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Reconstruction of Callisto's Valhalla basin using n-body and SPH simulations

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Abstract

We present results of n-body and smooth particle hydrodynamics (SPH) simulations, exploring the crater formation process of the Valhalla crater located on the Jovian Moon Callisto. We compute typical impact velocities and impact angles which we then use as input for the SPH simulations to reconstruct the actual crater formation. Using a three-layered Callisto model with a subsurface ocean, we find significant connections between the crater formation process and the interaction with the subsurface ocean. We also investigate the properties of the projectile and numerical effects of low-resolution projectiles in the context of SPH.

1. Introduction

Recently, subsurface oceans have moved into the focus of interest, especially when it comes to possible habitable regions in our Solar System. Jupiter offers icy moons which possibly have such oceans underneath their icy crust. We investigate a possible subsurface ocean of Callisto, Jupiters outermost big moon ([11],[12]).
Typically, subsurface oceans are found by satellite missions and advanced observation techniques ([5],[7]). We show our method to reconstruct the interior of Callisto. We reconstruct its biggest crater the Valhalla crater with some hundreds of kilometers in diameter and we reveal information about deeper layers.
Valhalla as well as other big impact basins were first found by the Voyager probes and analyzed in more detail later during the Galileo mission. The Valhalla crater system measures approx. 3000 km in diameter, containing a bright central area of about 700 km, a ridge system as well as a ring system in the outskirts of the crater. The crater formation process itself is very complex and many details are still poorly understood. We study the origin and the properties of the projectile, as well as the Valhalla crater formation process, and the inner structure of Callisto.

2. Methods

For the n-body simulations we use the Sun, Jupiter, Ganymede and Callisto as massive bodies and measure the moons collisions with a randomized set of initial particles. We determine impact velocities, impact angles, as well as other relevant information for further statistical analysis. We found typical, maximum, relative velocities to Jupiter to be $v_{\mathrm{rel,orbital}} = 670\,\mathrm{m/s}$, $v_{\mathrm{rel,radial}} = 65\,\mathrm{m/s}$ and $v_{\mathrm{rel,vertical}} = 4534\,\mathrm{m/s}$.
We perform the SPH simulations ([9],[14],[16],[17]) with the miluphCUDA code ([19]), designed to accurately model collision events of solid bodies including self-gravity and using the CUDA GPU-computing interface of Nvidia.
The three-layered inner structure we use for Callisto comprises a liquid water mantle of 100 km and an icy crust of 150 km in thickness on top of the core ([1],[2],[3],[6],[10],[13],[18],[20],[21]).

3. Results and conclusion

The collision analysis for the moons significantly favours retrograde impacts and particles which already had their closest approach to Jupiter. The high number of impacts in our simulation results in plausible impact velocities between 9 km/s up to 20 km/s. Apparently, there is a correlation between the impact angle and the latitude of the crater, favouring slightly steeper impact angles of about 40° (with 90° being a grazing impact) ([8]).
We use the newly attained knowledge of typical impact velocities and impact angles to perform SPH simulations of the impact itself. Knowing the velocities and angles, we constrain the mass limits for the projectile for different crater sizes.
Figure 1 shows the fully developed, temporary, transient crater with a diameter of about 350 km ([15]). During the following modification phase, the crater

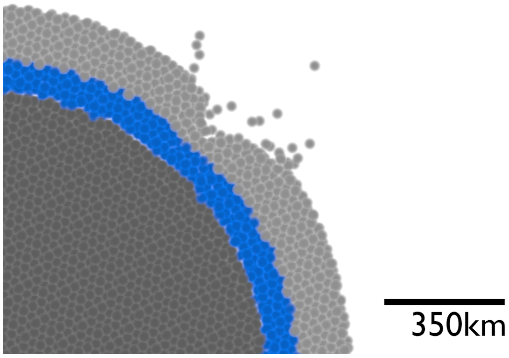

Figure 1: The transient crater disappears again during the following modification phase.

completely disappears and leaves a distorted surface, resembling observation data ([4]). Figure 2 shows the pattern of damaged material shortly after the impact. The results suggest that a non-damaged ring surrounds the crater, whereas the icy shell may break up due to large pressures from below.

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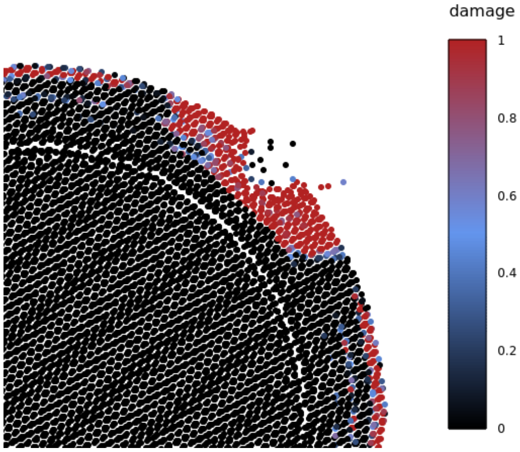

Figure 2: The damaging of the ice shell is caused by the impact event. Note the ring structure as indicated by the undamaged area around the crater.

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