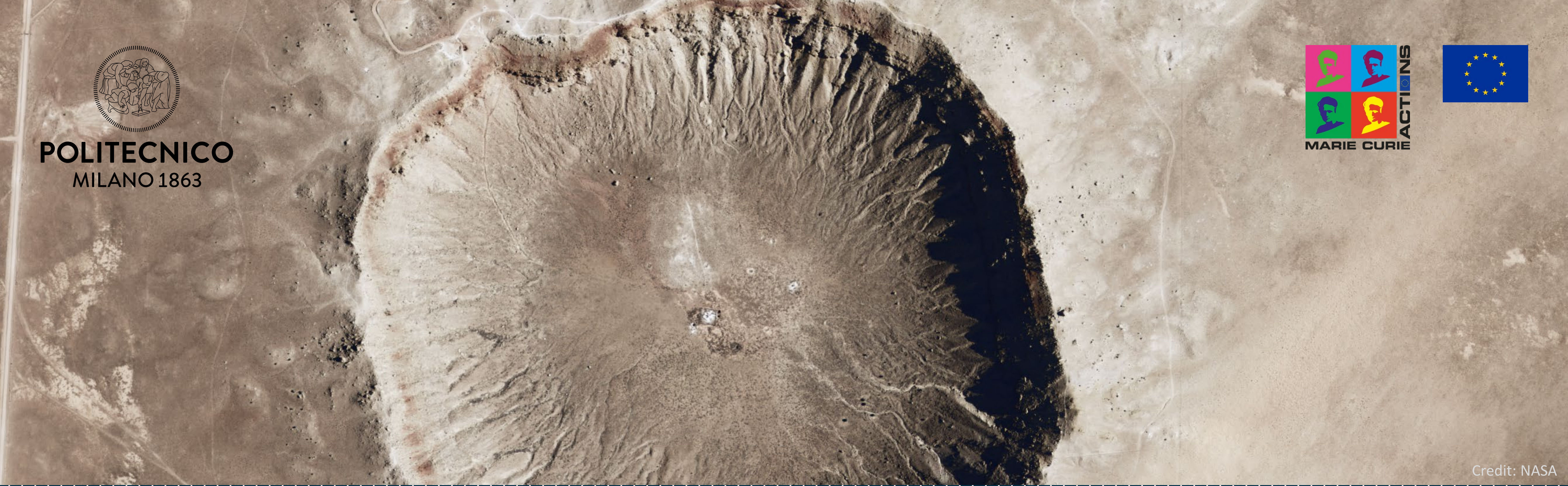

Credit: NASA

A mission concept for in-orbit particle collection around asteroids

Mirko Trisolini[1], Camilla Colombo[1], Yuichi Tsuda[2]

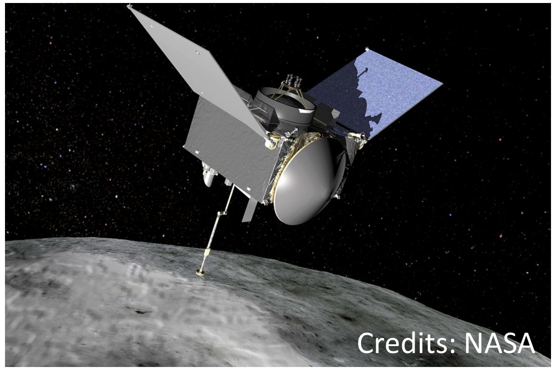
[1] *Department of Aerospace Science and Technology, Politecnico di Milano*
[2] *Institute of Space and Astronautical Science (ISAS) / Japan Aerospace Exploration Agency (JAXA).*

2nd International Stardust Conference, 7-11 November 2022, ESA, ESTEC

Background

- Increasing interest in asteroid exploration and sample collection missions
- Recent missions
  - JAXA’s Hayabusa2
    - Created an artificial crater on Ryugu via a small carry-on impactor
    - Collected samples via touch and go mechanism with sampler horn
  - NASA’s OSIRIS-REx
    - Sample collection on Bennu via touch and go using the TAGSAM arm
  - NASA’s DART and ESA’s Hera
    - Asteroid deflection technology demonstration

Credits: JAXA

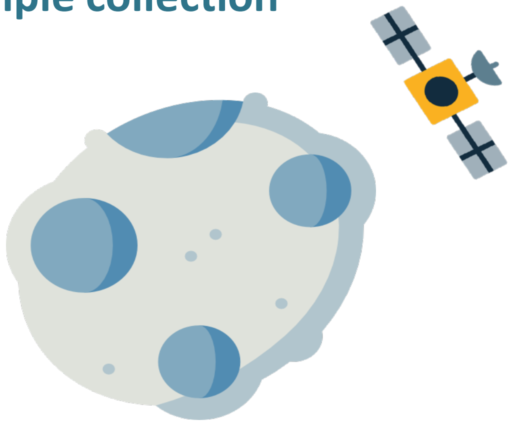


Credits: NASA

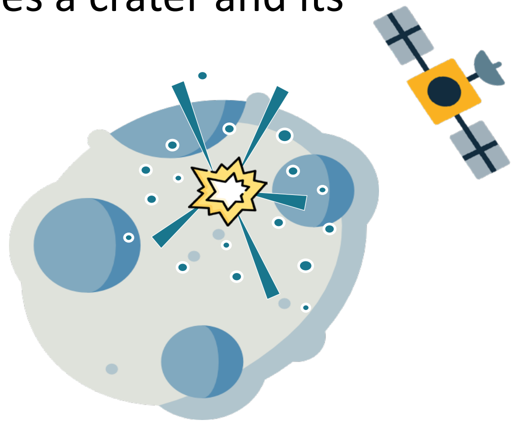
Credits: NASA

Background

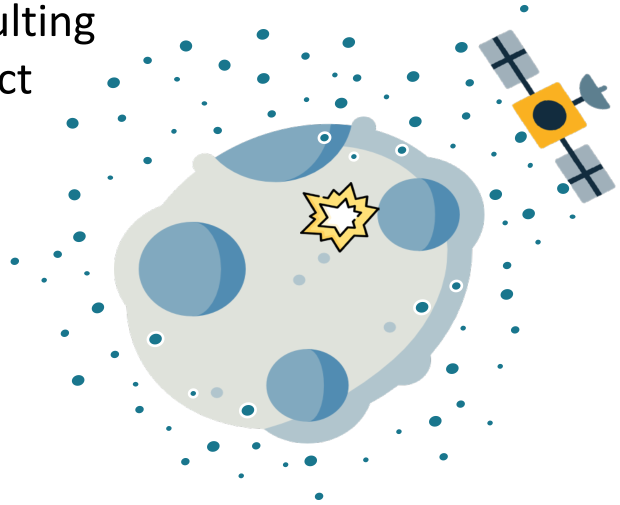
Mission concepts for **sample collection**



A **kinetic impactor** generates a crater and its ejecta



The spacecraft **collects the ejecta** resulting from the impact



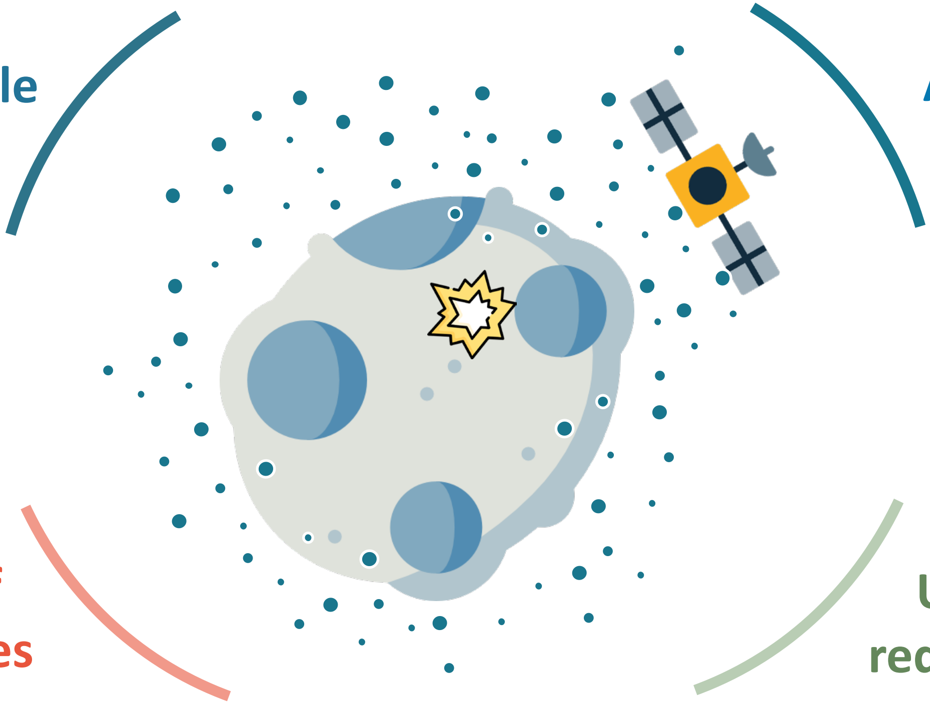
- Starting from the heritage of Hayabusa2, we propose a new concept for in-orbit sample collection
- Why an alternative approach?
  - Complementary to already existing methodologies
  - Potential implementation in challenging environmental conditions preventing landing or touch down
    - Hazardous terrain features
    - Fast rotating asteroid

This diagram has been designed using resources from Flaticon.com

Preliminary mission concept

Main building blocks

- Assessment of mission feasibility and principal mission drivers



Identifying possible collection strategies

Assessing the risk for the spacecraft

Estimating the amount of collectable samples

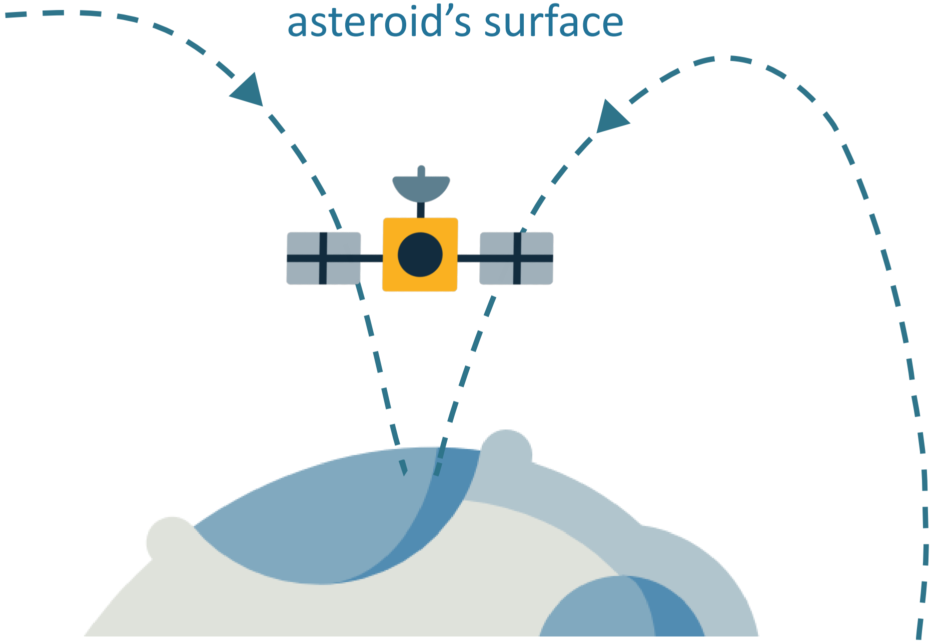
Understanding operational requirements and constraints

Ejecta collection analysis

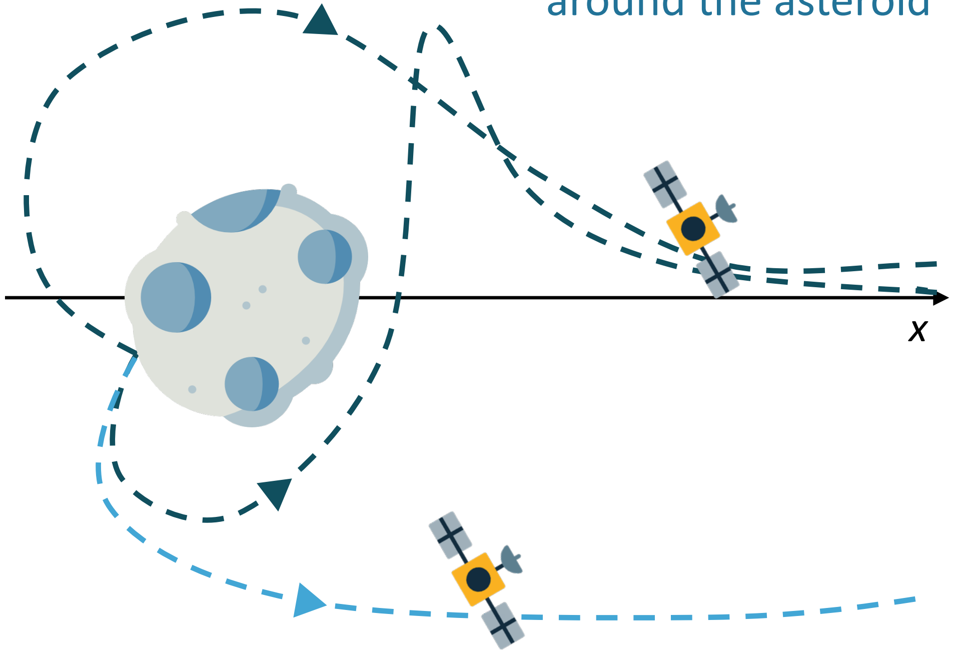
Possible collection strategies

- Collection strategies may exploit hovering of the spacecraft in specific locations
- Also orbiting solutions may be investigated

Hovering above the asteroid’s surface



Hovering in suitable locations around the asteroid

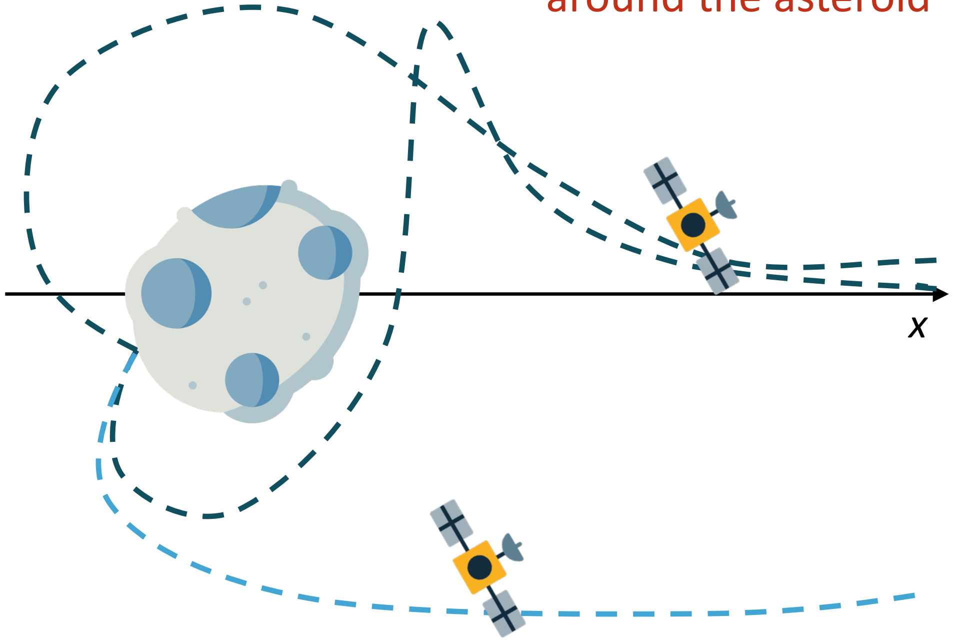


Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution of the particles density and speed** around the asteroid

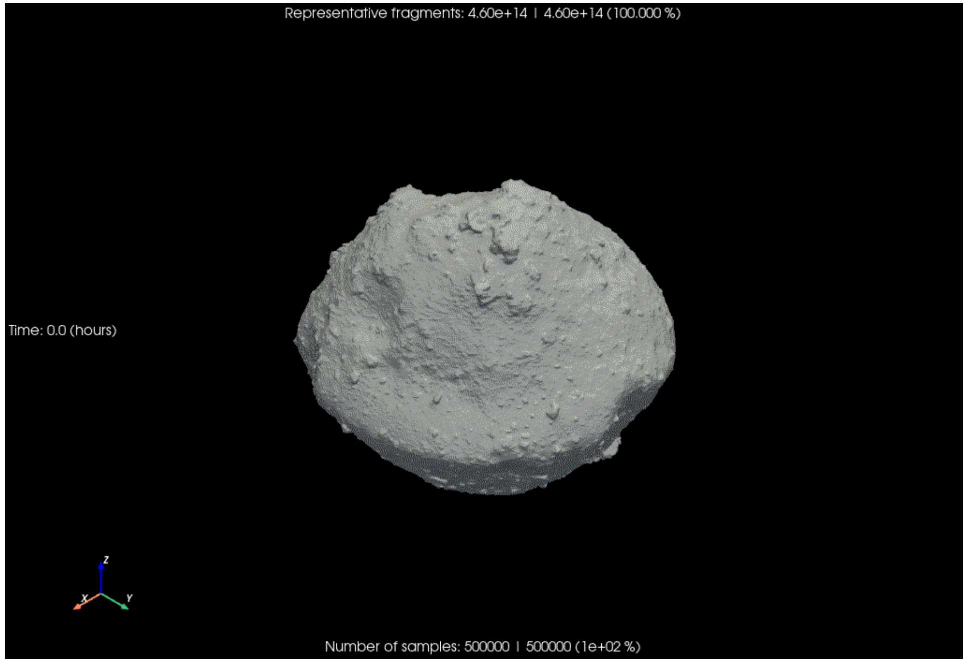
Hovering in suitable locations around the asteroid



Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution** of the **particles density and speed** around the asteroid



- Sample the ejecta distribution
- Propagate the samples and the representative fragments
- We store the propagation at specific **snapshots in time**

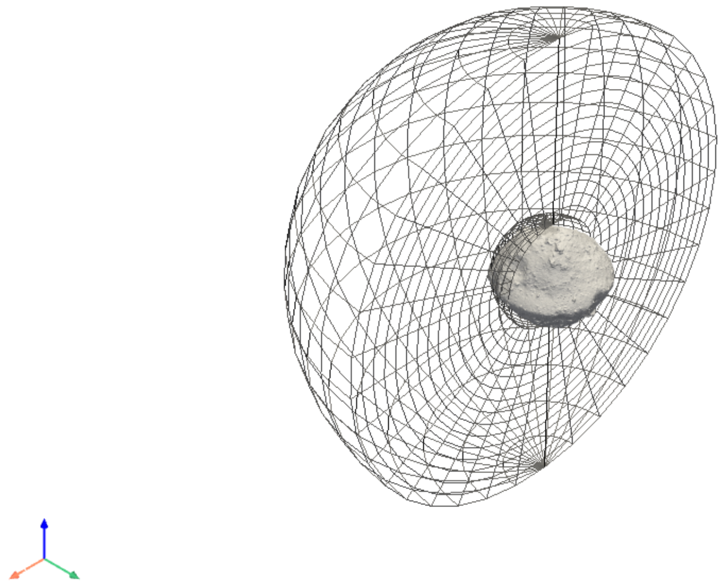
Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution** of the **particles density and speed** around the asteroid

$$\rho(r,\alpha,\delta) = \frac{\sum_i \; n_{f_i}(r,\alpha,\delta)}{\Delta V(r,\alpha,\delta)} = \frac{Number\ of\ fragments}{Sperical\ bin\ volume}$$

$$\boldsymbol{v}(r,\alpha,\delta) = \frac{\sum_i n_{f_i}(r,\alpha,\delta) \cdot \boldsymbol{v}_i}{\sum_i n_{f_i}(r,\alpha,\delta)}$$



- Discretise the space around the asteroid with a **spherical grid**
- Estimate the fragments density and speed inside each spherical bin

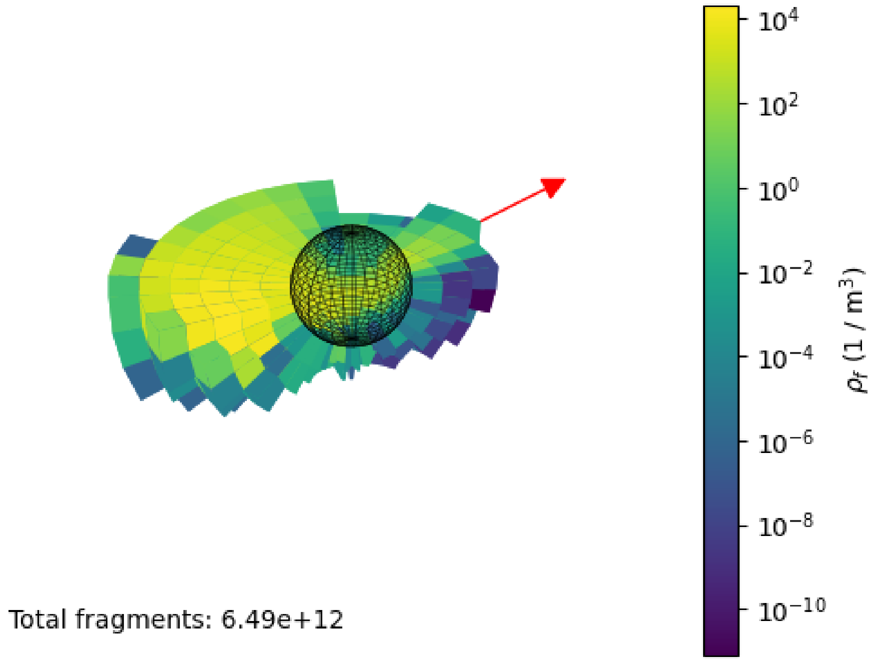
Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution** of the **particles density and speed** around the asteroid

$$\rho(r,\alpha,\delta)=\frac{\sum_i \ n_{f_i}(r,\alpha,\delta)}{\Delta V(r,\alpha,\delta)}=\frac{Number\ of\ fragments}{Sperical\ bin\ volume}$$

$$\boldsymbol{v}(r,\alpha,\delta)=\frac{\sum_i n_{f_i}(r,\alpha,\delta)\cdot\boldsymbol{v}_i}{\sum_i n_{f_i}(r,\alpha,\delta)}$$



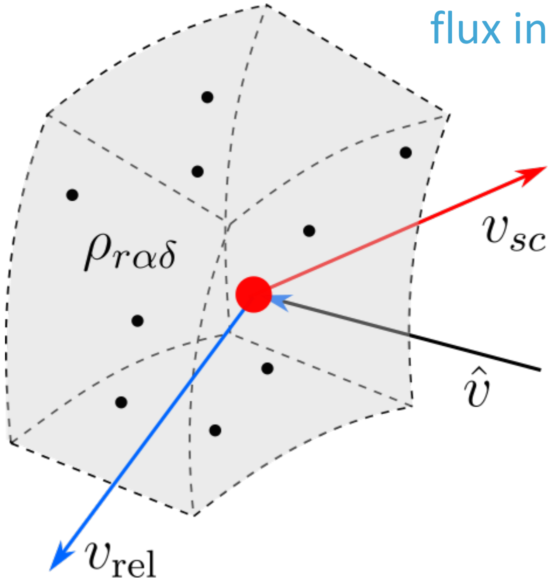
- Discretise the space around the asteroid with a **spherical grid**
- Estimate the fragments density and speed inside each spherical bin

Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution** of the **particles density and speed** around the asteroid
- We can then estimate the **flux of particles** on a given surface (**impact rate**)
    - The surface can represent the collection area of the instrument, *A*

Computation of the flux in a spherical bin

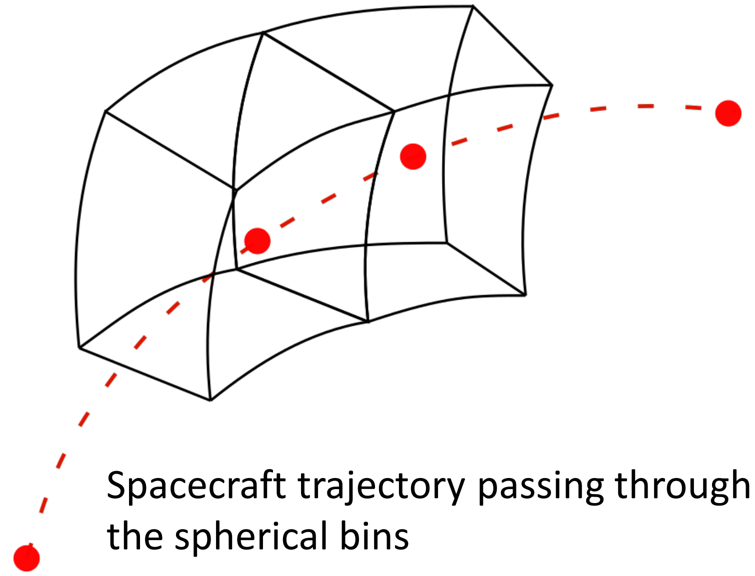


- $\dot{\eta}_{sc}(r,\alpha,\delta) = \rho(r,\alpha,\delta) \cdot |\underbrace{(\boldsymbol{v}(r,\alpha,\delta) - \boldsymbol{v}_{sc})}_{\boldsymbol{v}_{rel}}| \cdot A$

Ejecta collection analysis

Estimating the amount of collectable samples

- Use of a methodology borrowed from the space debris field
- Consists of computing **distribution** of the **particles density and speed** around the asteroid
- We can then estimate the **flux of particles** on a given surface (**impact rate**)
  - The surface can represent the collection area of the instrument, *A*
- We repeat the procedure for each of the bins crossed by the spacecraft
  - Estimate the **total impacts**



Spacecraft trajectory passing through the spherical bins

- $N_{imp} \cong \sum_{t=1}^{N_T} \dot{\eta}_{sc}^{t}(r_t, \alpha_t, \delta_t) \cdot \Delta T_t$

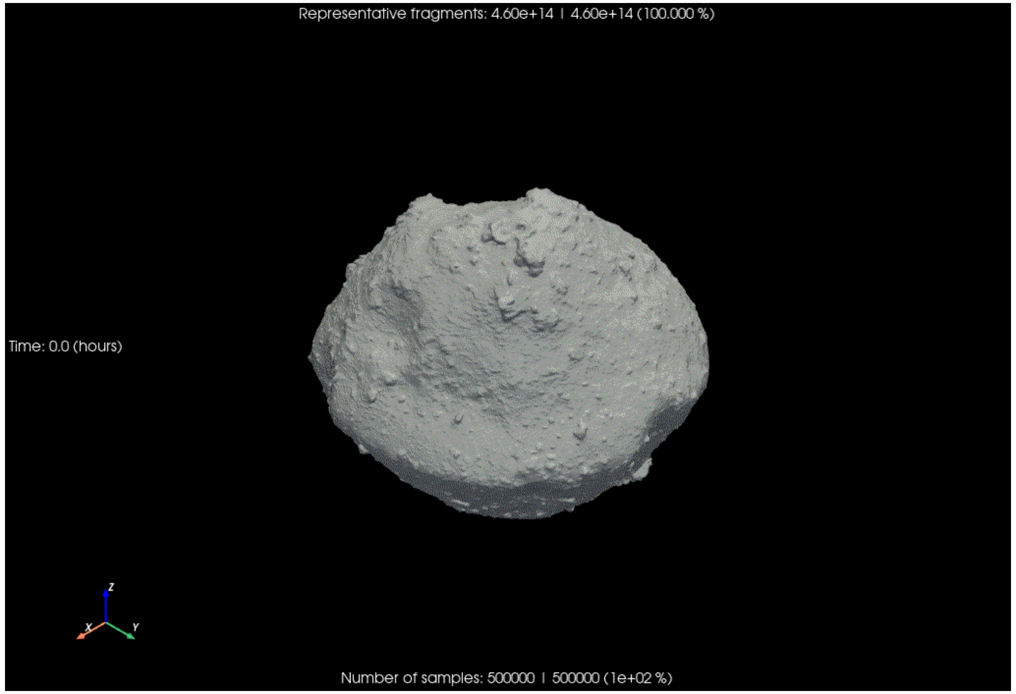
Time interval between consecutive spacecraft positions

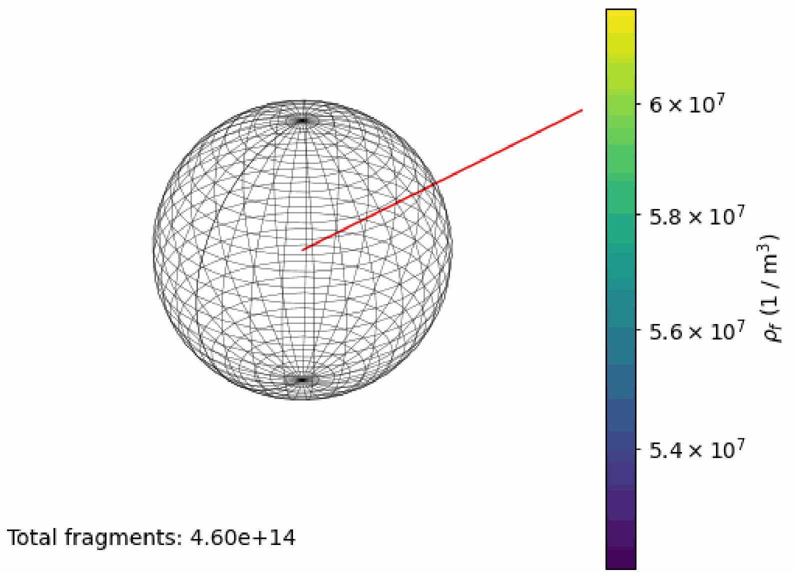
Ejecta collection analysis

Estimating the amount of collectable samples

Example

- Target
    - Asteroid Ryugu
    - Sand-like material → negligible strength
- Impact location (synodic frame)
    - α = 200°
    - δ = 10°
- Impactor
    - U = 2 km/s
    - m = 2 kg
    - Normal impact
- Particle distribution
    - Size range between 10 μm and 1 cm
    - Speed range: up to the escape speed of the asteroid



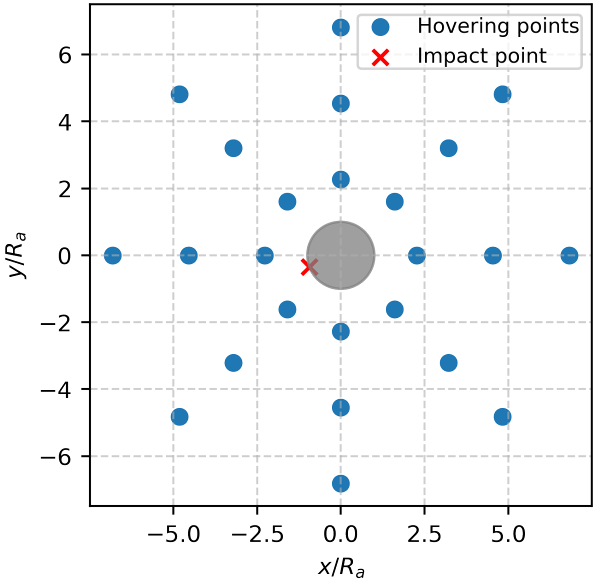


Ejecta collection analysis

Estimating the amount of collectable samples

- Assume now we want estimate the impact rate on a **hovering spacecraft**
- The S/C occupies a fixed position in the synodic frame
- The S/C is approximated with a **sphere of 1 m^2 cross-section**

Examples of hovering points

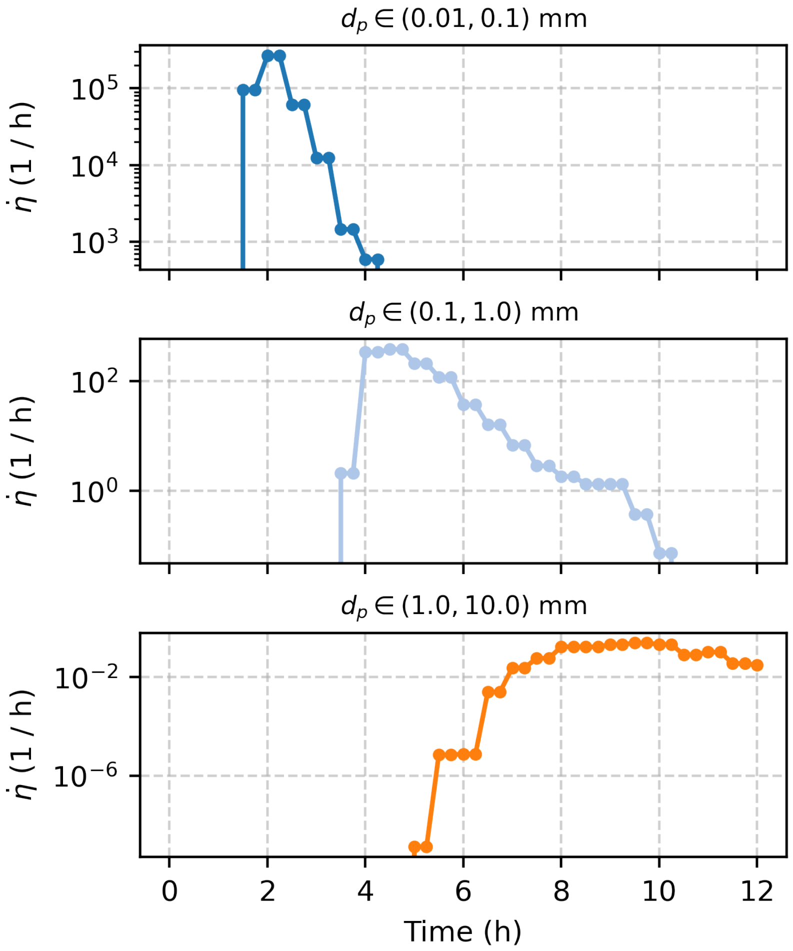


Ejecta collection analysis

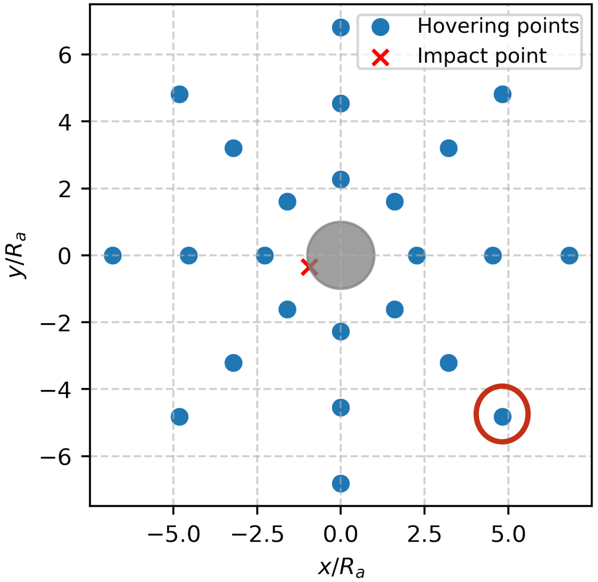
Estimating the amount of collectable samples

- Assume now we want estimate the impact rate on a **hovering spacecraft**
- The S/C occupies a fixed position in the synodic frame
- The S/C is approximated with a **sphere of 1 m^2 cross-section**

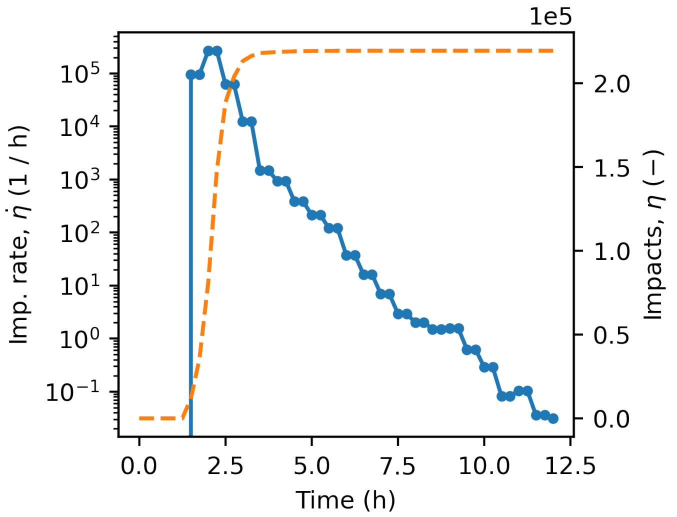
Impact rate by particle size range



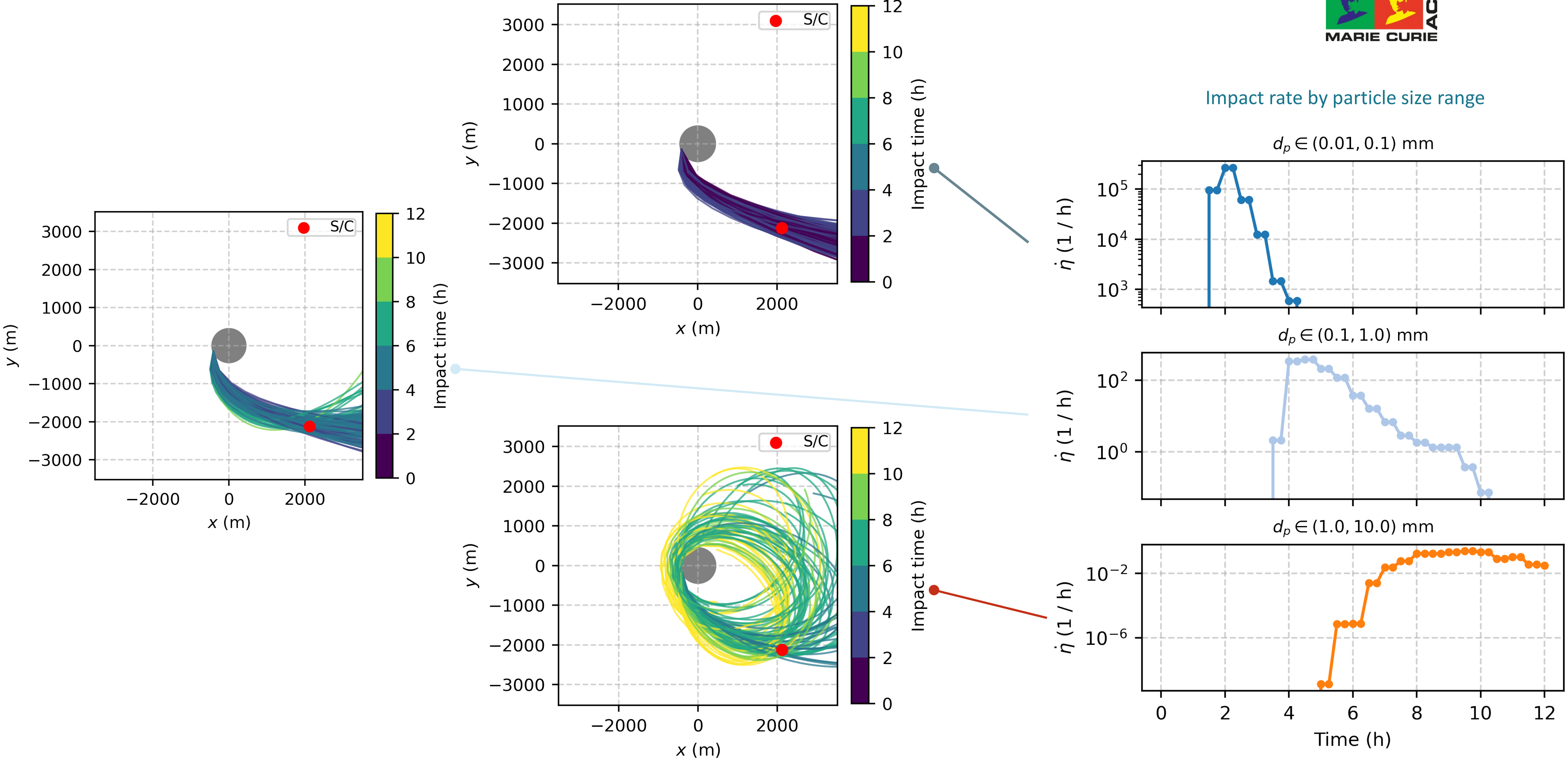
Examples of hovering points



Impact rate and cumulative impacts



Ejecta collection analysis

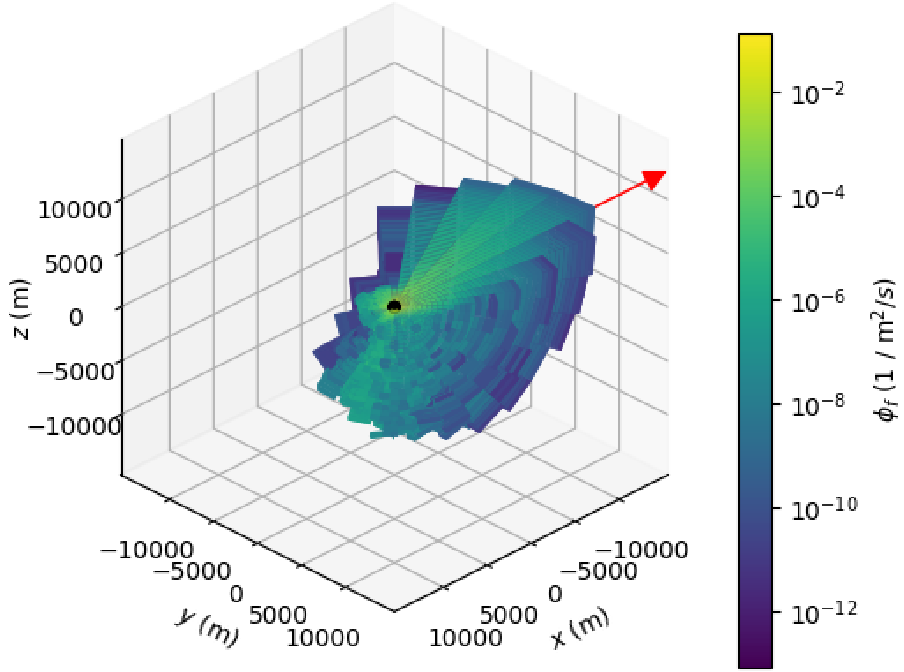


Impact rate by particle size range

Ejecta collection analysis

Preliminary collection trajectory design

- The particle fluxes around the asteroid can be exploited to **design a collection trajectory**
- We can create trajectory **waypoints** the spacecraft should pass to **improve the collection**
  - The waypoints can be selected as the location of maximum cumulative flux in a given time span

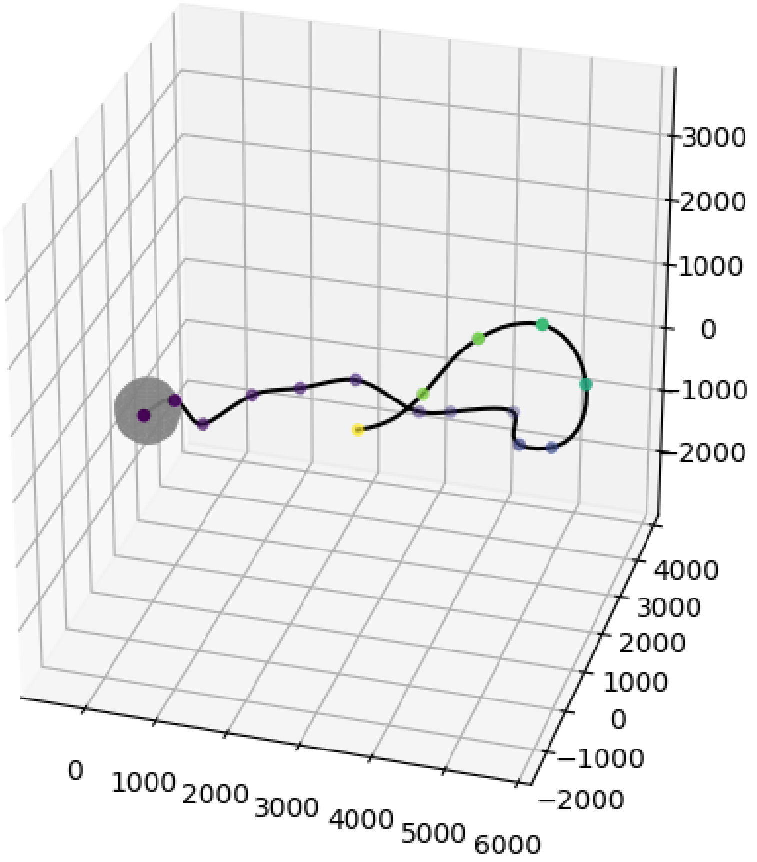


Ejecta collection analysis

Preliminary collection trajectory design

- The particle fluxes around the asteroid can be exploited to **design a collection trajectory**
- We can create trajectory **waypoints** the spacecraft should pass to **improve the collection**
  - The waypoints can be selected as the location of maximum cumulative flux in a given time span
- Example trajectory for an impact on Ryugu
  - Total manoeuvre time of 24 hours
  - Minimum distance from the asteroid surface of 300 m

    → avoids crashing on the asteroid
  - Maximum distance from the centre of the asteroid of 6 km
  - Minimum time between snapshots of 1 hour

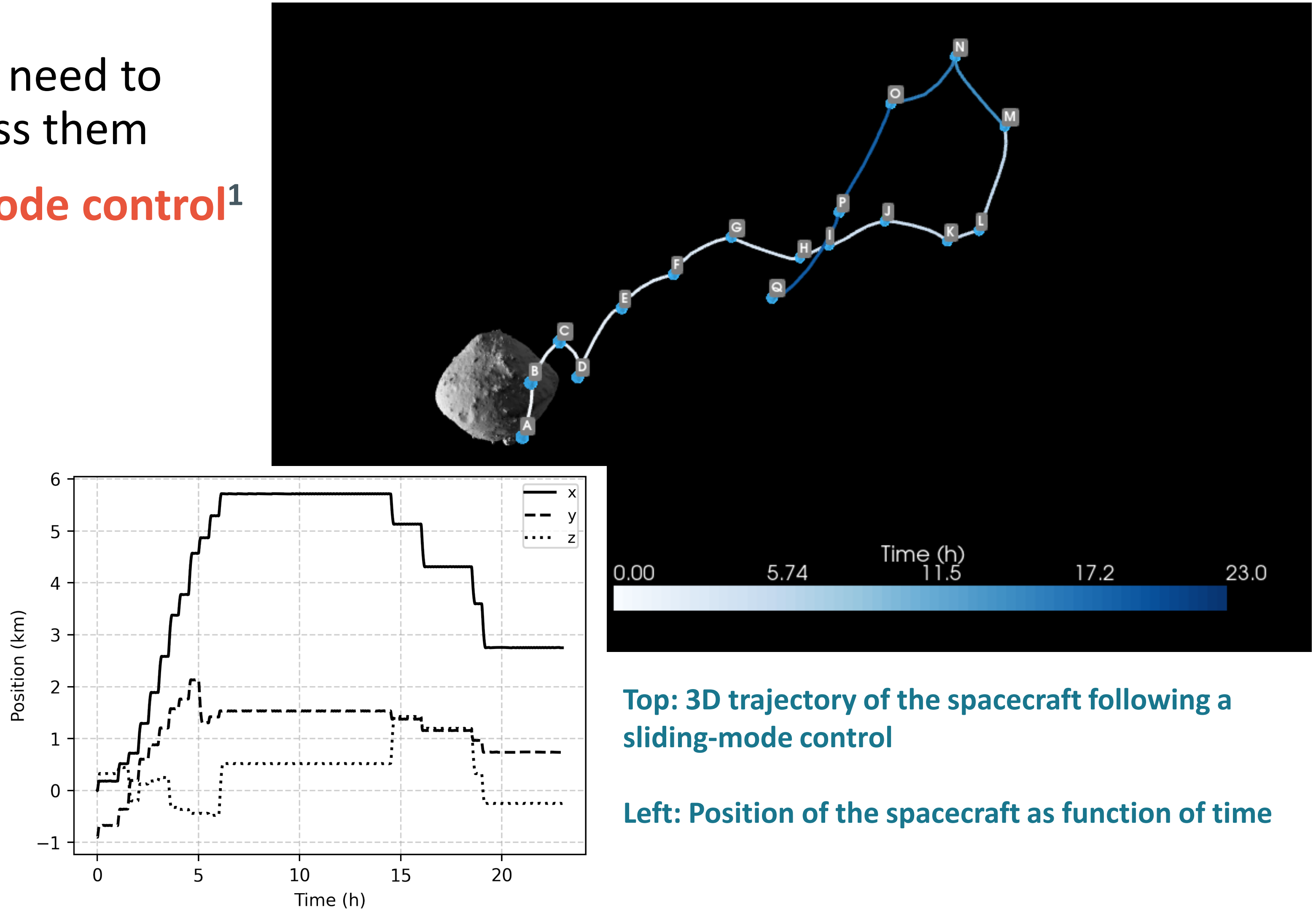


Waypoints selection example. The black line is a spline interpolation to represent a possible trajectory.

Ejecta collection analysis

Trajectory control

- Once generated the waypoints, we need to control the spacecraft motion across them
- We utilise a higher-order **sliding mode control**[1] between the waypoints
- Control **problem definition**
  - Hayabusa2-like spacecraft
  - Mass of 600 kg
  - Cross-section of 25 m^2
  - Maximum thrust of 20 N
  - Attitude motion not considered



Top: 3D trajectory of the spacecraft following a sliding-mode control

Left: Position of the spacecraft as function of time

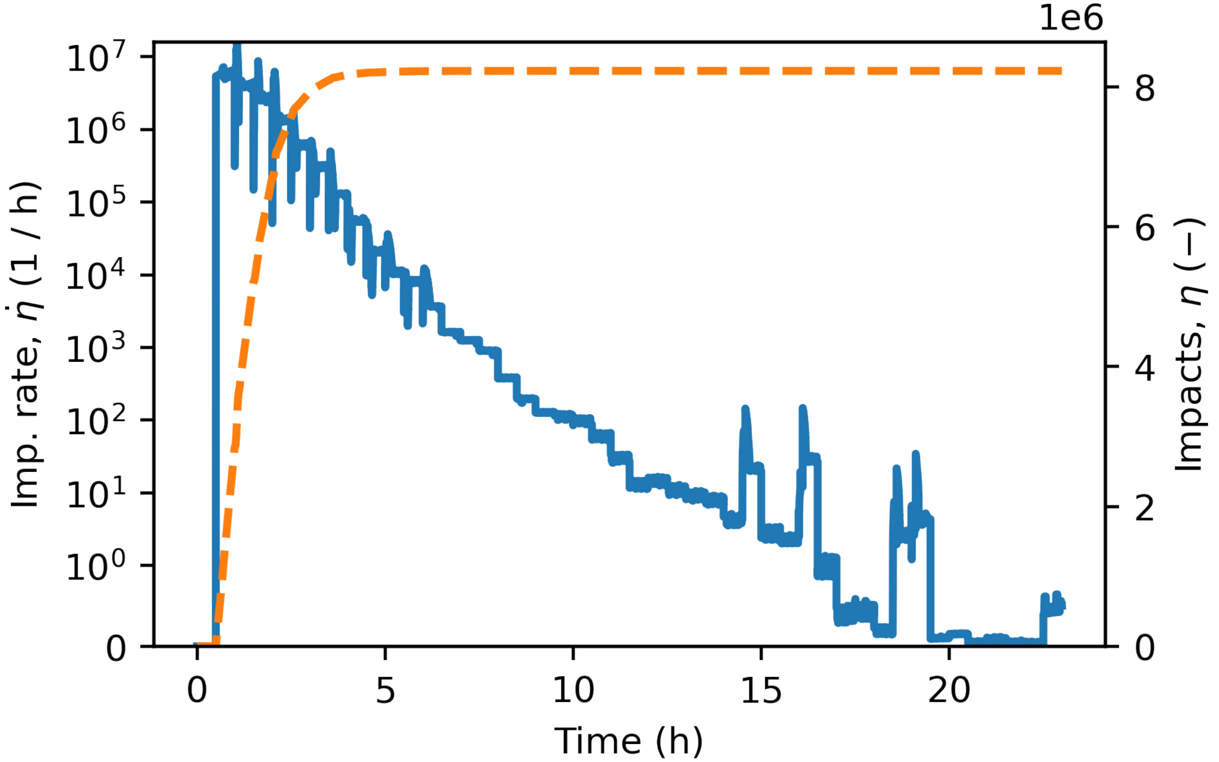
---

1 Furfaro, 2015, *Hovering in Asteroid Dynamical Environments Using Higher-Order Sliding Control*, JGCD.

Ejecta collection analysis

Impact rate estimate

- Once generated the waypoints, we need to control the spacecraft motion across them
- We utilise a higher-order **sliding mode control** between the waypoints
- Control **problem definition**
  - Hayabusa2-like spacecraft
  - Mass of 600 kg
  - Cross-section of 25 m^2
  - Maximum thrust of 20 N
  - Attitude motion not considered
- We can finally compute the **number of collectable particles** by the spacecraft along this trajectory (1 m^2 cross-section)



Impact rate (blue) and **cumulative number of impacts** (orange) in time, along the specified trajectory. Notice the oscillations of the impact rate as a result of the change of particle flux due to the change in velocity of the spacecraft during the manoeuvres.

Conclusions and future work

- Possible **collection strategies** have been explored for in-orbit sample collection
  - Collection in the anti-solar direction for particles mainly affected by SRP
  - Collection exploiting the location of re-impacting particles
  - Future efforts will also consider particles orbiting for a longer period
- A methodology has been presented to estimate the **collectability of samples in orbit**
  - The methodology is statistical in nature
  - Further analyses to study its sensitivity will be performed
  - The understanding of the sensitivity to impact uncertainties is under analysis
    - E.g.: impact angle, target properties
- This methodology is integrated with the design and control of a **collection trajectory** to maximise the collection
  - Introduction of operational constraints (e.g., eclipse periods, communication windows, etc.) is under consideration

POLITECNICO
MILANO 1863


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

A mission concept for in-orbit particle collection around asteroids

Mirko Trisolini, Camilla Colombo, Yuichi Tsuda

✉ mirko.trisolini@polimi.it

in www.linkedin.com/in/mirkotrisolini/

RG www.researchgate.net/profile/Mirko-Trisolini

Visit the project website
www.cradle.polimi.it

Assessing the risk for the spacecraft

- Preliminary analysis of **risk** from ejected particles
- Compute the **critical diameter** using Ballistic Limit Equations (BLEs)
    - Assuming normal impact on a 1 mm single-wall structure in Aluminium alloy

$$d_c = \left[\frac{\frac{1}{K_{3S}}\cdot t_w^{0.5}\cdot\left(\frac{\sigma_y}{40}\right)^{0.5}}{0.6\cdot(\cos\theta\,)^{\delta}\rho_p^{0.5}u_p^{2/3}}\right]^{18/19}$$

Risk area

Particle diameter greater than the critical diameter

Potential damage to the spacecraft

Estimated number of dangerous particles