Investigation of a Ninth Planet

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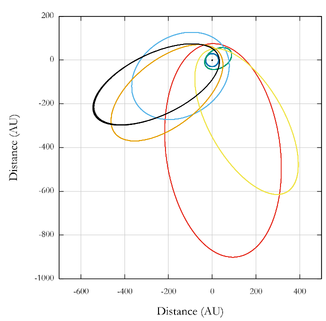
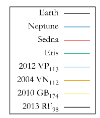
Supporting Evidence

Recent discoveries show a collection of distant Trans-Neptunian Objects (TNOs) exhibit unusual similarities in orbital behavior and physical location. This leads astronomers, most notably Batygin and Brown (2016a), to believe there exists a ninth, Neptune-sized, planet in our solar system that perturbs these small objects into similar orbits through long term interactions. This work seeks to provide further evidence of such a planet as well as an approximate location in space where it might be observed.

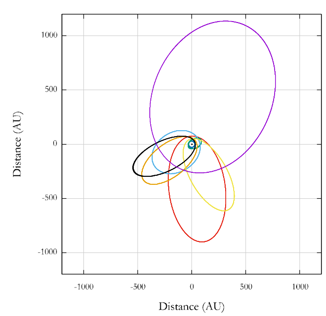
Distribution of TNOs

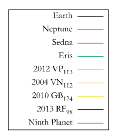




The distribution of Trans-Neptunian Objects (TNOs) is expected to be random and uniform, however recent discoveries of new TNOs show an unusual clustering of several distant objects.

Anti-Aligned Orbits





A leading hypothesis for this unlikely distribution is a massive (Neptune-sized) planet on an anti-aligned orbit, causing these smaller objects to have highly eccentric and inclined orbits.

Significance

A ninth planet could explain the observation of aligned TNOs. T origins of such a planet include theories of ejection from the in solar system to capture of a rouge planet [Malhotra et al. (2016), and Adams (2016)]. Currently, leading astronomers are searching this planet in images taken during the NASA's WISE missi Researcher Mike Brown is also utilizing the Subaru Telescope in Hav in hopes of directly observing this theoretical planet. Confirmation this potential member of the solar system can help explain previou unexplained deep space behavior.

Acknowledgements

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Referenced Material

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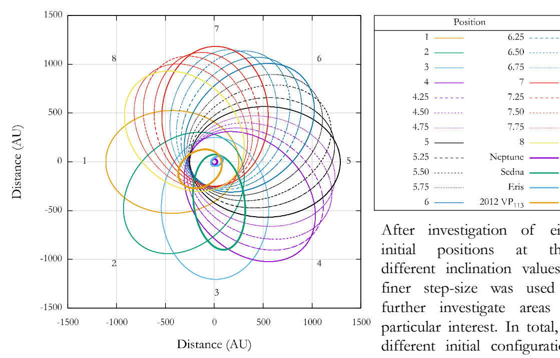
Malhotra et al. (2016) Coralling a Distant Planet with Extreme Resonant Kuiper Belt Objects
Lie G., Adams F. C., (2016) Interaction Cross Sections and Survival Rates for Proposed Solar System Member Planet Nine
Millholland S., Laughlin G., (2017) Constraints on Planet Nine's Orbit and Sky Position within a Framework of Mean Motion Resonances, AJ 153 (3):91

Method

Numerical models of the solar system were constructed to determine potential positions and characteristics of a ninth planet. Output information was analyzed against a control simulation in which no ninth planet was present. Simulation data was also compared to observational data for inconsistencies which would disqualify any possible configuration. A total of twenty eight TNOs were included in the simulations with all eight planets for a total of thirty six objects. Our theoretical planet was given characteristics similar to those described by Batygin and Brown (2016a) and Millholland and Laughlin (2017).

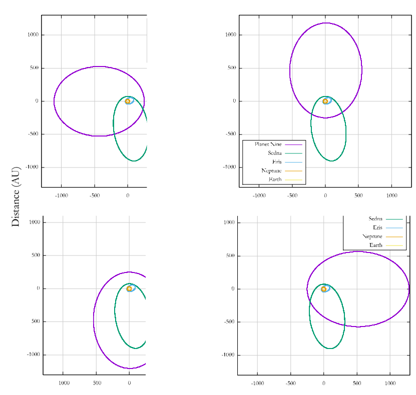
Investigated Orbits of a Ninth Planet with Reference Objects



After investigation of eight initial positions at three different inclination values, a finer step-size was used to further investigate areas of particular interest. In total, 61 different initial configurations were assessed.

Behavior of Interactions

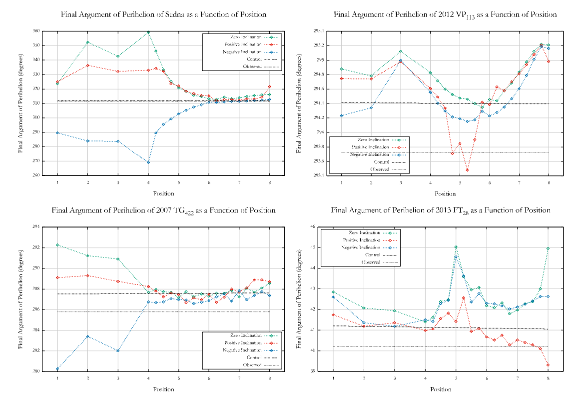
Interactions within a planetary system behave much like coupled oscillators, transferring energy back and forth over large time periods. For this reason, different spatial configurations will lead to vastly different planetary interactions. These differences were used to quantify the possibility of an additional planet and exclude simulations that lead to unstable solar system configurations. Using a large number of initial conditions allows for determination of possible orbits of a ninth planet. Instability and deviation from observed phenomenon are key criterion for significance.



Four examples of general configurations that would be expected to generate vastly different interactions between a distant detached object and a larger perturbing object. Instances in which the interacting planets are at right angles (top left and bottom right) would have the potential to produce the greatest changes in the smaller objects' orbit.

Analysis of Orbital Elements

The orbit and position of any celestial body can be completely described through six orbital elements. When combined, these elements: eccentricity, inclination, longitude of ascending node, argument of perihelion, mean anomaly, and semi-major axis, can locate an object in space. Tracking how these elements change over a large time interval can show how a smaller body is effected by a larger planet. In this study, we looked for orbital elements, such as inclination and argument of perihelion, to converge toward observed values over time.



Final argument of perihelion values for select Trans-Neptunian Objects of interest. Argument of perihelion is an orbital parameter that relates the point of closes approach of an object to a reference system.

Demonstration of Perihelion Precession

Analyzing values of argument of perihelion for each TNO as a function of the initial position of a ninth planet not only demonstrated a varying effect on the final argument of perihelion but also provided an interval over which the final argument of perihelion was driven toward the observed and accepted values for these TNOs. Although the integration was over 1Myr, the precession of argument of perihelion toward the observed value is a strong indicator of a stable solar system.

Simulation Results

The above plots demonstrate the precession of argument of perihelion and exhibit the ability of a ninth, Neptune-sized, planet to influence the orbits of smaller, distant objects. These intervals of existence are in direct agreement with the anti-aligned orbit proposed by Batygin and Brown (2016a). Although the characteristics of our ninth planet do not exactly match those of Batygin and Brown, we still see the same behavior. This would suggest there is a large uncertainty in the exact physical characteristics of this undiscovered planet as suggested by Millholland and Laughlin (2017).

Continuations

Throughout this work, the orbital element describing the radial direction of an orbit was analyzed. In future work, we seek to analyze more orbital elements, such as inclination, in order to better characterize the effects of a large body on these smaller distant objects. Future simulations would also incorporate more values of inclination as well as a finer step size for the potential orbits of this ninth planet.