N-body interactions in proto-planetary disks: A study of collision velocities and impact angles

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Abstract

We show the distribution of collision parameters of planetesimals and planetary embryos in an evolving protoplanetary disk for various binary star – giant planet configurations. This statistical study provides an overview which and how many of the mutual disk object collisions have to be studied in more detail with SPH (smooth particle hydrodynamics) simulations and which can be approximated by a "corrected" perfect merging process. In all configurations the gas has been already depleted and thus, only gravitational interactions are taken into account.
To study the gravitational interactions of the whole system our recently developed GPU N-body integrator GANBISS is used, which is able to simulate some thousand (massive) disk objects in binary star systems.

Supplementary material

Development of a and e of the disk objects of config1 for 1 Myr simulation time.

GPU N-body code GANBISS

GANBISS is written in CUDA C and runs on most modern NVIDIA GPUs. It uses the Bulirsch-Stoer method to solve the quations of motion.
GANBISS is designed to simulate the dynamical evolution of a planetesimal/embryo disk in a binary star system. The disk can handle up to 10000 interacting objects in a simulation. For details see [1].

Numerical setup

Name	a_b [au]	a_g [au]	a_{disk} [au]
config1	50	3.0	2.5
config2	50	5.0	4.0
config3	100	4.5	4.0
config4	100	6.0	5.0

The table shows the four system configurations (taken from [2]). Each configuration consists of two stars ($M = 1\ M_\odot$) with a seperation a_b and an eccentricity of $e_b = 0.3$. A gas giant ($M \approx M_J$) orbits the primary at a distance of a_g. Between the primary and the gas giant a disk of 1500 objects is placed from 0.7 to a_{disk}. The disk objects are either Ceres (planetesimals) or Moon (planetary embryos) sized objects.

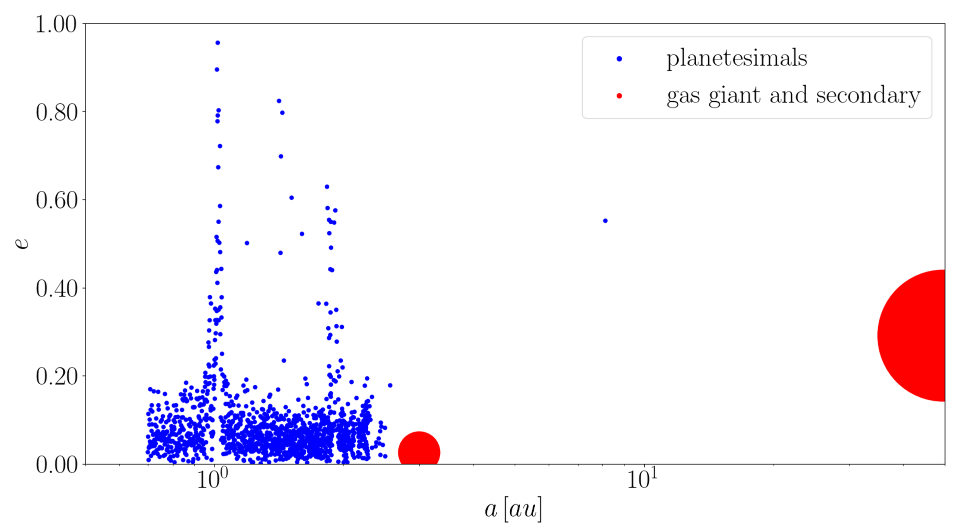

Figure 1: The evolution of the massless configuration after 1 Myr simulation time. This is the initial configuration for the full interaction simulations. The blue dots represent the planetesimals, the red dot the gas giant and the secondary star.

For some of the configurations a secular resonance is within the distribution of the disk objects, as well as mean motion resonances of the gas giant. To provide more realistic initial conditions we let the disk evolve without interaction of the small objects. The obtained distributions are then taken as initial configurations for the full interaction simulations.

Collision parameter: Impact angle α

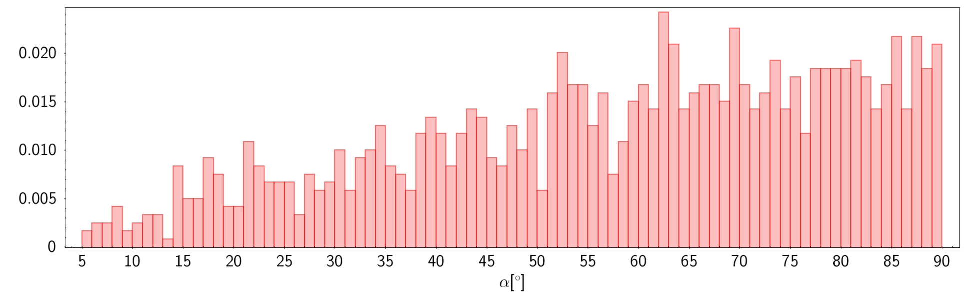

Figure 2: The distribution of the impact angles for Ceres sized objects in configuration 1 after 1 Myr simulation time. The other configurations show similar distributions.

Distribution of α:

$< 30°$: $\sim 14\%$
$30 - 45°$: $\sim 15\%$
$45 - 60°$: $\sim 19\%$
$> 60°$: $\sim 52\%$

Two-body collisions

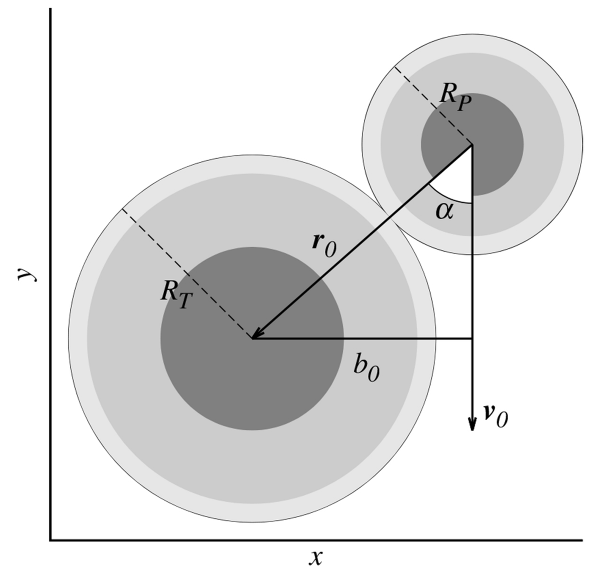

Figure 3: The geometry of a collision. Impact angle α ranges from 0° for a head-on to 90° for a grazing collision with an impact velocity $|\mathbf{v_0}|$. The larger object is labeled as target, the smaller on as impactor. The figure is taken from [3].

Collision parameter: Impact velocity v_0

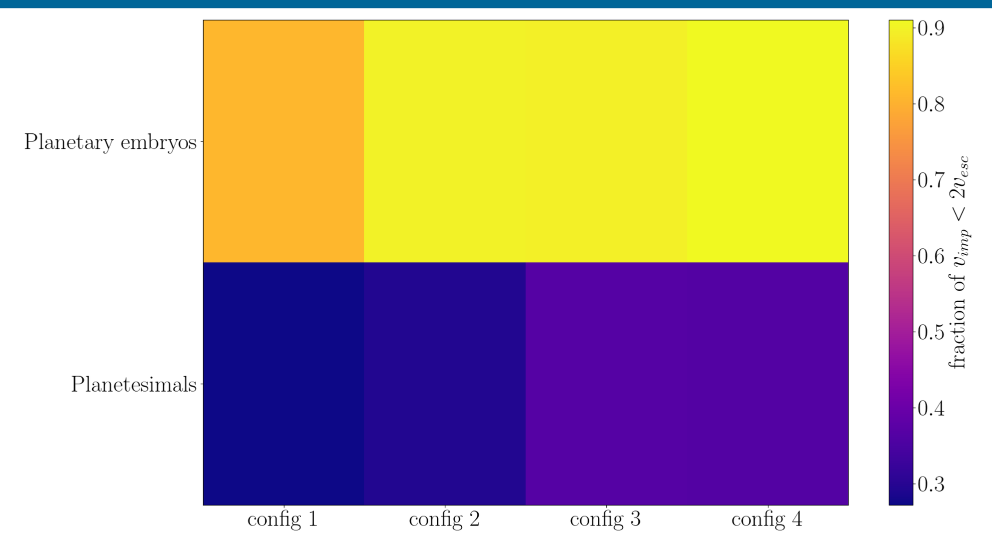

Figure 4: We show the fraction (color coded) of collisions with $v_0 < 2v_{esc}$ for the different configurations. Each configuration has been carried out with a different mass for the disk objects.
The planetesimals (Ceres sized objects) show in all configurations less than 50% of collisions with impact velocities $< 2v_{esc}$; for the close binary configurations ($a_b = 50$ au) even only about 30%.
In case of planetary embryos (Moon sized objects) the results show about 80 to 90%.
Configuration 1 is the densest configuration and shows the lowest fraction of $v_0 < 2v_{esc}$ for both object sizes.

Summary

In this presentation, we show our preliminary results of a study on collision parameters in a planetsimal/embryo disk for a binary star configuration with seperations of 50 and 100 au moving in eccentric orbits ($e_b = 0.3$) and a gas giant at different locations. Impact parameters (α, v_0) from N-body simulations provide important information on the validity and deviation of the commonly used perfect merging scenario compared with a more realistic two-body collision result obtained by SPH (for details of such studies see [4]) simulations.High impact velocities ($\gtrsim 2v_{esc}$) and high impact angles ($> 45 - 60°$) usually show a different outcome of a collision than perfect merging. While high impact velocities lead to destruction, high impact angles usually show a hit-and-run scenario. Both are present in these preliminary studies, especially for planetesimal-planetesimal collisions. The next step will be to simulate disks consisting both planetesimals and embryos, as we suppose that this is more in line with reality.

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FWF Der Wissenschaftsfonds.

References

1. Zimmermann, M. & Pilat-Lohinger, E. *CeMDA (in press)* (2023).
2. Bancelin, D. *et al. The Astronomical Journal* **153** (2017).
3. Burger, C. *et al. Astronomy and Astrophysics* **634** (2020).
4. Maindl, T. I. *et al. Astronomische Nachrichten* **334** (2013).