Status on action 5.11 – NEOtoolkit, TOOLBOX FOR A CHARACTERISATION PAYLOAD

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CNES CENTRE NATIONAL D'ÉTUDES SPATIALES

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Aim of action 5.11

To reach a consensus among SMPAG members regarding the objectives of a space mission designed for a NEO characterization, and then the instruments that can be made available for achieving it.

This consensual definition of a ‘straw man payload’ would be available on a reasonably short notice for a characterization mission targeted to NEOs that present a potential threat.

Lead : CNES

Support from Belgium, DLR, UKSA, ASI, ESA

Plan for action 5.11

Planned sequence :

- Summarize the outcomes of a study dedicated to Apophis (done)
- Identify some short notice mission scenarios and specify the objectives of the associated characterization mission
- Specify the instruments and mission requirements for achieving these objectives
- Review available existing instruments and, in case of gaps, assess the need for the development of new instruments
- Provide with cost estimates of such instruments, if available

Physical parameters needed for various mitigation methods

Tractor, slow push | Nuclear or impactor deflection | Civil Defence

Mitigation method→ Parameter ↓	Gravitational tractor	Solar sail, harpoon… techniques based on tracting and requiring anchoring the asteroid	Methods based on thermal properties modification	Impactor, Explosion to deflect	Atmospheric entry
Accurate orbit determination	X	X	X	X	X
Mass	X	X	X	X	X
Shape	X	X	X	X	X
Spin	X	X	X	X	X
Sub surface		X	X	X	X
Thermal properties			X	X	X
Chemical properties				X	X
Internal structure				X	X

Would need a RV

Table to be discussed, amended and complemented, in particular through the completion of actions 5.2, 5.3 & 5.4.

Potential mission scenarii

- 1 - Minimum characterization : **fly-by** of NEO target.

- 2 - Enhanced remote sensing : **RV** with NEO target.

- 3 – Same as 2 + **companion cubesat**
  => potential access to inner structure.

- 4 – Same as 2 + **one or several landers**
  => inner structure characterization.

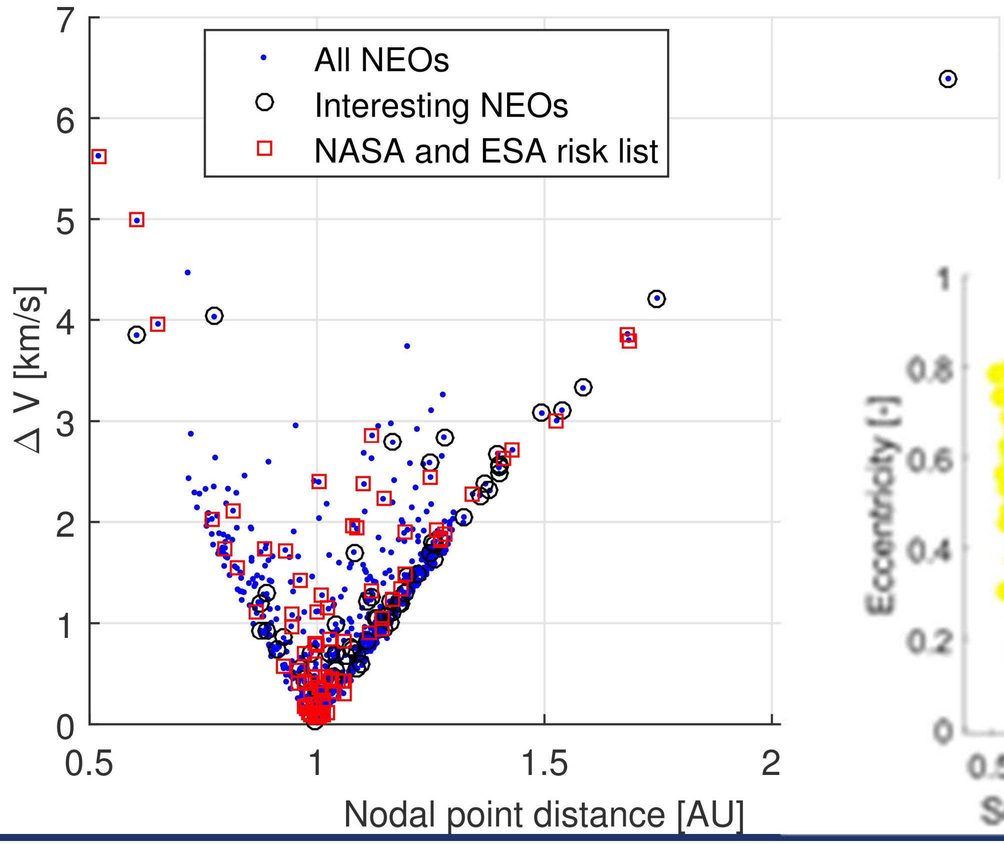
Accessibility

Flybies are much more accessible than RVs

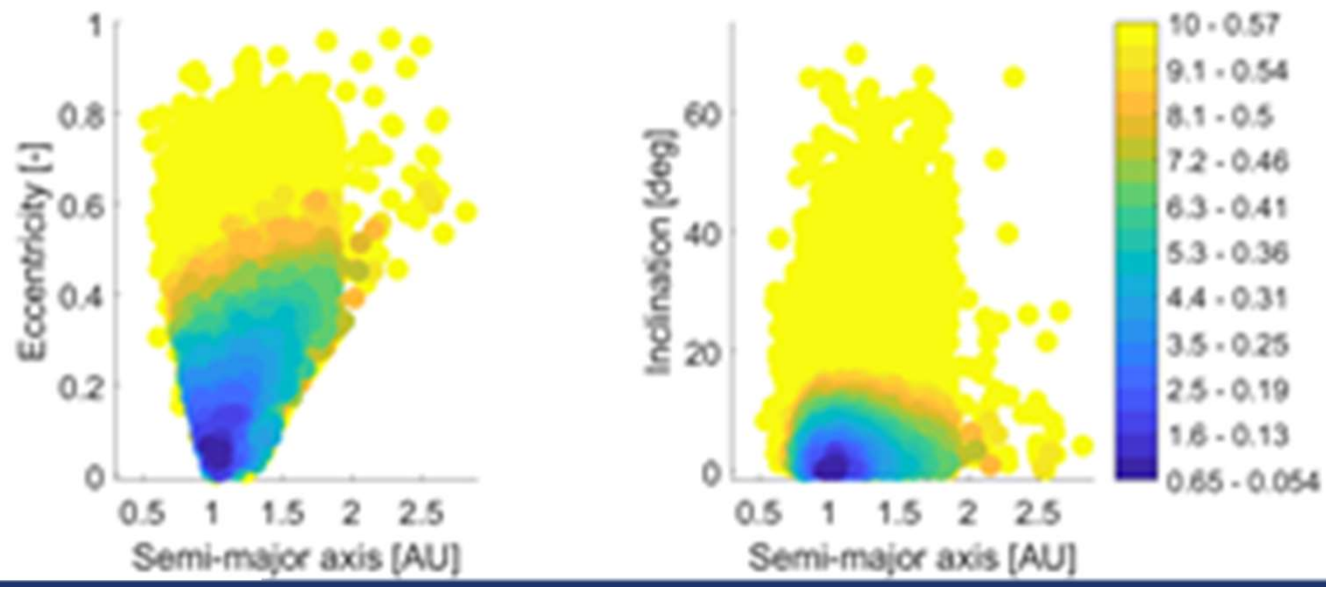
Impact or blast mitigators tend to apply to high eccentricity and inclination cases

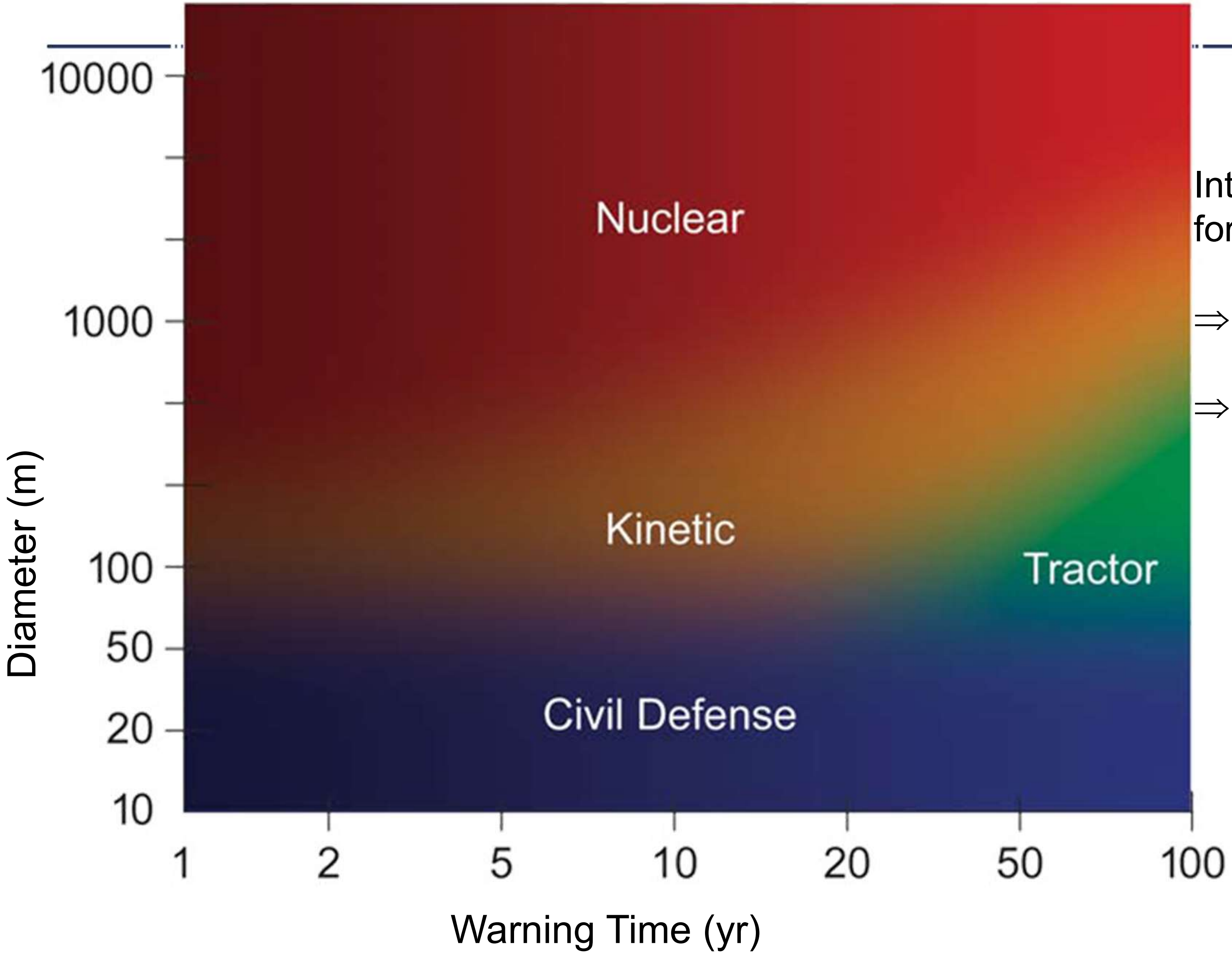
"Statistical Multi-Criteria Evaluation of Non-Nuclear Asteroid Deflection Methods", Thiry, N., Vasile, M., Acta Astronautica, Volume 140, November 2017, Pages 293-307, https://doi.org/10.1016/j.actaastro.2017.08.021.

ΔV cost to flyby NEOs at one of their nodal points.



ΔV and propellant mass fraction to rendezvous NEOs with low-thrust propulsion





Internal structure assesment is critical for Nuclear or kinetic deflection

⇒ Needs orbital RV + multi probes

⇒ Can only be arranged for a few cases

Fly by mission discussion

Only a limited subset of objectives can be met :

- **Orbital parameters** (enhanced with simultaneous fly-by by 2+ probes),
- **Size,**
- **Shape & large surface features** (limited extrapolation of inner structure),
- **Mass** (enhanced with simultaneous fly-by by 2+ probes),
- Large surface features,
- Possibly rough estimation of **thermal & chemical properties**

=> Minimal instrument package can be compatible with a small probe, possibly a multi U cubesat.

The possibility of sending several – small – fly-by probes is very attractive:

- For obvious reliability reasons
- To improve **shape characterization** through several angles of view (in particular for slow spinning asteroids)
- To improve **orbital parameters and mass** evaluation (see NEOCORE presentation)

Instrumentation for flyby probes

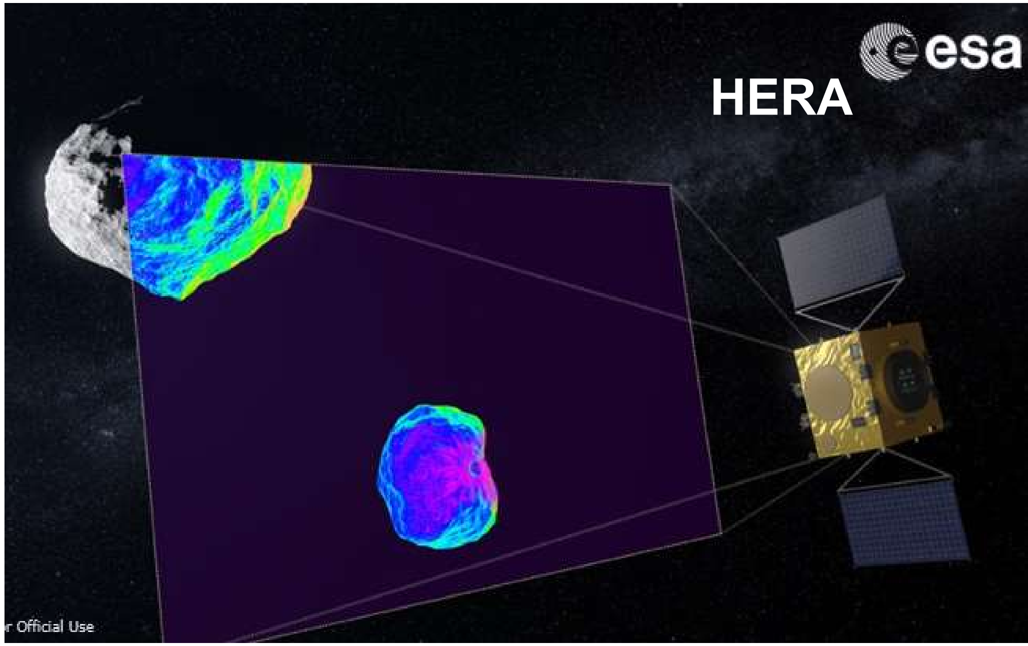
Minimum instrumentation compatible with 12 U smallsat:

- A **Narrow Angle Camera** to detect the target days ahead of flyby, and provide information on **size, shape, and local features**.
- Two-way ranging for **mass** estimation using a **LIDAR** and / or ISL **Radioscience** in S or X band
- Possible addition of **Thermal radiometer / Polarimetric camera / IR spectrometer for surface thermal and chemical properties.** However, remote sensing is affected by several limitations (one face visible, restricted sun illumination, high relative velocity, limited exposure time, target angular motion).

Instrumentation RV orbiters

A single spacecraft is OK. Same package as defined for a flyby mission (**Lidar, Narrow Angle Camera and RSE**).

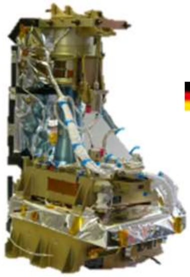
Enhanced estimation of size, shape, mass & local features through a complete scan repeated several times.



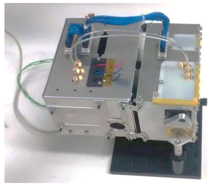
In addition:

- **Polarimetric camera & IR Spectrometer** to map the **mineralogical composition** and the **surface diversity**,
- **Thermal IR Spectrometer** to complement the **surface mineralogy**, coupled with a **thermal radiometer** for **surface thermal properties**,
- One or several **landers** for **sub-surface & internal structure**, with **seismometers and radar tomography** such as on Rosetta / Philae.

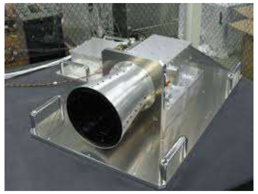
Hera Payload



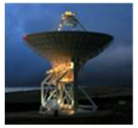
Asteroid Framing Cameras
(Visible Imaging in 8 filters)



PALT
(μLidar)

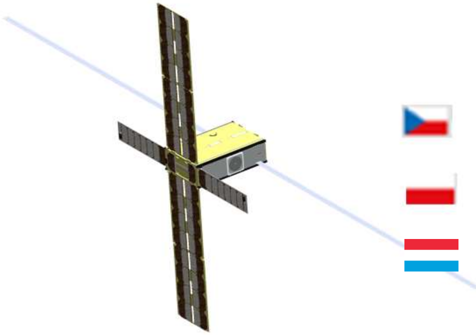


TIRA (Thermal Infrared Instrument)



RADIOSCIENCE

APEX Cubesat
- Vis and near-IR imaging spectrometer
- Secondary Ion Mass Analyzer
- Magnetometer



JUVENTAS Cubesat
- Radar
- Accelerometers
- Gravimeter

Posters : **Gordo:** Helena – Hera Lidar Engineering Model Altimeter Design
Herique Radar Package

talks: **Graziano:** on Autonomous GNC and data fusion GNC,
Kohout : APEX CubeSat

Conclusion (1 / 2)

Reconnaissance missions to a threatening NEO will often be limited to a flyby, which can improve the **orbital determination** and reduce the uncertainty on **mass, size and shape** with **NAC, Lidar and Radioscience**. Having 2 (or more) spacecraft performing a simultaneous flyby greatly enhances the mass estimation.

Orbiters can tackle **mineralogy, surface properties and inner structure, but will seldom be feasible prior to a mitigation mission using impact or blast deflection**.

The NEO and PEO catalogue is growing fast. With small probes, systematic characterization of NEOs - regardless of their expected danger - becomes affordable.

=> See NEOCORE presentation.

In case of a short warning threat, many references would then be available to support the definition of a mitigation mission.

Conclusion (2 / 2)

HERA **is** a planetary defence reconnaissance mission to a NEO

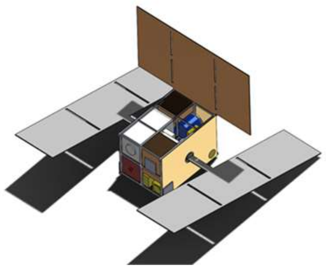
⇒ **State of the art instruments are available**

⇒ **Next phase of actions 5.11: survey of existing instruments (+ gaps)**

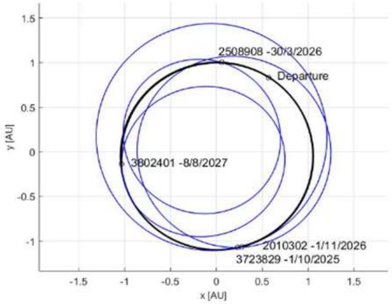
Instrument type	Radio Science (DTE or ISL)	Accelerometer	Lidar altimeter	WAC & NAC Camera	Polarimetric camera	Thermal IR radiometer	Thermal IR imager	Vis& near IR spectro-imager	X-/Gamma-ray spectrometer	Monostatic HF radar	Bi-static LF radar	Seismometer
Organisation												
Instrument name												
Instrument principle												
Mission (flown or planned)												
TRL												
Performances												
Mass												
Volume												
Electrical power												

Mission scenario	Radio Science	Accelerometer	WAC & NAC Camera	Lidar	Thermal IR imager	Monostatic HF radar	Bi-static LF radar	Seismometer (+ excitation ?)	Vis& near IR spectro-imager
Fly by			X	X	X				X
RV orbiter	X	X	X	X	X	X			X
RV orbiter + cubesat	X ++	X	X	X	X	X	X		X
RV orbiter + lander(s)	X	X	X	X	X	X	X	X	X
	Orbit improvement	Enhanced orbit improvement							
	Mass/Density	Mass/Size/ Density	Mass/Size/Density	CoG			CoG	CoG	
			Shape	Shape					
			Dynamical state						
			Surface & photometric properties	Topography & morphology	Surface roughness	Shallow sub-surface structure	Deep internal strcture	Deep internal structure	
			Chemical & mineral composition (?)		Thermal properties				Mineralogy

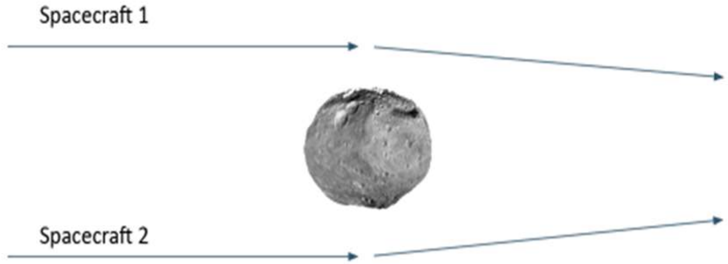
NEOCORE - NANOSPACECRAFT EXPLORATION OF ASTEROIDS BY COLLISION AND FLYBY RECONNAISSANCE



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



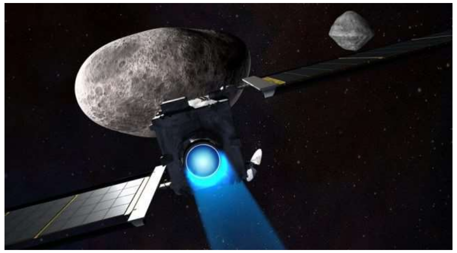
- Commercial prospection of asteroids
- Multiple launch opportunities every year
- Low-cost standard platform



NEACORE - MISSION SCENARIOS

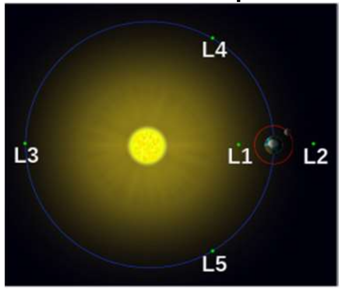
Dedicated Launch, 2 S/C, flyby only

Dedicated Launch, 2 S/C, flyby + impactor



Dedicated Launch, 1 S/C, flyby only

Piggyback launch to L2 parking orbit



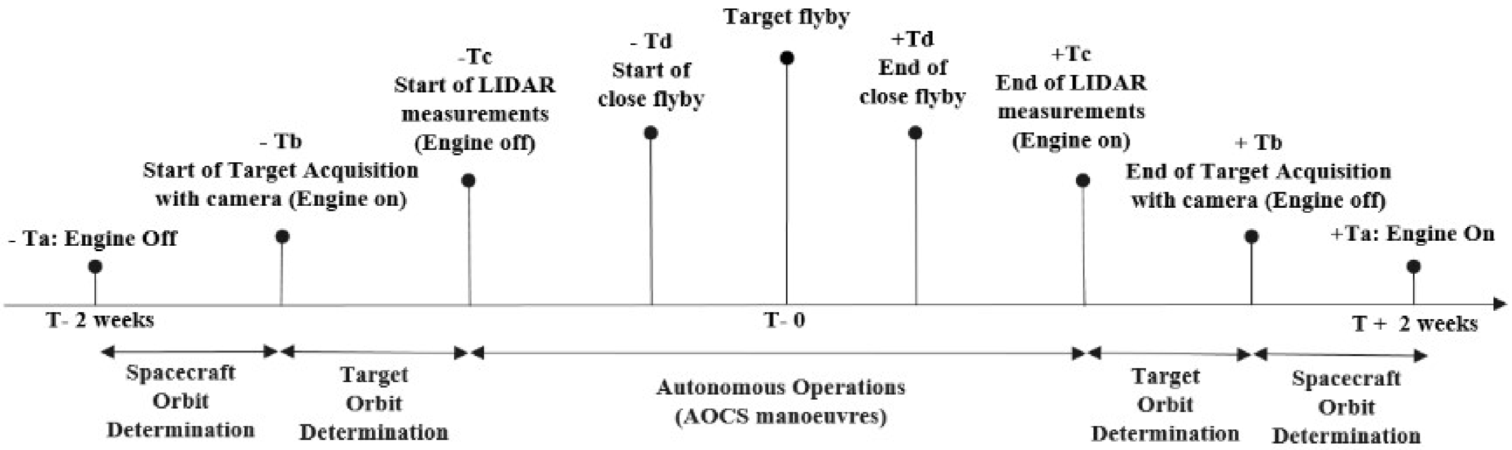
NEACORE - TARGET SELECTION

- Single target set selected for study
  - ‘Case study’ - framework intended for many possible target sets / trajectories.
  - Hundreds of possible trajectories generated (up to 2027)
  - Self imposed target size limitation >50m
  - Limit of 3 years of mission time

SPK ID	Family	Date of encounter	Diameter [m]	a [AU]	e	i [deg]	Flyby rel. vel. [km/s]
3723829	Apollo	1/10/2025	70.756219	1.09	0.18	14.8	8.91
2508908	Aten	30/3/2026	223.750812	0.88	0.27	5.6	7.89
2010302	Amor	1/11/2026	467.481706	1.27	0.14	4.37	3.06
3802401	Aten	8/8/2027	70.756219	0.89	0.20	18.49	9.53

Details of the chosen target set

NEACORE - SCIENTIFIC RETURN AND MEASUREMENT STRATEGY



Concept of operations for asteroid flyby

NEACORE - SCIENTIFIC RETURN AND MEASUREMENT STRATEGY

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- **Asteroid mass determination**
  - Opposing flyby trajectories ~20km altitude
  - Measure relative velocity pre flyby
  - Measure deflection via two-way ranging (LIDAR or ISL) over time

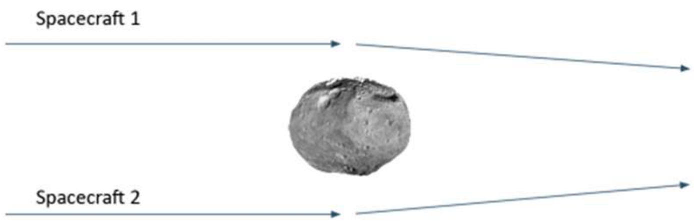
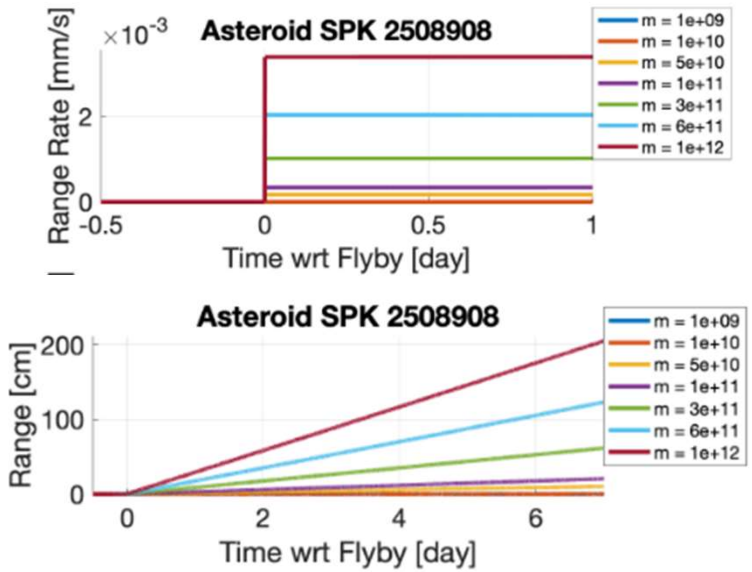


Illustration of gravitational deflection. Flyby altitude ~20km (Not to scale)



Deviation and rate thereof from expected intersatellite range post-flyby

PRELIMINARY SIMULATION RESULTS

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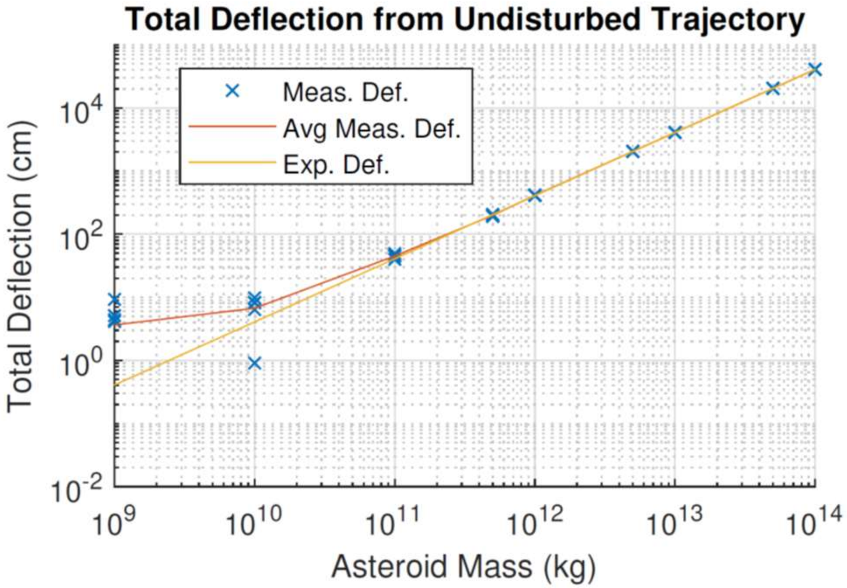

- Two way LIDAR system
- Measurement of range and line of sight
- Estimation of asteroid mass from differential of the relative displacement between the two spacecraft.
- Measurement 8 hours before and after the flyby

NEACORE – CURRENT WORK

- Accurate simulation of two way LIDAR
- Major error comes from pulse rate and pulse identification
- Significant improvement can be achieved with shorter higher intensity pulses → millimitre/sub-millimitre accuracy
- Millimetre or sub-millimitre accuracy is required for < 100m size
- Mass estimation integrated in the filtering process
- Longer integration time post close encounter

FUTURE PERSPECTIVE

AURORA proposal H2020 submitted in January 2020 – led by the University of Belgrade

Expected evaluation in May 2020

Expected start of AURORA, if successful Jan 2021

Key objectives:

- Characterisation of small asteroids and asteroid families
- Combine use of dynamical astronomy and machine learning

Proposal of support message from SMPAG

SMPAG also acknowledges the emergence at ESA and JAXA of two - small class – high velocity fly by missions to small bodies, Comet Interceptor and Destiny+. These intiatives pave the way towards similar reconnaissance missions to PHAs, and related instrumentation, that could be needed prior to mitigation missions.