Mechanical properties of rubble pile asteroids though surface boulder morphological analysis

Colas Q. Robin [1] , Alexia Duchene [1], Naomi Murdoch [1], David Mimoun [1]

[1]Institut Supérieur de l'Aéronautique et de l'Espace (ISAE-SUPAERO), Université de Toulouse, Toulouse, France.

Context

JAXA MMX mission (launch: 2026)

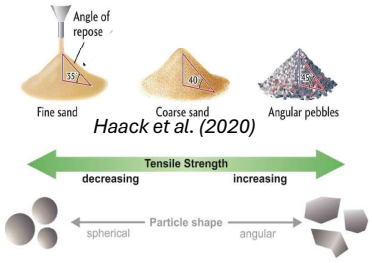
- Sample return from **Phobos**
- **CNES/DLR** Rover: **IDEFIX**

Rover with scientific payload

- **WheelCams**
- Cameras observing the wheels of the rover

What are the size/shapes of the boulders/rocks at the surface of Phobos ? What are the mechanical properties of the material ?

Link with mechanical properties



The morphology of boulders provides information about mechanical properties and their history

- **Roundness** and particle size are linked to the **angle of friction**
- Lower **roundness**/larger median **particle size** = **larger friction angle** *[Bareither & al., 2008]*
- **Elongation** ratio of boulders on asteroids has also been linked with the **formation mechanism** *[Michikami & al., 2016]*

Conclusions & Perspectives

Other studies proposed that **Dimorphos** were formed by very slow **mass-shedding** of Didymos *[Pajola & al., 2024, Barnouin & al., 2024]*

Here, we propose that boulders at the surface of **Dimorphos** were formed by **catastrophic disruption** (assuming the apparent b/a is different from the real b/a)

- A further argument for the mass-shedding scenario as the formation of the binary **did not change** the shapes of the boulders
  - Assuming these boulders were on Didymos surface before
- Dimorphos surface is **40-130x older** than Didymos' *[Barnouin & al., 2024]*

Could other processes have modified the shape of the boulders ?

- **Thermal fatigue** but only **horizontal cracks** has been observed
- Dimorphos surface is **too young** for thermal cracks to reshape boulders *[Lucchetti & al., 2024]*

Demonstration of the utility of the pipeline that will be used with the WheelCams images and can be used for any other cameras observing boulders, rocks, etc. with a good enough resolution

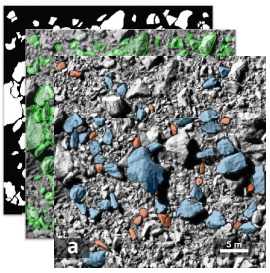
All these results has been published in **Nature Communications**:
https://doi.org/10.1038/s41467-024-50147-w

Method

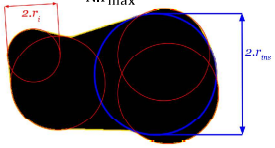
History and **physical** properties of the regolith of an asteroid may be recorded in the **shape of the boulders/pebbles** at its surface

Morphological analysis pipeline

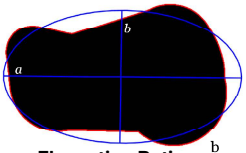
- **Semi-automatic** boulder detection/segmentation
  - ***segmentanygrain*** python package
- 2D analysis pipeline for morphological parameters



Roundness $= \frac{\Sigma_{i=1}^{N} r_i}{N.r_{max}}$



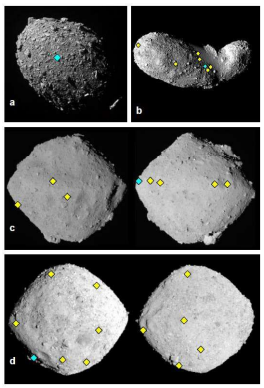
N : number of corners
r_i: radius of corner circles
r_{max}: radius of the maximum inscribed circle



Elongation Ratio $= \frac{b}{a}$

Application of the pipeline on rubble-piles asteroids

Application of the pipeline the last image of **Dimorphos** (secondary of the binary asteroid **Didymos**) captured by the **DART** spacecraft and other rubble-pile asteroids : **Itokawa, Ryugu and Bennu**



a) Dimorphos b) Itokawa
c) Ryugu d) Bennu

Angles of internal friction
(from boulders larger than 30px: minimal values):
Dimorphos : >32,7 ± 2,5°
Itokawa : >32,2 ± 2,5°
Ryugu : >31,6 ± 2,5°
Bennu : >31,1 ± 2,7°
In agreement with simulations or surface observations

Values derived from roundness values, method from *Suh & al., 2017*
$\varphi = 25,02 \times (1 - R) + 20$

Boulders formed by **catastrophic disruption**
In laboratory, disruptive impacts form fragments with b/a ~ 0,7-0,74 on average
In this study:
b/a **Dimorphos** = 0.66 ± 0.15
b/a **Itokawa** = 0.71 ± 0.15
b/a **Ryugu** = 0.71 ± 0.14
b/a **Bennu** = 0.68 ± 0.14
In agreement with other studies

References

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