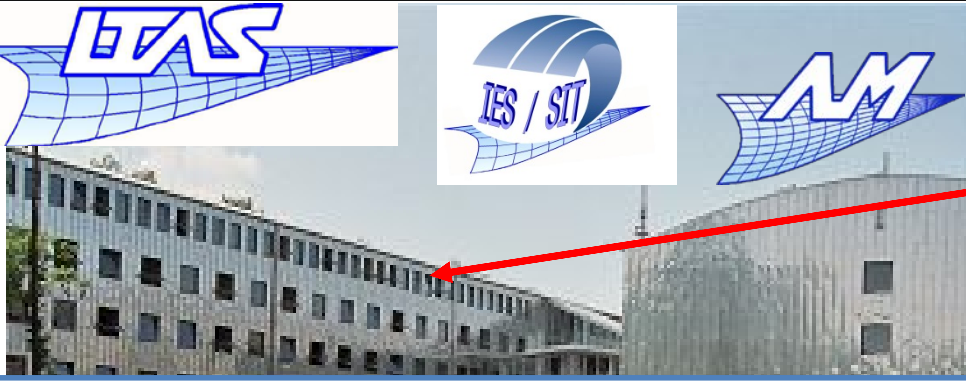


Space Activities of the Liège Space Center
University of LIEGE BELGIUM

https://www.recherche.uliege.be/cms/c_9112796/en/space

Pierre ROCHUS

Former Chairman of the IAF Space University Administrative Committee (SUAC)

Honorary Professor at the Faculty of Applied Sciences; Aerospace Department
LTAS, ULg
Head of IES (Space Instrumentation and Testing Lab.)

Invited Professor at KUL (Leuven)

Adjunct Professor of Harbin Institute of Technology Shenzhen

Guest Professor of Shandong University at Weihai

Past Scientific Director of Centre Spatial de Liege

Chairman of Liege Espace

prochus@uliege.be

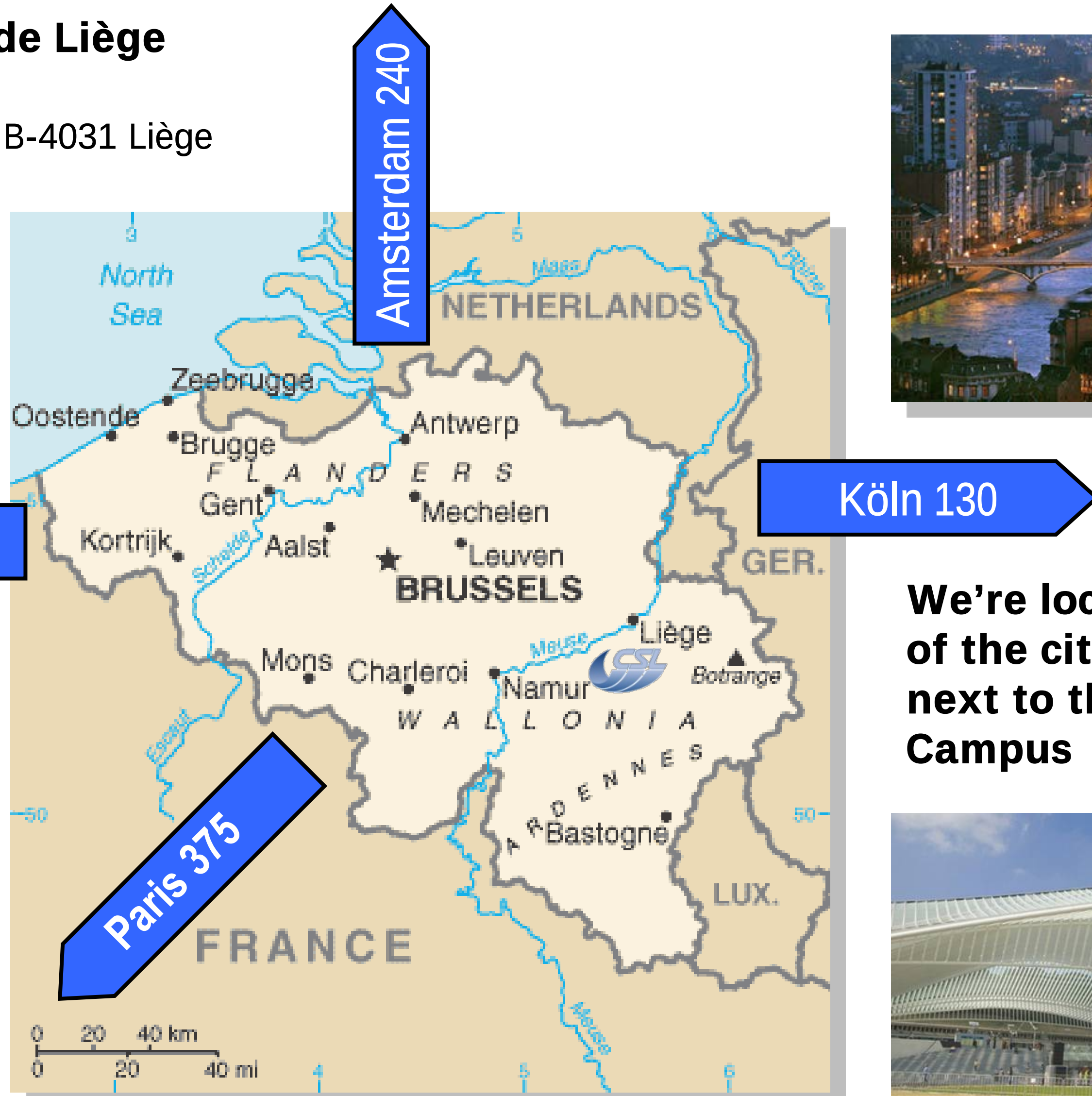
https://orcid.org/0000-0003-4290-9442

Meeting with Prof. Yan Jun,
Dean of the School of Mechanics and Aerospace Engineering
at Dalian University of Technology.
April 2024

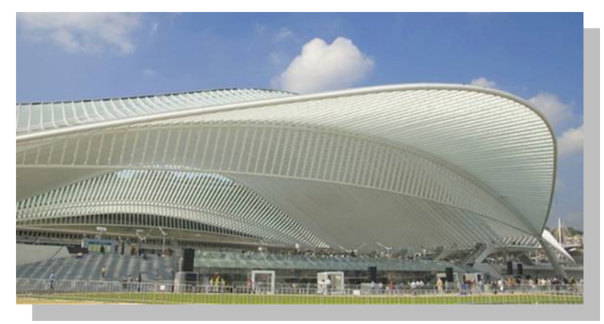
Location

Centre Spatial de Liège
Liege Science Park
Avenue du Pré-Aily, B-4031 Liège
Belgium
+32 4 382 46 00

GPS:
N 50.5980
E 5.5660



We're located 6 km south of the city centre of Liege, next to the University Campus



Training, research, expertise:

the University of Liège is at the forefront of the space field.

To understand the origin and evolution of the Earth and the Universe...

To participate in the development of advanced space missions.

The most comprehensive course programme in Belgium in Space Science and Technology in the Faculties of Science and Applied Sciences

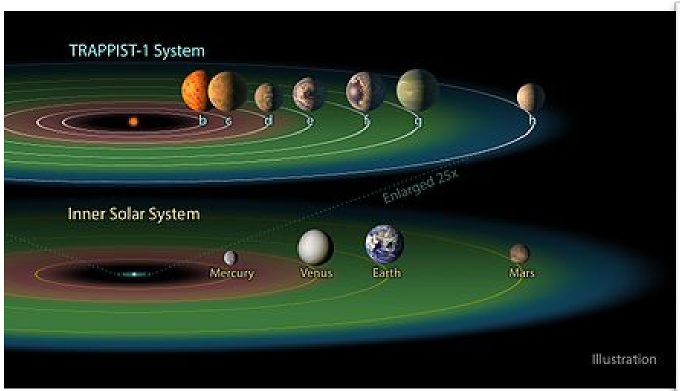
Research units *Non exhaustive*

- **STAR - Space sciences, Technologies and Astrophysics Research**
  - **TRAPPIST telescopes**
  - **SPECULOOS telescopes**
  - **TIGRE telescopes**
  - **Sphinx Observatory at the Jungfraujoch**
- **ASTROBIOLOGY**
- **A&M - Aerospace and Mechanics**
- **Montefiore**
- **CSL - Centre Spatial de Liège (Liège Space Centre)**

STAR - Space sciences, Technologies and Astrophysics Research

The STAR research unit conducts research in areas such as

- planetology (detection, characterization and direct imaging of exoplanets, study of planets and small bodies of the solar system, composition and dynamics of the Earth's atmosphere),
- Stellar astrophysics (observational characterisation and modelling of stars and their evolution, interaction of stars with their environment, high energy emission),
- cosmology, dark energy, extragalactic astrophysics and astro-particles (quasars, gravitational lenses, large-scale structures, dark matter, cosmic rays),
- Space instrumentation (Earth observation and other scientific satellites, ground instruments. STAR participates in the development of space missions and ground instruments
- Gravitational waves
- Solar Physics
- Space Weather



[LEARN MORE ; HTTPS://WWW.STAR.ULIEGE.BE/CMS/C_4265211/EN/STAR?ID=C_4265211](https://www.star.uliege.be/cms/c_4265211/en/star?id=c_4265211)

ASTROBIOLOGY

Astrobiology combines multidisciplinary approaches to study the origin, evolution, distribution and **future** of life in the universe, including the Earth, the only biological planet known so far. The ASTROBIOLOGY Research Unit studies the habitability of rocky planets and the detection and characterization of biosignatures, from early life traces and evolution on the early Earth, to the detection of possible extraterrestrial biosignatures in the solar system and in potentially habitable exoplanets.

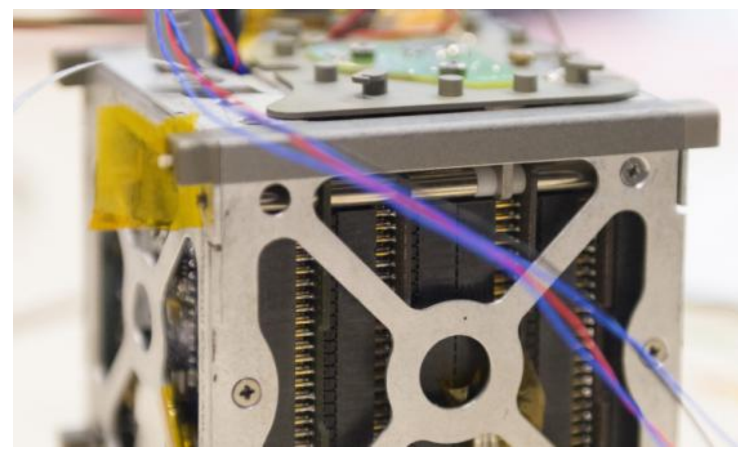
[LEARN MORE HTTPS://WWW.SCIENCES.ULIEGE.BE/CMS/C_5037156/EN/FACSC-ASTROBIOLOGY](https://www.sciences.uliege.be/cms/c_5037156/en/facsc-astrobiology)

A&M - Aerospace and Mechanics

(more than 120 people, including 24 academics (20 full-time), 4 permanent researchers, more than 80 researchers (including PhD candidates), and 15 people in the administrative and technical staff. The research unit is composed of 20 core research groups).

The disciplinary foundations of the research activities carried out within the A&M Research Unit are

- the physics of materials,
- the mechanics of continuum (solid and fluid),
- the dynamics of mechanical systems and thermodynamics.
- Astrodynamics (PR)
- Design of Space Instruments (PR)



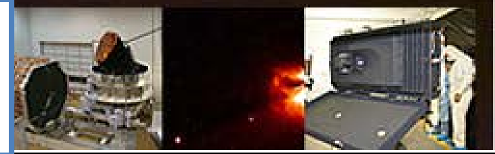
The main fields of application are

- aeronautics and space,
- land vehicle mechanics,
- mechanical engineering,
- energetics and biomedical engineering.

The methodological approach is based on the successful confrontation of mathematical and numerical modelling with the experimental study of phenomena and mechanical systems.

LEARN MORE HTTPS://WWW.AM.ULIEGE.BE/CMS/C_3711351/EN/AMNEW-RESEARCH-GROUPS
http://www.s3l.be/en/research

A&M (Former LTAS)



History

inherits a long tradition of high standard research from talented professors and researchers who have been active in the Institute of Mechanics of University of Liege.

The research in **computational mechanics and numerical simulation** in Aerospace can be traced back to the **LTAS**, *Laboratoire de Techniques Aéronautiques et Spatiales*, founded in **1961** by late **Professor Fraeijs de Veubeke** as a distinct entity in the Institute of Mechanics.

Prof. Fraeijs de Veubeke was a pioneer of the finite element method and variational principle (US Airforce contract). The research on the **finite element** method at LTAS started in 1965. The laboratory devoted most of its research efforts to the development of numerical methods and application software in aerospace engineering and, more generally, in applied mechanics.

Guy Sander, Michel Géradin, Michel Hogge, Pierre Beckers are the pioneer professors in the numerical methods aspects. This led in 1970 to the development of an integrated finite element package **SAMCEF** which has evolved in a very continuous manner since that period. Later LTAS developed a second generation FE code, **OOFELIE**, leveraging research in multiphysics simulation.

The research in computational mechanics and numerical simulation is still a very active topic in A&M and it is organized around several research groups sharing the common objective of developing numerical simulation methods and software tools in the field of aerospace and mechanical engineering.

- Besides computational mechanics, experimental research in mechanics, energy and propulsion systems stems from several laboratories that have developed cutting edge facilities in different engineering fields.
- **An aerospace wind tunnel** (since the 1930's a new in 2000).
- **CRM** *Centre de Recherche Metalurgique*
- **Thermodynamics Lab** (

A&M is committed to the development of **multilateral scientific collaborations with other academic partners, research institutes (CHILI (Universidad de Concepcion), CHINA (Northwestern Polytechnical University Xi'an)) and private companies/industries**, to contribute to the advancement of knowledge and to support high level education/training programs.
A&M has thus a large number of key industrial partners.

Exemple: Weihong ZHANG Professsor and Director at, Northwestern Polytechnical University Structural Optimization

Montefiore

The Montefiore Institute is

- the electricity,
- electronics and
- Information Tehnology
- AI

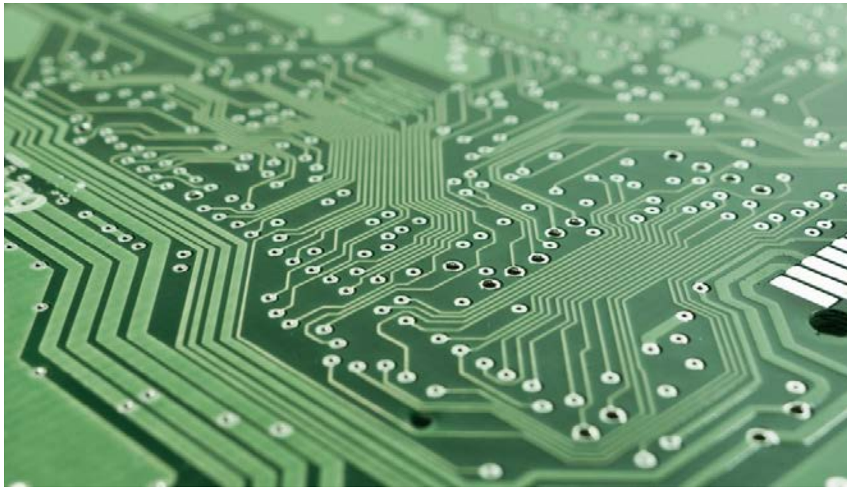
AI on board for EO
AI in the data treatment of EUCLID

It is active in a range of basic and applied research topics in various fields:

- information and communication technologies,
- computer science,
- electronics,
- power systems and
- mathematical applications.

Applied and Computational Electromagnetics (ACE)

EMC EMI tests of our payloads
Cryogenic low power dissipation electrical motor
Numerical Simulation of LiteBird experiment Tests



LEARN MORE HTTPS://WWW.MONTEFIORE.ULIEGE.BE/CMS/C_4570368/EN/RESEARCH-TOPICS

TRAPPIST telescopes

TRAPPIST (TRAnsiting Planets and PlanetesImals Small Telescope) is dedicated to the detection and characterisation of planets orbiting other stars than our Sun (**exoplanets**) and the study of **comets** and other small bodies of our solar system.
It consists of two 60 cm robotic telescopes, one in the southern hemisphere, installed at ESO's La Silla Observatory in **Chile** in June 2010 and the other in the northern hemisphere, installed in May 2016 at the observatory of Oukaimeden in **Morocco**.

SPECULOOS telescopes

The SPECULOOS Project (Search for habitable Planets EClipsing ULtra-cOOl Stars) aims to **detect telluric planets eclipsing some of the smallest and coldest stars** in the solar neighbourhood.
This strategy is motivated by the possibility of studying such planets in detail with future ambitious observatories such as the European Giant Telescope (E-ELT) or the James Webb Space Telescope (JWST). The exoplanets detected by SPECULOOS should thus offer us the opportunity to analyse the atmosphere of extrasolar worlds similar to our Earth, in particular to look for traces of a biological activity.

TIGRE telescopes

El Tigre (el Telescopio Internacional de Guanajuato, Robótico-Espectroscópico - initially known as "HRT" - Hamburg Robotic Telescope) is a private and flexible telescope partly funded by the University of Liège. The fruit of a German-Mexican-Liege partnership, it will enable the Liège astrophysicists to undertake many completely new studies on the **stars**, and is also an opportunity for amateurs and the general public to discover an unknown science.
LEARN MORE HTTPS://WWW.TRAPPIST.ULIEGE.BE/CMS/C_5006023/FR/TRAPPIST?ID=C_5006023
HTTP://WWW.GAPHE.ULG.AC.BE/HRT/INDEX_F.HTML

For decades now, the Group of the Institute of Astrophysics and Geophysics, and more particularly today the Infrared Group of Atmospheric and Solar Physics (GIRPAS) has been monitoring the visible and infrared solar spectrum at very high resolution. At the beginning, these researches aimed especially at defining the chemical composition of the external layers of the Sun. **Progressively, they have been reoriented towards the composition of the Earth's atmosphere**, using the Sun as a source of radiation.

The **high altitude** of the **Sphinx Observatory at the Jungfraujoch**, combined with **instrumentation providing high resolution** and a high signal-to-noise ratio, allow to overcome most of the absorption produced by high concentration gases in the troposphere and thus make the **quantification and monitoring of trace gases of interest, mainly concentrated in the stratosphere**, possible.

CSL - Centre Spatial de Liège (Liège Space Centre)

The Centre Spatial de Liège is an applied research centre of the University of Liège focused on

- the **design of space observation instruments**.
- The CSL also has a state-of-the-art environmental **Testing Facility** at the service of the European Space Agency (ESA), the space industry and regional companies. Its remarkable equipment consists in particular of tanks of different diameters installed in ultra-clean rooms, which make it possible to simulate the severe space environment in which the satellites and their instruments will have to function.
- CSL as a **Center of Excellence in Optics**, also has the **stimuli and optical calibration systems** needed to validate the systems and instruments it designs, or which are entrusted to it. CSL has numerical and experimental expertise in **STRAYLIGHT** characterization.

[LEARN MORE : HTTPS://WWW.CSL.ULIEGE.BE/CMS/C_10241774/EN/CSL?ID=C_10241774](HTTPS://WWW.CSL.ULIEGE.BE/CMS/C_10241774/EN/CSL?ID=C_10241774)

SPACE Topics of interest in the sixties:

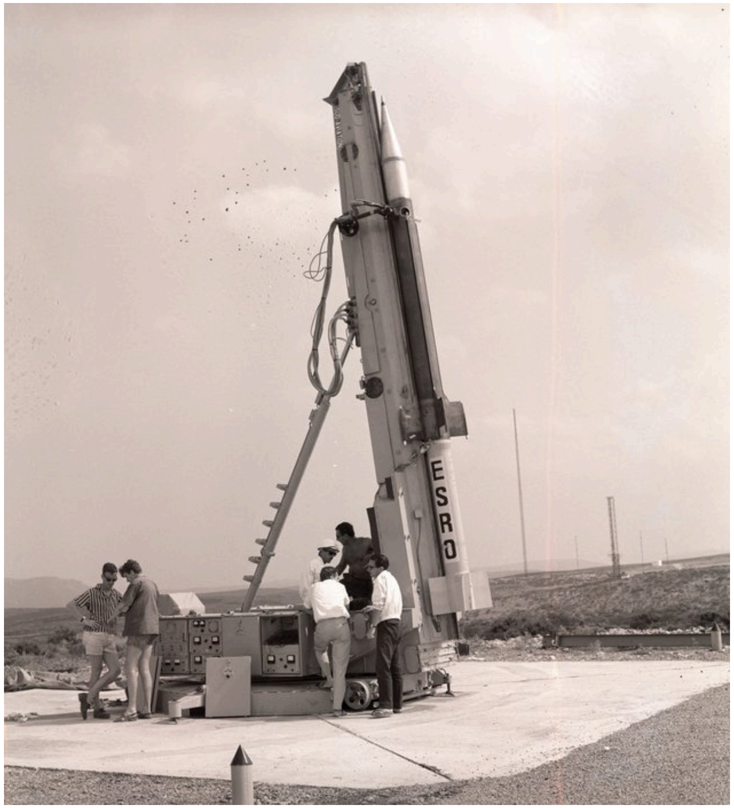
- « Radiations in Space »
- SKY at wavelengths not accessible from ground
- Solar Wind
- Sun Earth interactions
- Auroras
- Comets
- Spectroscopy

Discover of He first on the Sun→ Success of Spectroscopy.

Pioneers in Space observation were spectroscopists !

Artificial comet

- IAL Space
- MP Goetingen



6 and 8 July 1964 first sounding rockets Salto di Quirra range; Sardinia

Centre Spatial de Liège
Université de Liège

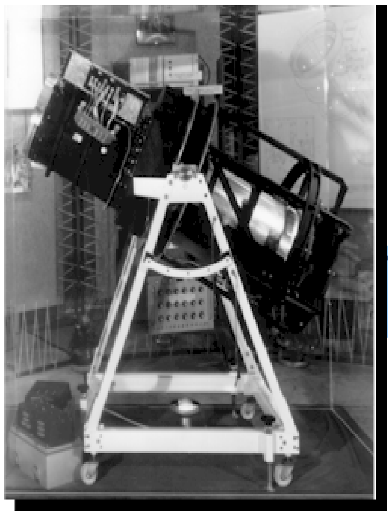
1959: Start of the group in Astrophysics

1962: Start of Space activities; launch of 22 sounding rockets

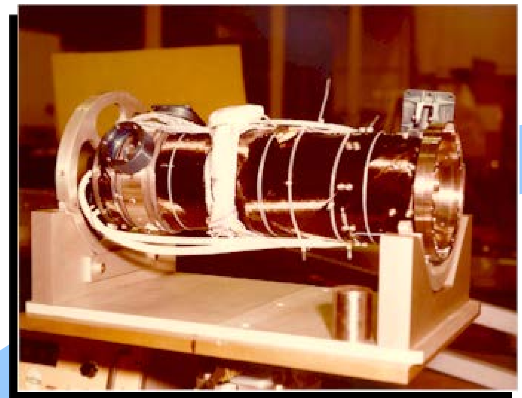
Start July 6, 1964

Space instruments before 1995

1967-1972 : Design, manufacture and calibration of the S2/S68 experiment aboard the TD1 satellite for a sky survey in the ultraviolet

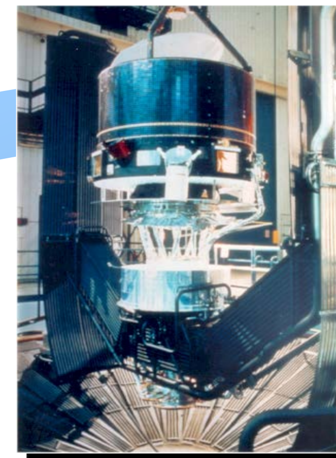


1978-1988 : HUBBLE Space Telescope



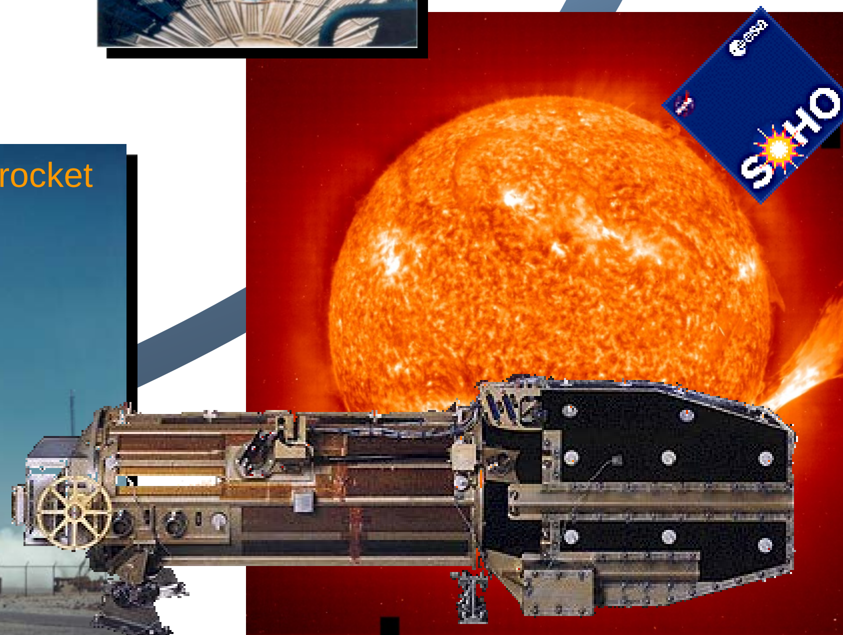
Qualification and calibration of the Photon Detector Assembly of the Faint Object Camera

1982-1985 : development of the Halley multicolour camera on the ESA Giotto satellite



1988-1995

SOHO-EIT



After 1995

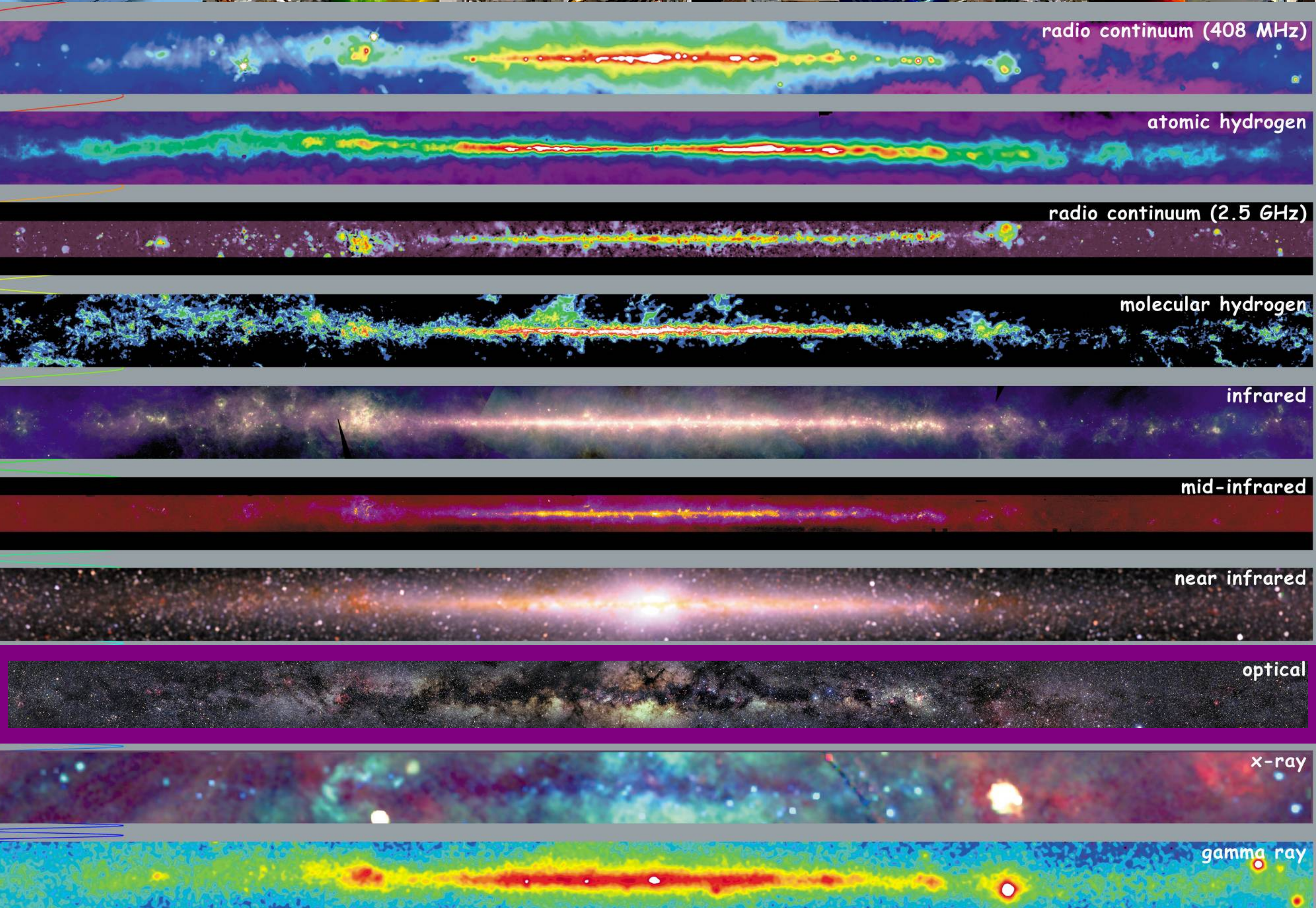
More than 20 in space in

L1, L2, LEO, HEO, EPO, SO

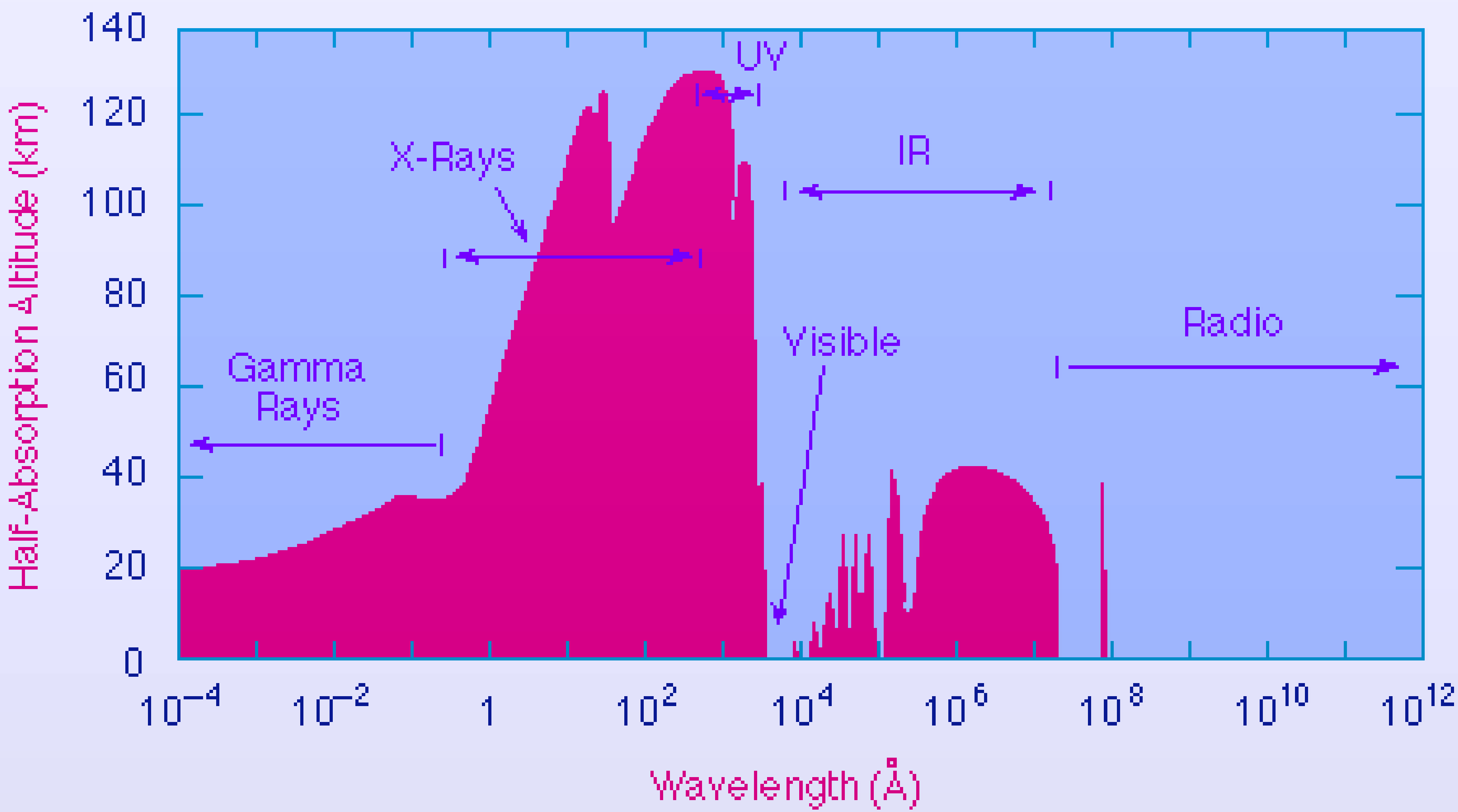
SSO, Jupiter, close to the Sun

After 1975: start of ESA coordinated Test Facility: METEOSAT Radiometer, HIPPARCOS, ISO, ...

The Milky Way at different wavelengths

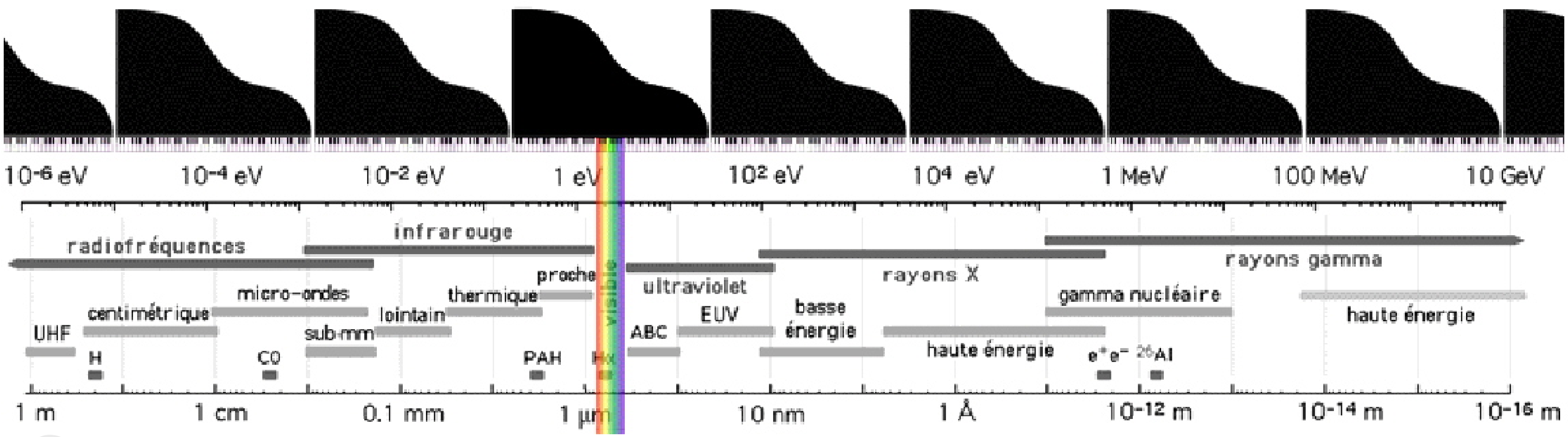


Need to go to Space



Space gives us access to 70 octaves

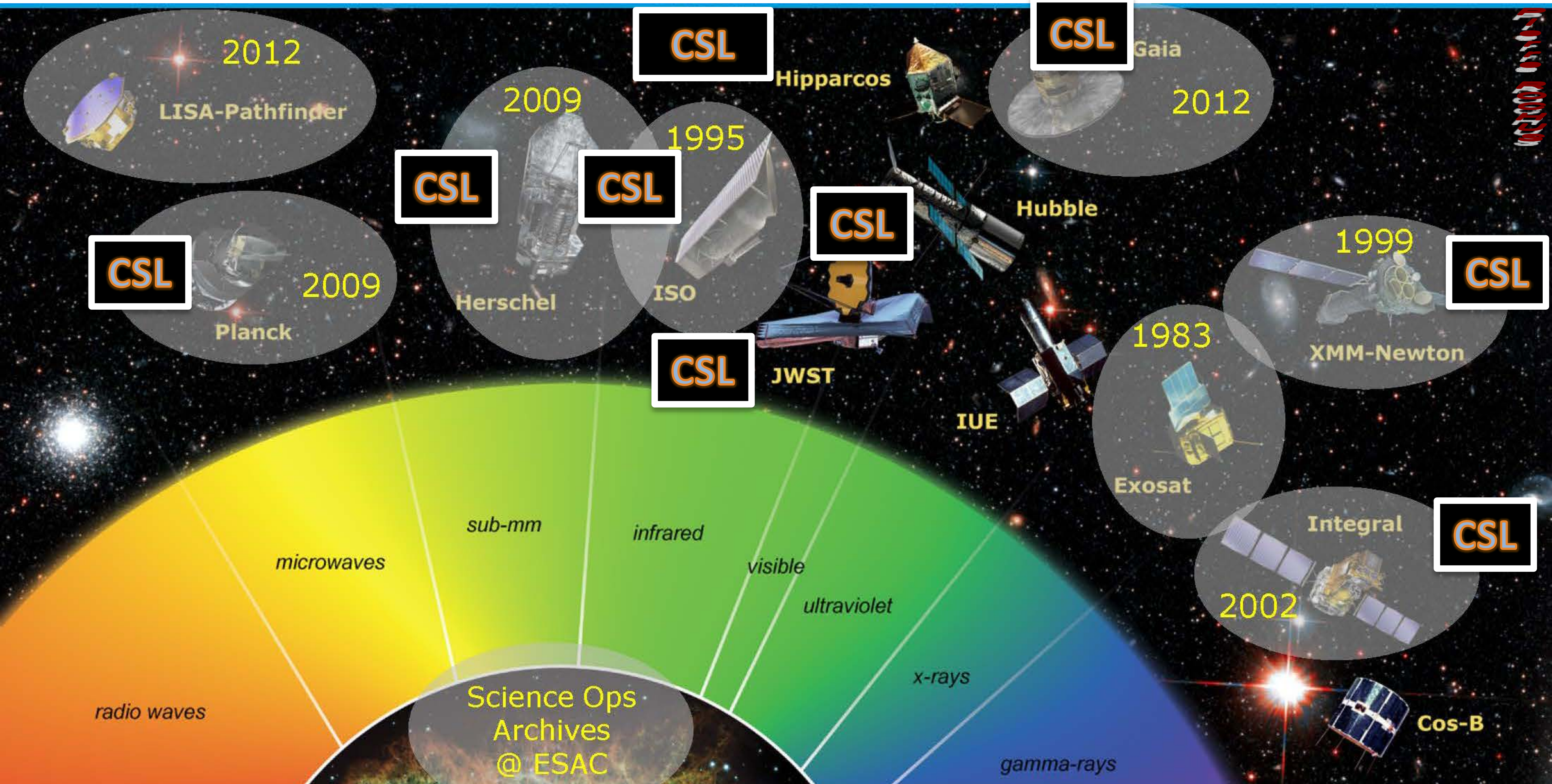
21 decades or 70 octaves



8 electromagnetic pianos

20 decades just for the sun !
when the sun is active

TD1, GIOTTO, HST, HIPPARCOS, ISO, SOHO, NEWTON, IMAGE, COROT, STEREO, PROBA2, JWST, INTEGRAL, PLANCK, HERSCHEL, GAIA, PLATO, Euclid, PSP, ICON, Solar Orbiter, JUNO, JUICE, EUCLID, PROBA 3, SMILE, ARIEL, Carruthers, PLATO, ARRAKIHS, LISA, ATHENA,...

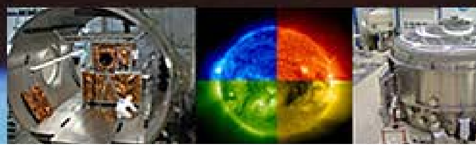


Why going in Space for Science ?

- Working out of the atmosphere: Astronomy (waves and particles detection)
- Approaching an object: planets, asteroids, comets, sun,
- Measuring in an environment: solar wind, magnetosphere, …
- Testing in an environment: µ-Gravity
- Observing continuously: solar and stellar oscillations, earth, exoplanets,
- Reconstructing an object in 3-dimensions: Stereoscopy

  EXAMPLE: See an object (the sun) in a completely different direction from the Earth: it is the STEREO mission or outside ecliptic (Ulysses, Solar Orbiter).
- Looking and comparing all around (HIPPARCOS, COBE, PLANCK, GAIA, EUCLID, ARRAKIHS, …, LISA)
- Measuring gravitational waves (LISA, ET)

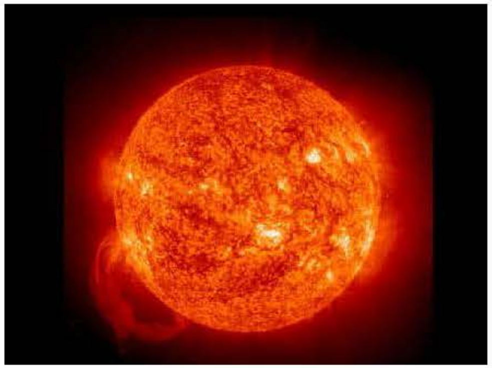
CSL has been involved with flight hardware in all these categories.

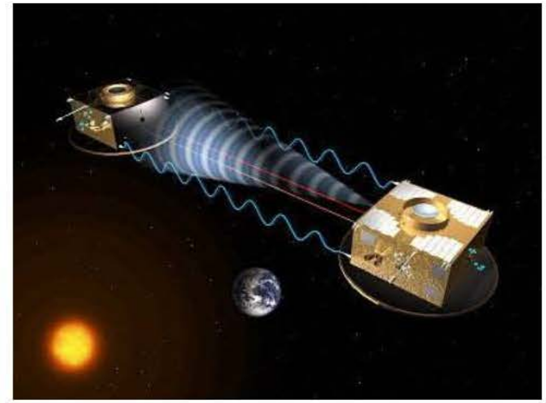


Sciences beside µ gravity, Earth Observation, Space Situation Awareness, Space Weather

Main subjects:

In SPACE SCIENCE





Fundamental physics

Space time telescopes

Solar System

Sun — Heliophysics

Planets — Magnetosphere

Astrophysics

Galactic

Extragalactic

In 1905, Einstein's ideas about the universe were considered improbable and unbelievable.
Over the last century, new technology has provided new evidence for the Big Bang, black holes, and even Dark Energy.
We are also preparing future missions to detect the gravitational waves

Missions from space are fundamental to elucidate these new concepts.

- Laws of Physics
- Structure and content of the Universe
- Evolution of the Universe: from the Big Bang to the formation of Earth-like planets
- Emergence of Life in the Universe
- Exoplanets

Space Systems Projects inside ESA structure

Science

- TD1, HST, SOHO, XMM, INTEGRAL, CoRoT, PROBA-2, Herschel, JWST…
- S1 (CHEOPS); M1 (SolO); M2 (Euclid); M3 (Plato); L1 (JUICE/Athena/LISA)…
- MoO (IMAGE, Proba-3, SPICA, ICON…)

Prof. Carole Mundell

Exploration

- ExoMars/TGO 2016 (NOMAD)
- LaRa, Lunar Lander

Daniel Neuenschwander

Simonetta Cheli

Earth Observation

- VEGETATION, ENVISAT, METOP, Sentinel-2, Sentinel-3, Sentinel-4, MTG…
- (SAOCOM/TreeVol), PROBA-V, PROBA-V Successor

Technologies
3D Printing; Tools for Exoplanet Det

SSA (Space Weather)

- IMAGE (with NASA) ICON (NASA)
- STEREO (with NASA)
- KuaFu (with China)
- ESIO, ICON, Smile, Carruthers,

Nicolas **Bobrinsky**

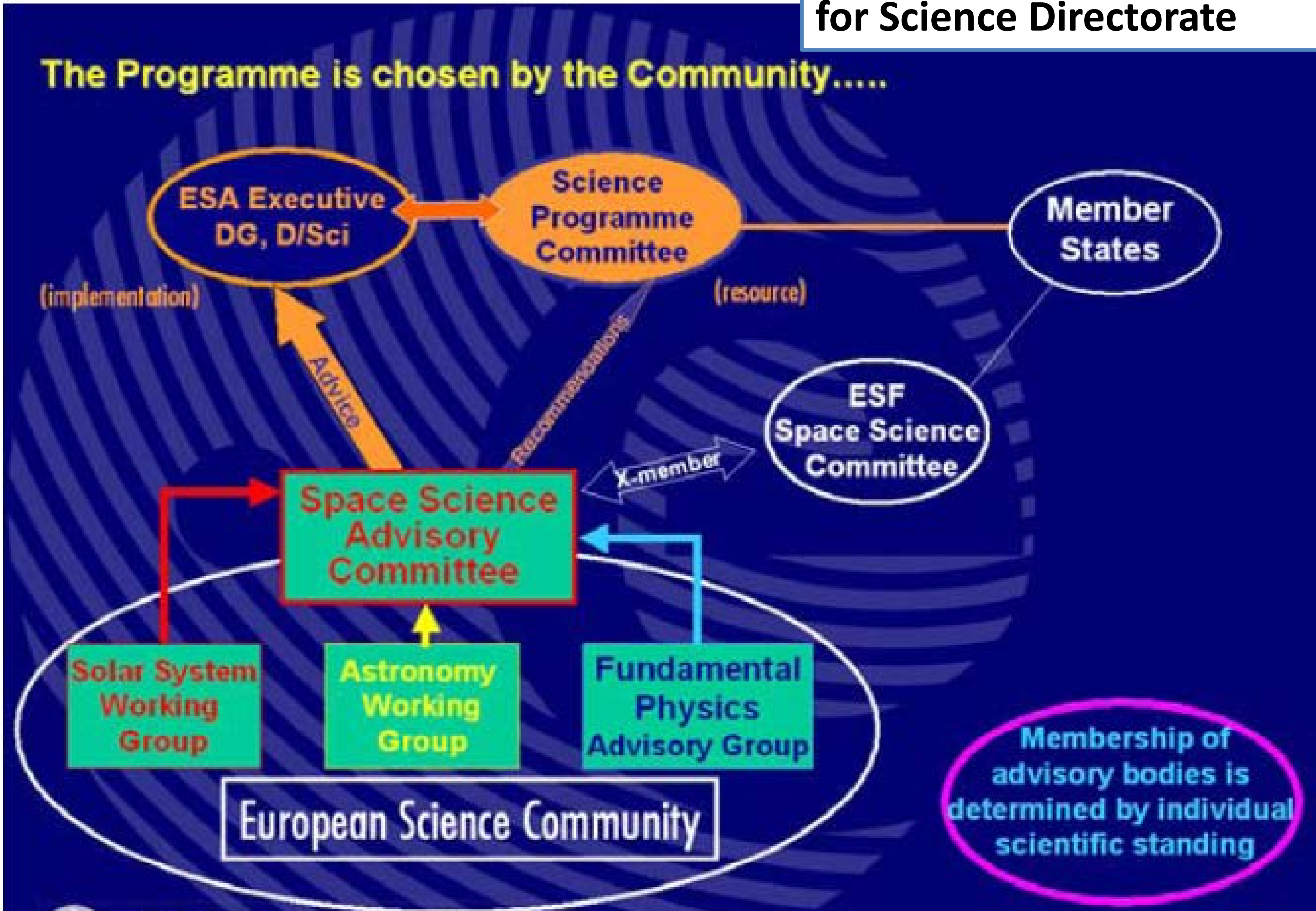
Head of ESA's Space Situational Awareness Programme (SSA)

Dr Dietmar Pilz

[Josef Aschbacher](#) -
[ESA Director General](#)

The Advisory Structure of ESA

for Science Directorate



Science Directorate

Types of missions and calls

	one every	cost	dev. time	techno	intern. coop.
L	10 y	≈ 2 LoR ≈ 900 M	15 y	challenging	≤ 20%
M	5 y	≈ 1 LoR ≈ 500 M	11 y	limited	any
S	4 y	≤ 50 M ESA 150 M total	4 y	no risks	national agencies
MoO (no call)	5 y	≈ 100 M			any
F	**Nominal duration of science operations typically < 2 years**	**≤ 175 M€**		**Prototypes exist; VEGA C Launcher**	**Cooperation possible The F mission must be ESA-led.**

ESA Missions in the Cosmic Vision 2015-2025 Programme

COSMIC VISION	
S-class missions	
	S1 – **CHEOPS**, launched December 2019, operational – space telescope mission focused on studying known exoplanets.
	S2 – **SMILE**, launching 2025, future – Joint ESA-CAS Earth observation mission, studying the interaction between the planet's magnetosphere and solar wind.[15]
M-class missions	
	M1 – ***Solar Orbiter***, launched February 2020, operational – Solar observatory mission, designed to perform in-situ studies of the Sun at a perihelion of 0.28 astronomical units.
	M2 – ***Euclid***, launched July 2023, operational – Visible and near-infrared space observatory mission focused on dark matter and dark energy.
	M3 – **PLATO**, launching 2026, future – *Kepler*-like space observatory mission, aimed at discovering and observing exoplanets.
	M4 – **ARIEL**, launching 2029, future – *Planck*-based space observatory mission studying the atmosphere of known exoplanets.[16]
	M5 – ***EnVision***, launching 2031, future – Venus mapping orbiter mission.[17]
L-class missions	
	L1 – **JUICE**, launched April 2023 with an orbital insertion in July 2031, in transit – Jupiter orbiter mission, focused on studying the Galilean moons Europa, Ganymede and Callisto.
	L2 – **Athena**, launching 2035, future – X-ray space observatory mission, designed as a successor to the *XMM-Newton* telescope.
	L3 – **LISA**, launching 2035, future – the first dedicated gravitational wave space observatory mission.[18][19]
F-class missions	
	F1 - **Comet Interceptor**, launching 2029, future – Comet flyby mission.[16][20]
	F2 – **ARRAKIHS**, launching in the early 2030s, future – Survey of one hundred nearby galaxies and their surroundings to investigate dwarf galaxies and stellar streams.

Living Planet Programme	
	Core missions
	Earth Explorer 1 – **GOCE**, launched March 2009, completed — Gravimetry mission, aimed at accurately mapping Earth's gravity field.
	Earth Explorer 5 – **ADM-Aeolus**, re-entry July 2023, completed – Meteorology mission, performed by a spacecraft equipped to create global wind component profiles to aid more advanced weather forecasting.
	Earth Explorer 6 – **EarthCARE**, launching early 2024, future – Joint ESA-JAXA meteorology and climatology mission, aimed at the characterization of clouds and aerosols, along with measurements of reflected and emitted radiation from Earth's surface.
	Earth Explorer 7 – **Biomass**, launching 2024, future – Ecology mission, studying the carbon cycle and forest ecology, observing the development of forests and their characteristics.
	Earth Explorer 9 – **FORUM**, launching 2027, future – Climatology mission, aimed at measuring far-infrared outgoing radiation emissions in order to understand Earth's surface temperature regulation.

Living Planet Programme	Opportunity missions
	Earth Explorer 2 – **SMOS**, launched November 2009, operational — Climatology mission, focused on studying Earth's water cycle and climate.
	Earth Explorer 3 – **CryoSat-2**, launched April 2010, operational — Environmental science and glaciology mission, focused on studying Earth's polar ice caps. Successful relaunch of the failed *CryoSat* mission.
	Earth Explorer 4 – **Swarm**, launched November 2013, operational — Magnetosphere mission, carried out by a trio of spacecraft launched to study Earth's magnetic field.
	Earth Explorer 8 – **FLEX**, launching 2025, future – Biology mission, aimed at measuring the amount of chlorophyll fluorescence in terrestrial vegetation.

Earth Observation missions
Sentinel programme

ESA is currently developing seven missions under the Sentinel programme (Sentinel 1, 2, 3, 4, 5P, 5, 6). The Sentinel missions include radar and super-spectral imaging for land, ocean and atmospheric monitoring. Each Sentinel mission is based on a constellation of two satellites to fulfill and revisit the coverage requirements for each mission, providing robust datasets for all Copernicus services.

The Sentinel missions have the following objectives:

Sentinel-1 provides all-weather, day and night radar imaging for land and ocean services.[16]

Sentinel-1A satellite was successfully launched on 3 April 2014, by a Soyuz, from the Centre Spatial Guyanais.[17]

Sentinel-1B satellite was launched on 25 April 2016. Mission declared as ended 3 August 2022.

Sentinel-2 provides high-resolution optical imaging for land services (e.g. imagery of vegetation, soil and water cover, inland waterways and coastal areas).[18] Sentinel-2 will also provide information for emergency services. Both satellites launched aboard Vega rockets from Centre Spatial Guyanais.

Sentinel-2A, successfully launched on 23 June 2015.[19]

Sentinel-2B, followed 7 March 2017.

Sentinel-3 provides ocean and global land monitoring services.[20] Both satellites were launched by a Eurockot Rokot vehicle from the Plesetsk Cosmodrome in Russia.[21][22]

Sentinel-3A satellite was launched on 16 February 2016.

Sentinel-3B satellite followed on 25 April 2018.

Sentinel-4 will provide data for atmospheric composition monitoring as a payload upon a Meteosat Third Generation satellite.[23] It will be launched in 2024.[24][25]

Sentinel-5 Precursor, launched 13 October 2017.[26] The primary purpose of this mission is to reduce the data gap (especially SCIAMACHY atmospheric observations) between the loss of Envisat in 2012, and the launch of Sentinel-5 in 2021.[27]

Sentinel-5 will also provide data for atmospheric composition monitoring.[28] It will be embarked on a EUMETSAT Polar System Second Generation (EPS-SG) spacecraft and launched in 2021.[25]

Sentinel-6 is intended to provide continuity in high precision altimetry sea level measurements following the Jason-3 satellite.[29]

Sentinel-6A, was launched in November 2020 by a SpaceX Falcon 9 vehicle from Vandenberg SLC-4E.[30]

Sentinel-6B, is scheduled for launch in November 2025 by a SpaceX Falcon 9.[31]

Earth Observation missions
Sentinel programme

In preparation for the second-generation of Copernicus (Copernicus 2.0), six High Priority Candidate "expansion" missions are currently being studied by ESA to address EU Policy and gaps in Copernicus user needs, and to increase the current capabilities of the Copernicus Space Component:
Sentinel-7: Anthropogenic CO_2 emissions monitoring (CO2M)[32]
Sentinel-8: High spatio-temporal resolution land surface temperature (LSTM)[33]
Sentinel-9: Copernicus Polar Ice and Snow Topography Altimeter (CRISTAL)[32]
Sentinel-10: Copernicus Hyperspectral Imaging Mission for the Environment (CHIME)[32]
Sentinel-11: Copernicus Imaging Microwave Radiometer (CIMR)[32]
Sentinel-12: Radar Observing System for Europe – L-band SAR (ROSE-L), scheduled for launch no earlier than 2028[32][34]

Before the Sentinel missions, numerous space missions provide or will provide data useful to the provision of Copernicus services. These missions are often referred to as **"Copernicus Contributing Missions (CCMs)"**

ERS: the European Remote Sensing Satellite ERS-1 (1991–2000) was ESA's first Earth observation satellite.

ERS-2 (1995–2011) provided data related to ocean surface temperature, winds at sea and atmospheric ozone.

Envisat (2002–2012): launched in 2002, ESA's Envisat was the largest civilian Earth Observation spacecraft ever built. It carried sophisticated optical and radar instruments among which the Advanced Synthetic Aperture Radar (ASAR) and the Medium Resolution Imaging Spectrometer (MERIS). Envisat provided continuous observation and monitoring of the Earth's land, atmosphere, oceans and ice caps.After losing contact with the satellite on 8 April 2012, ESA formally announced the end of Envisat's mission on 9 May 2012.

Earth Explorers: ESA's Earth Explorers are smaller research missions dedicated to specific aspects of our Earth environment. Earth Explorer missions focus on research of the atmosphere, biosphere, hydrosphere, cryosphere and the Earth's interior with the overall emphasis on learning more about the interactions between these components and the impact that human activity is having on natural Earth processes.

SMOS (Soil Moisture and Ocean Salinity), launched on 2 November 2009.

CryoSat-2 (the measurement of the thickness of floating ice), launched on 8 April 2010.

MSG: the Meteosat Second Generation is a joint project between ESA and EUMETSAT.

MetOp is Europe's first polar-orbiting satellite dedicated to operational meteorology.

SPOT (Satellite Pour l'Observation de la Terre)

SPOT-4 and SPOT-5 include sensors called **VEGETATION** able to monitor continental ecosystems.

Involvement of CSL in Space Instrumentation

Sun	Solar System	Astrophysics	Fundamental Physics
	IMPLEMENTATION		
[2018] Solar Orbiter	[2017] BepiColombo [2022] JUICE	[2017] CHEOPS [2018] JWST [2020] Euclid	[2015] LISA Pathfinder LISA
	OPERATIONS / POST-OPERATIONS		
[2009] PROBA2 [1995] SOHO 2024 PROBA 3 [1990] Ulysses	[2005] Venus Express [2004] Rosetta [2003] Mars Express [2003] Double Star [2000] Cluster [1997] Cassini-Huygens	[2013] Gaia [2009] Planck [2009] Herschel [2002] INTEGRAL [1999] XMM-Newton [1990] Hubble	CSL
	COMPLETED		
	[2003] SMART-1 [1986] Giotto	[1995] ISO [1989] Hipparcos [1983] EXOSAT [1978] IUE [1975] Cos-B [1972] TD-1	

NASA Scientific Missions
2018 JWST
2018 SPP →PSP
2017 ICON
2011 JUNO
2006 STEREO
1995 IMAGE
1990 HST

Historically, students did their Master Thesis on Instruments developed at CSL. Since 2005, we also involve students on Student µSat (ESEO, ESMO, FLT) and nSat (Oufti, QB50, ExoPlanet Det.)

Astrophysics (continued)

ATHENA (2028)
PLATO (2024

Instruments recently developed

JUNO – UVS (2011)

Launched Aug. 5, 2011

Sentinel 2 – MSI (2012)

SENTINEL 2

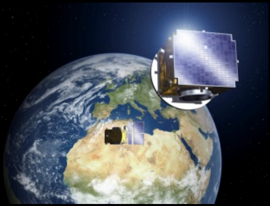
Launch 2-A 23 June 2015
Sentinel-2B 2017

Sentinel 3 – OLCI (2012)

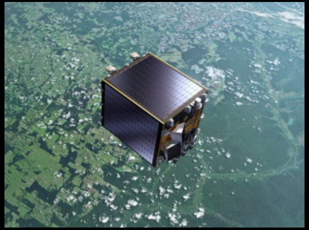
Sentinel 4-UVN (2017)

SENTINEL 3

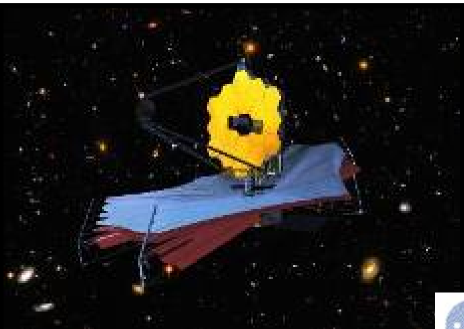
Launch Sentinel-3A - February 2016
Sentinel-3B - Scheduled for 2017
Sentinel-3C - Before 2020



PROBA-3(2 sat.)
ASPIICS(coronograph)

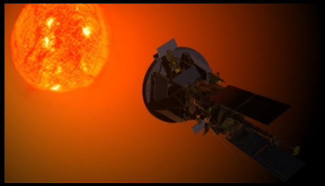


PROBA-V Launched 7 May 2013



JWST – MIRI (2014)

Solar Orbiter - EUI
& Sun Sensor (2018)
Solar Orbiter – HI (2018)

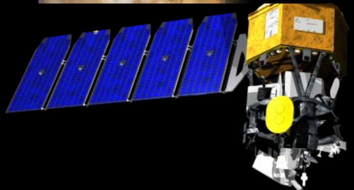


SPP WISPR

JULY 30, 2018

[ExM2016] NOMAD

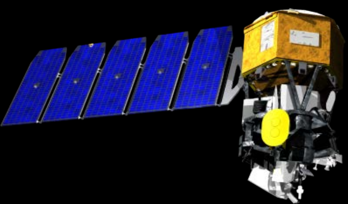
Launched March 2016



ICON FUVSI

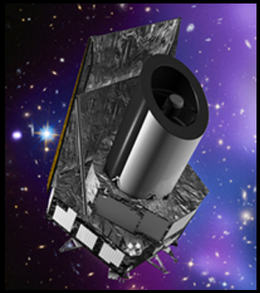
June 2017

Instruments at CSL



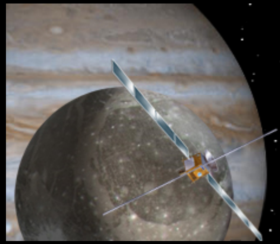
ICON FUV
June 2017

CHEOPS Baffle & Cover Assembly
End 2017

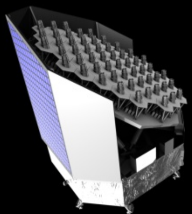


EUCLID

2020

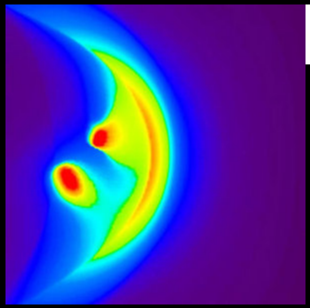


JUICE
UVS & MAJIS
Launch 2022 and arrival at Jupiter in 2030

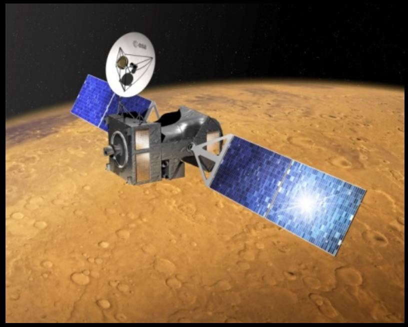


PLATO Camera AIV
Around 2024

ATHENA X-IFU
Around 2028



SMILE UVSI
2021



[ExM2018] LaRa
2018

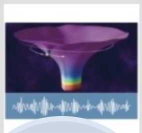
ESA Scientific Missions

SCIENCE MISSIONS

FUTURE MISSIONS


Athena
[2034]

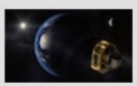

EnVision
[2031]

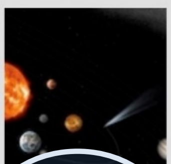

LISA
[2037]


ARRAKIHS (ESA F2)
(2031)

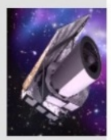
IN DEVELOPMENT


ACES
[2025]


ARIEL
[2029]

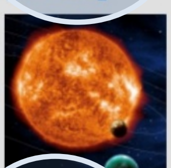

Comet
Interceptor
[2029]

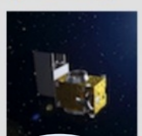

Einstein
Probe
[2023]


Euclid
[2023]


ExoMars
[2022]


JUICE
[2023]

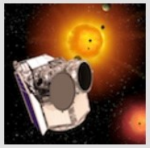

PLATO
[2026]

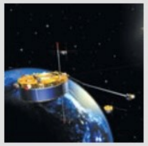

Proba-3
[2024]


SMILE
[2024]

OPERATIONAL AND POST-OPERATIONAL


Bepicolombo
[2018]

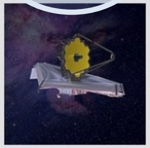

CHEOPS
[2019]


Cluster
[2000]

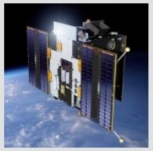

ExoMars
[2016]


Gaia
[2013

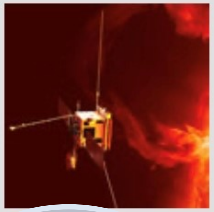

INTEGRAL
[2002]


JWST
[2021]


Mars
Express
[2003]


Proba-2
[2009]


SOHO
[1995

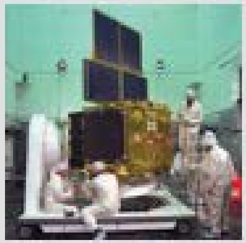

Solar
Orbiter
[2020]


XMM-
Newton
[1999]

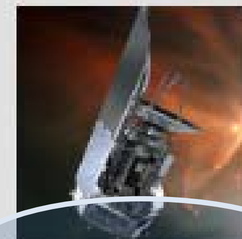
Our Missions - Cosmos (esa.int)

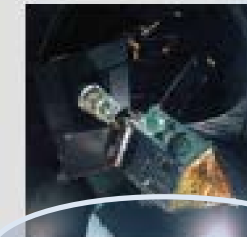
COMPLETED

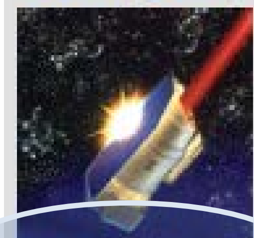

COS-B [1975]


EXOSAT [1983]

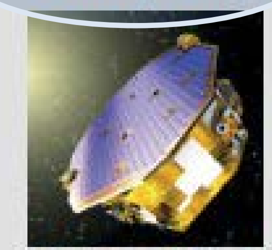

Giotto [1985]


Herschel [2009]


Hipparcos [1989]

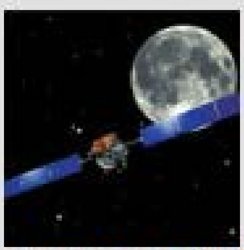

ISO [1995]

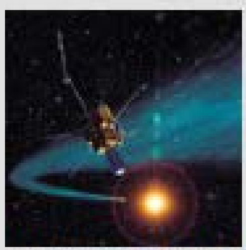

IUE [1978]

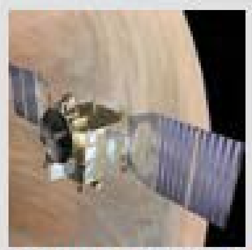

LISA Pathfinder [2015]


Planck [2009]

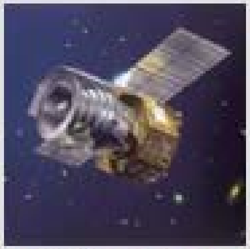

Rosetta [2004]


SMART-1 [2003]


Ulysses [1990]


Venus Express [2005]

COLLABORATIVE MISSIONS


AKARI [2006]

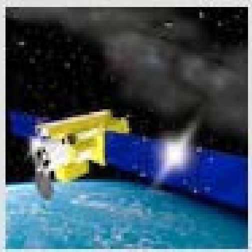

Cassini Huygens [1997]

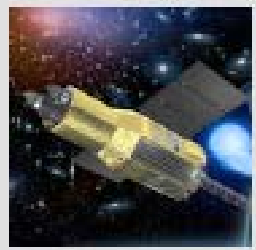

Chandrayaan-1 [2008]


Chang'E [2007]


CoRoT [2006]

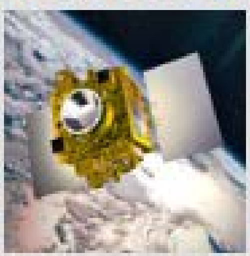

Double Star [2003]


Hinode [2006]


Hitomi [2016]

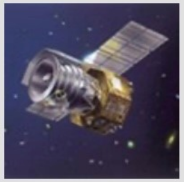

Hubble [1990]


IRIS [2013]


Microscope [2016]


Suzaku [2005]

COLLABORATIVE MISSIONS

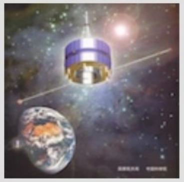

AKARI [2006]


Cassini Huygens [1997]

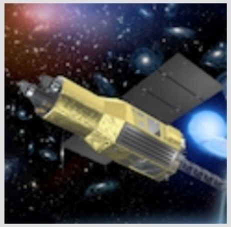

Chandrayaan-1 [2008]


Chang'E [2007]

CoR [200


Double Star [2003]


Hinode [2006]


Hitomi [2016]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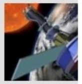
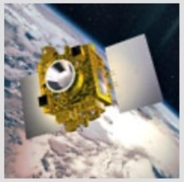
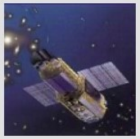
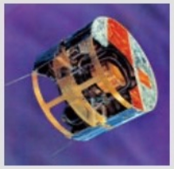
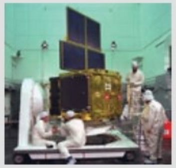

IRIS [201

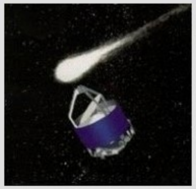

Microscope [2016]


Suzaku [2005]

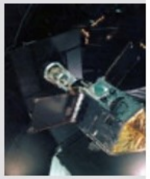
COMPLETED

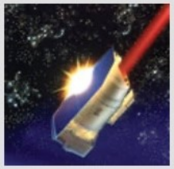

COS-B [1975]

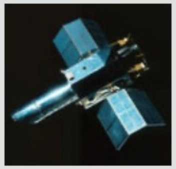

EXOSAT [1983]

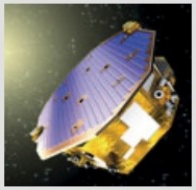

Giotto [1985]


Herschel [2009]

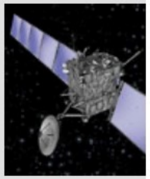

Hipparc [1989]

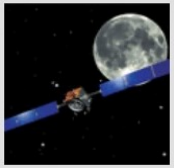

ISO [1995]

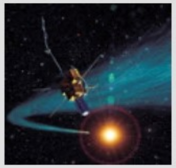

IUE [1978]


LISA Pathfinder [2015]

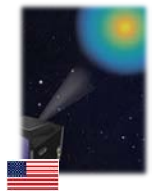

Planck [2009]


Rosetta [2004]


SMART-1 [2003]

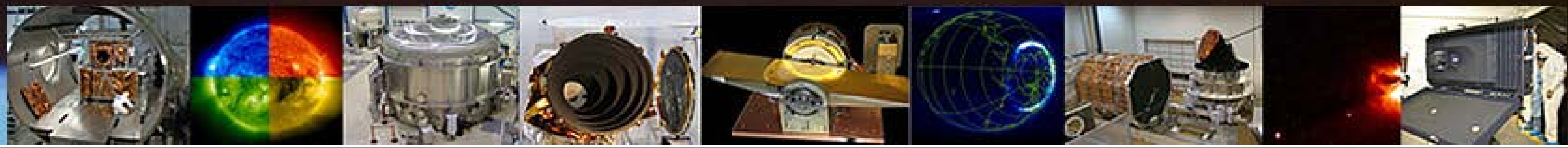

Ulysses [1990]


Venus Express [2005]



GLIDE GCI
(CARRUTHERS)
(2025)

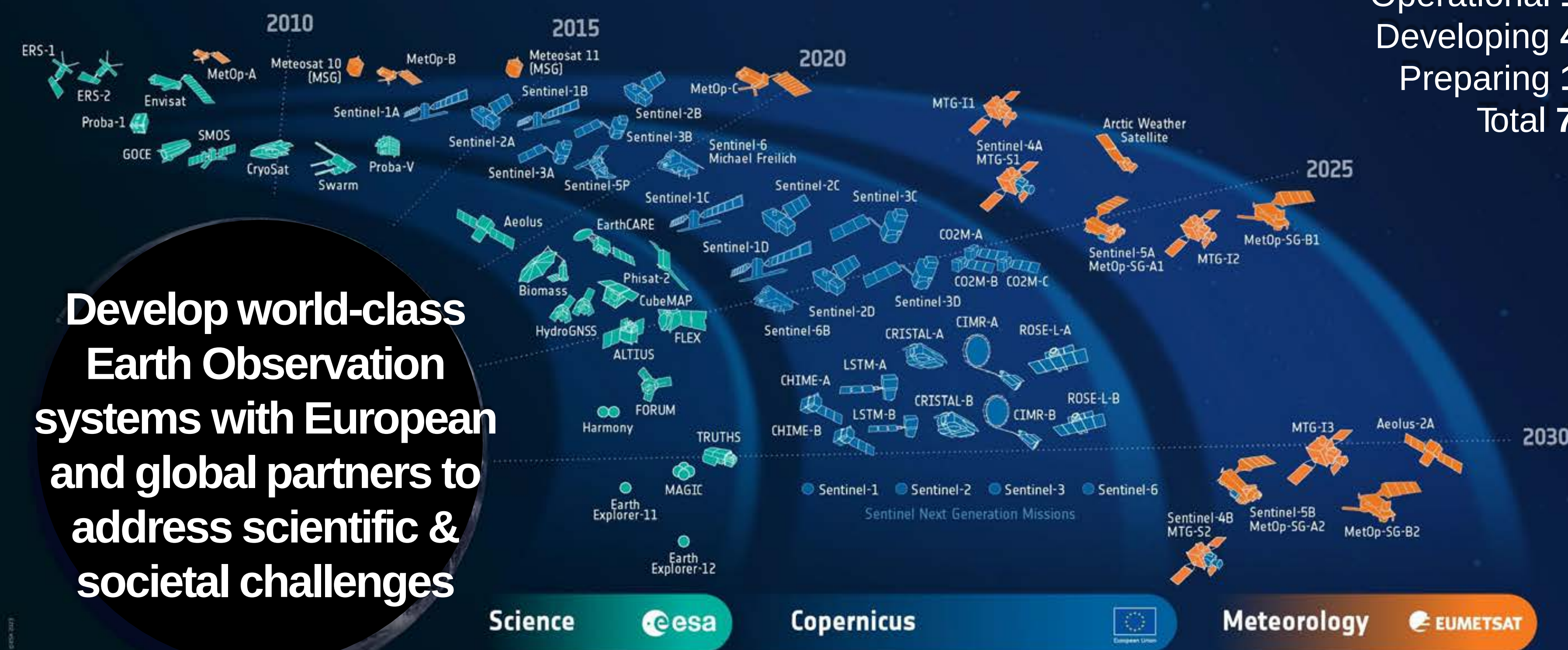
ARRAKIHS (ESA F2)
(2031)



ESA's Earth Observation Mission

Satellites

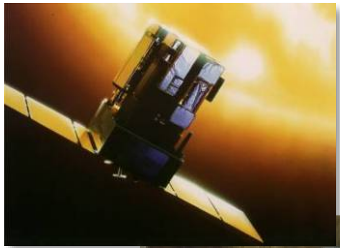
Heritage **04**
Operational **14**
Developing **42**
Preparing **19**
Total **79**



Develop world-class Earth Observation systems with European and global partners to address scientific & societal challenges

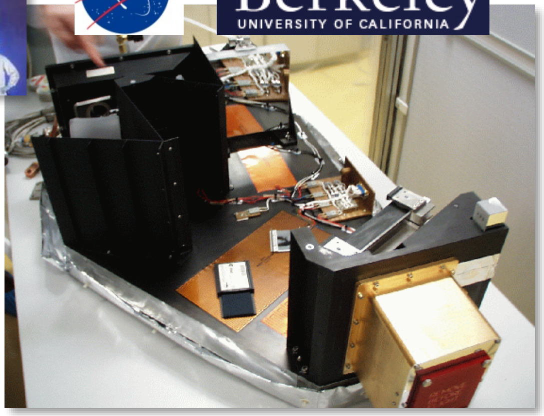
→ THE EUROPEAN SPACE AGENCY

Past Projects (1/2)

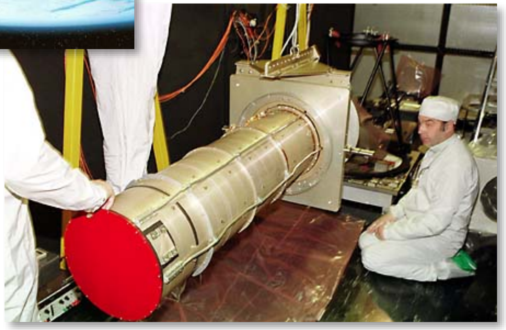


SOHO/EIT (1995)

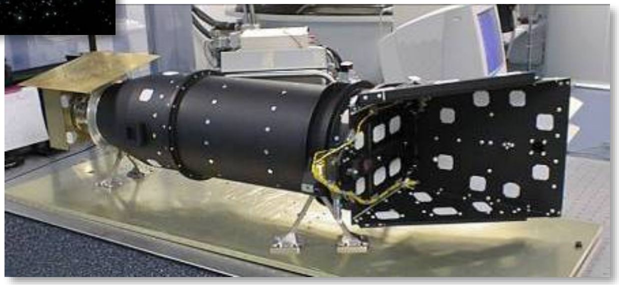
IMAGE/FUV-SI (2000)



XMM/OM (1999)

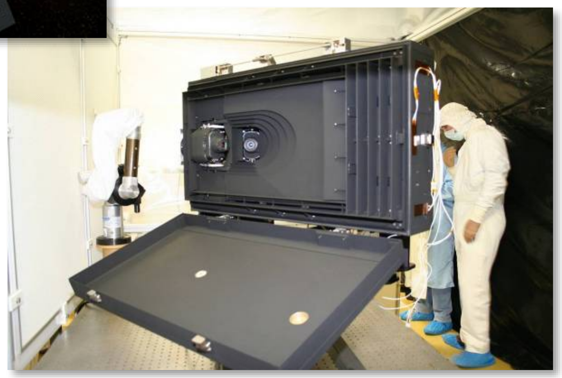


INTEGRAL/OMC (2002)

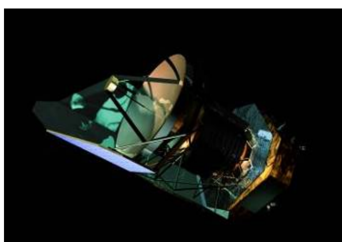


Past Projects (2/2)

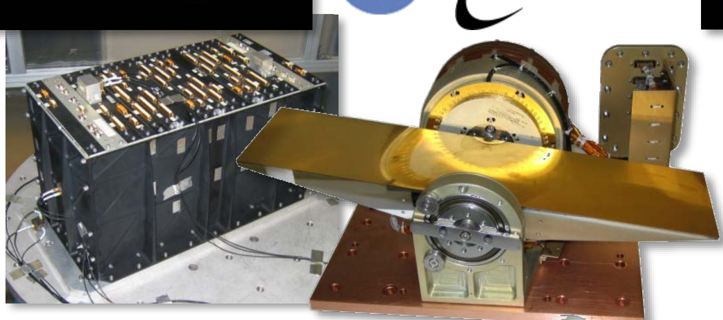
STEREO/HI (2006)



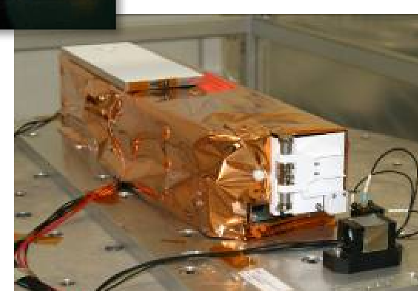
CoRoT (2006)

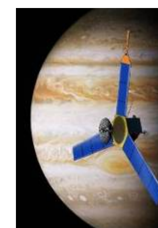


Herschel/PACS (2009)



PROBA-2/SWAP & LYRA (2009)





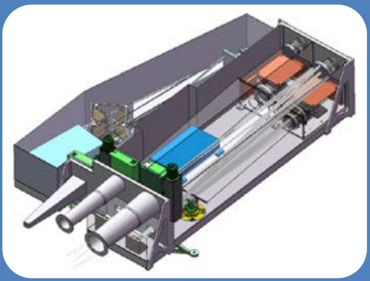
JUNO/UVS (2011)

Products & Services: 3 Business Lines

Testing (Resp. Christophe Grodent)

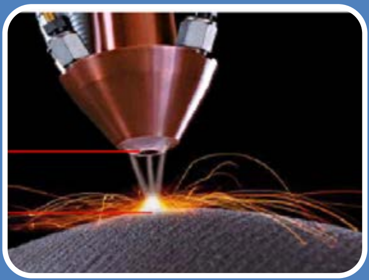
- Environmental test services (thermal-vacuum, vibration…)
- Development of test systems (thermal systems…)
- Rare & complex test equipment

HIPPARCOS, ISO, NEWTON, HERSCHEL Tel, PLANCK, GAIA, PROBAV, TROPOMI, …, 3MI



Space Systems (Resp. Christian KINTZIGER)

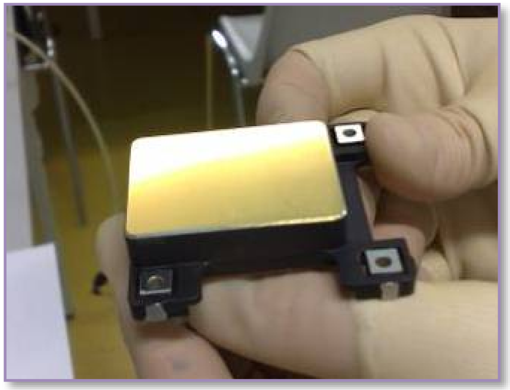
- Space mission studies
- Space instrument, payload elements
- Technology development for space applications
- Ground calibration, ground support equipment



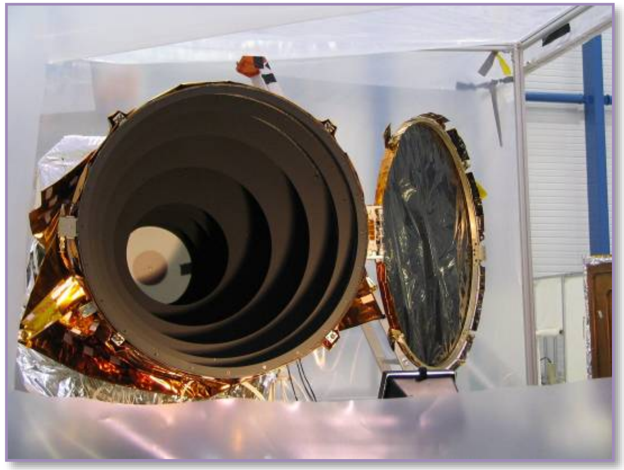
Technological Partnering (Resp. Karl FLEURY)

- R&D support, expertise to industry
- Technology upgrade or validation (TRL raising)
- Technology transfer and services
- Customized training

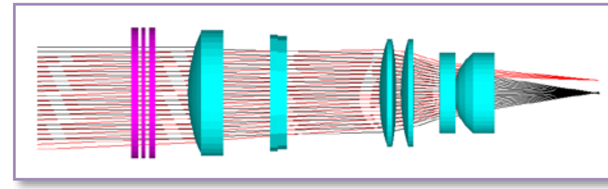
Optical Systems



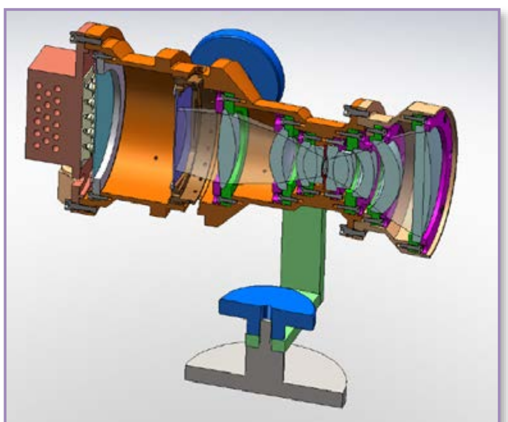
Optics & coatings

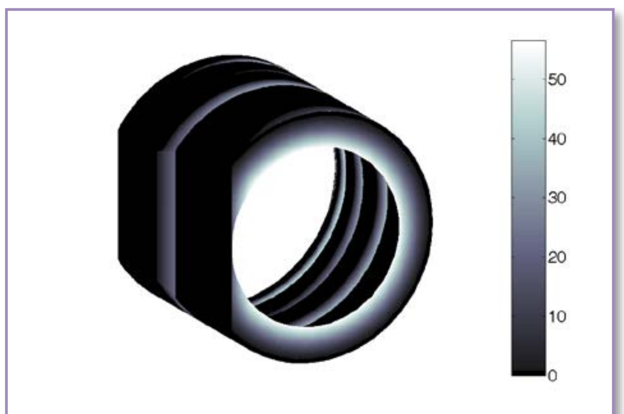


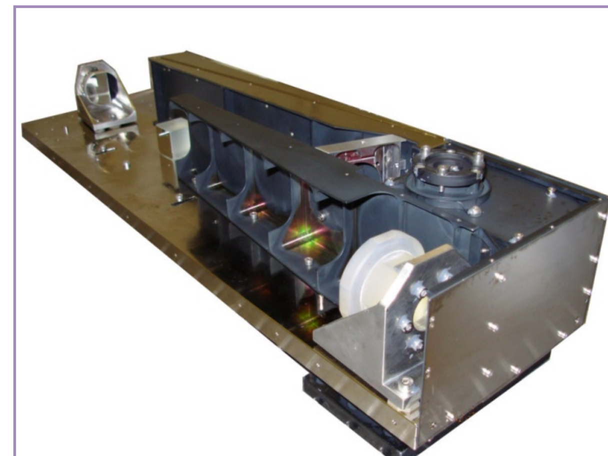
Baffle design &
stray-light analyses



Ray-tracing

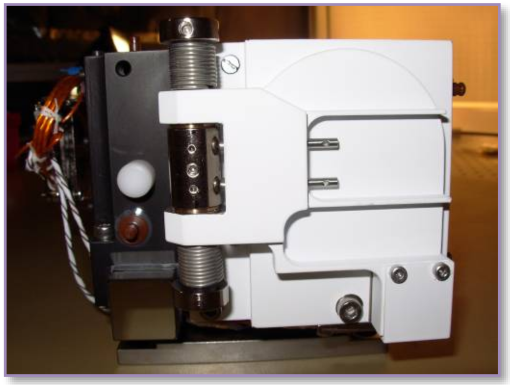




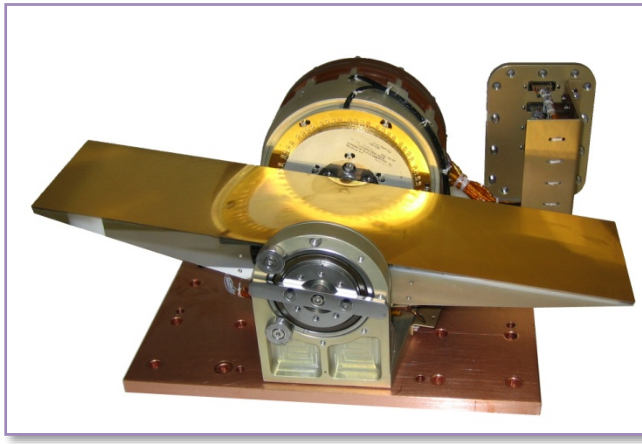


Complete optical instruments
or sub-assemblies

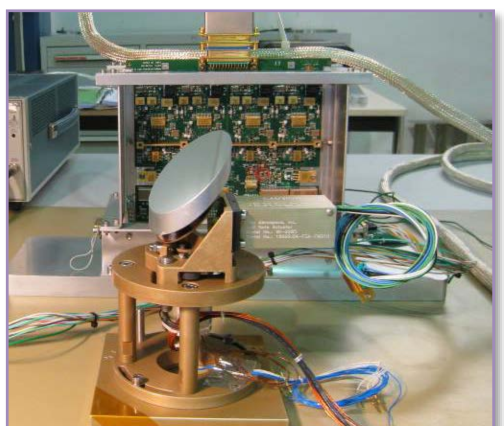
Mechanisms



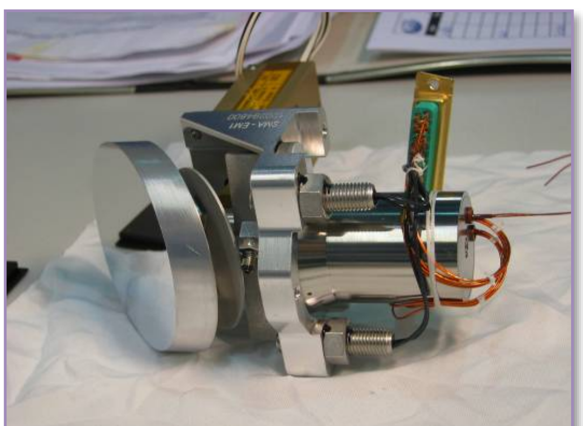
Cover mechanisms

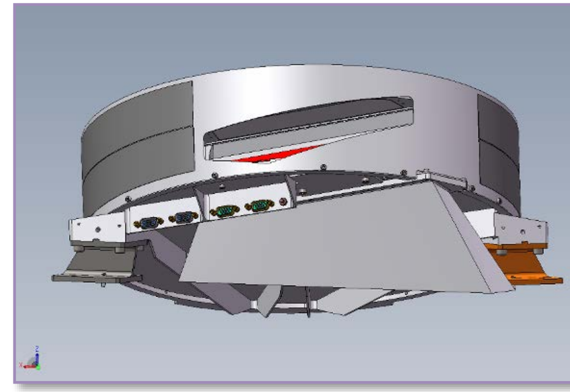


Positioning mechanisms operating in extreme environment (4K)



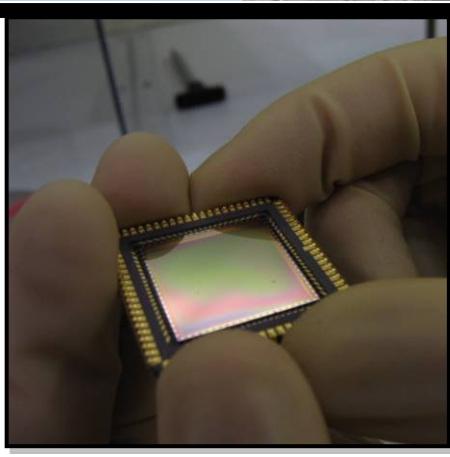
Scan mirror





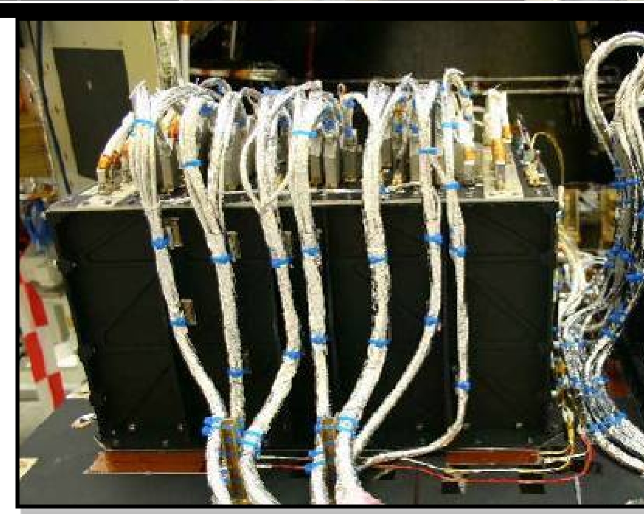
Wheel mechanism

Electronics



Detectors

Processor & software



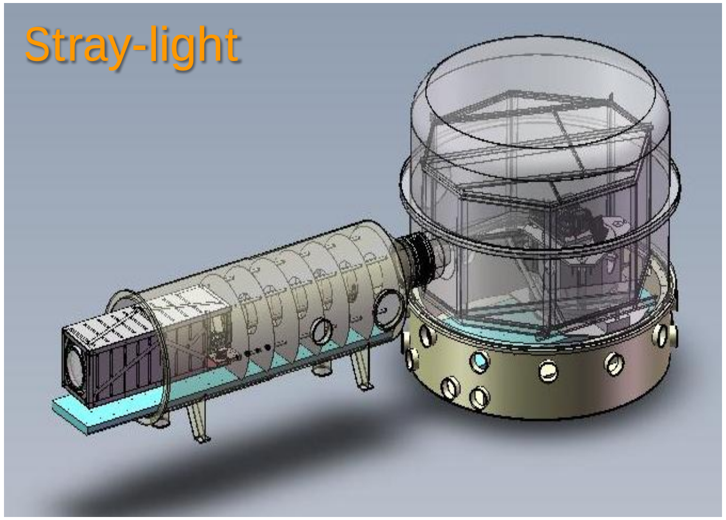
Detector controllers

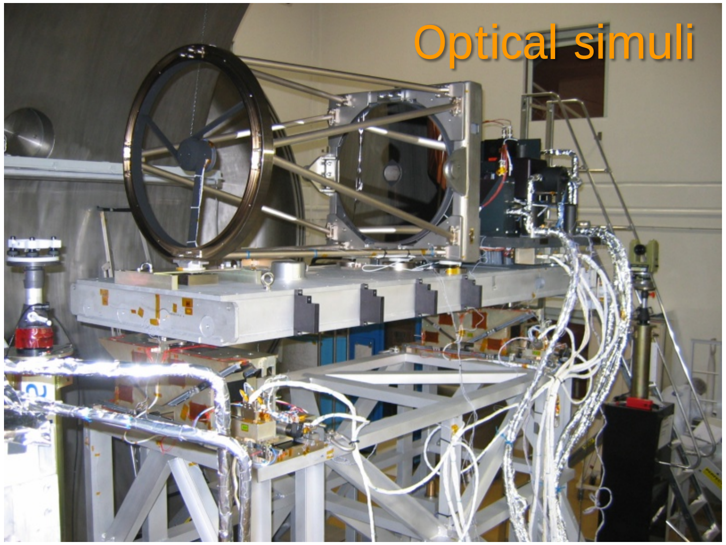
Power conditioning

EGSE

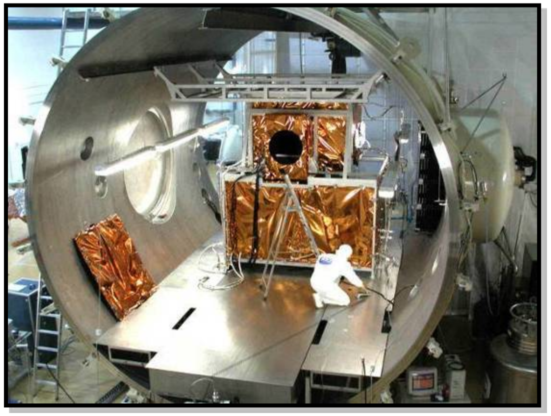
Mechanism controllers

GSE & Calibration Facilities





AIV, Testing Facilities



1,000-m² integration clean rooms (ISO-7 / ISO-5)

Cryogenics (LN_2 & LHe)

Th. Vac. chambers from ∅1.5-m… up to ∅6.5-m

Shakers (90 kN – 200 kN)

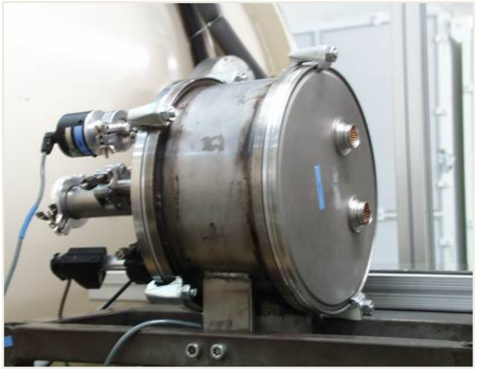
Vacuum Environment

✓ CSL houses chambers with extended vacuum capabilities and with 0.25-m to 6.5-m diameter

✓ The chambers are equipped with primary and turbo pumping system

✓ Cryogenic pumping available as well

✓ Most of the chambers are equipped with optical bench laying on seismic device allowing ground vibration decoupling






Vibration Facilities

✓ Allows vibration (200-kN shaker) on 3 axis under cryogenic and vacuum conditions (down to 15K).

Shaker 4522 LX:

- Slip table: 1500 x 1500 mm^2
- Head expander: 1500-mm diameter
- Maximum sine force 200 kN
- Maximum random force: 160 kN
- Bandwidth: 5-2000 Hz

Shaker 2016U:

- Slip table: 900 x 900 mm^2
- Head expander: 900-mm diameter
- Maximum sine force: 88 kN
- Maximum random force: 72 kN
- Bandwidth: 5-3000 Hz

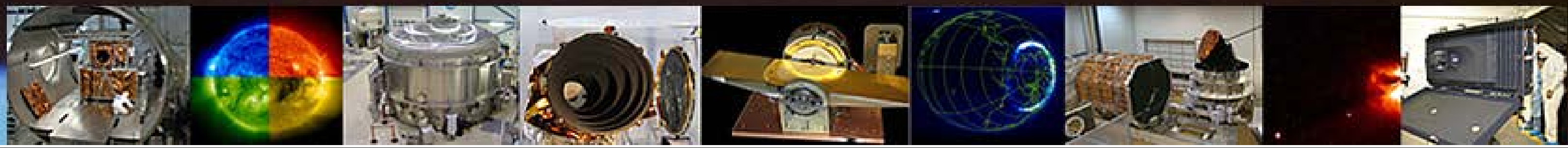
Cooling system specification

- Available cooling power
  - 1 liquefier / refrigerator KOCH 1630 (installed 1987)
  - customised for ISO telescope testing (LHe + GHe available)
  - 45 [l h^{-1}] in LHe, about 150 [W] @ 6 [K] and 300 [W] @ 18 [K]

Cooling system upgrade

- Cooling machines
  - second Helium liquefier / refrigerator installed
  - Linde TCF20, also customised
  - 50 [l h^{-1}] in LHe, ~150 [W] @ 6 [K] and 300 [W] @ 18 [K]
  - installation by CSL
    commissioning by Linde

COLLABORATION WITH CHINA ?



SPACE UNIVERSITIES ADMINISTRATIVE COMMITTEE (SUAC)

If your university is member of IAF, join the SUAC.

Participate to the SUAC student CubeSat Challenge proposed by Professor Xiaozhou Yu

First IAF-SUAC International Workshop in 2013 at Tsinghua University

AEROSPACE CHINA WINTER 2018| VOL.19 No.4 : INTERNATIONAL EXCHANGES AND COOPERATION: Collaboration between SUAC , the Centre Spatial de Liège and China

Paper can be found at https://orbi.uliege.be/handle/2268/233926

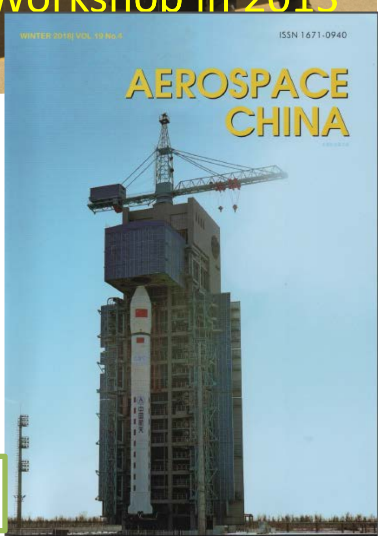
[IAF-CSA Space Universities CubeSat Challenge]()

[Space Universities Administrative Committee (SUAC) (2018-2021) (iafastro.org)]()

[IAF-SUAC International Student Workshop, Saturday 28 September | Flickr]()

[IAF SUAC CubeSat Competitions (iafastro.org)]()

[(1218) IAF Capsules: Pierre Rochus Chair of SUAC Space Universities Administrative Committee - YouTube]()



IAF-CSA Space Universities CubeSat Challenge https://www.iafastro.org/activities/iaf-suac-cube-sat-competitions/iaf-space-universities-cubesat-challenge.html

COLLABORATIONS WITH CHINA

Scientific Missions

2004 - 2010

Mrs. ZHANG Qiyue
Ambassador of China
to the Kingdom of Belgium during a visit at CSL / University of Liège with Cl. Jamar General Manager of CSL,
Professor Ronglan Xu
and Dr Lei Li, Center for Space Science and Applied Research (CSSAR), Chinese Academy of Sciences

2006

Optical design and calibration of Plasmaspheric EUV camera

With CSSAR CAS

[Ronglan Xu's research works | Chinese Academy of Sciences, Beijing (CAS) and other places (researchgate.net)]

COLLABORATIONS WITH CHINA

Scientific Missions

2006

2004 - 2010

A PROTOCOL OF JOINT OPTICAL DESIGN AND THE CALIBRATION OF EUV CAMERA FOR THE SECOND PHASE OF CHINESE LUNAR EXPLORATION PROGRAM

Optical design and calibration of Plasmaspheric EUV camera

In March 23-24, 2006, Professor Ronglan Xu and Dr Lei Li, Center for Space Science and Applied Research (CSSAR), Chinese Academy of Sciences (CAS) paid a visit to Centre Spatial de Liege (CSL) discussing for the cooperation of the joint Optical Design and the Calibration of the Plasmaspheric EUV Camera for the Second Phase of Chinese Lunar Exploration Program. The two parties also discussed the joint data analysis of the EUV camera using Institut d'Aeronomie Spatiale de Belgique (IASB) plasmaspheric models. The preliminary protocol between CSSAR, IASB and CSL during the preparation time (2006-2007) is attached as Appendix I.

In July 10, 2006, CSL proposed the CSL's testing activities for the joint Optical Design and the Calibration of the prototype Plasmaspheric EUV Camera including philosophy and required H/W. The document is attached as Appendix II.

We confirm that both CSSAR and CSL will strongly support the cooperation in the joint Optical Design and Calibration of the prototype Plasmaspheric EUV Camera between CSSAR and CSL. This protocol is of course subject to the agreement of our funding agencies (BELSPO for Belgian activities, CAS and China National Space Agency for Chinese activities).

Professor Ji Wu
Director
Center for Space Sciences and Applied Research
Chinese Academy of Science
China
July 22 2006

Professor Pierre Rochus
Deputy Director
Centre Spatial de Liege

Belgium
July 22 2006

Dr. Ji WU (Former Director National Space Science Center, China) CSSAR

Dr. Ji WU ,Professor Ronglan Xu and Dr Lei Li, (CSSAR), CAS

With CSSAR CAS

Publication in NATURE : Moon-based Extreme Ultraviolet Camera (EUVC) of the Chang'e 3 mission : https://www.nature.com/articles/srep32362

Scientific Missions

COLLABORATIONS 2004 - 2010

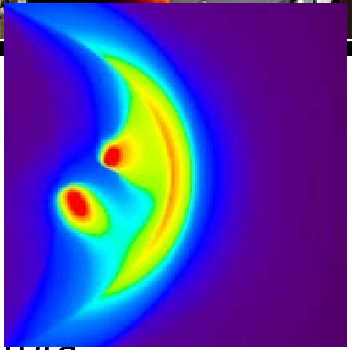
KUAFU

KuaFu is an "L1 + Polar" triple Star Project, and an essential element of the ILWS mission lineup. KuaFu is composed of three spacecraft :

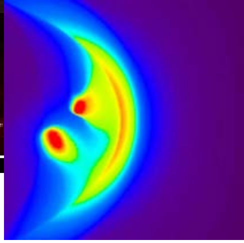
With CSSAR

Scientific Missions

SMILE

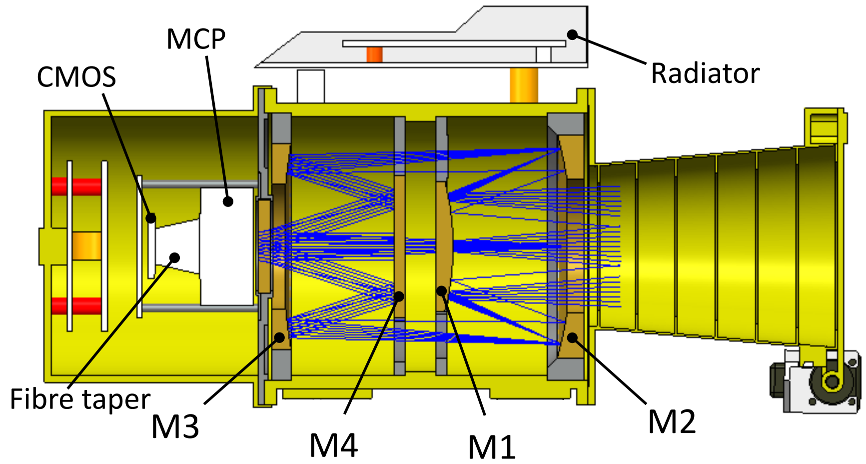


- **Joint ESA – CAS mission (S2)** to investigate the dynamic response of the Earth's magnetosphere to the solar wind impact in a global manner
- Combine Solar Wind Charge exchange (SWCX) X-ray imaging of the dayside magnetosheath and the cusps with simultaneous UV imaging of the northern aurora, while monitoring the solar wind conditions in situ
- **Small satellite (300 kg)** in highly elliptical polar orbit (out to 20 Re)
- Instrumentation
  - **SXI** – Soft X-ray Imager of SWCX emission with spectral capability
  - **UVI – UV Imager of the whole northern auroral oval at high temporal and spatial resolution (under fully sunlit conditions)**
  - **LIA** – Light Ion Analyser (p+ and a) for monitoring of solar wind / magnetosheath conditions (density, velocity, temperature)
  - **MAG** – Magnetometer for monitoring of the magnetic field
- The Principal Investigators are Graziella Branduardi-Raymont from Mullard Space Science Laboratory, University College London, UK, and **Chi Wang** from the **State Key Laboratory of Space Weather, NSSC, CAS**.



SMILE | UV Imager (UVI)

- Science: Imaging Earth's northern aurora under fully sunlit conditions
- Wavelengths: 155 – 175 nm fraction of Lyman-Birge-Hopfield N2 band
- Instrument concept
  - Four mirror on-axis telescope, band defining filter coating applied directly onto mirrors (additional filtering through LiF window and detector system)
  - Detector system based on MCP image intensifier and CMOS detector array (1k x 1k pixels)
  - Images binned to 256 x 256 elements
  - FoV: 10° x 10°, offset to SXI: 26°
- Resource requirements:
  - Instrument: 361 x Ø140 mm
  - E-Box: 191 x 101 x 89 mm
  - Mass: 10.5 kg / Power: 32 W
- Pointing: APE, AKE = 0.5°
  Stability 0.05° in 1 min



CSL contributions:

- **Full calibration of the Instrument in the UV**
- **Very specific (155 – 175 nm multilayer coating with very high rejection in the visible) development design and manufacturing**

With NSSC

Framework of future potential collaborations with Laboratory of Structural Analysis for Industrial Equipment of DUT (Professor Xiaozhou Yu)

CSL + University of Liège have the expertise in

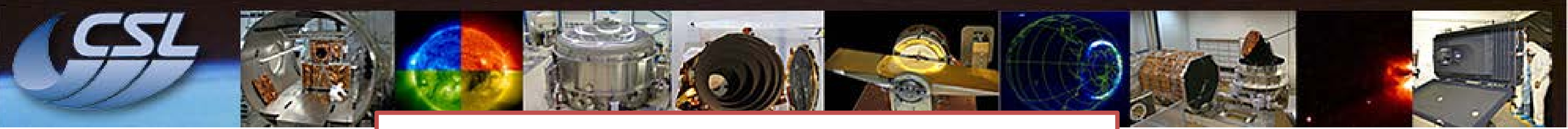
- payload development, calibration, qualification testing,…
- Technologies developments

State Key Laboratory of Structural Analysis for Industrial Equipment of Dalian University of Technology has the expertise in

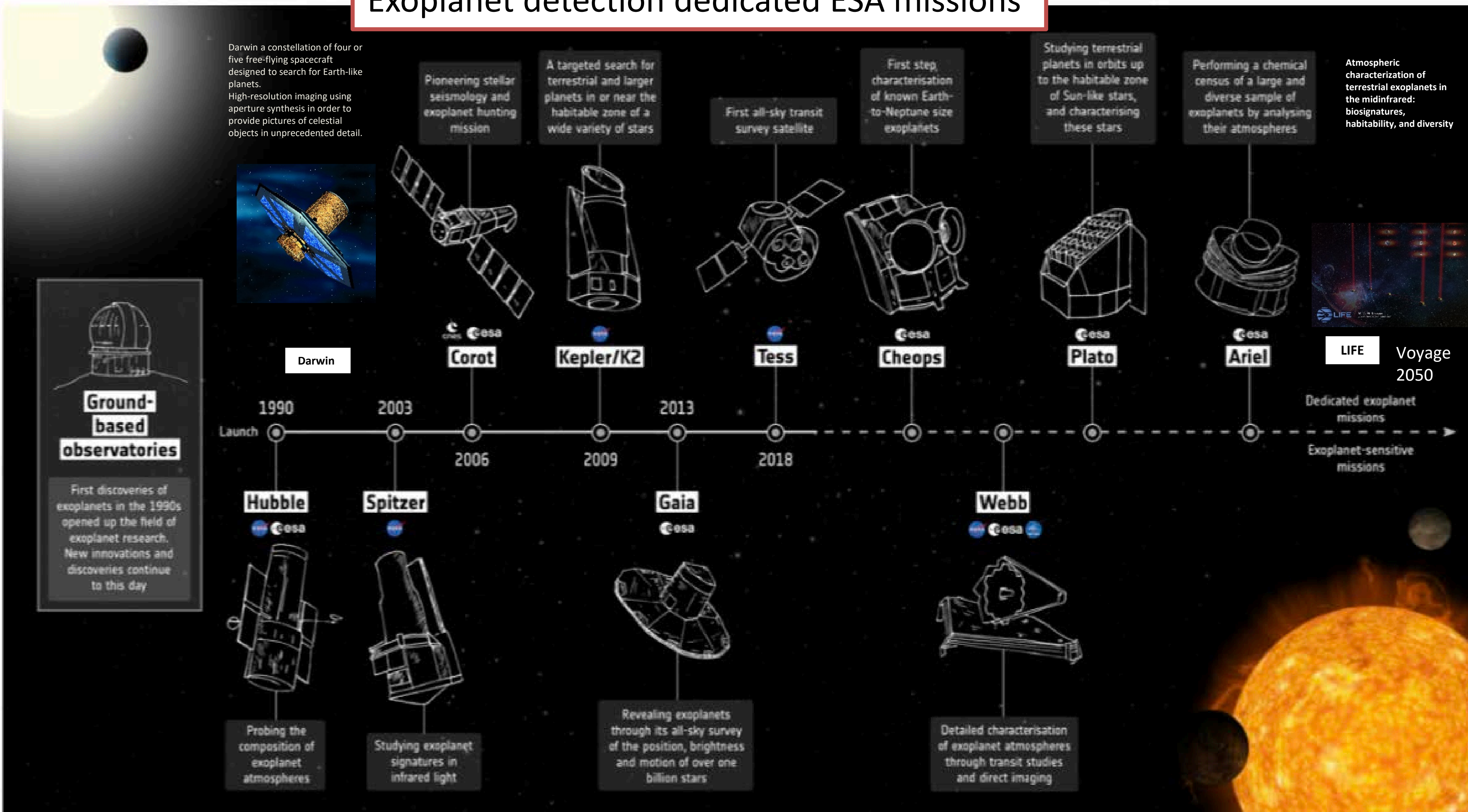
- small satellite with service module development, qualification and launch
- Access to space with launchers or to Tiangong space station

We are complementary in expertise's, in resources and in developments →

1. **Academic exchanges (Professors and Students) (Already successful)**
2. **Promote the development of future needed technologies (just started)**
3. **Contribute and test with small satellites some of these technologies**
4. **Integrate some of CSL mature « payload » design for Space Station or Moon or others (Asteroid, Mars, …).**
5. **Try to stimulate a new Joint ESA – CAS mission ??**



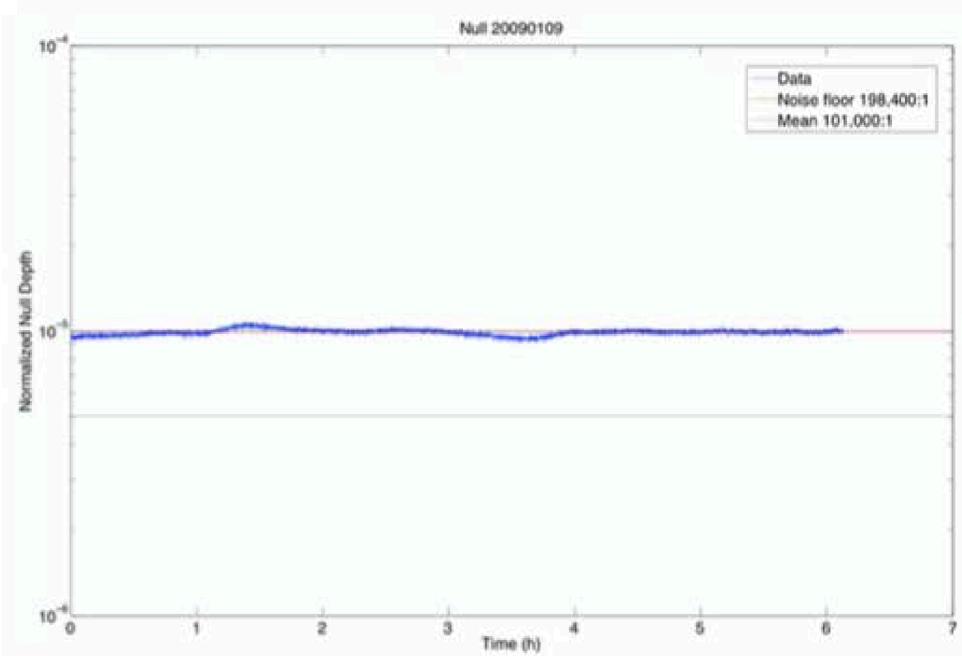
Exoplanet detection dedicated ESA missions

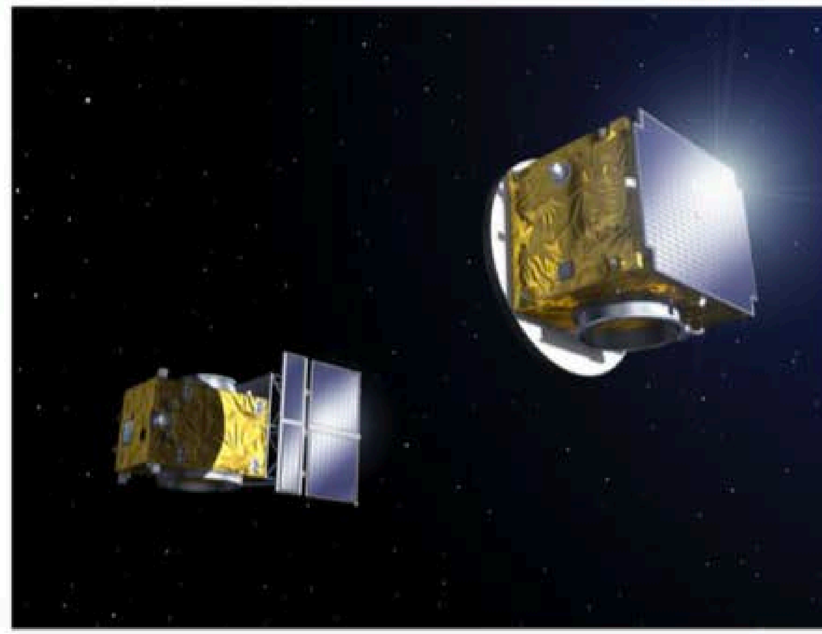


Vortex coronagraph invented in 2005 by Dimitri Mawet while he was at the University of Liège in Belgium. Mawet is currently associate professor of astronomy at Caltech and a senior research scientist at NASA's Jet Propulsion Laboratory (JPL). The Keck vortex coronagraph was built by the University of Liège, Uppsala University in Sweden, JPL, and Caltech.

Olivier Absil, University of Liège, Belgium
Denis Defrère, University of Liège, Belgium
Jérôme Loicq, Liège Space Center, Belgium
Sascha P. Quanz, ETH Zurich, Switzerland
Willy Benz, University of Bern, Switzerland
Xavier Bonfils, Université Grenoble Alpes, France
Jean-Philippe Berger, Université Grenoble Alpes, F
Ewine van Dishoeck, University of Leiden, The Net

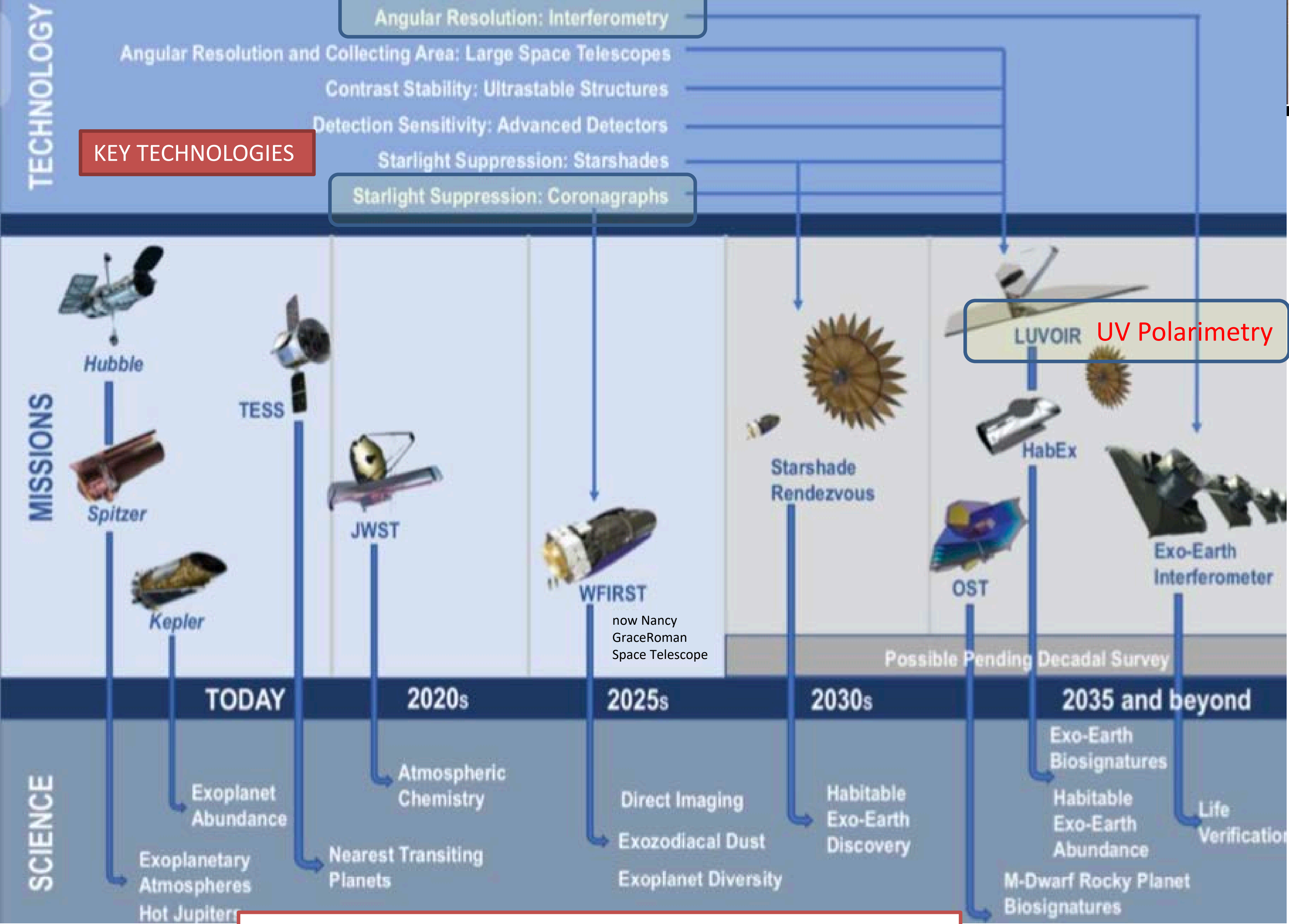
An additional key milestone for formation flying technology was the space-based demonstration by the PRISMA mission (2012). PRISMA demonstrated a sub-cm positioning accuracy between two spacecraft, mainly limited by the metrology system (GPS and radio frequency ranging).
The launch of ESA's PROBA-3 mission, currently scheduled for 2023, will mark the next step in formation flying. Its two satellites will maintain formation to **millimeter and arc second precision** at distances of 150 m or more autonomously, i.e., without relying on guidance from the ground.
This separation is of the same order as the one needed for a space-based nulling interferometer and the formation flying precision exceeds even the requirements (cf. Defrère et al., 2018a).





Left: 6-hour measurement of the null-depth achieved at 10 μm wavelength with the "Adaptive Nuller" at JPL (NASA, 2009

Artist impression of ESA's PROBA 3 spacecraft, the first mission to demonstrate autonomous precision formation flying



Space missions related to exoplanet science from NASA

Promote the development of future needed technologies

Professor Xiaozhou Yu, Professor Pierre ROCHUS and Dr. HUO Zhuoxi, Center for Frontier Cross-Disciplinary Research, China Academy of Aerospace Science and Innovation (CASI) proposed to **SATC (Space Astronomy Technical Committee) of IAF**, *on the 26/03/2024,* to support ***the needed technologies to enable an international development of space optical interferometric mission concept & technologies for exoplanet detection***

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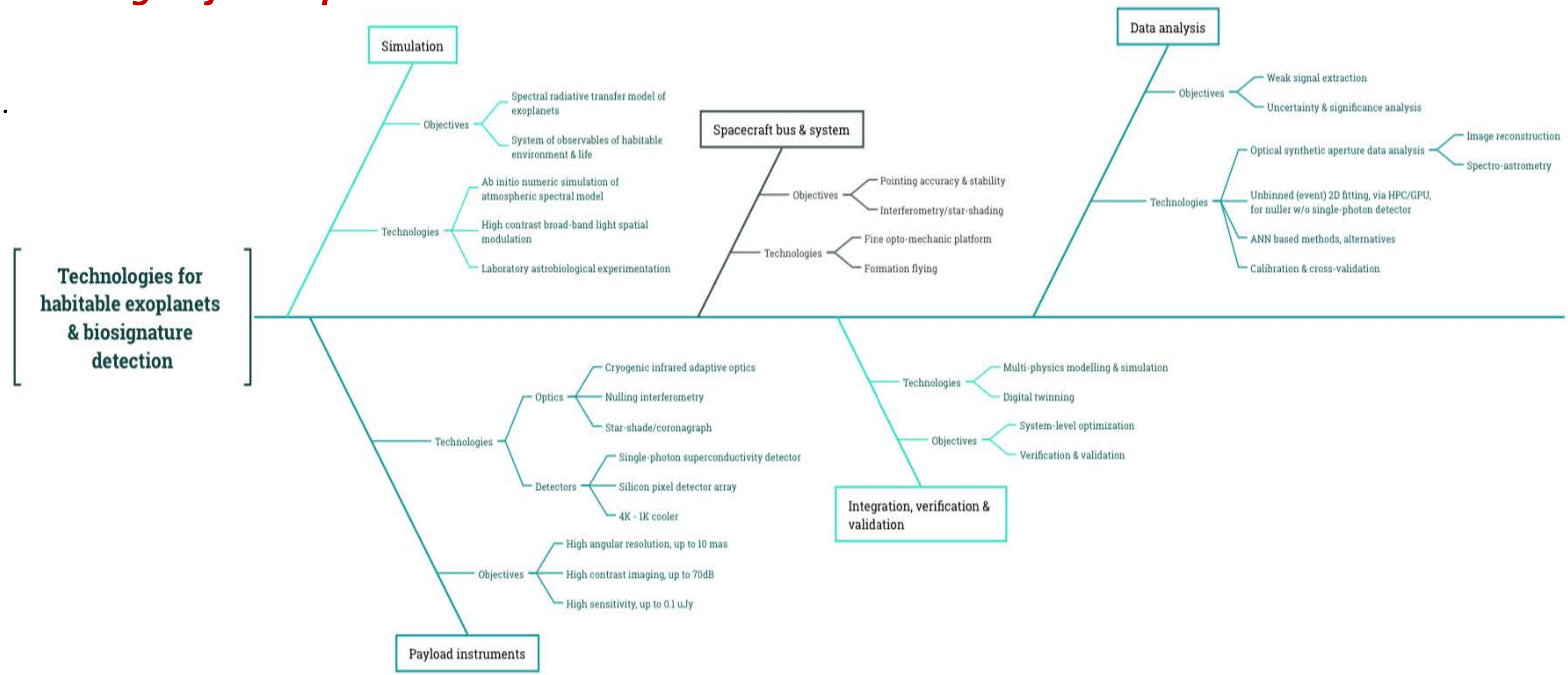
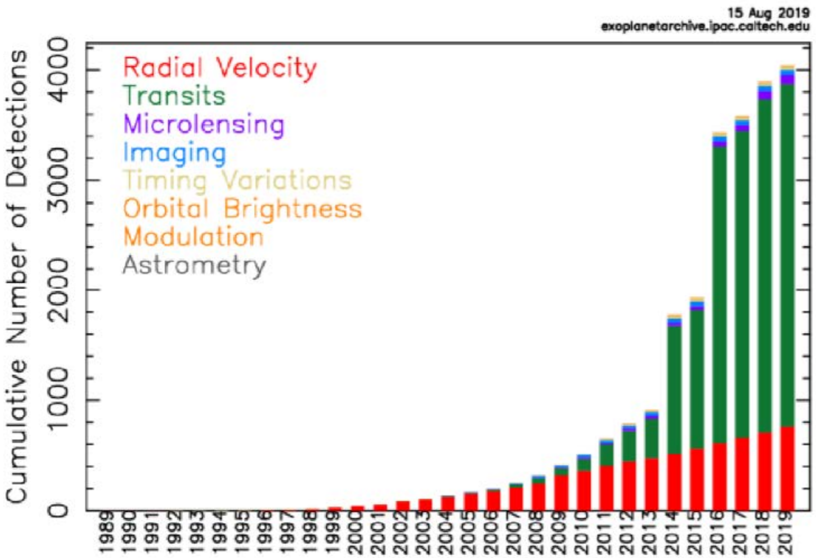


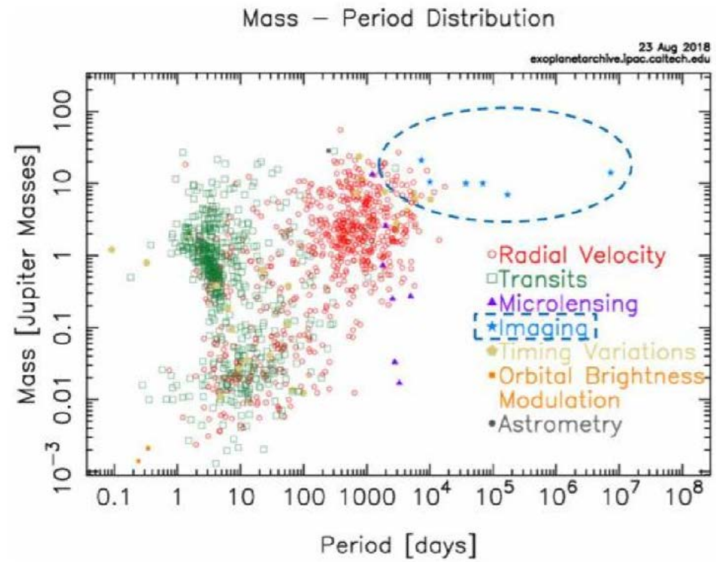
This is an smart and elegant way to extend the potential collaboration

Contribute and test with small satellites some of these technologies :

The development of small space-based platforms for nulling interferometric observations could be the pathfinder of a new era in exoplanetology



Cumulative number of exoplanet detections since the first discovery. The transit and radial velocity methods are the most common

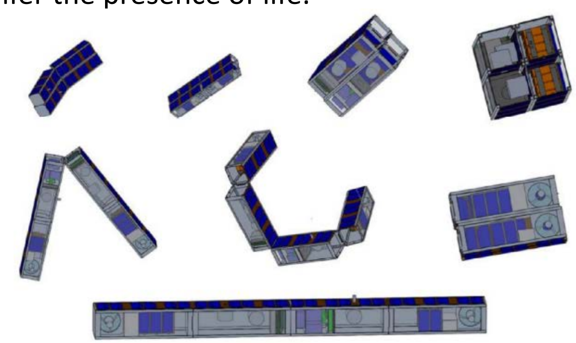


Distribution of discovered exoplanets in the function of its revolution period and its mass

« Exoplanetary Search and Characterization Research Based on CubeSat Platform »

Objective: development of a spatial interferometric nulling instrument capable of directly detecting and characterizing nearby exoplanets. One project will make the research of the direct detection techniques of Exoplanetary. By injecting direct light coming from exoplanets into spectrometers, we could study their chemical composition, search for biosignatures, and possibly infer the presence of life.

By combining the light of two or more telescopes, we would considerably increase the angular resolution and thus could potentially lead to the detection of Earth size rocky exoplanets around Solar-type stars. Moreover, with a π-phase shift between the two interferometer arms, the starlight is reduced which allows the detection of much fainter objects around the star. This topic is the subject of master theses and of a going on PhD thesis (Subject: Study of a CubeSat nulling interferometer to detect exoplanets) at CSL.



12U CubeSat deployment. The interferometer basis is 1.2 m allowing the characterization of Proxima-b

https://orbi.uliege.be/bitstream/2268/239370/2/Feasibility%20study%20of%20an%20interferometric%20CubeSat%20to%20detect%20exoplanets.pdf
https://orbi.uliege.be/bitstream/2268/254701/1/Dandumontetal2020bPoster.pdf
https://orbi.uliege.be/bitstream/2268/251075/1/JATIS-20025_online.pdf

Integrate some of CSL mature « payload » design for Space Station or Moon or others (Asteroid, Mars, …).

XRF instrument for the moon: soil/rock composition analysis

China Lunar Exploration Program Lunar mission

Make use of a recently developed XRF instrument for the moon or others (asteroid, Mars, …) : soil/rock composition analysis

CSL started this activity through a PhD thesis by Alain Carapelle for applications on Earth.

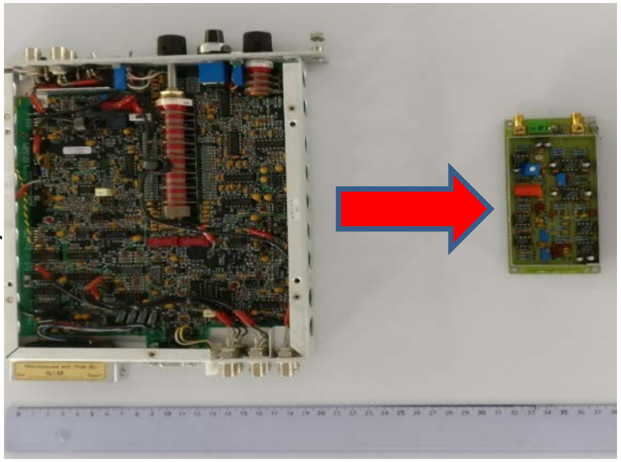
CSL got a funding from ESA to make this instrument lighter, more compact and space qualified.

The preliminary results are :

- Measurements of all atoms in one measurement
- Limit of detection: ~200 ppm
- Peak power < 10 W
- Lightweight (< 500 g)
- No radioactive source
- TRL level 4 or 5 Our device is not yet ready for a FM but we have improved TRL to 6-7.

The final test is foreseen in vacuum in the near future and the electronic design is radhard... not yet a FM but almost ...

Electronic size reduction



Videos on the subject and with the LUVMI rover are presented here (This is LUVMI-X: the Lunar Rover that will explore the resources of the Moon)

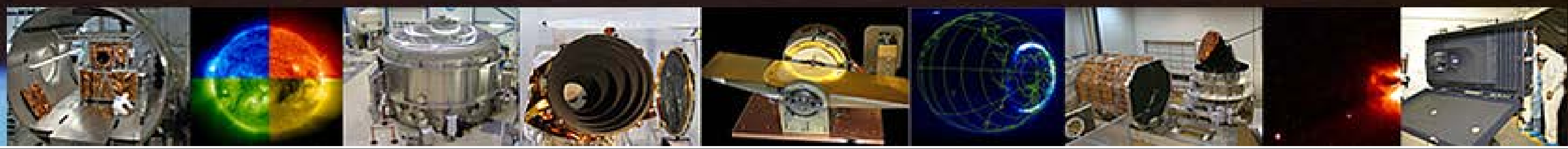
https://youtu.be/A_2YbkNn-bE

Several possible general cooperations

1) University CubeSat research cooperation: several projects are from Beihang University, Tianjin Normal University, Northwestern Polytechnical University, and at School of Aeronautics and Astronautics, Dalian University of Technology. China will build one or two 6U CubeSat, and any team at Belgium university would like to join the team, it would be a good opportunity to cooperate. The project is in PHASE A.
2） Exchange of academic visits between the teams of two countries, especially the faculty members and students.
3) The possible cooperation of private space companies of two countries.

THANK YOU FOR YOUR ATTENTION

COMMENTS ?



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Optical Remote Sensing Payloads, from Design to Flight Test

Guest Editors

Dr. Xing Zhong, Prof. Pierre Rochus, Prof. Dr. Fei Xing, Prof. Dr. Xiuqing Hu

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