Impact of Surface Density on Planetary Migration in Protoplanetary disks

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May 22, 2024

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1 Introduction

Protoplanetary disk are disk of dense dust and gas that orbit a newly formed star. These disk are involved in phenomenon like planet migration, planet formation, and evolution of a planetary systems (Armitage & Rice (2005). For this paper however, we will be most interested in planet migration. There are many directions one can go involving planet migration, one being angular momentum transport and how that drives accretion flows, migration in viscous disks, migration in low viscosity disk, and so on (Nelson (2018). In this paper we will be focusing more on surface density Σ_0.

Protoplanetary disk (as far as I know) are the go to models for anything involving planet migration, angular momentum transport to a disk, or anything disk-planet related. While observation is one method to glean information regarding disk-planet interaction, most of the information we've developed involving protoplanetary disk have been through theoretical simulations Nelson (2018)). And theoretical simulations will be where we next explore.

Throughout the literature, many parameters are explored, such as energy and angular momentum transfer (Goldreich & Tremaine (1980), an altering of temperature, and an altering of the mass of planets, to name a few. However, in many cases, the surface density Σ_0 is rarely ever altered. In this paper, I would like to explore, what, if any, impact changing surface density Σ_0 has on the planets and the protoplanetary disk. My assumption is that at the very least, the magnitude of the torque should change, an increase as surface density decreases, and a decrease as surface density increases.

This is relevant to our class because in the classroom we did go over protoplanetary disks and surface density, and we covered this as well in a homework assignment. However, in the homework assignment, we didn't alter Σ_0 and (as far as I can remember) did not truly explore protoplanetary disks. This final project seemed like a good opportunity to at least check out what would happen if we changed the density from the typically used value of 1700 $g\ cm^{-}2$.

2 Modeling Planetary Migration in Protoplanetary Disks

In working on this model I began by making use of FARGO (fast advection in rotating gaseous objects), a hydrodynamic simulation code. Since I wanted to attempt several different iterations of a similar setup, FARGO was the best choice in that matter due to how quickly and accurately it is able to run a simulation Li & Li (n.d.). With that in mind, since I am making use of protoplanetary disk, it was safe to assume that the star at the center should be a few solar masses, in this case it was set to the mass of our sun $1.989x10^{33}$ g. I then chose the mass of the two planets to be that of the Earth, $1.67443x10^{28}$ g. I originally chose two planets because I then wanted to alter their mass while also altering the surface density Σ_0 but, due to time constraints could not follow through.

I then set these two planets 1 AU and 1.25 AU respectively away from the center star. The reasoning being that I wanted to slightly emulate the solar system without having them being too close or too far away from the star. I then set the inner and outer radius of the system to be 0.5 AU and 1.5 AU, to give the planets room, so to speak, to migrate around the disk. The secondary reason for doing this was that if the inner and outer boundaries were set too small or too large, it would produce errors in the simulation. Adding to that, the resolution of the simulation was set at 512x512, using a cylindrical coordinate system. Aspect ratio was set to 0.0035 and alpha viscosity was set $1x10^{-3}$. All of these values were chosen based on the values and assumptions in Nelson 2018.

The most important value of course was Σ_0, which is normally taken to be 1700 g $cm^{-}2$. The initial simulation setup was run with this value, to provide a benchmark to compare the other potential values of Σ_0 to. Those additional values were 3400 g $cm^{-}2$, 850 g $cm^{-}2$, and 567 g $cm^{-}2$. The motivation being that there should be at least somewhat noticeable change in torque, if the values of surface density changed by half, double, or a third.

3 Results

In (Figure 1) we have a comparison across different timesteps, of surface density Σ_0, which go from the typical value of 1700 g $cm^{-}2$, to 3400 g $cm^{-}2$, 850 g $cm^{-}2$, and 567 g $cm^{-}2$, which are ordered from top to bottom, while the timesteps are ordered from left to right. This meant to serve as a visual representation of whether or not we would be able to see any meaningful change in the torque in the disk.

In (Figure 2) we see a comparison of surface density and orbit. This was also additional method of seeing whether or not the torque of the disk would be changed if the surface density value was altered.

4 Discussion and Summary

Admittedly, these were not the results I was expecting when I completed the simulations and analyzed the data. Regarding (Figure 1) I was at least expecting the orbits to vary to some degree. Instead it turns out that changing the surface density value did little, if anything, to the planet migration and torque. Even across similar time steps, one would expect some kind of change, from the various surface densities, but that does not seem to be the case here. For the most part it seems as if changing the surface density did nothing to change anything else, as far as we can see in Figure 1.

For (Figure 2) there seems to be something slightly promising here. Looking at the figure on the left side, which presents just one of the planets and it's orbit around the star, we can see that a change in surface density also produces a small change in the planets orbital radius. The more interesting thing here is that when the surface density was doubled, we see, while still relatively small, a significant change in the radius. This is also similarly reflected in the Planet 2 graph as well. I would argue that surface density would have to change by orders of magnitudes before we would notice a significant enough change to justify whether or not the magnitude of torque is actually changing or not.

The difficult thing as this point, having seen the results of the data, is figuring out if this is consistent with known models. On this front, I am honestly unsure. While searching for papers that may have done

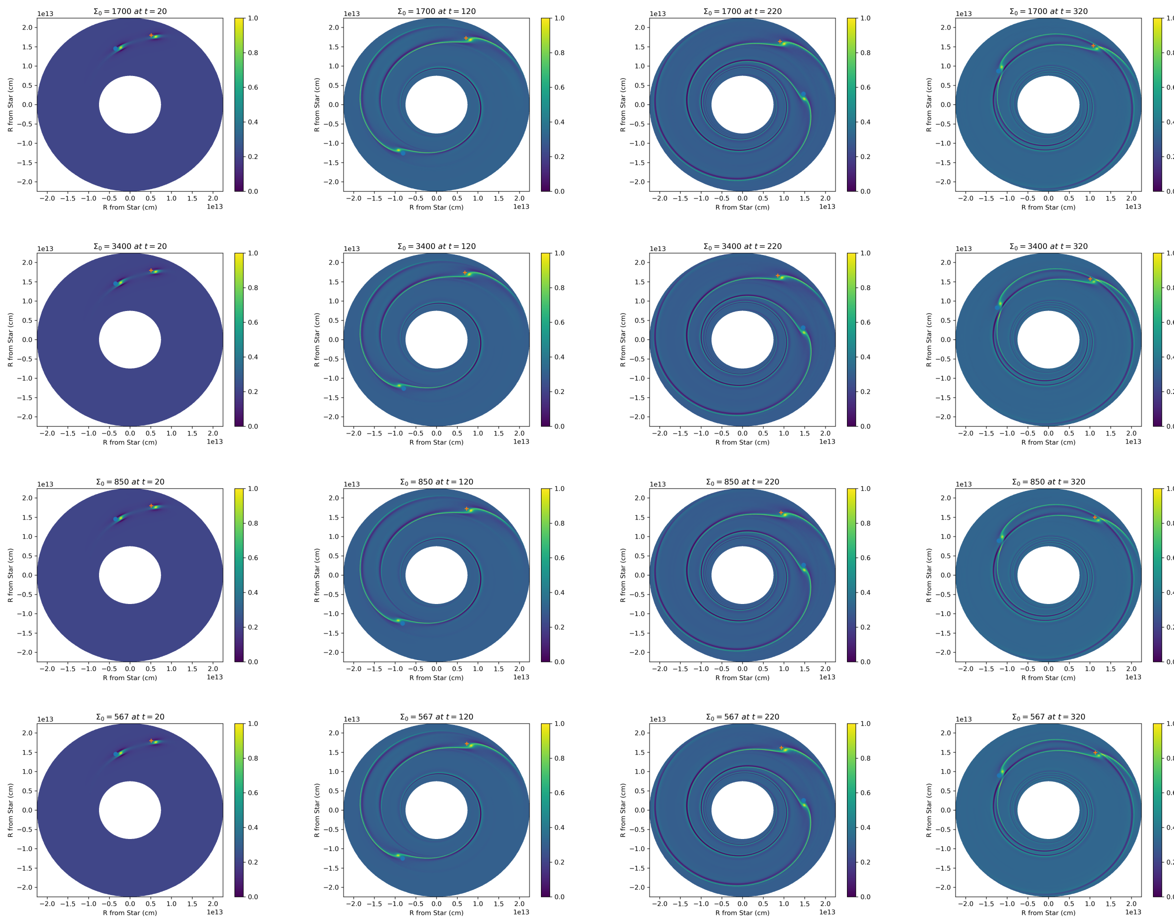

Figure 1: From top to bottom: $\Sigma_0 = 1700, 3400, 850, 567$. From left to right: at some timestep t= 20, 120, 220, 320

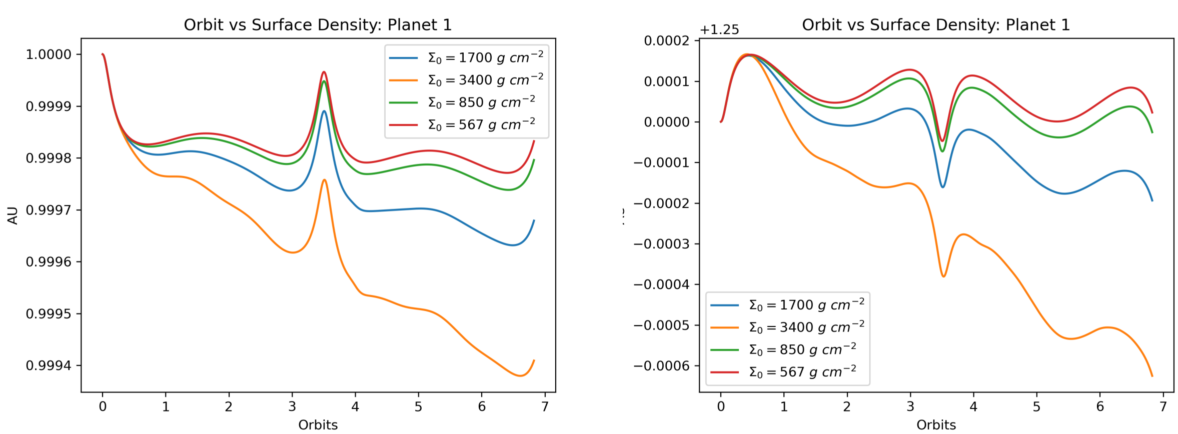

Figure 2: Looking at how Orbit changed based on the change in surface density

similar things, so I had a point of reference based on the simulations I ran, I was unable to find anything that quite fit to what I was doing.

Summary and Future Work In short, the hydrodynamical simulation code FARGO was used to changed the normally used value of surface density Σ_0 from 1700 $g\ cm^{-}2$ to several other values, halving, doubling, or a third of the initial value, to see what influence it would have on the torque (or anything else in the protoplanetary disk). It turns out that if the change in surface density did have any impact, it was fairly minimal at best. For future work, one of things that I would like to do is rerun this simulation, but making the changes in surface density at least an order of magnitude smaller or larger. I would also like to vary the masses of the planet, while also varying the surface density, to see if there's any information that could be learned. Finally, I would like to spend more time searching for a paper that has attempted this previous, and build from that work, so at least I would have a proper frame of reference to figure out what, if anything, went wrong with what was done here.

References

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