TASK 5.2 – UPDATE MARCH 2021

Massimiliano Vasile

Agenda

- Task 5.2
- NEOCORE
- Future Work

TASK 5.2

- Restarted the activities on Task 5.2 within Stardust-R
  - Initial results on kinetic impactor under uncertainty
  - Revisited the concept of smart clouds for asteroid deflection

- Work on Task 5.11 - Development of the NEOCORE mission concept and related sensor and measurement simulations.
  - Mission proposal shortlisted by ESA
  - Scoping meeting with ESA on the 26th of March

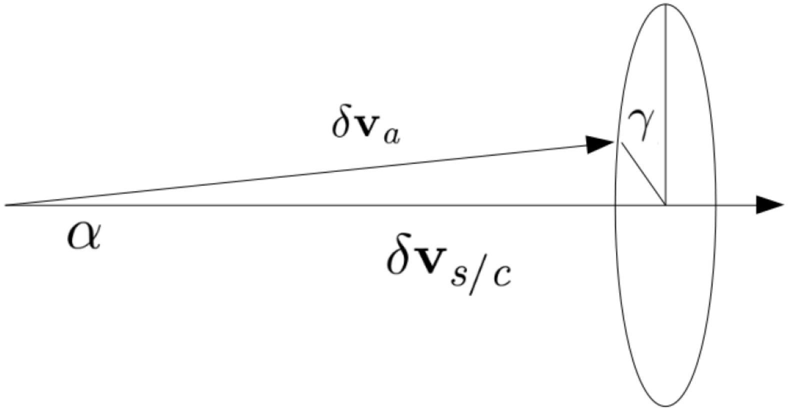
Lewis Walker, Marilena Di Carlo, Cristian Greco, Massimiliano Vasile, Matthew Warden, A mission concept for the low-cost large-scale exploration and characterisation of near earth objects, Advances in Space Research, 2020.

KINETIC IMPACTOR UNDER UNCERTAINTY

Simple deflection model with uncertainty on β and deflection direction.

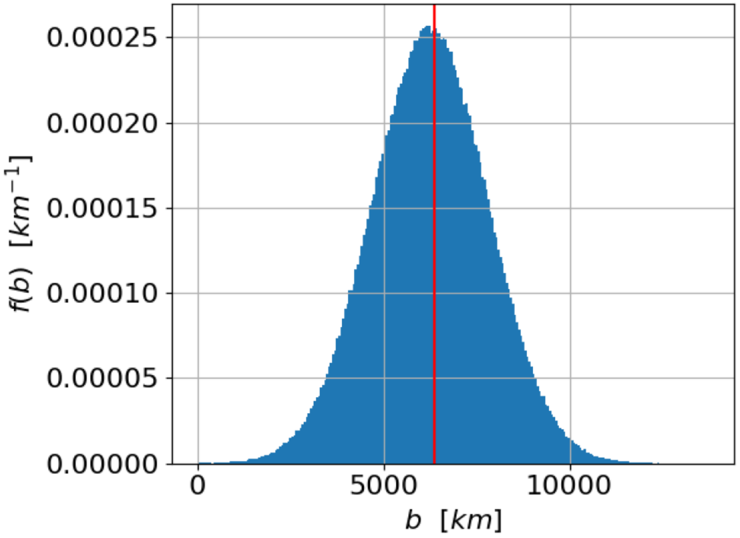
Uncertainty on the direction is due to the uncertainty on the ejecta and on the uncertainty on the surface of impact.

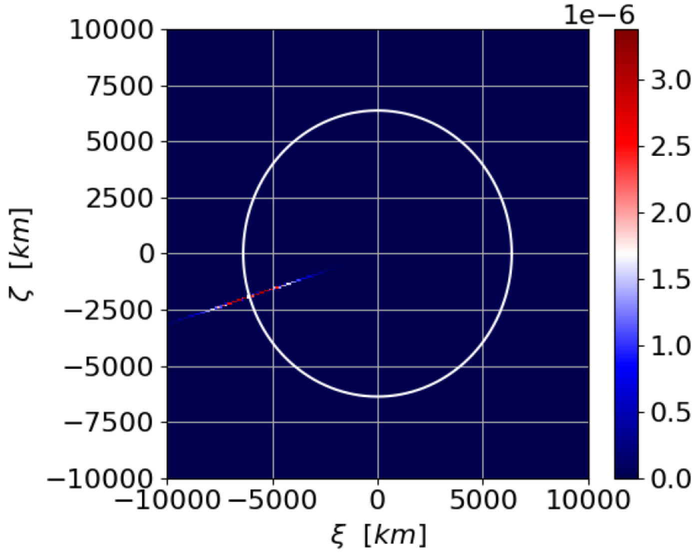
$$\delta\mathbf{v}_a = \beta\frac{m_{s/c}}{m_a}\delta v_{s/c}[\cos(\alpha),\ \ \sin(\alpha)\cos(\gamma),\ \ \sin(\alpha)\sin(\gamma)]$$



KINETIC IMPACTOR UNDER UNCERTAINTY

Fast propagation of the probability distribution with intrusive PCE till the point of expected impact.

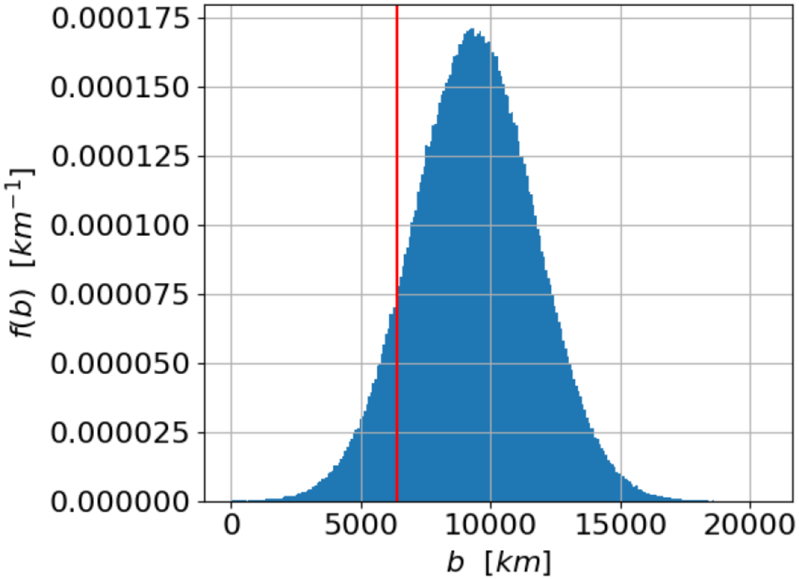


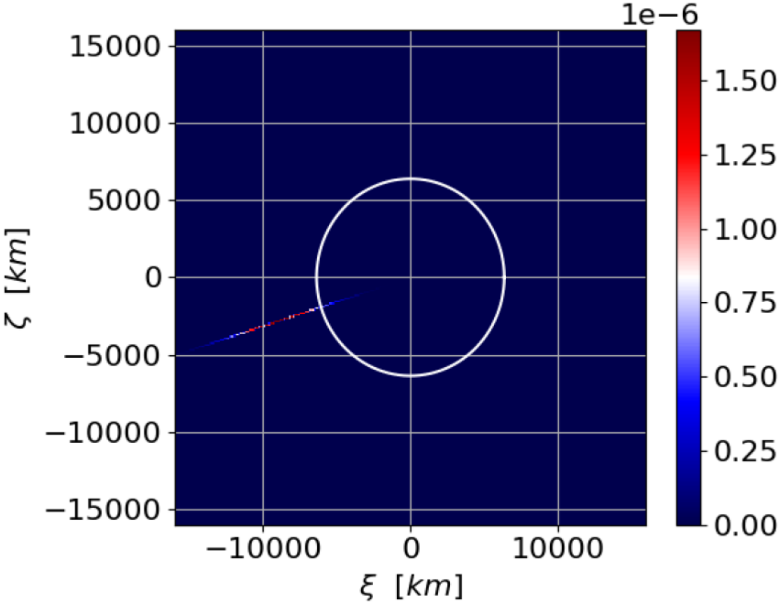


KINETIC IMPACTOR UNDER UNCERTAINTY

Analysis of required action to guarantee minimum deflection probability.

Example: probability of impact < 0.1



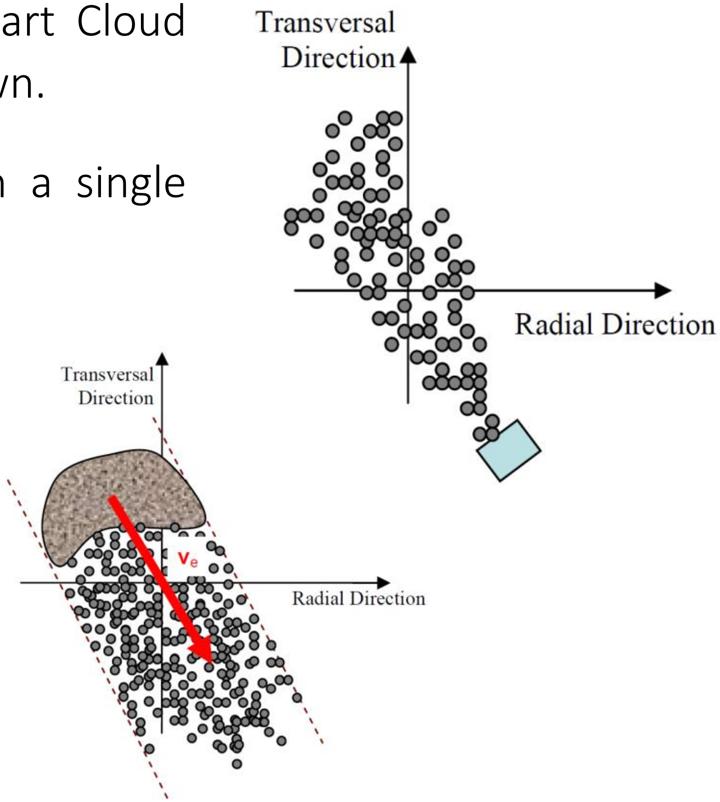


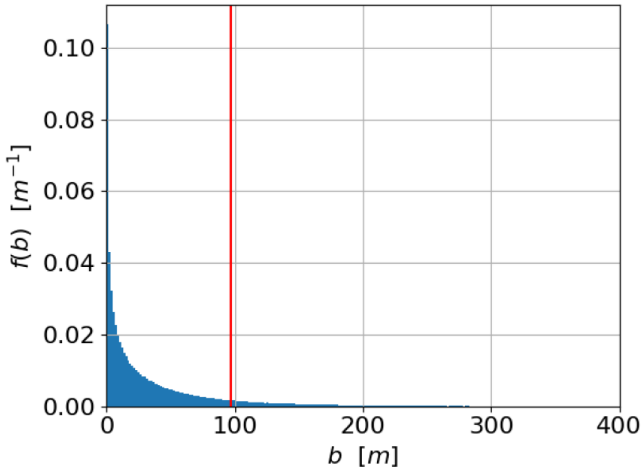
SMART CLOUDS FOR KINETIC IMPACT

Proposed in 2011, see Gibbings and Vasile “A Smart Cloud Approach to Asteroid Deflection”, 62nd IAC, Cape Town.

Uses a swarm of nanosats to impact rather than a single spacecraft.

Cloud modelled as a probability distribution. Distribution of impacts on the surface of the asteroid:





$$P(b < R_a) = 0.907528, \quad R_a = 97 \ m$$

SMART CLOUDS FOR KINETIC IMPACT

From the distribution of the impacts on the surface of the asteroid one can calculate the resultant δv.

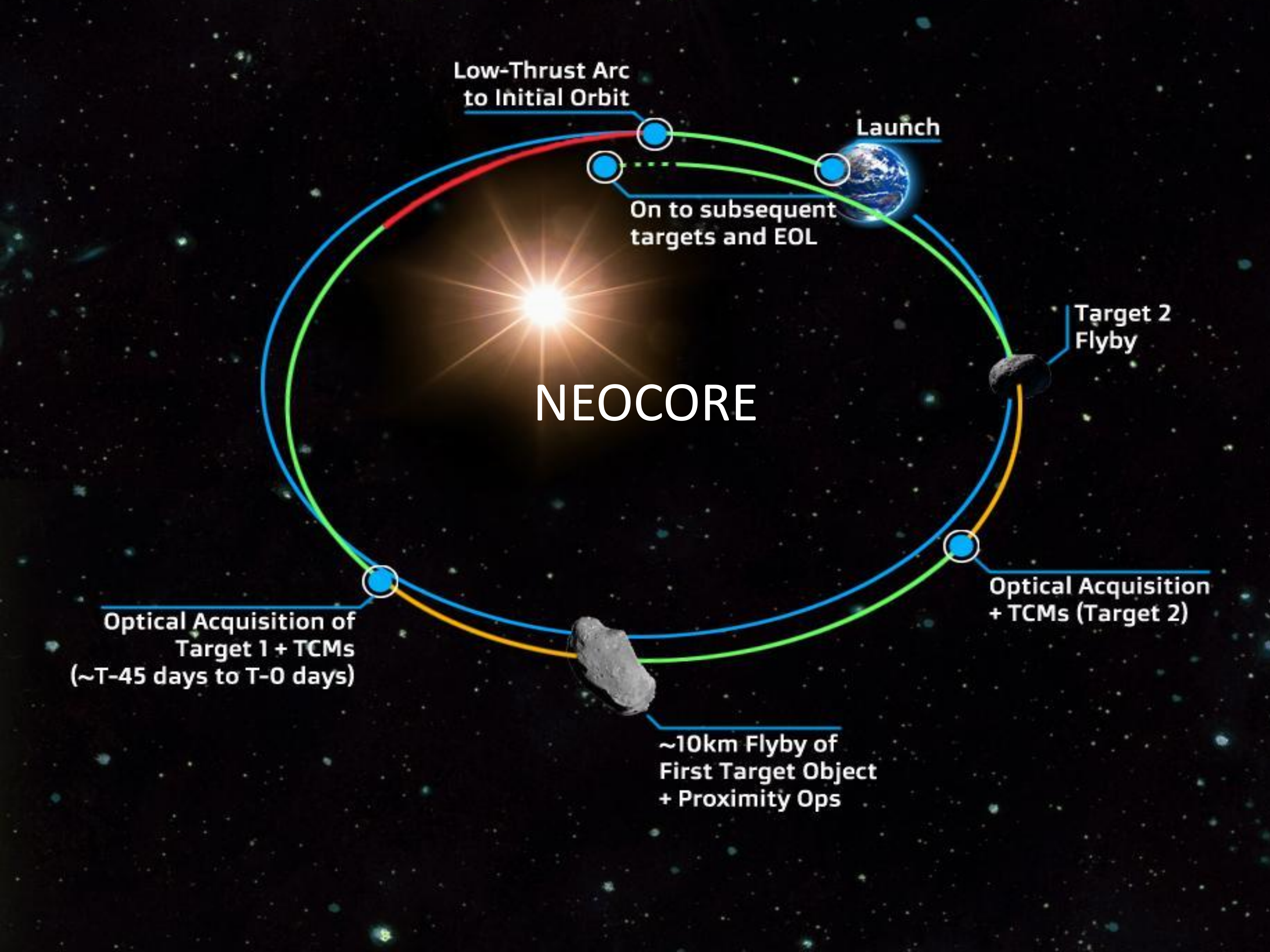
$$\delta v_a = \beta \frac{m_{s/c}}{m_a} \int_{\Omega} (b(\omega) < R_a) \delta v_{s/c}(\omega) p(\omega) \mathrm{d}\omega = \beta \frac{m_{s/c}}{m_a} \mathbb{E}((b < R_a) \delta v_{s/c})$$

and the deflection on the b-plane at the Earth

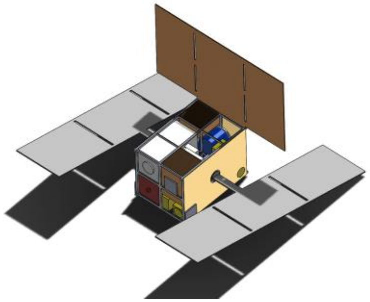
$$\delta v_a = [-1.71 \cdot 10^{-9}, -0.0142] \;\; m/s$$

In this example.

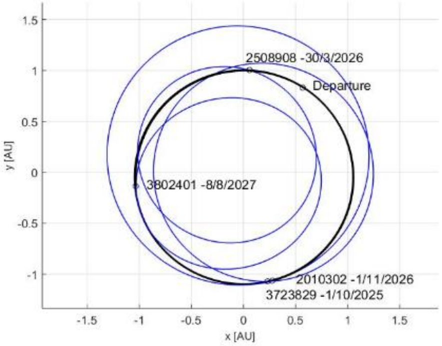
NEOCORE


Low-Thrust Arc to Initial Orbit
Launch
On to subsequent targets and EOL
Target 2 Flyby
Optical Acquisition + TCMs (Target 2)
Optical Acquisition of Target 1 + TCMs (~T-45 days to T-0 days)
~10km Flyby of First Target Object + Proximity Ops

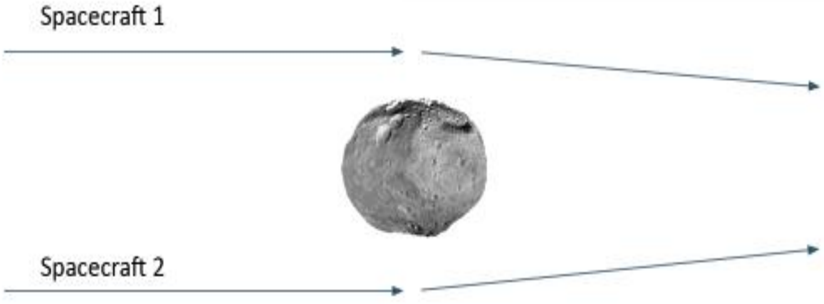
NEOCORE - NEAR EARTH OBJECT COMPREHENSIVE OBSERVATION AND RECONNAISSANCE



- Gravimetric measurement via intersatellite ranging
- Ephemerides improvement
- 3D shape and size
- Bond albedo
- Hyperspectral imaging



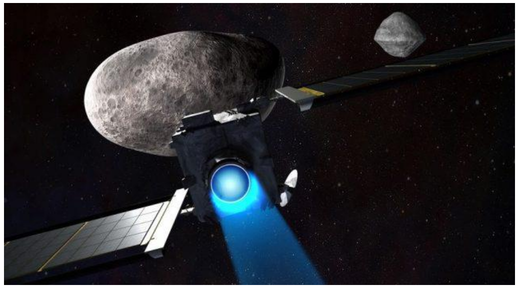
- Commercial prospection of asteroids
- Multiple launch opportunities every year
- Low-cost standard platform



NEOCORE - MISSION SCENARIOS

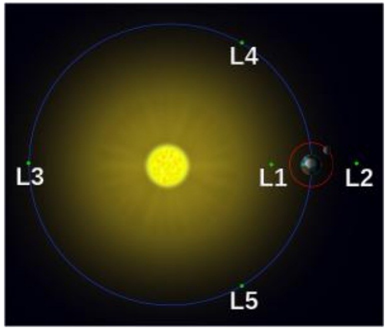
Dedicated Launch, 2 S/C, flyby only

Dedicated Launch, 2 S/C, flyby + impactor



Dedicated Launch, 1 S/C, flyby only

Piggyback launch to L2 parking orbit



Target selection and Detailed Trajectory Study

- Aim to maximize number of visited NEAs with minimum propellant expenditure

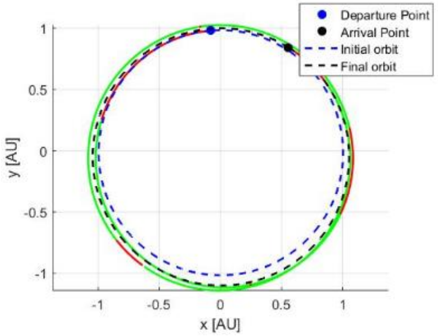
- Find candidate solar obits with many NEA approaches
  - Low-thrust burns adjust trajectory to achieve close flybys

- Searched entire JPL SBDB to find set of possible tours

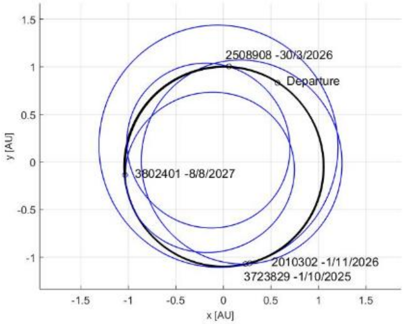
- Selection criteria
  - NEA size >50m
  - Initial Orbit (IO) lies on the ecliptic
    - r_a,r_p between [0.8, 1.2] au
  - Asteroid MOID < 0.01 au
  - Phasing Analysis for initial M_0
  - Low-thrust burn
    - Reduce MOID to zero
    - Total <2km/s in TCMs for tour
  - ≥1 object per tour ≥150m

- Found tours with up to 15 NEAs

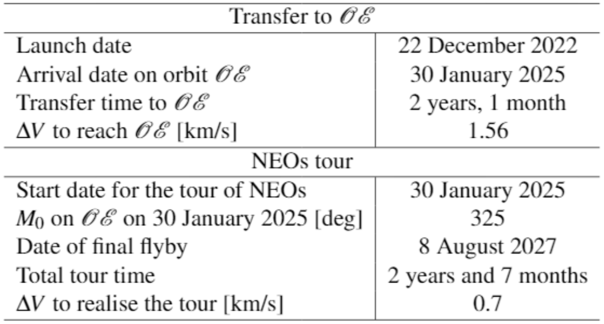
- Reference tour (right) selected as basis for study



Low thrust transfers to initial orbit



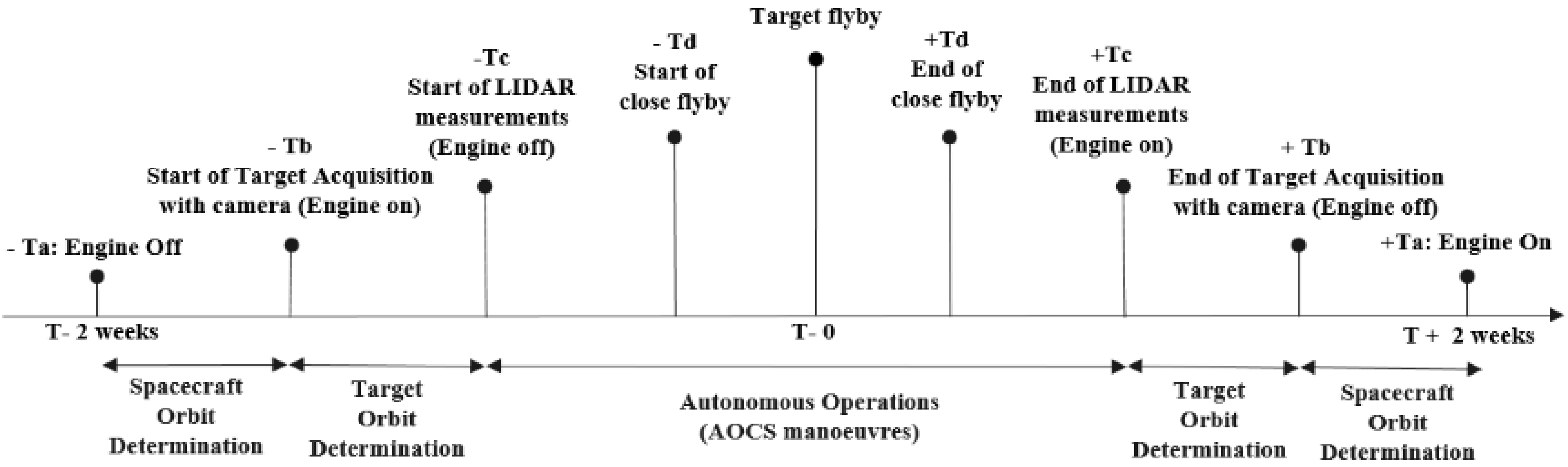
Initial spacecraft orbit (black) and target asteroid orbits (blue)



Transfer to $\mathcal{OE}$	
Launch date	22 December 2022
Arrival date on orbit $\mathcal{OE}$	30 January 2025
Transfer time to $\mathcal{OE}$	2 years, 1 month
ΔV to reach $\mathcal{OE}$ [km/s]	1.56
NEOs tour	
Start date for the tour of NEOs	30 January 2025
M_0 on $\mathcal{OE}$ on 30 January 2025 [deg]	325
Date of final flyby	8 August 2027
Total tour time	2 years and 7 months
ΔV to realise the tour [km/s]	0.7

Details of the reference tour

NEOCORE - SCIENTIFIC RETURN AND MEASUREMENT STRATEGY



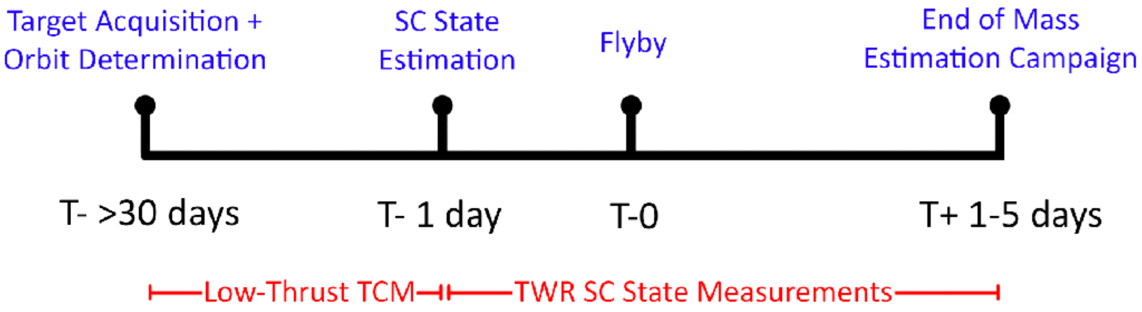
Concept of operations for asteroid flyby

Mass Estimation Technique

- Estimate asteroid mass by precise measurement of SC separation and relative state
  - Range measured my LIDAR in TWR mode
  - Relative position measured by CCD sensitive to LIDAR wavelength

- Compare measured states with initial state propagated in a 3D dynamic model where M_{ast} is the key variable

- Least-squares fit of model to data yields mass estimate



Target Acquisition + Orbit Determination

SC State Estimation

Flyby

End of Mass Estimation Campaign

T- >30 days

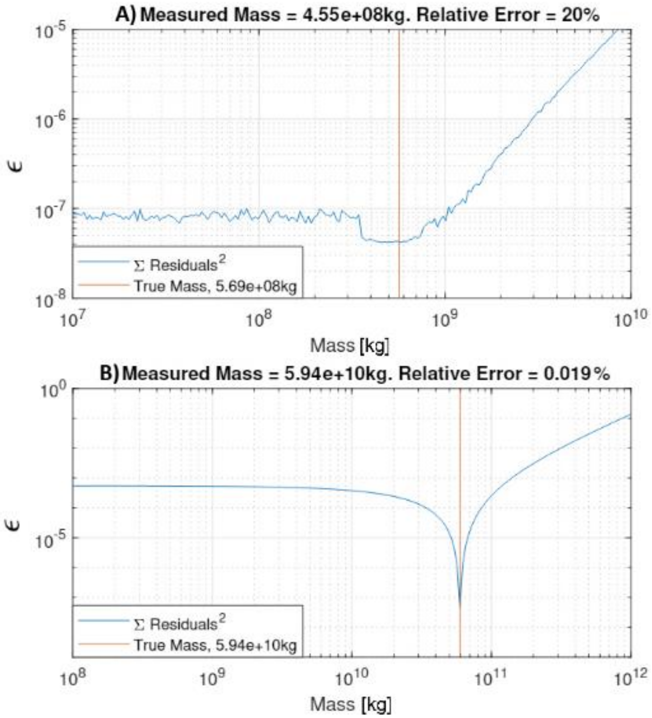
T- 1 day

T-0

T+ 1-5 days

Low-Thrust TCM

TWR SC State Measurements

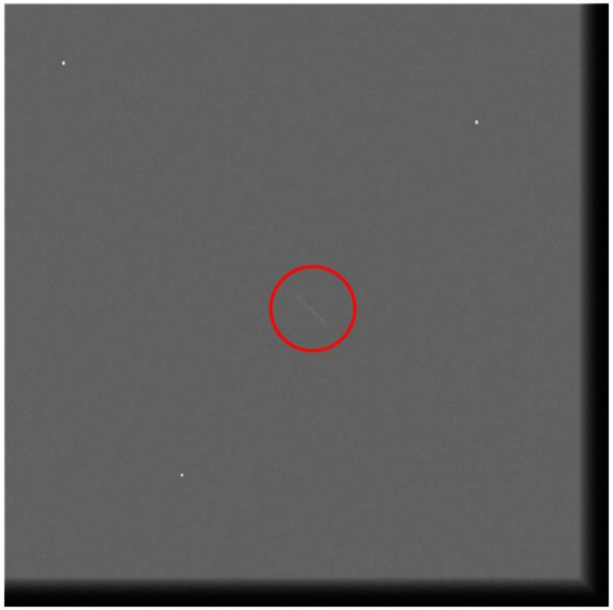


A) Measured Mass = 4.55e+08kg. Relative Error = 20%

B) Measured Mass = 5.94e+10kg. Relative Error = 0.019%

Early Target Acquisition with Frame stacking

- Very close flyby (<10km) enhances gravitational interaction. TCMs required.
- Early asteroid OD enables TCMs to be performed with low-thrust propulsion
- SNR limits observability
  - $+t_{exp}$ -> +SNR
  - t_{exp} limited by jitter, motion blur
- NavCam with frame stacking technique proposed
  - Large effective t_{exp}
  - Individual frames short enough to be unaffected by jitter



Frame stacking model test.
Frames aligned using three anchor stars

Primary Engine

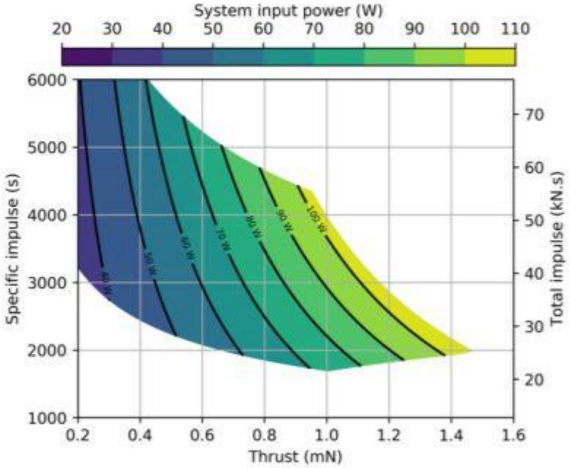
Main engine trade-off:

- Chemical micropropulsion systems limit the available Delta-V and have issues in meeting volume/mass requirements

- Electric propulsion meets volume/mass requirements and allows larger Delta-V at the expenses of a larger power consumption

Enpulsion IFM Micro 100:

- Electric micropropulsion system (electrospray technology)
- Most promising option as main engine
- Tunable characteristics:
  Isp up to 6000 s
  T down to 25μN
- Delta-V up to 2.6 km/s depending on the thrust settings (meeting mass and volume budget with 10% margin)



Flyby Targeting

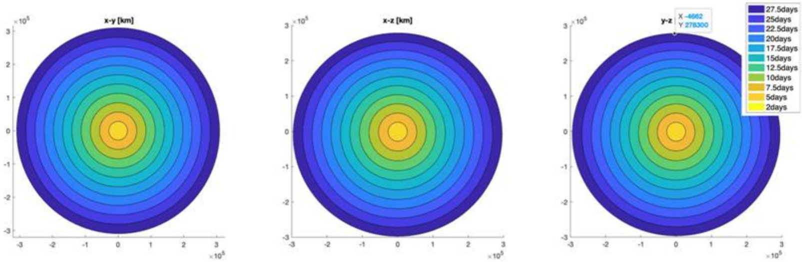
Primary approach:

- After asteroid detection, TCMs are carried out with two Aerojet Rocketdyne MPS-130-1U
- Sequence of sparse high-thrust impulses to correct trajectory while enabling other satellite operations

Contingency plan:

- If actual deviations are larger than high-thrust reachable set, primary low-thrust engine can be used
- Expand reachable deviations with continuous thrust for small additional ΔV
- Long thrusting arcs before flyby

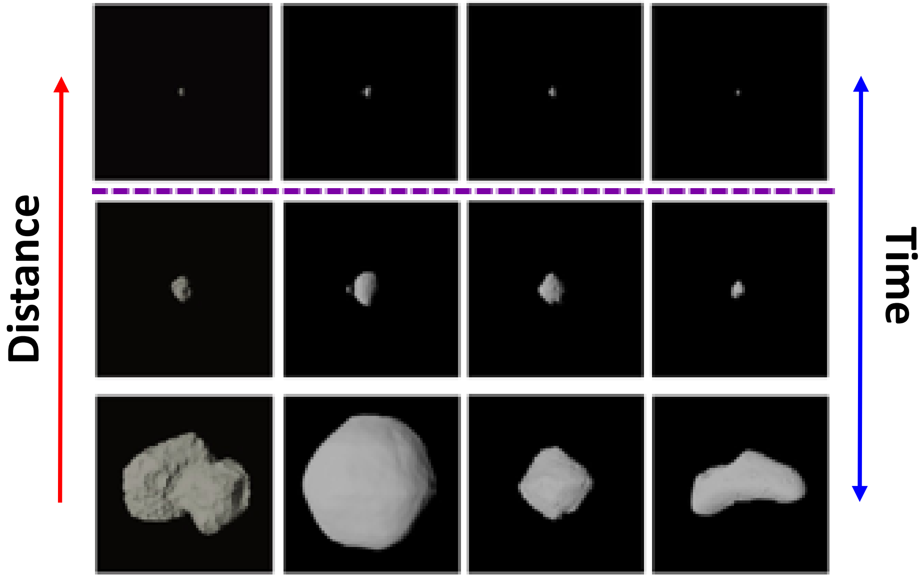
- 2x4 engines mounted at different corners of the spacecraft
- Total thrust of 2N
- Total ΔV ≈ 110 m/s



High-thrust reachable set with asteroid detection N days before flyby

OpNav

Flyby simulator



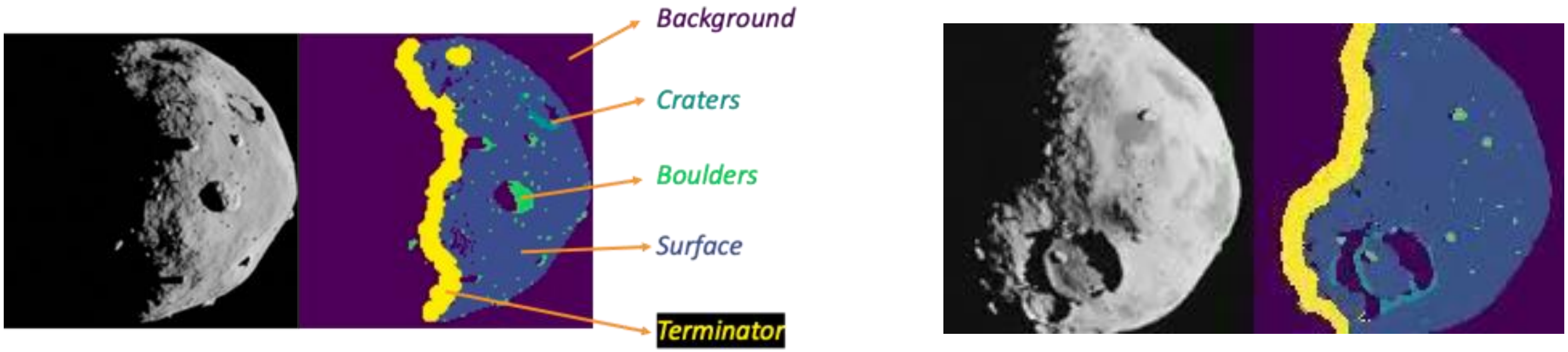
Flyby Optical Simulators:

Far range: Blob of pixels, simple ray-tracing

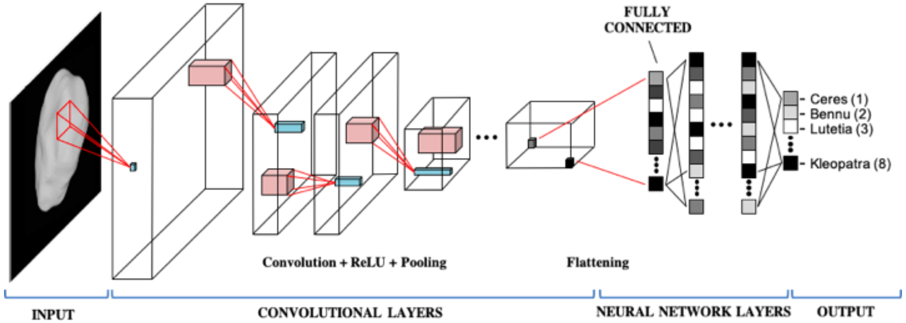
Close range: Shape models, complex ray-tracing

- Any shape model can be plugged in to simulate the proximity phase of the flyby
- Test the robustness of the GNC strategy to large shape model uncertainties
- Embedded into a closed-loop flyby GNC system

AI Enhancement



“*On-Board small-body semantic segmentation based on morphological features with U-Net*”, **M. Pugliatti**, M. Maestrini, P. di Lizia, F. Topputo, 2021 AAS/AIAA Space Flight Mechanics Meeting



“*Small-body shape recognition with Convolutional Neural Network and comparison with explicit features based methods*”, **M. Pugliatti**, F. Topputo, 2020 AAS/AIAA Astrodynamics specialist Conference

FUTURE WORK

- Analysis of kinetic impactor under uncertainty for different mission scenarios
- Analysis of slow-push deflection under uncertainty building on previous work – see Zuiani, F., Vasile, M., & Gibbings, A. (2012). Evidence-based robust design of deflection actions for near Earth objects. Celestial Mechanics and Dynamical Astronomy, 114(1-2), 107-136. https://doi.org/10.1007/s10569-012-9423-1
- NEOCORE – scoping meeting with ESA on the 26th

University of
Strathclyde
Glasgow