4. Semester report

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PhD program: Astronomy and Space Physics

Supervisors: Tamás Kovács, Áron Süli

PhD Thesis Title: Dynamics and morphology of protoplanetary disks and galaxies

Introduction

One of the questions that have been fascinating humanity since the dawn of history is how the Earth and other celestial bodies came into existence. Initially, the explanations were mythological, philosophical and not scientific in nature. As astronomy, physics and mathematics developed, we learnt more and more about our place in the world and how it currently works.

Newton successfully explained why planets orbit the Sun on an elliptic trajectory, but not how the Solar System came to be. The first scientific explanation was given by Kant then Laplace, who said that the Sun and planets were formed by the gravitational collapse of a nebula. The current theory is built on this idea, but it is significantly more complex. We know that gravitational collapse is not the only effect that matters, the interaction of dust particles with gas and themselves is very important, as well. This modern theory of planet formation can be attributed to Safronov. The current research is about refining his model and matching it to observational data.

The concept of (extra)galaxies is relatively recent. Besides the stars, other objects can be seen in the sky, for example “spiral nebulae”. It was an open question for some time whether they are inside the disk formed by stars, or outside of it. This was answered by Hubble, as he managed to resolve individual stars in the Andromeda nebula, as well as measure its distance. It was settled, that multiple galaxies exist and our Milky Way is only one of them. Hubble also created a classification scheme for galaxies. Since then, as technology evolved, we observed more and more galaxies with lots of different properties and measured quantities. The formation and evolution of galaxies and the connection between different properties is still an open field of study. As galaxies are complex systems, studying them with analytical calculations is almost impossible, thus we use numerical simulations.

Summary of research work carried out in the previous three semesters

With my co-supervisor, Áron Süli, we examined the one-particle dust sedimentation and grain growth model in protoplanetary disks, its history and different versions. We compared the numerical solutions of the different models given the same initial conditions.

An important result is that the models that take into account grain growth by coagulation during settling give practically the same results, and in a simpler one of these we can analytically express the final grain size with the initial conditions and disk parameters.

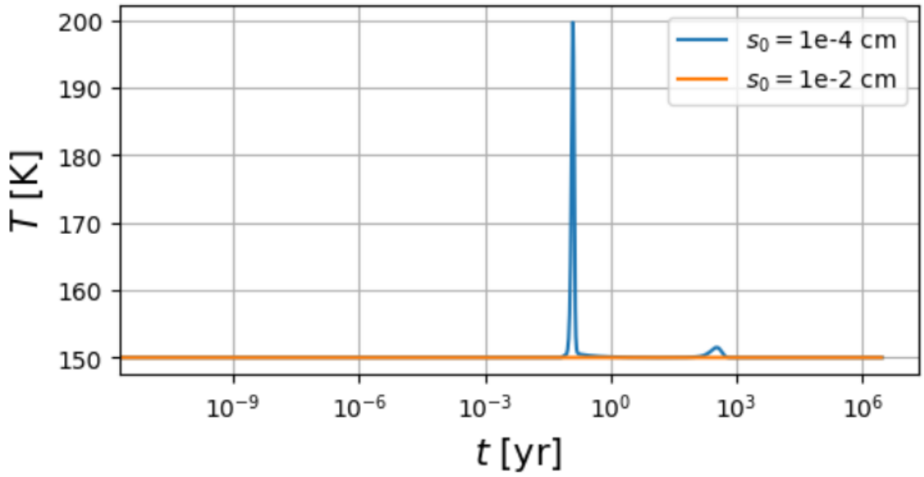
$$s_{\mathrm{fin}} = s_0 + \frac{\sqrt{\pi}\alpha^2 H' f \rho_0}{8\rho_{\mathrm{m}}} \mathrm{erf}(z_0/H)$$

In fact, for a large set of initial conditions it can be approximated by just the constant factor before the Gauss error function, making it independent of initial conditions.

Furthermore, we also investigated if the settling dust grains could melt due to friction and collisions, which might explain the creation of chondrules. The equation derived for the temperature change of the dust grain is the following:

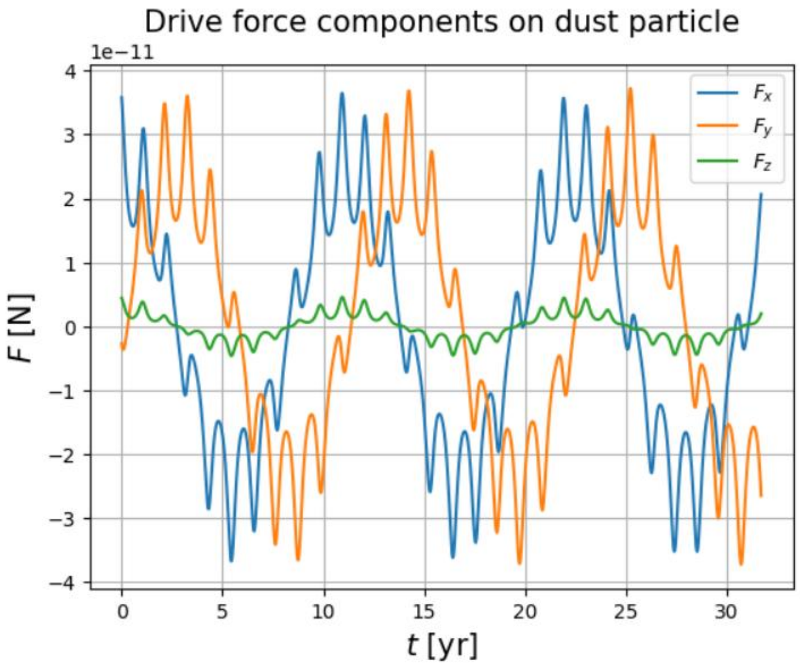
$$\frac{\mathrm{d}T}{\mathrm{d}t} = \frac{v_{\mathrm{th}}}{c\rho_{\mathrm{m}}}\frac{1}{s}\rho(z)v_z^2 + \frac{3f}{8c\rho_{\mathrm{m}}}\frac{1}{s}\rho(z)v_z^3 - \frac{3h}{c\rho_{\mathrm{m}}}\frac{1}{s}(T-T_0) - \frac{3\varepsilon\sigma_{\mathrm{SB}}}{c\rho_{\mathrm{m}}}\frac{1}{s}(T^4-T_0^4) + \frac{3fT_0}{4\rho_{\mathrm{m}}}\frac{1}{s}\rho(z)v_z$$

This differential equation has to be solved alongside the ones for position and size numerically.



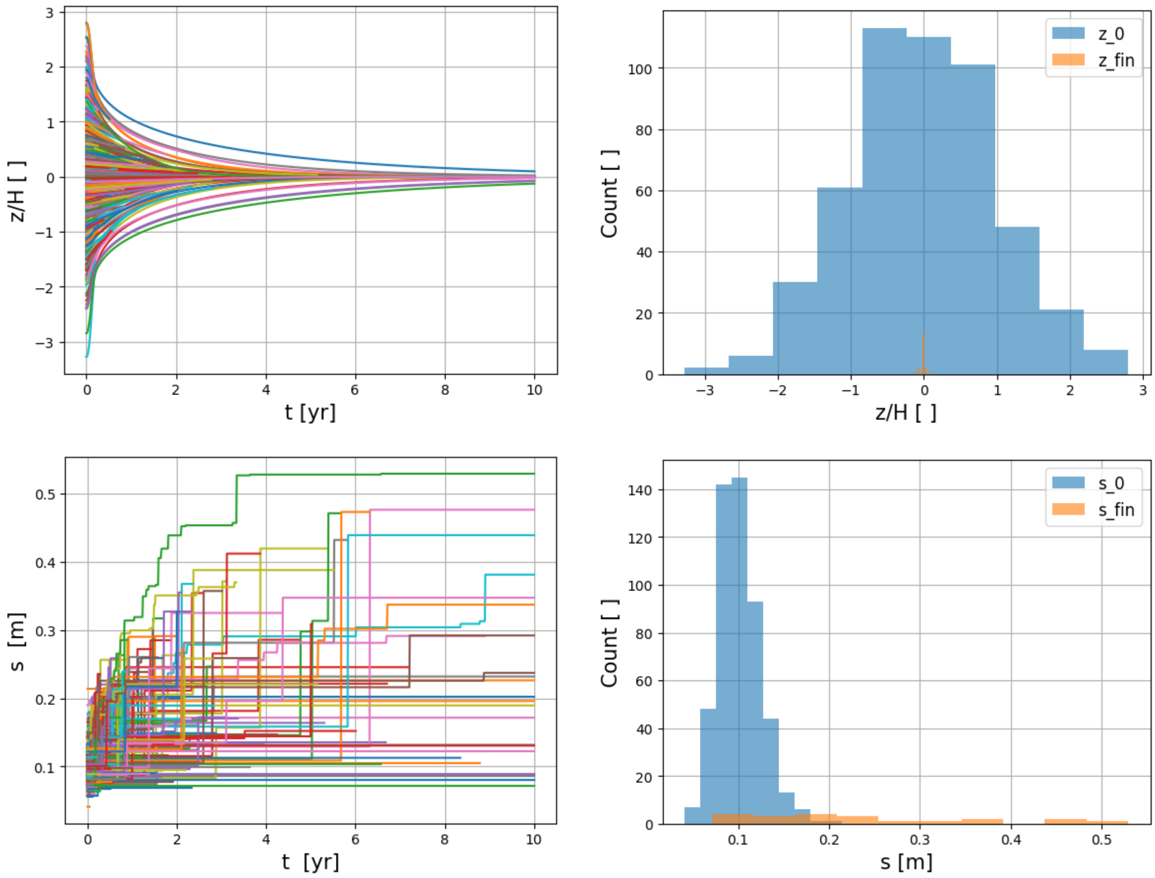
The conclusion is that the heat loss mostly due to radiation is much greater than the overall gain, thus the dust particle does not reach melting temperatures.

We also began creating a model about how the gravity of an already formed planet with some inclination might make a settled pebble oscillate, which could lead to further growth.



Description of research work carried out in current semester

In the current semester we further developed the simulations modeling a population of settling dust particles treating coagulation by collision as discrete events, as opposed to the previous 1-particle model where growth was continuous.



I also help alongside my supervisors with an HLLC simulation being developed by Bertalan Szuchovszky, modeling the effect of the settling dust particle on the surrounding gas.

Publications

With my co-supervisor, Áron Süli, we are planning to publish in Fizikai Szemle, then in A&A about models of dust sedimentation and grain growth. The first of the two articles we wish to publish in Fizikai Szemle is complete, and has been sent in for review. The reply was that they would like to see the second part, so that they can decide whether to publish them in two parts or in one. The second article is about 60% ready.

Studies in current semester

In the fourth semester I signed up for 3 subjects:

- FIZ/5/048, At the edge of the Solar System 2 (lecturer: Emese Forgácsné Dajka), grade: TBA
- FIZ/5/021, Gravitational wave astrophysics (lecturer: Péter Raffai), grade: good (4)
- FIZ/5/025, The structure of compact stars (lecturer: Gergely Barnaföldi), grade: excellent (5)

Conference participations during the doctoral studies

In 2025 June I participated in the Bálint Érdi 80 Conference with a 20-minute contributed talk about dust sedimentation and coagulation in protoplanetary disks.

Teaching activity

In the 2025/26//1 semester I participated in the teaching of the Detection Methods in Astronomy 4 course.