LES NANO-SATELLITES DANS LES DEFIS DE LA PROSPECTIVE INSU 2020

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CNRS

OBSERVATOIRE DE PARIS & INSTITUT D'ASTROPHYSIQUE DE PARIS

INSU : LES DEFIS DE LA PROSPECTIVE

Défi 12 : nanosatellites

En relations avec le défi « instrumentation en milieux extrêmes » et le défi « capteurs »

Contexte

Séminaire janvier 2020 (Observatoire de Paris et IAP) – un rapport d'étape a été publié

site https://extra.core-cloud.net/collaborations/ProspectiveTransverseINSU2020/

Séminaire de synthèse novembre 2020

Dans l'attente du rapport final INSU

DÉFI 12 : SÉMINAIRE IAP/OP 9&10 JANVIER 2020

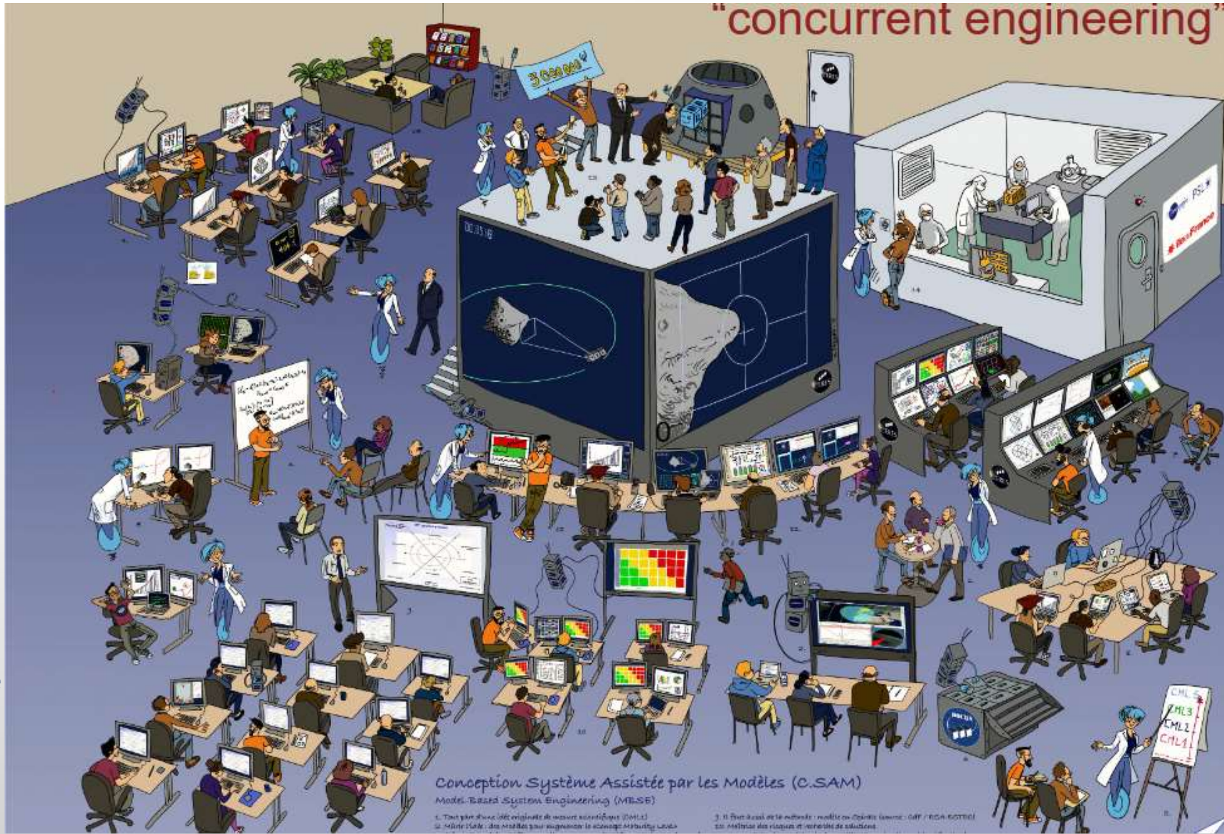
Programme :

1) Etat des lieux de la prospective INSU/AA & CNES
2) Présentations de divers projets (AA, OA &STIC, ST, SHM)
3) Centres spatiaux universitaires et d'établissements
4) Moyens de tests, plateformes d'intégration et de tests
5) Evolution de la loi sur les opérations spatiales
6) Coopérations internationales
7) Visions à plus long terme & conclusions

WHAT IS A NANOSAT ?

Not only a miniaturized satellite ! The development includes a full ecosystem with:

- An end-to-end project, with medium size teams (one laboratory usually)
- Develpment philosophy : **integrated and iterative (« concurrent ingineering »)**
- Short development time (if possible !)
- Close collaboration with teaching projects (internships from graduate or undergraduate levels, PhD thesis)



Crédit : S. Cnudde, LESIA

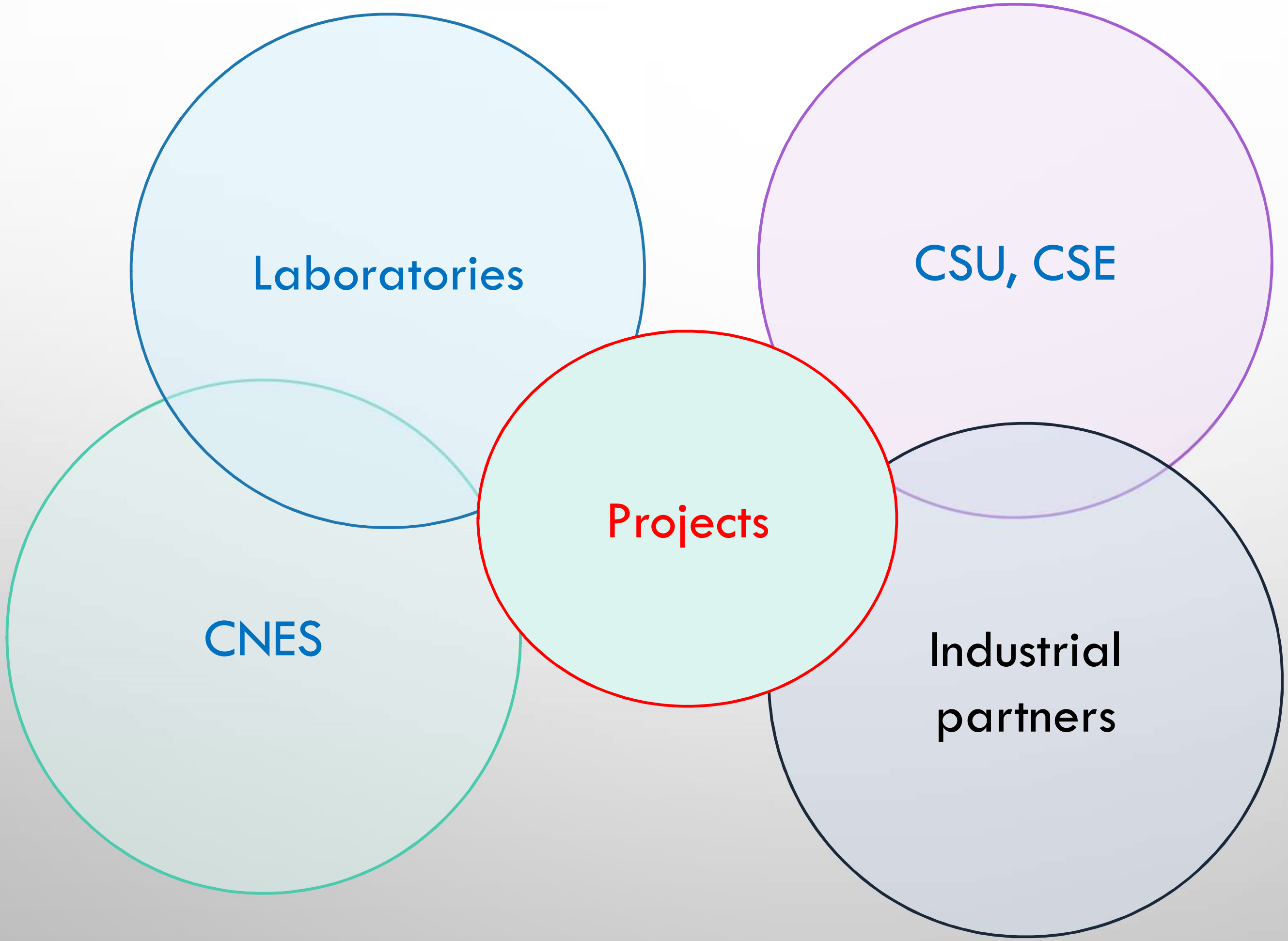
CONSTRAINTS AND BOUNDARY CONDITIONS (1)

- Scientific cubesat/nanosats = projects devoted to science objectives (or technological objectives in preparation of future science objectives) – generic term : newspace
- Excluding commercial developments (telecoms, global positioning, operational developments for meteorology or Earth observations, etc.)
- Excluding direct application domain (technological developments per se)
- A fortiori excluding defense domain activities
- Implication of research laboratories => focusing on science payload more than satellite subsystems
- Not limited to purely student project

CONSTRAINTS AND BOUNDARY CONDITIONS (2)

- Which science objectives are accessible to small systems ?
- Quality insurance : lower level implies higher risk : definition of acceptable risk/cost
- Short development => new strategy for mission phases (AGILE procedures)
- Small systems => high interaction between payload and satellite subsystems
- Research activity : devoted to payload development, but flexibility for platform choices mandatory
- Legal obligations : in France « Loi des Opérations Spatiales » - translation in French juridiction of the international legal obligations

MAIN ACTORS IN THE DOMAIN IN FRANCE



Partnerships involved in the nanosats sector

THE NEWSPACE SECTOR

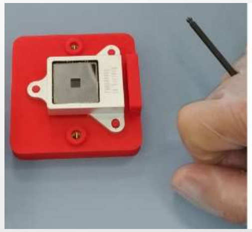
- New access to space for new entities (laboratories, teams)
- Rapidity in development compared to usual programs of space agencies
- Cheap ? (tbc !)
- New institutional actors (university labs not currently involved in the space sector)
- Large involvement of students (internships, PhD)
- Limitation to one or two science objectives => limited number of collaborating laboratories

SOME DEVELOPMENTS IN 2020 (1)

- CNES and CNRS/INSU-Astronomy&Astrophysics prospective – meetings & reports for a growing branch devoted to nanosatellites
- International situation :
  - Many new projects, supported by universities in the context of larger missions (piggy bag)
  - Growing sector for nanosatellites for telecommunication, positioning, teledetection applications
- National Situation in France :
  - Launches since 2019 : Eyesat (CNES/UVSQ), Angels, AmicalSat (IPAG), UVSQ-sat (UVSQ)
  - Reorganization in CNES with two branches : student programs (Janus) and research program with nanosatellites
  - The network of CSU/CSE is being coordinated : mutualisation, information sharing, collaborations in progress
  - Several platforms available for nanosatellites (U-Space, NEXEYA, ISIS)

SOME DEVELOPMENTS IN 2020 (2)

- Subsystems including developments with startups or micro-enterprises
    - Launchers
    - Structural models(« testpods »),
    - Attitude control
    - Micro-propulsion
    - EGSE
    - Ground Segment (including communication facility



- In the lab : science payload, software development, operation

CHALLENGES

- Technical support for the H/W development => through dedicated space campus (testing, integration)
- Strong administrative support needed for the projects
- Budget to find outside general scientific programmation by agencies
- **Are there first order science objectives accessible to the newspace sector ?**

(the tendency today is towards a positive answer)

LIST OF PROJECTS IN STUDY OR IN DEVELOPMENT AT VARIOUS STAGES IN FRANCE

Domain	thematics	Observations	Missions	type of nanosatellite
Atmosphere, Ocean, Surfaces	Clouds (microphysics and dynamics)	3D imaging	C3IEL, C2OMODO	Train LEO
Atmosphere, Ocean, Surfaces	Soil humidity	microwave interferometry	ULID	Cluster LEO
Ocean, Solid Earth, Continental surfaces	Dynamics of ocean and ices	Earth gravity	MARVEL	Cluster LEO & MEO
Ocean	Ocean surface dynamics	Solar reflection	GLISTERO	Isolated satellite
Continental Surfaces	Hydrologie continentale	Nadir altimetry	SMASH	Constellation LEO
Solid Earth, SHM	Intern Earth	High precision magnetic field	NanoMagSat	Constellation LEO
Astronomie	Source localisation	chronometry of pulsars	CubeSatGRB	Constellation LEO
Exobio-Exoplanètes	Biologie in space environment	biological experiments		Isolated satellite
Exobio-Exoplanètes	Planetary exploration	imaging spectroscopy		additional payloads
Solar System	Small bodies	imaging spectroscopy	HERA, mission F ESA, Zhenghe CNSA	additional payloads
SHM, Solar System	Martian Environment	Field and particles	RENSEM	Martian constellation
SHM	Earth magnetospherer and Space Weather	Field and particles	NUAM, CIRCUS	Constellation LEO

Domain : today only in Science of the Universe – Future : human sciences ? Sociology (habitat) ; archaeology, etc.

CHOICE OF EXAMPLES

Among dozen of projects and three still flying, a nanosat project launched in 2018 :

- PICSAT – 2018 : a failure, but a very productive failure

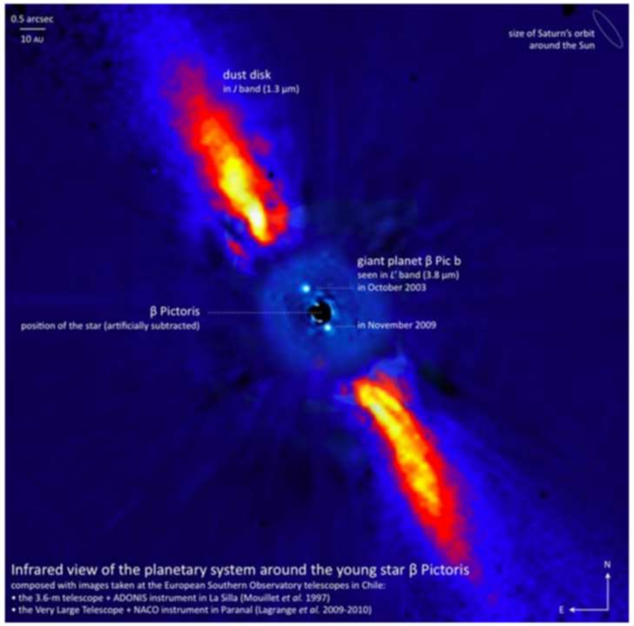
Among 12 Space campus in France

- CCERES -> CENSUS in Meudon Observatory

Preliminary design: 1) A good science case

β Pic : a young planetary system

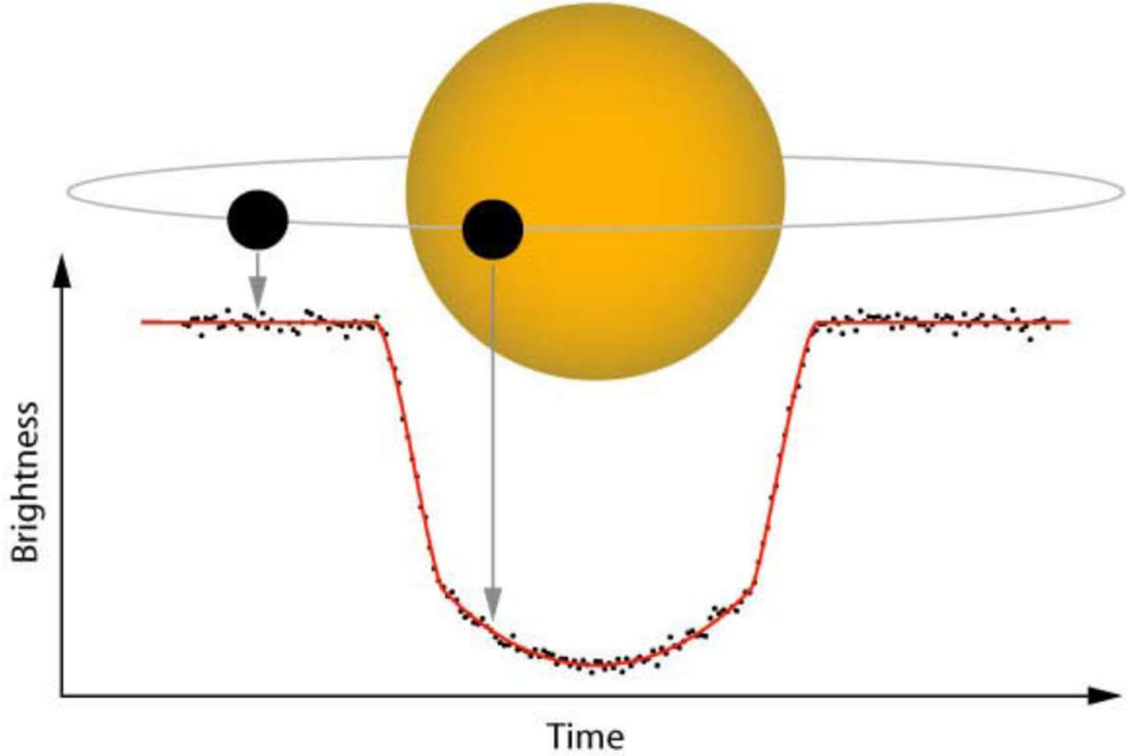
- First sight of the planet: 2003 (Lagrange et al. 2009)
- Six years later: planet on the other side of the star



l'Observatoire de Paris — LESIA

Sylvestre Lacour, LESIA (Presentation at Paris Observatory, January 2020)

Preliminary design: 1) A good science case

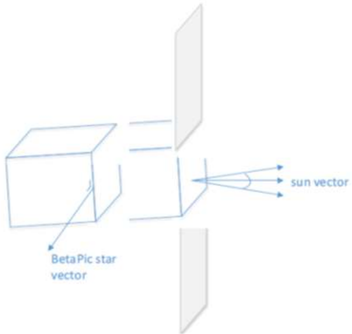


Sylvestre Lacour, LESIA (Presentation at Paris Observatory, January 2020)

Preliminary design: 2) A creative design

ISSUE 1: STRAY LIGHT

- Main difficulty because
  - It does not fit in a CubeSat



Baffle, COROT mission, Liège

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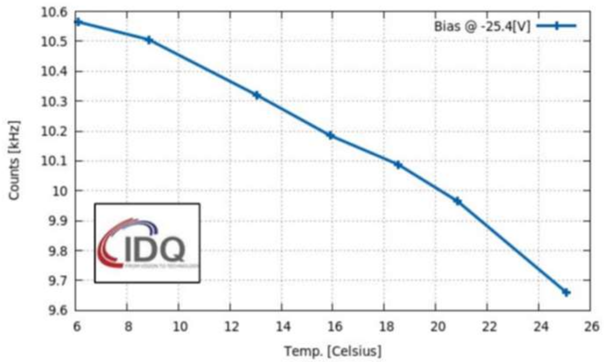
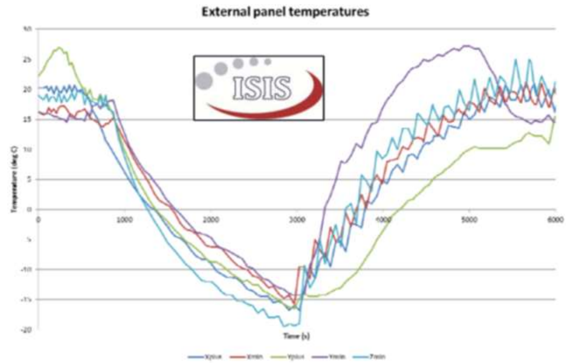
Preliminary design: 2) A creative design

ISSUE 2: TEMPERATURE CONTROL

- Does affect:
  - Optical setup (focus, etc..)
  - Detector (gain varies by ~0.4% per degree Celsius)



Detection as function of temperature of detector
(mesurement by ID Quantique)



Temperature of CubeSat satellite
SSO – 600km – LTAN 10:30AM
(mesurement by ISIS)

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Preliminary design: 2) A creative design

ISSUE 3: POINTING ACCURACY

- PSF size of 0.001° :
- Choice between over sampling or under sampling the PSF
- inter-pixel gain variations
- Gap between pixels

XACT Capability	
Specification	**Performance**
Spacecraft Pointing Accuracy	± 0.003 deg (1-sigma) for 2 axes ± 0.007 deg (1-sigma) for 3rd axis
Spacecraft Lifetime	3 Years (LEO)
XACT Mass	0.85 kg
XACT Volume	10 x 10 x 5 cm (0.5U)
XACT Electronics Voltage	5V
XACT Reaction Wheel Voltage	12V
Data Interface	RS-422 (can support I2C and SPI)
Slew Rate (8kg, 3U CubeSat)	[illegible]deg/sec

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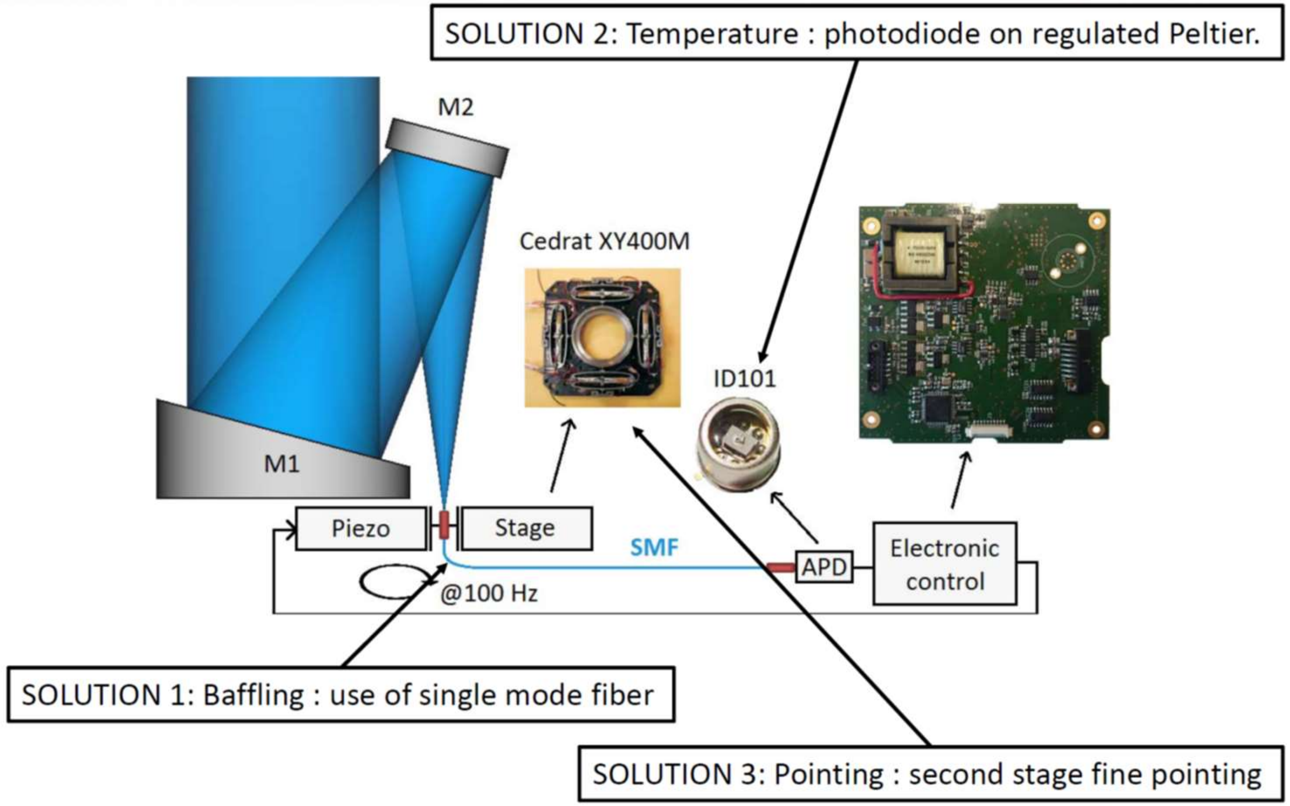
Preliminary design: 2) A creative design



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Preliminary design: 2) A creative design

PICSAT

Star

- Beta Pictoris
- RA=5h, dec = -51°
- Vmag= 3.8

Requirements

- Observability:
  - 1 point each hour
- Photometric Accuracy:

	Parameters	Error	Error (ppm/hour)
Photon noise	Nphoton = 10^5 ev/s	1./Sqrt(Nphoton)	60
Readout noise	0	0	0
Dark noise	Ncurrent = 10^3 ev/s	Sqrt(Ncurrent / Nphoton)	6
Scattered light	Nmoon = 150 ev/s	Nmoon / Nphoton	77
Thermal stability	sT = 0.01 °C	0.4% per °C	40
Voltage stability	sV = 100uV	20% per Volts	20
Pointing accuracy	Delta Inj=5% @ 100Hz	Delta Inj x sqrt(t*100Hz)	83
Stellar variability	1mmag	Correction 10%	100
TOTAL			**168**

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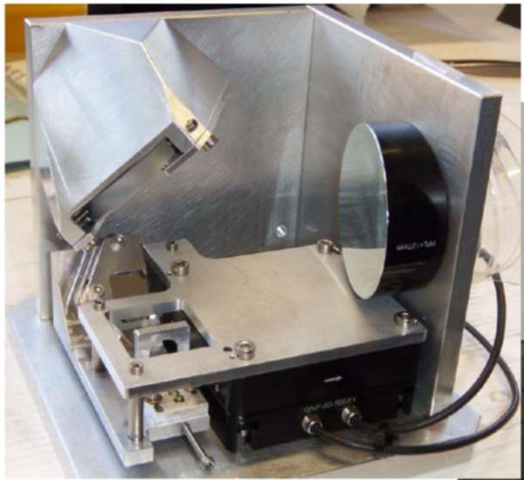
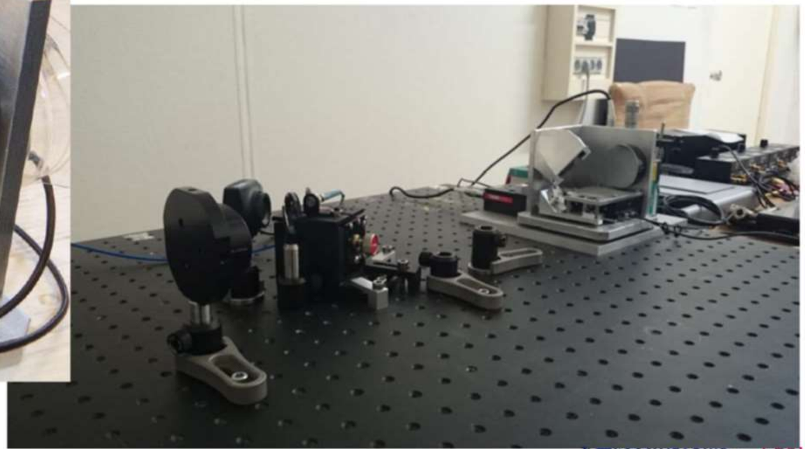
1. FAISABILITY

SUMMER 2015

- First bench to demonstrate that the concept:
  1. Fit into a 10cm³ volume
  2. Tracking algorithm





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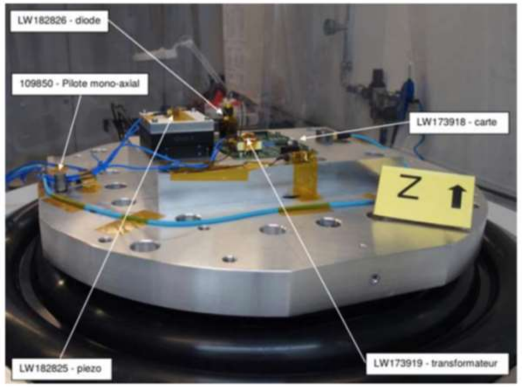
2. QUALIFICATION

WINTER 2015

- Vibration tests / Thermal cycles / Radiation tests
  1. Electronics
  2. Detector
  3. Piezo



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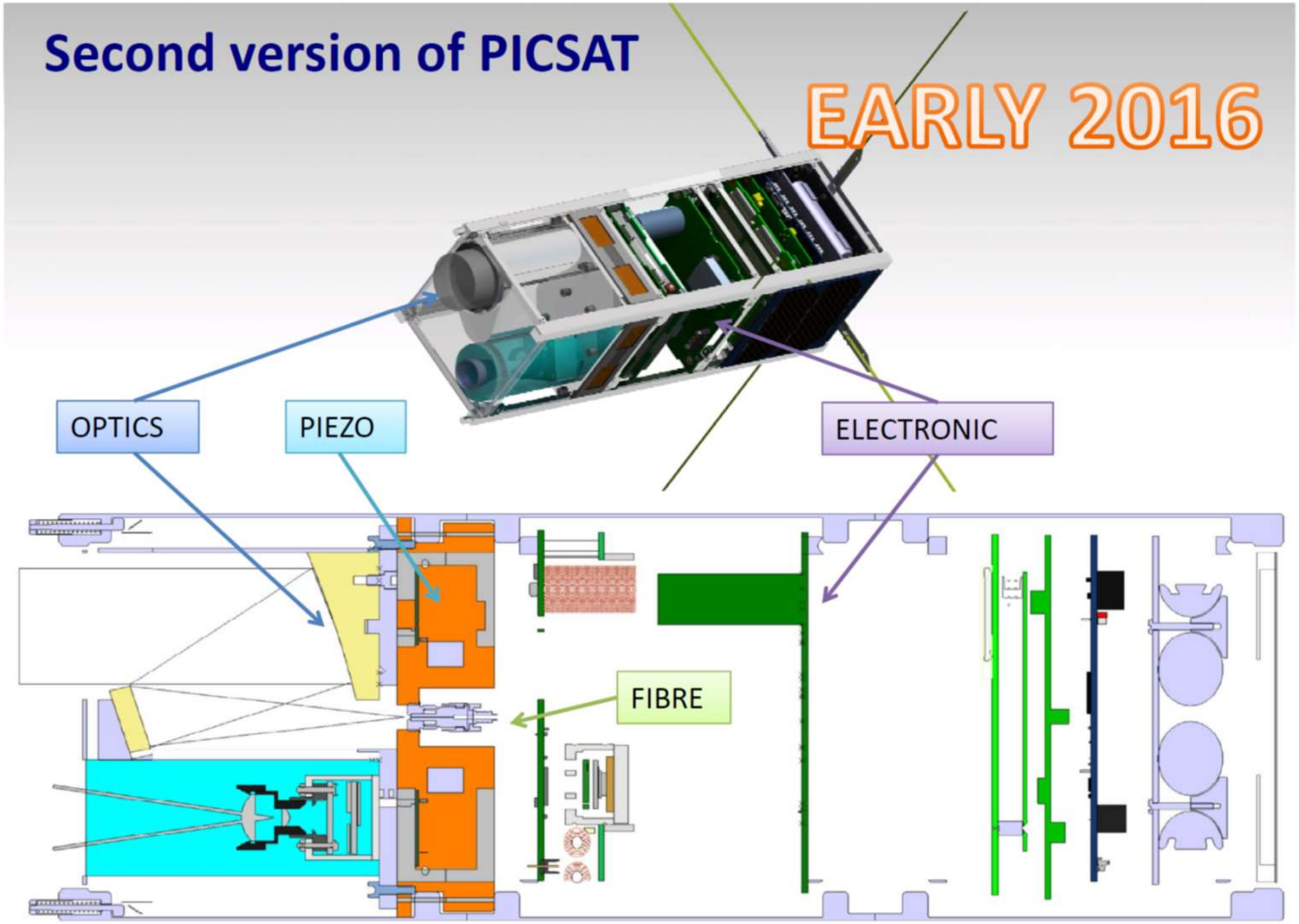

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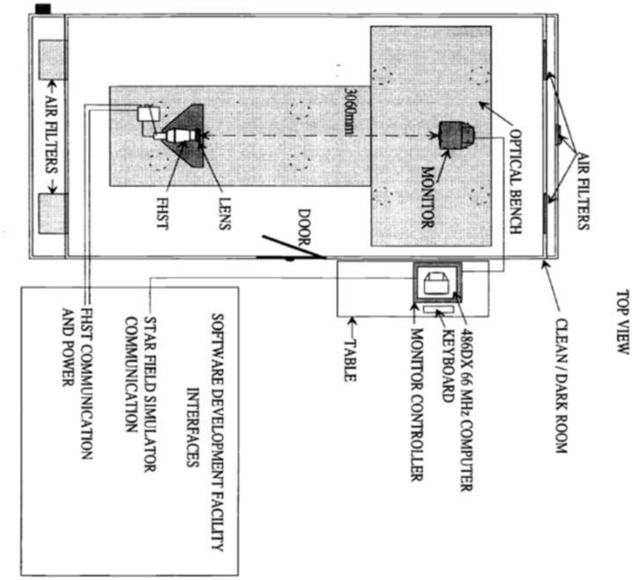
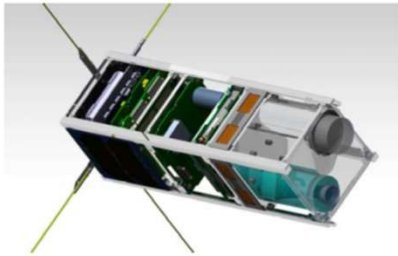
3.VALIDATION

SUMMER 2016



« Star field simulator for the Spacelab instrument pointing system fixed-head star trackers »
Wessling & Van DerDoes, SPIE, 1994



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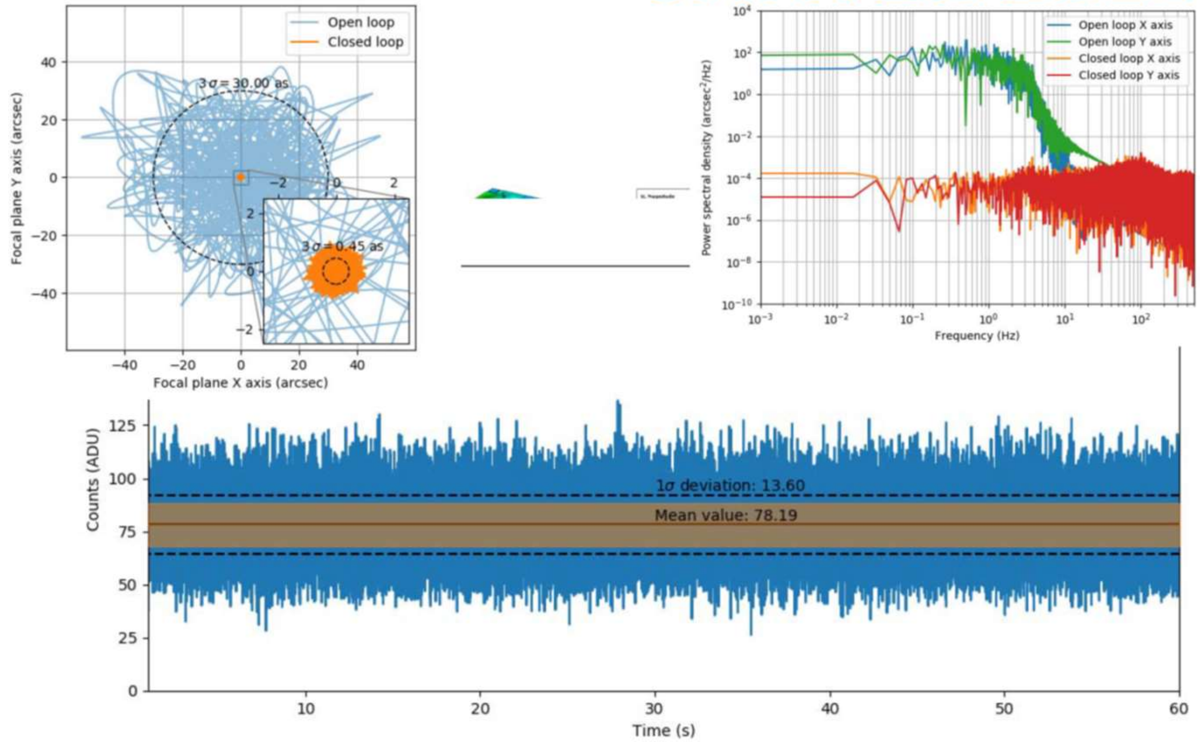
3.VALIDATION

WINTER 2016



Wessling & Van DerDoes, SPIE, 1994

Sylvestre Lacour, LESIA (Presentation at Paris Observatory, January 2020)

Software …………… SUMMER 2017

- On Board Computer software
  - FreeRTOS + GERICOS framework
- Ground segment
  - Antenna
  - Software

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Launch

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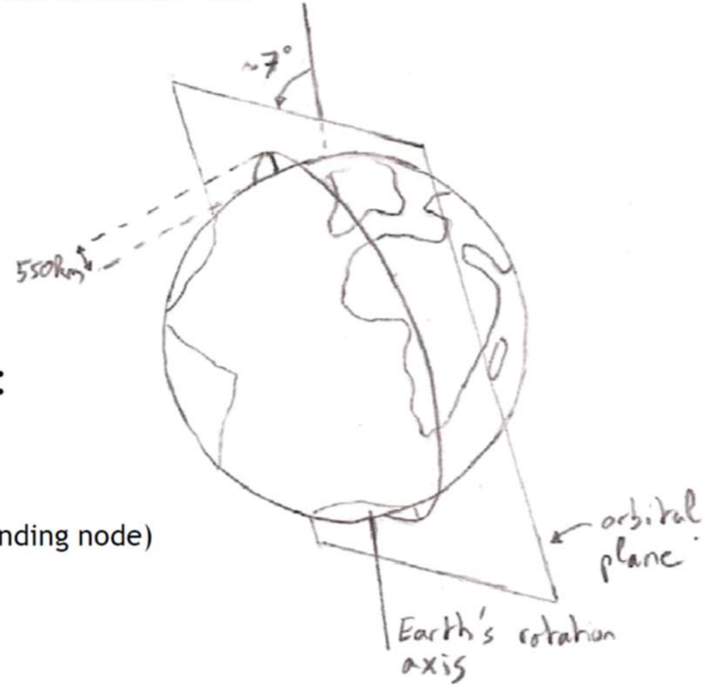
Operations : UHF/VHF ground station

```
PICSAT
1 43131U 18004W   18021.60551509  .00001940  00000-0  87505-4 0  9991
2 43131  97.5546  83.7702 0008572 247.1439 112.8892 15.22227881  1414
```

PicSat summary:

- Mass: 3.7 kg
- Volume: 3U
- Power: 5.7W
- Orbital parameters:
  - SSO at 505km
  - RAAN 9:am

(right ascension of the ascending node)



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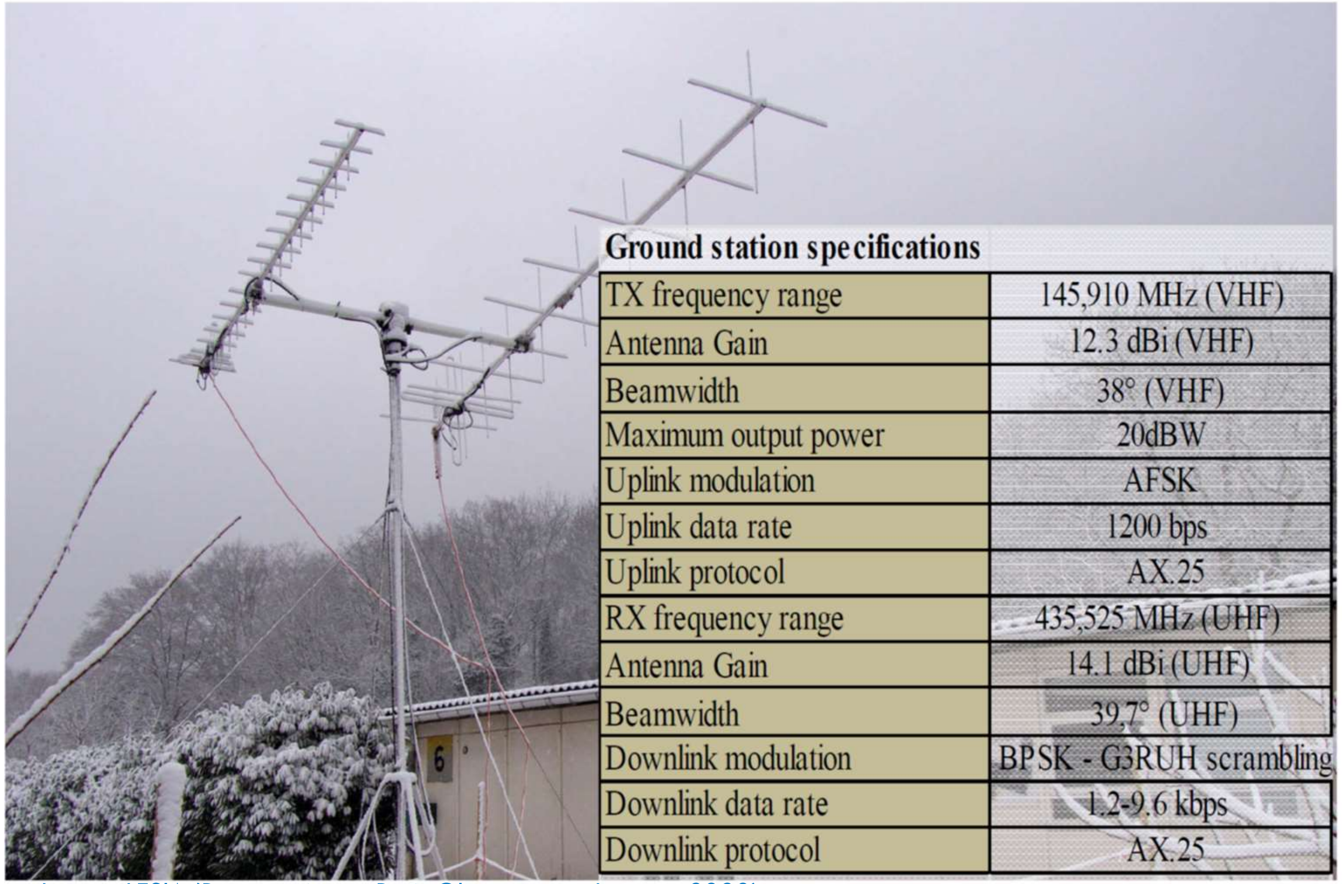
Operations : UHF/VHF ground station

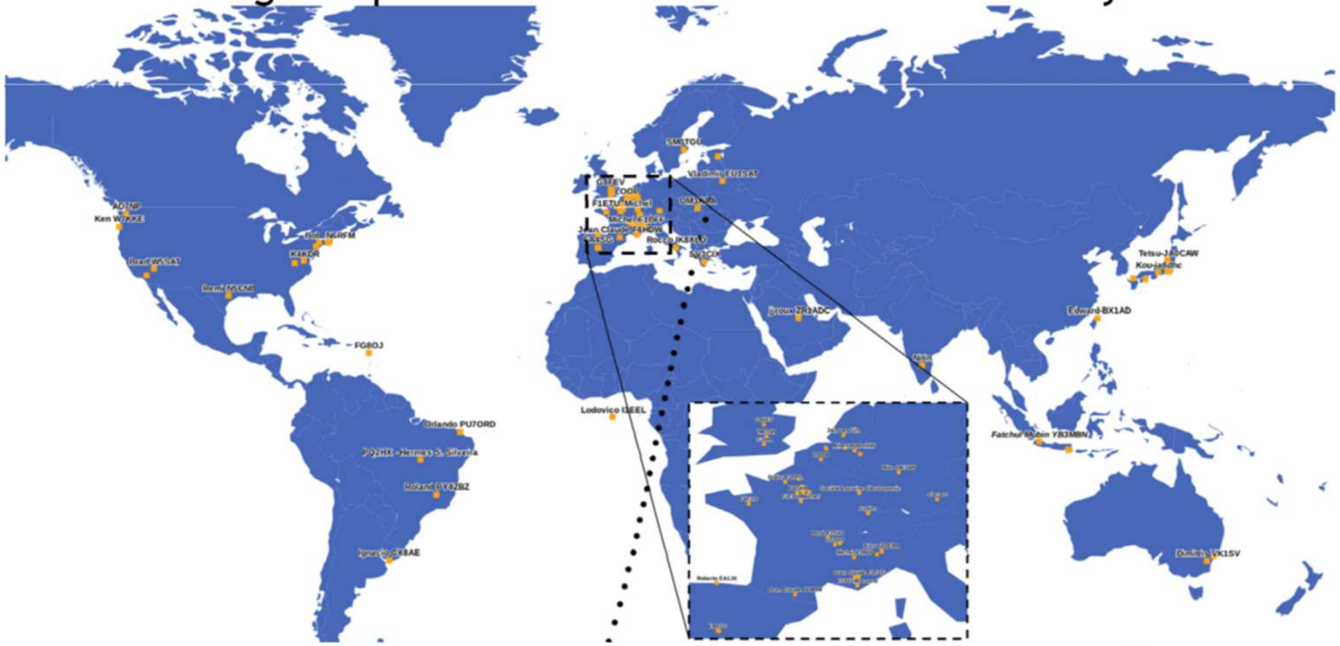


Ground station specifications	
TX frequency range	145,910 MHz (VHF)
Antenna Gain	12.3 dBi (VHF)
Beamwidth	38° (VHF)
Maximum output power	20dBW
Uplink modulation	AFSK
Uplink data rate	1200 bps
Uplink protocol	AX.25
RX frequency range	435,525 MHz (UHF)
Antenna Gain	14.1 dBi (UHF)
Beamwidth	39,7° (UHF)
Downlink modulation	BPSK - G3RUH scrambling
Downlink data rate	1.2-9.6 kbps
Downlink protocol	AX.25

Sylvestre Lacour, LESIA (Presentation at Paris Observatory, January 2020)

Operations: HAM network

- Huge response from amateur radio community



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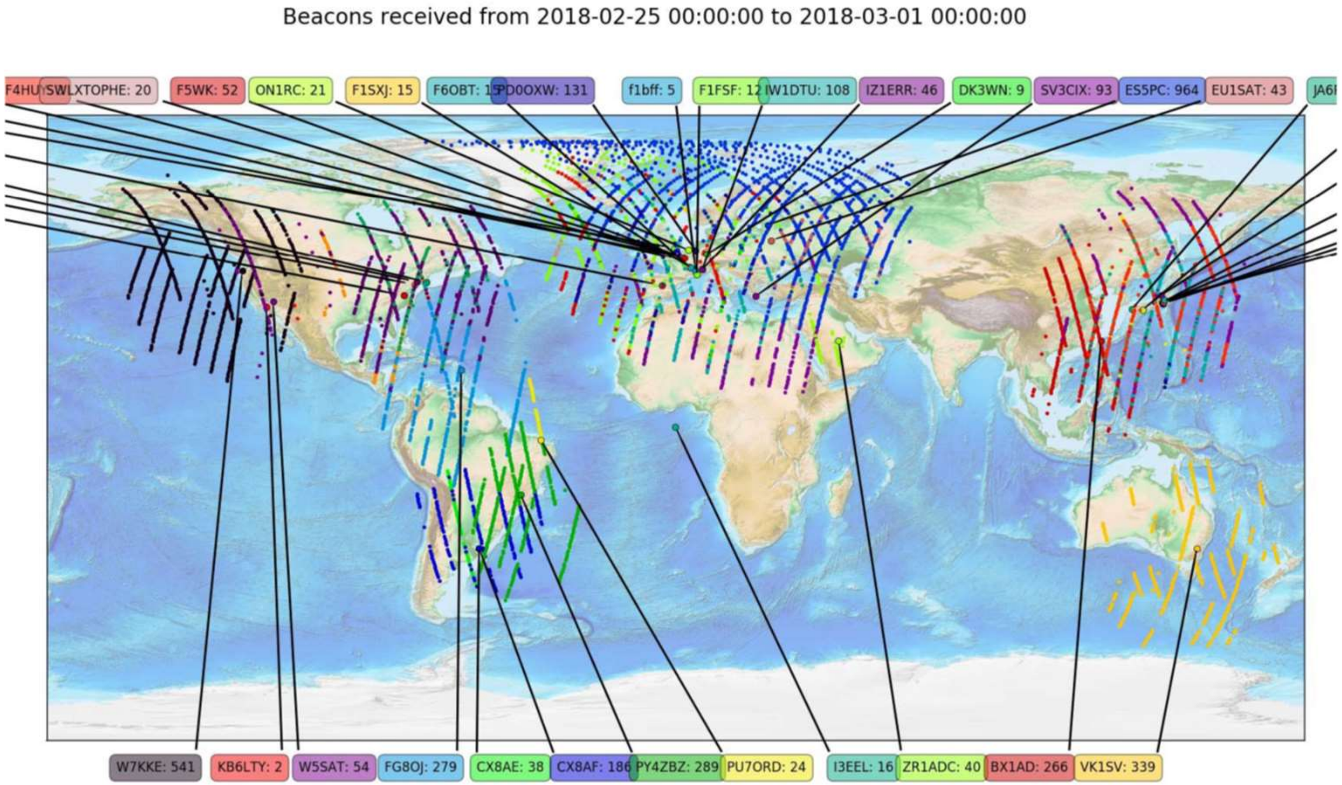
Operations: HAM network



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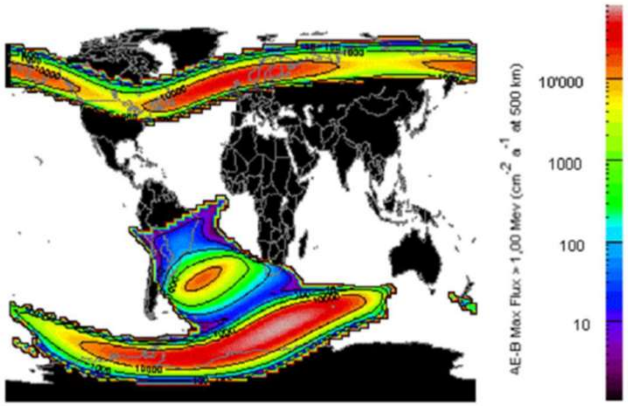
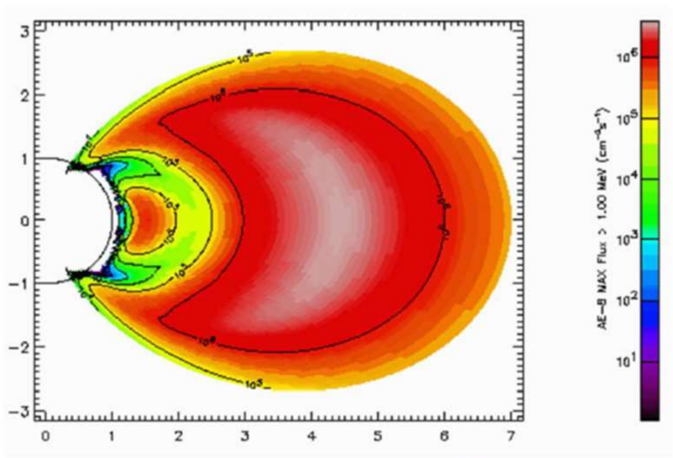
End of Mission

- TLE analysis:
  - High ballistic coefficient at the date of the 19 March
- Geomagnetic activity:
  - High activity on the 19th





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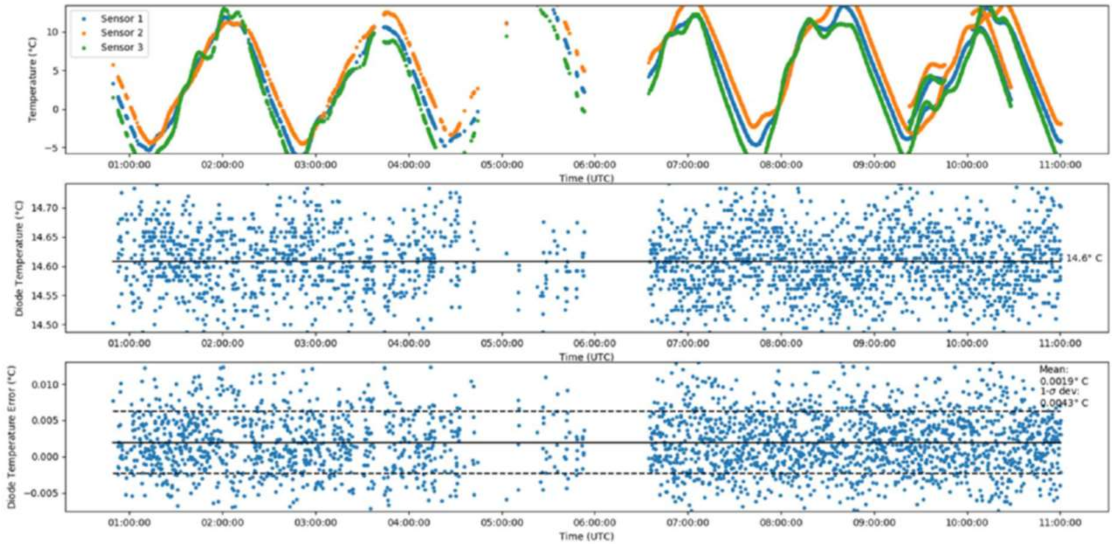
Retour d'expérience – Données en vol

- Charge utile
  - Température electronique
  - Régulation photodiode.



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HERITAGE FROM PICSAT

- GOOD EXPERTISE AND TEAM KNOWLEDGE
- RETURN OF EXPERIENCE WITH POST-OPERATION FULL INTERNATIONAL REVIEW TEAM
- NEW MISSION DEFINITION UNDER STUDY
- CONTEXT : SUPPORT TO ARIEL PREPARATION OF CATALOG
- FUTURE CONTEXT FOR INTERFEROMETRY

A LIST OF SPACE CAMPUSES IN FRANCE FOR RESEACH NANOSATELLITES

Structuration is in progress with a network of space campus and a coordination for relations with CNES or CNRS

Paris area:

- CENSUS (PSL - Coralie Neiner, LESIA)
- CurieSat (Sorbonne Université, Nicolas Rambaux, IMCCE)
- CS Paris-Diderot (Université de Paris – G. Hulot, IPGP)
- CS3 : Paris-Saclay
- CSUPEC : Paris-Créteil (H. Cottin, LISA)

CSUM : Montpellier (L. Dusseau)

CSUG : Grenoble (M. Barthelemy, LPG)

CSUT : Toulouse

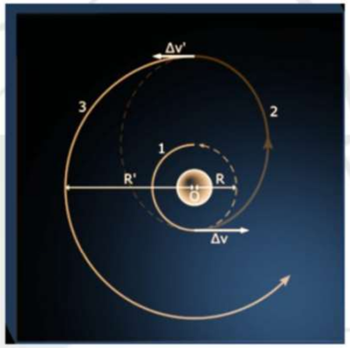
NAASC : Bordeaux

CENSUS – SPACE CAMPUS AT PARIS OBSERVATORY

Organized from labex ESEP initiative in 2015

https://census.psl.eu/

Three Pillars



SCIENCE
Pierre DROSSART Until 2020
Coralie Neiner (LESIA)

TECHNOLOGIES
Boris SEGRET

ESEP OSAE

EDUCATION
Benoît MOSSER

SCIENTIFIC COMITTEE
Yearly Call

14 selected projects
70+ people*year (2018)

Ecosystem =
Support + Tools + Facility

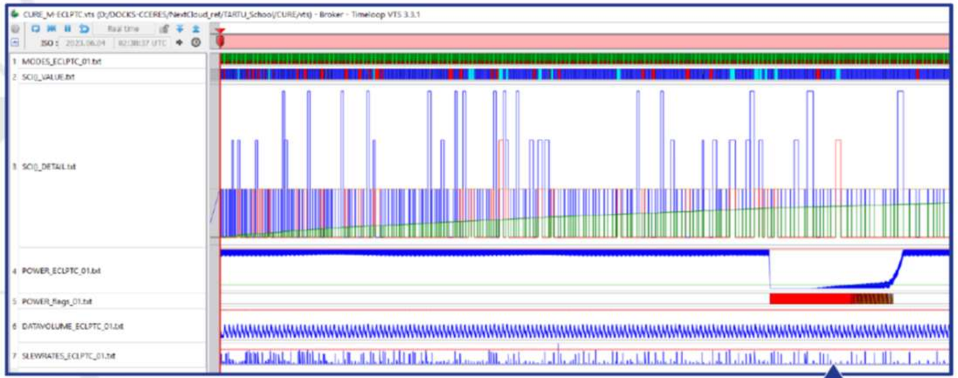
300+ students
16+ origins

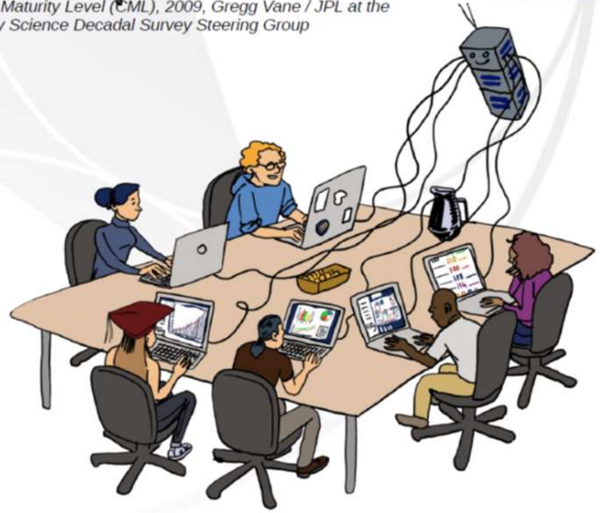
Past projects
- GPU4SPACE
- CosmOrbitrap
- NANOPOT
- NSR2019
- PICSAT

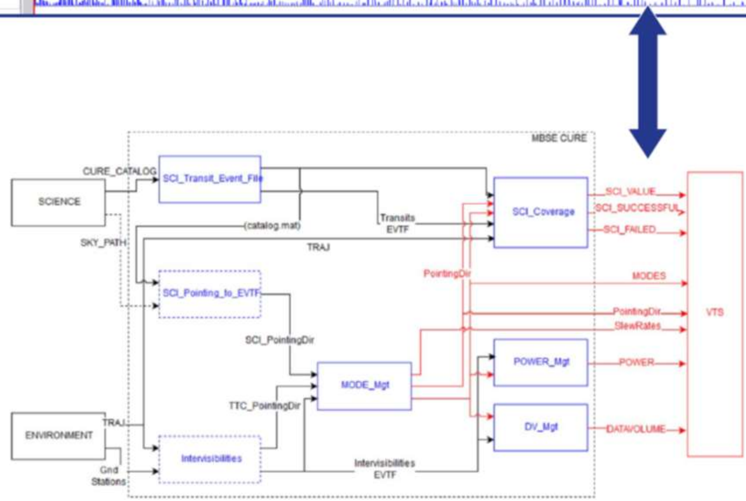
Current projects
- BIRDY
- C²ERES
- CIRCUS
- CURE
- OGMS-SA
- SERB
- SPACEFIRST
- TERACUBE

Engineering: “MBSE”, a method

Concept Maturity Level (CML), 2009, Gregg Vane / JPL at the Planetary Science Decadal Survey Steering Group

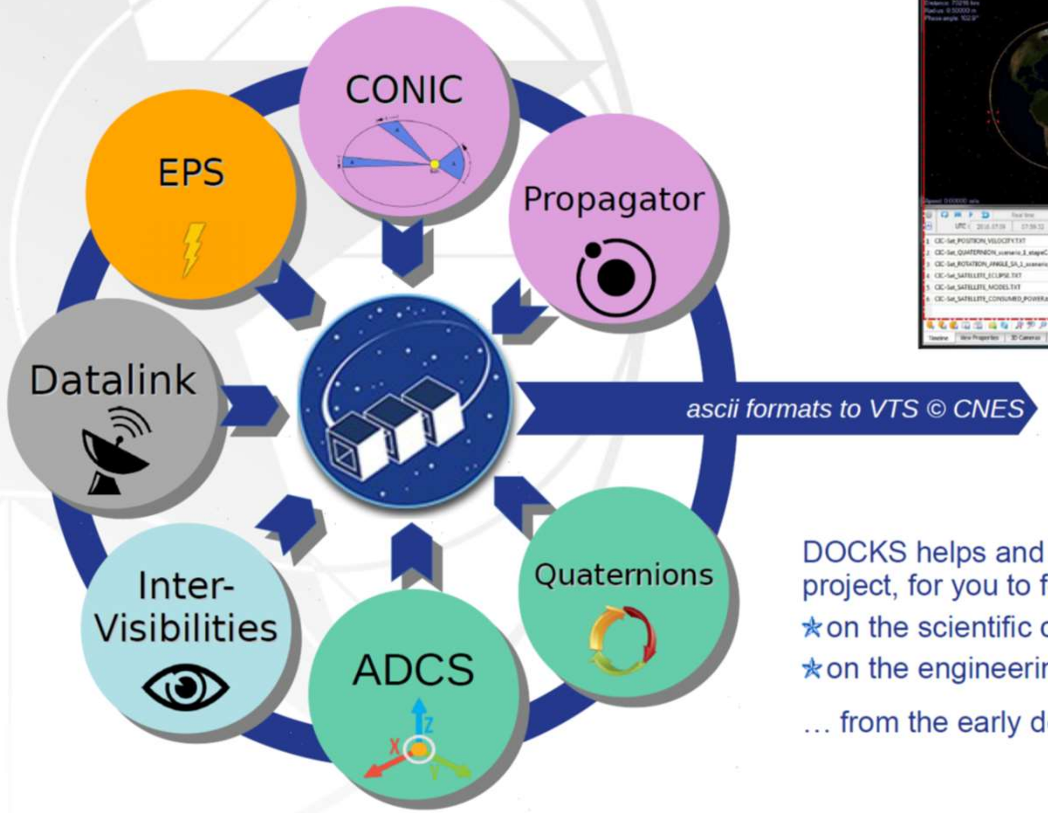


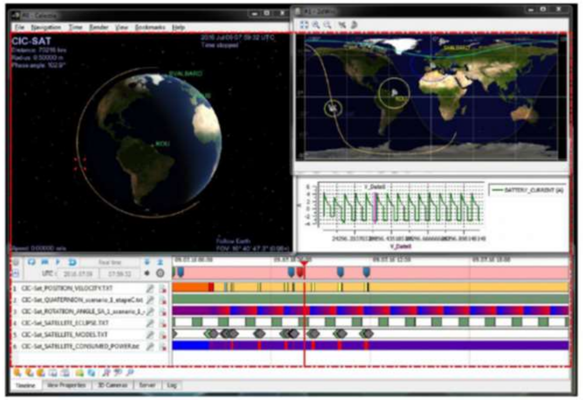




Segret, CCERES, Atelier INSU Nano-satellites (9-10/01/2020)

Engineering: DOCKS, a tool



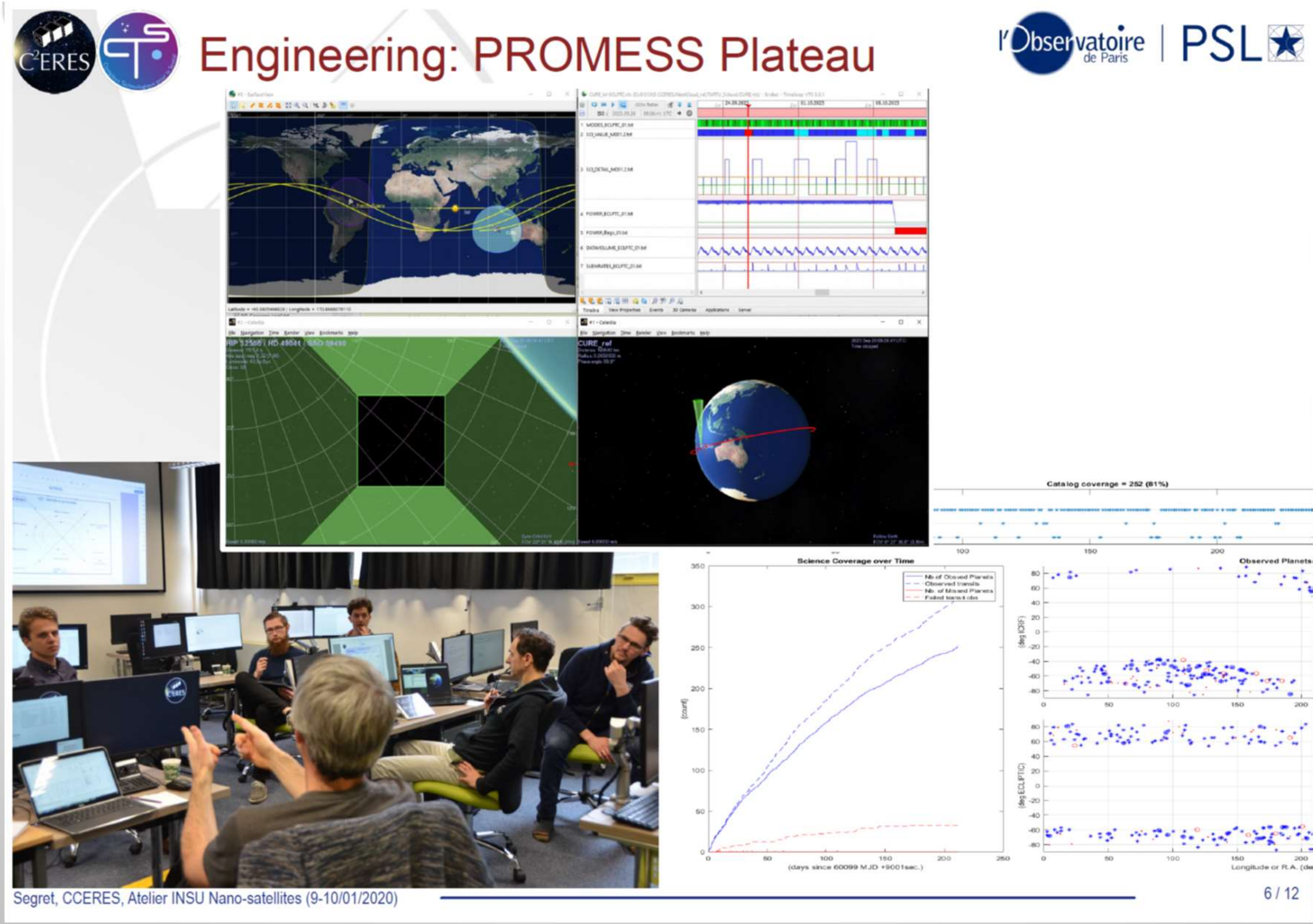


Version 3.3.1 Build 7809 Arch 32bits

DOCKS helps and structures your CubeSat project, for you to focus:

- on the scientific coverage
- on the engineering sizing

… from the early design up to AIT/AIV


C²ERES
Engineering: PROMESS Plateau
l'Observatoire de Paris | PSL
Catalog coverage = 252 (81%)
Science Coverage over Time
Observed Planets
Segret, CCERES, Atelier INSU Nano-satellites (9-10/01/2020)
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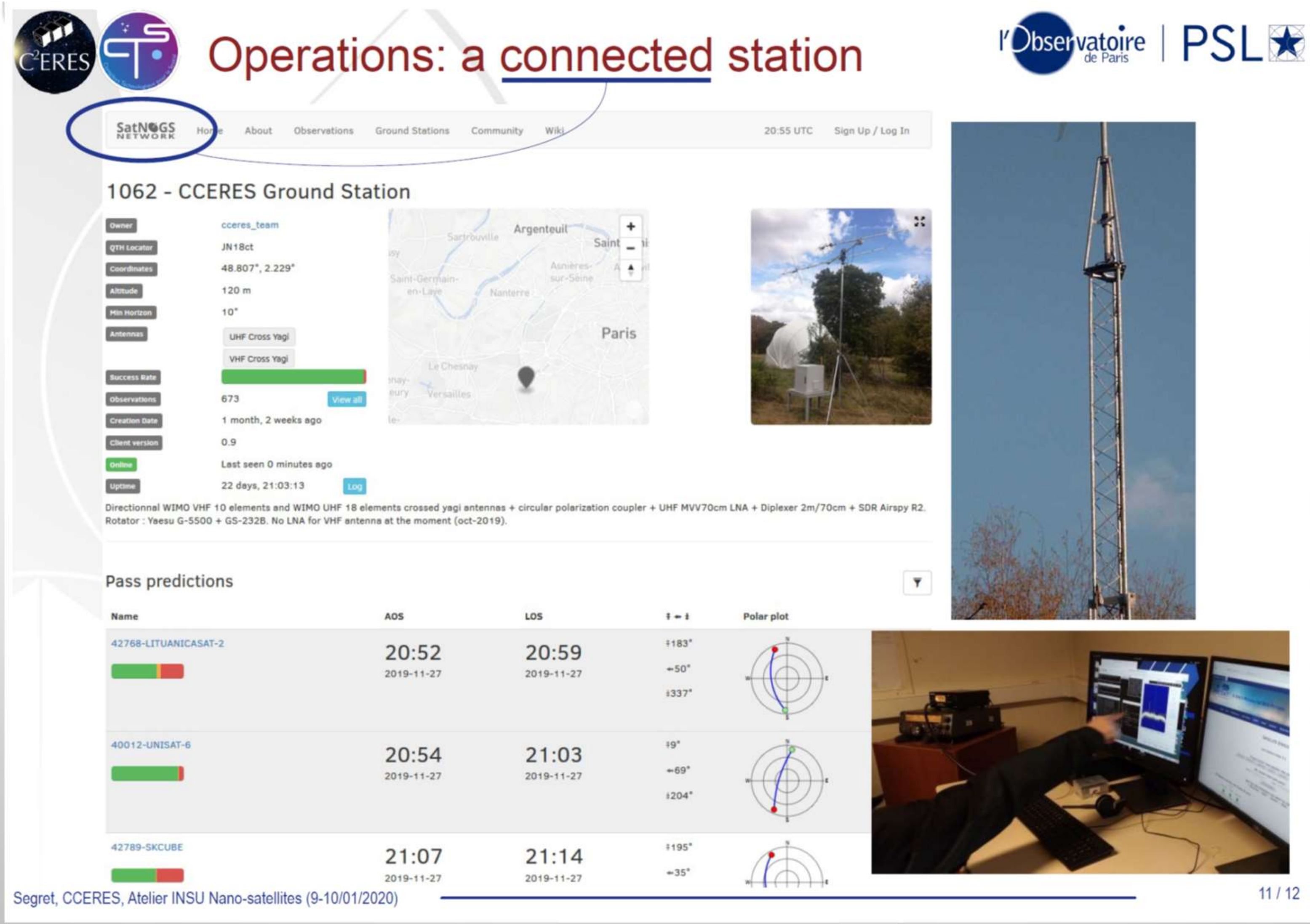
Tests: VEGA, a clean room


Operations: a connected station
l'Observatoire de Paris | PSL
SatNOGS NETWORK
Home About Observations Ground Stations Community Wiki
20:55 UTC Sign Up / Log In
1062 - CCERES Ground Station
Owner cceres_team
QTH Locator JN18ct
Coordinates 48.807°, 2.229°
Altitude 120 m
Min Horizon 10°
Antennas UHF Cross Yagi VHF Cross Yagi
Success Rate
Observations 673 View all
Creation Date 1 month, 2 weeks ago
Client version 0.9
Online Last seen 0 minutes ago
Uptime 22 days, 21:03:13 Log
Directionnal WIMO VHF 10 elements and WIMO UHF 18 elements crossed yagi antennas + circular polarization coupler + UHF MVV70cm LNA + Diplexer 2m/70cm + SDR Airspy R2.
Rotator : Yaesu G-5500 + GS-232B. No LNA for VHF antenna at the moment (oct-2019).
Argenteuil
Paris
Nanterre
Versailles
Pass predictions
Name AOS LOS Polar plot
42768-LITUANICASAT-2 20:52 2019-11-27 20:59 2019-11-27 183° 50° 337°
40012-UNISAT-6 20:54 2019-11-27 21:03 2019-11-27 9° 69° 204°
42789-SKCUBE 21:07 2019-11-27 21:14 2019-11-27 195° 35°
Segret, CCERES, Atelier INSU Nano-satellites (9-10/01/2020)
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FUTURE SCIENCE

- In help of major mission (cf Insight/MARCO etc)
- In preliminary support of major mission : Ariel /ESA
- Beyond the niche science : a network for future science objectives => in development with AI systems
- Nanosats in interplanetary orbits

NOIRE project in short

Space Radio Observatory

- Swarm of nanosatellites (homogeneous), with several 10 nodes (50?)
- « Low frequency » spectral range: < 100 MHz
- Observation modes: waveform (raw data), beam-formed (phased array) or imaging (interferometry)

Individual node science payload

- 3 channels (3 axis E-field) radio receiver 1kHz – 100 MHz
- Clean environnement required (EMC) + relative location/attitude knowlegde

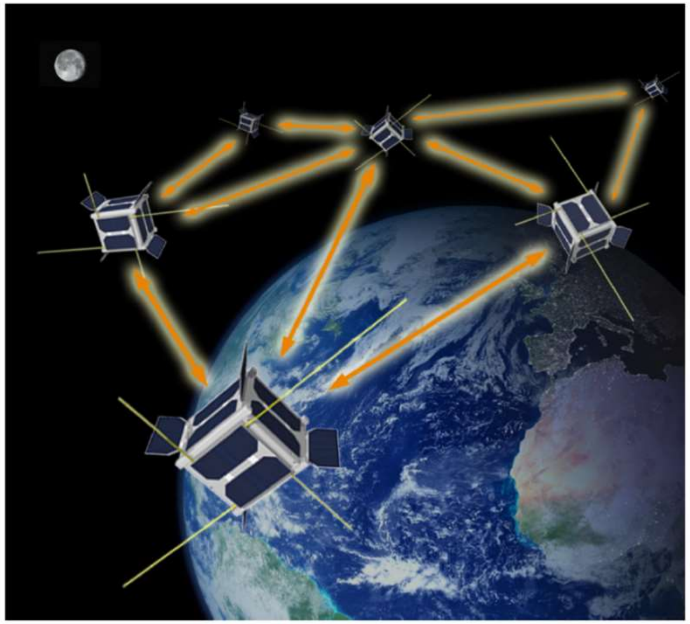
System = instrument

- Swarm (autonomous) is platform ➔ science contraints on swarm system performance (clock, location, data transfer, computing…)

NOIRE project context – a new type of platform

Rising of a new platform: nanosatellites

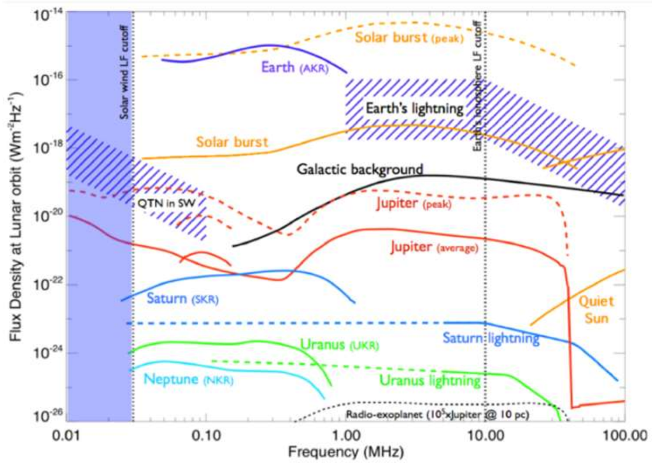
- Mass ranges from ~1 to ~10 kg (for instance, cubesats)
- Small Platform
  - Few instruments per satellites (single instrument?)
  - Miniaturization of instrumentation
  - « Low cost » platform most of the time
  - Fast development track,
  - Standardized launcher interfaces
- New opportunities and new challenges



NOIRE project context – the nanosat opportunity

Opening a new window on the Universe

- Frequency range < 30 MHz not fully accessible from ground
- Multiple science topics
  - Cosmology
  - Interstellar matter and cold universe
  - High energy astrophysics
  - Solar system: planetary magnetospheres
  - Solar physics



Nanosat platform: rethink the way space platform are designed

- Scattered or distributed instrumental concepts based on interferometry
- Nanosatellites for multi-point or multi-mode scientific sending
- Several such projects are being studied in the world

CONCLUSIONS

- Nanosats still have to find their place in the space sector,
- Within a decade, we should now if we are seeing the beginning of a new era, or if the nanosats will remain confined to support activities for larger missions.
- From the institution :
- CNRS/INSU : report soon available
- CNES : new organization for nanosatellite projects