UNIVERSITAT POLITÈCNICA DE CATALUNYA BARCELONATECH

NANOSAT LAB

"2007-2024: Misiones CubeSat del NanoSatLab de la Universitat Politècnica de Catalunya, de la Idea al Espacio"

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Special thanks to all the UPC NanoSatLabbers for their enthusiastic hard work!

Outline

I. How SmallSats are making a revolution in our way to access to space

1.1. Introduction to Small Satellites (i)

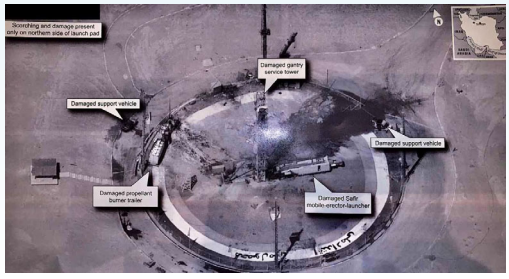
- At the beginning of the space age all satellites were "small."

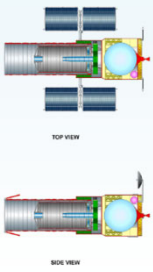

Sputnik-1


Explorer-1


Vanguard-1

- Well… not really!



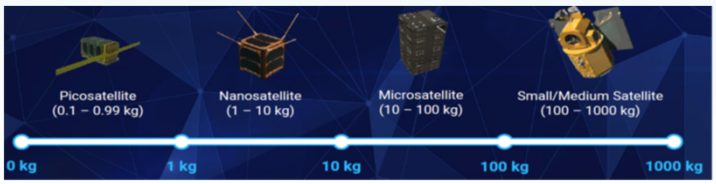


Conceptual drawing of **KH-11**:
- Spy satellite collecting 10 cm resolution images
- ~19,600 kg
- > 10 m longitude,
- > 3 m diameter (2.4 m mirror)
- Launched since 1976

"like a Hubble telescope"

1.1. Introduction to Small Satellites (ii)

- 1st two decades of the space age: each satellite had its own design.
- Standard spacecraft buses practically unknown until end of '70s.
- Early '80s micro-satellites emerged and adopted a radically different design approach to reduce costs, focusing on available and existing technologies, and using COTS components.
- "Small satellite mission philosophy": design-to-cost approach, with strict cost and schedule constraints, mostly combined with a single mission objective, to reduce complexity.

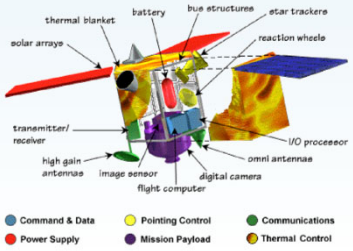


[From "2019 Nano/Microsatellite Market Forecast, 9th Edition", SpaceWorks]

1.1. Introduction to Small Satellites (iii)

- "CubeSat standard" (1999) profs. J. Puig-Suari of CalPoly and Bob Twiggs of Stanford Univ.
- Goal: to allow graduate students to conceive, design, implement, test and operate in space a complete spacecraft, often using COTS components.
- Because of the simplicity of the CubeSat "standard", it became a "de facto" standard.
- Includes **ALL subsystems** as in large satellites

  - On Board Computer
  - Electrical Power Supply
  - Attitude Determination and Control System
  - Communications
  - Thermal control
  - Payload(s)



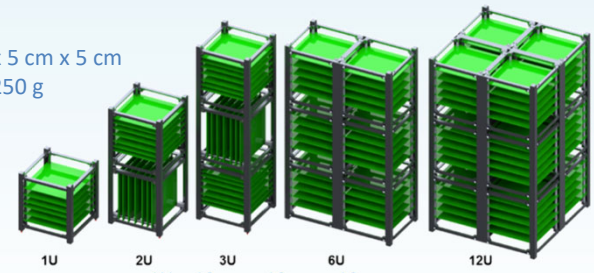
1st CubeSats launched on a Russian Eurockot in June 2003: Japanese Cubesat and CUTE-1, the Canadian Can X-1, the Danish AAU Cubesat and DTUsat, the US Quakesat

1.1. Introduction to Small Satellites (iv)

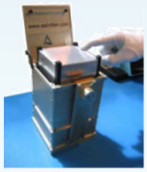
- Current CubeSat Design Specification defines the envelopes for 1U to 12U (rev 14).
- Also there is a standard for "PocketQubes" (Cube of 5 cm side)

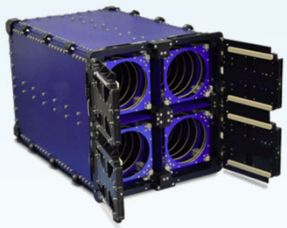
1P

1P = 5 cm x 5 cm x 5 cm
Weight: < 250 g



1U = 10 cm x 10 cm x 10 cm
Weight: < 1.3 kg
Average power : ~1 W, peak power: ~2-3 W

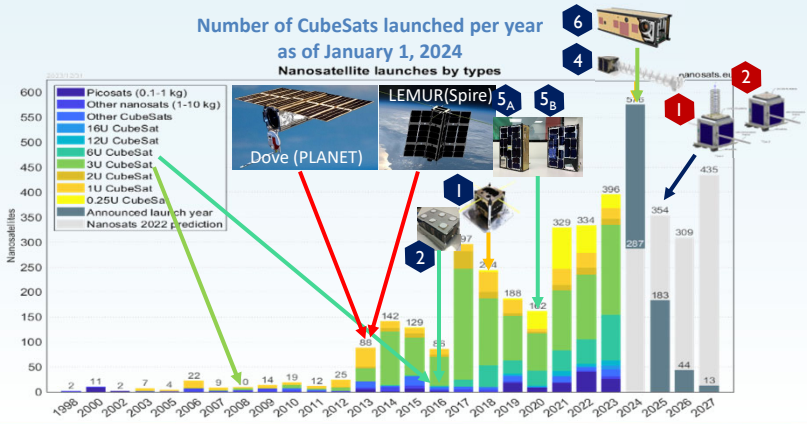




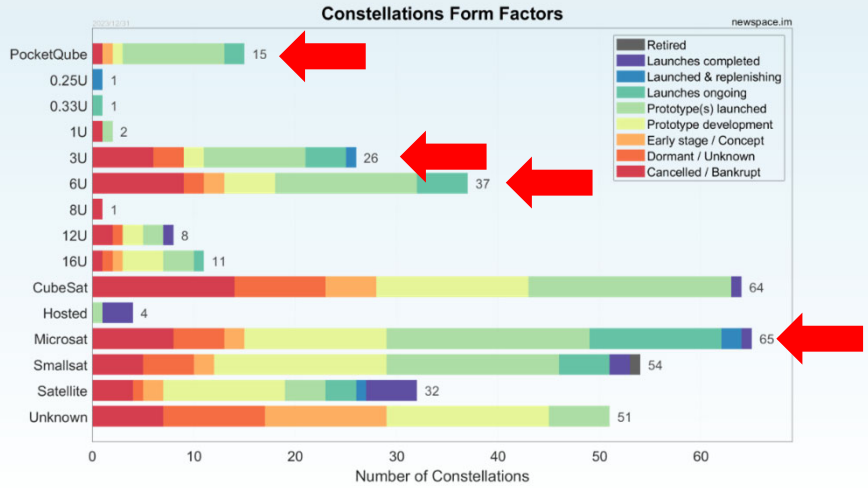
P-PODs

1.1. Introduction to Small Satellites (v)

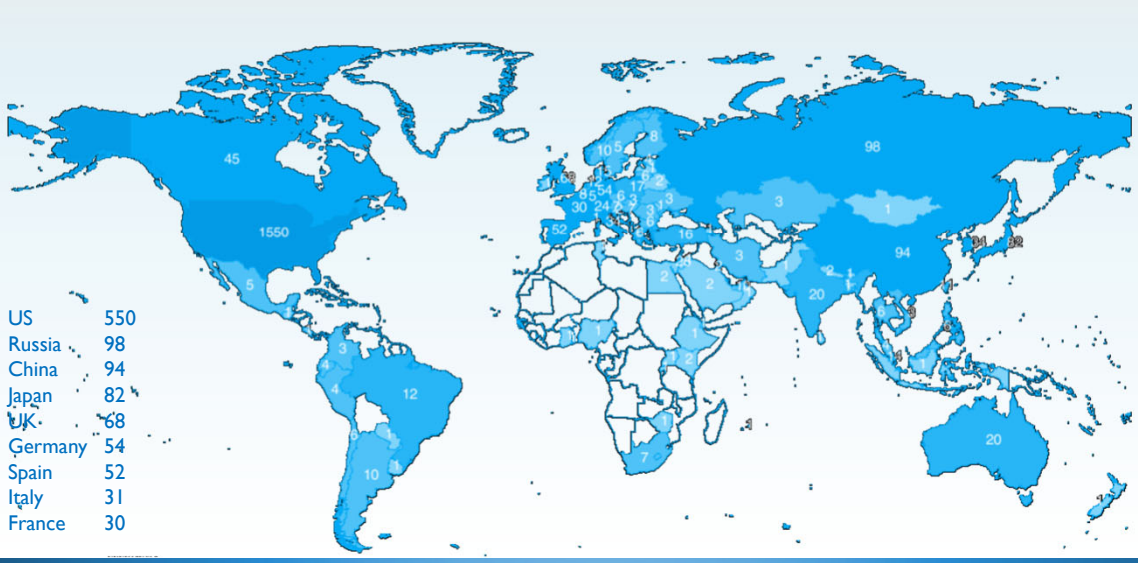
- Today 3U CubeSats are dominating the scene, and they will over the next decade.
- Next wave of growth will be based on 6U and 12U CubeSats:
  right balance between very capable payloads, and limited manufacturing and launch costs.



1.1. Introduction to Small Satellites (vi)



1.1. Introduction to Small Satellites (vii)

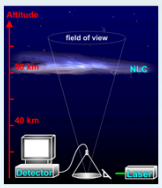


1.2. Applications of Small Satellites (i): to Earth Observation

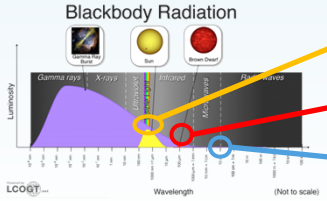
- **First wave of CubeSats** were **Techdemos** and **Passive Earth Observation**
- Most CubeSats originally performed Optical and Passive Microwave EO missions due to power (and bandwidth) limitations

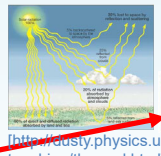
	Frequency	
Active:	Microwaves **RADAR**	Optical **LIDAR**
Passive:	Microwave Radiometers	Optical Radiometers

[http://www.srh.noaa.gov/srh/sod/radar/radinfo/radinfo.html]

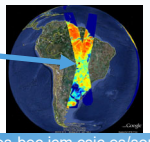


[http://web.physik.uni-rostock.de/cluster/students/fp3/lidar_en.html[]



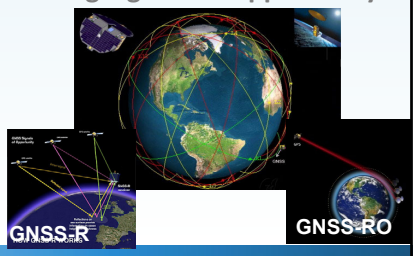


[http://dusty.physics.uiowa.edu/~goree/teaching/thermal.html]



[http://www.smos-bec.icm.csic.es/south_america_seen_by_smos]

Using Signals of Opportunity

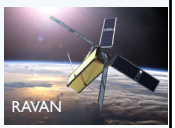


1.2. Applications of Small Satellites (ii): to Earth Observation

- **Science mission feasibility** based on nanosatellites: **from 2012 to 2017 huge change in just 5 years!**
  Huge investments in P/L developements, deployable solar panels and improved downlinks

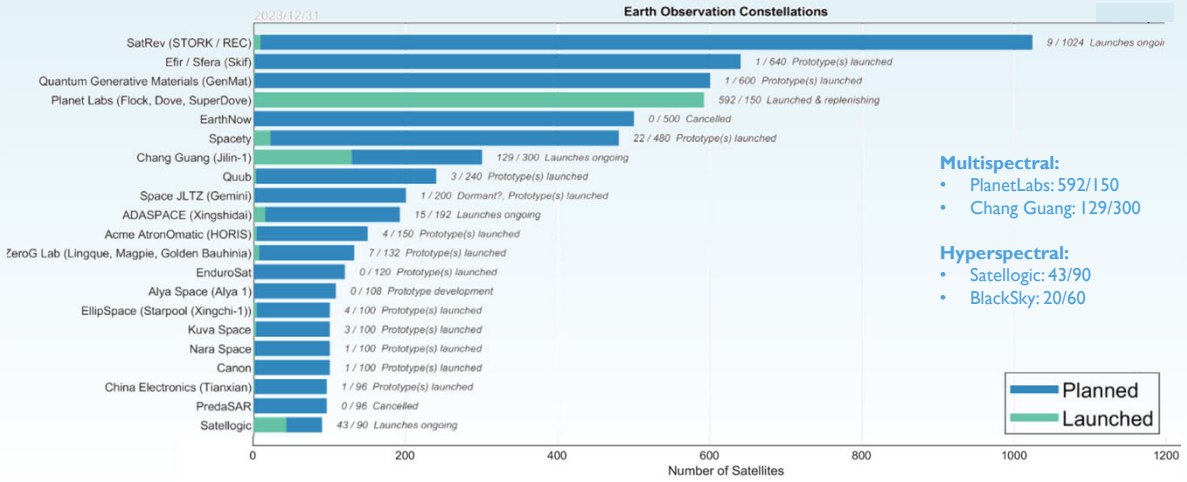
Technology	Selva and Krejci, 2012	Freeman et al. 2017	Justification
Atmospheric chemistry instruments	Problematic	Feasible	**PICASSO,** IR sounders
Atmospheric temperature and humidity sounders	Feasible	Feasible	-
Cloud profile and rain radars	Infeasible	Feasible	JPL **RainCube** demo
Earth radiation budget radiometers	Feasible	Feasible	SERB, **RAVAN**
Gravity instruments	Feasible	Feasible	No demo mission
Hi-res optical imagers	Infeasible	Feasible	Planet
Imaging microwave radars	Infeasible	Feasible	Ka-Band 12U design
Imaging multi-spectral radiometers (Vis/IR)	Problematic	Feasible	AstroDigital
Imaging multi-spectral radiometers (μW)	Problematic	Feasible	**TEMPEST**
Lidars	Infeasible	Feasible	DIAL laser occultation
Lightning imagers	Feasible	Feasible	-
Magnetic field	Feasible	Feasible	InSPIRE
Multiple direction / polarization radiometers	Problematic	Feasible	HARP Polarimeter
Ocean color instruments	Feasible	Feasible	SeaHawk
Precision orbit	Feasible	Feasible	CanX-4 and -5
Radar altimeters	Infeasible	Feasible	Bistatic LEO-GEO
Scatterometers	Infeasible	Feasible	CYGNSS (GNSS-R)

[adapted from "Deep Space cubesats and nanosats at JPL," T. Freeman, May 2017]



1.2. Applications of Small Satellites (iii): to Earth Observation

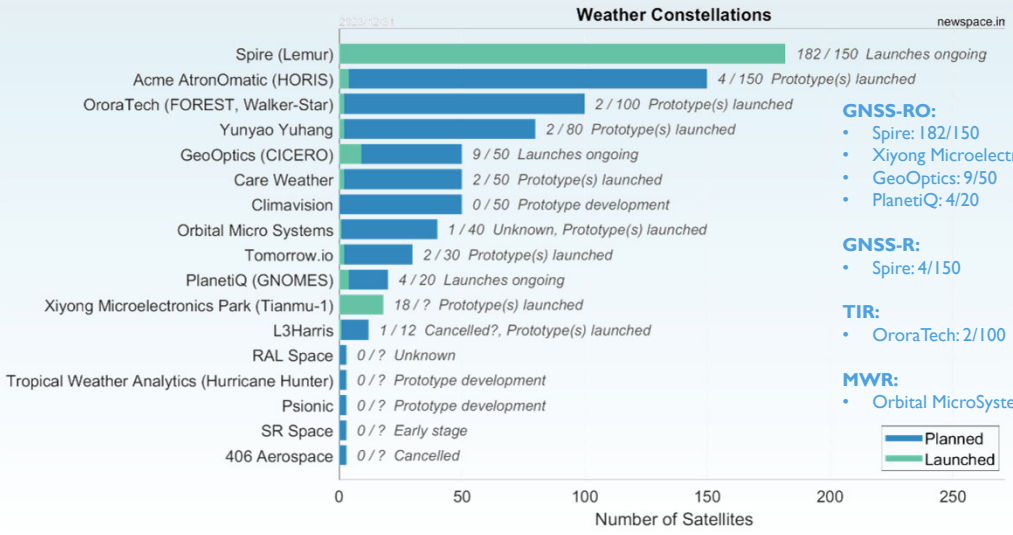
Optical EO followed by **GNSS-RO**.



Multispectral:
- PlanetLabs: 592/150
- Chang Guang: 129/300

Hyperspectral:
- Satellogic: 43/90
- BlackSky: 20/60

1.2. Applications of Small Satellites (iv): to Earth Observation



GNSS-RO:
- Spire: 182/150
- Xiyong Microelectronics Park: 18/?
- GeoOptics: 9/50
- PlanetiQ: 4/20

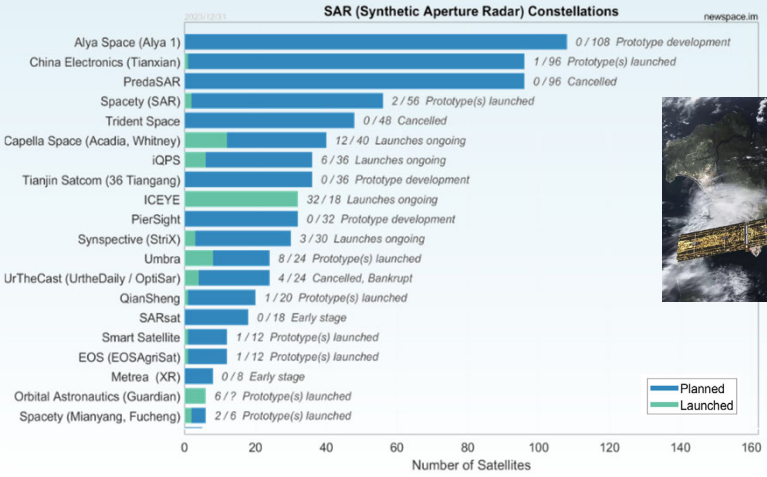
GNSS-R:
- Spire: 4/150

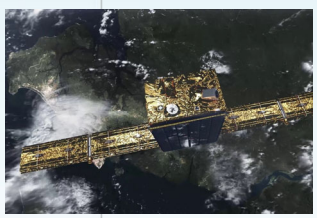
TIR:
- OroraTech: 2/100

MWR:
- Orbital MicroSystems: 1/40

1.2. Applications of (not that) Small Satellites (v): to EO

Actually these are MicroSatellites (~100 kg)

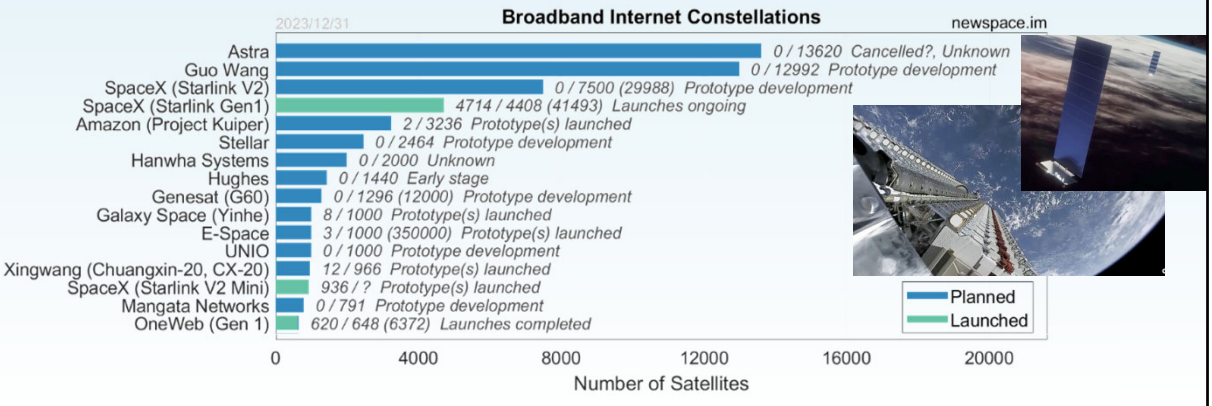




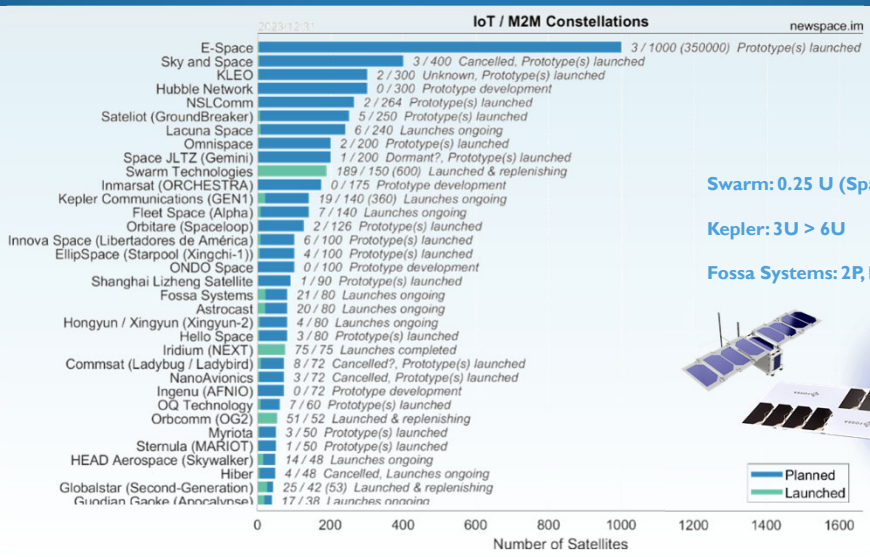
1.2. Applications of (not so) Small Satellites (vi): to Communications

- **Telecom is coming fast!** (also to support EO constellations – Inter-Satellite Links)
- > 10% of all nano/microsatellites launched in 2018 were for communications

Actually these are MiniSatellites!! (Starlink v1 ~230-300 kg, Starlink v2 ~730-1250 kg)



1.2. Applications of Small Satellites (vii): to Communications

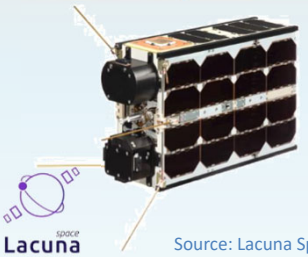


Swarm: 0.25 U (SpaceBEE)

Kepler: 3U > 6U

Fossa Systems: 2P, Ferrox 1/3x6U

1.2. Applications of Small Satellites (viii): to Communications

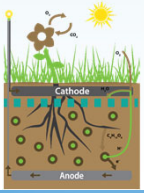


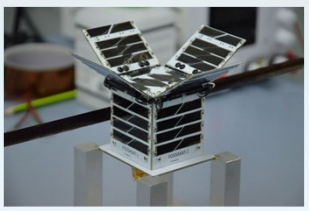
Lacuna space

Source: Lacuna Space

Lacuna Space: 1st satellite launch Apr. 2019
- LoRaWAN Payload
- **6U CubeSat (30x20x10 cm) from Nanoavionics**
- Semtech SX126x transceiver
- Quadrifilar helix antenna

Plant-powered sensors send signal to space
[https://artes.esa.int/news/plantpowered-sensor-sends-signal-space; 15 January 2020]

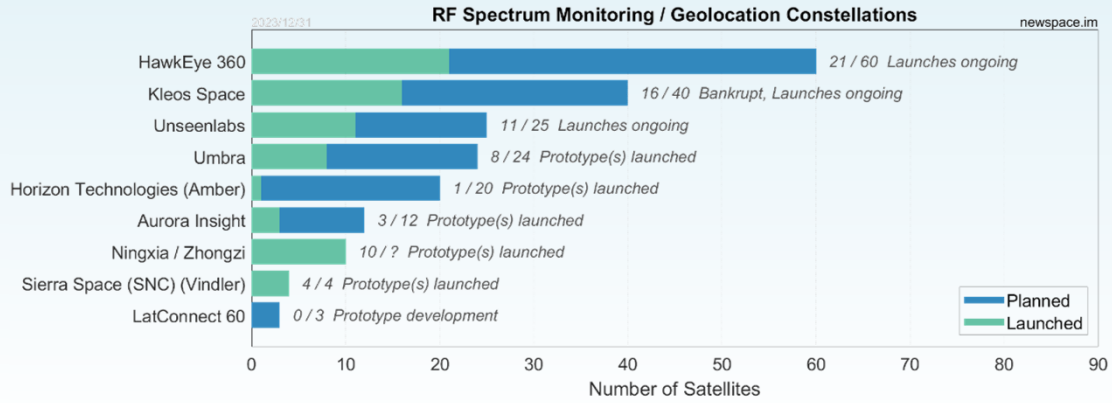




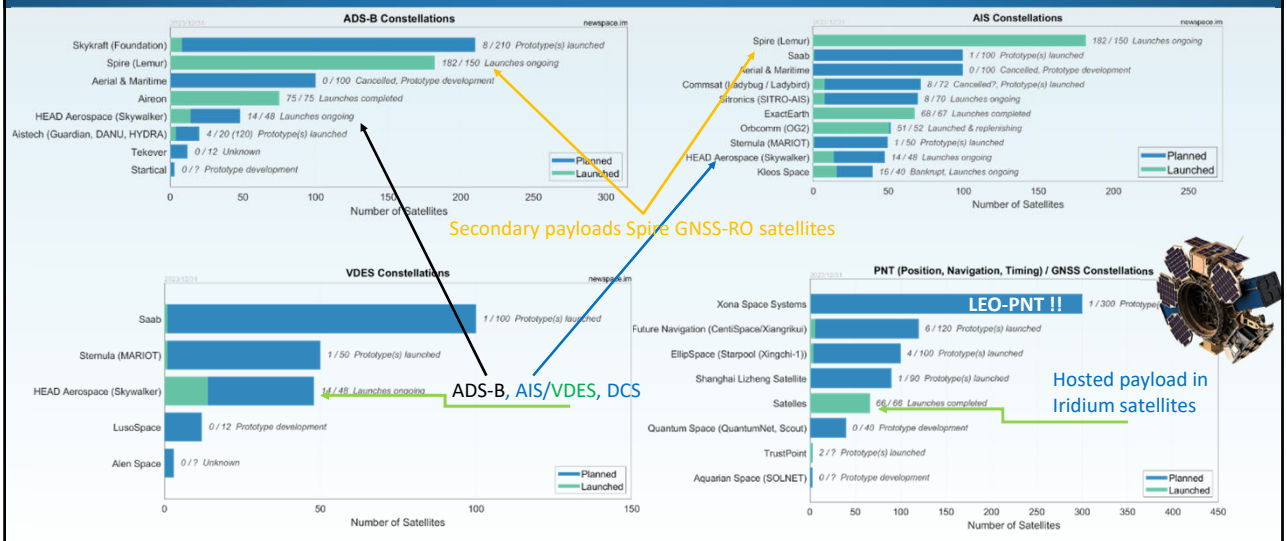
FOSSA

Fossa Systems: 1st satellite launch Dec. 2019)
- LoRa transceiver used for telemetry
- **1Q PocketQube (5x5x5 cm)**
- Commercial LoRa transceiver
- Monopole antenna

1.2. Applications of Small Satellites (ix): to Communications

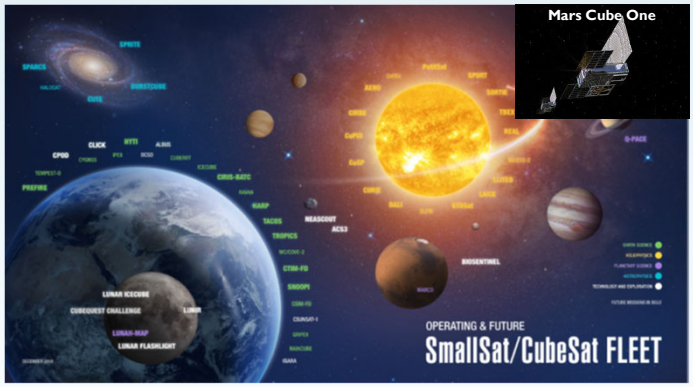


1.2. Applications of Small Satellites (x): to positioning



1.2. Applications of Small Satellites (xi): to Astrophysics

- **NASA Science Mission Directorate sponsored SmallSat/CubeSat missions** in operation or under development



- **ASTERIA – exoplanets**
- **PicSat** - giant planet β Pictoris b

NASA astronomy missions

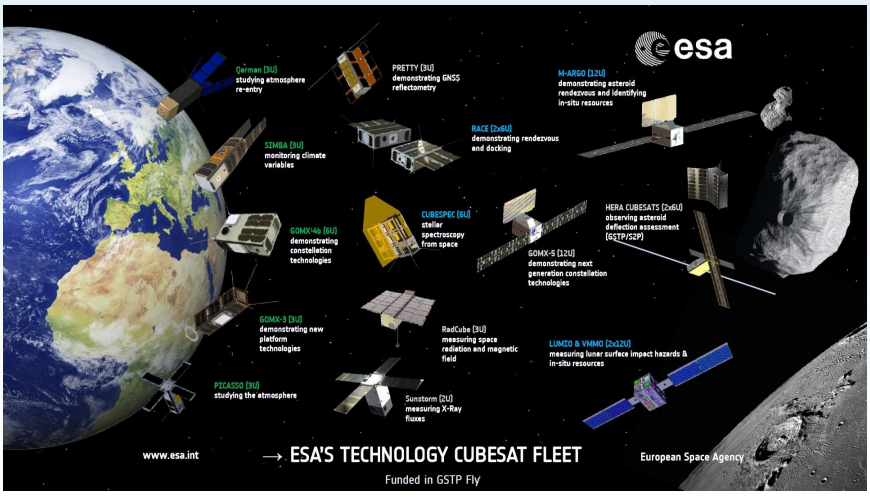
- **HaloSat** - soft X-ray emission from Milky Way hot halo
- **CUTE** - exoplanet transit spectroscopy in near-UV
- **SPARCS** - far- and near-UV low-mass stars
- **BurstCube** gamma ray transients

[E. Shkolnik, "On the verge of an astronomy CubeSat revolution", Nature Astronomy, May 2018]

- From 2003-2018, only 14 nano/microsatellites intended for destinations outside of LEO: MARCO 1st interplanetary cubesat mission (launch May 2018)
- Four nano/microsatellites made their way beyond Earth Orbit in 2018, more than in the past 5 years combined.

1.2. Applications of Small Satellites (xii)

ESA fleet of Technology Demonstrators, EO and Astrophysics missions



II. CubeSats missions at the UPC NanoSatLab: from the idea to the space

2.1. History (i)

- **Kicking off the UPC NanoSat-Lab facilities:**
  - 2007: a slow beginning at UPC Omega building (TVAC + Sun Simulator)
  - 2013: moving to B3 building basement (shaker)
  - 2018: moving to C4 building (clean room)

- **And the ground station:**
  - 2012: first ground station at B3 (VHF+UHF) [#2]
  - 2016: ground station upgrade at D3 (addition of S-band dish)
  - 2018: moving to Observatori Astronòmic del Montsec

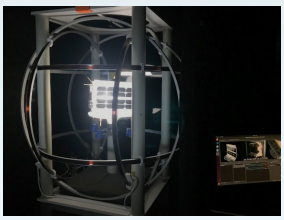
2.1. History (ii)

- After Bologna process started **ETSETB-UPC** identified the **Conceive-Design-Implement-Operate**
  - **(CDIO) initiative** as the most complete and coherent model.
  - In the new curricula, the **CDIO** initiative is implemented with four subjects:
    - Introduction to Information and Communication Technologies (ICT) engineering (or ENTIC),
    - Basic Engineering Project (or PBE),
    - **Advanced Engineering Project (or PAE, the capstone project), and**
    - Final Degree Project.
- A PAE subject called **"^{3}Cat-NXT"** offered to students for more than 6 years: 11 h tutorial + team work trying to follow methodology as in company (weekly meeting + PDR+CDR+FRM).
- Topics change every semester, but typically they are connected along 3-4 semesters.
- Since ^{3}Cat-NXT PAE subject started, **400+ students** have followed this class, and many have continue…
- **Lab not restricted to students from the ETSETB-UPC**, students from other UPC Schools or from different countries are welcome to join an international multi-disciplinary, and "multi-generation" (from freshmen to post-docs) working environment.

2.2. Facilities

2017-2021

Class 8 Clean Room with TVAC and Shaker

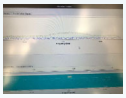


Helmholtz coils during ADCS testing of a 6U CubeSat [courtesy of NanoAvionics]

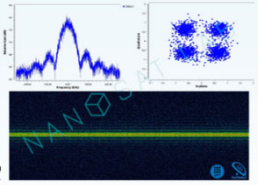
FOSSA SAT-1 PocketQube being tested at UPC NanoSat-Lab

IEEC

2017-2021



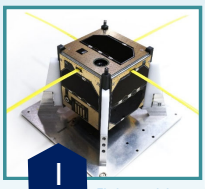
1st ^{3}Cat-1 beacon received



#3B5GSAT nanosatellite (Enxaneta) from Sateliot received at Montsec S-band ground station designed and operated by UPC NanoSat Lab students, while downloading data to Svalbard.

2.3. Missions (i)

Activities started in 3/2007
Launch: PSLV 29 Nov. 2018
7 small P/Ls

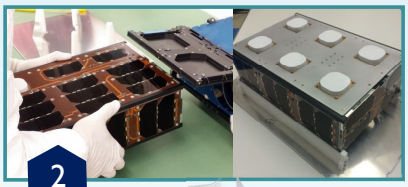


1

Flight model

NORAD ID: 43728

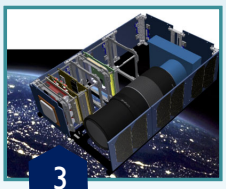
Launch: LMD2, 15 August 2016
PYCARO: GNSS-R P/L: L1+L2, R&LHCP



2

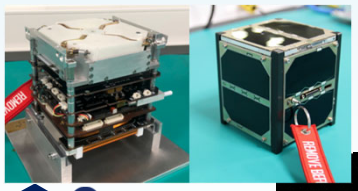
Flight model
NORAD ID: 41732

Multispectral imager (standby)
Customer: ICGC



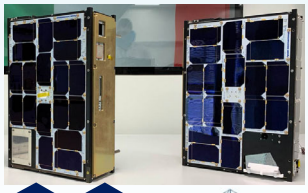
3

Artist view



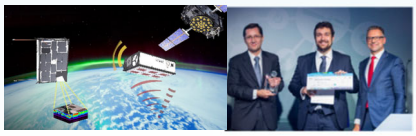
4

https://www.esa.int/Enabling_Support/Space_Transportation/Ariane/ESA_selects_payloads_for_Ariane_6_first_flight



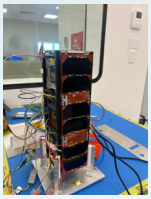
5A 5B

NORAD IDs: 46292 and 46293

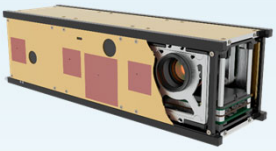


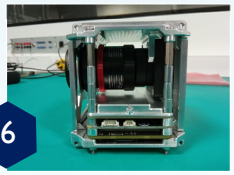
https://youtu.be/IQAaoYUPIuA
https://youtu.be/xT-PRYXwLY4

2.3. Missions (ii)



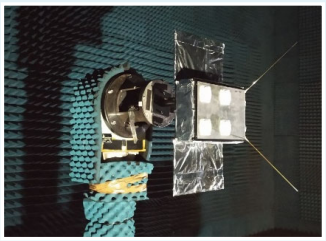
Launch: Q1-2025

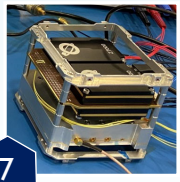




6

Launch: TBC

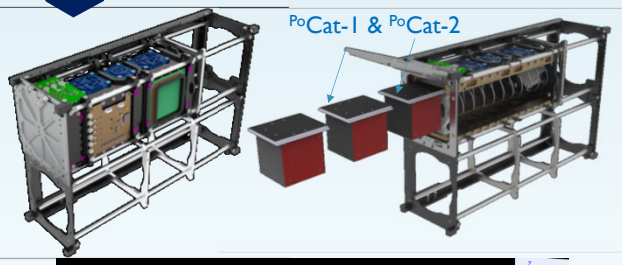


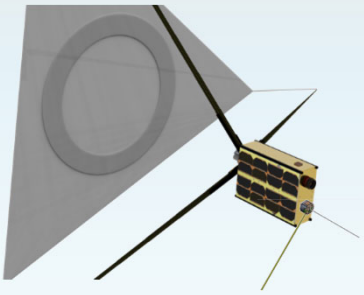


7

2.3. Missions (iii)

8





Mission concept & development
GNSS-RO scintillation P/L

3Cat-Gea: Optical P/L

PoCat's constellations Federated Satellite Systems experiemnt

2.3. Missions (iv)

- **IEEE Open PocketQube Kit:**
  - 3 x 1P PocketQubes developed (VGA camera, L-band RFI monitoring, Ka-band RFI monitoring
  - All designs will be open to anyone, including software, EGSE and MGSE
  - Reception using TinyGS network of ground stations (~1500 worldwide)

[https://nanosatlab.upc.edu/en/academy]

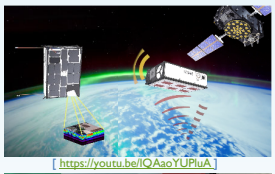
III. Two success stories of CubeSat missions developed at UPC NanoSatLab

3.1. FSSCat Mission (i)

FSSCat in a nutshell:

- **Innovative mission** consisting of **two federated 6U Cubesats**
- Winner of 2017 ESA Sentinel Small Satellite challenge and Copernicus Masters overall winner
- Payloads:
  - **FMPL-2**: microwave radiometer + GNSS-Reflectometer
  - **HyperScout-2**: hyperspectral + TIR imager enhanced with PhiSat-1 AI experiment
  - **Radio & optical inter-satellite links.**
- Goals: to measure **soil moisture, ice extent and thickness**, and to test novel **techniques for future satellite federations**.
- Potential precursor of **scalable constellation of federated small EO satellites**.
- **First CubeSat-based mission contributing to the Copernicus program:**

https://catalogue.nextgeoss.eu/
https://earth.esa.int/eogateway/news/introducing-the-newest-esa-third-party-missions

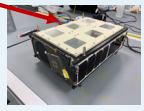
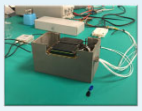


[https://youtu.be/lQAaoYUPluA]

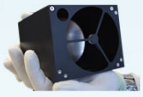
[3]Cat-5/A (NORAD ID: 46292) and [3]Cat-5/B (NORAD ID: 46293)

3.1. FSSCat Mission (ii)

Mission proposer and provider of the **FMPL-2** (L-band Radiometer, the GNSS Reflectometer) and the Radio Inter-Satellite link


Provider of the Optical Inter-satellite link

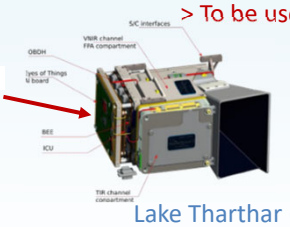


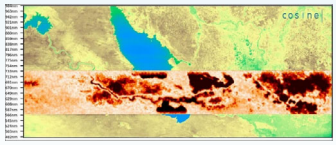
Provider of Hyperscout (VNIR Hyperspectral + TIR imager)

> To be used for pixel downscaling as in SMOS

Not in the original proposal

PhiSat-1 experiment





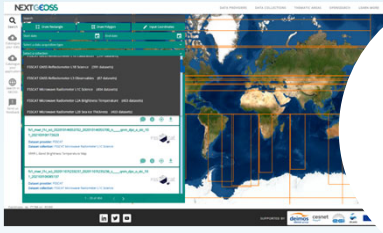
- **HyperScout-2**
  - Hyperspectral VNIR, Multispectral TIR
  - 300 km swath
  - 1st AI processor for in orbit processing (Myriad-2)

Lake Tharthar (Irak), 1st hyperspectral VNIR-TIR fully co-registered image (image credit: cosine remote sensing B.V.)

[https://eoportal.org/web/eoportal/satellite-missions/p/phisat-1] [https://www.cosine.nl/hyperscout-2-delivers-spectacular-images-during-commissioning-phase/]

3.1. FSSCat Mission (iii)

DPGS provider and prime contractor of FSSCAT



Products publicly available
https://catalogue.nextgeoss.eu/data-providers/fsscat

User Manual
http://deimos.pt/FSSCAT-ProductsUsersGuide.pdf

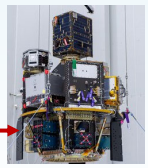
Copernicus free and open data products distribution policy applies

Processors

- Reused expertise from previous MWR and GNSS-R P/Ls
- Tailored to FSSCAT (FMPL-2) instrument and products requirements
- 24 Product Types / Collections, including
  - GRF : L1B, L1C
  - MWR : L1B, L1C, L2A TB
  - SIT, SM, … (excl. NNP)

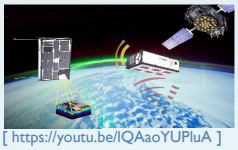
Not in the original proposal

Platform provider, system integrator, operations, Cubesat Deployer provider and launch interface



Technical and programmatic advise and expertise, funding scheme, ESA facilities & ESA Small Satellite Challenge initiator

3.1. FSSCat Mission (iv)



[https://youtu.be/lQAaoYUPluA]

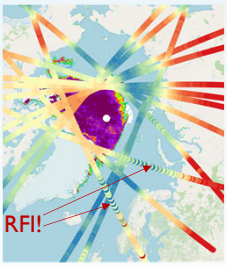
First CubeSat-based mission contributing to the Copernicus program:

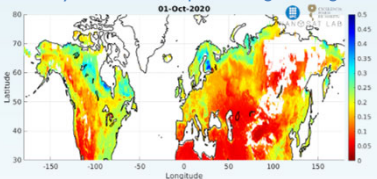
- ECVs derived from MWR, GNSS-R, detecting/mitigating RFI

  ... using neural networks + AI (PhiSat-1 experiment on ^{3}Cat-5/B) to discard cloud-covered images

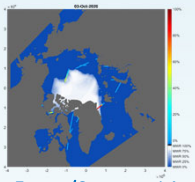
https://earth.esa.int/eogateway/news/introducing-the-newest-esa-third-party-missions

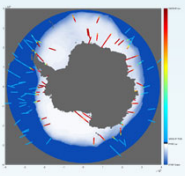
Data freely available at: https://catalogue.nextgeoss.eu/



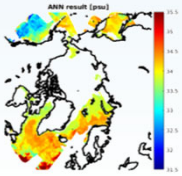


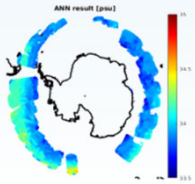
Soil Moisture L3 product



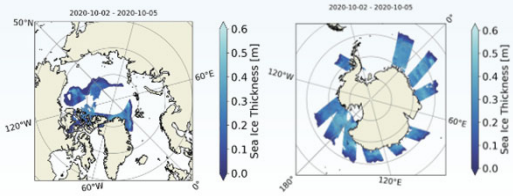


Sea Ice Extent/Coverage L4 product using GNSS-R and MWR maps





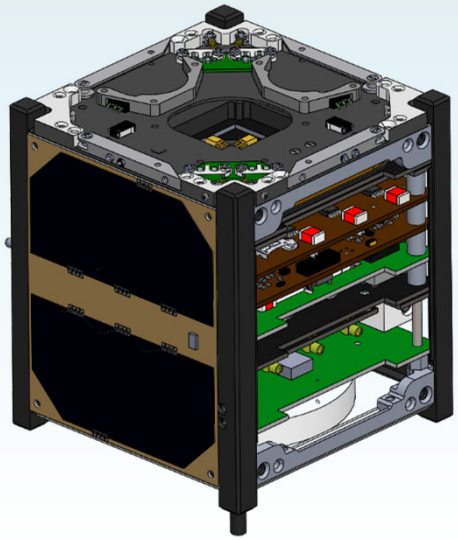
Sea Surface Salinity L4 product using GNSS-R and MWR maps



Sea Ice Thickness L4 product using MWR maps

3.2. ^{3}Cat-4 Mission (i)

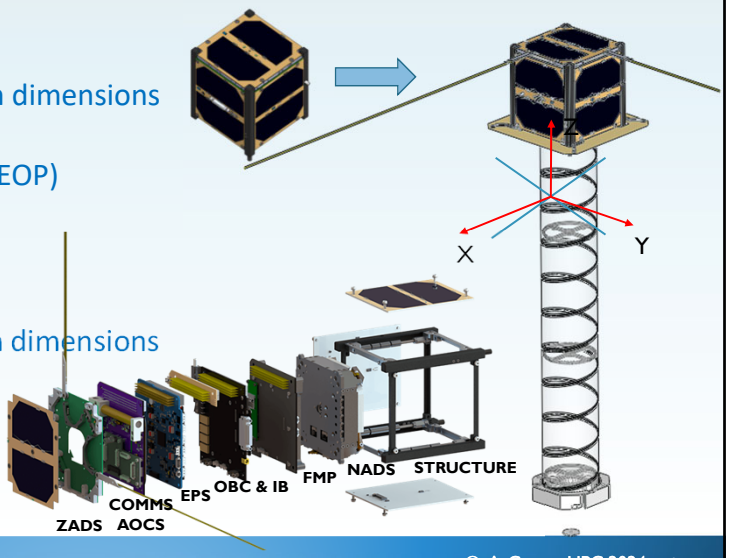
- → 1-Unit CubeSat → ISISpace 1U Structure
  - Dimensions: 100 x 100 x 113,5 mm
  - Mass: 950 g – 1050 g
- → Subsystems
  - On-Board Computer: GomSpace NanoMind A3200
  - Electrical Power System: GomSpace NanoPower P31u
    GaAs based Solar Panels
  - Custom UHF Half Duplex Communications (435-438 MHz)
    - NanoSat Lab UHF Transceiver
    - ISISpace Deployable UHF Antenna
  - Attitude Determination & Control System
    - Active control with magnetorquers
    - Passive control with gravity boom
    - Determination: magnetometer, gyro, sun sensors
- → **Payload**
  - **GNSS Reflectometer**
  - **L-Band Radiometer**
  - **AIS Receiver**



3.2. ^{3}Cat-4 Mission (ii)

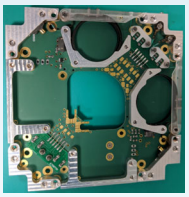
- 1U Cubesat in **stowed configuration**
  - ISIS 1U structure
  - 121.50 mm x 100 mm x 100 mm dimensions
  - Launch Campaign
  - Launch and Early Orbit Phase (LEOP)

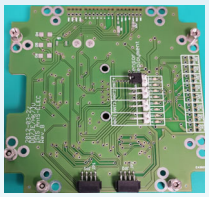
- **Deployed configuration**
  - 595.75 mm x 150 mm x 150 mm dimensions
  - Deployment by stages
  - All antennas deployed
  - Operational phase



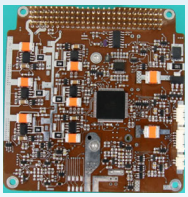
3.2. ^{3}Cat-4 Mission (iii)

Zenith & Antenna Deployment Subsystem

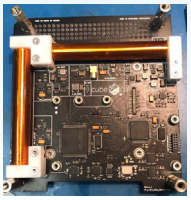




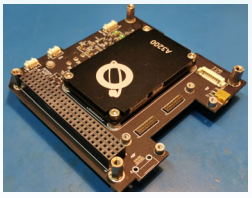
EPS board

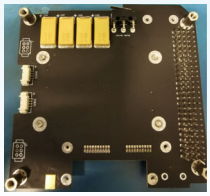


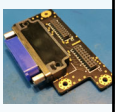
ADCS board



OBC and I/F boards

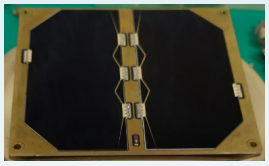




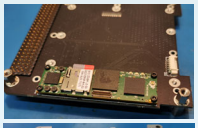


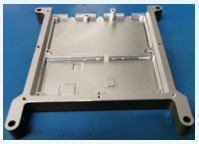
3.2. 3Cat-4 Mission (iv)

Solar panels

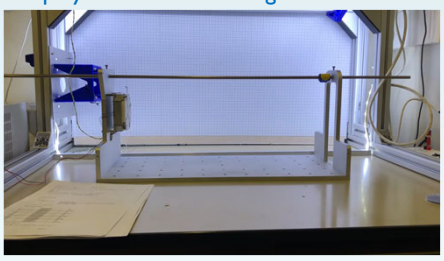


FMPL-1 payload

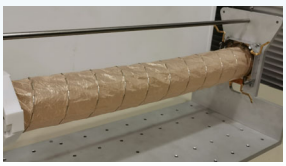


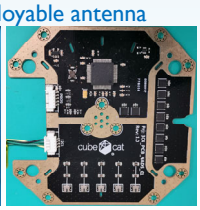


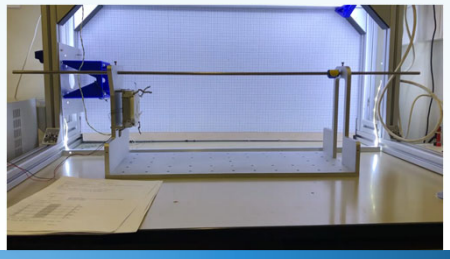
Deployable antenna testing



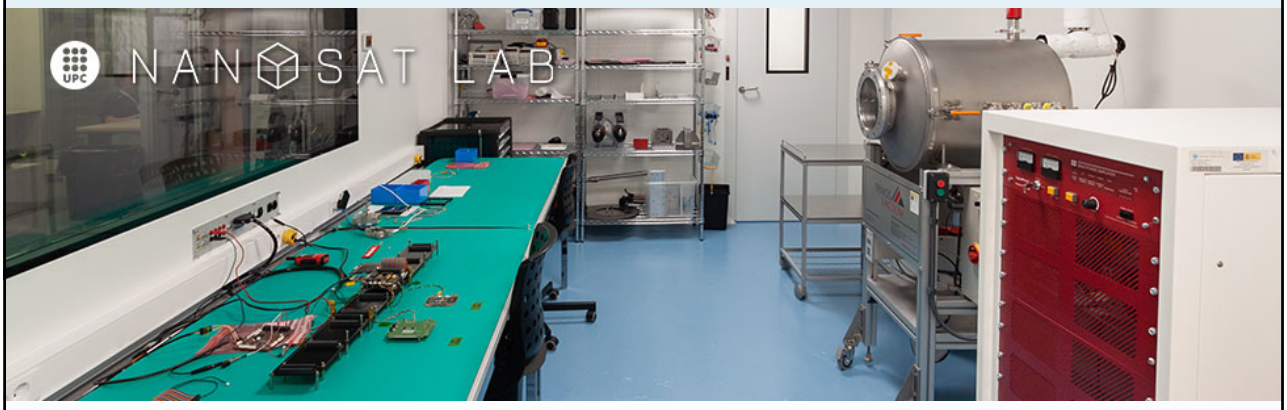
NADS board and deployable antenna



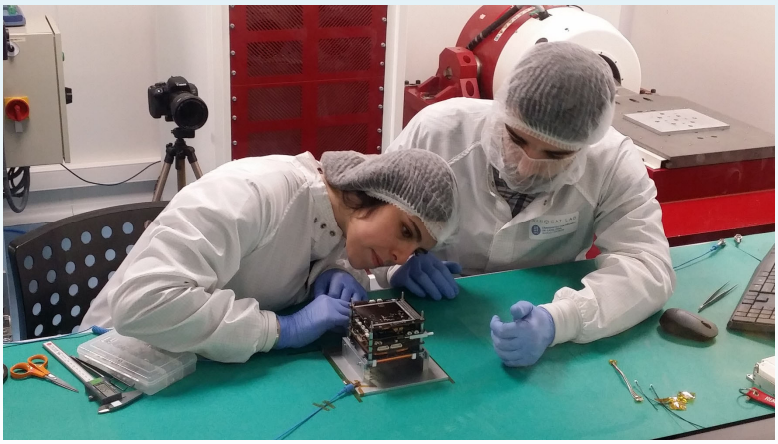


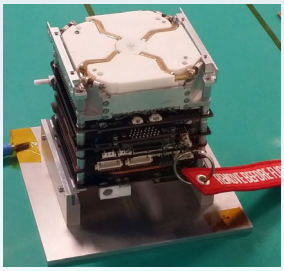


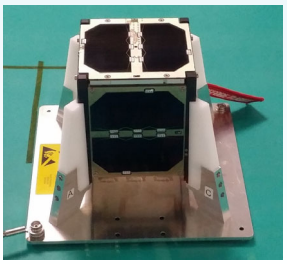
3.2. 3Cat-4 Mission (vii): surviving covid…



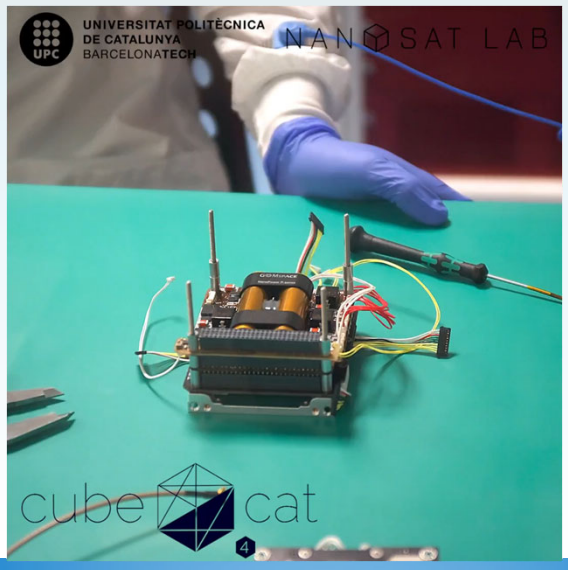
3.2. ³Cat-4 Mission (viii)



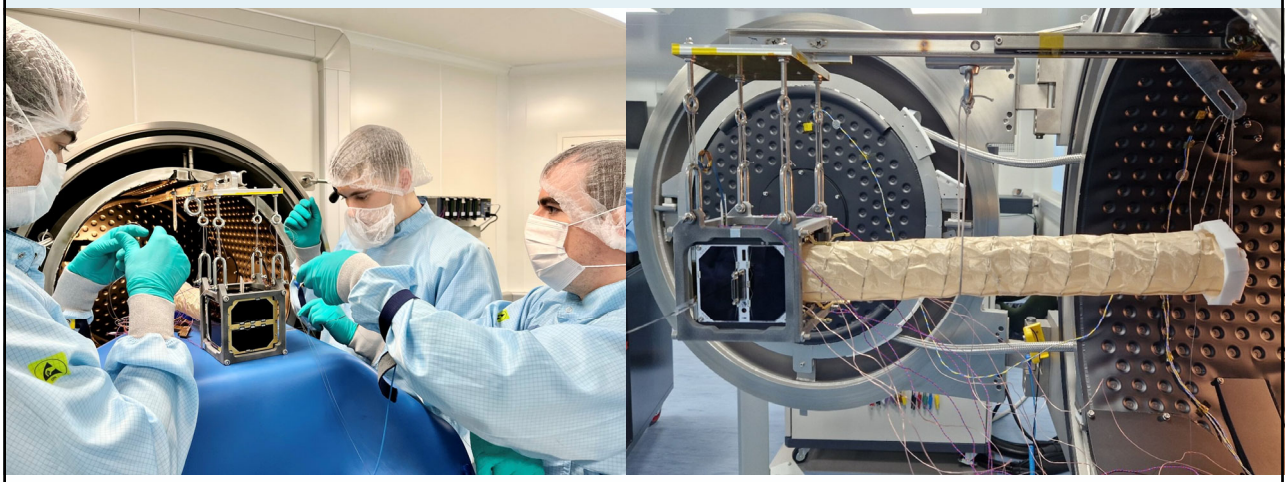




3.2. ³Cat-4 Mission (ix)

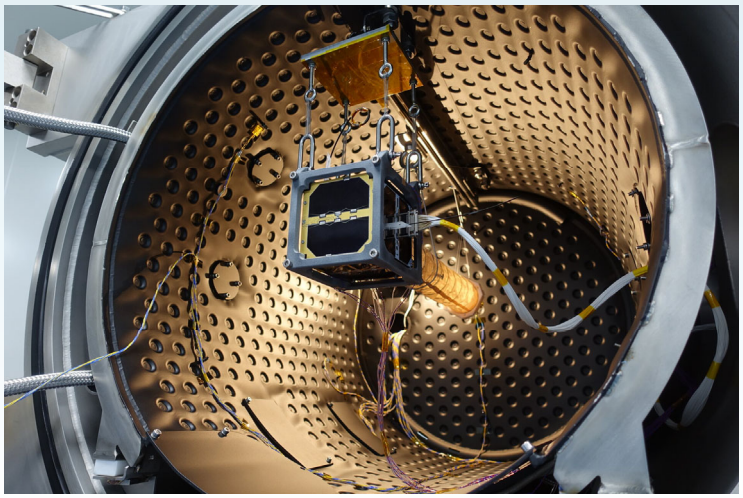


3.2. ^{3}Cat-4 Mission (x)



[credit ESA]

3.2. ^{3}Cat-4 Mission (xi)



[credit ESA]

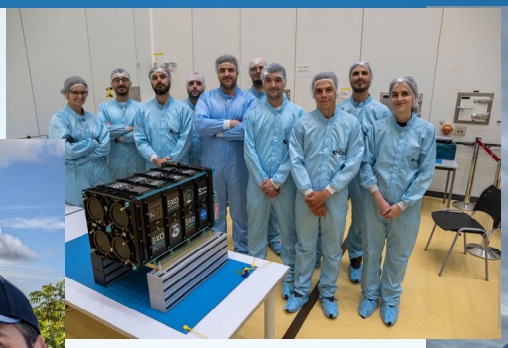
3.2. 3Cat-4 Mission (xii)

[credit ESA]

3.2. 3Cat-4 Mission (xiii)

[credit ESA]

3.2. ^{3}Cat-4 Mission (xiv)



[credit ESA]

3.2. ^{3}Cat-4 Mission (xv)

[credit ESA]

3.2. 3Cat-4 Mission (xvi)

[credit ESA]

4. Conclusions (i)

- CubeSats have produced a "disruptive innovation," and are displacing some established competitors.
- Early CubeSats typically had short lifetimes (a few months), but now it has increased significantly.
- CubeSats cannot displace all large space missions, but they are finding their own niche in many EO, Astrophysics, and Communications (IoT and M2M) applications where NRT or even continuous monitoring are required.
- Still many new technologies to be developed: large deployable antennas, high precision attitude control systems (OISL…), Improved RF ISLs to stablish satellite federations and constellations, AI on-board processing to reduce the amount of data to be downloaded or for situational awareness

… and also administrative regulations should be streamlined.

5. Conclusions (ii)

- Massive constellations of EO + communications will be the newest space revolution
- This is just the begining, there are endless possibilities to "imagine a future where AI, 5G …" can play a major role in space!
- **Small Satellites are a real opportunity for many nations, but for students and YPs too!!**
- **"Challenging" projects like FSSCat and ^{3}Cat-4 would be imposible without a "dream team" of dedicated and competent students!!**
- **You can also be part of this adventure !!**
- To know more:
  https://www.intechopen.com/online-first/nanosatellites-and-applications-to-commercial-and-scientific-missions]
  https://doi.org/10.1016/B978-0-12-824541-5.00027-3

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Thank you!