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Towards a Scaling Law for Core Formation

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ABSTRACT

The separation of the metal and silicate phase into a core and a mantle of a growing planet is one of the most important processes in the early evolution of terrestrial planets. Together with the formation of the planets it determines the further evolution of the planetary body. It is widely assumed that the separation of metal and silicates was a rather rapid process. Observations and laboratory measurements have shown that also small bodies (e.g., asteriods) can be differentiated. Although planet formation and differentiation probably occurred simultaneously, we concentrate on one process only for simplicity: sinking of iron diapirs. We assume the iron drops distributed inside the proto–planet. Since the size of the proto–planet varies with time, and the size of the iron drops is difficult to determine for a given planet at a given time, we perform a parameter study. We investigate the influence of the drop size as well as the planet's radius on the differentiation time.

Introduction

Core formation is one of the earliest processes occurring in planet formation and evolution and it determines the initial conditions for the later evolution. It is presently accepted that the terrestrial planets and some icy moons are differentiated bodies with a core in the centre and an overlying mantle.

The processes that lead to a planet separated into a core and an overlying mantle are still not well understood. Since planet wide differentiation started during the planet formation process already the scenario becomes rather complicated and almost impossible to simulate consistently with a numerical model. Recent research has lead to the conclusion that even relatively small bodies like asteroids can be differentiated. [1] showed that the interior is strongly heated due to the decay of ^{26}Al. Sometimes even the solidus temperature of silicates is exceed. [2] show that heating within planetesimals by decay of short-lived radionuclides can increase the temperature sufficiently above the iron-sulphur melting point ($\approx 1000°$C) and thus trigger the fast segregation of iron alloy. Therefore even small planetesimals (30 km radius) are expected to be at least partially differentiated. Since these objects would have been most abundant in the terrestrial region of the protoplanetary nebula [3,], it is not unlikely that the Earth and other terrestrial planets formed by accretion of previously differentiated planetesimals. We conducted a preliminary study already, where the collision timescales during planet formation was compared to the differentiation timescales of different proto–planetesimals.

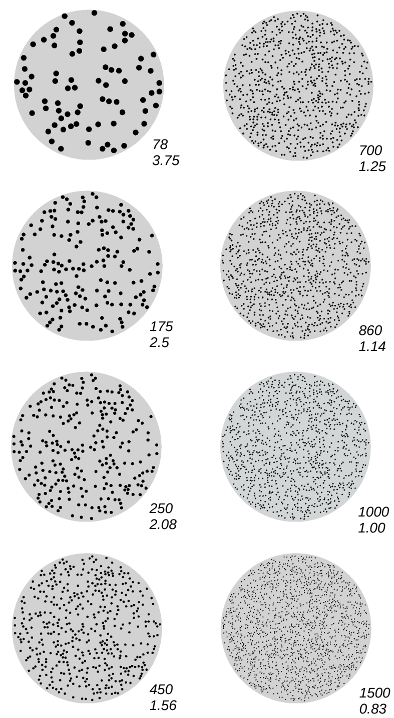

Figure 1: Setup for all models. The grey areas are the silicate material, the black dots or circles denote the iron drops. The iron drops are randomly distributed. Beside each panel the number of drops is given. Also the corresponding size with respect to the planets radius in percent is labeled.

The timescale of planet differentiation strongly depends on the given thermodynamical conditions. The energy input due to decay of radioactive heat sources and impact heating increases the temperature of a proto–planet. Increasing temperature results in lower viscosities of the material in the interior of planets. Henceforth a given proto–planet would differentiate faster if its interior is warmer. However, if the iron drops are very finely distributed differentiation might as well become frustrated, because the droplets would

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be kept in suspension. Furthermore a larger proto–planet features a higher gravitational acceleration, which then decreases the time required to build the core out of homogeneously distributed iron drops. To setup a differentiation model with correct or realistic initial conditions is nearly impossible, since the uncertainties regarding parameters in the early stages in our solar system are quite large. However, it is possible to model a reasonable parameter range and investigate the influence of various parameters.

Model

We investigated a set of proto–planets, which consist of a mixture of iron and silicate. The iron is modelled by randomly distributed drops, which should represent the pre–formed iron diapirs. The total amount of iron drops is chosen to result in a core, which is 40% of the proto–planet's radius. Although the ratio of core radius to planet radius R_c/R_p for today's terrestrial planets is rather 0.5 (except Mercury), we use 0.4, because we assume some of the iron is still contained in the silicate matrix. The size of the iron drops is difficult to determine. Local percolation (local temperature increase, shear stresses) could collect iron into larger 'pockets', which then sink down in larger drops. Impacts could lead to melt and form an iron pond, that sinks down towards the proto–planet's centre. Since the size of the drops is a crucial parameter in determining the settling time, we set up a number of models, which differ in the size of the present iron drops. We investigate a size range between 0.8% and 3.75% of the proto–planets radius.

Results

Figure 2 shows the results for the temporal evolution of the differentiation process of the proto–planet. Eventually all iron particles sink to the planet's centre and form a dense core in the middle due to gravity pointing inwards. The fact that the core is not completely dense is related to the fact, that the models used cannot handle the merging of diapirs. The core formation process was considered to be finished, when the core radius is roughly 0.6 the planet's radius. During their descent through the silicate mantle the iron diapirs contradict which each other, which either increases or decreases their effective sinking velocity. If drops push each other away from the ideal path to the planet's centre the core formation process would be slowed down, while speeding up could happen when the drops draft in each other's wakes.

Discussion and Conclusion

The first preliminary simulations show the expected behaviour: The model featuring the smallest drop sizes require longer time to form a core. However, first estimations show that the

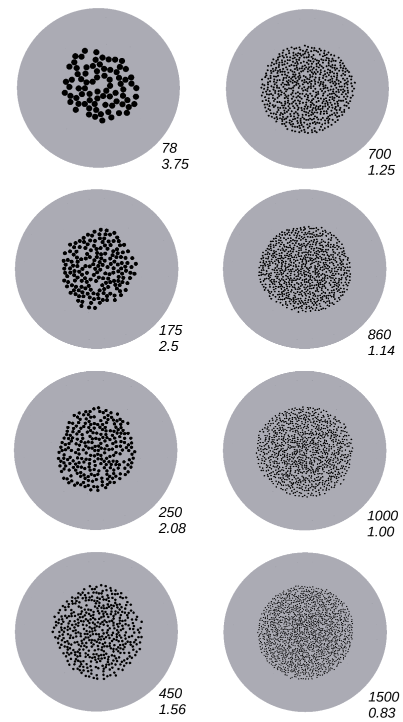

Figure 2: Final stage for all models. The cores are approximately 60% of the planets radius.

core formation time approaches an upper limit with decreasing diapir sizes. Eventually the influence of the iron drops onto each other favors the accelerating processes rather than the slowing down. Since the merging of diapirs is not accounted for in the models yet, the core formatio times are possibly underestimated, because the likely 'runaway process' cannot set in. It is planned for the future to implement this in the model too.

References

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