The Effect of the Subcritical Baroclinic Instability on Kinetic Energy of Vortices in Proto-planetary Disks

American Museum of Natural History

By Maimuna Hossain, Kate Gindinova, and Steven Liu

Mentor: Jeff Oishi

Abstract

Long-lived vortices, which are theorized to lead to planet formation, are created in accretion disks, where a newborn star is surrounded by dust and gas. In this project, we see whether the vortices created by the SBI will have enough kinetic energy to sustain themselves and lead to dust particles' coagulations (i.e. forming planets). We hypothesize that the vortices generated by SBI will have enough kinetic energy to sustain themselves and to coagulate dust particles. We look at a shearing box that represents a small portion of the accretion disk in computer simulations. After adding a "noise" in the velocity-gradient and temperature-gradient local region and masking out the vortices generated within the box, we see that the kinetic energy of the vortices is enough to lead to dust coagulation.

Methodology: Masking Our Vortices

Vorticity is the measurement of the rotation of a velocity field at any given location. We use a python program to identify vortices in a dataset and generates a double-line graph that maps out the total kinetic energy of a given field and the kinetic energy within the identified vortices. We discretized our local region and defined a vortex as a cell that has a vorticity ($\omega\rightarrow$) -5</ $\omega\rightarrow$</-40. Afterwards, we generated function to filter our data into a set of Booleans such that we created a mask outlining the coherent cells of a vortex (figure 3). We applied the kinetic energy equation both on this mask to obtain the average kinetic energy of the vortices themselves throughout time and on the original data to calculate the total average kinetic energy of the system (figure 6), from which calculated the impact velocities of dust particles within the turbulence in various possible situations where turbulence was 0.1, 0.05 and 0.01 of the total kinetic energy of the vortices.

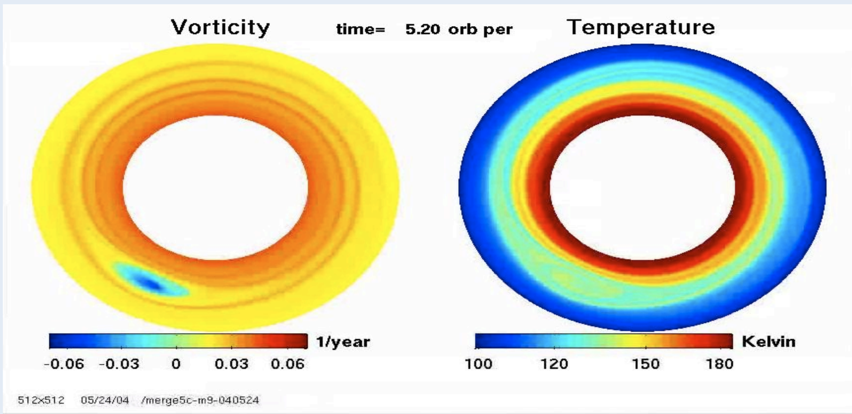

Figure 1: This is a picture of a vortex. The left image shows the vorticity of the vortex while the right image shows the temperature of the vortex.

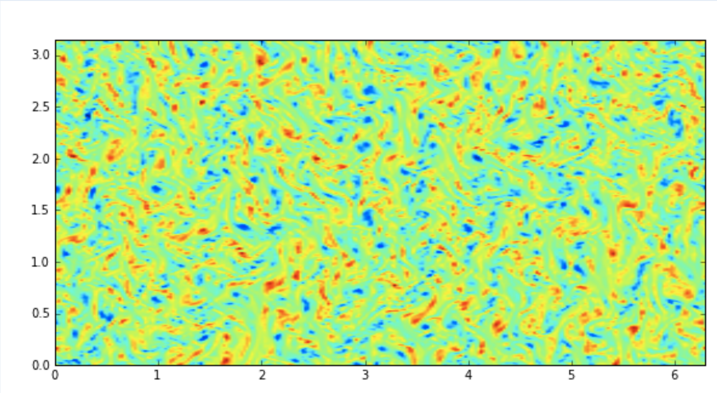

Figure 2: This is an image of our system, the local shearing box, after we put in a noise and before we defined our vortices

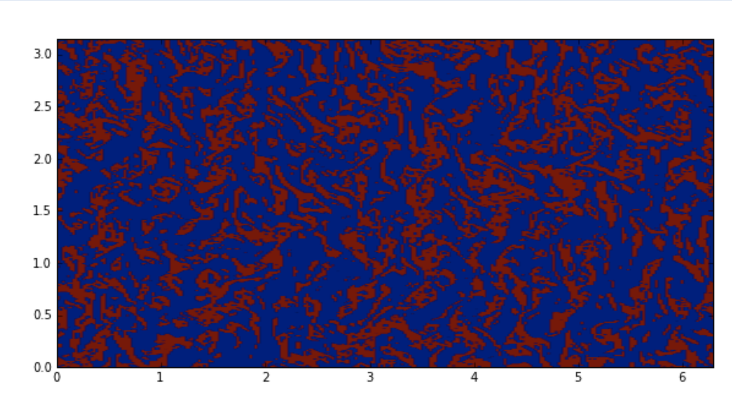

Figure 3: An image of our system after we defined our vortices using a mask.

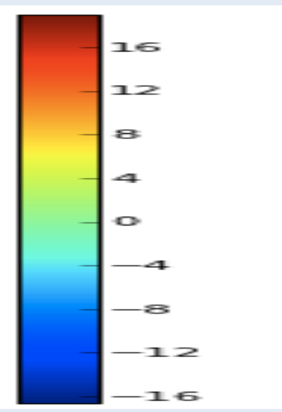

Figure 4: The vorticity scale used

Evolution of Vortices

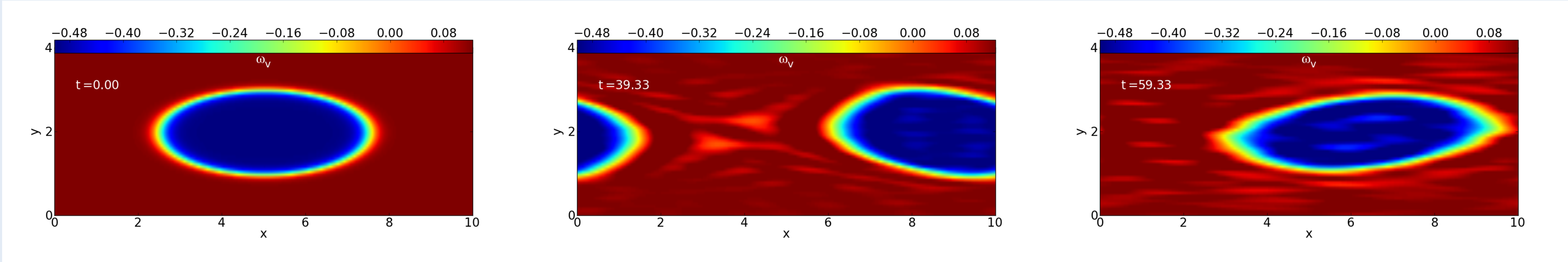

Figure 5: These are snapshots, generated by the computer simulation, which show the behavior of vortices over time. This behavior is influenced by viscosity, temperature and pressure gradient, and some dimensionless parameters.

Results & Discussion

After masking our vortices, we find that 22 percent of the total kinetic energy in the local region is the kinetic energy of the masked vortices.

Then, we calculate the colliding velocities of our 12 milligrams and 1mm3 particles for 10%, 5% and 1% of the kinetic energy in the vortices and find that the velocities are 3.28 m/s, 2.32 m/s, and 1.04 m/s, respectively. According to Langkowski and Blum, most particles do stick together with the velocity ranges from 0 m/s to 3 m/s. Hence, our hypothesis has been proven correct.

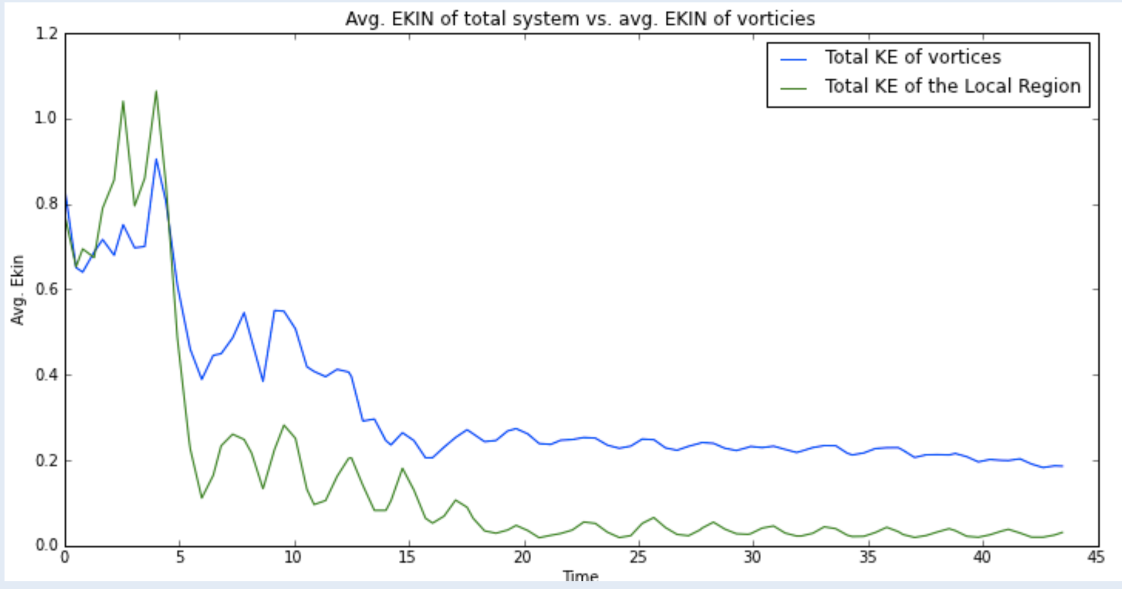

Figure 6: Comparison of the kinetic energy of the entire system and that of the vortices.

Some sources of errors in our project would be the approximation of particle masses and our extrapolated
analysis of data. This finding is important because that it can be a possible causation for planet formation. However, some further research on other instabilities, such as Rossby-Wave Instability, can be really helpful for understanding the nature of planet formation.

Acknowledgements

Thank you to Jeff Oishi, Brian Levine, Sebastien Lepine, Oscar Pineda, American Museum of Natural History, NASA, and Dedalus

The Science Research Mentoring Programs are supported by the National Science Foundation under Grant No. DRL-0833537, and by NASA under grant award NNX09AL36G.