

Overview of ESA Lunar and Interplanetary CubeSat Missions

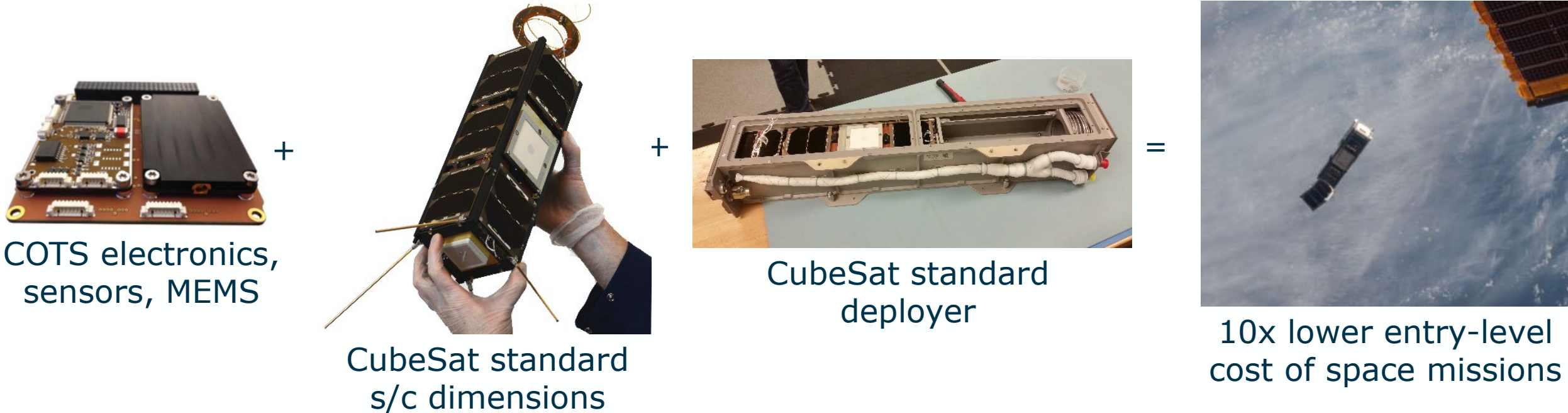
Dr. Roger Walker
Head of the CubeSat Systems Unit
Directorate of Technology, Engineering & Quality

Interplanetary Small Satellite Conference
California Institute Of Technology
Pasadena CA, USA

2 May 2023

The CubeSat story so far...

Low Earth Orbit: more than 2000 launched, almost all in last decade



First ever interplanetary CubeSats successful (MarCO flyby of Mars 2018)

First ever lunar CubeSats successful (CAPSTONE, Artemis-1 CubeSats 2022)

First ever NEO CubeSat successful (LICIACube flyby of Dimorphos 2022)

Beyond LEO Mission Scenario Assessment



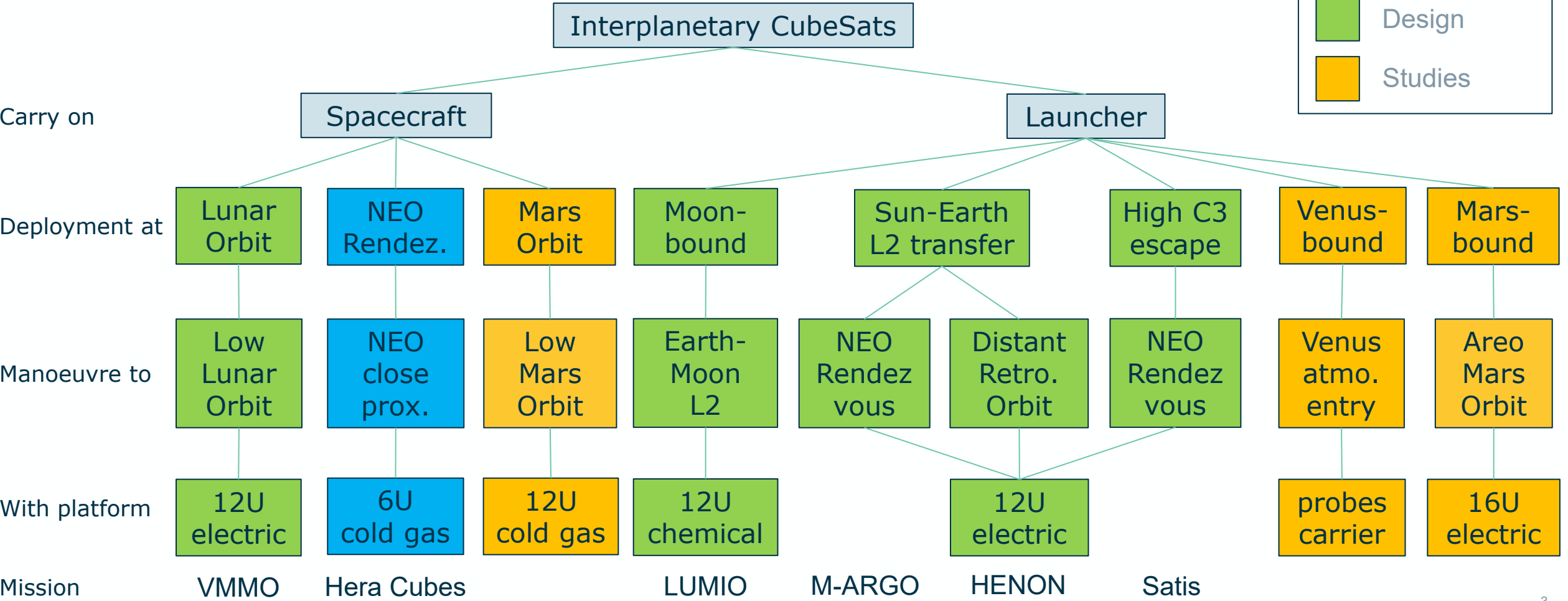
How far can this new paradigm be extended from LEO out to lunar and deep space?

What unique new missions can be performed?

Development

Design

Studies

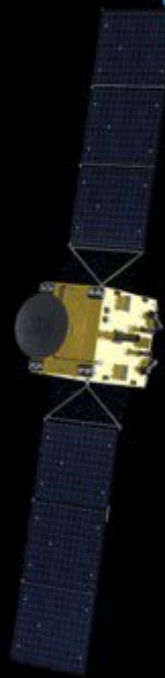


Piggyback missions

CubeSats as an integral part of larger missions



08/10-2024
HERA LAUNCH



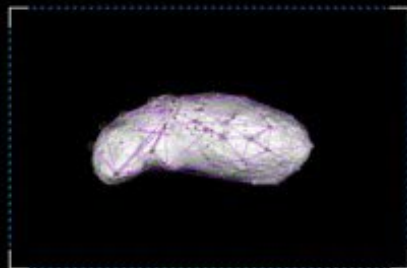
2.3 YEARS CRUISE

2 x Asteroid Framing Cameras
2 x 6U CubeSats
Laser Altimeter
Thermal Infrared Camera (JAXA)
Hyperspectral Imager

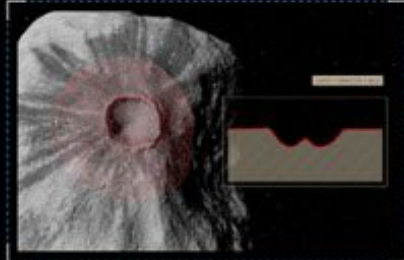
28/12-2026
ASTEROID ARRIVAL



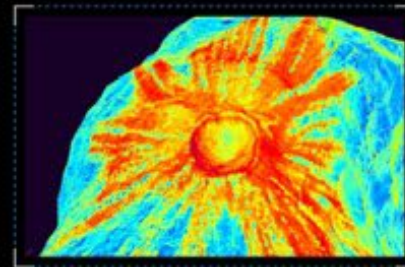
AUTONOMOUS PROXIMITY
OPERATIONS DEMONSTRATION



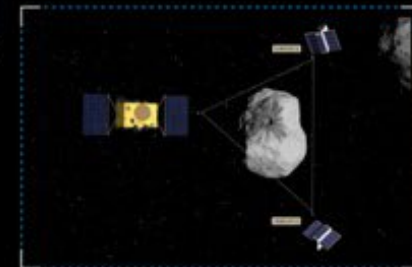
DETAILED CRATER
SHAPE INVESTIGATION



DETAILED SUBSURFACE
CRATER INVESTIGATION



MULTI-POINT ASTEROID INVESTIGATION
low-frequency radar, multispectral imager,
dust detector, gravimeter.

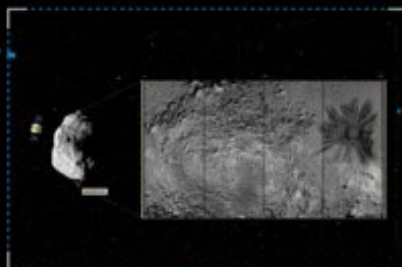


LANDING ON DIDYMOS
MISSION ENDS

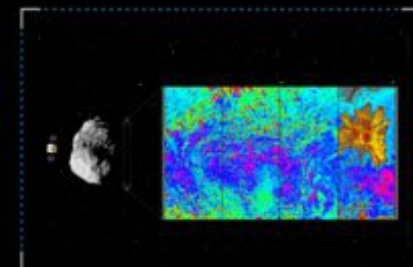
DIMORPHOS



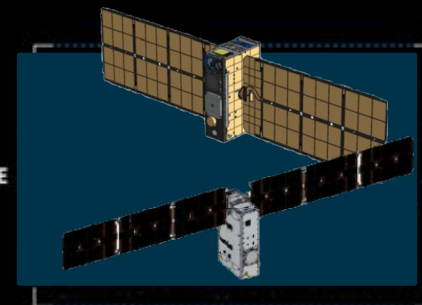
EARLY CHARACTERISATION PHASE
Measuring mass and dynamics



CUBESATS RELEASE

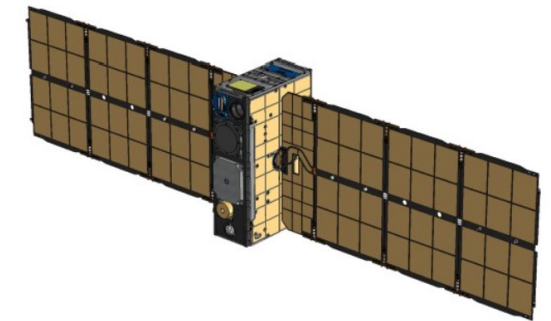
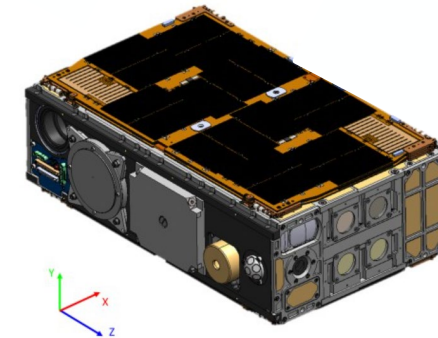
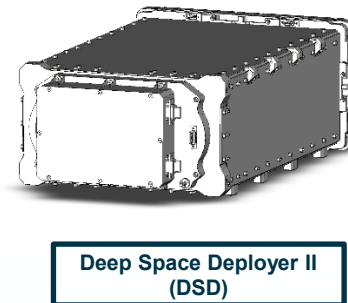
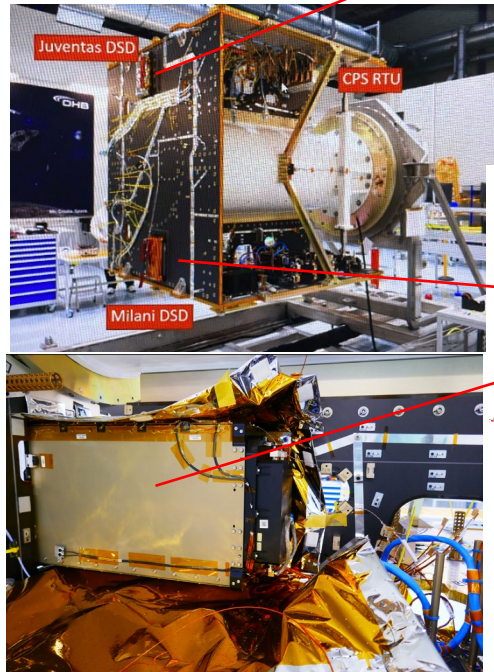
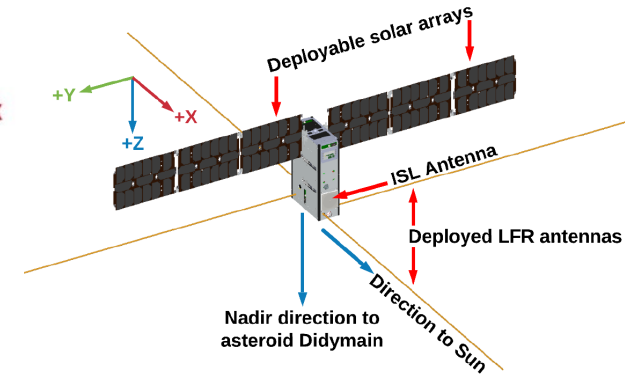
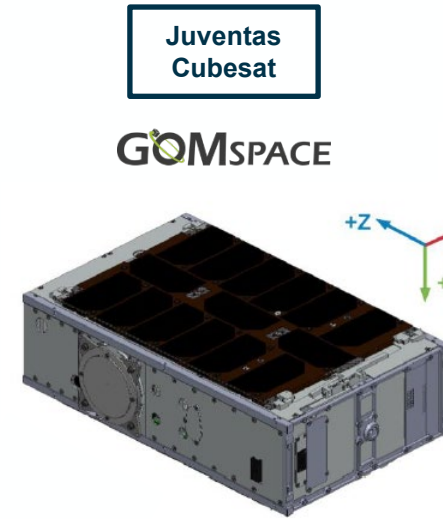
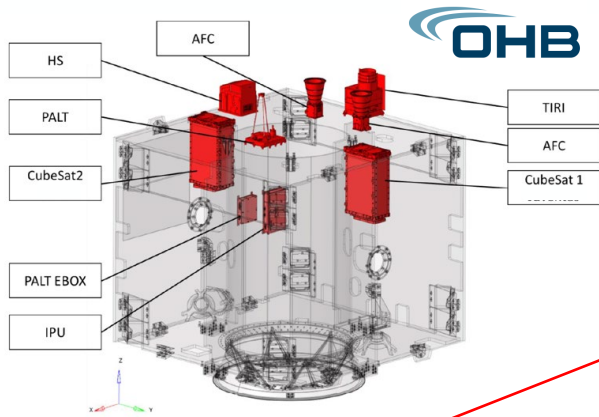


DETAILED CHARACTERISATION PHASE
Measuring surface and interior properties



Intersatellite Link

HERA Platform – Cubesats accommodation on Hera S/C



Milani Mission



ESA Contract led by Tyvak International (IT) -
POLIMI (IT), POLITO (IT), INAF (IT), CIRA (IT), VTT (FI), Uni. Helsinki (FI), KUVA (FI),
HULD (CZ), Czech Institute of Geology (CZ) and Brno University of Technology (CZ),
T4I (IT), CNES (FR)

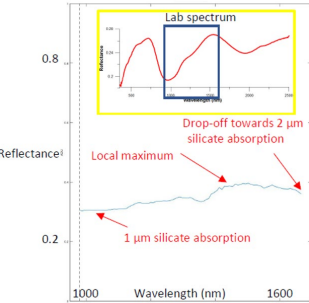
Mission funded by the Italian Space Agency (ASI)

Payloads focused on geophysical investigations:

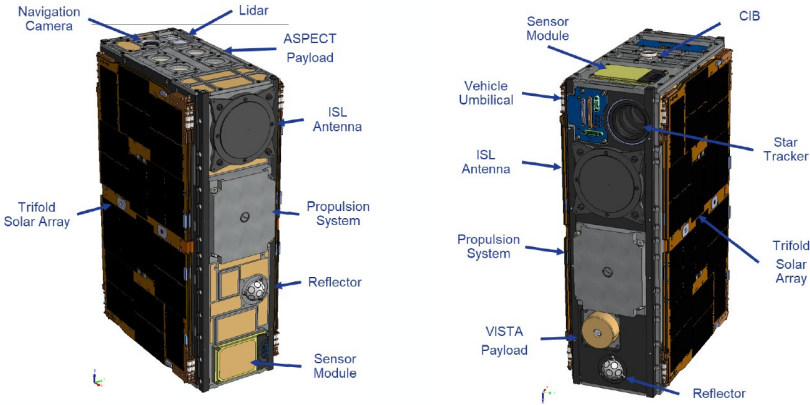
- 1. Multispectral imager (ASPECT)
- 2. Volatile In-situ Thermogravimeter Analyser (VISTA)

Scientific objectives:

- Map global composition of Didymos and Dimorphos
- Multispectral characterization of Didymos surface
- Characterize dust clouds around the system



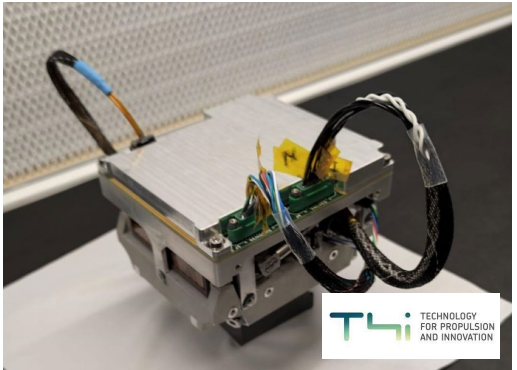
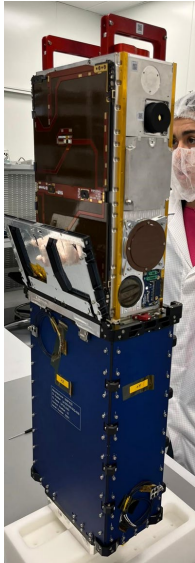
Parameter	VIS channel	NIR1 channel	NIR2 channel	SWIR channel
Field of View [deg]	10° x 10°	6.7° x 5.4°	6.7° x 5.4°	ca. 5.85° circular
Spectral range [nm]	500 – 900	850 – 1250	1200 - 1600	1650 - 2500
Image size [pixels]	1024 x 1024	640 x 512	640 x 512	1 pixel
No. spectral bands	Ca. 14	Ca. 14	Ca. 14	Ca. 30
Spectral resolution [nm]	< 20 nm	< 40 nm	< 40 nm	< 40 nm



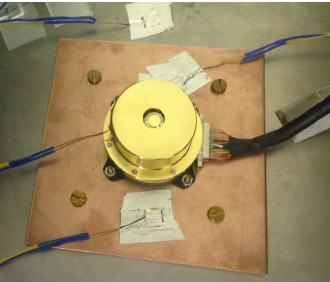
Structural Thermal Interface Model. Credits Tyvak international



EM Unit + DSD EQM



Cold Gas Propulsion System QM
Credit: T4i Italy



Vista Instrument
Flight Unit. Credit INAF



ASPECT FM Camera
Assembly. Credit VTT



Juventas Mission

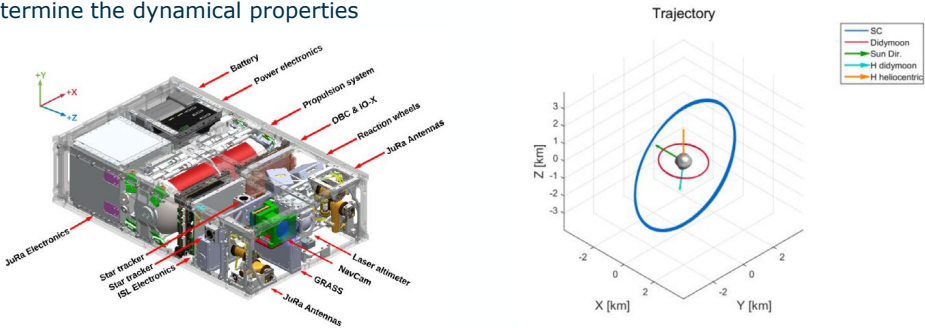


ESA Contract with GomSpace (LUX) and the following consortium
GMV(RO), Emtronix (LUX), IPAG (Institut de Planétologie et d'Astrophysique de Grenoble), Astronika(PL), Brno University(CZ), CSRC(CZ),Royal Observatory of Belgium (BE), Emxys (ES), CNES (FR)

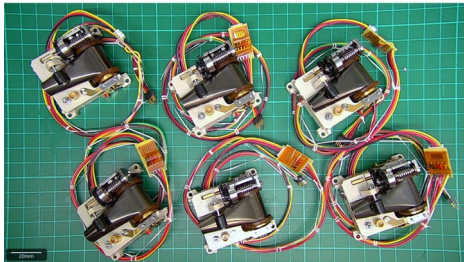
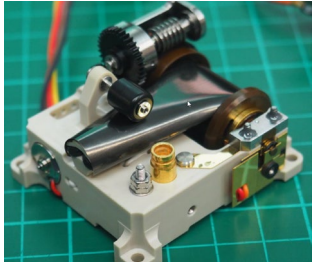
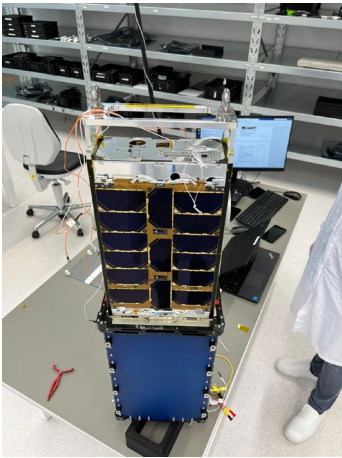
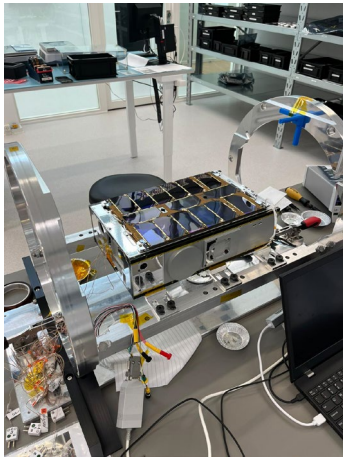
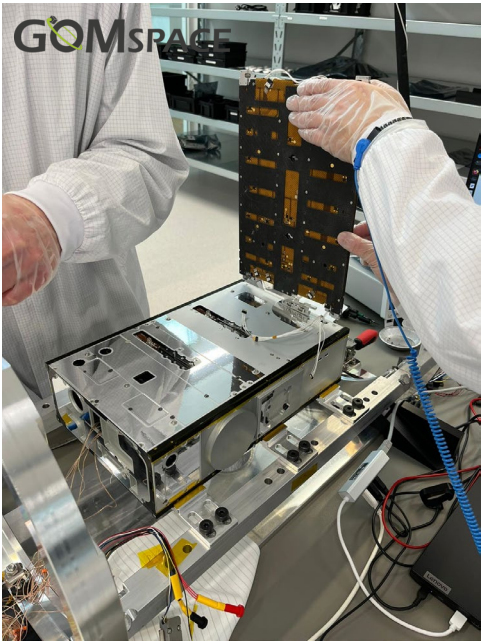
Structure	6U-XL CubeSat bus	
Solar distance	1.02 – 1.71 AU (max 2.0 AU)	
Mission lifetime	2 years cruise and 3 months nominal proximity operations,	
Launch date	October 2024	
Mass	Mass	Dry 10.4 kg , Wet Mass: 12 kg
Dimensions	Stowed	~130 x 246 x 366 mm
	Deployed	~1420 x 910 x 366 mm including arrays and antennas
Instrument	Low-frequency radar Gravimeter	
Power	Solar Array	2x deployable wings
	Bus	28V unregulated.
	Max consumption	42W-80W
Propulsion	Delta-V	10 m/s
	Thrusters	8x 1 mN thrusters
	Tanks	1x 420 g butane (5 bar MEOP)

Scientific objectives:

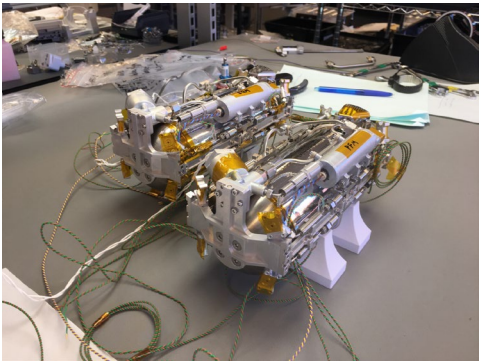
- Characterize the gravity field (Gravimeter)
- Characterize the internal structure (Low Frequency Radar)
- Determine the surface properties
- Determine the dynamical properties



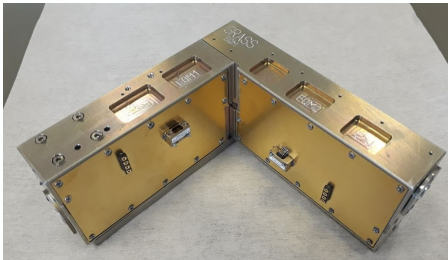
Structural Thermal Interface Model. Credits GOMSpace LUX & DK



Low Frequency Radar Antennas FM and Flight Spares. Credit: Astronika PL



Cold Gas Propulsion System QM and FM
Credit: GOMSpace SE



GRASS (Gravimeter Instrument)
Flight Unit. Credit: ROB



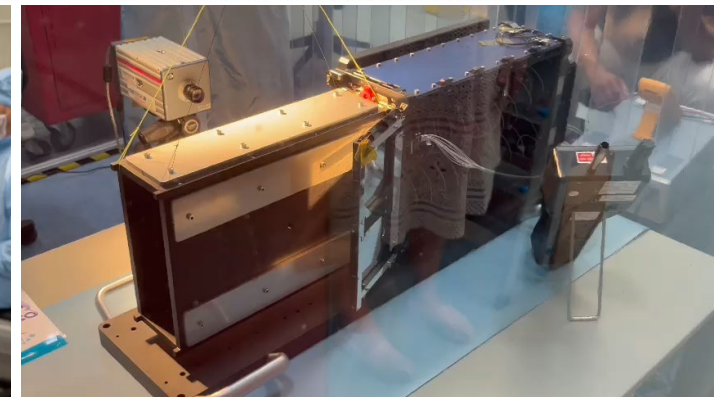
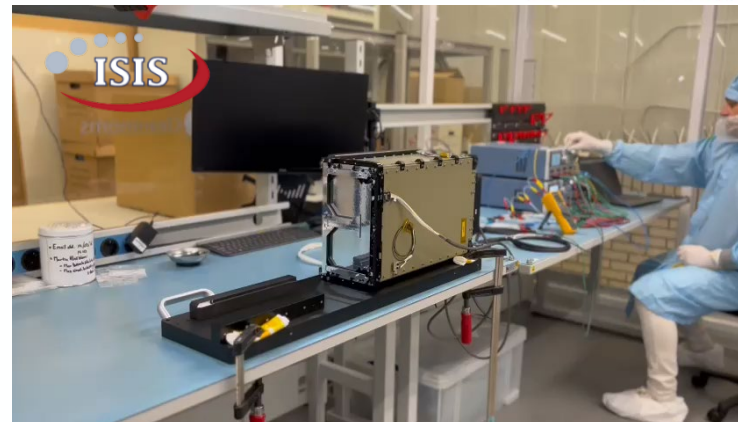
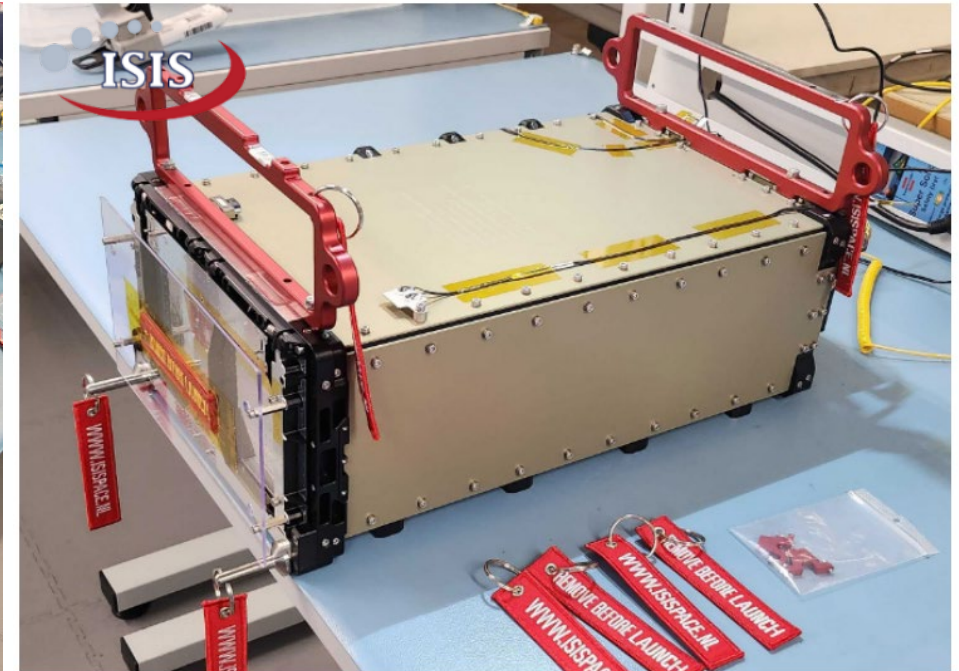
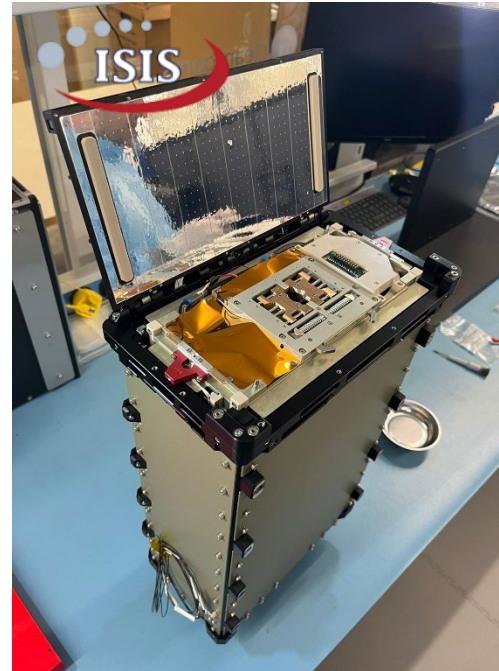
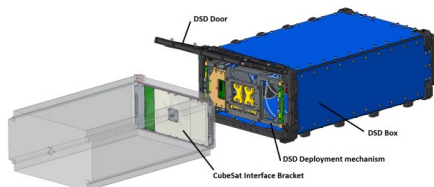
JURA Instrument (Low
Frequency Radar Electronics)
Flight Unit. Credit: Emtronix

Hera Deep Space Deployer (DSD)



DSD Characteristics:

- **ESA** contract with **ISIS** Space NL
- **SC Size:** 6U-XL
- **Max Payload Mass:** 12.5 kg
- **Umbilical Connection to CubeSat:** 20 pins (spring loaded connector)
- **Three stages operations**
 - **Stowed** (CubeSat inside DSD and elect connected to Hera)
 - **Exposed** (CubeSat exposed to Space Environment but mechanically and electrically attached to Hera)
 - **Low Velocity Deployment:** CubeSat separated at 2 cm/s and less than 2 deg/s tip-off rate
- **Redundant actuation** for all mechanisms and TM provided to Hera
- **Thermistors** installed inside DSD for Hera Thermal control
- **Qualification status**
 - Vibration (**finished**)
 - Random: GEVS Qual
 - Sine: 12 g
 - QSL: 23 g
 - Shock: 2000 g
 - TVAC (**finished**)
 - -40 to +60 degC with functional tests at extremes
 - 3 x Flight Units (**Delivered**) to Hera Prime (OHB)
- **CubeSat Electrical connection** to Hera platform through
 - Life Support Interface Board (LSIB)



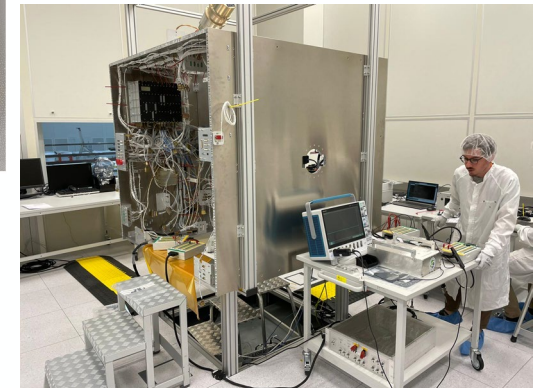
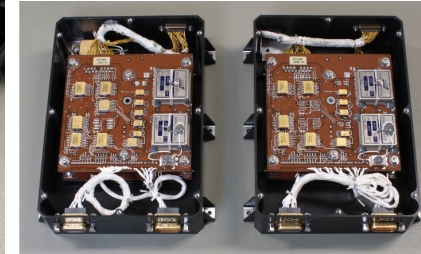
Life Support Interface Board (LSIB)



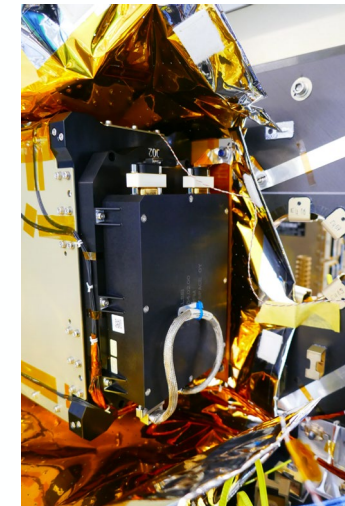
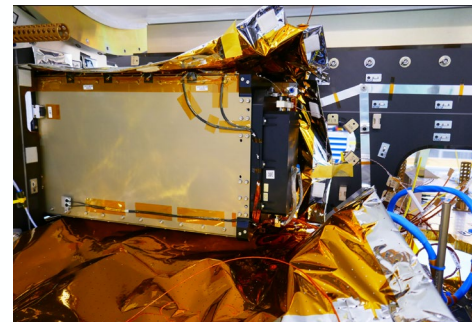
LSIBs Flight Units final Inspection and Fully integrated units

LSIB Characteristics:

- **ESA Contract with KUVA Space, FMI and Beyond Gravity FI**
- **Interface Board** for Hera to Cubesats electrical interfaces
 - **Galvanic Isolation** for Power and Data lines (Firewall for electrical failures propagation)
 - **Power regulation** from Hera bus voltage to Cubesats bus
 - **Battery Charging**
 - **UART lines** enabling **TMTC exchange** during Cruise and Exposed phases (CubeSat health checks, SW updates, etc)
 - **Conducted Emissions** (from Cubesats) shield for Hera
- **Mechanically** attached to DSD
- **Max Mass:** 450 g
- **Umbilical Connection to CubeSat:** 21 pins (Power and Data with independent EMC classes connectors to Hera platform)
- **Thermistors** installed inside LSIB for Hera Thermal control
- **Qualification status**
 - Vibration (**finished**)
 - Random: GEVS Qual
 - Sine: 12 g
 - QSL: 23 g
 - TVAC (**finished**)
 - -40 to +60 degC with functional tests at extremes
 - EMC (**finished**)
 - Conducted and Radiated Emissions and Susceptibility
 - 2 x Flight Units (**Delivered**) to Hera Prime (OHB)
 - 2 x EM units (**Delivered**) to CubeSat Providers for Avionic Test Bench Testing



LSIB + Cubesats EM testing at OHB Hera Platform Avionics Test Bench (ATB)



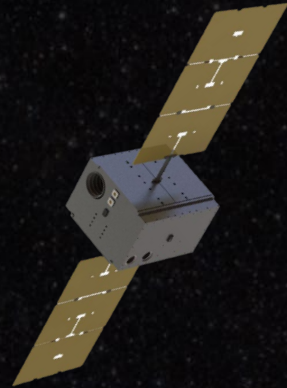
LSIB + DSD Integrated in Hera FM spacecraft

Stand-alone missions

CubeSats executing their own independent missions

LUMIO Lunar Meteoroid Impact Flash Mission

- 12U XL CubeSat platform
- High frame rate camera
- Observes meteoroid impact flashes on the lunar far side for science & exploration hazard assessment



PoliMi (mission lead, optical nav & ops)
Leonardo (camera payload)
Argotec (system eng., AIV & P/F)
S&T Norway (payload OB processing)

Potential launch opportunities (2026+):

- Piggyback launch to WSB transfer
- NASA Commercial Lunar Payload Services carrier to lunar orbit

Mission profile:

- Earth-Moon L2 halo orbit
- Far side night observations
- Day time optical navigation (full disk)

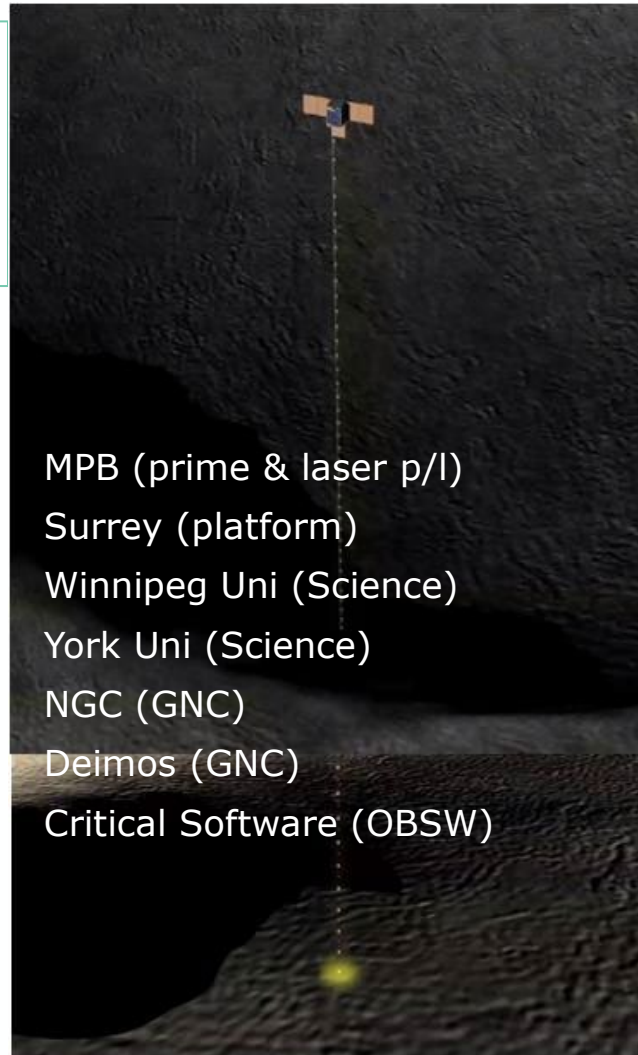
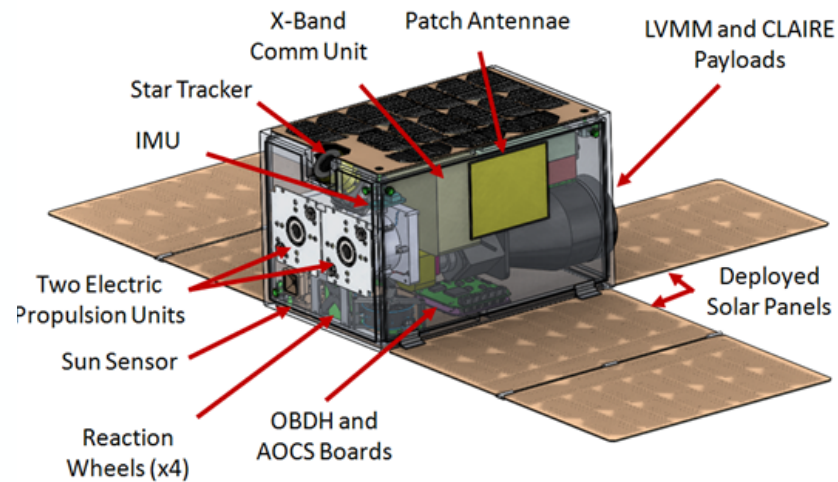
Propulsion:

- Chemical mono-propellant
- Delta-V capability 80 m/s

Status:

Phase A completed successfully
Phase B ongoing
SRR completed in March 2023
PDR planned in October 2023

Charting the Moon's water ice in permanently shadowed polar regions at high resolution (<100m) & high accuracy using a dual-channel fibre laser spectrometer



Potential launch opportunities (2025+):

- NASA Commercial Lunar Payload Services carrier to lunar orbit
- NASA SLS Artemis (lunar swingby)

Mission profile:

- Low altitude frozen polar orbit
- Payload ops @40-80 km south pole
- Laser altimetry & comms experiment

Propulsion:

- Electric FEEP
- Delta-V 240-670 m/s depending on launch option

Status:

Phase A completed successfully
Funding for Phase B1 TBC

M-ARGO NEO Rendezvous Mission

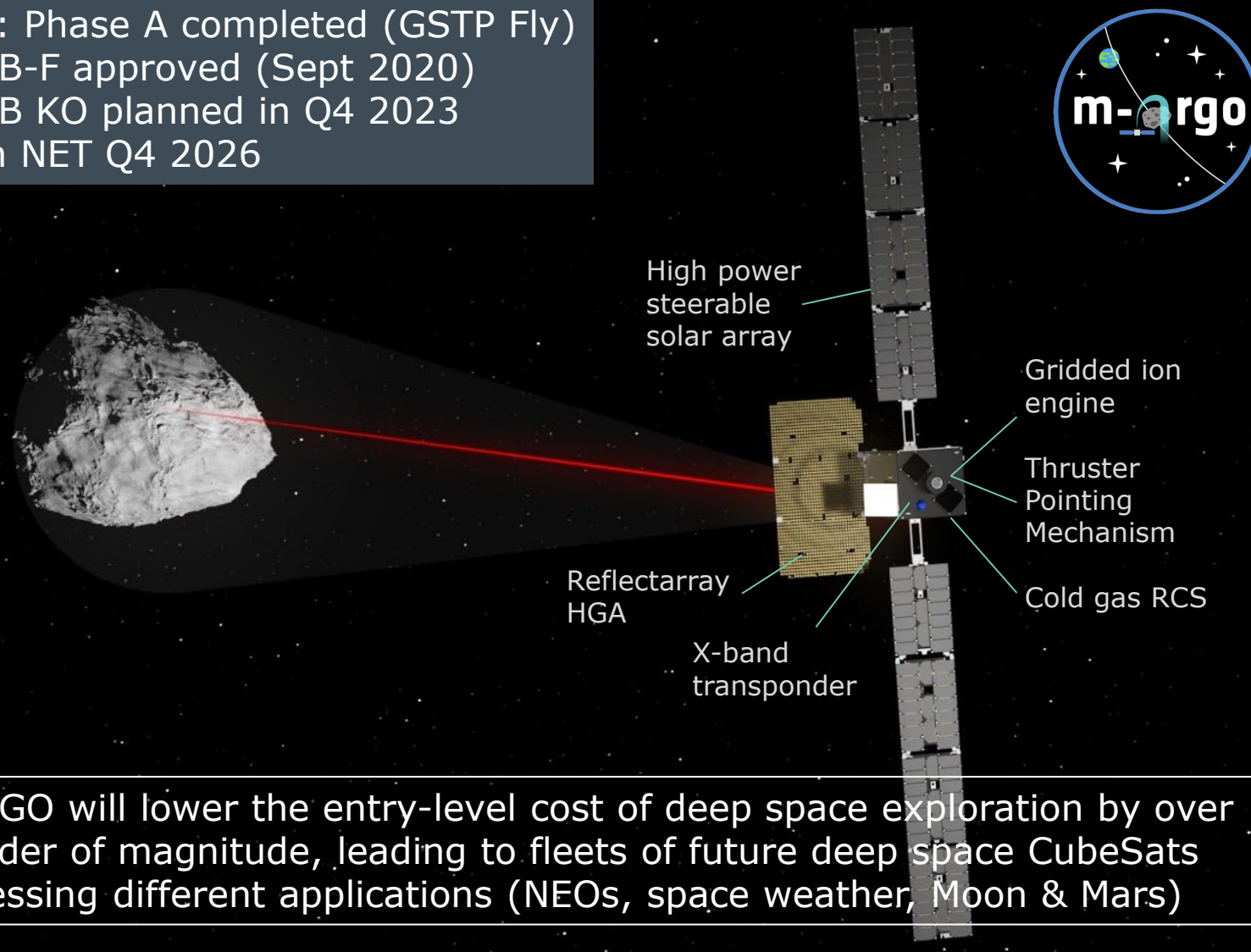
Status: Phase A completed (GSTP Fly)
Phase B-F approved (Sept 2020)
Phase B KO planned in Q4 2023
Launch NET Q4 2026

Objectives:

- Demonstrate critical technologies & operations for stand-alone deep space CubeSats in the relevant environment
- Rendezvous with a Near Earth Object
- NEO physical characterisation for in-situ resource exploration purposes
- Test autonomous GNC techniques

Mission concept:

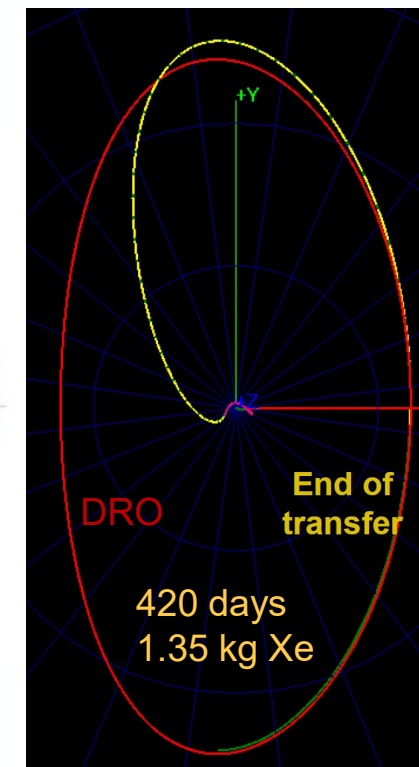
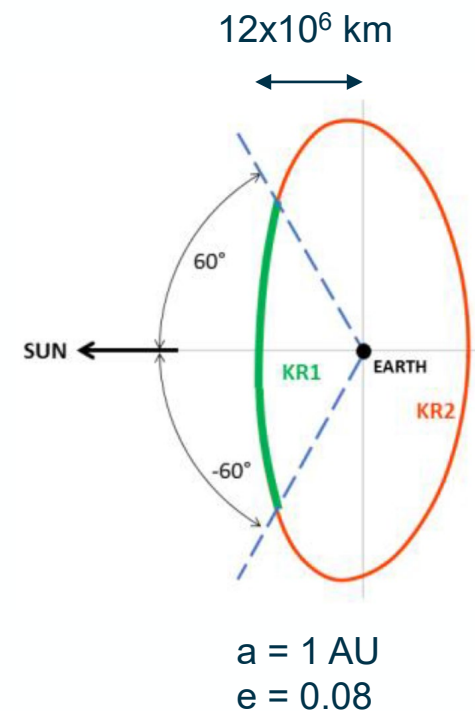
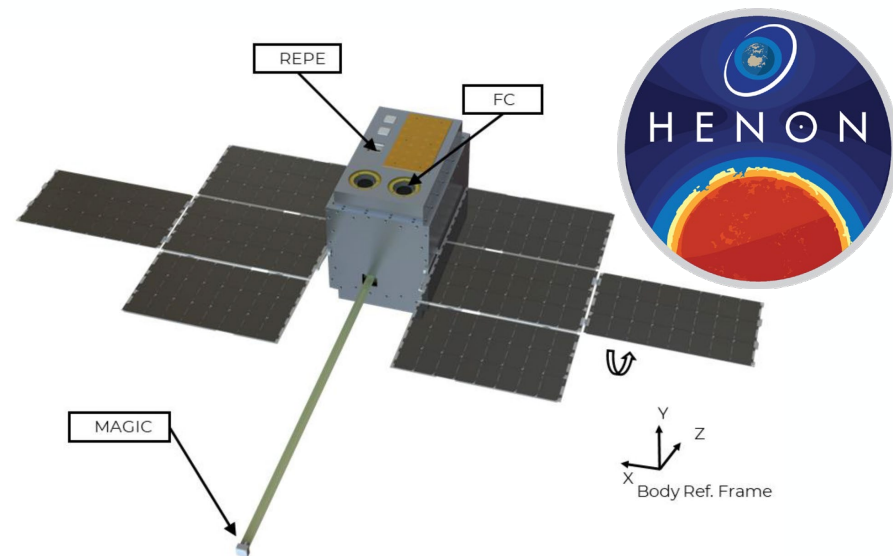
- 12U XL CubeSat with hyperspectral imager VIS/NIR/SWIR, laser altimeter
- piggyback launch to Sun-Earth L2 transfer or Earth escape
- 1-3 year low-thrust interplanetary transfer (ΔV 2-3 km/s)
- 6-month close proximity ops at NEO
- 120 different NEO targets accessible



M-ARGO will lower the entry-level cost of deep space exploration by over an order of magnitude, leading to fleets of future deep space CubeSats addressing different applications (NEOs, space weather, Moon & Mars)

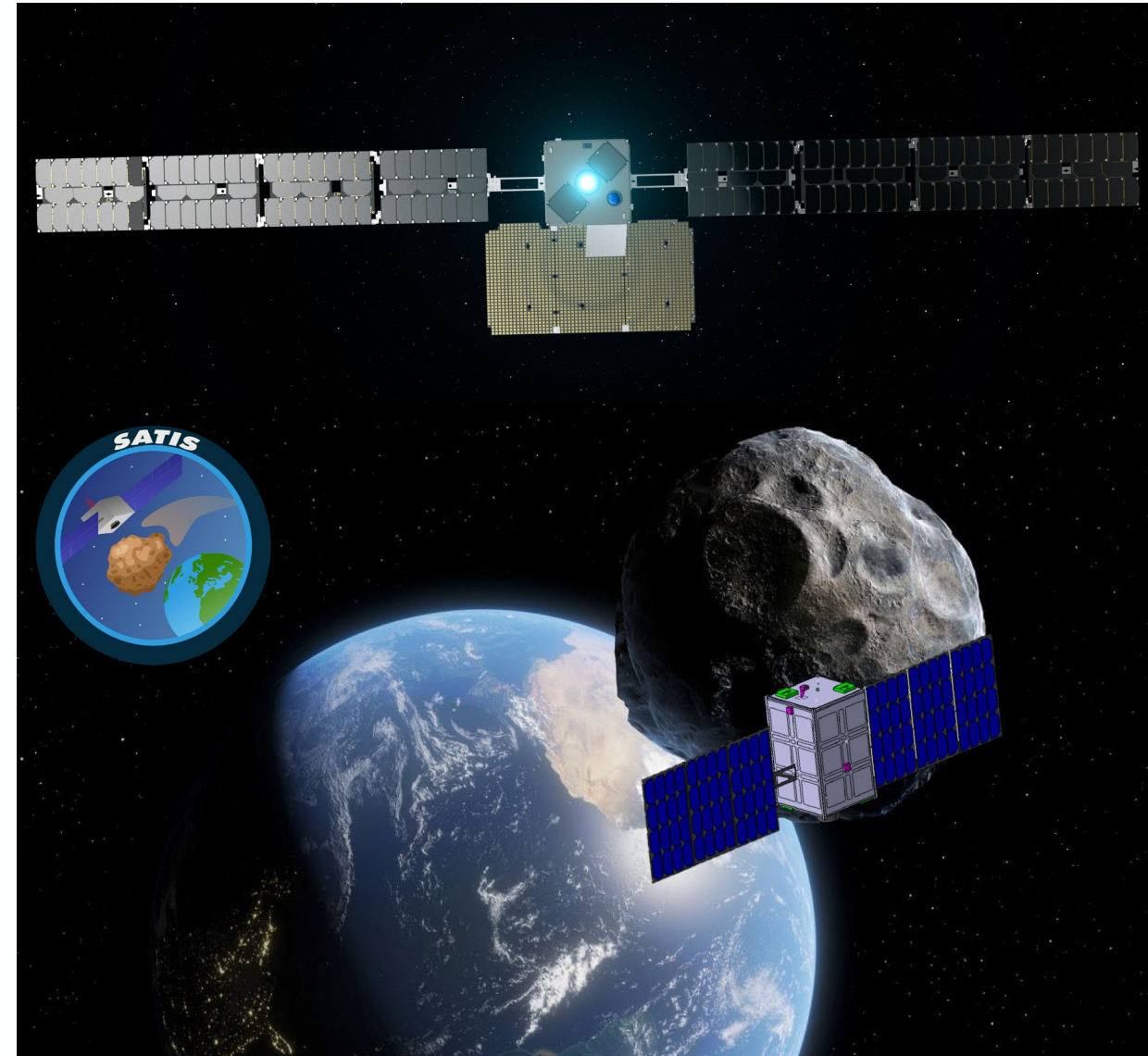
HENON Space Weather Warning Mission

- Project: HEliospheric pioNeer for sOLar and interplanetary threats defeNce (HENON)
- Contractor: Argotec, INAF, Uni. Calabria, Uni. Florence, SpaceDys
- Platform: 12U XL CubeSat
- Payloads:
 - Energetic particle flux telescope (proton/electron/heavy ion energy spectra) from Solar Proton Events (SPEs)
 - Magnetometer on boom, Faraday Cup Analyzer
- Mission:
 - Space weather measurements in Distant Retrograde Orbit (DRO) for 3-hour advanced warning of solar storms (when on sunward side)
 - Transfer from Sun-Earth L1/L2 to DRO using M-ARGO propulsion
- Launch: Sun-Earth L1/L2 transfer, Q3 2026, Launch opportunity TBD
- Status: Phase A/B KO kicked off in Sept. 2022, PRR completed in Dec. 2022, PDR in Sept. 2023



Satis Apophis Rendezvous Mission

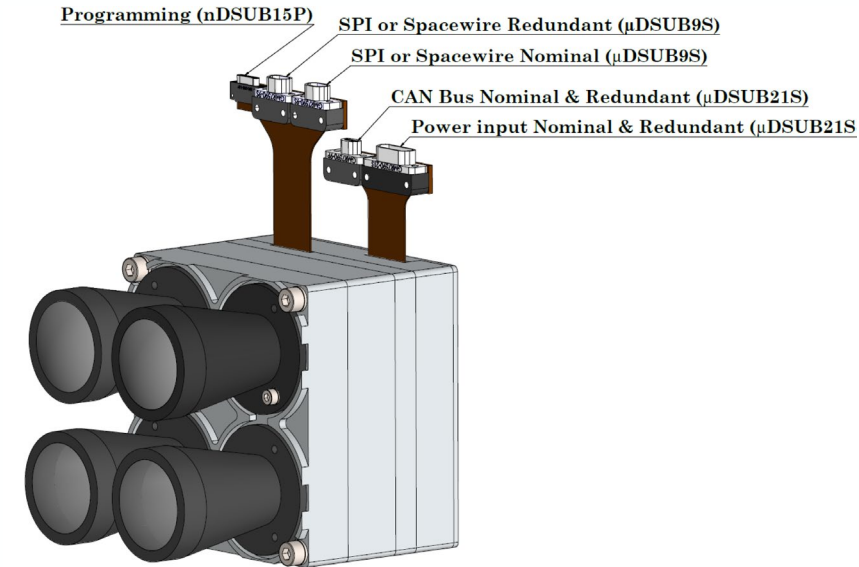
- Programme: Space Safety (Planetary Defence)
- Platform: 12U XL CubeSat
- Payloads:
 - Hyperspectral imager VIS/NIR/SWIR, TIR imager
 - Laser altimeter, radio science experiment
- Mission:
 - Rendezvous with Apophis two months prior to its close encounter with Earth on Friday 13th April 2029 at 31,500 km altitude over Atlantic ocean
 - Characterise change in physical properties before/during/after close encounter
- Profile: launch May 2027 to SSO 500 km with 350 kg kick stage, kick stage burn to Earth escape, 2-year transfer with M-ARGO electric propulsion
- Status: Phase A/B approved, two parallel Phase A studies planned to start in Q3 2023 (open competition)



Key technologies

Enabling stand-alone deep space missions

- Contractor: TSD Space & Optec (IT)
- Payload:
 - CHIEDES Hyperspectral Imager
 - VIS, 2 x NIR, SWIR channels
- Physical characteristics:
 - Mass: 1.3kg
 - Dimensions: 1.4U
 - Power: 7.7W (All Channels), 3W (nominal)
- Environment:
 - Deep space radiation-tolerant by design
- Status:
 - Preliminary design completed
 - Breadboard development ongoing
 - TRL 4 targeted in Q4 2023

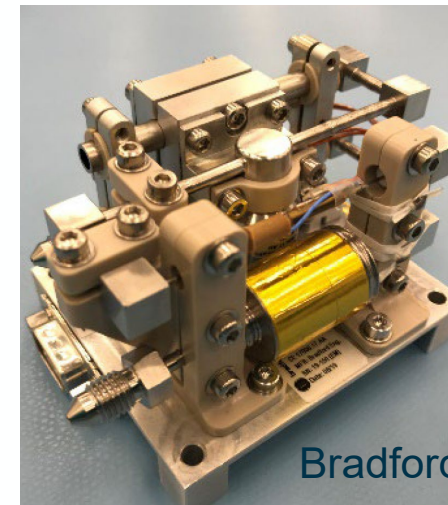
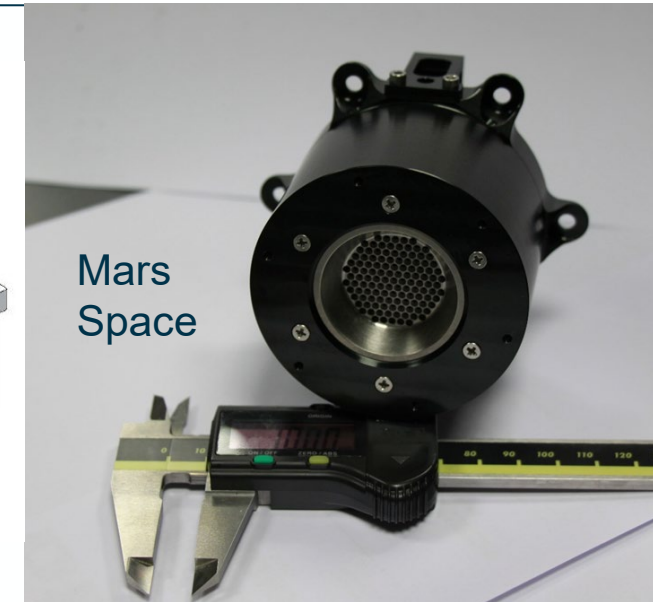
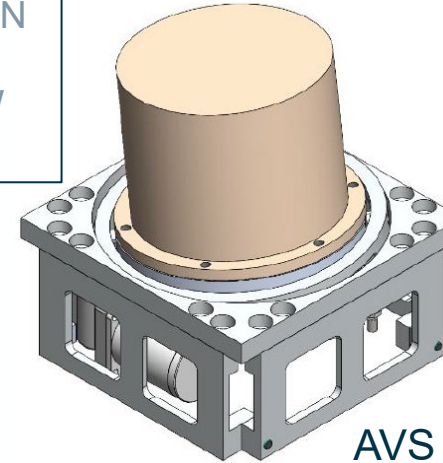


Pixels	2048 x 2048	640 x 512	640 x 512	320 x 256
Spectral range (nm)	500-900	850-1250	1200-1600	1700-2300
No. of bands	10	16	16	12
Spatial resolution (cm/pix) @ 1800 m	9.9	30	30	36
Spatial resolution (cm/pix) @ 550 m	3	9.2	9.2	11
Spatial resolution (cm/pix) @ 275 m	1.5	4.6	4.6	5.5
Bit Mode (bit/pix)	10	13	13	9
Full image size (Mb)	41.9	4.3	4.3	0.7

High Specific Impulse Electric Propulsion & Integrated Cold Gas Reaction Control System

- Programme: GSTP Develop
- Subsystem Prime: Mars Space Ltd (UK)
- Elements:
 - RIT 3.5 thruster & neutralizer (Mars Space UK)
 - Titanium tanks (TWI UK)
 - Flow Control Unit (NAMMO UK / Bradford NL)
 - Power Processing Unit (Techline UK)
 - Thruster Pointing Mechanism (AVS UK)
 - Xe-fed RCS (company TBD)
- Status:
 - Coupling tests between thruster, neutralizer, PPU BB and FCU BB completed successfully
 - thruster & neutraliser development / qualification ongoing
 - TPM development ongoing, tank development initiated

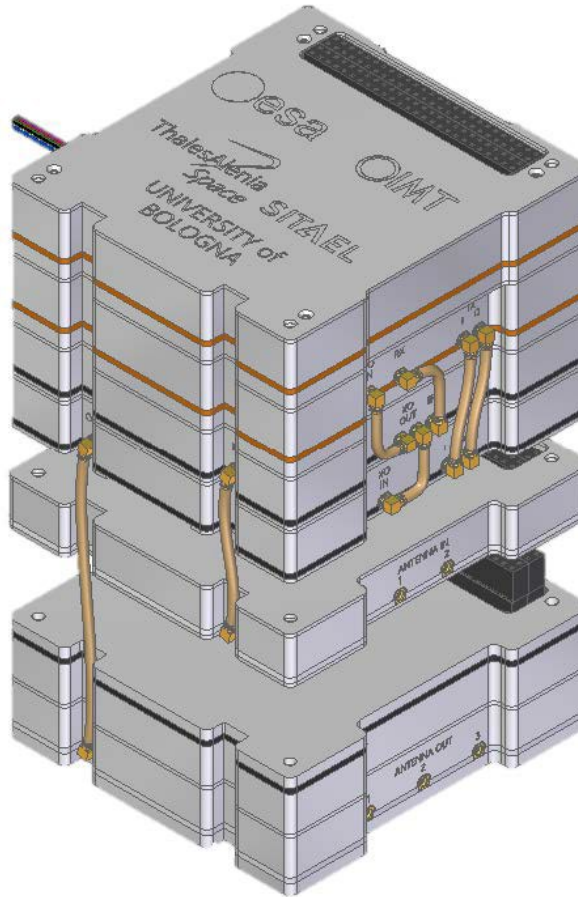
Thrust: 0.8 – 2.2 mN
Isp: 3250 – 3600 s
Power: 80 – 130 W
Itot: >90 kNs



Target TRL: 6 (complete subsystem) in late 2025 / early 2026

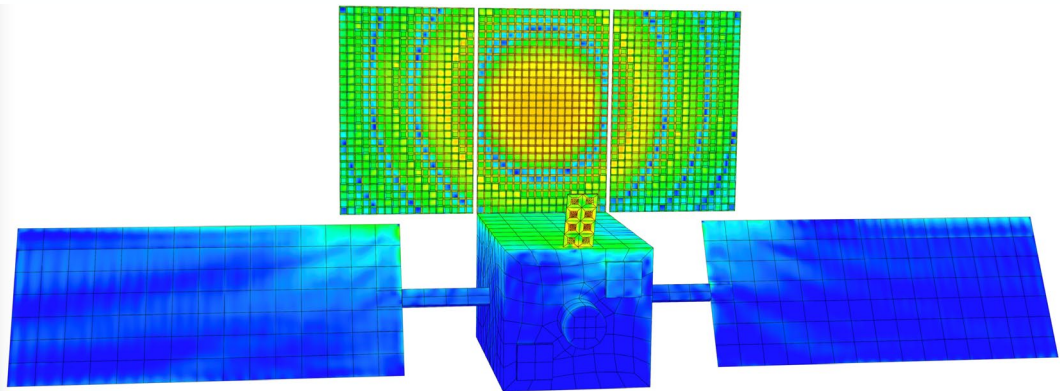
X-band Deep Space Transponder

- Programme: GSTP Develop
- Prime: IMT (IT)
- Sub-co: TAS-I, Sitael, Uni. Bologna (IT)
- Functions:
 - TM/TC
 - Ranging & Doppler
 - Radio science
- Target TRL: 6 (EM functional, EMC, perf. & environmental tests)
- Status: EM testing ongoing, to be completed in Q3 2023



Parameter	Value
Frequency	Rx: 7145-7190 MHz Tx: 8400-8450 MHz
Modulation	Rx: PCM/PSK/PM (sine) Tx: PCM/PSK/PM (sine/sq)
Encoding	Rx: BCH Tx: Concat RS (255,223), conv. Code rate $\frac{1}{2}$
Carrier acquisition	-145 dBm
RF Output Power	15 W
Mass	<1.5 kg
Volume	<1.5 U
Power	5V, 24-36V
Interfaces	CAN, LVDS

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- Programme: GSTP Develop
- Prime: IMT (IT)
- Scope: EM development
- Functions:
 - hold down & release, deployment
 - 1-axis rotation of 2-wing deployable solar array
 - suitable for 6U/12U CubeSats
 - radiation-tolerant version for deep space environment
- Target TRL: 6 (EM functional, life & environmental tests)
- Status: EM testing completed successfully, activity completed

Solar array assembly:

118 W power @BOL
from 2 wings
(3 panels each)

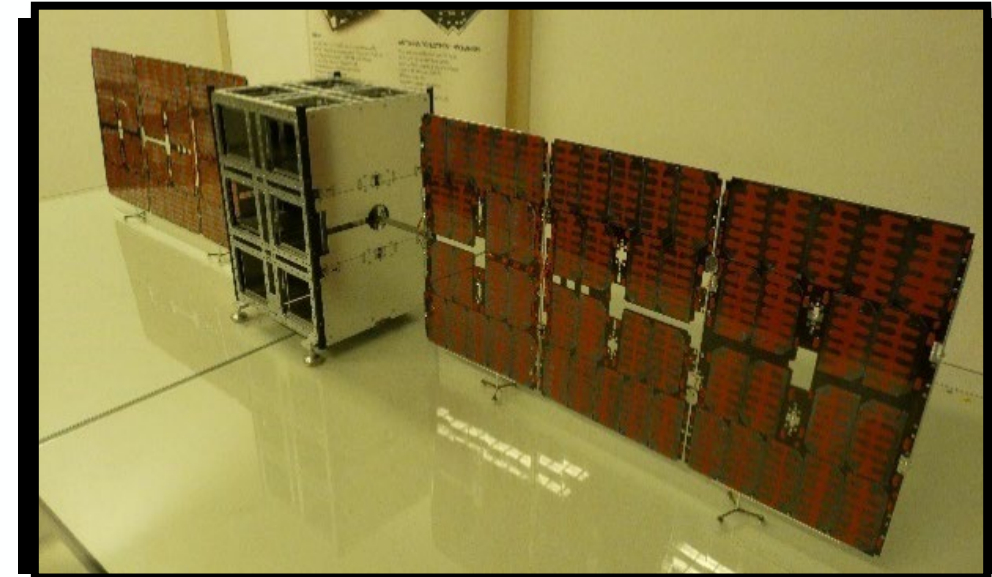
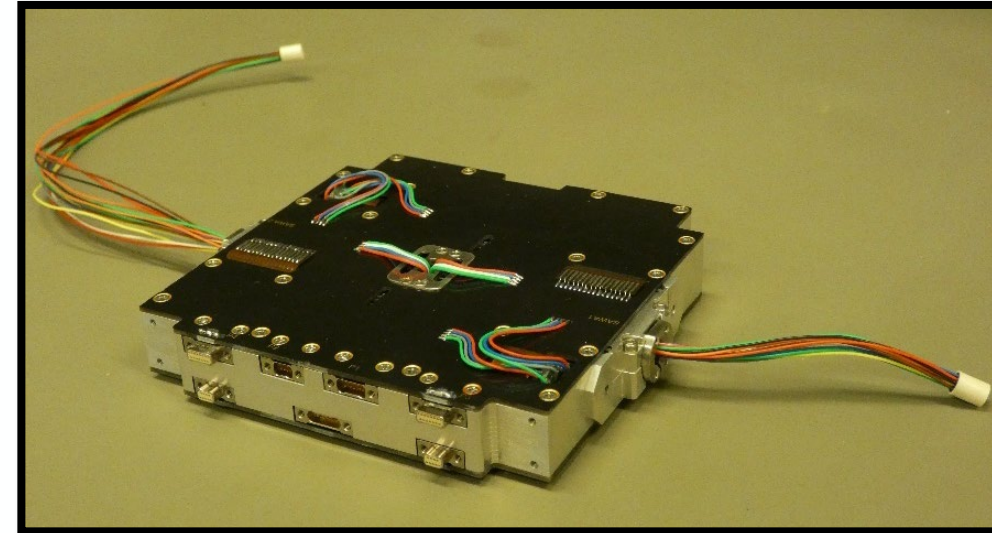
Expandable to 190 W
(5 panels each wing)

Solar Array Drive Mechanism (SADM):

Independent N-times rotation for each wing via slip rings

Redundant motor windings & drive electronics

Angle controlled to 0.3° accuracy



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