The Flexible Microwave Payload -2: A SDR-based GNSS-R instrument for CubeSats

Joan Francesc Muñoz Martin (presenter), Lara Fernandez, Joan Adrià Ruiz-de-Azúa, Adriano Camps

Dept. of Signal Theory and Communications, Universitat Politècnica de Catalunya (UPC)

Universitat Politècnica de Catalunya and Institut d'Estudis Espacials de Catalunya, Barcelona, Spain

Outline

→ Introduction:
- FSSCat science case
- FSSCat mission overview

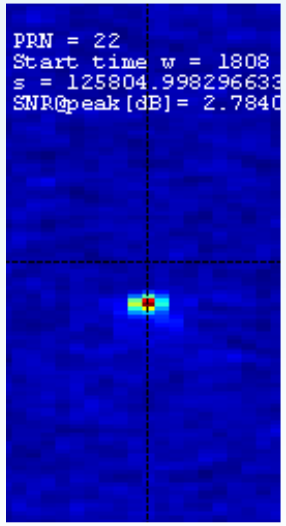
→ The FMPL-2:
- Instrument overview
- Detailed design:
  - Block diagram
  - Acquisition strategy
  - Software design
- Implementation overview
- Testing campaign

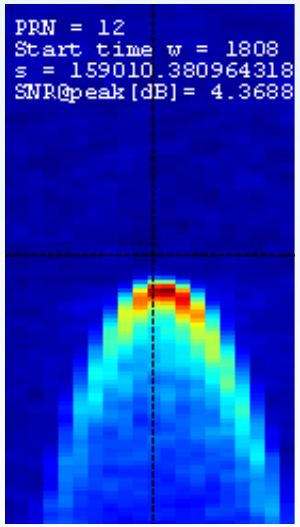
→ Conclusions

Introduction: FSSCat Mission, Science case – Needs & antecedents (i)

- **Soil moisture**: No SMOS or SMAP follow-on mission. CIMR L-band channel?
- **Polar and Snow monitoring:** Ice cover and thickness (≤ 60 cm) can be inferred from GNSS-R and L-band microwave radiometry ⇒ Floating ice, caps and ice sheets

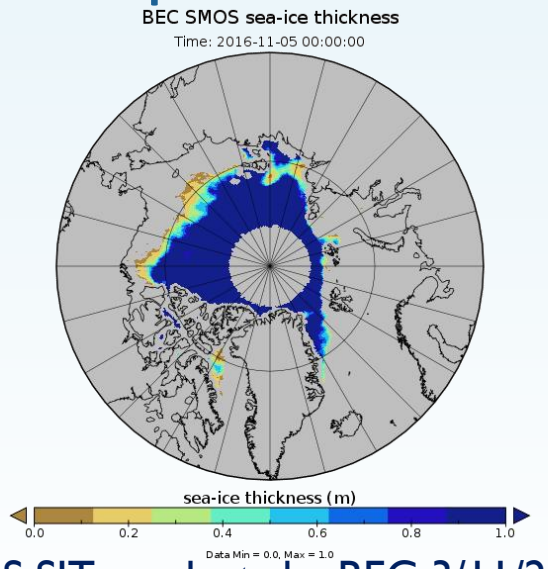
UK TDS-1 experience GNSS-R over ice and over water





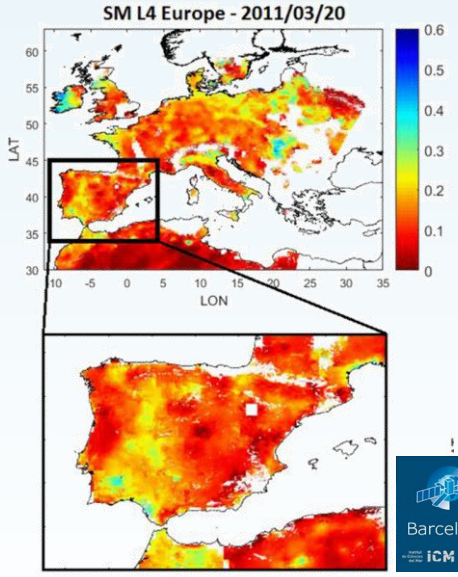
Spatial resolution (nadir reflection):
Diameter 1st Fresnel zone ~600 m from h= 500 km

SMOS Artic ice thickness up to ~60 cm



SMOS SIT products by BEC 3/11/2014
Spatial resolution (antenna footprint)
Also produced by U. Hamburg

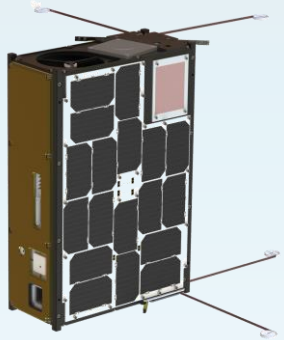
SMOS downscaled soil moisture



Spatial resolution from ~50 km to 1 km

Introduction: FSSCat Mission Overview – Satellites (ii)

An innovative mission consisting of two federated 6U CubeSats (^{3}Cat-5/A and ^{3}Cat-5/B).



- ^{3}Cat-5/A payloads:
  - FMPL-2: Dual microwave payload (Microwave radiometer + GNSS reflectometer) in a single instrument using a Software Defined Radio,
  - FSSExp and OISL: Radio and optical inter-satellite link technology demonstrators.
- Science: Soil moisture, ice thickness and extent, and water ponds on ice maps.

- ^{3}Cat-5/B payloads:
  - Hyperscout-2: Hyperspectral instrument combining for first time VNIR/TIR channels,
  - FSSExp and OISL: Radio and optical inter-satellite link technology demonstrators.
- Science: Terrain classification and pixel de-composition, cross-calibration with Sentinel-2, and on-board cloud detection using artificial intelligence.

Both ^{3}Cat-5/A and ^{3}Cat-5/B will test radio and optical communication technologies for future satellite federations.

- **FMPL-2 and FSSExp** developed by **UPC**
- **O-ISL** developed by **Golbriak Space**
- **Hyperscout-2** developed by **Cosine**
- **Platform** design and integration from **Tyvak International**
- Data Processing Ground System (**DPGS**) implemented by **Deimos Portugal**
- Technical, financial, and management support from **ESA**

UPC

esa European Space Agency

GOLBRIAK SPACE

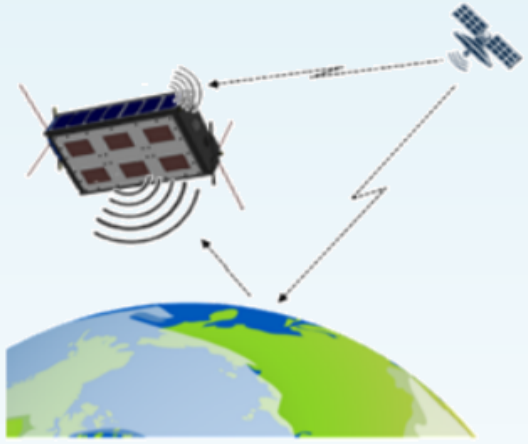
deimos elecnor group

Tyvak International SRL

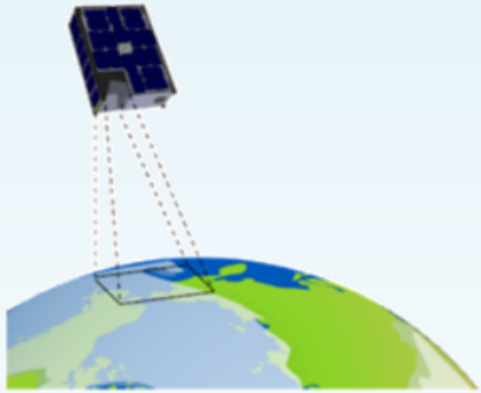
cosine measurement systems

Introduction: FSSCat Mission Overview – Experiments/Observations (iii)

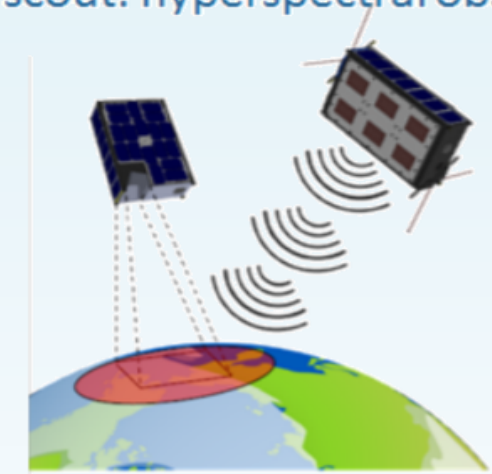
FMPL-2 Sea Ice Experiment:
GNSS-R: sea ice & water pond mapping
Microwave radiometer: ice thickness



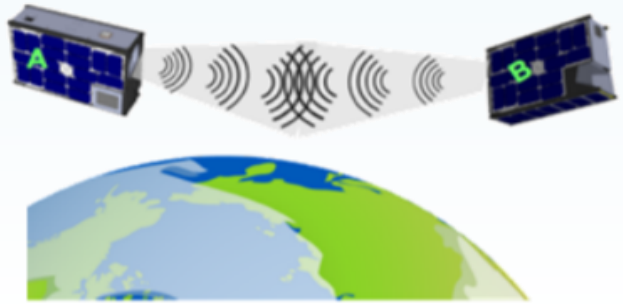
Hyperscout Observations:
Terrain classification
Change detection
On-board cloud detection with AI



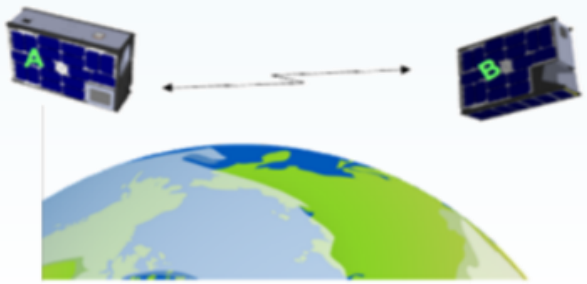
FMPL-2 + Hyperscout Observations:
Microwave radiometer: soil moisture
Hyperscout: hyperspectral observation



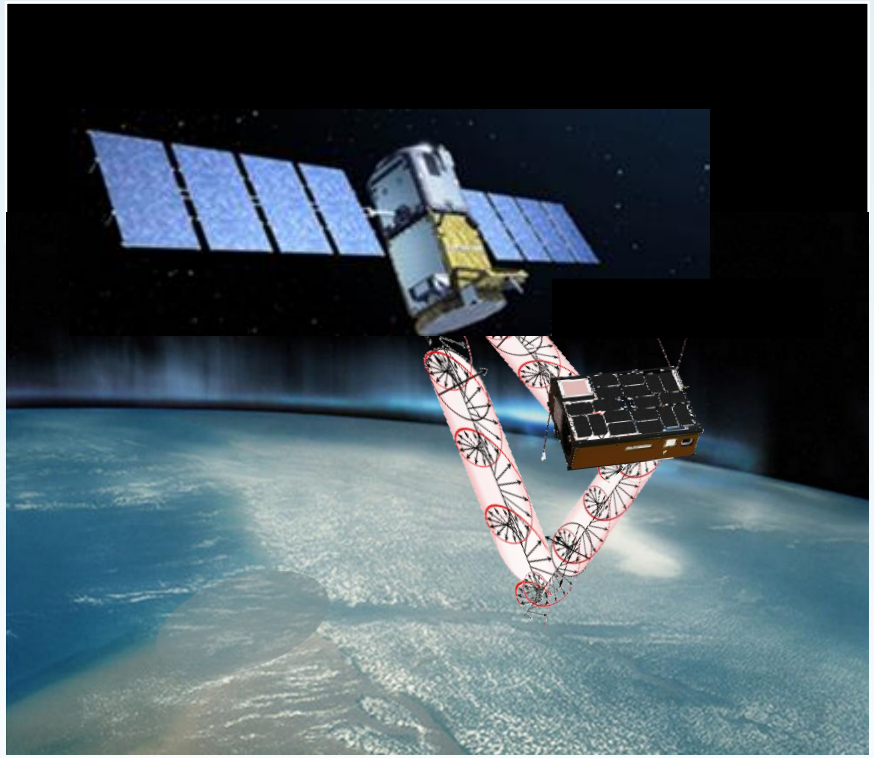
Optical Inter-Satellite Link (O-ISL) experiment



Federated Satellite Systems experiment (FSSExp)



FMPL-2: Instrument Overview



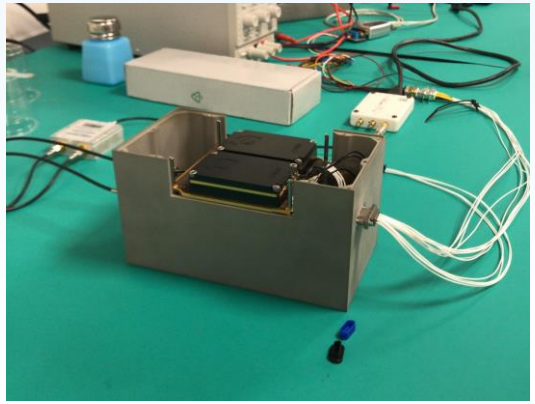
Artist view of FMPL-2 performing cGNSS-R

Flexible Microwave Payload -2:

Combined GNSS-R scatterometer and L-band Microwave Radiometer in a single instrument using Software Defined Radio.

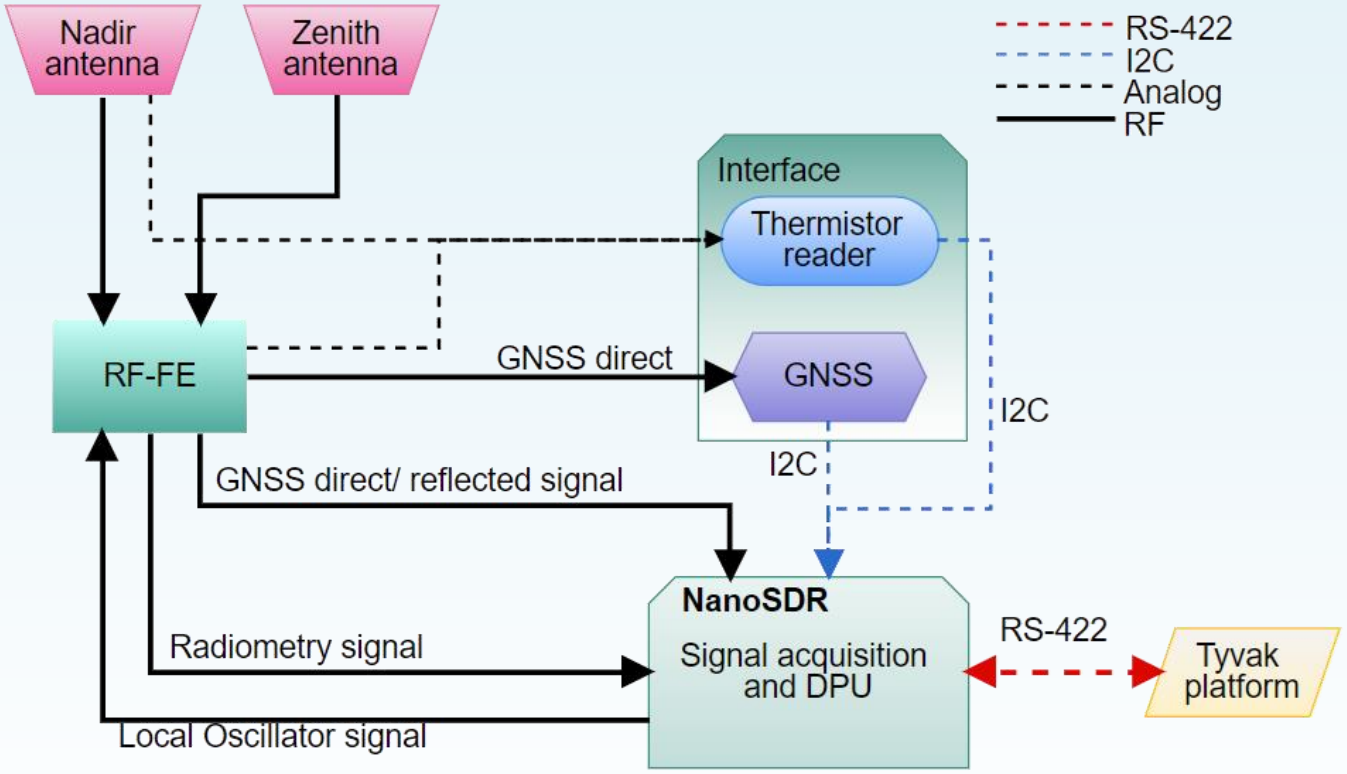
Applications:

- Sea-ice detection (GNSS-R) and sea-ice thickness monitoring (MWR)
- Water ponds over ice (GNSS-R)
- Low resolution soil moisture (MWR)
- High resolution soil moisture after data fusion with Hyperscout-2 data



FMPL-2 integrated in its aluminum box

FMPL-2: Design overview



→ FMPL-2 is a dual microwave payload (**cGNSS-R** and **L-band radiometer)** implemented using an **SDR**.

→ **SDR** based on a GomSpace **NanoSDR**.

→ Novatel OEM719B GNSS receiver is used to geo-reference and time-tag all the observables and provide satellites in view to speed search.

→ **RF-FE** amplifies and conditions the signal before the SDR.

→ **Up-** and **down-looking** passive-patch antenna for both GNSS-R and L-band radiometry.

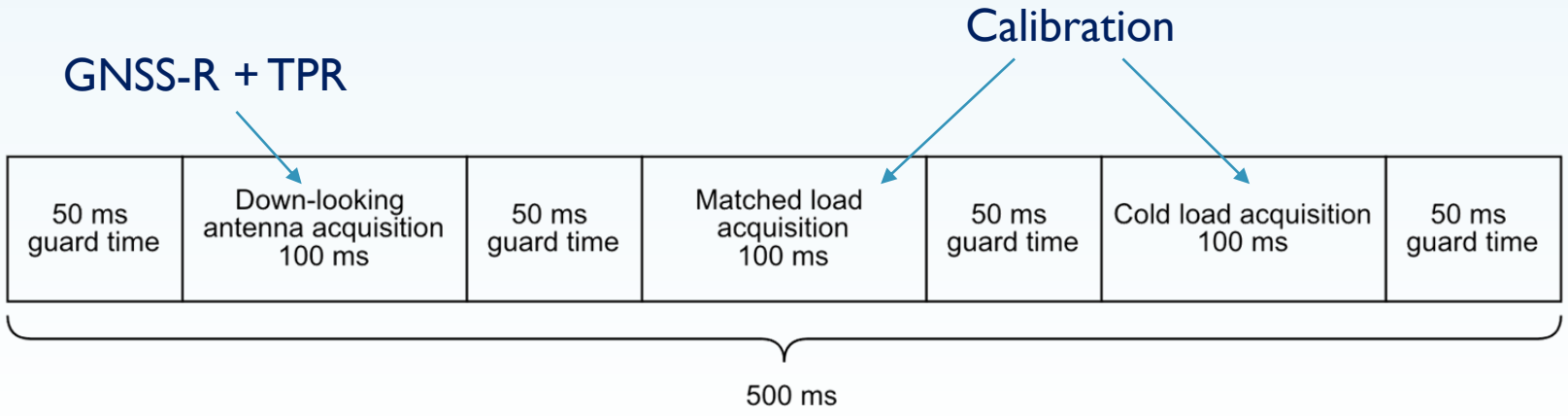
FMPL-2 Software Design: Acquisition strategy

→ Data acquisition:

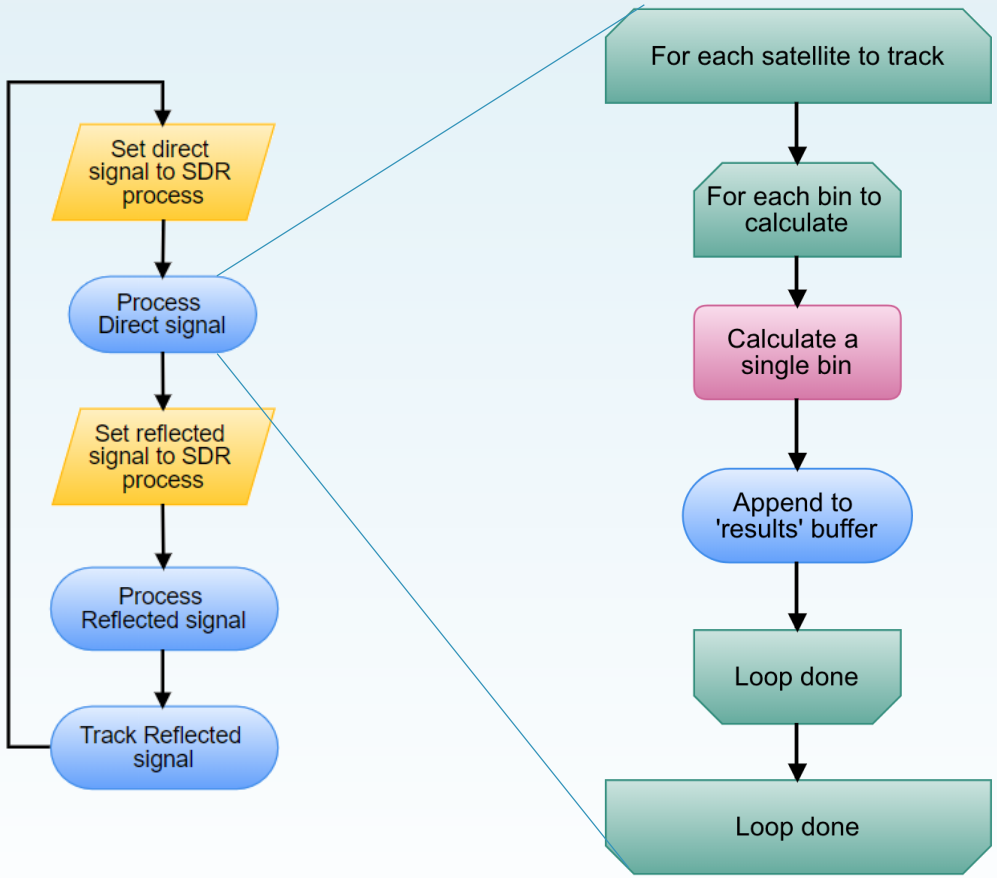
- Sampling rate = 4 MHz,
- Central frequency = 1413 MHz for both channels (GNSS L1/E1 signals down-converted from 1575.42 MHz)

→ GNSS signal sent upon request to the GNSS-R processor.

→ Calibration performed in both GNSS-R chains and L-band Radiometer chains as a Total Power Radiometer with Active Cold Load & matched load.



FMPL-2 Software Design: GNSS-R processor flowgraph



→ Data Processing Unit performs 3 different steps:

- **Direct** signal acquisition
- **Reflected** signal acquisition
- **Reflected** signal tracking

→ Signal processing block is always the same but with different Earth-configurable parameters:

- Amount of averaging (coherent/incoherent)
- Number of bins
- Number of satellites to be tracked
- Step repetition

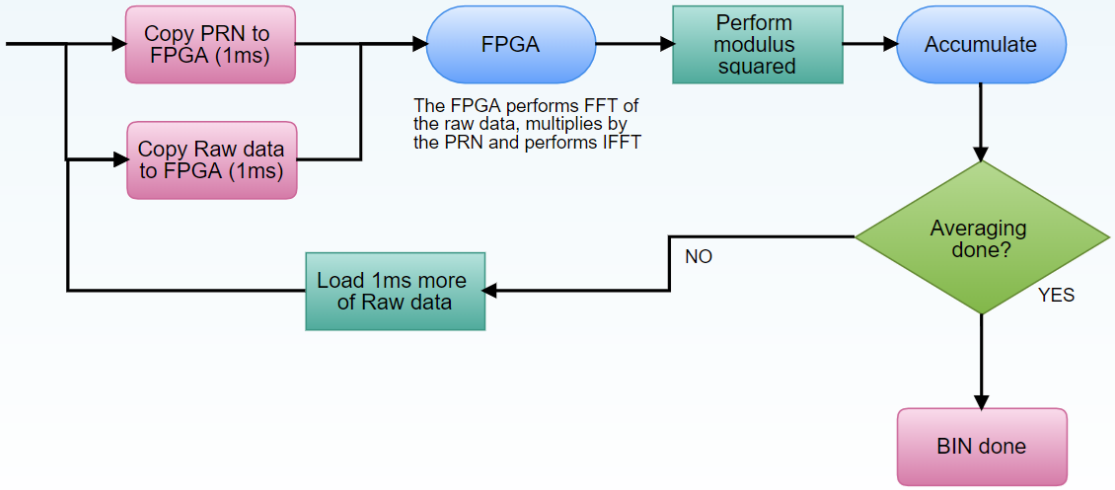
FMPL-2 Software Design: Modified PCPS algorithm

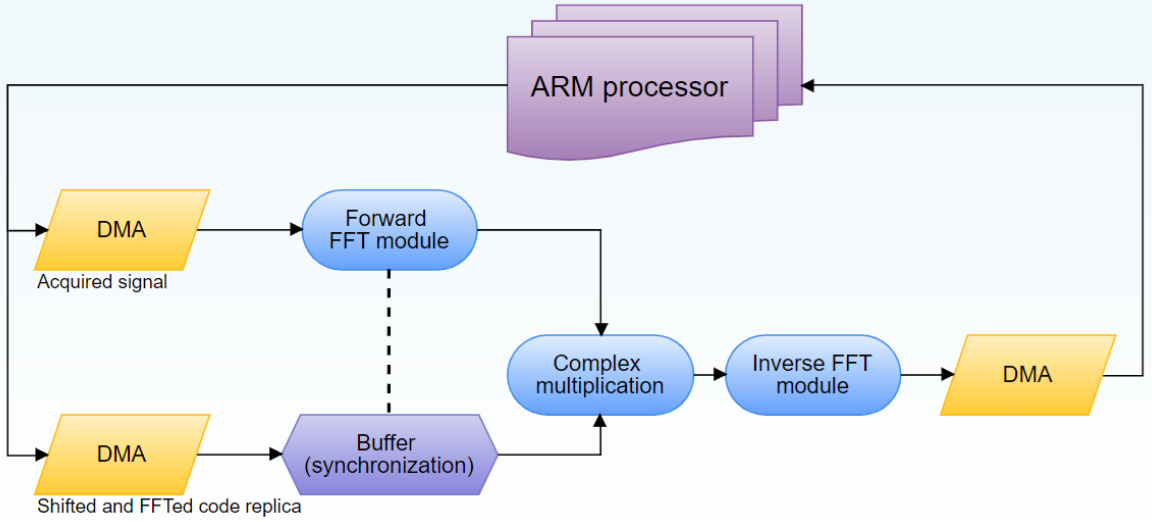
→ Data Processing Unit takes continuous blocks of 40 ms raw data and performs the cross-correlation with **pre-computed FFTs** of a GNSS sequence in blocks of 1 ms for GPS and 4 ms for Galileo.

→ 40 ms sequence length to **limit waveform/DDM blurring** if retracking is not correct (retracking performed on ground)

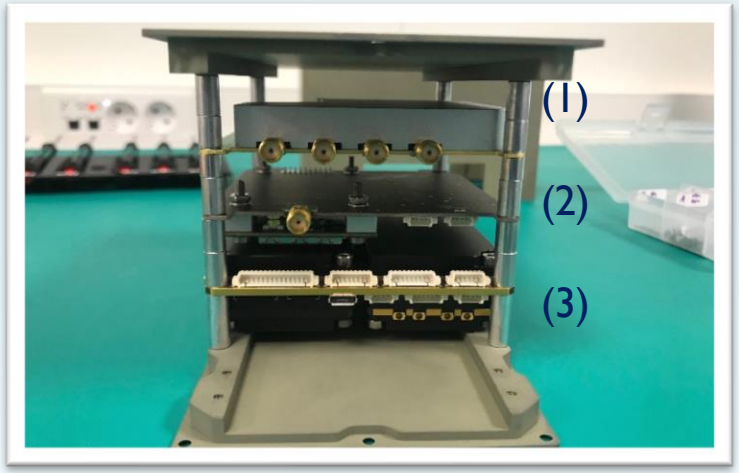
→ **161-bin 500 Hz** spaced matrix containing all PRNs (**already FFT'ed**) stored in the processor persistent memory.

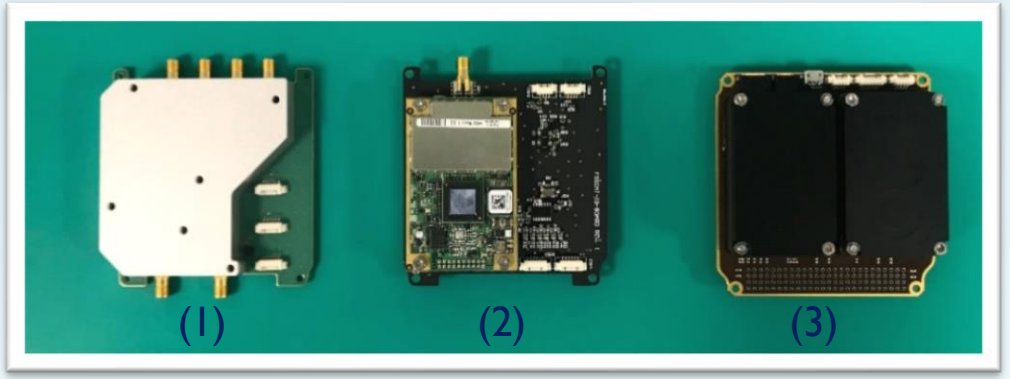
→ Each averaged DDM stored as 16-bit PGM image in the processor memory for download.





FMPL-2: Implementation overview

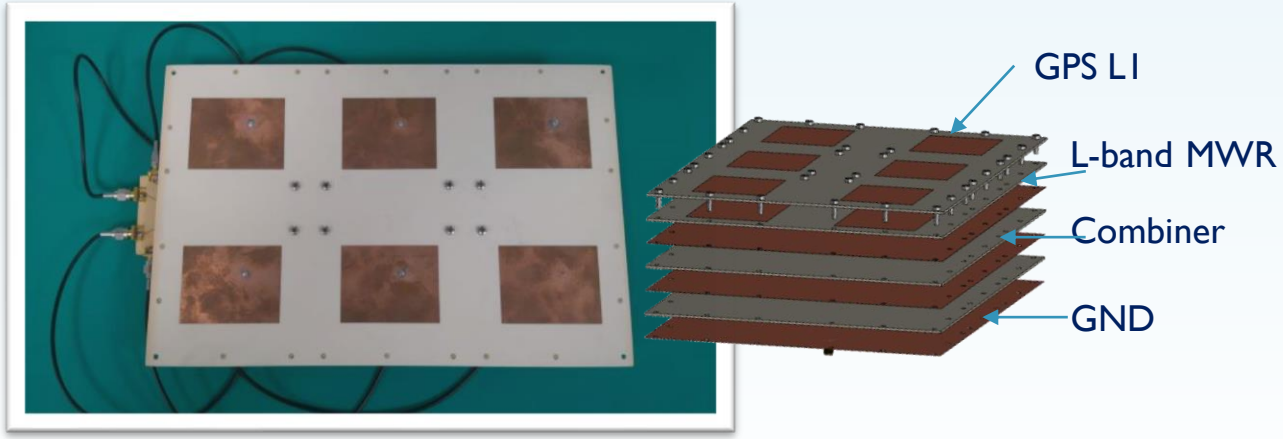




(1) RF-Front End
(2) Interface Board
(3) NanoSDR

→ Design to fit on a 1-Unit CubeSat:

- Based on CubeSat PC104 standard, adapted for FSSCat mission (custom CubeSat backplane),
- Weight: 1.4 kg,
- Peak power consumption: 5 V @ 1.7 A (8.5 W).



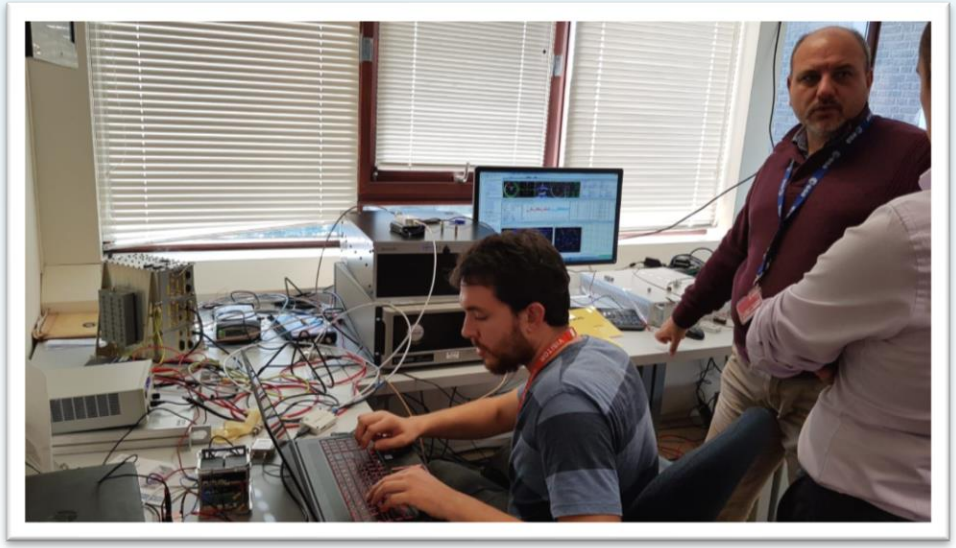
Dual-band six-element patch antenna prototype

FMPL-2: Ambient test campaign

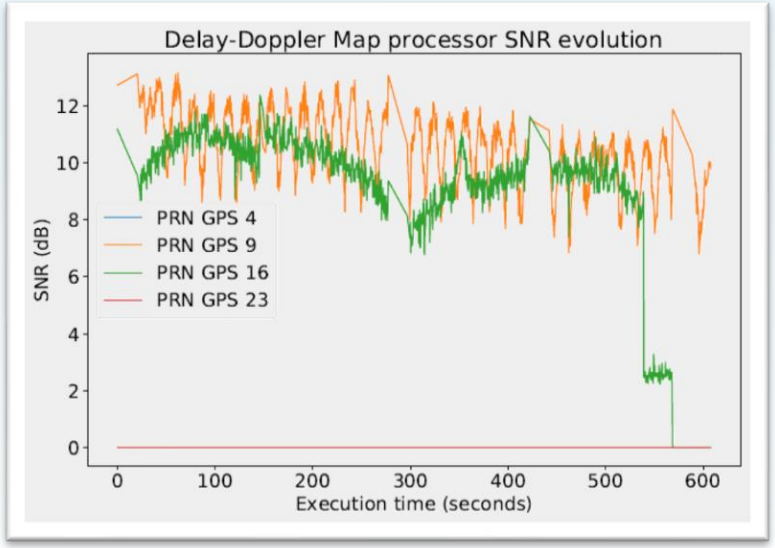
→ Functional verification with direct GNSS signals,

→ Test at **ESA-ESTEC** premises with Spirent simulator to check the GPS/DDM calculator in **high-dynamics** (LEO orbit).

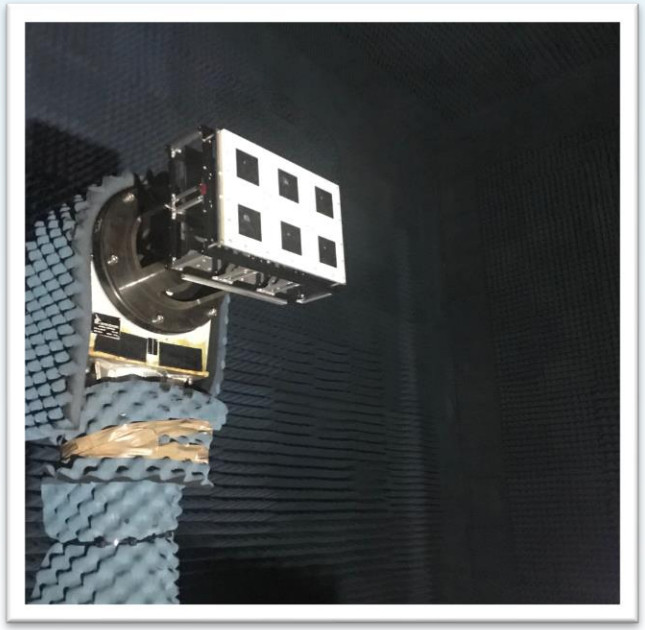
→ Antenna pattern measurements measured in representative 6U CubeSat model



Test at ESTEC with SPIRENT GNSS simulator



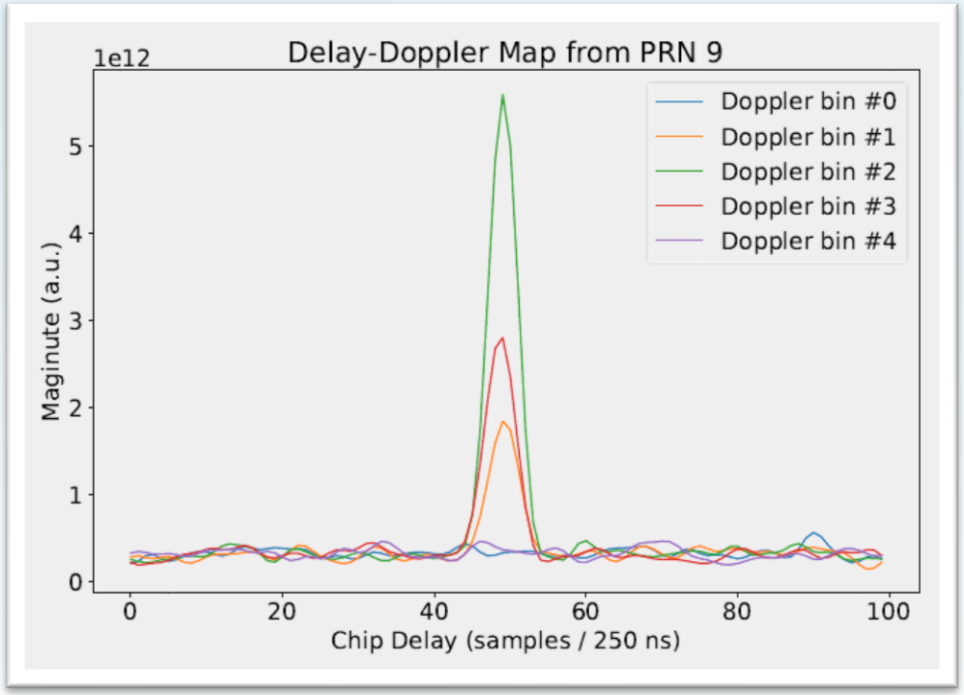
SNR evolution of different PRNs during the Test



Antenna pattern measurements in UPC Anechoic Chamber

FMPL-2: Ambient Test Campaign

→ Reflected signal simulated with a **direct** High-dynamics signal



Waveform of a simulated GPS L1 reflected signal:
5-bin DDM at 40 ms of averaging

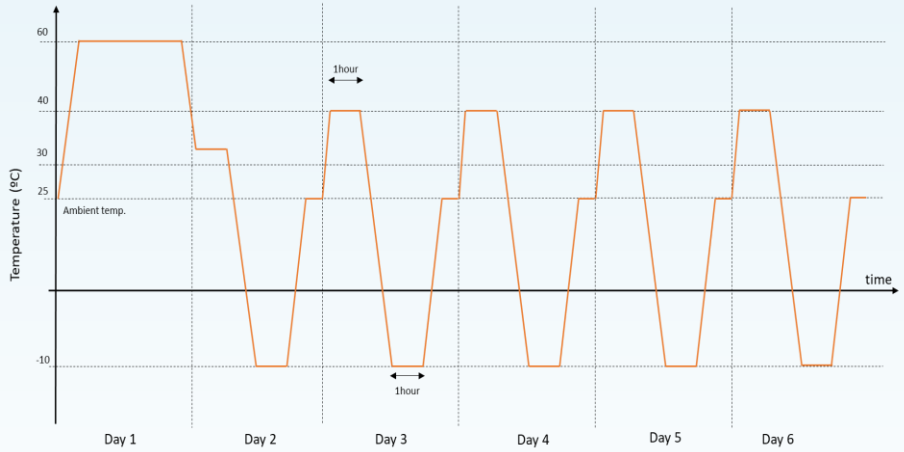
FMPL-2 sample DDMs:

- Direct signal: 80 bins, 10 ms of averaging
- Reflected signal: 21 bins, 40 ms of averaging
- Reflected tracked signal: 5 bins, 40 ms of averaging

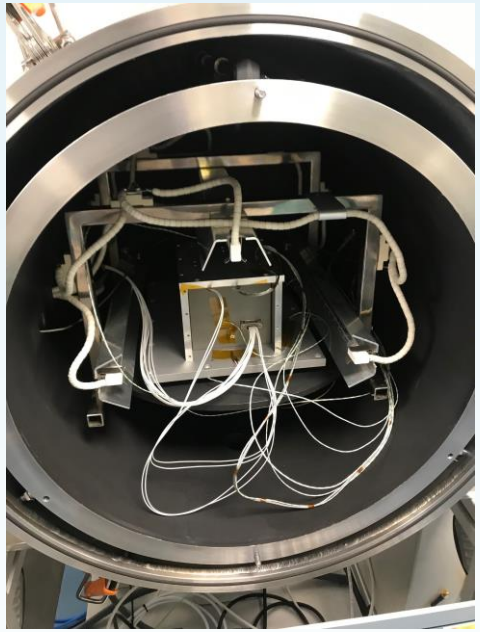
FMPL-2: Environmental test campaign at UPC NanoSat Lab

→ Check that the instrument is able to withstand the launch (vibrations) and to perform in a wide range of temperatures:

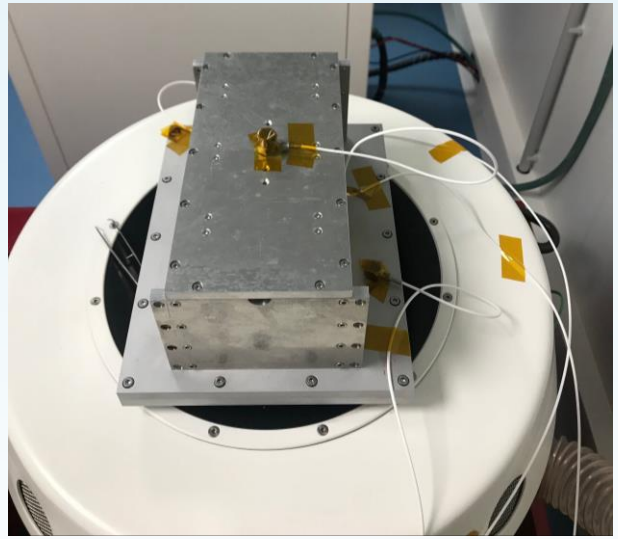
- Thermal-vacuum chamber test:
  - 4 cycles, each cycle from -10 °C to 40 °C



- Shake table test:
  - Sine and random vibrations for each axis (X, Y, Z) at 12.5 g_{rms}



(a) TVAC test (-10 °C / +40 °C)



(b) Shake table test (12.5g_{rms})

Conclusions

→ **Smallsats and CubeSats** in particular are creating a revolution in the space business:

- New market and business models for Nano-satellites,
- New instruments and techniques for Remote Sensing fit into CubeSat philosophy:
  - Decrease Earth Observation revisit time and overall mission cost,
  - Fast test/deploy of new technologies → Proof-of-concept missions.

→ FMPL-2 is a CubeSat-based cGNSS-R remote sensing instrument

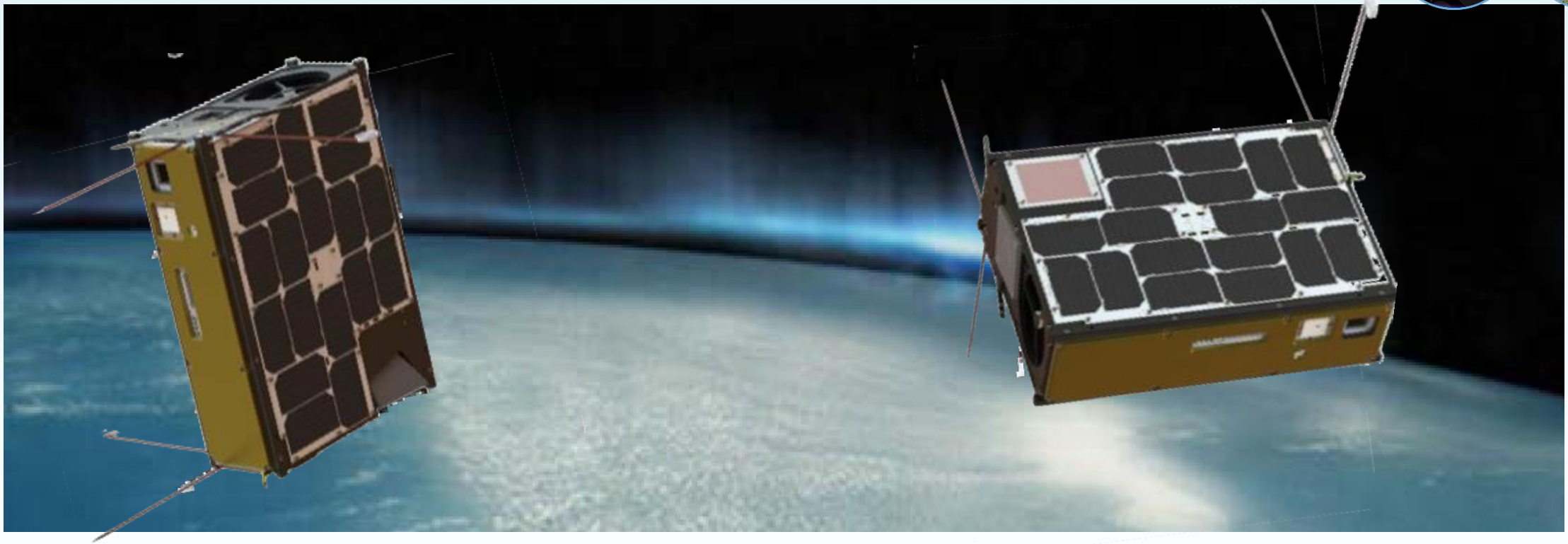
- Block diagram design and software design/implementation details presented,
- FMPL-2 full functional tests performed at both ambient and environmental levels,
- Already integrated in **^{3}Cat-5/A** and **ready** to launch!

→ Lack of Functional testing for GNSS-Reflections:

- Test-bench needed to test GNSS-R payloads,
- **GNSS-R simulator** conceived, implemented and tested by UPC together with a RFI detection/mitigation system
- See demo at **GNSS+R 2019 In-Lab sessions "Implementation of a testbed for GNSS-R payload performance evaluation"**

Thank you for your attention and see you during In-Lab sessions!

Winner of the 2017 Copernicus Master
"ESA Small Satellite Challenge S^3" and overall Winner



^{3}Cat-5/B

^{3}Cat-5/A