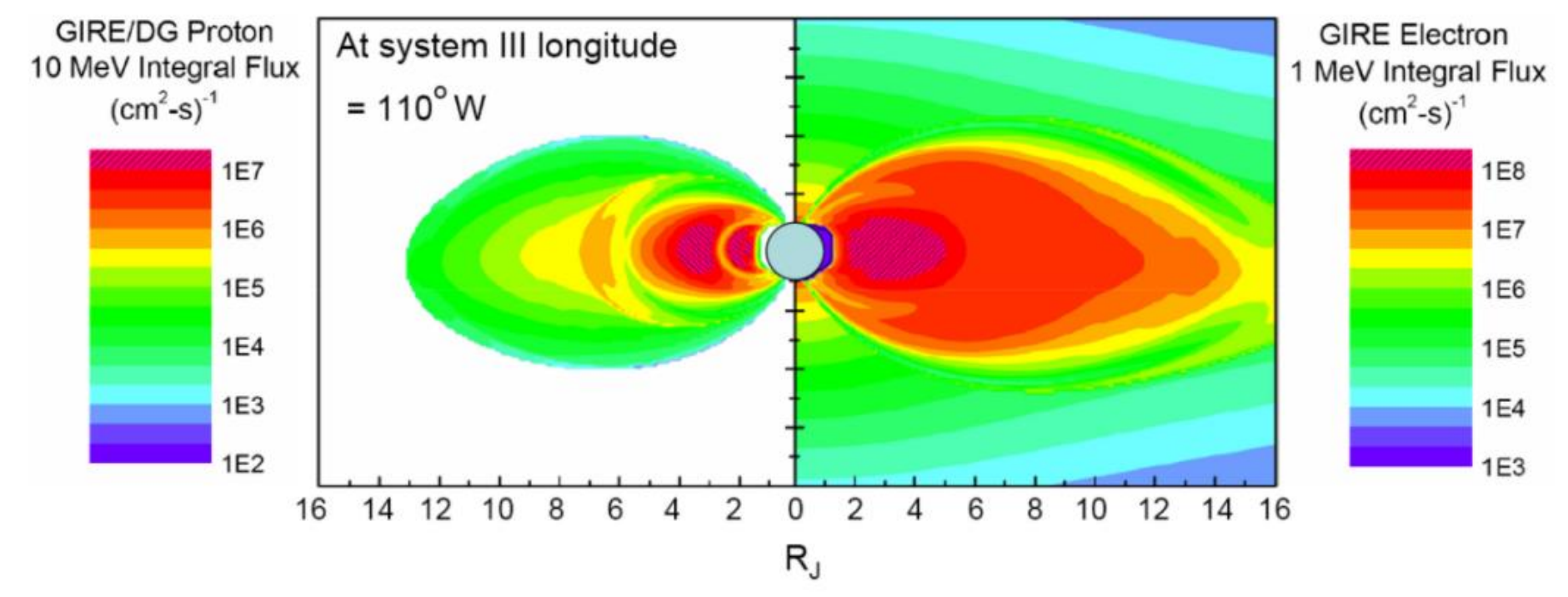


Figure 3: GIRE/DG83 model –JPL [5]

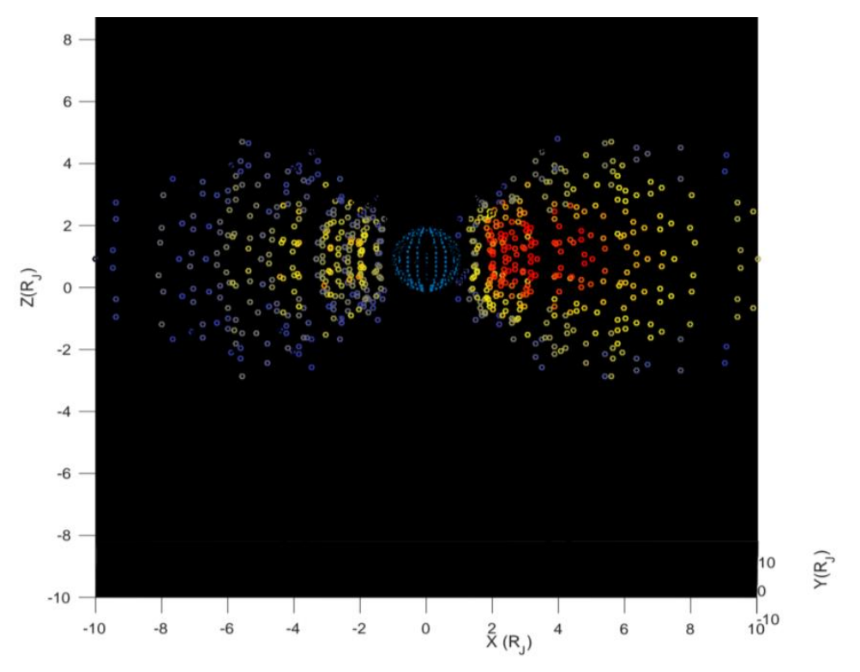


Figure 4: MATLAB Simple Radiation Model

The radiation model is run with the test orbits and saves the flux at each point along the orbit into the database. The database in total contains the period of each orbit, all orbital parameters, position and velocity vectors in Cartesian coordinates, the radiation associated with the electron flux, and the radiation associated with the proton flux. This database is then used in the other part of the research which is being conducted by Shannen Acedillo. The final radiation damage for each orbit is calculated and stored in another database.

Optimization:

The final section of this research is the optimization. This section uses the output from Shannen's research [6]. There are two major parameters that are used to find the optimum orbit: mission time and radiation exposure. The optimum orbit is the one that has a maximum number of visits or fly-by of Europa with the lowest radiation damage.

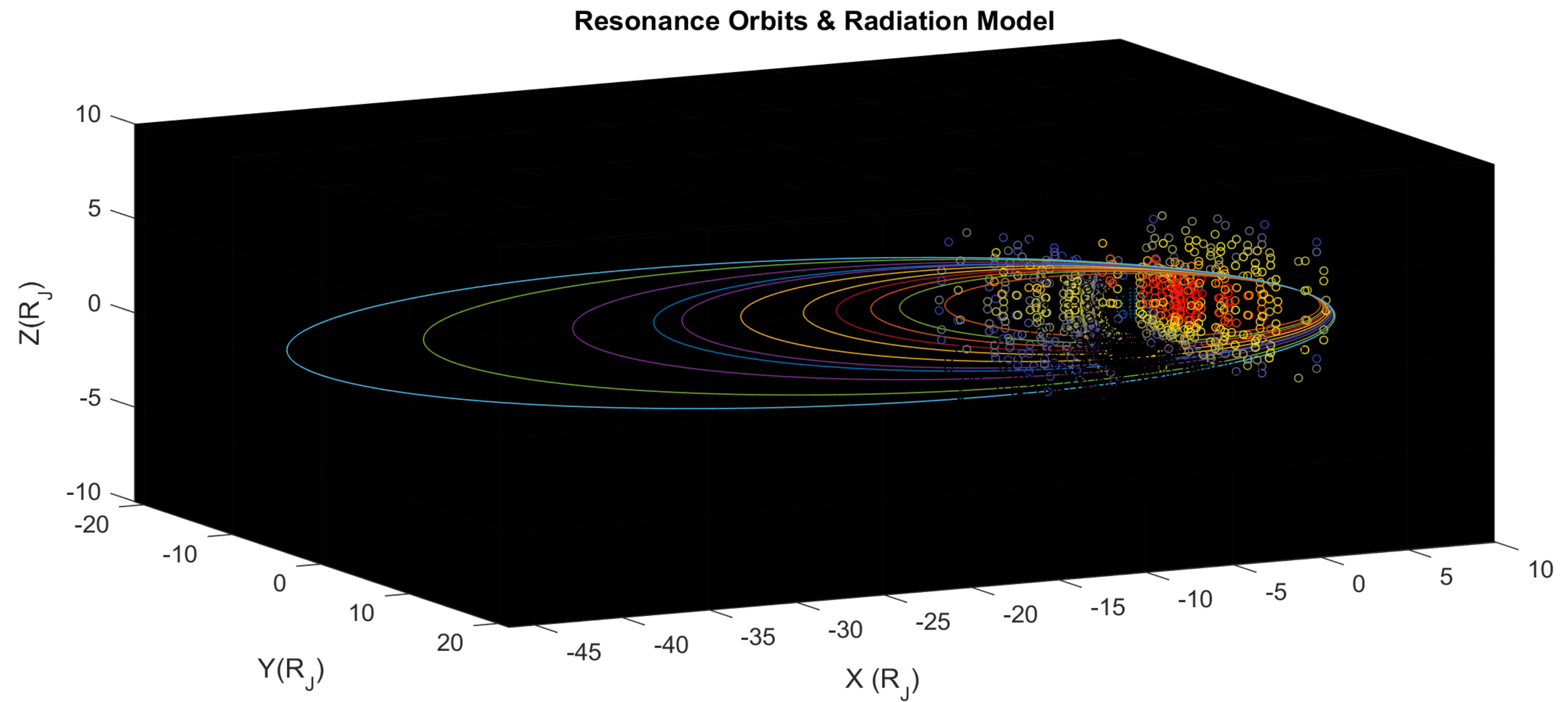


Figure 5: Resonance Orbits overlaid on Simply Radiation Model

Results and Analysis

The final radiation model and the various resonance orbits can be seen above in Figure 5. A final collection of 1716 test orbits is shown in Figure 6. Since it is required that at the end of a satellite's mission it must be destroyed and disposed of, the optimization algorithm calculates the number of visits based on a predetermined mission time. Then, the number of visits based on the maximum radiation damage allowed for the satellite is estimated. By comparing the number of visits for all orbits in the dataset, the optimum resonance orbit is determined as the orbit that has the greatest number of visits and lowest radiation damage.

The predetermined value for the mission time was set to be three years and the max allowable radiation damage is calculated to be 5492.7 (reaction/cm^2). It was assumed that the max radiation is around 30% of the max radiation on the data base. These values are used as the baseline for the optimization algorithm. The optimum orbit was determined to be an orbit with **resonate 1:5, inclination of 108˚, argument of periapsis of 360˚, and right ascension of the ascending node to be 0˚**. This orbit provides **61 visits of Europa** throughout the course of a **3 year mission time** with the **radiation level of 2394.8 (reaction/cm^3)**. This shows that the determining constraint was the set mission time. Figure 7 shows the optimum orbit overlaid on the radiation model.

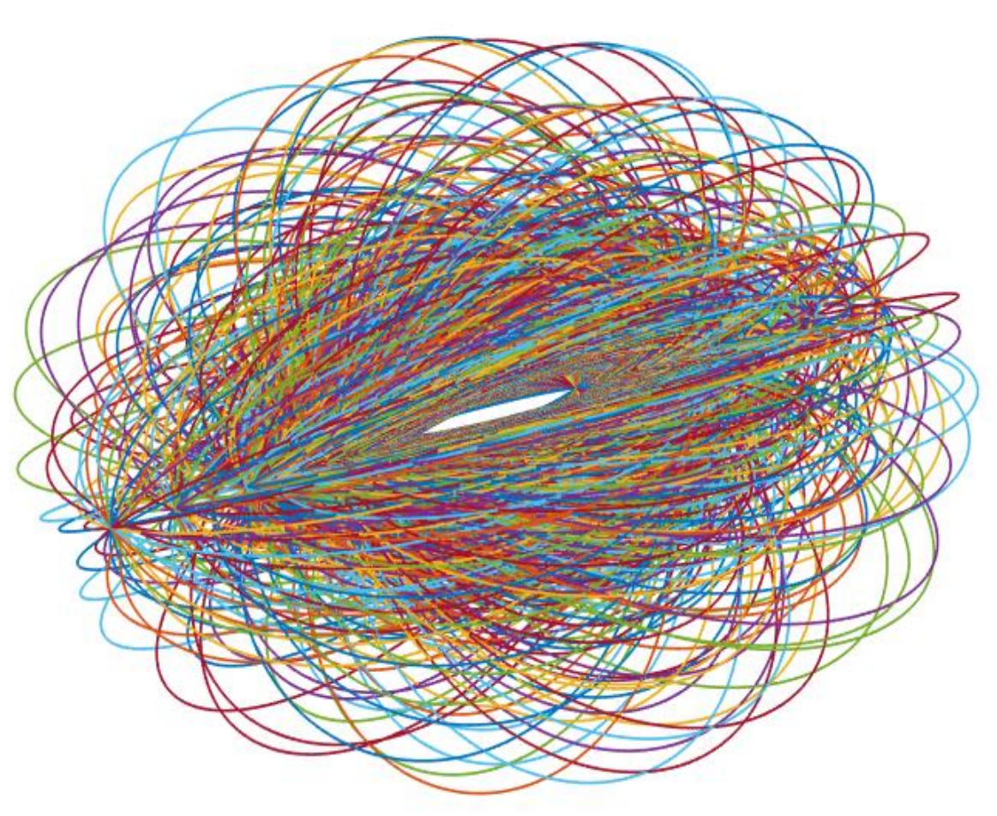


Figure 6: Collection of Test Orbits (1716 orbits)

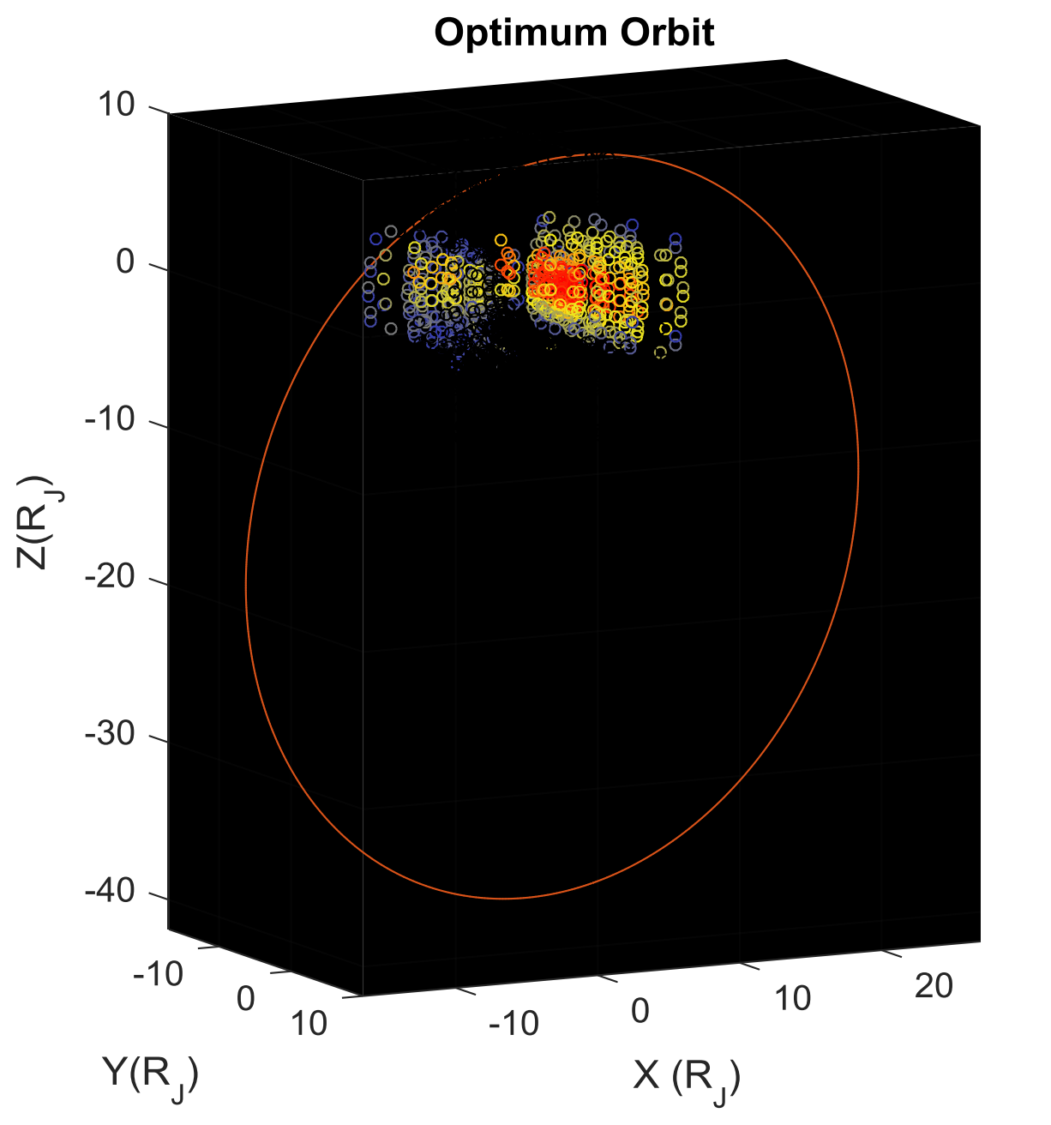


Figure 7: Optimum Orbit with Radiation Model (Orbit # 711)

Conclusion and Future Work

This algorithm and research provides a simple way to determine the radiation exposure and damage based on input orbits and determines the optimum orbit.

The future work involves creating a more complex radiation model around Jupiter to obtain more accurate radiation exposure. The optimization algorithm will also be expanded on based on more parameters such as ΔV to maneuver into an orbit. From all of this information a final optimized mission trajectory can be created.

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Try Lam – JPL/Lecturer, Aerospace Engineering Department

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