COLLISION SCENARIOS IN AN EMBRYO / PLANETESIMAL DISK IN A TIGHT BINARY STAR

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Abstract: We present a study for two-body collisions of embryos, i.e. Moon to Mars size objects, and planetesimals in circum-stellar motion in a tight binary star system. Based on a recent study [1] -- which showed the strong influence of fragmentation and water-loss from small bodies on the final outcome of impacts in binary star systems -- we analyse the collision parameters, i.e. impact velocity and impact angles. These parameters may indicate the deviation of perfect merging and a more realistic two-body collision scenario using Smooth Particle Hydrodynamics (SPH)-simulations. SPH results provide information about volatile and material loss during impact. For the N-body computations we use our recently developed GPU N-body integrator [2] which allows to study the gravitational interaction of some thousand bodies.

System Configuration

Figure 1: Initial Configuration

Binary Star: 2 GV Stars (Sun); a_{Binary} = 50 au; e_{Binary}=0.1
Giant Planet: Jupiter (1 M_{Jup}) at a_{GP}=3 au; e_{GP}=0, i_{GP}=0
Embryo / Planetesimal Disk: 1500 objects of Ceres / Moon / Mars mass; a_D=0.7 – 2.5 au; $e_{E/P}$ < 0.2; $i_{E/P}$ < 0.1

The gravitational interaction of the full system is simulated for 10^6 years.

N-Body Simulations

GPU N-body code GANBISS

The numerical simulations are carried out with our recently developed GPU N-body integrator GANBISS (GPU Accelerated N-body code for Binary Star Systems [3]). The code is written in CUDA C and can be run on NVIDIA GPUs. It uses the Bulirsch-Stoer method to solve the equations of motion.

GANBISS is designed to simulate the dynamics and evolution of planetesimal disks in binary star systems which contains of some thousand (up to 10000) interacting disk objects. A study of non-interacting disk objects can comprise up to 50 million test particles.

Collision Velocities of Ceres- / Moon- / Mars-size Objects

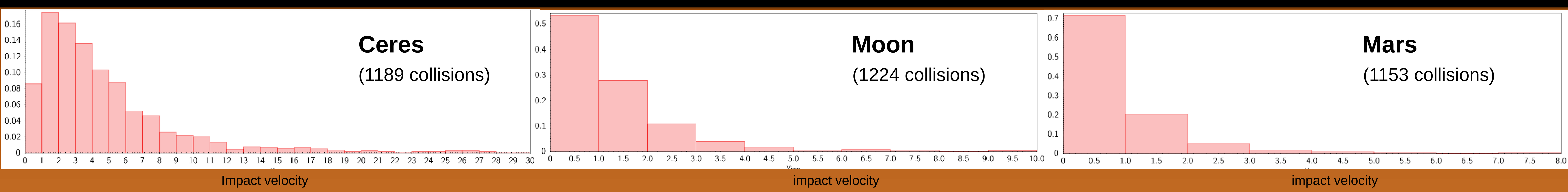

Figure 2: Distributions of collision velocities of Ceres / Moon / Mars-size objects. Smaller objects have a larger range of collision velocities v_{coll} (compare the different x-axes). The distributions result from N-body simulations over 10^6 years.

Collisions of Ceres-size bodies: ~ 9% with 1 v_{esc}, ~70% with v_{coll} between 2 and 6 v_{esc}, 20% with v_{coll} between 7 and 12 v_{esc} and a few with v_{coll} up to 30 v_{esc}
Collisions of Moon-size bodies: ~ 50% with 1 v_{esc} , ~ 30% with 2 v_{esc}, ~10% with 3 v_{esc} and a few collision with higher -- up to 10 v_{esc}
Collisions of Mars-size bodies: ~ 70% with 1 v_{esc}, 20% with 2 v_{esc}, 5% with 3 v_{esc} and a few collisions with up to 8 v_{esc}

SPH Collision Studies

Moon Mars

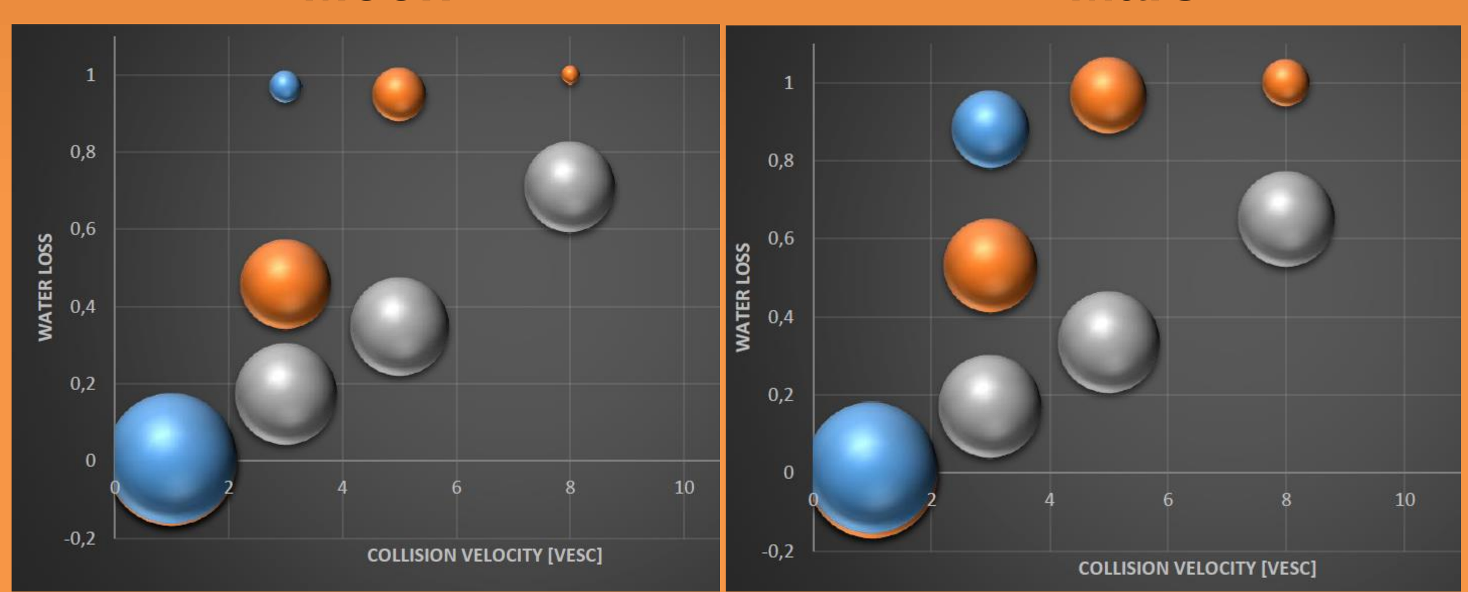

Figure 3: SPH Collision results for Moon- and Mars-size bodies. The collision velocity varies between 1 and 8 mutual escape velocities (x-axis); the impact angle is either 15° (blue), 30° (orange) or 45° (gray). Impact angles of 15° and 30° show a higher mass-loss especially for Moon-size objects.

Mass-loss is indicated by the size of the bubbles which corresponds to the size of the largest surviving fragment. The initial size is given by the bubble at 1v_{esc} where no significant mass-loss has been found.

Water loss (y-axis) after collisions of two Moon- or Mars-size objects with 15wt-% water mass-fraction (This is important for habitability studies)

Collision velocity and impact angle are the input parameters for the SPH code which includes self-gravity and implements solid-body continuum mechanics. The colliding bodies consist of 500000 SPH particles with a water mass fraction of 15%. For details of the SPH-code see [4, 5]

Results and Conclusions

In this presentation , we show an example of an extensive study of collisions in embryo/planetesimal disks in binary stars with stellar separations between 50 and 100 au.

From N-body simulations, we get the collision parameters (impact velocity and impact angle) which are used for SPH collision simulations that show the influence of fragmentation and water loss during a two-body collision of planetesimals or embryos. Collisions of planetesimals show higher impact velocities than collisions of two embryos.

For impact velocities around 1 v_{esc} the fragmentation is insignificant thus perfect merging might yield results close to an improved collision scenario (as shown in [1]) with only small (nearly constant) divergence of the results. Gravitational perturbations (resonances) in the disk induce high impact velocities which increase the fragmentation and depending on the impact angle significant differences in the results perfect merging vs detail collision study are observed. Probably, detailed collision studies can be reduced to regions of resonances.

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