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Tidal effects on the shape and structure of Apophis during the Earth flyby in 2029

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ABSTRACT

99942 Apophis (2004 MN4) was well known over the last two decades because it set the record for the highest rating on the Torino impact hazard scale with level 4 on December 27, 2004. With subsequent improved observations, the possibility of an impact on Earth was ruled out. As calculated by the JPL Center for NEO Studies (CNEOS) and by the ESA NEODyS-2, Apophis will have a non-threatening close encounter with the Earth at 39000 km from its centre on April 13, 2029. The tidal effect on Apophis induced by such an extraordinarily close approach with the Earth is not yet determined since the internal structure of the asteroid is unknown. Asteroids larger than 100-200 m and smaller than some 100 km in diameter are most likely gravitational aggregates (GAs) [1][2], gravitationally reaccumulated leftovers of catastrophic collisions to their parent asteroids. Therefore, their

components are held together mainly by self-gravity, with contribution from other forces (cohesion, friction, interlocking, etc.).
In this work, we assume a GA internal structure for Apophis and we apply our internal structure model to the currently available shape model. We model internal structure by means of irregular shape components of different sizes using a SSDEM high-performance parallel gravitational *N*-body code, PKDGRAV [3][4][5]. Irregular components are obtained by grouping together particles forming irregular overall shapes, in which relative particle motion is inhibited (rigid-aggregates). Such components may be produced according to arbitrary mass distributions.
We perform simulations of the 2029 close encounter with the Earth and follow the evolution of the object. We present the model outcome of possible changes in the shape and structure of Apophis as well as changes to its spin state. DeMartini et al. (2019) [6] tackled this problem with PKDGRAV, using mono-disperse hexagonal-close-packing configuration of spherical particles for the internal structure of Apophis. Further refinement included poly-disperse distributions of spherical particles mixed with some larger rigid-aggregate components (PDC 2021). They also suggested future work to model Apophis as two large rigid-aggregate cores covered by layers of regolith that resemble a contact binary, since the most recent best-fit shape model of Apophis suggest such structure [7]. The outcome of the present model will be compared with DeMartini's outcome.
Furthermore, we compute the gravity field of the body before and after the encounter with the aim to set requirements to the needed sensitivity of a gravimeter on board a rendezvous space mission. Such measurements may potentially reveal Apophis structural changes during the Earth encounter.

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