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Collisional water transport in late-stage planet formation: Self-consistent modeling by a N-body – SPH hybrid code

Christoph Burger (1,2), Christoph Schäfer (2) and Akos Bazso (1)
(1) Department of Astrophysics, University of Vienna, Austria (c.burger@univie.ac.at), (2) Institut für Astronomie und Astrophysik, University of Tübingen, Germany

Abstract

Terrestrial planet formation is believed to proceed in several relatively distinct steps, where it is especially during the last stage that material is mixed over large distances, which sets the stage for transport of water-rich material that condensed beyond the ice-line (snow-line) towards the forming inner planets. This final phase of planet formation starts when planetary embryos have already formed, still embedded in a large number of smaller bodies, and is marked by giant collisions among similar sized proto-planets. In recent years sophisticated semi-analytical models for predicting collision outcomes have been developed and applied to simulations of late-stage accretion, but so far only for tracing refractory material, and it has been shown that these models are not well-suited for predicting the fate of minor constituents like water inventories [1]. Frequently occurring hit-and-run events that constitute roughly half of all giant collisions, complicate matters additionally, where not only (global) water losses, but also transfer, e.g. from a water-rich to a dry body have to be taken into account.

In order to model collisional water transfer and loss in an active planet formation environment in a self-consistent way for the first time, we developed a hybrid framework, where an underlying long-term N-body simulation is combined with 3D Smooth Particle Hydrodynamics (SPH) computations of the actual collision events. The results of these SPH simulations, including both post-collision bodies in hit-and-run, are then included in the further N-body evolution.

1. Methods

Our hybrid framework includes computations of long-term dynamics over several 100 Myrs, based on the Rebound N-body package [2]. The scenarios include a solar-system-like architecture with gas giants resembling Jupiter and Saturn, and a debris disk of several dozen ~Mars-sized embryos + 150 ~Moon-sized smaller bodies (planetesimals), distributed between 0.5 and 4 AU. The collision simulations themselves are performed with our SPH code [3], which utilizes GPU hardware to efficiently compute the outcome of individual collision events. The colliding bodies are in general comprised of a three-layered structure, with an iron core a silicate mantle and a water shell. An example (hit-and-run) collision is illustrated in Fig. 1.

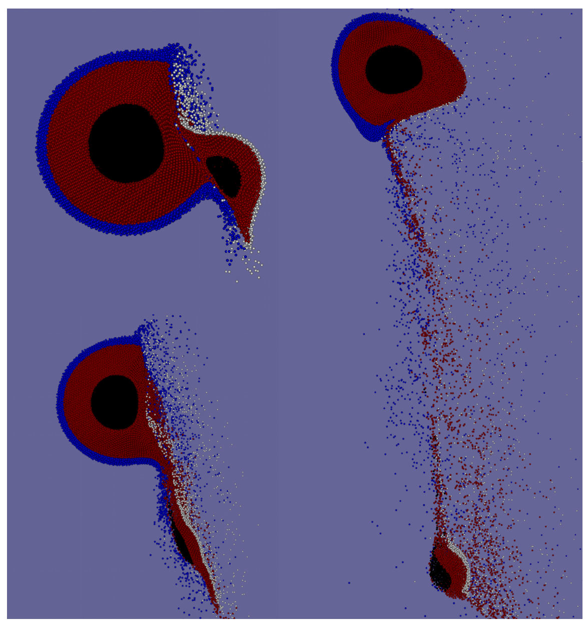

Figure 1: Snapshots (cut views) illustrating water (both white and blue) transfer and loss in a hit-and-run collision between embryo-sized bodies. The objects' mass ratio is 1:9, the impact angle 45° and the impact velocity is 2.5 times the mutual escape velocity.

2. Results and conclusions

Besides the well-known highly stochastic nature of late-stage accretion, several parameters crucially influence results in general. In our solar-system-like architecture with gas giants on in principle static orbits, their (initial) eccentricity has a decisive effect, where our results confirm the strongly detrimental effect of eccentric gas giants on water transport to the forming terrestrial planets, compared to giant planets on circular orbits. However, including a realistic collision treatment alleviates those differences, especially due to high collisional water losses in the scenarios with circular gas giants compared with considerably longer accretion times compared to simple perfect merging simulations.

Figure 2 illustrates an example growth curve of a planet which would perhaps be classified rather as an ocean planet in a perfect merging simulation, but ends up with – considering further loss mechanisms not included in our model – an approximately Earth-like water inventory. Besides the well-visible frequent collisional losses, the example in Fig. 2 also illustrates that often rather few events essentially set the bulk of the final water inventory of formed planets. These are just a few important results out of many based on including realistic collisional water transport in late-stage accretion simulations for the first time.

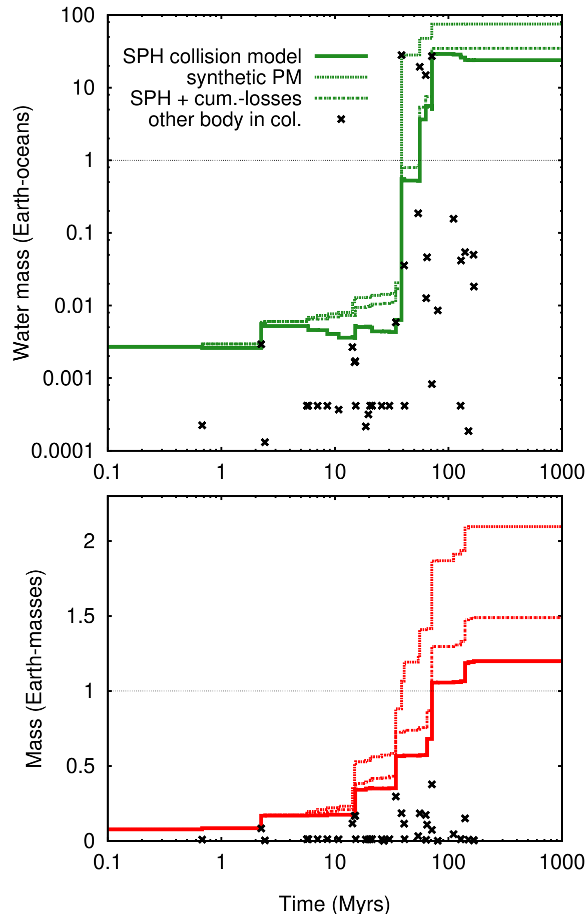

Figure 2: Growth curves for water mass and total mass of one example planet that forms at ∼1.1 AU, with 1.2 Earth-masses, and 24 Earth-oceans of water inventory, with gas giants on circular orbits. Besides the actual evolution tracks (solid), the theoretical tracks with added collision losses (35 Earth-oceans in the end), and also with perfect merging in all collisions (75 Earth-oceans in the end) are plotted. The crosses mark the respective properties of the impacting body (the 2^{nd}/other body in the collision).

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References

[1] C. Burger, T. I. Maindl, and C. M. Schäfer. Transfer, loss and physical processing of water in hit-and-run collisions of planetary embryos. *Celestial Mechanics and Dynamical Astronomy*, 130:2, January 2018.

[2] H. Rein and S.-F. Liu. REBOUND: an open-source multi-purpose N-body code for collisional dynamics. A&A, 537:A128, January 2012.

[3] C. Schäfer, S. Riecker, T. I. Maindl, R. Speith, S. Scherrer, and W. Kley. A smooth particle hydrodynamics code to model collisions between solid, self-gravitating objects. A&A, 590:A19, April 2016.