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Improved encounter scenario for planetary embryos – A comparison between single-star and binary-star systems

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Abstract

For terrestrial planet formation the so-called perfect merging is commonly used even if this assumption is a weak point in the formation scenario. Including results from simulations of real collisions using SPH (Smooth Particle Hydrodynamics) provide better results for the growth of planetary embryos and lead therefore to a more realistic formation scenario. The improvements due to SPH simulations will be figured out for single and binary star systems as part for comparison.

1. Introduction

The growth of terrestrial planets from proto-planetary embryos is usually simulated with the aid of perfect merging without considering fragmentation so that two bodies merge completely once their mutual distance becomes smaller than a pre-defined collision threshold. The consideration of fragmentation in different collision outcome regimes as suggested by [1] is a first step to a more sophisticated model. Recently [2] showed the strong influence of fragmentation of and water-loss from small bodies on the final outcome of impacts in the context of a water-transport-study in binary star systems.

We therefore continue this study and present in a similar way a more realistic formation scenario which includes SPH-simulations of collisions. Such simulations provide information about volatile and material loss during impact which improves the simple hit and stick scenario.

In this context, we study collisions of Moon and Mars sized objects which obit the sun in the habitable zone (HZ) – i.e. between 0.95 and 1.7 au according to [3]. These proto-planetary embryos are perturbed by a Jupiter-mass planet at 3 au and a secondary star with distances between 25 and 100 au from the host-star. The system configuration influences the impact velocity and angle which quantifies the mass-loss during a collision. Moreover, as indicated already in [2], this study reveals also a significant increase in the encounter velocity in binary stars in contrast to single stars.

2. Computations

Part I: N-body simulation of a circumstellar disk of planetesimals and proto-planetary embryos have been performed in a binary star system of two Sun-like stars with a stellar separation of 50 au and an eccentricity of 0.3. Additional perturbations are caused by a Jupiter-like planet orbiting the host-star at about 3 au. For the embryos we took Moon- and Mars-size bodies.

Part II: Detailed simulations of water-rich Ceres-sized asteroids with dry target bodies of a Moon or Mars mass using a 3D SPH code [4], [5]. For the collision scenario 500,000 SPH particles are used in general (only in some cases this number was increased to more than 1 million SPH particles). The key parameters for the SPH collisions are the impact angles and impact velocities of the planetesimals.

Part III: Combining the results of Part I and Part II lead to more realistic values for the growth of bodies and water transport.

3. Results

An example for this 3-step scenario is shown in figure 1 where we compare a pure N-body simulation assuming perfect merging (black dashed line) with our proposed 3-step procedure (blue line). The two lines indicate significant modifications in the result when fragmentation and water-loss is taken into account (blue line). This sample plot shows the amount of water transported to terrestrial planets in the HZ via Ceres-sized planetesimals. Especially, in case of strong gravitational perturbations (i.e. resonances) which cause a higher eccentricity of the planetary motion, the assumption of perfect merging will overestimate the growth and water transport to a planet as it has been pointed out already in [2]. This difference is caused by higher impact velocities which lead to a higher water-loss.

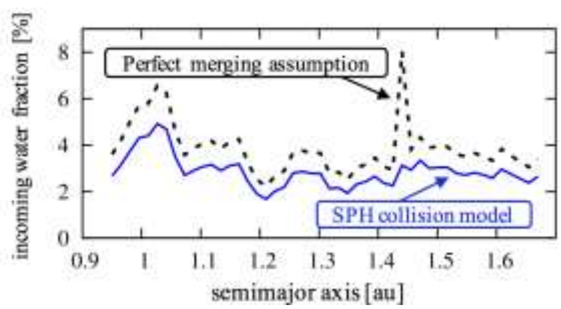

Figure 1: The water fraction transported via planetesimals onto a planet moving in the HZ when perfect merging is assumed (black dashed line) and when fragmentation and water-loss is taken into account (blue line).

Comparing the impact velocities of planetesimals and embryos in single and binary star systems, we recognized significantly higher impact velocities in binary stars. A more detailed study thereto is in progress and will be published soon.

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