# CubeSats: State-of-the-art and future potential for small low-cost science missions

Roger Walker (IOD CubeSat lead)
Directorate of Technology, Engineering & Quality, ESA

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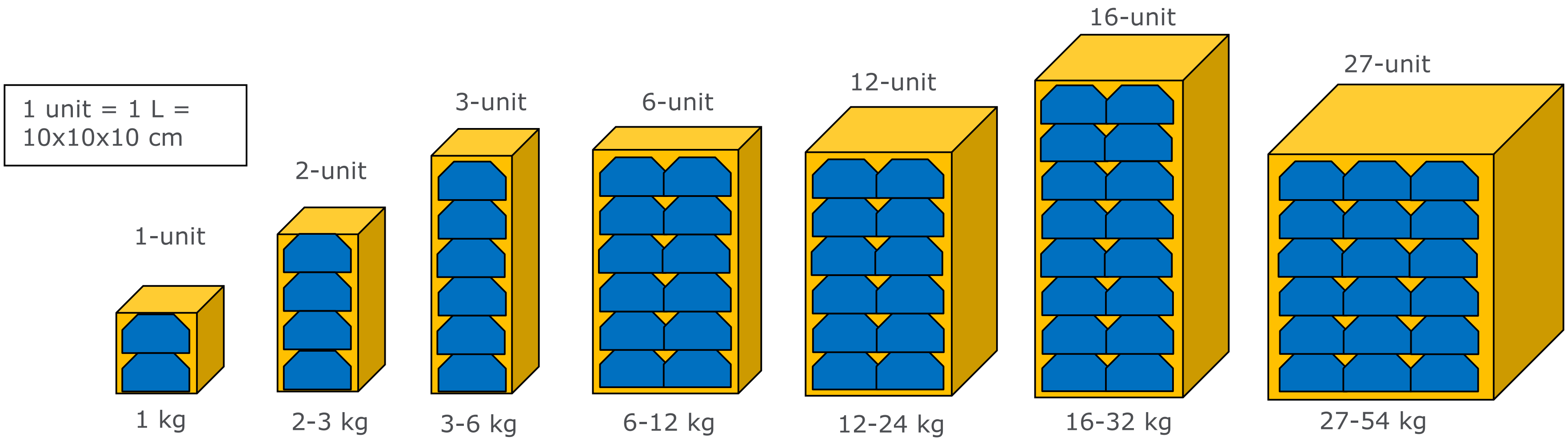
1. CubeSat Technical & Programmatic Overview
2. Current technology state-of-the-art & ESA tech demo missions
3. Near-term technology developments & upcoming demonstration missions
4. Examples of potential future small low-cost science missions

CubeSat Technical & Programmatic Overview

# WELCOME TO NANO-WORLD

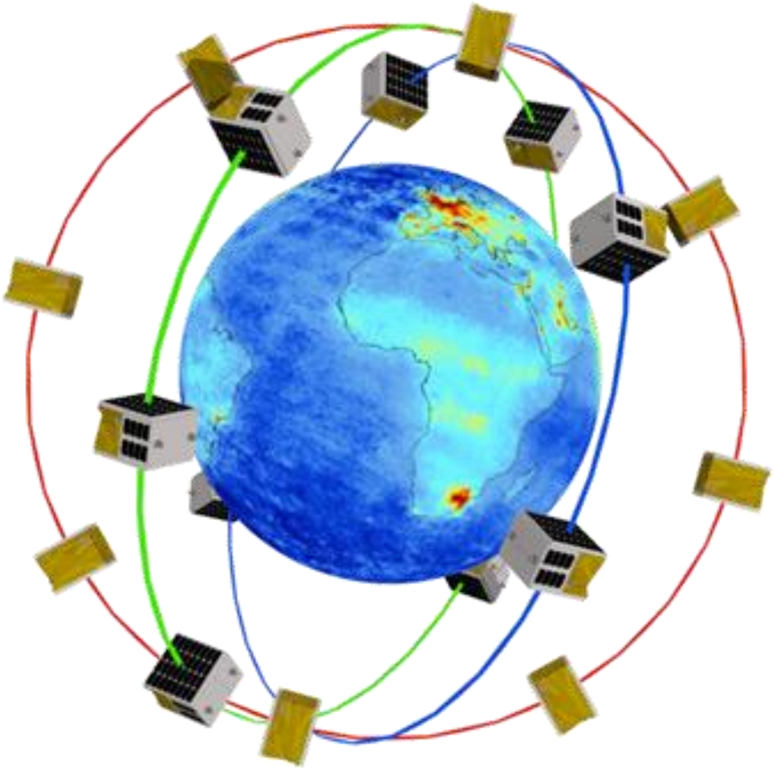
# What are CubeSats?

- Small satellites of standardised external cubic unit dimensions launched inside a container



# Why CubeSats?

- Factor 10 reduction in cost
- Fast to develop (1-3 years)
- Driver for miniaturisation
- Ideal for technology in-orbit demonstration (IOD)
- Increasing space system engineering capabilities of New Member States
- Enabling for highly distributed systems
- Unique applications in constellations & swarms



# IOD CubeSat mission implementation in GSTP

## >16 MEuro in ESA GSTP FLY Element since 2013 for 12 IOD CubeSat missions

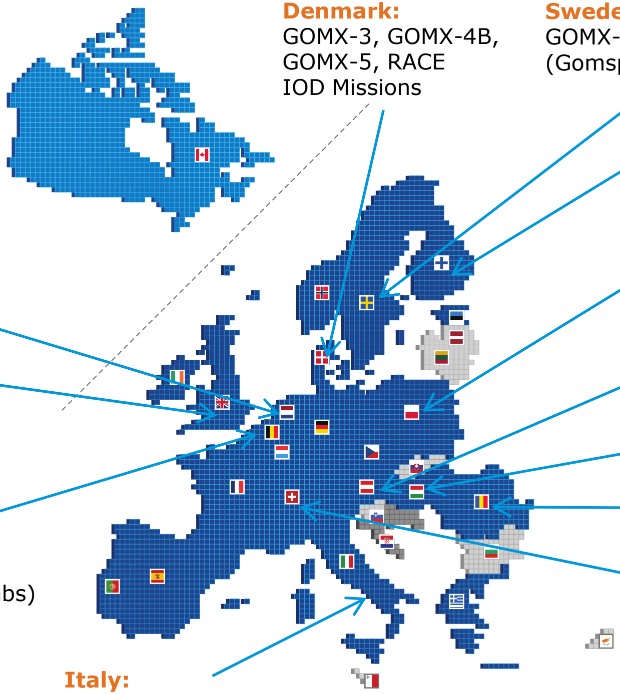
**Netherlands:**
Star tracker devt & TFO,
S-band radio devt
(ISISpace),
HyperScout TFO (Cosine)

**United Kingdom:**
PICASSO p/f (Clyde Space)
QARMAN s/w (Bright
Ascension)
RADCUBE magnetometer (ICL)

**Belgium:**
QARMAN (VKI)
PICASSO (BISA)
SIMBA (RMIB, KUL)
PROBA V Companion (Aerospacelabs)
IOD Missions

**Denmark:**
GOMX-3, GOMX-4B,
GOMX-5, RACE
IOD Missions

**Sweden:**
GOMX-4B Propulsion
(Gomspace SE)



**Italy:**
CubeSat dispenser

**Finland:**
PICASSO Multi-spectral imager (VTT)
Solar X-ray Flux Monitor IOD mission
(Reaktor Space)

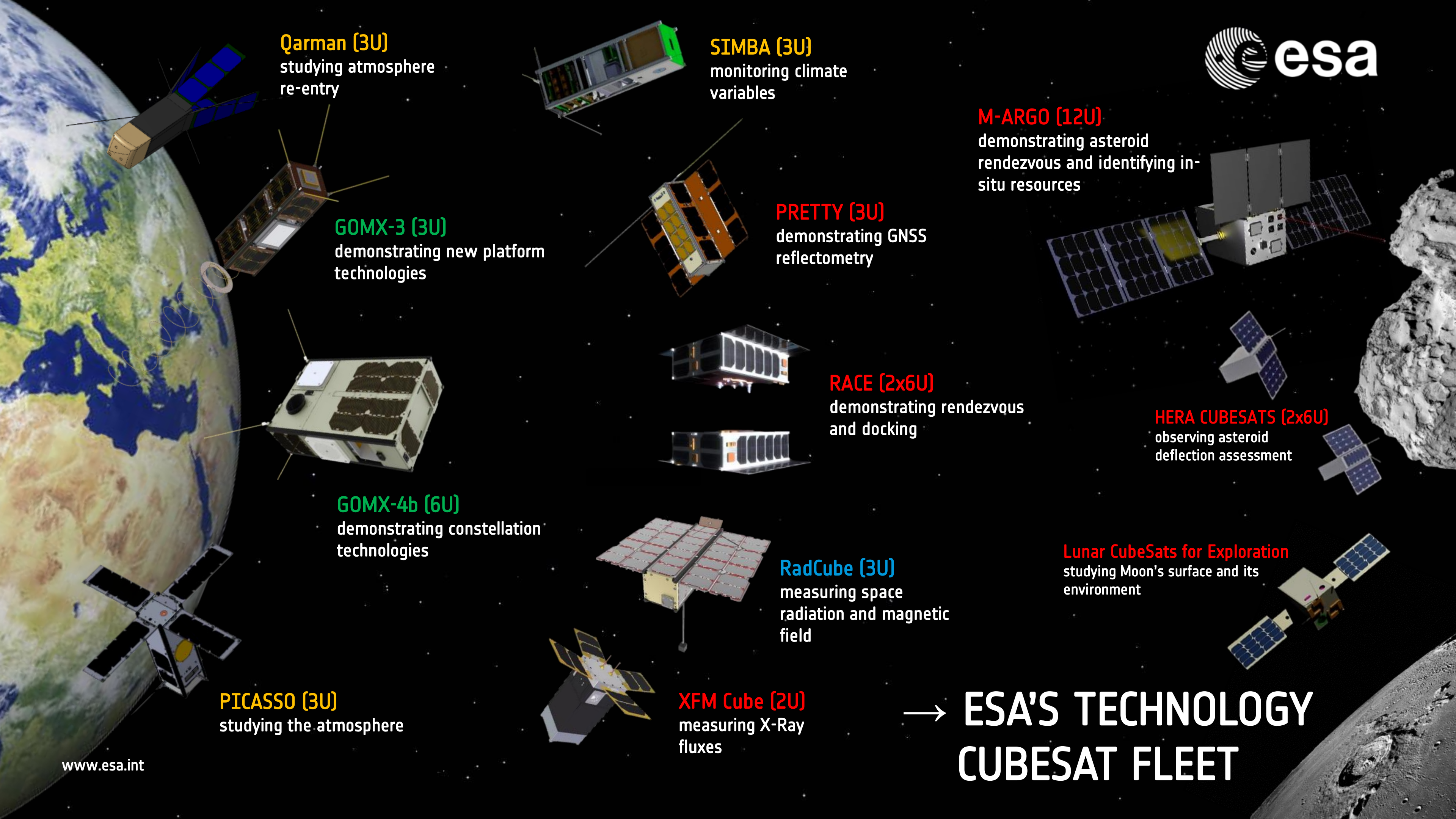
**Poland:**
OPS-SAT (GMV OBSW, SRC/CreoTech TMTC)
RACE GNC (GMV)
RADCUBE mag boom (Astronika)

**Austria:**
OPS-SAT IOD Mission
(TU Graz tech lead/SE, Magna Steyr)
PRETTY IOD Misssion
(RAUG, TU Graz, Seibersdorf)

**Hungary:**
RadCube IOD mission
(C3S/MTA EK)

**Romania:**
RACE GNC testing

**Switzerland**:
RACE viscam (MICOS) &
docking mech. (Almatech)



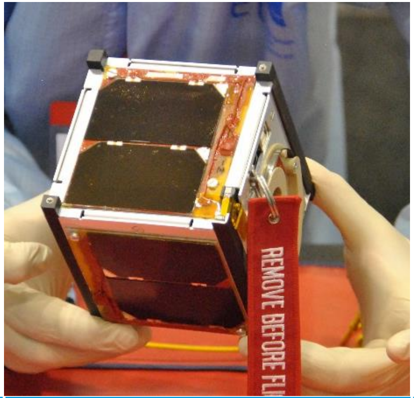
esa
Qarman (3U)
studying atmosphere re-entry
SIMBA (3U)
monitoring climate variables
M-ARGO (12U)
demonstrating asteroid rendezvous and identifying in-situ resources
GOMX-3 (3U)
demonstrating new platform technologies
PRETTY (3U)
demonstrating GNSS reflectometry
RACE (2x6U)
demonstrating rendezvous and docking
HERA CUBESATS (2x6U)
observing asteroid deflection assessment
GOMX-4b (6U)
demonstrating constellation technologies
Lunar CubeSats for Exploration
studying Moon's surface and its environment
RadCube (3U)
measuring space radiation and magnetic field
PICASSO (3U)
studying the atmosphere
XFM Cube (2U)
measuring X-Ray fluxes
→ ESA'S TECHNOLOGY CUBESAT FLEET
www.esa.int

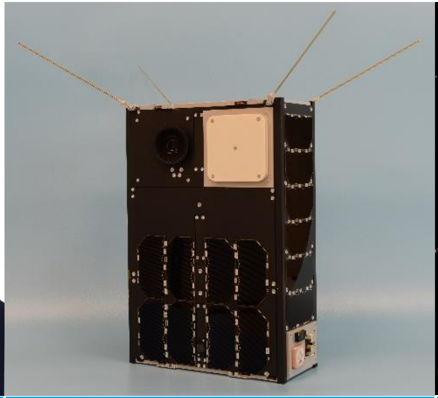
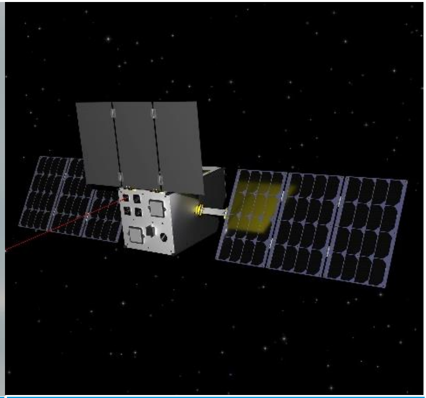
Current technology state-of-the-art & ESA tech demo missions

# PREPARING FOR UTILITY

# The Evolution of the CubeSat

## Rapid growth in size & advances in performance for real missions



| Size | 1U | 3U | 6U | 12U |
|---|---|---|---|---|
| Mission | Vega Edu CubeSats | GOMX-3 tech demo | GOMX-4B tech demo | M-ARGO tech demo |
| Power (max) | 3 W | 6 W | 12 W | 120 W |
| Pointing acc. | 25 deg (2-axis) | 2 deg (3-axis) | 0.2 deg (3-axis) | 0.2 deg (3-axis) |
| Downlink | 9.6 kbps (LEO UHF) | 3 Mbps (LEO X-band) | 1 Mbps @ 3300km (ISL) | 10 kbps (1 AU X-band) |
| Delta-V | 0 m/s | 0 m/s | 10 m/s | 3750 m/s |
| Launch | 2012 | 2015 | 2018 | 2022 |

# ESA’s First Technology CubeSat in Space

**Project: GOMX-3**

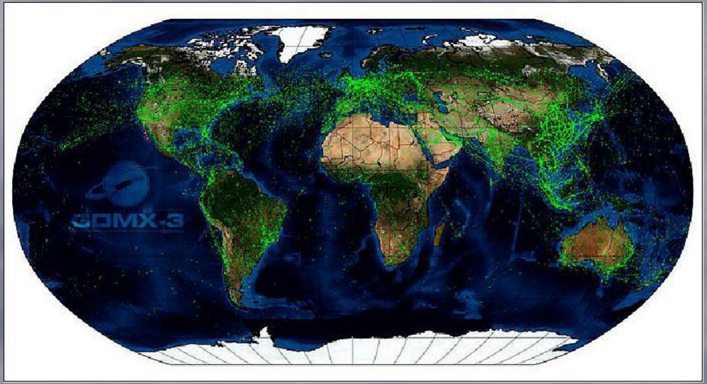
Contractor: GomSpace DK

Platform: 3U CubeSat (3 kg)

Duration: 1 year KO to flight readiness

Deployed from ISS: 5 October 2015

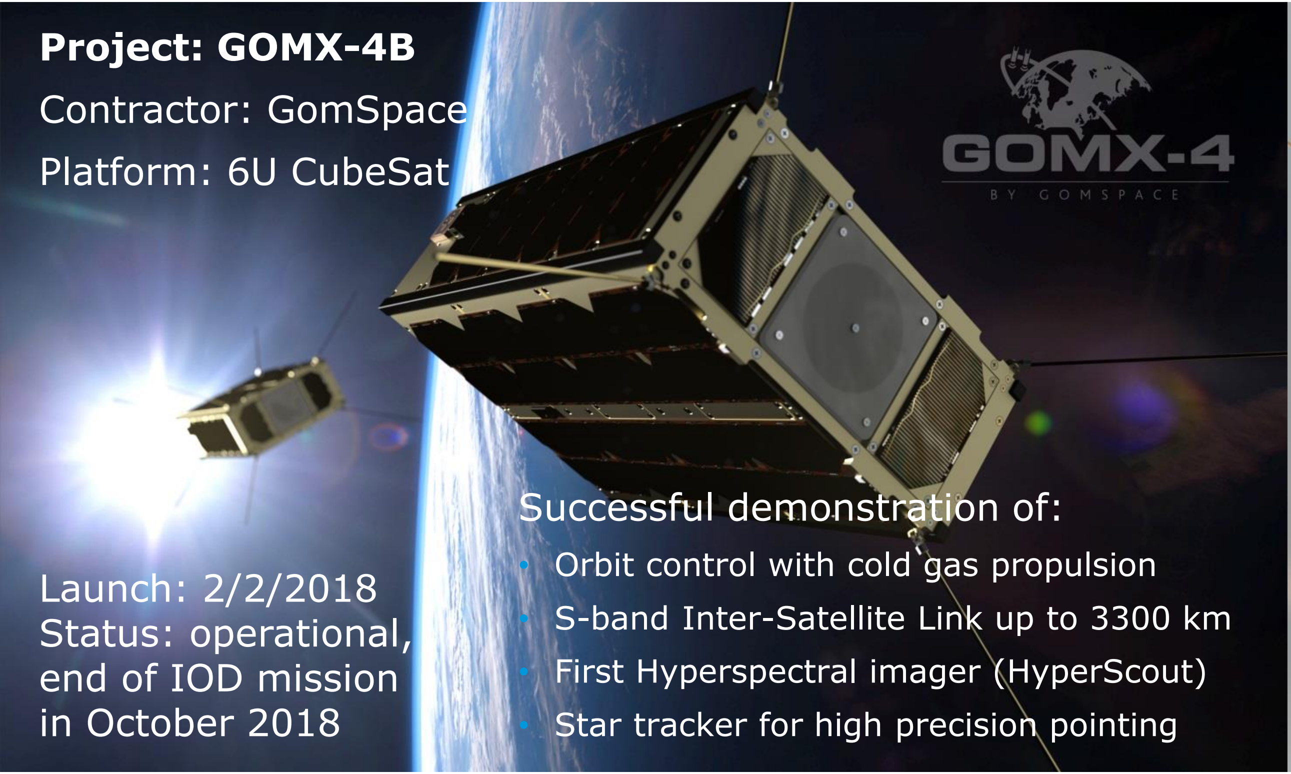
Status: 1 year of operation, mission success




Achievements:

- 3-axis pointing acc. <2° (25° eclipse)
- X-band Downlink @ 3 Mbps
- Reconfigurable software-defined radio
- GEO Telecom L-band signal analysis
- ADS-B Aircraft tracking from a CubeSat
- Global wind data from ADS-B messages

# IOD for 1st generation LEO constellations




**Project: GOMX-4B**

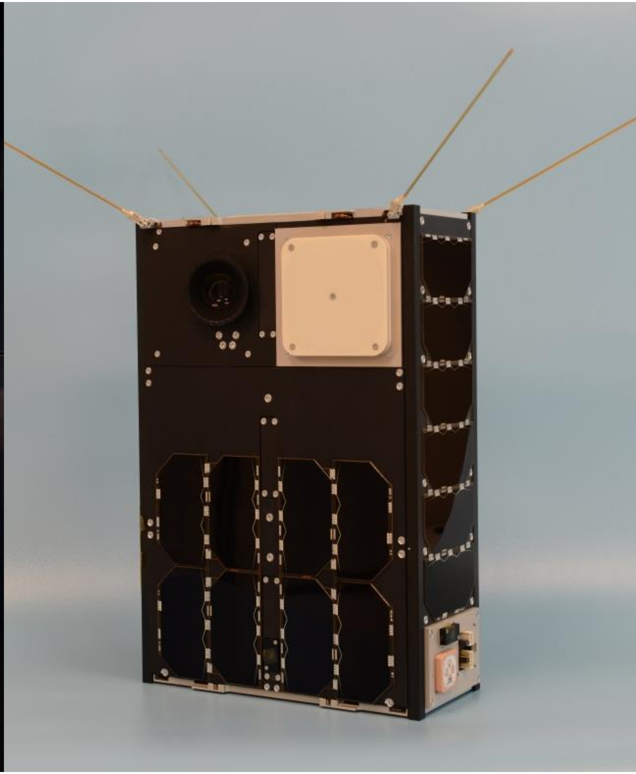
Contractor: GomSpace

Platform: 6U CubeSat

Launch: 2/2/2018
Status: operational, end of IOD mission in October 2018

Successful demonstration of:

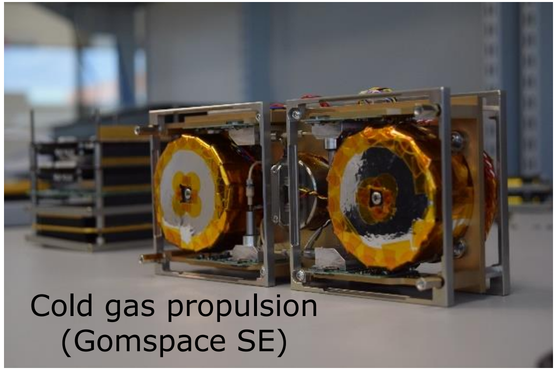
- Orbit control with cold gas propulsion
- S-band Inter-Satellite Link up to 3300 km
- First Hyperspectral imager (HyperScout)
- Star tracker for high precision pointing



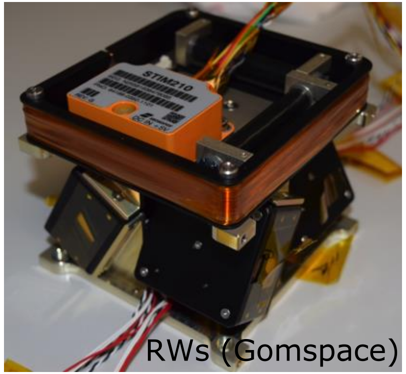
# GOMX-4B AOCS Overview

Full 3-axis controllable AOCS

- Sensors:
  - 6 Coarse Sun Sensors
  - 6 Fine Sun Sensors
  - Gyroscope
  - Magnetometer
  - GNSS receiver
- Actuators:
  - 3-axis magnetorquers
  - 4 RWs in redundant setup
  - Butane Propulsion unit



Cold gas propulsion (Gomspace SE)



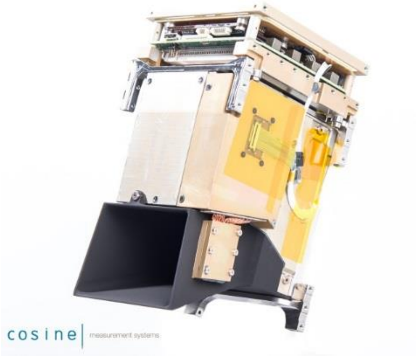
RWs (Gomspace)

Without STR:
AKE <1° (1σ)
APE <1.2° (13° ecl.)

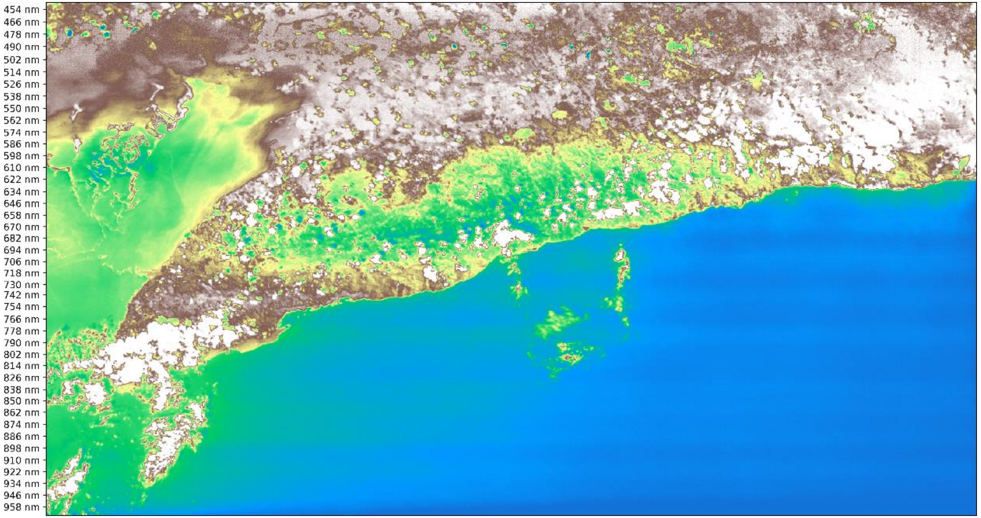
With STR (est.):
AKE 30″ (1σ)
APE <0.2°

Star tracker (ISISpace NL)

# HyperScout: First CubeSat Hyperspectral imager

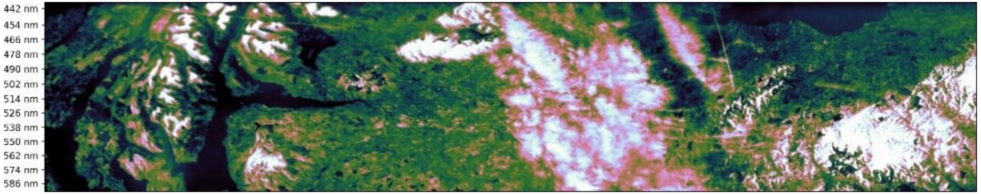



HyperScout Flight Model on GOMX-4B


Cuba

Credit: Cosine




Scotland

Near-term technology developments & key demonstration missions

# PUSHING THE BOUNDARIES

# From AOCS to GNC for Rendezvous & Docking


6 DoF
Cold Gas Propulsion
(Gomspace SE)

↓

Fine relative position/attitude manoeuvres

Vision Based Navigation
(EPFL CH)

↓

Close relative position/attitude estimation

Software-Defined Radio
ISL & GNSS Rx
(Gomspace DK)

↓

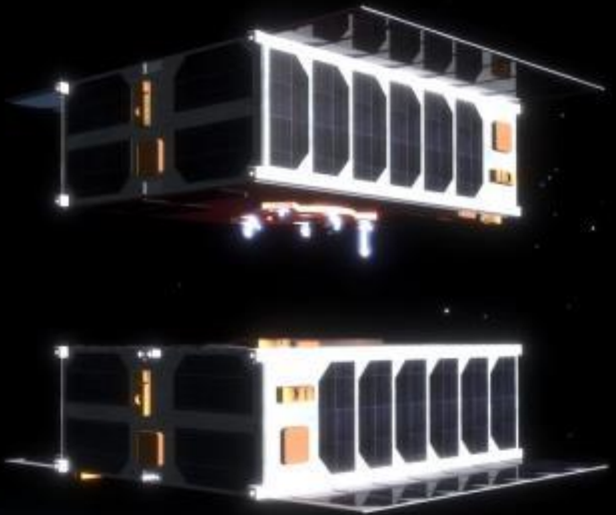
Far relative position/velocity estimation

# Rendezvous Autonomous Cubesats Experiment (RACE)

System demo of:
-Rendezvous & docking
-Target close fly-around

Enabling Tech demo (TRL4):
-6 DoF propulsion
-RelNav sensors (vis, GNSS)
-autonomous GNC
-docking mechanism

Future application:
-autonomous on-orbit assembly of large structures using building blocks



Mission concept:
- two 6U CubeSats
- joined together in 12U POD for launch
- joint commissioning and separation in orbit
- series of docking and fly around trajectories
- testbed for different GNC algorithms

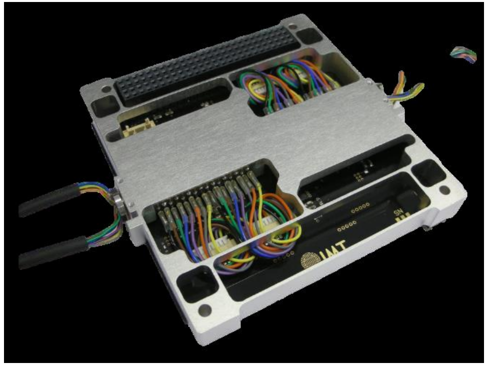
Phase A/B started with GomSpace, GMV, Almatech, Micos

PDR Q4 2019
Launch Q4 2021

RACE will open up the path to completely new space system architectures based on aggregation that are not feasible or cost-effective today due to launcher fairing constraints

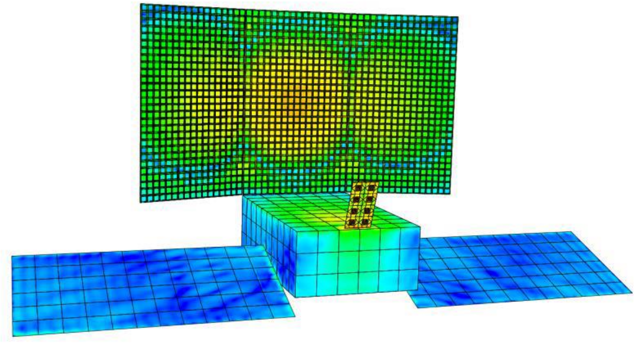
# GSTP-funded Technologies Enabling New Missions

Ongoing Developments



Solar Array Drive Assembly
(IMT Italy)

High power generation
(120 W)



Reflectarray Flat Antenna
(TICRA/Gomspace Denmark)

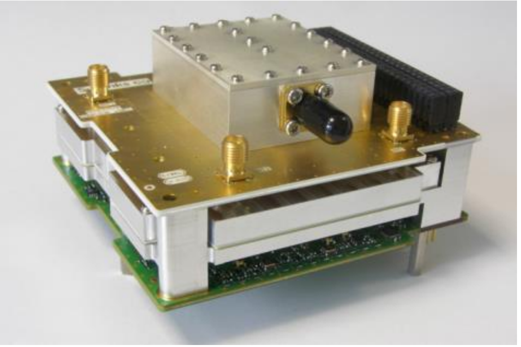
High RF gain
(29 dBi)

Cold Gas RCS
(Gomspace Sweden)

Reaction control in
deep space

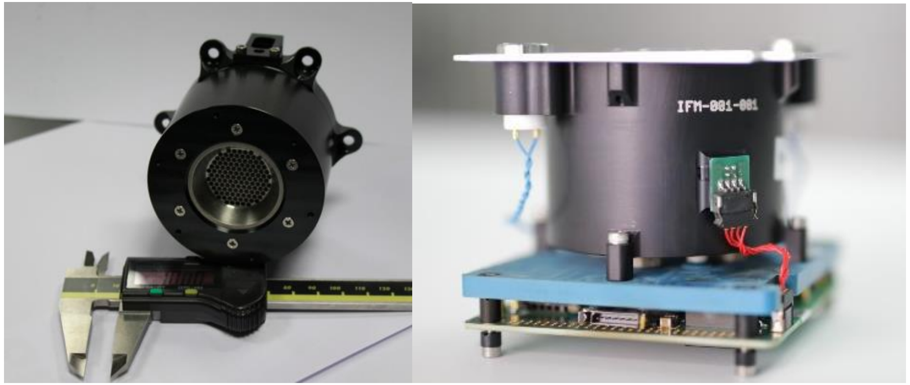
# GSTP-funded Technologies Enabling New Missions

Planned Near-term Developments



Nanosat X-band TT&C
transponder EM

Deep space
communication & ranging
(10 kbps @ 1AU)

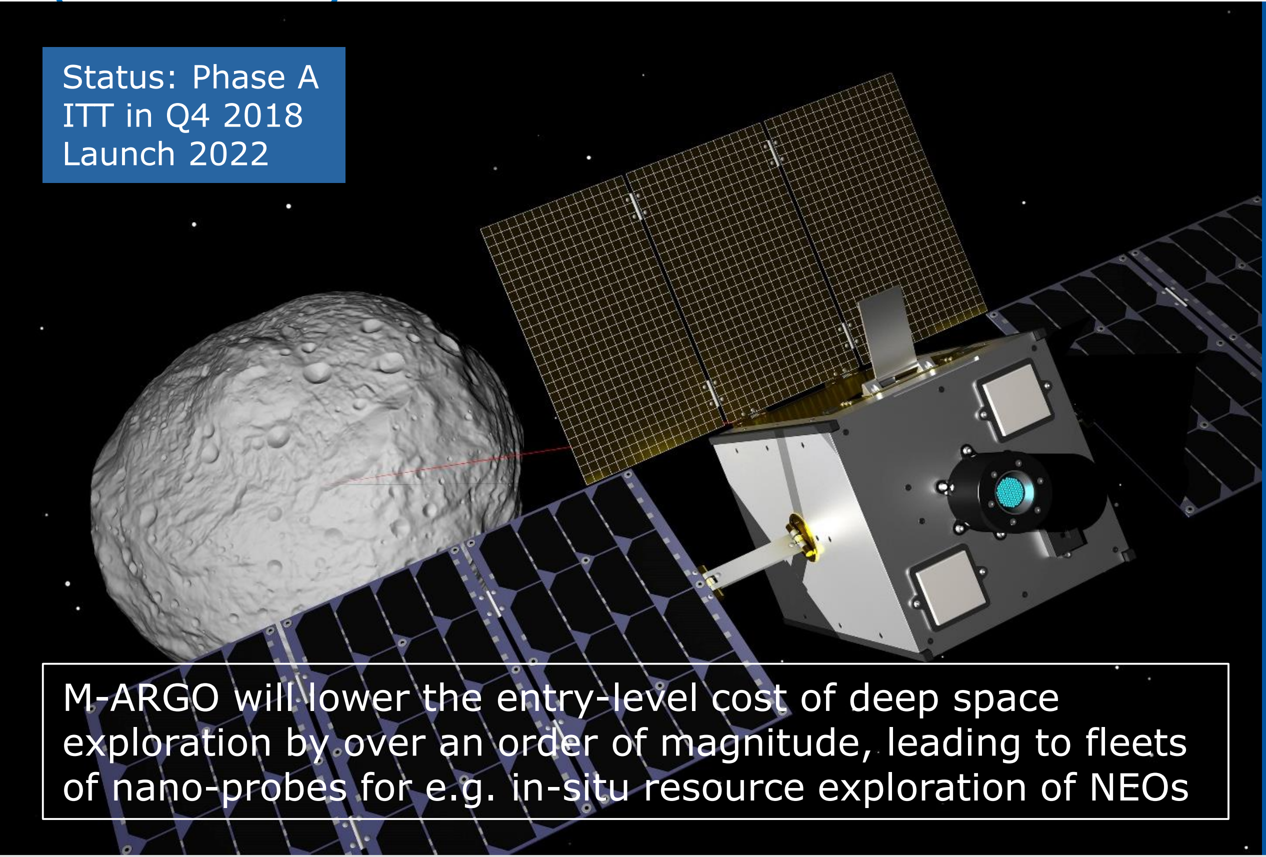



High specific impulsion
electric propulsion system

LEO re-/de-orbiting
Deep space manoeuvres
(3750 m/s @ Isp 3000s)

# Miniaturised Asteroid Remote Geophysical Observer (M-ARGO)

Status: Phase A
ITT in Q4 2018
Launch 2022



M-ARGO will lower the entry-level cost of deep space exploration by over an order of magnitude, leading to fleets of nano-probes for e.g. in-situ resource exploration of NEOs

## Objectives:

- Demonstrate critical technologies & operations for stand-alone deep space CubeSats in the relevant environment
- Rendezvous with a Near Earth Object (NEO)
- Physical characterisation of NEO with a small payload suite for in-situ resource exploration purposes

## Mission concept:

- 12U CubeSat
- piggyback launch to Sun-Earth L2 transfer or lunar swing-by
- parking in L2 halo orbit
- 1-2 year low-thrust interplanetary transfer
- 6-month close proximity ops at NEO target
- 83 different NEO targets accessible

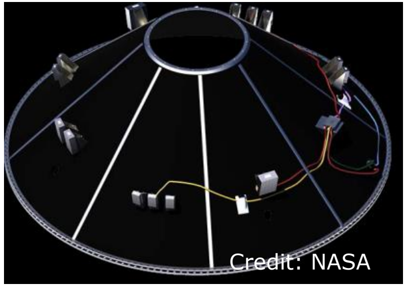
Examples of potential future small low-cost science missions

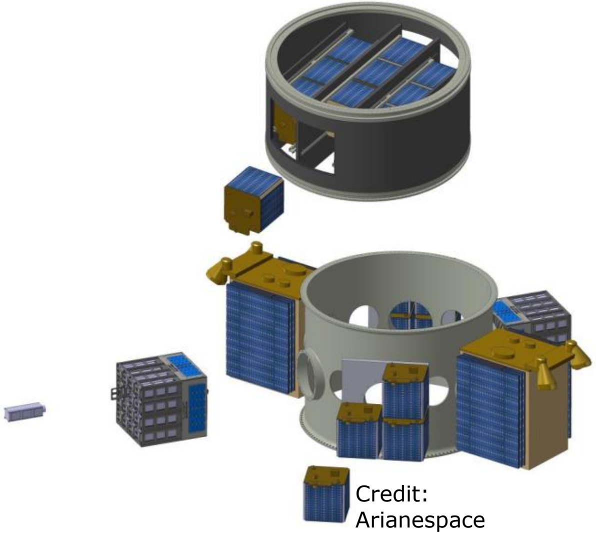
# KEEP IT FOCUSSED

# "Beyond LEO" Science & Exploration

- CubeSats are now being considered for applications beyond low Earth Orbit as piggyback opportunities are arising on both launch vehicles & spacecraft:
  - GTO and Molniya orbit (commercial)
  - NASA SLS/Orion EM flights to the Moon
  - ESA/SSTL Lunar Pathfinder mission to carry CubeSats to lunar orbit and provide comms data delay
  - Ariane 6 launches with excess capacity e.g. to Sun-Earth L2
  - ESA's proposed HERA mission to carry a CubeSat to Didymos NEO

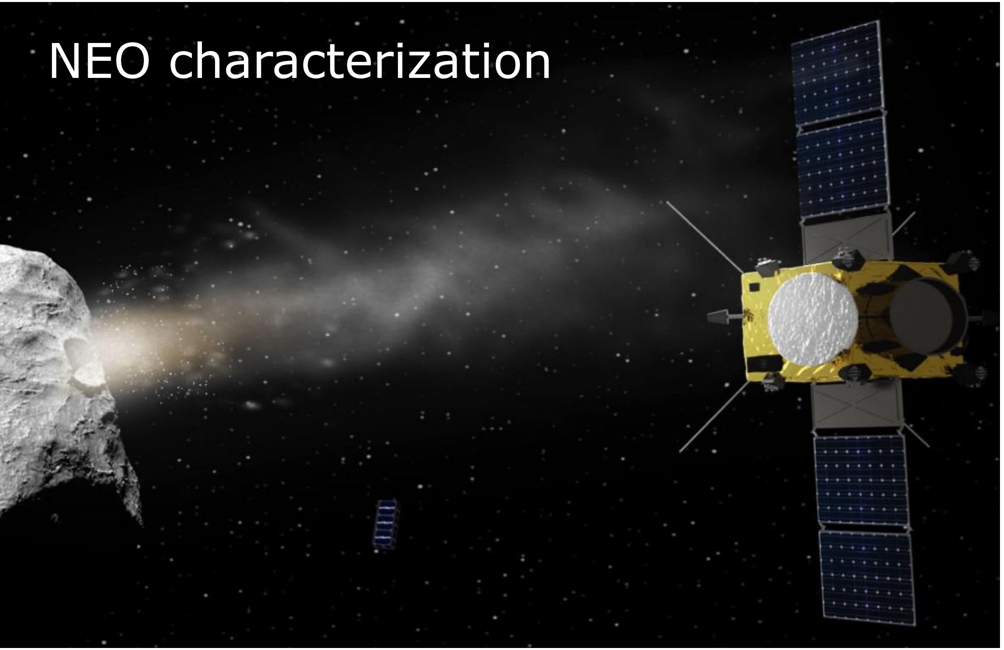
- As for LEO, order of magnitude reduction in entry-level cost is expected to enable distributed systems

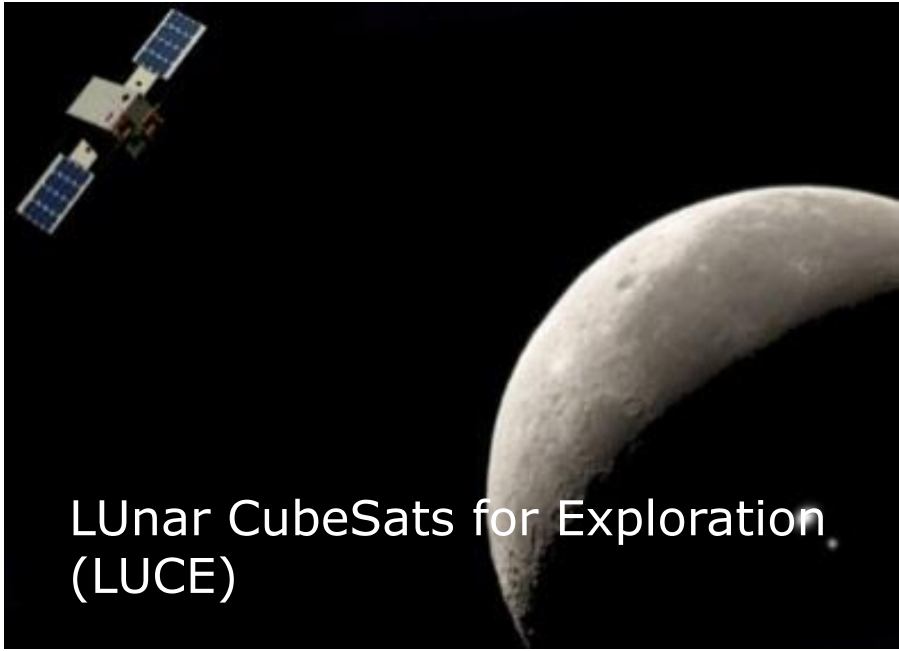

Credit: NASA


Credit: Arianespace

# Mother-daughter architectures at planetary bodies

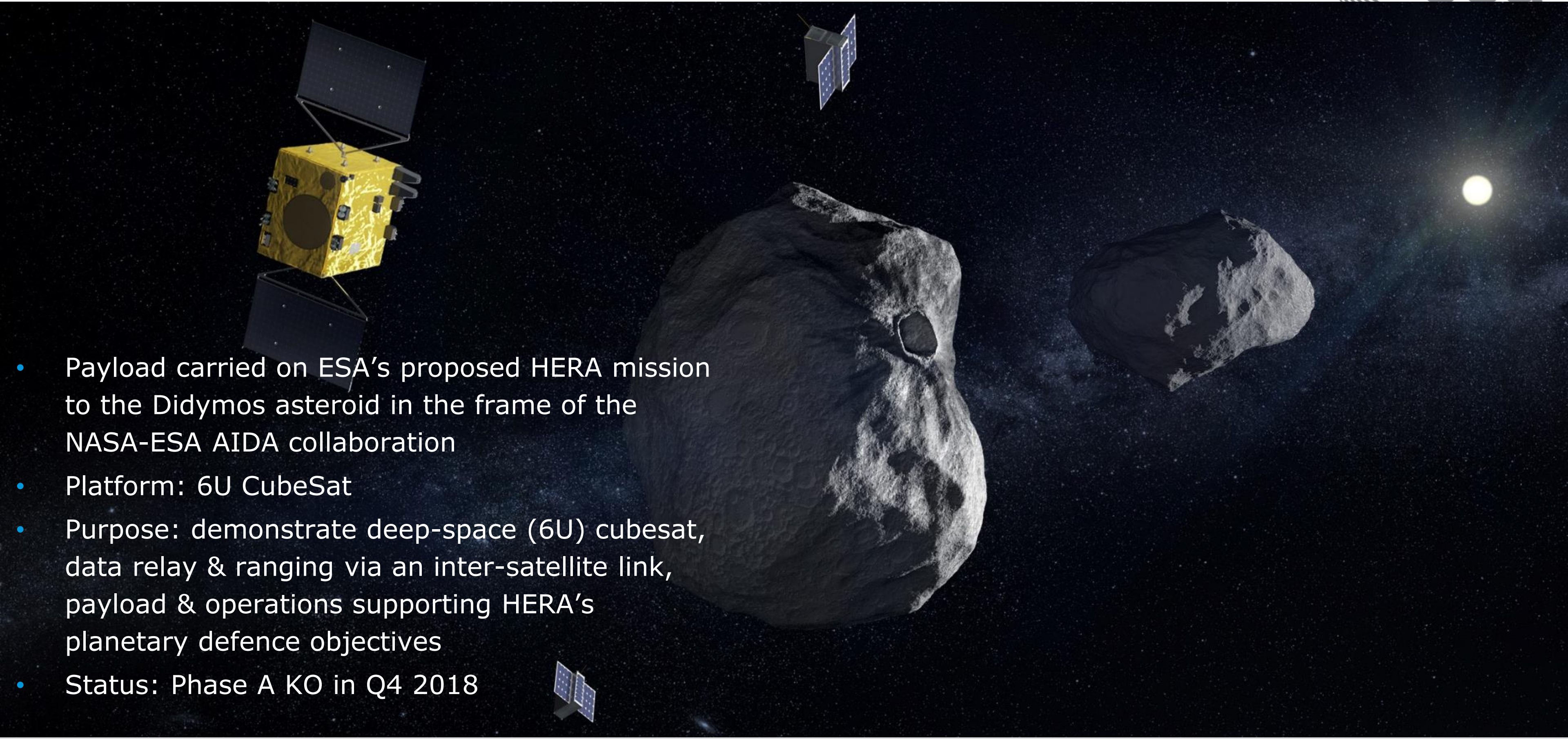
**Deployment of a swarm of CubeSats by a larger mothercraft**



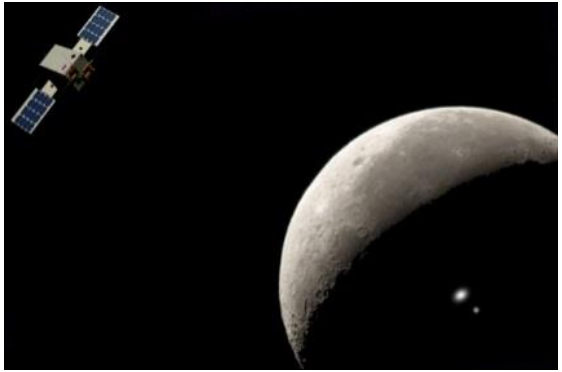

Transportation & data relay provided by larger mothercraft
Deep investigation of a single target body with multi-point measurements

# CubeSats on the HERA mission



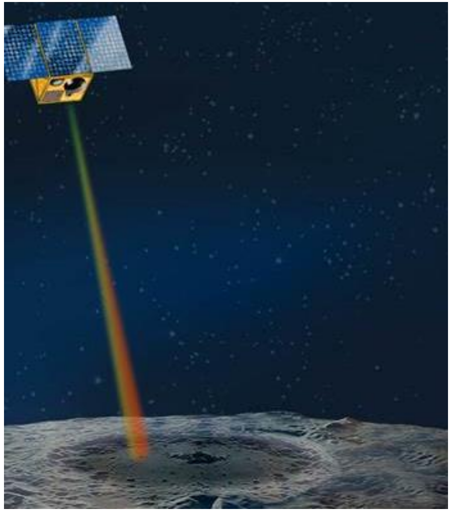
- Payload carried on ESA's proposed HERA mission to the Didymos asteroid in the frame of the NASA-ESA AIDA collaboration
- Platform: 6U CubeSat
- Purpose: demonstrate deep-space (6U) cubesat, data relay & ranging via an inter-satellite link, payload & operations supporting HERA's planetary defence objectives
- Status: Phase A KO in Q4 2018

# LUnar Cubesats for Exploration (LUCE)



**LUMIO (Lunar Meteoroid Impacts Observer)**

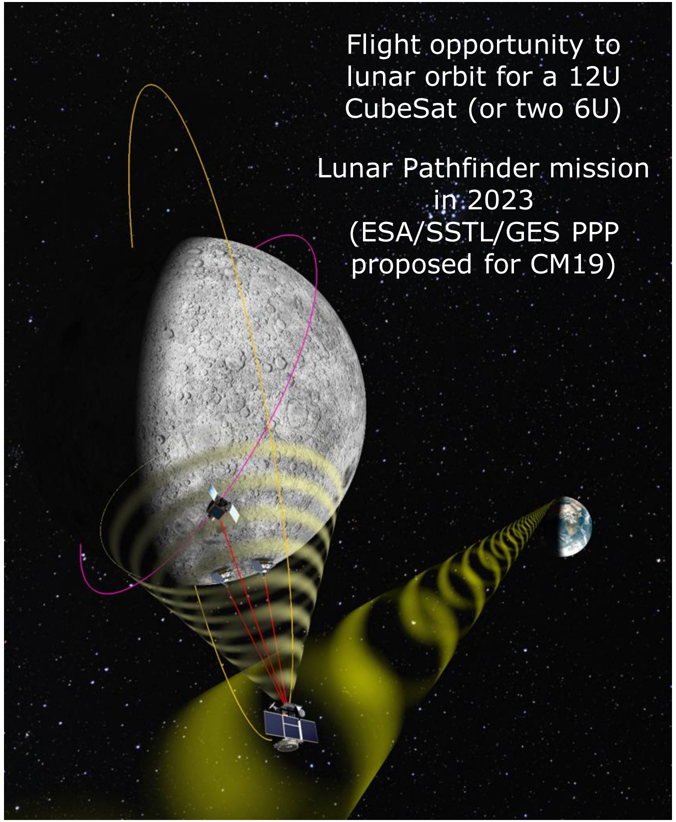
Carrying sophisticated camera to capture flashes of meteoroids impacting the far side



**VMMO (Volatile and Mineralogy Mapping Orbiter)**

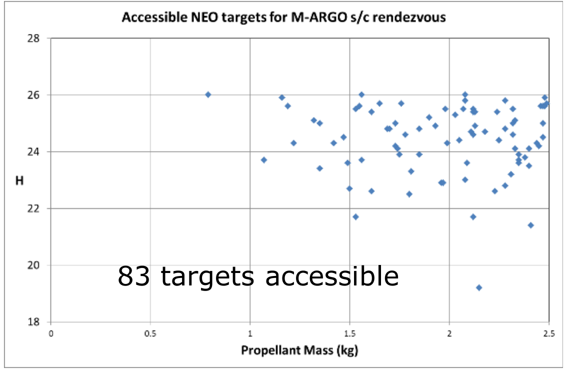
Charting the Moon's water ice in permanently shadowed polar regions using active fibre laser

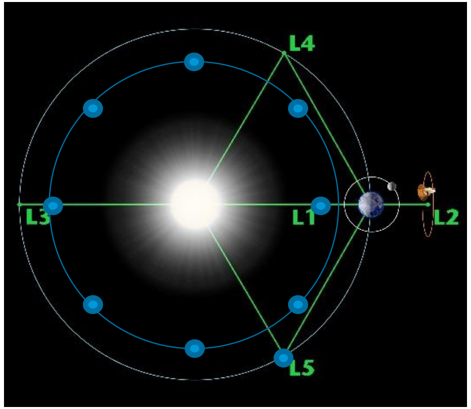
Example concepts studied in GSP Sysnova



# Fleets of Stand-Alone Deep Space Cubesats: a new paradigm in deep space exploration

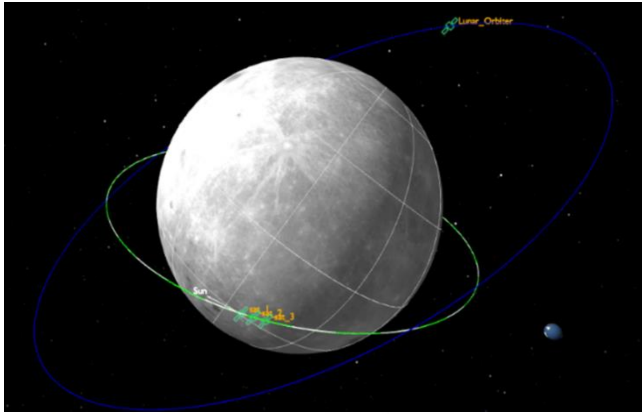
- High potential of technology miniaturisation to cut the entry-level cost of interplanetary missions by <u>an order of magnitude</u>:
    - facilitate entry of new actors to space exploration (government, commercial, PPPs)
    - stimulate low-cost single spacecraft technology demo missions
    - deploy and operate fleets of nano-spacecraft distributed in interplanetary space
- Applications of distributed nano-spacecraft fleets:
    - wide survey of the Near Earth Asteroid population for:
        - science (diversity of early solar system bodies)
        - planetary defence (know your enemy)
        - in-situ resource exploration (prerequisite for exploitation)
    - simultaneous in-situ monitoring of space weather at multiple locations in the heliosphere (L1, L5, inner Earth orbits)

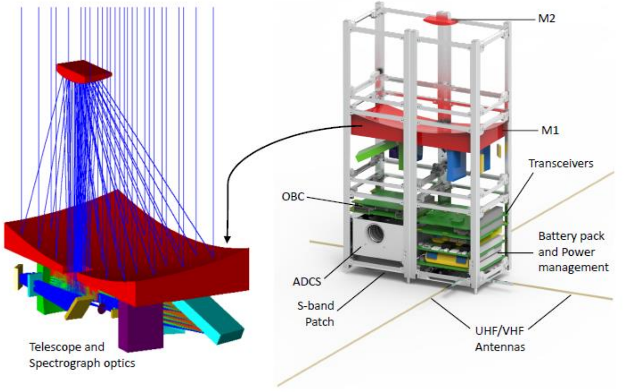


# Astronomy CubeSats(?)

- Low-frequency Radio Interferometric Array
    - Studied concepts: OLFAR, DARIS etc
    - 1 large mother s/c + swarm of 10-50 small daughter s/c, loose formation, deployed in lunar orbit or Sun-Earth L2 halo orbit, <20 MHz frequencies
    - Enabling tech: high-rate inter-satellite links with ranging, high perf. signal processing, software-defined radio, deployable 3m booms
- Optical Spectrometer
    - Studied concepts: CubeSpec
    - Long-term follow-up observations of bright stars
    - UV/VIS/VNIR wavelengths
    - Enabling tech: arcsecond line of sight pointing (piezo-electric), high thermal stability (10 mK)
    - proven on NASA JPL Asteria mission



# THANK YOU

Roger Walker
ESA/ESTEC
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel: +31 71 565 3349
e-mail: roger.walker@esa.int