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Laboratory experiments on catastrophic disruption of icy ocean worlds

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Abstract

Icy ocean worlds are found in various places in the outer Solar System. They are subject to the same evolutionary forces as other bodies, including impact events. An extreme outcome of impacts is catastrophic disruption. Given that these worlds are multi-layered bodies with an internal fluid layer in particular, it is not clear how they will respond to impact events including catastrophic distruption, and how or if this response differs to that of solid homogeneous icy bodies of similar size. Therefore, here we report on laboratory experiments which contrast impact outcomes on solid ice bodies, ice bodies with a purely liquid (water) interior, and bodies with an icy surface, liquid intermediate layer and a solid (rocky) core. We find that having a liquid interior does not significantly change the energy density required for disruption.

1. Introduction

Bodies such as Europa and Enceladus are icy ocean worlds (see [1] for a review). As atmosphere-less solar system bodies, their surfaces are subject to impacts by objects of a wide size range. Small impactors will produce craters. At very small impactor sizes, the resultant impact craters form in what is effectively semi-infinite ice. As impactor and crater size increase, the thickness of the ice surface becomes an issue, and the nature of the subsurface layer becomes important (see [2] for an experimental examination of this). At the largest size scales, the outcome of an impact event is disruption of the target. The particular energy density (Q) required to break the target apart is called Q^*, and is the energy per total mass when the largest single surviving fragment has a mass equal to half that of the pre-impact body. At the size scales of asteroids and satellites, the disrupted fragments also have to disperse against self-gravity to be a truly disrupted body and prevent re-assembly. This is discussed for rocky bodies in many papers, including for example [3].

The responses of icy bodies as targets for impacts have previously been considered in various ways. For example, simulations of disruption of icy bodies are reported [4] and an analytical model of disruption in [5]. Experimental reports of disruption on solid icy bodies are given for example in [6]. Recently the role of internal oceans and solid cores have also been considered in terms of how they influence impacts, with for example a report based on modelling in [7].

2. Experiments.

Here we report on a series of laboratory experiments which contrast disruption of a solid icy body, with disruption of a body with a surface ice shell and a purely liquid interior, and bodies with a tripartite structure of solid core, liquid intermediate layer and icy surface (see Fig. 1).

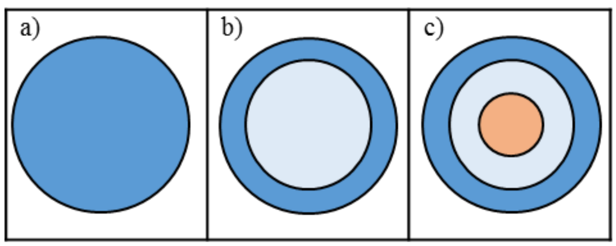

Figure 1: Schematics of targets in cross-section (not to scale). (a) Water ice only (dark blue). (b) Water ice surface layer (dark blue) and liquid water interior (light blue). (c) Has an icy surface (dark blue), liquid water layer (pale blue) and a solid rocky core (orange).

The experiments were performed with a two-stage light gas gun at the University of Kent [8]. This fired 1.5 m diameter glass spheres at targets of approximately 18 cm diameter and a ~2 cm thick surface ice layer (Fig. 1, b and c). Impact speeds ranged from 1 to 7 km s^{-1}, permitting variation of the impact energy density *Q*. The ice targets were made in our lab using a precise freezing method to prevent freezing throughout the body. The targets were at a temperature of -20ºC during the shots.

We performed: 7 impacts on type a targets (solid ice targets), 10 impacts on type b targets (surface ice, water interior) and 13 impacts on type c targets (surface ice, water interior, rocky core). A typical type b target is shown after impact in Fig. 2. In this case, the icy surface layer was penetrated but the target did not break apart.

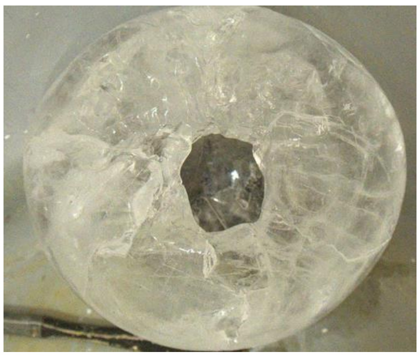

Figure 2: Type b target (icy surface, liquid water interior) after impact. A hole can be seen in the ice surface where the impact crater penetrated the surface. Despite the evident damage, this target was not disrupted.

3. Summary and Conclusions

We found no difference between the Q^* needed to disrupt a purely solid ice target and one with an interior liquid water filling (at laboratory scales where the response is strength dominated). The Q^* range in these cases was 16 – 18 J kg^{-1}. In the case where there was a central core, we found that the presence of the core had no significant effect on the craters formed and disruption that occurred. The video of the impacts also show that the core was not displaced or moved by any resulting shockwave.

The next step in these investigations would be to explore how the thickness of the ice shell influences the outcome of the results. Here we used a relatively thick surface ice layer, but it has been shown [2] that the thickness of the layer does influence cratering and penetration outcomes, so this should be explored further for disruption purposes.

Acknowledgements

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