A future constellation of CubeSats yielding 10,000 soundings per day

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Foreword

The concept study performed by CNES with some collaborations

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CNES : French national centre for space research
MÉTÉO-FRANCE/CNRM : French national meteorological research centre
IPSL/LATMOS : Atmosphere and Spatial Observation Lab
IPGP : Earth physics institute

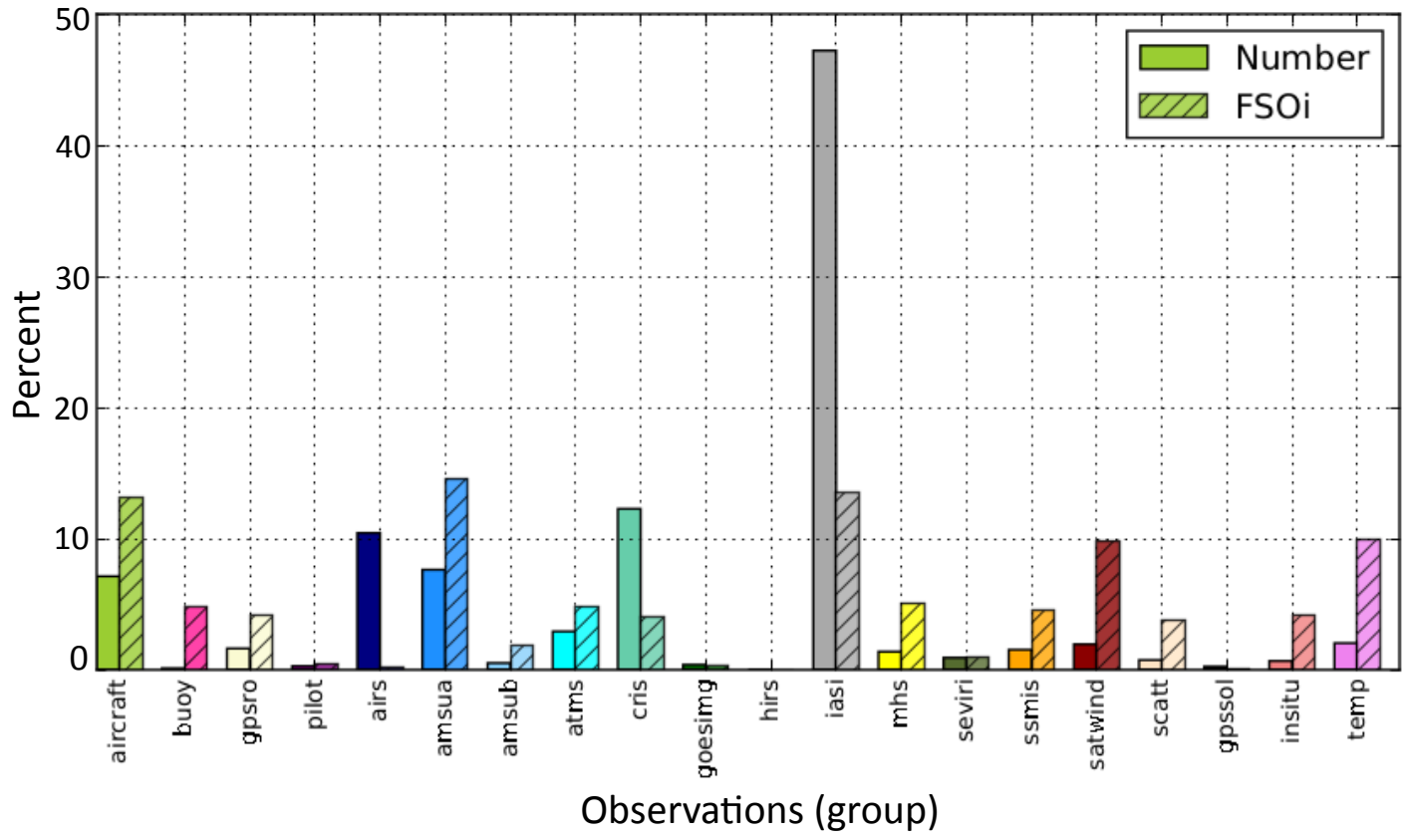
Outline

Outline

Motivation for the mission

Impact of GNSS-RO data on NWP at Météo-France

Percentage of observation types assimilated in Météo-France global model ARPEGE (january 2017) together with the corresponding FSO impact



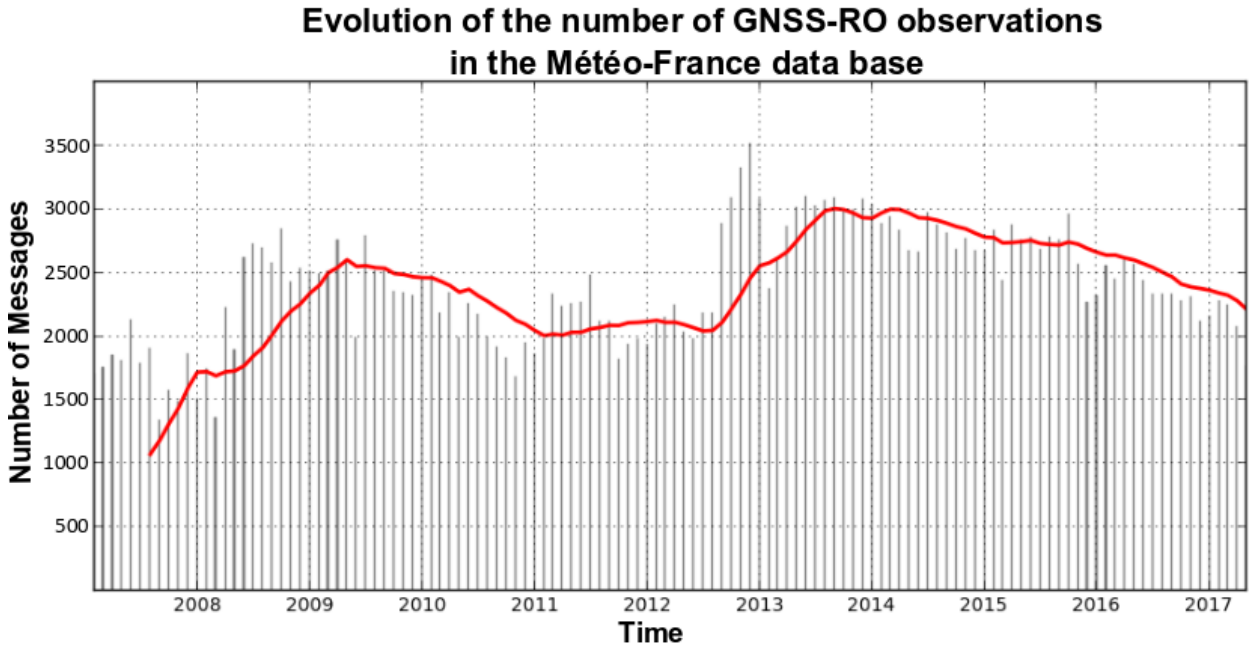
- GNSS-RO represent only **1.7**% of the observations but contribute to the reduction of the forecast error by **4.3**%.

Motivation for the mission

Decrease of the number of available occultations

Current GNSS-RO measurements available for NWP

- Currently 2,500 occultations per day
- Tendency to decrease of the number of available occultations (ending COSMIC-1)



Outline

Objective : increase the number of GNSS-RO data

Targeted number of occultations

- Refering to *Harnisch et al (2013)*, no saturation effect in the impact of the number of occultations per day assimilated by numerical weather prediction models
- Objective of the mission : **10,000 occultations** per day beyond 2025 in addition to the planned operational programs (EPS-SG (METOP-SG), COSMIC-2)

  ► a total of **16,000 occultations** per day beyond 2025.

Outline

Mission requirements

Analysis of the end user needs

Requirements for NWP and climate

- The requirements have to cope with the end user needs while remaining a low cost mission.

	NWP	Climate
Bending Angle Accuracy		
80 to 150 km	4 µrad	
50 to 80 km	3 µrad	
30 to 50 km	2 µrad	
10 to 30 km	0.8 %	
0 to 10 km	0.8 to 5 %	
Vertical Resolution		
50 to 80 km	1 km	1 km
30 to 50 km	500 m	
10 to 30 km	350 m	
0 to 10 km	200 m	
Horizontal Resolution	100 to 200 km	
Data Latency	1 to 3 hours	~ 1 month

Mission requirements

Analysis of the end user needs

Requirements for space weather

- The requirements have to cope with the end user needs while remaining a low cost mission.

	Space Weather
Measurement Accuracy **TEC** **Sensibility** **Scintillation**	 < 3 TECU < 0.1 TECU Amplitude S4 and phase σ_φ
Vertical Resolution **150 to 800 km** **80 to 150 km**	 5 km 1 km
Data Latency	10 to 60 minutes

Outline

A constellation of CubeSats

Small size, low energy, low cost satellites

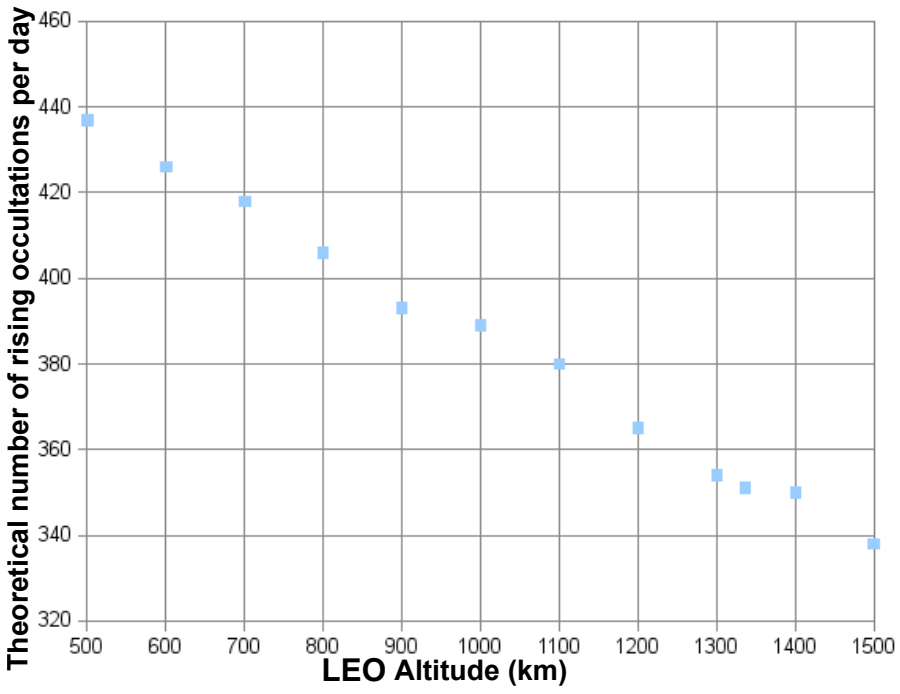
- analysis of the existing preliminary studies based on small satellites
- targets for sizing : use of small GNSS-RO receivers, mass of the instrument 1 kg using a minimalist instrumentation
- consumption of 30 Watts

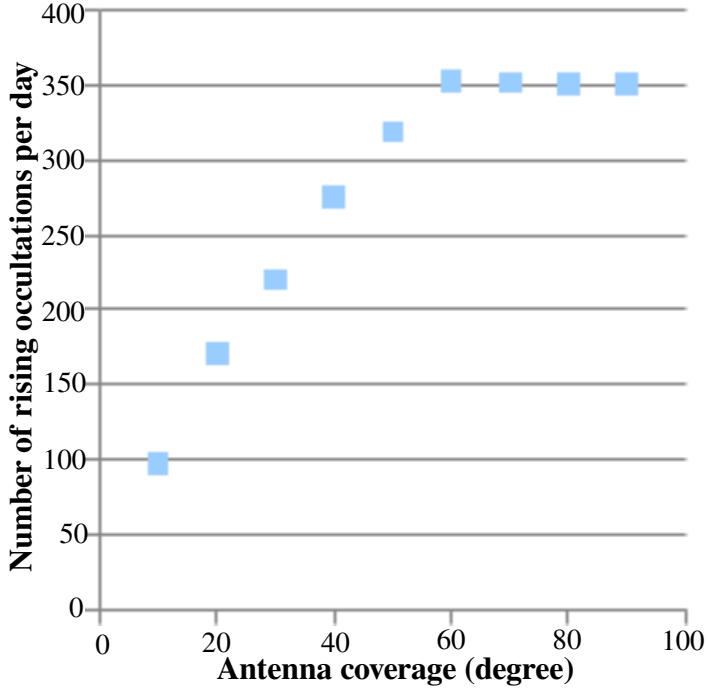
System architecture

Constellation

Number of satellites for a worldwide and uniform coverage

- Depends on the altitude of the LEO, number and coverage of antennas, number of GNSS constellations used





System architecture

Constellation

Number of satellites for a worldwide and uniform coverage

Main options to cope with the 10,000 per day required occultations :

- 2 antennas (speed and anti-speed side) with coverage **40 degrees**
- using **GPS+Galileo** constellations :
  ► need for **8** LEO satellites, altitude **600 km**
- other option : 4 constellations (GPS+Galileo+GLONASS+Beidou)
  ► need for only **4** LEO satellites, altitude **600 km**
  but more complexity regarding the receiver instrument

System architecture

Constellation

Orbital planes

- The number of orbital planes has an impact on the **temporal distribution** of the measurements.
- Main option : **1 orbital plane : 06h** / **18h** for all satellites
  - ► to increase the capacity of the solar panels
  - ► complement the other missions placed on planes with different local hours
  - ► temporal sampling compatible with the needs of NWP

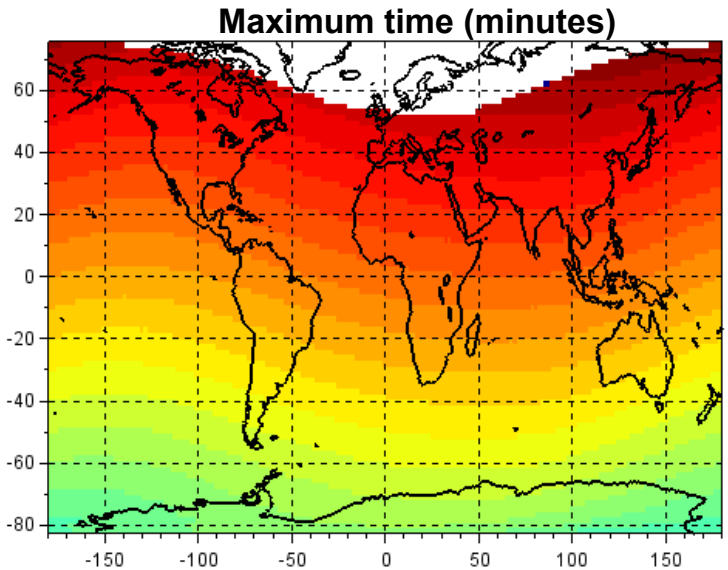
  but doesn't enable climate and space weather to consider the diurnal cycle.

System architecture

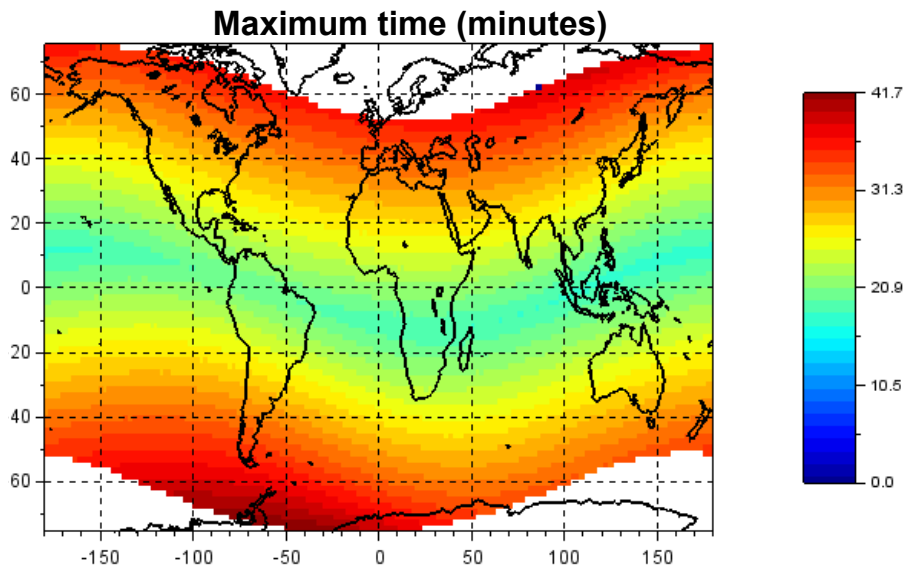
Ground stations

Ground station network

- Maximum data latency with 1 (Northern hemisphere) and 2 polar stations (Northern and Southern hemisphere) :



1 ground station

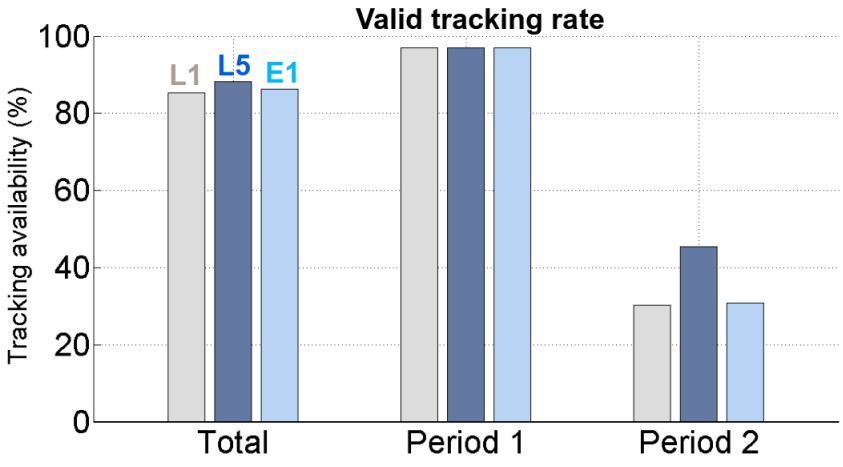


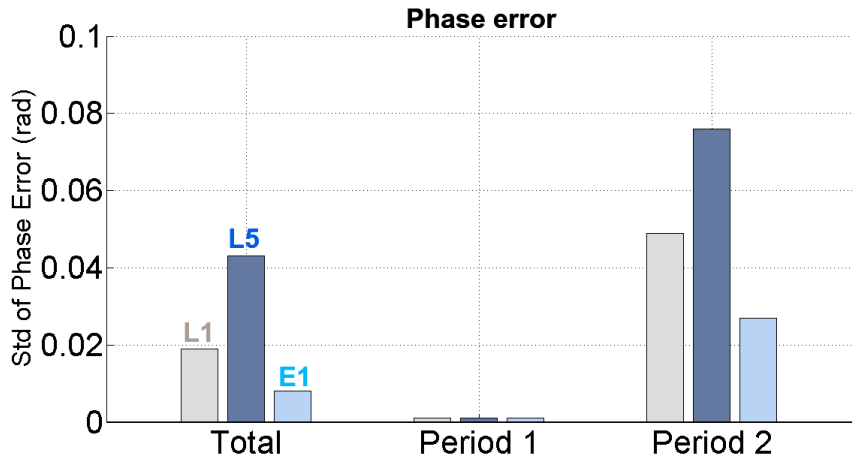
2 ground stations

- Data latency compatible for NWP (target : 1 hour) and space weather (< 25 min in the tropical band) with **2 ground stations**.

Choice of the GNSS frequencies

- Impact of the different GNSS frequencies on the instrumental performances :





- The highest tracking availability and the lowest tracking loss (not shown) for L5
- The most precise phase measurement for E1

  ► Main option : receiver **bi-frequencies** (L1/E1 and L5/E5) and **bi-GNSS constellation** (GPS and Galileo)

- Receiver based on SDR (Software Defined Radio) technique

Payload

Antenna

Requirements

- Capture of GNSS signals from any point on the horizon of the Earth
- Frequency bands L1 and L5
- Minimum gain of 8 dBi *(result of the analysis of the impact of the antenna gain on the instrumental performances)*
- Low dimensions, low mass and low cost

Payload

Antenna

Main technical specifications

- array antenna (favorite option, prefered to aperture antenna) : patch elements (good RF performance, compact, mature technology)

Coverage	Radiation surface (cm × cm)	Maximum gain (dB)	Gain on edge of coverage (dB)
-50°/+50°	15.5 × 31	8.54	5.54
-40°/+40°	**18.5 × 44**	**10.82**	**7.82**
-30°/+30°	24 × 68	13.85	10.85

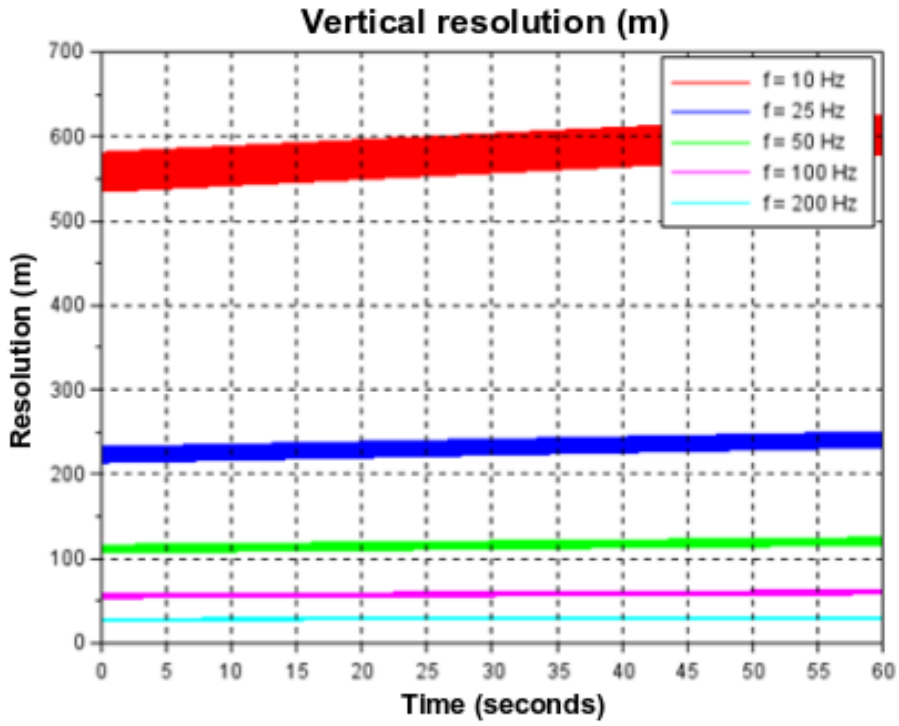
For a gain of at least 8 dBi :

- azimuth (coverage) : +/- 40 degrees around the speed and anti-speed vectors
- small-size antenna : radiation surface (cm × cm) 18.5 × 44

Payload

Antenna

The choice of the sampling frequency of the measurements linked to the vertical resolution targeted performances

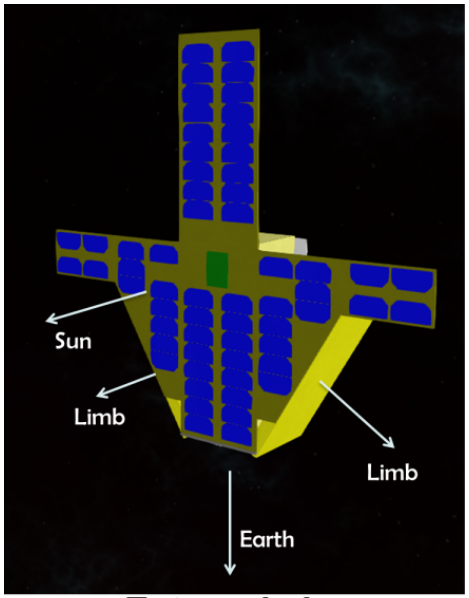


- Frequency of **50 Hz** to satisfy the requirements of vertical resolution ($<$ 200 m)

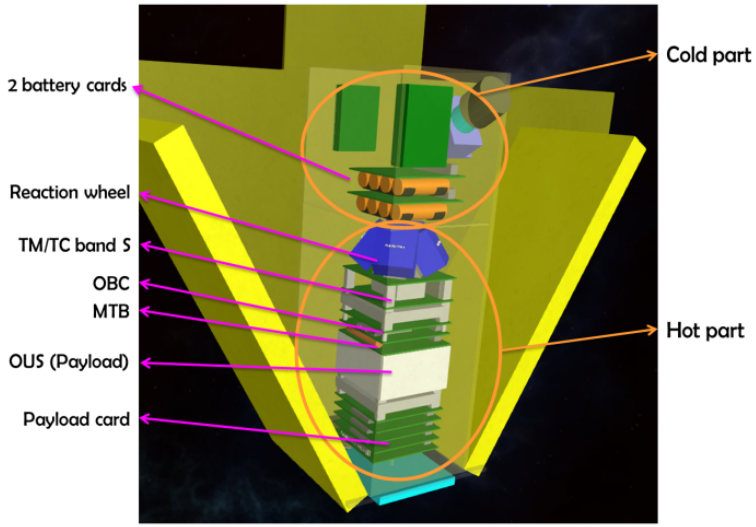
Satellite architecture

Platform as an 'extended 12U'

- Volume : **20** $\times$ **20** $\times$ **50** (cm $\times$ cm $\times$ cm) to accomodate the antennas and the solar generator
- Total mass (payload + platform) : 19.8 kg
- Power system : solar array and battery (42 Ah)



External view



Internal view

Outline

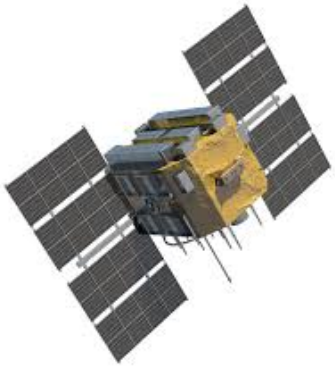
Conclusion and prospect

Progress of the mission

CNES has performed the preliminary design studies of a mission for a future nanosatellite constellation of GNSS-RO receivers :

- targeted number of occultations : 10,000 per day
- main identified technical specifications to meet the end user requirements and comply with the low cost constraint :
  - main planned option for the constellation : 8 LEO satellites, altitude of 600 km
  - 1 orbital plane (06h/18h)
  - receiver bi-frequencies (L1/E1 and L5/E5) and bi-GNSS constellation (GPS+Galileo)
  - 2 polar ground stations
  - array antenna with at least 8 dB gain, 40 degree coverage
  - 'extended 12U' platform
- further underway studies for the different technical options, open loop, new tracking loop . . .

Thank you for your attention !



Any questions ?

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