SMALLSAT TECHNOLOGIES, FUTURE APPLICATIONS & IOD MISSION ROADMAP

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ESA CubeSat/nano-satellite technical lead

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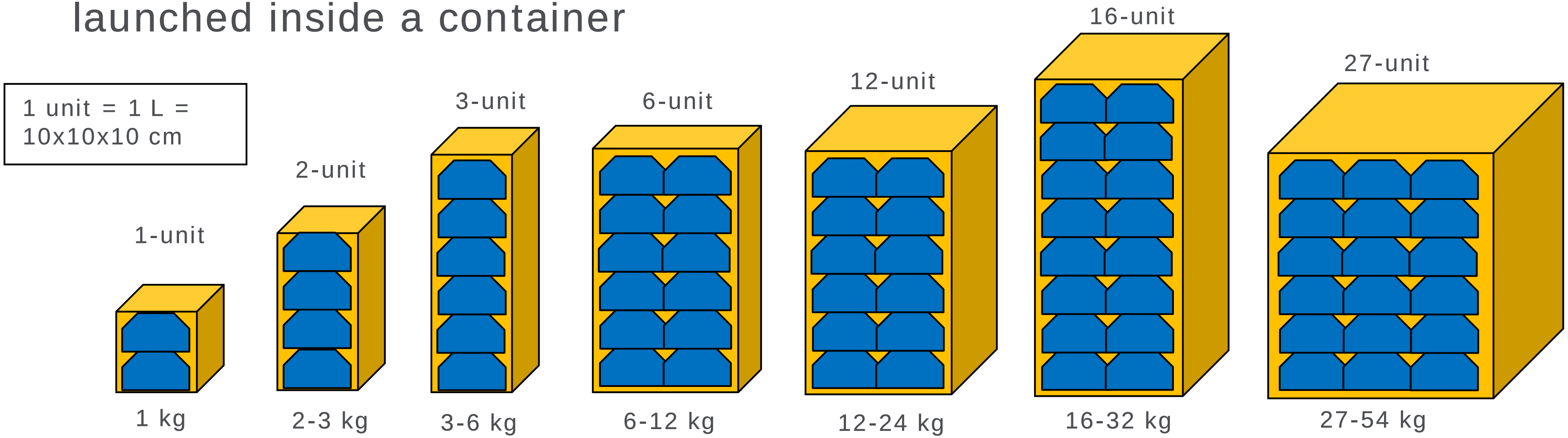
Norwegian Space Centre, Oslo, 31 August 2017

Small satellite terminology

- CubeSats: small satellites of standardised external cubic unit dimensions launched inside a container



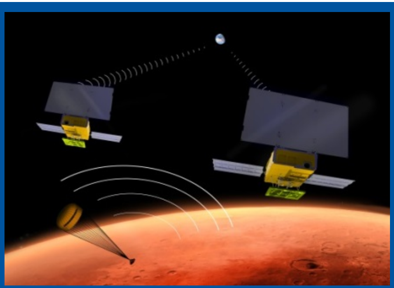
- Nanosats: small satellites with mass <10 kg (any form factor)
- Microsats: small satellites with mass <100 kg (any form factor)
- This presentation is focussed on small sats up to 50 kg, primarily CubeSats

Why Small Sats?

- Extensive spin in of terrestrial COTS components/products qualified for space use
- Significant reduction in the entry level cost of space activities
- Short satellite development schedules allow rapid in-orbit demonstration of new technologies
- High availability of (piggyback) launch opportunities on many different launch vehicles
- High availability of commercial off-the-shelf products & developer support

International Context

- Small sats widely adopted by US government agencies (NASA, DoD, NSF) for IOD of new technologies and system capabilities
- Significant US Venture Capital funding commercial small sat constellations for ‘big data’ applications
- China now entering the sector with its own technology, systems and launches
- Highly dynamic and competitive environment developing worldwide



European Industrial Landscape -CubeSats

- Emerging sector of rapidly growing SMEs with 6 system integrators and over 30 subsystem developers
- Advanced technology in some technical domains, but slightly lags behind in others
- Trend towards larger CubeSat platforms (12-27U) for operational missions with more payload resources, higher performance subsystems
- Access to Venture Capital funding limited in Europe
- Rapid growth trajectory and competitiveness can only be sustained by Institutional investments

GOMSPACE | ISIS Innovative Solutions In Space | ÅAC Microtec | CLYDE SPACE | SURREY SATELLITE TECHNOLOGY LTD | COMPLEX SYSTEMS & SMALL SATELLITES

European Industrial Landscape <50 kg Microsats

- Sector consists of SMEs with 7 system integrators and numerous subsystem developers
- Non-CubeSat form factors (no distinct dimensional standard)
- Hold-down & release mechanism as launcher interface
- Equipment has some overlap with CubeSats, but not all due to sizing and more relaxed volume constraints
- Use of COTS components as with CubeSats
- Some market players (e.g. SSTL, Astrofein) have entered from mini-sat class (>100 kg) by miniaturising their larger platforms

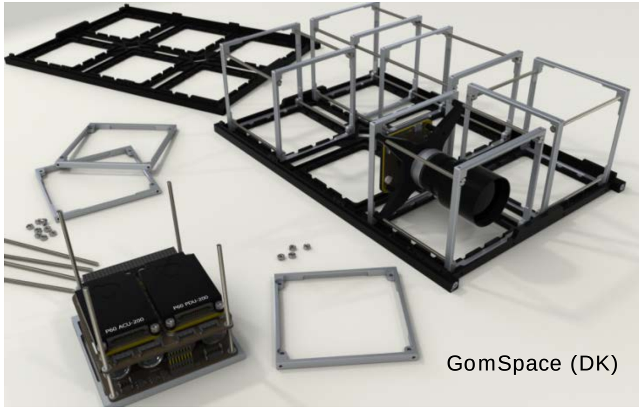
MINIATURISED TECHNOLOGIES

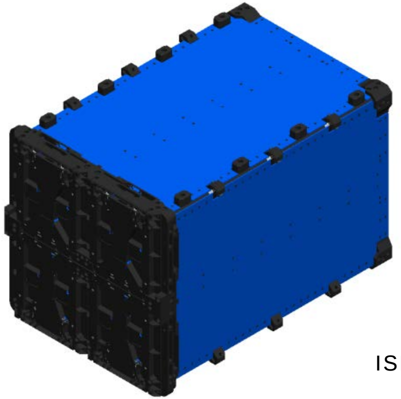
What is the European CubeSat Technology state-of-art and near-term evolution?

Structures & Deployers

Move to larger structures to accommodate higher performance subsystems & larger payloads

Form factor	Structure	Deployer
3U	Flight heritage	Flight heritage
6U	In development	Flight heritage
8U	In design	Use of 12U
12U	In design	Flight heritage
16U	In design	In design
27U	Concept	Concept


GomSpace (DK)


ISISpace (NL)

Avionics

- Further COTS electronics miniaturisation leading to highly integrated/modular Platform avionics
  - Architecture options:
    - Single Motherboard + 4 daughterboards
    - Stacked boards architecture with dual redundancy on each board
  - Move from I2C to CAN bus for robustness
  - Most products tested to 15-20 kRad, latch-up protection
- Powerful COTS processors enabling significant on-board computational capability
  - Image data processing L0 to L2 products
  - Near real-time image processing => machine vision for relative navigation
  - Advanced autonomy algorithms (neural nets)
  - Waveform processing for software-define radio
  - High speed LVDS interfaces

GomSpace (DK)

C3S (HU)

BAP (SE)

Communications

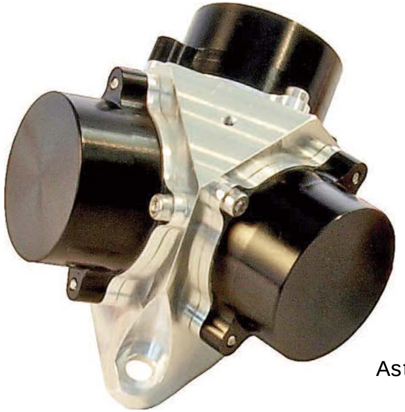
1. Downlink data rates have increased significantly
    a. UHF transceivers (10 kbps from LEO)
    b. S-band transmitter (1 Mbps from LEO)
    c. X-band transmitter (3 Mbps from LEO up to 50 Mbps future)
2. TT&C radios are becoming CCSDS compatible for operation with non-amateur bands/stations
    a. UHF transceiver (qualified)
    b. S-band transponder with ranging (in development)
3. Inter-satellite Links (in development)
    a. S-band software-defined radio
    b. Long-range 10 kbps @ 4000 km for constellations
    c. Short-range 10 Mbps @ 100 km for formations
    d. Ranging for relative navigation

Attitude Control

- 3-axis stabilisation flight heritage (GOMX-3)
- Pointing errors reducing significantly due to development of miniaturised star trackers and reaction wheels for 3U and 6U/12U CubeSats
- Star trackers ground qualified, awaiting flight in 2017/18 (PICASSO, SIMBA, GOMX-4B, OPS-SAT)

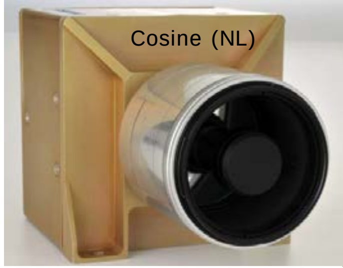
Configuration	Accuracy (3U/6U)	Accuracy (12U)
SS + MTM + MTQs	10-20°	10-20°
SS + RWs + MTM + MTQs	2° (sunlight) 20° (eclipse)	2° (sunlight) 20° (eclipse)
STR + RWs	0.2°	0.1°


Hyperion (NL)


Astrofein (D)

Navigation

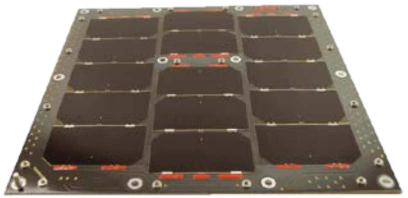
- GPS Receivers providing Absolute & Relative navigation in LEO:
  - Absolute position (2 m accuracy with filtering)
  - Relative position with carrier phase differential GPS (few cm accuracy)
- Visual relative navigation sensors in development
  - Mini camera for mid-/close- range
  - Close proximity sensor (MASCOT/Hayabusa-2)
- Miniaturised LiDAR (mil spec to be space qualified):
  - Solid-state LiDAR for mid range relative nav (few 100 m range)
- Miniaturised RaDAR studied in GSTP 6.3 for future development:
  - X-band RaDAR based on Software-Defined Radio & MMICs for far range detection & relative nav (5-10 km range)

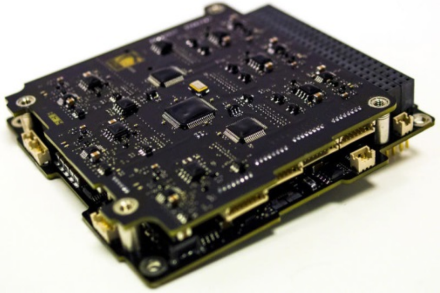


Jenoptik (D)

Power

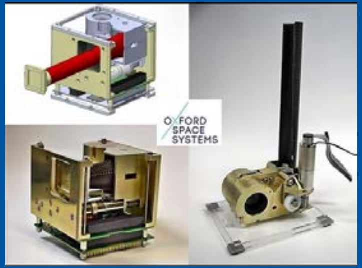
- Power generation is increasing:
  - 3U Solar panels (10x30 cm, 10 W) with extensive flight heritage
  - 6U Solar panels (20x30 cm, 20 W) in development
  - Double deployable to fixed position (up to 60 W for a 6U CubeSat)
- Power storage is increasing via use of modular battery packs (on single board)
  - Li-ion cylindrical and pouch (flight heritage)
  - Up to 30 Wh capacity per pack
- Power conditioning and distribution of higher power inputs/outputs
  - Multiple MPPT/BCRs for solar array inputs up to 100W for up to 12U CubeSats
  - Bus & battery protection and LCLs

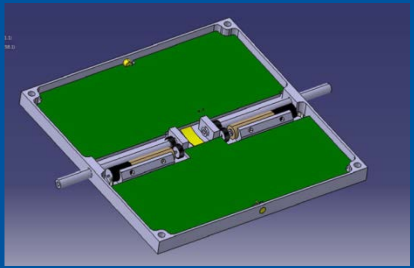




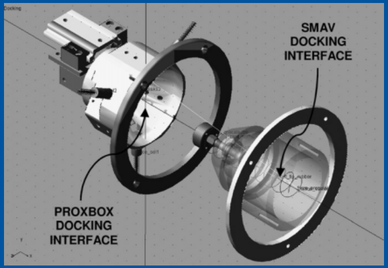
Mechanisms

- Hinge/Hold-Down & Release Mechanisms in wide use for deployable solar panels/UHF antennas
  - Thermal knife with dual redundancy
  - Various deployment angles
- Solar Array Drive Assembly (in development) enabling steering of deployable solar arrays
  - Potential to significantly increase solar power generation with pointing constraints
- Miniaturised docking mechanisms and deployable booms in development





IMT (I)

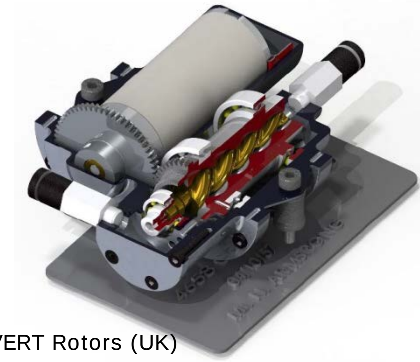


CISAS (I)

Thermal

- Little consideration of thermal design in CubeSats to date due to low heat dissipation/no thermally sensitive payload
- If done, thermal control is currently passive
  - Thermo-optical surface coatings
  - Battery heaters
  - Insufficient for higher power generation & dissipation payloads
- Active thermal control systems in development
  - Two-phase heat transport system with fluid loop, MEMS micro-pumps & radiator
  - Low-vibration cryo-cooler for IR detectors (20 W heat lift, cooling to 120-150 K)

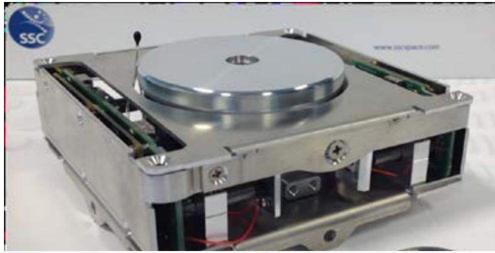
NLR (NL)

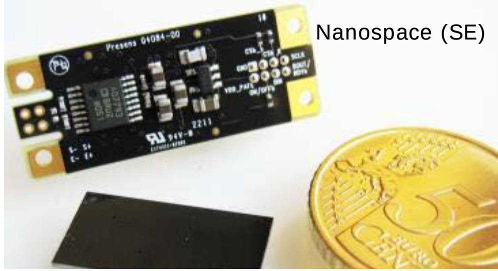


VERT Rotors (UK)

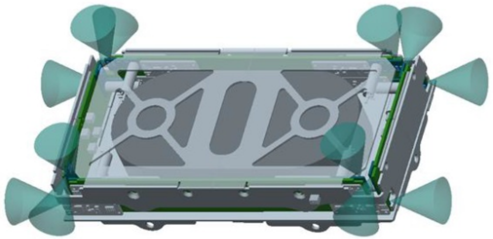
Propulsion (cold gas)

- Cold gas/resistojet propulsion system based on MEMS thrusters now flying on 3U CubeSat
  - 4 x 1 mN thrusters, 40 Ns from butane
  - Translational thrust for orbit raising
- Larger system for 6U CubeSats in development
  - 4 x 1 mN thrusters, 70 Ns from butane
  - Constellation station acquisition/keeping
  - Flight on GOMX-4B in 2017
- GSTP 6.1 development ongoing for 12 thruster system to provide 6 Degree of Freedom (DoF) control
  - Enables Close Proximity Operations
  - Only possible due to highly compact MEMS thrusters





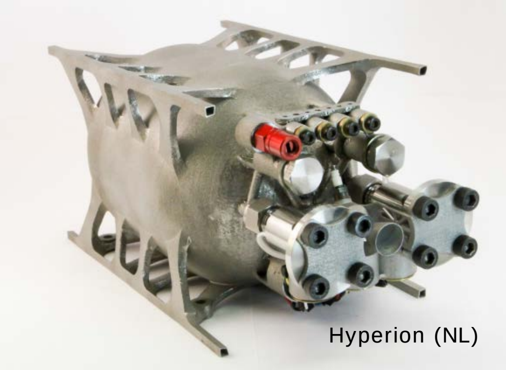
Nanospace (SE)



Propulsion (chemical)

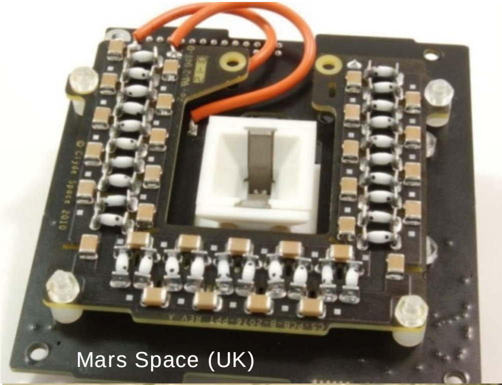
- ADN “green” monopropellant system in development for CubeSats
  - 0.3 N thrust, Isp 250 s, delta-V 160 m/s on a 3U CubeSat
  - Flight on LithuaniaSat-2 on QB50 in 2017
- LMP103 “green” monopropellant system in development for nano-sats
  - 0.5 N version of the ECAPS 1 N thruster flown on PRISMA
  - 2 small tanks based on resized US off-the-shelf item
  - Isp 225 s, Delta-V 120 m/s on a 30 kg nano-sat
- Bipropellant system in development for nano-sats
  - NO2 and propane
  - 1 N thrust, Isp >250 s, delta-V 230 m/s on a 6U CubeSat (8 kg)

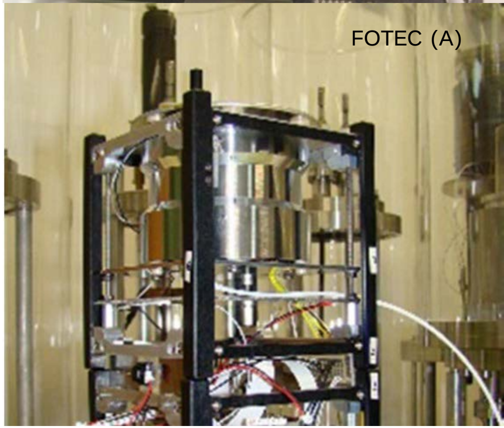

NanoAvionics (LI)


Hyperion (NL)

Propulsion (electric)

- Pulsed plasma thrusters have been developed/ qualified for 3U CubeSats
  - Low power & thrust (3W, 50 µN)
  - Moderate specific & total impulse (620 s, 44 Ns)
  - Larger version in development
- Electrospray/colloid propulsion in development
- FEEP in development with high delta-V
  - In propellant, Power 75 W, thrust 0.6 mN, Isp 4000 s
- Miniaturised Gridded Ion Thruster systems in development with high delta-V
  - Power 90 W, thrust 1.7 mN, Isp >3000 s (Xe gas)
  - Suitable only for larger CubeSats/nanosats
  - Iodine propellant with bellows feed needed to reduce propellant tank volume

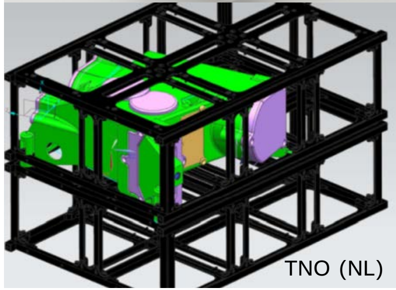




Optical Payloads

- Multi-spectral imager qualified for 3U CubeSats
  - MEMS Fabry-Perot Interferometer for in flight control of spectral bands
  - Flight in 2017 for Land imaging (Aalto-1), and 2018 for vertical Ozone profiling (PICASSO)
- Hyper-spectral imager in development for 3U/6U CubeSats
  - HyperCube generation in 40 VNIR spectral bands
  - On-board data processing for L0->L2 products
  - Change detection for vegetation/land cover/flood monitoring; Flight on GOMX-4B in 2017
- NO_2 monitoring instruments in development for 12U CubeSats/ 20-30 kg nano-sats
  - High-resolution Anthropogenic Imager (HAPI) by Uni. Leicester (UK): <0.5 km GSD @500 km alt. / 140 km swath
  - TropoLite by TNO (NL): <1 km GSD @500 km alt. / 600 km swath
  - Intended for use in constellations for diurnal coverage of polluted cities

Cosine (NL)

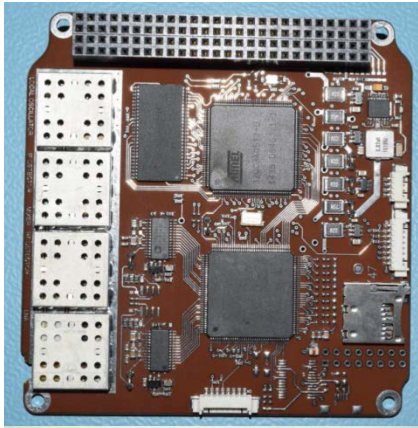


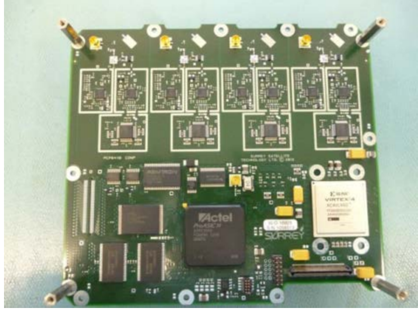
TNO (NL)

RF Payloads

- AIS and ADS-B receivers/antennas flight demonstrated on numerous CubeSats/nano-sats for future ship/aircraft tracking services
- GNSS-Reflectometry receivers/antennas in development for severe weather prediction
  - Sea surface wave height/wind speed
  - SSTL payload flown on NASA CYGNSS mission in late 2016
  - RUAG Austria PACO receiver
- Potential for GNSS-Reflectometry payload to be extended to GNSS-Radio Occultation
  - Tropospheric variables (temp./pressure/humidity) for terrestrial weather prediction services
  - Ionospheric variables (total electron content) for space weather prediction services

GomSpace (DK)

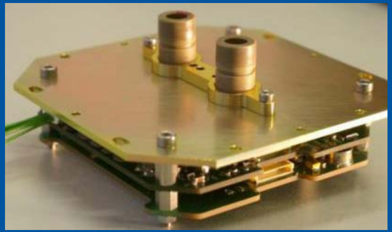




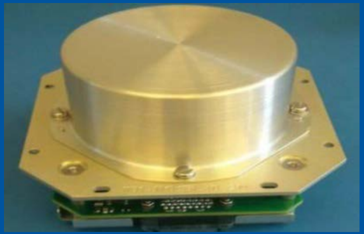
SSTL (UK)

Scientific Payloads

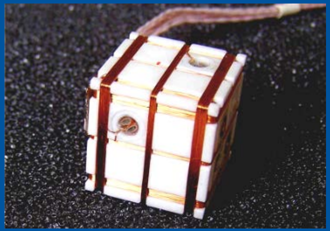
- In-situ space environment sensors in development/flown
  - Ion & neutral mass spectrometer, ATOX detectors flight on QB50 2017
  - Langmuir probes for flight on 2U QB50, 3U PICASSO CubeSat
  - Magnetometer mounted on boom for flight on RadCube 3U CubeSat in 2019
  - High energy particle detectors (HMRM, TimePix, RadMag)
- Astronomical detectors in design/development
  - X-ray lobster eye detector (flight on QB50)
  - Gamma-ray detector
- Microgravity payloads in development
  - UV & IR spectrometers + biological/chemical sample handling mechanism for flight on ISS (CubeSat form factor)



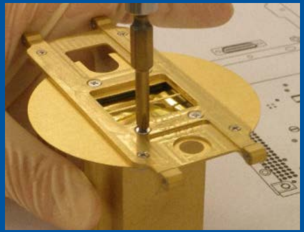
CISAS (I)



TU Dresden (D)



KTH (SE)

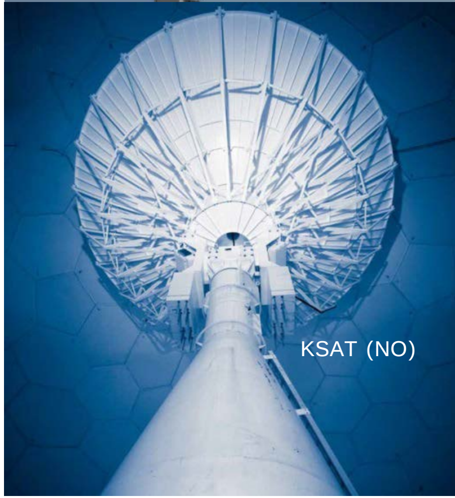


VZLU (CZ)

Ground Segment

- Low-cost UHF/VHF/S-band ground station kits available off-the-shelf for installation
  - Yagi antennas for UHF/VHF (9.6-19.6 kbps)
  - 2-3 m dish antennas for S-band (up to 1 Mbps)
  - Software-defined radio transceivers
- Commercial Polar ground station networks available to support constellations
  - S/X-band 3.7 m dish antennas at Svalbard/Troll for higher downlink rates, low latency, pay per pass
  - Problem of congestion for multiple planes due to multiple s/c in visibility simultaneously
  - Antenna slewing time reduces pass duration/data volume
- Potential for development of a ground station with Electronic beam-forming based on SDR & patch antennas
  - Simultaneous communication with multiple constellation s/c for higher data throughput


ISISpace (NL)


KSAT (NO)

Operations (OPS-SAT demo)

- New Space-Ground interfaces and standards
  - High speed uplink (256 kbps – 1 Mbps)
  - CCSDS Mission Operations services
  - CCSDS File Delivery Protocol
  - Delay Tolerant Networks
  - Adaptive Channel Coding Schemes
  - Housekeeping Telemetry Compression (POCKET)

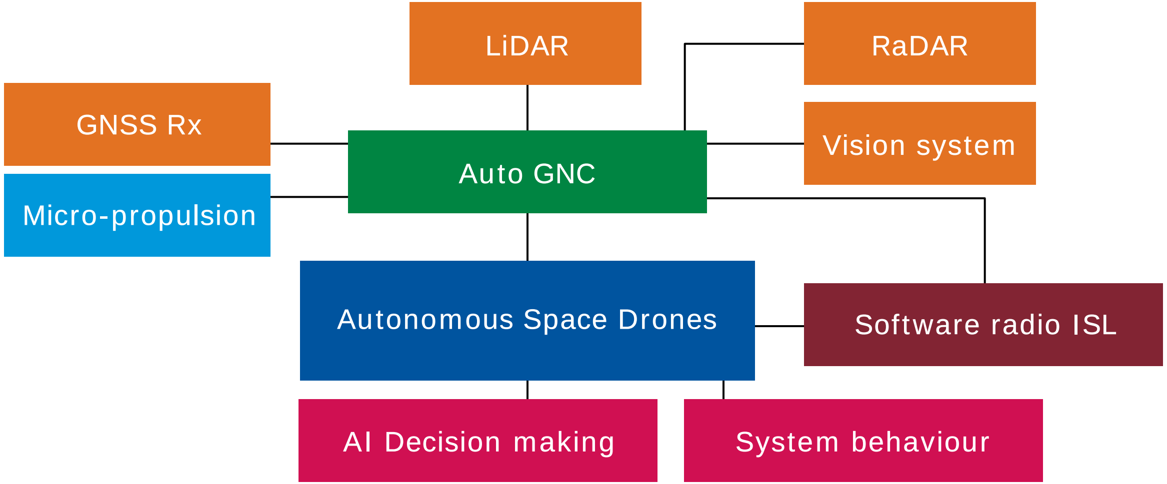
- Innovative Mission Operations Concepts
  - Advanced Mission Planning (ground and on-board)
  - File Based Operations
  - On-board Autonomy
  - Ground Segment Automation
  - Remote & Direct Experimenter Access to Payloads
  - Data diagnostics
  - Rapid on-board software update handling

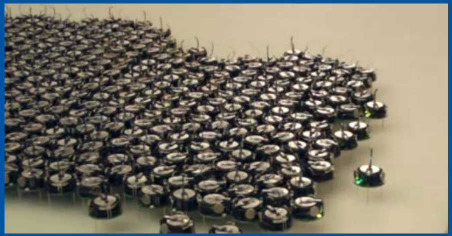
FUTURE APPLICATIONS

What missions can be enabled with CubeSats/nano-sats in the near-term future?

Future evolution: autonomous space drones

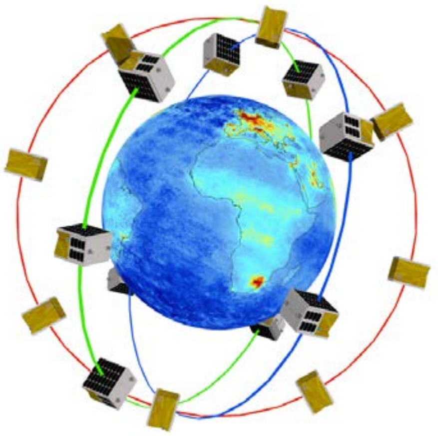
- Leveraging miniaturised technologies and R&D in terrestrial autonomous vehicles
- Enabling the cost-effective realisation of breakthrough space systems concepts



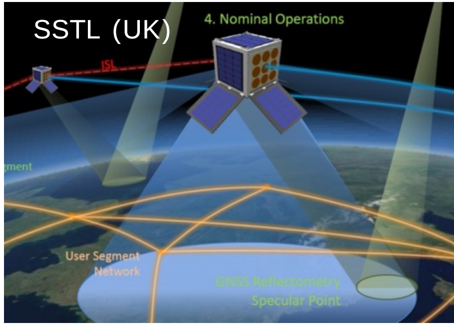



Constellations for Earth/Space Environment Monitoring/Telecom

- Numerous studies performed under ESA GSP & ARTES funding
- Applications:
  - High-resolution NO_2 pollution monitoring of urban areas over the diurnal cycle
  - Global ionospheric, tropospheric and sea surface wind measurements for space, land and ocean weather prediction
  - Change detection of land, flood, fire hazards
  - In-situ radiation belt monitoring
  - Aircraft/ship/asset tracking & monitoring
- Autonomous self-organising constellation systems enable lower operations costs

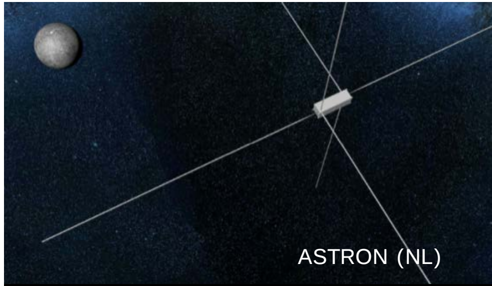


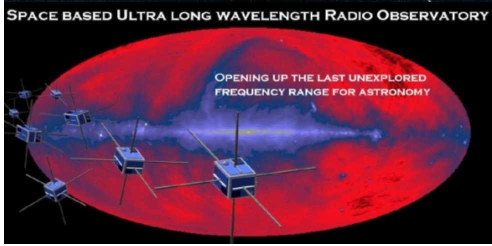
TAS/Uni. Leicester (UK)

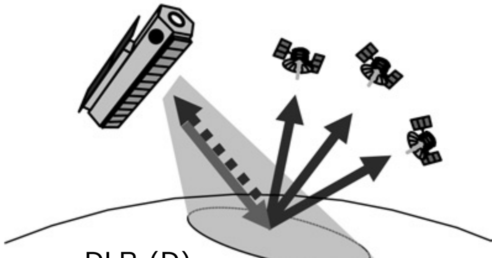


Close Proximity Operations: Swarm Formations

- Numerous studies conducted in Europe
- Multi-static SAR for remote sensing in LEO:
  - wide-swath imaging
  - scene classification
  - single pass cross-track interferometry
  - MTI, resolution enhancement
- Low-frequency Radio Astronomy Interferometric array in lunar orbit or Lagrange for cosmology & solar physics
- Autonomous connected CubeSats/nanosats are an enabler for swarm formations







DLR (D)

Close Proximity Operations: Rendezvous, Fly Around & Docking

- Numerous studies conducted through ESA GSP, GSTP, NPI PhD research
- Applications:
  - On-Orbit Assembly of large structures
  - Close inspection/servicing of cooperative targets (e.g. large satellites, human habitation modules)
  - Close inspection of uncooperative targets (e.g. orbital debris, Near-Earth Objects)
- ESA Rendezvous Autonomous CubeSats Experiment (RACE) mission planned for launch in 2020 (open ITT for Phase A/B coming soon)

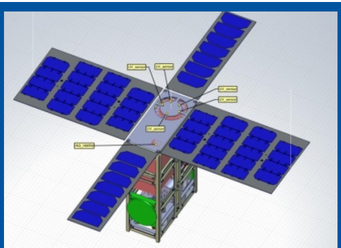
SSTL (UK)

EPFL (CH)

AIM (ESA) + COPINS teams

“Beyond LEO” Support to Science & Exploration

- Piggyback launch opportunities exist into GTO and Molniya orbits:
  - SpectroCube mission CDF study on a 6U CubeSat with Astro-chemistry & radiation environment payloads
- Piggyback flight opportunity on the ESA Asteroid Impact Mission (AIM)
  - Five parallel GSP Sysnova studies completed, under mission consolidation
- Piggyback launch opportunities on SLS/Orion flights for cis-lunar/lunar orbit:
  - GSP Sysnova competition on LUnar CubeSats for Exploration (LUCE) (four parallel studies ongoing)

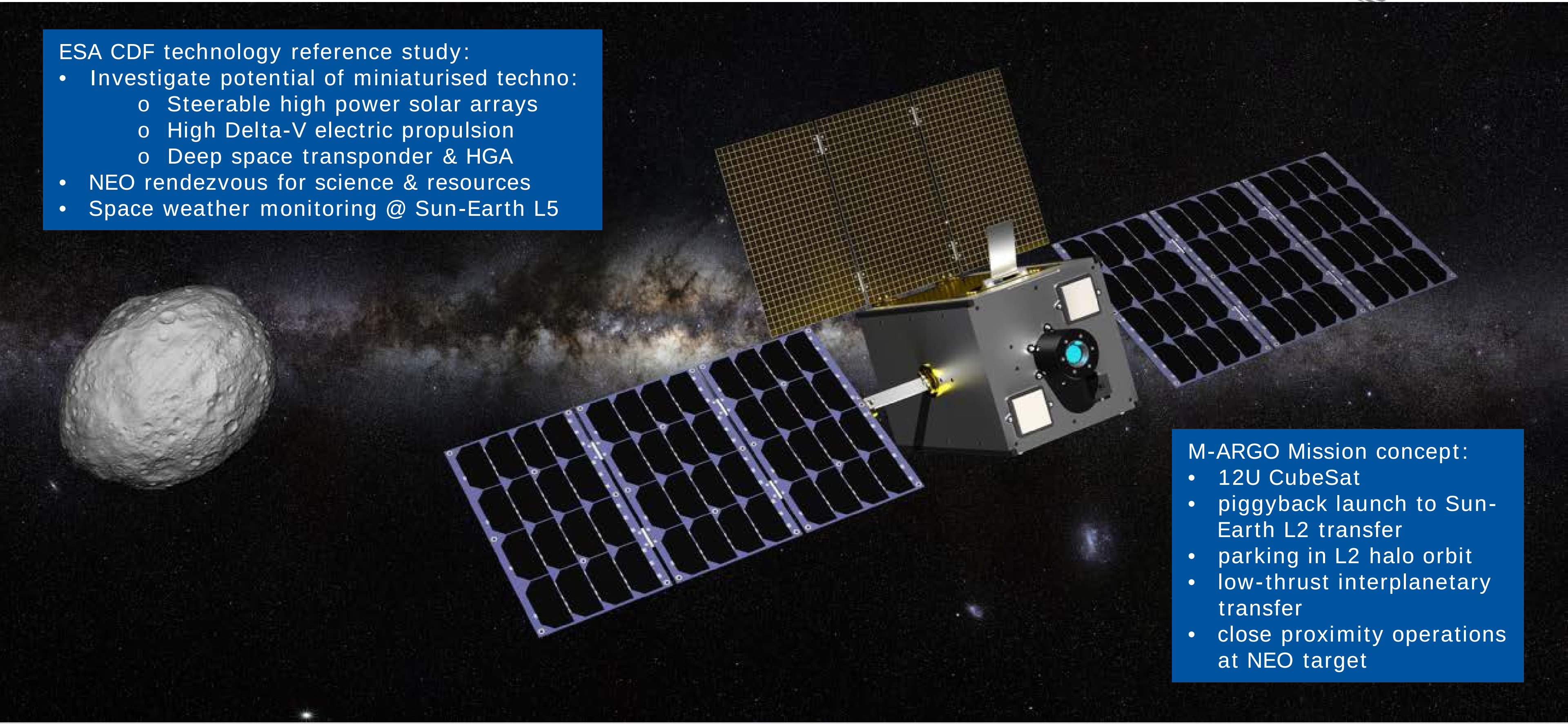


SpectroCube (ESA)

VTT/Aalto (FI)

ROB (BE)
Supaero (F)

Stand-Alone Deep Space Cubesats



ESA CDF technology reference study:

- Investigate potential of miniaturised techno:
    - o Steerable high power solar arrays
    - o High Delta-V electric propulsion
    - o Deep space transponder & HGA
- NEO rendezvous for science & resources
- Space weather monitoring @ Sun-Earth L5

M-ARGO Mission concept:

- 12U CubeSat
- piggyback launch to Sun-Earth L2 transfer
- parking in L2 halo orbit
- low-thrust interplanetary transfer
- close proximity operations at NEO target

ONGOING ESA IOD CUBESAT MISSIONS

What is ESA currently doing in the CubeSat/nano-sat domain?

Second wave: technology demo CubeSats at ESA

>10 MEuro in ESA GSTP FLY Element since 2013 for 7 IOD CubeSat missions

Germany:
OPS-SAT s/sys
(BST FDIR, ADCS;
MEW SDR, optical p/l)

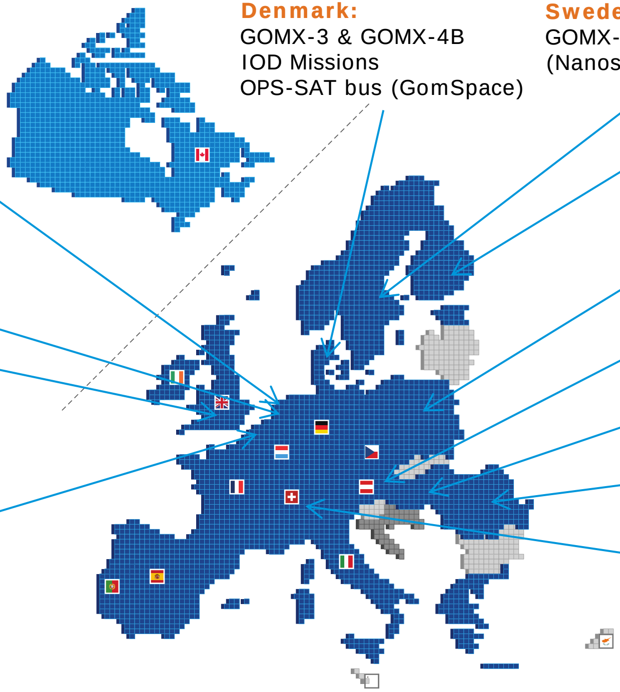
Netherlands:
SIMBA p/f (ISISpace)
Star tracker, S-band radio
devt (ISISpace)

United Kingdom:
PICASSO p/f (Clyde Space)
URSA IOD Missions study
(SSTL)

Belgium:
QARMAN (VKI)
PICASSO (BISA prime)
SIMBA (RMIB, KUL)
IOD Missions

Denmark:
GOMX-3 & GOMX-4B
IOD Missions
OPS-SAT bus (GomSpace)

Sweden:
GOMX-4B Propulsion
(Nanospace SSC)



Finland:
PICASSO
Multi-spectral imager
(VTT)

Poland:
OPS-SAT
(GMV OBSW, SRC/CreoTech TMTC)

Austria:
OPS-SAT IOD Mission
(TU Graz tech lead/SE, Magna Steyr)

Hungary:
RadCube IOD mission
(C3S/MTA EK)

Romania:
URSA IOD missions study
(Inst. Space Sciences)

Switzerland:
Pre-capture phase
Active Debris Removal
IOD mission study
(EPFL & partners)

ESA's First IOD CubeSat in Space

Project: GOMX-3

Contractor: GomSpace DK

Platform: 3U CubeSat (3 kg)

Duration: 1 year KO to flight readiness

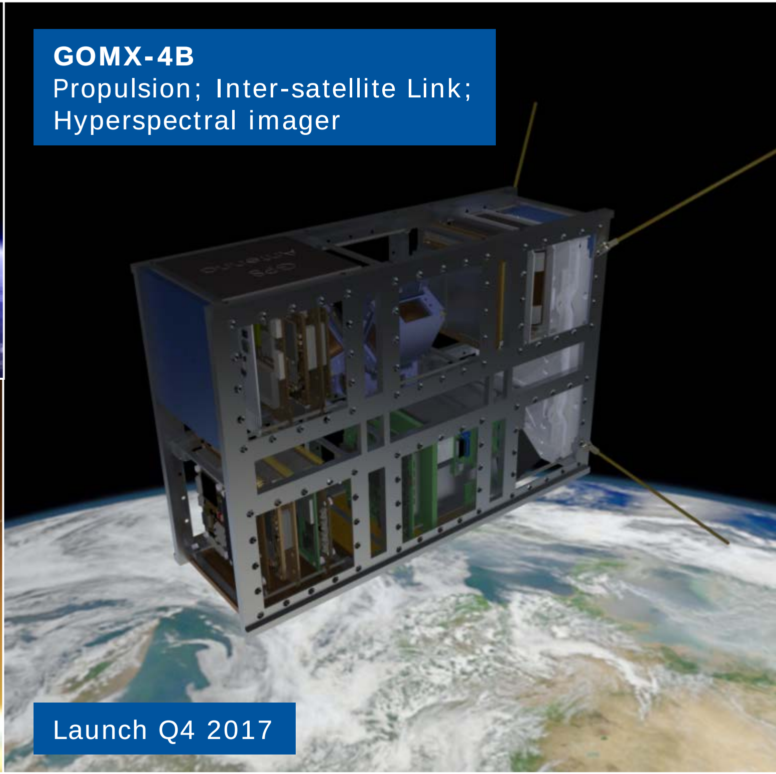
Deployed from ISS: 5 October 2015

Status: Full mission success, re-entered

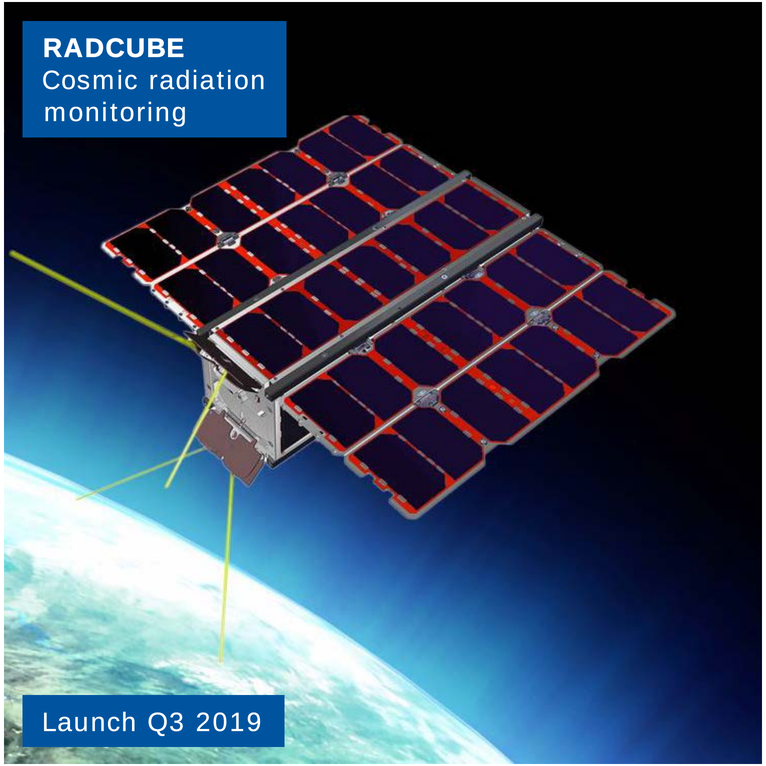
Achievements:

- 3-axis pointing <3° (3σ)
- X-band Downlink @ 3 Mbps
- Reconfigurable software-defined radio
- GEO Telecom L-band signal analysis
- ADS-B Aircraft tracking from a CubeSat

ESA IOD CubeSat Missions in development (1)



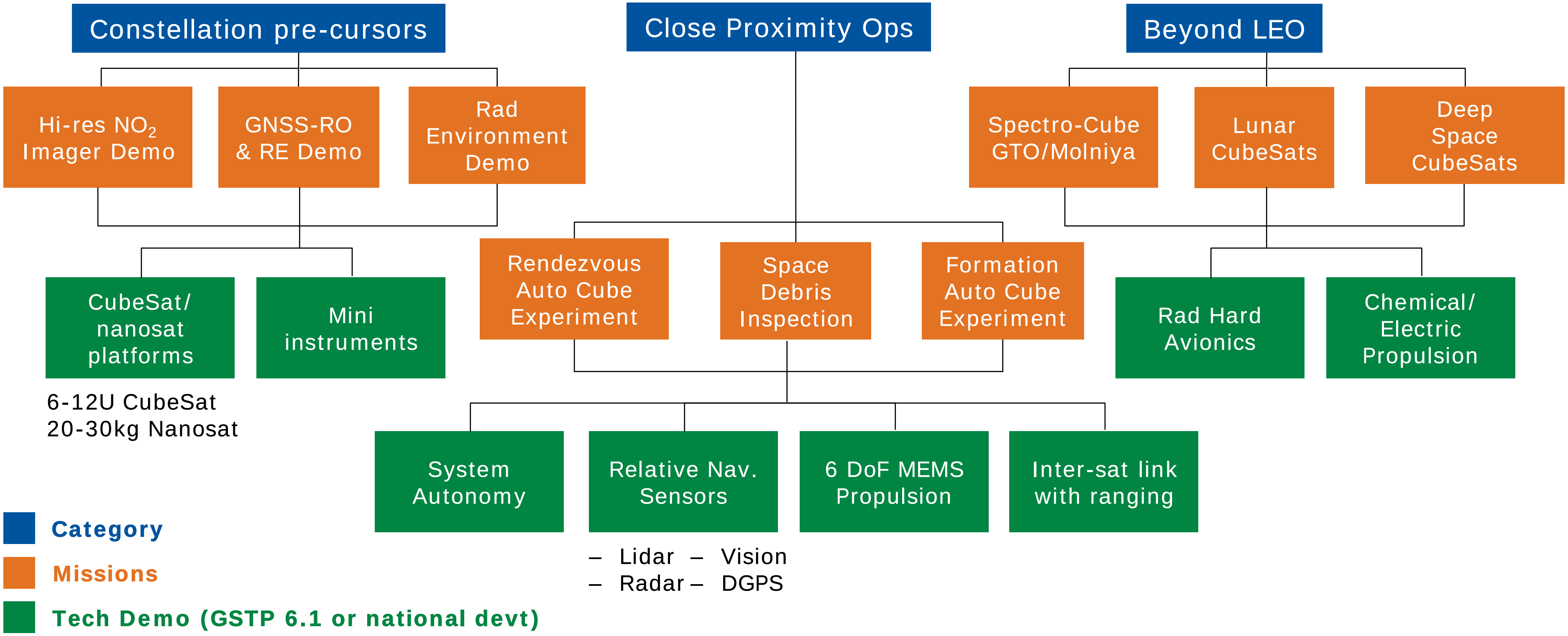
ESA IOD CubeSat Missions in development (2)



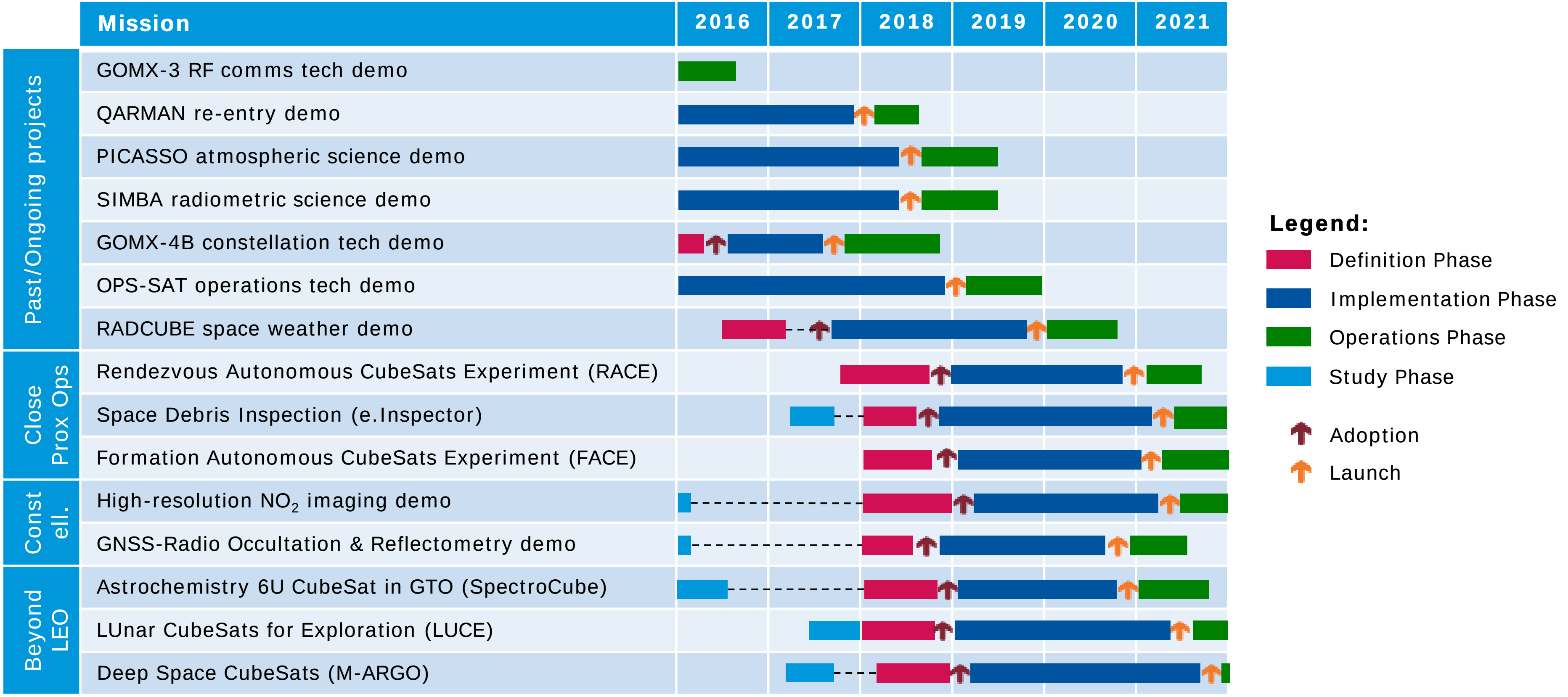
FUTURE CUBESAT/ NANO-SAT ROADMAP

What In-Orbit Demonstration missions are needed now to enable future applications & breakthrough concepts?

Proposed IOD CubeSat/Nanosat Missions



ESA IOD CubeSat/Nano-sat Missions Roadmap



Conclusions

- ESA IOD CubeSat/nano-sat mission roadmap presented at CM16 for GSTP Fly aims to keep European industry at the cutting edge in this dynamic sector
- Following CM16 subscriptions, the execution of the roadmap is starting now with a number of procurement actions planned in 2017
- The missions rapidly demonstrate new niche applications from constellations, breakthrough concepts, and space exploration at much lower entry-level cost
- Key European technologies have been identified and their pre-development is planned to be fast-tracked in GSTP (as needed) before flight demonstrator development in the relevant IOD mission
- A new framework activity for “CubeSat missions & technology pre-development” is planned to allow industry to submit innovative TDA & IOD mission proposals for evaluation and implementation (given availability of Member State funding)

THANK YOU

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