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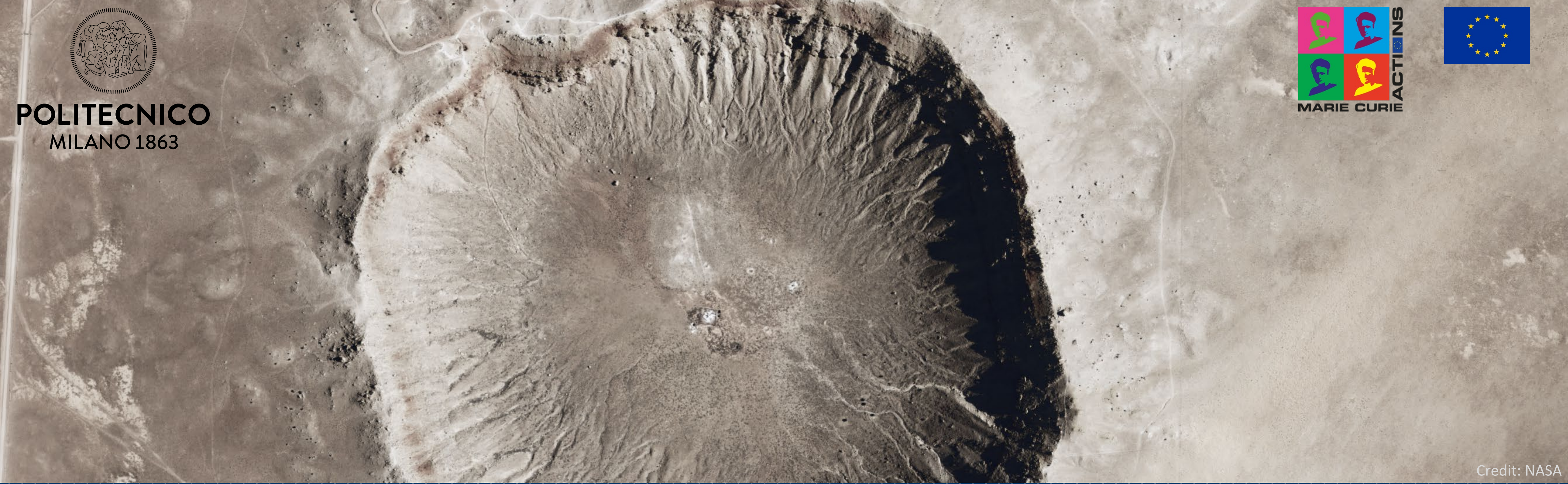
Credit: NASA

Ejecta analysis for an asteroid impact event in the perturbed circular restricted three body problem

Mirko Trisolini, Camilla Colombo, Yuichi Tsuda

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Background

The CRADLE project

- CRADLE is a project funded by the European Union under the MSCA Actions
- Global fellowship hosted by Politecnico di Milano in collaboration with

- Started in late March this year
- The focus is on exploration missions towards asteroids and other small bodies

Background

The CRADLE project

- Start from the knowledge acquired by Hayabusa-2 mission

Objective

- Study the feasibility of in-orbit particle collection missions
- In-orbit particle sample and return devices

Focus areas

- Dynamics of fragments generated by kinetic impactors
- Modelling the ejecta behaviour
- Finding feasible conditions for material collection

Contributions

- Extend the knowledge of asteroid composition
- Enable multi-asteroid sampling

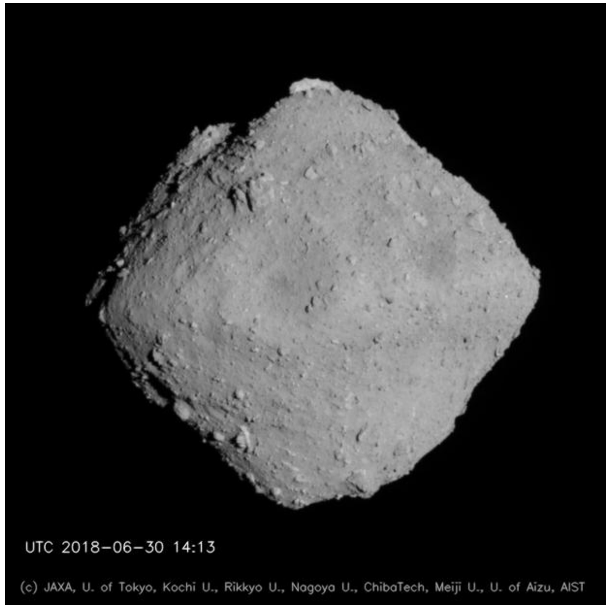
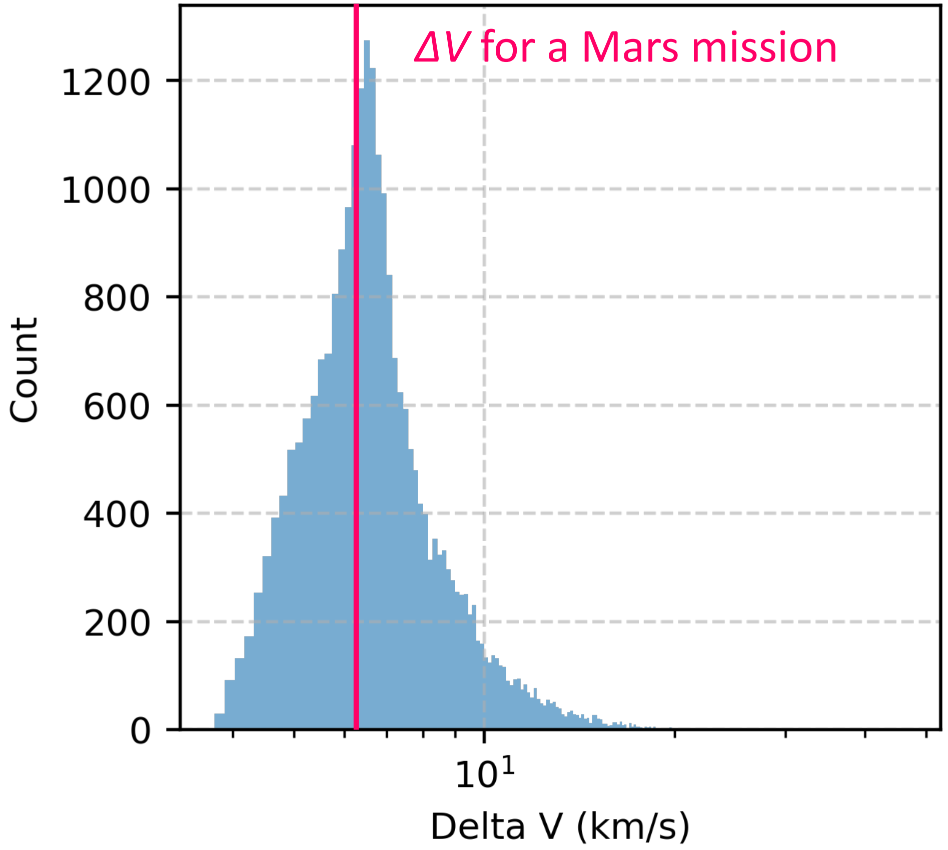


Image of Ryugu asteroid from Hayabusa-2 mission. Credit: JAXA

Introduction

Target analysis

- Possible ways to select viable targets for future missions
- **Reachability**
  - *ΔV* estimated with two-burn manouevre[1]
  - Several options with delta-V comparable or lower than the required for Mars missions



Shoemaker, Helin, “Earth-approaching asteroids as targets for exploration”, 1978.

Introduction

Target analysis

- Possible ways to select viable targets for future missions
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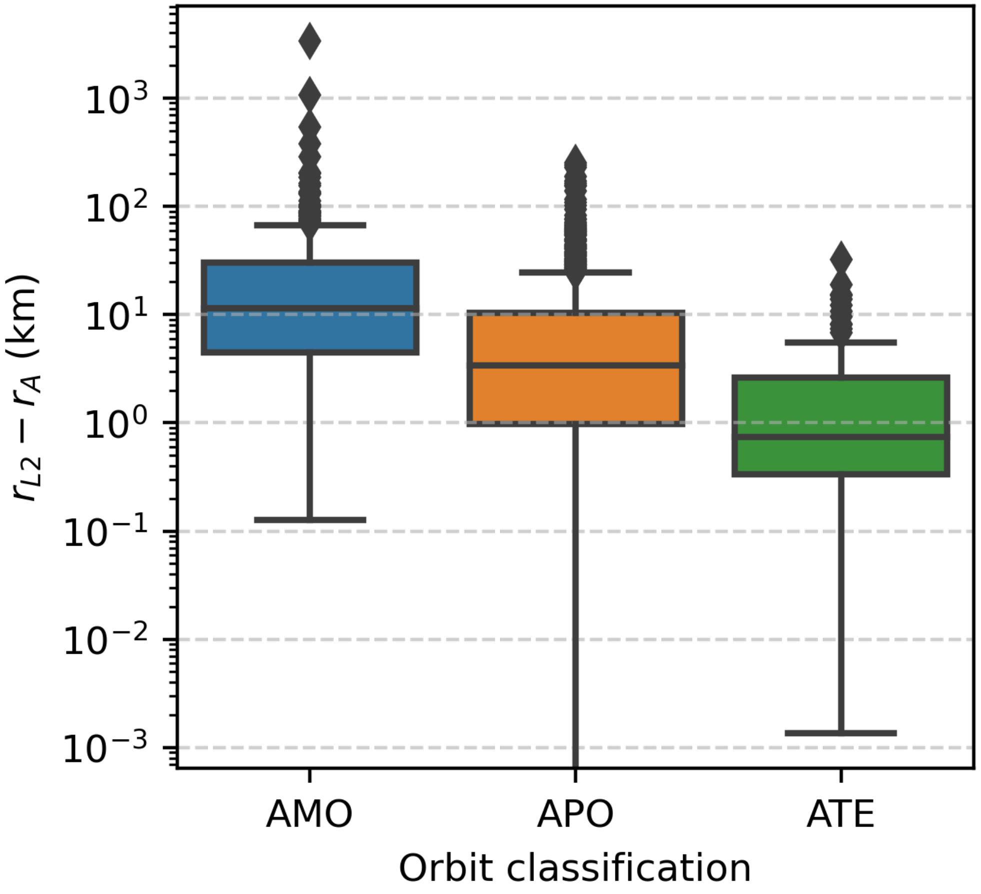
- **Exploitability**
  - Position of Lagrangian point L2 as indicator of possible collection regions
  - Small L2 altitudes lead to complex collection scenarios

Average L2 altitude for 1 mm size particles



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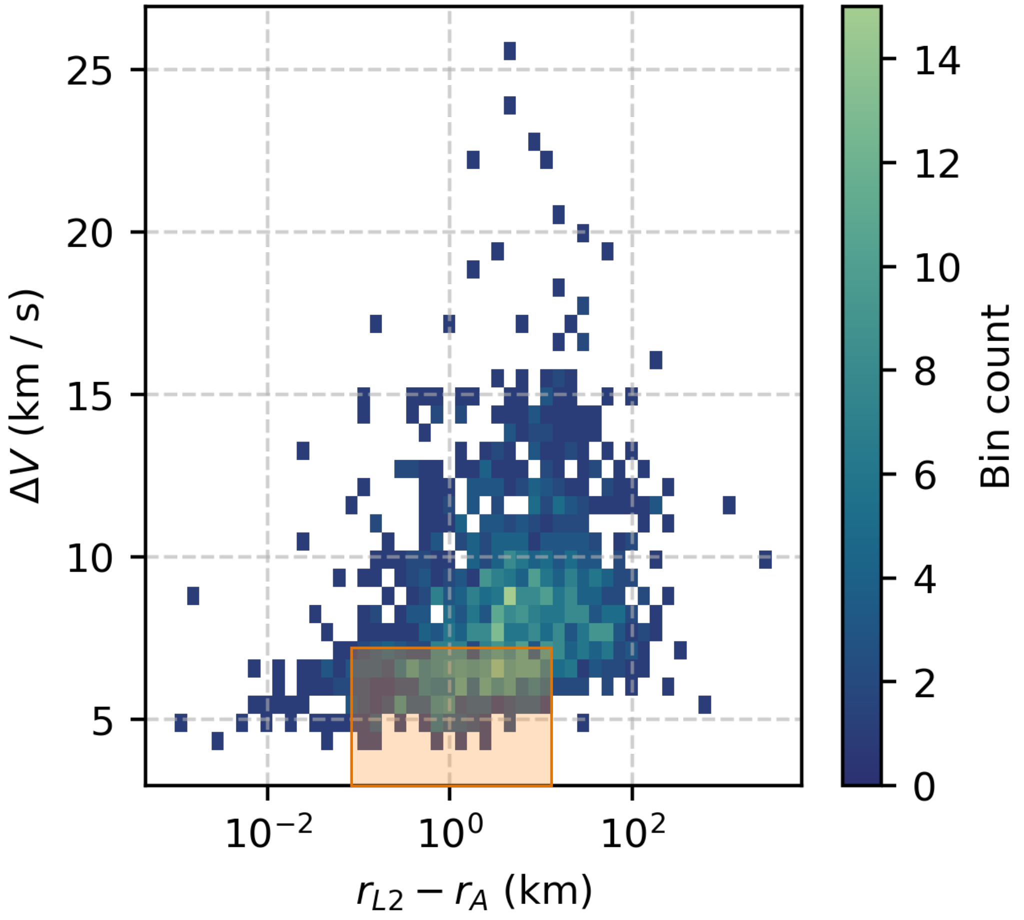
  - Small L2 altitudes lead to complex collection scenarios
- Combined L2 altitude – *ΔV* analysis



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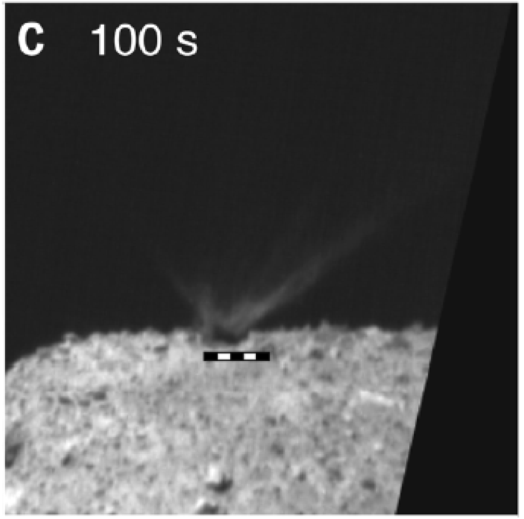
Ejecta model

A distribution derivation

- Predicting the fate of the ejecta requires modelling the ejecta behaviour after the impact
- Distribution of particle size (s), velocity (u), and launch direction (ϑ, Ψ)
- We assume the particle size and velocity distribution can be modelled independently from the launch direction



Crater ejecta after impact on Ryugu[1]

Uncorrelated distribution

$$f(s,u) = as^{-\alpha-1}u^{-\gamma-1}$$

The ejection velocity is independent form the particle size

Correlated distribution

$$f(s,u) = as^{-\alpha-1}u^{-\gamma-1} \cdot \Theta[bs^{-\beta} - u]$$

Ejection velocity depends on particle size
Larger particles are limited to lower velocities

- The coefficients of the distributions can be estimated from experimental correlations and conservation laws

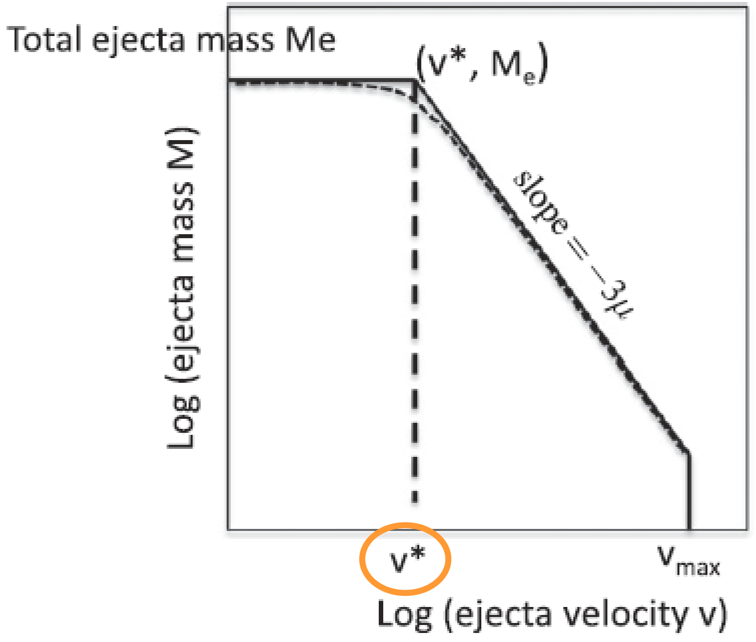
[1] Arakawa et al., "An artificial impact on the asteroid (162173) Ryugu formed a crater in the gravity-dominated regime", Science, 368, 67-71, 2020 Science

Ejecta model

Parameters selection

- ***s**$_{min}$*: typical values range between 10 μm and 100 μm in diameter
- ***s**$_{max}$*: a common threshold is 10 cm. Alternatively, a diameter corresponding to 10% of the ejected mass is suggested
- ***u**$_{min}$*: ***knee velocity*** from experimental results
- ***u**$_{max}$*: selected from experimental correlations[2]
- ***b***: only for the correlated distribution. Can be selected imposing: $bs_{min}^{-\overline{\beta}} - u_{max} = 0$
- ***a***: obtained from mass conservation

Ejected mass vs ejection velocity[1]



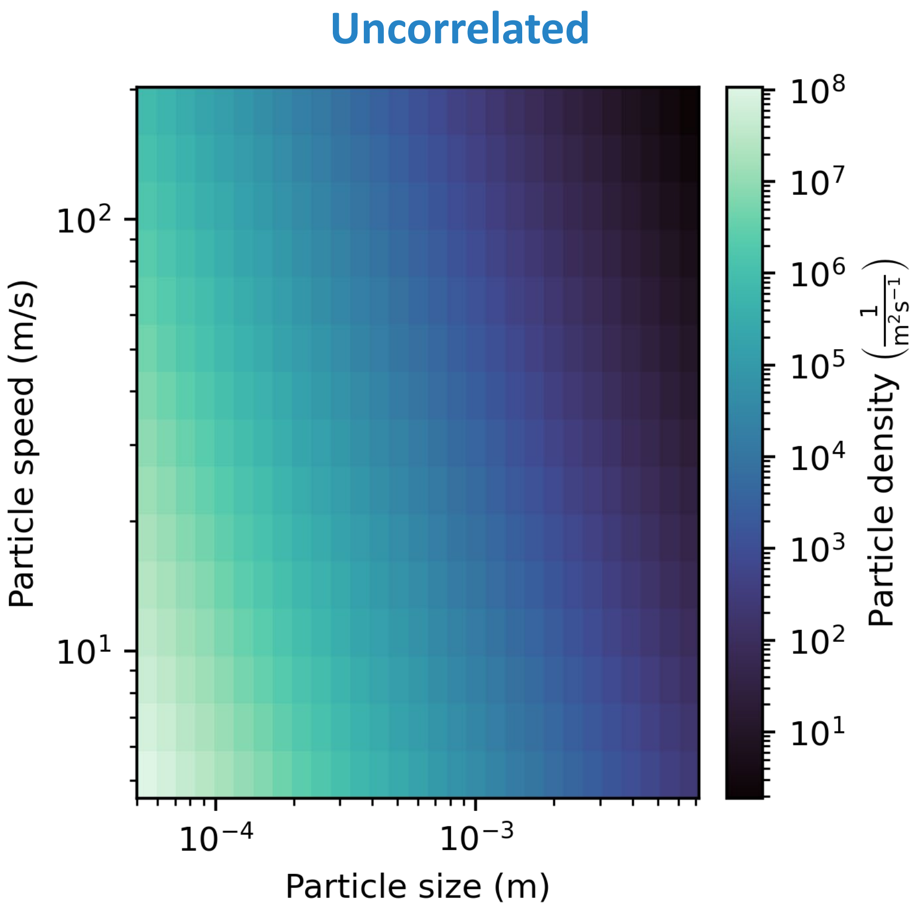
[1] Holsapple, Housen, "Momentum transfer in asteroid impacts. I. Theory and scaling", Icarus, Vol 221, pp. 875-887, 2012

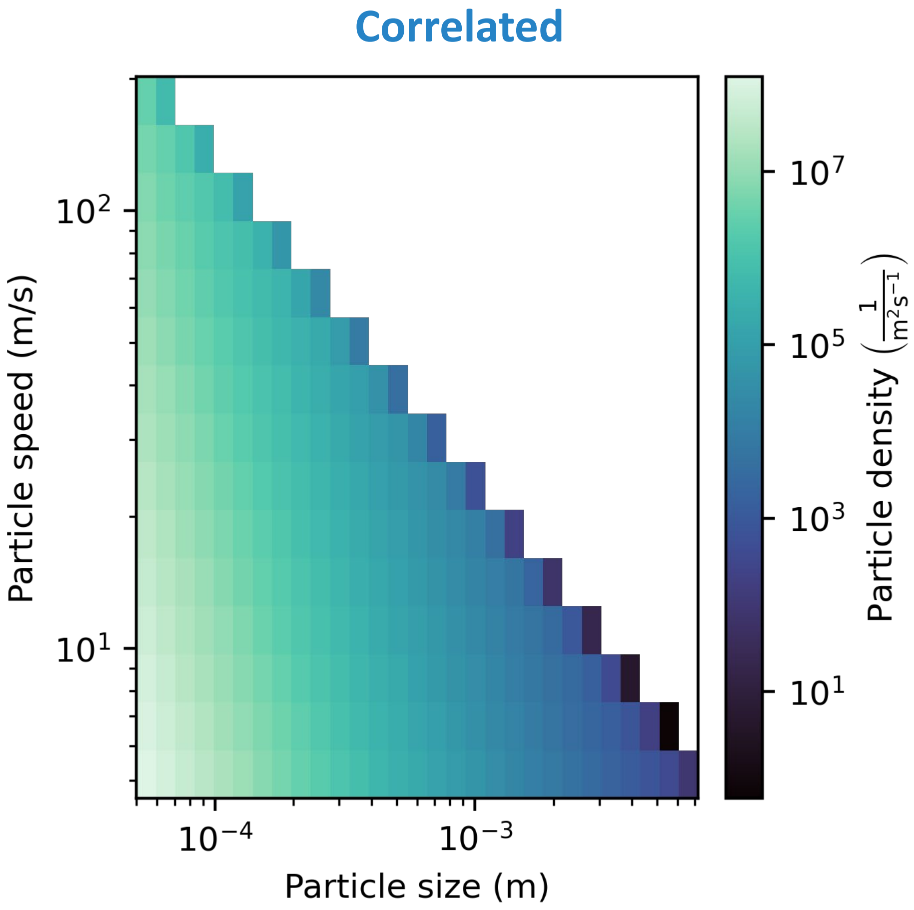
[2] Housen, Holsapple, "Ejecta from impact craters", Icarus, Vol. 211, pp. 856-875, 2011

Ejecta model

Distribution example

- Comparing the particle density for the correlated and uncorrelated distributions

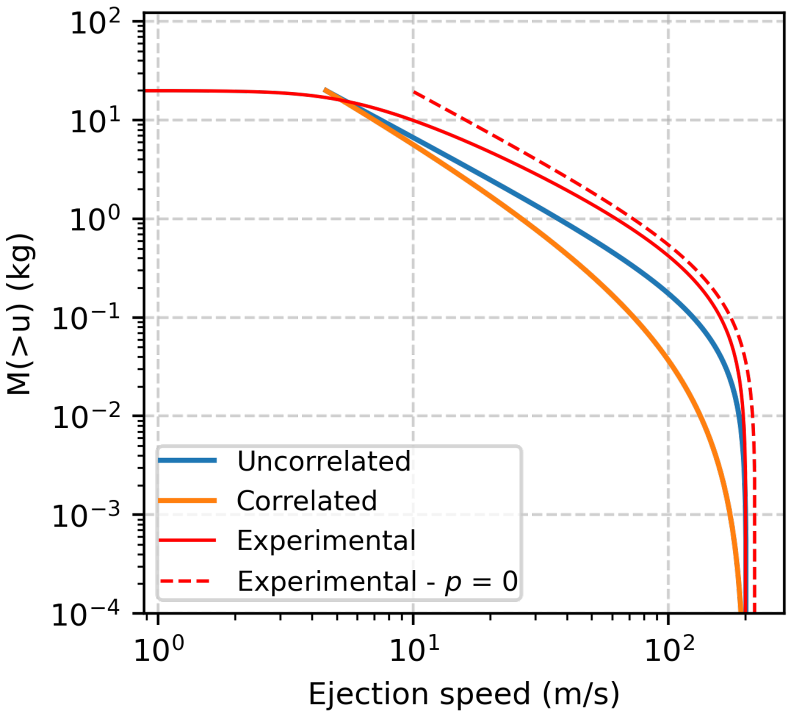


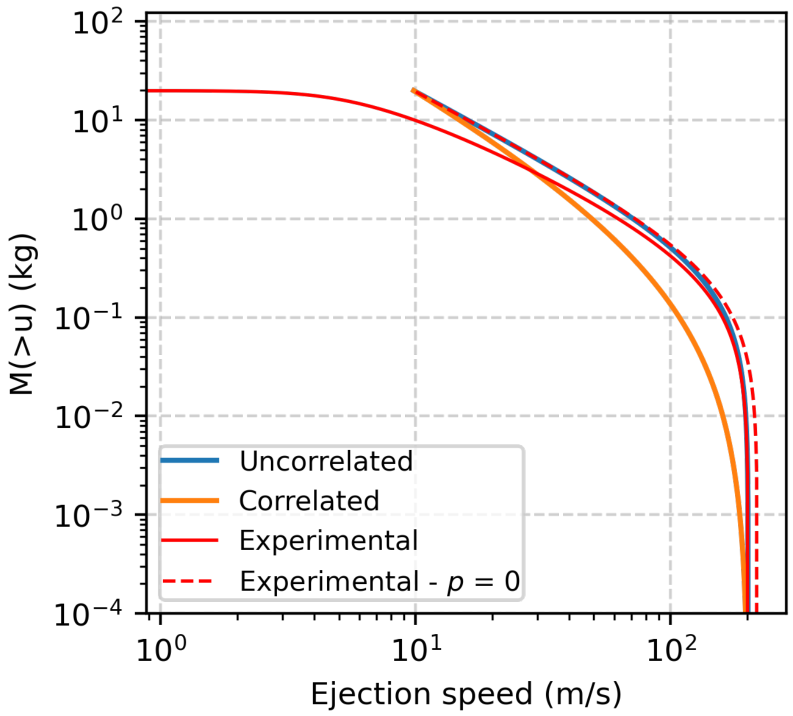


Ejecta model

Comparison with experimental correlations

- The two behaviours depend on the selection of the minimum ejection speed





- The distributions more closely follow the experimental correlations[1] without porosity correction
- The correlated distribution is steeper → coherent with the limitations on the maximum velocity vs particle size.

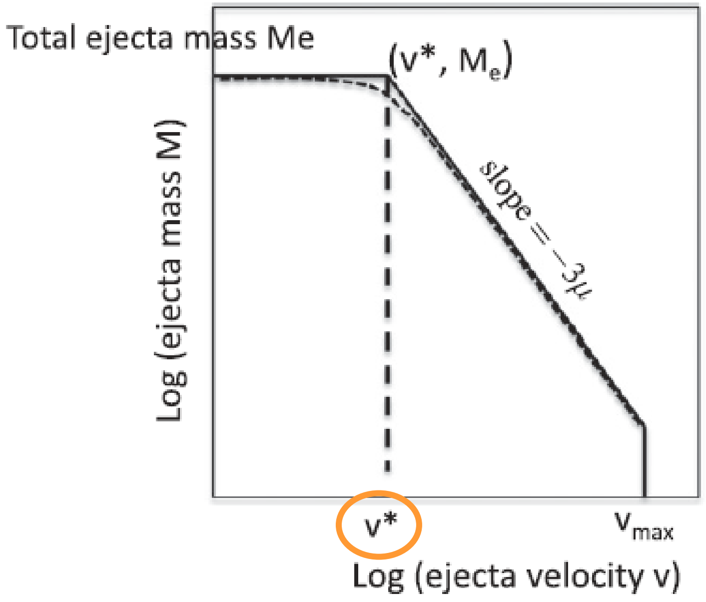
[1] Housen, Holsapple, “Ejecta from impact craters”, Icarus, Vol. 211, pp. 856-875, 2011

Sensitivity analysis

Minimum ejection speed

- Focus on the minimum ejection speed
  - Assumed approximately equal to the *knee velocity*
- The **minimum ejection speed** determines the possibility of having particles trapped around the asteroid and eventually leaving through L2
- Gives important information on the feasibility of the mission
  - If the minimum velocity is greater than the escape velocity, all the particles will quickly leave the neighborhood of the asteroid
- Depends on the target properties and the impactor properties
  - The **target material strength** (*Y*) strongly affects the outcome

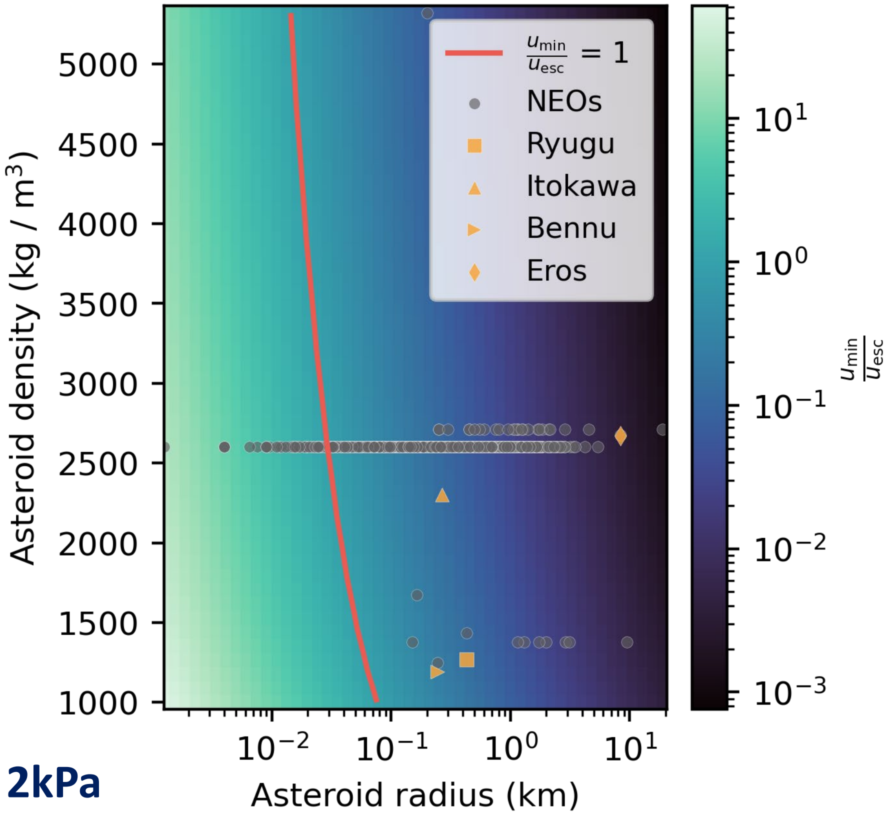
Ejected mass vs ejection velocity[1]



Sensitivity analysis

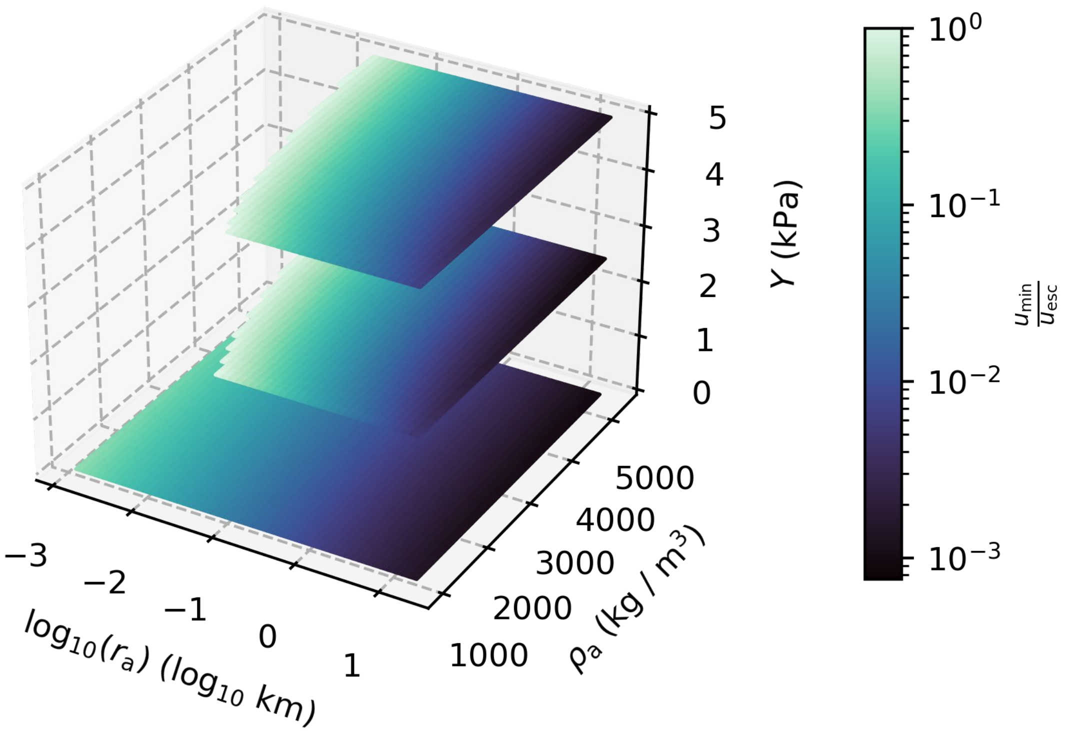
Minimum ejection speed vs. target properties

- Assuming a fixed impact scenario with characteristics similar to Hayabusa2.
- Comparing the ratio u_{min} / u_{esc} as a function of the asteroid size, density, and strength.



***Y* = 2kPa**

Sand-like material

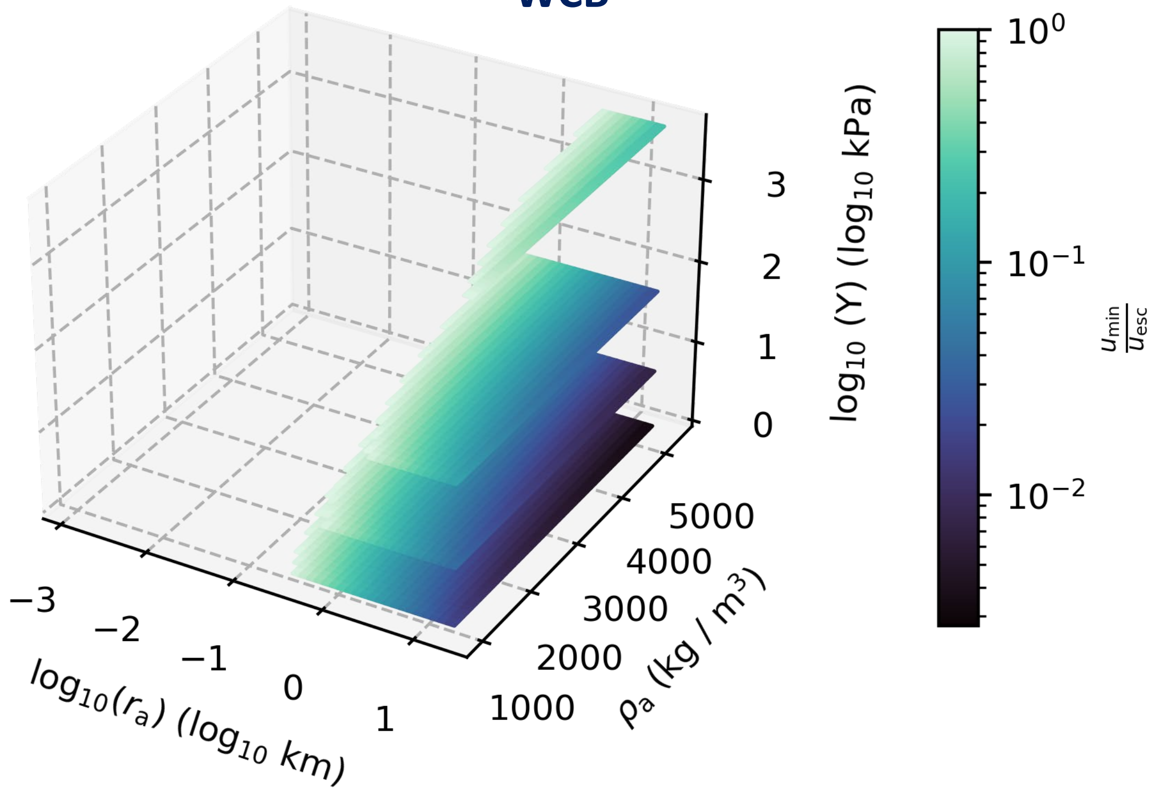


Sensitivity analysis

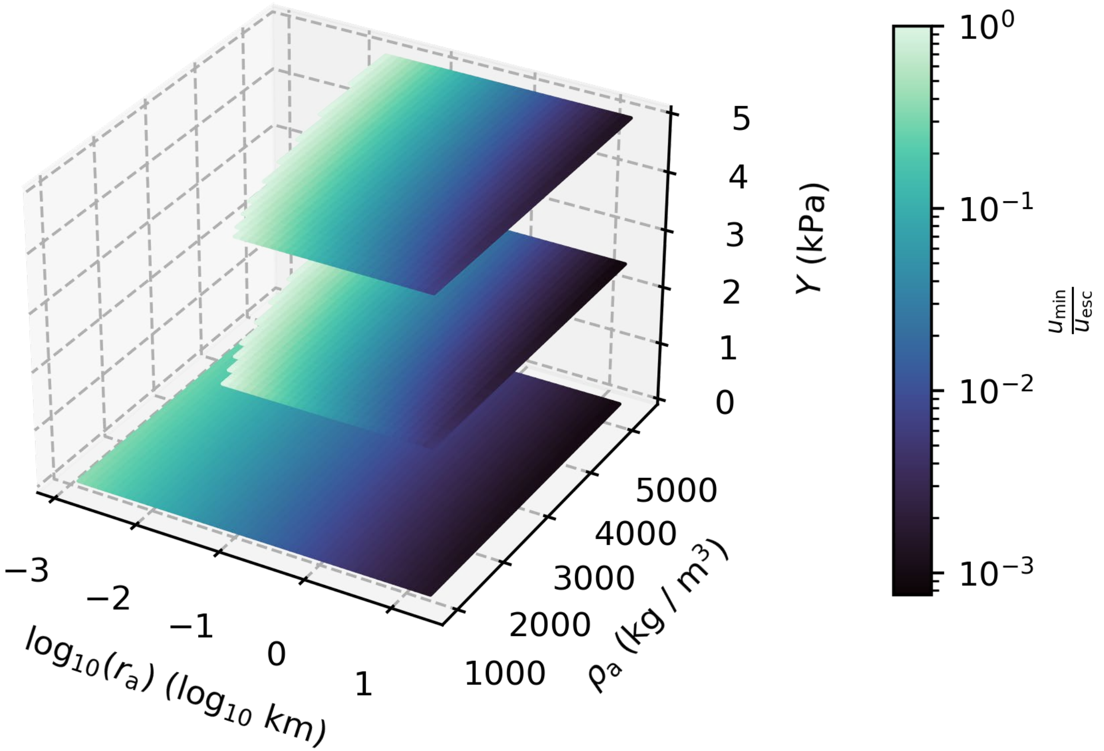
Comparison between materials

- Comparing two different materials: weekly cemented basalt (WCB) and sand-like material

WCB



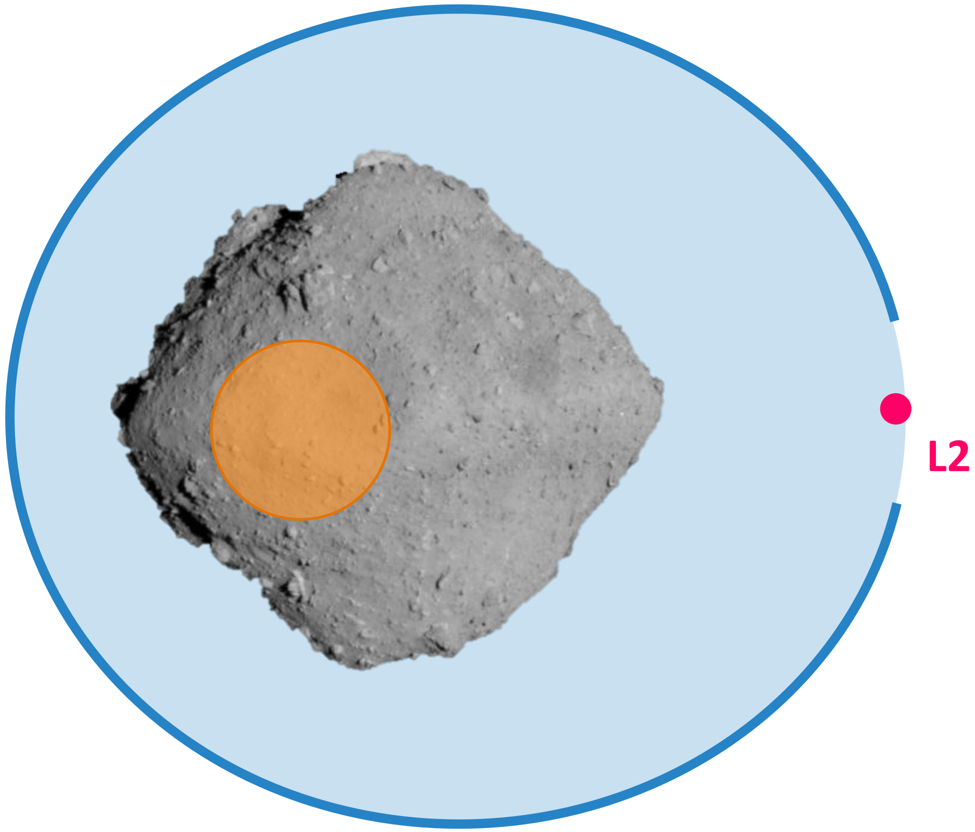
Sand-like material



Collection options

Possible particle collection methods:

- **In-situ collection**:
  - Touch-down collection
    - Hayabusa 2 mission
  - Landing and collection
    - Rosetta mission
- **In-orbit collection**:
  - Orbital region around the asteroid
    - Close to the impact location
  - L2 region
    - Exploiting the three-body problem

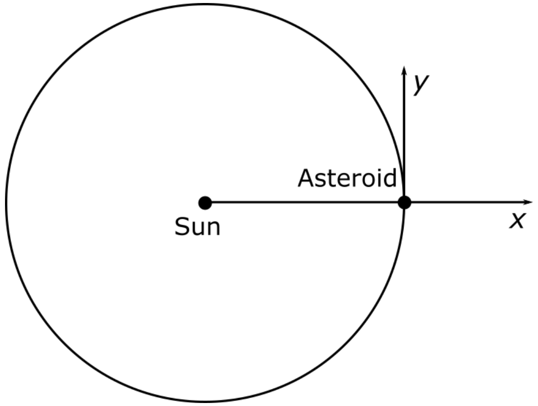


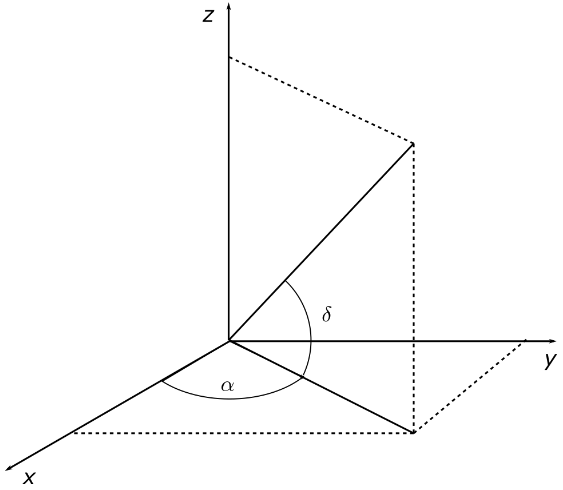
First analysis based on L2 collection methods

L2 collection analysis

Preliminary results

- Fixed the particle diameter
- Fixed the velocity
  - The velocity is $v_{C2} + \epsilon \cdot (v_{esc} - v_{C2})$ to slightly "open" L2[1]
  - v_{C2} is the ejection velocity corresponding to a zero velocity at L2
  - ϵ is user parameter that defines the opening ($\epsilon = 0.02$ in this work)
- Compute the Jacobi constant and use it as a constraint for the ejection speed at the surface of the asteroid.
- Performed a grid search
  - $\boldsymbol{\alpha}$, $\boldsymbol{\delta}$ grid of 5 deg bins on the asteroid surface
  - Ejection angles (in-plane and out-of-plane) grid of 5 deg bins
  - Check which conditions lead to escape through L2
- Limited the search to the 1st and 4th quadrant
- Analysis on a Ryugu-like asteroid





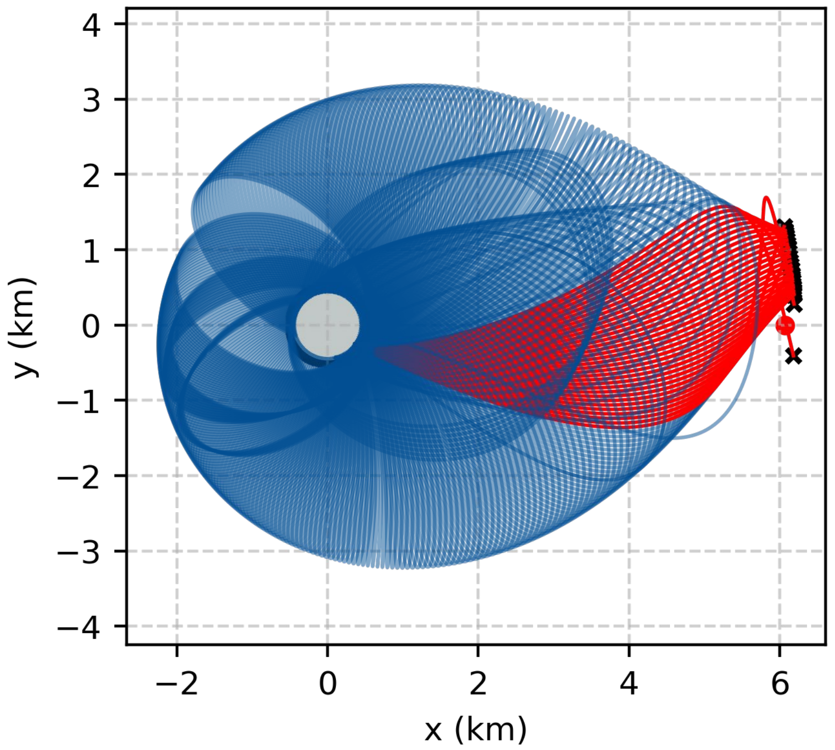
[1] Latino, Soldini, Colombo, Tsuda, Ejecta orbital and bouncing dynamics around asteroid Ryugu, 70th IAC, October 2019

L2 collection analysis

Preliminary results

- Example of ejecta trajectories for 5 mm particles ejected in all directions from a location on the asteroid's surface
- In red the portion of particles escaping via the L2 gap

Example of ejecta trajectories

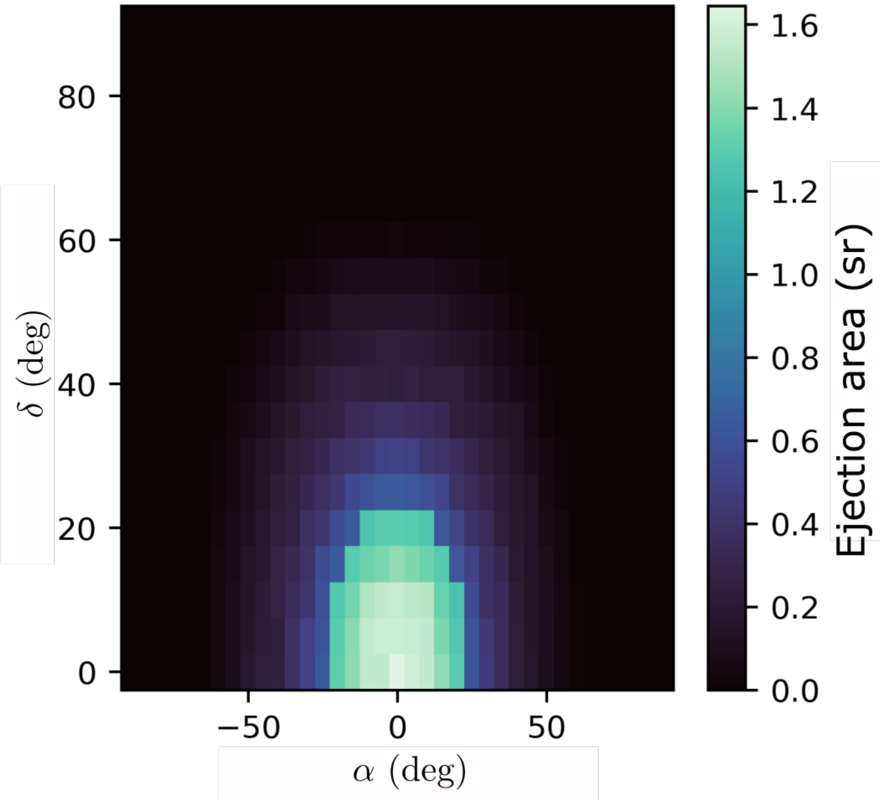


L2 collection analysis

Preliminary results

- Example of ejecta trajectories for 5 mm particles ejected in all directions from a location on the asteroid's surface
- In red the portion of particles escaping via the L2 gap
- We compute the portion of spherical angle (available ejection area) that leads to escape trajectories

Available ejection area



L2 collection analysis

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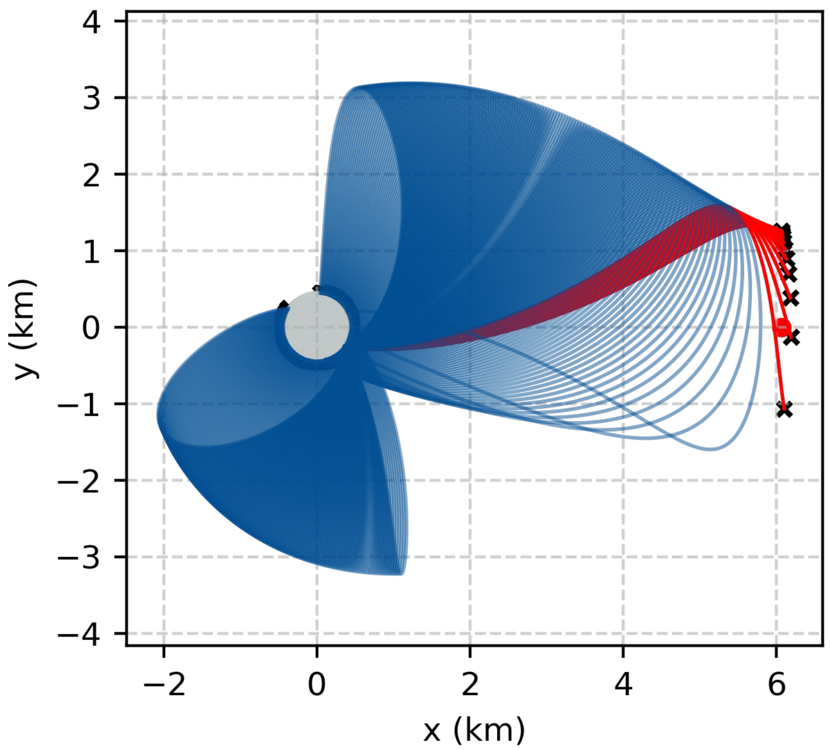
- Example of ejecta trajectories for 5 mm particles ejected in all directions from a location on the asteroid's surface
- In red the portion of particles escaping via the L2 gap
- We compute the portion of spherical angle (available ejection area) that leads to escape trajectories
- However, experimental results shows ejection angles are limited
  - We assume possible ejection angles between 25° and 65°

Example of ejecta trajectories

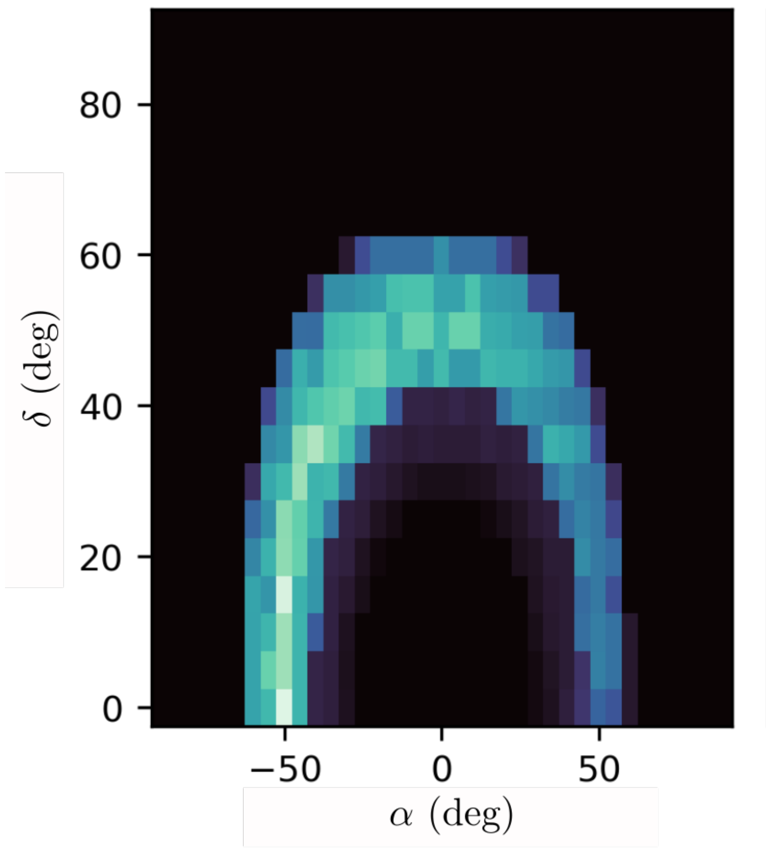


L2 collection analysis

Preliminary results

- Example of ejecta trajectories for 5 mm particles ejected in all directions from a location on the asteroid's surface
- In red the portion of particles escaping via the L2 gap
- We compute the portion of spherical angle (available ejection area) that leads to escape trajectories
- However, experimental results shows ejection angles are limited
  - We assume possible ejection angles between 25° and 65°
- We thus have a reduction of the available ejection area
- Particularly, several regions in the (α, δ) plane do not lead to escape trajectories

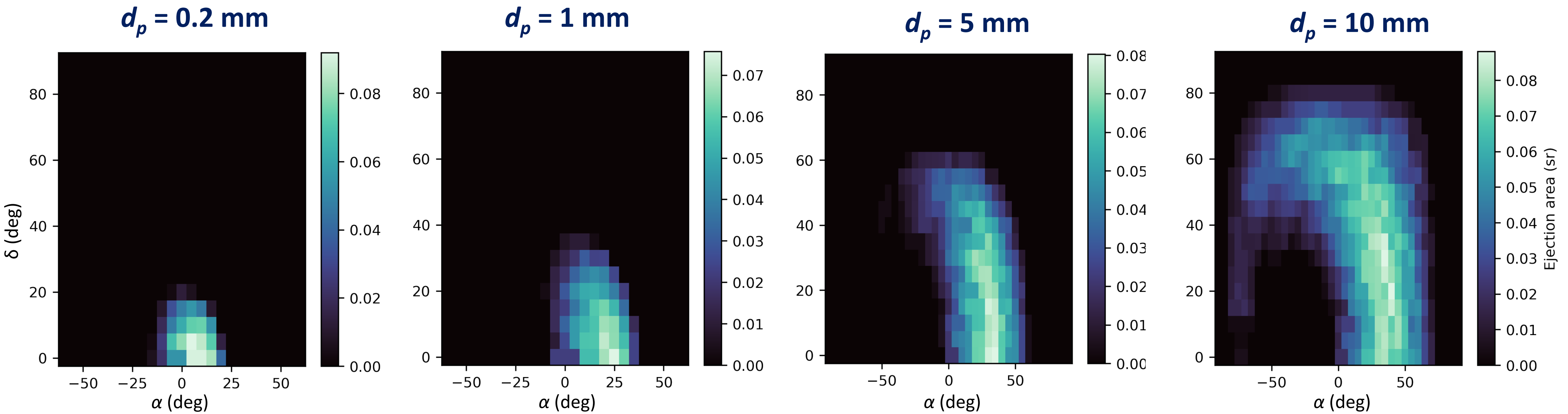
Available ejection area



L2 collection analysis

Asteroid rotation contribution

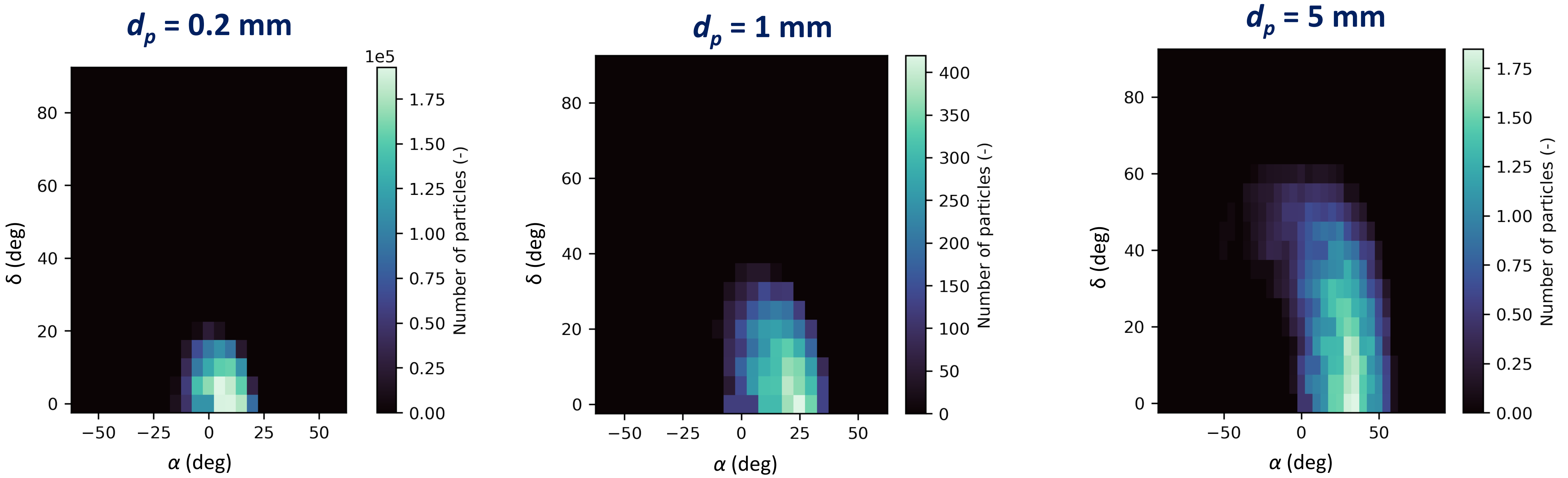
- We included the contribution of the asteroid rotation
- Assuming a uniform rotation around the z-axis
- The ejection locations leading to escape trajectories change significantly



L2 collection analysis

Particle number estimation

- Combine the previous area with the uncorrelated ejection distribution
- Assuming a uniform ejection angle between 25° and 65°
- Assuming a small interval of 1 µm around d_p to estimate the number of particles



Conclusion and future work

- Preliminary analysis of a in-orbit particle collection mission concept
- Ongoing development of a distribution-based ejection model
  - Correlated and uncorrelated distributions
  - Future work to include launch direction distributions
- Sensitivity analysis to compare the minimum ejection speed with the escape velocity
  - Target properties are more influential than impactor properties
  - Larger and denser asteroids allow for more possibilities for collection
- Preliminary analysis of collection region at L2
  - Collection is feasible but limited to impacts in specific region of the asteroid surface
  - Contribution of asteroid rotation can be relevant

Credit: NASA

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 896404 - CRADLE

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