8th IAA Planetary Defense Conference, April 3-7 2023, Vienna, Austria

THE EFFECT OF DIDYMOS INTERNAL STRUCTURE ON PARTCLE DYNAMICS NEAR ITS SURFACE

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DART

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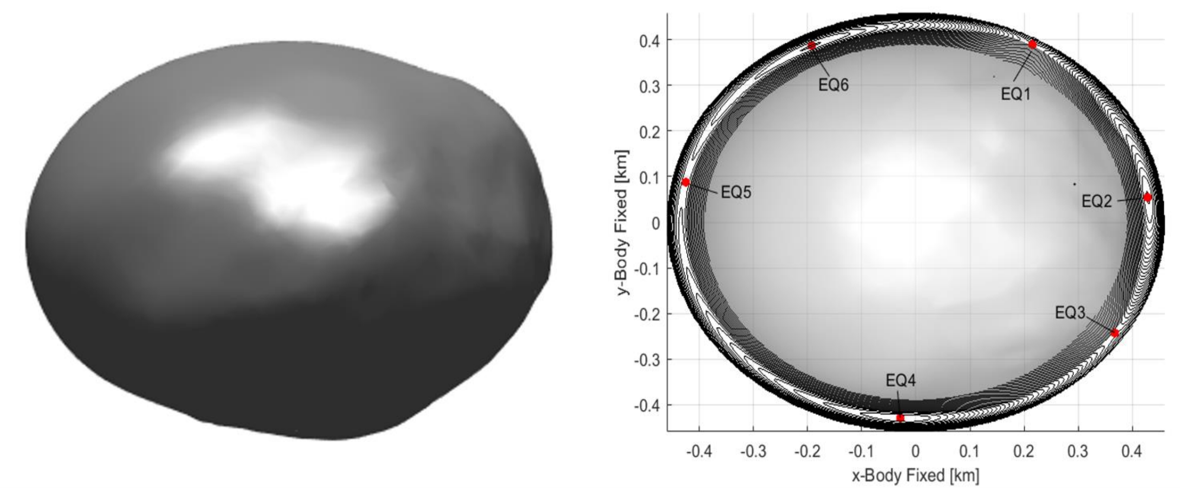
Summary

On 26th September, 2022, the DART spacecraft intentionally impacted on Dimorphos, the secondary member of the Didymos system, successfully demonstrating the first planetary defense test in space [1]. The images captured by the DRACO camera [1] and LICIACube [2] have provided an initial understanding of the local topography of both Didymos and Dimorphos. Thus, a preliminary estimation of both asteroids' shapes models is now available [1]. In this work, we examine the internal rubble-pile structure of Didymos by using the numerical model PKDGRAV to estimate dynamical properties due to variations in internal structure and grain density. To cross-compare different internal structure models, a sphere-cluster-based gravity model (mascons) is used. This method provides a semi-analytical expression of the linearised equations around the asteroids' gravitational equilibrium [3] and an easy way to search for families of periodic orbits around them.

Figure 1. Didymos shape model and zero velocity curves for a homogeneous uniform density distribution.



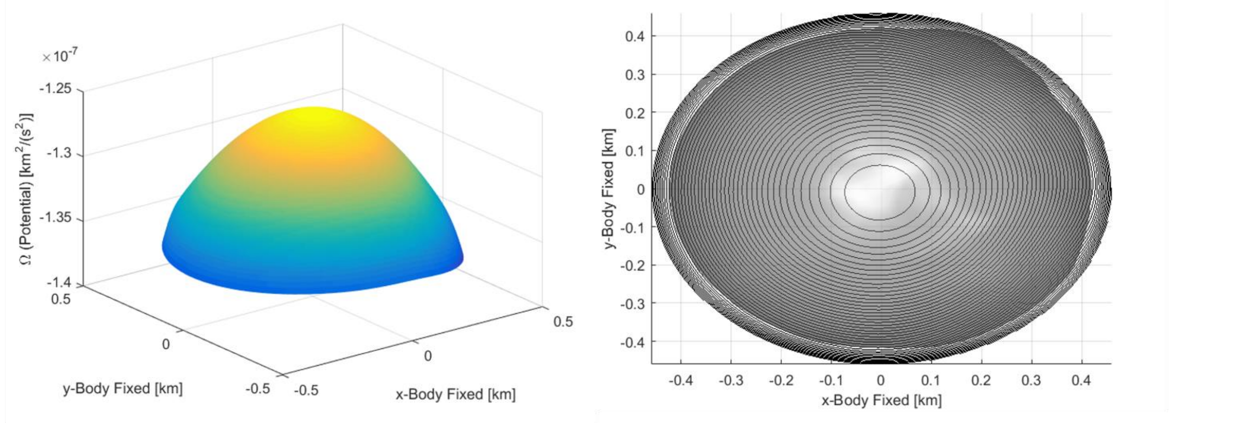
(a) Didymos Shape Model: 3074 vertices and 6144 Faces

(b) Zero velocity curves: polyhedron gravity model (2700 kg/m^3)

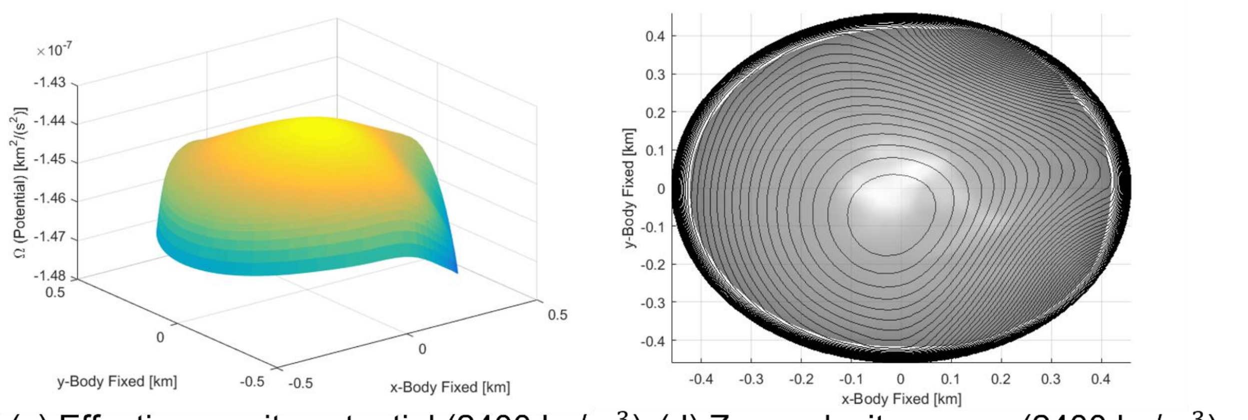
Polyhedron vs Mascons Gravity Model

The generalised methodology derived by Soldini et al. [4] is used to study the dynamics around Equilibrium Points (EPs) of Didymos [5]. At the core of our study, a comparison among different initial conditions for the rubble-pile models is performed by evaluating dynamical properties and global gravity information as Stokes coefficients. The evaluation of the dynamical properties of Didymos constrains the assumption made for the internal structure and provides a direct comparison of models. Moreover, this study provides a database of expected gravity estimates that is beneficial for the inverse problem of estimation of the asteroid internal properties from Hera's gravity measurements during the Juventas CubeSat radio science campaign [6].

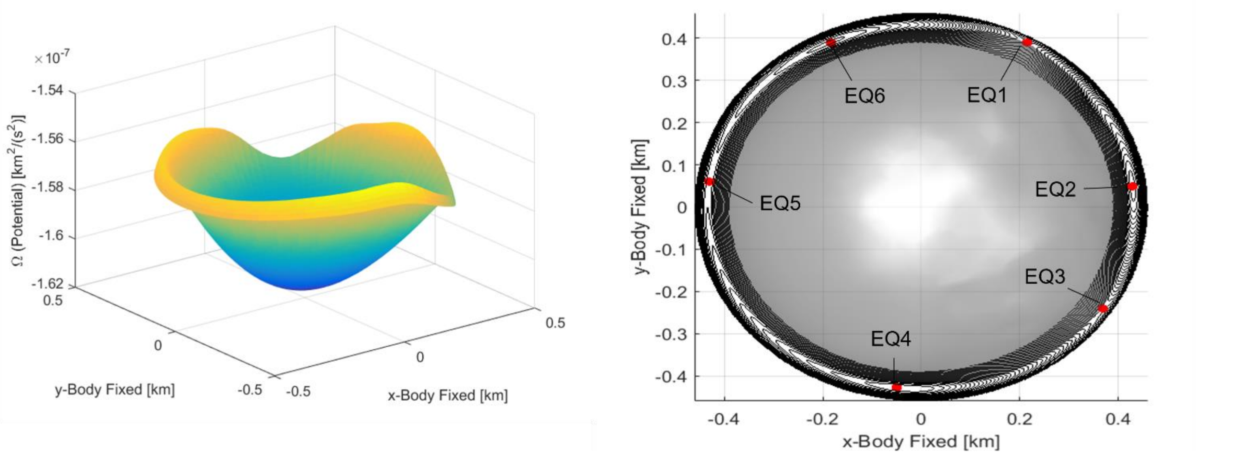
Figure 2. Effective gravity potential and zero velocity curves for a homogeneous density distribution.



(a) Effective gravity potential (2100 kg/m^3) (b) Zero velocity curves (2100 kg/m^3)



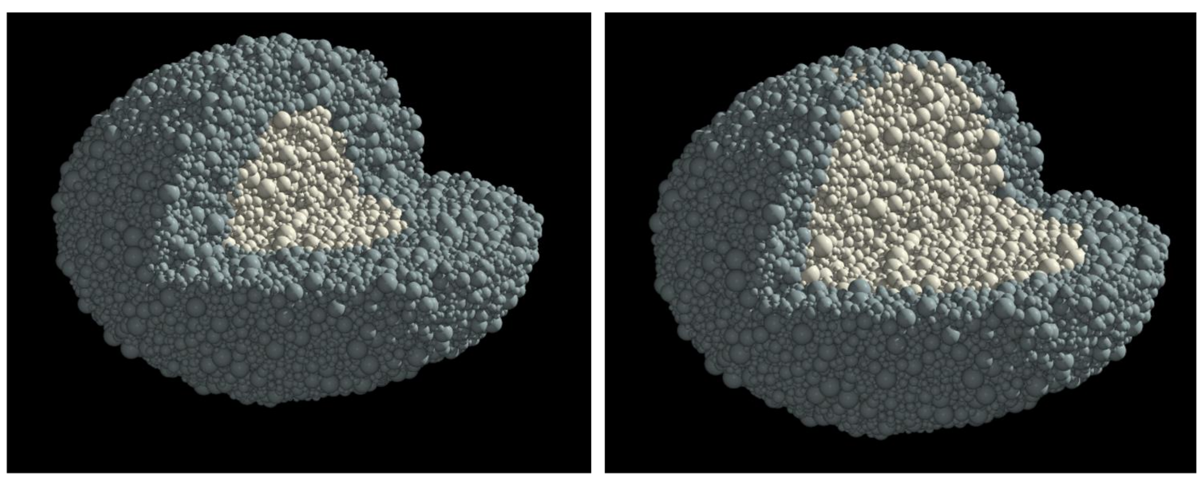
(c) Effective gravity potential (2400 kg/m^3) (d) Zero velocity curves (2400 kg/m^3)



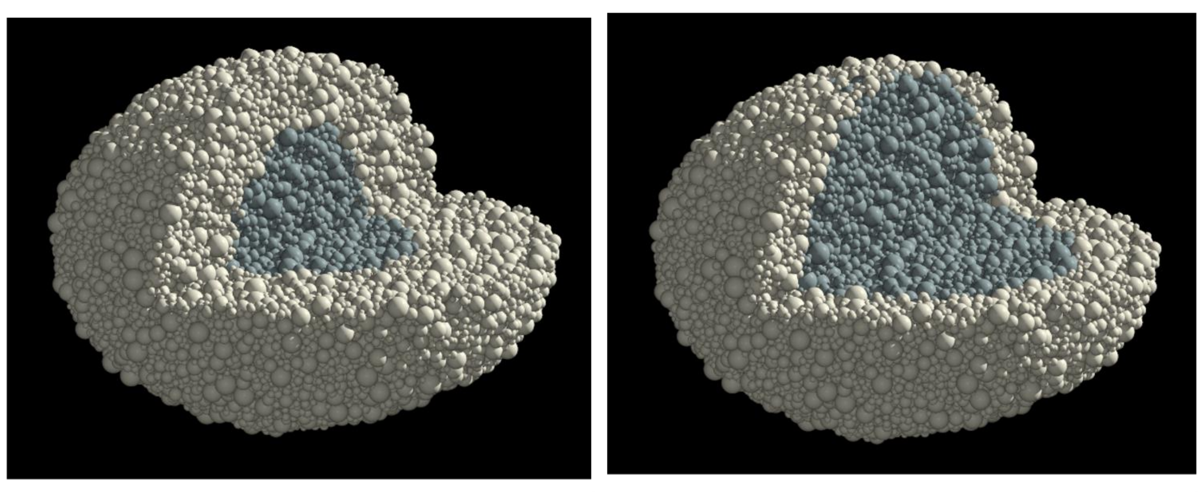
(e) Effective gravity potential (2700 kg/m^3) (f) Zero velocity curves (2700 kg/m^3)

Figure 1 shows the shape model of Didymos obtained with the DART mission's data [1], the zero velocity curves and the equilibrium points (marked in red in the figure). It was evaluated that 1.2M mascons were an adequate number of masses to retrieve the same dynamical properties (i.e., EPs) of the polyhedron gravity model. Figure 2 shows the gravity effective potential for z-axis coordinates equal to zero (left column Fig.2a,2c,2e) and the correspondent contour lines of the effective potential at a fixed energy level known as zero velocity curves (right columnFig.2b,2d,2f). As shown in Fig. 2, no equilibrium points can be located externally to the asteroid for bulk densities below and equal 2400 kg/m3. In this case, the entire surface of Didymos is prone to escape thus particles could be naturally ejected from its surface. This is due the fast rotational spin period of the asteroid close to its critical value and a low bulk density. On the other hand, a higher bulk density of 2700 kg/m3 shows the existence of six equilibrium (Fig. 2f). Three equilibrium points are unstable (EQ1,3,5) and three are stable (EQ2,4,6) which imply a more complex motion evolution in the vicinity of Didymos surface.

Figure 3. Assumed rubble pile internal structure distribution of Didymos with bulk density of 2170 kg/m3 [9,10].



(a) Looser core 200 (2325.28 kg/m^3) (b) Looser core 300 (2271.91 kg/m^3)

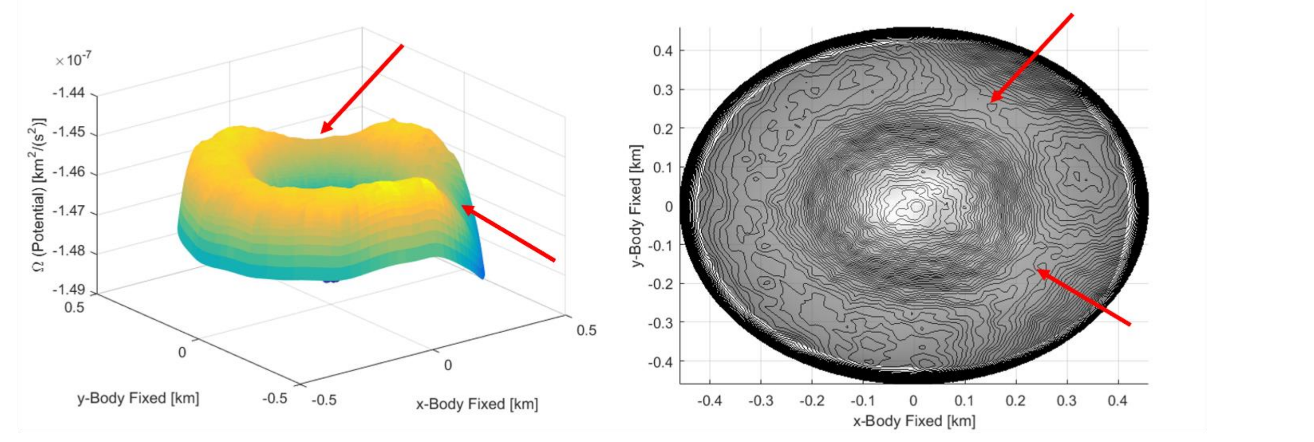


(c) Denser core 200 (2474.26 kg/m^3) (d) Denser core 300 (2516.18 kg/m^3)

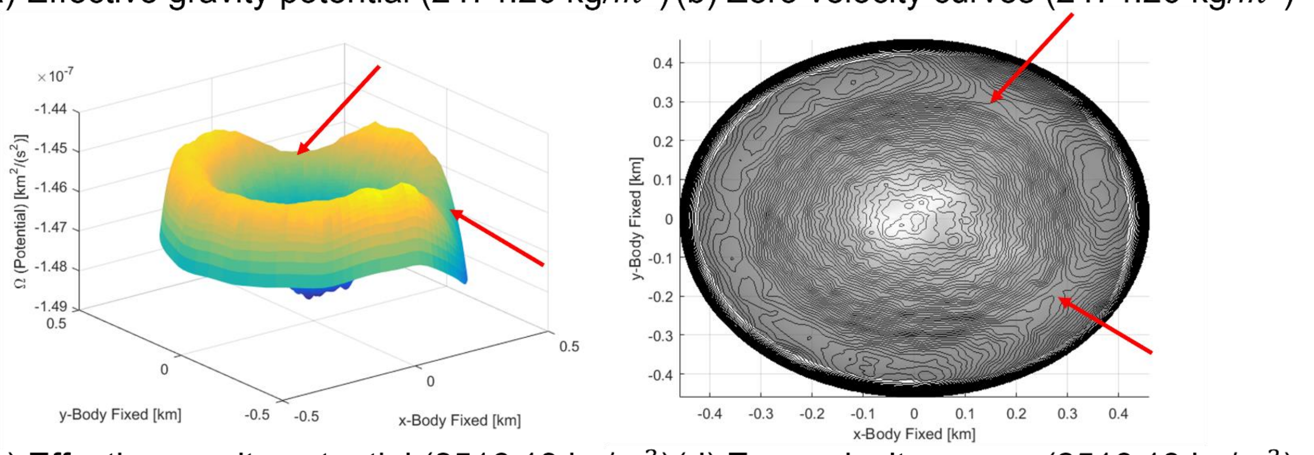
Mascons Gravity Model for PKDGRAV

Figure 3 shows the assumed PKDGRAV rubble-pile models for Didymos [9, 10]. In the figure, the case of loser core below 200 (Fig. 5.a) and 300 (Fig. 5.b) meters from the center with bulk density of 2325.28 kg/m3 and 2271.91 kg/m3 respectively. While the case of denser core below 200 (Fig. 5.c) and 300 (Fig. 5.d) meters from the center correspond to bulk density of 2474.26 kg/m3 and 2516.18 kg/m3 respectively. Figure 7 shows the case of bulk density with denser core above 2400 kg/m3. While there are no equilibrium points outside the shape of Didymos, it is important to notice an interesting pattern in the ridge of the effective potential.a-.c shown in Fig. 7.a-.c. Indeed, the potential ridge presents maximum (yellow) and minimum (marked with a red arrow) regions right below a thin substrate material. The minimum in the potential corresponds to unstable regions where particle are prone to escape while the maximum represents areas of stability.

Figure 4. Effective gravity potential and zero velocity curves for a rubble-pile with denser core as shown in Fig. 5.c-.d.



(a) Effective gravity potential (2474.26 kg/m^3) (b) Zero velocity curves (2474.26 kg/m^3)



(c) Effective gravity potential (2516.18 kg/m^3) (d) Zero velocity curves (2516.18 kg/m^3)

Conclusions

The mascons gravity model has served as benchmark to compare several models and gain information of gravity coefficients and dynamical stability (i.e., equilibrium points). The aim is to then extend the study to other rubble-pile models as SPH and multi-polyhedron models. It has been demonstrated the importance in the mascons resolution for the accuracy in the gravity coefficients and location of equilibrium points. The rubble-pile models here analysed present non uniformly distributed voids when compared with the polyhedron case or homogeneous mascons case which affects the dynamical stability and gravity coefficients. For denser core rubble-piles, it was still possible to identify a ridge in the effective potential right below a thin substrate material under the surface where regions of stability and instability could be identified. The evaluation of the dynamical properties of Didymos constrains the assumption made for the internal structure and provides a direct comparison of models.

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Acknowledgement

This work was supported by UKRI-FLF Grant Number MR/W009498/1

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