FUNDAMENTAL PHYSICS AT CNES

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Astronomy & Cosmology
(*CMB, Planck, EUCLID, …*)

Link with space science :
- Anisotropy of the CMB PLANCK
- Characterization of dark matter, dark energy EUCLID
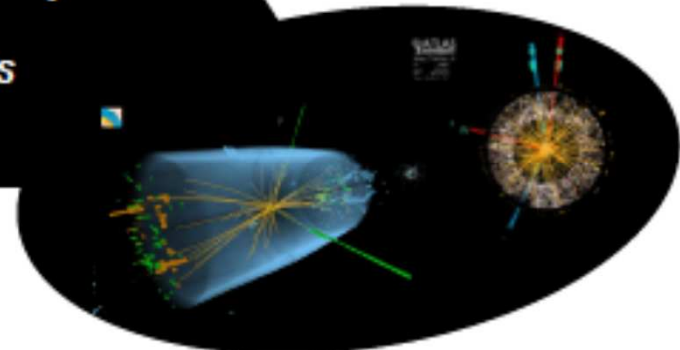- Distribution of dark matter in our galaxy GAIA
- ….

Fundamental Physics is a way to new physics at the boundary between quantum physics and general relativity

Quantum-Gravity Unification
Strings
Superstrings
Supersymmetry
Loop Quantum Gravity
M-theory
Brane scenarios
…

Link with particle physics
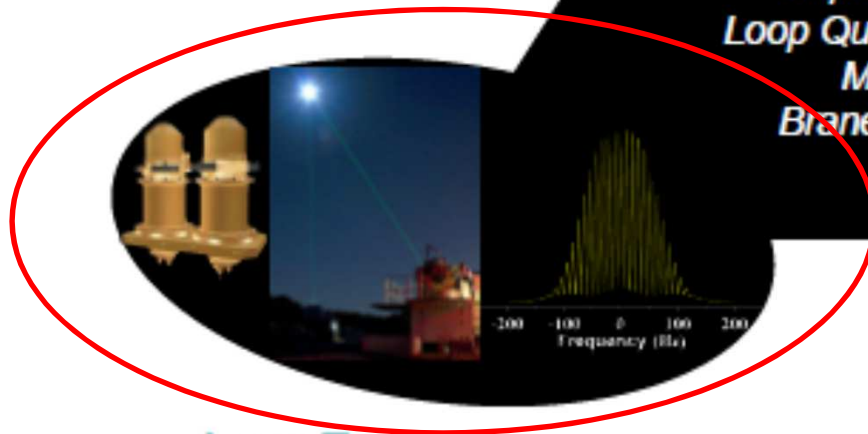
Low Energy
(LLR, lab tests, ACES, μ–SCOPE, …)

High Energy
(CERN-LHC, Fermilab, DESY, .

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FUNDAMENTAL PHYSICS

Three main experimental roads have been defined by the scientific community

- Tests of the Equivalence Principle and its various aspects, variation of the fundamental constants, redshift (Einstein effect)

- Tests of General Relativity in the solar system

- Observation of gravitational waves

⇒ Develop space instruments to make direct measurements: clocks, laser links, accelerometers…

⇒ Use data of solar system missions (radioscience, navigation) meanwhile

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CNES AND THE SCIENTIFIC COMMUNITY

- CNES as an agency :
  - ✦ Is responsible for coordinating French space research
  - ✦ does not have own research labs but has special links with national research institutes (CNRS, CEA, ONERA, Universities, Observatories…)
    - » Annual announcement for research proposals
    - » Joint research groups and programmes
      - GRAM (Gravitation, Références, Astronomie et Métrologie), PNC,PNHE…
      - CESDN (Consortium Etude des Données de Navigation)
    - » Support to doctoral & post-doctoral positions, colloquiums…
    - » Semi decadal surveys : Fundamental Physics Group
  - ✦ CNES represents France in ESA boards (SPC, PB-HME…)

- CNES as a technical center :
  - » R&T
  - » Assessment studies (missions, instruments)
  - » Project development (involvement on a case by case basis)
  - » Operations & data processing

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THE BIRTH CERTIFICATE

Séminaire de prospective

Saint-Malo 1993

LES SCIENCES
DE L'UNIVERS

Séminaire de prospective

Saint - Malo, octobre 1993

LA PHYSIQUE FONDAMENTALE

Groupe de travail : A. Bernard, L. Blanchet, R. Bonneville, A. Brillet, P. Fayet, C. Salomon (rapporteur), C. Veillet.

Pour la première fois, un groupe de travail "Physique fondamentale" a été constitué pour le séminaire de prospective scientifique du CNES à Saint-Malo. Cette création répond à l'émergence de thématiques nouvelles dans le domaine de l'utilisation de l'espace pour la réalisation d'expériences en physique fondamentale qui ne rentrent pas naturellement dans le cadre des disciplines déjà existantes en sciences de l'Univers ou en micropesanteur.

On assiste en effet actuellement à une convergence entre la physique des particules, l'astrophysique et la physique gravitationnelle (matière noire, physique des trous noirs, cosmologie,...), et l'espace sera demain un laboratoire privilégié pour la physique fondamentale.

Fundamental Physics as a new topic in CNES Space Science Programme

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USE SPACE AS A LABORATORY TO MAKE MEASUREMENTS

1993 Saint Malo : recommendations

      STEP Test of the Equivalence Principle

      SORT Test of GR in solar orbit

      LISA Detection of gravitational waves

1998 Arcachon : reduced but determined ambition

      Microscope (2016)

      PHARAO/ACES (2016), T2L2/JASON-2 (2008)

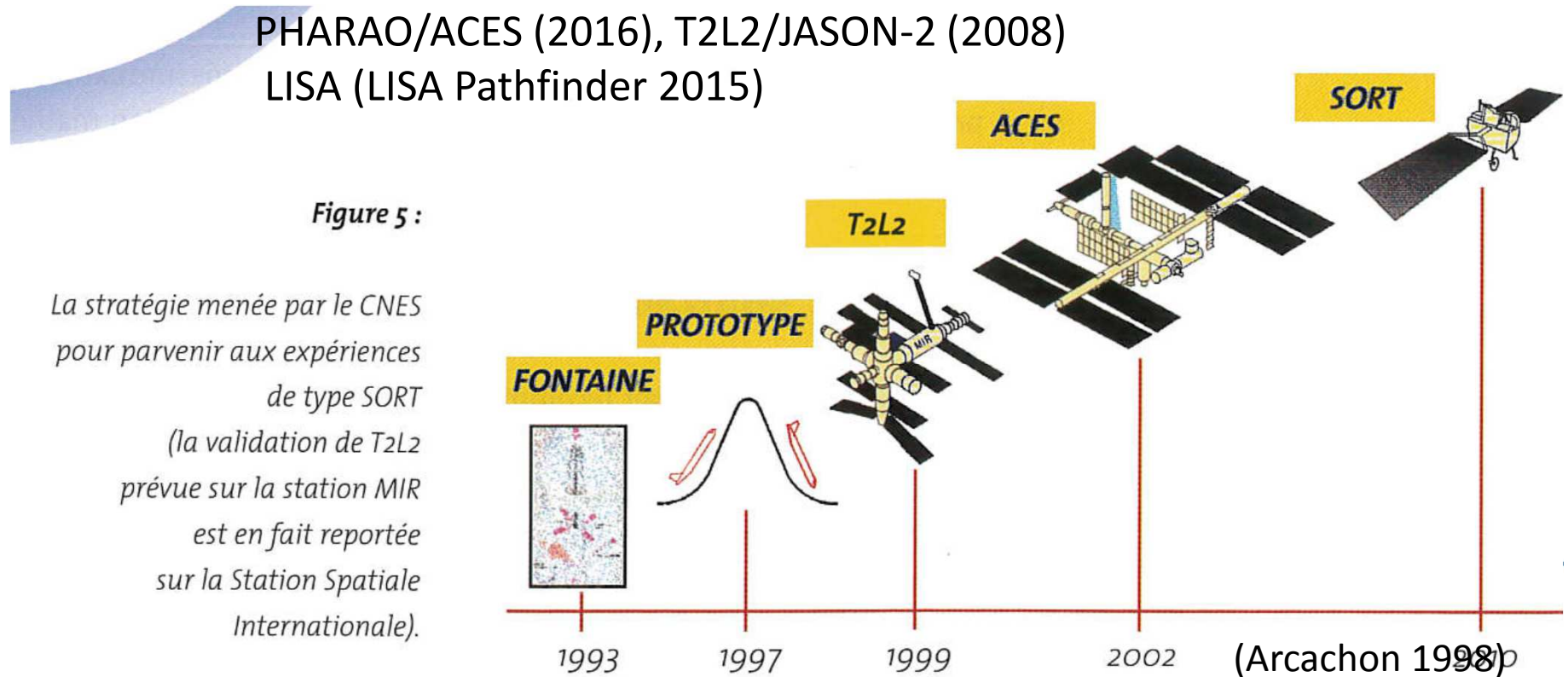   LISA (LISA Pathfinder 2015)

Figure 5 :

La stratégie menée par le CNES pour parvenir aux expériences de type SORT (la validation de T2L2 prévue sur la station MIR est en fait reportée sur la Station Spatiale Internationale).

FONTAINE   PROTOTYPE   T2L2   ACES   SORT

1993   1997   1999   2002

(Arcachon 1998)

T2L2 (TIME TRANSFER BY LASER LINK)

**Launched in June 2008 as a passenger
on the altimetry mission JASON-2**

**Proposed by OCA Géoazur
Developped by CNES (prime)**
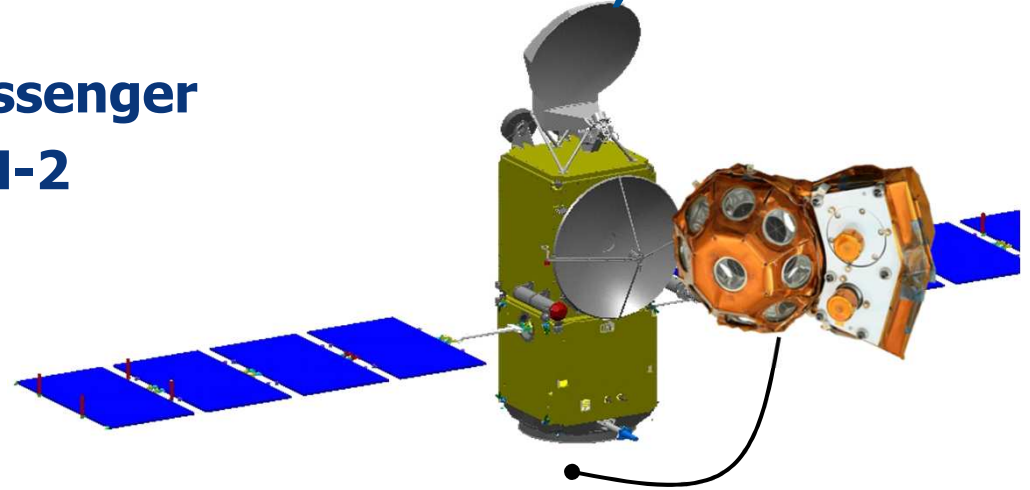
- **Payload**
  - ◆ T2L2 instrument (10 kg / 40 W) :
    - • Photo detection : From single photon, triggered by laser shots
    - • Event timer : ps resolution
  - ◆ LRA (Retro reflector, US)
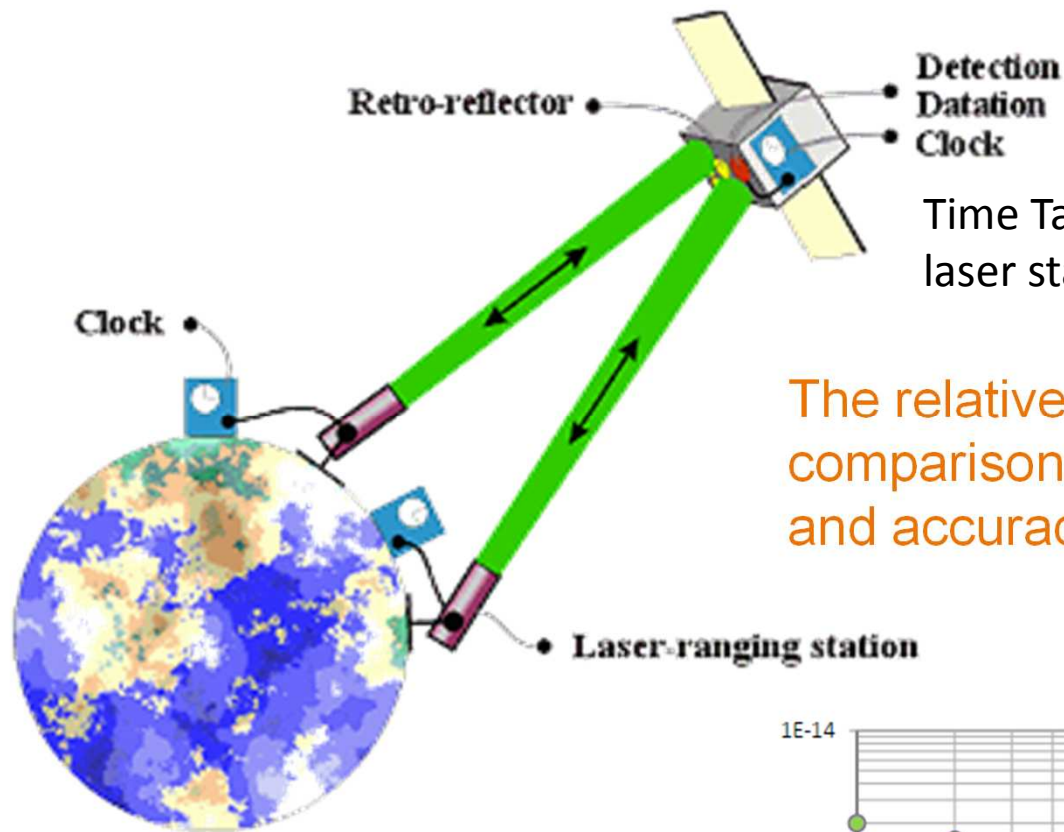 - ◆ DORIS USO (Clock, CNES)
- **Ground Segment :**
  - ◆ Instrument Mission Center : CNES (on-board operations)
  - ◆ Science Mission Center : OCA/Geoazur (data processing)
  - ◆ Laser Ranging Stations :   532 nm, 10 Hz to 1 kHz
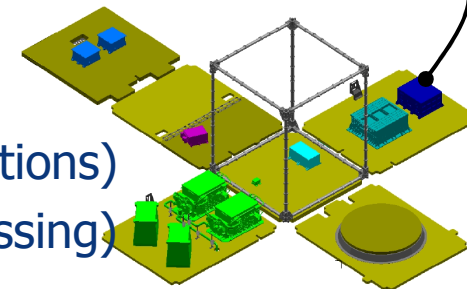
T2L2 (TIME TRANSFER BY LASER LINK)

Time Tagging of laser pulses emitted from a laser station towards the satellite

The relative frequency stability for clock comparison is below 10^{-16} on the long term, and accuracy in time is better than 100 ps

Colocate clock and laser station
- Mobile clock (Pharao fountain)
- Mobile laser station (FTLRS)
- Optical fiber network (Refimeve)
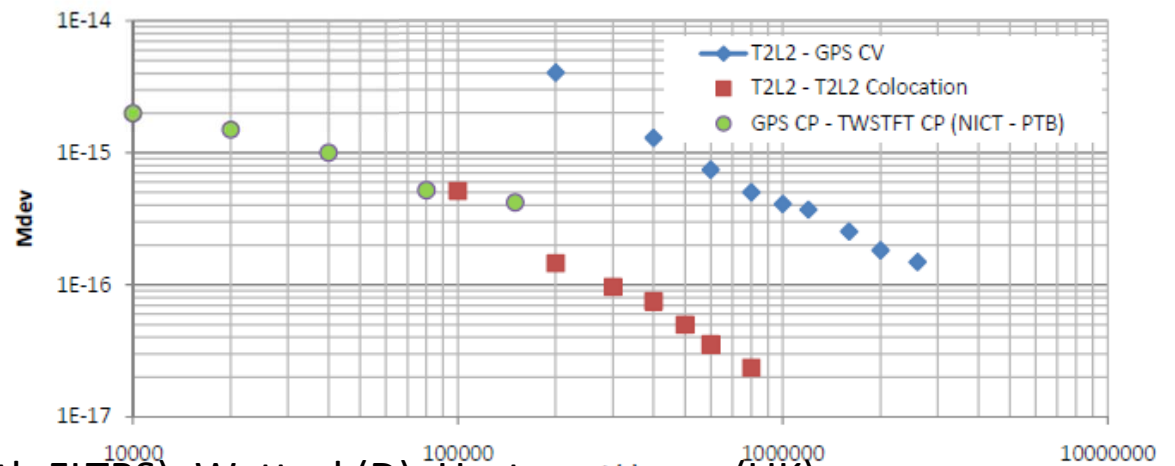
Campaigns : Grasse (Fr), Paris (Fr, with FLTRS), Wettzel (D), Hertsmonceux (UK)
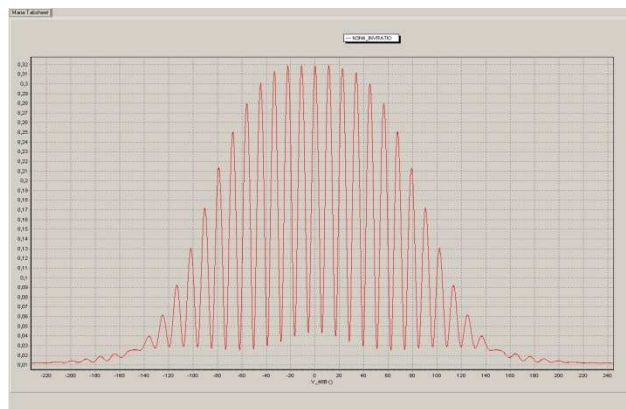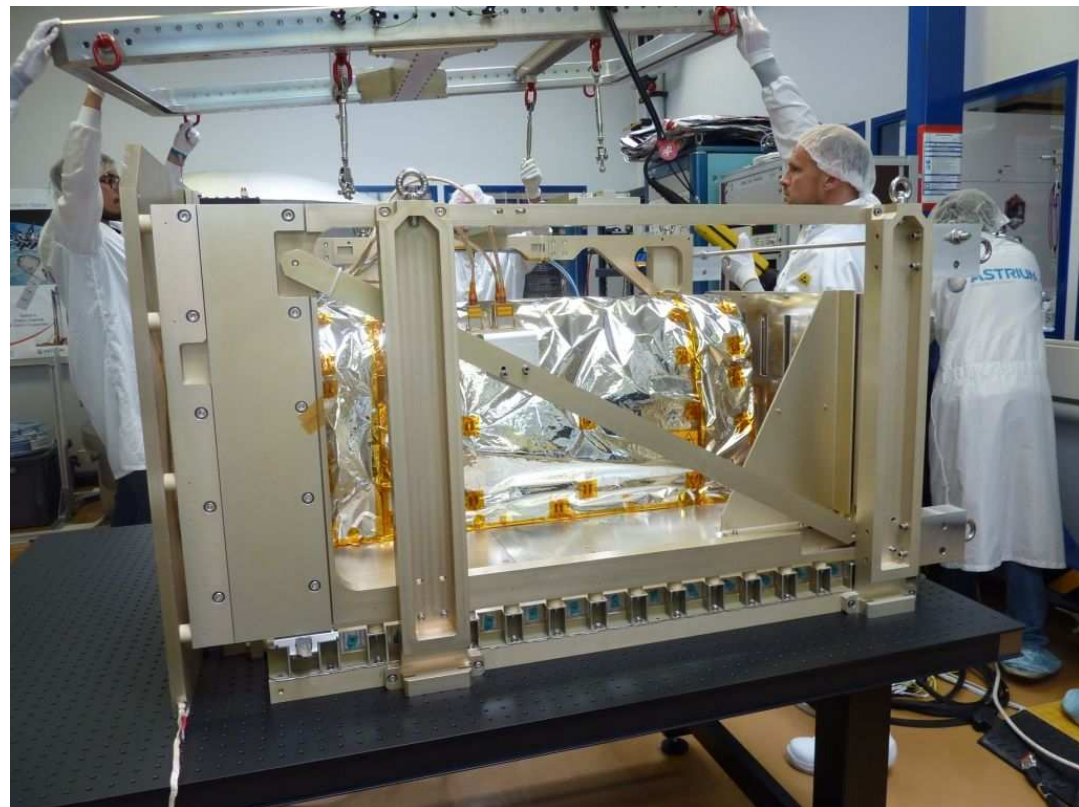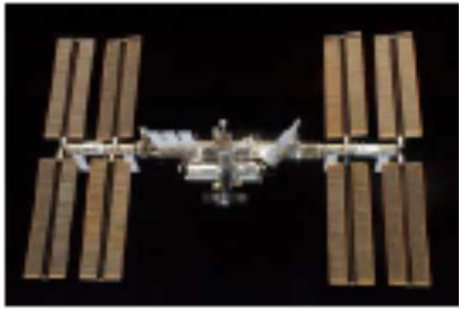
PHARAO DELIVERED TO ACES

"Timely arrival of Pharao space clock 25-07-2014 02:12 PM CEST

ESA has welcomed the arrival of Pharao, an important part of ESA's atomic clock experiment that will be attached to the International Space Station in 2016"

«Integrated CNES-LabTeam »

- Prime : CNES
  - ✦ Sodern (laser source, caesium tube)
  - ✦ TAS (microwave source)
  - ✦ Erems (electronics)…
- Labs : LKB, SYRTE
- Integration & tests in CNES

Pharao on ACES table in ADS premisses

clock comparison @ 10-17 using ground optical clocks in 2016-2019

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MICROSCOPE (2016)

Myriade Microsatellite

- Science mission
  - Test of the Equivalence Principe @ 10^{-15}
- Technology mission
  - Drag-free system (cold gas)
  - Deorbitation system
  - GNSS

- CNES prime for system and satellite & responsible for
  - Spacecraft bus
  - Gas distribution module & pressure regulation module (thrusters and their electronics are provided by ESA)
  - Satellite integration and tests
  - Control center and launch
- Instrument delivered by ONERA on 16 oct 2014
- Joint performance working group
- Cooperation

CNES, ONERA, OCA, ESA, DLR, ZARM, PTB

© CNES/S.GIRARD, 2014
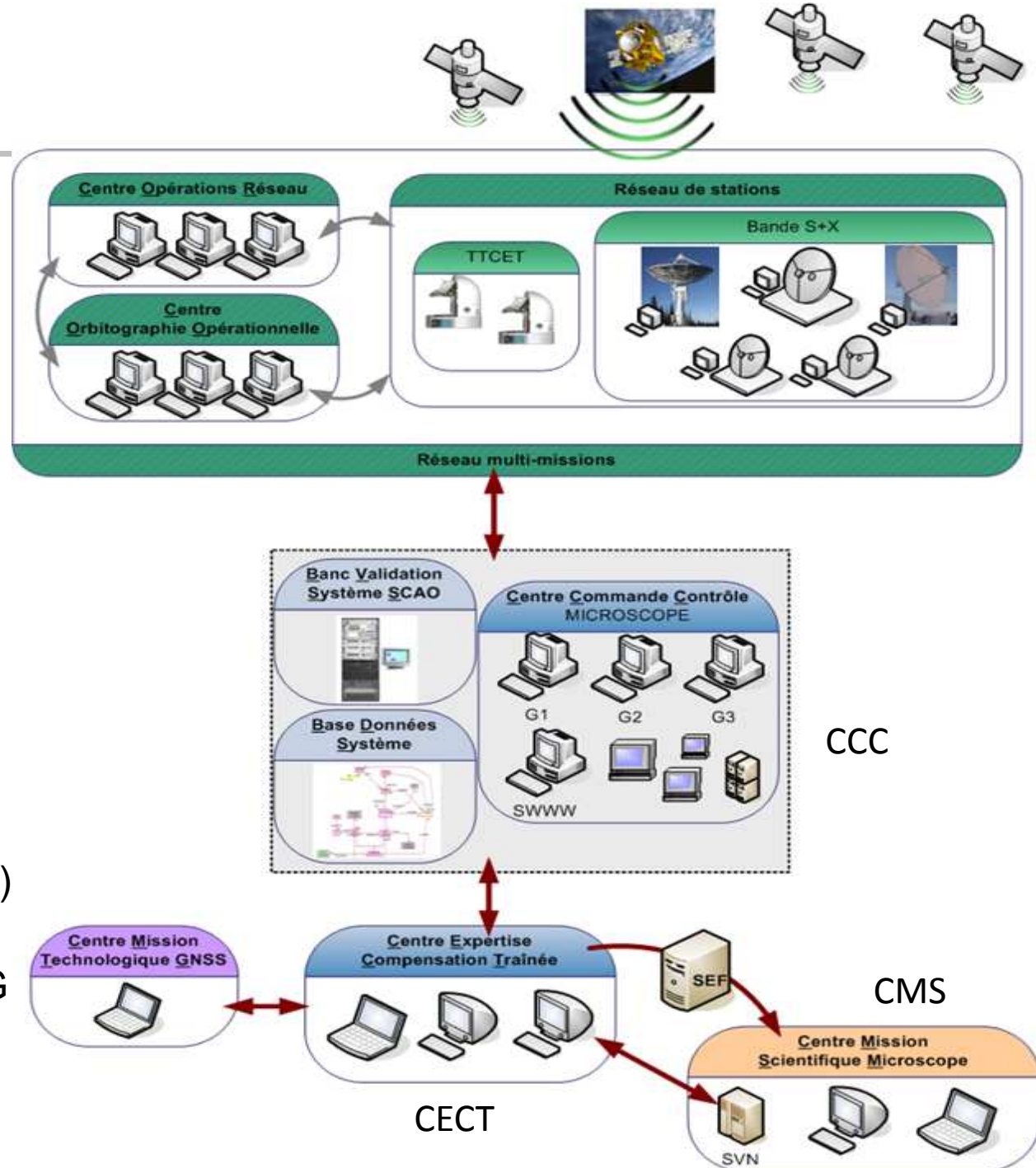

Amortisseurs

FEEU
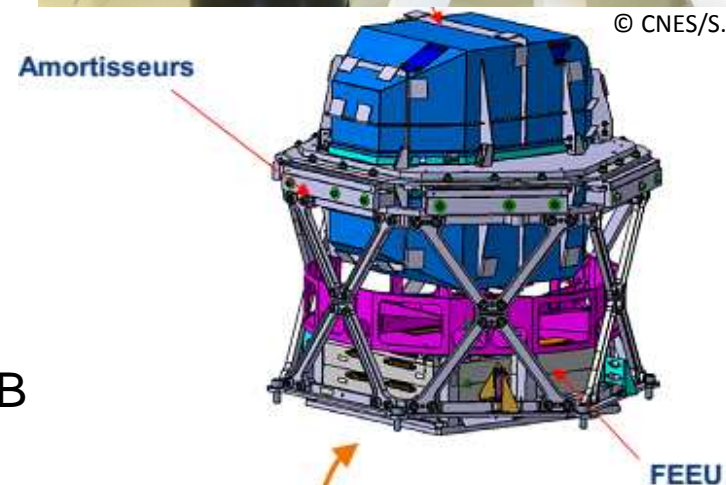
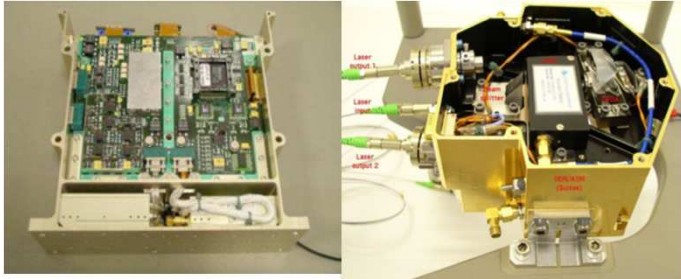# MICROSCOPE

Myriade microsatellite

- developped & operated by CNES

Ground segment

- Command control center CCC
- Drag free expertise center CECT
- Science mission center CMS (ONERA)
- GNSS technological mission center CMTG

CCC

CMS

CECT

LISA PATHFINDER & L3 MISSION (GRAVITATIONAL UNIVERSE)

Lisa pathfinder (July 2015)

- Laser modulator : provision of the FM to ESA in august 2009
- STOC (Science and Technology Operation Center) simulation campaigns in ESAC
  - supported by Data processing Center in FACe (François Arago Center, APC, Université. Paris-Diderot)

L3 mission (2034, selection 2018-19)

- Assessment study for the data processing center DPC (final report end of 2014, CNES, APC, industry) on the basis of e-LISA
  - organisation, architecture, development strategy, ressources, risks..

  (based on Gaia experience)
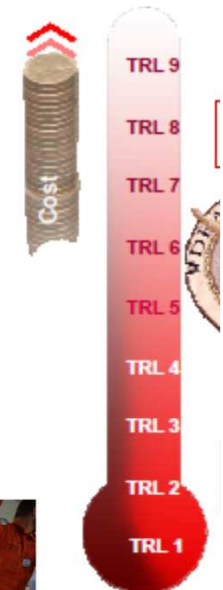- ESA GO-AT presently analyses possible alternatives

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R&T

Preparation of future missions (Odyssey, Sagas, STE-QUEST, e-LISA….)

- GAP : electrostatic accelerometer for solar system missions
  $$1 \text{ nm/s2/Hz1/2 sur } [10\text{-}5 - 0.1] \text{ Hz}$$
  3kg,3w,3l
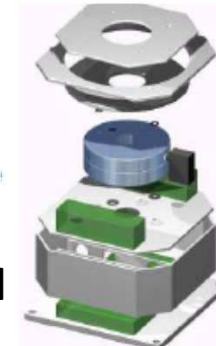
- ICE : atom interferometer
  Differential acceleration measurement
  Rb, K, in parabolic flight

- MiniDoll : coherent laser link
  tests on satellite
  adaptative optics

- LOT : Lisa On Table , end to end performance simulator for low noise interferometry
- LASIC : laser stabilisation on a molecular reference
- Optical clocks Hg, Sr
- Miniclocks: Rubiclock, Horace
- …

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ESA PROGRAMME

Astro-H (JAXA)
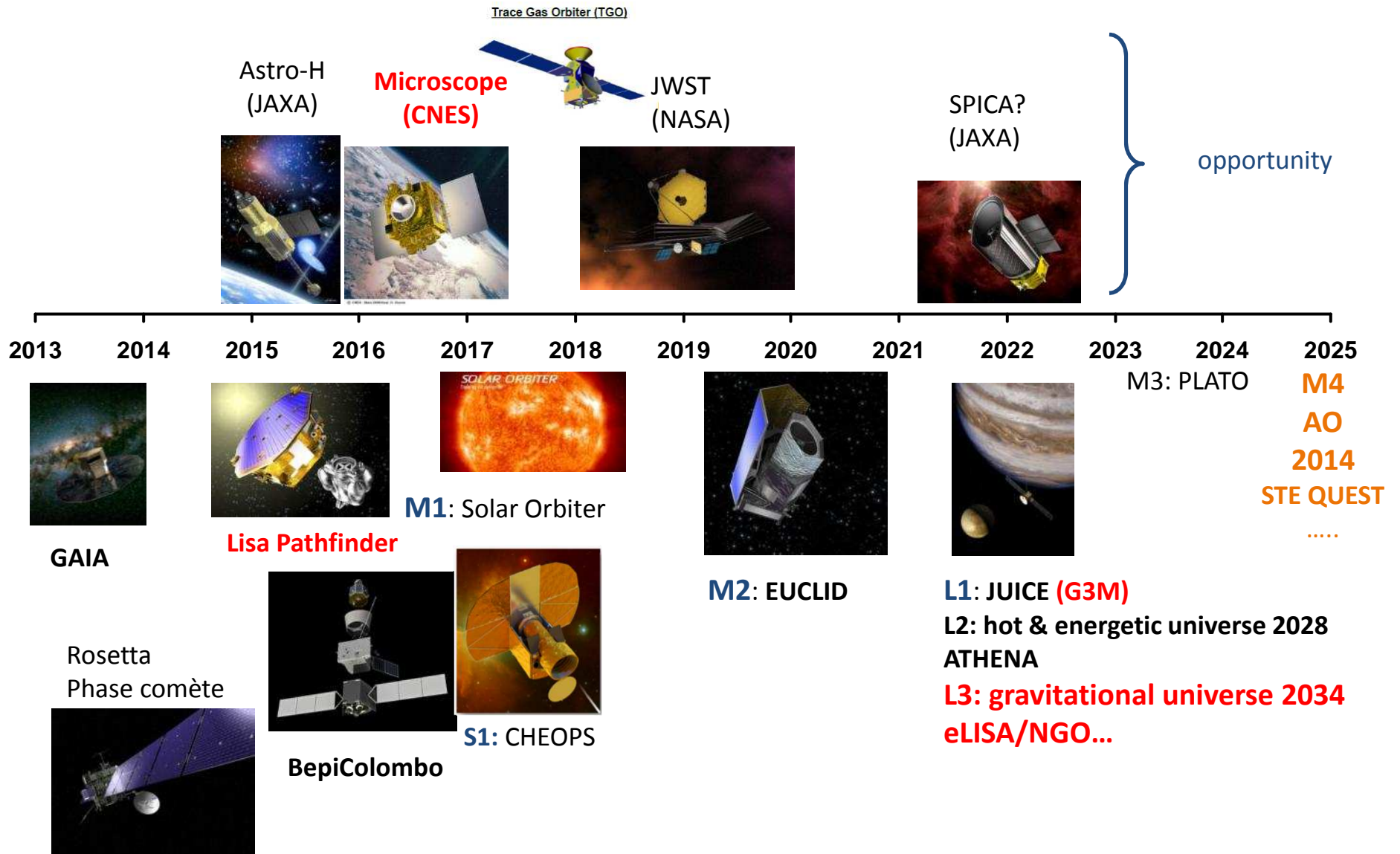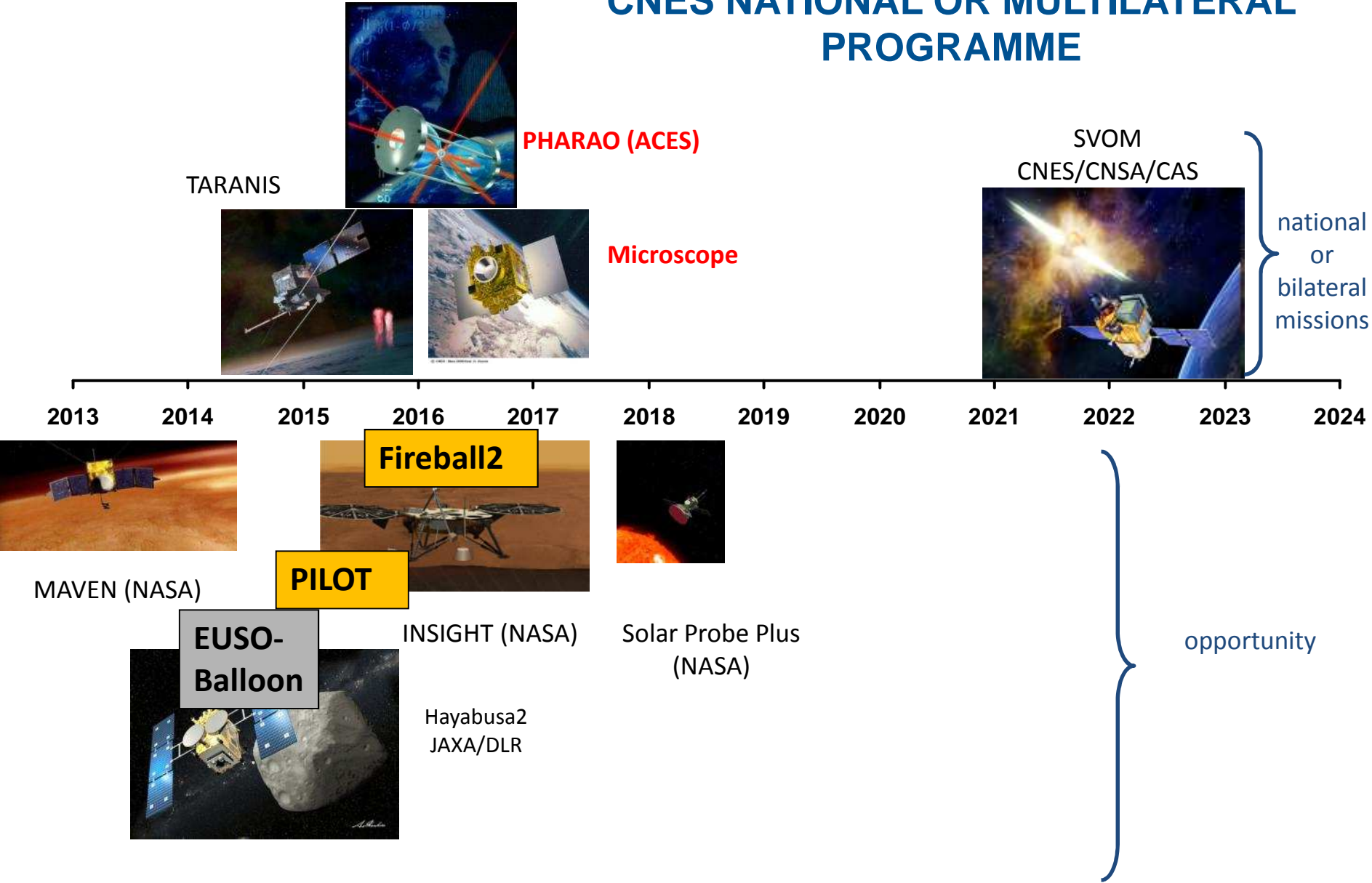
Microscope (CNES)

Trace Gas Orbiter (TGO)

JWST (NASA)

SPICA? (JAXA)

opportunity

2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025

M3: PLATO

M4 AO 2014 STE QUEST
.....

M1: Solar Orbiter

Lisa Pathfinder

GAIA

M2: EUCLID

L1: JUICE **(G3M)**
L2: hot & energetic universe 2028 ATHENA
L3: gravitational universe 2034 eLISA/NGO…

Rosetta
Phase comète

BepiColombo

S1: CHEOPS

Mission exploitation : Planck, Cassini, Messenger, ..

CNES NATIONAL OR MULTILATERAL PROGRAMME

PHARAO (ACES)

TARANIS

Microscope

SVOM
CNES/CNSA/CAS

national
or
bilateral
missions

2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024

Fireball2

PILOT

EUSO-
Balloon

MAVEN (NASA)

INSIGHT (NASA)

Solar Probe Plus
(NASA)

Hayabusa2
JAXA/DLR

opportunity

Mission exploitation (JASON-2/T2L2, MSL/Curiosity, Rosetta..,)