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The Outer Solar System Perihelion Gap

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Abstract

In the outer solar system there is a gap where no distant high eccentricity objects have perihelia between 50 au and roughly 65 au. Objects are present on either side of this gap, however, suggesting that the gap is not merely a result of a lack of data. We have modeled the effect that a distant giant planet would have on a distribution of tens of thousands of test particles seeded in a grid in and around the gap and run for the age of the solar system. By utilizing a variety of parameters for the distant giant planet, we provide insight into the structure of the outer solar systems and for the search for additional planets beyond Neptune.

1. Introduction

In 2014, Trujillo and Sheppard noticed that there was a gap in perihelion between the detached Trans-Neptunian population and objects like Sedna. In the same work, they also noted that objects with large semimajor axes and perihelia exhibit orbital clustering and they suggested that this clustering could be explained by the presence of a distant undiscovered planet orbiting in the far reaches of our solar system [9]. The effects of the proposed planet have been explored extensively using dynamical simulations [1][2][4] (and references therein) and telescopic observations [5][7] (and references therein). However, the perihelion gap has remained largely unexplained and unexplored.

Recently, another outer solar system object, 2015 TG387, has been discovered on the distant side of the gap [8]. This object simultaneously constrains the size of the gap and solidifies the gap as feature of the outer solar system.

Examinations of the orbital properties of the most distant outer solar system objects suggest the gap in perihelion extends from 50 to about 65 au for high eccentricity objects (see Figure 1). Because the brightness of an object in reflected light drops off with distance R as R^{-4}, it should be significantly easier to detect objects within the gap, if they are present, than to detect objects past the gap such as Sedna.

This gap may help answer fundamental questions regarding gravitational interactions in our solar system by highlighting the dominant processes at the outer edge of the Kuiper belt. For instance, Neptune affects trans-Neptunian objects out to a distance of 60 au [3] and distant trans-Neptunian objects may be affected by a distant undiscovered giant planet [1]; thus, the gap may be an important transition region between Neptune and more distant objects.

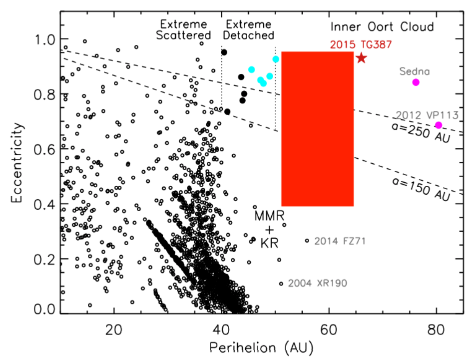

Figure 1: Eccentricity vs. Perihelion of every minor planet. Notice the lack of high eccentricity objects between 50 and 65 au as indicated by the red box. These missing objects are the subject of this investigation. Note that objects within the gap should be significantly easier to detect than objects beyond the gap as brightness in reflected light drops off with distance R as R^{-4}. (Adapted from Figure 1 in [8])

2. Methods

To explore the perihelion gap, we utilize the REBOUND N-body dynamics Python package [6]. Simulations contain the Sun, the giant planets, and one distant giant planet. Each simulation is run with different parameters for the distant giant planet in order to determine the effect that various estimates for the planet parameters have on creating and maintaining the perihelion gap. Additionally, tens of thousands of test particles are included in each simulation. These particles are distributed in a grid in orbital element space in and around the gap.

Simulations are carried out on the Northern Arizona University High Performance Computing Cluster, *Monsoon*. The test particles are affected by the gravity of the other bodies and are tracked for the age of the solar system (i.e. 4.5 Gyr). By determining which parameters for the planet clear out the gap, we provide a constraint on where a potential planet could be in orbital element space.

3. Summary

The outer solar system perihelion gap is thus far unexplained and relatively little has been done to explore its characteristics. Preliminary results from our modeling approach indicate that when only the Sun and giant planets are allowed to act on a suite of test particles (without a distant giant planet) a gap does not form. Moreover, if a gap matching observed perihelia (50-65 au) is present at the beginning of the simulation, particles from outside the gap have begun to fill in the gap within 700 Myr. This indicates that some mechanism for forming and maintaining the gap is required to satisfy observational constraints.

As more objects are discovered on both sides of the gap, we will be able to improve constraints on the formation and evolution of this intriguing phenomenon of the outer solar system.

Acknowledgements

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