The Iby and Aladar Fleischman Faculty of Engineering
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Subject: Planetesimal Capture - Calculations of the Efficiency of Planetesimal Accretion

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Graphs

1. Introduction

This year I took part in the Research Project for Excellence Program in which I joined Prof. Morris Podolak's research. The subject of the research I participated in is Planetesimal capture and the purpose is to compute the trajectories of small bodies, called planetesimals, to see how many are captured by Jupiter as it grows and how it affects the planet. Later on we added Saturn to the calculation in order to compute how many planetesimals are captured by each planet in this case, how it affects the planets and what are the differences between both those cases. The long term goal is to understand how the presence of Saturn affects the capture rate and how originally Jupiter was created.

2. Background

Planetesimal accretion is a crucial part of planet formation because it determines the composition of the core and envelope, amongst other things. The accreted mass of planetesimals depends strongly on their size and composition. The rate of planetesimal accretion consists of two processes. The first is the trajectory of the planetesimal about the Sun and the second is the trajectory of the planetesimal through the envelope of the planet. The trajectory about the Sun determines the parameters of the encounter with the envelope. These, in turn determine the interaction of the planetesimal with the envelope, and whether it is captured. In order to carry out the calculations in this study we used a program called Mercury to calculate the accretion rate of planetesimals in the presence of the Sun and a growing Jupiter and Saturn as the purpose was to calculate a more accurate mass accretion rate for the growing protoplanet. By running Mercury with and without Saturn, we were better able to understand what effect Saturn has. [1]

3. The Process

At the first stage of the study we considered a three body system of the Sun, Jupiter and a planetesimal of negligible mass. Jupiter orbits the sun at a distance of around 5.2 AU. We used a file that has a list of over 1000 planetesimals that start at distances of between 3.7 and 6.7 AU from the sun, so they are in a ring around Jupiter with a Hill sphere radius on either side. A challenge we encountered was that Mercury can only handle 50 planetesimals at a time so I had to copy 50 planetesimals from the file, run

Mercury, record the results, and then copy another 50 and so on until I had gone through the whole set.

In the second stage I added to the calculation the effect of Saturn, and repeated the process of the first stage. Since Saturn was growing in the meantime and we did not know how fast it grew, we performed the calculations with different values of Saturn's mass. At each step of the integration Mercury fit an orbit to the different bodies and tried to estimate if they will collide or if the planet will eject the planetesimal. My main role in the study was to do a preliminary investigation of what changed when we added Saturn.

After we received the data, the third stage occurred and it included organizing the data in Excel sheets and analyzing it for the first stage and second stage separately. The relevant data that we observed was the planetesimals' coordinates and velocities at the beginning and end of the run and which if any planetesimals collided or were ejected. For each of the planetesimals that was captured or ejected I added the time at which this happened to the excel file. I also took note of the planetesimals that hit Saturn and the time it happened. In addition, I calculated the semi-major axis of the orbit and it's eccentricity at the beginning and end of the run. In a separate Excel sheet I documented the planetesimals that were not captured in each case and their final and initial eccentricities.

4. Comparisons

The case in which Saturn was always small will be referred to as the first case and the case in which Saturn grew quickly compared to Jupiter will be referred to as the second case. In each case time is expressed relatively to integration start time. The radius of central body is 1.496×10^{10} and central mass (solar units) is 1.0. In both cases I ran the planetesimals for the same total time, 1.1×10^{9} days.

I found that if you assume that Saturn grew slowly compared to Jupiter, and was always small while Jupiter was growing, then Jupiter was able to pick up about 65% of the planetesimals in its vicinity. But if Saturn grew quickly compared to Jupiter, and was already at a full Saturn mass while Jupiter was still forming, then its gravitational field perturbed the planetesimals in such a way that Jupiter could only capture about 35% of the planetesimals. Other findings were that in the first case 133 planetesimals were ejected from the system while in the second case 427 planetesimals were ejected from the system.

By analyzing the data we received from the first case we could see that some of the final eccentricities produced errors. A reason why that could happen is that it may be a problem of round-off. The formula requires the difference between two numbers that are close to each other. If there is a problem with the round-off and the numbers are very close, you might get a negative number and then the calculation will fail. A second possibility is that the planetesimal is about to hit Jupiter. The eccentricity formula only works for elliptic orbits around the Sun. If the planetesimal is about to hit Jupiter or is close enough to Jupiter to have its orbit seriously affected, then the motion will not be an ellipse around the Sun and the formula will not work. For each case I made a graph that describes the initial eccentricities and the final eccentricities of all the planetesimals as functions of the initial semi-major axis. For example, Fig 1 is referred to the first case and describes the initial eccentricities as functions of the initial semi-major axis. Fig 2 is referred to the second case and describes the final eccentricities as functions of the initial semi-major axis, as seen below.

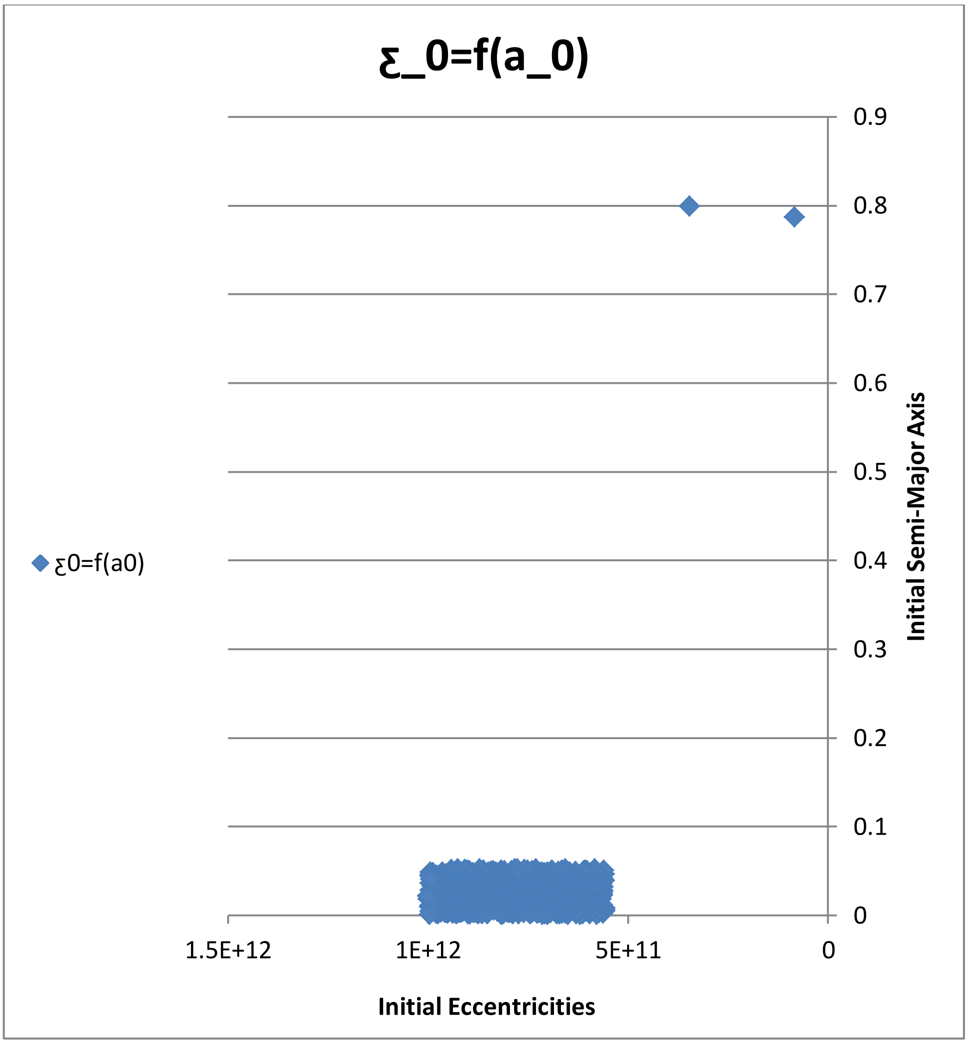

Fig 1

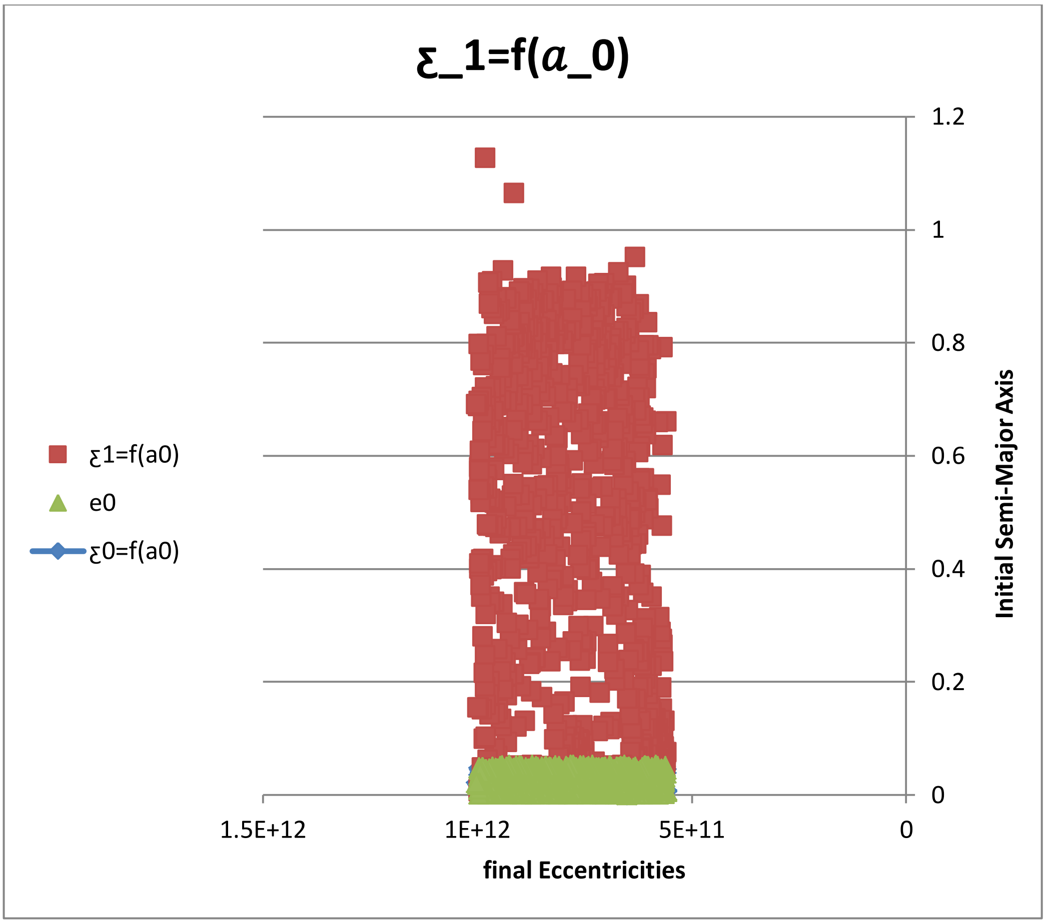

Fig 2

Furthermore, I created a graph that describes the mass fraction accreted as a function of time, for each case (Fig 3 and Fig 4).

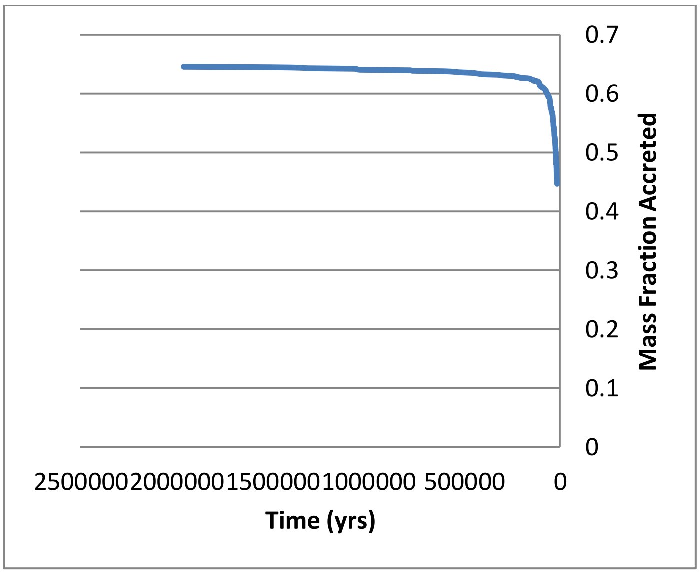

Fig 3 – First Case

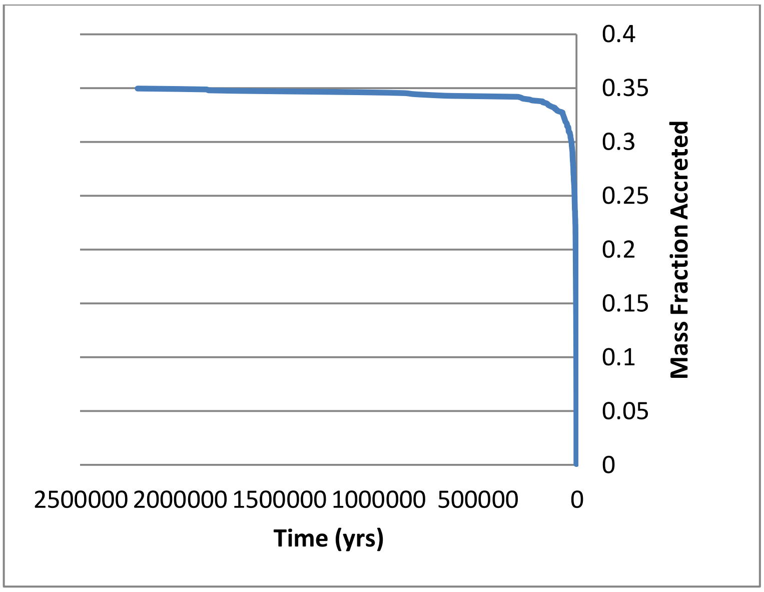

Fig 4 – Second Case

5. Summery and Conclusions

During the time I helped conduct this research I learned about Planetesimal capture, which is a subject I have not explored before, I learned about a program called Mercury and learned how to use it, I extended my skills using the Excel program and I even got to practice python programming. The most significant part of my role was analyzing all the data we received and trying to draw conclusions from it. Learning new things was interesting and exciting as well as enriching, I got to experience academic research for the first time and see what it entails and I enjoyed the process. I would like to thank Prof. Morris Podolak for giving me the opportunity to work with him and for the time and effort he invested in guiding and teaching me.

6. Bibliography

1. Podolak, Morris, et al. "Detailed Calculations of the Efficiency of Planetesimal Accretion in the Core-accretion Model." *The Astrophysical Journal* 899.1 (2020): 45.