# Visualization of Planetesimal Close Encounters with Jovian Planets

Phu Kieu[1]
Mentor: Kevin R. Grazier[2]

California State University, Los Angeles[1],
Jet Propulsion Laboratory, California Institute of Technology[2]

**Abstract**

In a series of dynamical simulations, the trajectories and evolutions of 40,000 particles in the presence of the Jovian planets were simulated: 10,000 particles were in each of the inter-Jovian-planet gaps, and 10,000 in the Kuiper Belt. These simulations have shown that the perturbations from the Jovian planets destabilize a large amount of these orbits over relatively short periods of time compared to the age of the Solar System. In order to track the evolution of the planetesimals, the simulation software kept a database of information from every close planet/planetesimal encounter. In order to better analyze the simulation output, it would be beneficial to be able to visualize any of those encounters in order identify geometric trends in the evolution of the planetesimal swarm.

## Background

Earlier simulations have shown that the perturbation from the Jovian planets will destabilize the inter-planet orbits of planetesimals over time scales shorter than the age of the Solar System (1). It employed a total of 40,000 massless particles having both inclined and eccentric orbits. 10,000 were placed in each of the inter-Jovian planet gaps, and another 10,000 in the Kuiper belt. The planetesimal's orbits will destabilize due to close approaches to the Jovian planets. This may explain why observable planetesimals are absent from the zones between the Jovian planets.

These simulations kept a database of every planet/planetesimal close encounter since it is essentially the turning point of the planetesimals' life in the Solar System. To better understand the behavior of the planetesimals under the influence of the Jovian planets, the database will be revisited in order to recreate their trajectories. The trajectory information will be used to create a visual representation of the data.

## Methodology

The database contains the state vectors of the Jovian planets and the planetesimal for each close encounter. As with the original simulation, the inner planets were considered dynamically unimportant and having their masses combined with the Sun. The planetesimals were treated as massless and subject to the gravitational influences of the Jovian planets as well as the Sun, where the Sun and the planets were mutually interacting (2).

The fourth-order Runge-Kutta integration method is used in addition to Richardson extrapolation (RK4R) to recreate the trajectories of the particles to high precision. This is the same method used to generate the initial iterations required for to start the modified Störmer integrator (1).

The integrator performs on barycentric coordinates, so the values are converted before being passed to it. It will integrate until the planetesimal has exited the planet's gravitational sphere of influence, or a planetary collision has occurred.

However, there have been problems achieving the convergence criteria of maximum velocity error of $1.0 \times 10^{-18}$; the tolerance has thus been loosened to $1.0 \times 10^{-15}$. The RK4R method converges too slowly when the curvature of the orbit is too large, which occurs when the planetesimal is close to a planet.

**Visualization**

The particle trajectories are forwarded to the rendering module. It utilizes OpenGL using the help of an open source version of the OpenGL Utility Toolkit (GLUT), freeglut. The visualization module renders the positions of the particles in a three-dimensional space. It allows for frame-by-frame rendering (in terms of $\Delta t$) and playback. Camera controls are fairly primitive, but includes zoom, rotate, and follow. It also allows for particle scaling and the display of the gravitational sphere of influence.
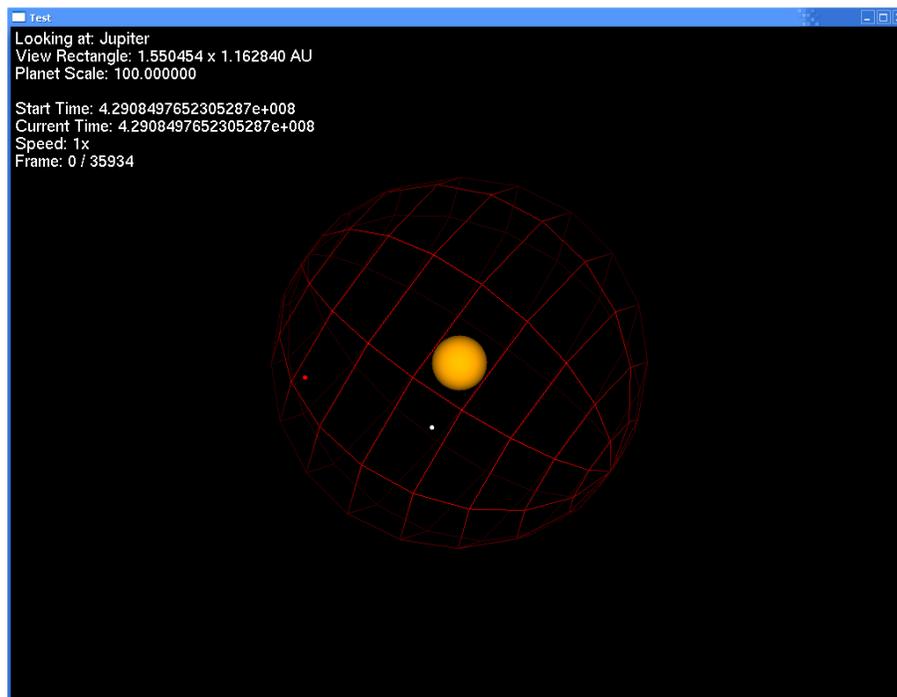


**Figure 1**. Visualization module. White particle is planetesimal at current frame, red particle is corresponding final frame. Red wireframe sphere indicates gravitational sphere of influence.

**Future Work**

The integrator will need to be changed or modified to achieve the precision desired. Tests have shown that over a time span of about 10 years, the error in the final particle position will be about 3 times Pluto's radius. To give another perspective on the error bounds achieved using the current method: a parse of one of the databases identified 2 planet collisions, but the original data indicates 162. The current plan is to implement the Bulirsch-Stoer algorithm.

To facilitate statistical analysis of the events during the close encounter, the visualization module may be missing a few features and some data output will be desired. In particular, the output of positions with respect to some rotational frame of reference is desired. With this, it will be simple to identify whether a planetesimal enters/exits a close counter sunward or anti-sunward, and the quadrant where each occurs.

**Acknowledgements**

**References**

1. **Grazier, Kevin R.** *The Stability of Planetesimal Niches in the Outer Solar System: A Numerical Investigation.* 1999.

2. *Dynamical Evolution of Planetesimal in the Outer Solar System.* **Grazier, Kevin R., et al.** Icarus, s.l. : Academic Press, 1999, Vol. 140.