CubeSats:

- **From student satellites to interplanetary missions**
- **OUFTI-1**
- **QARMAN**

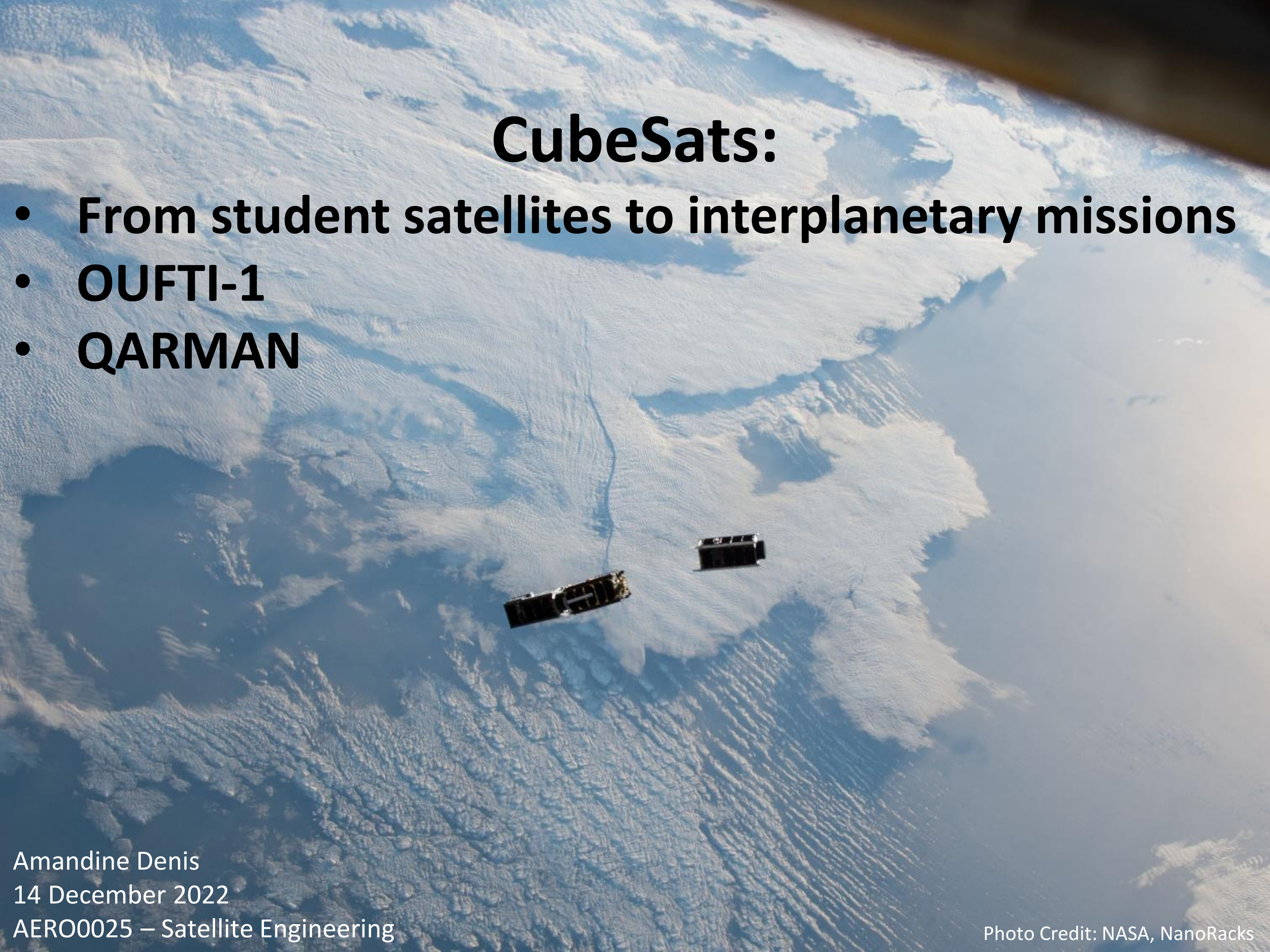


Photo Credit: NASA, NanoRacks

Amandine Denis
14 December 2022
AERO0025 – Satellite Engineering

My background

2007: ULg, Physics engineer (Space Techniques)

2007-2014: ULg, Teaching assistant
Project manager for OUFTI-1

2014-…: VKI, Research engineer / Project manager:

QB50 Space Segment Engineer & CubeSat Coordinator

QARMAN system engineer, project leader

…

von Karman Institute for Fluid Dynamics

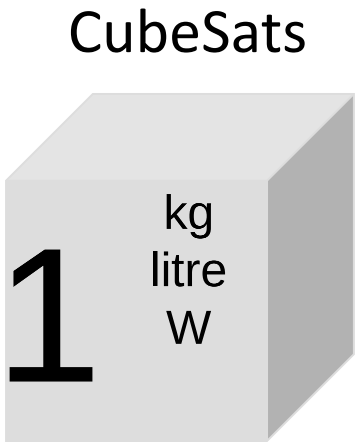
International Center for Advanced Education and Research in Fluid Dynamics

- Post-graduate education
- World unique test facilities
- Consulting and research
- QB50 project
- QARMAN re-entry CubeSat
- DRACO, EARS, ….

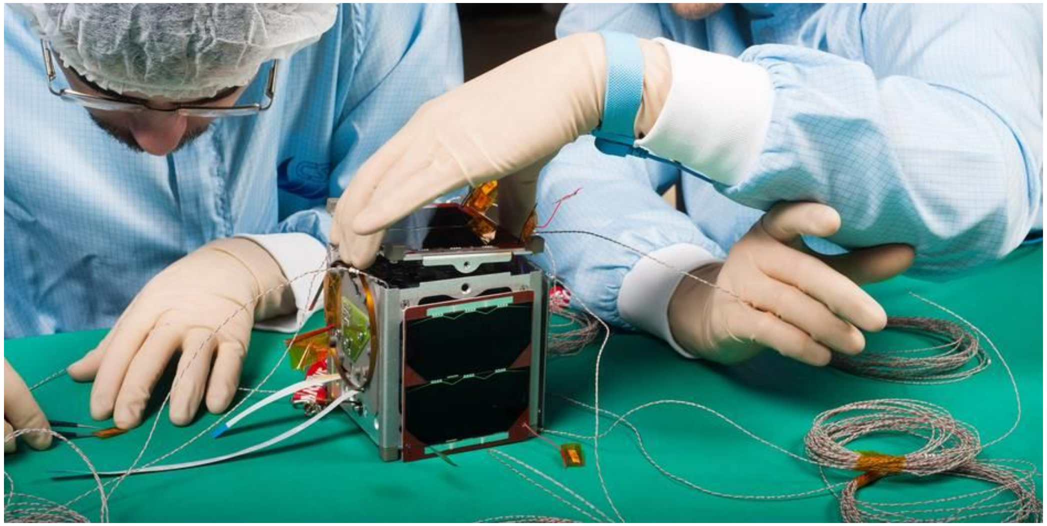
For you:
- Master thesis
- Internships
- Master after master

→ www.vki.ac.be

1. « CubeSats » ?



= Space for students !



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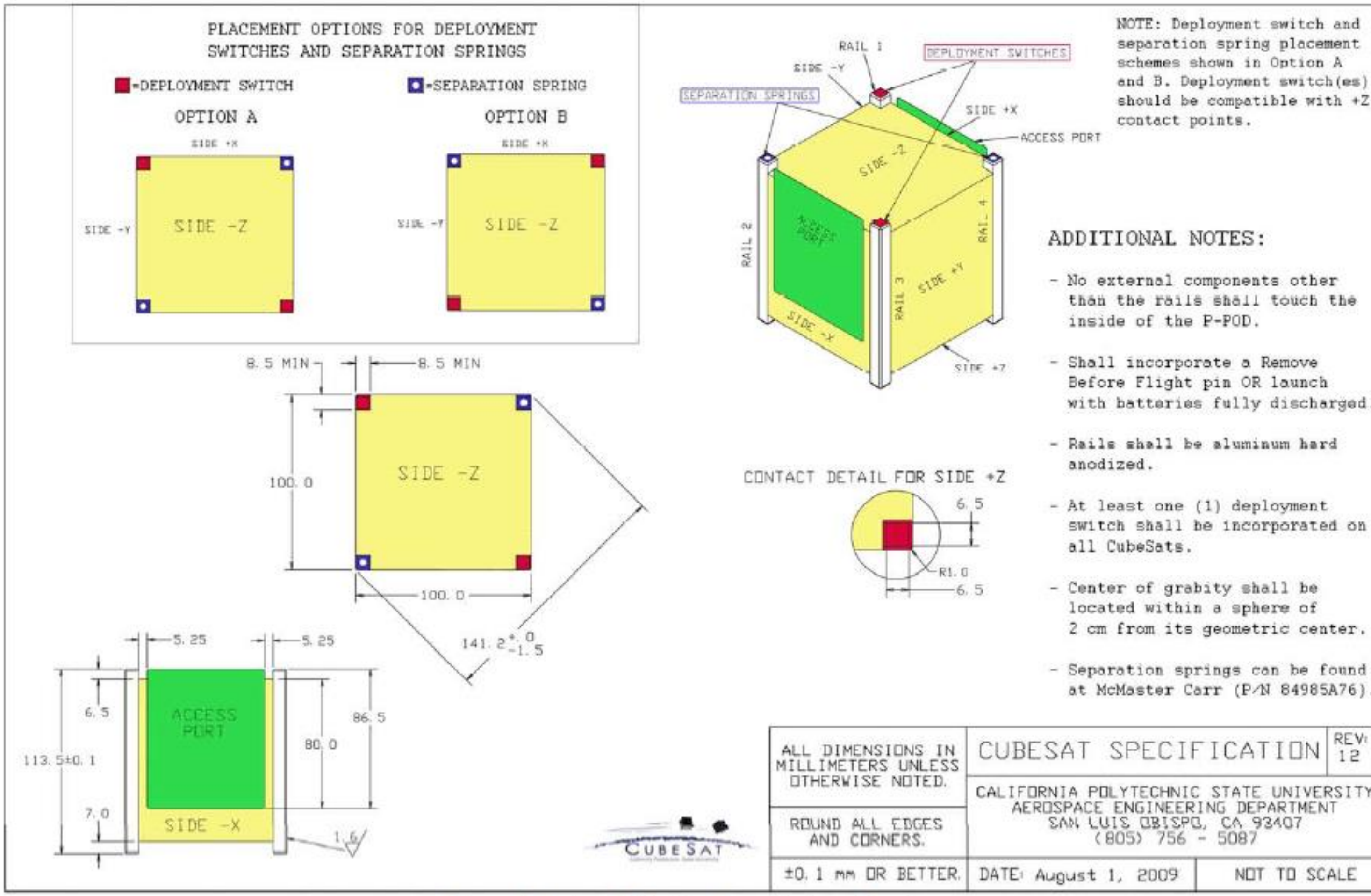
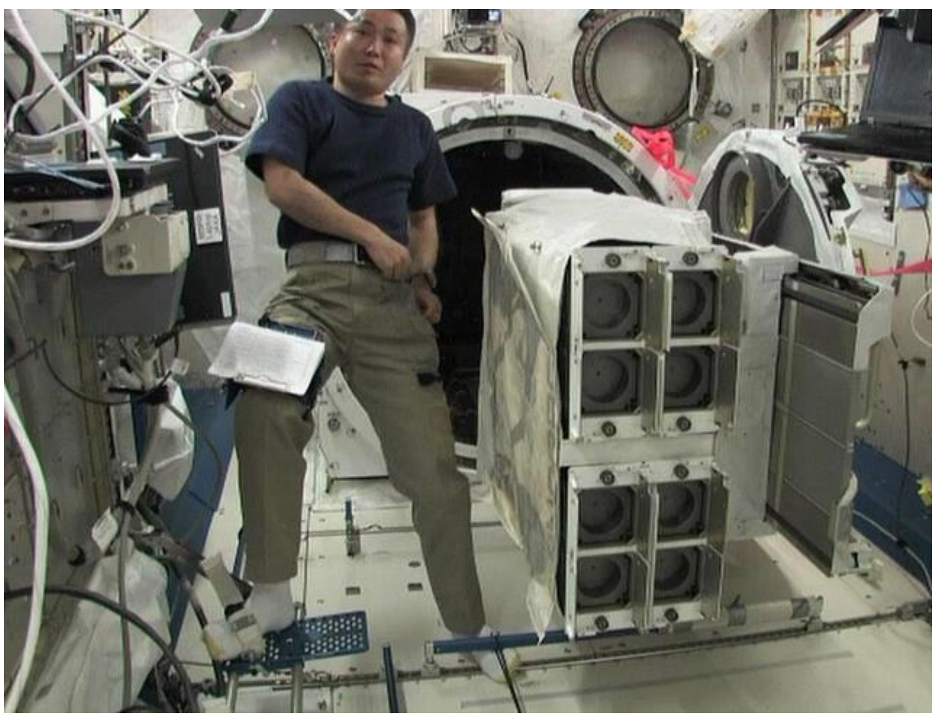
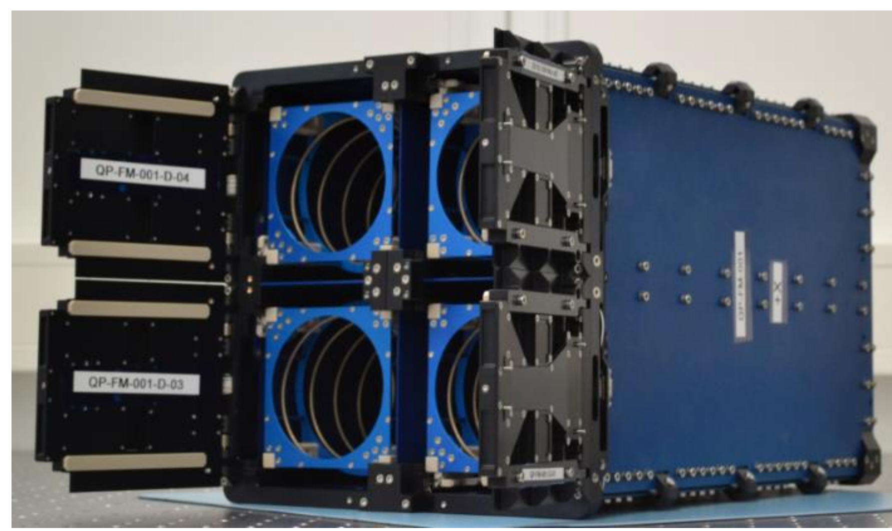


Figure 5: CubeSat Design Specification Drawing

1. « CubeSats » ?

Deployer provides with decoupling from launcher:
- mechanically
- programmatic
- risk (technical, schedule)





1. « CubeSats » ?

1999: Standard issued by CalPoly + Stanford (Prof. Twiggs)

2003: 1st launch (Eurockot, Russia)

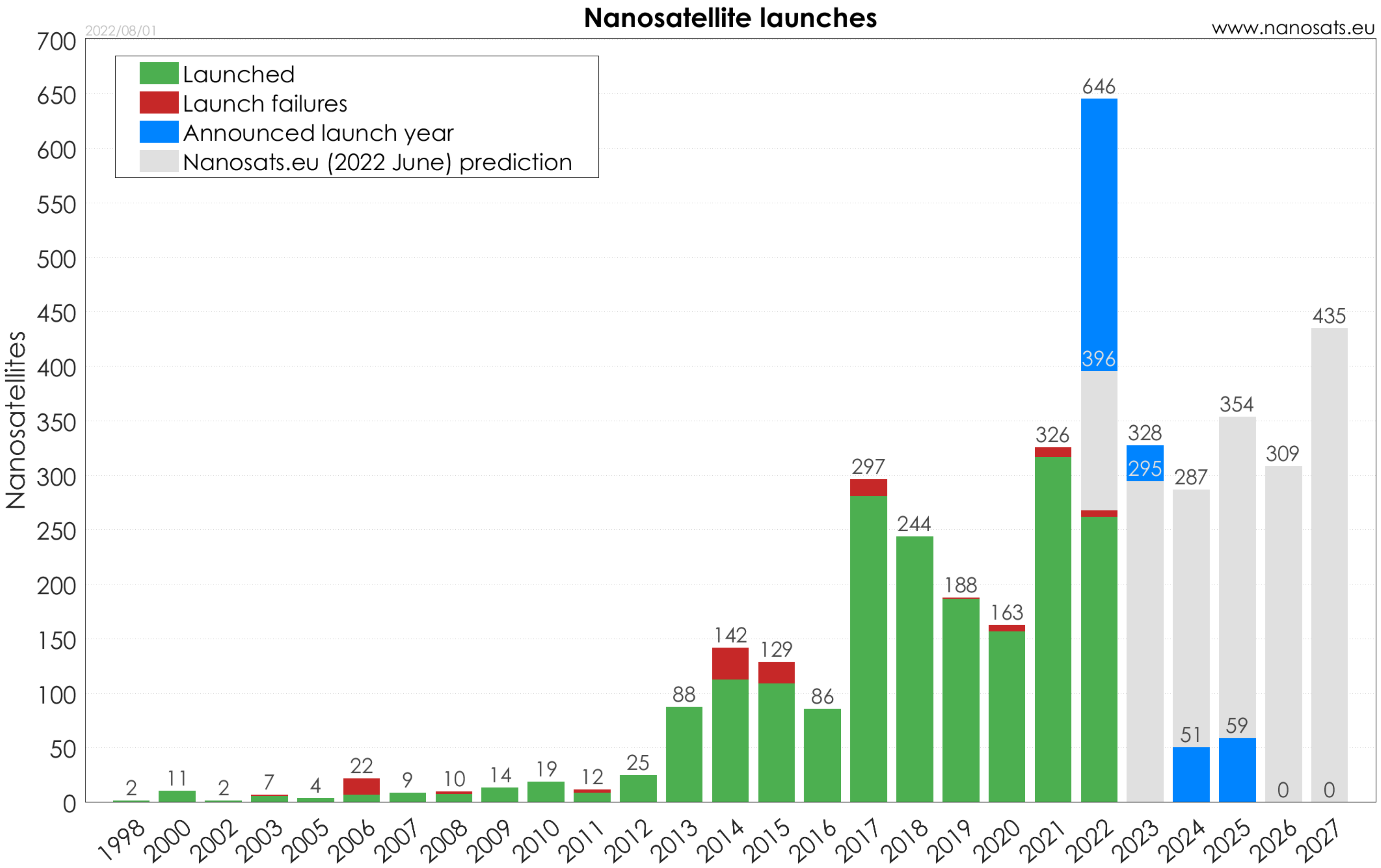
2012: 1st deployment from ISS

2014: 1st constellation (PlanetLabs)

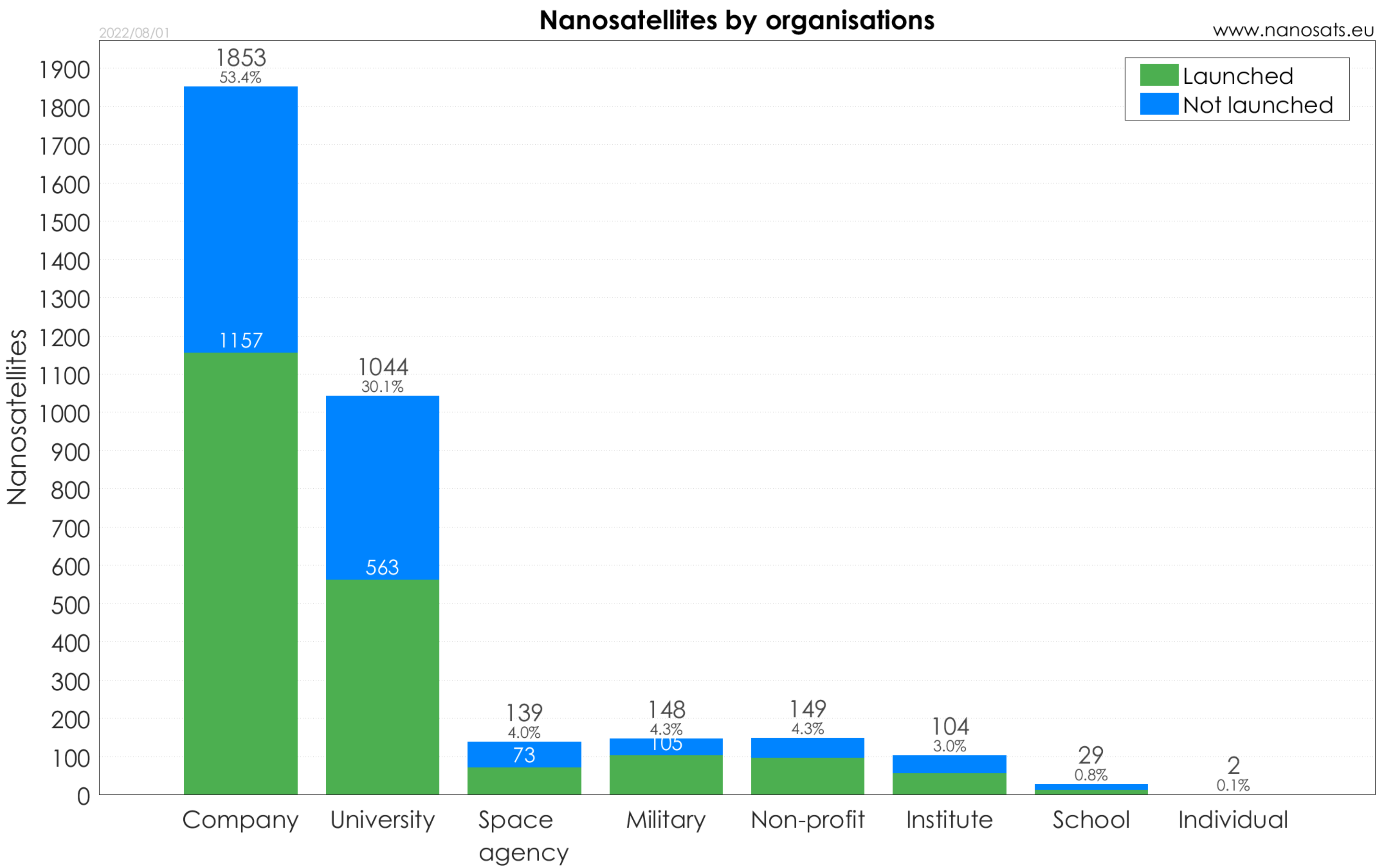
Now: 1897 CubeSats launched

? in development

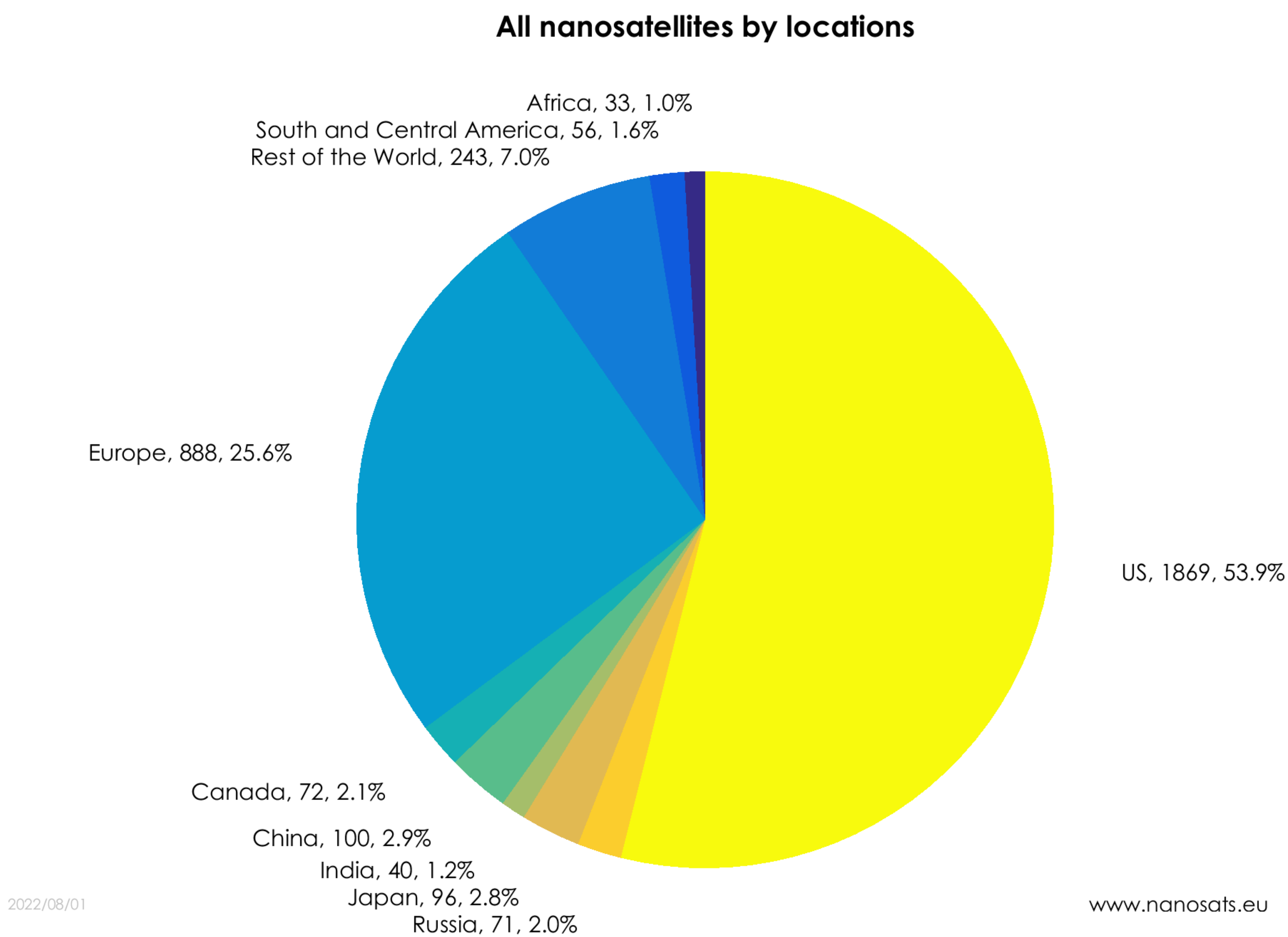
1. « CubeSats » ? – In numbers



1. « CubeSats » ? – In numbers



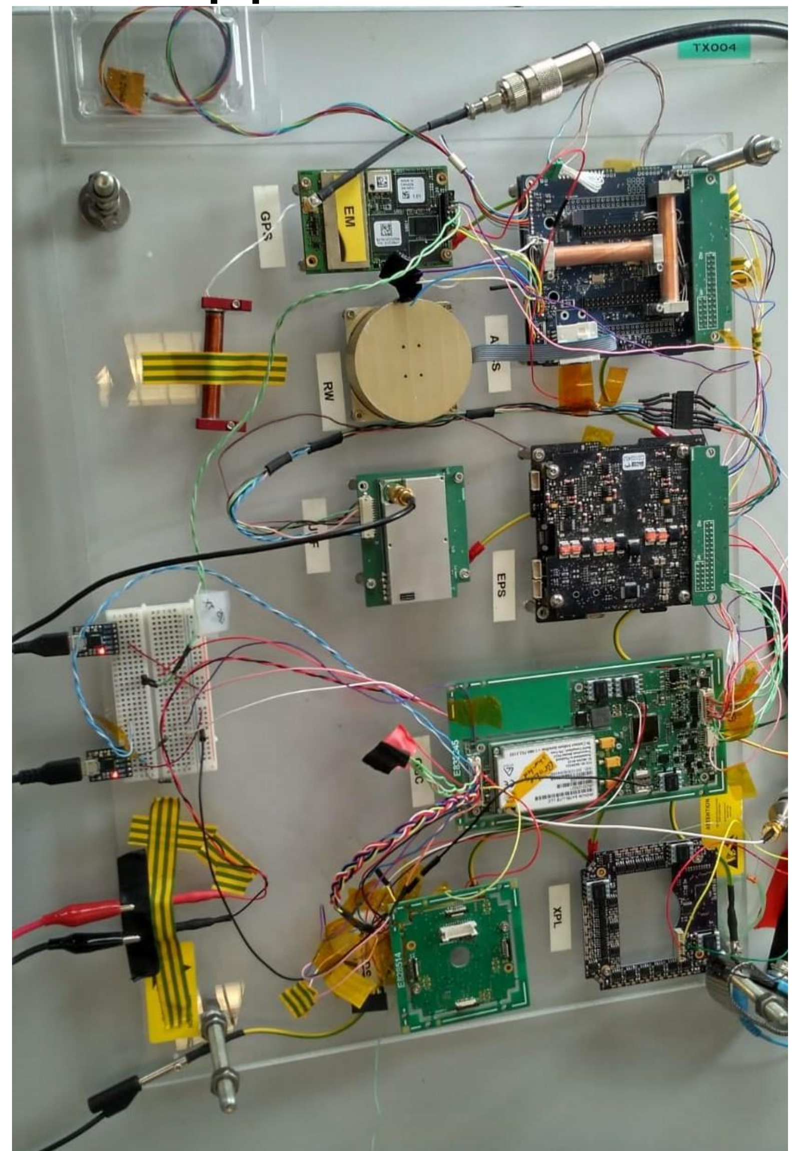
1. « CubeSats » ? – In numbers



1. « CubeSats » ?

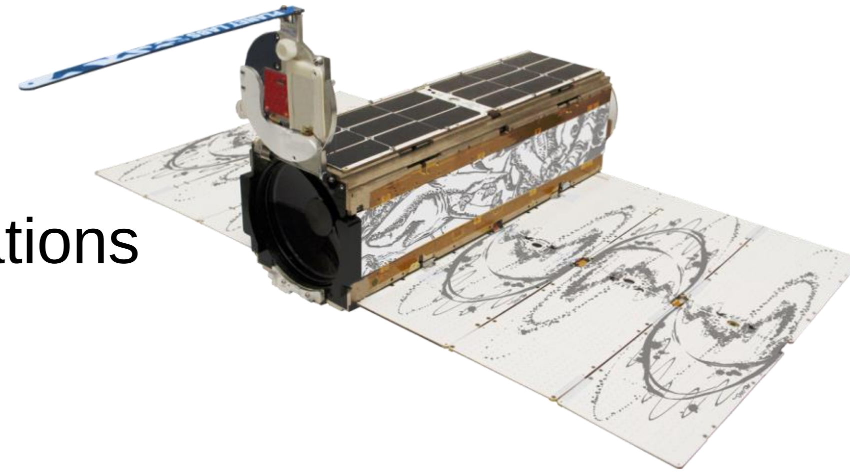
… but also a specific development approach:

- Agile development
- Hardware oriented (flatsat)
- Risk accepting
- No/little redundancy
- COTS subsystems widely available
- (often) protoflight model philosophy



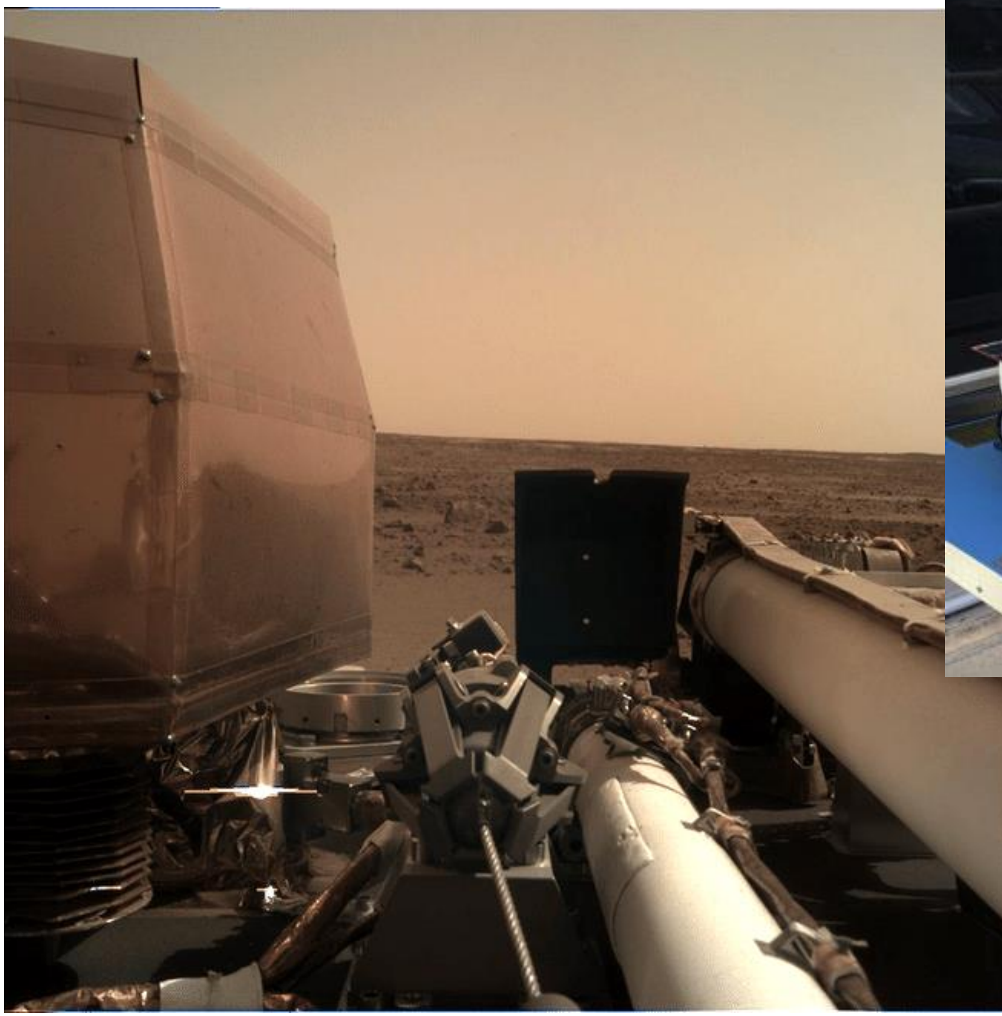
1. « CubeSats » ? – A few remarkable examples

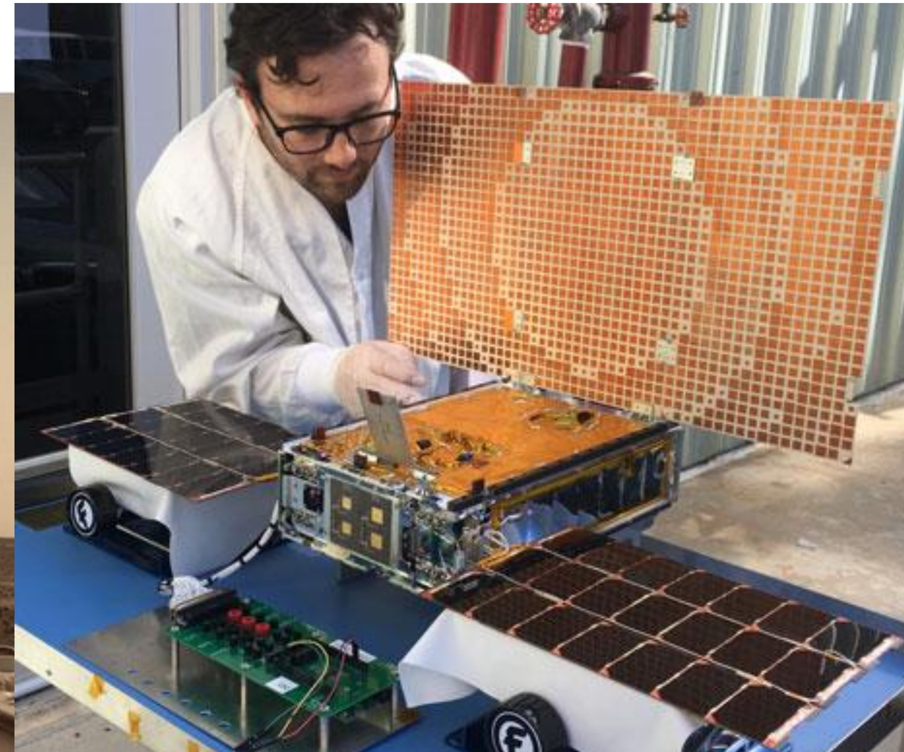
Planet (previously Planet Labs):
- Private company, commercial
- Earth imaging, monitoring applications
- 519 3U CubeSats launched
- Launching every 3-4 months
- 3-5 m resolution
- Now imaging the entire Earth’s landmass every day!




Credits: NASA/JPL-Caltech

1. « CubeSats » ? – A few remarkable examples



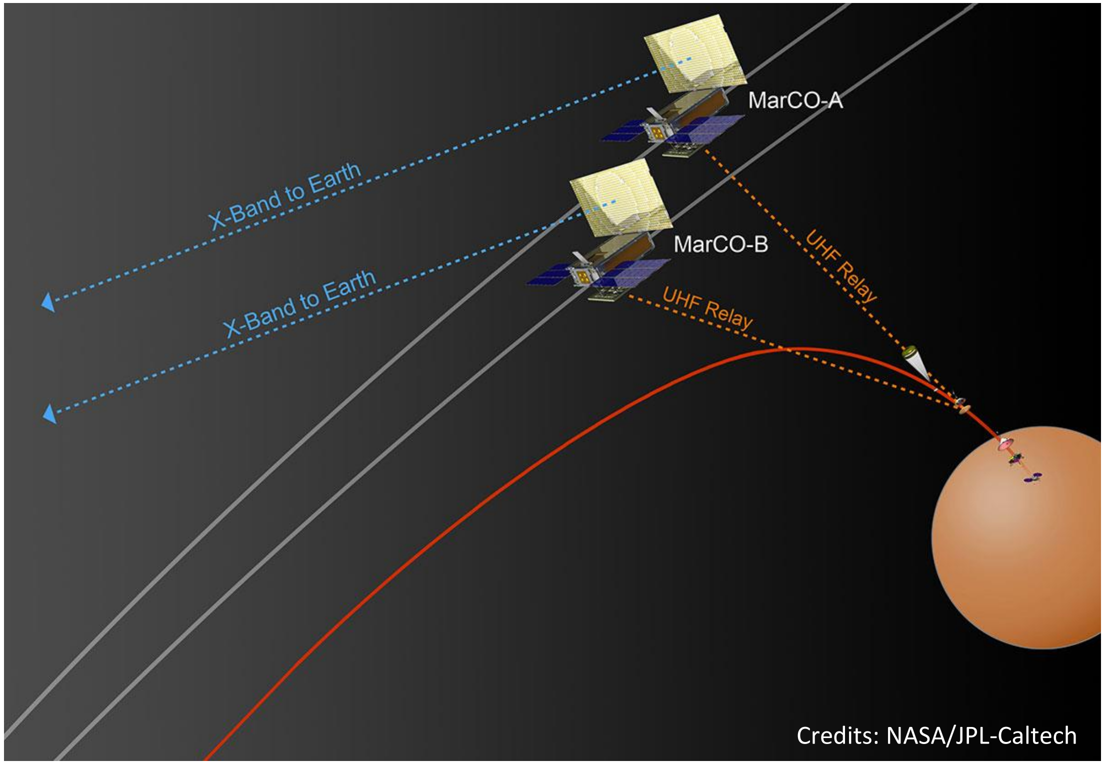


Credits: NASA/JPL-Caltech

1. « CubeSats » ? – A few remarkable examples

Mars Cube One (MarCO)

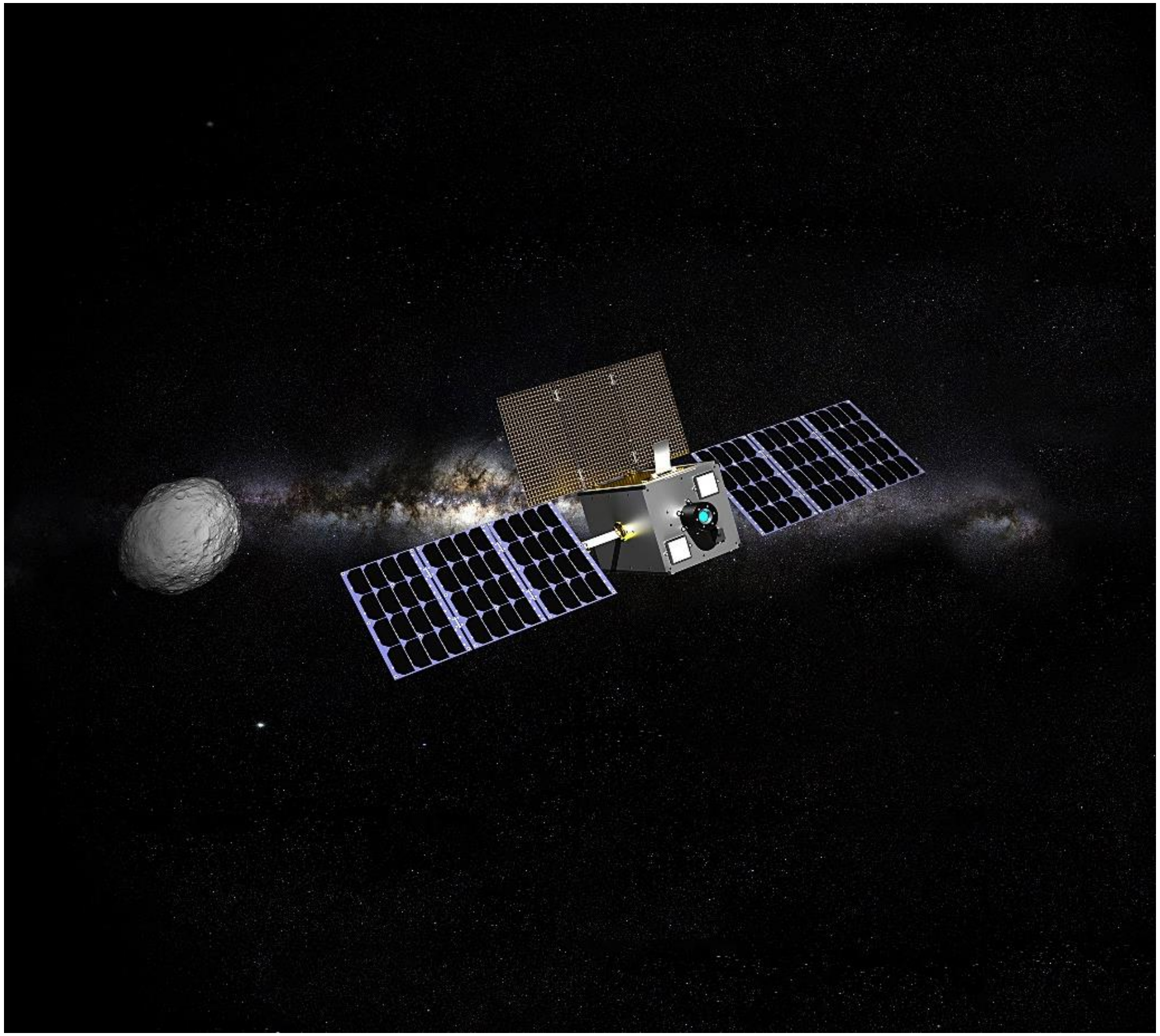
- Two 6-U CubeSats
- Launched with NASA InSight mission to Mars (May 2018)
- Navigated to Mars independently
- Communications relay during entry, descent, & landing of Insight (Nov. 2018)



1. « CubeSats » ? – A few remarkable examples

M-ARGO

- ESA
- 12U CubeSat
- Deep space
- Small asteroid (NEO)
- Stand alone
- Targeting 2024-2025

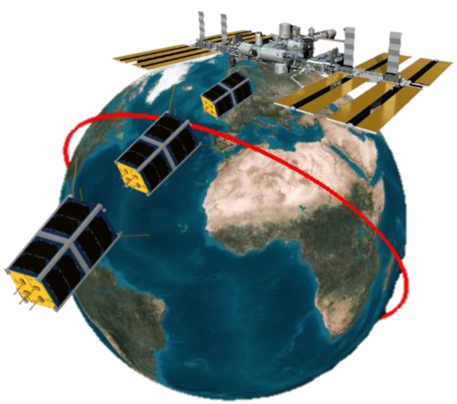


1. « CubeSats » ? – A few remarkable examples

- An international project aiming at developing a constellation of CubeSats to investigate the Earth Mid/Lower Thermosphere
- VKI was project leader and coordinates the work of 50+ partners and teams around the world
- A project funded by the European Commission under the FP7 Framework

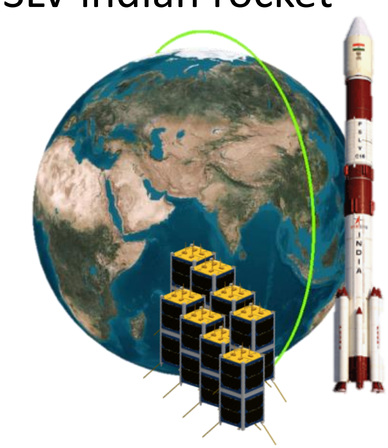
➔Constellation of 36 CubeSats deployed into Space:

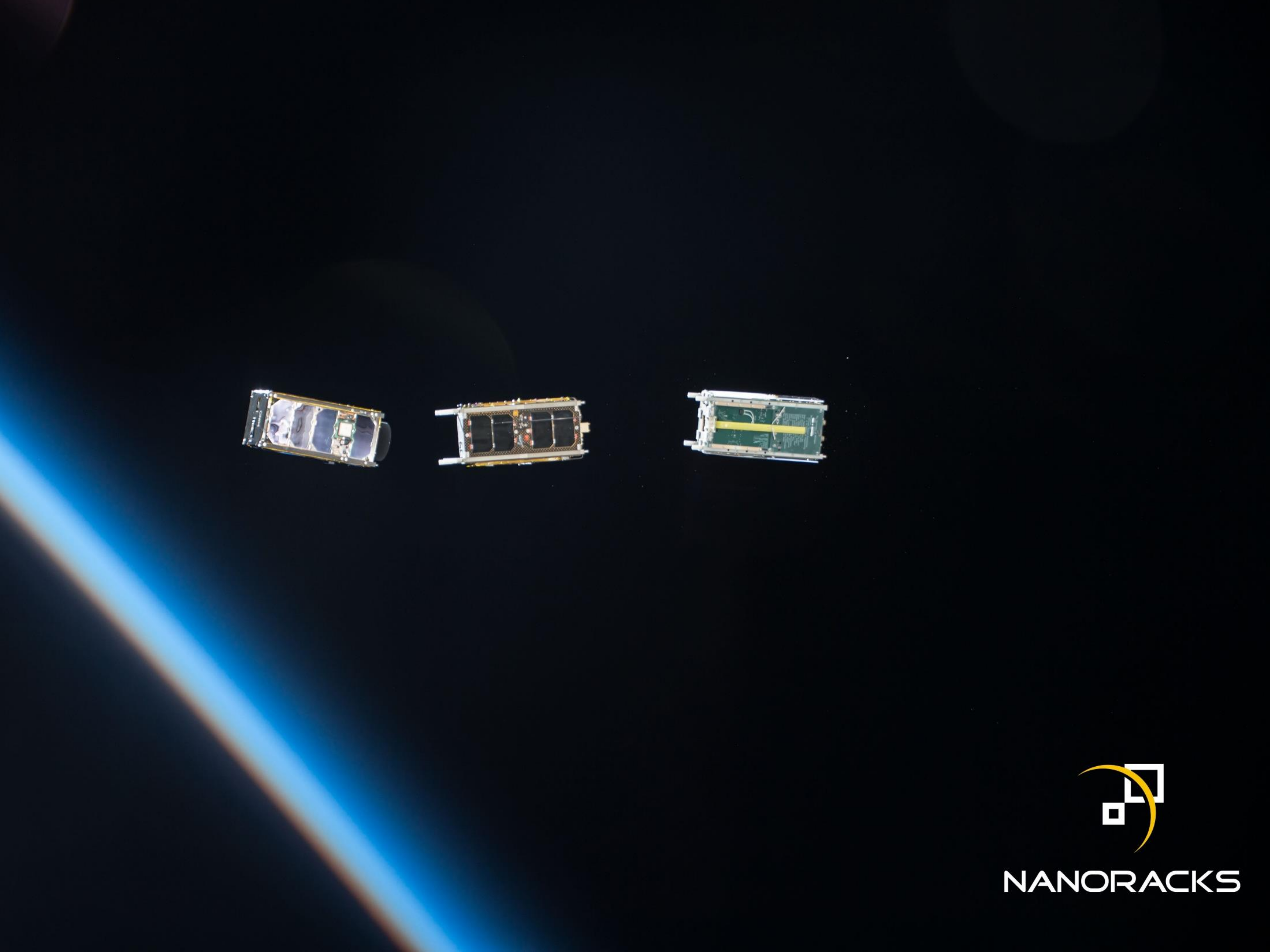
28 from the International Space Station

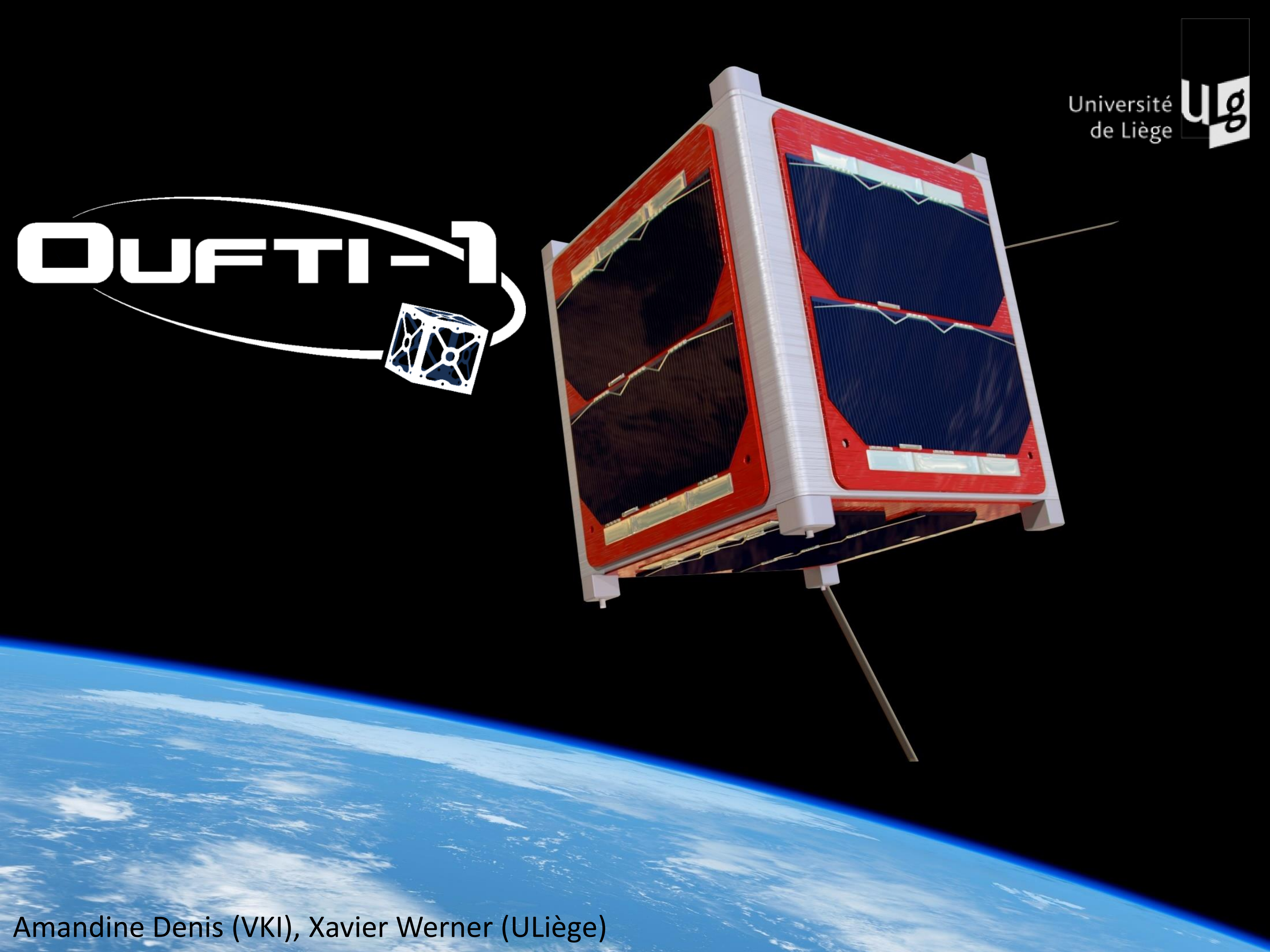


+

8 with the PSLV indian rocket




NANORACKS



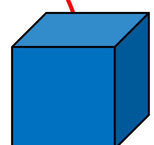
Amandine Denis (VKI), Xavier Werner (ULiège)

Outline

1. Objectives
2. Space Segment
    1. Payloads
    2. Orbit and mission analysis
    3. Platform
    4. Protoflight model
3. Ground segment

1. Objectives

Matière
1. Introduction
2. Satellite orbits
3. Launch vehicle
4. History
5. Earth observation
6. Propulsion & attitude control
7. Astrophysics
8. Thermal control
9. Space environment
10. Spacecraft structures
11. Electrical power
12. Telecommunications
13. Nanosatellites
14. Software
15. The PROBA family



Decrease size,
Increase interactions!

1. Objectives

Primary Goal

→ Hands-on satellite experience for students

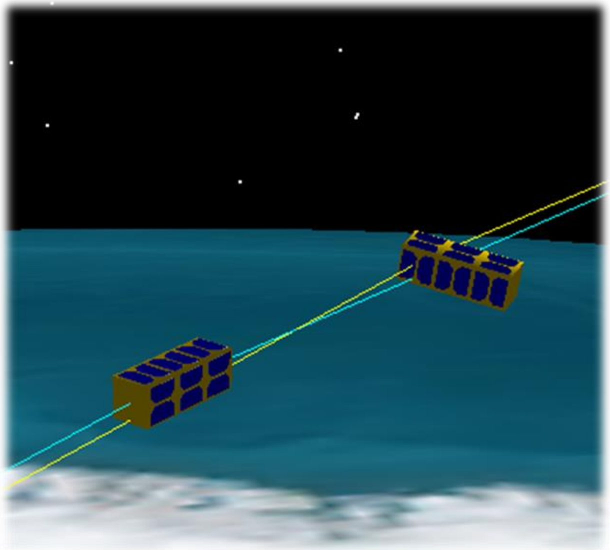
1. Objectives

Primary Goal

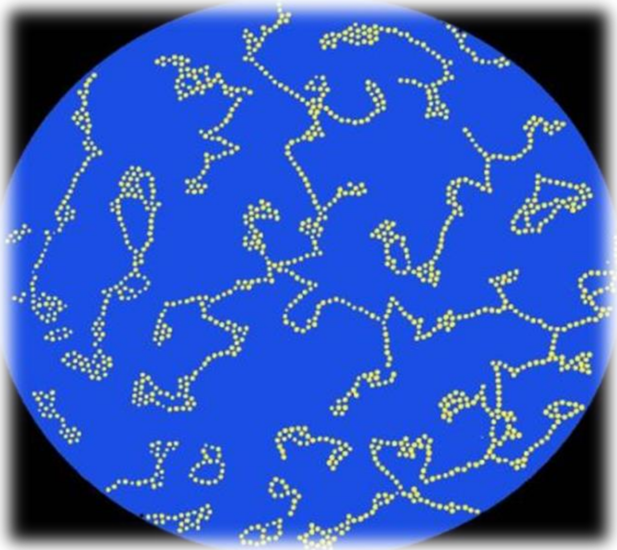
→ Hands-on satellite experience for students

Long-term Goal

→ Series of CubeSats for scientific experiments



Formation flying



Granular materials

1. Objectives

Primary Goal

→ Hands-on satellite experience for students

Long-term Goal

→ Series of CubeSats for scientific experiments

Short-term Goal

Orbital Utility For Telecommunication Innovation

Outline

1. Objectives
2. Space Segment
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2.1 Payloads – D-STAR

- Digital-Smart Technology for Amateur Radio

- Simultaneous data and voice digital transmission

- Complete routing capacity, including roaming

- 3 frequencies and 2 data rates

- VHF: 144 MHz	(2m)	4.8 kbit/sec
- UHF: 435 MHz	(70cm)	4.8 kbit/sec
- SHF: 1.2 GHz	(23cm)	4.8 kbit/sec or 128kbit/sec

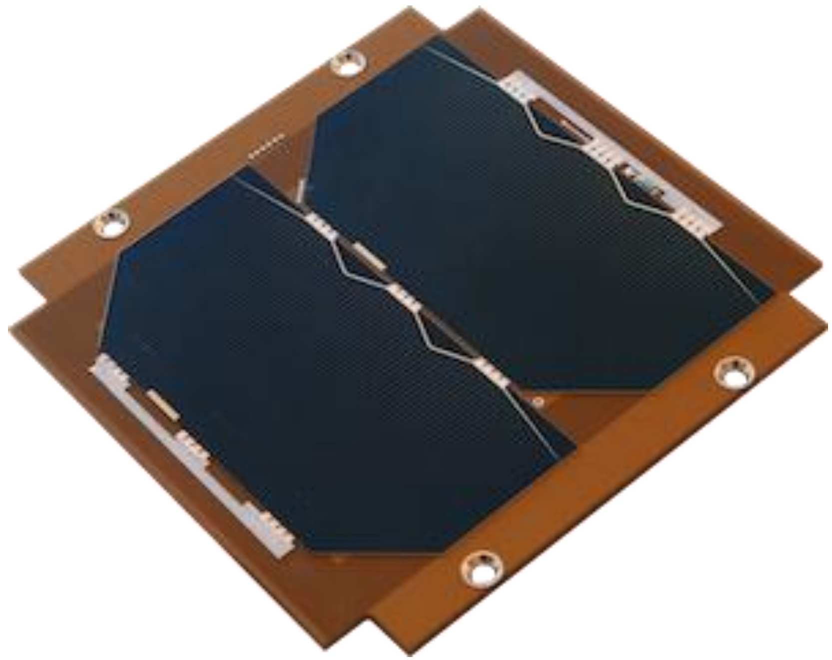
- Data : 1200 bps - Voice : 3600 bps

- Open protocol (! AMBE)

- GMSK modulation

2.1 Payloads – solar cells

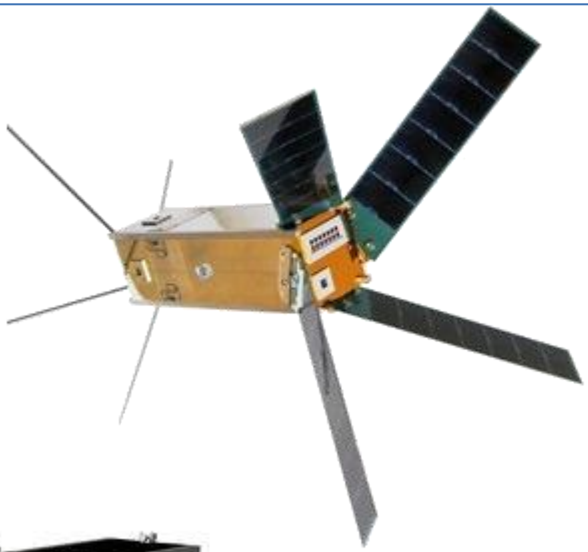
- High-performance solar cells (30% GaAs triple junction)



AZURSPACE

Payloads – More and more applications!

- Technology demonstration (…)
- Imaging
- Communications
- Earth remote sensing
- Biology
- Re-entry
- Debris removal
- Security (AIS, ADS-B…)
- Deep Space
- …



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2.2 Orbit and mission analysis

CubeSats = secondary payloads

➔ Orbit imposed by primary payload

➔ Mission analysis
=
Analyze impact of this imposed orbit

designed for Vega maiden flight

1447 x 354 km, i = 71°

Very demanding!

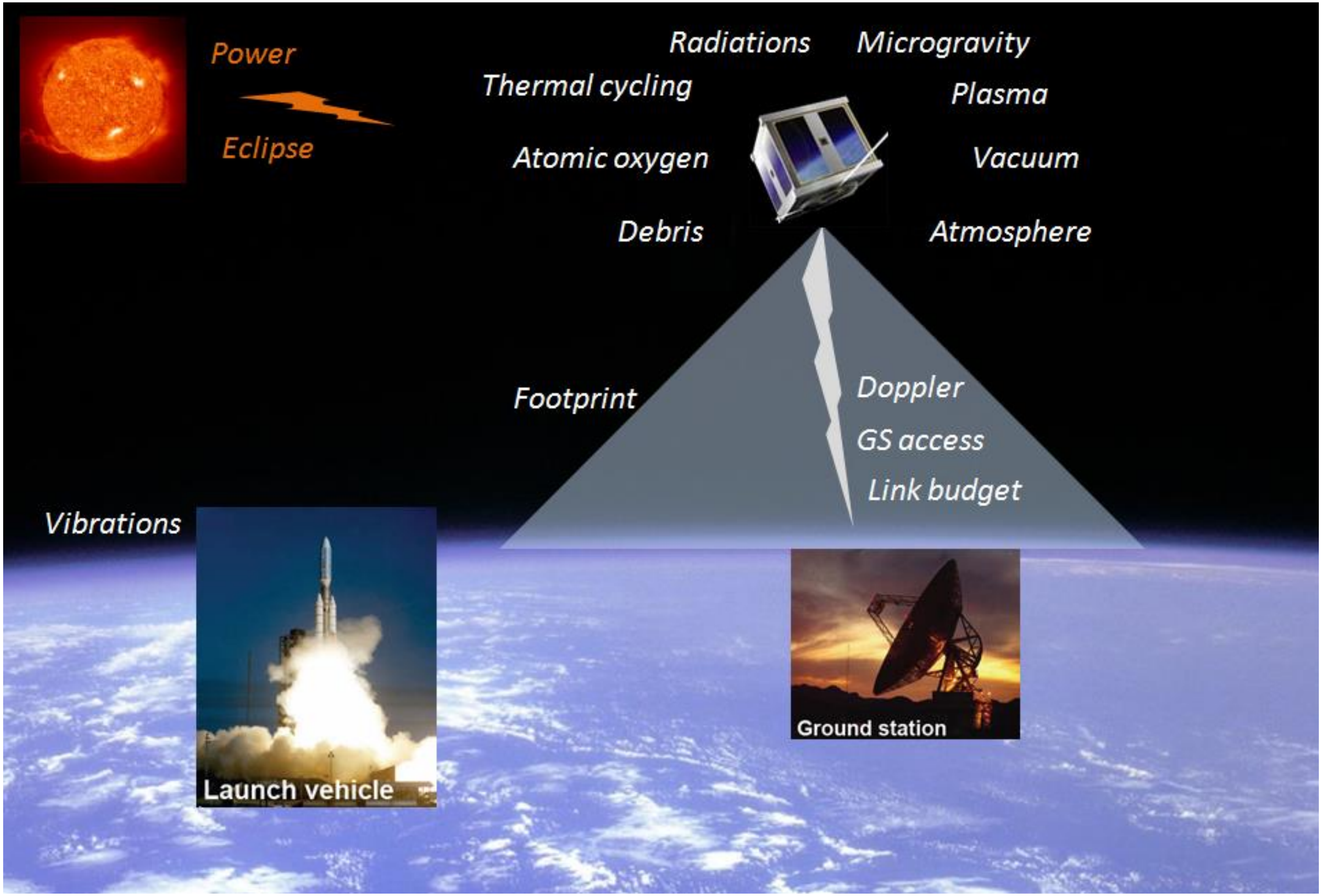
But finally:

Soyuz VS14

437 x 683 km, i = 98°

More comfortable!

2.2 Orbit and mission analysis



2.2 Orbit and mission analysis

Parameter	Value	Impact on the design
LAUNCH		
Launch vibrations	Severe vibrations (13.98 g RMS qual. Level) [Vega]	Automotive electronic components [STRU]
ORBIT		
Footprint length	Apogee: 6837 km Perigee : 3183 km	
GS access	Mean: 14.33 min/access Max: 20.35 min/access Min: 7.42 min/access Mean : 47 min/day 29 % over oceans	Power saving strategy [OBC]
Sunlight	75.8 % in sunlight Max eclipse: 35.9 %	Thermal design [THER]
Integrated power	Mean: 2365.5 mW/orbit Max: 3247.1 mW/orbit Min: 1491.8 mW/orbit	5 solar panels instead of 6: ok [EPS2]
Doppler	"worst case": 7 min	Communication times ok => successful mission
Link budget	Apogee: 14.9 dB uplink margin (S/N) Perigee: 22.5 dB uplink margin (S/N) Apogee: 15.1 dB downlink margin (S/N) Perigee: 22.7 dB downlink margin (S/N)	Link closes: ok

2.2 Orbit and mission analysis

ENVIRONMENT		
Vacuum	Apogee: 5.21 E-16 kg/m^3 [SMAD] Perigee: 6.98 E-12 kg/m^3	Batteries and antenna tested in vacuum chambers at CSL [EPS2] [MECH] Careful material selection [STRU] Glue [STRU] Out-gassing protection film on electronic cards [EPS]
Atomic oxygen	Concentration at perigee: 2.52 E14/m^3	Coverglass
Atmosphere	Lifetime: 4.8 years	
Radiation	1E-2mm shielding: 8.4E3 krad/year 2 mm shielding: 13.7 krad/year Perigee p+ flux(>10MeV): 8.0 E2/cm^2/s Perigee e- flux(>1MeV): 6.9 E4/cm^2/s Apogee p+ flux(>10MeV): 2.9 E4/cm^2/s Apogee e- flux(>1MeV): 4.2 E5/cm^2/s	Sensors [OBC] Battery (use it for shielding) [CR CSL] Thickness of solar panels [STRU] Redundant OBC with watchdog [OBC] Redundant beacon [Beacon] Choice of electronic components [EPS] [EPS2]
Debris	Prob. : 7.2 E-4 Destructive impact/year	
Microgravity		No convection. Careful thermal design [THER]
Thermal cycling	Outer surfaces: -30°C to +60°C Inner surfaces: -10°C to +40°C	Careful thermal design [THER]

Outline

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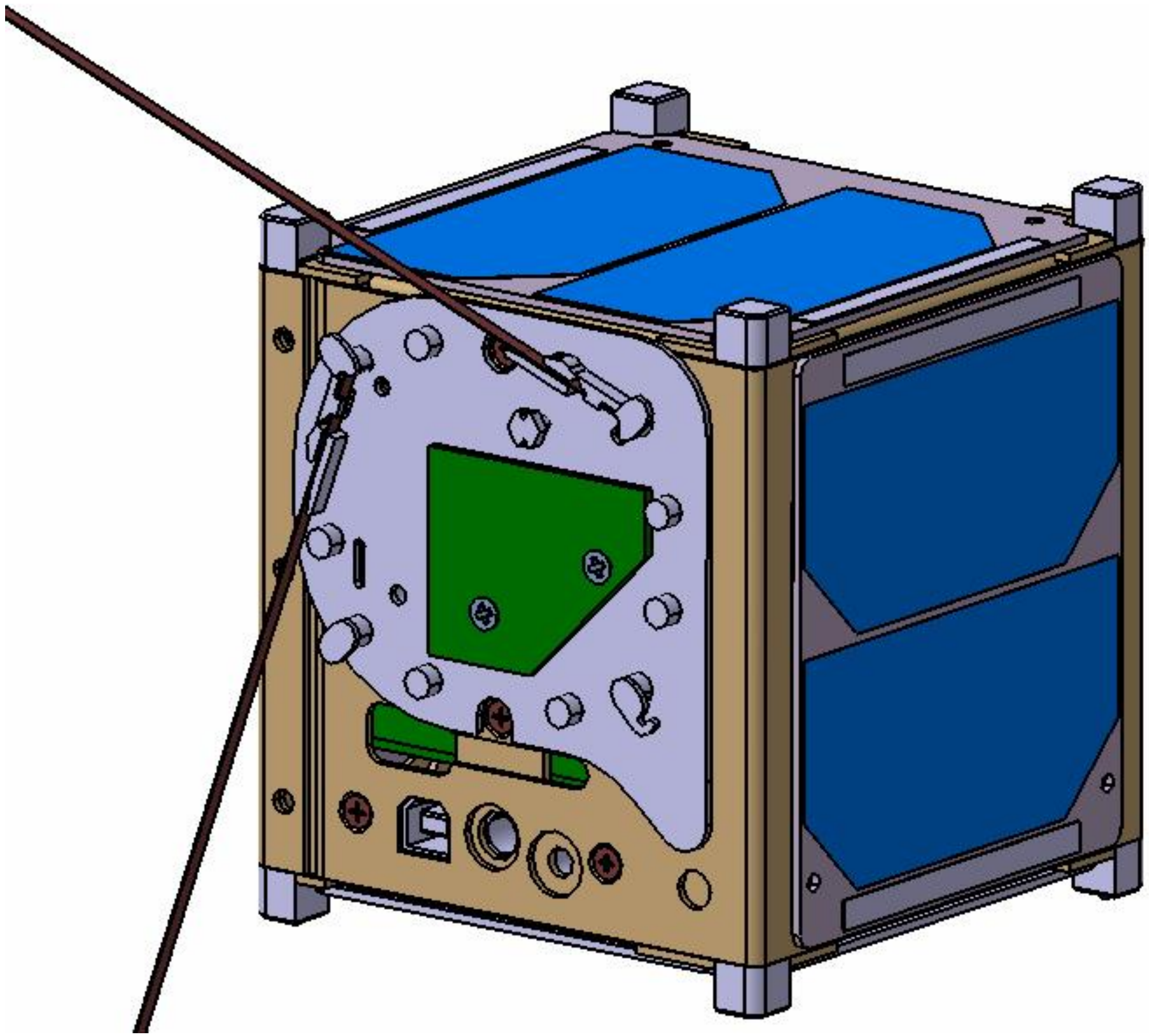
2.3 Platform



2.3 Platform – ADCS: requirements

- Payloads: no specific pointing requirement
- COMM: max 10°/s (avoid signal modulation)
- Mass, volume, and power constraints

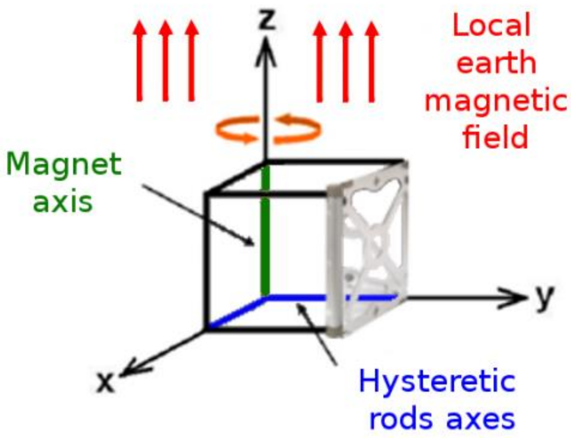
Passive control is sufficient!

2.3 Platform – ADCS: passive magnetic

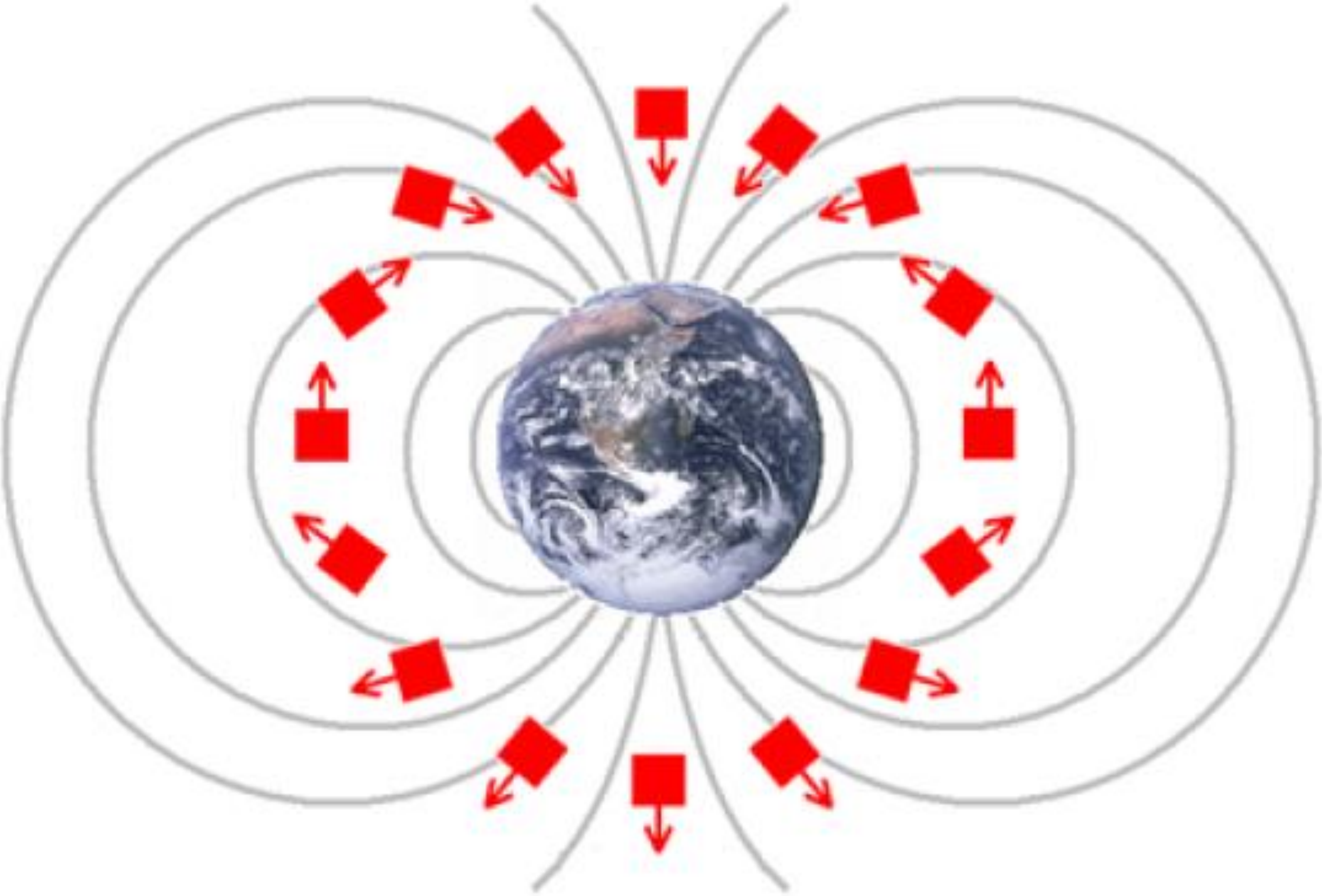
A **permanent magnet** interacts with the geomagnetic field, producing a restoring torque, which align satellite axis with Earth’s magnetic field.

The spacecraft will oscillate around energy minima

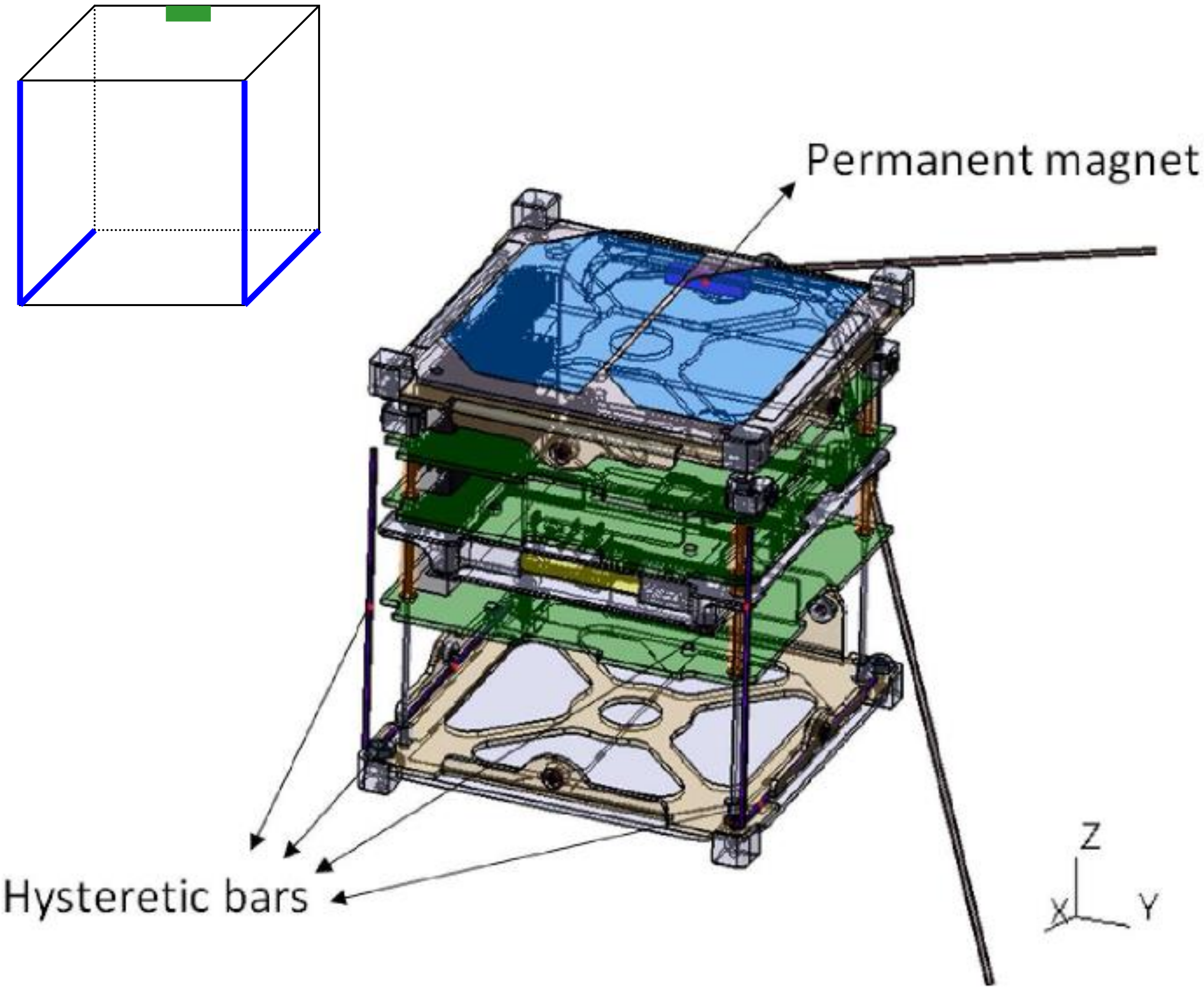
The oscillation are damped out by **hysteretic rods**.



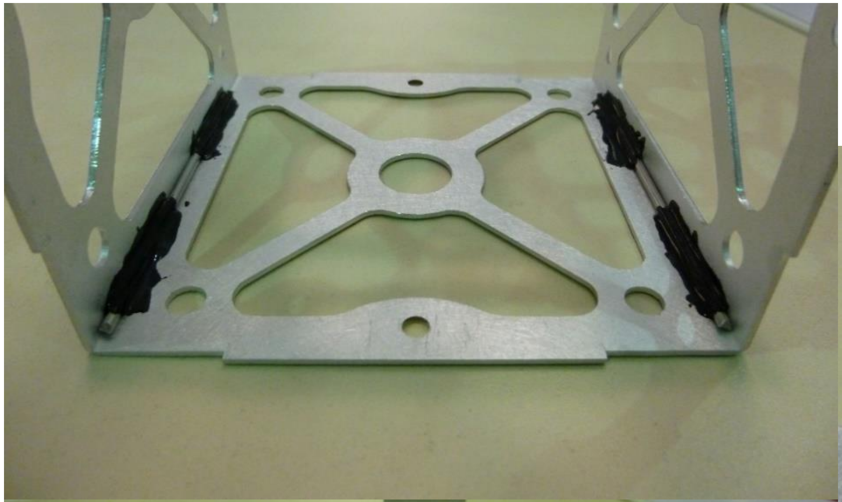
2.3 Platform – ADCS: orientation

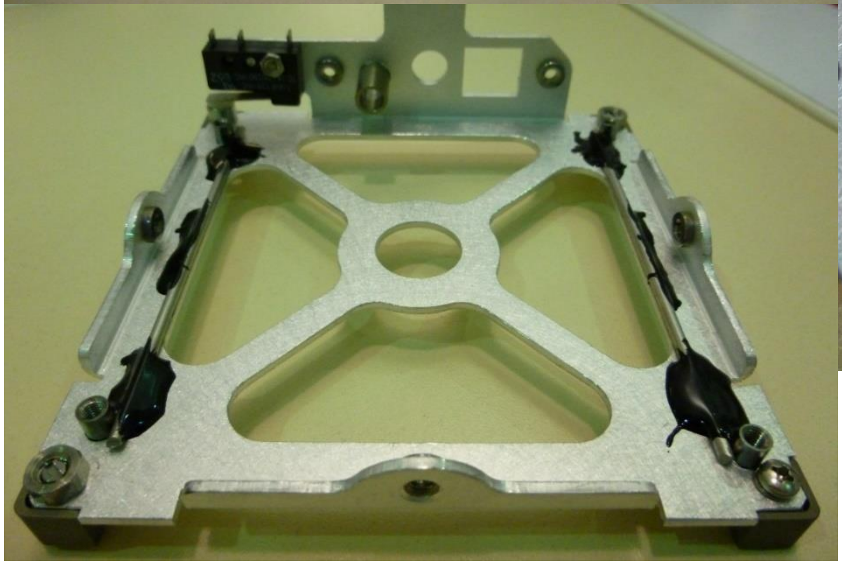


2.3 Platform – ADCS: final design



2.3 Platform – ADCS: flight model



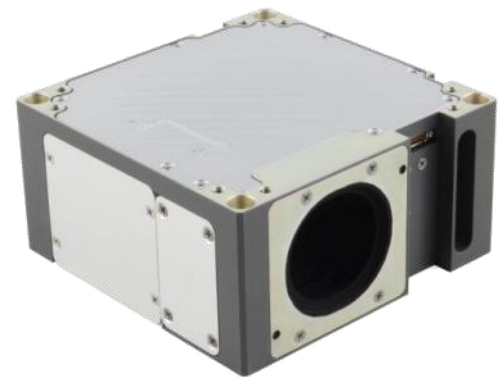


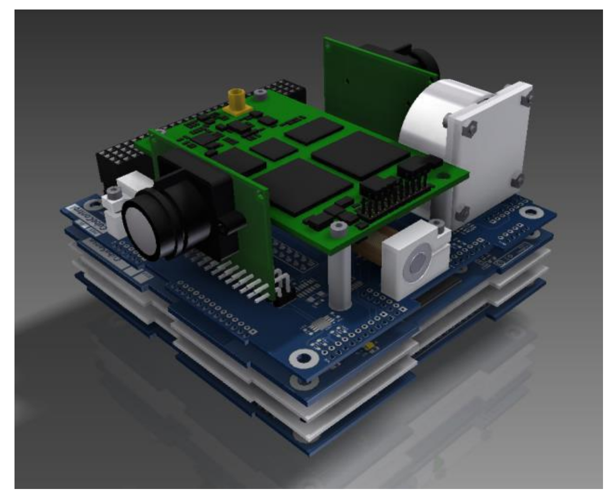
ADCS – State of the Art

Actuators:
- Magnetorquers
- Reaction wheels

Sensors:
- Magnetometers
- Star trackers
- Sun/Earth sensors
- Gyroscopes

➔ Pointing accuracy << 1°





+ propulsion (cold gas thrusters, pulsed plasma thrusters)

2.3 Platform – COMM: requirements

ITU:

ANNEX V. EXTRACT FROM ARTICLE 22 OF THE RADIO REGULATIONS – SPACE STATIONS

Section I – Cessation of emissions

22.1 § 1 Space stations shall be fitted with devices to ensure immediate cessation of their radio emissions by telecommand, whenever such cessation is required under the provisions of these Regulations.

25.11 § 7 Administrations authorising space stations in the amateur-satellite service shall ensure that sufficient Earth command stations are established before launch to insure that any harmful interference caused by emissions from a station in the amateur-satellite service can be terminated immediately. (See No. 22.1).

2.3 Platform – COMM: IARU

- All links must be located within the agreed ham band specific space allocations
- Coordination process

The International Amateur Radio Union

Since 1925, the Federation of National Amateur Radio Societies
Representing the Interests of Two-Way Amateur Radio Communication

IARU Amateur Satellite Frequency Coordination

Back to List of Sats whose Frequencies have been coordinated

OUFTI-1	Updated: 04/06/2010		Responsible Operator	Prof. Jacques Verly ON9CWD
Supporting Organisation	University of Liège			
Contact Person	Amandine Denis ON4 amandine.denis@ulg.ac.be.nospam			

Headline Details: A cubesat project. Coordinated uplink frequencies on the 145MHz band and downlinks of 435.015 and 435.045MHz have been agreed. It is planned for a launch on Vega not before November 2009.The key, innovative, feature of OUFTI-1 is the use of the D-STAR amateur-radio digital-communication protocol. This means of radio-communication will be used for control and telemetry, and will of course be made available to ham-radio operators worldwide. In the future, it will also be used to control space experiments. More info is available at www.oufti.ulg.ac.be

Applications Date:	01/11/2008	Freq coordination completed on	26/05/2010

The IARU Amateur Satellite Frequency Coordination Status pages are hosted by AMSAT-UK as a service to the world wide Amateur Satellite Community

2.3 Platform – COMM: frequency bands

Uplink: 70-cm band (435 MHz, UHF)

Downlink: 2-m band (145 MHz, VHF)

Recommendation CT08_C5_Rec22
(Paper CT08_C5_16 Increased Amateur Satellite Service 2 Metre Usage) *The presence of interfering non-amateur signals in the 145.80-146.00MHz part of this band, in many parts of the world, is well documented. To prevent the retransmission of interfering terrestrial signals, satellites in the Amateur Satellite Service that plan to use the 145MHz Amateur band for transponders, are encouraged to use this band for downlink (satellite to ground) modes only, regardless of modulation type*
Proposed MARL, Seconded HRS, agreed unanimously

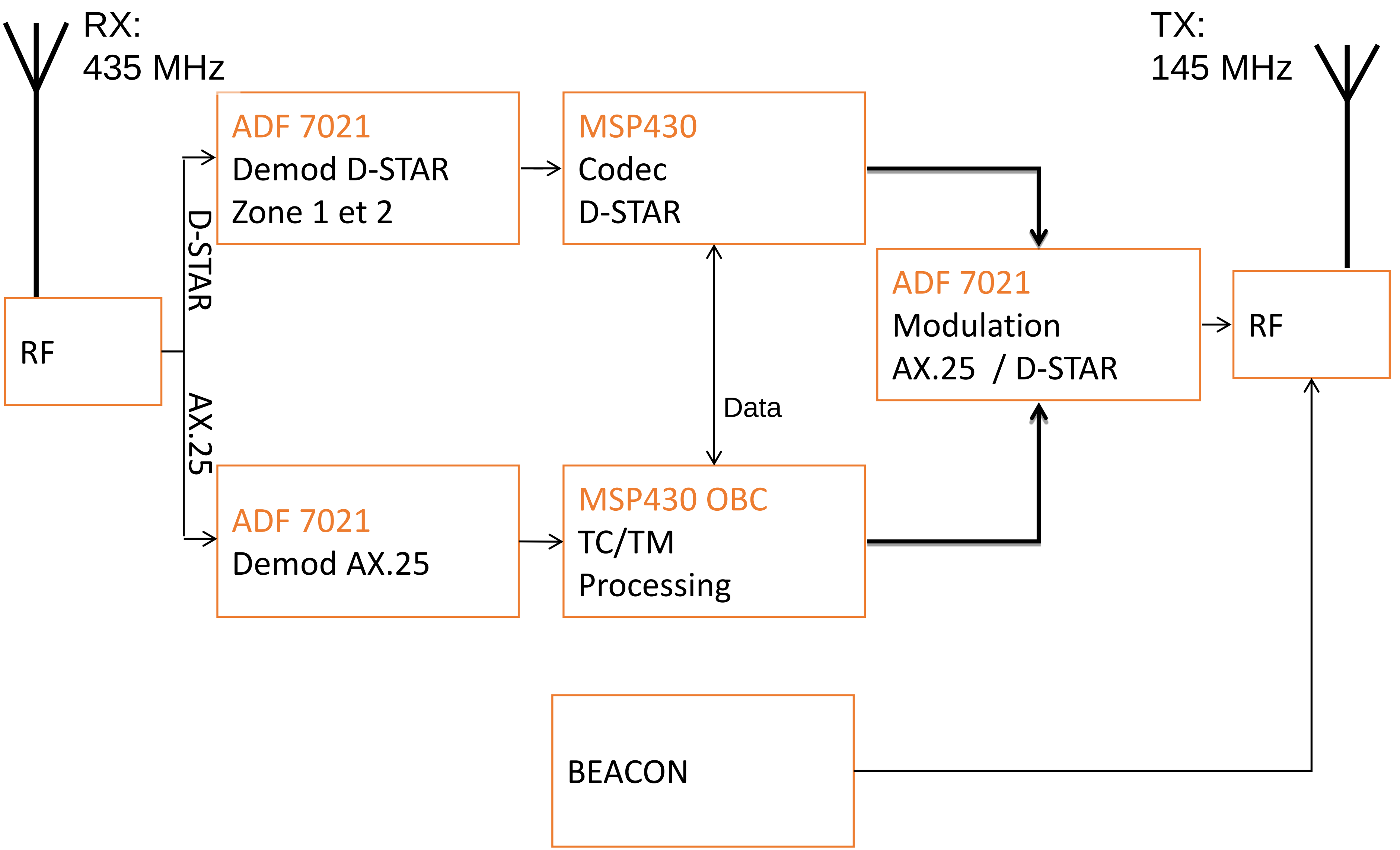
2.3 Platform – COMM: 3 channels

- Payload:
  D-STAR (GMSK, 4800 bauds)

- TC/TM:
  AX.25 telecommunication protocol:
  - simple and standard within the ham community
  - 2FSK, 9600 bauds.

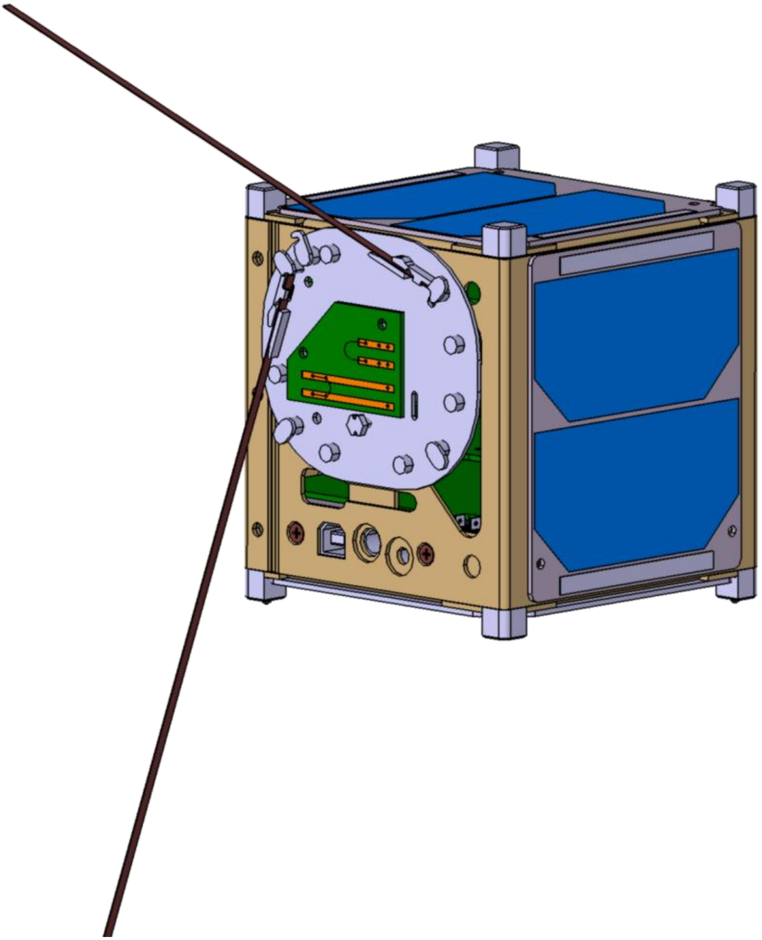
- Beacon:
  extreme reliability (Morse code).

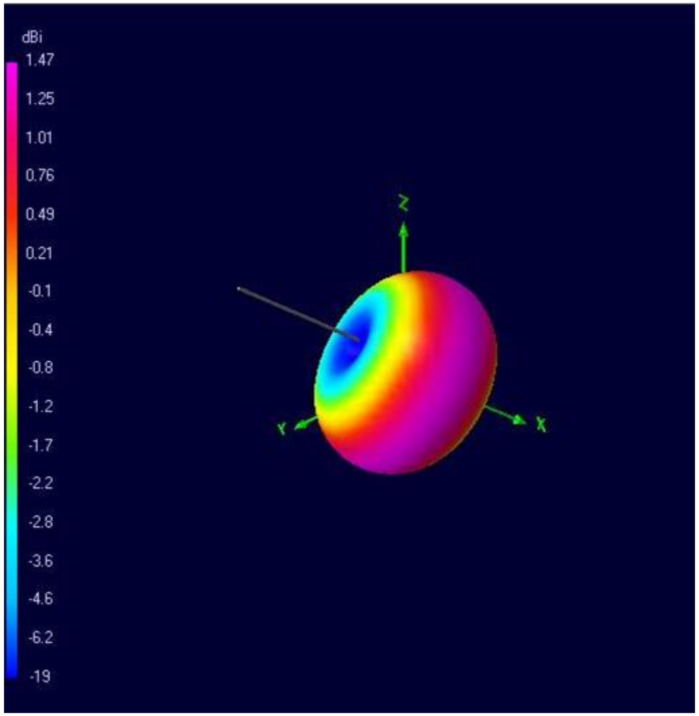
2.3 Platform – COMM: block diagram



2.3 Platform – COMM: low-gain antennas

Two monopole (quarter-wave) antennas : 17 and 50 cm





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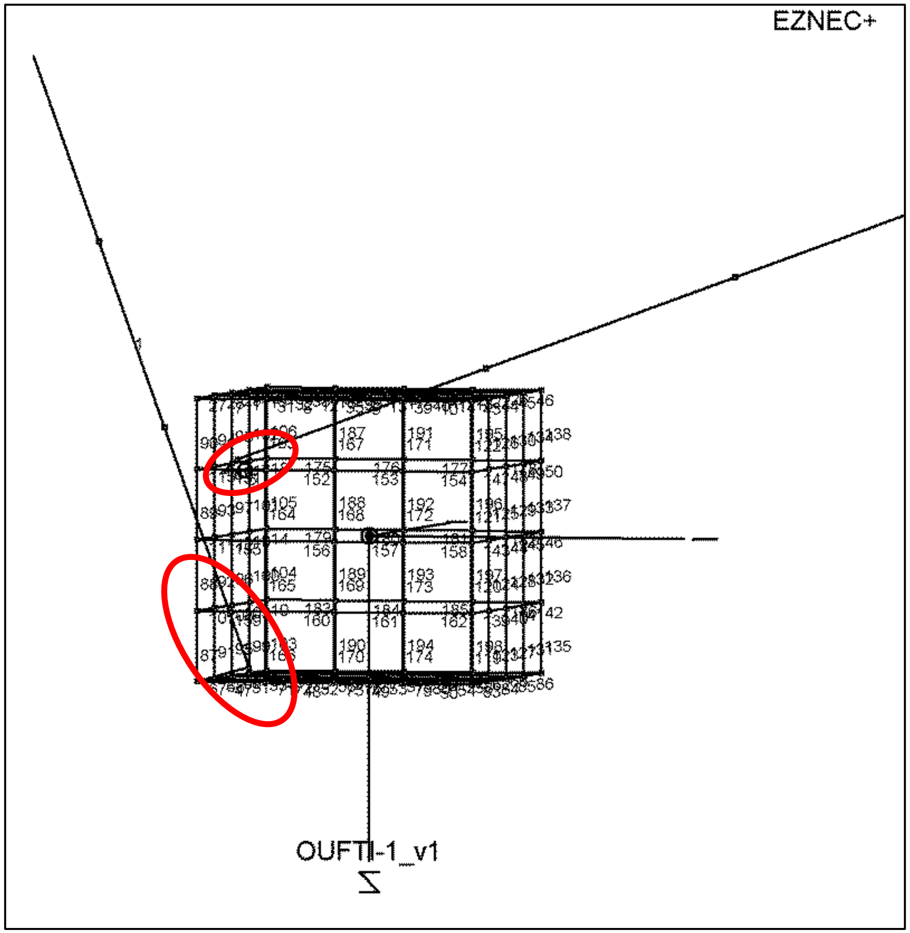


→ Too short !
(non-radiating parts)

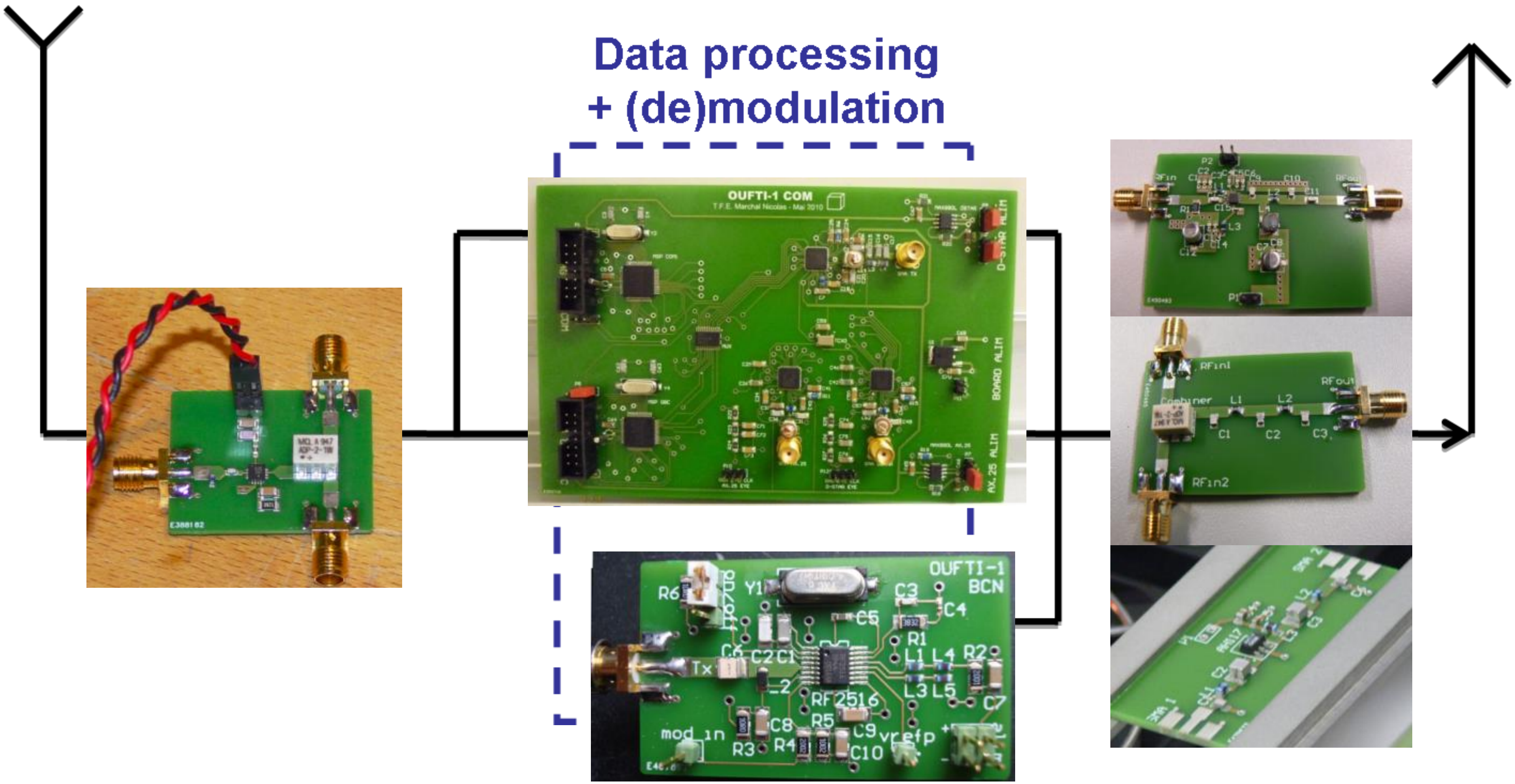
➔ Re-dimensionning
➔ Impact on MECH

2.3 Platform – COMM: propagation

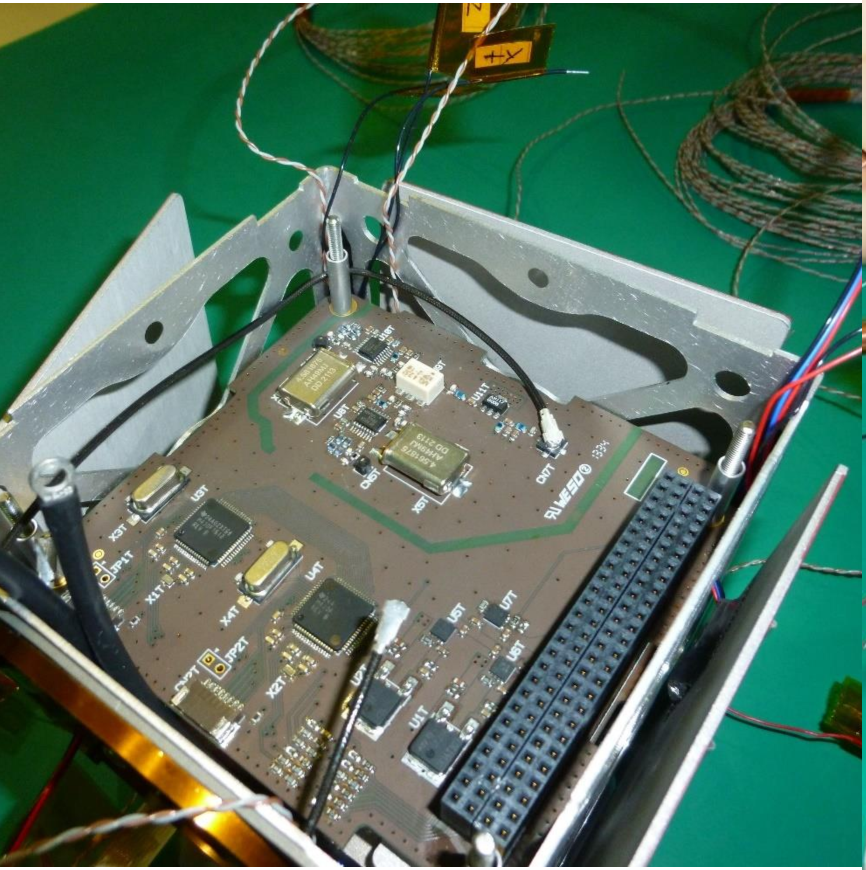
OUFTI-1 Uplink Command Budget:	NOTE:	
Parameter:	*Value:*	*Units:*
Ground Station:		
Ground Station Transmitter Power Output:	100,0	watts
In dBW:	20,0	dBW
In dBm:	50,0	dBm
Ground Stn. Total Transmission Line Losses:	2,9	dB
Antenna Gain:	12,8	dBi
Ground Station EIRP:	29,9	dBW
Uplink Path:		
Ground Station Antenna Pointing Loss:	0,3	dB
Gnd-to-S/C Antenna Polarization Losses:	3,0	dB
Path Loss:	153,4	dB
Atmospheric Losses:	1,1	dB
Ionospheric Losses:	0,7	dB
Rain Losses:	0,0	dB
Isotropic Signal Level at Spacecraft:	-128,6	dBW
Spacecraft (Eb/No Method):		
------- Eb/No Method -------		
Spacecraft Antenna Pointing Loss:	1,5	dB
Spacecraft Antenna Gain:	2,2	dBi
Spacecraft Total Transmission Line Losses:	1,1	dB
Spacecraft Effective Noise Temperature:	241	K
Spacecraft Figure of Merrit (G/T):	-22,8	dB/K
S/C Signal-to-Noise Power Density (S/No):	75,7	dBHz
System Desired Data Rate:	9600	bps
In dBHz:	39,8	dBHz
Command System Eb/No:	35,9	dB
Demodulation Method Seleted:	G3RUH FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1,0E-05	
Demodulator Implementation Loss:	1,0	dB
Telemetry System Required Eb/No:	18	dB
Eb/No Threshold:	19	dB
System Link Margin:	16,9	dB

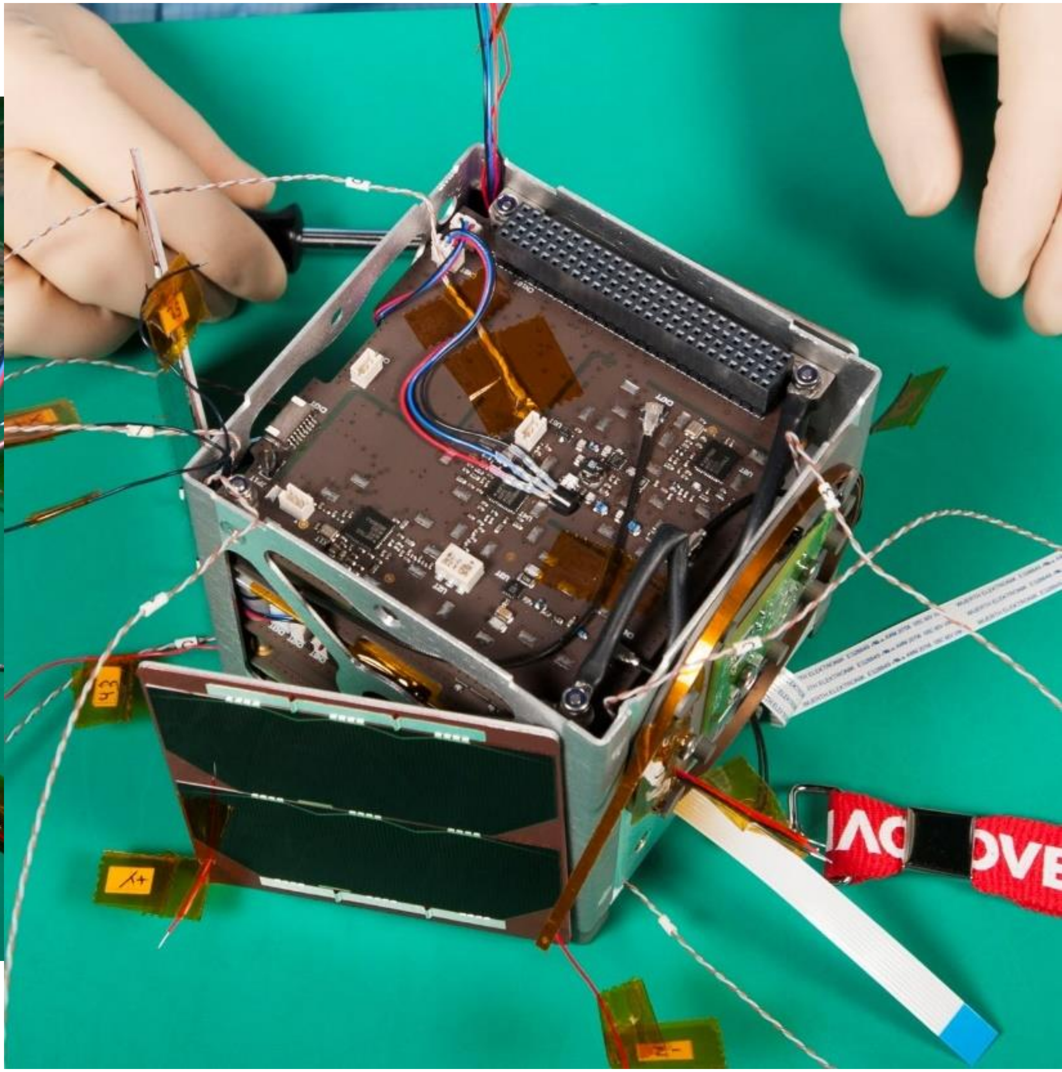
OUFTI-1 Downlink Telemetry Budget:	NOTE:	
Parameter:	*Value:*	*Units:*
Spacecraft:		
Spacecraft Transmitter Power Output:	0,7	watts
In dBW:	-1,9	dBW
In dBm:	28,1	dBm
Spacecraft Total Transmission Line Losses:	1,1	dB
Spacecraft Antenna Gain:	2,2	dBi
Spacecraft EIRP:	-0,8	dBW
Downlink Path:		
Spacecraft Antenna Pointing Loss:	1,5	dB
S/C-to-Ground Antenna Polarization Loss:	3,0	dB
Path Loss:	143,9	dB
Atmospheric Loss:	1,1	dB
Ionospheric Loss:	0,7	dB
Rain Loss:	0,0	dB
Isotropic Signal Level at Ground Station:	-151,1	dBW
Ground Station (EbNo Method):		
------- Eb/No Method -------		
Ground Station Antenna Pointing Loss:	0,5	dB
Ground Station Antenna Gain:	18,5	dBi
Ground Station Total Transmission Line Losses:	2,4	dB
Ground Station Effective Noise Temperature:	480	K
Ground Station Figure of Merrit (G/T):	-10,7	dB/K
G.S. Signal-to-Noise Power Density (S/No):	66,4	dBHz
System Desired Data Rate:	9600	bps
In dBHz:	39,8	dBHz
Telemetry System Eb/No for the Downlink:	26,5	dB
Demodulation Method Seleted:	G3RUH FSK	
Forward Error Correction Coding Used:	None	
System Allowed or Specified Bit-Error-Rate:	1,0E-05	
Demodulator Implementation Loss:	1	dB
Telemetry System Required Eb/No:	18	dB
Eb/No Threshold:	19	dB
System Link Margin:	7,5	dB

2.3 Platform – COMM: prototypes



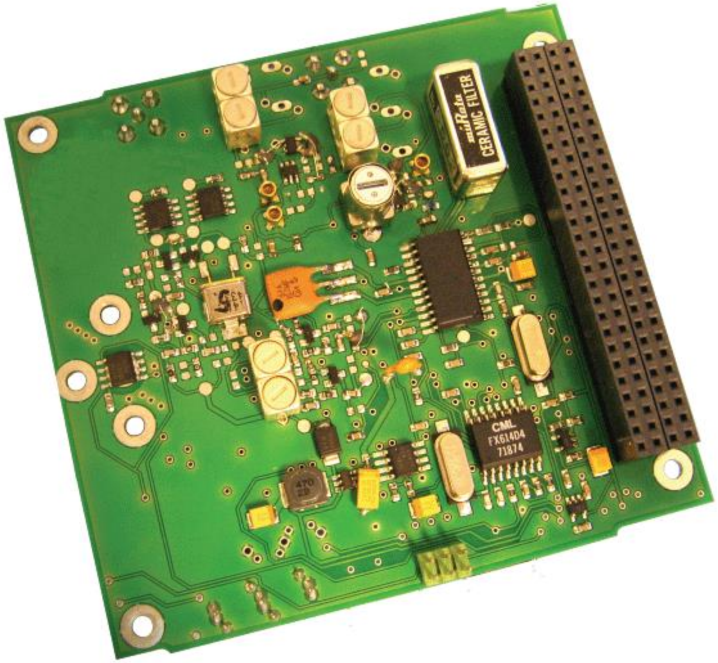
2.3 Platform – COMM: flight model

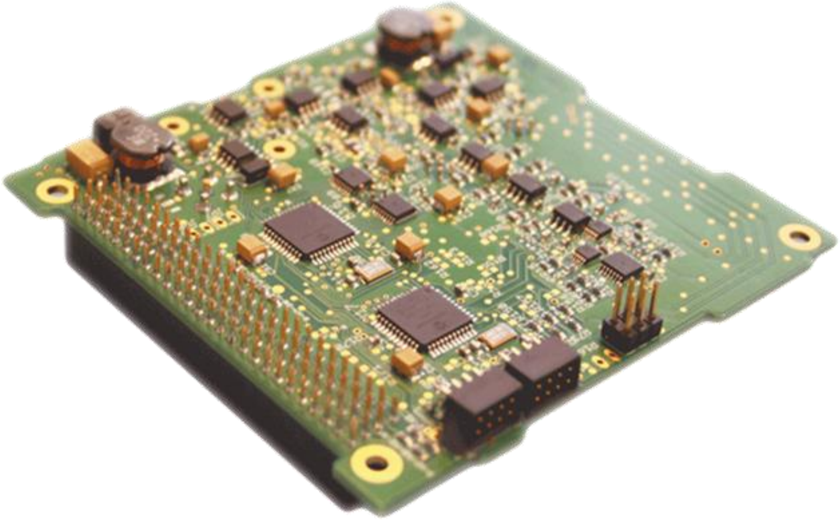




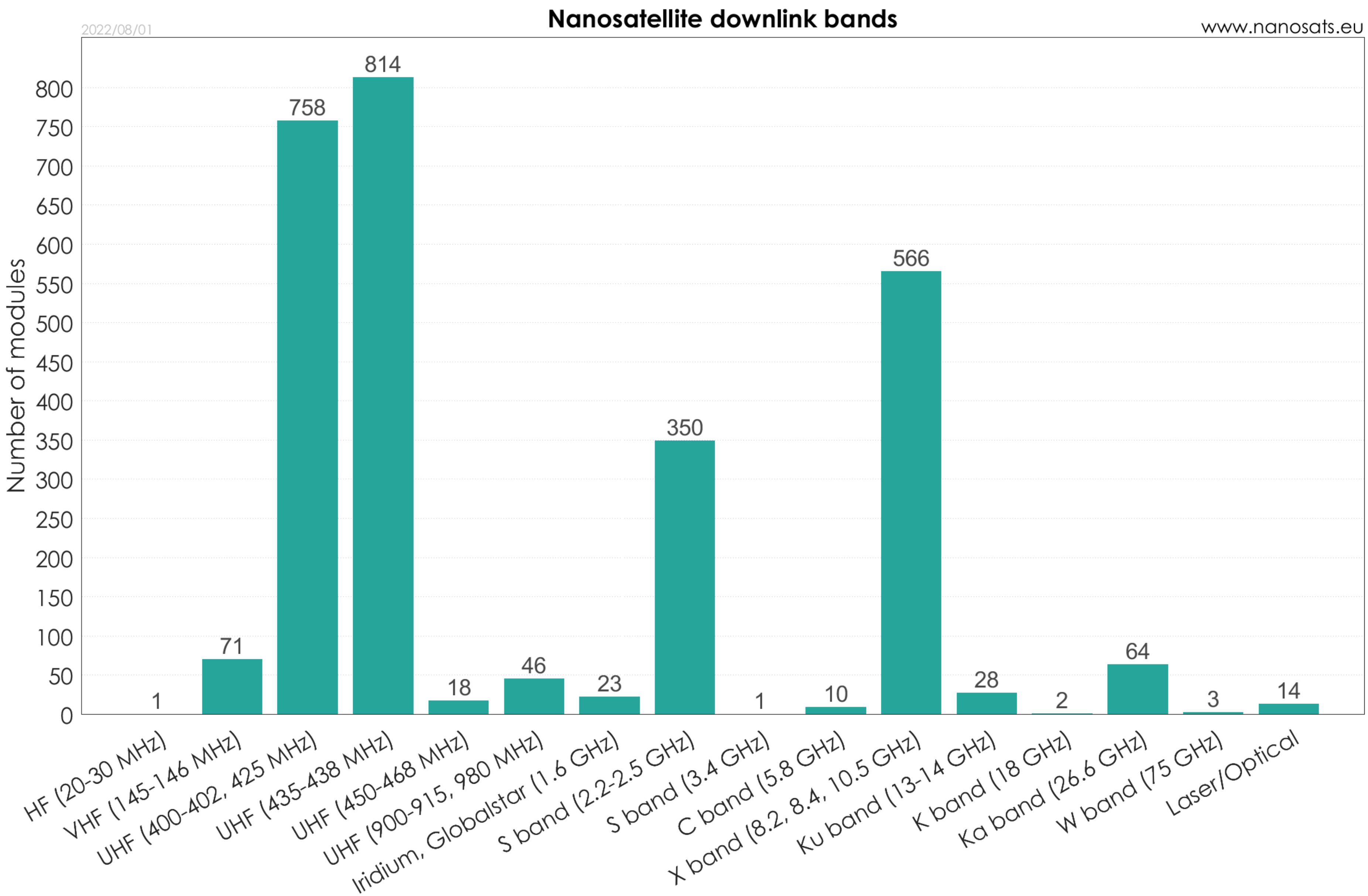
COMM: State of the art

- Mainly VHF & UHF
- S-band
- X-band (COTS available)
- Limitations: licensing, power, ground segment
- Inter-satellites link





COMM: State of the art

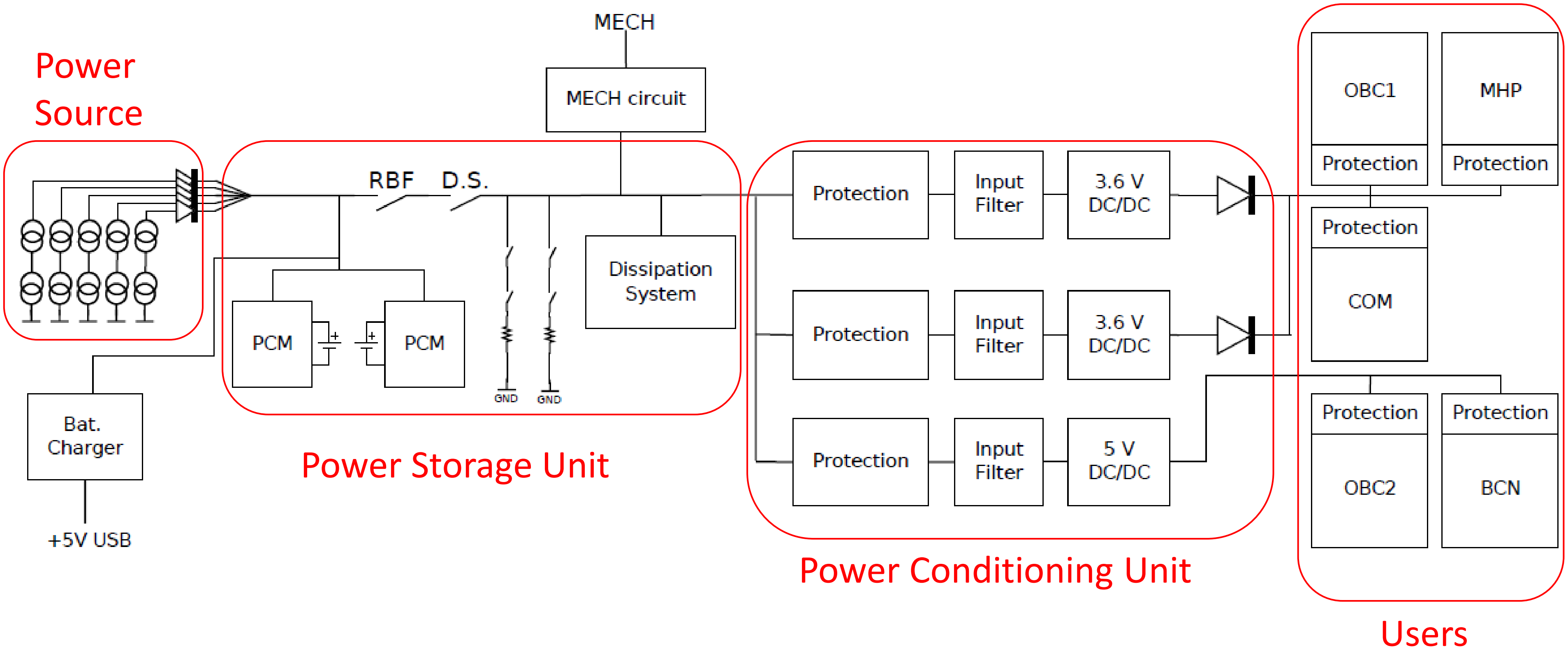


2.3 Platform – EPS: requirements

- Defined by other subsystems
  - Power needed by client
  - Voltage required by hardware
- Influenced by orbit
  - Eclipse duration
- Influenced by the mission
  - Payload operation

→ Power budget

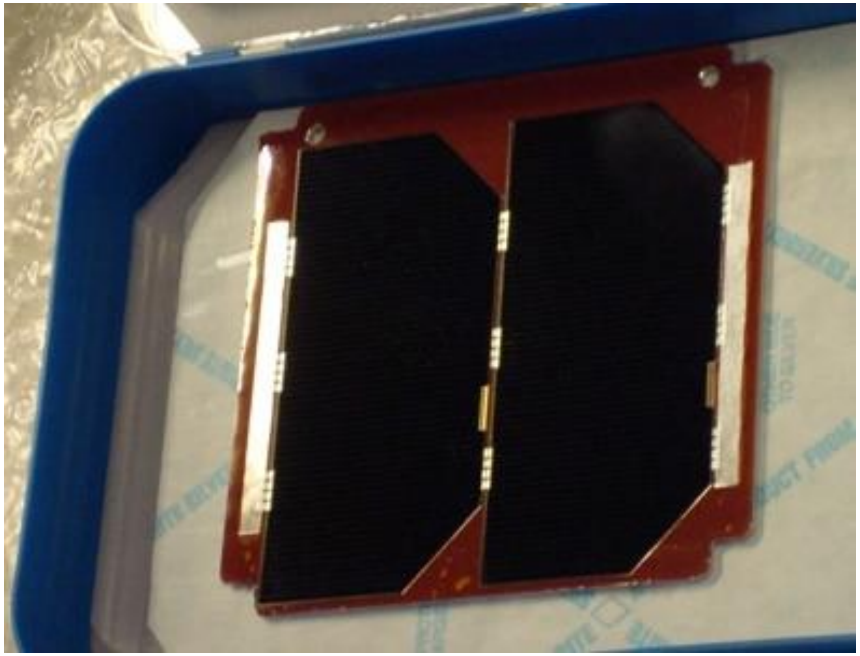
2.3 Platform – EPS: block diagram



2.3 Platform – EPS: solar cells

GaInP/GaAs/Ge on Ge substrate

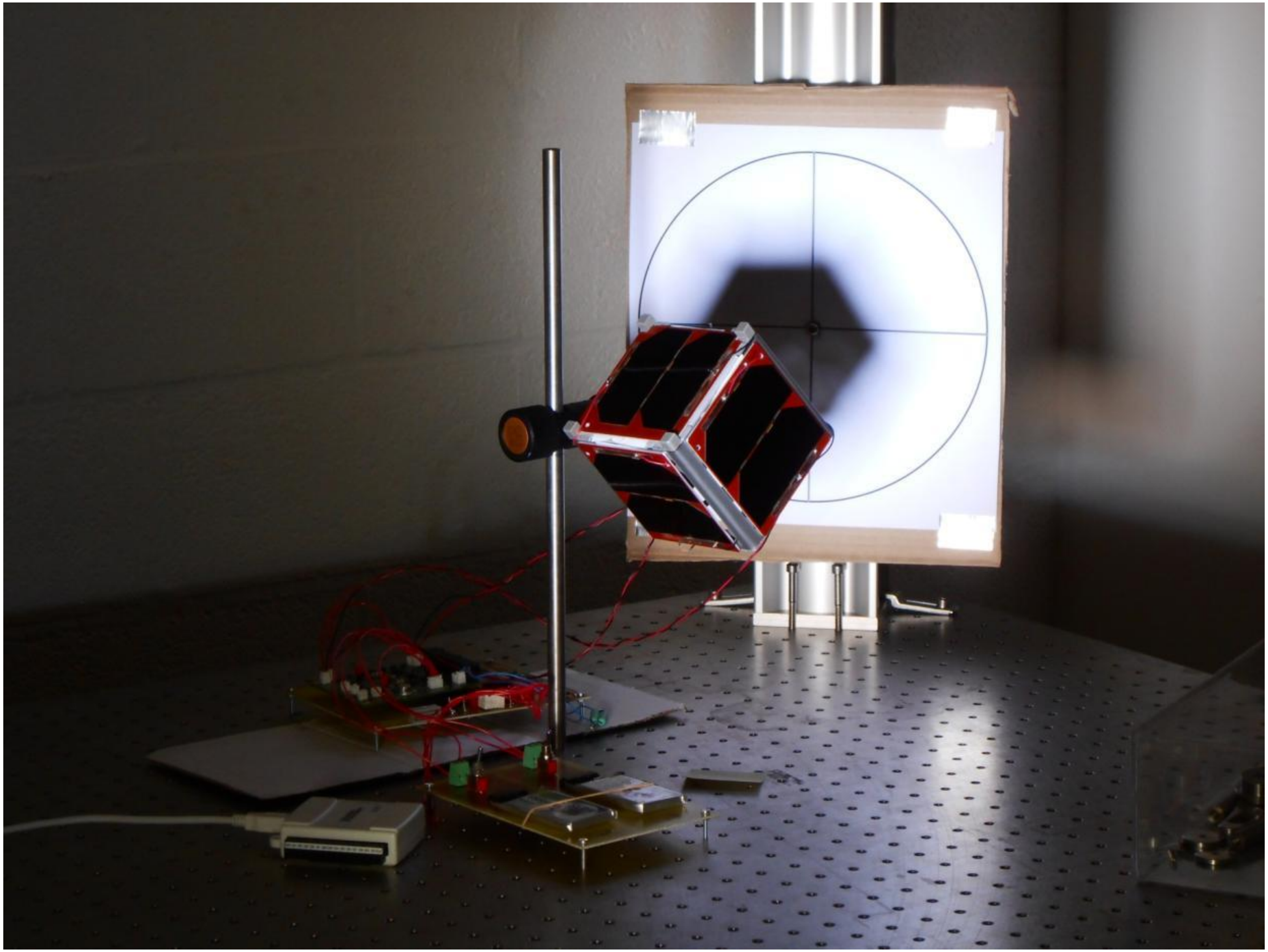
Triple junction solar cells



Open Circuit Voltage $V_{OC}[mV]$	2,716
Short Circuit Current $J_{SC}[mA/cm^2]$	17.5
Voltage at max. Power $V_{pmax}[mV]$	2,427
Current at max. Power $J_{pmax}[mA/cm^2]$	17.0
Maximum Power $P_{pmax}[mW/cm^2]$	41
Average Efficiency $\eta_{bare}[\%]$	30.1

At 28ºC

2.3 Platform – EPS: solar arrays

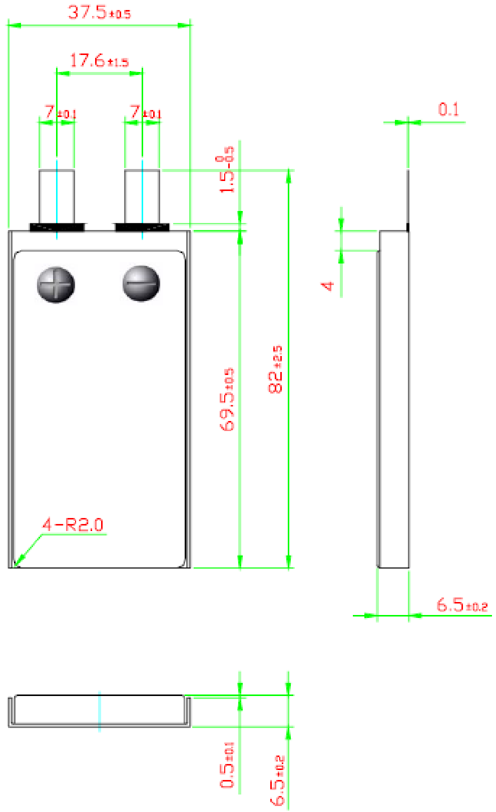


2.3 Platform – EPS: 2 Kokam batteries

Kokam™ Global Leader in Power Solution

Cell Specification

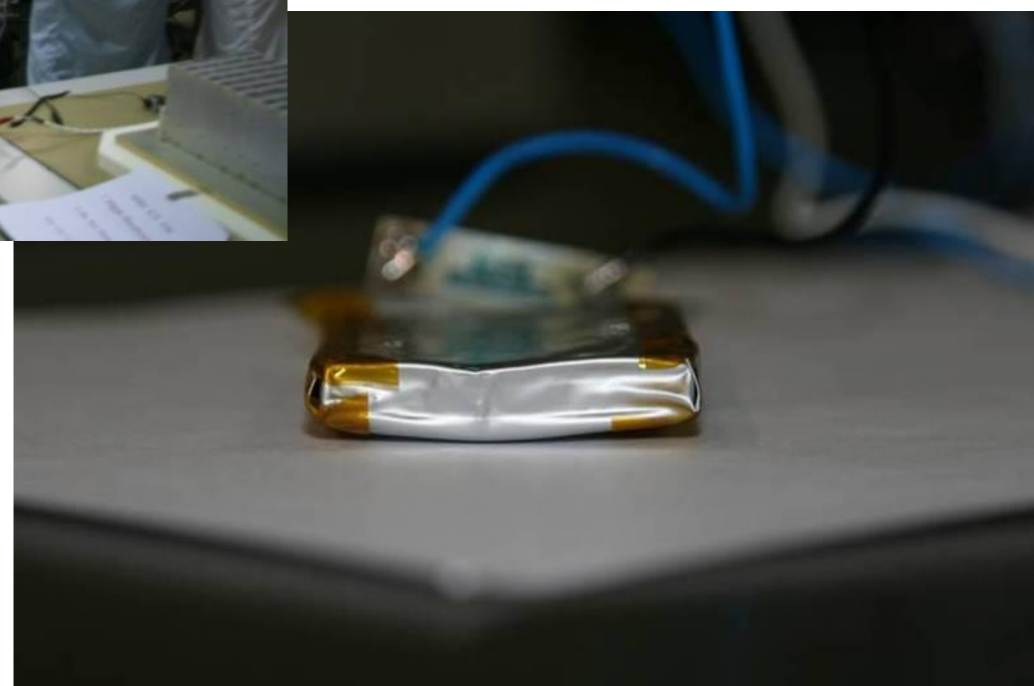
Kokam SLB 603870H



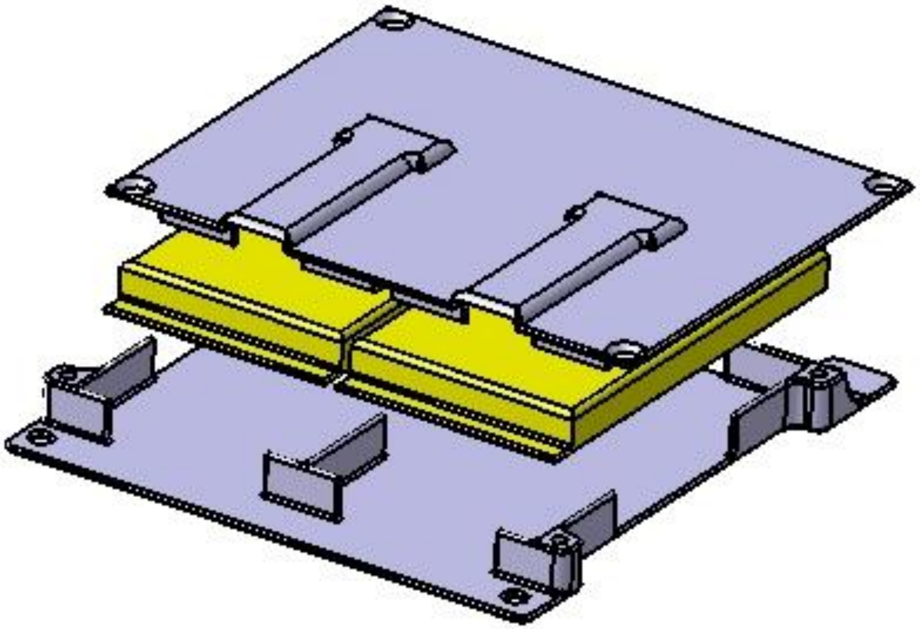
Typical Capacity[1]		1.5 Ah
Nominal Voltage		3.7 V
Charge Condition	Max. Current	3.0 A
	Voltage	4.2V ± 0.03V
Discharge Condition	Continuous Current	12.0 A
	Peak Current	24.0 A
	Cut-off Voltage	2.7 V
Cycle Life		> 500 Cycles
Operating Temp.	Charge	0 ~ 40℃
	Discharge	-20 ~ 60 ℃
Dimension	Thickness (mm)	6.5 ± 0.2
	Width (mm)	37.5 ± 0.5
	Length (mm)	69.5 ± 0.5
Weight (g)		32.0 ± 1.0

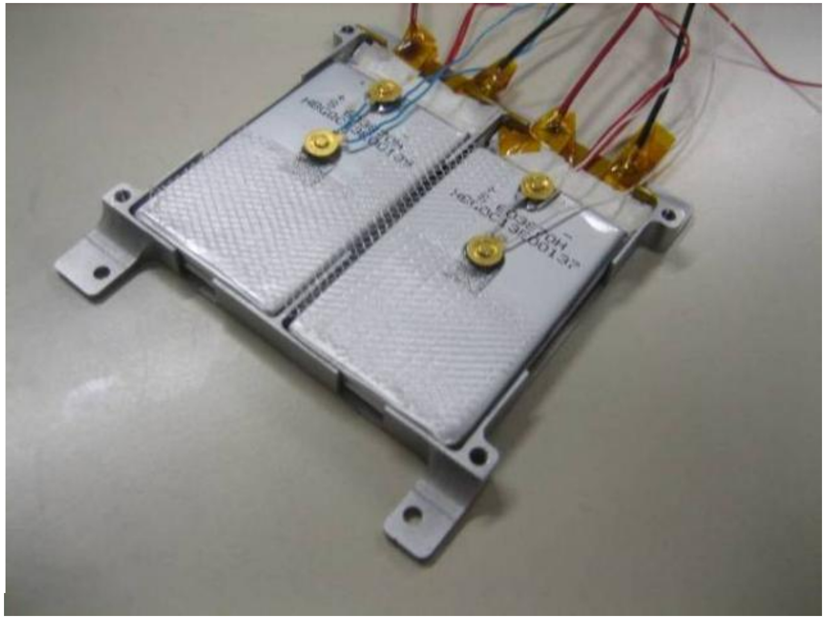
1) Typical Capacity : 0.5C, 4.2 ~ 2.7V @25°C,

2.3 Platform – EPS: batteries test



2.3 Platform – EPS: batteries support





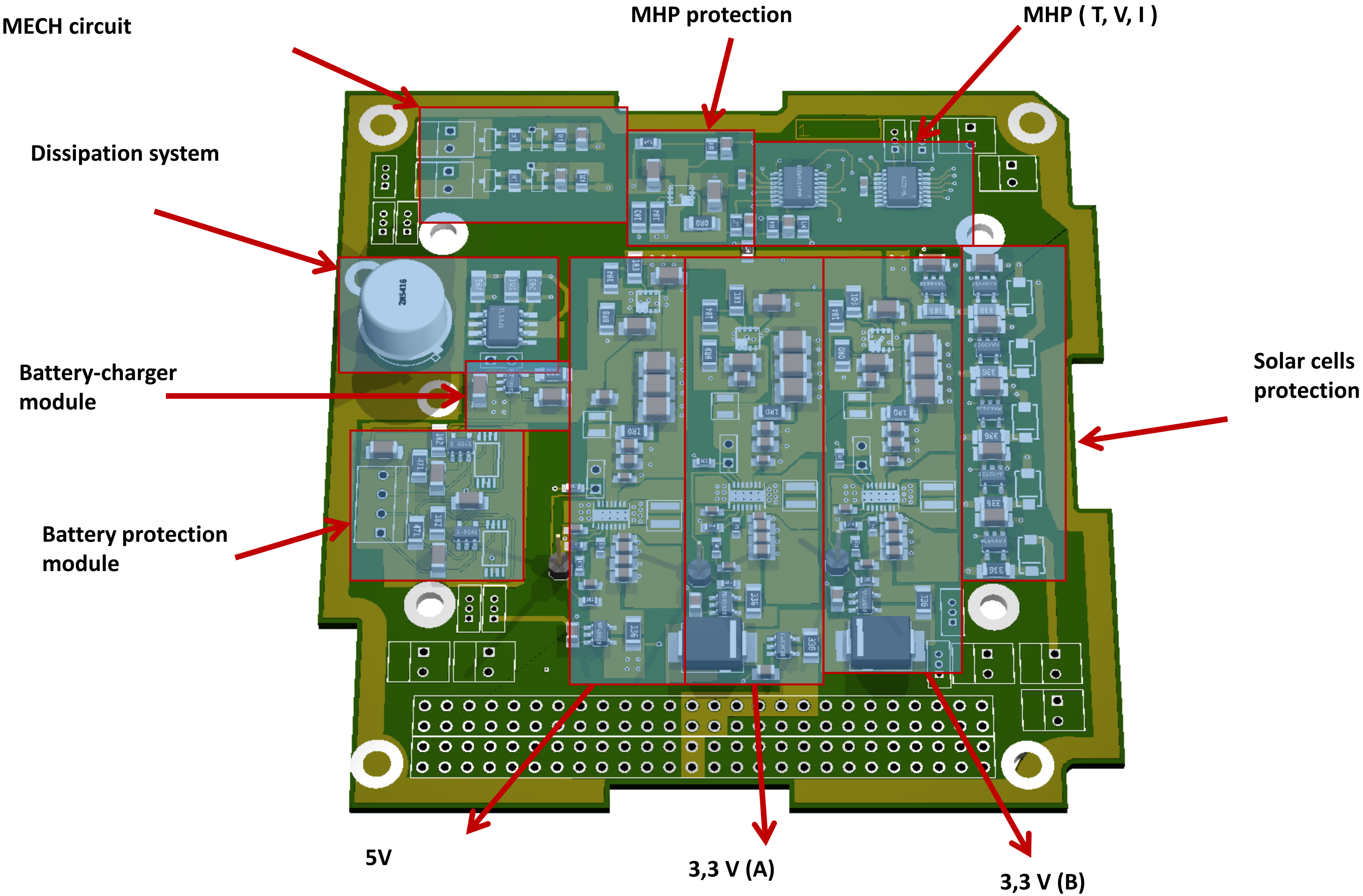
2.3 Platform – EPS: conditioning

- Direct energy transfer

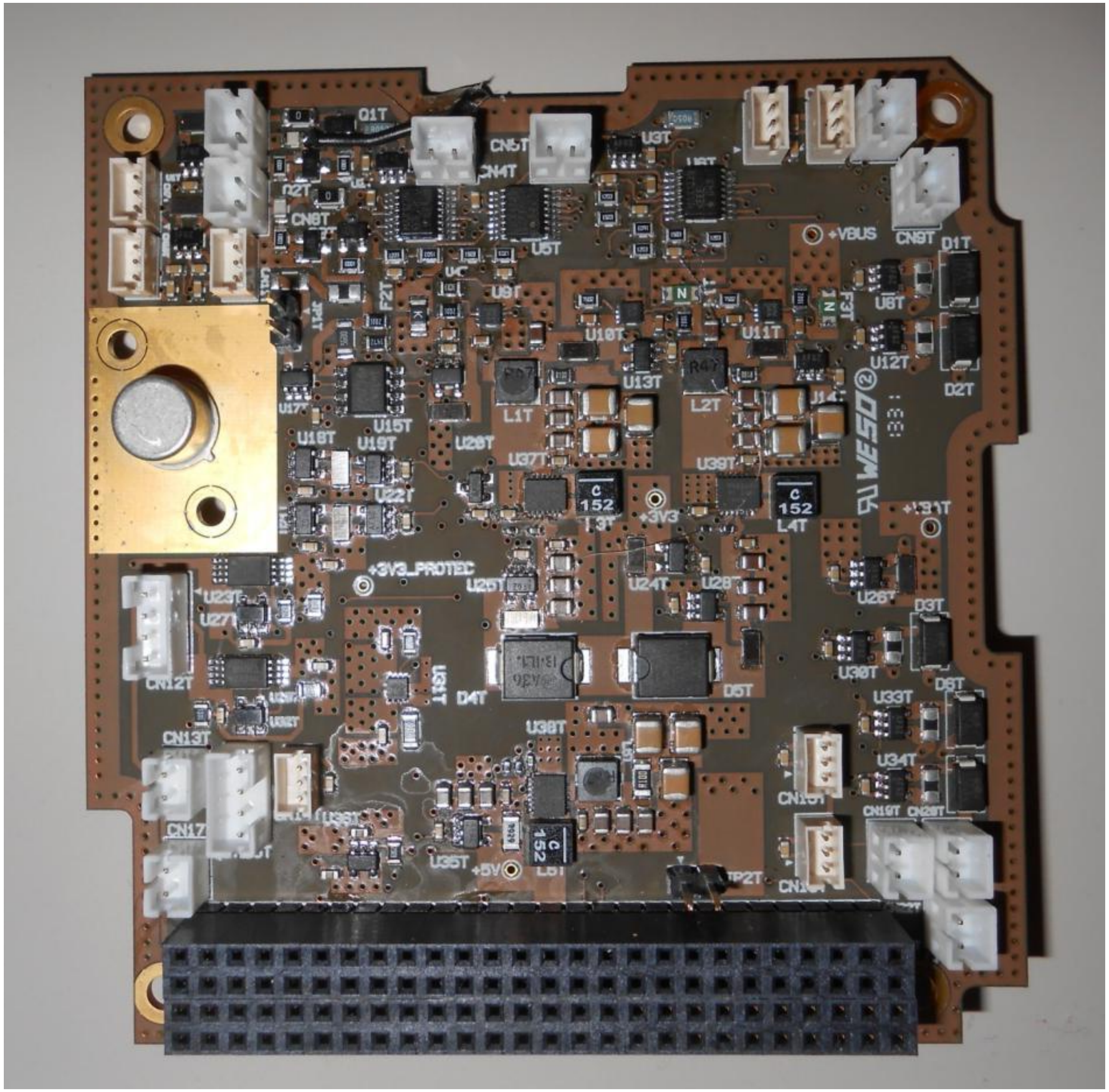
- Choice of unregulated bus with three DC/DC converters:
  - 5 V
  - redundant 3,3 V

➔ Design validated by Thales Alenia Space ETCA

2.3 Platform – EPS: engineering model

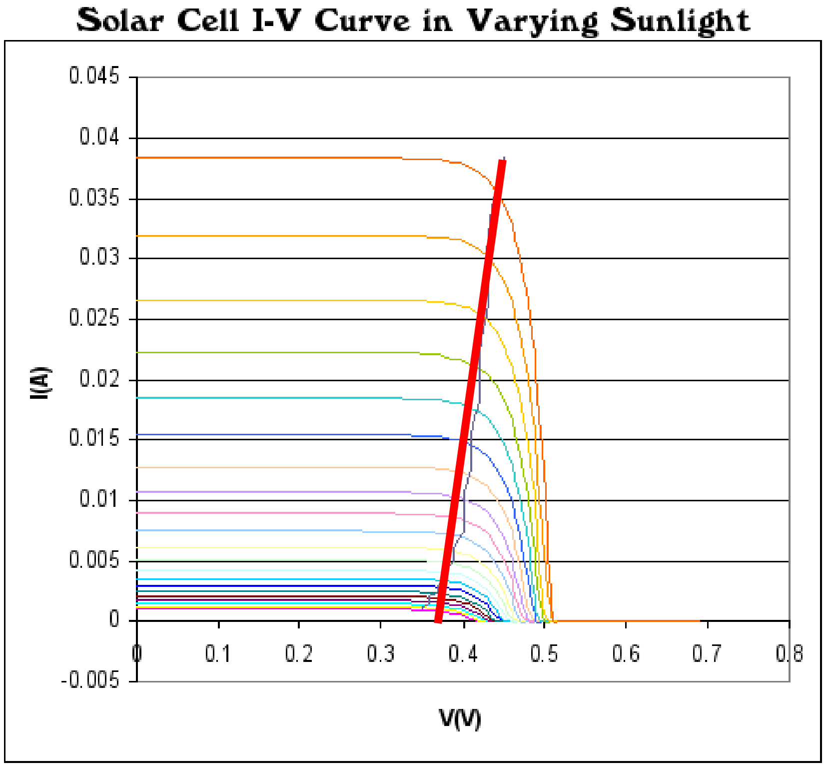


2.3 Platform – EPS: flight model



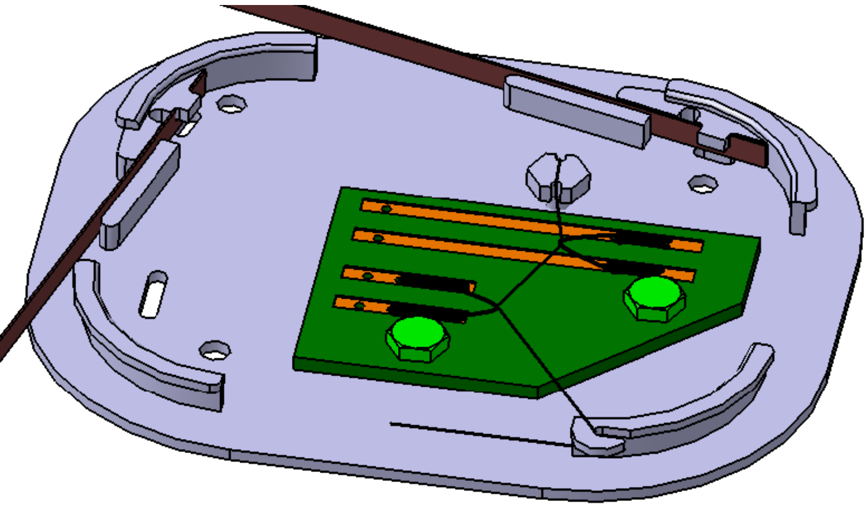
EPS: State of the art

- High efficiency solar cells (28-30 % efficiency)
- Li-Ion batteries (200 Wh/kg)
- MPPT: Maximum Power Point Tracking



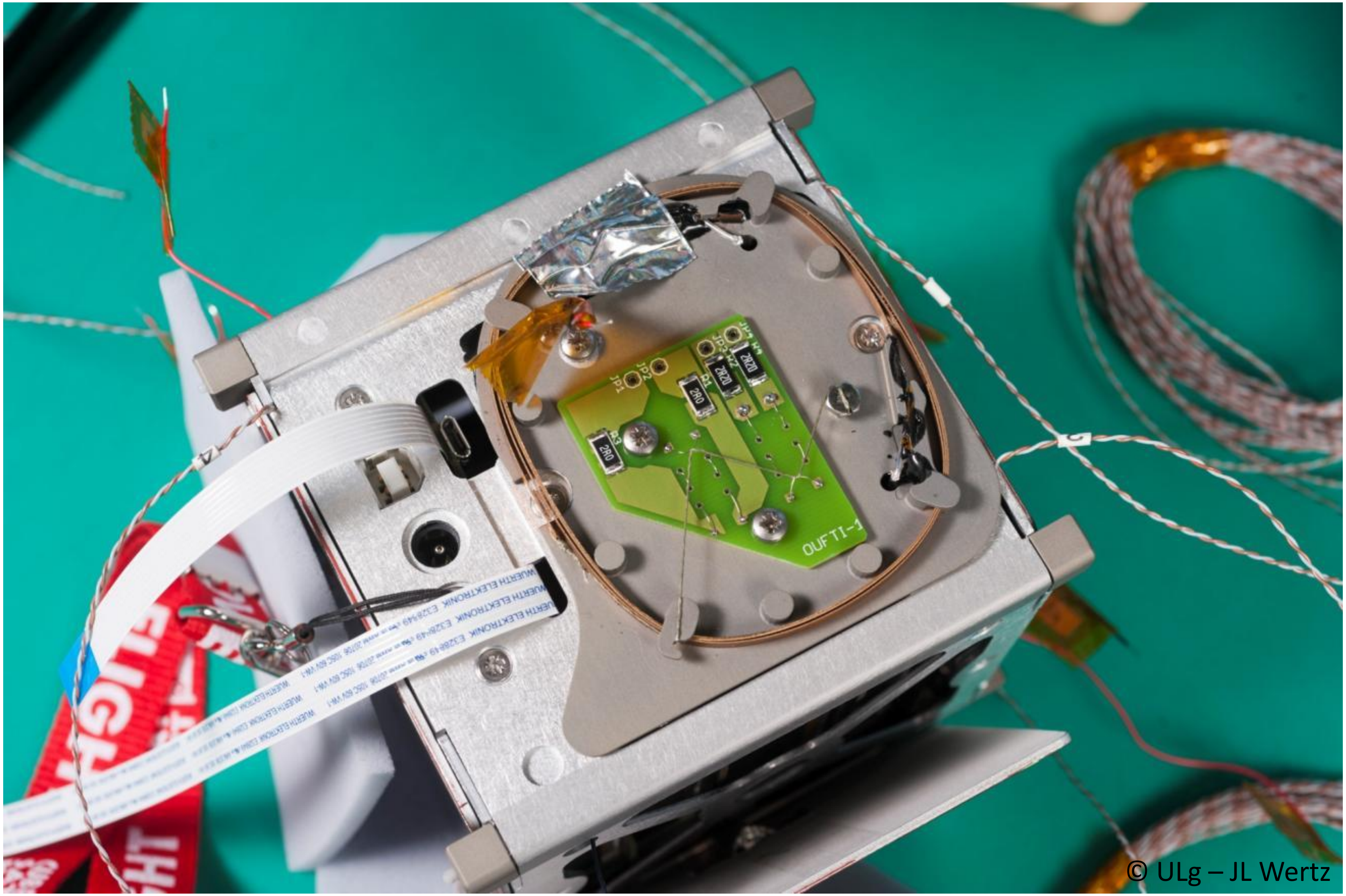
2.3 Platform – MECH: requirements

CubeSat Design Specification:
“ 2.4.2. All deployables such as booms, antennas, and solar panels shall wait to deploy a minimum of 30 minutes after the CubeSat’s deployment switch(es) are activated from P-POD ejection.”



- Antennas are wound around a guide before deployement
- Dyneema retention wire is used
- Retention wire is melted by a thermal knife

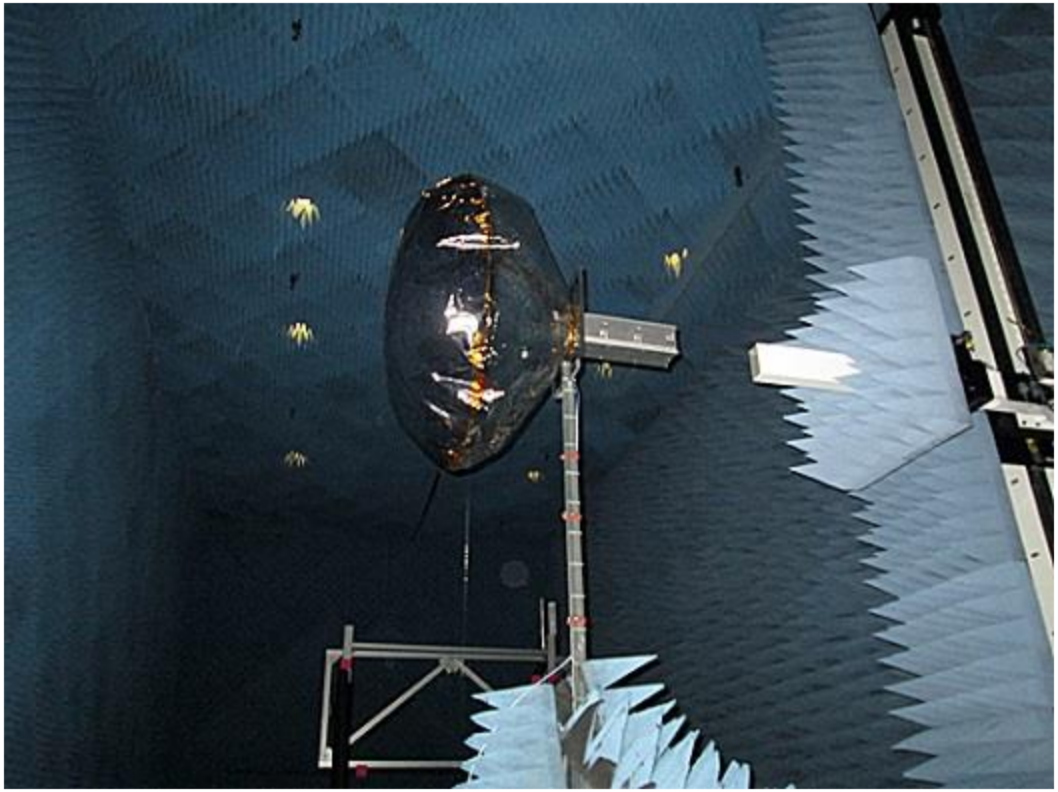
2.3 Platform – MECH: flight model



© ULg – JL Wertz

Antenna – State of the art

- Mostly burned wire and spring material
- Patch antennas for higher frequencies (S, X)
- Inflatable devices under development

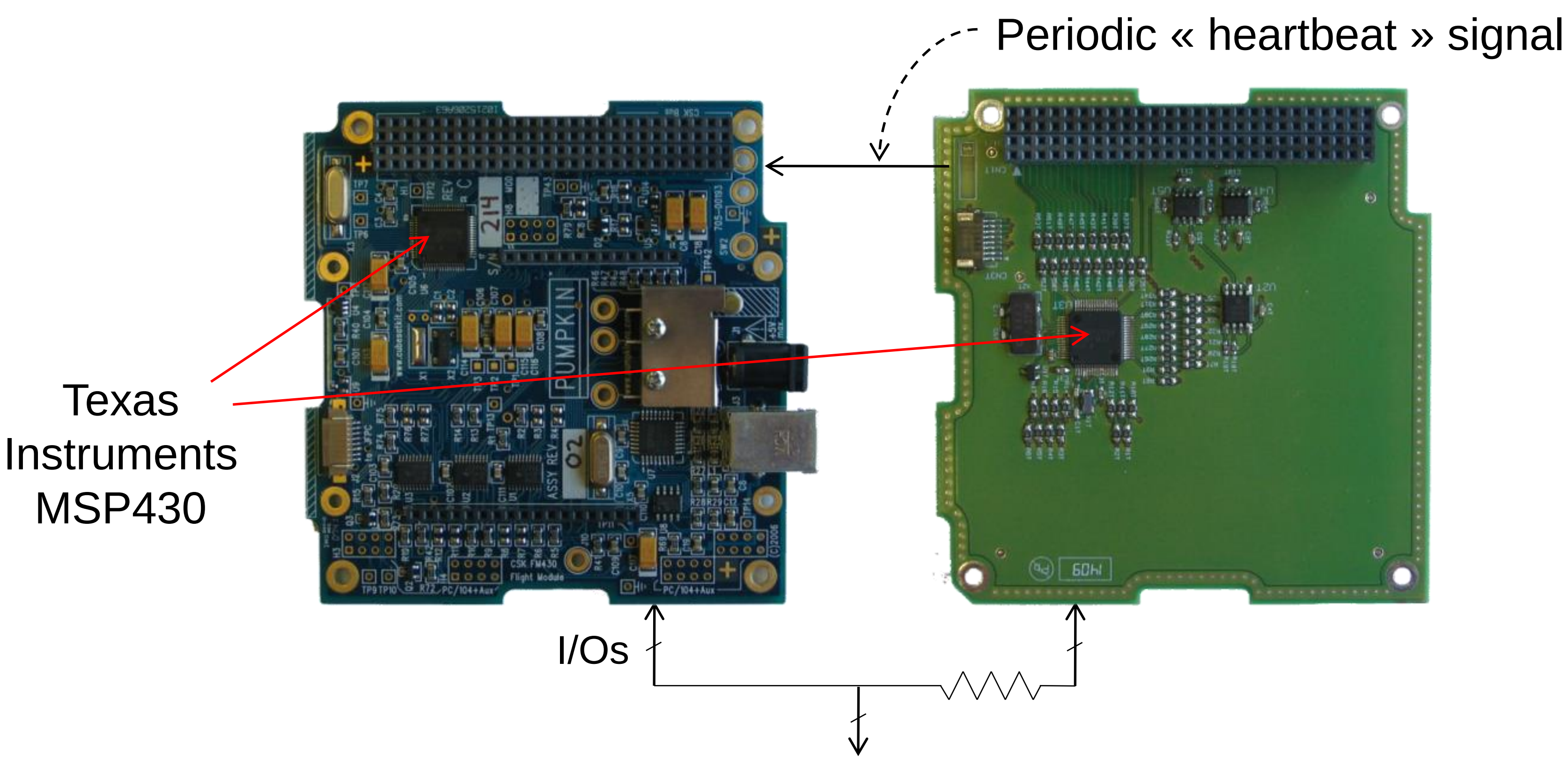


Credit: Alessandra Babuscia

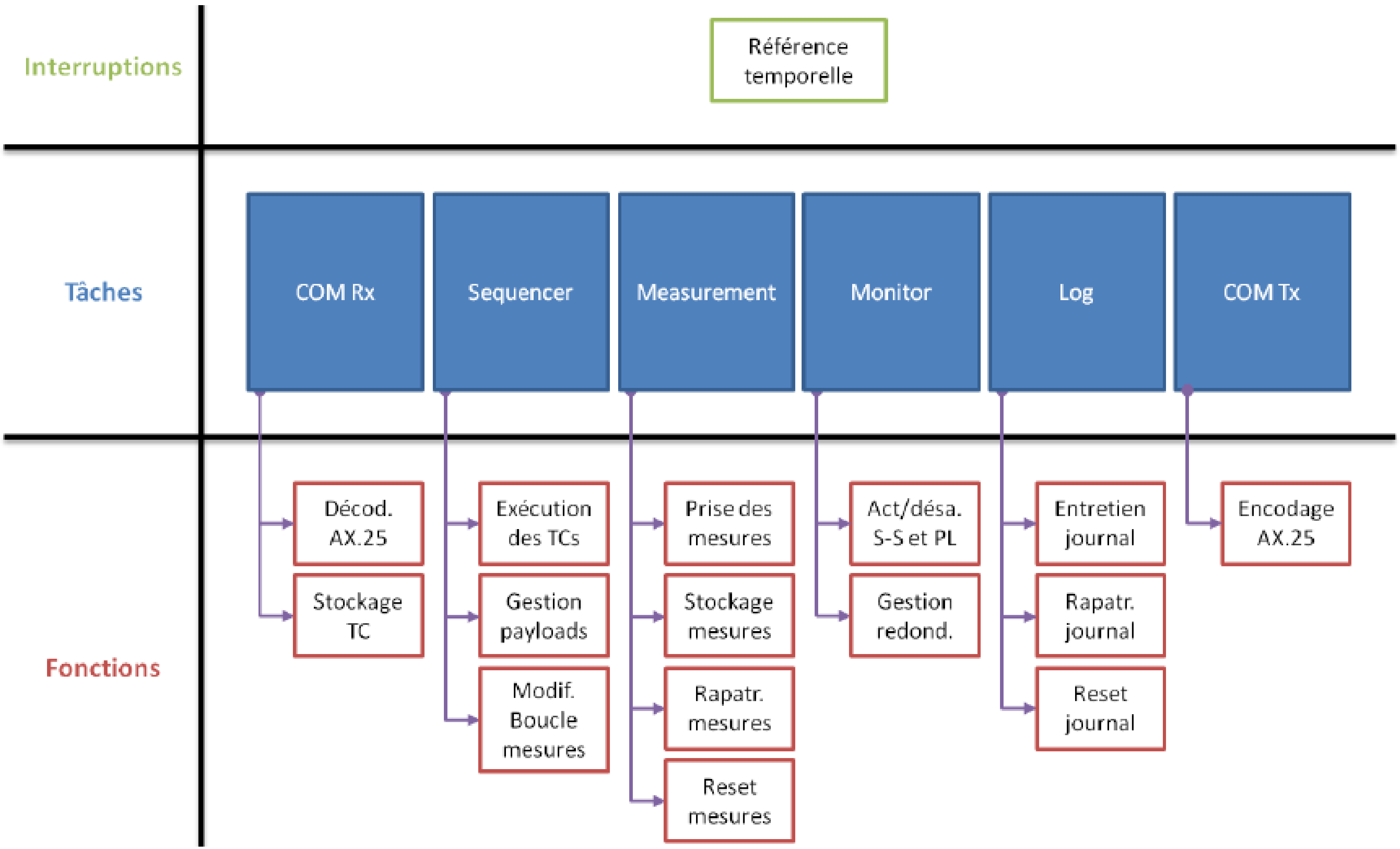
2.3 Platform – OBC: hardware

Reliability and simplicity

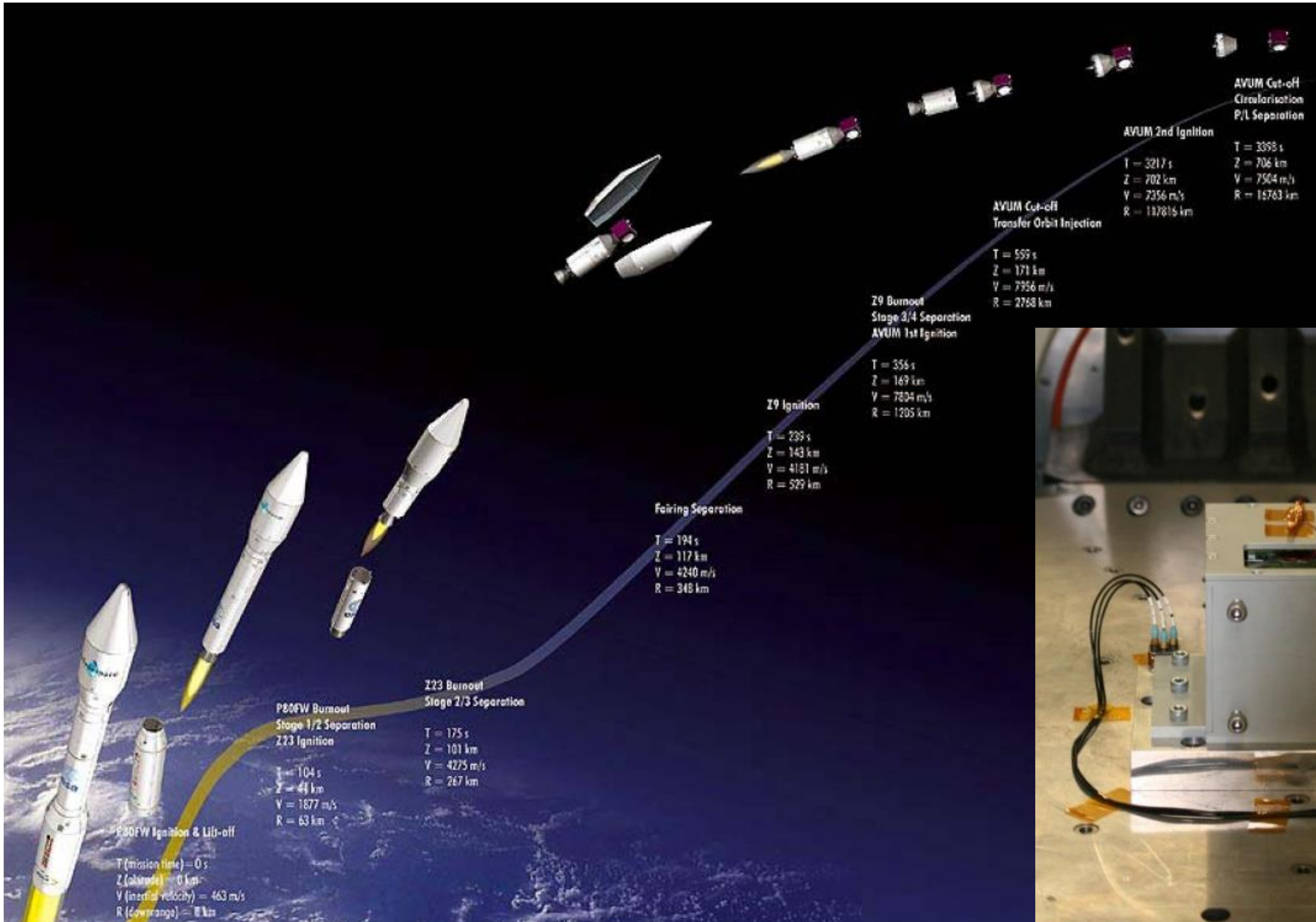
- One central processor, handles all tasks
- Doubled for redundancy: only one active at a time

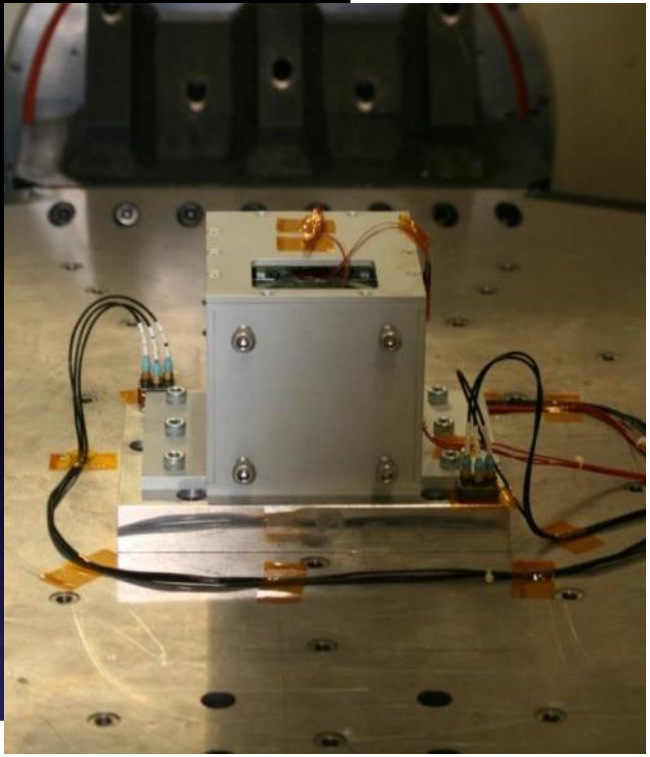


2.3 Platform – OBC: software



2.3 Platform – STRU: launch environment





2.3 Platform – STRU: requirements

4.3.2.1 Quasi-static loads (TBC)

→ accelerations, low frequencies

The following table shows the quasi-static load factors.

It shall be considered that:

- The minus signs indicate compression along the longitudinal axis and the plus signs tension.
- Lateral loads may act in any direction simultaneously with longitudinal loads.
- The gravity load is included.

	Longitudinal (g)	Lateral (g)
	Total	Total
Lift-off	-3.5/+0.5	+/-1.2
Flight max dyn. press.	-3.0/-2.0	+/-1.2
First stage max accel.	-5.0/-4.0	+/-0.5
Third stage max accel.	-6.3/-5.9	+/-0.2
Stage ignition	-5.0/+3.0	+/-0.2

Tab. 4-1 – Quasi-static loads; (+ tension; - compression)

2.3 Platform – STRU: requirements

→ Engines, wind ; high frequencies

4.3.2.2 Random Vibration (TBC)

The P-POD/Cubesats shall comply with the following random vibration level of acceptance and qualification.

	3-axes PSD	
Freq. [Hz]	**Acceptance Levels (g^2/Hz)**	**Qualification Levels (g^2/Hz)**
20	0.029	0.0727
60	0.029	0.0727
70	0.040	0.1
200	0.040	0.1
300	0.080	0.2
700	0.080	0.2
2000	0.008	0.02
Duration	2 min per axis	2.5 min per axis

Tab. 4-2: Random vibration levels

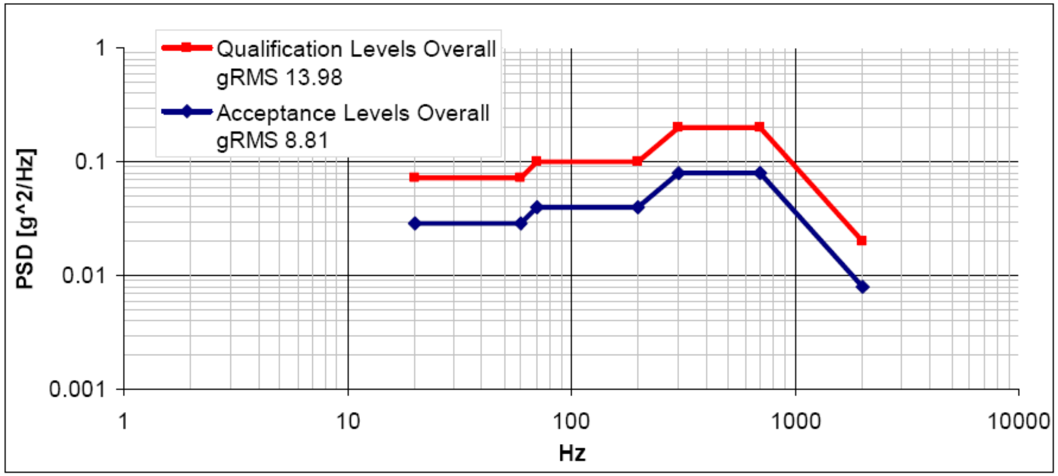


Figure 4-1: Random Vibration

2.3 Platform – STRU: requirements

4.3.2.3 Acoustic Spectra (TBC)

→ Engines, turbulences

The P-POD/Cubesats shall comply with the following spectrum of acoustic noise (the values do not take into account any fill factor correction).

Octave Band (Centre Frequency - Hz)	QM Test Qualification Level (dB)	FM Test Acceptance Level (dB)	Test tolerance
31.5	128	124	- 2 / +4
63	133	129	- 1 / +3
125	139	135	- 1 / +3
250	136	132	- 1 / +3
500	135	131	- 1 / +3
1000	124	120	- 1 / +3
2000	104	100	- 1 / +3
Overall level	142.5	138.5	-1 / +3
Test Duration	**120 s**	**60 s**	-

Figure 4-2: Acoustic Spectra

Acoustic noise spectra for acceptance and qualification

Notes:

- 0 dB reference corresponds to a sound pressure level of 2 x 10-5 Pascal
- 4 dB has been added to the Flight Levels, to arrive at the QM Qualification Levels.
- Microphones are installed at 1 m from the satellite

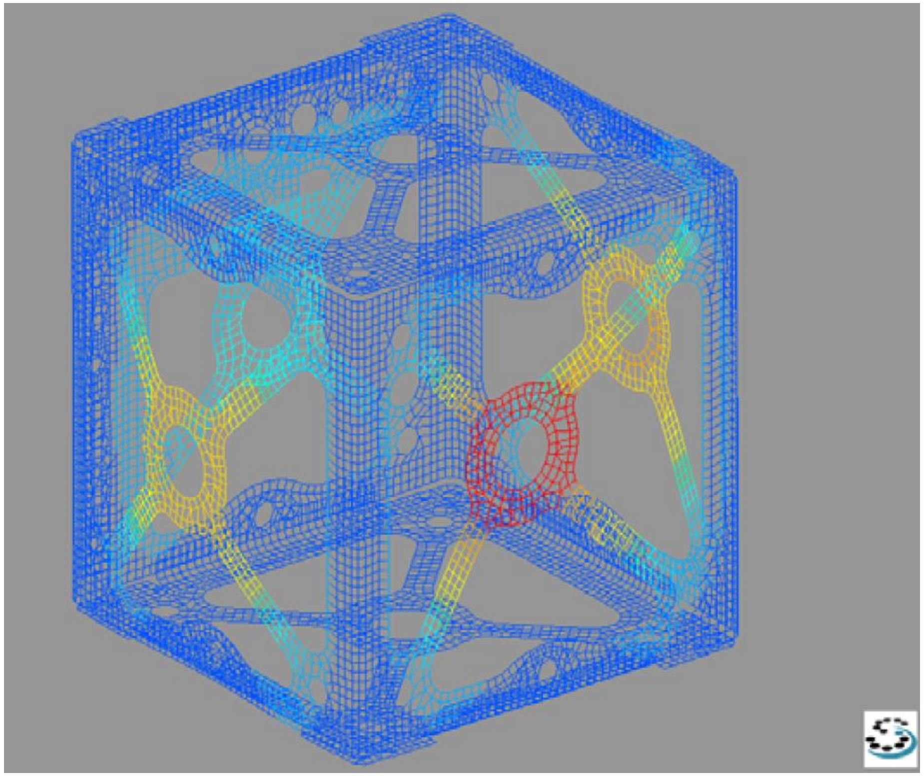
4.3.2.4 Shock Load (TBC)

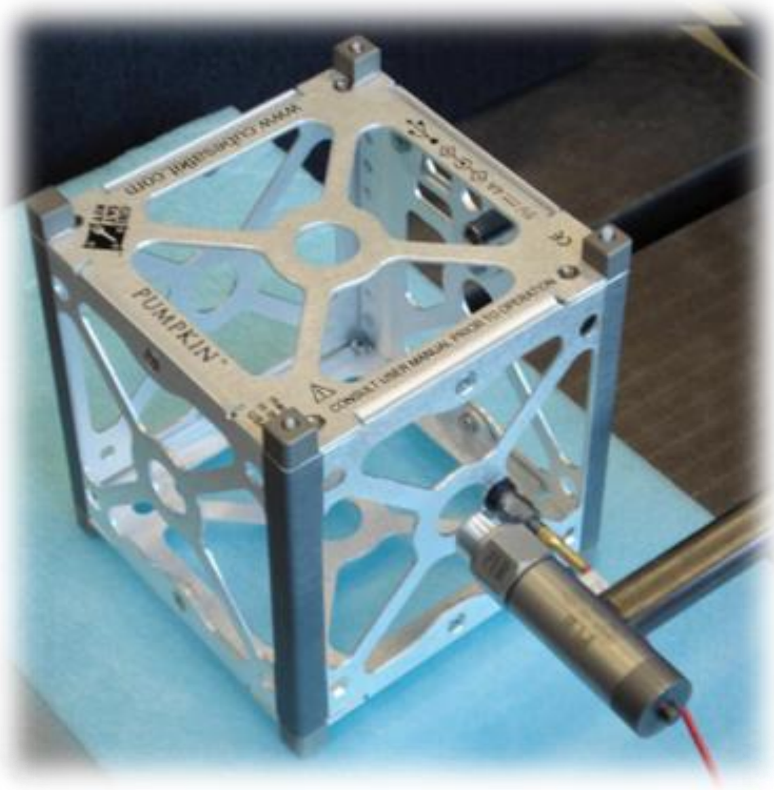
→ Fairing jettison, stages separation

The P-POD/Cubesats shall comply with the following shock qualification spectrum.

- The shock spectrum in each direction of the three orthogonal axes shall be equivalent to a half sinusoidal pulse of 0.5 ms duration and 200 g (0-peak) amplitude.

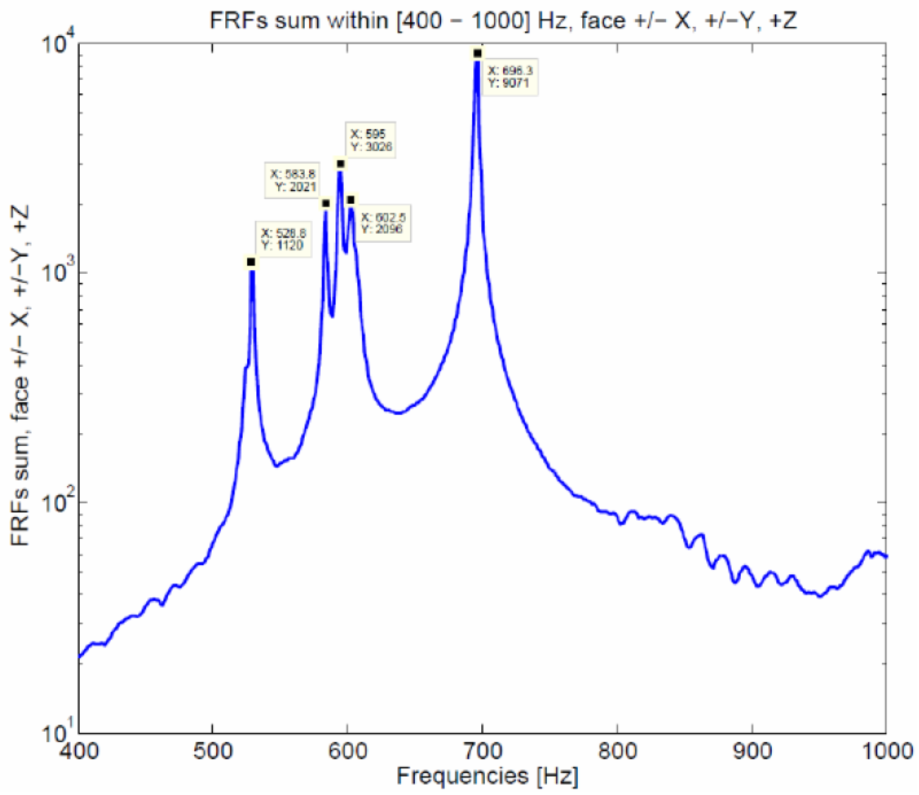
2.3 Platform – STRU: models vs reality



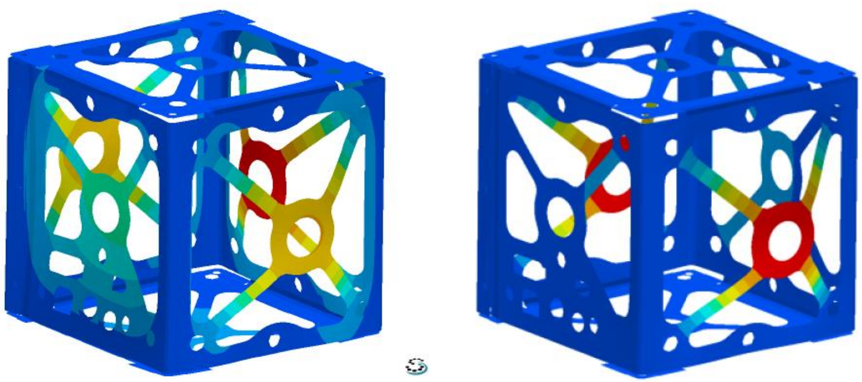


2.3 Platform – STRU: models vs reality

3. The Cubesats shall not have structural modes at frequencies lower than 120 Hz in hard-mounted configuration

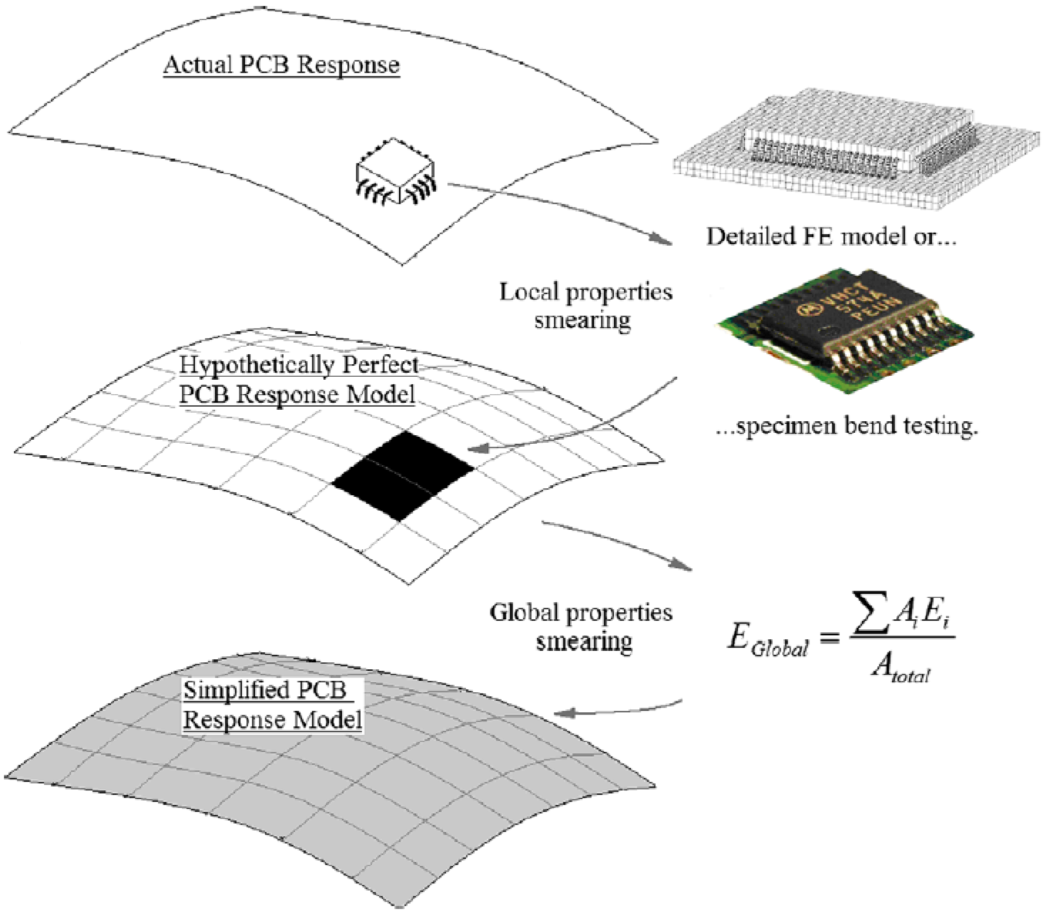


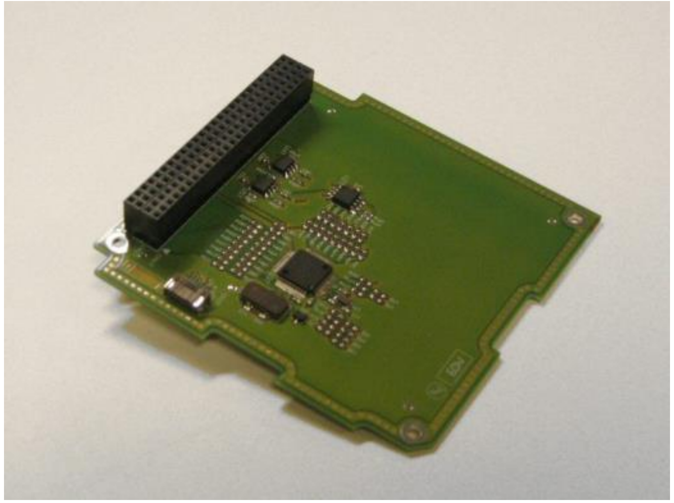
Mode	Experimental (Hz)	Samcef (Hz)	Error (%)
1	528,8	539,3	1,9
2	583,8	602,1	3,1
3	595	610,5	2,6
4	602,5	669	11
5	696,3	727,3	4,4
6	808,8	814,4	0,7

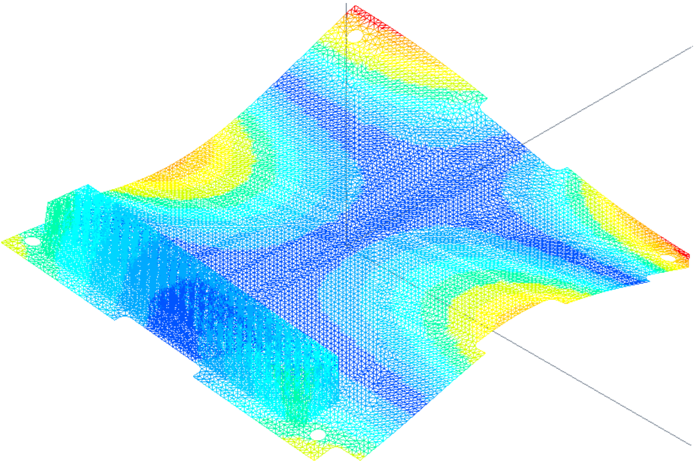


Modes 1 & 2

2.3 Platform – STRU: electronic cards

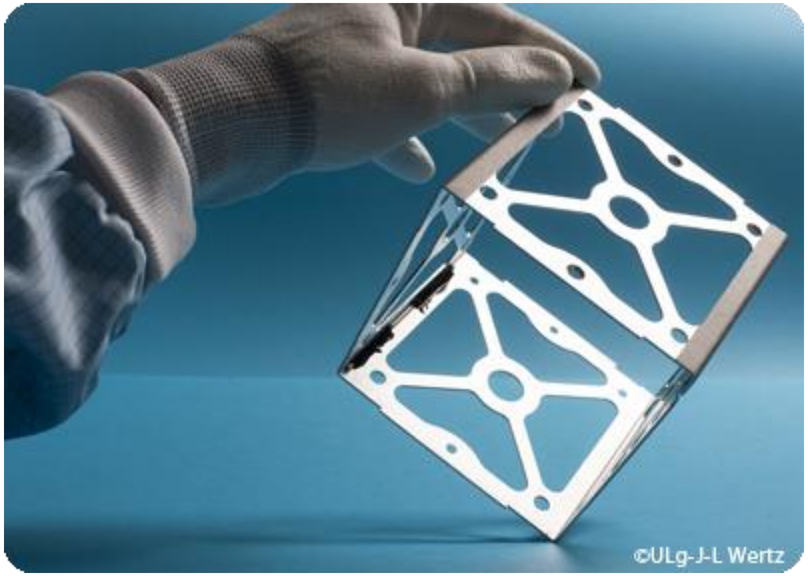


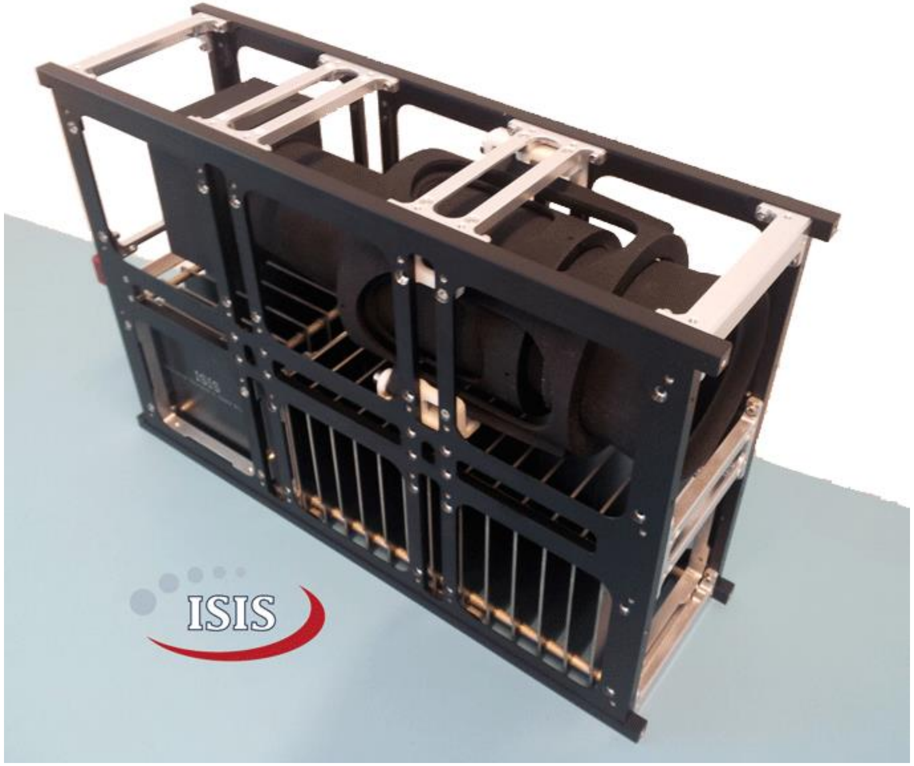




STRU – State of the art

- Aluminum
- COTS or homemade structures, very similar
- Composites, 3D printed
- 3U, 6U, 12U and more





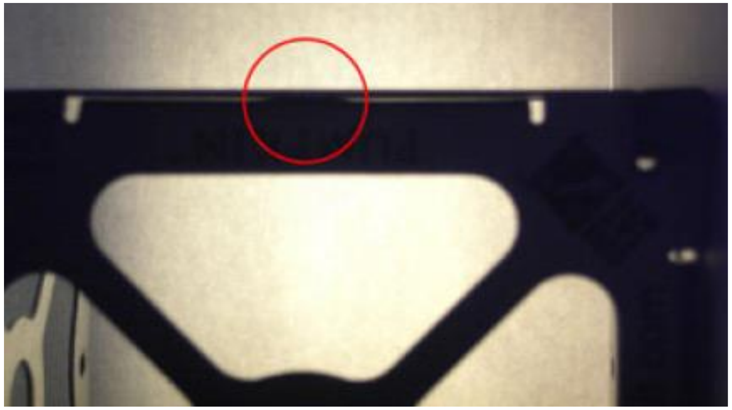
2.3 Platform – THER: requirements

Component	T_{min} [°C]	T_{max} [°C]	Note
Main structure	-40	+85	
Solar cells	-100	+100	
Electronics	-40	+85	
LiPo Batteries	0	45	charge
	-20	60	discharge

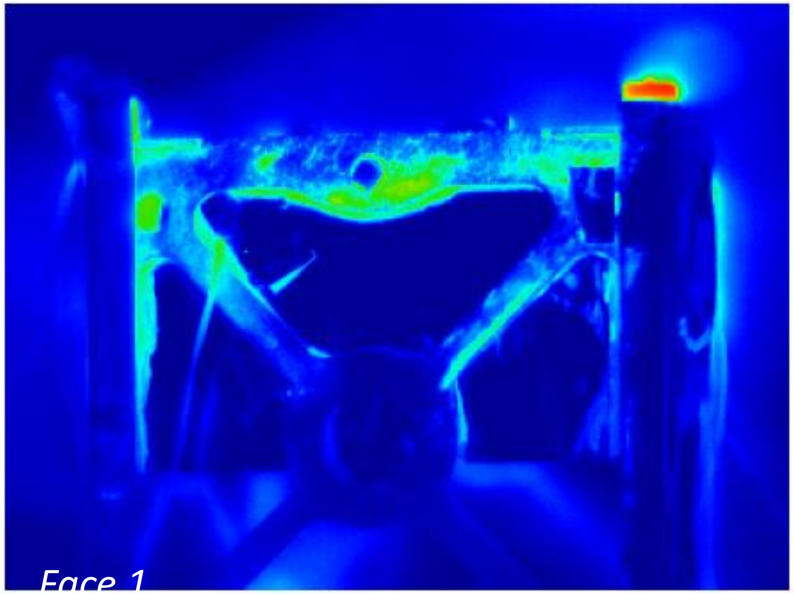
2.3 Platform – THER: hot and colds cases

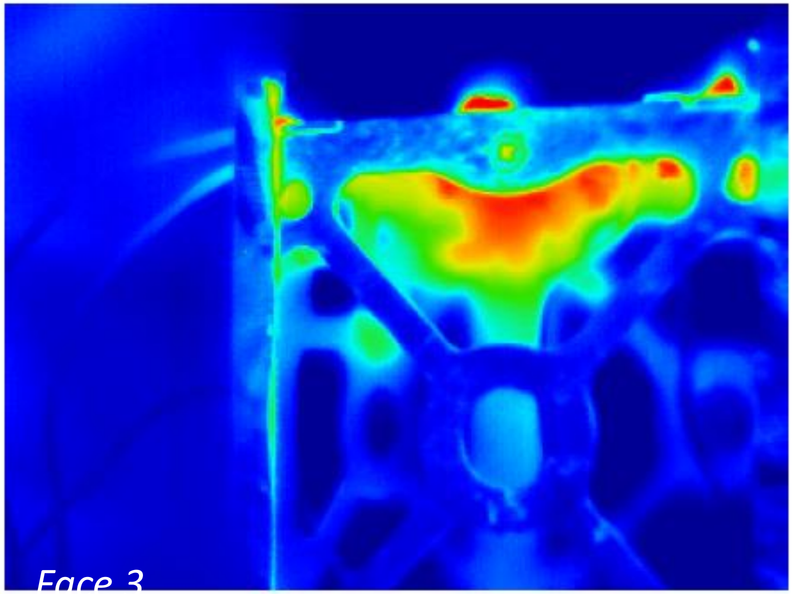
Parameter	Hot Case	Cold Case
Orbital parameters	permanently illuminated	max eclipse time
Solar constant	1414 $[W/m^2]$	1322 $[W/m^2]$
Albedo coefficient	0.35	0.25
Earth temperature	250K ($\Leftrightarrow$ 220$[W/m^2]$)	260K ($\Leftrightarrow$ 260$[W/m^2]$)
Internal dissipation	full	none

2.3 Platform – THER: measurements

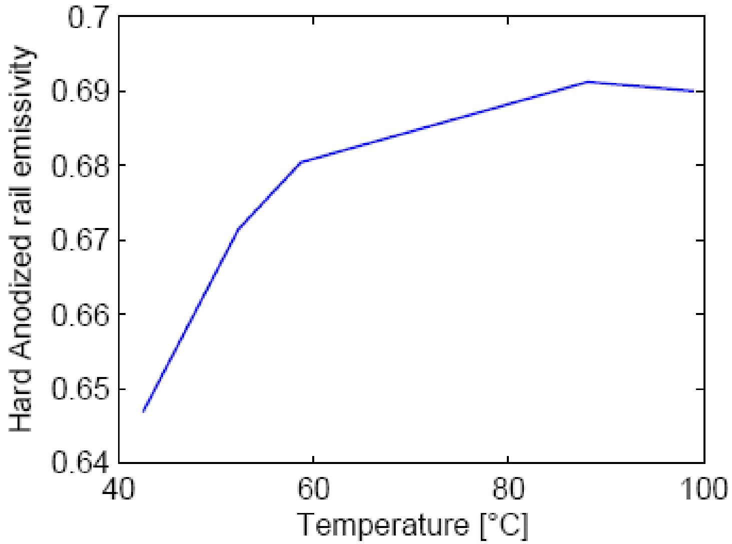


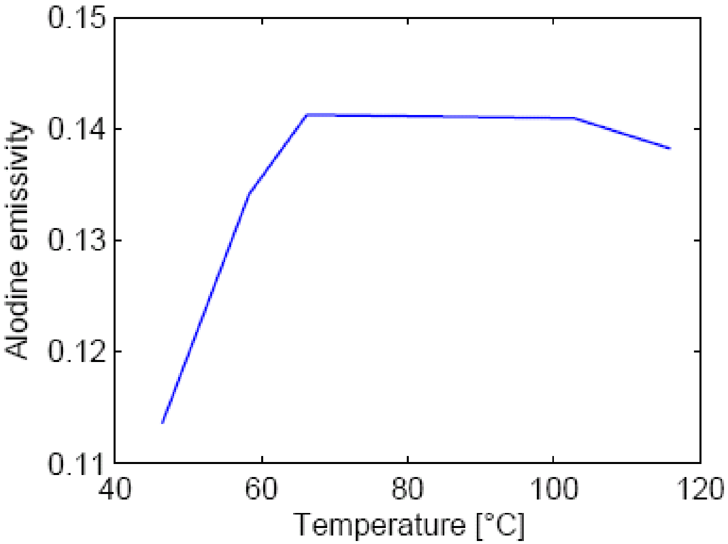
Determination of the frame contact resistance: face 6 is heated up



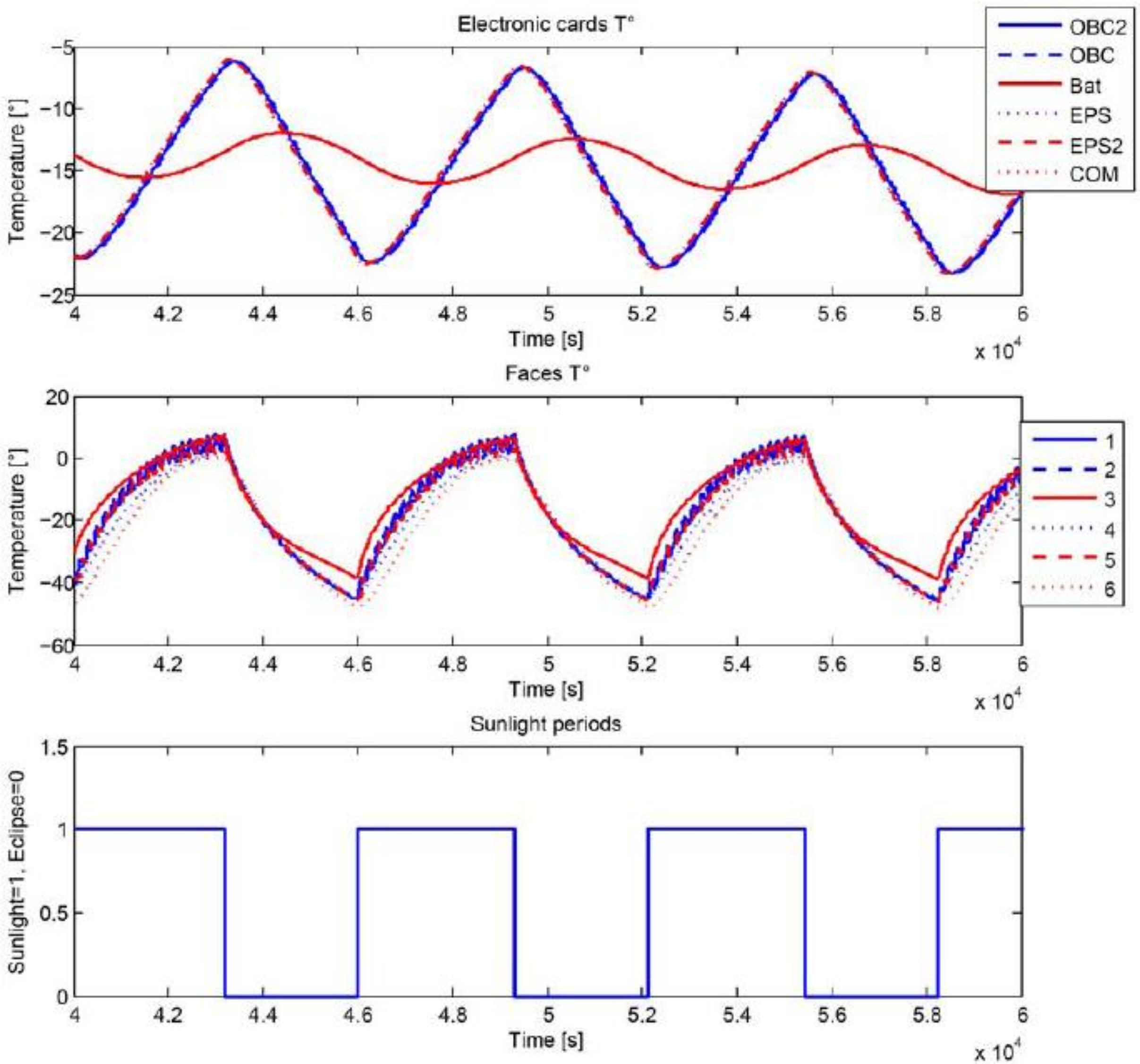


2.3 Platform – THER: measurements



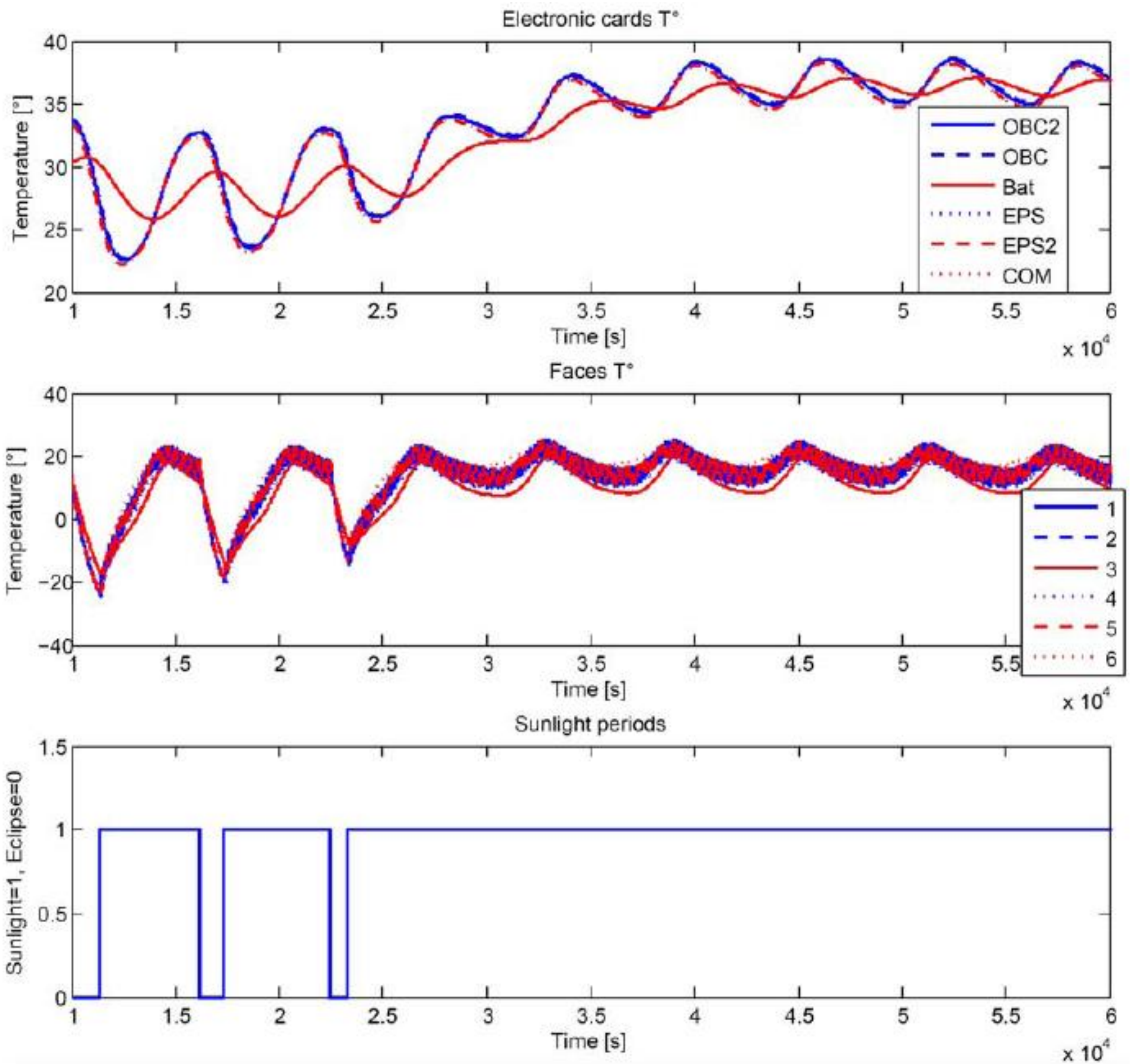


2.3 Platform – THER: analysis (cold)

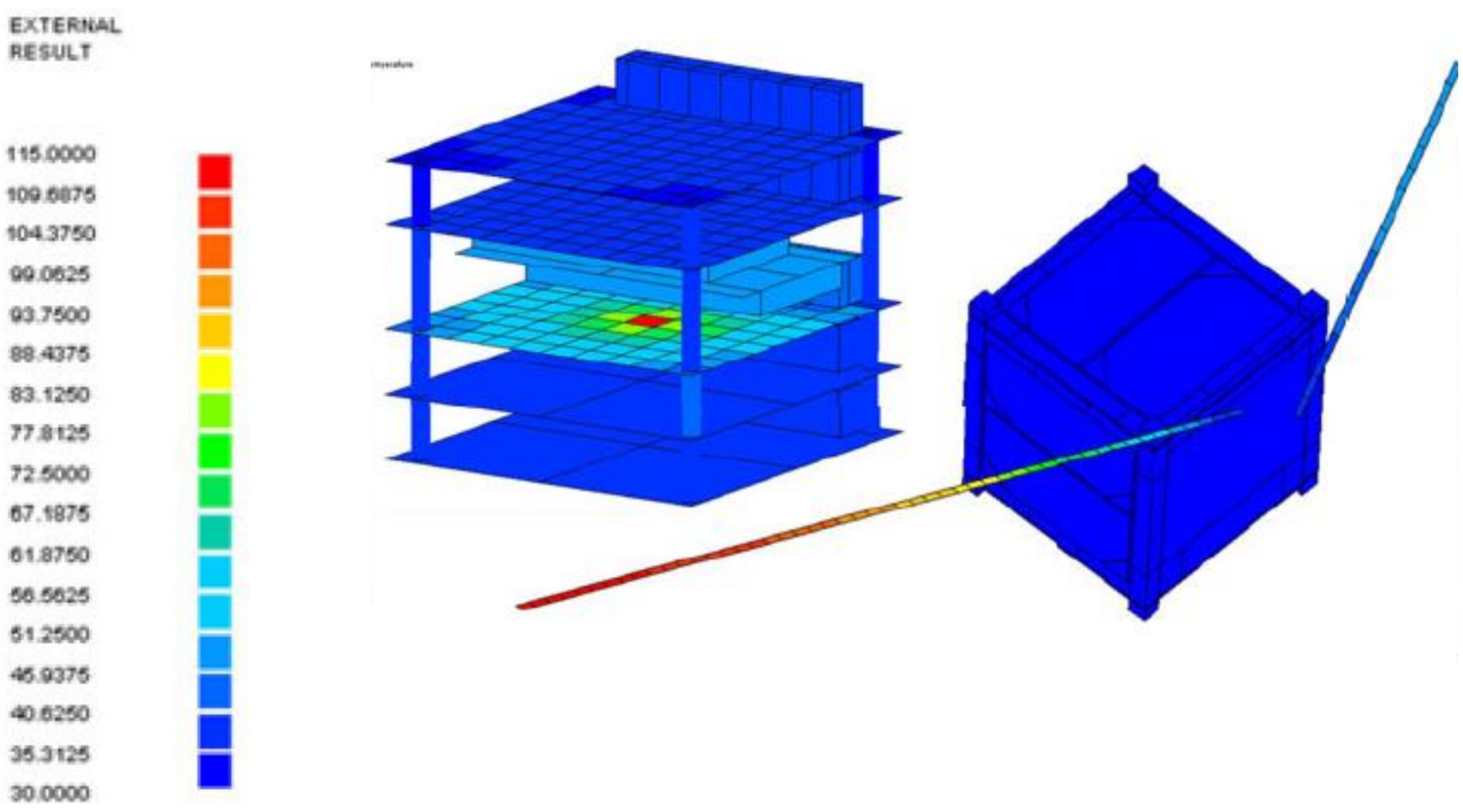


Battery is too cold !

2.3 Platform – THER: analysis (hot)



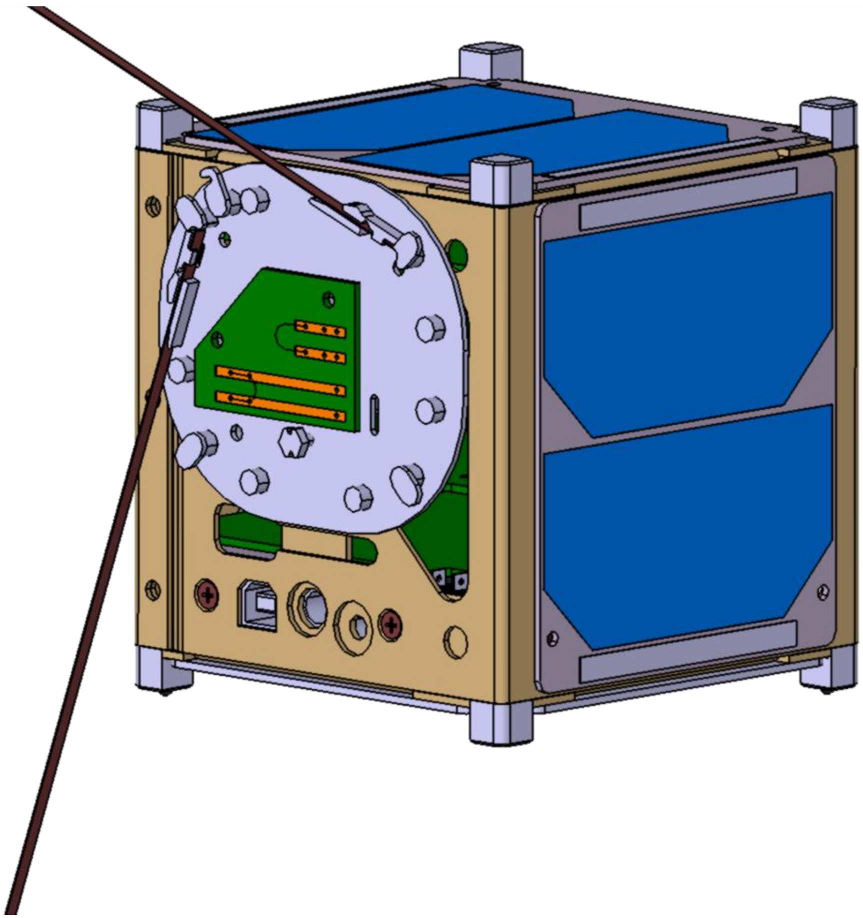
2.3 Platform – THER: analysis (hot)



Hot spot due to dissipation transistor !

2.3 Platform – THER: thermal control

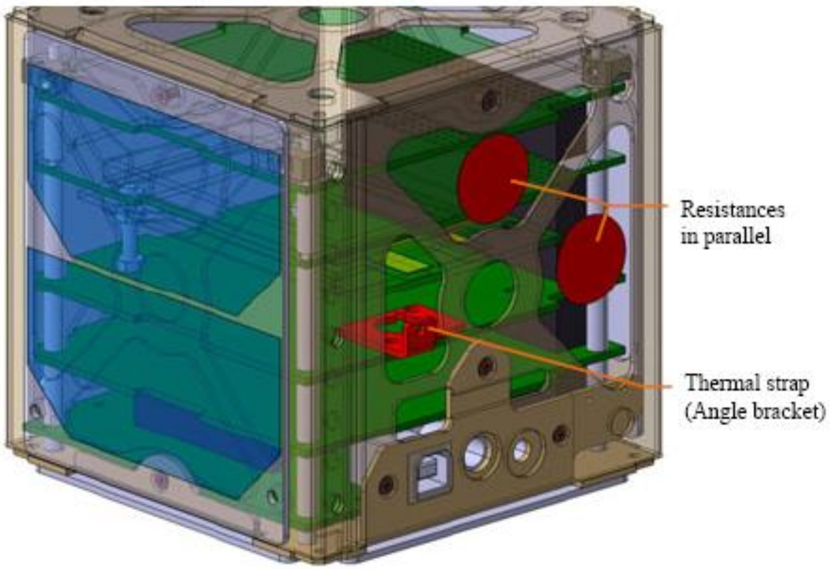
The available surface on the satellite panels is very limited.



⇒ Difficult to control the overall energy balance between the spacecraft and its environment.

2.3 Platform – THER: conductive links

Thermal control can be achieved by an appropriate study and design of the conductive links within the satellite.

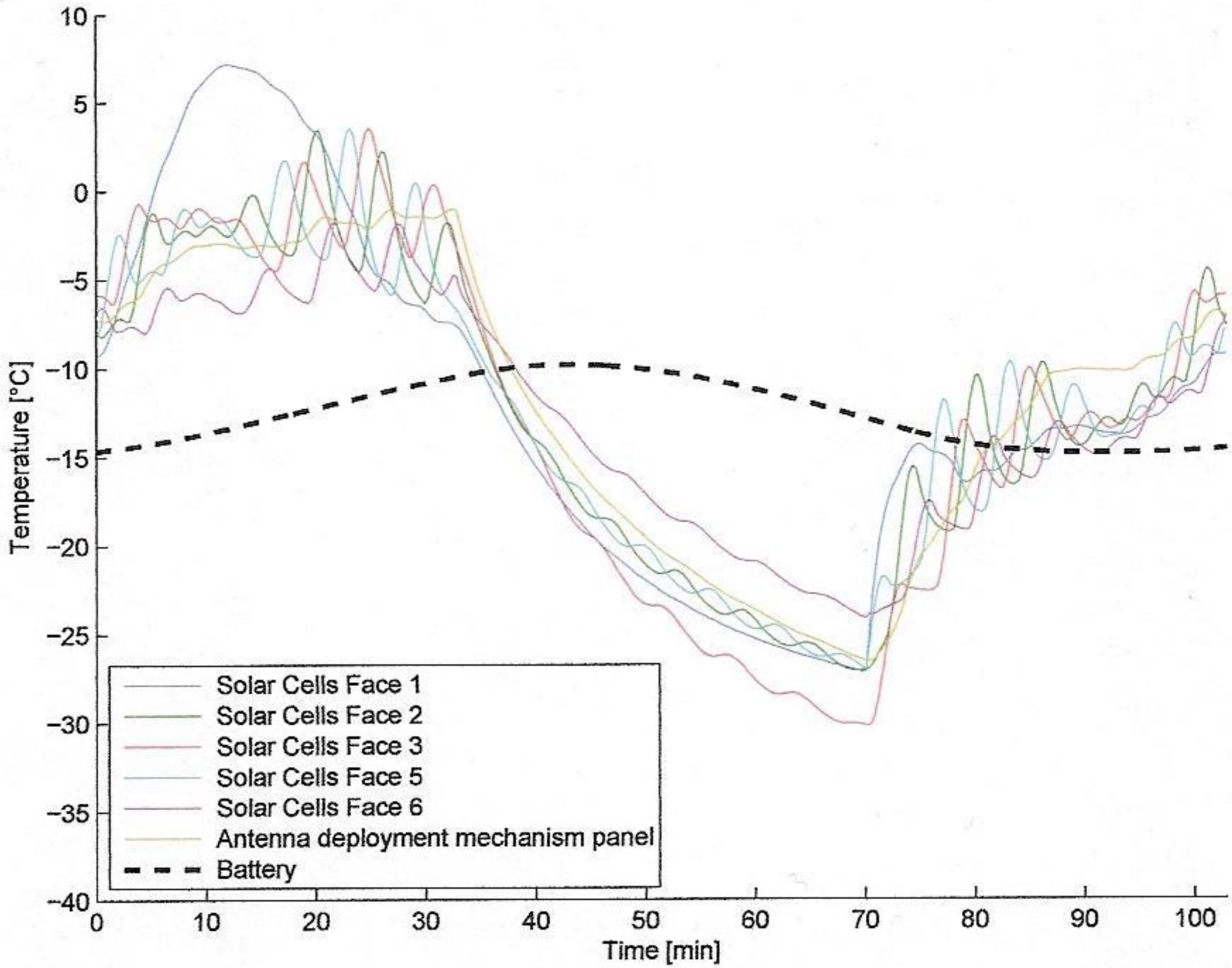


Copper angle bracket

2.3 Platform – THER: conductive links

Element	T°before [°C]	T°after [°C]
Solar cells	32	32
Aluminum panels	32	32
Aluminum frame	32	33
Antennas' panel	33	38
Antennas	127	129
OBC PCB	36	33
OBC2 PCB	40	34
EPS PCB	55	37
EPS2 PCB	39	34
COM PCB	36	34
Batteries	**48**	**35**
Dissipation Transistor	**114**	**67**

2.3 Platform – THER: batteries issue

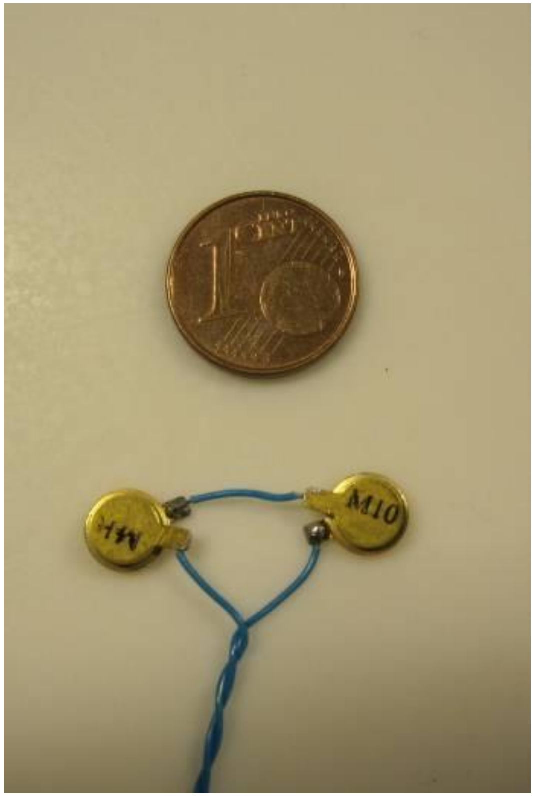


2.3 Platform – THER: active control

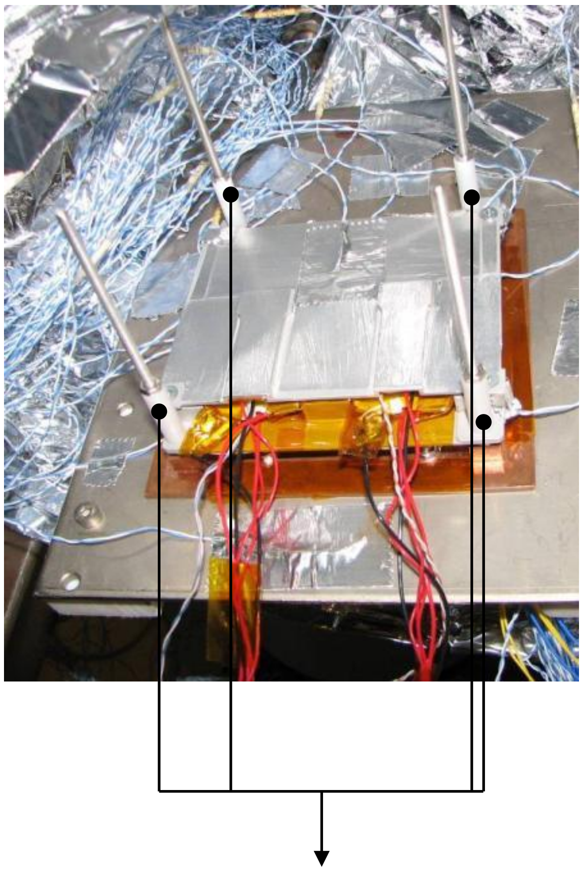
Heaters + Thermostats

- 1 heater per battery
- 2 x 250mW patch heaters
- 26.3 Ω
- 59.4 x 35.6 mm

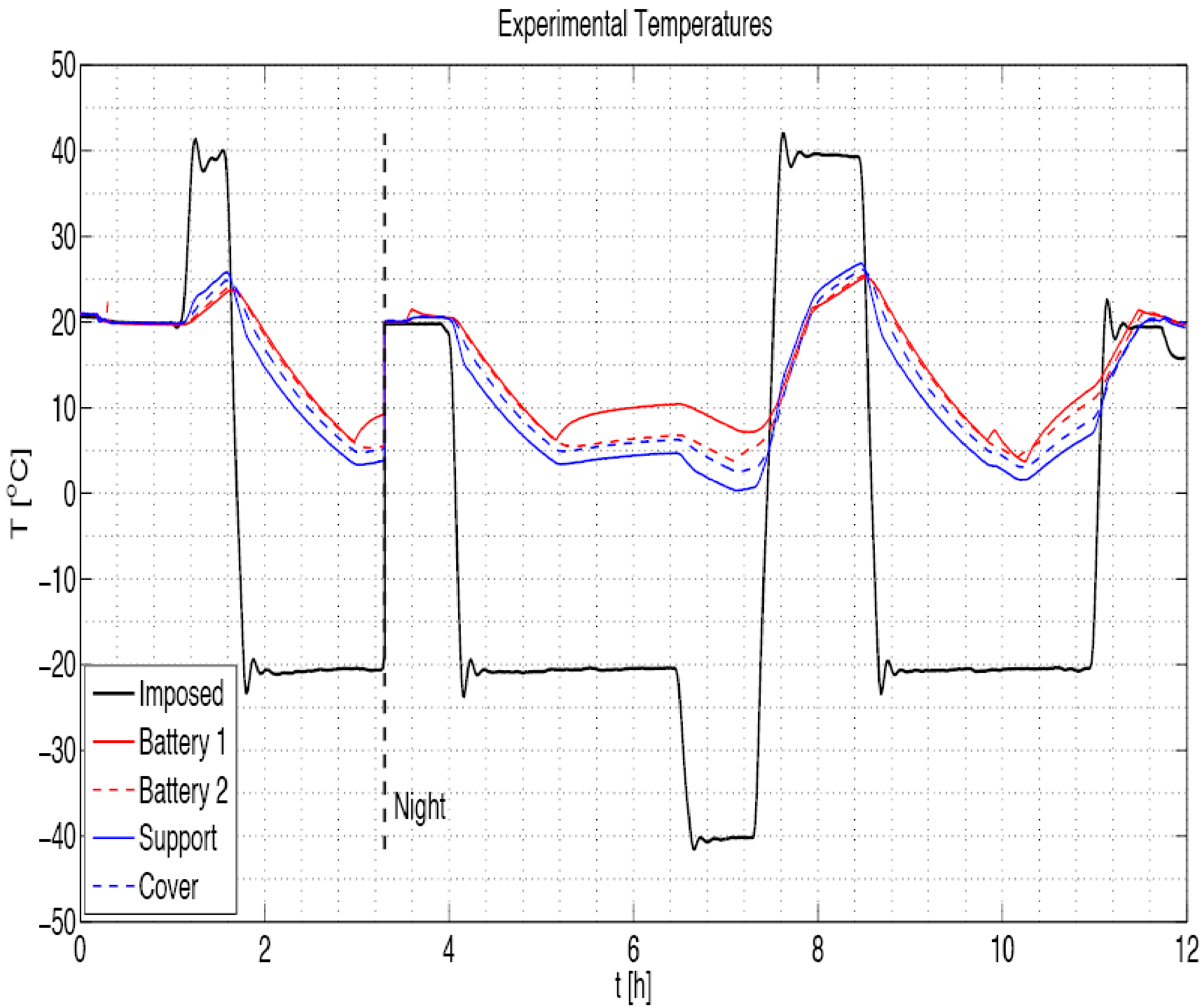
- Mechanical thermostats
- 2 thermostats per battery, in series
- 7.2°C 23.9°C



2.3 Platform – THER: tests

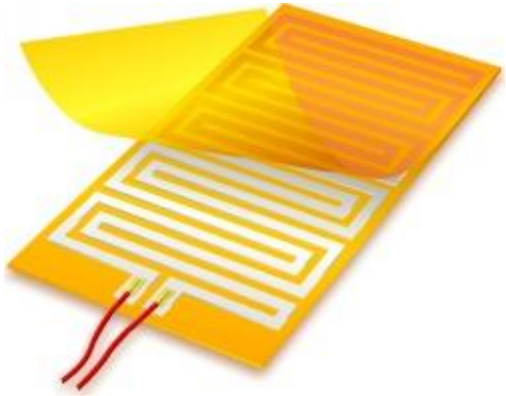


POM spacers

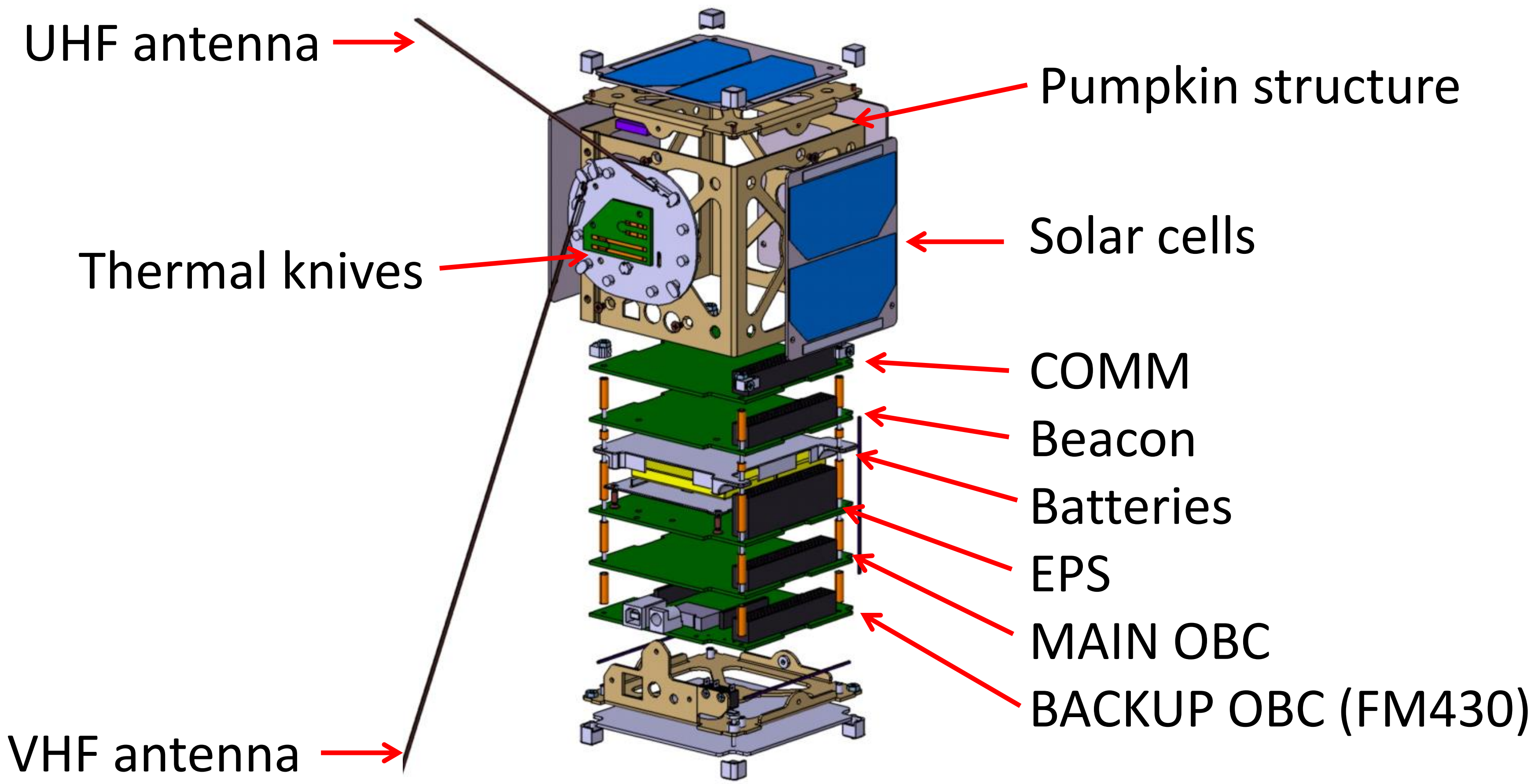


THER – State of the art

- Passive means (MLI, coating, cold finger, …)
- Heaters for sensitive equipment



2.3 Platform – Configuration



Outline

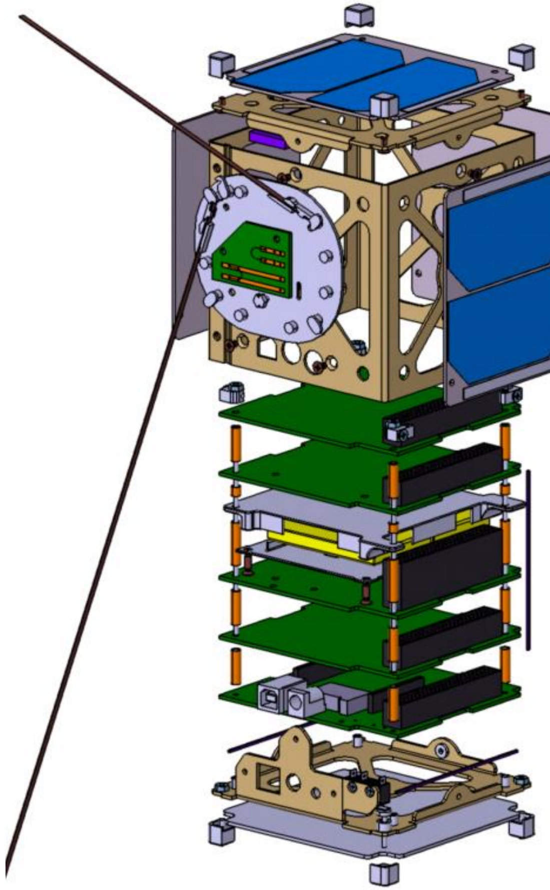
1. Objectives
2. Space Segment
    1. Payloads
    2. Orbit and mission analysis
    3. Platform
    4. Protoflight model
3. Ground segment

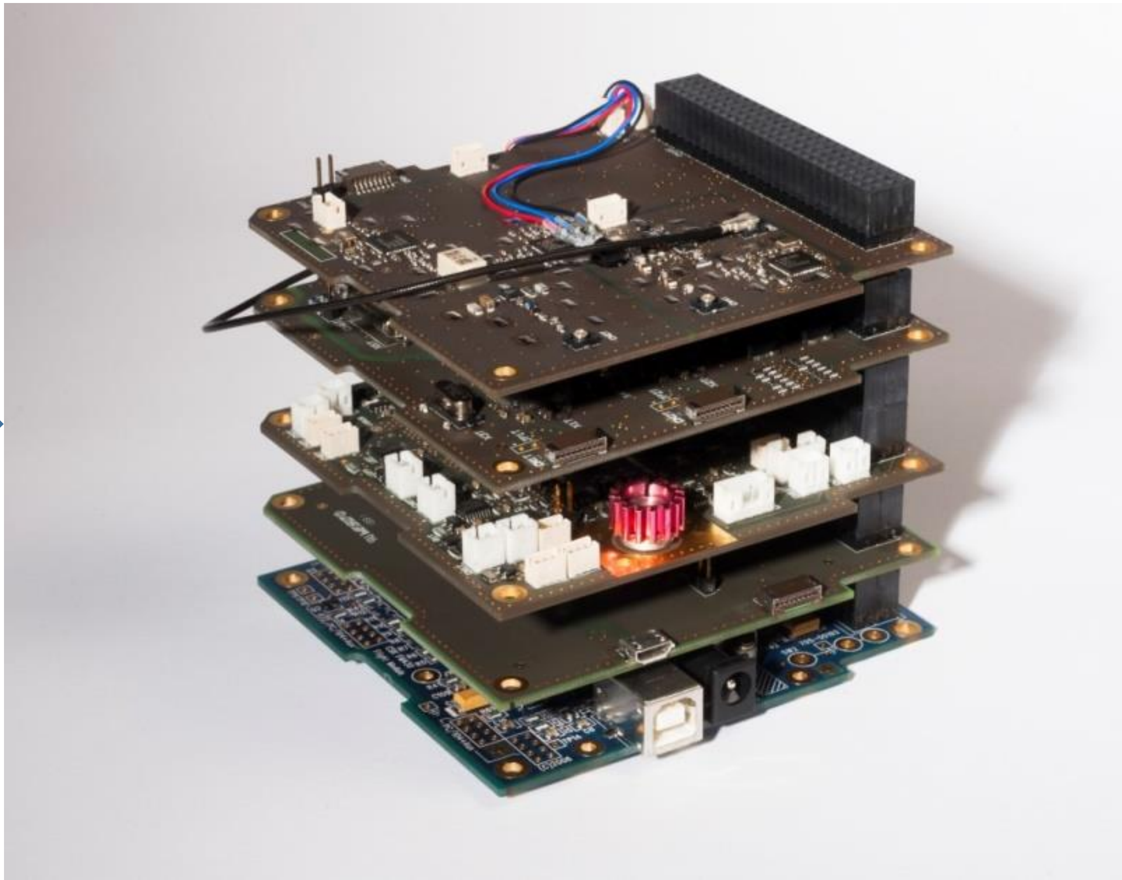
2.4 Protoflight model: philosophy

Engineering model → qualification tests
+ Flight model → acceptance tests **+ Space**

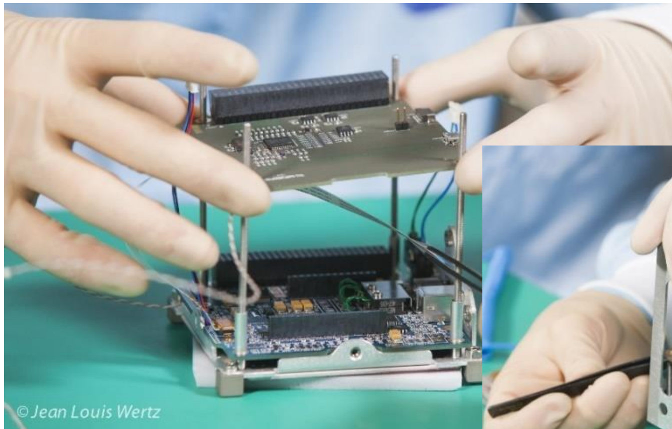
Protoflight model → protoflight tests **+ Space**
(= qualification levels with acceptance duration)

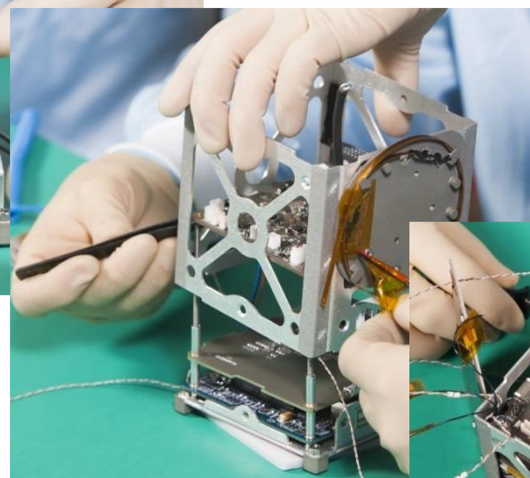
2.4 Protoflight model

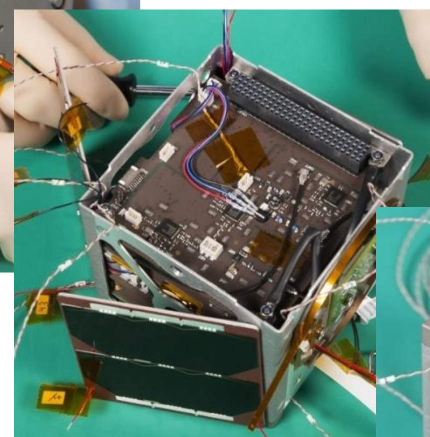


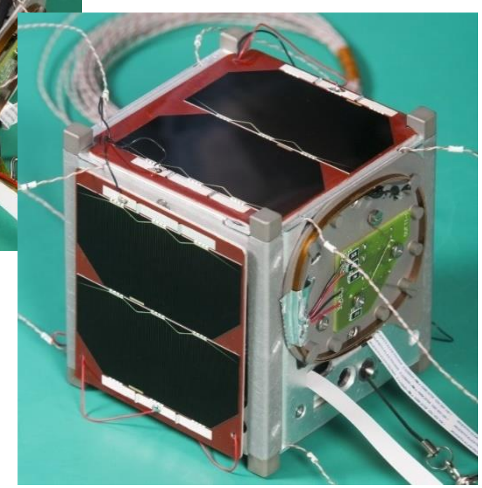


2.4 Protoflight model





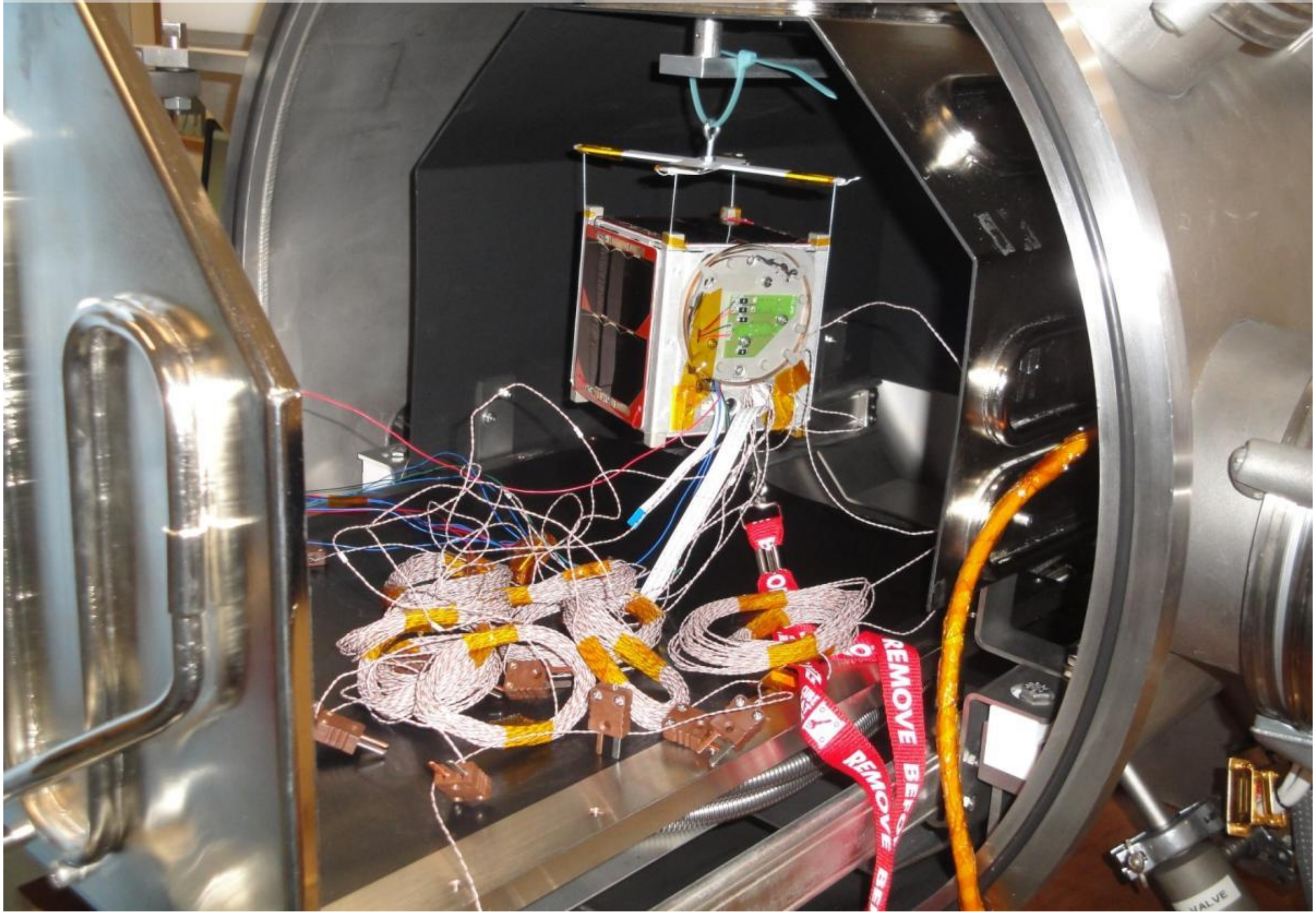




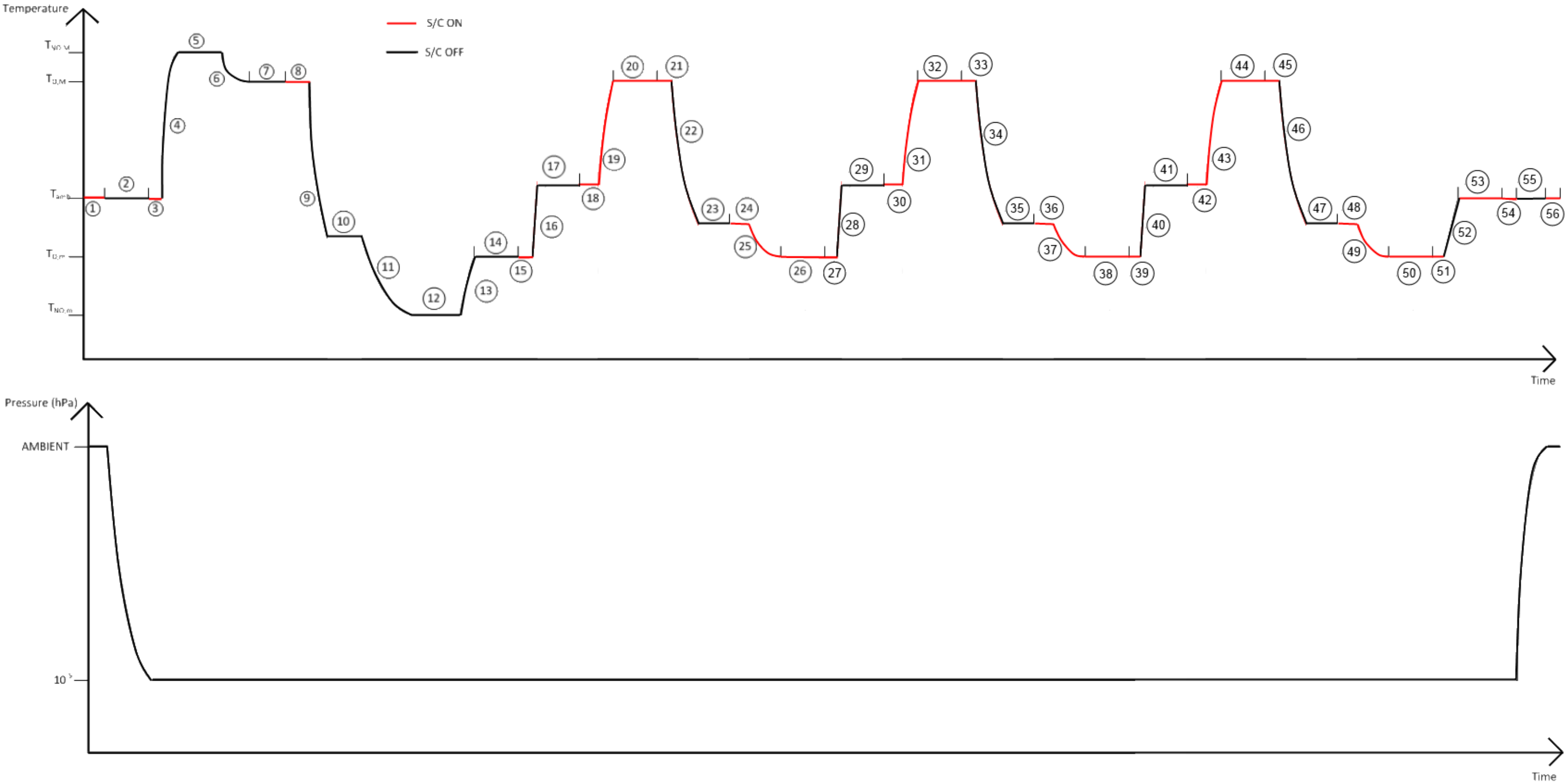
- Write, test, and correct integration procedures
- Perform integration at Centre Spatial de Liège (CSL) of ULg

2.4 Protoflight model: TVC

Tests at ESA/ESTEC thanks to *ESA Fly Your Satellite!* program



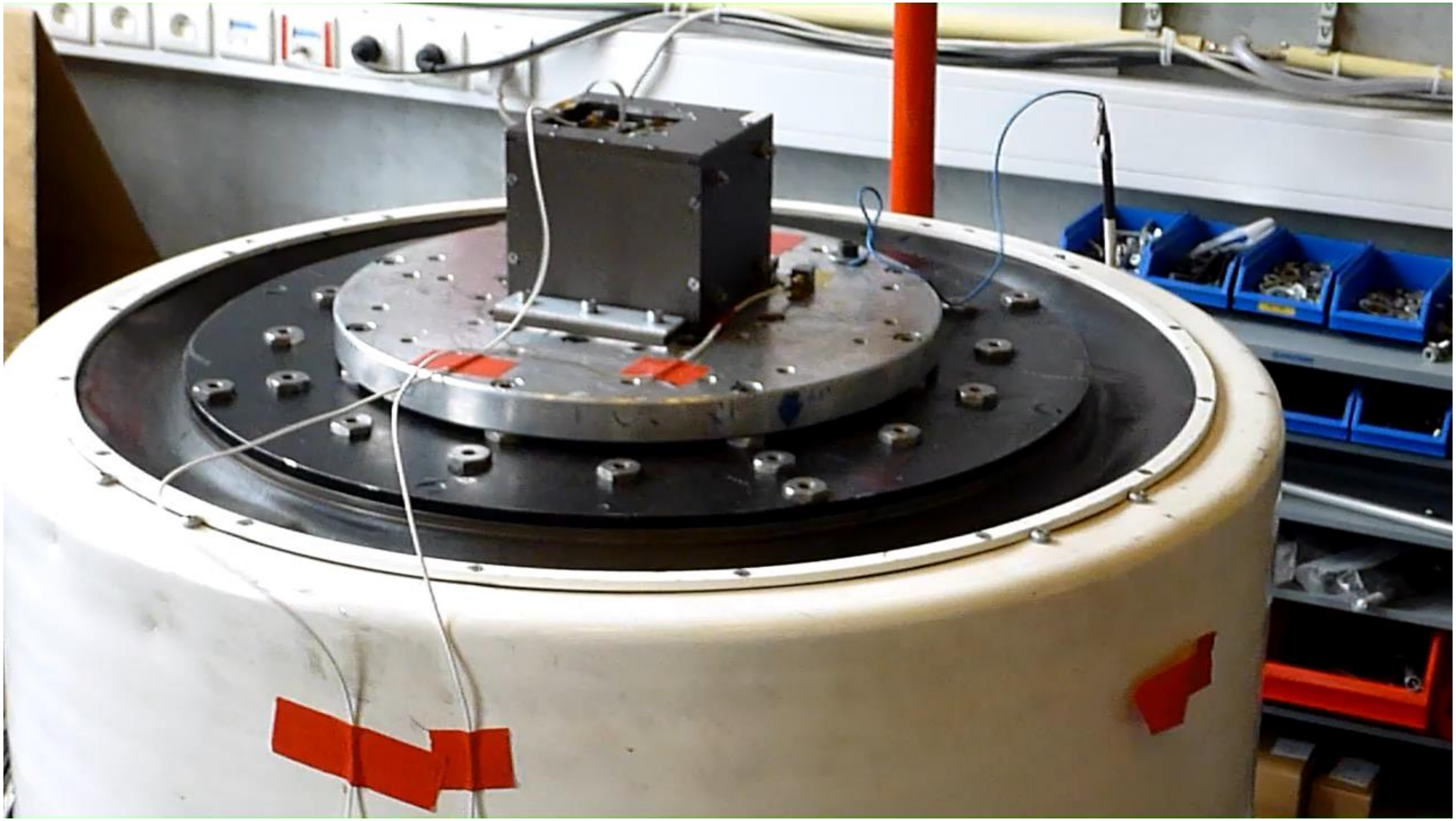
2.4 Protoflight model: TVC



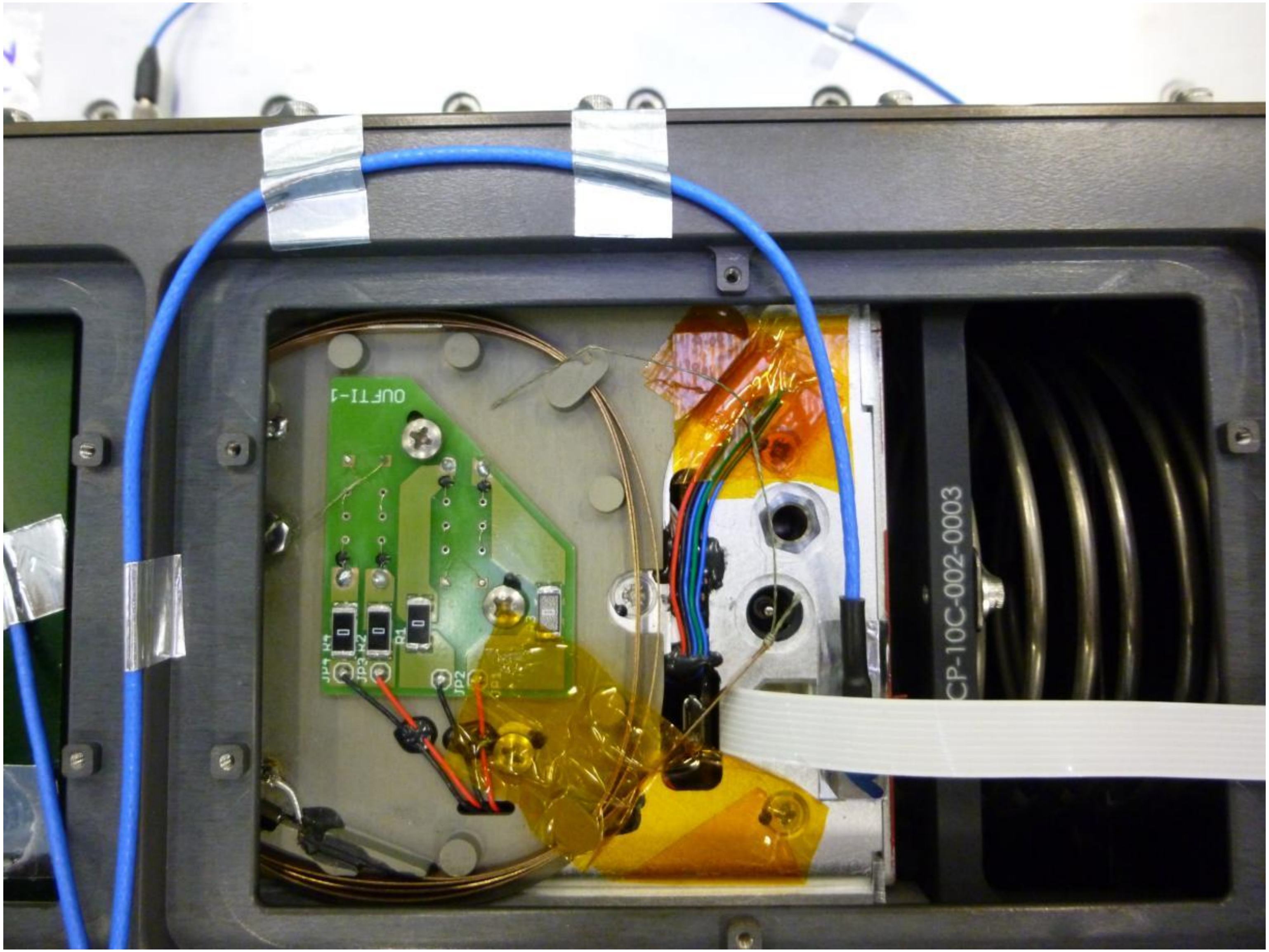
2.4 Protoflight model: vibration tests

Tests at ESA/ESTEC thanks to
ESA Fly Your Satellite! program

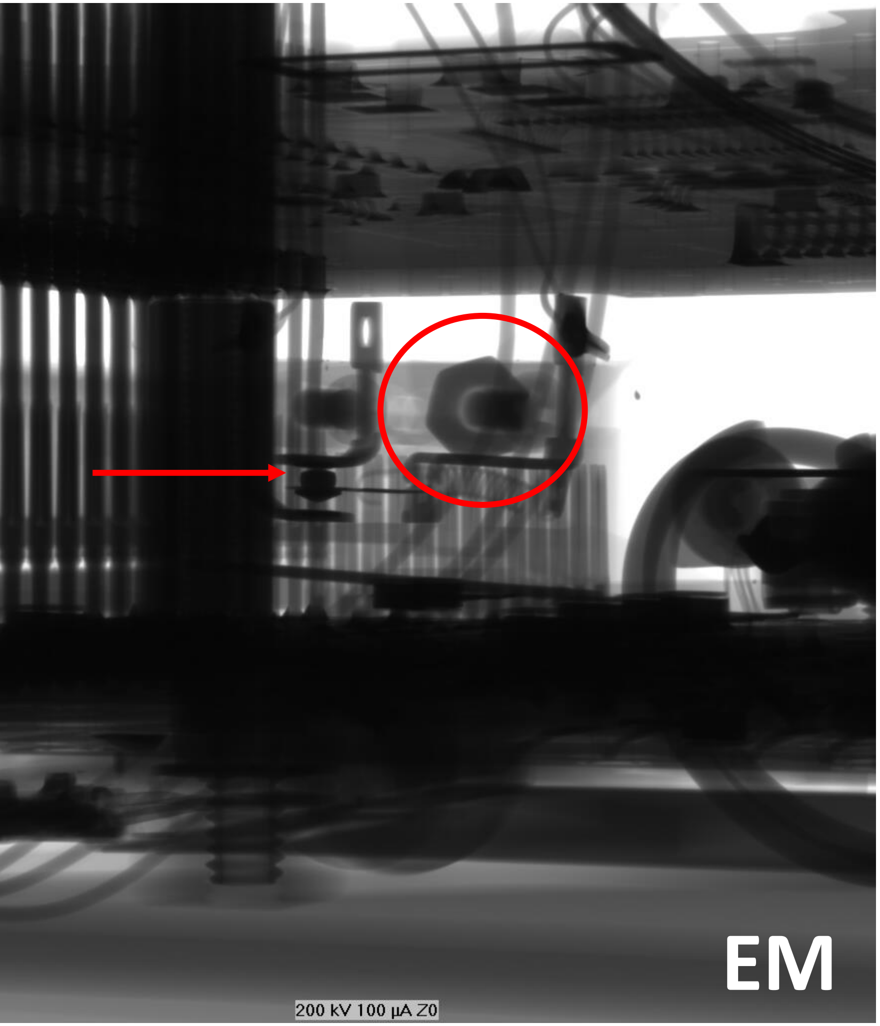
2.4 Protoflight model: vibration tests



2.4 Protoflight model: vibration tests

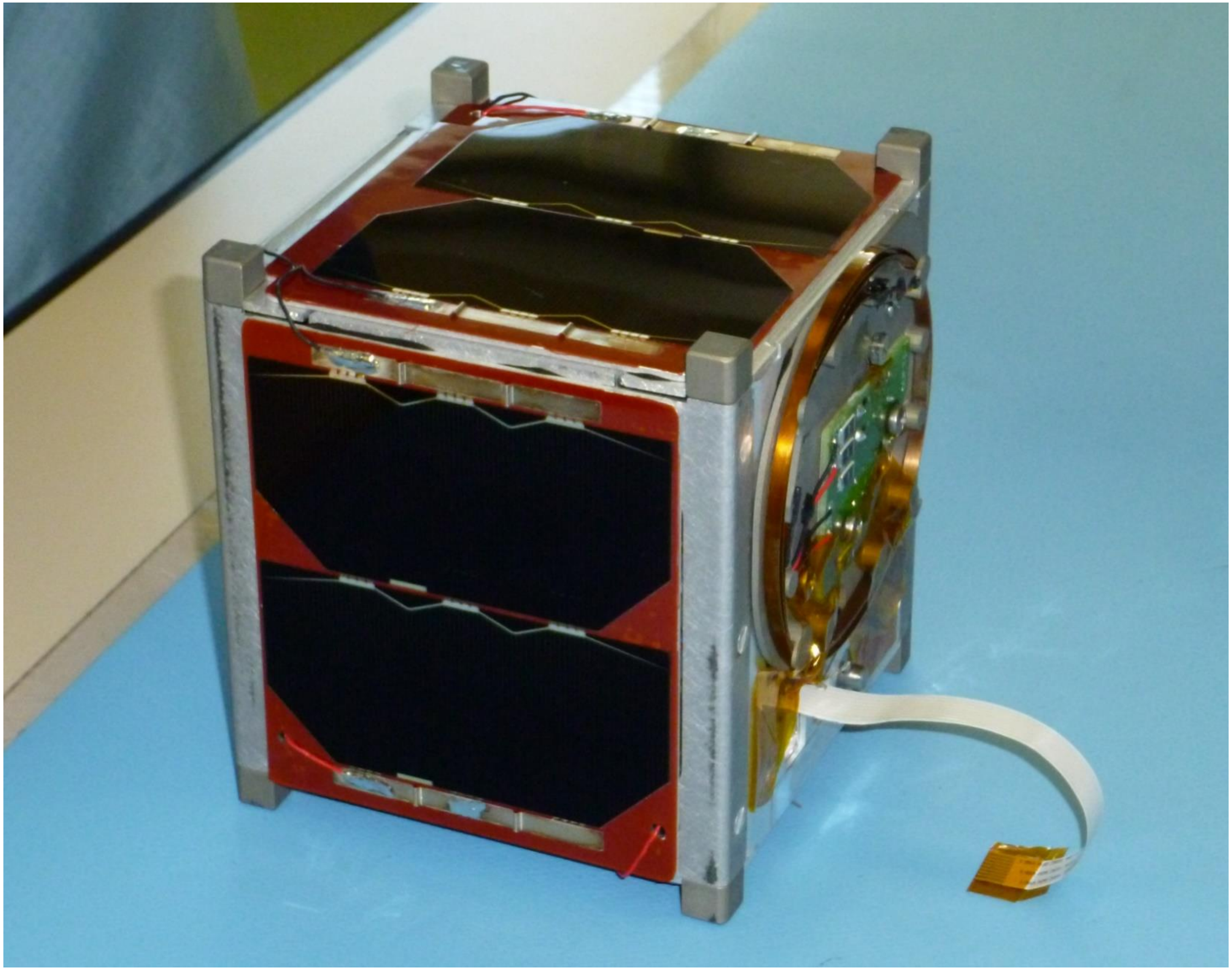


2.4 Protoflight model: X-rays



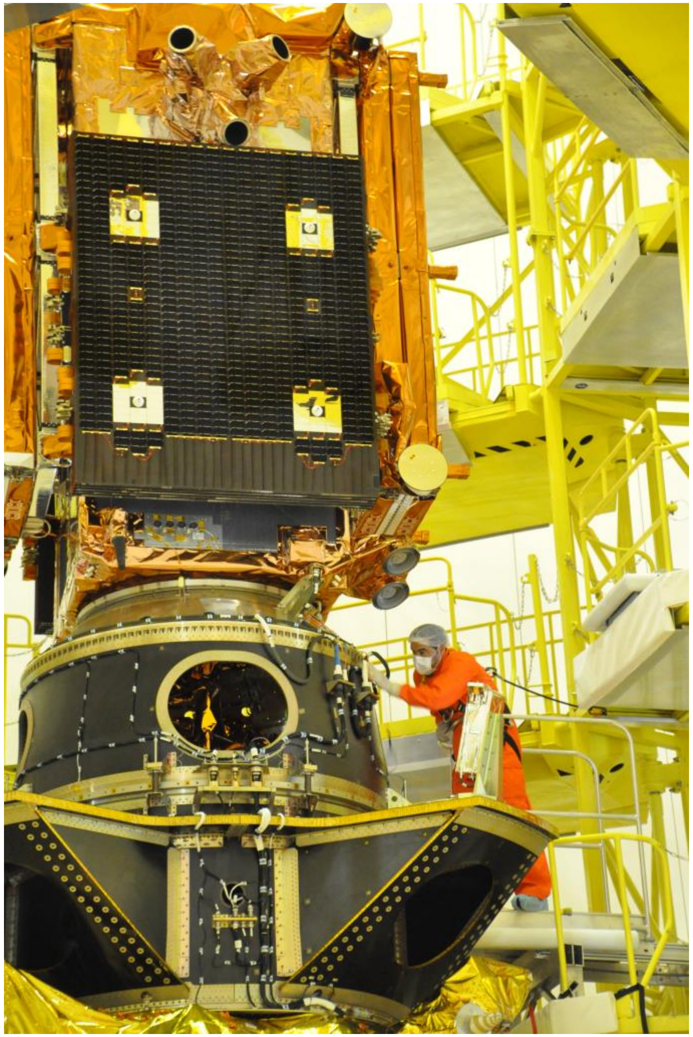
X-rays at ESA/ESTEC thanks to *ESA Fly Your Satellite!* program

2.4 Protoflight model: ready for launch!

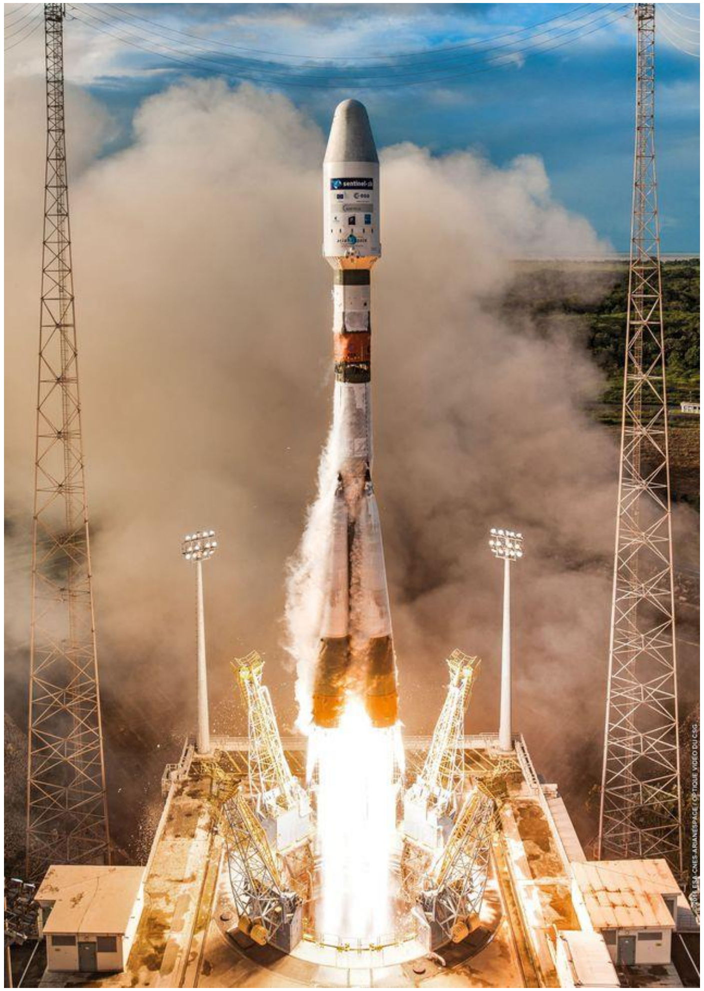


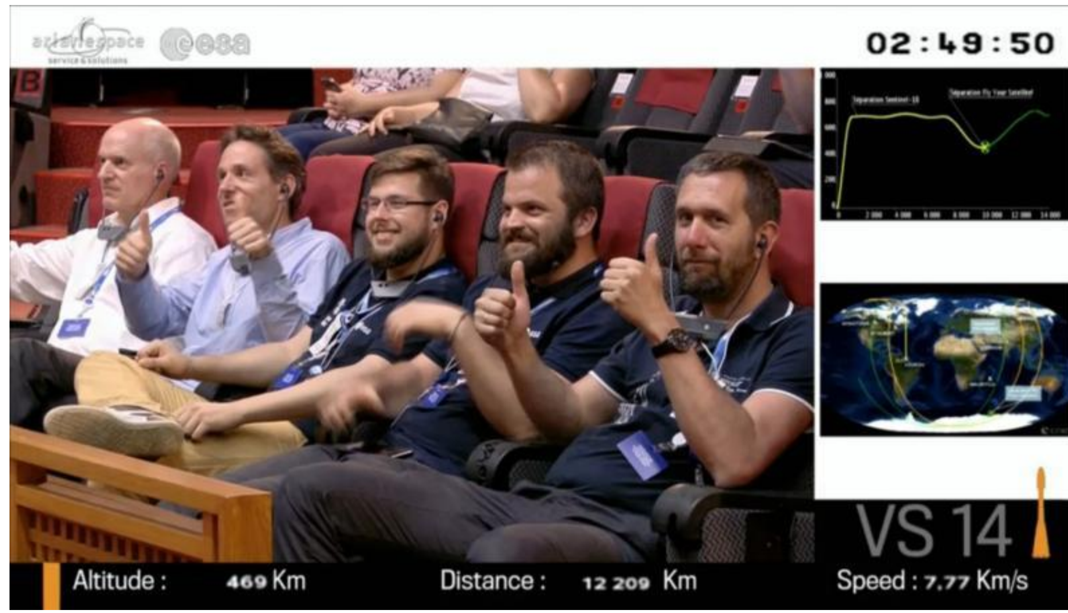
2.4 Protoflight model: P-POD integration

2.4 Protoflight model: on ASAP-S



2.4 Protoflight model: Launched!





Soyuz Flight VS14
Centre Spatial Guyanais, Kourou
25 April 2016

2.4 Protoflight model: signal received

> 500 Beacon messages received from HAM operators

Outline

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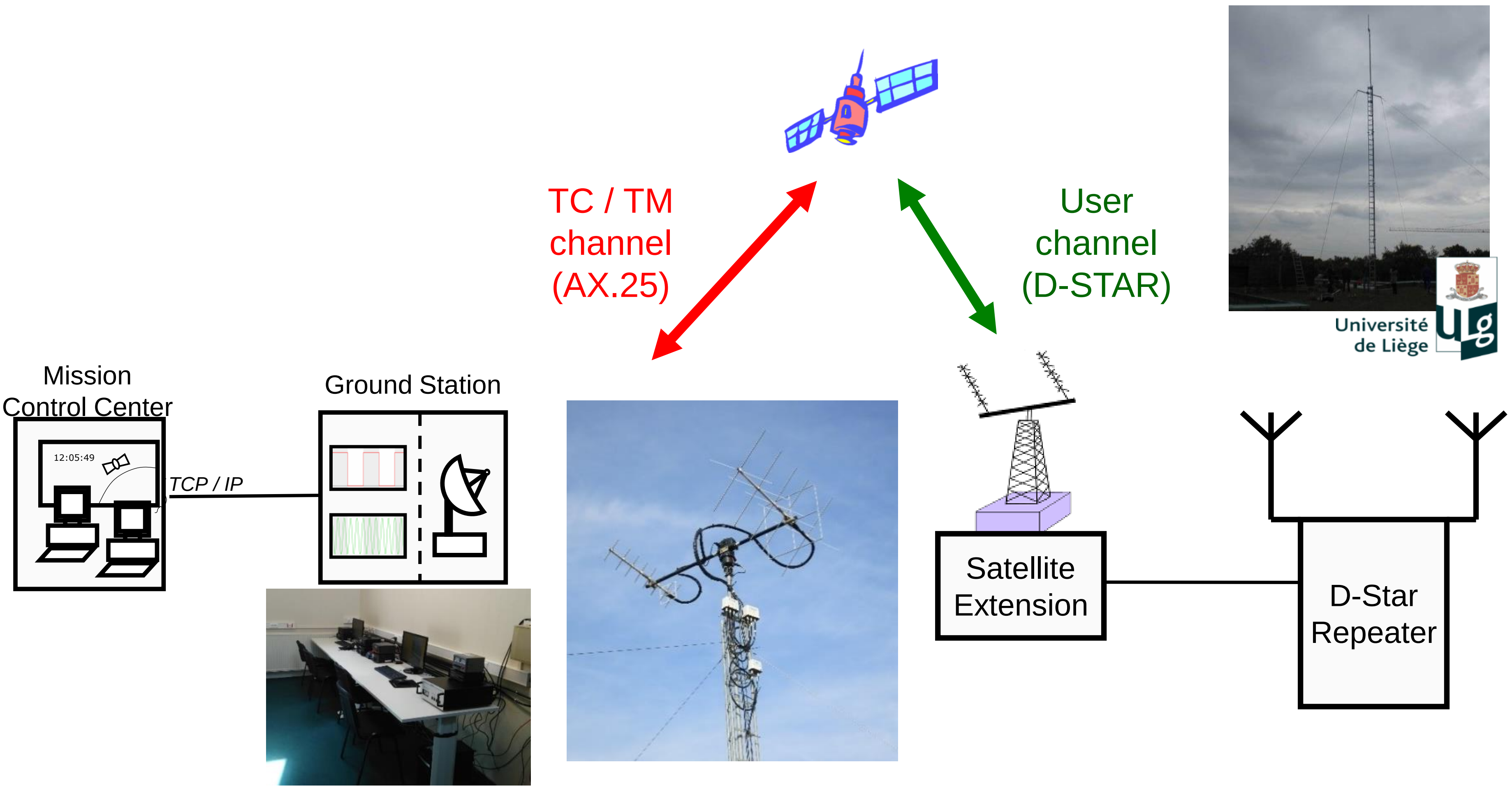
3. Ground segment

3. Ground segment



Control segment

D-STAR segment

QARMAN, the VKI fearless CubeSat!

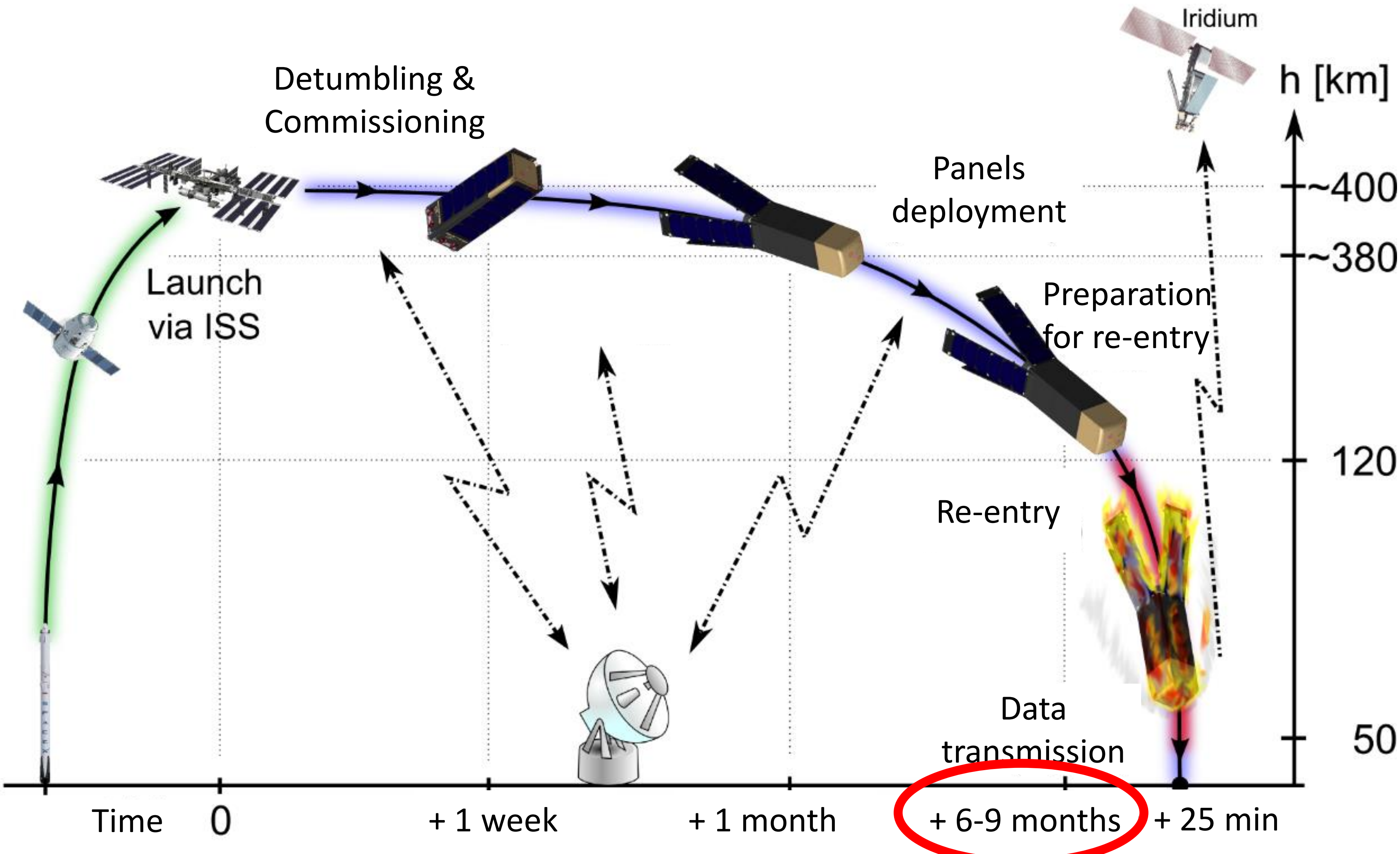
Why QARMAN?

- 2 main goals:
  - Demonstrate the feasibility of a CubeSat as a re-entry platform
  - Investigate the scientific phenomena related to re-entry

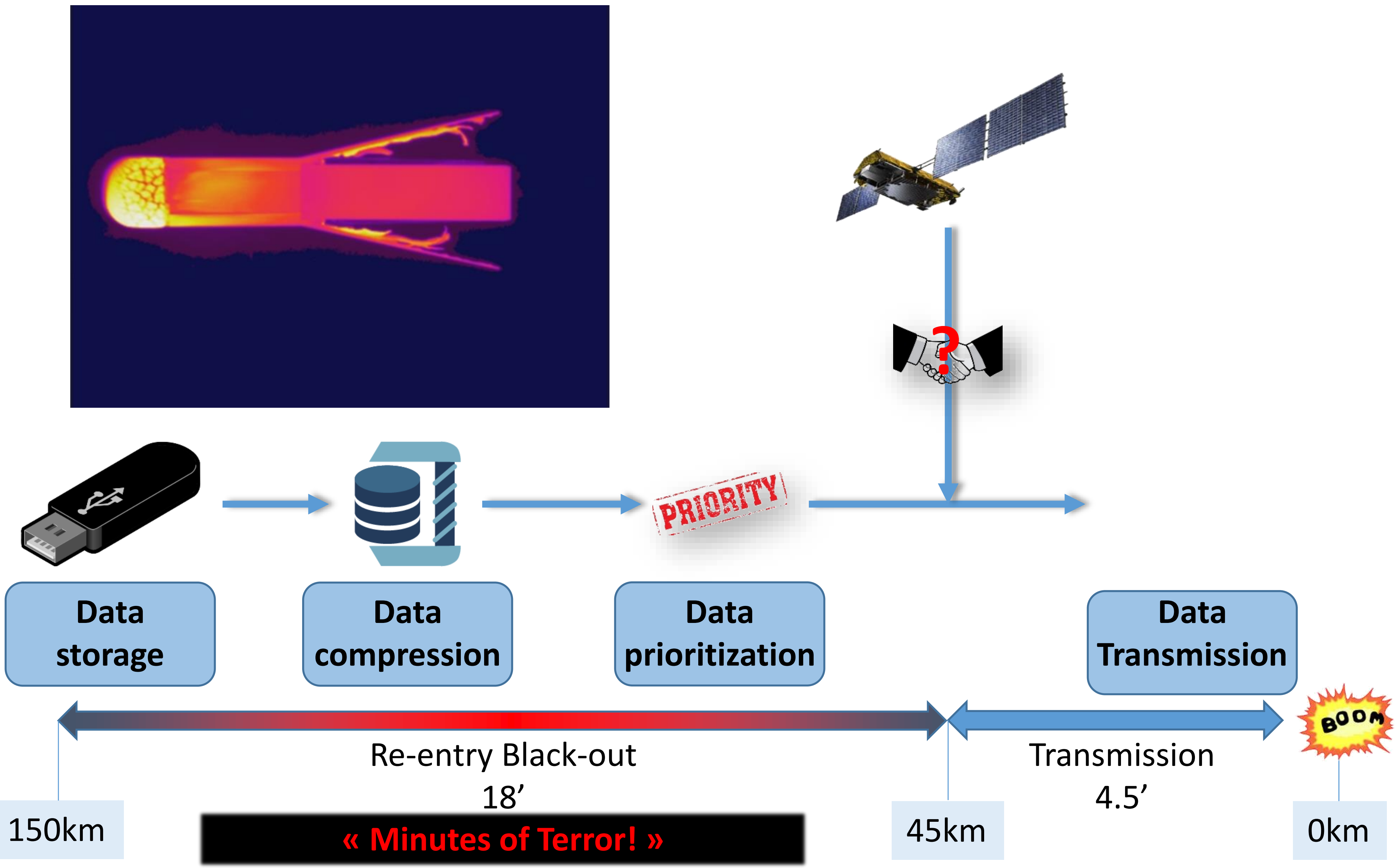
- 2 main challenges:
  - Thermal environment
  - Communication black-out

➔ A unique and ambitious mission!

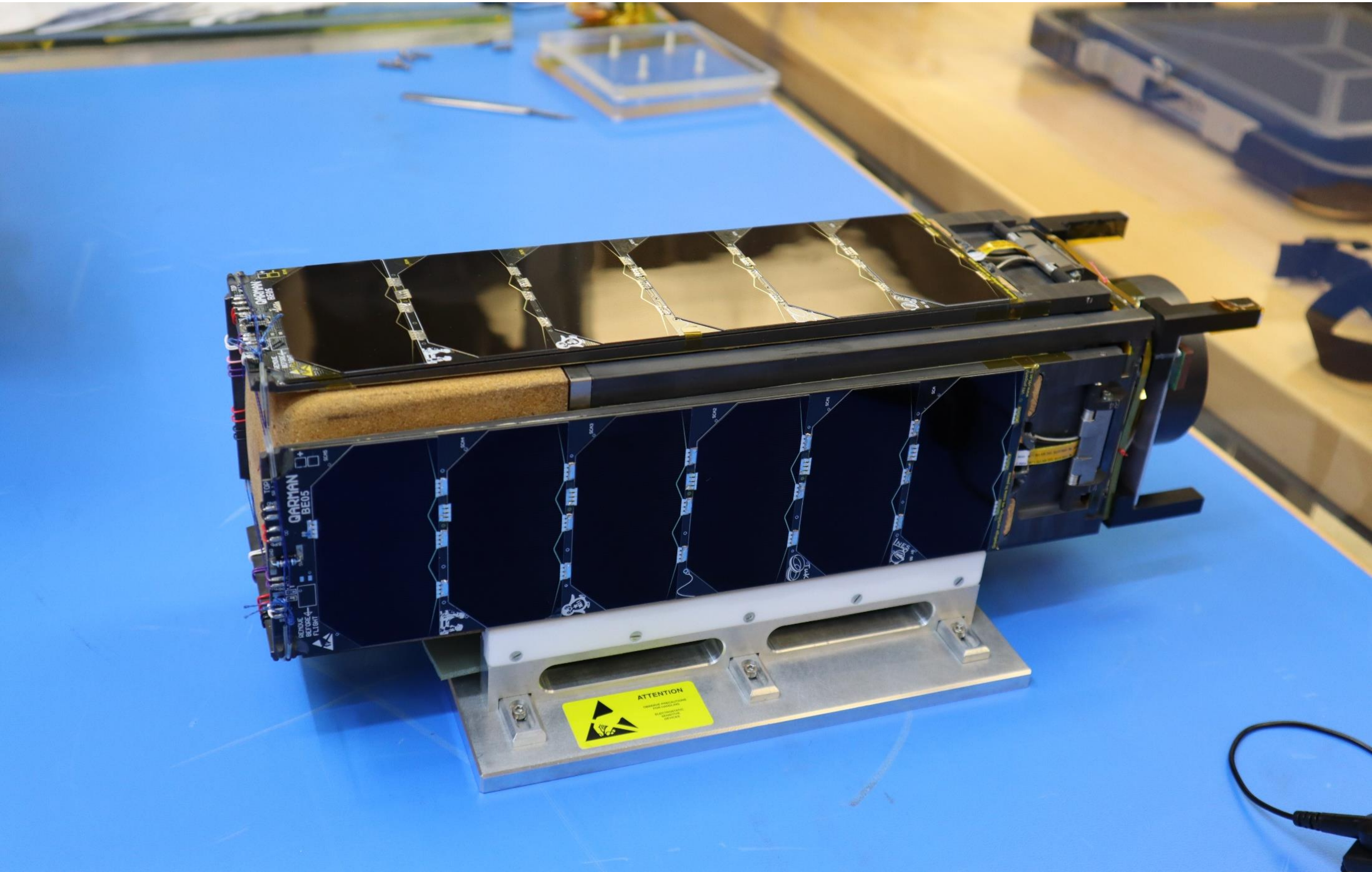
QARMAN in orbit



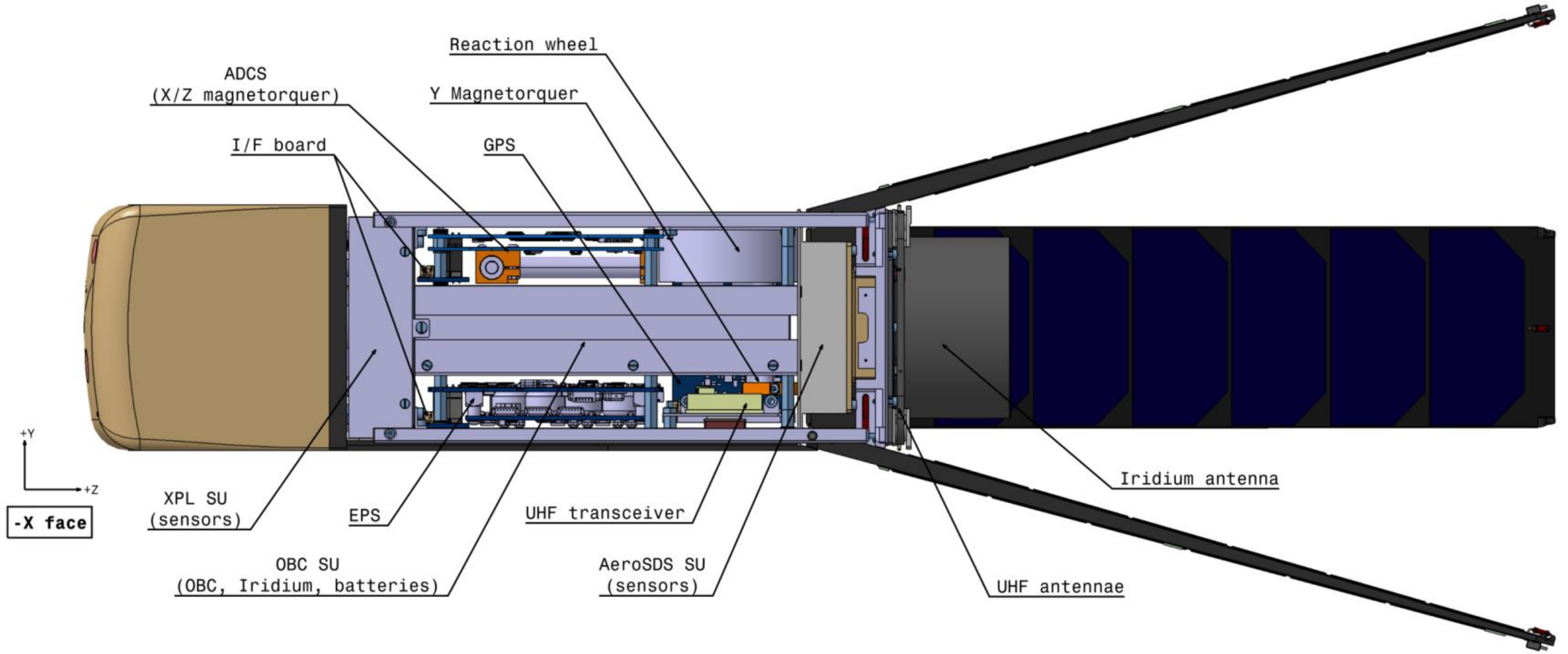
Re-entry phase



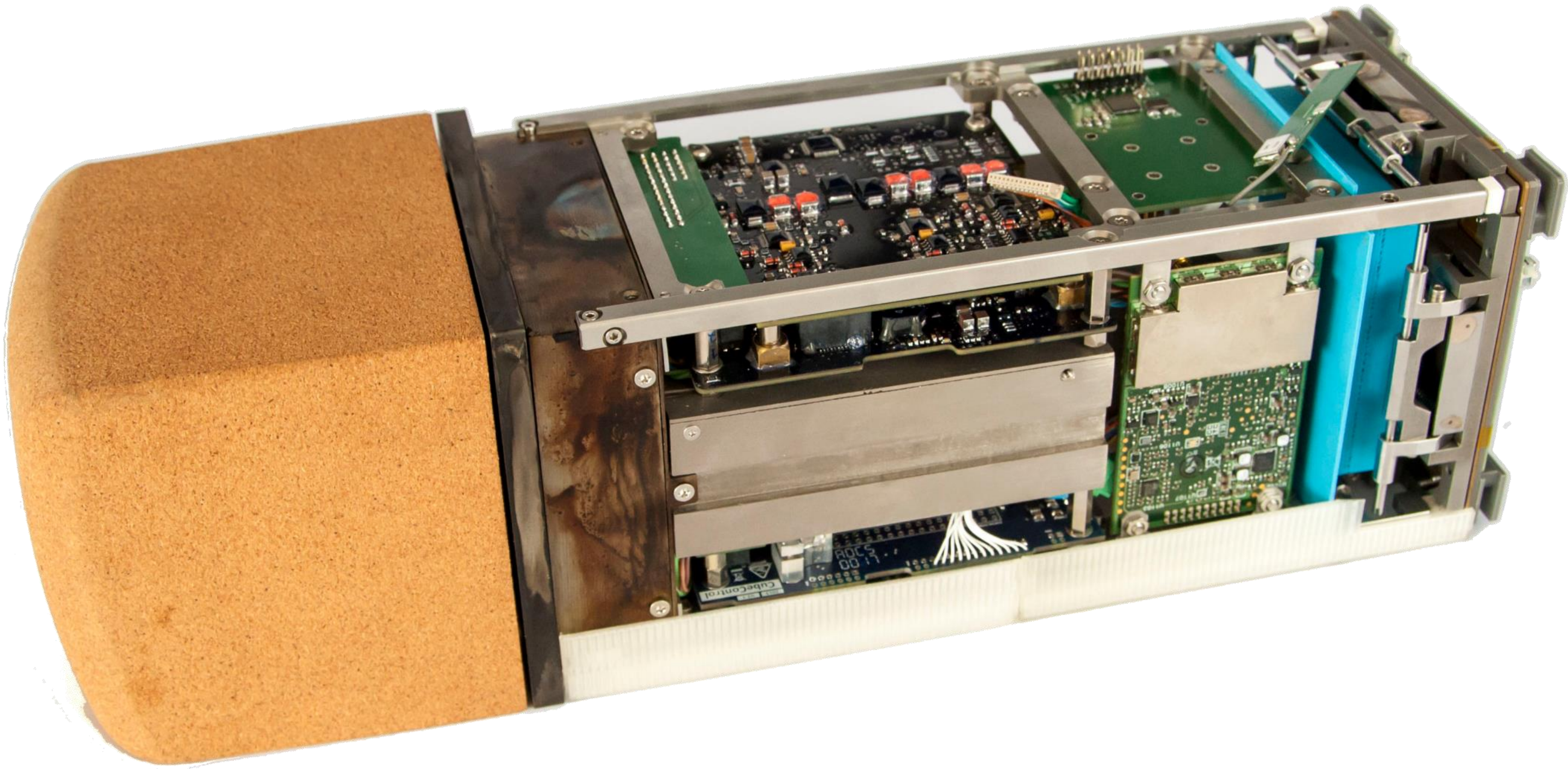
QARMAN design



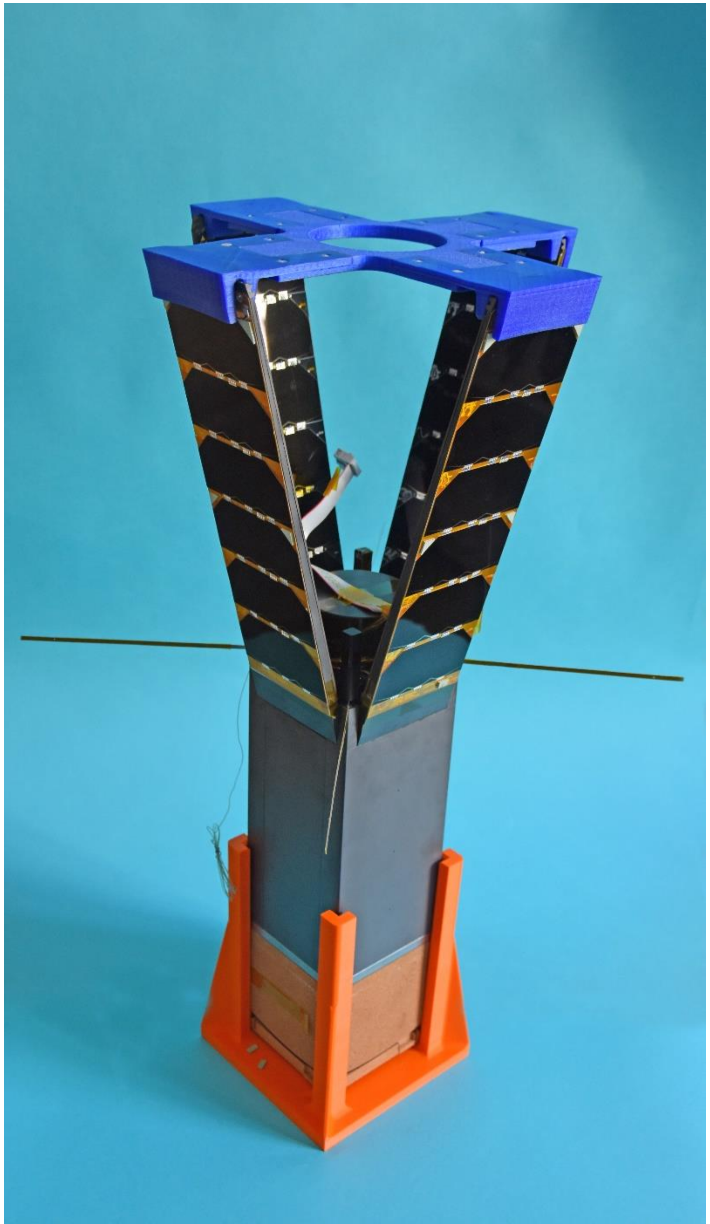
QARMAN design

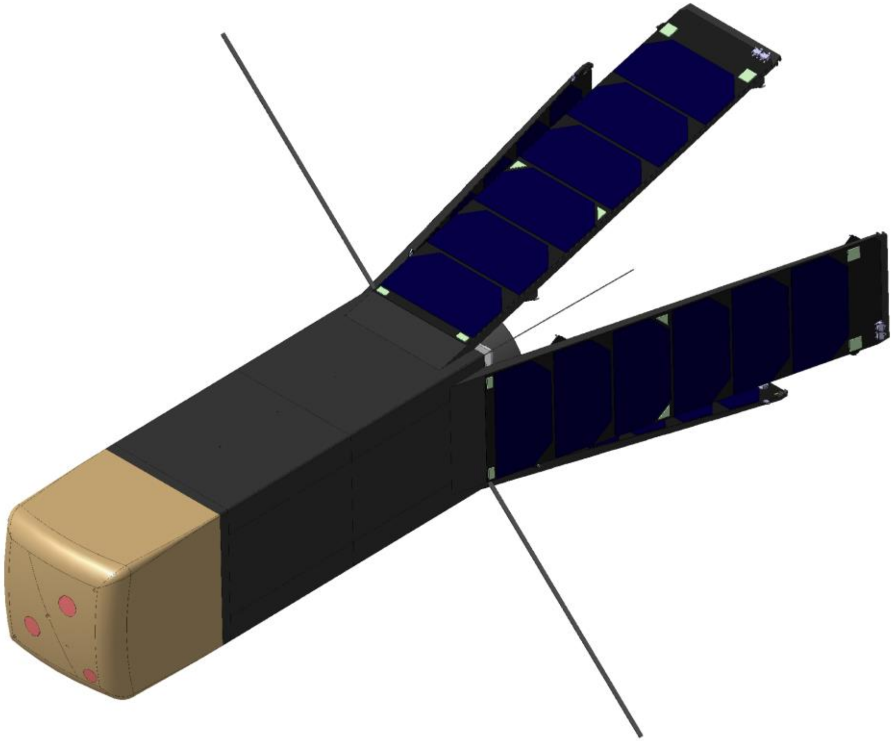


QARMAN design



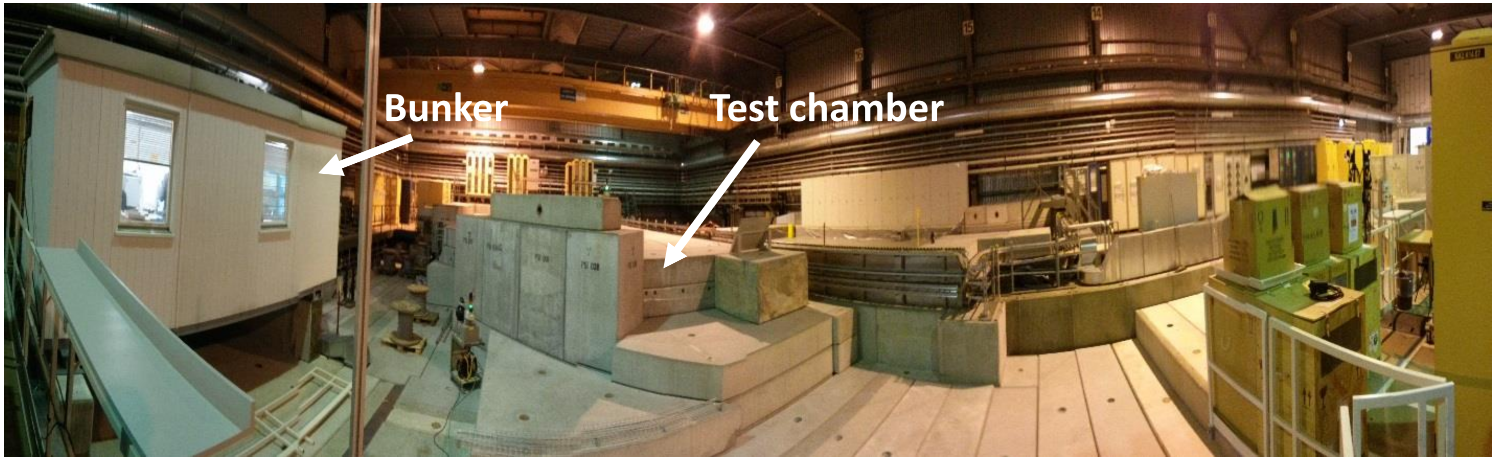
QARMAN design

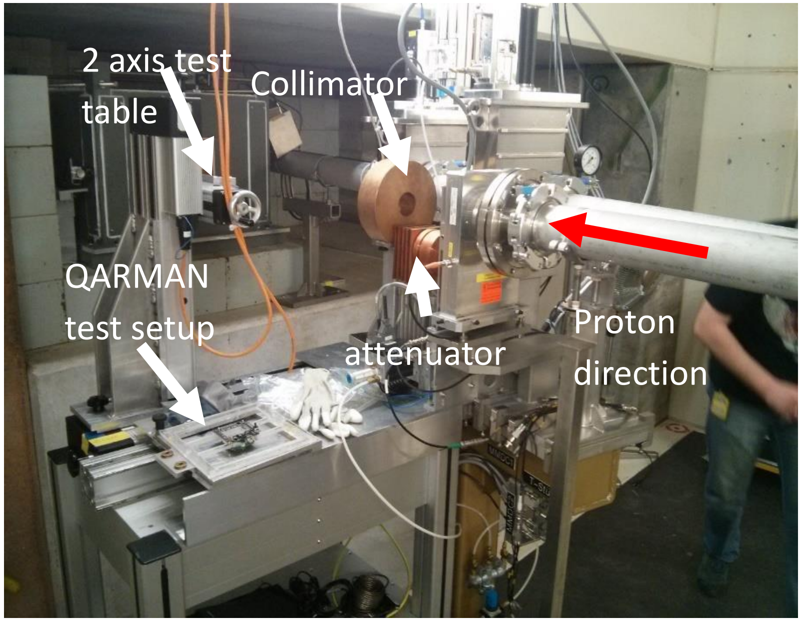


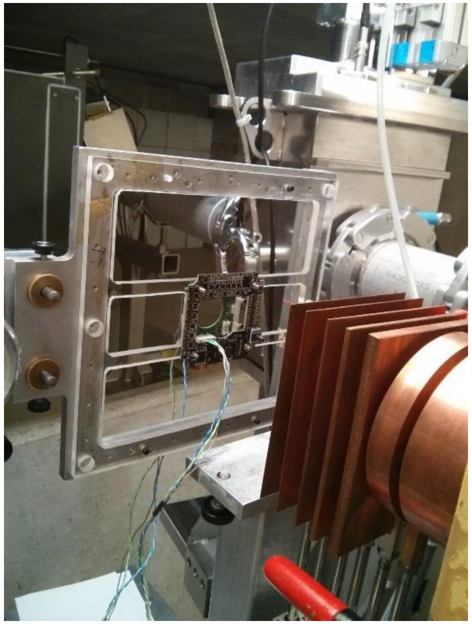


2018-19: Integration and tests

- 11-12 April 2015: radiation test (Switzerland)

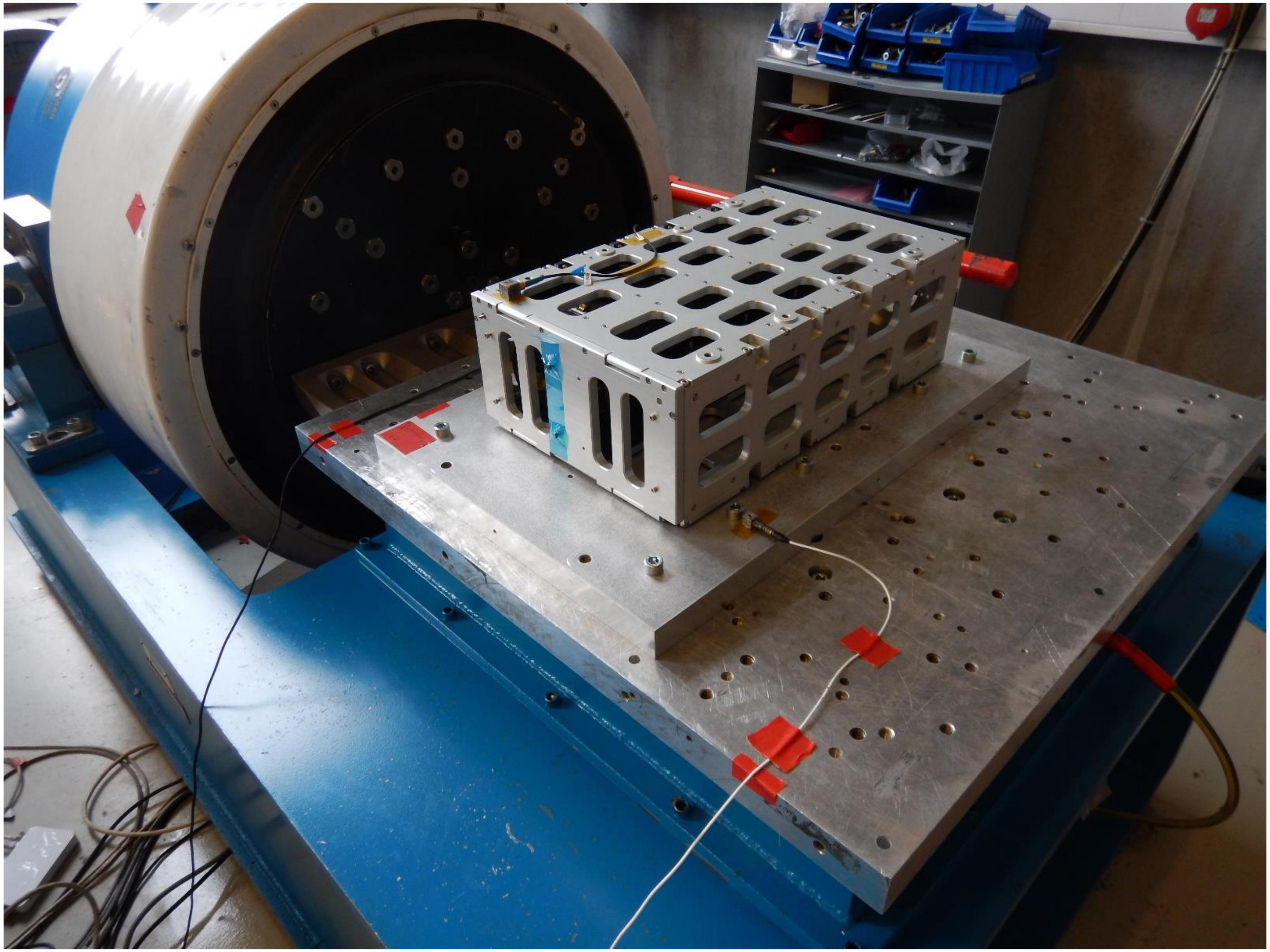






2018-19: Integration and tests

- 4 April 2019: vibration test (Liège)



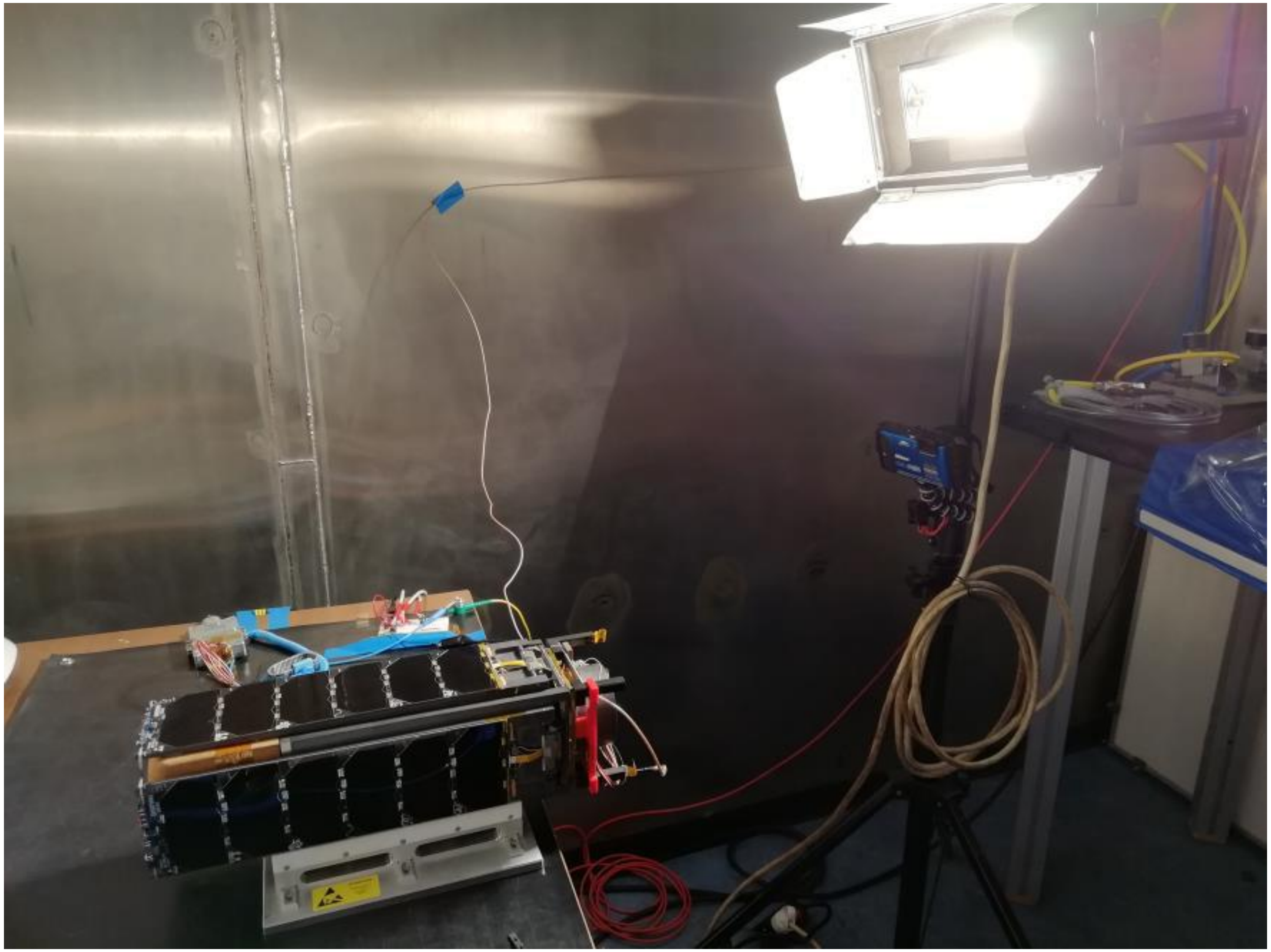
2018-19: Integration and tests

- 24/4 – 13/5/19: Bake-out and TVAC (Toulouse)

- 8 days
- 4 cold & hot cycles
- -10°C → +45°C
- Functional tests
- Antenna deployment at -10°C

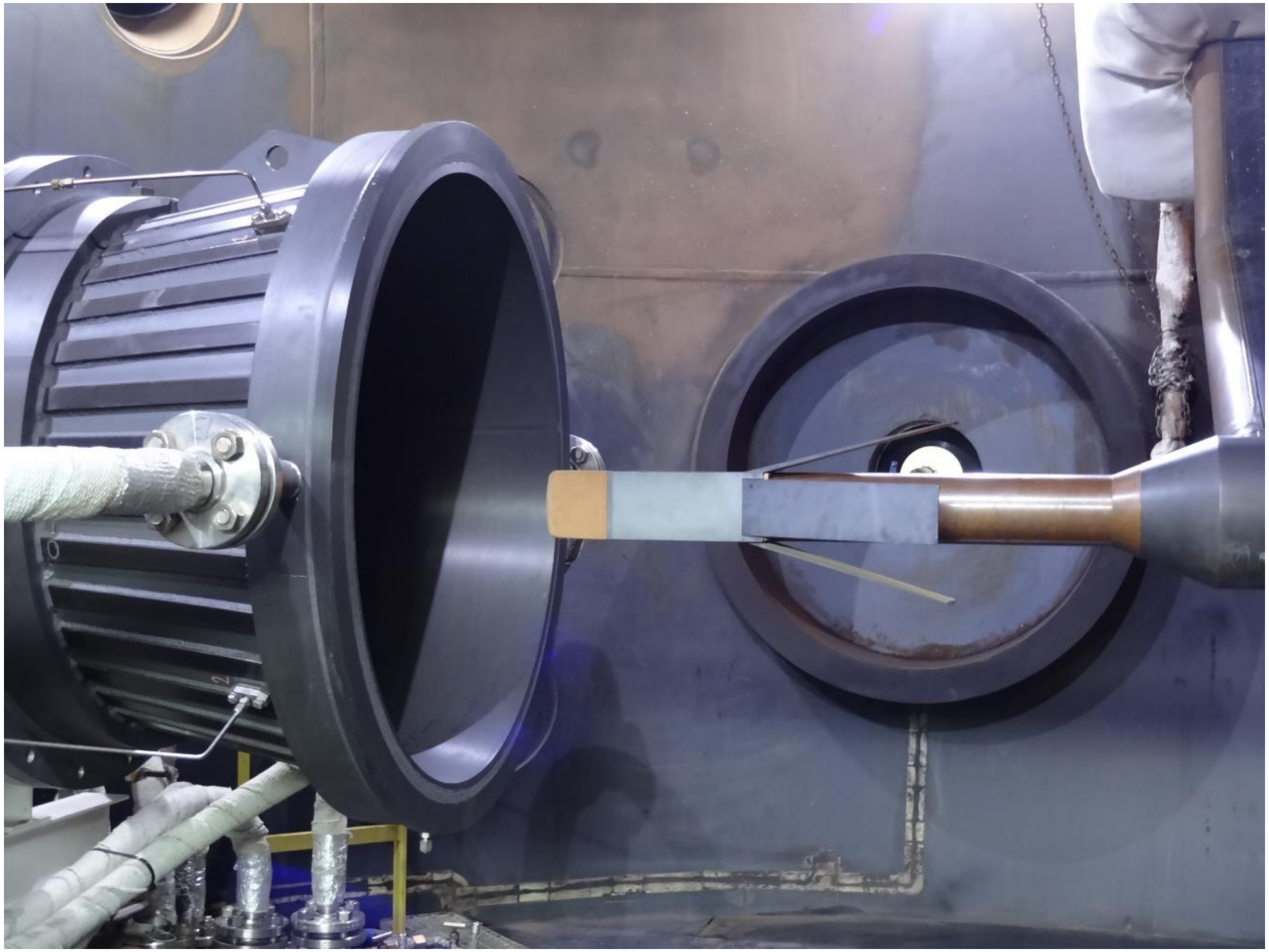
2018-19: Integration and tests

- 29/5 – 3/6/19: final ambient tests



2018-19: Integration and tests

- April 2018: SCIROCCO full scale test campaign (dedicated model)



2018-19: Integration and tests

World premiere in arc jet testing of a full-scale spacecraft - QARMAN re-entry CubeSat in SCIROCCO Plasma Wind Tunnel

CIRA
Centro Italiano Ricerche Aerospaziali

von KARMAN INSTITUTE FOR FLUID DYNAMICS

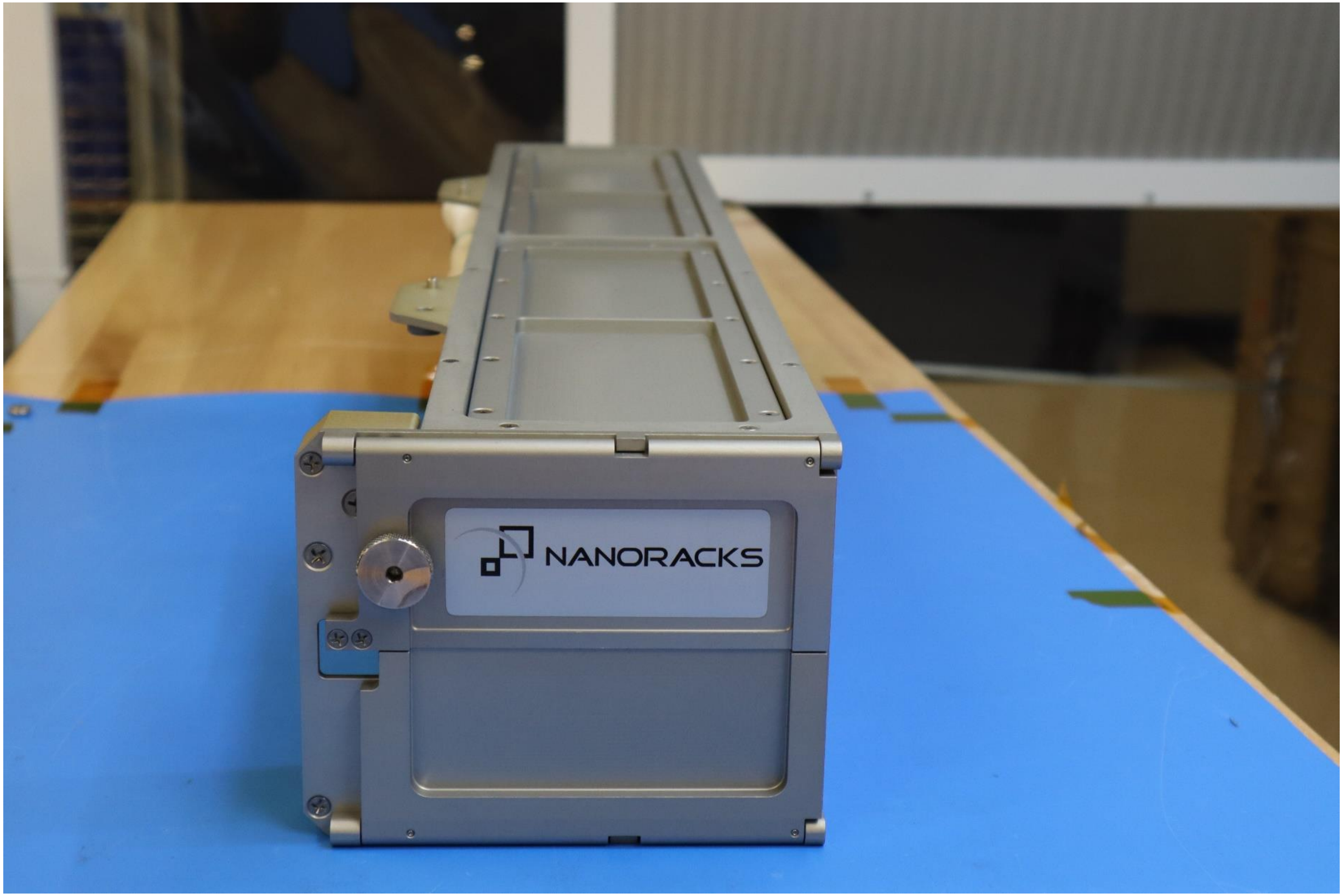
esa

Launch & deployment

- October 2019: integration into the deployer

Launch & deployment

- October 2019: integration into the deployer

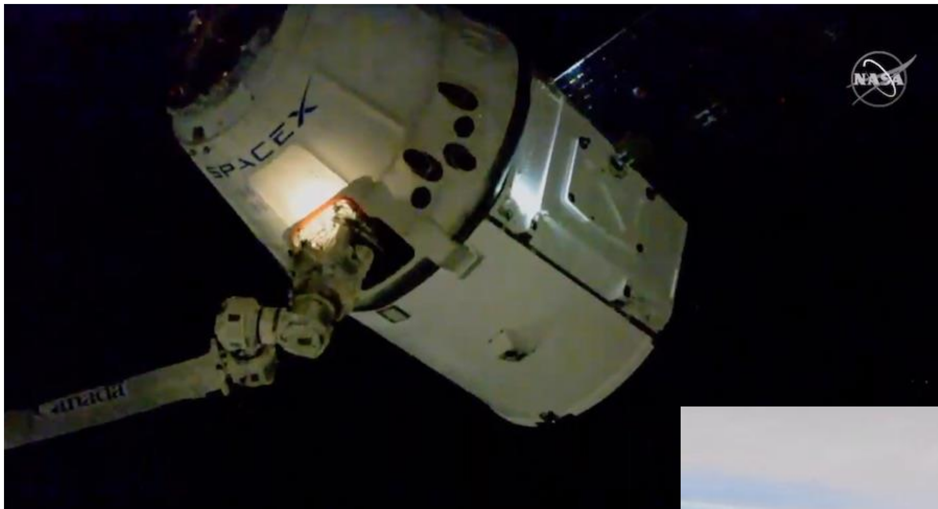


Launch & deployment

- 5 Dec. 2019: launch from Cape Canaveral

Launch & deployment

- 8 Dec. 2019 : docking of Dragon at ISS



(credit: NASA)

Launch & deployment

- 19 Feb. 2020 : release of QARMAN into orbit

Operations

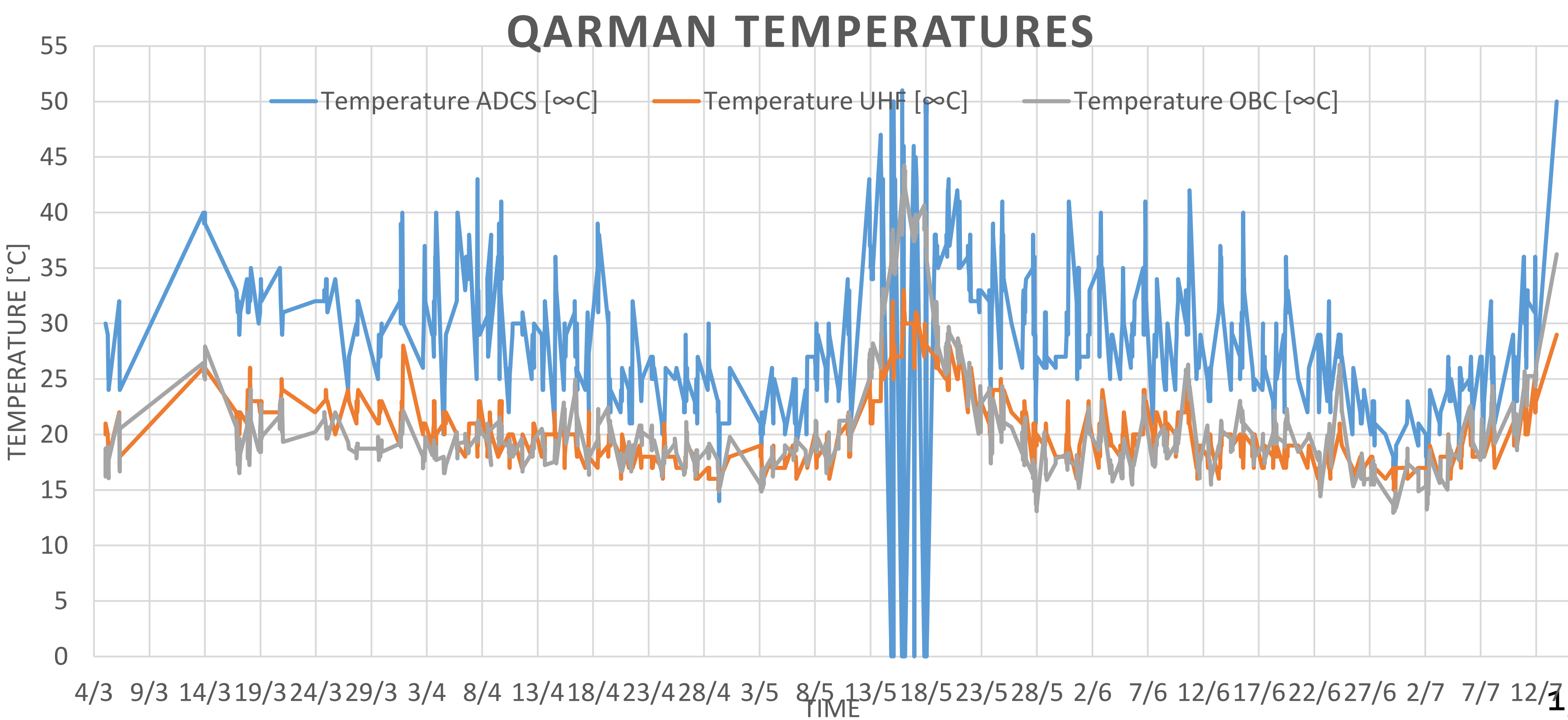
- From VKI ground station
- Receiving data (« beacons »)
- Sending out commands (trying to…)

Mission timeline

- From 19 Feb. : daily reception of beacons
- 24 March:
    - Successful deployment of solar panels
    - First successful commands
- Routine operations
- 14 July: transmission stopped

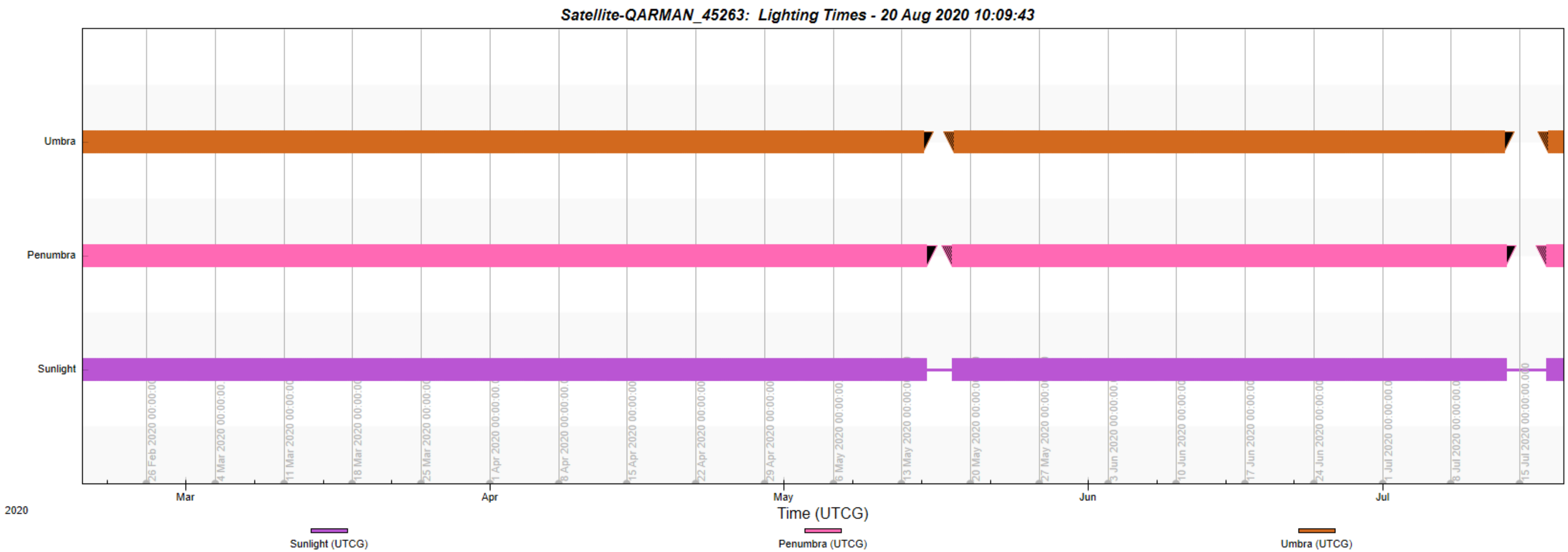
Situation / symptoms

- No beacon received since 14 July 9:22 UTC
- Last beacons show increasing temperatures
- Similar temperature raise also observed in May



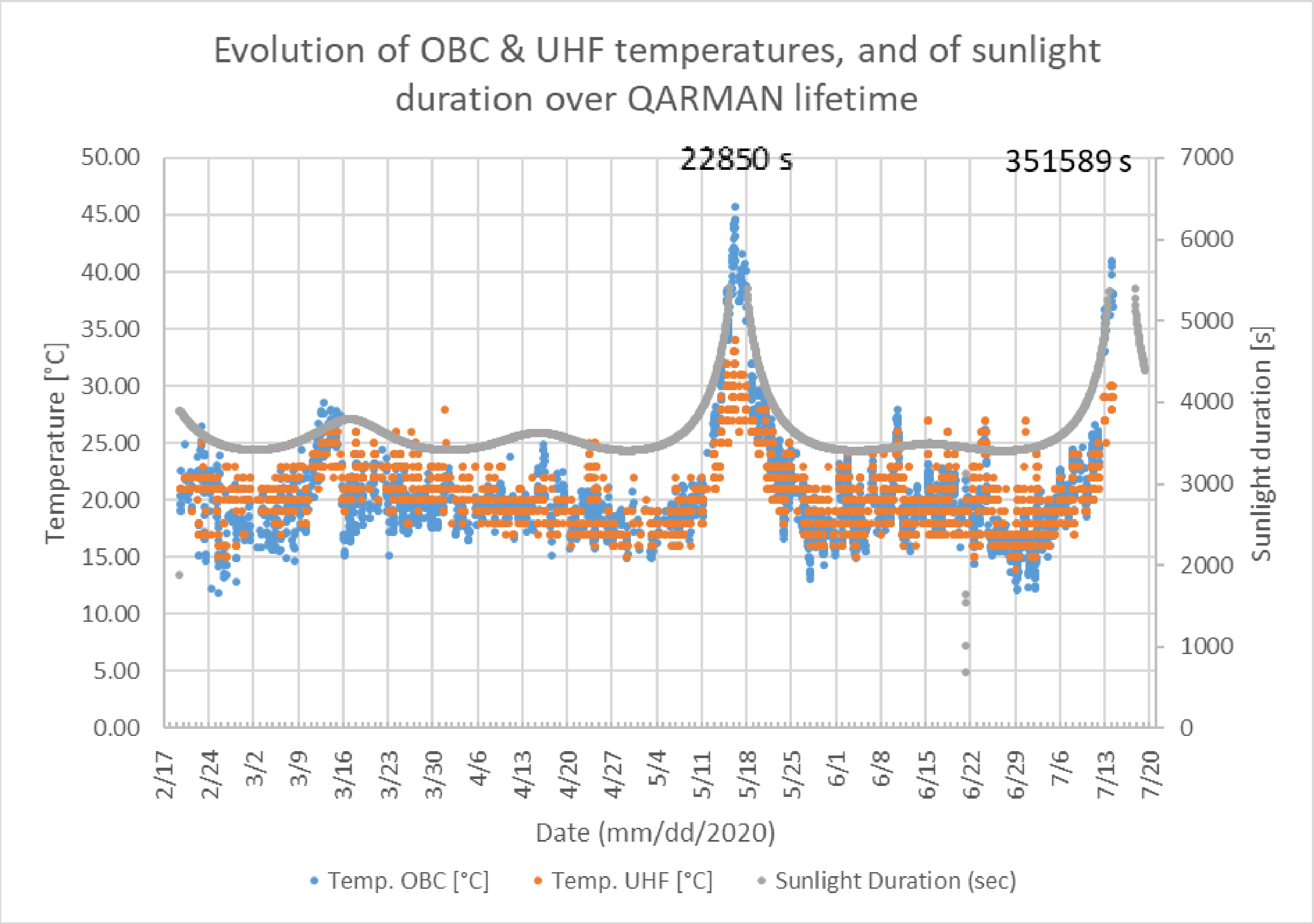
Investigation & analysis

- Sunlight conditions:
  - Typically 60 min sunlight / 30 min eclipse
  - 15/5/20: 63h34min of continuous sunlight
  - 13/7/20: 97h39min of continuous sunlight



Failure analysis – signal loss

- Temperatures seem to follow sunlight duration:



Failure analysis – signal loss

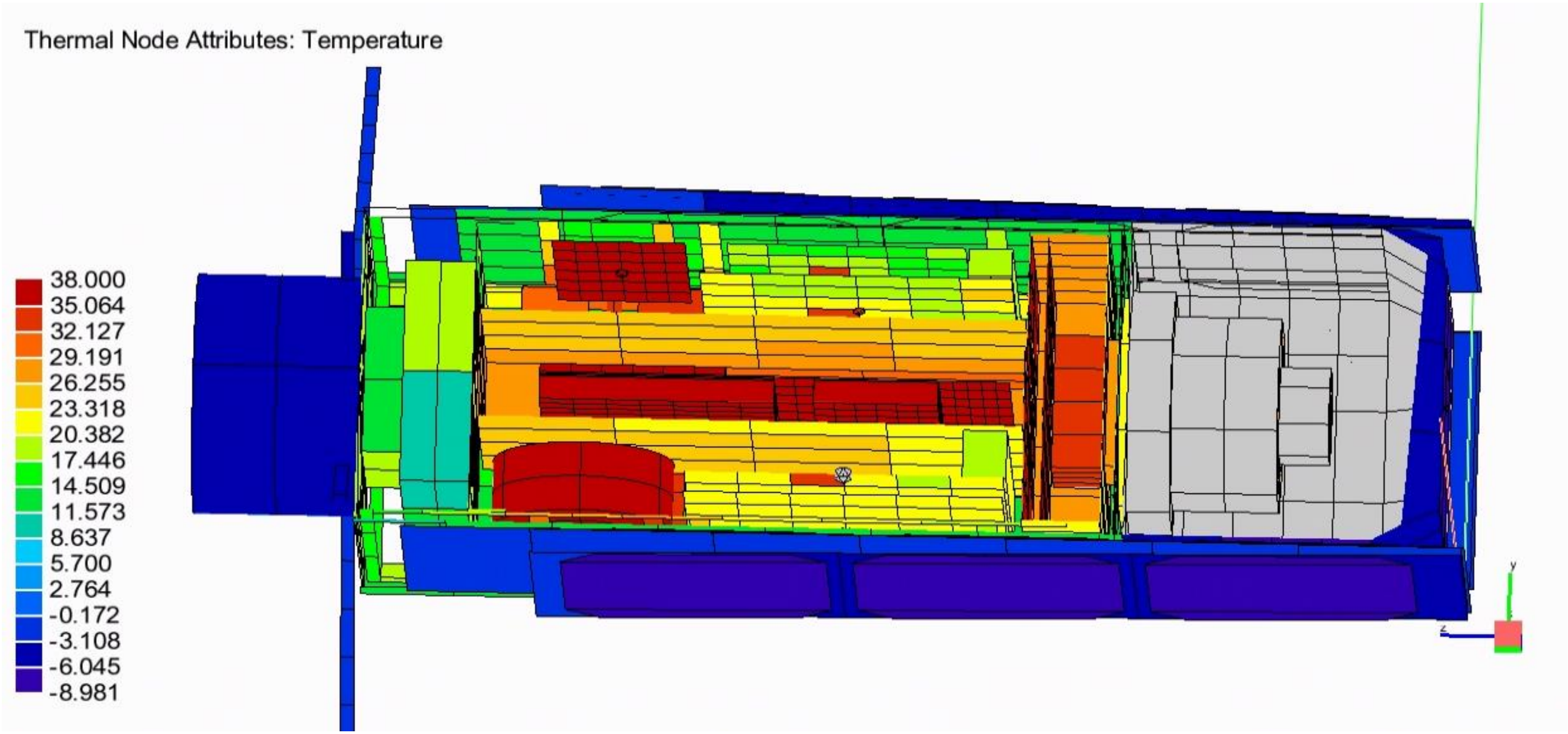
➔Thermal issue? Batteries (LiPo) thermal runaway?

Component	Min Operational Temperature [°C]	Max Operational Temperature [°C]	Min Non-Operational Temperature [°C]	Max Non-Operational Temperature [°C]
Batteries	+0	+50	-20	+50
Flex-EPS (2 boards)	-40	+85	-50	+100
UHF/VHF radio	-30	+70	N/A	N/A
OBC	-20	+85	-55	+105
Iridium Modem/Antenna	-30	+70	-40	+85
ADCS 1 and 4	-10	+60	-10	+60
Spectrometer	0	+ 50 (10 degree/hour ramp)	-30	+70
AeroSDS and XPL DAQ**	-20	+85	-40	+85
GPS	-20	+85		

** Compensated operating range is 0 to +50

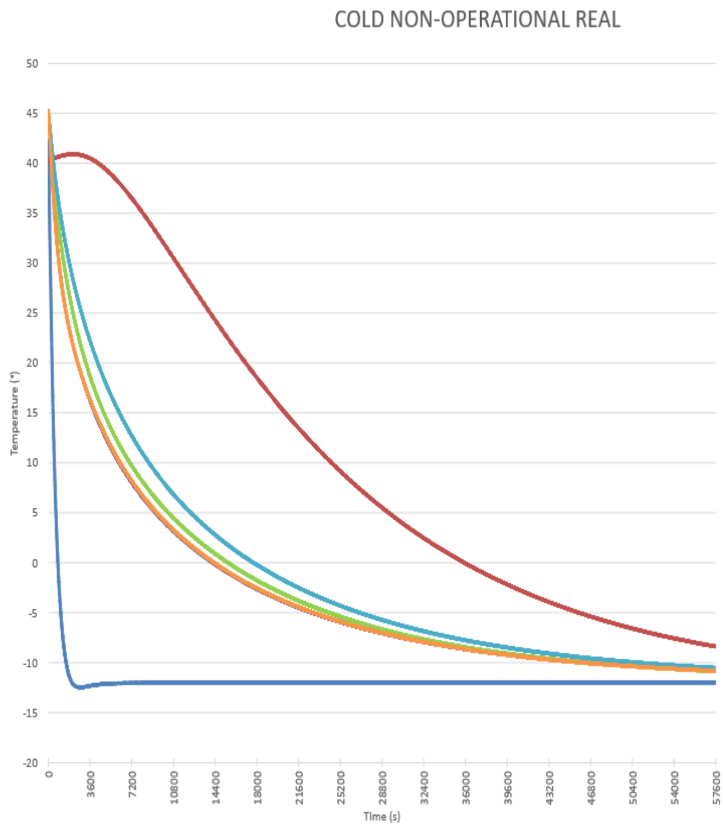
Failure analysis – signal loss

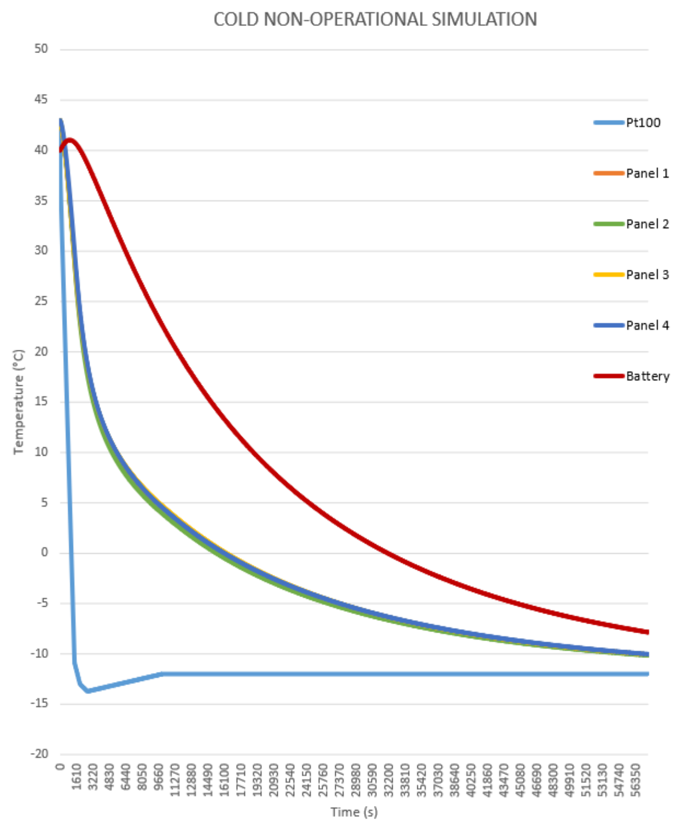
➔ Thermal analysis, including model correlation (TVAC + orbital data)



Failure analysis – signal loss

- TVAC correlation



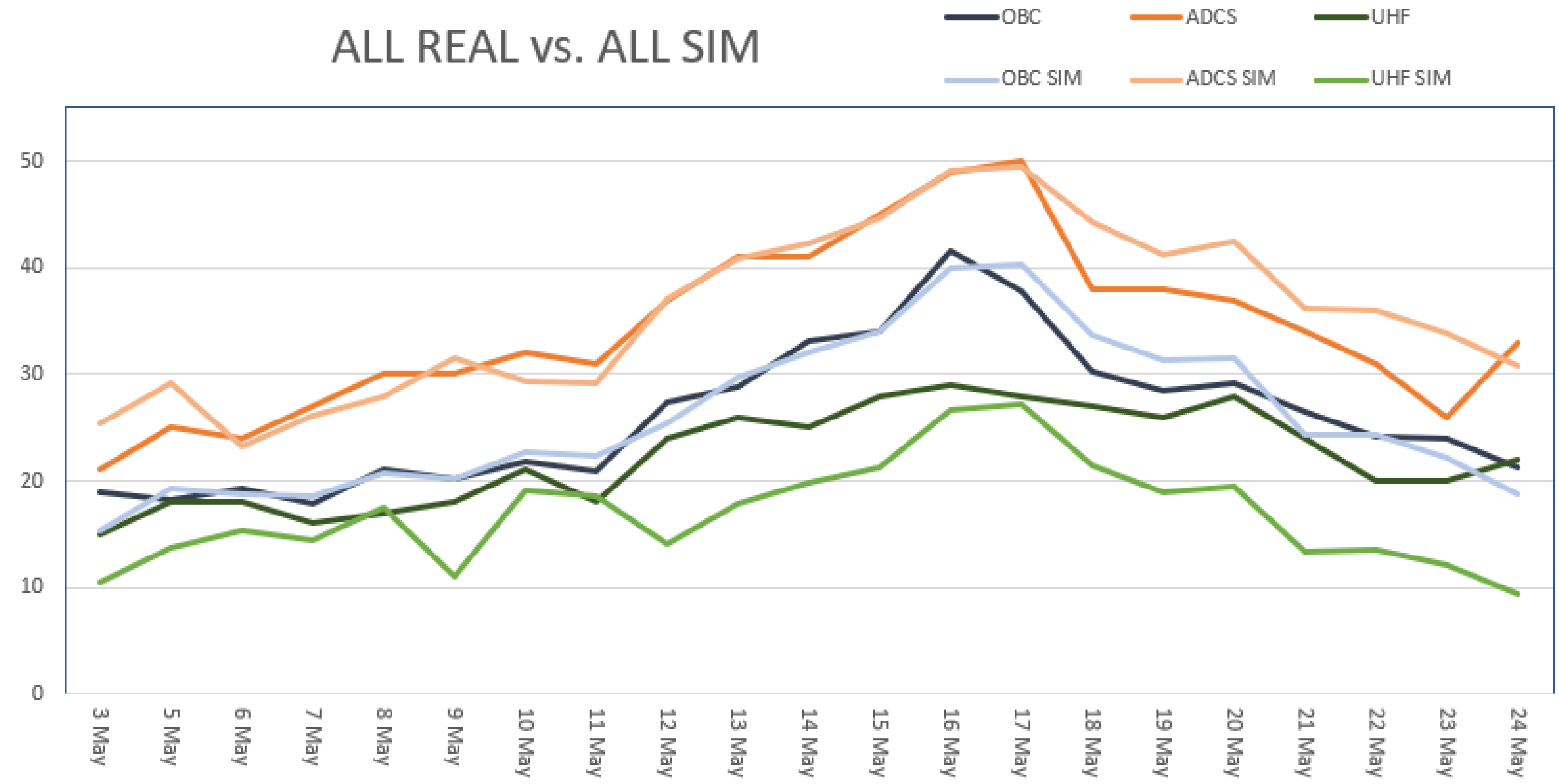


	Panel 1	Panel 2	Panel 3	Panel 4	Battery
START	42,32	44,87	45,24	43,45	40,23
END	-10,89	-10,53	-10,82	-10,58	-8,39
ΔT	53,21	55,4	56,06	54,03	48,62

	Panel 1	Panel 2	Panel 3	Panel 4	Battery
START	43	43	43	43	40
END	-10,0843	-10,157	-10,052	-10,029	-7,857
ΔT	53,0843	53,157	53,052	53,029	47,857

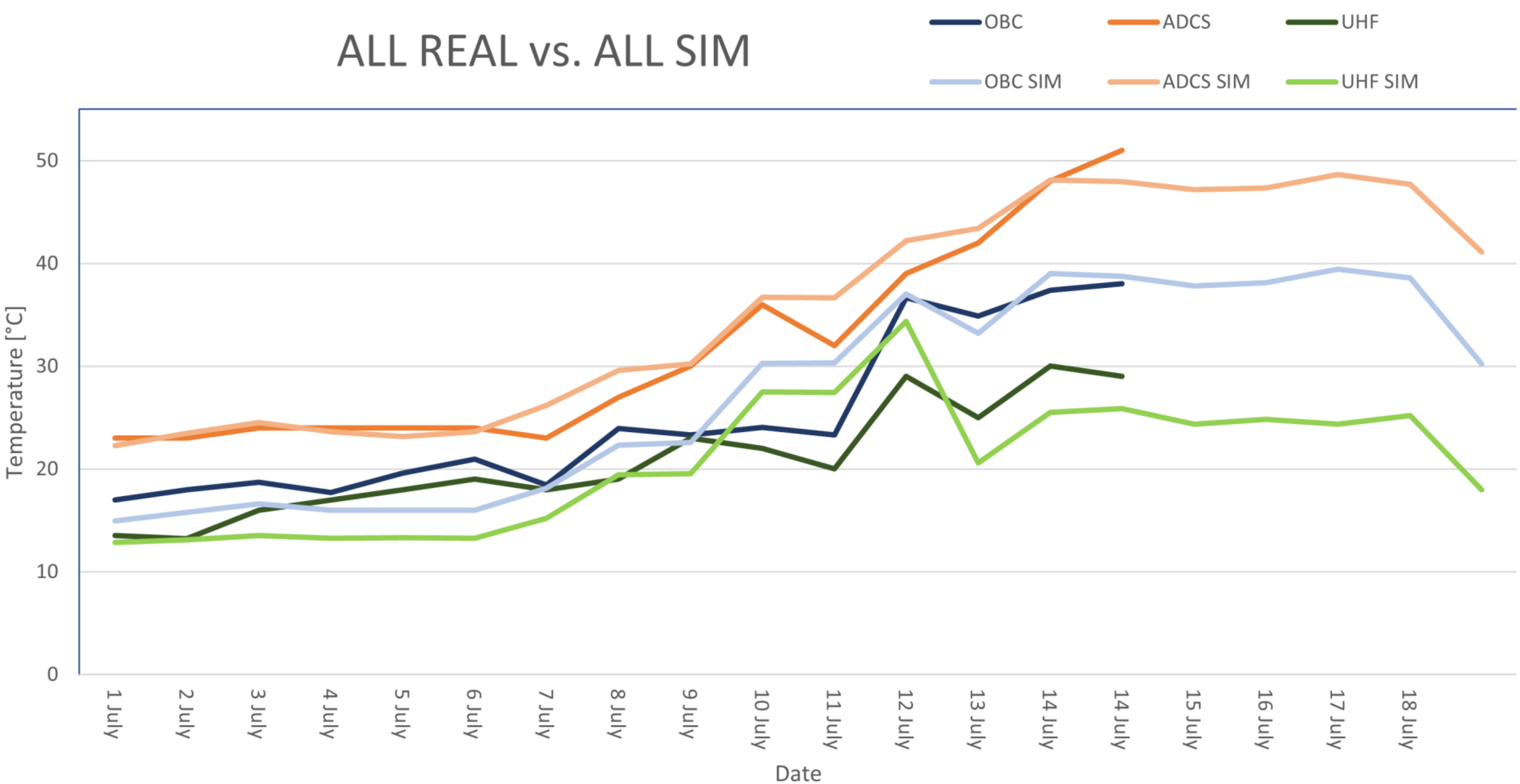
Failure analysis – signal loss

- Orbital correlation (May peak): scarce data, unknown attitude



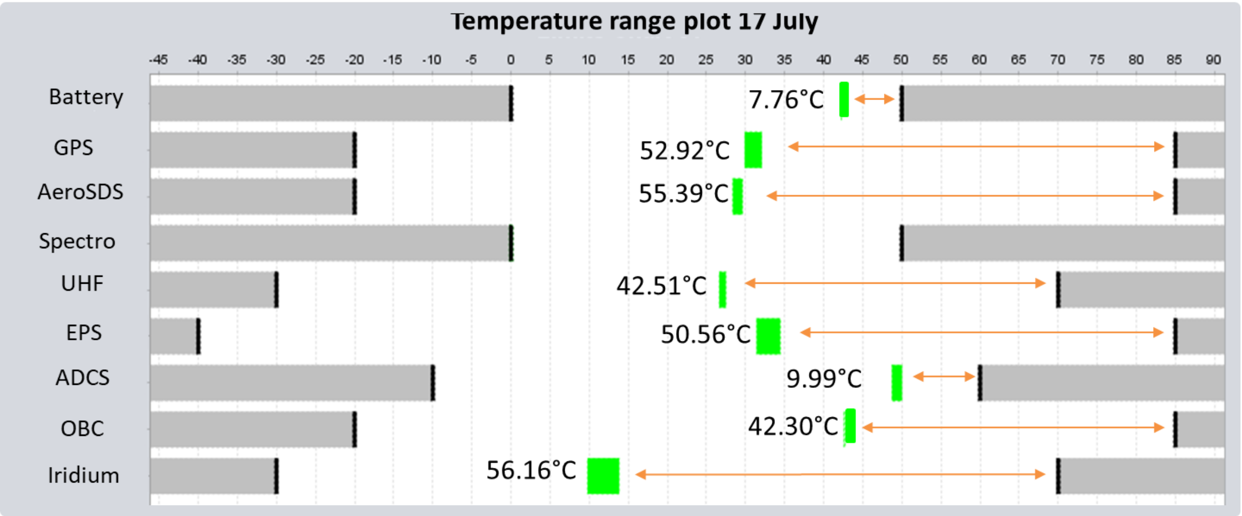
Failure analysis – signal loss

- Correlated model used for July peak



Failure analysis – signal loss

- Correlated model used for July peak



- No equipment out of operationnal range
- Batteries are the closest to their limit, but non-destructive (cfr. ESTEC tests)

➔ Difficult to conclude with certainty

Failure analysis – signal loss

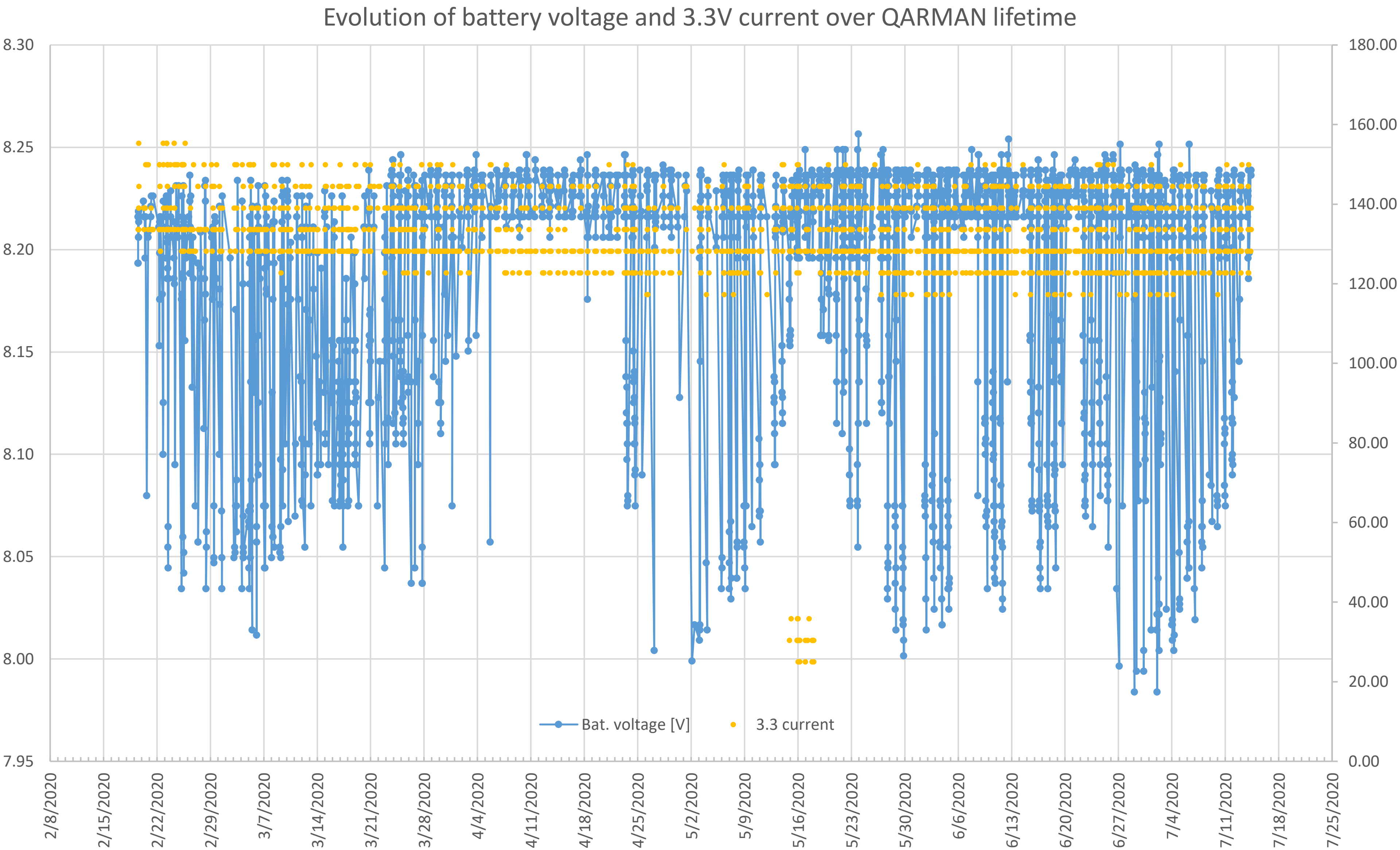
- Consequences on mission:
  - Battery failure ➔ OBC not powered ➔ end of mission

  - UHF transceiver failure

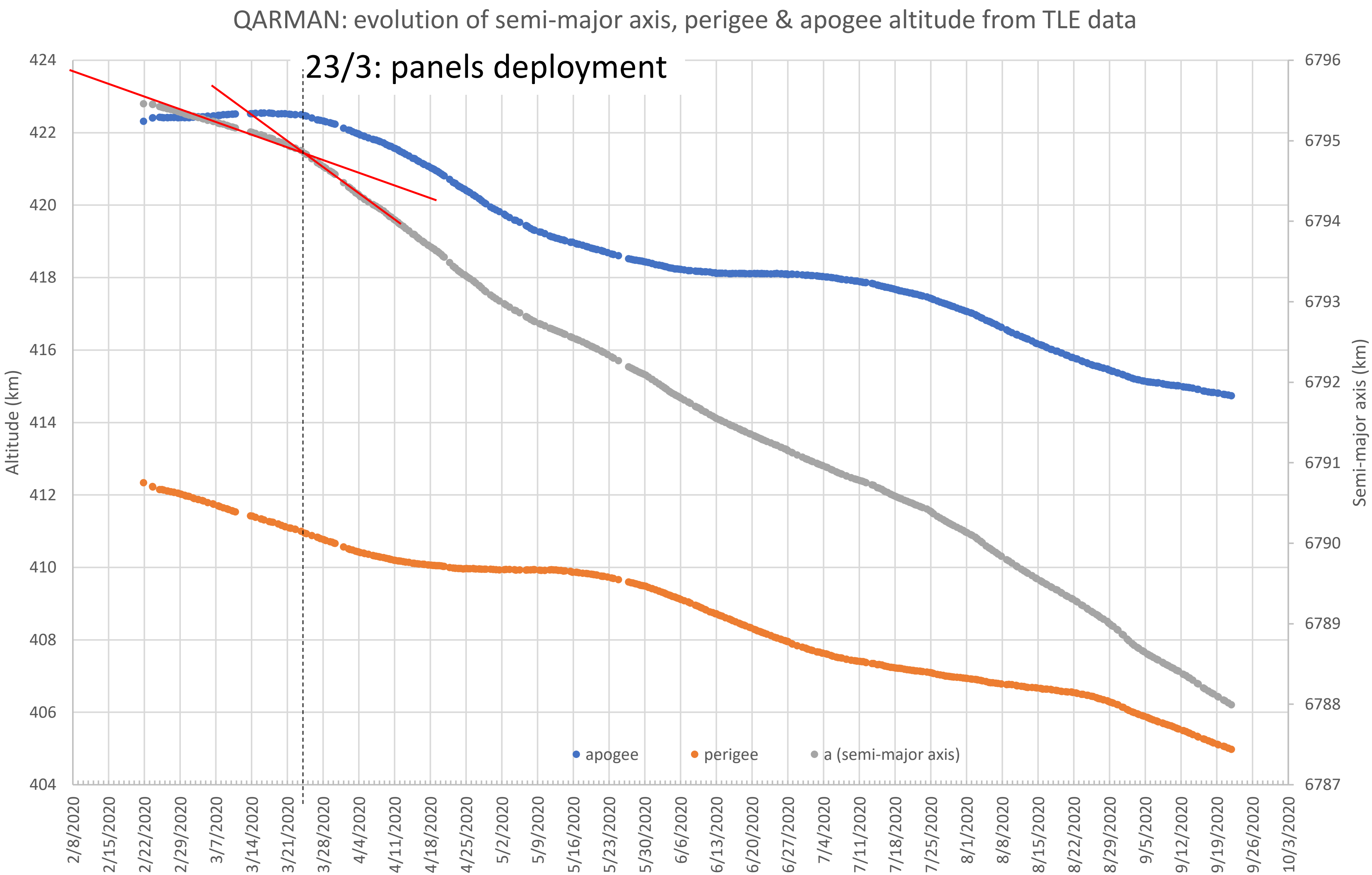
    ➔ mission continue autonomously

    ➔ Ground station and Iridium server kept listening until re-entry

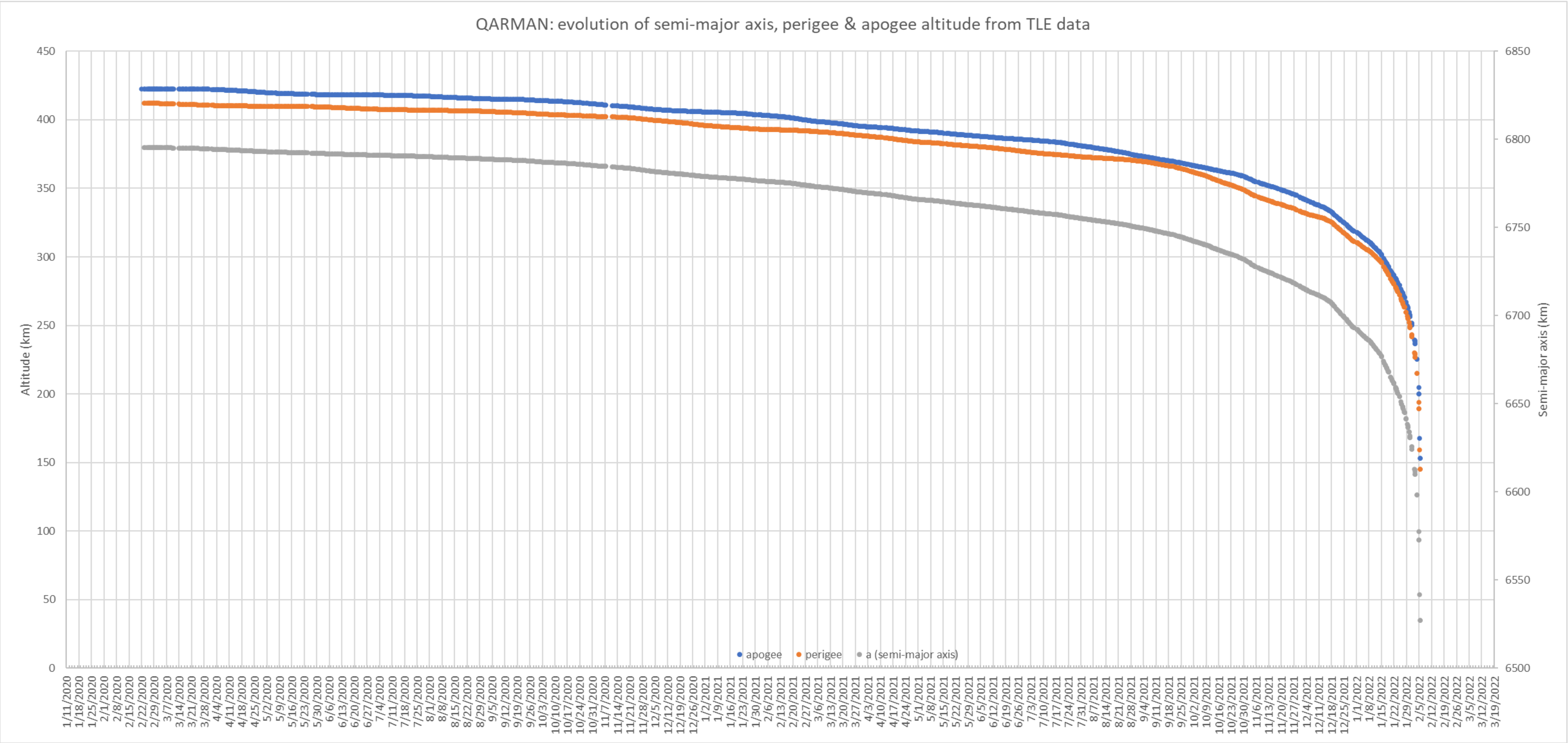
Other orbital data: V_bat



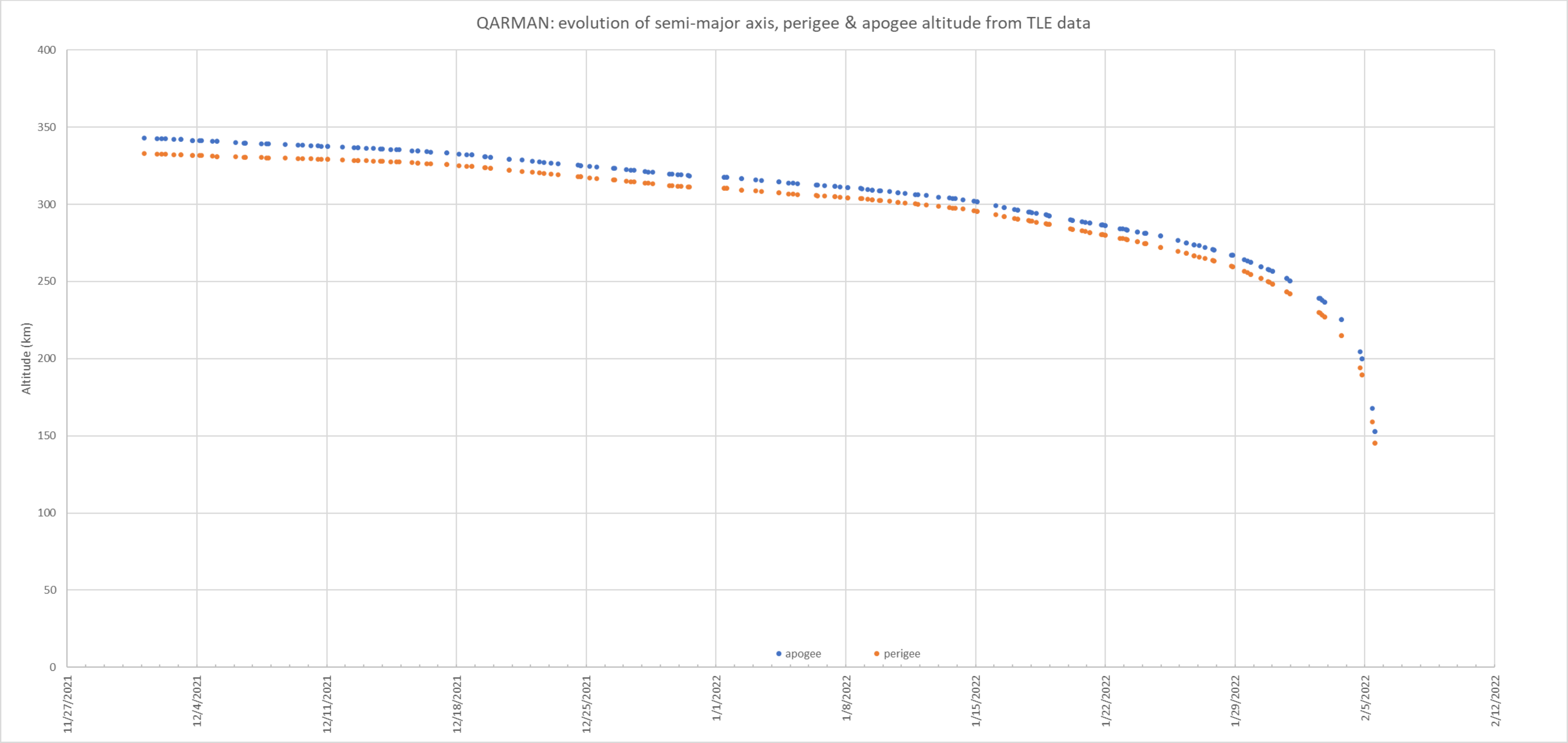
Other orbital data: altitude



Re-entry: 5 February 2022



Re-entry: 5 February 2022



Outcome & achievements

✓ Demonstrate the feasibility of a CubeSat as a re-entry platform:

- ✓ Designed
- ✓ Built
- ✓ Tested
- ✓ Qualified for launch
- ✓ Complying with international regulations
- ✓ Launched
- ✓ Nominal functioning of main subsystems
- ✓ Scale 1 test at Scirocco

✓Technical heritage:

- ✓AeroSDS reached TRL9
- ✓Overall architecture (mechanical + avionics) validated, flight-qualified, operated for 5 months
- ✓TPS + survival units: validated through ground testing + qualified for flight

So many thanks!

- ESA, for their relentless support
- BELSPO
- CIRA, ULiège, ISAE-SUPAERO, ESTEC, amongst other labs
- NanoRacks
- The radioamateur community, UBA, SatNOGS
- The QARMAN team: Isil, Vincent, Cem, Thorsten, Paride, Lamberto, Davide, Gilles, Alessandro, Damien, Remy, Jimmy, Filip, Terence, Ertan & so many VKI colleagues!