

Overview of ESA Lunar and Interplanetary CubeSat Missions

Dr. Roger Walker

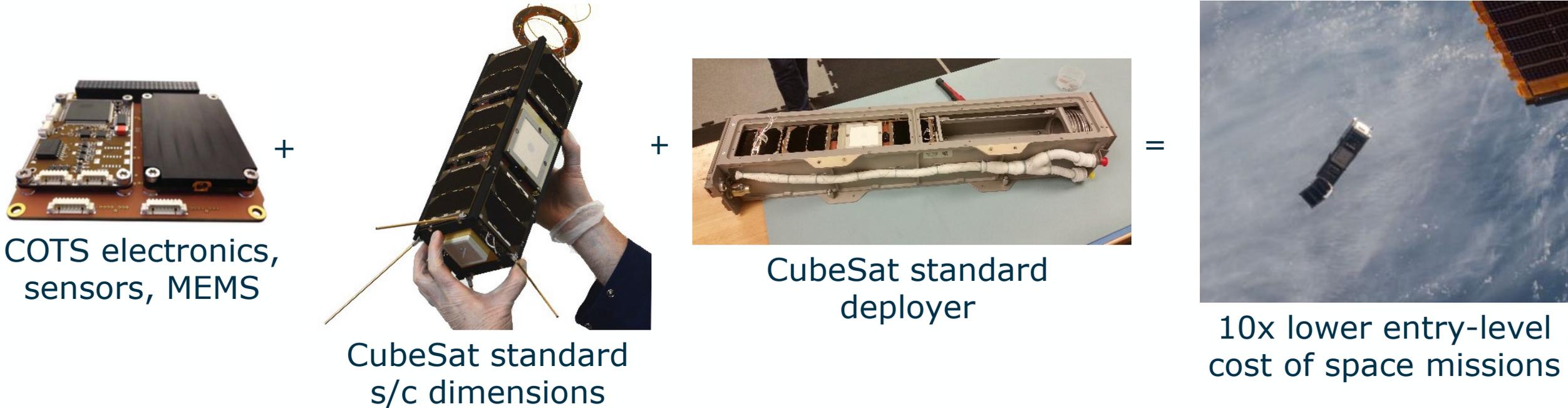
Head of the CubeSat Systems Unit
Projects Office, Systems Department
Directorate of Technology, Engineering & Quality

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)

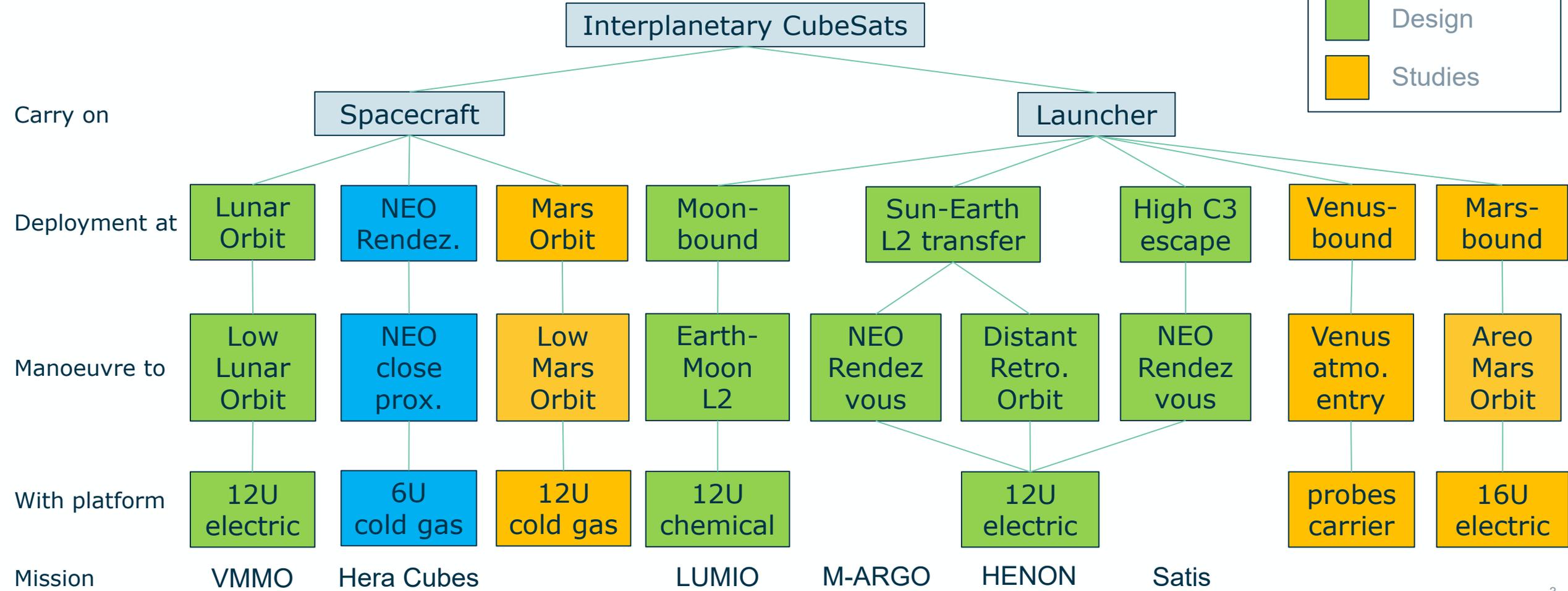
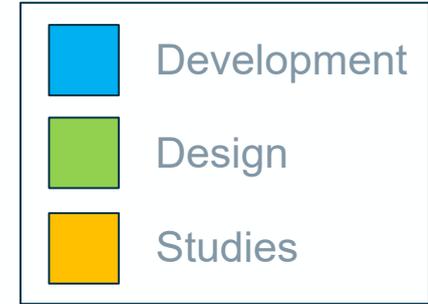
First ever lunar CubeSats successful (CAPSTONE, Artemis-1 CubeSats 2022)

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

Interplanetary 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?

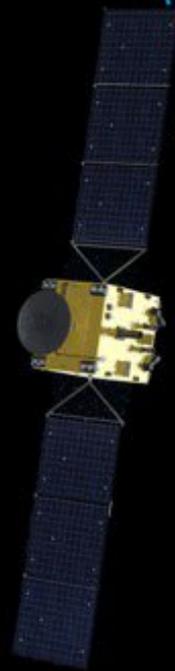


Companion missions

CubeSats as an integral part of larger missions



08/10/2024
HERA LAUNCH



2.3 YEARS CRUISE

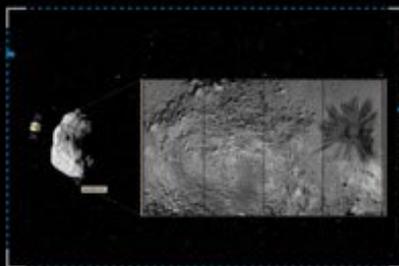
- 2 x Asteroid Framing Cameras
- 2 x 6U CubeSats
- Laser Altimeter
- Thermal Infrared Camera (JAXA)
- Hyperspectral Imager

28/12/2026
ASTEROID ARRIVAL



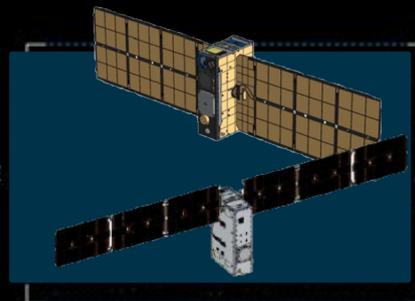
LANDING ON DIDYMOS
MISSION ENDS

DIMORPHOS



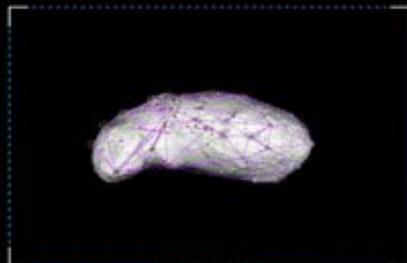
EARLY CHARACTERISATION PHASE
Measuring mass and dynamics

CUBESATS RELEASE

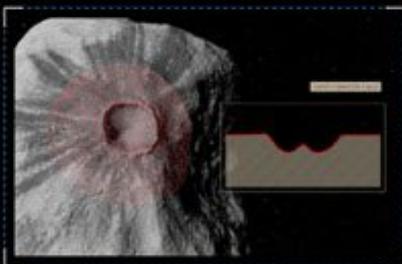


Intersatellite Link

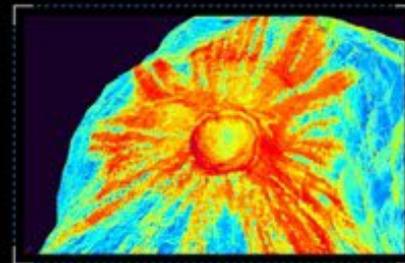
AUTONOMOUS PROXIMITY
OPERATIONS DEMONSTRATION



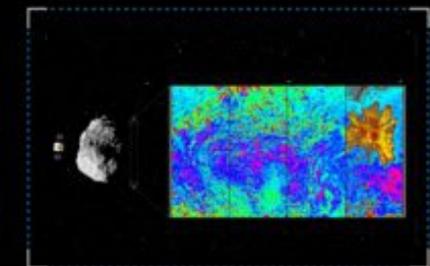
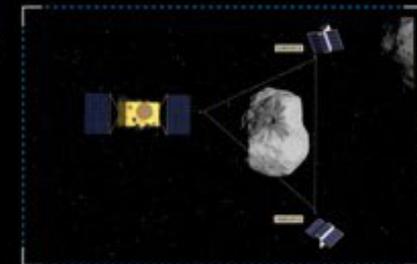
DETAILED CRATER
SHAPE INVESTIGATION



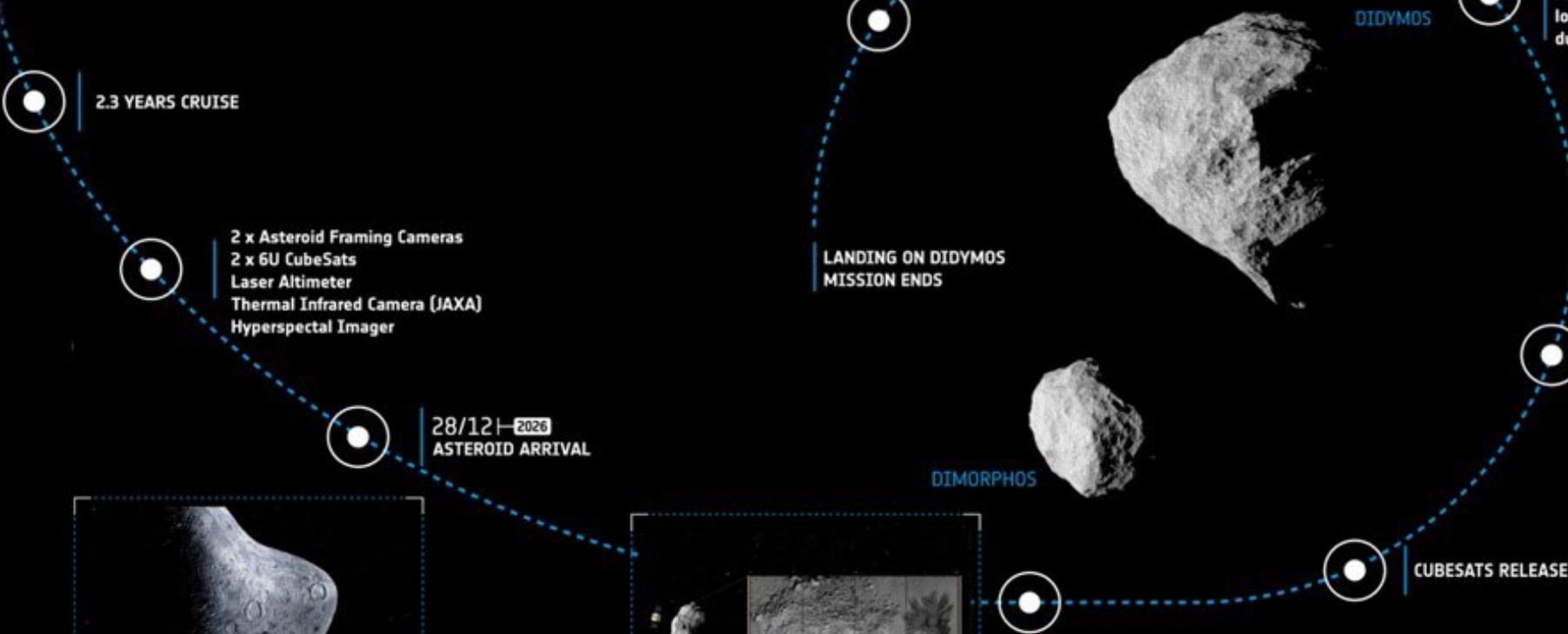
DETAILED SUBSURFACE
CRATER INVESTIGATION



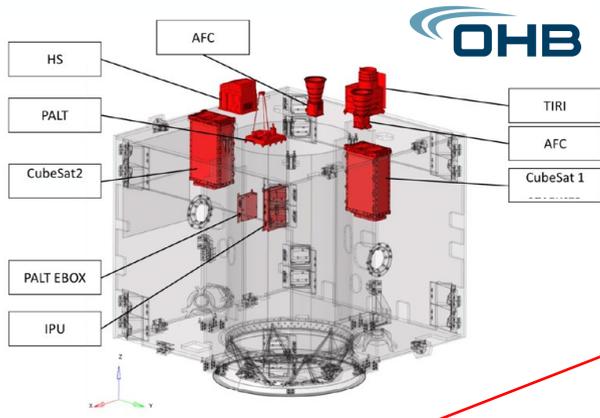
MULTI-POINT ASTEROID INVESTIGATION
low-frequency radar, multispectral imager,
dust detector, gravimeter.



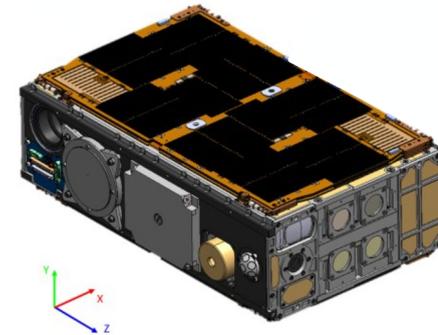
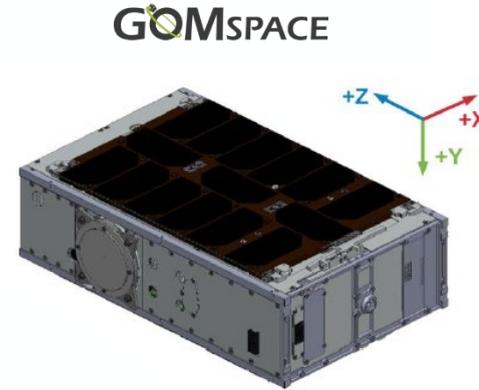
DETAILED CHARACTERISATION PHASE
Measuring surface and interior properties



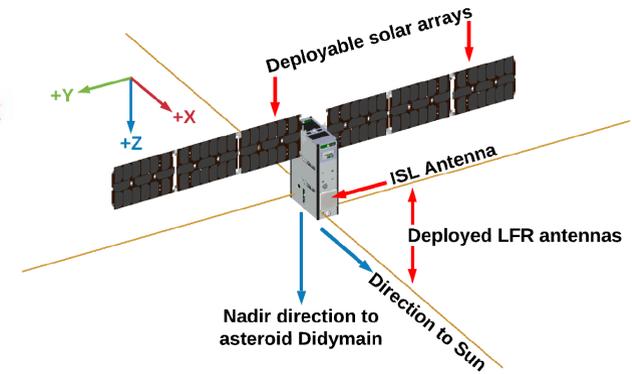
HERA Platform – Cubesats accommodation on Hera S/C



Juventas Cubesat



Milani Cubesat



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)

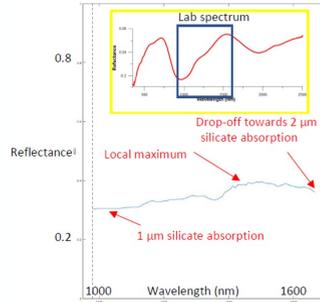
Mission funded by the Italian Space Agency (ASI)

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

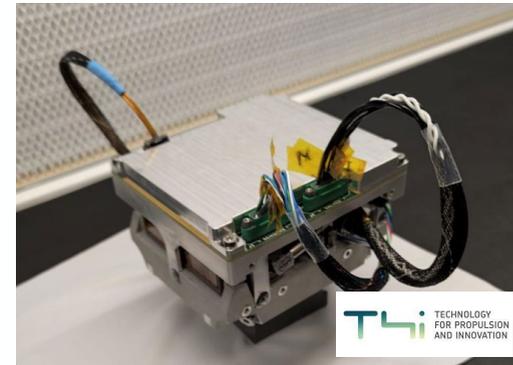
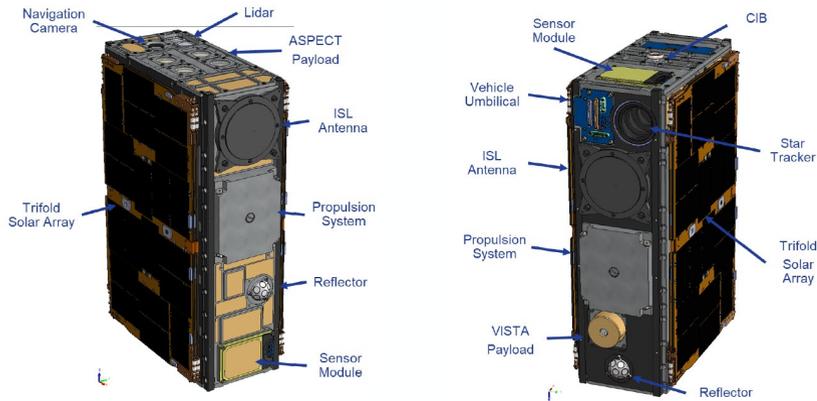
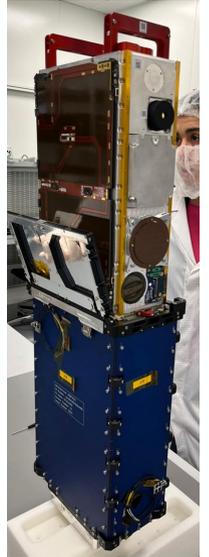


Parameter	VIS channel	NIR1 channel	NIR2 channel	SWIR channel
Field of View [deg]	10° x 10°	6.7° x 5.4°	6.7° x 5.4°	ca. 5.85° circular
Spectral range [nm]	500 – 900	850 – 1250	1200 - 1600	1650 - 2500
Image size [pixels]	1024 x 1024	640 x 512	640 x 512	1 pixel
No. spectral bands	Ca. 14	Ca. 14	Ca. 14	Ca.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

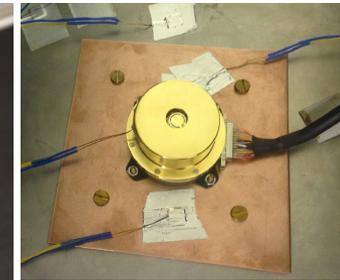
Structural Thermal Interface Model. Credits Tyvak international



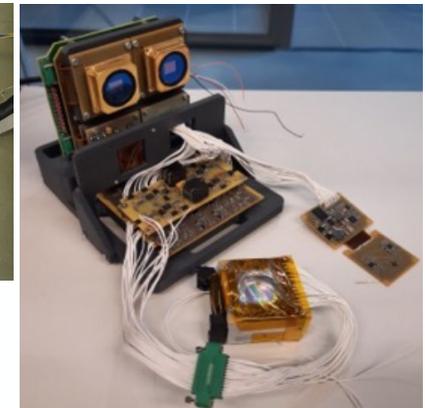
EM Unit + DSD EQM



Cold Gas Propulsion System QM
Credit: T4i Italy



Vista Instrument Flight Unit. Credit INAF



ASPECT FM Camera Assembly. Credit VTT

Juventas Mission



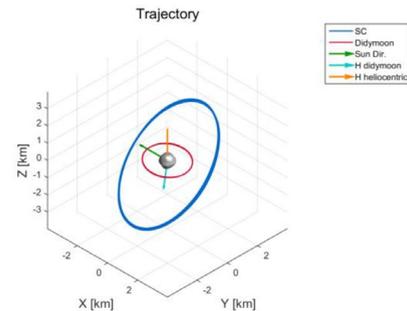
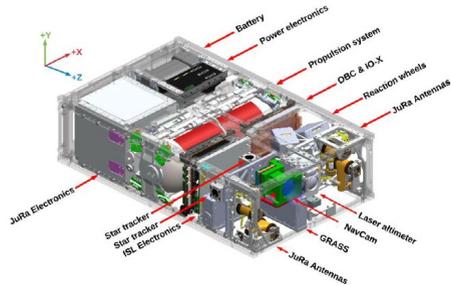
ESA Contract with GomSpace (LUX) and the following consortium

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)

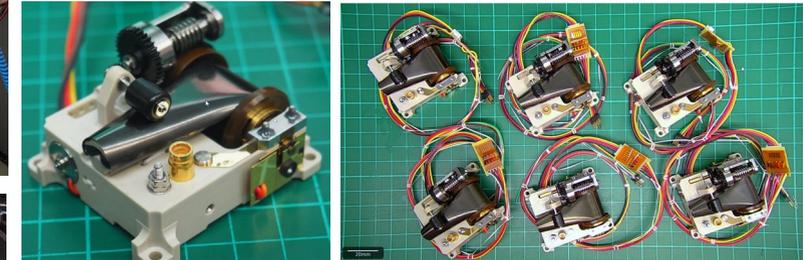
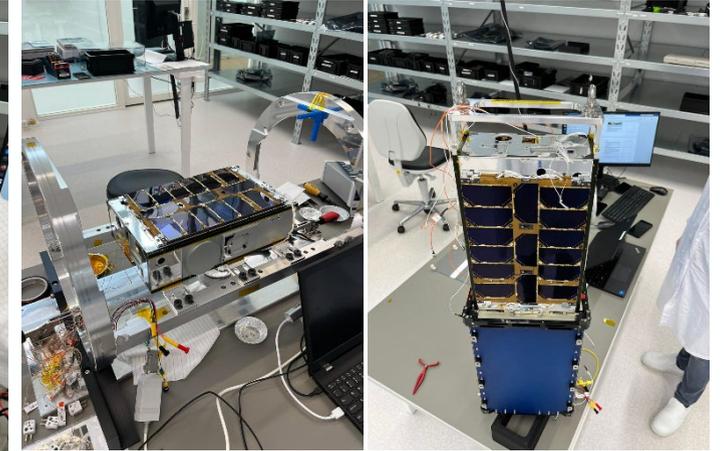
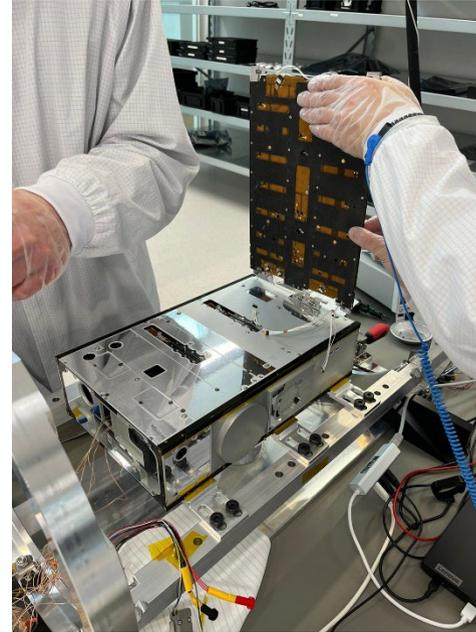
Structure	6U-XL CubeSat bus	
<i>Solar distance</i>	1.02 – 1.71 AU (max 2.0 AU)	
<i>Mission lifetime</i>	2 years cruise and 3 months nominal proximity operations,	
<i>Launch date</i>	October 2024	
Mass	<i>Mass</i>	Dry 10.4 kg , Wet Mass: 12 kg
Dimensions	<i>Stowed</i>	~130 x 246 x 366 mm
	<i>Deployed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

Scientific objectives:

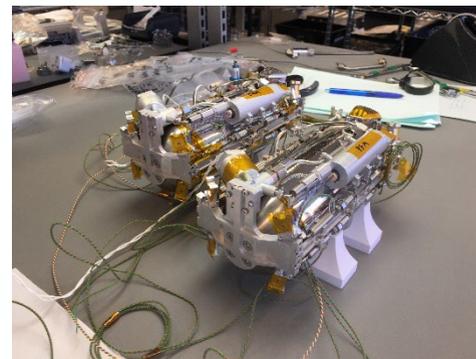
- Characterize the gravity field (Gravimeter)
- Characterize the internal structure (Low Frequency Radar)
- Determine the surface properties
- Determine the dynamical properties



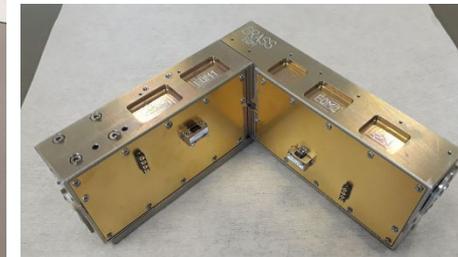
Structural Thermal Interface Model. Credits GOMSpace LUX & DK



Low Frequency Radar Antennas FMs 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: Emtronix₃

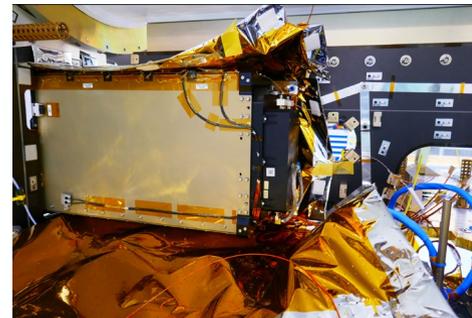
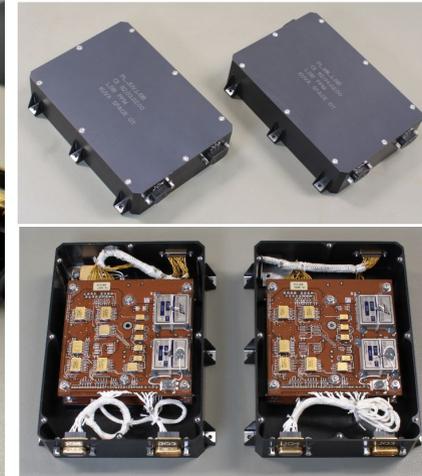


Life Support Interface Board (LSIB)

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

Hera Inter Satellite Link (ISL) System

ESA Contract with Tekever (PT)

ISL Features:

S-Band (2.43GHz) ISL base on Proba-3, Class-3 rad-tolerant design:

- Full duplex data exchange links with Hera. Direct exchange among CSs option not implemented.
- Near Omni-directional coverage with use of patch-antenna
- Adaptive Rates in the range 6kbps to 120kbps
- Ranging (<0.5m accuracy) and Range-rate (high-accuracy RSE <30mm/s.)
- Time (OBT) distribution function (from Hera to each cubesat)

Key Parameters/Performance:

- RF Power: 1W
- DC Power: 5.4W Rx-only, 6.8 (Average), 9.9W (Max)
- Range: 10cm to 60+Km

Two units form factor:

- Hera (160x120x65mm, 900g)
- Cubesats (95x90x46mm, 450g)

Qualification Status: (Qualified)

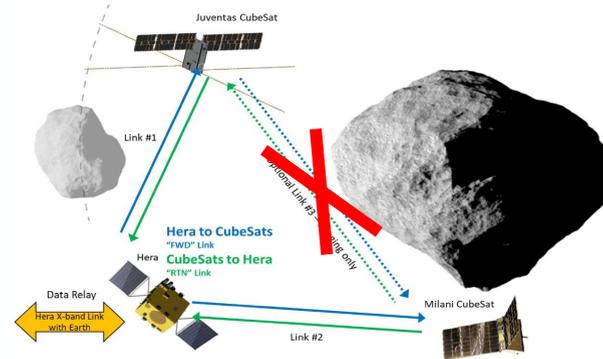
FM units: under assembly



Hera CubeSat ISL terminal QM



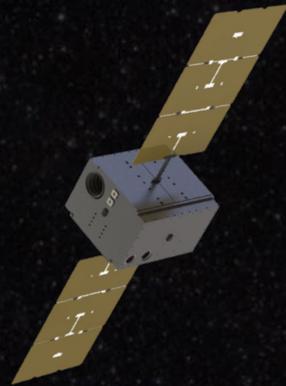
CubeSat ISL Antenna QM



Stand-alone missions

CubeSats executing their own independent missions

- 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:

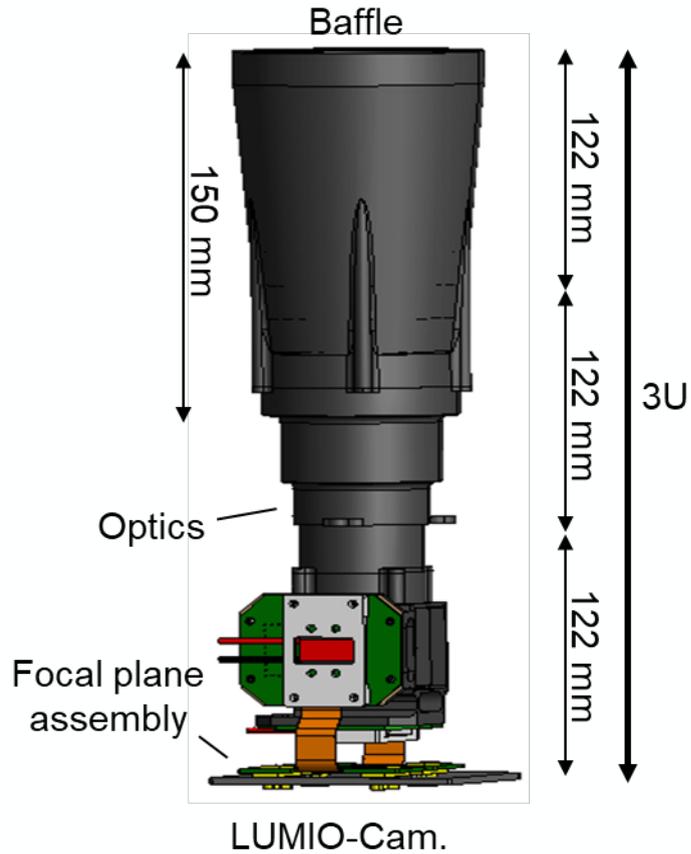
Phase A completed successfully
Phase B ongoing
SRR completed in March 2023
PDR planned in October 2023

Key Technologies – LUMIO-Cam

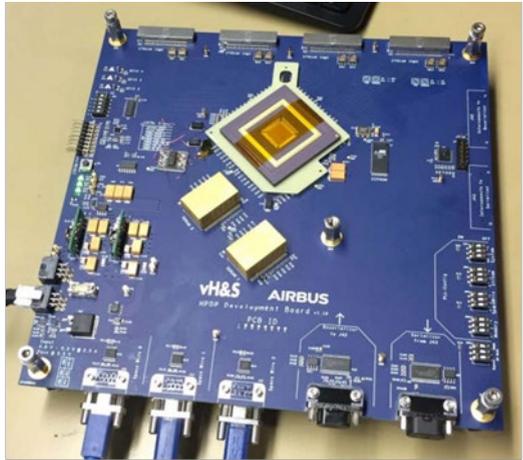
2 Channels: VIS & NIR
 $\lambda_{dic} = 820 \text{ nm}$

Real-time on-board
 image processing

Post-processing to
 meteoroid models

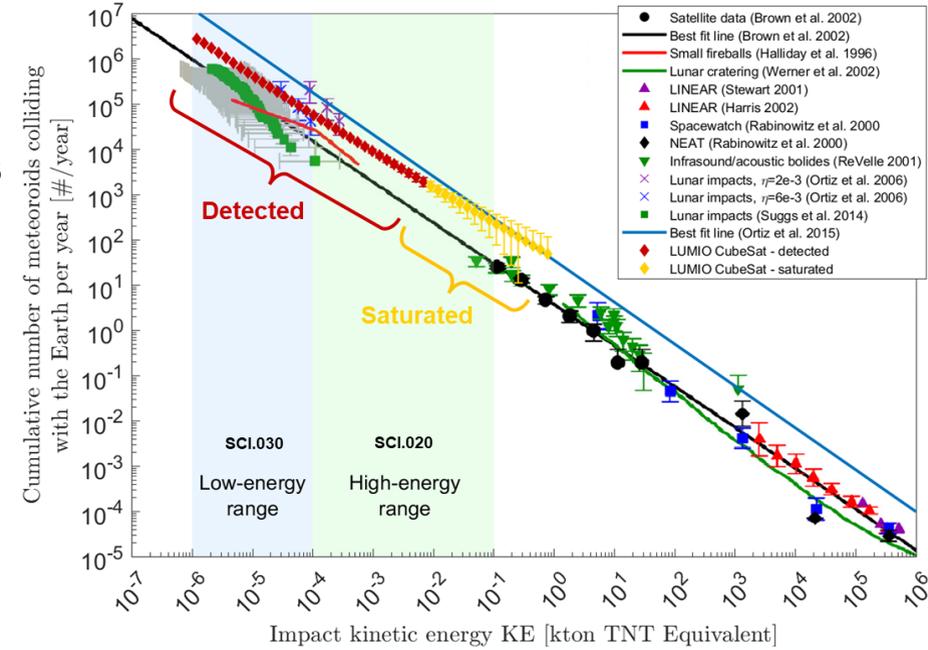


15 fps



Airbus/ISD HPDP-40 demo board

0-4000
 impacts
 per day



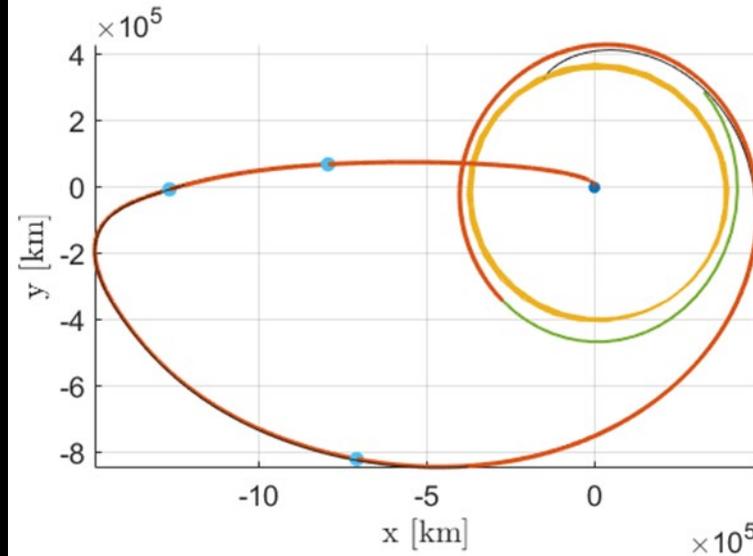
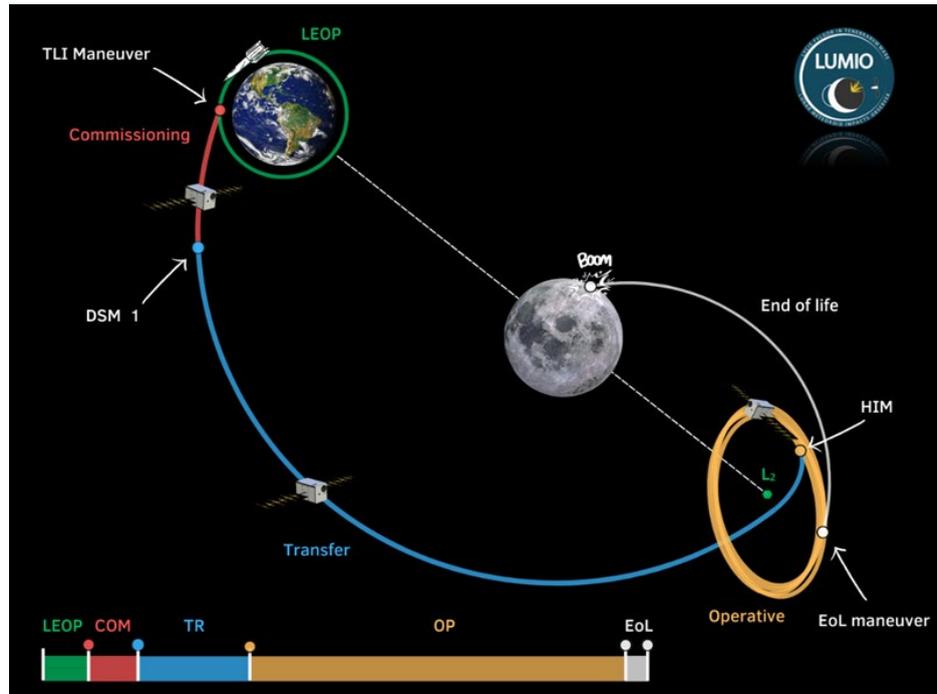
Suggs et al. (2014) +
 overlay of LUMIO
 simulations

Key technologies – chemical propulsion & RCS

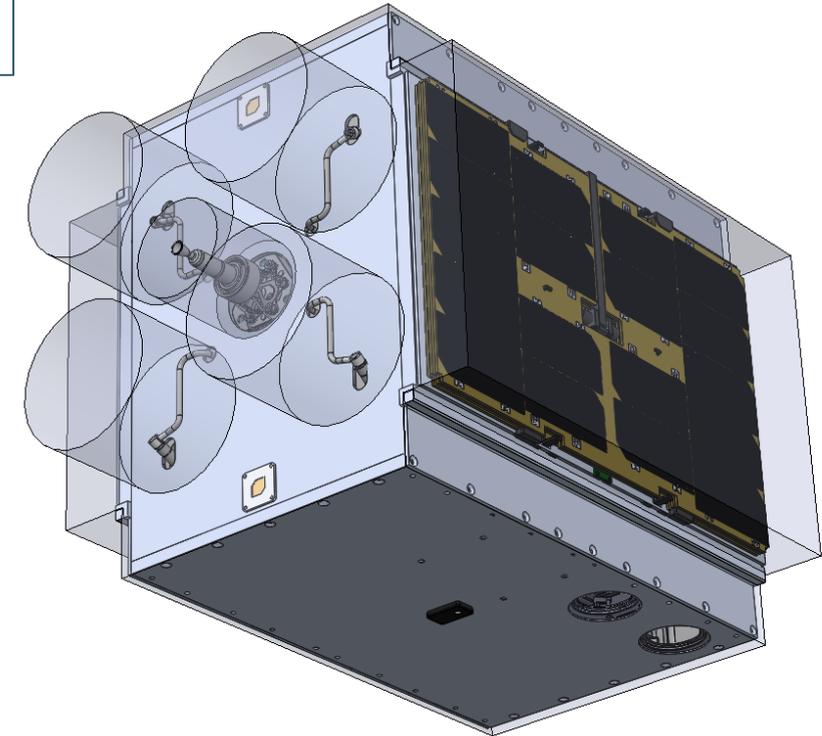
Piggyback launch & injection onto WSB trajectory

Manoeuvres:
3x Deep Space transfer
Halo Injection
Halo Station Keeping
EoL Disposal

1 x main thruster
(ECAPS R134a 0.3-0.8 N blowdown)
4 x RCS thrusters

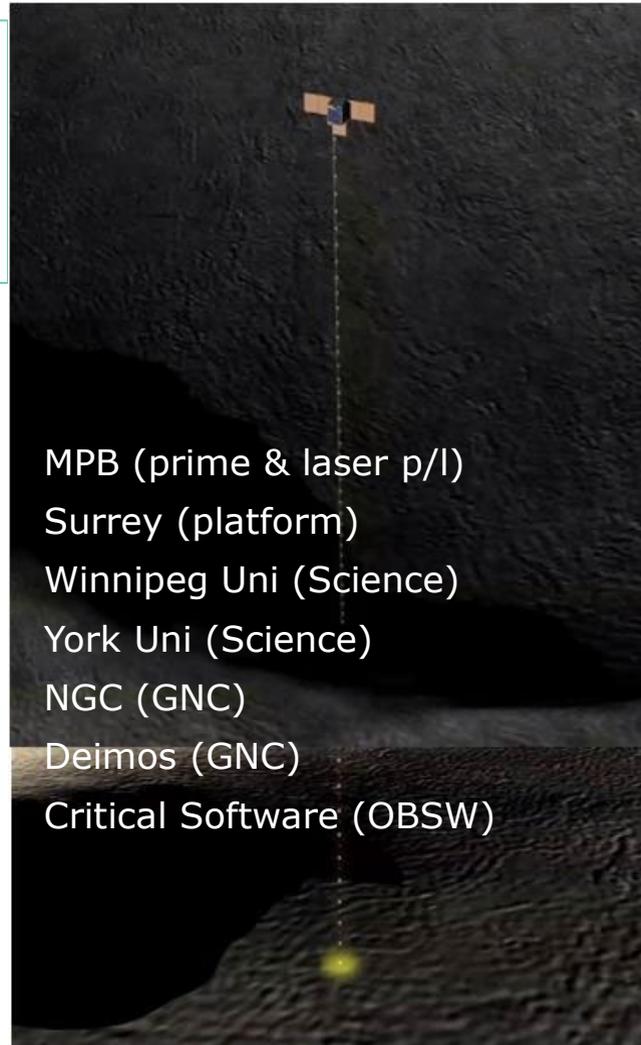
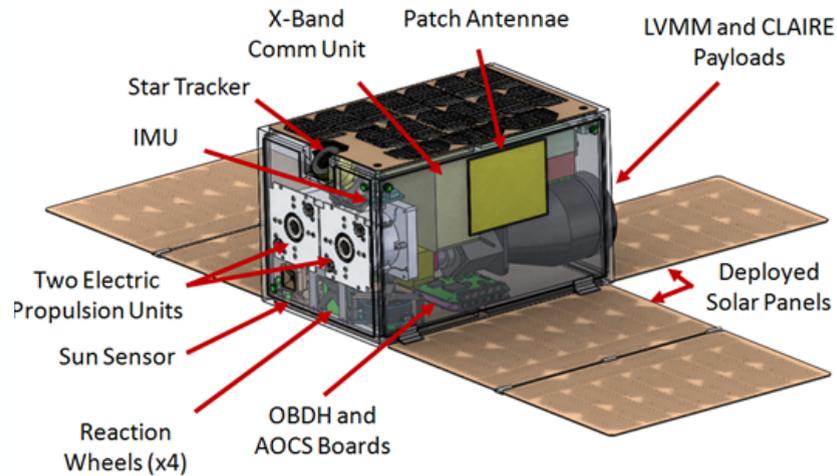


$\Delta V = 80 \text{ m/s}$



Developer:
Bradford (NL) / Lift Me Off (UK)

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



MPB (prime & laser p/l)
 Surrey (platform)
 Winnipeg Uni (Science)
 York Uni (Science)
 NGC (GNC)
 Deimos (GNC)
 Critical Software (OSW)

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

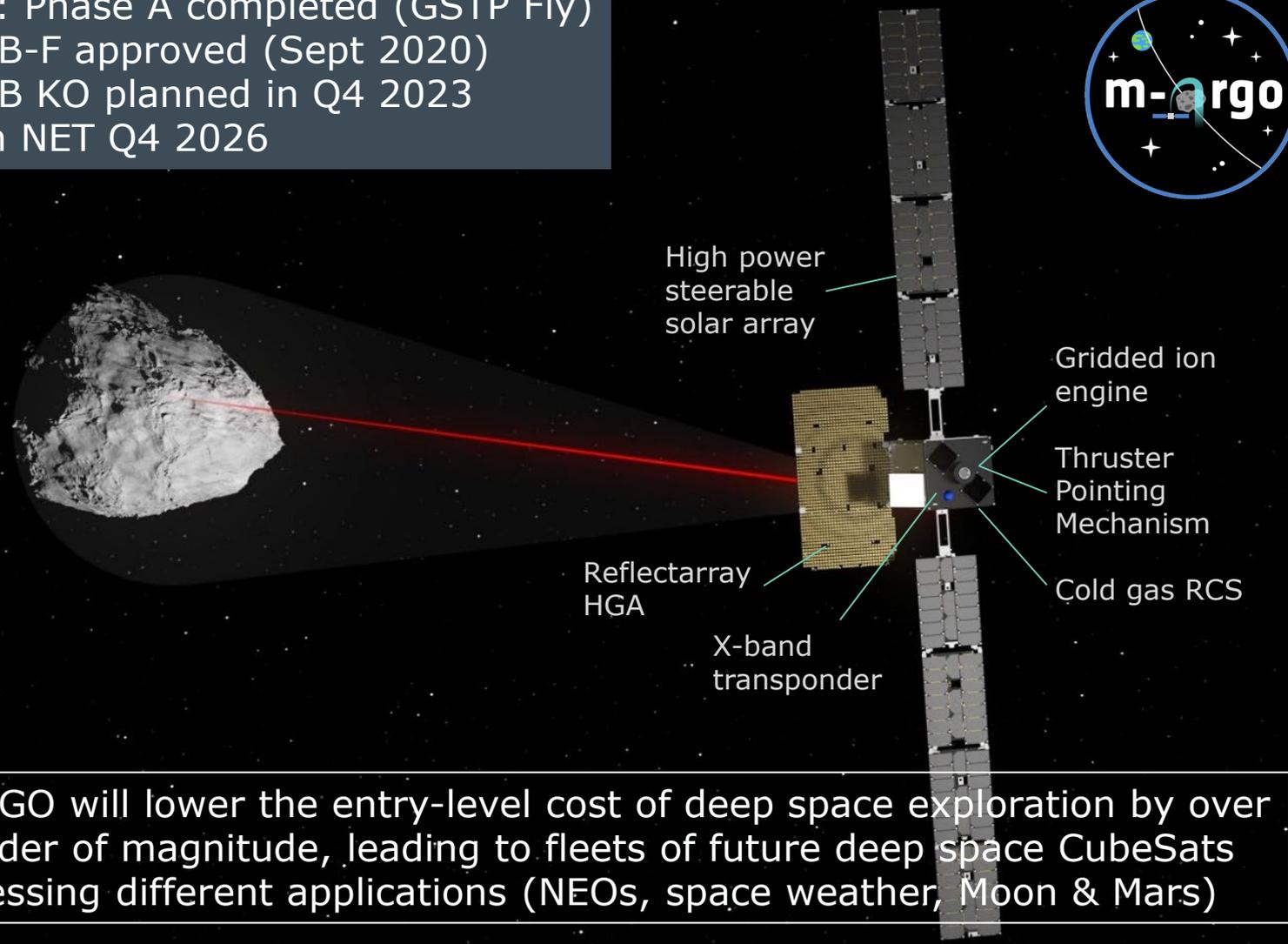
Status: Phase A completed (GSTP Fly)
Phase B-F approved (Sept 2020)
Phase B KO planned in Q4 2023
Launch NET Q4 2026

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



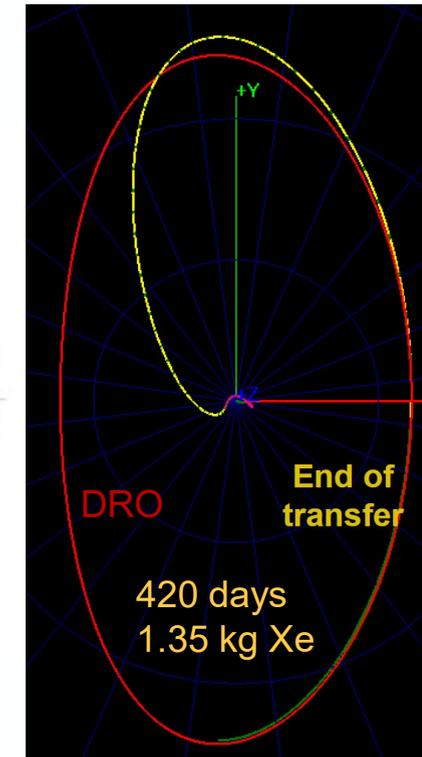
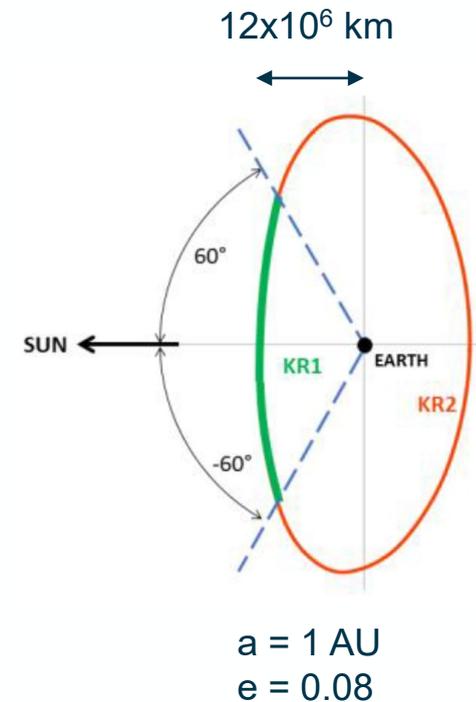
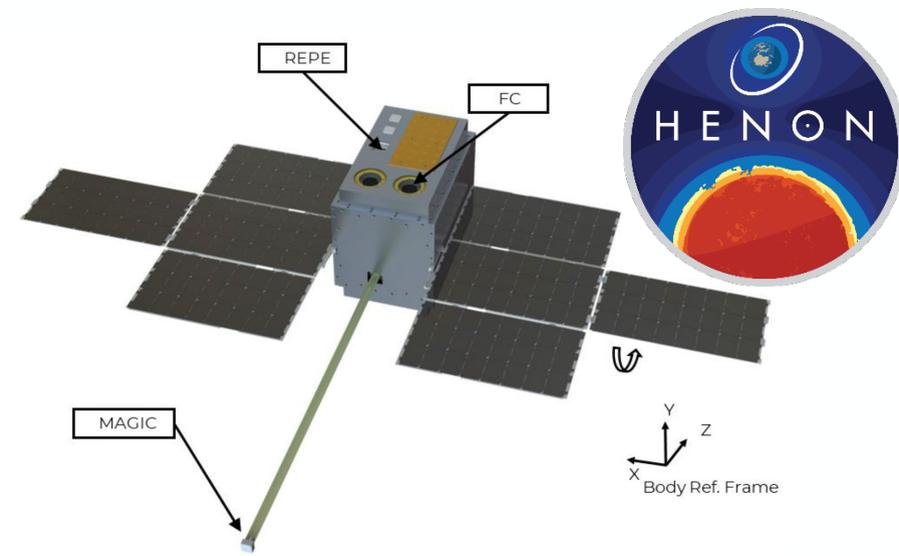
M-ARGO will lower the entry-level cost of deep space exploration by over an order of magnitude, leading to fleets of future deep space CubeSats addressing different applications (NEOs, space weather, Moon & Mars)

M-ARGO Mission Phases



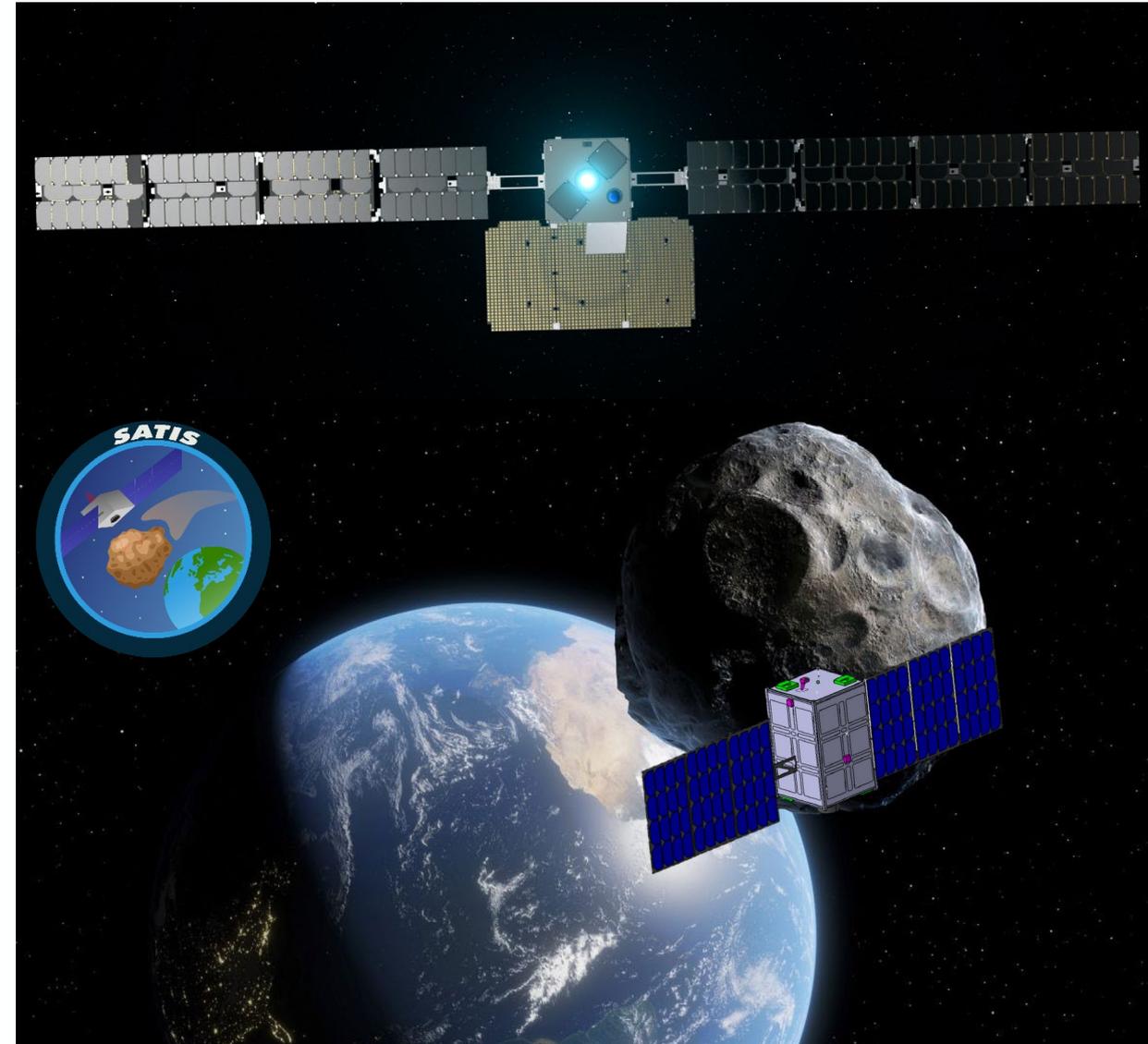
HENON Space Weather Warning Mission

- 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)

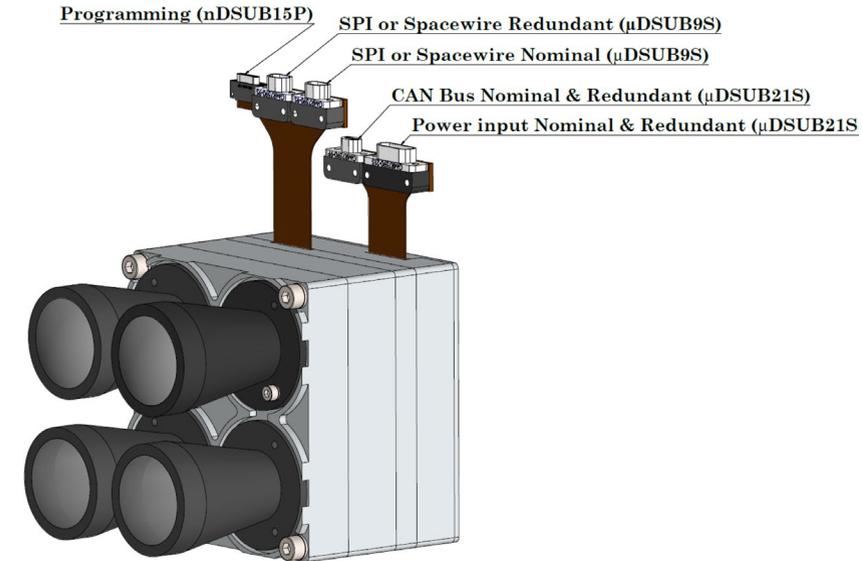


Key technologies

Enabling stand-alone deep space missions

Payload for NEO In-Situ Resources Characterisation

- 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

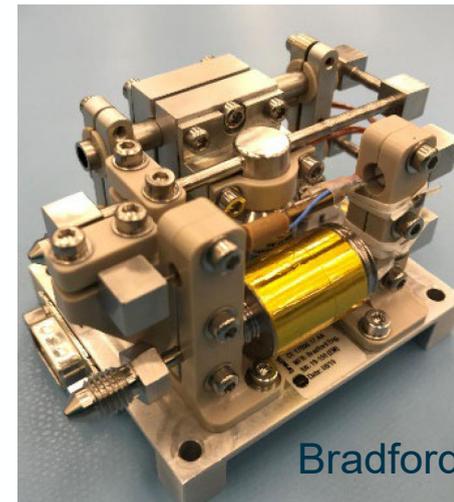
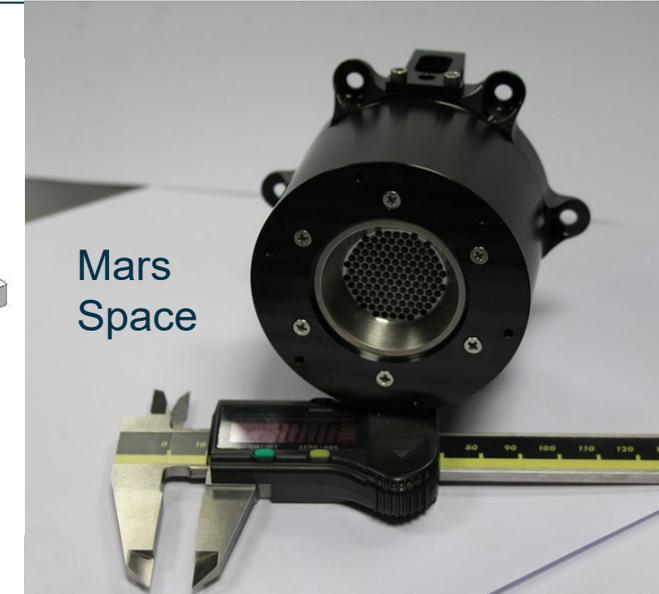
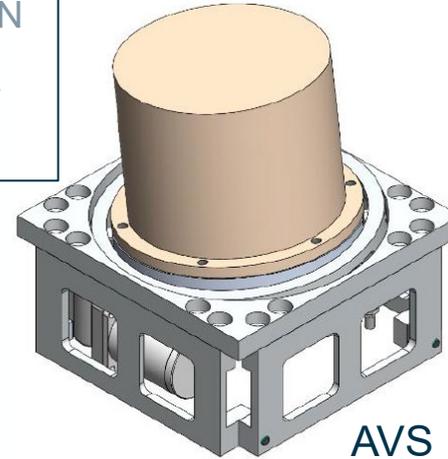


Pixels	2048 x 2048	640 x 512	640 x 512	320 x 256
Spectral range (nm)	500-900	850-1250	1200-1600	1700-2300
No. of bands	10	16	16	12
Spatial resolution (cm/pix) @ 1800 m	9.9	30	30	36
Spatial resolution (cm/pix) @ 550 m	3	9.2	9.2	11
Spatial resolution (cm/pix) @ 275 m	1.5	4.6	4.6	5.5
Bit Mode (bit/pix)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

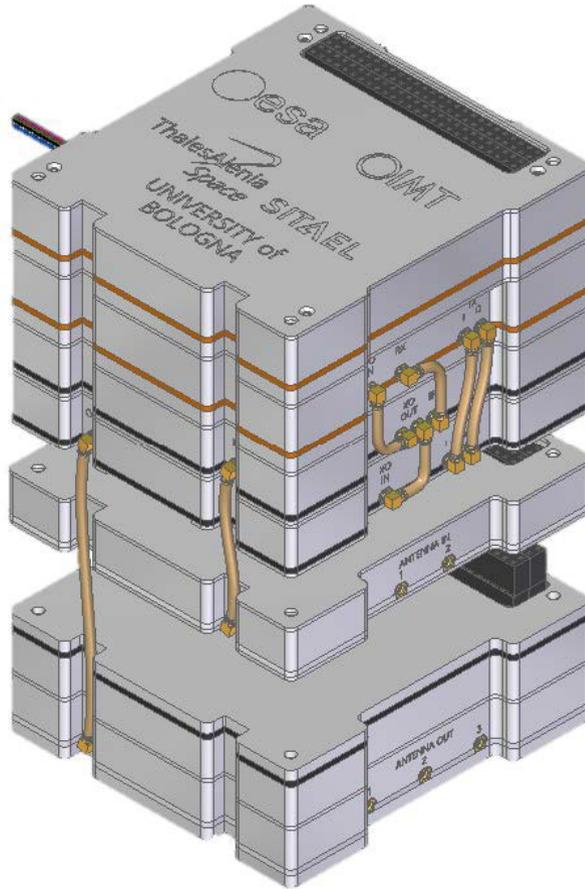
Thrust: 0.8 – 2.2 mN
Isp: 3250 – 3600 s
Power: 80 – 130 W
I_{tot}: >90 kNs



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

X-band Deep Space Transponder

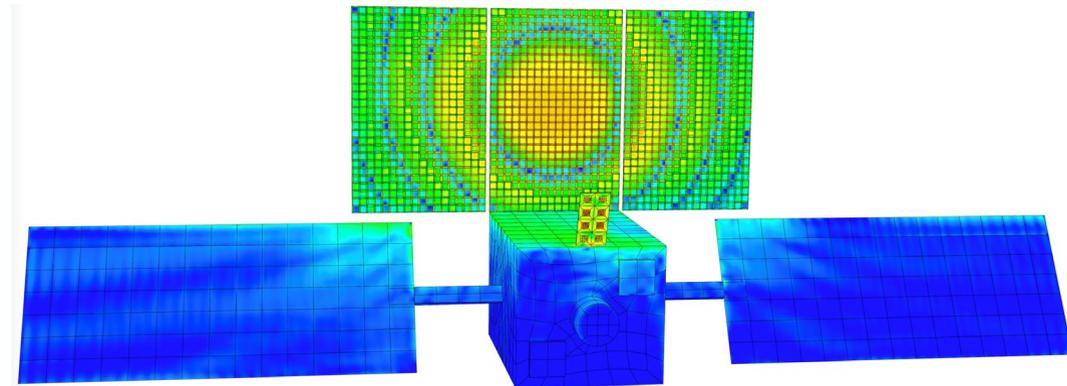
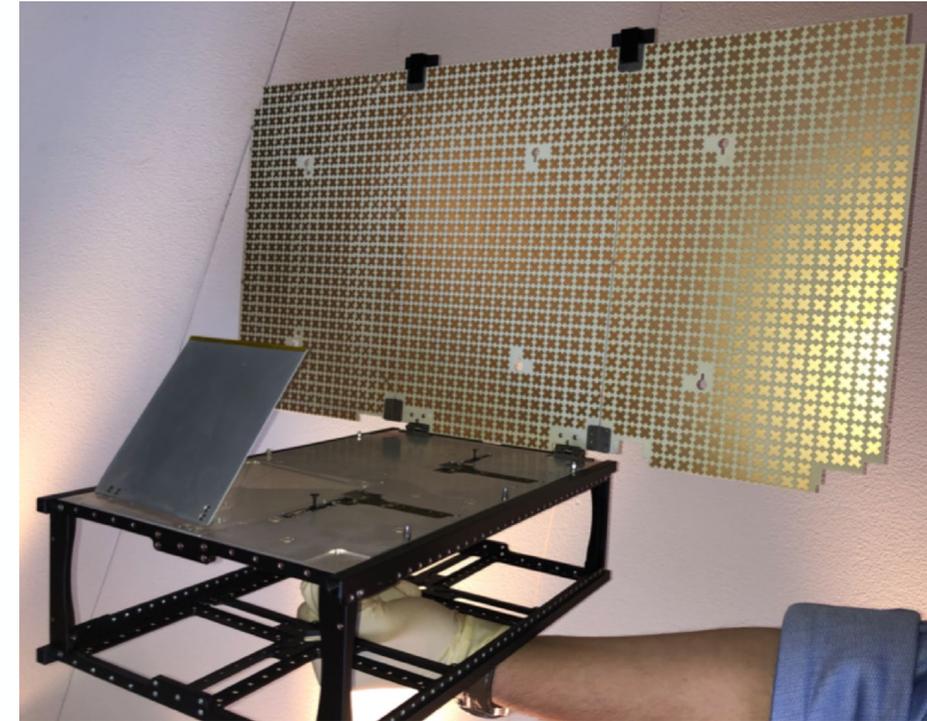
- Programme: GSTP Develop
- Prime: IMT (IT)
- Sub-co: TAS-I, Sitael, Uni. Bologna (IT)
- Functions:
 - TM/TC
 - Ranging & Doppler
 - Radio science
- Target TRL: 6 (EM functional, EMC, perf. & environmental tests)
- Status: EM testing ongoing, to be completed in Q3 2023



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 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

X-band Reflectarray High Gain Antenna

- Programme: GSTP Develop
- Prime: TICRA (DK) - RF
- Sub-co: GomSpace (DK) - mechanical
- Scope: EQM development
- Specs:
 - High gain transmit (28.5 dBi)
 - High gain receive (24 dBi)
 - RHCP, mass <1 kg
- Target TRL: 7 (then IOD in LEO)
- Status:
 - EQM testing completed
 - RF & panel/HDRM mechanical qualification successful
 - hinge delta-qualification planned



Solar Array Drive Assembly

- 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)

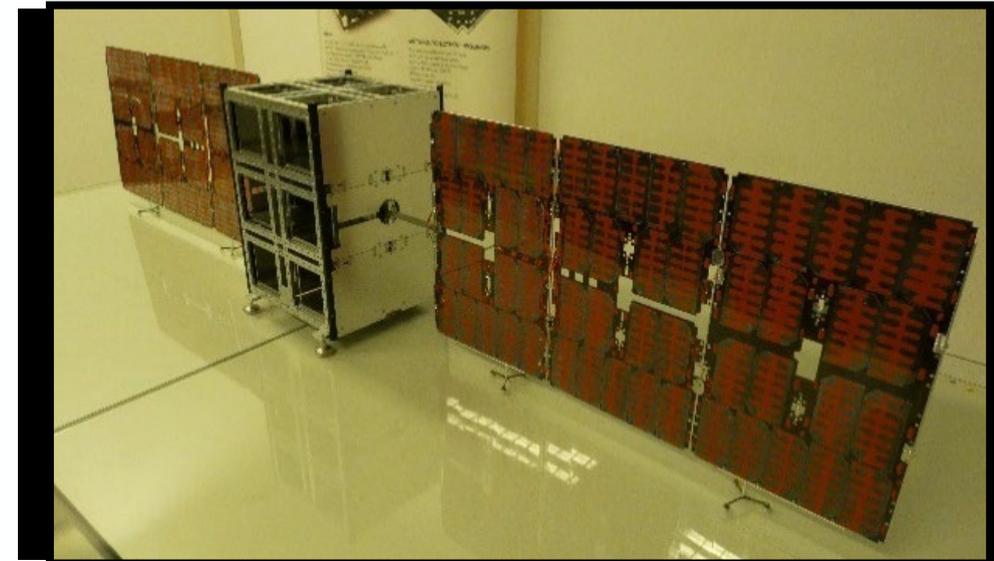
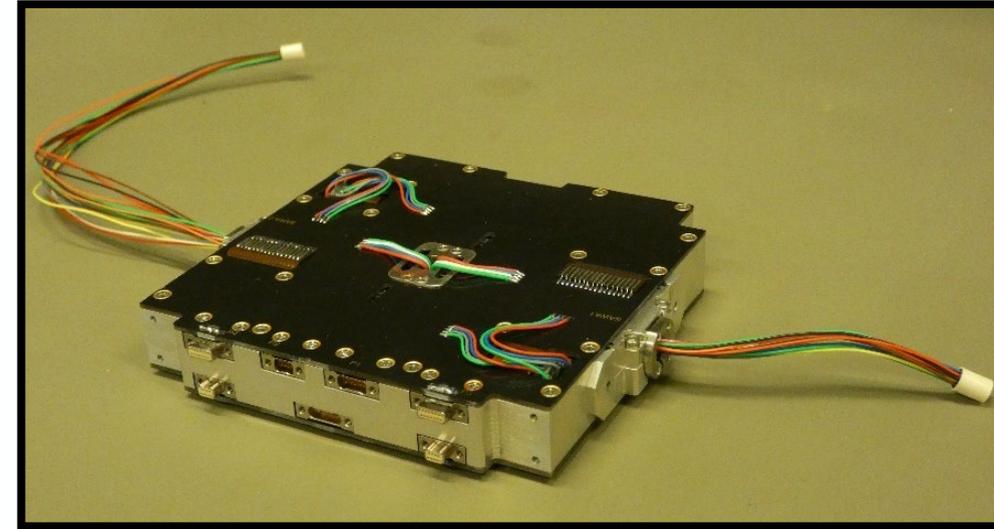
Expandable to 190 W
(5 panels each wing)

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



- First wave of interplanetary CubeSats has started a new era of truly low-cost missions
 - reaching a variety of destinations: Moon, Mars and asteroids
 - operating in the harsh cislunar & deep space environment: for several months (so far)
 - demonstrating utility: as part of larger missions and as stand-alone missions
- First wave has paved the way for an even more ambitious second wave:
 - focussing on achieving relevant science & exploration objectives
 - operating for longer durations at destinations with increased reliability & availability
 - demonstrating higher performance at low cost with larger 12U/16U platforms
- ESA playing its part in pushing the boundaries of this expanding frontier:
 - first ESA interplanetary CubeSats set to launch in 2024 on the Hera mission to Didymos
 - innovative stand-alone missions now in preliminary design phase (launch 2026-27)
 - leveraging key enabling technologies developed in ESA Technology Programme