Apr 22nd, 8:30 AM - 10:00 AM

Distant Giant Planets and their Influence on Inner Planet Formation

Caroline Witt
Missouri State University

Distant Giant Planets and their Influence on Inner Planet Formation

Caroline Witt
Missouri State University
Dr. Sarah J. Morrison

Abstract

The most common planets within 1 AU of a star are a few Earth radii in size, dubbed 'super-Earths', and these planets exhibit a wide range of compositions and orbit properties. Yet our Solar system lacks a super-Earth. It is also known that it is possible for exoplanet systems to include a massive planet with an orbit distance of a few AU from the host star, similar to Jupiter in our solar system. It is natural to then question how the presence of such a massive, distant planet may affect the overall exoplanet system. This project investigated how the presence of a Jupiter-like planet impacts the formation history of the inner planets in an exoplanet system by running simulations of evolving planetary systems, analyzing their results, and comparing them against simulations that were nearly identical, except that they did not have a Jupiter-like planet present.

Introduction

It's fairly common for planets within 1 AU of their host star to be a few Earth radii in size[1]. Such planets are known as 'super-Earths' and can otherwise have a wide variety of compositions and orbital properties[2 3]. Noticeably, our solar system has no super-Earth. However, we do have Jupiter, a gaseous giant planet that is more than twice as massive as all the other planets in our solar system combined. It is natural to then wonder how much Jupiter affected our solar system's evolution and question if Jupiter is responsible for our lack of a super-Earth.

To help answer such questions, this project investigated the effects an already-present distant giant planet may have on still-forming planets near their host star. Using code and base initial condition parameters for planetary embryos from previous studies[4], this project conducted simulations in two stages. The first stage spans 1 Myr and simulates the presence of a dissipating disk and planetesimal mergers. The second stage, which lasts 27 Myr, operates like there is no residual disk remaining and focuses on simulating dynamical evolution within the system.

Simulating the Giant Impact Phase of Planet Formation within 1 AU

Stage 1:

Pre-existing input files detailing the initial conditions of planetary embryos[4] were modified to include the presence of a planet at 5 AU with Jupiter's mass. Compiled mercury code and shell script were utilized to run the Stage 1 simulations for 5 solar systems. Once the Stage 1 simulations were complete, compiled Fortran code was used to convert raw output binary files and produce text output files with data about time, orbital elements, and planetary mass.

Stage 2:

Files containing information at restore points generated from the Stage 1 simulations were used to create the input files for Stage 2. However, the epoch was reset to be 0. Additionally, the input file used for Stage 2 that denotes start and end times, as well as output timesteps, was independent of Stage 1's similar input file. The compiled mercury code and shell script mentioned earlier was also used to run the Stage 2 simulations. After the Stage 2 simulations were complete, compiled Fortran code was again used to convert raw output binary files into text output files containing data about time, orbital elements, and planetary mass.

Examining the Planet Mass and Orbit Eccentricity Distributions After Disk Dispersal and Subsequent Evolution

Planet mass distributions with distance from the host star were analyzed for one set of initial conditions and shown in Figures 1 and 2. Excluding Jupiter, there were 18 planets that survived to the end of Stage 1 (as the disk dispersed). However, by the end of Stage 2, these planets grew into just 9 planets. So while merging events occurred in both stages, such events were much more frequent in Stage 1 during the disk stage, considering that there were 162 planetary embryos to begin with.

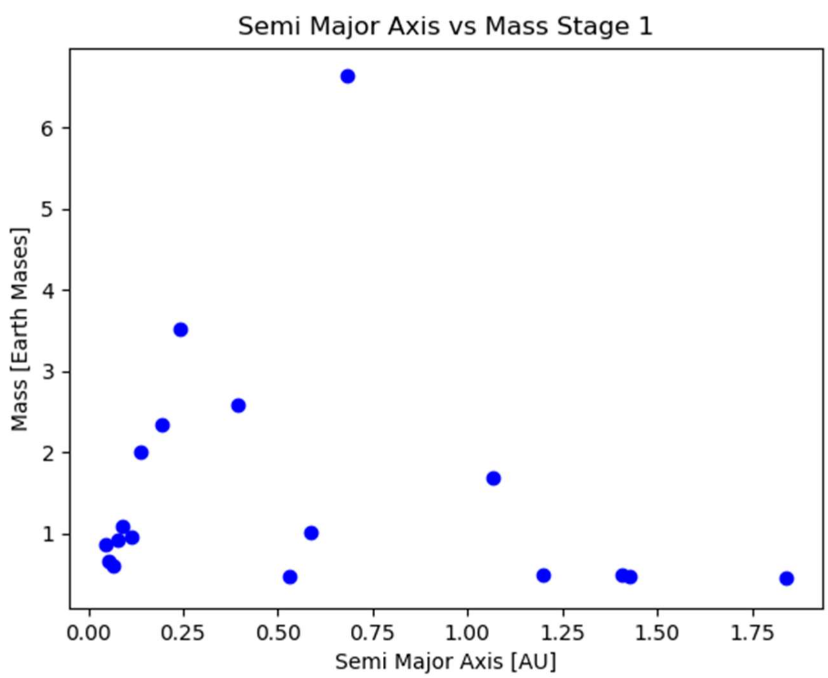

Figure 1: Example initial mass distributions of planetary material shortly before disk dispersal.

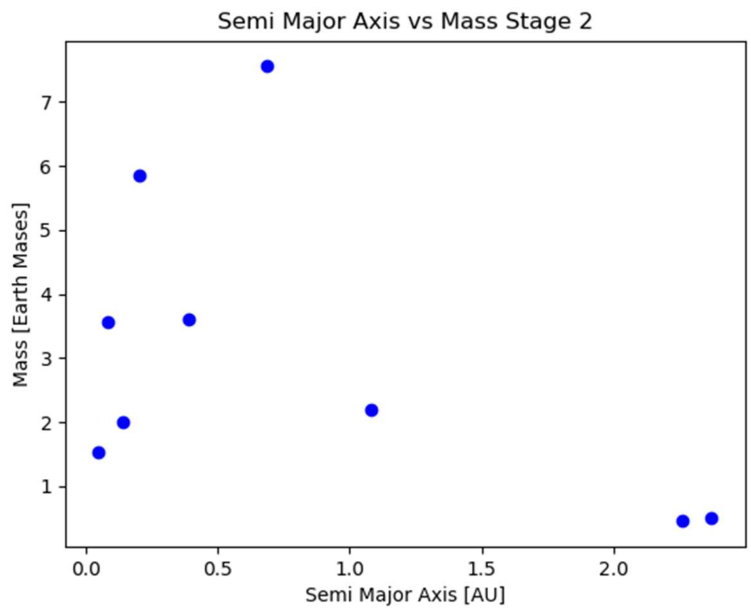

Figure 2: Example final mass distributions of planetary material after subsequent evolution.

The figures below demonstrate that over time, the planets migrate farther out and the overall range of eccentricity in the system lessens. Notably, the orbit eccentricity is much more evenly distributed with distance from the host star in Stage 2 than Stage 1. This could be a result of Stage 2 having half as many planets present as Stage 1. In addition, the 27 Myr span of Stage 2 may have also been a factor in allowing the eccentricities to disperse more evenly.

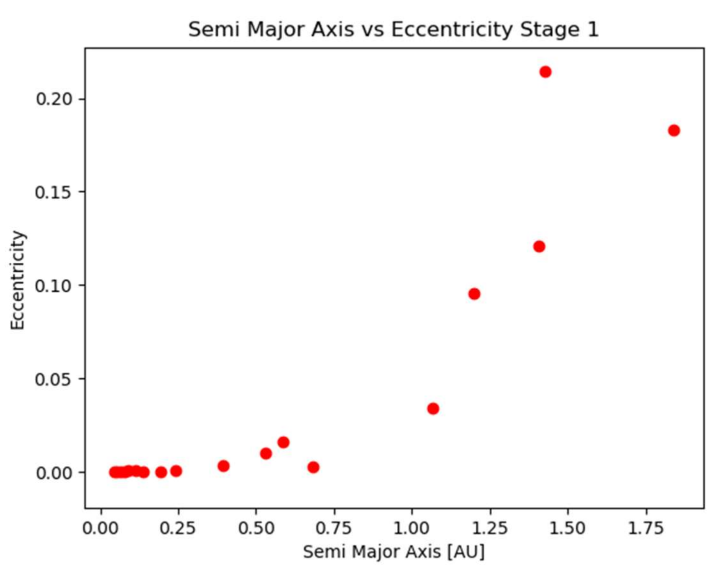

Figure 3: Example initial eccentricities before disk dispersal.

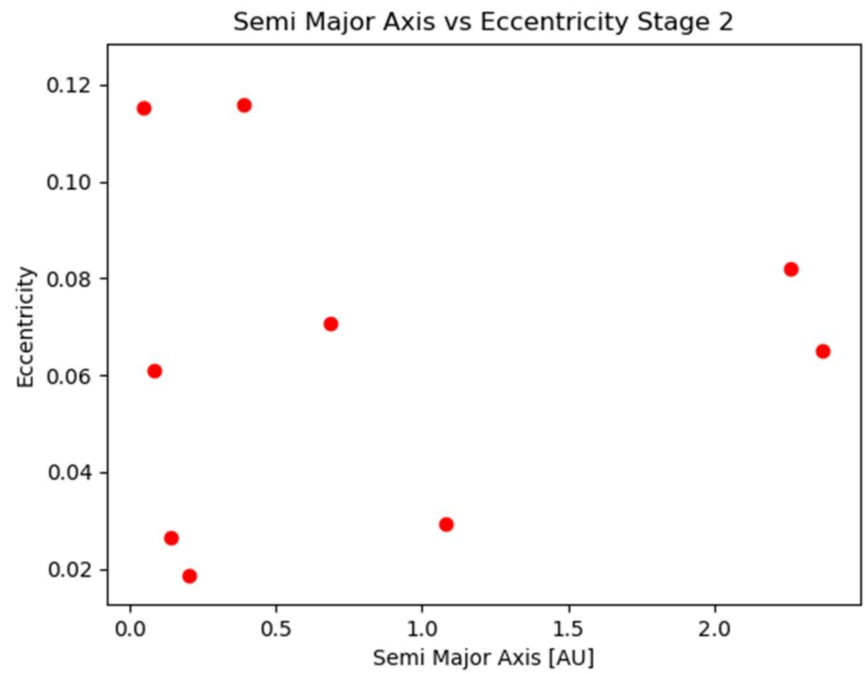

Figure 4: Example final eccentricities after subsequent dynamical evolution.

Comparisons of Planet Production, Merger Occurrence, and Average Eccentricity of Planetary Systems

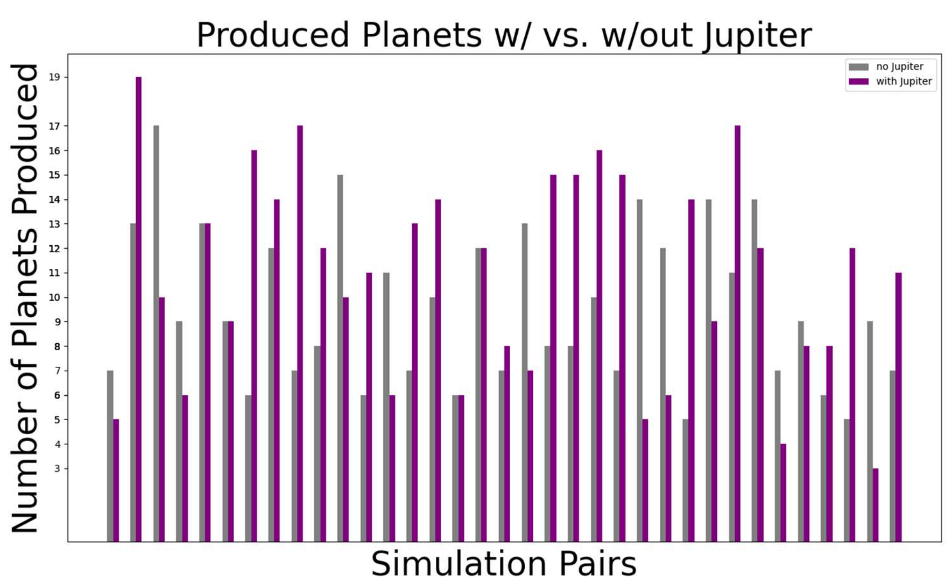

Figure 5: This figure displays a direct comparison of the number of planets produced in systems with and without a Jupiter-like planet.

As shown in Figure 5, there is a slight tendency for a system with a Jupiter-like planet to produce a higher number of planets than its Jupiter-less equivalent system. It should also be noted that while it is uncommon, we found that it is possible for the planetary systems to end up with the same number of planets regardless of whether the giant distant planet was present or not.

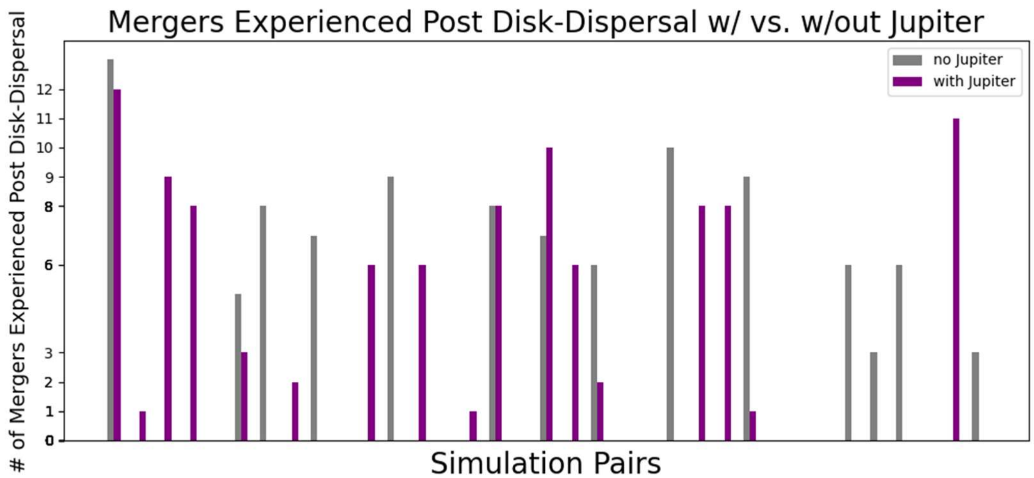

Figure 6: This figure displays the number of mergers experienced and the average system eccentricity for many simulations.

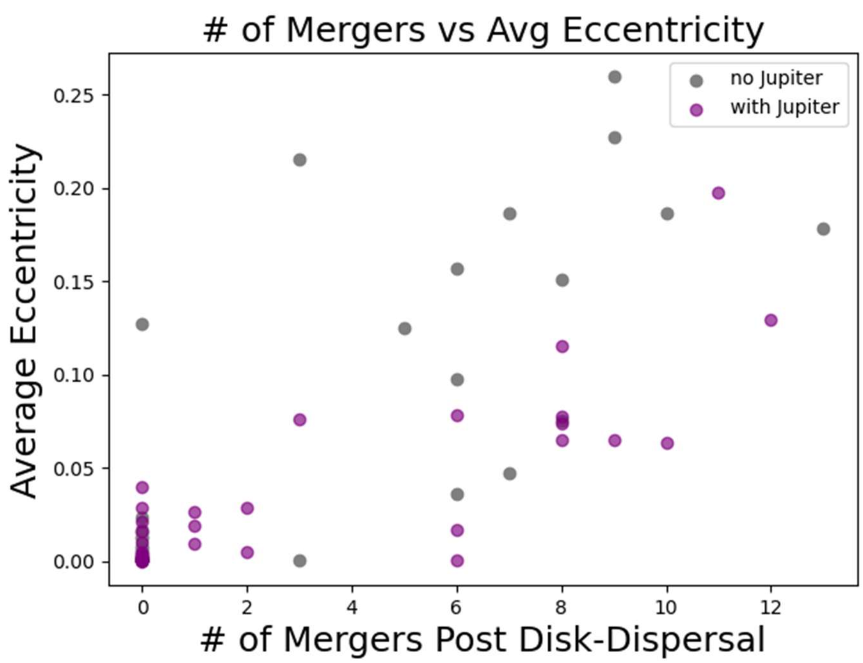

Figure 7: This figure displays the number of mergers experienced and the average system eccentricity for many simulations.

Our results also show that the systems with a Jupiter-like planet present seem to have lower average eccentricity in general, and that the Jupiter-having systems overall reach a lower maximum average eccentricity than the systems that are without a Jupiter-like planet. It should be noted, however, that it seems as if both versions of the exoplanet systems can produce the same general range of possible mergers to be experienced post disk-dispersal. Additionally, we found that when considering all of our simulated systems (not on a one-to-one comparative basis), Jupiter-having systems are more likely to undergo mergers post disk-dispersal.

Discussion and Future Work

As this project progresses, the results from all simulations will be analyzed to identify trends in the planet mass and orbit eccentricity distributions with distance from the host star. The outcomes of simulations run without a Jupiter from previous studies[4] will also be compared to simulations from this project with a Jupiter present. The comparisons made will give insight on if the resulting distributions of planet multiplicity, masses and orbit eccentricities share any similarities when the inner planets formed in a system with a Jupiter versus a system without one.

Acknowledgements

This research was conducted under the supervision of Dr. Sarah Morrison and was supported by NASA-Missouri Space Grant Consortium Cooperative Agreement #80NSSC20M0100 and Missouri State University.

Biography

Caroline Witt is an undergraduate junior at Missouri State University studying Physics with an emphasis in Astrophysics. She plans on continuing to participate in research-oriented environments in the industry after graduation.

References

[1] Burke, C. J. and 24 colleagues (2015)., Terrestrial Planet Occurrence Rates for the Kepler GK Dwarf Sample. The Astrophysical Journal 809. doi:10.1088/0004-637X/809/1/8

[2] Weiss, L. M., Marcy, G. W. (2014). The Mass-Radius Relation for 65 Exoplanets Smaller than 4 Earth Radii. The Astrophysical Journal 783. doi:10.1088/2041-8205/783/1/L6

[3] Wolfgang, A., Rogers, L. A., Ford, E. B. (2016). Probabilistic Mass-Radius Relationship for Sub-Neptune-Sized Planets. The Astrophysical Journal 825. doi:10.3847/0004-637X/825/1/19

[4] Morrison, S., Dawson, R. I., MacDonald, M. (2020), Chains of Planets in Mean Motion Resonances Arising from Oligarchic Growth, The Astrophysical Journal 904, doi:10.3847/1538-4357/abbee8