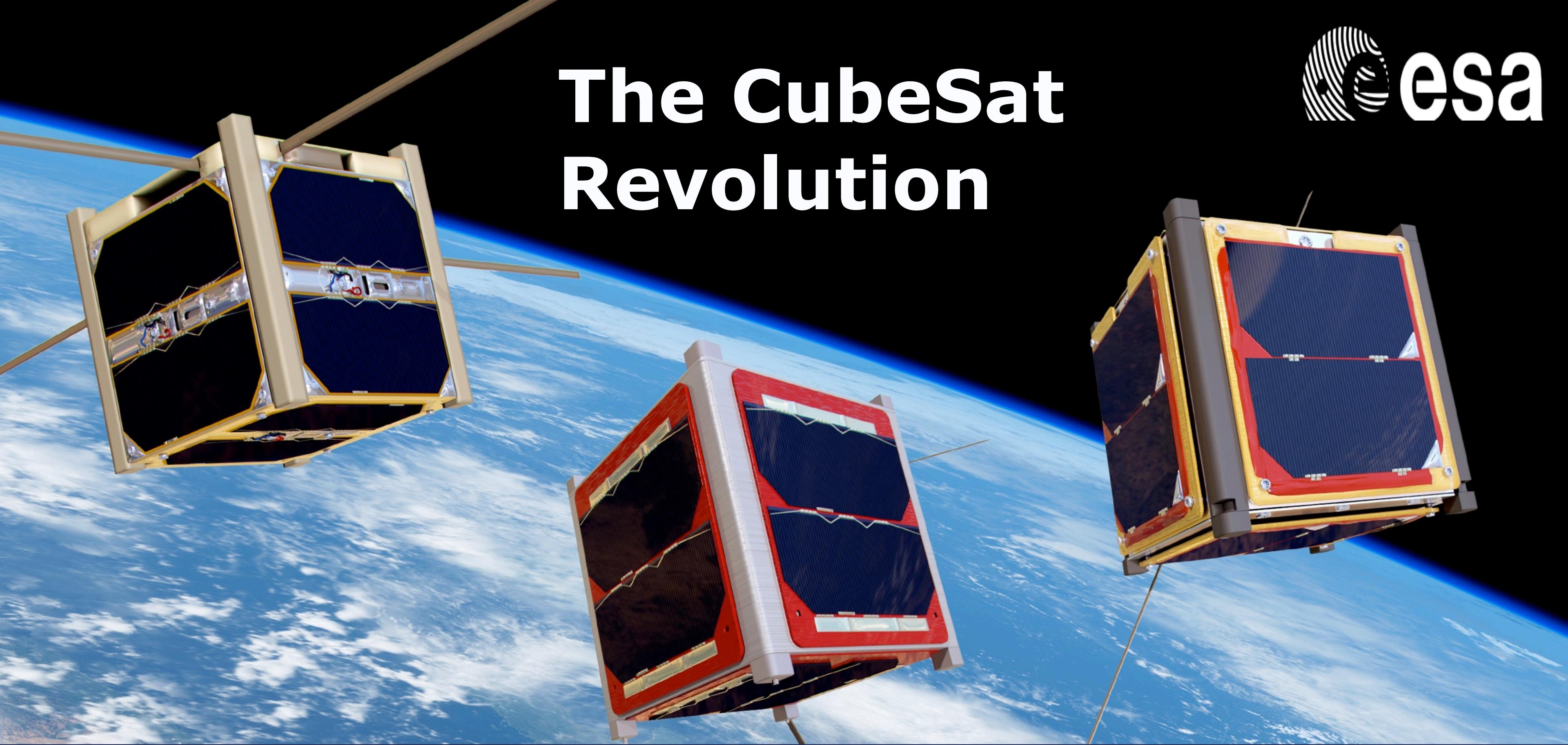


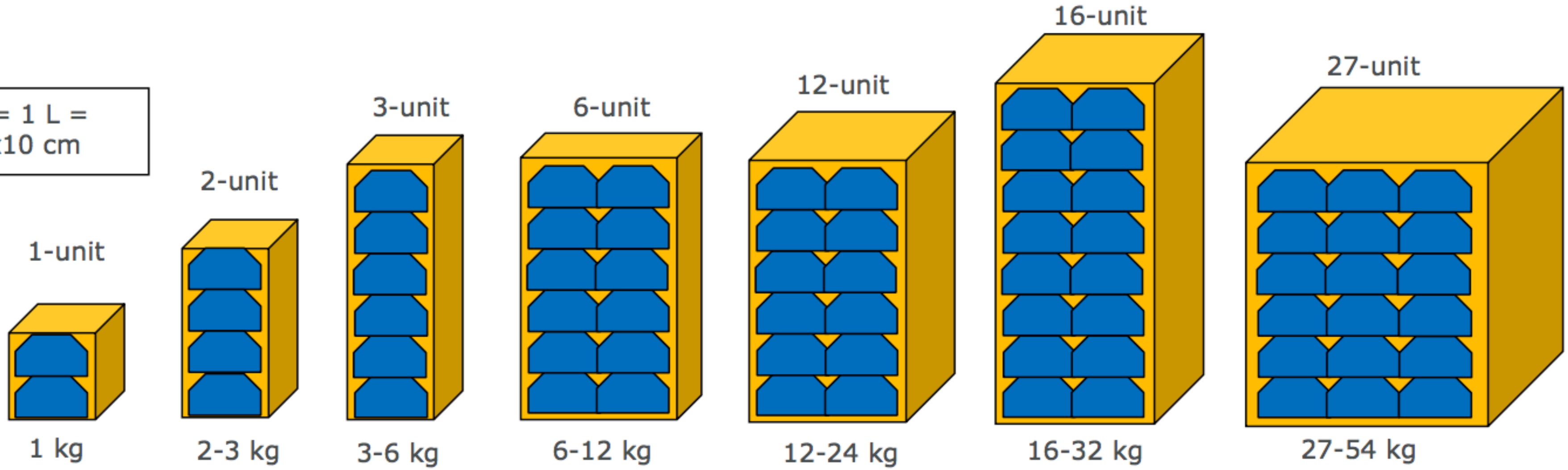
The CubeSat Revolution

Peter Kretschmar & Michael Küppers, with inputs by Roger Walker and others

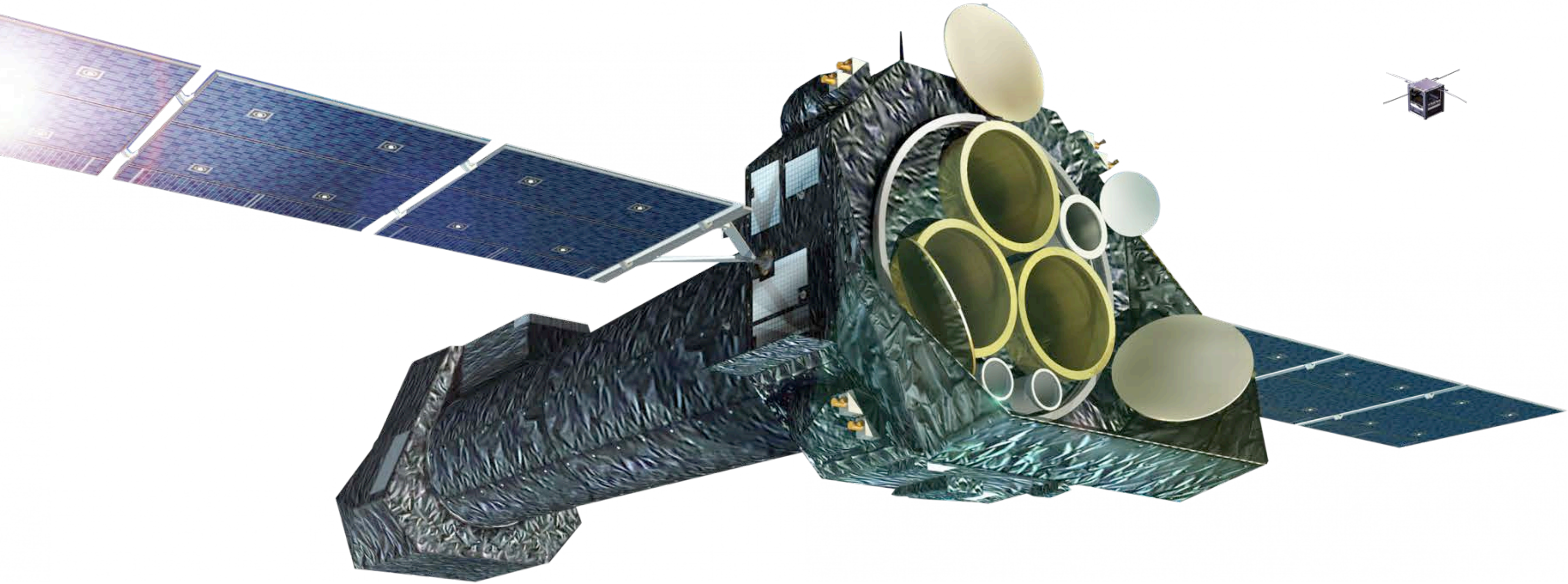
What are we talking about?

- Small satellites of standardised external cubic unit dimensions launched inside a container.
- Small, cheap, fast to develop. In reach of universities and of countries without major space sector.

1 unit = 1 L = 10x10x10 cm



CubeSats are **really** small



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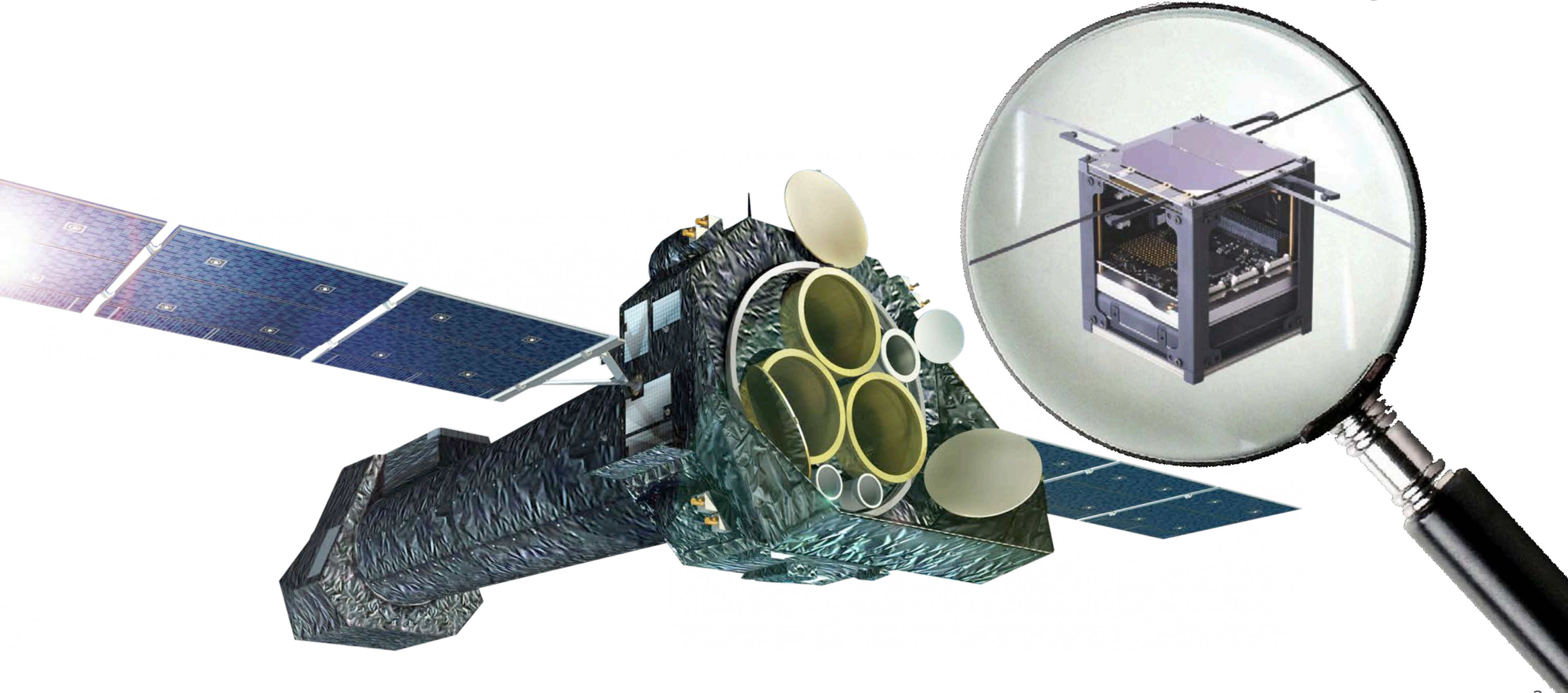
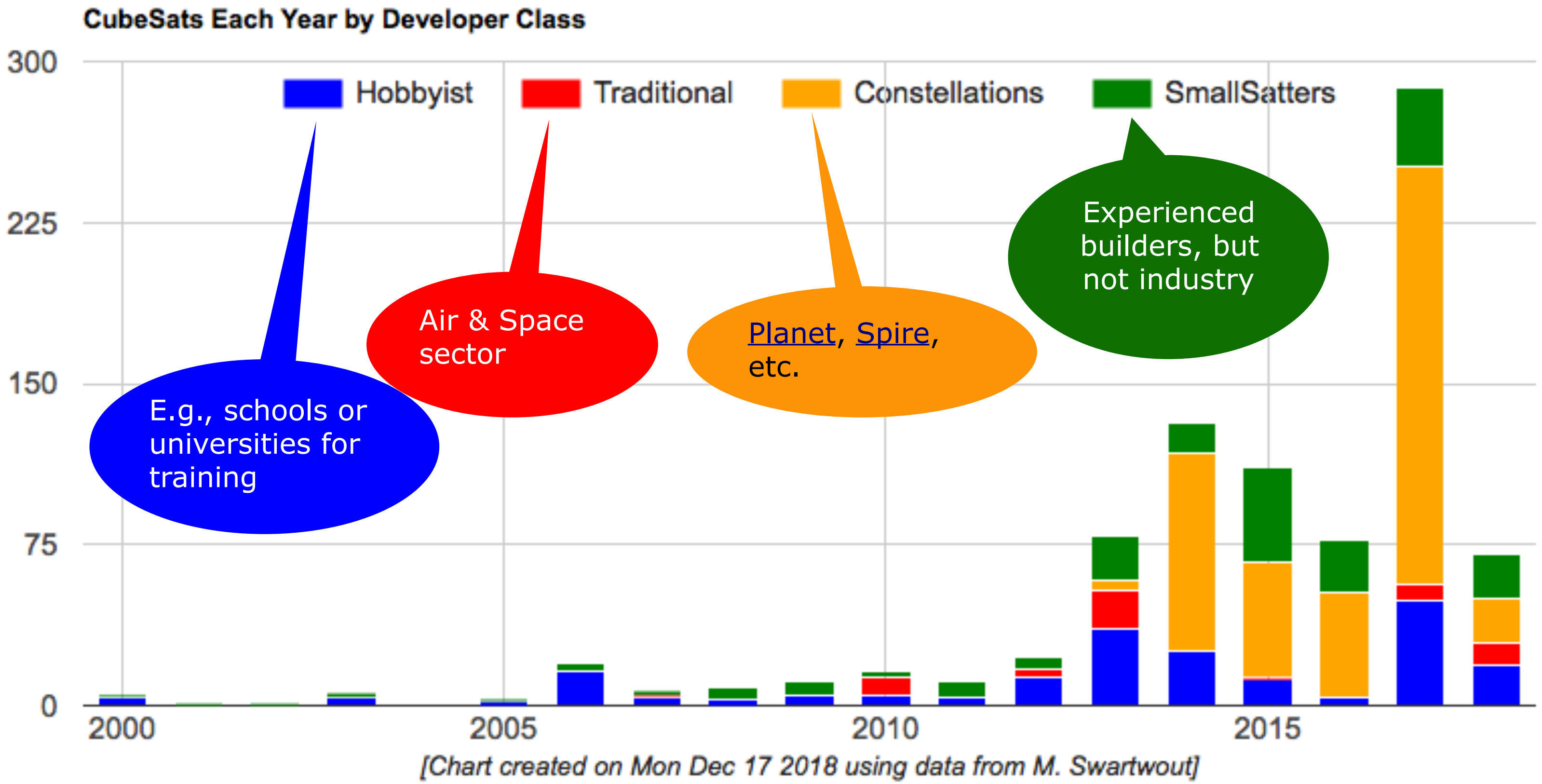
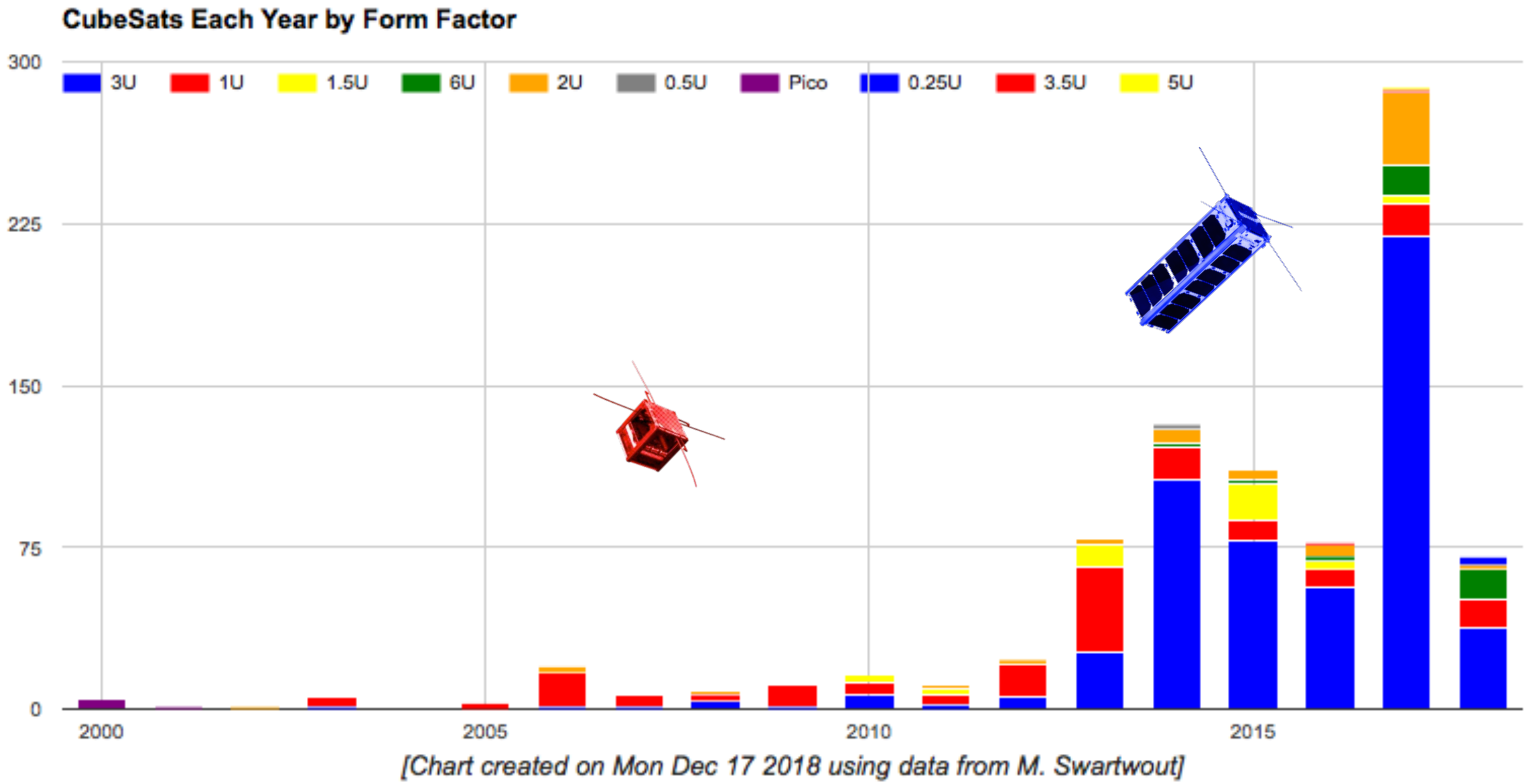


But there are a lot now (approaching 1000)



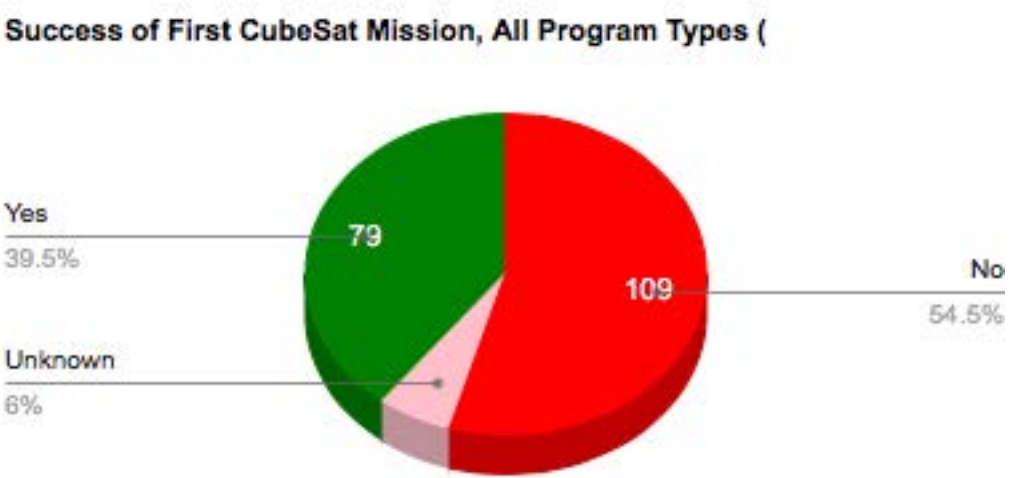
https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

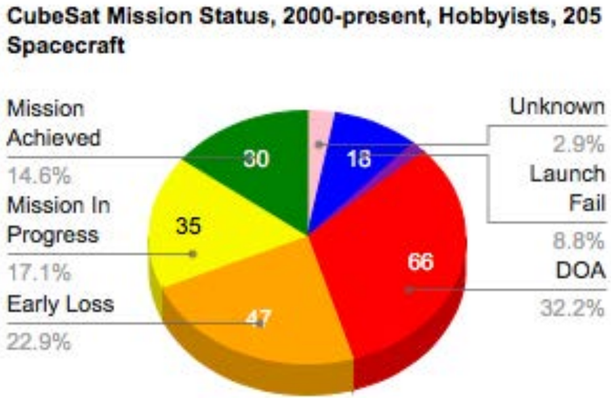
Their average size is increasing

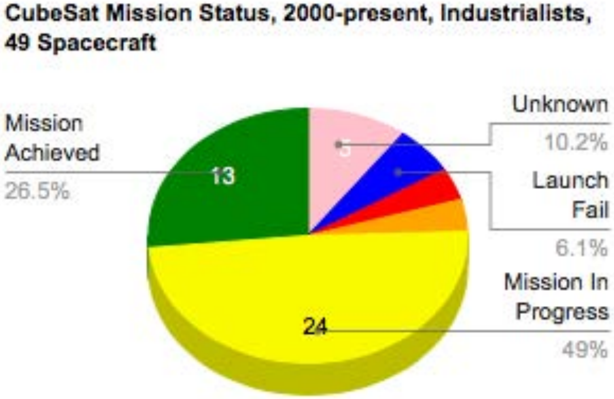


https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

But reliability could still be improved

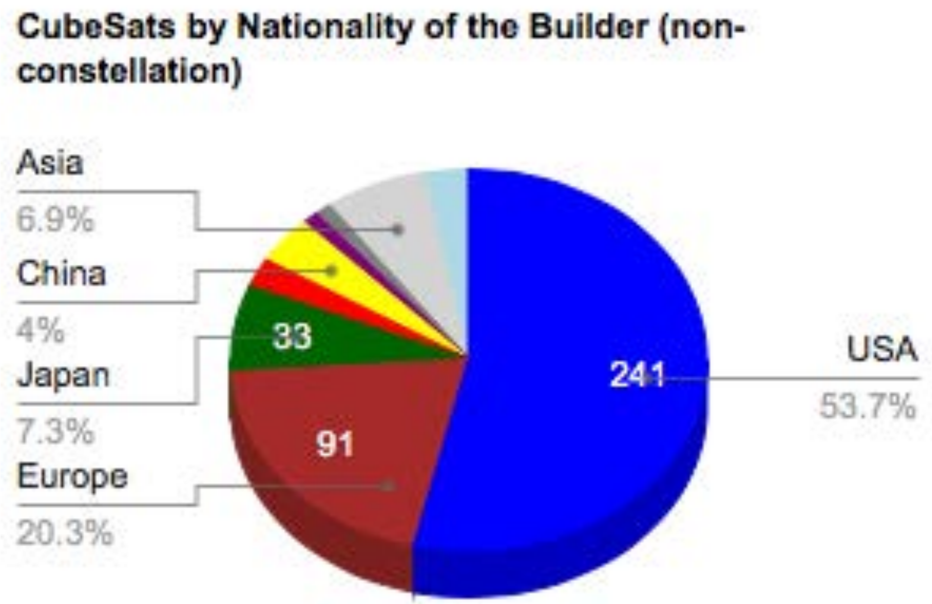


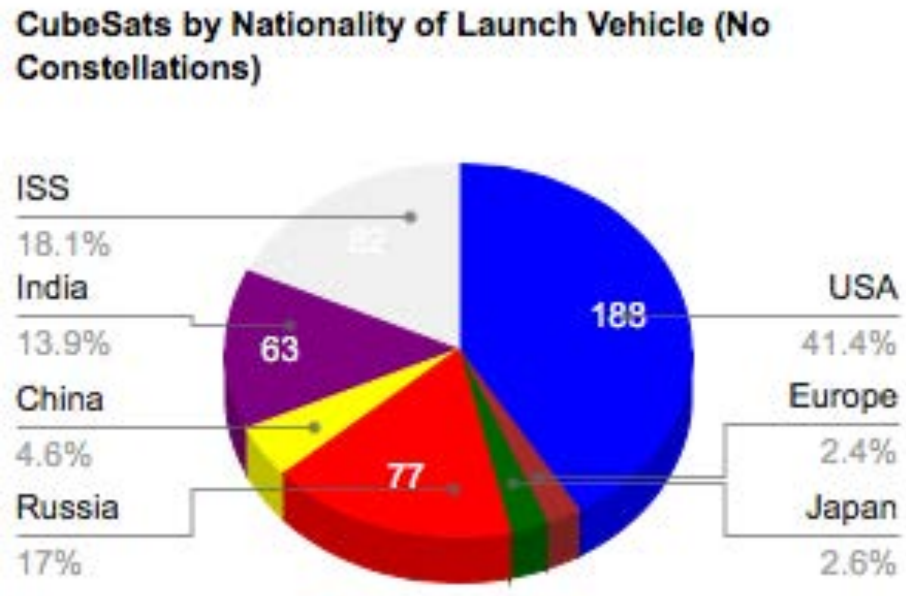




https://sites.google.com/a/slu.edu/swartwout/home/cubesat-database

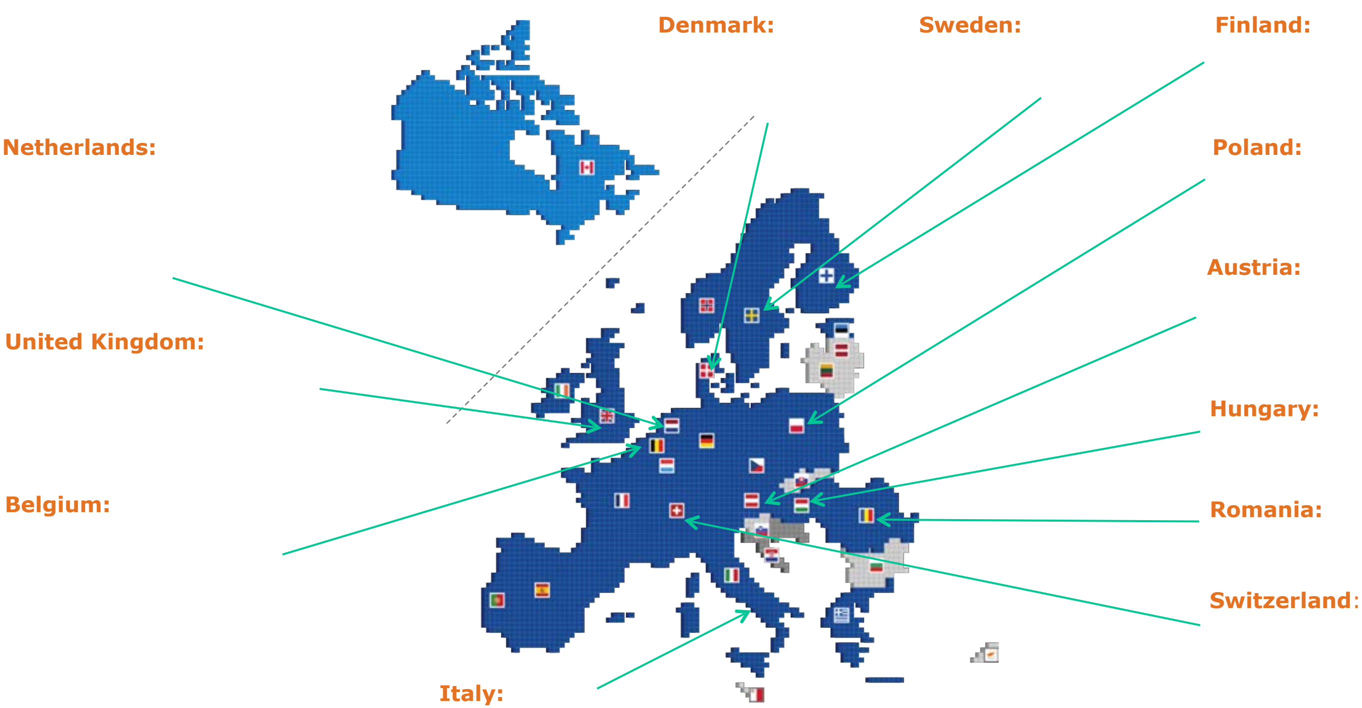
Geographical distributions, builders & launchers

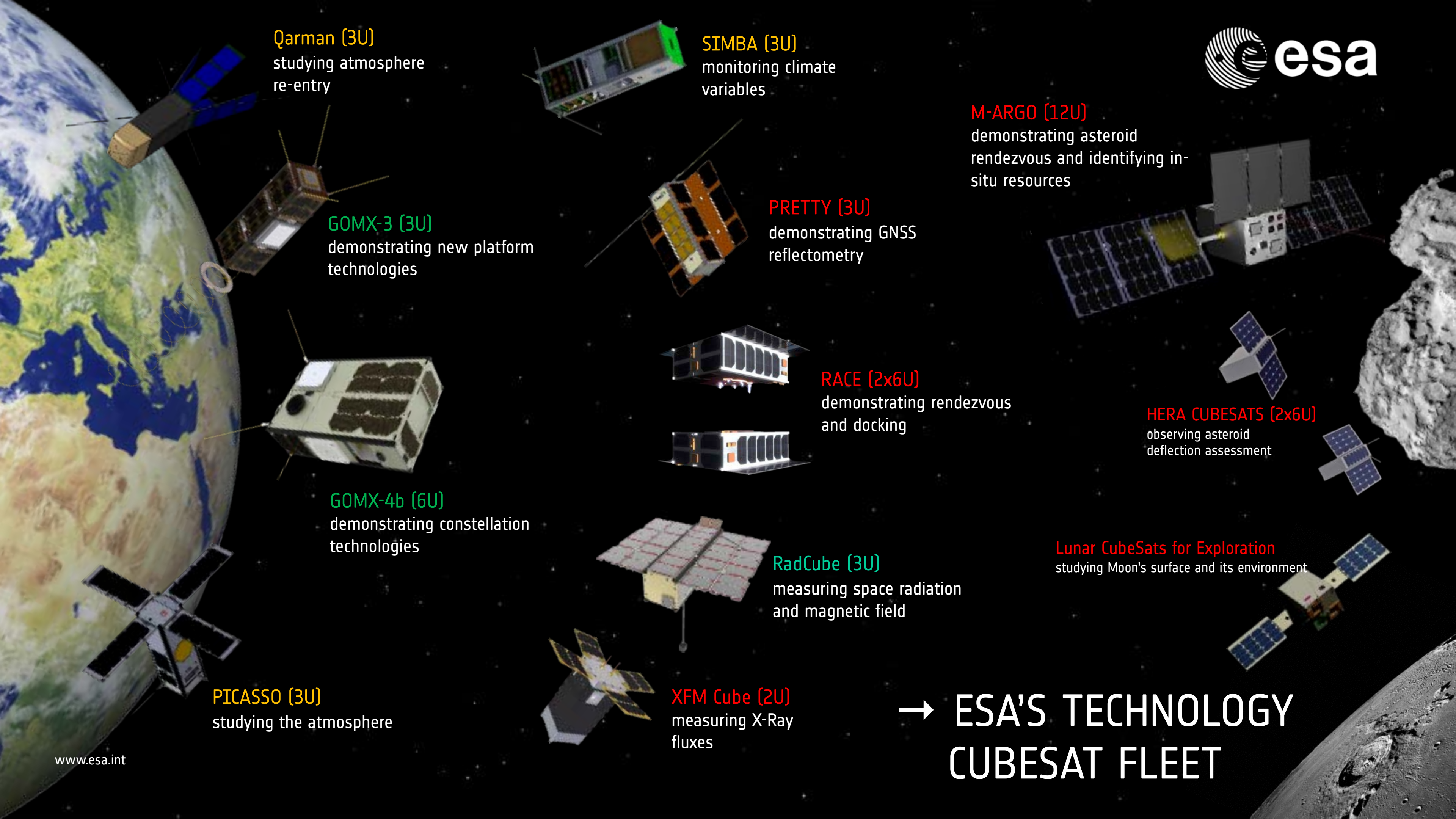




IOD CubeSat mission implementation in GSTP

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





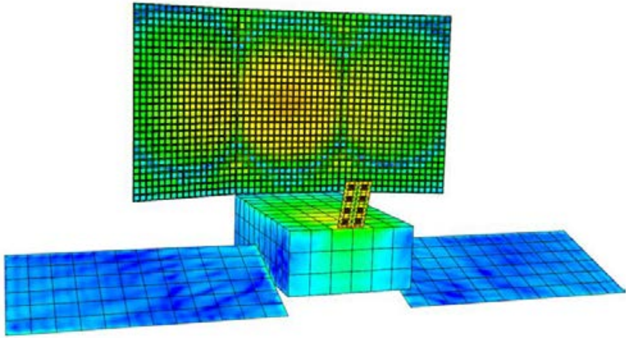
esa
Qarman (3U)
studying atmosphere re-entry
SIMBA (3U)
monitoring climate variables
M-ARGO (12U)
demonstrating asteroid rendezvous and identifying in-situ resources
GOMX-3 (3U)
demonstrating new platform technologies
PRETTY (3U)
demonstrating GNSS reflectometry
RACE (2x6U)
demonstrating rendezvous and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

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

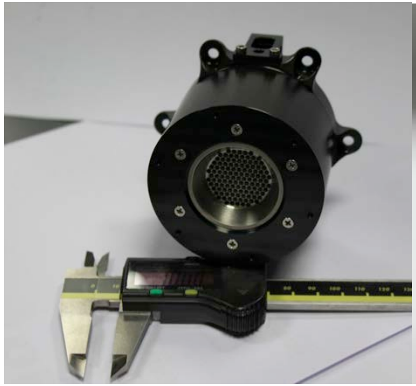
GSTP-funded Technologies Enabling New Missions

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)

CubeSats for astronomy

PERSPECTIVE
https://doi.org/10.1038/s41550-018-0438-8

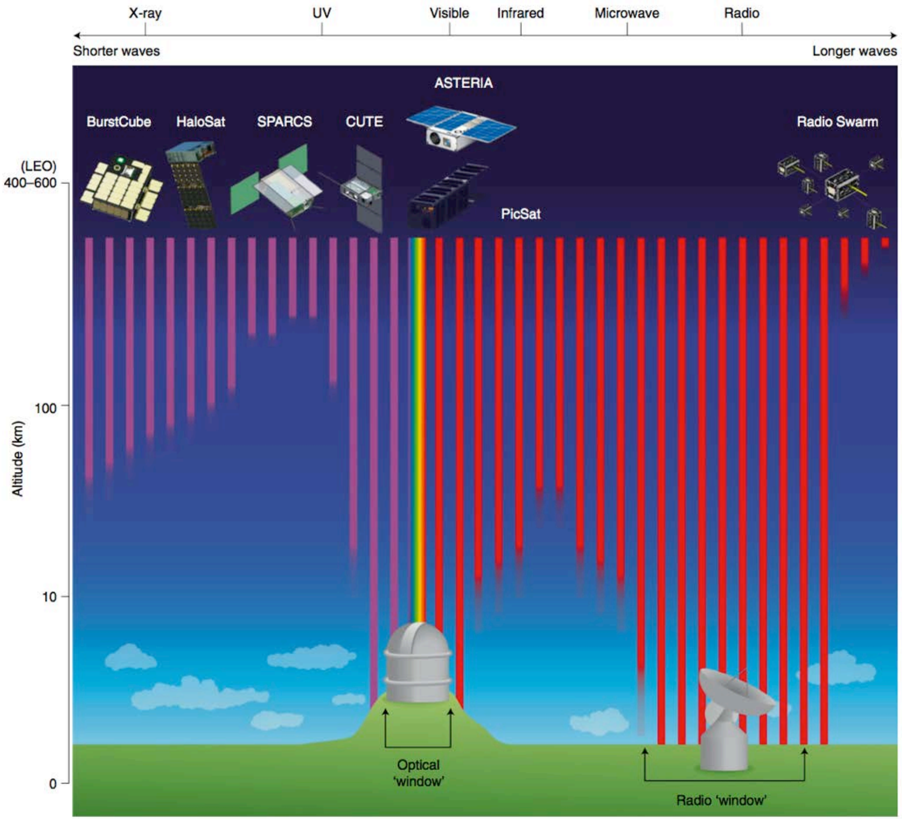
nature astronomy

On the verge of an astronomy CubeSat revolution

Evgenya L. Shkolnik

CubeSats are small satellites built in standard sizes and form factors, which have been growing in popularity but have thus far been largely ignored within the field of astronomy. When deployed as space-based telescopes, they enable science experiments not possible with existing or planned large space missions, filling several key gaps in astronomical research. Unlike expensive and highly sought after space telescopes such as the Hubble Space Telescope, whose time must be shared among many instruments and science programs, CubeSats can monitor sources for weeks or months at time, and at wavelengths not accessible from the ground such as the ultraviolet, far-infrared and low-frequency radio. Science cases for CubeSats being developed now include a wide variety of astrophysical experiments, including exoplanets, stars, black holes and radio transients. Achieving high-impact astronomical research with CubeSats is becoming increasingly feasible with advances in technologies such as precision pointing, compact sensitive detectors and the miniaturization of propulsion systems. CubeSats may also pair with the large space- and ground-based telescopes to provide complementary data to better explain the physical processes observed.

- A handful of small satellite astronomy missions are working or on their way.
- Covering radio to X-/gamma-rays.



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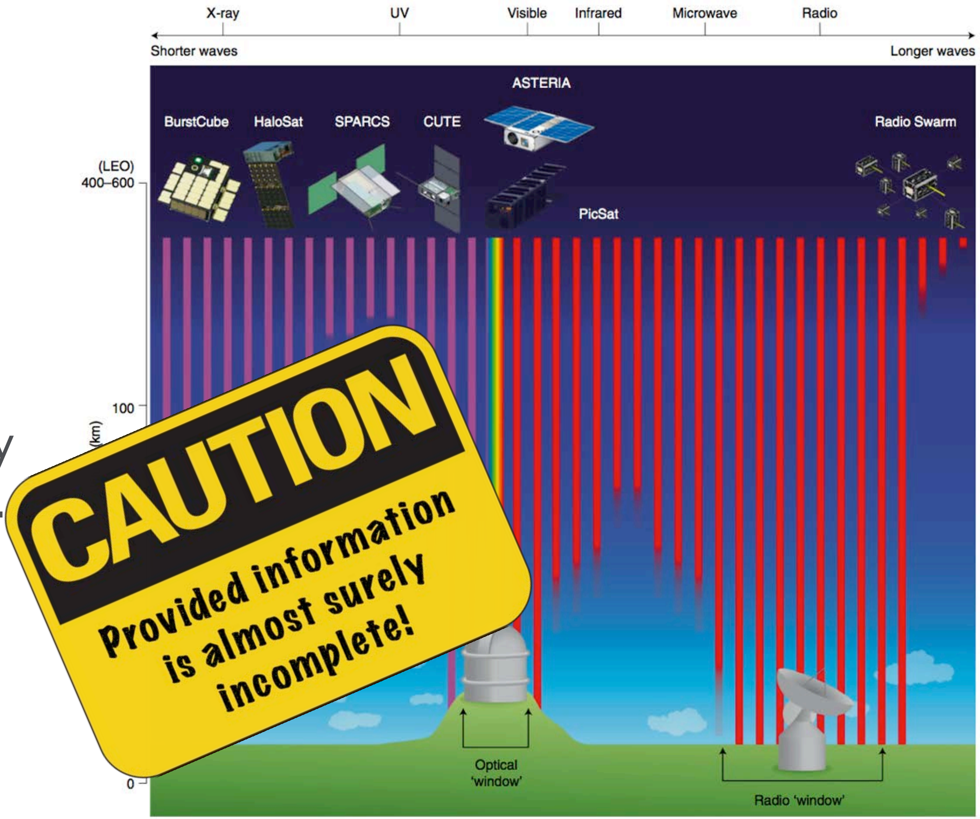
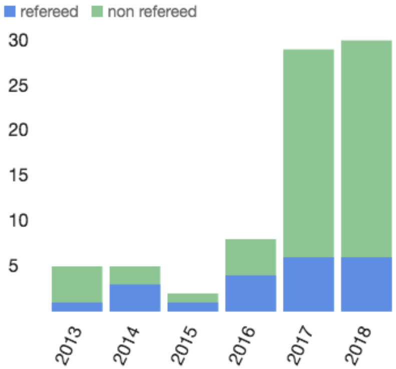


BRITE (BRIght Target Explorer) Constellation

- Network of five working nanosatellites (Austria, Poland, Canada).
- Stellar variability of bright stars followed by high precision long-term photometry in two colours (red and blue).

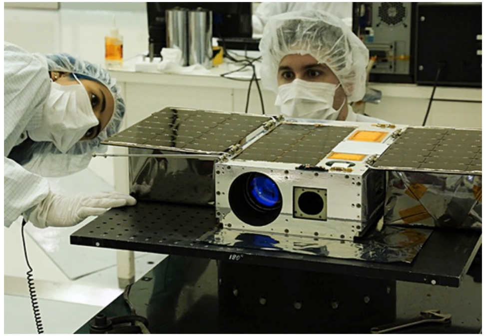


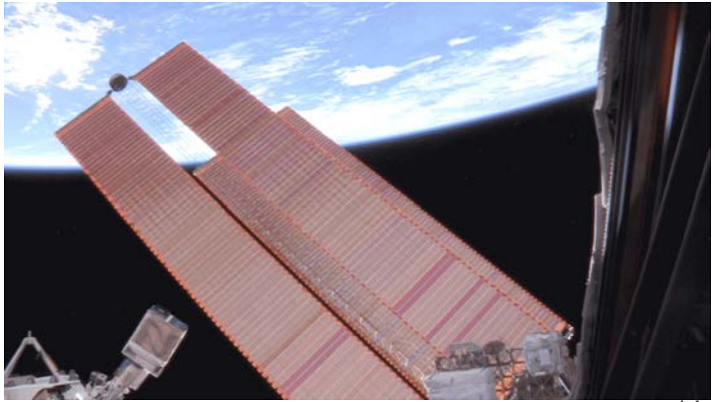
Organisation	Consortium
Deployed	2013–2014
Size Factor	2×2 U
Status	Working

ASTERIA (Arcsecond Space Telescope Enabling Research in Astrophysics)

- Technology demonstration and opportunistic science mission.
- Demonstrated pointing stability better than 0.5 arcsec RMS over 20 minutes and pointing repeatability of 1 milliarcsec RMS from orbit-to-orbit. Thermal stability of +/-0.01 K
- Optics: f/1.4 85 mm Zeiss lens 28.6-deg FOV.
- In extended mission to search for new exoplanet transits around nearby, bright stars.

Organisation	JPL
Deployed	Nov 2017
Size Factor	6U (3×2)
Status	Working





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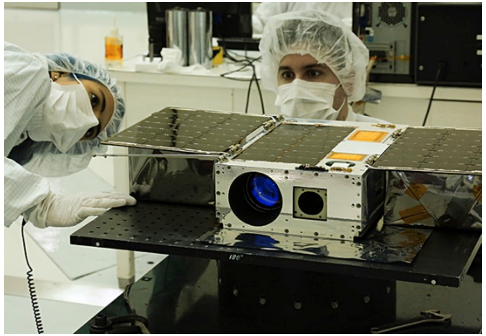
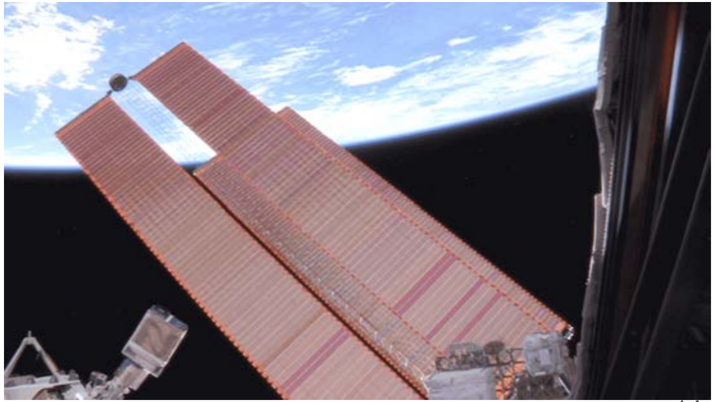


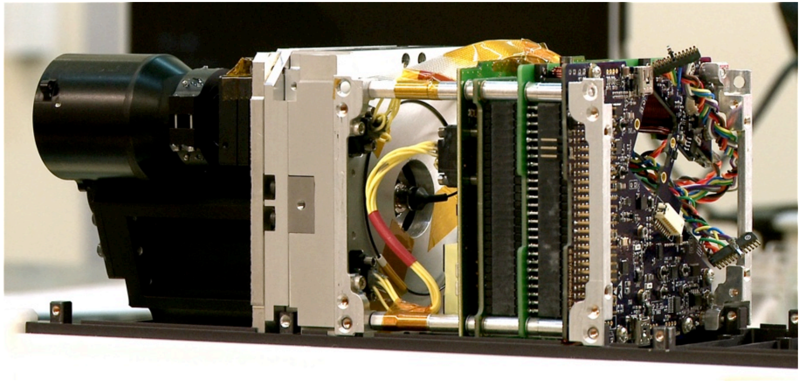


PicSat: (Not) unravelling the Beta Pictoris system

- Try to observe the transit of the young exoplanet Beta Pictoris b in front of its bright and equally young star Beta Pictoris. Secondary goal: transits of smaller bodies.
- Payload designed for main goal: 5 cm telescope coupled to a single-pixel avalanche photodiode by a single-mode optical fiber (fits in 1U).

Organisation	Paris Obs.
Launched	Jan 2018
Fell silent	**Mar 2018**
Size Factor	3U
Status	Failed

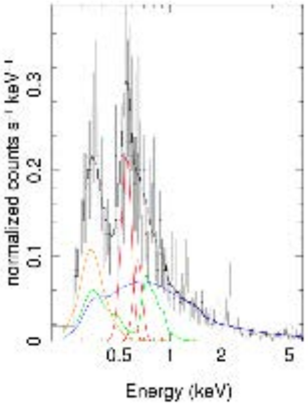
PICSAT

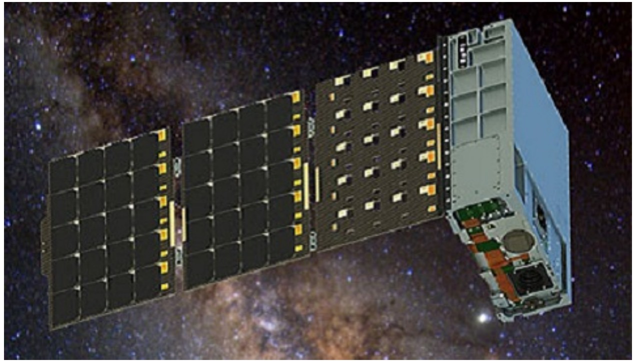


HaloSat

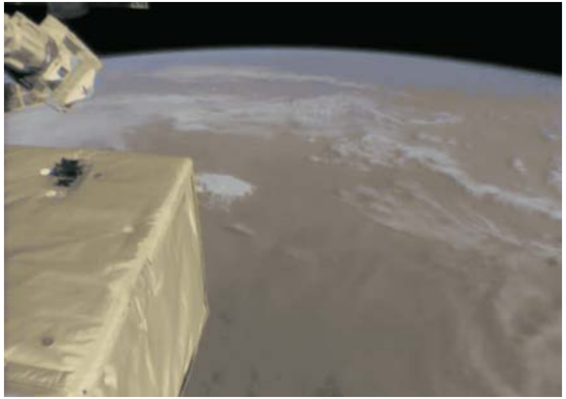
- Study hot halo of Galaxy in soft X-rays (0.4–2 keV). Map OVII and OVIII line emission in ~200 fields of ~10 deg diameter each ➟ distribution of halo.
- Addresses "missing baryon problem", implications for cosmology.
- Planned 1-year mission, results some months later.

Organisation	Univ. Iowa & NASA
Deployed	Jul 2018
Size Factor	6U (3×2)
Status	Working





Kaaret, HaloSat Overview, 2016



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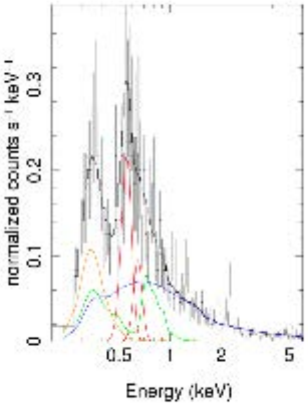
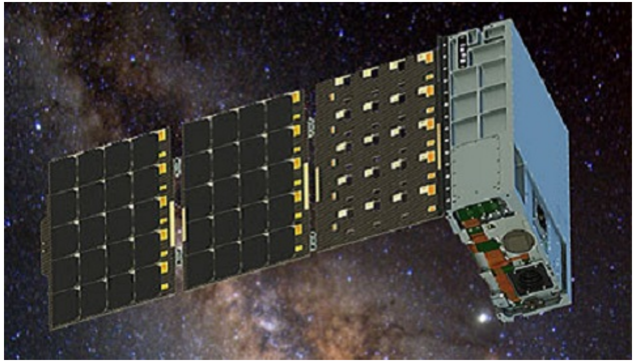
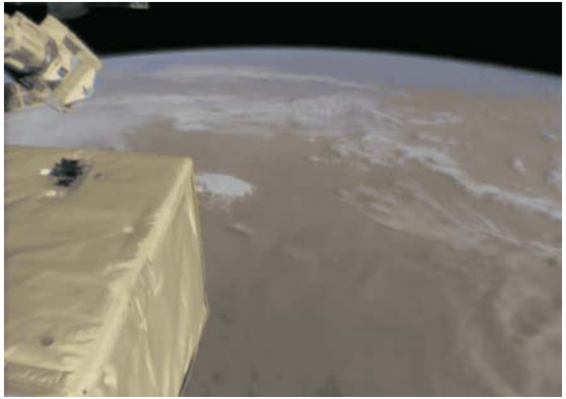




Kaaret, HaloSat Overview, 2016



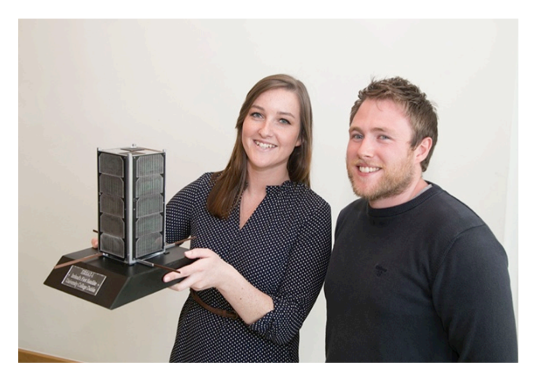
Educational Irish Research Satellite (EIRSAT) 1

- Educational and technology test. Selected in Fly your Satellite competition 2017.
- Includes Gamma-ray Module (GMOD) with new silicon photomultiplier technology, novel attitude control system (Wave-Based Control, WBC), and test of protective coatings used for Solar Orbiter.
- Expected to detect ~20 GRBs per year.

Organisation	UCD & ESA Edu. Office
Deployed	*2020 (TBC)*
Size Factor	2U
Status	Develop

fly your satellite!

EIRSAT-1 Educational Irish Research Satellite



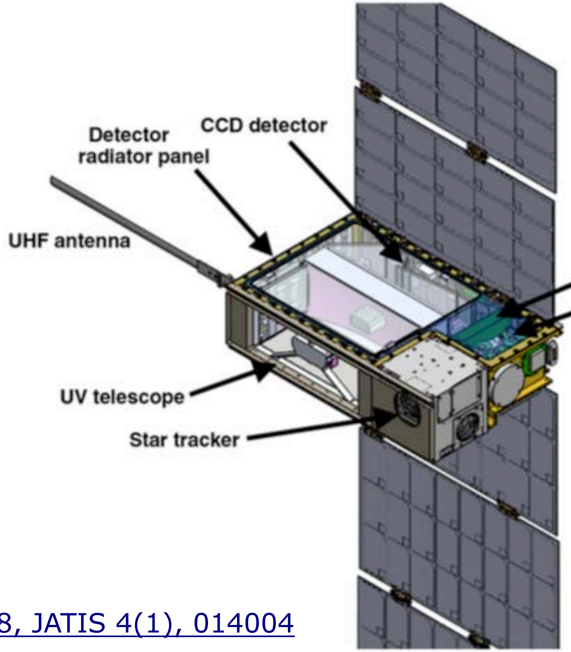
Murphy et al., Proc. SSEA 2018

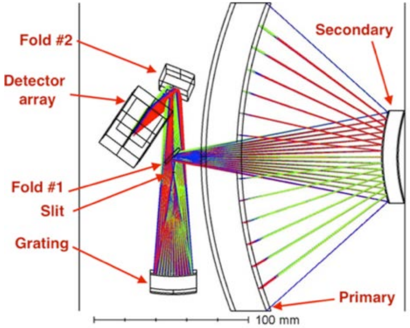
Colorado Ultraviolet Transit Experiment (CUTE)

esa

- Characterize the composition and mass-loss rates of exoplanet (hot Jupiter) atmospheres during transits.
- Near-ultraviolet (NUV) transmission spectroscopy from 255 to 330 nanometers (nm). Spectrally resolved lightcurves.
- Nominal mission: 7 months.
- *Not to be confused with other CUTE CubeSats …*

Organisation	Univ. Colorado & NASA
Deployed	*2020 (TBC)*
Size Factor	6U (3×2)
Status	Develop



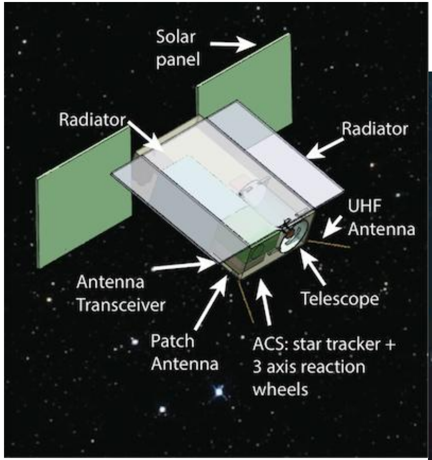


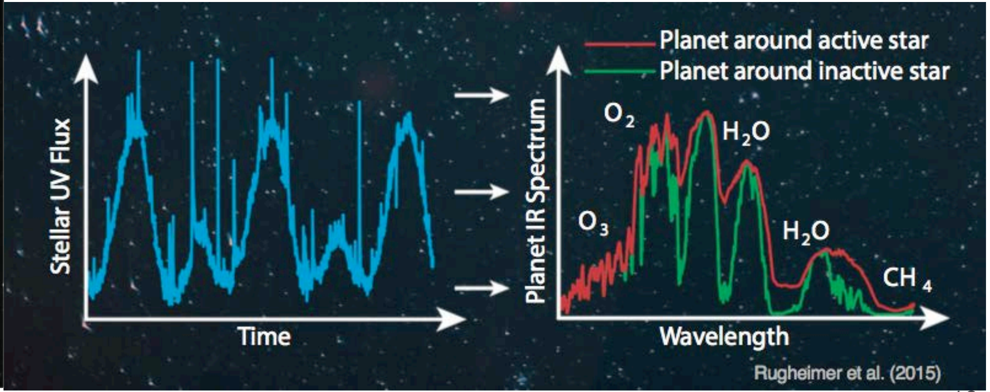
Fleming et al. 2018, JATIS 4(1), 014004

Star-Planet Activity Research CubeSat (SPARCS)

- High-energy radiation environment of exoplanets.
- FUV (153–171 nm) and NUV (258–308 nm) monitoring of low-mass stars (0.2–0.6 $M_\odot$).
- Each star observed for at least one stellar rotation (4–45 days). 25 M stars in 2 years.
- Stellar UV activity impacts atmospheric loss, composition and habitability.

Organisation	Arizona State Univ. & NASA
Deployed	*2021 (TBC)*
Size Factor	6U (3×2)
Status	Develop

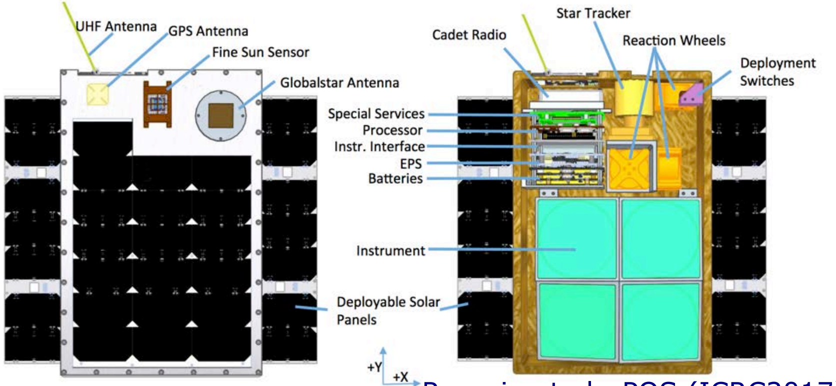




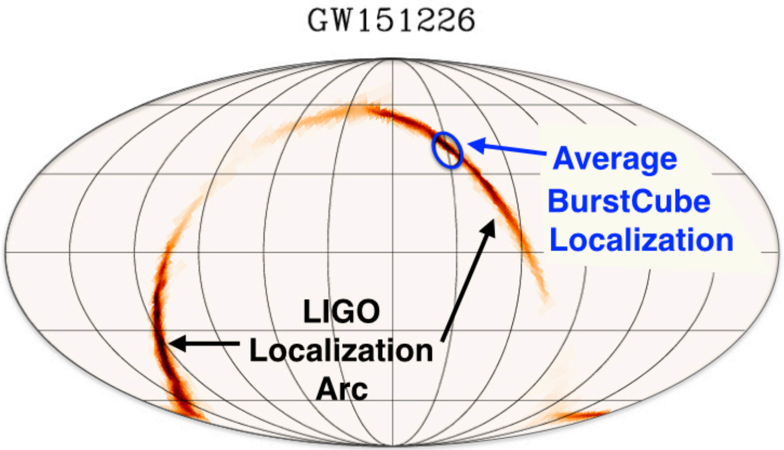
BurstCube

- Detect gamma ray transients, *possibly GW event counterparts*, in the 10–1,000 keV energy range.
- Detectors similar to Fermi-GBM.
- Rapid localization distribution via GCN.
- Ultimate goal: fleet of 10 BurstCubes for full all-sky coverage.

Organisation	GSFC
Deployed	*2021 (TBC)*
Size Factor	6U (3×2)
Status	Develop



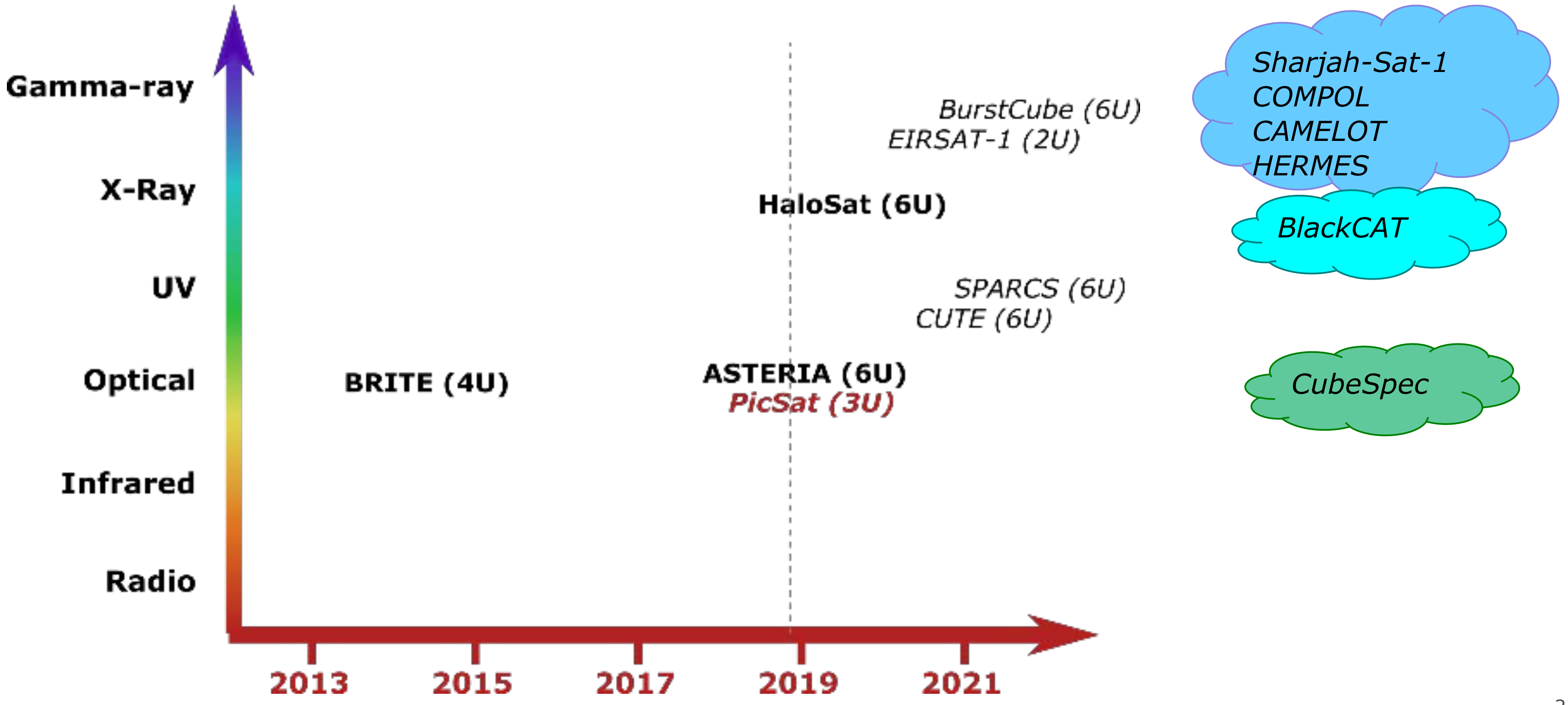
Racusin et al.. POS (ICRC2017) 760



A subjective selection of further ideas

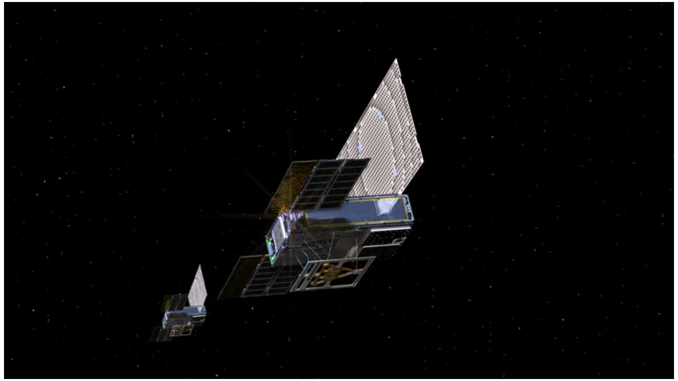
- **CubeSpec** [Belgium]: 6U CubeSat for near-UV/optical/near-IR spectroscopy.
- **BlackCAT** [USA]: 6U CubeSat for GRB prompt and afterglow emission and detection of electromagnetic counterparts of gravitational waves in soft X-rays.
- **CAMELOT** [Hungary, Czech Republic, Japan]: Fleet of at least nine 3U CubeSats for all-sky monitoring and localisation of soft gamma-ray transients.
- **Sharjah-Sat-1** [UAE, Turkey]: Hard X-ray (25–200 keV) CubeSat based on detector first flown in Turkish BeEagleSat (not accepting commands).
- **HERMES** [Italy, Germany]: Constellation of up to hundreds of 1U CubeSats covering few keV to 2 MeV.
- **COMPOL** [France]: 3U CubeSats dedicated to the spectral/timing/polarization study of bright X-ray/γ-ray sources in the 20–200 keV energy range. Each CubeSat focussing on ***one*** source (20 Msec / year).

Current state and outlook



Cubesats in Interplanetary Space

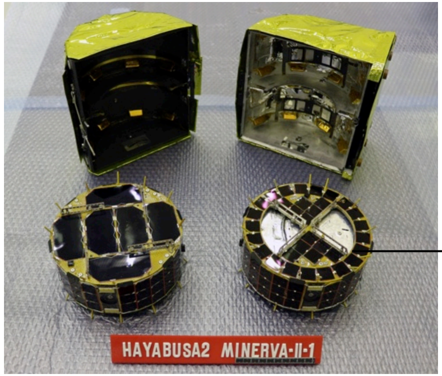
- First interplanetary cubesats just arrived at Mars
- All missions in the next few years are piggyback opportunities
  - Propulsion and Communications are the main challenges for stand-alone cubesats beyond earth orbit



MARs Cube One

Terminology

- In what follows, we limit ourselves to cubesats (smallsats that follow the cubesat form factor, made of 10 x 10 x 10 cm³ boxes)
- There are other smallsats (e.g. Minerva rovers carried to Ryugu on Hayabusa 2)



18 x 7 cm
< 2U
~1kg

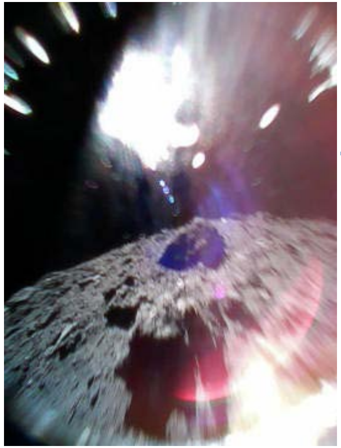
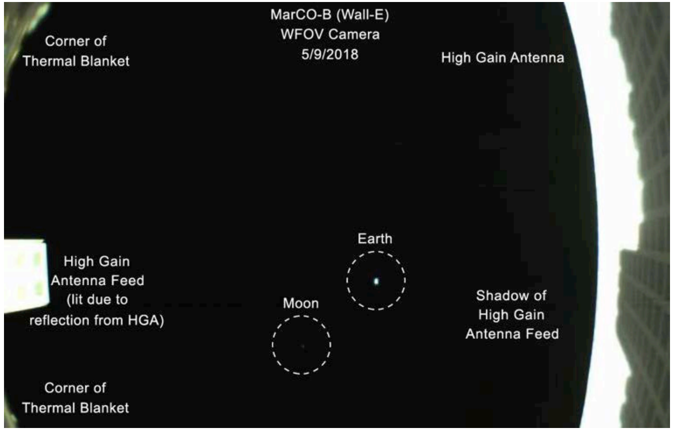


Image of Ryugu taken by Minerva II-1a after landing

First cubesats on a planetary mission

- MARs Cube One (MARCO) cubesats launched with Insight
- Separated shortly after launch
- Flew by Mars and served as communications relay for insight during descent and landing
- 18.5 M$ mission cost, 2 x 6U



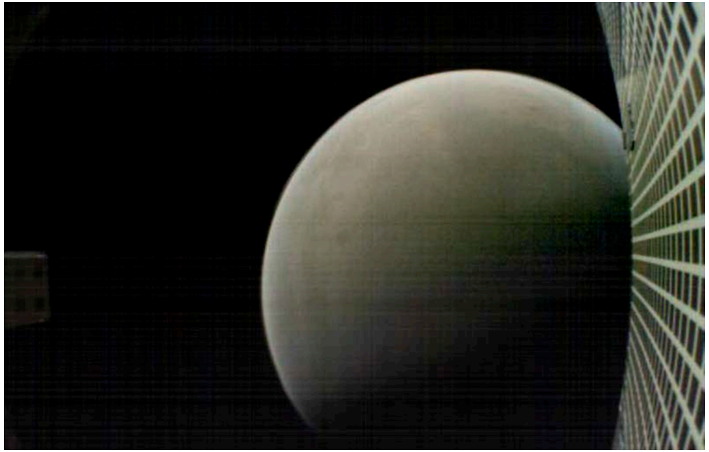
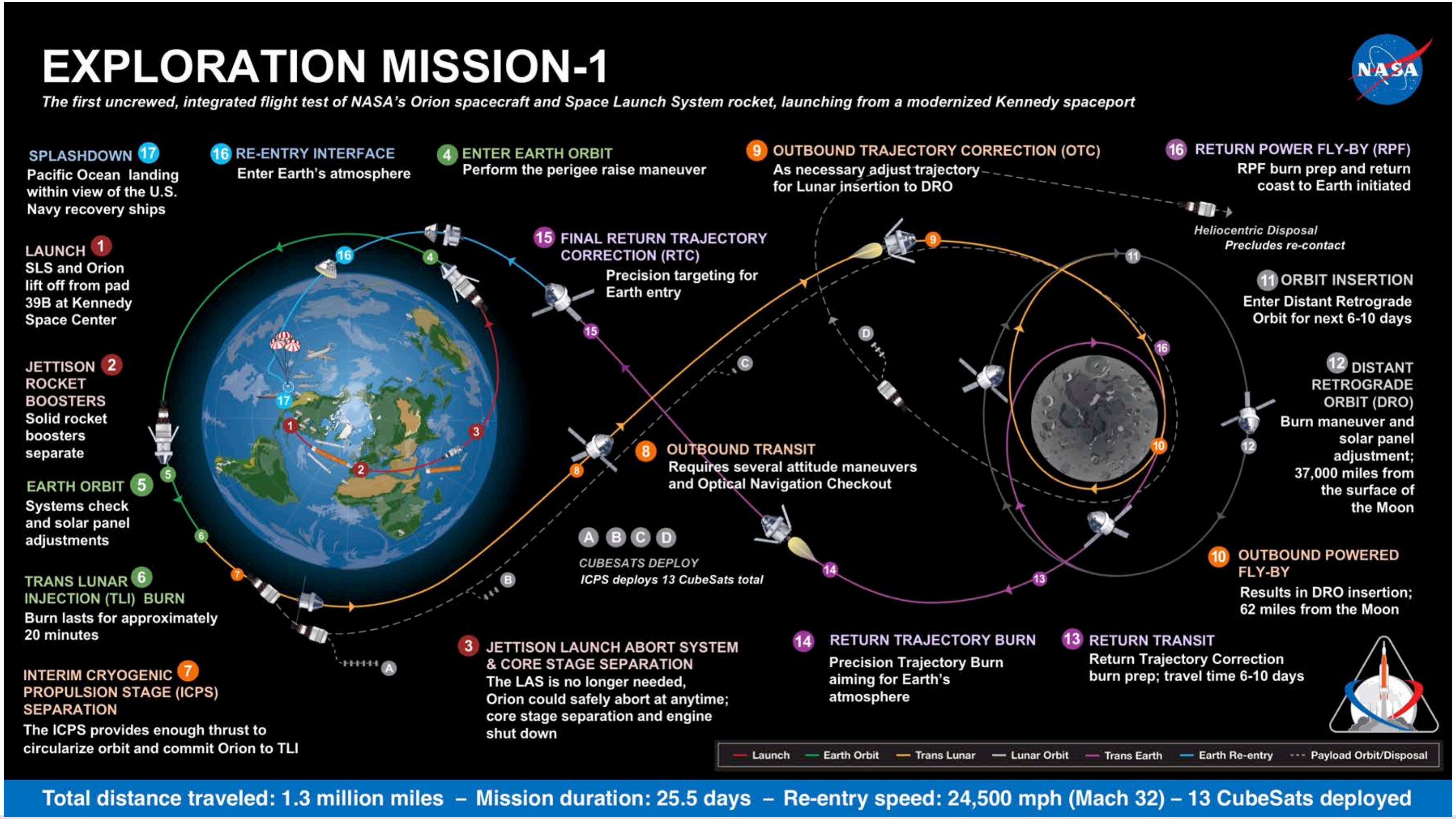


Image of Mars from 7600 km (Marco-B)

Next projects:SLS-ORION Exploration Mission 1 (2020)

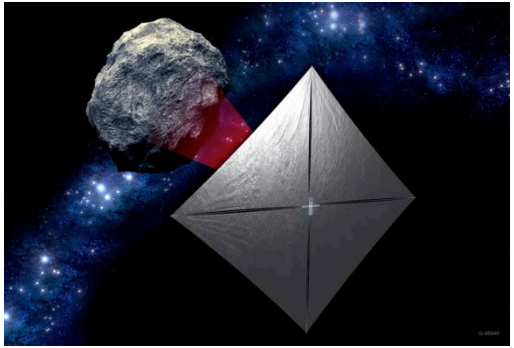


13 Cubesats on Exploration Mission 1

Lunar Flashlight

- Lunar polar orbit
- IR spectrometer to search for water ice deposits

Near-Earth Asteroid Scout

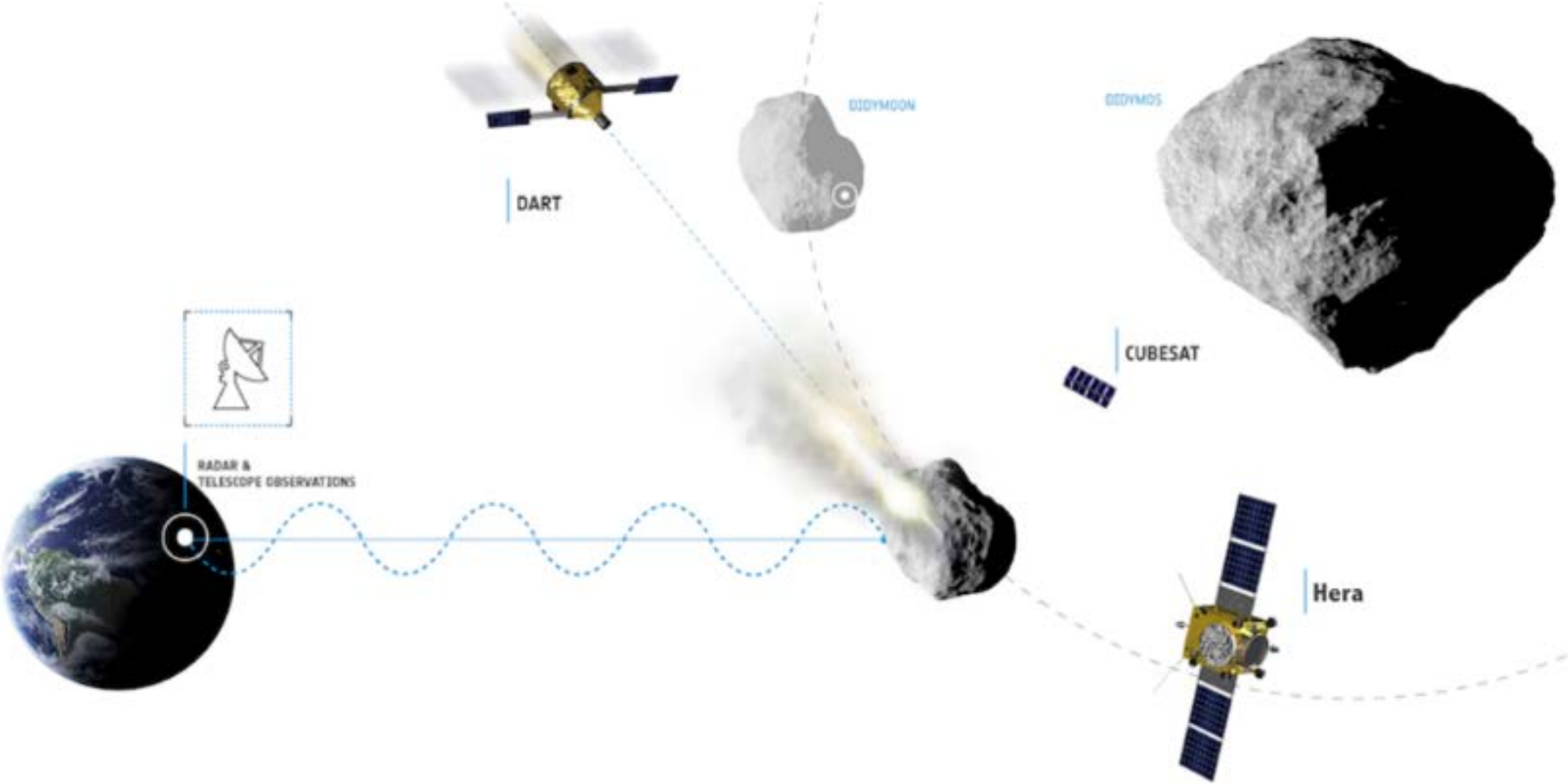


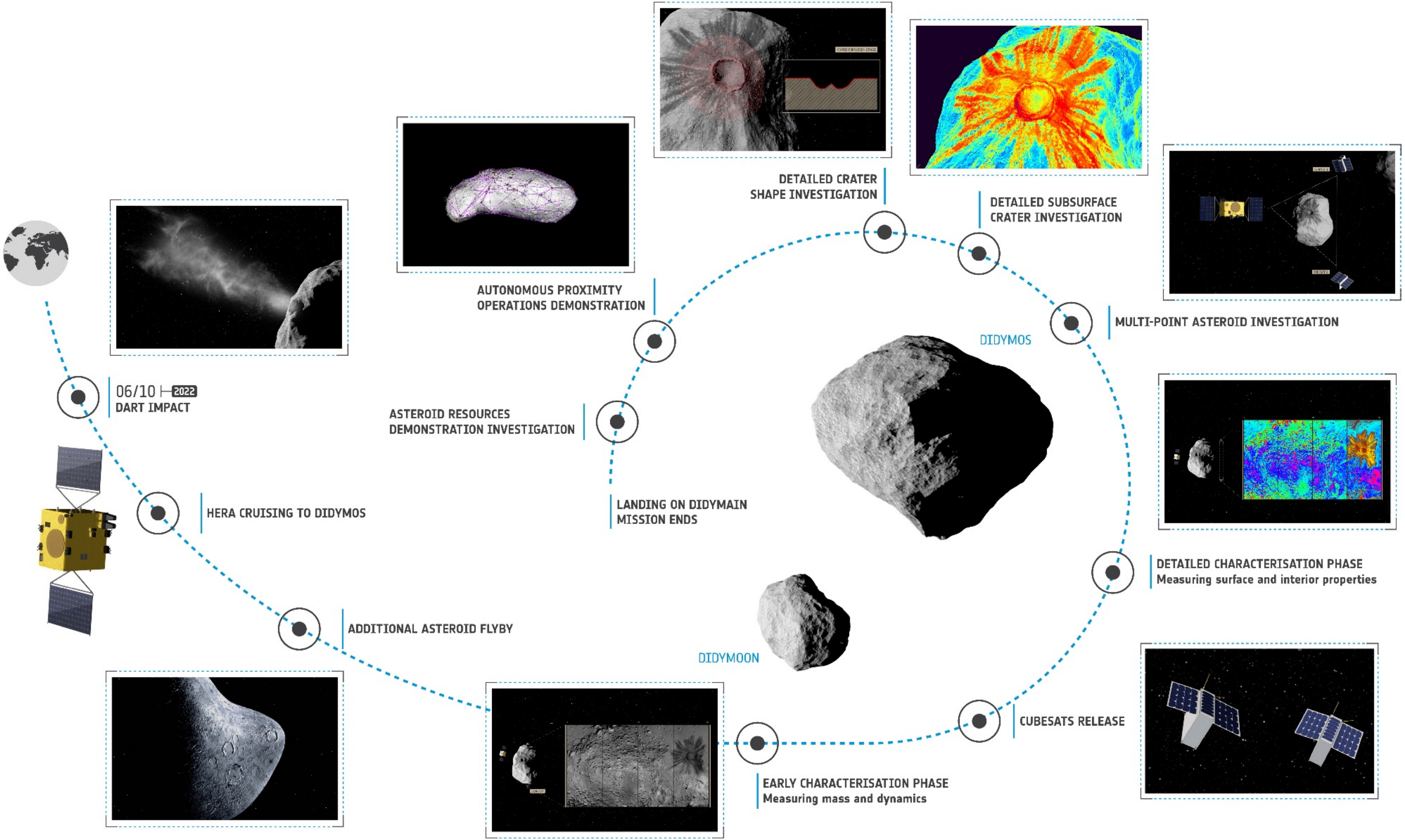
Close flyby of a near-earth asteroid using a solar sail

Cislunar Explorers

Demonstrate water propulsion and optical telecommunications

Asteroid Impact Deflection Assessment (AIDA)




06/10 2022
DART IMPACT
HERA CRUISING TO DIDYMOS
ADDITIONAL ASTEROID FLYBY
EARLY CHARACTERISATION PHASE
Measuring mass and dynamics
CUBESATS RELEASE
DETAILED CHARACTERISATION PHASE
Measuring surface and interior properties
MULTI-POINT ASTEROID INVESTIGATION
DETAILED SUBSURFACE CRATER INVESTIGATION
DETAILED CRATER SHAPE INVESTIGATION
AUTONOMOUS PROXIMITY OPERATIONS DEMONSTRATION
ASTEROID RESOURCES DEMONSTRATION INVESTIGATION
LANDING ON DIDYMAIN
MISSION ENDS
DIDYMOS
DIDYMOON

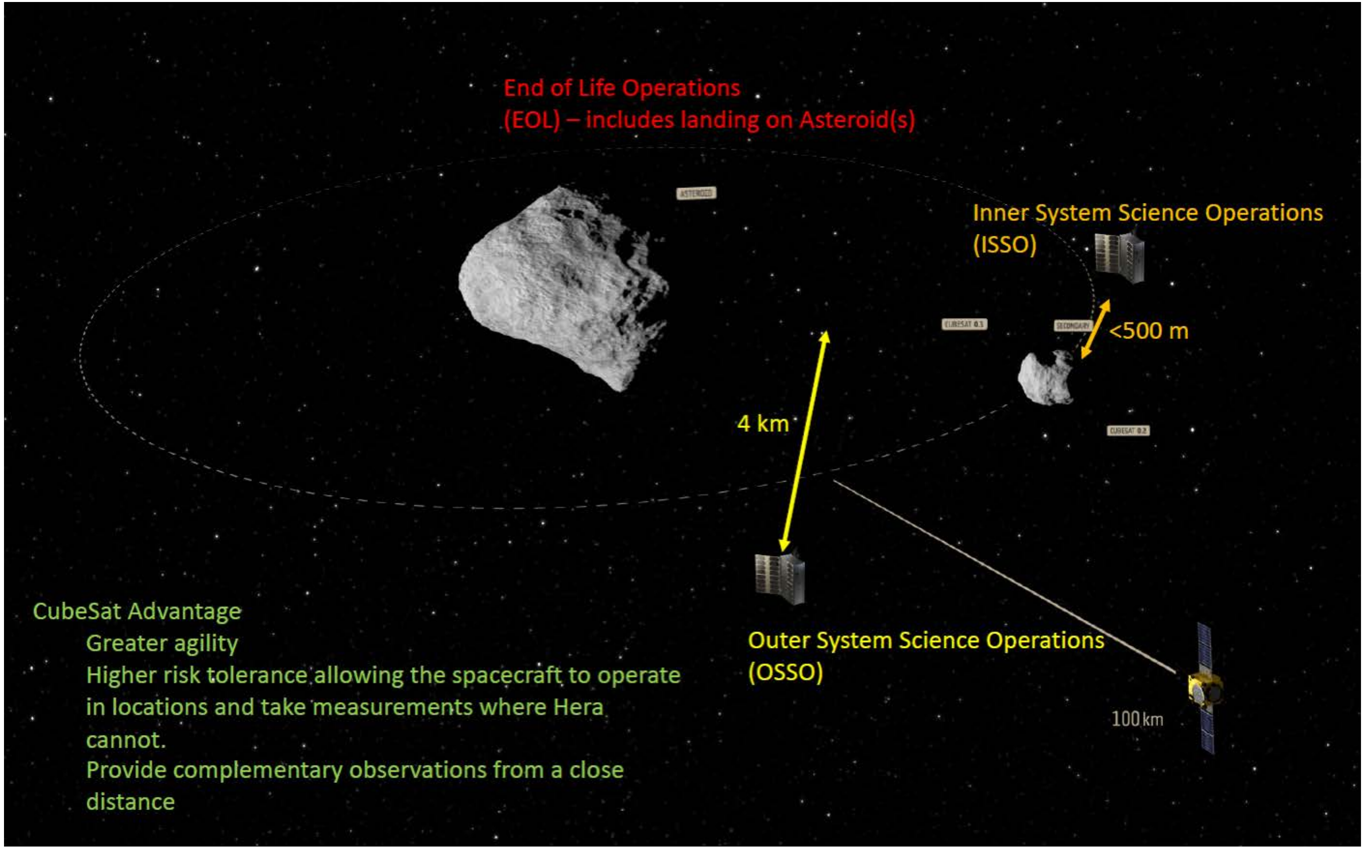
- Imager: Based on Argomoon cubesat on Exploration mission 1
- Will be deployed from DART before impact and flyby the asteroid
- Imaging of impact ejecta
- Imaging of impact crater ?

Cubesats on AIDA: 2 APEX on Hera

Apex

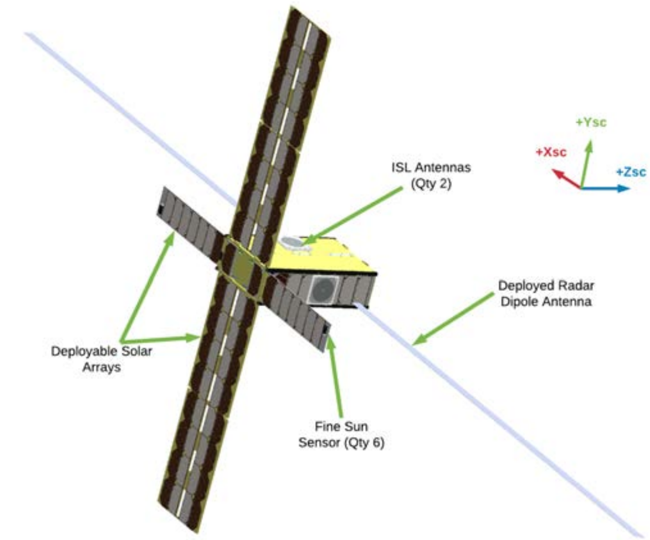
Payload:

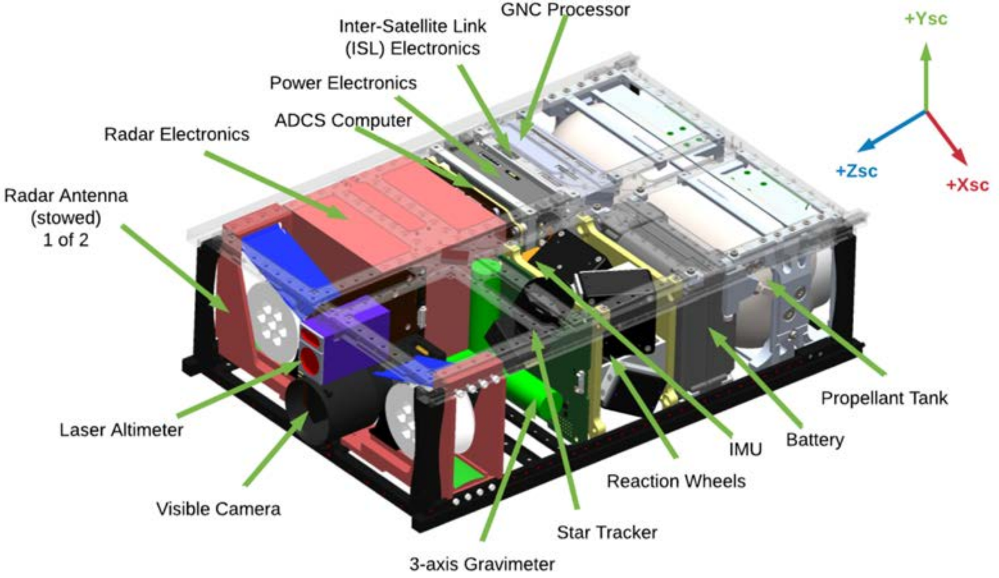
- Fabry-Perot imaging spectrometer (vis. + near-IR)
- Secondary ion mass analyser
- Magnetometer



Cubesats on AIDA: 3 Juventas on Hera

30 x 20 x 10 cm^3!



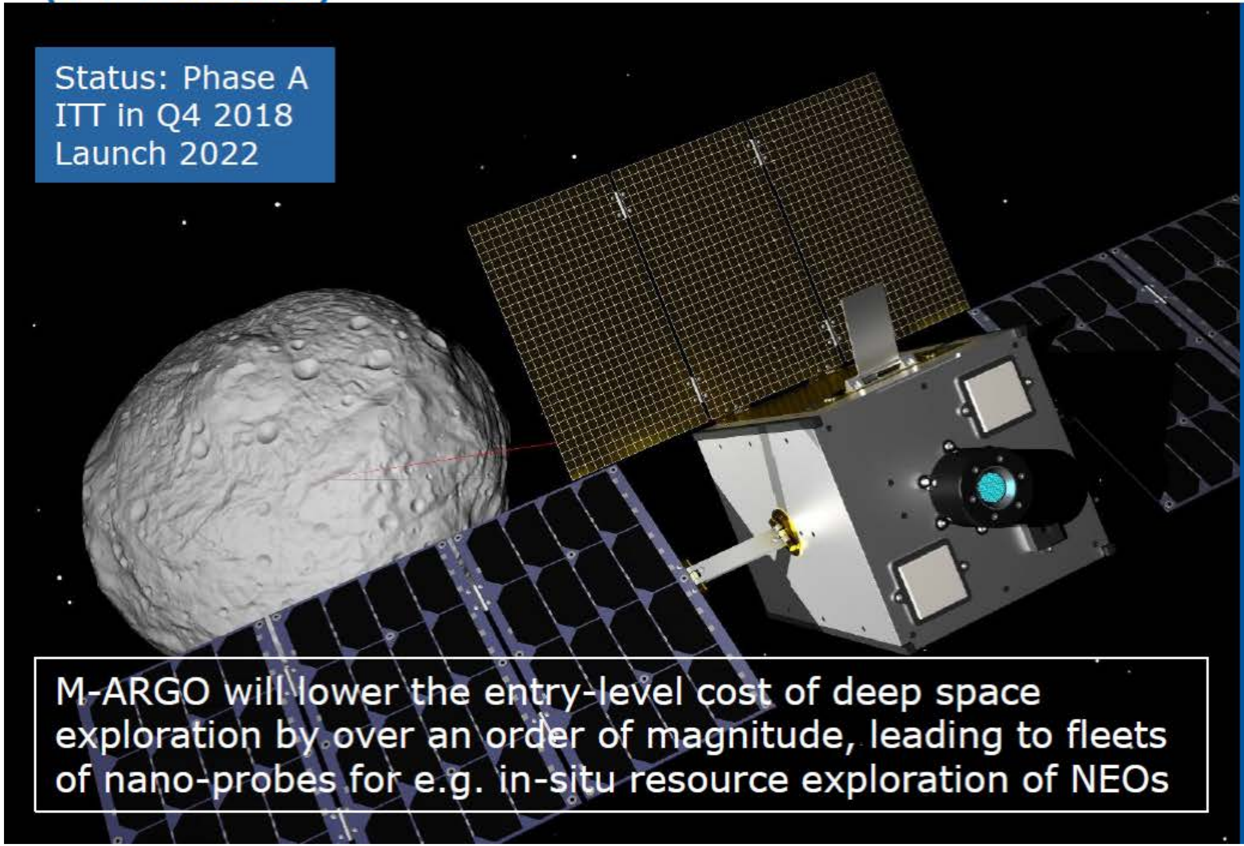


The Future

- NASA considers to send cubesats regularly on future planetary mission (e.g. on Psyche and Lucy)

- Stand-alone cubesat missions are in sight

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

Perspective of missions like M-Argo

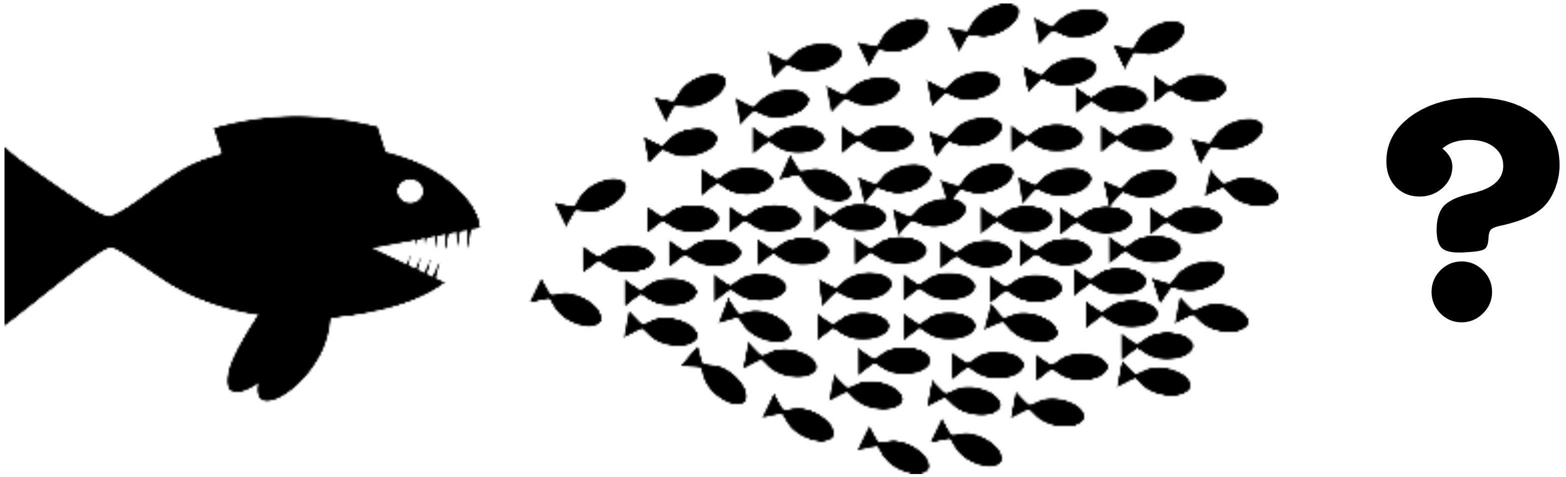
- A single cubesat mission to an asteroid costs a few 10s of M€
- For the price of one M-class mission 10s of cubesats could be launched to different asteroids
- Consideration for ESAC (and ESOC): Is there a way to do operations differently/at lower price?

Finally: Cubesats as a business

- Planet Labs images the earth daily at a resolution of ~3 m
- ~300 cubesats launched
    - ❑ About 150 active
- Little detail available about the specifications of their systems

Planet Labs cubesats released from ISS

So how will the future be?



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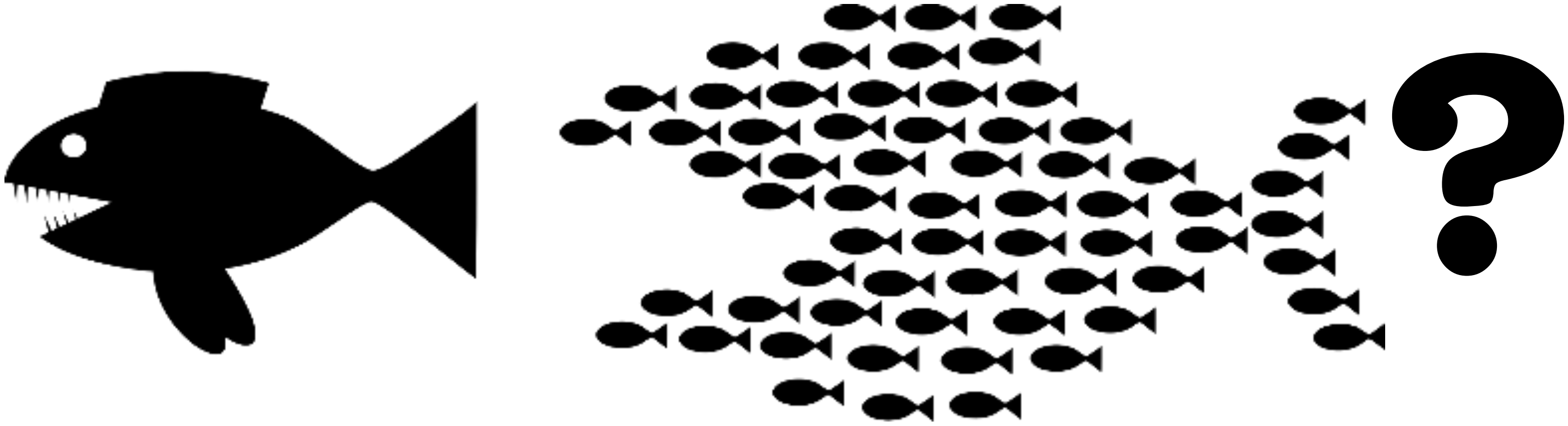

So how will the future be?