Influence of Hypothetical Planet 9 on Dwarf Planet Pluto By Baron Li, Sophia Kressy

Abstract

In this paper, we study the influence of the hypothetical "Planet 9" on other objects in the solar system, especially inside the Kuiper Belt; we chose to focus on Pluto. We found that the mass of the 9th planet has a near-linear relationship with the eccentricity, orbital period, and semi-major axis of Pluto. Knowing the change in those parameters can help give a reasonable suggestion of the mass and distance of the theoretical "Planet 9".

Introduction

In early 2016, Caltech researchers Konstantin Batygin and Mike Brown analyzed irregular movements of objects in the Kuiper Belt to suggest the existence of an undetected mass large enough to be in the scope of our Solar System and named it "Planet 9" [1]. They used mathematical models to plot out Planet Nine's orbit after noticing a strange alignment in six other objects' orbits in the Kuiper Belt. They argued that this theoretical "9th Planet" has avoided human detection for centuries by lurking outside the Kuiper Belt, around 20 times farther from the Sun than Neptune is. The hypothetical planet was estimated to take between 10,000 and 20,000 Earth years to orbit the Sun fully.

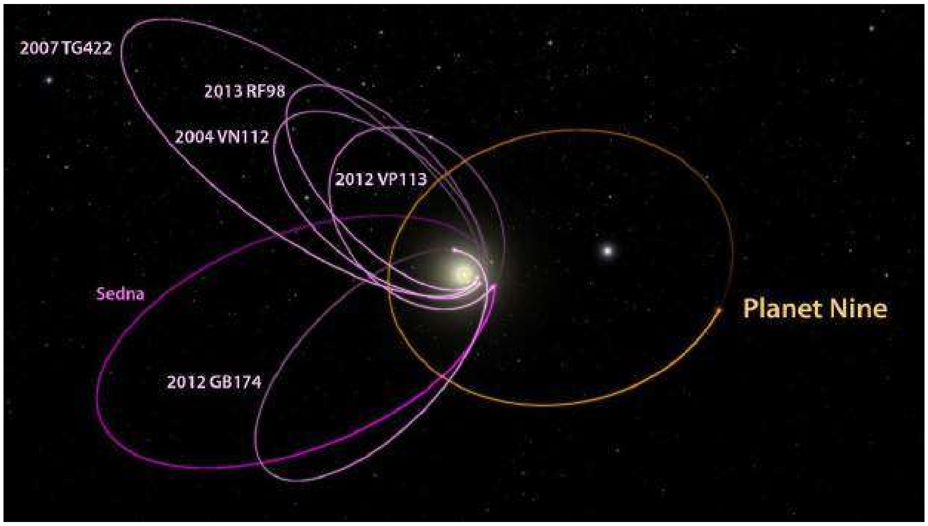

Fig 1: Hypothesized Orbit of Planet 9 Credit: R. Hurt (IPAC)/Caltech.

The existence of this planet remains theoretical at this point since it has yet to be observed directly. However, researchers found that the hypothetical object explains the tilt of the orbits of certain trans-Neptunian objects and the overall tilt of the solar system's orbit. Researchers from Cornell University also supported the existence of planet Nine [2, 3].

Although the existence of the 9th Planet has yet to be confirmed, in this paper, we research how the presence of a ninth planet might affect other objects in the Solar System. More specifically, we study the effects that would be made on the dwarf planet Pluto inside the Kuiper Belt.

Methods

We started with the GitHub repository SolarSystem [4] to simulate the solar system for our data collection. The software uses OpenGL, an API developed to render 3D and 2D vector graphics, to display Solar System movement scaled for visibility. The user can observe how each planet/moon rotates around the sun simultaneously.

The initial input of the software is the parameter data of 21 objects, including the Sun, the eight known planets, and some large moons around those planets. The parameters provide the necessary initial information for each object, including the mass and radius, initial xy coordinates for location, initial xy velocity, and color and scale factors for display purposes. A timestep is also defined as taking the orbit samples at certain time gaps.

We are interested in data collection using this software, with a hypothetical Planet 9, and studying the changes caused by this new planet. The original setup did not account for the tilts of each planet's orbit, i.e., z-coordinates and z-velocity. However, those values can be added to the parameter set if desired. In this project, we conducted the study in a two-dimensional plane because we decided it would be a minuscule change and better start with a simplified approach.

To precisely describe the forces between the planets, the simulation uses Newtonian Gravity and Mechanics, namely Newton's law of universal gravitation and Newton's second law of motion:

$$\vec{F}_i = \sum_{j \neq i}^{N} G \frac{m_i m_j}{r_{ij}^2} \hat{r}_{ij}$$

$$\text{With acceleration } \vec{a}_i = \frac{\vec{F}_i}{m_i}$$

G is the Gravitational constant (~$6.6743 \cdot 10^{-11} \frac{m^3}{kg \cdot s^2}$)

Here, m_i denotes the mass of an object i.

r_{ij} denotes the distance between two objects, i and j as a scalar; $\hat{r}_{ij}$ denotes the unit vector.

$\vec{F}_i$ and $\vec{a}_i$ denotes the force and acceleration on an object i.

For each object, the force and acceleration at a time will be calculated with the distance from and mass of every other object. The vector calculations were split into x and y directions separately. Velocity Verlet [5] is used in the simulation to track the object's movement. This algorithm approximates the position $\vec{x}$ and velocity $\vec{v}$ of the objects after a small timestep Δt by using the following equations:

$$\vec{x}(t + \Delta t) = \vec{x}(t) + \vec{v}(t)\Delta t + \frac{1}{2}\vec{a}(t)\Delta t^2$$

$$\vec{v}(t + \Delta t) = \vec{v}(t) + \vec{a}(t)\Delta t,$$

where
x is position
t is time
v is velocity
a is acceleration

The accuracy of this numerical method depends on the size of the timesteps. The smaller the timestep, the more accurate it is, with an error term of $O(\Delta t^2)$, but a smaller timestep also ends up taking a lot more processing power and time. Therefore, choosing a proper step size is necessary to tradeoff between accuracy and power/speed. Due to limited processing power and time, we experimented with a few options and decided to use 1800 seconds (i.e. 30 minutes) for the Velocity Verlet between each calculation.

We then added Planet 9 as the 22nd object in the simulation to see how things would change. Here are the prerequisites we made for Planet 9:

- The distance between Sun and Planet 9 is 20 times the distance from the Sun to Neptune. It shows as the initial x-coordinate in the parameter set.
- We tested the simulation with a Planet 9 of mass 20, 50, 100, and 200 times that of Earth individually.
- The timestep for data collection is 1800 seconds.
- Based on the assumption that the distance D from Planet 9 to the Sun is about 20 times as far from Neptune to the Sun and the orbit period P is around 10,000 years, we set the initial velocity parameter as 1700 by roughly calculating it as (2π*D/P).

To efficiently collect the data while running the simulation, we dumped the object position (x and y coordinates) and velocity (x and y components) into one file after every Verlet step. We also calculated roughly how many iterations it would take each object to complete one orbit cycle, then stopped the data collection afterward to limit the running power and output file size for processing. Python scripts were used for further data processing and figure plots.

We chose to focus on Pluto for this study because it is far from the Sun, and has a small mass, both of which would make it more vulnerable to the effect of Planet 9's gravitational pull. Figure 2 is the graph of the orbit made by Pluto with the simulation:

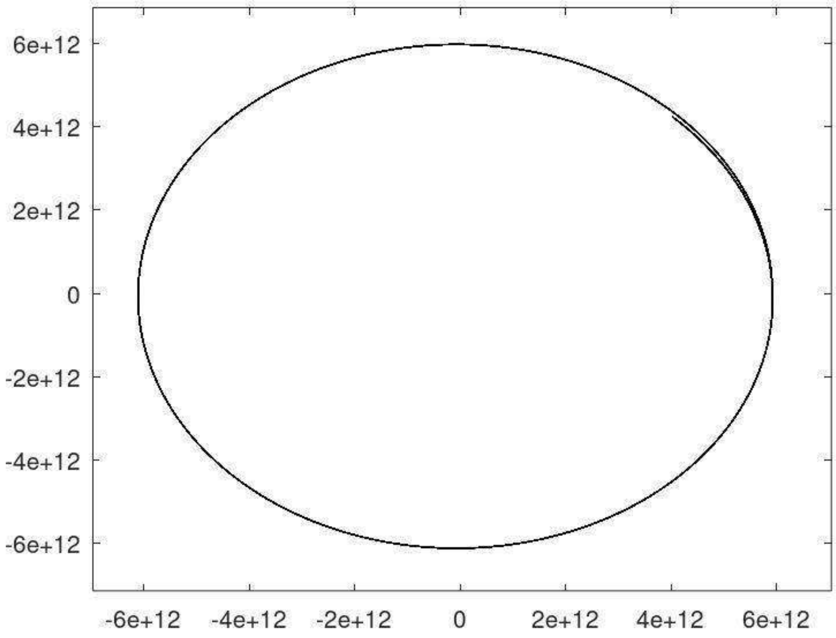

Fig 2: The orbit of Pluto without Planet 9 (Distance from the sun in km; Sun is at (0,0)).

Data Processing

We first explored the relationship between the orbital period of Pluto and Planet 9. The orbital period was detected by counting the timestamps Pluto took to overlap its original position. The orbital period of Pluto showed a directly proportional relationship with the mass of Planet 9 (Fig. 3). The bigger the mass of Planet 9, the faster Pluto orbits. Notice that the difference is small, with about a 0.02% change from no Planet 9 to Planet 9 being 200 times the mass of Earth. Also notice how linear it is, with only small fluctuations between the lines formed from connecting each point.

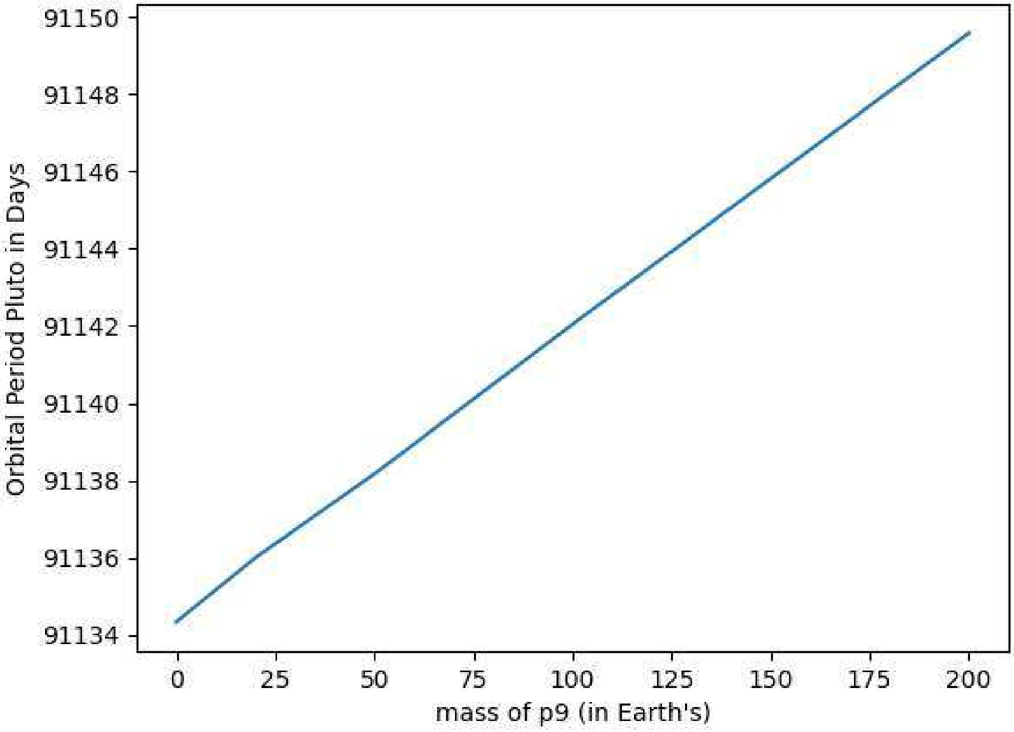

Fig 3: Orbital period of Pluto vs Mass of Planet 9.

Given the above curve, we can fit the data with linear regression (Least Mean Square Error):

$$y = 454011.25x + 6.14514 \cdot 10^{12}$$

We also looked into the length of the semi-major axis and eccentricity. Figure 4 shows the variation of these conditions between different hypothetical masses of Planet 9.

To find the semimajor axis and eccentricity, we ran the data through code that found the largest and smallest distances from the center of the orbit to Pluto. We treated the largest as the semimajor axis and the smallest as the semiminor axis; we found the eccentricity with the following formula:

$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

with a being the semimajor axis, and b being the semiminor axis.

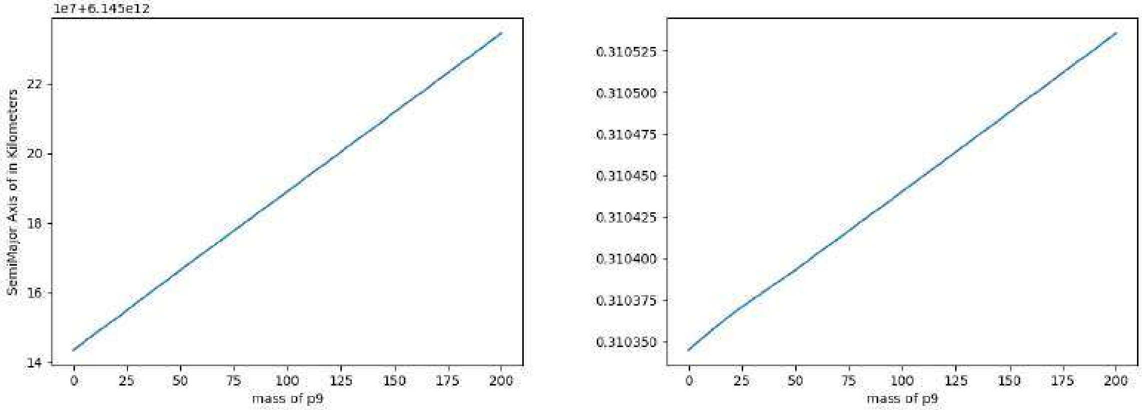

Fig 4: SemiMajor Axis (in km) and eccentricity of Pluto vs Mass of Planet 9 (in Earth's)

Our study showed that the mass of the ninth planet would be directly proportional to the eccentricity, orbital period of Pluto, and the Semi-Major axis of Pluto. All 3 of these conditions were near-linear and increased at very similar slopes.

Even though our data is not completely accurate, it still can represent the relationship between the mass of a hypothetical ninth planet and the objects in the Solar System. The results would help to understand the actual effect on Pluto and other objects in the Kuiper Belt, given any mass of Planet Nine.

Conclusion

We researched the effects of a hypothetical Planet 9, given its mass, on the objects of the Solar System. We used a simulation [4] to collect data for our study and processed it to find Pluto's orbital period, eccentricity, and semimajor axis with 5 separate masses of Planet 9. Our findings were that the mass of Planet Nine had a directly proportional relationship to the eccentricity, orbital period, and the Semi-Major axis of Pluto.

This research can help us redefine what we know about the solar system if the existence of a 9th planet is further considered or confirmed in the future. Further study can also use a similar approach to identify the mass and distance of Planet 9, given the real-time ground truth orbital information of other planets in the Kuiper belt.

Future Studies

Here is a list of some things that could be done to further this research:

- A more precise algorithm, such as Verlet Integration, can be used to calculate the movements of the Solar System objects.
- Add more objects to a simulation of the Solar System, such as the rest of the Kuiper Belt
- More accurate initial parameters should be added to the study, such as the z-axis.
- Use the ground truth of movements observed in our Solar System to reach further conclusions.

Works Cited

1. Batygin, Konstantin, and Michael E. Brown. "EVIDENCE for a DISTANT GIANT PLANET in the SOLAR SYSTEM." The Astronomical Journal, vol. 151, no. 2, 20 Jan. 2016, p. 22, arxiv.org/pdf/1601.05438.pdf, https://doi.org/10.3847/0004-6256/151/2/22.
2. Brown, Michael E, et al. "A Pan-STARRS1 Search for Planet Nine." ArXiv (Cornell University), 31 Jan. 2024, https://doi.org/10.48550/arxiv.2401.17977. Accessed 30 Dec. 2024.
3. Naess, Sigurd, et al. "The Atacama Cosmology Telescope: A Search for Planet 9." The Astrophysical Journal, vol. 923, no. 2, 1 Dec. 2021, p. 224, https://doi.org/10.3847/1538-4357/ac2307. Accessed 25 May 2022.
4. aromanro. "SolarSystem/README.md at Master · Aromanro/SolarSystem." GitHub, 2016, github.com/aromanro/SolarSystem/blob/master/README.md.
5. Verlet, Loup. "Computer "Experiments" on Classical Fluids. I. Thermodynamical Properties of Lennard-Jones Molecules." Physical Review, vol. 159, no. 1, 5 July 1967, pp. 98–103, https://doi.org/10.1103/physrev.159.98.