HORIZON 2020

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NEOTωIST – DESIGN STUDY OF A KINETIC IMPACTOR DEMONSTRATION MISSION FEATURING NEO SPIN CHANGE AND OBSERVER SUB-SPACECRAFT

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Outline

- Introduction
- Mission Architecture and Implementation Options
- Observation geometry
- Impactor concept
- Flyby module concept
- Chaser concept
- Concluding remarks

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Introduction

NEOTωIST Mission Feasibility Study

Alternative Impactor Demonstration Mission that promises reduced cost, programmatic flexibility & high value

⇒ Higher probability of implementation

Scientific/programmatic objectives and measurement principle

as explained by previous speaker

Execute and NEOShield-2 Project

EC-funded activity to study various aspects of Asteroid threat mitigation executed by Europe-wide consortium of Industry & Science Institutes

Tunguska, 1908

Chelyabinsk, 2013

Somewhere, sometime

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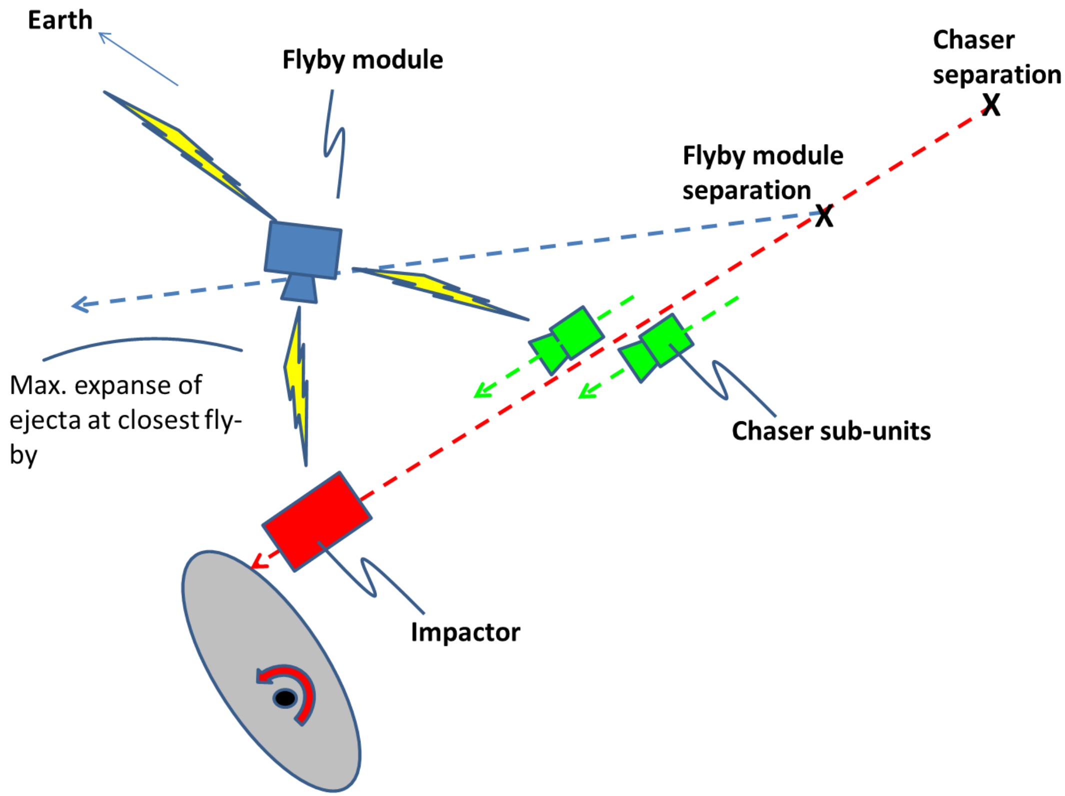
Mission Architecture

Concept

- One impactor spacecraft also functioning as interplanetary carrier
- One flyby sub-spacecraft (Flyby Module / FMB) ejected prior to impact
- FBM passes at safe distance functioning as observation platform and communications node
- One or two Chaser sub-spacecraft ejected prior to impact
- Chasers follow impactor trajectory and are potentially destroyed after performing observation tasks
- Observation of impact from different vantage points
- Spin change detection by observation from Earth



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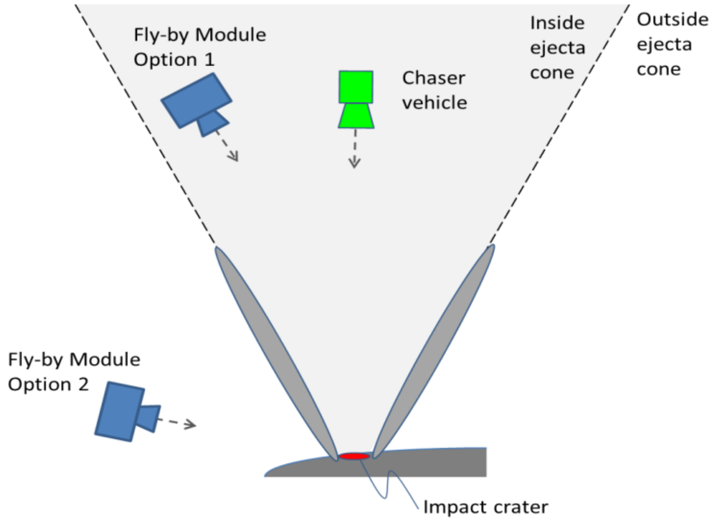
Mission Architecture & Implementation Options

Vehicle	Functions	Information generated
Impactor	• End game GNC • Interplanetary carrier	• Impact location (Navigation data)
Flyby module	• Observation of ejecta geometry (camera + radiometer) • Reception & downlink of data from all S/C	• Direction of overall ejecta cloud vector • Ejecta dynamics & optical density • Radiometry of blast
Chaser(s)	• Observation of impact crater • (Long range observation of ejecta)	• Constraint on ejecta volume / crater volume

O1 (Impactor, Flyby module, Chaser(s)); O2 (Impactor, Flyby module); O3 (Impactor)



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Observation geometry of flyby

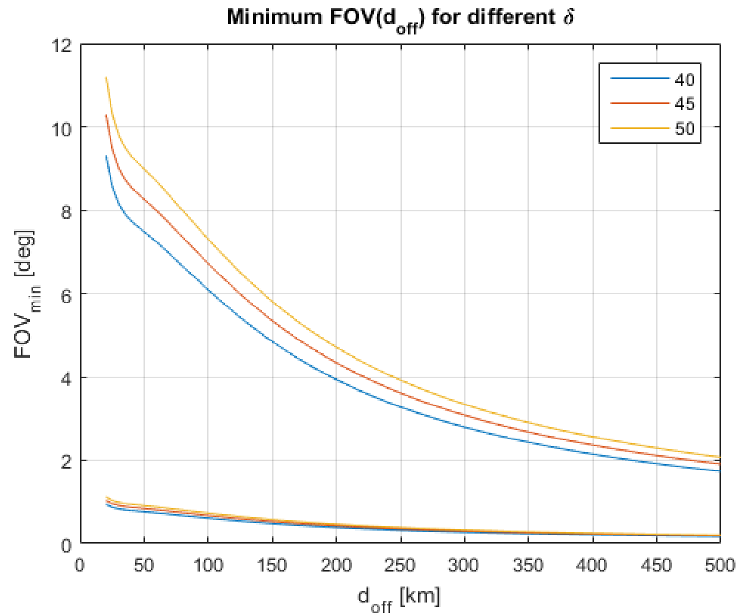
Flyby observation geometry defined by offset distance and timing of passage with respect to impact time

Constraints

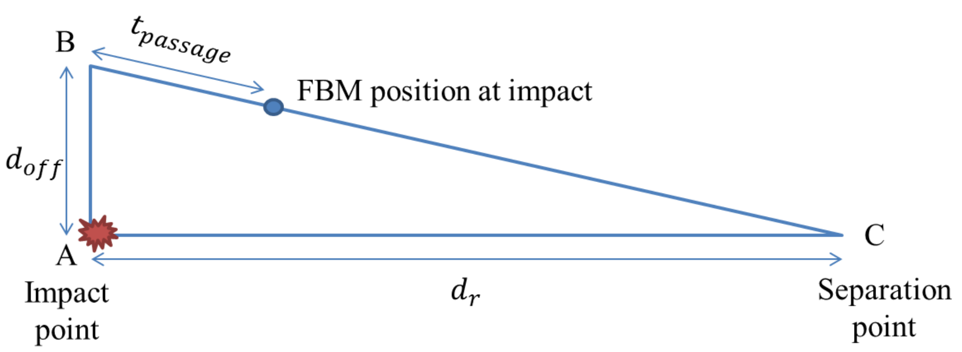
- Sensitivity of field of view to uncertainty of size of ejecta cloud
- Variation of apparent size of ejecta cloud over flyby
- Image tracking azimuth rate
- Sensitivity of observation parameters to trajectory errors
- Size of required optics

Selected parameters

- d-offset: ~70 km
- Time of closest passage @ impact + 2s
- FOV: 8.35°
- Max azimuth rate: 7deg/sec
- Pointing targets "middle" of predicted ejecta cloud (offset from Impact point)



FOV sensitivity to ejecta velocity assumptions



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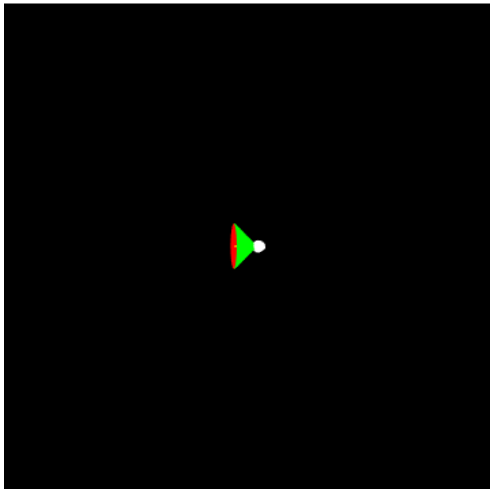
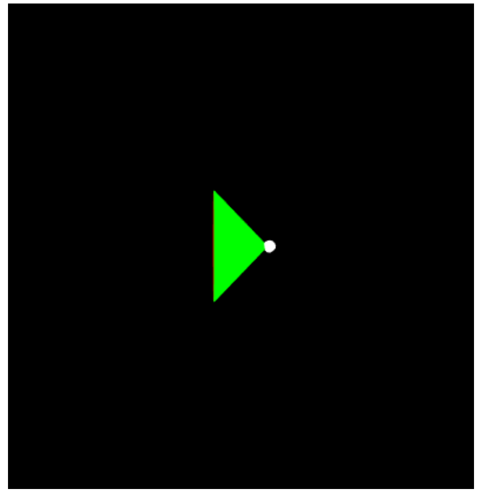
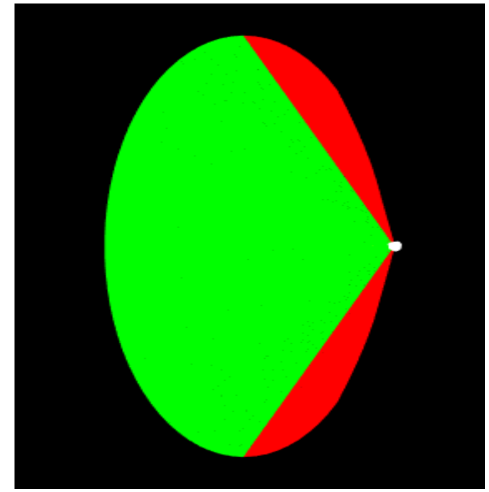
Visualisation of Flyby Observation



Impact + 0.8 s



Impact + 2 s
(Closest approach, perfect observability in one plane)

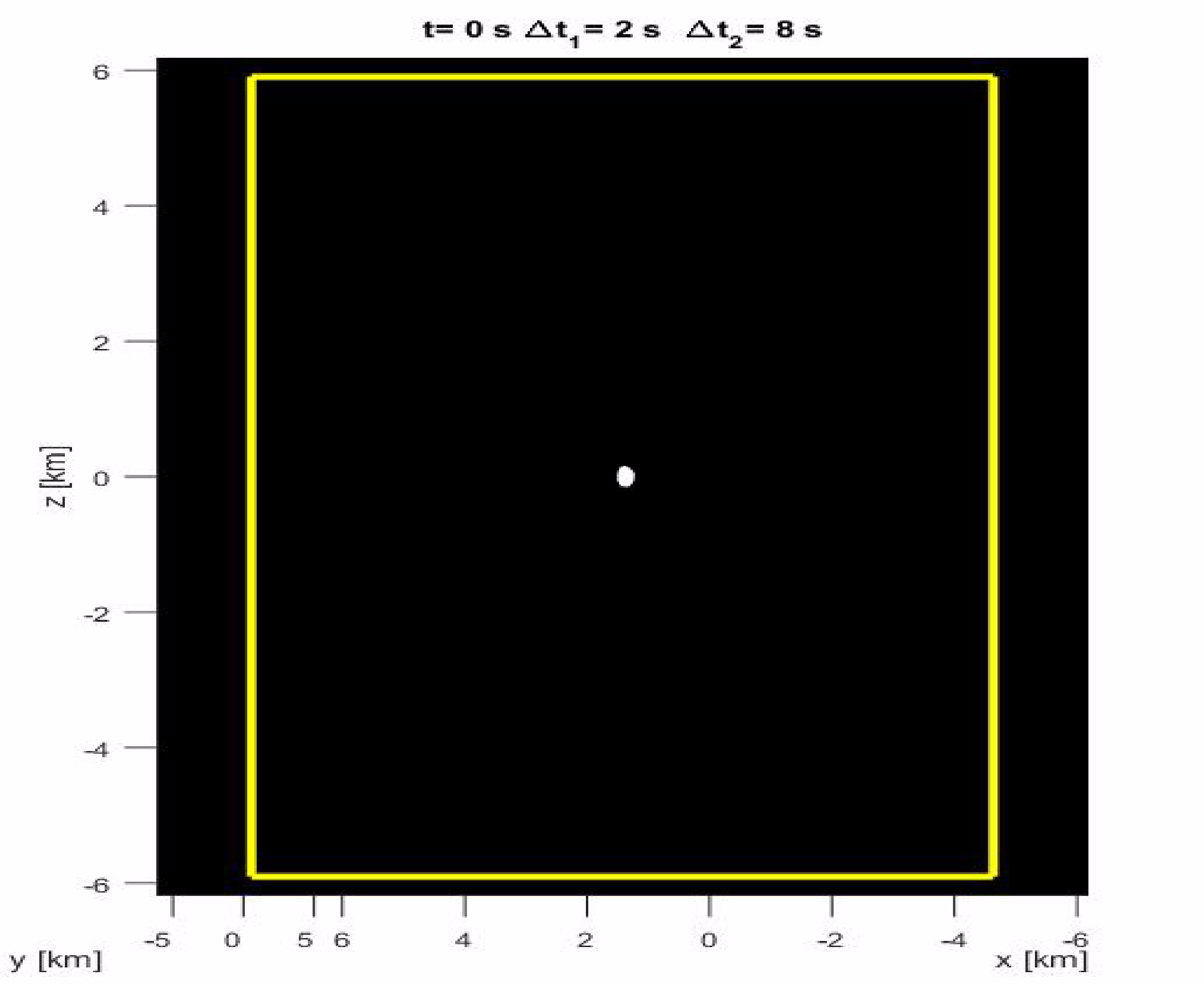


Impact + 10 s
(partial observability of second plane)

Green = Near side of ejecta cone

Red = Far side of ejecta cone

Visualisation of flyby observation



Green = Near side of ejecta cone

Red = Far side of ejecta cone

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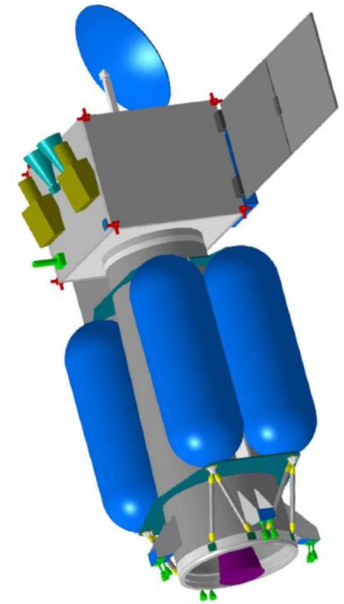
Impactor and stack overview

- Small Mission Module based on updated Don Quijote design
- Propulsion using slightly modified existing propulsion module from Lisa Pathfinder
- Propulsion module contributes to impacting mass
- Visual GNC for final approach
- Launch on VEGA



Vehicle stack mass synopsis		
	Dry [kg]	**Wet [kg]**
Fly-by Module	104.1	104.6
Chaser	25.7	26.2
Impactor Mission Module	263	263
Propulsion module (incl. resid.)	280	1420
Stack	673	**1814**
Stack at launch incl. adapter		**1929**
Delivered mass w/o prop. mod.		**394**
Min. impacting mass	**543**	

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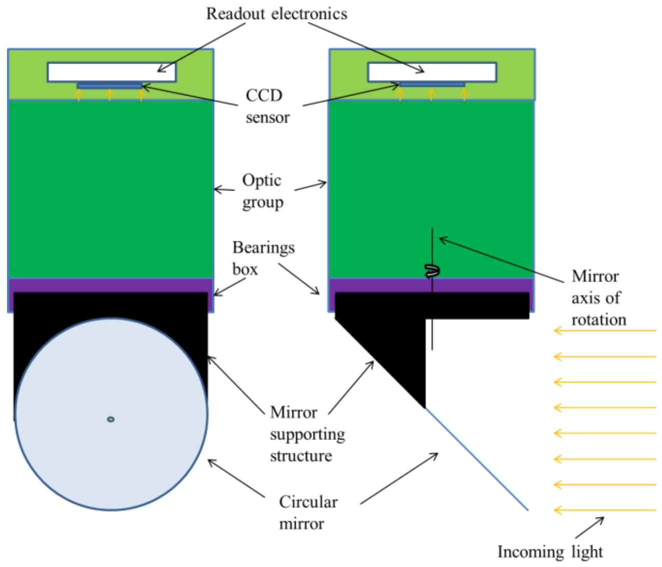
Flyby module drivers & payload

Design drivers

- High quality imaging of ejecta cloud during high velocity pass
- Imaging geometry in light of uncertainties in approach trajectory
- Data buffering & transmission for entire constellation
- Size and mass constraints imposed by mission concept
- Mission cost
- Required reliability
- Deep space environment



Payload	• Medium angle camera • Field of view: 8° • Aperture: ~ 9 cm • Detector: 2048 x 2048 pixel • Max. resolution at 70 km: 5m • Field of view pointing: pointing mirror • Image targeting based on visual navigation using payload camera • Non-imaging radiometer

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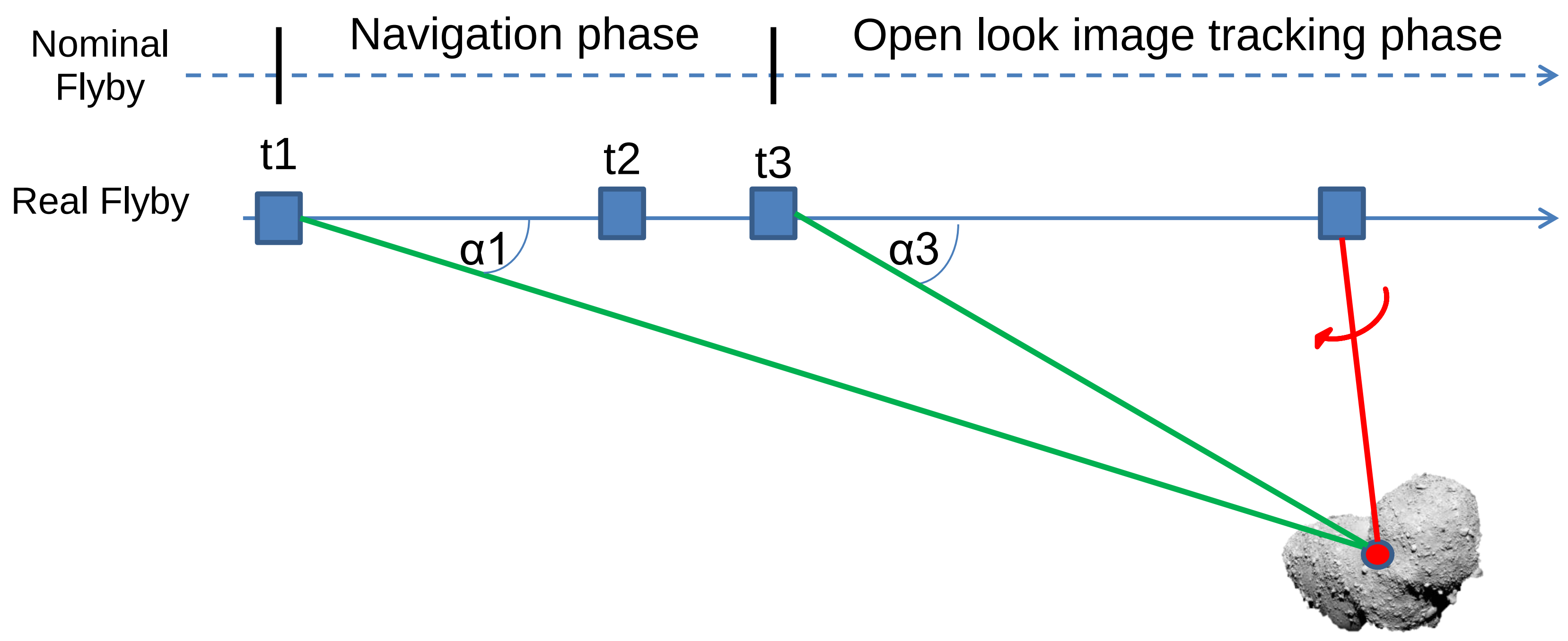
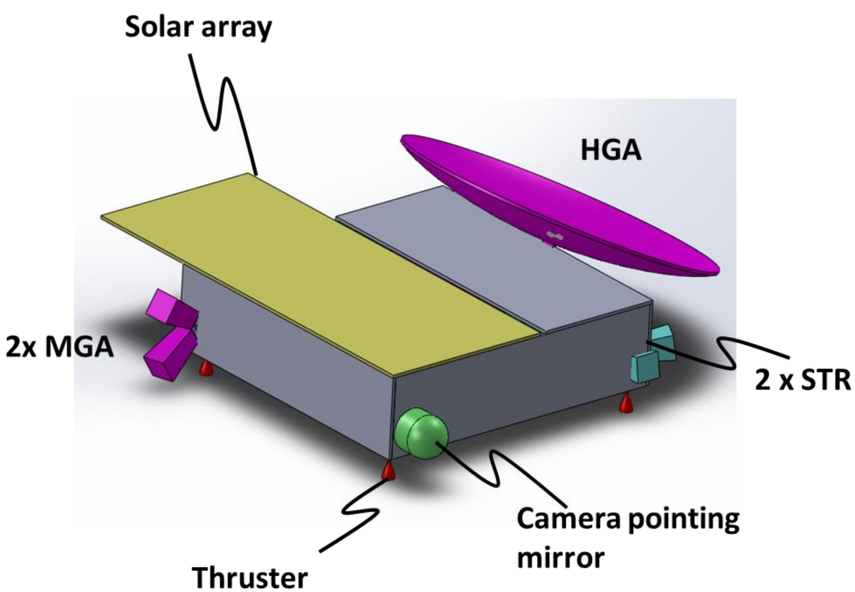
Flyby Module Navigation

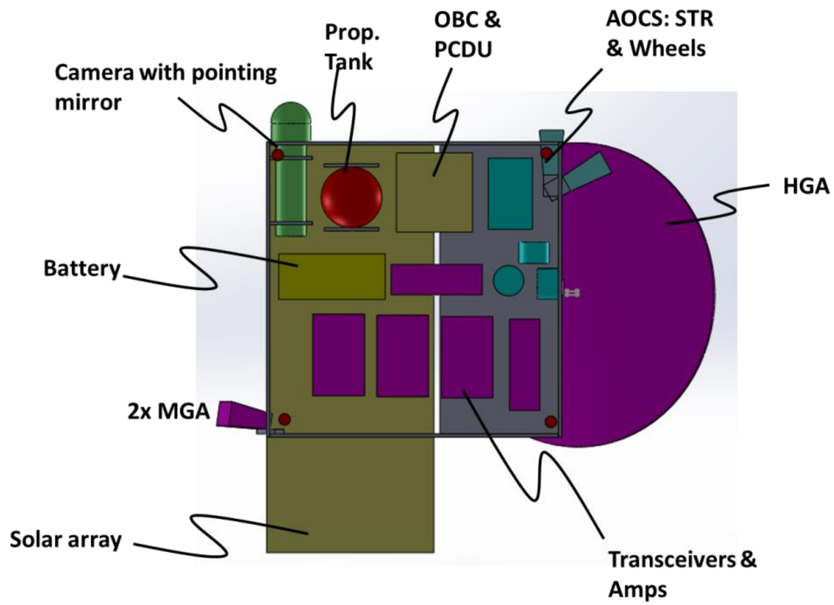
- **Challenge:** Point the FMB camera at the target accurately despite uncertainties in the flyby trajectory (mainly offset distance)
- **Sources of uncertainty:** Errors in impactor trajectory at separation; and errors in separation delta-V
- **Solution:** relative navigation during approach using payload camera



Flyby module configuraton



Overview



Equipment accommodation

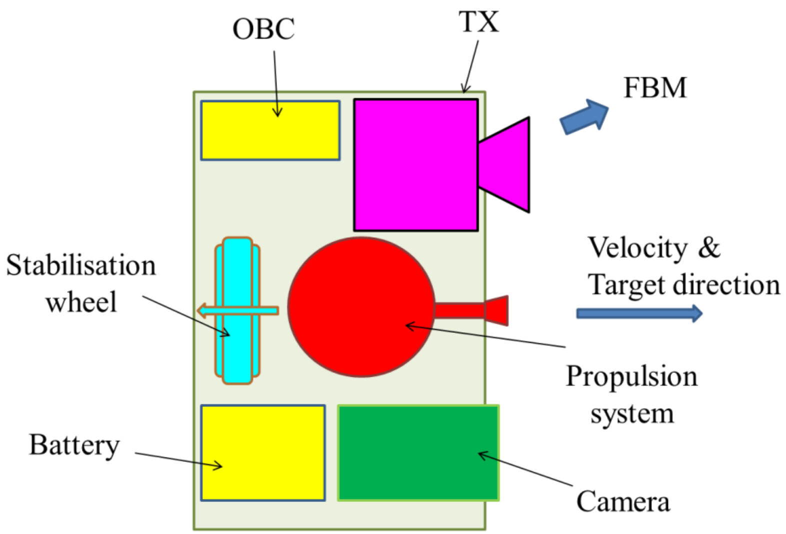
Flyby module preliminary specs

Item	Description
Mass	Dry/ Wet: 104.1 / 104.6 kg
Power	DC: 100 W S/A : 0.75 m^2 Battery: 150 Wh (usable)
Dimensions	Bus structure: 100 x 100 x 25 cm^3
Power and data handling	PROBA-NEXT avionics integrated power and data handling, >1 Gbit mass memory
Comms.	Earth-link: X-band, 1m HGA, 20 W RF, 50 kb/s Impactor link: X-band, MGA, Rx only, < 10 Mbit/s Chaser link: X-band, MGA, Rx only, ~ 20 Mbit/s
AOCS	3-axis stabilised 2 x STR (DTU Micro ASC) 2x Coarse sun sensors 3 x Micro-wheels, 0.42 Nms (e.g. SSTL) IMU (DTU, int. with STR electronics) RCS: 4 x cold gas thrusters for momentum management (0.5 kg of N_2)

Chaser concept

Design drivers

- Small size of main target (crater)
- Uncertainty in imaging geometry
- Real-time transmission of imaging data before vehicle destruction
- Large delta-V for separation from Impactor
- Mission cost and mass constraints
- Deep space environment



Chaser concept

Item	Description
Mass	Dry/Wet: 25.7 / 26.2 kg
Power	DC: 40 W Battery: 60 Wh (usable)
Dimensions	20 x 30 x 10 cm^3 (TBC)
Payload	Medium angle camera Field of view: 16° Aperture: still to be determined Detector: 2048 x 2048 pixel Max. resolution: 4m @ 30 km, 2m @ 15 km No active target tracking
Power & data	Cube-sat/ small sat equipment (details still to be selected)
Comms.	Link to FBM: X-band, MGA, TX only, ~ 20 Mbit/s
AOCS	Stabilization along velocity direction with single uncontrolled momentum wheel, spun up before ejection from Impactor
Propulsion	Hydrazine, single thruster in anti-velocity direction, stabilization with momentum wheel, dV capability 70 m/s
Thermal	Heaters & radiators, non-stationary design for terminal phase possible

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Concluding remarks

NEOTωIST Mission Concept addresses objectives of Kinetic Impactor Demo Mission at reduced cost and with flexible implementation options

Advantages achieved by

- New measurement principle for quantifying the achieved momentum transfer to target
- Replacing large rendezvousing reconnaissance spacecraft with small sub-spacecraft

Current snapshot of feasibility work shows no show stopper

Future work & iterations on

- Refinement of the payload
- Refinement of combined AOCS image targeting concept
- Equipment selection and overall vehicle design
- Refinement of communications and data management

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Thank you for your attention!

Questions?

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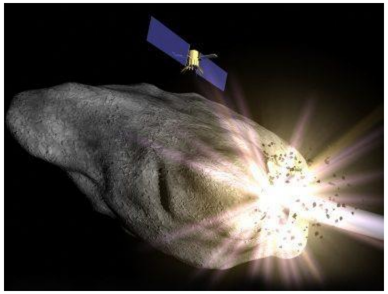
Backup: Demonstration mission objectives

#	Objective	Derived functionality
O1	**Technology demonstration Kinetic Impactor**	Impact target NEO with a spacecraft in hypervelocity regime with sufficient accuracy
O2	**Technology demonstration of an observer spacecraft for impact verification**	Demonstrate observation, from a flyby vehicle, of the impact event with sufficient quality to verify that the impact took place as required for deflection
O3	**Deflection validation**	Measure target NEO orbit or rotation before and after impact to prove transfer of (angular) momentum.
O4	**β determination / quantification of momentum transfer augmentation from ejecta**	Quantify the magnitude of momentum carried by the ejecta
O5	**Observational data to validate/ improve impact modelling**	Measurement of the dynamics and effects of the impact event

Note on β:



Augmentation of imparted momentum caused by ejecta

$$\beta = \frac{p_{KI} + p_{Ej}}{p_{KI}}$$

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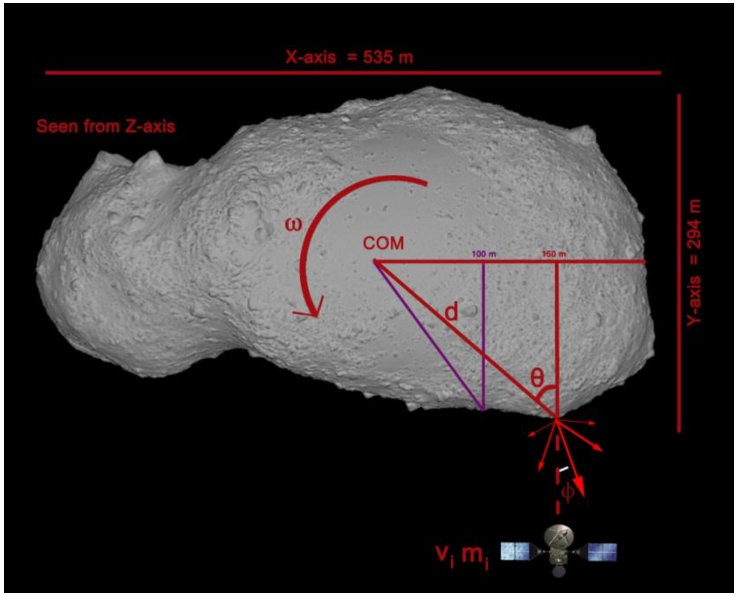
Backup: Measurement principles



Itokawa target with impact geometry

(O4) β Quantification = Determination of magnitude of ejecta momentum vector (O4)

- Spacecraft strikes target NEO off-center inducing spin rate change
- **Spin rate change** determined by ground-based observation of brightness curves
- **Geometry of impact and ejecta** determined from a-priory knowledge and spacecraft observations
- **NEO mass properties and targeting information** available from previous characterisation (by Hayabusa)

Combination of these parameters allows reconstruction of ejecta momentum vector reconstruction.

(O5) Impact phenomenon observation also achieved by observations by spacecraft

(O1, O2, O3) Technology demonstration & deflection validation achieved implicitly by above observation

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