Miniaturised Asteroid Remote Geophysical Observer (M-ARGO): A stand-alone deep space CubeSat system for low-cost science and exploration missions

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IPPW Small Sat Short Course, Boulder, CO, USA, 10th of June 2018

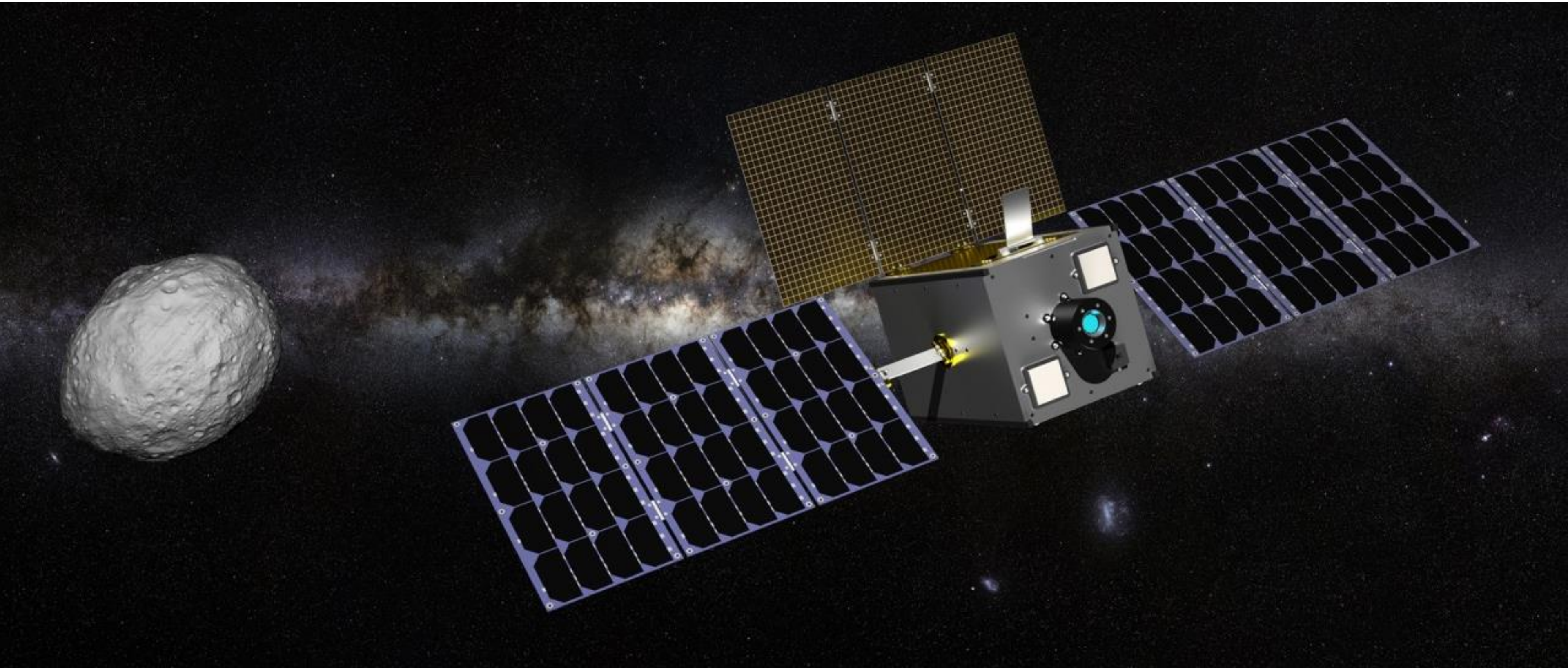
Miniaturised – Asteroid Remote Geophysical Observer (M-ARGO) Mission Concept

- Mission objectives:
  - rendezvous with an asteroid
  - characterise the physical properties of asteroid (shape, surface, mass)
  - assess potential for resource exploitation (composition, hydration)
- Mission phases:
  - piggyback launch on Sun-Earth L2 transfer (astronomy mission)
  - parking in Sun-Earth L2 halo orbit
  - interplanetary transfer using low-thrust solar electric propulsion
  - close proximity operations for 6 months of remote sensing
- Ground segment:
  - 15/35 m ESA ESTRACK stations + Sardinia Radio Telescope (64 m)
  - Mission Operations Centre with flight dynamics, Science Ops Centre
- Programmatics:
  - Budget (1st mission incl. NRE): <25 MEuro ROM
  - Schedule: launch 2021

M-ARGO System Overview

Attribute	Specification	
S/C volume	• 12U form factor (226x226x340 mm)	
Payload volume	• 1U available	
Propulsion	• µRIT Gridded Ion Engine, gimbal, PPU, neutraliser • 2 Xenon propellant tanks & feed system (Max. 2.8 kg)	
Communications	• X-band DS transponder with ranging/doppler (2 Rx, 3 Tx channels) • 4x patch antennas for omni-directional TT&C • Deployable HGA reflect-array for P/L data	
Power	• Single body mounted panel (6U face) + Li-ion battery • 2-wing deployable solar array with solar array drive mechanism (SADM)	
Power to EP @ 1 AU	93 W (6 panels)	120 W (8 panels)
Thrust @ 1 AU	1.7 mN	2.4 mN
Isp @ 1 AU	3050 s	3180 s
S/C wet mass (w/ margins)	21.6 kg	22.3 kg
AOCS	• Sensors: visnav camera, star tracker, 6 sun sensors, IMU • Actuators: 3 reaction wheels, 8 Xe cold gas RCS thrusters	
Data handling	• Modular avionics with payload data processing	
Thermal control	• Passive with radiators & heaters	

M-ARGO Spacecraft Configuration



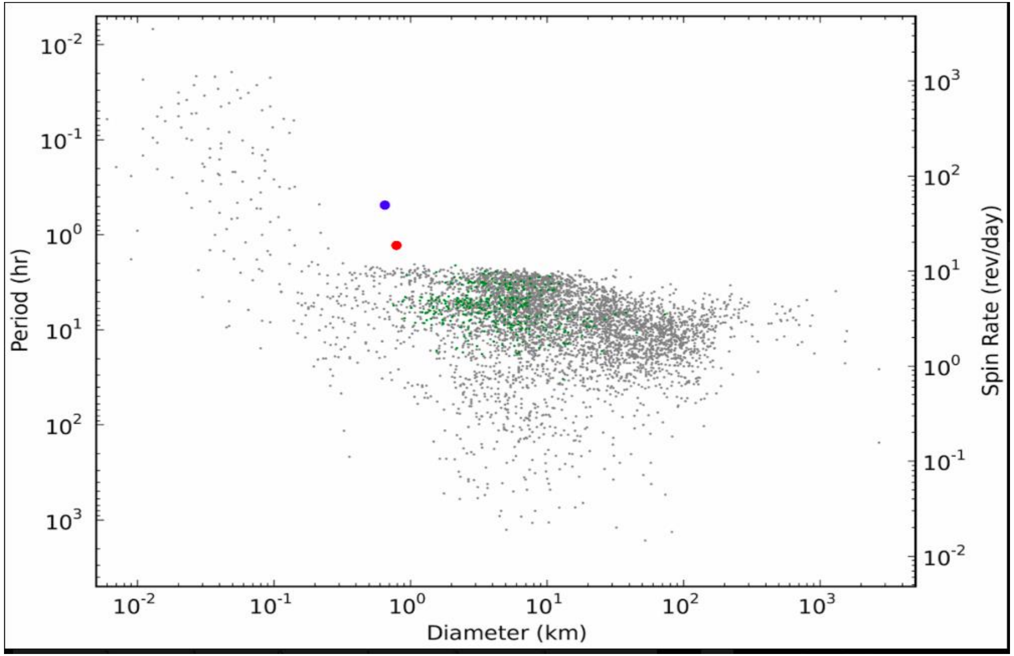
Science rationale

- All asteroids visited so far are >300 m in size

- For asteroids with a size <100 m, models predict a compact monolithic body which has no regolith and is fast spinning

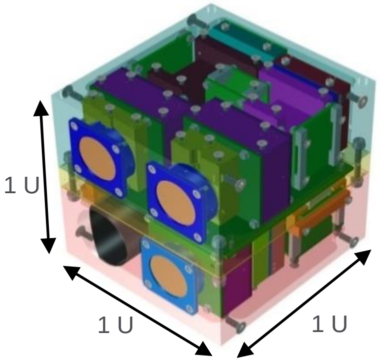
-> New science!

Other mission scenarios were also considered.



Multi-Spectral Imager

ASPECT Multi-spectral imager (VTT, Finland)	VIS channel 500 – 900 nm	NIR channel 900 – 1600 nm	SWIR channel 1600 – 2500 nm
Field of View [deg]	6° x 6°	5.3° x 5.3°	5° circular
Spectral res. [nm]	< 20 nm	< 50 nm	< 25 nm
Spectral bands (tunable in flight)	~ 14	~ 24	~ 30
Image size [pixels]	614 x 614	256 x 256	1 pixel
Pixel size (um)	5.5	30	1000
Focal length (mm)	32.3	81.5	11.7
F/#	3.3	5.04	0.9
GSD at 500 m	9 cm	18 cm	44 m
SNR at phase angle <20°	>40 (t_{int} = 50 ms) at 500-800nm	>40 (t_{int} = 15 ms) at 900-1500nm	>100 (t_{int} = 10 ms) at 1600-2500nm



Mass: 950g

Power: 7 W

TRL 6, Aalto-1 heritage (space qualified)

LASER Altimeter

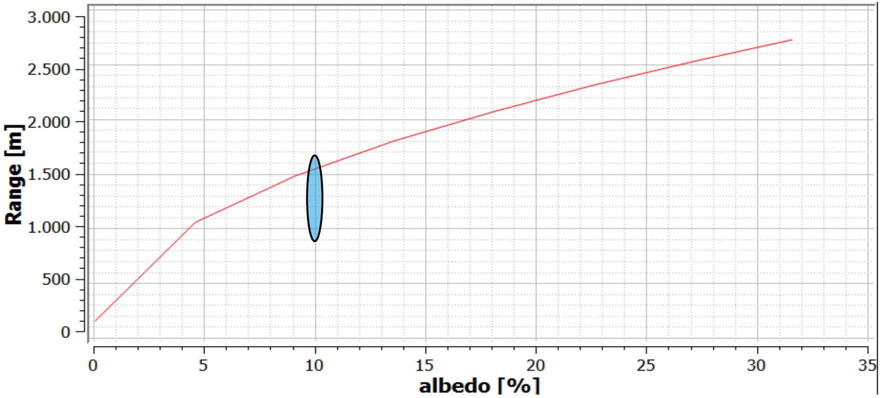
DLEM 20 (Jenoptik, Germany):

- Up to 5 km measurement range
- Measurement accuracy 0.5-1 mm
- Mass < 33g
- Dimensions: 50 mm x 22 mm x 34 mm
- Power on < 1.8 W
- Operational Temp.: -40 °C to + 80 °C
- COTS (not space qualified)

100 ms measuring time

Up to 1500 m measuring distance

(Acc. ±0.5 m up to 1000 m)



NEO Target Screening

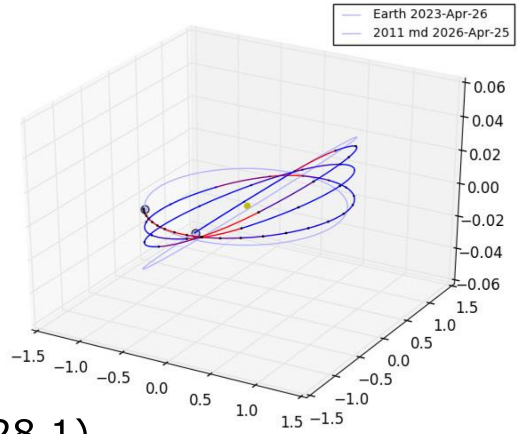
MPCORB database (23/1/2017)
725,896 objects

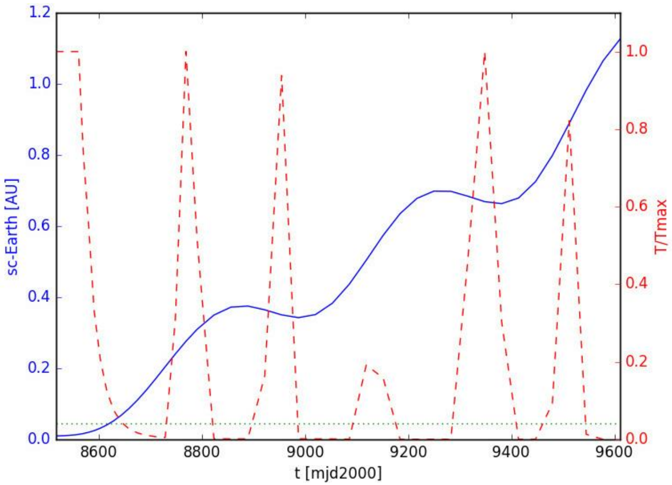
Pre-filtering
(3-impulse chemical)

63 objects (<2.6 km/s, n>80, V<28.1)

Low-thrust trajectory optimisation tool

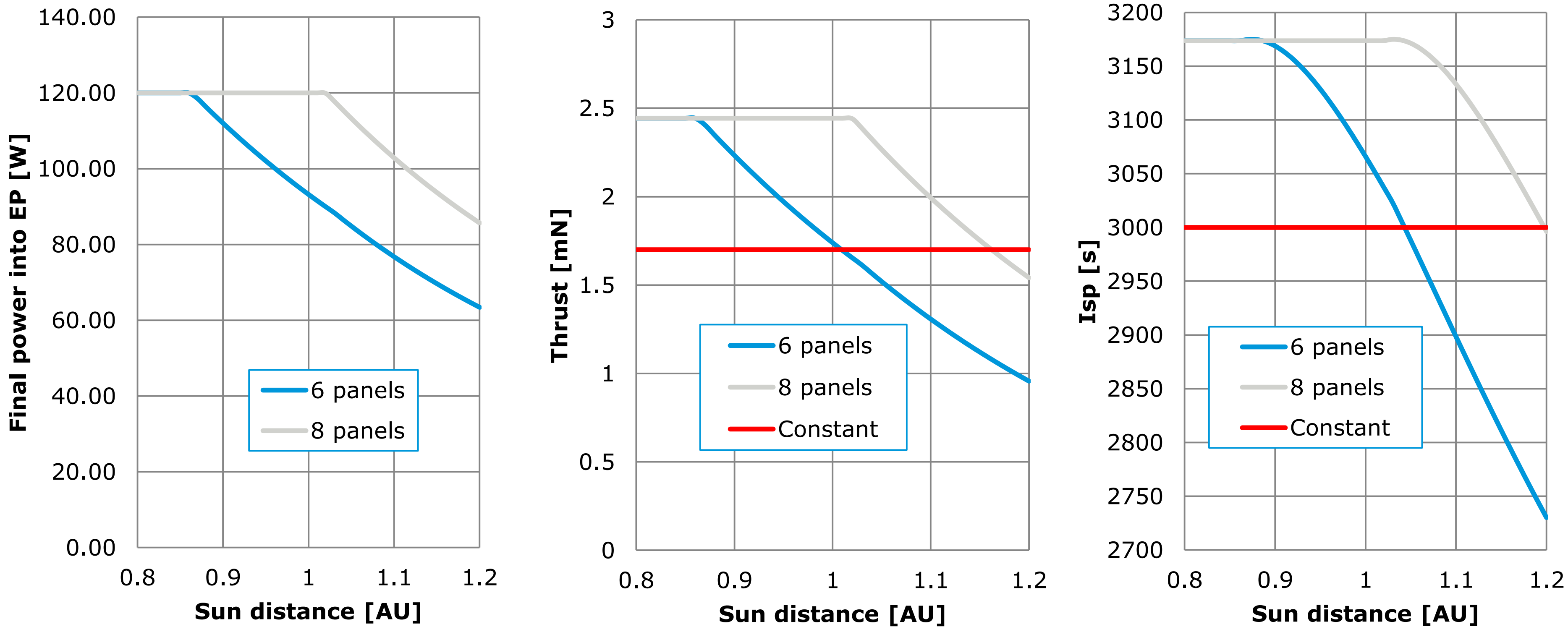
30 objects (mp <2.5 kg)





Assumptions
Starting from Earth-Sun L2 with no initial C3
Spacecraft initial mass 20 kg
Maximum thrust of 1.7 mN, specific impulse of 3000 s
Launch window: between 2020 and 2023 (included)
Maximum time of flight: 3 years
Maximum propellant mass: 2.5 kg

Sun Beam to Ion Beam Optimisation



Mission Analysis of Potential Targets

Designation	a [AU]	r_a [AU]	r_p [AU]	e	i [°]	H	ΔV [km/s]	m_P [kg]
2012 UV136	1.008	1.148	0.868	0.14	2.21	25.5	3.17	2.2
2014 EK24	1.006	1.077	0.935	0.07	**4.81**	23.3	3.92	2.50
1996 XB27	1.189	1.258	1.120	0.06	2.47	21.7	3.62	2.32
YORP	1.006	1.238	0.775	0.23	1.60	22.7	6.74	4.10
2013 BS45	0.992	1.075	0.909	0.08	0.77	25.9	1.88	1.31
2016 FU12	1.003	1.170	0.836	0.17	2.06	26.9	2.7	1.88
2011 MD	1.056	1.095	1.017	0.04	2.45	28.0	3.19	2.17

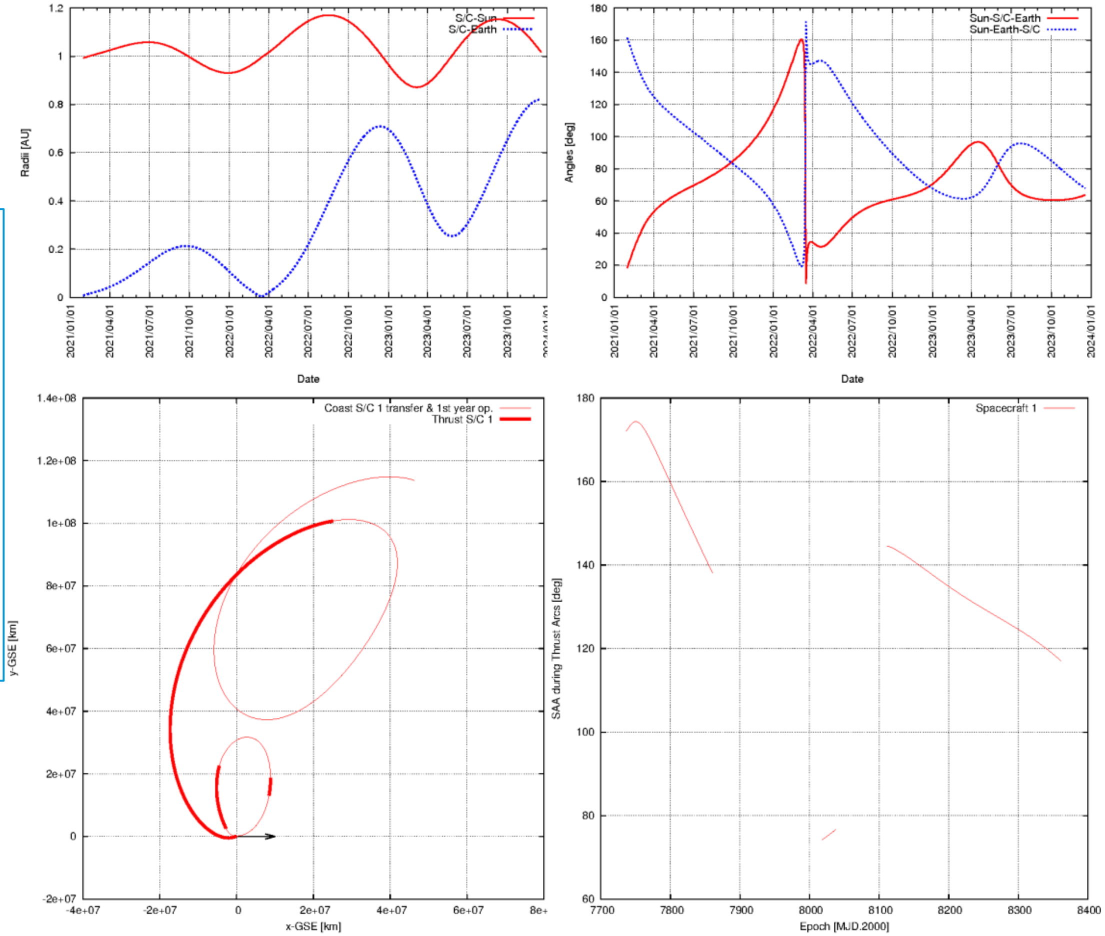
YORP: orbital elements seem promising but from 2020 on, YORP is getting away from the Earth.

2014 EK24: all orbital elements are in the good ranges but inclination is too high

1996 XB27: at rendezvous the range to Earth is too large for communication

Mission Analysis

- Variable thrust & Isp vs. sun distance
- 8 panels option
- Delta-v: 3.17 km/s
- Xe mass: 2.2 kg
- Thrust-on: 395 d
- Sun distance <1.2 AU
- Earth range: <0.8 AU
- SAA during thrust-on phases 75-175 deg



2012 UV136

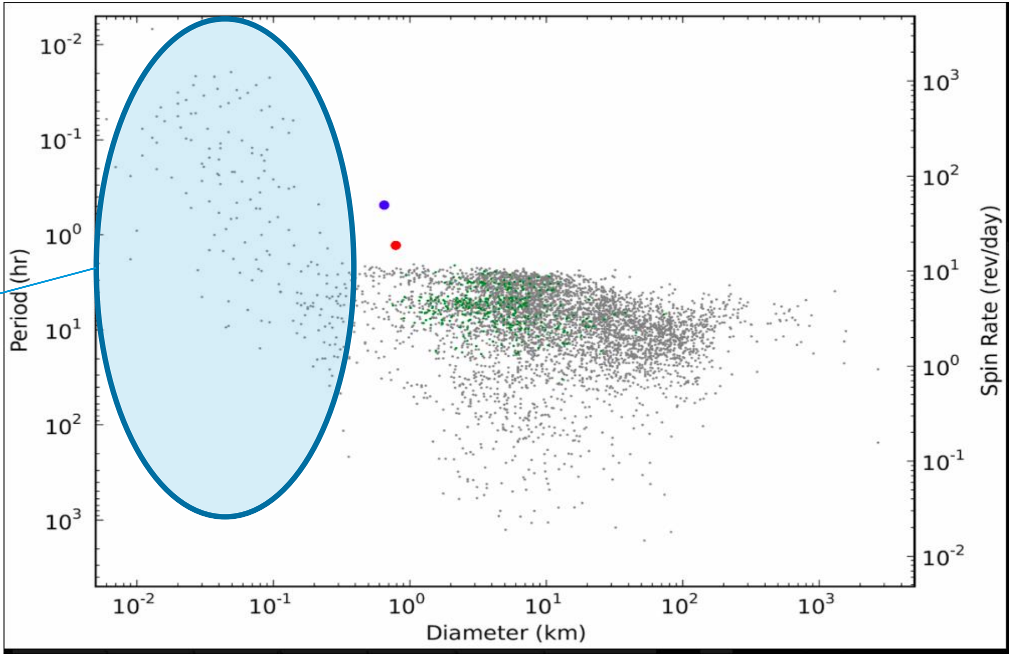
Science rationale and asteroid assessment

- All asteroids visited
  so far are >300 m in size

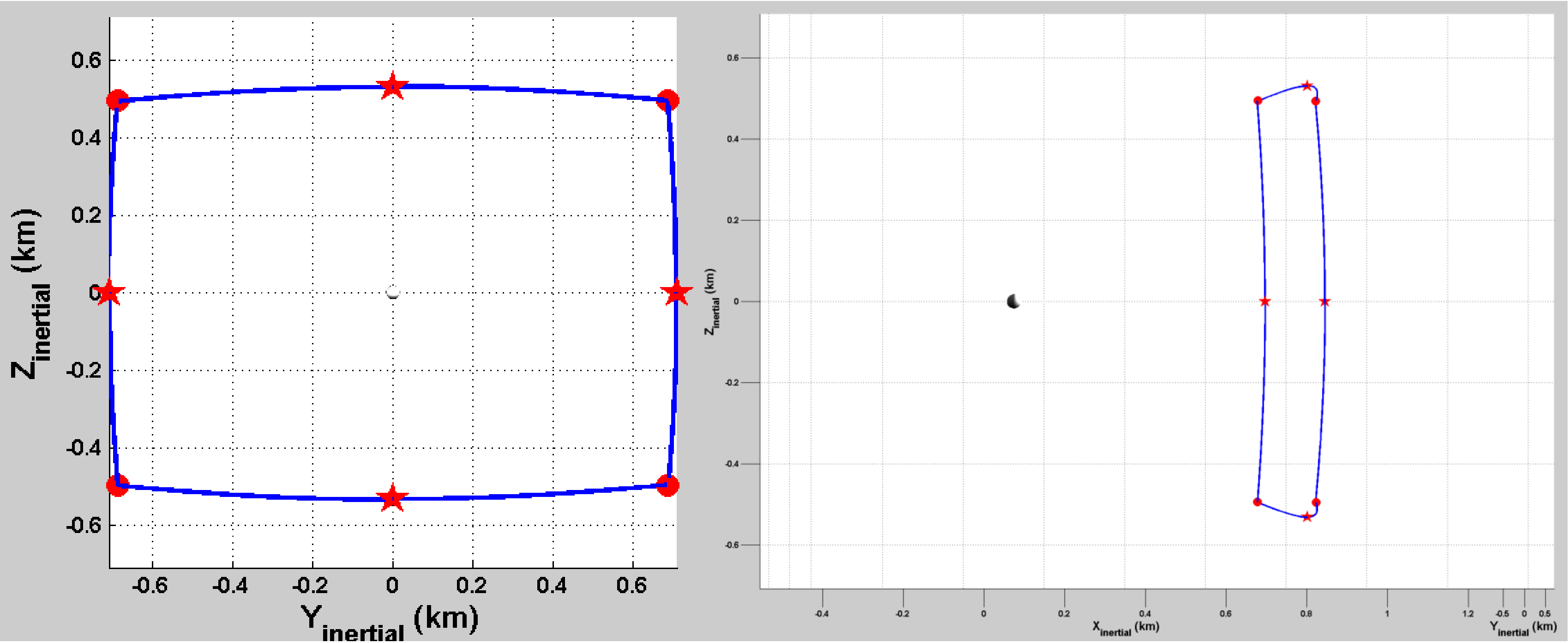
- All 4 accessible targets are <50 m

- For this size, models predict a compact monolithic body which has no regolith and is fast spinning

-> New science!

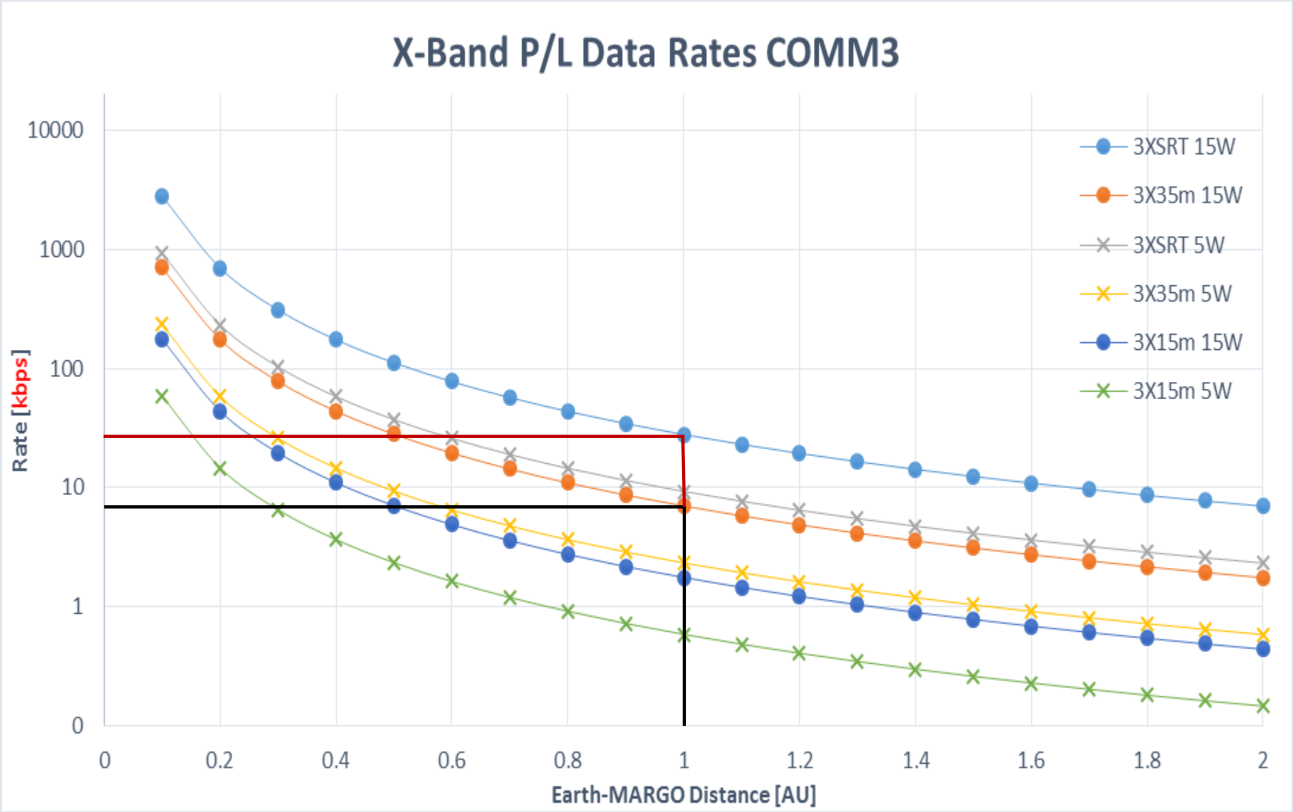


Close Proximity Operations



Target 2012 UV136, 7 day repeat cycle

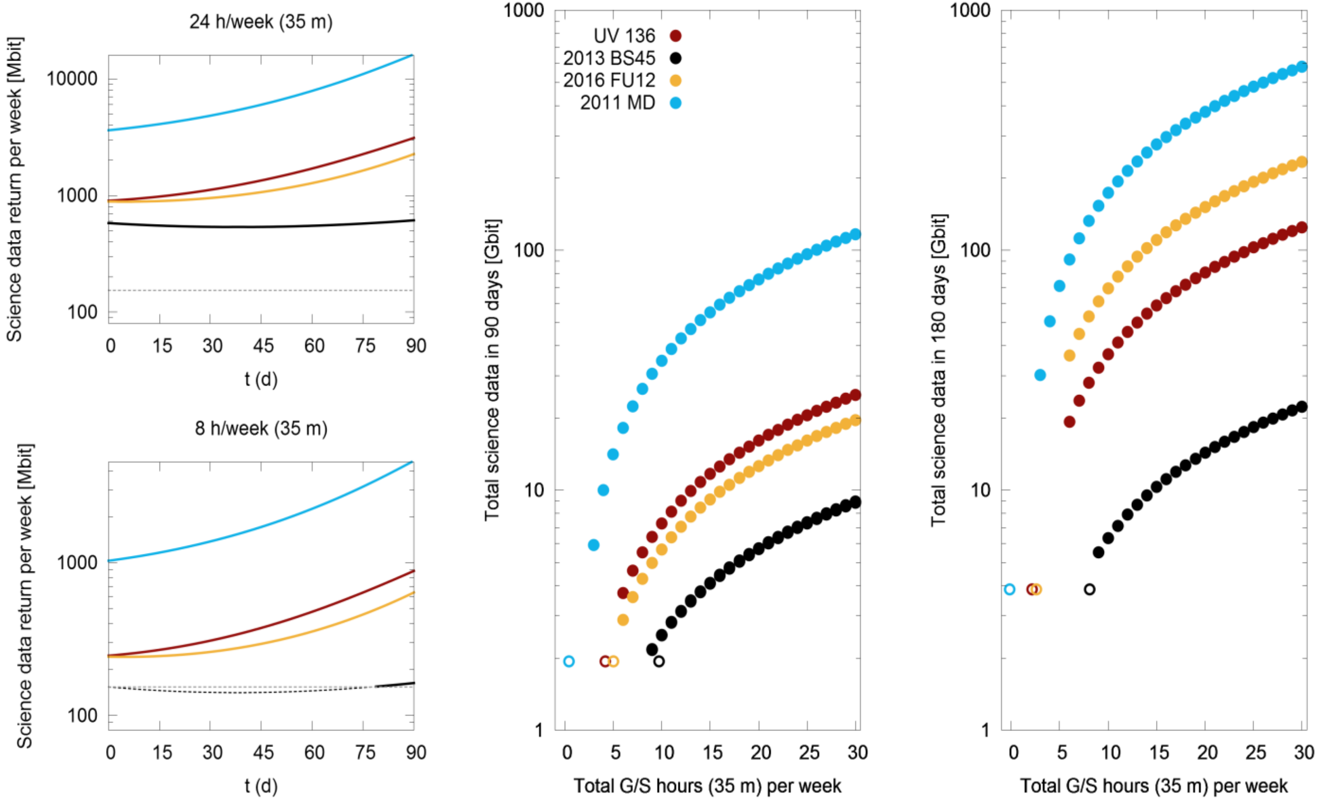
Communications



25 kbps @ 1 AU
15 W RF power
64 m Sardinia

7 kbps @ 1 AU
15 W RF power
35 m ESTRACK

Science Data Return



Thermal Design

Thermal design Drivers:

- Distance from Sun, spacecraft attitude, dissipation modes (EPROP, COM, Science), Sensitive Equipment

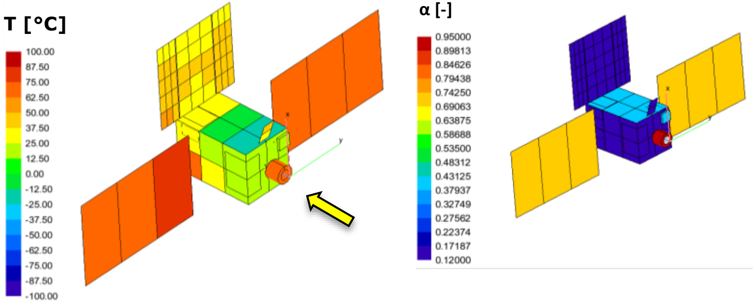
Thermal Control:

- Passive thermal design plus heaters
- Kapton foil thermal straps (increase TRL for miniaturized thermal straps)
- Heaters, thermistors, optical coatings,
- 44 W - maximum required heater power

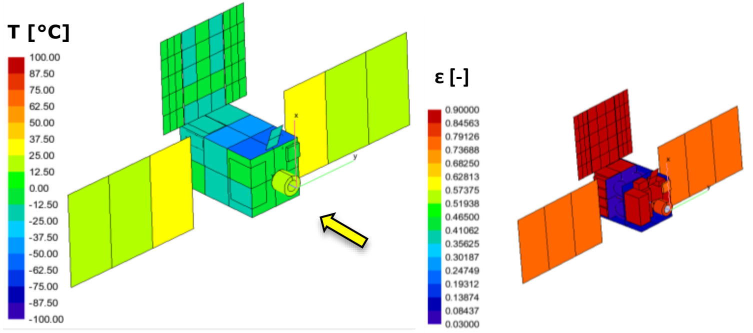
Option: deployable radiators

- Free structural area for other equipment
- Reduce heater power in cold modes

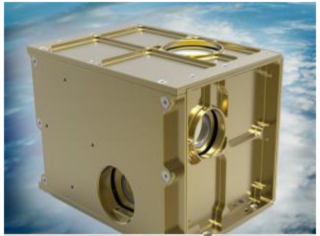
Worst Hot Case - COM



Worst Cold Case - Slew

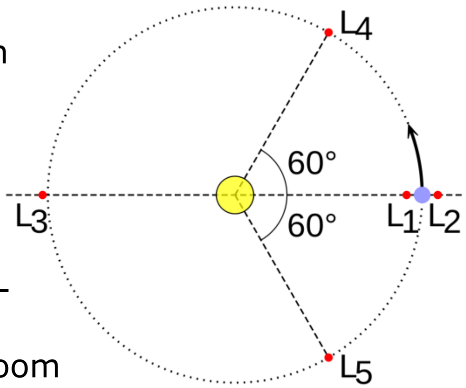


Alternative L5 Space Weather Mission

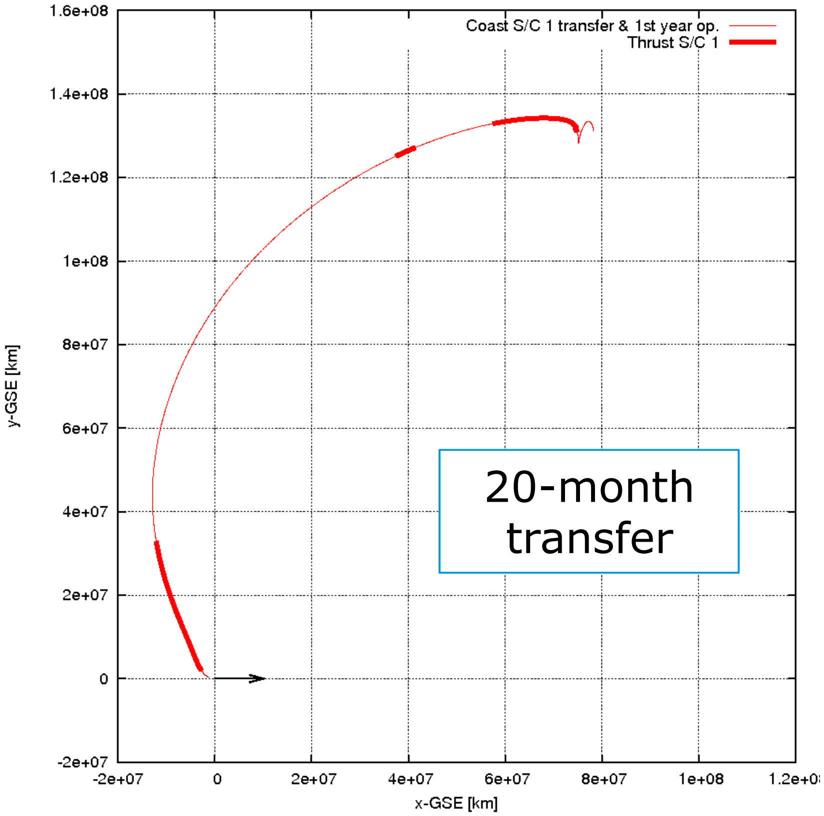


Radiation monitor

Magneto-meter + 1 m boom

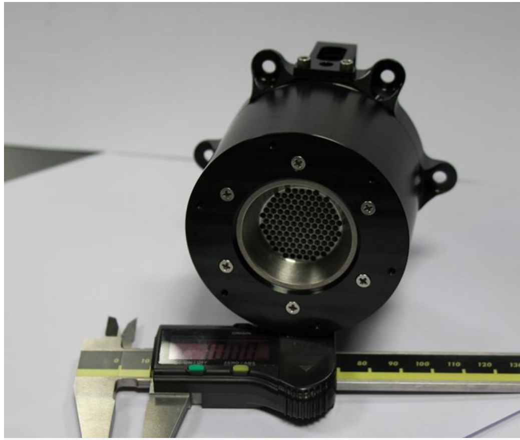


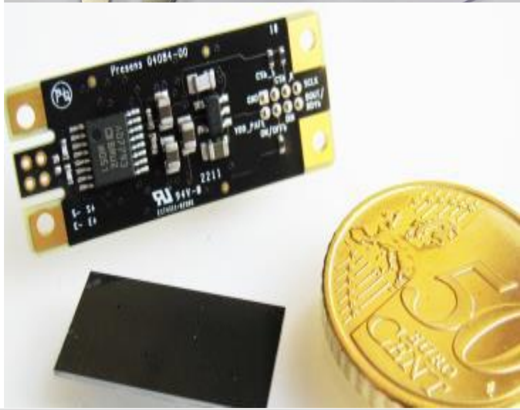
Departure date (from SEL2)	2024/2/6
Earth encounter	N/A
Asteroid arrival date	2025/9/22
Delta-V	2.62 km/s
Propellant mass (without margin)	1.70 kg
Thrust-on time	342 days
Range of distance from Sun	0.99-1.15 AU
Range of distance from Earth	0-1.02 AU
Range of SAA value during thrust-on	80-135 deg



Stand-Alone Deep Space Cubesats

- High potential to cut the entry-level cost of space exploration by an order of magnitude
- Piggyback launch options to near Earth escape:
    - Lunar transfer/orbit, Sun-Earth L1/L2 transfer, outer planet
- 12U CubeSat with enabling miniaturised technologies:
    - high specific impulse electric propulsion system & cold gas RCS
    - deep space transponder & HGA
    - “high power” deployable steerable solar array
    - highly integrated rad-hardened avionics
- Potential missions:
    - NEO rendezvous for physical characterisation (science, resources)
    - Sun-Earth L5 for space weather (storm advance warning)
- Technology Reference Study performed in ESA Concurrent Design Facility to assess feasibility, tech developments, cost/schedule





Conclusions

- Stand-alone Deep Space CubeSats are technically feasible in the near-term
- Delta-V capability (3.75 km/s) encompasses at least 4 NEO targets for rendezvous (up to 30 as of time of study), and transfer to Sun-Earth L5 for space weather mission
- Technologies are either high TRL for CubeSat COTS products or TRL 3/4 to be developed to TRL 6 within the frame of the ESA Technology Programme (SADM, EPROP subsystem, X-band transponder & HGA)
- Radiation hardness assurance of COTS electronics components wrt destructive latch-ups needed in the project, and some delta-qualification of equipment
- Schedule to flight readiness in early 2021, launch July 2021 assuming technology developments start soon
- ROM cost is considered to be marginally feasible within 25 MEuro budget
- Major cost driver is the Flight Dynamics support cost (50% of the overall ROM cost estimate) -> lower cost approaches to be investigated
- Next steps: kick-off tech dev activities & identify piggyback launch, then start Phase A/B

Acknowledgements to ESA CDF Study Team

CUSTOMER	I. Carnelli (General Studies Programme)		
TEAM LEADER	R. Walker		
AOCS	M. Casasco J. Gil Fernandez T. Muresan	PROGRAMMATICS/ AIV	D. Hagelschuer Y. Le Deuff
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PAYLOAD/ DETECTORS	P. Corradi O. Sqalli	THERMAL	P. Hager V. Laneve T. Flecht
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THANK YOU

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Acknowledgments:
- Based on slides and input by Roger Walker and the M-ARGO CDF study team