HORIZON 2020

Collecting Asteroid-Orbiting Samples: enabling a safer, sustainable, and autonomous exploration of asteroids

Rendicontazione

Informazioni relative al progetto

CRADLE

ID dell'accordo di sovvenzione: 896404

Sito web del progetto

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Questo progetto è apparso in...

Periodic Reporting for period 2 - CRADLE (Collecting Asteroid-Orbiting Samples: enabling a safer, sustainable, and autonomous exploration of asteroids)

Periodo di rendicontazione: 2022-11-15 al 2023-11-14

Sintesi del contesto e degli obiettivi generali del progetto

Asteroids are rich in valuable resources (e.g. metals, silicates, and water), which could be exploited through future mining missions, and enable long-duration missions. Some asteroids have a chance to hit our planet with catastrophic consequences. Collecting and studying their samples improves the knowledge of their physical composition, resulting in a better target selection for mining and deflection missions. Missions such as JAXA's Hayabusa and Hayabusa2, and NASA's OSIRIS-REx have orbited, landed or impacted into asteroids. Landing or touch-down are complex and hazardous operations. Only Hayabusa2 had a successful touch-down. In CRADLE, we investigate sample collection in orbit by generating the ejecta via a small kinetic impactor. Such a mission is also viable for distributed systems of small spacecraft and in case of challenging environmental conditions.
The first objective of CRADLE project is to study the dynamics of ejected particles as a function of impact conditions and asteroid properties. These aspects are investigated to assess what types of particles are most suitable to be collected and where they can be collected safely by a spacecraft.
The second objective is the preliminary design of a particle collection device for millimetre- and sub-millimetre-sized fragments. Its sizing depends on the asteroid's ejecta distribution and flux prediction studied in the first objective. The final objective is to leverage the collaboration with the Japan Aerospace Exploration Agency (JAXA) for of using images of the impact event to improve the modelling of the ejecta cloud.

Lavoro eseguito dall’inizio del progetto fino alla fine del periodo coperto dalla relazione e principali risultati finora ottenuti

First, we developed a dynamical simulator of the particle motion around asteroids. Second, we implemented a novel statistical ejecta model. This novel formulation describes the ejecta field as a continuum via probability density functions. The obtained distributions are used to statistically sample the ejecta and they can be integrated analytically to estimate the number of fragments. This feature has been exploited for devising a novel sampling technique to effectively describe the entire ejecta field via “representative fragments.” High-velocity impact on small bodies can create as many as 1014 fragments. It is impossible to generate and propagate such many samples in a timely fashion. The “representative fragments” strategy considerably reduces the number of samples to simulate, allowing a faster propagation and maintaining accuracy (Figure 6, Figure 7). This work was presented at the 2022 AIAA SciTech Forum in January 2022 and published in peer-reviewed journal Icarus (https://doi.org/10.1016/j.icarus.2023.115432).

Two possible collection methods have been identified: (1) a collection of particles orbiting the asteroid for a sufficient time after the impact and (2) the collection of those particles passing in the neighbourhood of the Lagrangian point, L2. We studied the effect of the target asteroid's density, size, and equivalent strength; we also considered the impact location. The results of this work include the generation of maps to quickly evaluate a target potential based on its macroscopic properties (i.e. size and density), and the identification of a shortlist of "best targets" for the two collection strategies. The work's outcome was presented at the 72nd International Astronautical Congress (IAC) in October 2021. It is published in the peer-reviewed journal Acta Astronautica (Figure 1, Figure 2, Figure 3, Figure 4.

We also studied the long-term behaviour of the ejected particles. This is important to assess the availability of samples after several days, allowing easier planning of mission operations. We characterised the number of available particles, their size, and residence time as a function of impact location (Figure 8). This analysis's results were presented at the 73rd International Astronautical Congress in September 2022.

We also performed preliminary analyses of the Hayabusa2 extended mission that still has a projectile among its payloads. We analysed the effects of the projectile impact on the asteroid surface, under the challenging dynamical environment (Figure 9), and the spacecraft's safety during the proximity operations for the projectile release. These analyses have been presented in several meetings held with the astrodynamics and science team of the Hayabusa2 SHARP mission.

A particle density and flux estimation methodology has been developed to assess the number of particles encountered by a collection device as a function of the spacecraft trajectory (Figure 10). Given a specific impact and instrument size, we design optimal collection paths for the spacecraft. Finally, we developed a control algorithm to guide the spacecraft along the optimal path (Figure 11). We investigated several scenarios, proving that in-orbit collection is feasible with the potential to collect hundreds of thousands of samples in the sub-millimetre and millimetre range. These results were presented at the 32nd JAXA Workshop on Flight Mechanics and Astrodynamics in July 2022 and the 73rd International Astronautical Congress in September 2022. They were also presented at the 2nd International Stardust Conference in November 2023.

Finally, we developed a tool for characterising the ejecta plume generated by an impactor. The importance of such an analysis is twofold: a deeper understanding of the impact phenomena for better model developments and knowledge of asteroid composition and formation, and the plume characterisation to identify regions of higher concentrations of particles. We also propose a visualisation tool to generate synthetic images of impact cratering events by exploiting the fragment's sampling, propagation and density estimate procedures (Figure 12).

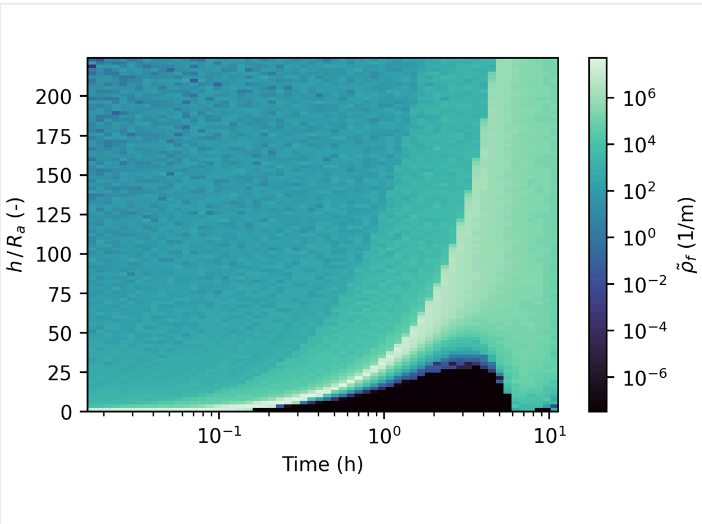
Progressi oltre lo stato dell’arte e potenziale impatto previsto (incluso l’impatto socioeconomico e le implicazioni sociali più ampie del progetto fino ad ora)

The first contribution beyond the state-of-the-art has been identifying two possible collection scenarios. Their feasibility has been evaluated and suitable target asteroids have been identified. We obtained an asteroid's ranking for future in-orbit sample collection missions, based on a trade-off between the collection's feasibility and mission cost.

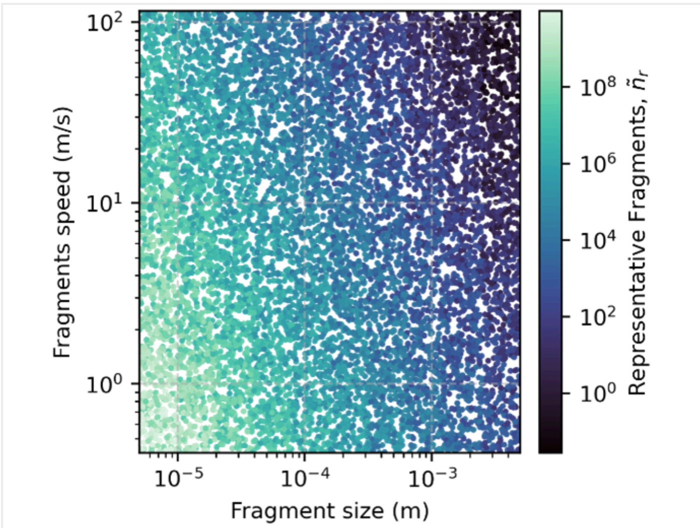
A second progress is the development of a novel ejecta cloud density-based model that features a probabilistic approach. This allows innovative sampling techniques that improve the robustness and speed of the simulations.

A third relevant contribution has been the sensitivity analysis of ejecta fate as a function of the modelling assumptions. Such an analysis was still missing in the literature on impact cratering events. However, this is a crucial aspect for evaluating the robustness of the collection scenario. The CRADLE project contributed to advancing the knowledge in this field, which is relevant not only for sample collection but also for asteroid deflection and planetary protection applications.

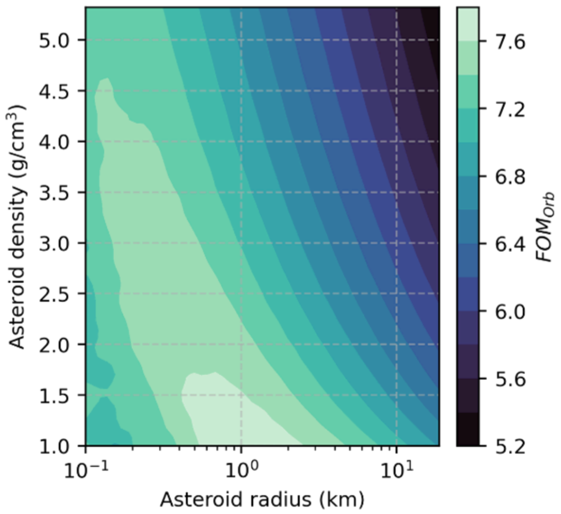
We further developed a methodology that estimates the ejecta fluxes in time, which are used to determine the fragments' number encountered by the spacecraft and the potential for collection given the size of the instrument. By predicting the ejecta flux in time, the spacecraft optimise its trajectory to follow the areas of high sample density. Consequently, in CRADLE, we developed a novel approach for designing the optimal path to maximise sample collection capabilities. Such a procedure considers preliminary operational constraints.



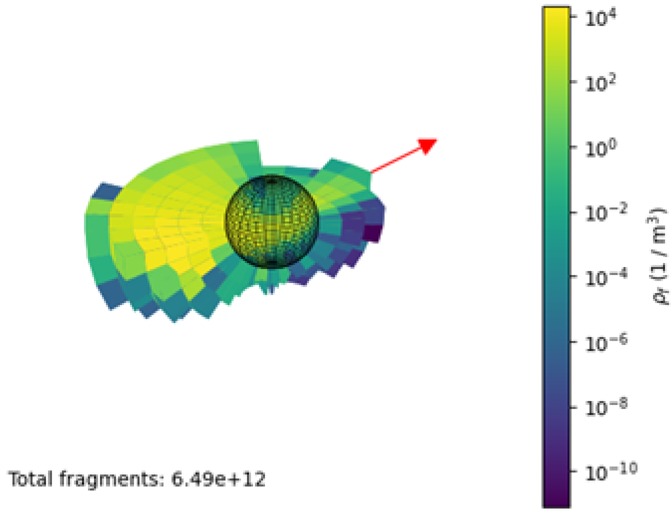
Fragments’ density vs time and disance from the asteroid’s surface. Case of asteroid 1998KY26.



Example of space-filling sampling technique with associated representative fragments.



FOM distribution as function of the asteroid size and density. Sand-like mater

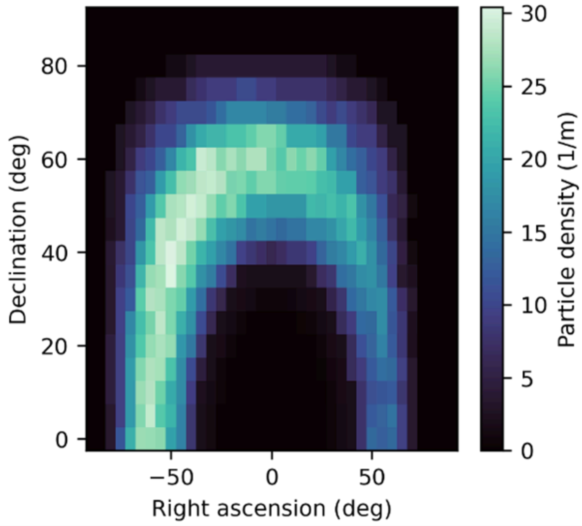


Example of fragments' density distribution around the asteroid using a binning approach.

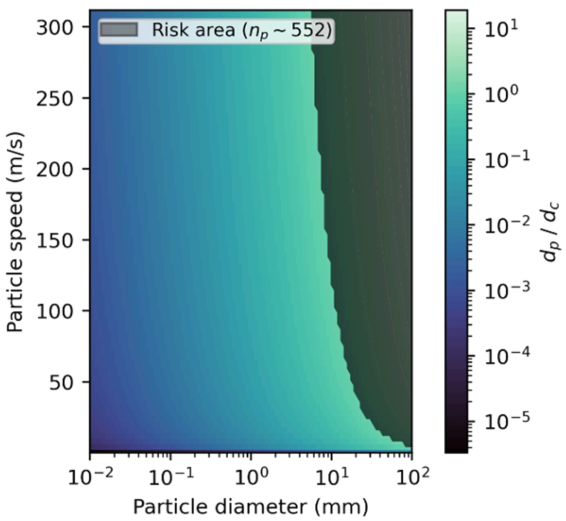
Target asteroid ranking for the *orbiting* strategy. Ranking from the lowest Δv.

Name	Sand	WCB 1 kPa	WCB 10 kPa	WCB 50 kPa	SFA 1 kPa	SFA 4 kPa	Δv (km/s)
Anteros	**7.25**	**7.93**	**7.86**	–	**7.08**	–	**5.11**
Eros	6.33	6.89	6.89	6.89	6.26	6.26	5.58
Zephyr	**7.29**	**7.98**	**7.65**	–	**6.87**	–	**5.86**
Geographos	7.21	7.89	7.93	–	7.15	–	6.08
Ivar	6.64	7.24	7.24	7.24	6.56	6.56	6.15
McAuliffe	7.17	7.84	7.86	–	7.09	–	6.18
Seleucus	6.96	7.63	7.62	–	6.86	–	6.20
Oze	6.74	7.37	7.37	7.36	6.65	6.63	6.33
Toro	7.08	7.74	7.73	–	6.98	–	6.43
Toutatis	6.89	7.52	7.52	7.51	6.80	6.85	6.50
Melissabrucker	6.84	7.47	7.47	7.46	6.75	6.74	6.60
Wilson-Harrington	**7.53**	**8.20**	**7.81**	–	**7.07**	–	**6.61**
Beltrovata	7.25	7.93	7.86	–	7.08	–	6.66
Cacus	**7.29**	**7.98**	**7.65**	–	**6.87**	–	**6.93**
Pygmalion	7.06	7.71	7.71	–	6.97	5.96	6.96
Alinda	6.99	7.63	7.63	7.10	6.90	6.76	6.96

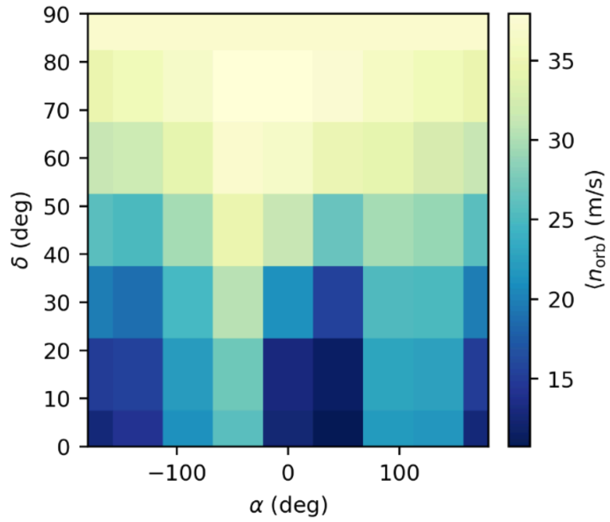
Target asteroid ranking for the orbiting collection strategy. Ranking from the lowest delta-v.



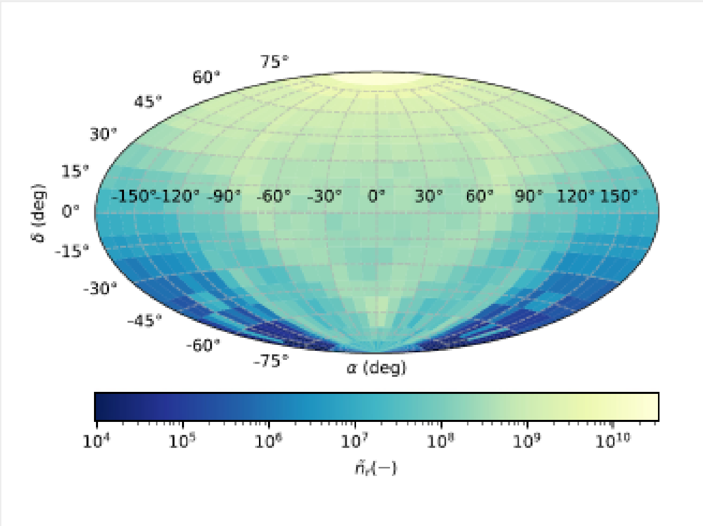
Density of particles ejected from the asteroid surface that reach the L2 gap.



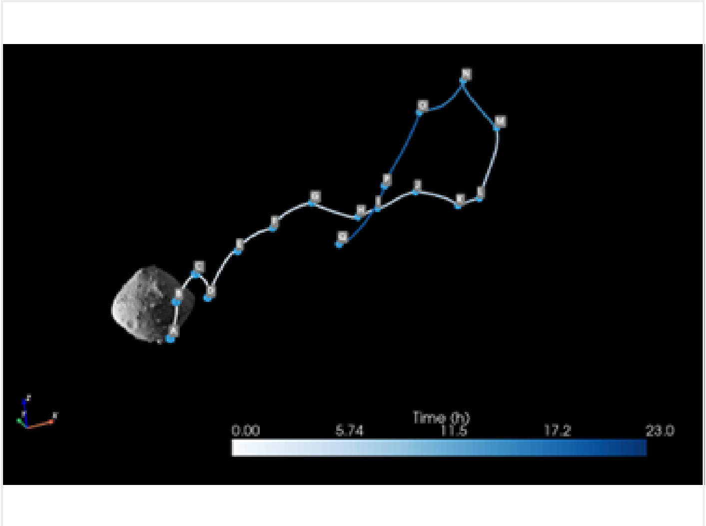
Ratio between particle diameter and critical diameter to cause damage.



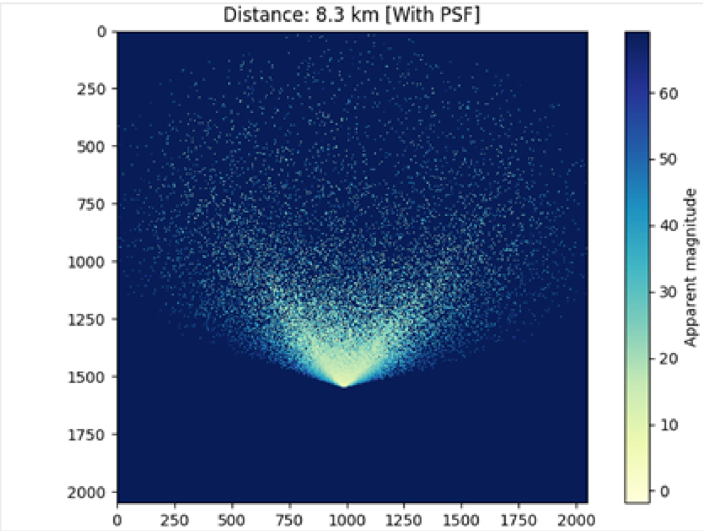
Number of orbit revolutions for particles in multi-pass orbits as a function of the impact location.



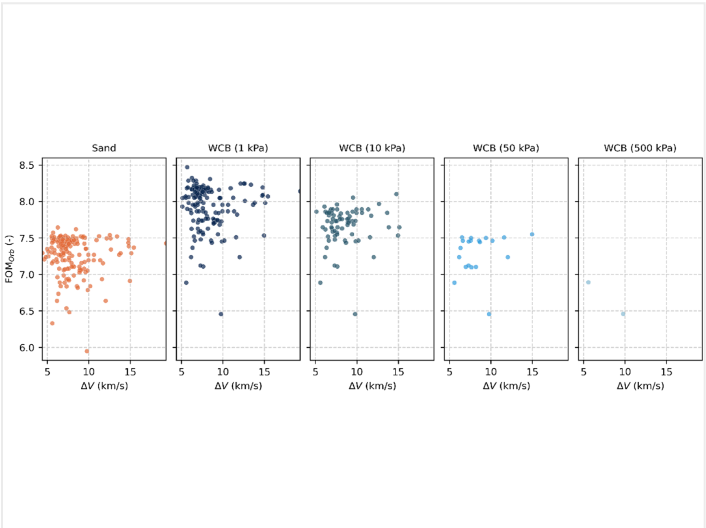
Distribution of fragments impacting the asteroid after the ejection.



Collection trajectory obtained from the sliding-mode control with optimised waypoints.



Synthetic image of an impact onto the surface of asteroid 1998KY26.



Delta-V vs FOM of target asteroids for in-orbit collection strategy for 5 materials.

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Permalink: https://cordis.europa.eu/project/id/896404/reporting/it