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The orbit of Planet Nine

Michael Brown ,Konstantin Batygin
Caltech, Pasadena, CA, USA (mbrown@caltech.edu)

1. Introduction

The most distant objects in the Kuiper belt show statistically significant clustering in longitude of perihelion and in pole position which can be explained by the presence of a giant planet on an inclined, circular orbit with a semimajor axis of hundreds of astronomical units, known as Planet Nine [1]. To date the only constraints on its mass and orbital elements have come from attempts to compare specific features in the orbital distribution of bodies from the output of N-body simulations to the known distribution of objects [2,3]. This technique suffers from a lack of taking into account observational bias [4] and from potentially arbitrary choices made in selecting parameters. We present a method that, instead, compares a full suite of N-body models to the known observations fully taking into account observational bias and using a maximum likelihood method to directly compare models and data. From these we derive orbital elements of Planet Nine along with realistic uncertainties.

2 Method

Correctly understanding the observational biases is a critical step that must be undertaken in order to compare an unbiased model with the real observations. We have performed a meta-analysis of all KBO discoveries in order to determine the bias function for each of the known distant KBOs. These bias functions give the probability of detection an object with the semimajor axis and eccentricity of a known distant object if such objects were uniformly distributed in pole position and in longitude of perihelion. A separate bias function is computed for each distant object

We create a suite of ∼100 simulations of the effects of Planet Nine on the scattered disk of the Kuiper belt. In each simulation we integrate ∼30,000 particles with semimajor axes between 100 and 500 AU and perihelion between 30 and 50 AU for 4 billion years. The simulations include Planet Nine masses between 4 and 20 Earth masses, semimajor axis between 280 and 1500 AU, and inclinations from 0 to 40 degrees.

For each simulation, we create determine a probability distribution for the detection of each distant object for all combinations of longitude of perihelion and pole position. Each of these is multiplied by the bias function to find the likelihood of finding each of the real distant objects at its observed location in each simulation. The sum of the log-likelihoods is then the overall likelihood for each simulation. While the likelihoods can be used to find maximumlikelihood values for each of the orbital elements (and the mass), we instead use the observed likelihoods to build a Gaussian process emulator that can be run to build a full set of posterior distributions from a Markov Chain Monte Carlo model.

3 Results

The final results to be presented will be the first full sets of orbital elements of Planet Nine along with realistic uncertainties. From these we will also determine the probability distribution of position of Planet Nine on the sky and discuss possibilities for imminent discovery.

3.1 References

[1] K. Batygin and M.E. Brown, Evidence for a distant giant planet in the outer solar system, AJ, 151, 22, 2016.
[2] M.E. Brown and K. Batygin, Observational constraints on the orbit and location of Planet Nine in the outer solar system, ApJ, 824, L23, 2016.
[3] K. Batygin, F.C. Adams, M.E. Brown, J.C. Becker, The Planet Nine Hypothesis, Physics Reports, in press, 2019
[4] M.E. Brown, K. Batygin, Orbital clustering in the distant solar system, AJ, in press, 2019.