

# SWARM & CNES A LONG HISTORY

MIOARA MANDEA  
Head Science Coordination Department  
Strategy Directory

SWARM 10 YEAR ANNIVERSARY  
**08-12 APRIL 2024**

# OUTLINE & QUESTION - WHY IS SWARM KNOWN IN COPENHAGEN ?

01 BEFORE THE DATE

02 EMOTIONAL MOMENT

03 CNES CONTINUING SUPPORT

OLAFUR ELIASSON  
**KIG OP**  
**LITTLE SUN  
LIGHT SWARM**

GEOMETRISKE FORMER & FORSKELLIGE FARVER

Den dansk-islandske kunstner Olafur Eliasson og hans sociale virksomhed Little Sun har skabt Little Sun Light Swarm, der svæver mellem træerne langs Tivoli Søen. Little Sun Light Swarm består af 33 lamper, der skifter udtryk alt efter vejr, lys og position. Lamperne er af bronze med paneler af dikromatisk glas og spejle.



GEOMETRIC SHAPES & CHANGING COLOURS

Danish-Icelandic artist Olafur Eliasson and his social business Little Sun have created Little Sun Light Swarm, hovering among the trees along the Tivoli Lake. Little Sun Light Swarm consists of 33 lamps which change appearance according to weather and light conditions and position. The lamps are made of bronze with panels of dichromatic glass and mirrors.

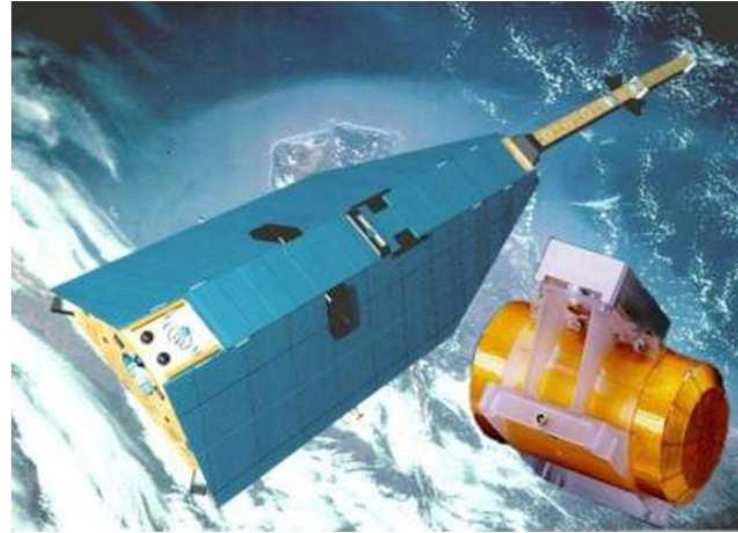
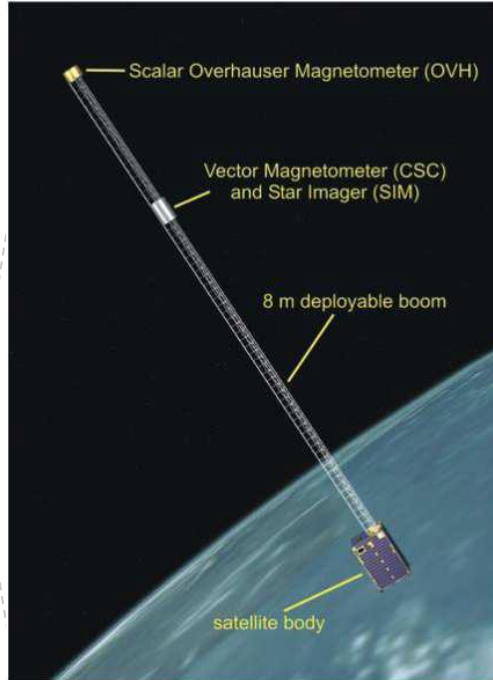




# 01

**BEFORE THE DATE  
... 10<sup>TH</sup> & 20<sup>TH</sup> ANNIVERSARY!**

# BEFORE THE DATE



CNES

CEA/LETI

IPGP

- Oersted: launched on 23/02/1999 for 14 months... x10 in service!!  
Elliptical polar orbit 650-850 km Scalar sensor: CEA/LETI
- CHAMP: launch on 17/07/2000, re-entry into the atmosphere on 09/2011  
Circular orbit 530 km Scalar sensor: CEA/LETI
- CNES supported the developments



Isabelle FRATTER



Pascale ULTRE-GUERARD



Steven HOSFORD



Mioara MANDEA



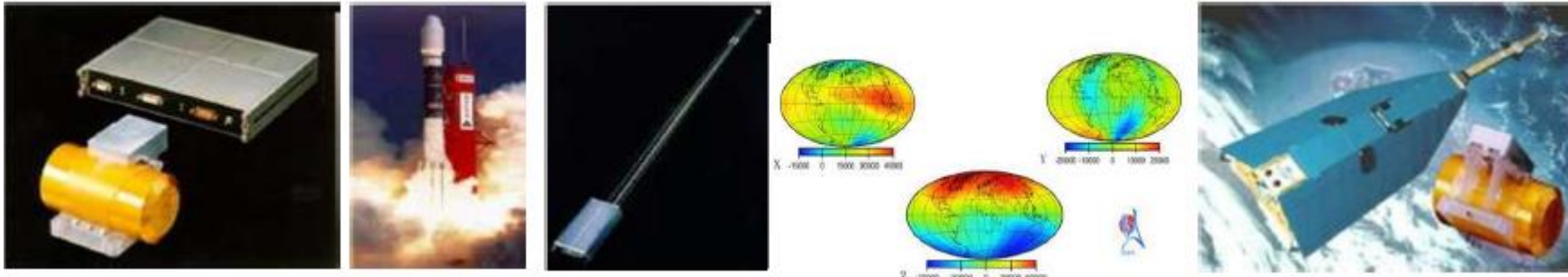
Gauthier HULOT



Jean-Michel LEGER

# BEFORE THE DATE

Continuous observation of the geomagnetic field (continuation of Oersted/CHAMP)



- Scalar magnetometers developed by CEA/LETI – with CNES implication –
- From Oersted to Swarm – 2 technologies for 3 space missions



# BEFORE THE DATE

- 1997 – 2020 Preparation started (“Design and realization of a vector He pumped magnetometer” by Olivier Gravrand, supervisors Jean-Louis LE MOUËL and Jean-Michel LEGER - PhD co-financed by CNES)
- 2000 – CNES notice to engage either the Ampère mission (CNES  $\mu$ satellite) or to support Swarm if this mission was selected by the ESA
- 2001 – CNES R&T support from 2001 to prepare for spatialisation
- 2002 – autumn - visit CEA/LETI facilities with E. Friis-Christensen and H. Luhr
- 2004 – spring visit CEA/LETI facilities – CNES, ESA, EADS, IPGP
- In April 2004, just before the selection of Swarm by the ESA, CNES sent a letter to the ESA to show its support for the CEA/LETI magnetometer and to offer to take charge of their development if the mission was selected and if the scientific and programmatic decision-making bodies issued a positive opinion.





# BEFORE THE



## Swarm - The Earth's Magnetic Field Environment Explorers

### Scientific Background

Magnetic fields play an important role in many of the physical processes throughout the Universe. In particular, the Earth has a large and complicated magnetic field:

- produced to a large extent by a **self-sustaining dynamo**, operating in the fluid outer-core
- but also caused by **magnetised rocks** in the Earth's crust,
- and due to electric currents flowing in the **ionosphere, magnetosphere and oceans**
- and by currents **induced in the Earth** by time-varying external fields.

The challenge is to improve our knowledge of the composition and processes in the interior of the Earth from magnetic field and other measurements as important contribution understand

### Mission Objectives

The **Swarm** mission will provide the best ever survey of the geomagnetic field and its temporal evolution, in order to gain new insights into the Earth System by improving our understanding of the Earth's interior and physical climate.

#### Research objectives:

Related to the Earth's interior:

- Map the core flow
- Determine core dynamics
- Investigate jerks: their time-space structure and recurrence
- Understand core-mantle coupling and its implication for Earth rotation
- Perform 3D imaging of mantle conductivity
- Determine remanent and induced magnetisation of the lithosphere

Related to the Earth's environment:

- Determine the position and development of the radiation belts and their near-Earth effects
- Investigate the time-space structure of the magnetospheric and ionospheric current systems on all time scales
- Monitor the solar wind energy input into the upper atmosphere and assess its effect on the thermospheric density
- Sound the electron density of the ionosphere/plasmasphere and relate it to magnetic activity

Swarm is a constellation to study the dynamics of the Earth's magnetic field and its interactions within the Earth System

### Observational Requirements (in

Magnetic Field Magnitude	global -
Accuracy, stability	0.15 nT
Vector Magnetic Field	global -
Accuracy, stability	0.5 nT
Vector Electric Field	global -
Accuracy, stability	1.5 mV
Electron Density Distribution	global -
Precision	0.5 10 <sup>11</sup>
Air Drag	global -
Accuracy	2.5 10 <sup>4</sup>
Local times distribution	changing
Mission duration	4 years

### Mission elements

#### Space segment:

- Constellation of three satellites of two, where the lower pair, for the first time,
- Orbital planes, drifting apart, to optimise measurements in space and time for all objectives during different periods of the
- Spacecraft with boom to provide magnetic accommodation for magnetometer instruments

#### Instruments and sensors:

- Scalar magnetometer
- Vector magnetometer supported by an
- Electric field instrument
- GNSS receiver for precise orbit determin
- Accelerometer for observing non-gravit

#### Ground segment:

- Satellite operation and control
- Data processing and archiving centre
- Level 1B data products:**
  - Magnetic field magnitude and vector co
  - Ion drift and vector electric field, electro
  - Acceleration vector, and air drag and p
- At Level 2 global models will be produce

- EarthCare** - Earth Clouds, Aerosols and Radiation Explorer
- SPECTRA** - Surface Processes and Ecosystem Changes Through Exposure Analysis
- WALLS** - Water Vapour Lidar Experiment in Space
- ACE+** - Atmosphere and Climate Explorer
- ISPM** - European Contribution to Global Precipitation Measurement
- Swarm** - The Earth's Magnetic Field and Environment Explorers



The Swarm candidate mission is based on the mission proposal co-written and submitted in 2002 by a team lead by Eigil Friis-Christensen, Hermann Lühr, and Gauthier Hulot. This Report for Mission Selection for Swarm was prepared based on contributions from the Mission Advisory group (MAG) consisting of: Angelo De Santis, Eigil Friis-Christensen, Andrew Jackson, Gauthier Hulot, Hermann Lühr, Michael Purucker, Markus Rothacher, and Pieter Visser. Parts of the Report have been prepared by the Executive based on input provided by the industrial Phase A contractors. Nils Olsen, Mioara Mandea, Susanne Vennerstrøm, Terence Sabaka, Stefan Maus, Alexei Kuvshinov, Alan Thomson and all others, who participated in the supporting studies during Phase A, are acknowledged for their direct or indirect contributions to this report. A special expression of gratitude goes to John LaBrecque who made a vital contribution by supporting the studies performed by NASA scientists Michael Purucker and Terence Sabaka.

European Space Agency  
Agence spatiale européenne

Earth Explorers Users Consultation Meeting, 19-20 April 2004

# BEFORE THE DATE

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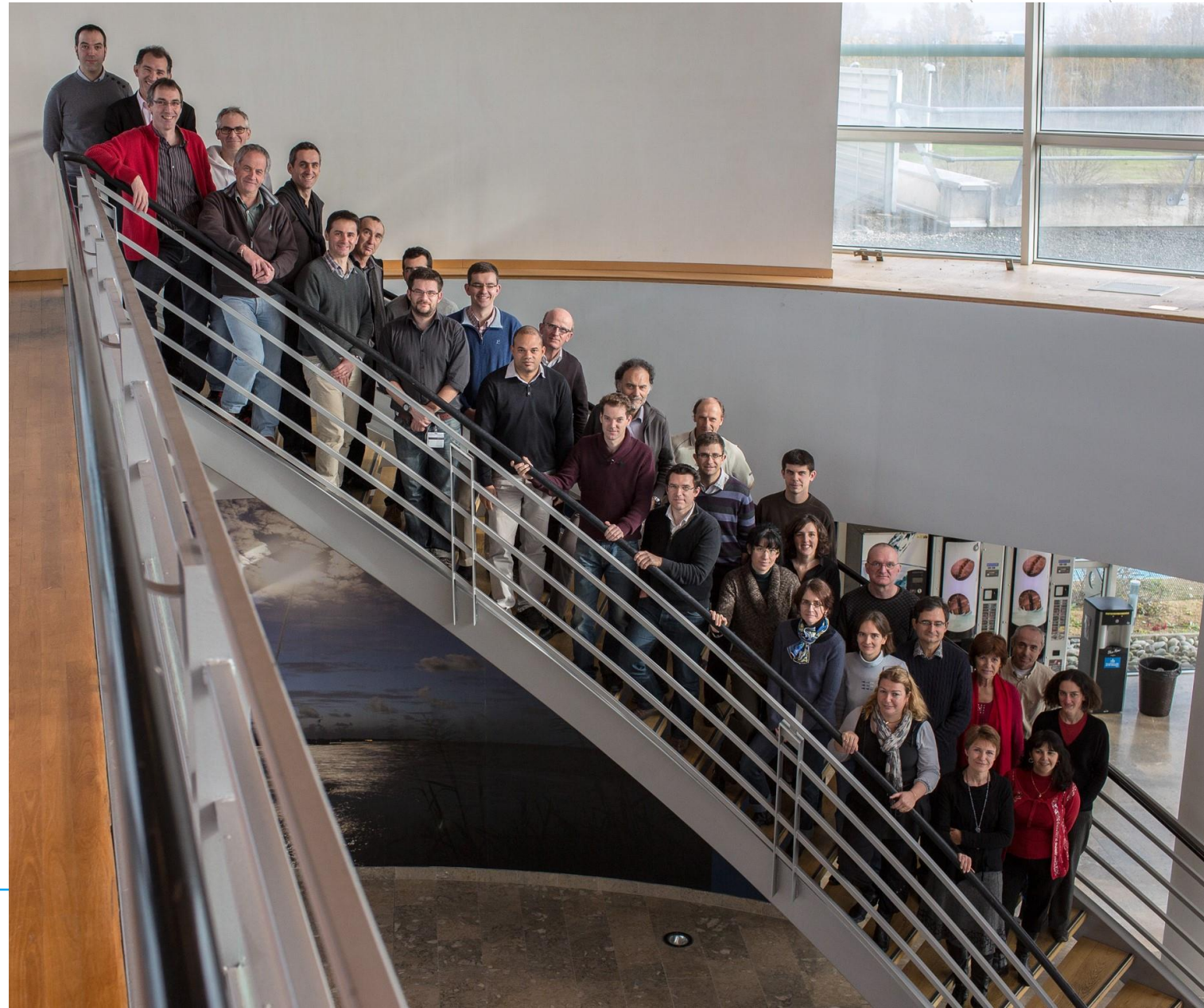
- After a favorable opinion from the Scientific Programs Committee, following the Scientific Prospective Seminar in 2004 (July) and a positive internal evaluation, the CNES decided the phase A of the Swarm magnetometer which took place from the end of 2004 to the beginning of June 2005.
- In April 2005, a second letter was sent by CNES to ESA to reaffirm CNES's intention to participate in the mission, provide the programmatic context of the project and the decision deadlines for CNES. A draft MoU draft was sent by CNES to ESA to define the respective responsibilities between the two agencies and an exchange of letters between ESA and CNES made it possible to validate the sharing of responsibilities between the two agencies.

# BEFORE THE DATE

- In 2007, in accordance with the decisions of the RDP ASM Steering Committee - CNES and CEA/LETI re-evaluated the human (CNES and CEA/LETI) and financial resources to be put in place to complete the project taking into account additional phase C/D work.
- During the PB EO of July 28, 2010, to take into account the delays, the ESA formalized the postponement of the launch to July 17 2012, a date partly driven by the availability of the launcher. The need for CNES HR has therefore increased again.
- Between December 2010 and March 2011, the 6 flight models for the three satellites were delivered to ESA / EADS.

# BEFORE THE DATE

CNES Swarm team



# BEFORE THE DATE

## CONTRAT INTERNE

Numéro : DSP/TEC 2012-13397 Version : **DCT-1.2** du : **10/09/2012**

### MAGNETOMETRES ABSOLUS POUR LA MISSION SWARM PHASES B/C/D/E1

	Nom - Sigle	Date - Visa
Directeur de la stratégie, des programmes et des relations internationales	Thierry Duquesne DSP/D	le :
Directeur du Centre de Toulouse	Marc Pircher DCT/D	le :
Responsable de Thème	Mioara Mandaia DSP/TEC	le :
Chef de Projet	Isabelle Fratter DCT/PO/EV	le :

### 4.3.2. COUT COMPLET A ACHEVEMENT

A partir des détails de consommation fournis au chapitre 4.2 et à l'aide des hypothèses de calcul du chapitre 4.3.1, le coût complet à achèvement du projet s'élève à :

- **22,293 M€** qui s'appuient à hauteur de **21,303 M€** sur la subvention de service public

### 4.4. CONDITIONS PATRIMONIALES ET FISCALES

Ce projet n'est pas éligible à la PII ; la propriété des modèles étant répartie en :

- 1 modèle ~~prototypé~~ (modèle de vol de rechange) dont la propriété reste au CNES,
- 3 modèles d'ingénierie dont la propriété est au CNES mais qui ne sont que des éléments du développement, pas des produits finis.
- 6 modèles de vols dont la propriété a été transférée à l'ESA lors de la livraison,

L'objectif du projet étant la fourniture des modèles de vol, sur les modèles restant au CNES, il n'y a donc pas de notion d'immobilisation.

**Le taux de TVA utilisé est conforme à la nature décidée habituellement pratiquée.**

## 5. ESTIMATION DES PHASES ULTERIEURES

**Le budget d'exploitation est estimé à 880 k€** pour les 4 ans de la mission. Il couvre les activités de soutien aux scientifiques liés au projet et un support industriel pour les aspects instrumentaux, **y compris un support opérationnel sur le traitement des données de la partie vectorielle de l'ASM, en cas de demande par l'ESA.** Ce support industriel **au LETI** sera suivi et accompagné pendant les 4 ans d'exploitation de la mission par l'équivalent d'1 ETP/an.

Le financement de cette ressource sera réparti entre le CNES (1,5 ETP) et l'ESA (2,5 ETP).



# 02

## EMOTIONAL MOMENT

The Russian Rockot light  
launcher

Plesetsk Cosmodrome

three ESA scientific  
satellites - Swarm

# 03

## CNES CONTINUING SUPPORT

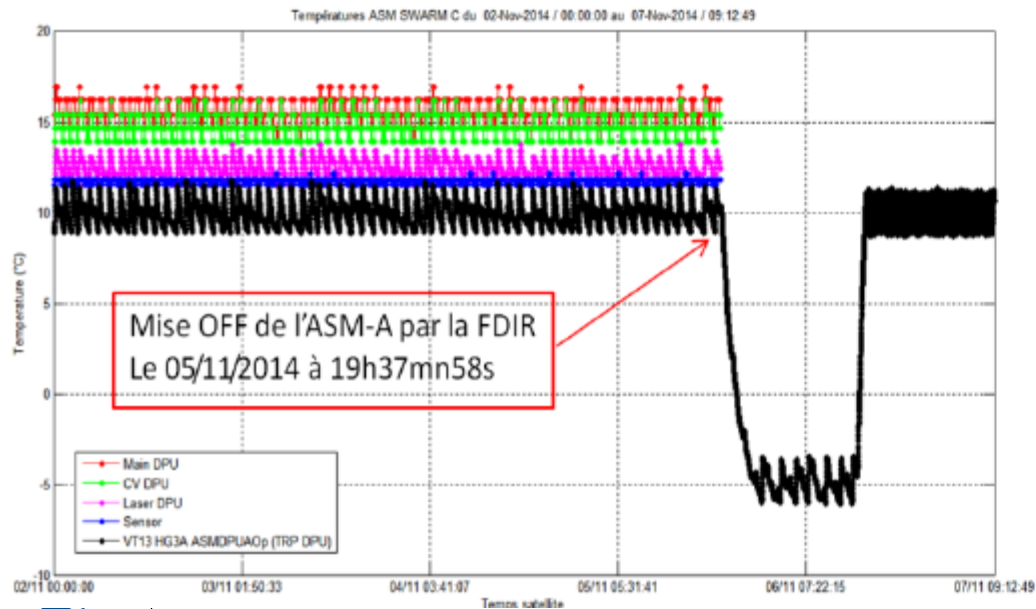


# CNES CONTINUING SUPPORT

## What occurred on November 5, 2014 ?

At the North Pole, latitude 80 °, longitude -157 ° equator local time 7:50

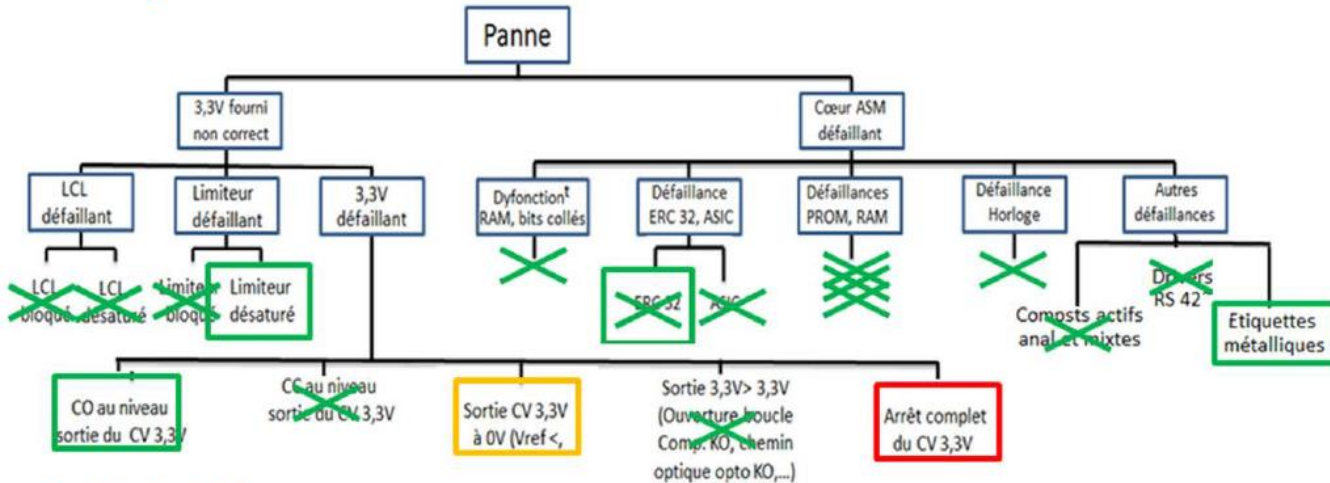
- 7:37:18 p.m.: Last ASM-A TM with nominal PF current TM : 0209 A,
- 7:37:22 p.m.: first satellite TMs with fault PF current TM : ~ 0109 A,  
The voltage was -32.22 V, the DPU temperature around + 10 ° C,
- 7:37:27 p.m.: Stop order of the ASM-A given by the PF FDIR
- 7:37:58 p.m.: Off setting of the ASM-A by FDIR (detection of an input electric current value of ASM-A too low (~ 0,109A < 0.161A, threshold FDIR).



Temperatures measured by ASM-A:  
November 2, 2014 0:00 until failure (not available after the failure)  
Temperature steady and without fault before the failure of the ASM-A.

# CNES CONTINUING SUPPORT

Analyzed fault tree to determine the root cause



## Synthesis table :

Hypothesis	Compatible with no TMs	Compatible with the consumption	Comments	Status
Output of the 3.3V CV at 0V or very low with a saturated loop (opto leak, Vref too low, etc.)	Yes	Yes	Consumption consistent with the measurement in flight, but unlikely because Vref, delivered by the LM136 (bipolar technology) is immune to latchup and the risk of breakdown at the opto level (HCPL-550k-circuit 300) having a floating metal part is very low.	Unlikely
Full shutdown of the 3.3V CV	Yes	Yes	Consumption consistent with the measurement in flight. The destruction of the PWM is highly unlikely if we consider the published results, but extremely probable with the results of heavy ions tests in KVI-CART. In addition the failure occurred at North Pole	Very likely

## RECOMMENDATIONS TO AVOID THIS DESTRUCTIVE PHENOMENON:

- Decrease the PWM UCCx802 supply voltage between 8.3 and 11V after the start up sequence.
- **Preferably** replace this PWM by another one as for example UCCx800 from the same manufacturer (see table below)
  - Can be turned on at 7,2V
  - 100% duty cycle
  - **DO NOT FORGET TO LIMIT THE SUPPLY VOLTAGE UNDER 10V** (Derating vs 12V and safe operating area regarding heavy ion test results)

Part Number	Maximum Duty Cycle	Reference Voltage	Turn-On Threshold	Turn-Off Threshold
UCCx800	100%	5V	7.2V	6.9V
UCCx801	50%	5V	9.4V	7.4V
UCCx802	100%	5V	12.5V	8.3V
UCCx803	100%	4V	4.1V	3.6V
UCCx804	50%	5V	12.5V	8.3V
UCCx805	50%	4V	4.1V	3.6V

**UNFORTUNATELY, NONE OF THESE RECOMMENDATIONS IS APPLICABLE TO SWARM PROJECT:**

**But taking into account the calculated error rates, the best compromise is probably to continue the SWARM mission as it is (No change such as, in particular, OFF/ON sequences)**

# CNES CONTINUING SUPPORT

## 4 strategic priorities

Geared to the key challenges of the coming decade. We are serving all public policies supported by the space sector. These priorities are laid out in the CNES-government contract for 2022-2025, under the banner "New Spaces".



Strengthen our strategic independence



Sustain a competitive space ecosystem



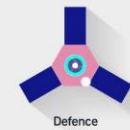
Extend our scientific excellence



Work towards a sustainable world

## +100 space projects

Currently led by CNES in 5 key domains.



## 45 Nations

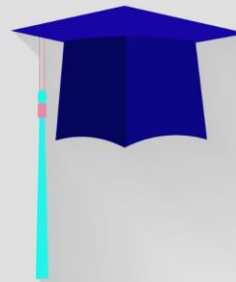
we are working with around the world.



2,400 employees



at 4 centres



## 100 doctoral

and post-doctoral research grants awarded every year to French and foreign students.



## €37

Mean yearly per-capita amount that France devotes to space, the world's 2<sup>nd</sup> largest space budget.



## 2,566 million euros

Budget for 2022, including France's contribution to ESA of €1,184m.



## >40 firms

Receive support every year from CNES to develop and diversify the French and European space ecosystem, including new entrants and start-ups in the space sector.

## CNES by the numbers



#CNES60ans

cnes.fr



YouTube

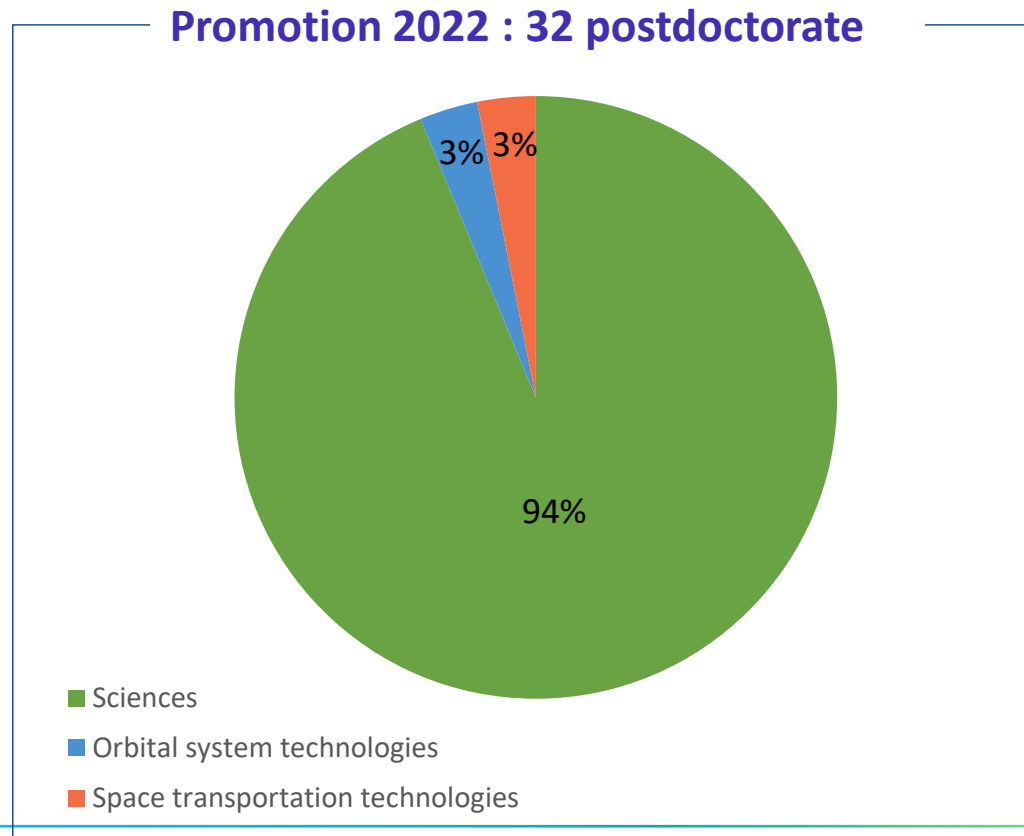
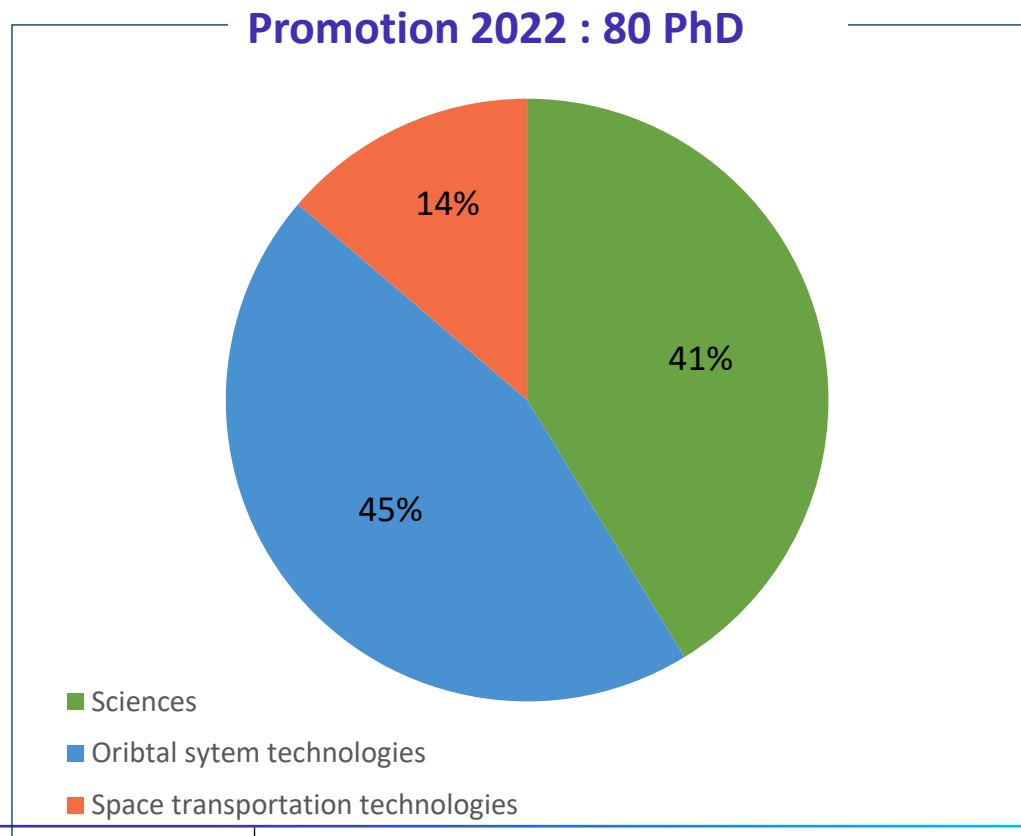


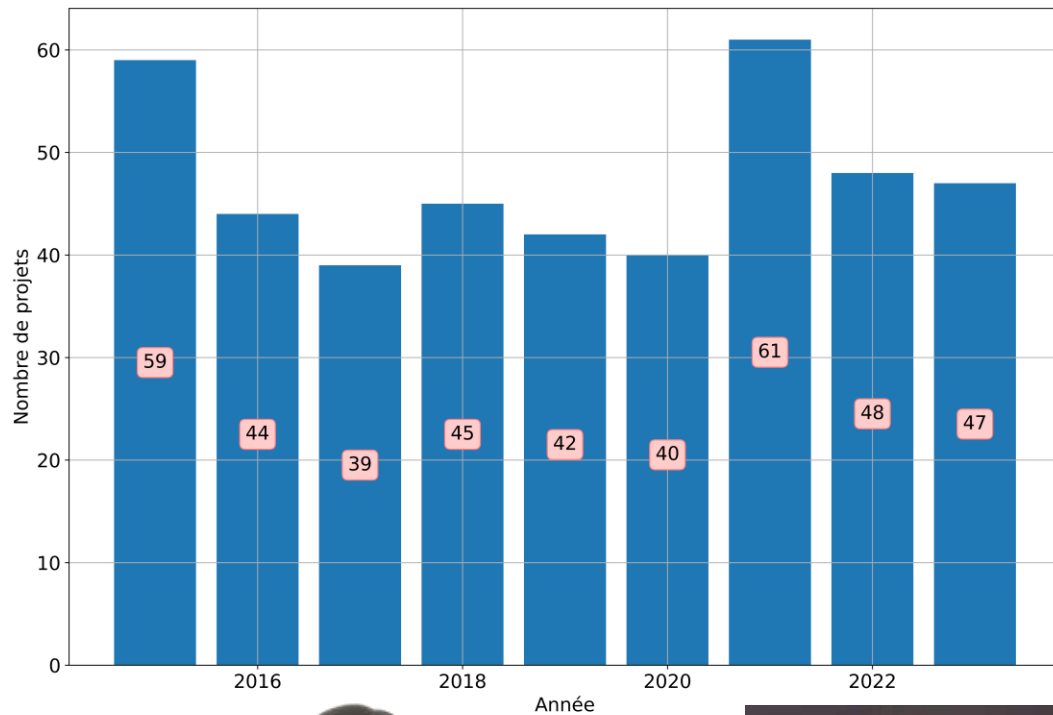
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# CNES CONTINUING SUPPORT

## Some figures:

- Since 1986 > 2800 ECS have received a CNES support
- > 300 labs involved in the CNES PhD & post-doc programs





Selma Cherchali - Head Earth Observation Department



Felix Perosanz – Solid Earth Program Manager



ionosphere gravimétrie  
enseignement géodésie  
magnétisme  
magnétisme imagerie  
océanologie planétologie

**CNES wishes a Happy Birthday  
again to Swarm and to all those who  
make the mission so rich...**

**... go, go NANOMAGSAT!**