TIDAL ENCOUNTERS OF RUBBLE PILES REVISITED: SIMULATIONS WITH SOFT SPHERES AND VARIOUS PACKINGS. P. Michel[1] and Y. Zhang[1], [1]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, CS 34229, 06304 Nice Cedex 4, France, michelp@oca.eu.

Introduction: A close approach of an asteroid to a planet, such as the one of Apophis to the Earth in 2029, can cause surface motion, reshaping or even a catastrophic disruption. A good understanding of tidal effects is crucial as such effects may be at the origin of some of the observed characteristics of small bodies and therefore may give important clues on their history and structures [1]. We revisit this important process [2], which was already the subject of several past studies [3, 4, 5], by performing simulations with a more realistic numerical treatment of contact forces and frictions between the rubble pile constituent during the encounter, and a more natural internal packing of the modeled rubble pile. We then discuss the differences in the outcome with previous works.

Numerical approach: We use the parallel *N*-body tree code *pkdgrav* and its implementation of the Soft-Sphere Discrete Element Method (SSDEM; see [6, 7] for details on this implementation). In granular physics model, four dissipation/friction components in the normal, tangential, rolling, and twisting directions are applied for computing particle contact forces. The compressive strength of the material is controlled by two stiffness constants for the normal and tangential directions; the contact energy dissipation is controlled by two coefficients of restitution for the normal and tangential directions; the magnitude of material shear strength is controlled by three friction coefficients for the tangential, rolling, and twisting directions, and a shape parameter that represents a statistical measure of real particle shape.

This technique was recently used [8] to simulate the encounter of Apophis with the Earth, but an Hexagonal Close Packing (HCP) for the internal packing of the asteroid, modeled as a rubble pile, was considered, while a Random Close Packing (RCP) may be more appropriate to represent the actual packing of such an object. Here we perform a general investigation of tidal encounters, with an application to Apophis, and consider both an HCP and an RCP model of the rubble pile. We then compare with previous works using different techniques and with results from the continuum theory [9].

Rubble pile and encounter setup: The rubble-pile progenitor is modeled as a spherical granular assembly consisting of ~10,000 identical spherical particles. Regarding the internal packing, we explore two possible configurations in this study: an HCP configuration with a number of particles $N = 11577$ and a particle radius of 40 m, and an RCP configuration with $N = 10011$ and a particle radius of 40 m. In order to make direct comparisons with past Hard Sphere Discrete Element Method (HSDEM) results, the initial conditions of our simulated rubble piles are the same as those considered in [5] who used HSDEM to simulate the tidal encounter process. Because contact forces are not physically computed in HSDEM, the angle of friction of the HCP rubble pile simulated with this technique is controlled by the interlocking geometry and gets the value of 40° (see, e.g., [10]). For our SSDEM HCP rubble pile, we adjust the friction coefficients so that the resulting angle of friction is also 40° for a direct comparison. On the other hand, for our SSDEM RCP rubble pile, to investigate the influence of the angle of friction on the tidal encounter outcome, we consider 3 sets of values of friction parameters, resulting in 3 different angles of friction (i.e., 18°, 27° and 32°).

We then perform simulations of approaches of our rubble piles with the Earth on different hyperbolic orbits, which are defined by the encounter velocity at infinity, V_∞, which ranges from 0 km/s (parabolic orbit) to 20 km/s, and the perigee distance q, which ranges from 1.1 to 2.5 Earth's radius. Each run ends when all the tide-induced fragments (or the reshaping rubble piles) have settled down to stable states, which typically occurs 1–2 days after perigee.

Results: Figure 1 shows typical outcomes of our SSDEM tidal encounter simulations. Our results are very different than previous ones using HSDEM [4]. In particular, we find that the latter method overestimates the efficiency of planetary approaches to cause a mass loss of the rubble pile undergoing tidal forces. Thus, asteroid family formation resulting from tidal disruption cannot be as frequent as previously estimated using the hard-sphere treatment.

We also find that the packing of a rubble pile has great influence on the encounter outcome. As shown in Fig. 2, the RCP leads in general to an effect of tidal forces at larger periapses than the HCP. We also observe for the RCP case a continuous trend in the effect of tidal forces with decreasing periapses and speed at infinity, while a tidal encounter for an HCP model depends sensitively on the precise internal configuration and orientation of the model towards the tidal force directions.

For a same packing and encounter conditions, the strength of a rubble pile against a tidal encounter depends also on the number of boulders composing it.

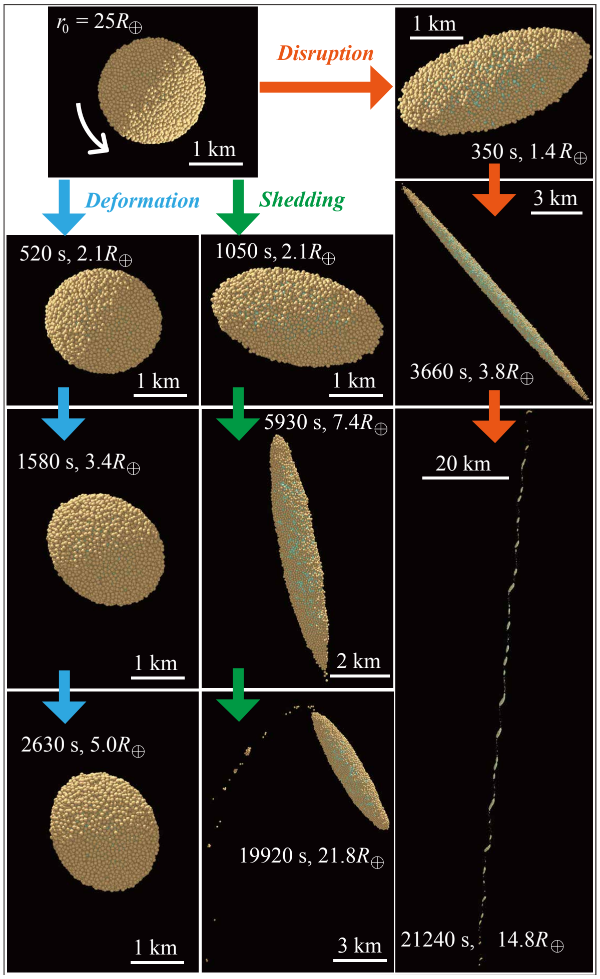

Figure 1. Three types of tidal encounter outcome examples for the RCP rubble pile model.

Finally, our simulations find a good agreement with the static continuum theory. But complementary to the tidal disruption limiting distance given by this theory, our simulations describe the dynamics of the process and provide a description of the final state of the rubble pile (e.g., shape, spin, surface and internal motions as well as number, shape and spin rate of fragments in case of disruption), once the encounter is over.

Conclusion: Our investigation shows that predicting what will happen during the tidal encounter of a small body needs some knowledge about the internal configuration of the object. On the other hand, measuring the end result of a tidal encounter can allow us to provide some constraints on the internal and mechanical properties of the object.

For now, we focused on global outcomes, and not in the detailed of what may happen on the surface or in the interior, in a subtle but still possibly measurable way.

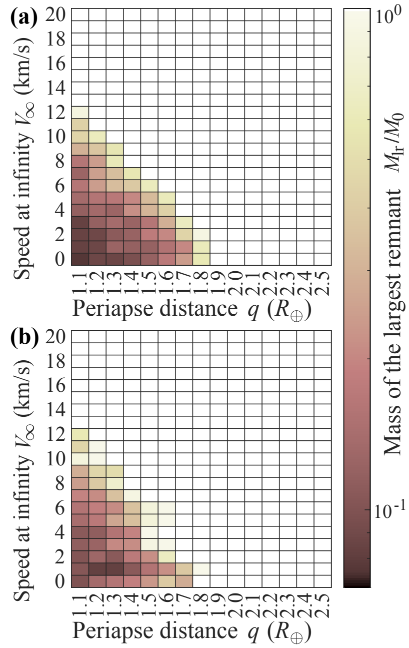

Figure 2. The mass ratio of the largest remnant to the original mass of the rubble-pile as a function of V_∞ and q for (a) the RCP model and (b) the HCP model.

Monitoring a very close planetary approach, like the one by the Asteroid Apophis in 2029, and being able to measure even subtle changes can allow us to progress in this kind of modeling and give clues about the mechanical and internal structures of the asteroid, which is a gold mine to understand how these bodies form and then evolve against external processes.

Acknowledgments: This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 870377 (project NEO-MAPP). Y.Z. acknowledges funding from the Univ. Côte d'Azur "Individual grants for young researchers" program of IDEX JEDI. P.M. acknowledges support from CNES and from the Acad. 2 and 3 of Univ. Côte d'Azur IDEX JEDI. Simulations were performed on the LICALLO cluster hosted at the Obs. Côte d'Azur and on the Deepthought2 HPC cluster administered by the DIT at the University of Maryland.

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