

European Space Agency Solar System Missions



Dr. Alejandro Cardesín Moinelo

ESA Science Operations

Mars Express, ExoMars 2016, Juice

IAC Winter School, Tenerife, November 2016

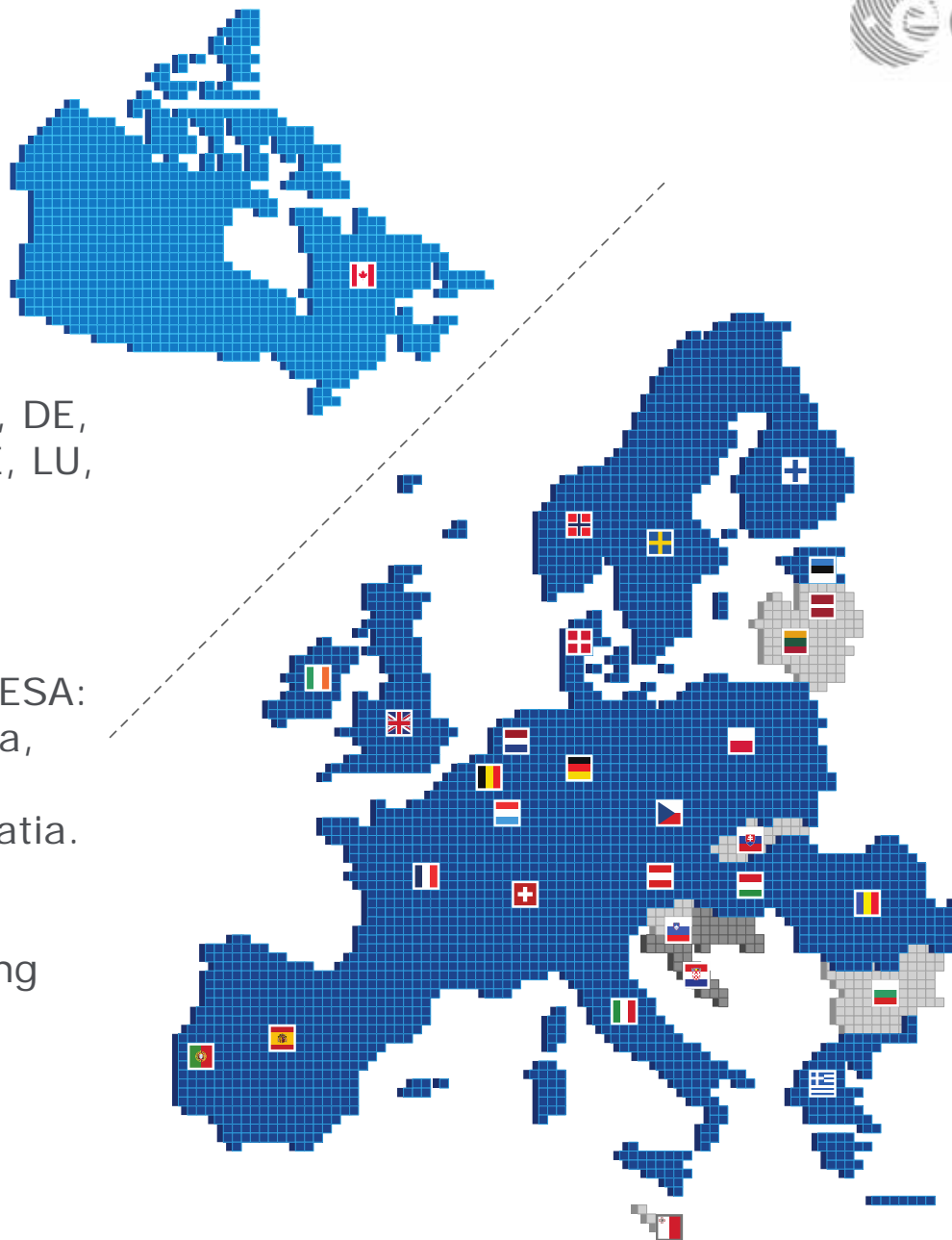
Europe's Gateway to Space

*“To provide and promote cooperation among European states
in **space research, technology**
and their **space applications**
for exclusively peaceful
purposes.”*

Article 2 of ESA Convention

**We can go
further together!**





ESA has 22 Member States:
20 states of the EU (AT, BE, CZ, DE, DK, EE, ES, FI, FR, IT, GR, HU, IE, LU, NL, PT, PL, RO, SE, UK)
plus Norway and Switzerland.

7 other EU states have **Cooperation Agreements** with ESA:
Bulgaria, Cyprus, Latvia, Lithuania, Malta, Slovakia and Slovenia.
Discussions are ongoing with Croatia.

Canada takes part in some programmes under a long-standing **Cooperation Agreement**



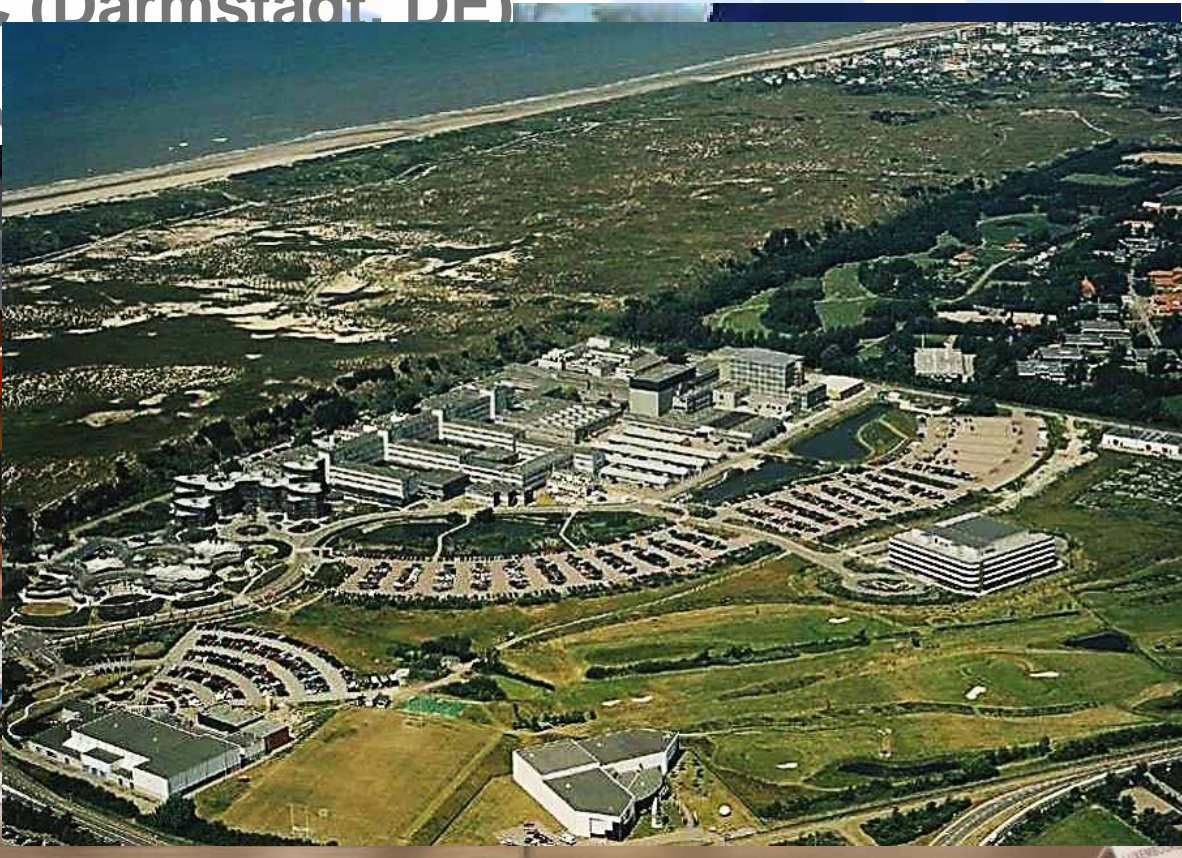
ESA's main sites



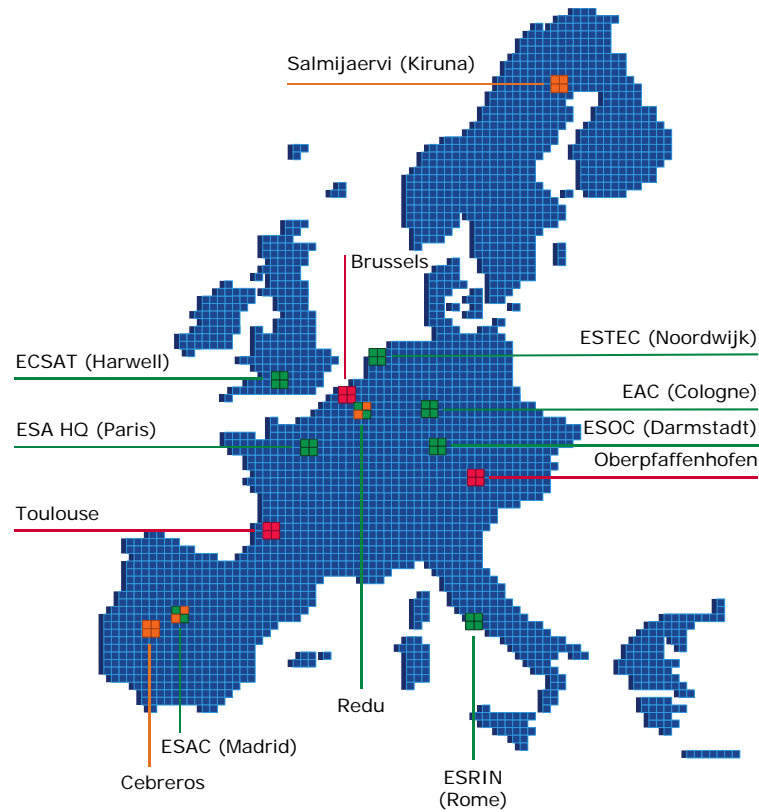
ESTEC (Noordwijk, NL)

ESOC (Darmstadt, DE)

ESRIN



All ESA's locations



- ESA sites
- Offices
- ESA sites + ESA Ground Station

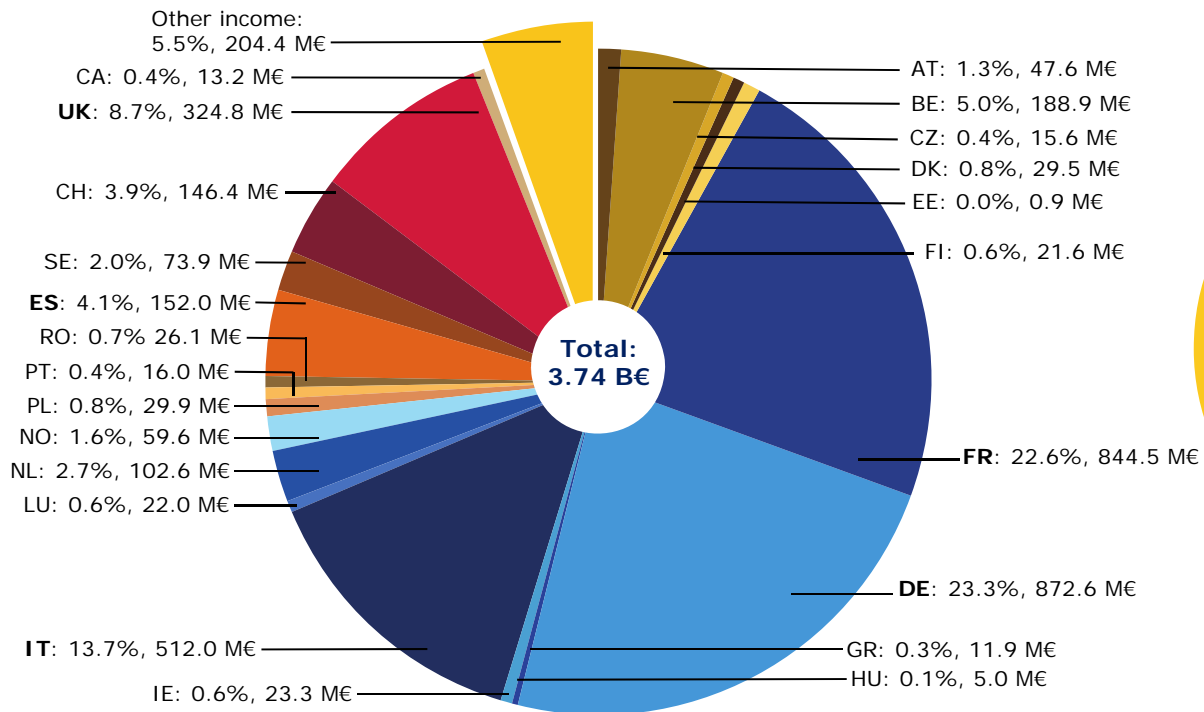
- ESA Ground Station
- ESA Ground Station + Offices



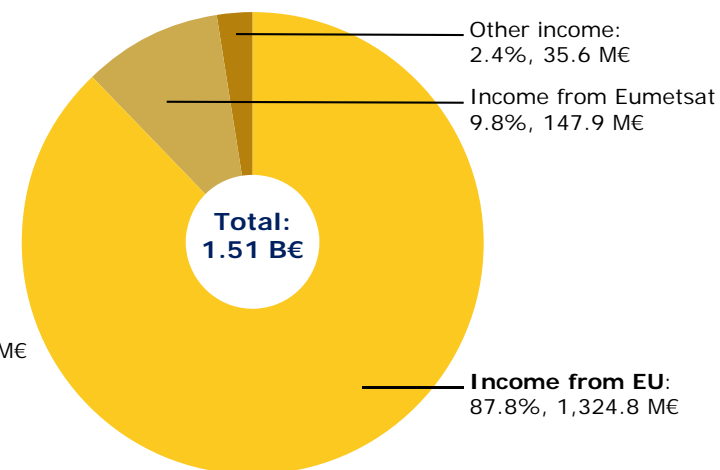
ESA 2016 budget by country



ESA Activities and Programmes



Programmes implemented for other Institutional Partners



B€: Billion Euro

Total ESA budget for 2016: **5.25 B€**



Naples Ministerial Council, 2012

Ministers of ESA Member States defined strategic objectives for the next decade, starting a process for evolution of ESA and funding programmes/activities for an amount of around €10 billion.

Decisions are testimony to the fact that space spells effective investment in growth, innovation and knowledge for the benefit of all citizens.

New investment approved was carefully balanced between three complementary strategic objectives:

- pushing the frontiers of knowledge;
- supporting an innovative and competitive Europe;
- enabling space-based services.





About 85% of ESA's budget is spent on contracts with European industry.

ESA's industrial policy:

- ensures that Member States get a fair return on their investment;
- improves competitiveness of European industry
- maintains and develops space technology;
- exploits the advantages of free competitive bidding, except where incompatible with objectives of the industrial policy.

ESA ExoMars Industrial Participation



Russia



Khronichev, Lavochkin Association, TsENKI

United States



ATK-PSI, EMS, ERG, GD-OTS, Haigh-Farr, Honeywell, Mu Space

Canada



MDA, Neptec

Israel



Rafael

Netherlands

Bradford, TNO, TNO-TPD, SSBV, Airbus DS-NL

United Kingdom



ABSL, Airbus DS-UK, Fluid Gravity Engineering Ltd, Qinetiq, TAS, Tessella, Vorticity

Belgium



ASTEK, OHB-BE, Qinetiq, TAS-BE, Trasys

France



Airbus DS-FR, ETS, SAFT, Souriau, TAS-F Cannes

Switzerland



Almatech, APCO
Clemessey, Maxon, RUAG

Portugal



Active Space Technologies,
Critical Software, Deimos,
GMV, HPS, IST

Spain



Casa, Crisa, Deimos, GMV, Iberespacio,
Rymasa, Sener, TAS-ES

Finland



Patria, Space Systems

Norway



Kongsberg

Sweden



RUAG

Denmark



Terma

Poland



Sener

Germany



Airbus DS-DE, Airbus DE, DLR, DSI, ETS,
Gerling Holz & Co., Kayser-Threde, OHB,
Rockwell Collins

Austria



RUAG, Siemens

Italy



Acotek, Aerosekur, Altec, Corista, D'Appollonia,
Elital, IRSPS, Selex-Galileo Firenze, Selex-Galileo
Avionica Milano, Sitael, Aerospace, TAS-I Torino,
TAS-I Rome, Tecnomare, Telespazio

Greece



TEMMA



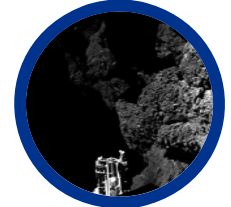
ESA is one of the few space agencies in the world to combine responsibility in nearly all areas of space activity.



space science*



human spaceflight



exploration



earth observation



launchers



navigation



operations



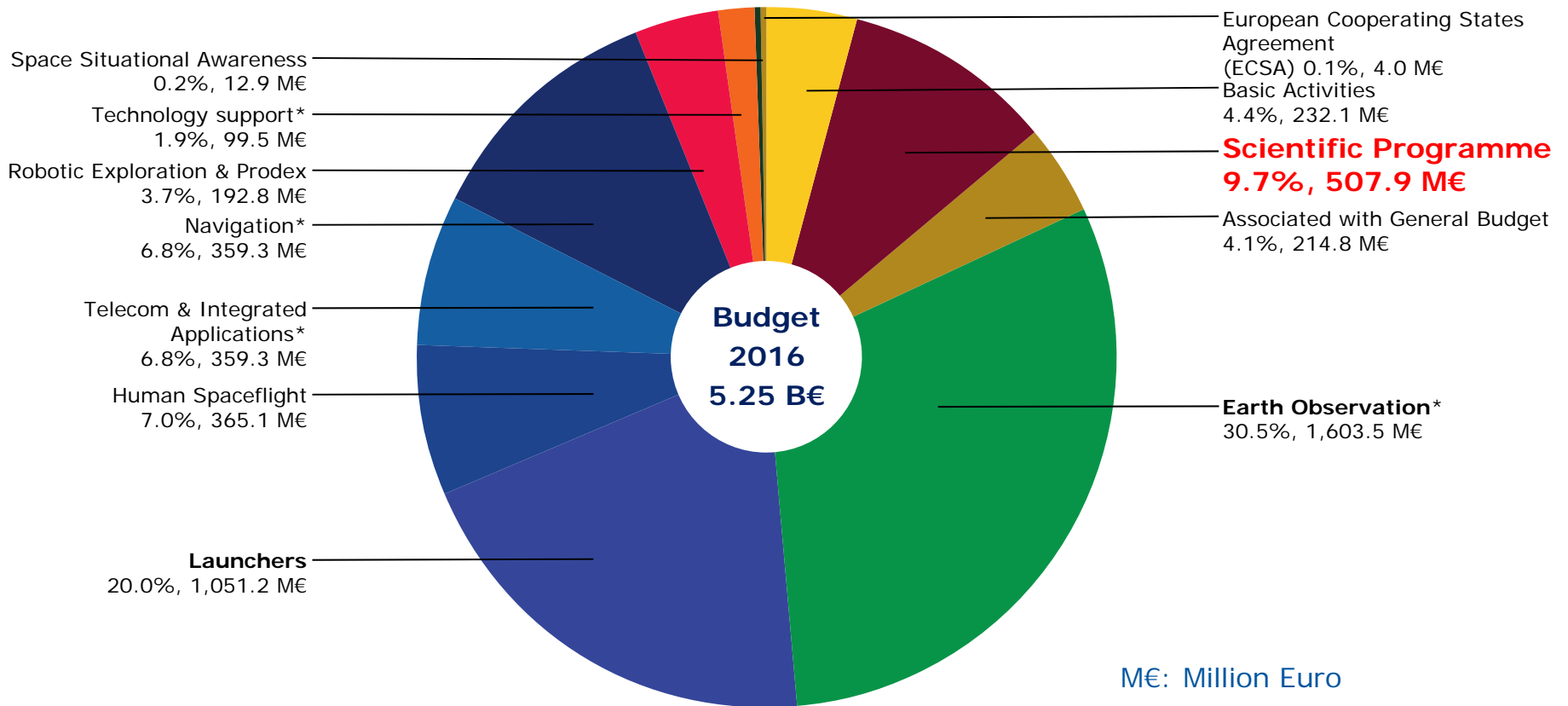
technology



telecommunications

* **Space science is a Mandatory programme**, all Member States contribute according to GNP. **All other programmes are Optional**, funded 'a la carte' by Participating States.

ESA 2016 budget by domain



M€: Million Euro

*includes Programmes implemented for other Institutional Partners



Mandatory Program

- All ESA member states must contribute proportionally to national gross
- Key for **long term** missions in astronomy, solar system and fundamental physics

* Note **exploration is not mandatory**: optional programme (e.g. ExoMars)

Mission Cost Share model

- ESA funding covers the **spacecraft, launcher** and **operations**,
- **Member States** fund the **payloads** (and parts of the science operations).

Driven by the Science Program Committee

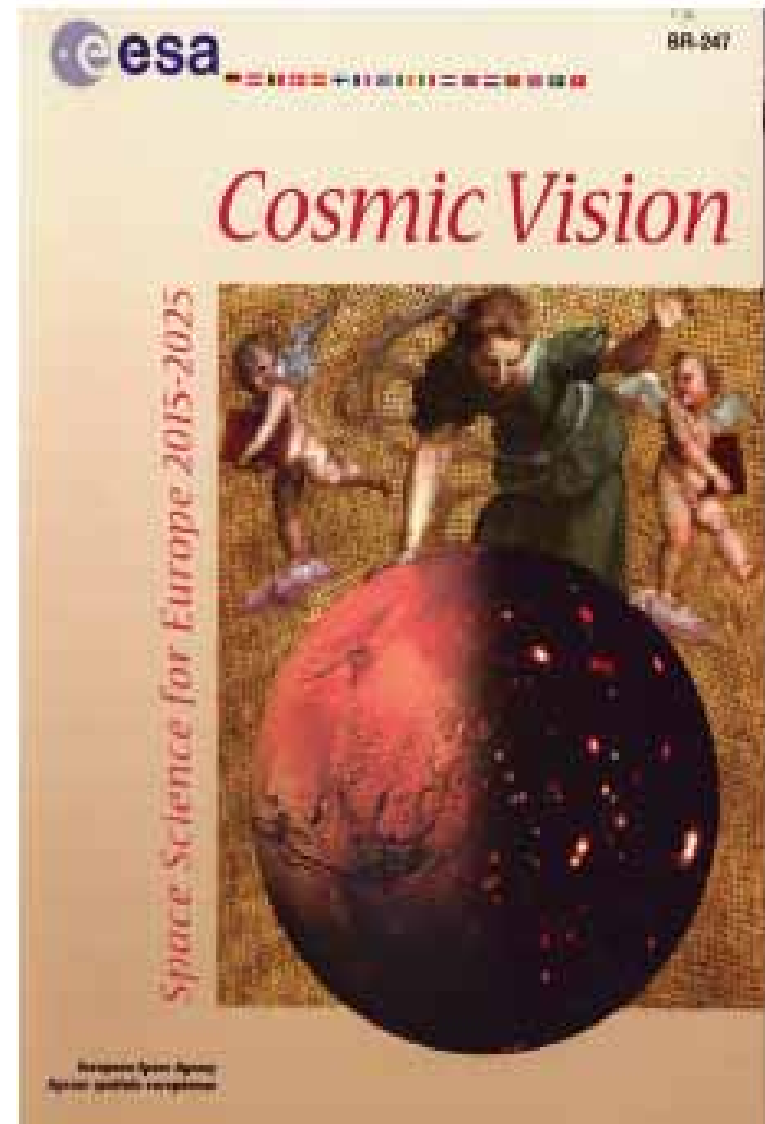
- **SSAC** : Space Science Advisory Group
- **SSEWG** : Solar System Exploration Working Group
- **AWG** : Astronomy Working Group
- **FPWG** : Fundamental Physics Working Group

Mankind's fundamental questions:

1. Where do we come from?
2. How/where did life originate?
3. Are we alone?

Cosmic Vision is ESA's long term plan to answer the following questions

1. **What** are the conditions for planetary formation and the emergence of life ?
2. **How** does the Solar System work?
3. **What** are the physical fundamental laws of the Universe?
4. **How** did the Universe originate and what is it made of?



Science Program Mission Elements



L-missions (L1 JUICE , L2 ATHENA, L3 Gravitational Waves Observatory)

Cost to ESA of around 2 annual budgets (**1000 M€**)

European led flagships with <20% international contributions

May need technology development

M-missions (M1 Solar Orbiter, M2 Euclid, M3 Plato, M4 ARIEL/THOR/XIPE?, ...)

Cost to ESA of around one annual budget (**550 M€**)

ESA led or contribution to international collaboration.

No technology development

S-missions (S1 CHEOPS, S2 SMILE, ...)

Cost to ESA of 0.1 annual budgets (**50 M€**)

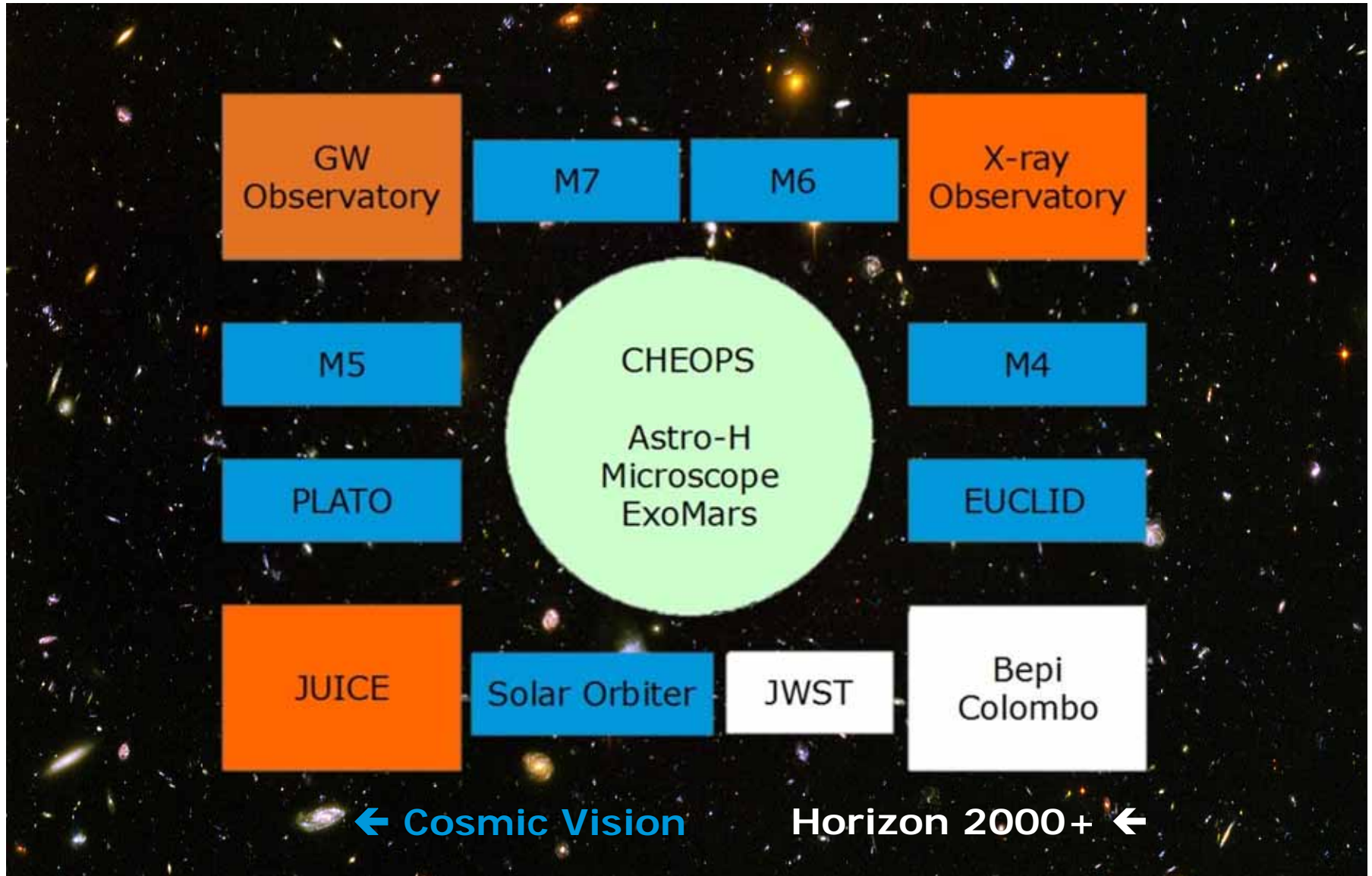
National agencies play a leading role

No technology development

O-missions

Missions of opportunity, led by other agencies, small contributions.

Science Program Roadmap



soho
Facing the Sun (1995)

giotto
Close encounter with comet Halley
(1985-1992)

Venus express
Studying Venus' atmosphere
(2006-2014)

juice
Studying Jupiter's icy moons
(in development)

cassini
Studying the
Saturnian system
(1997-)

bepicolombo
Exploring Mercury
(in development)

proba-2
Observing coronal
dynamics and solar eruptions
(2009-)

huygens
Landing on Titan
(15 January 2005)

solar orbiter
The Sun up close
(in development)

smart-1
Exploring our Moon
(2003-2006)

mars express
Investigating the Red Planet
(2003-)

ulysses
Watching over the Sun's poles
(1990-2009)

cluster
Measuring Earth's magnetic shield (2000-)

rosetta
Chasing a comet (2004-)
Landing on a comet (12 November 2014)

→ ESA'S SPACE SCIENCE LEGACY

ESA has a long history of space science missions that have explored our Solar System, charted the Milky Way Galaxy, and probed the fabric of the Universe. Even after completing operations, the legacy of these missions lives on in the form of vast databanks, and pave the way for the next generation of spacecraft.

Voyage to the planets and the minor bodies of the Solar System



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Giotto, 1985-1992

close encounter with comet Halley



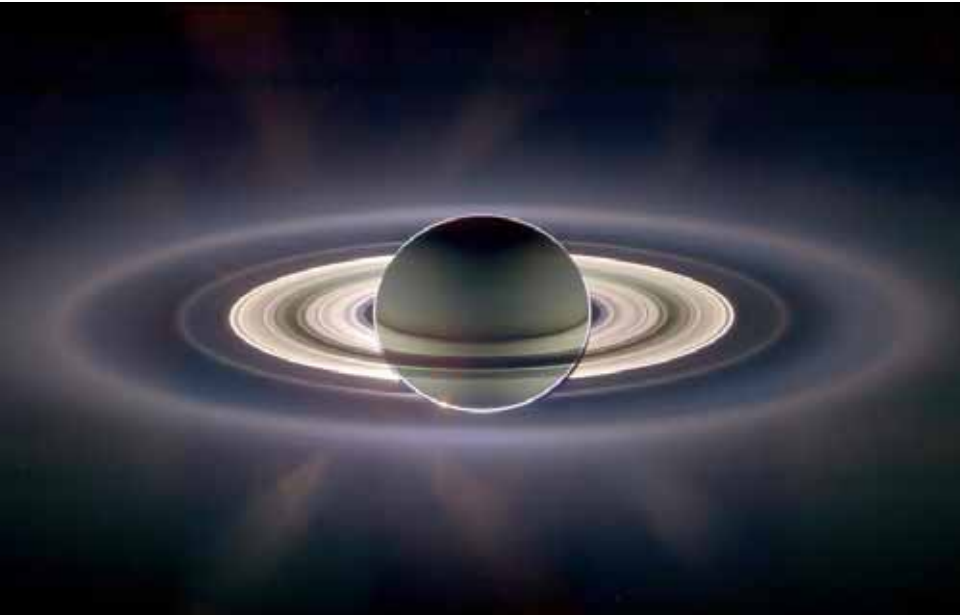
- Europe's first deep-space mission
- Part of the "Halley Armada" in 1986
- Closest comet fly-by until Rosetta
- First close-up images of a comet nucleus
- First evidence of organic material in a comet
- First mission to encounter two comets (Halley and Grigg-Skjellerup)

Launch: 2 July 1985, Ariane-1
Halley encounter: 14 March 1986
Grigg-Skjellerup fly-by: 10 July
1992
Status: concluded



Cassini-Huygens, 1997-2004...2017

unveiling the secrets of Saturn, its rings and moons



- Joint NASA/ESA/ASI mission
- In-depth studies of the planet, its moons, rings and magnetic environment
- Best ever views of Saturn's rings
- Discovery of giant cyclones at Saturn's poles
- Discovery of geysers of water-ice and organic compounds from Enceladus' surface

Launch: 15 Oct 1997, Titan-IVB/Centaur

Arrival at Saturn: 1 Jul 2004

Status: operational



- Discovery of hydrocarbons lakes on **Titan**
- Discovery of building blocks for complex organic molecules in Titan's atmosphere
- First ever in-situ analysis of Titan's atmosphere and surface with ESA's Huygens

Huygens landing on Titan: 14 Jan 2005

Status: concluded

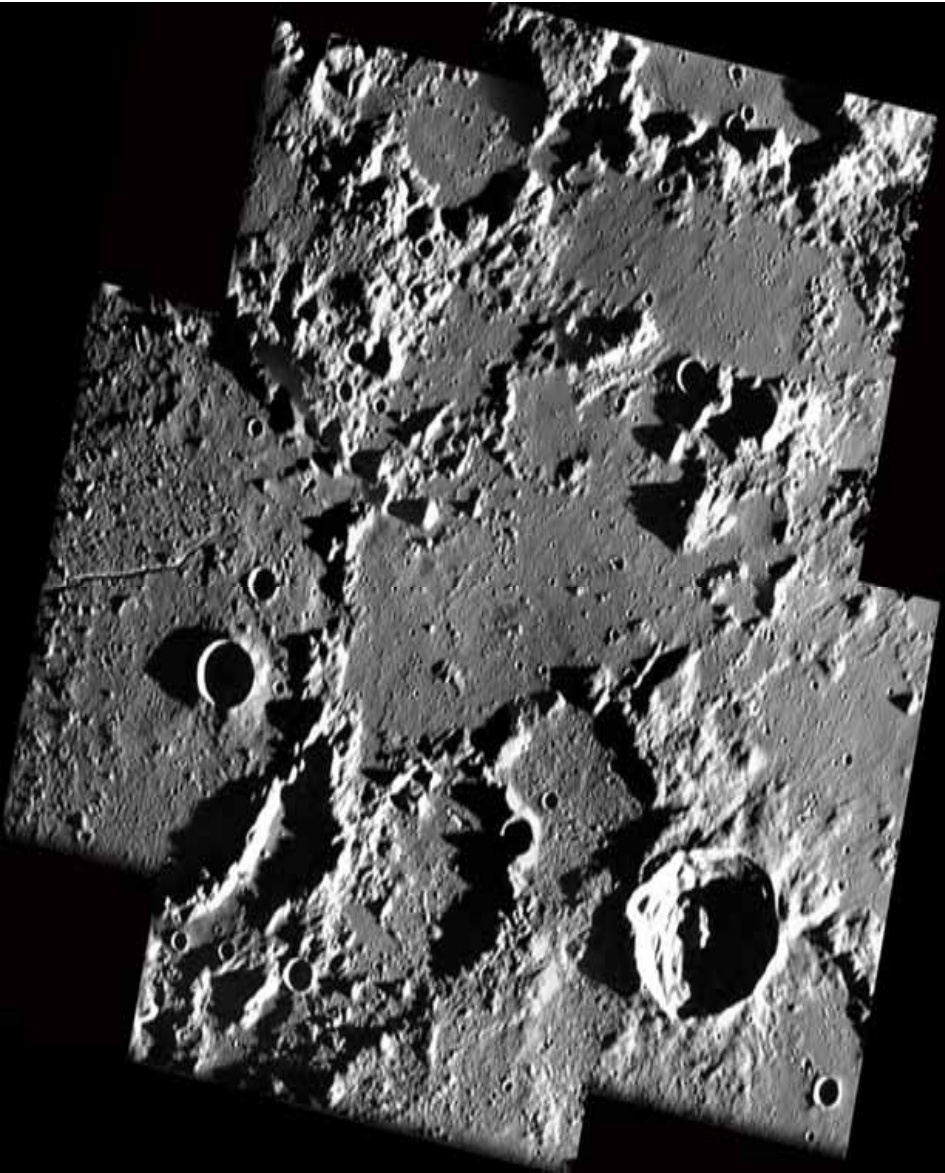


The
Descent Imager / Spectral Radiometer
During the Descent of Huygens
onto Titan on January 14, 2005

Erich Karkoschka, University of Arizona,
the DISR Team, NASA, ESA

SMART-1, 2003-2006

Europe to the Moon



First European mission to the Moon

Technology demonstrator for solar-electric propulsion and miniaturised instruments

Images of the surface, also in colour

Best ever views of the lunar poles

First mission to observe the Moon in X-ray and infrared from orbit

Best mineral mapping, including first detection of calcium

Launch: 27 Sep 2003, Ariane 5

Arrival at the Moon: 13 Nov 2004

Orbit: polar, elliptical

Moon crashing: 3 Sep 2006

Status: concluded



Mars Express, 2003-...

global view of the Red Planet



First European mission to Mars

Astonishing, high-resolution images of the surface

First sub-surface probing, and discovery of water-ice deposits underneath the surface

Discovery of traces of atmospheric methane, pointing to possible volcanic or biological activity

Mineralogical evidence that abundant liquid water was present in the early history of Mars

First ozone map of Mars

Identification of solar wind contributing to atmospheric escape

Launch: 2 Jun 2003, Soyuz-Fregat

Arrival at Mars: 25 Dec 2003

Orbit: polar, elliptical

Status: operational



Rosetta, 2004-2016

Rendez-vous with comet Churyumov-Gerasimenko



First mission to orbit a comet nucleus and deploy a lander (Philae) onto its surface

Studying the evolution of the comet's phenomena while it approaches the Sun

Bringing a full lab to a comet for chemical analysis in situ

Helping to understand if comets contributed to the origin of life and to the formation of oceans on Earth

Studying two asteroids from close quarters during the journey

Helping to understand the origin and evolution of the Solar System

Launch: 2 Mar 2004, Ariane 5 ECA

Gravity assists: Earth, Mar 2005, Nov 2007, Nov 2009; Mars, Feb 2007

Asteroid Steins fly-by: 5 Sep 2008

Asteroid Lutetia fly-by: 10 Jun 2010

Comet encounter: 6 August 2014

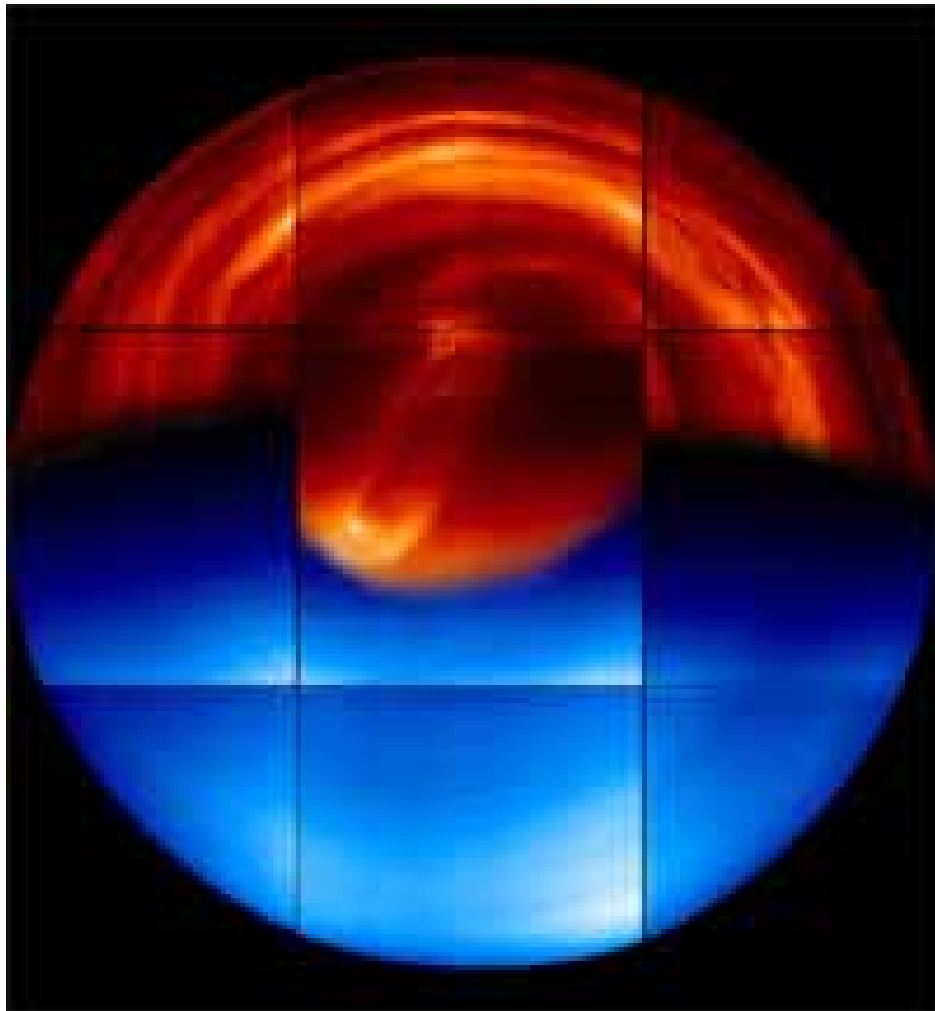
Lander delivery: 12 Nov 2014

Status: Post-operations



Venus Express, 2005-2014

Lifting the veil on Venus



First European mission to Venus

First global examination of Venus' cryptic atmosphere, Earth's 'twin separated at birth'

First global and 3D views of the double-eyed vortex at the South Pole, of clouds, waves and convection cells

First extensive meteorological maps of Venus, with wind fields and temperatures

First unambiguous detection of lightening

Most complete data set of the chemical species in the atmosphere

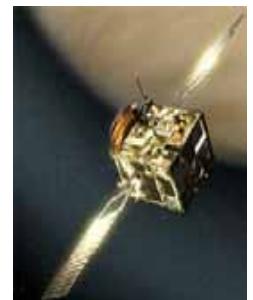
Detection of water escape from the atmosphere into space

Launch: 9 Nov 2005, Soyuz-Fregat

Arrival at Venus: 11 Apr 2006

Orbit: polar, elliptical

Status: post-operations



ExoMars 2016 – 2020 - ...

Mars long term exploration program



Collaboration ESA/ROSCOSMOS

Technological objectives: Landing Technology

Scientific Objectives: Exobiology in Atmosphere, Surface and Subsurface

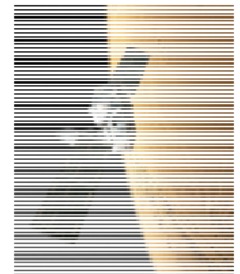
2 Missions:

EXOMARS 2016

Launch: March 2016, Proton

Arrival at Mars: 19 Oct 2016

Orbit: aerobraking, circular 350km



EXOMARS 2020

Lanzamiento: July 2020, Proton

Arrival at Mars: ±March 2021

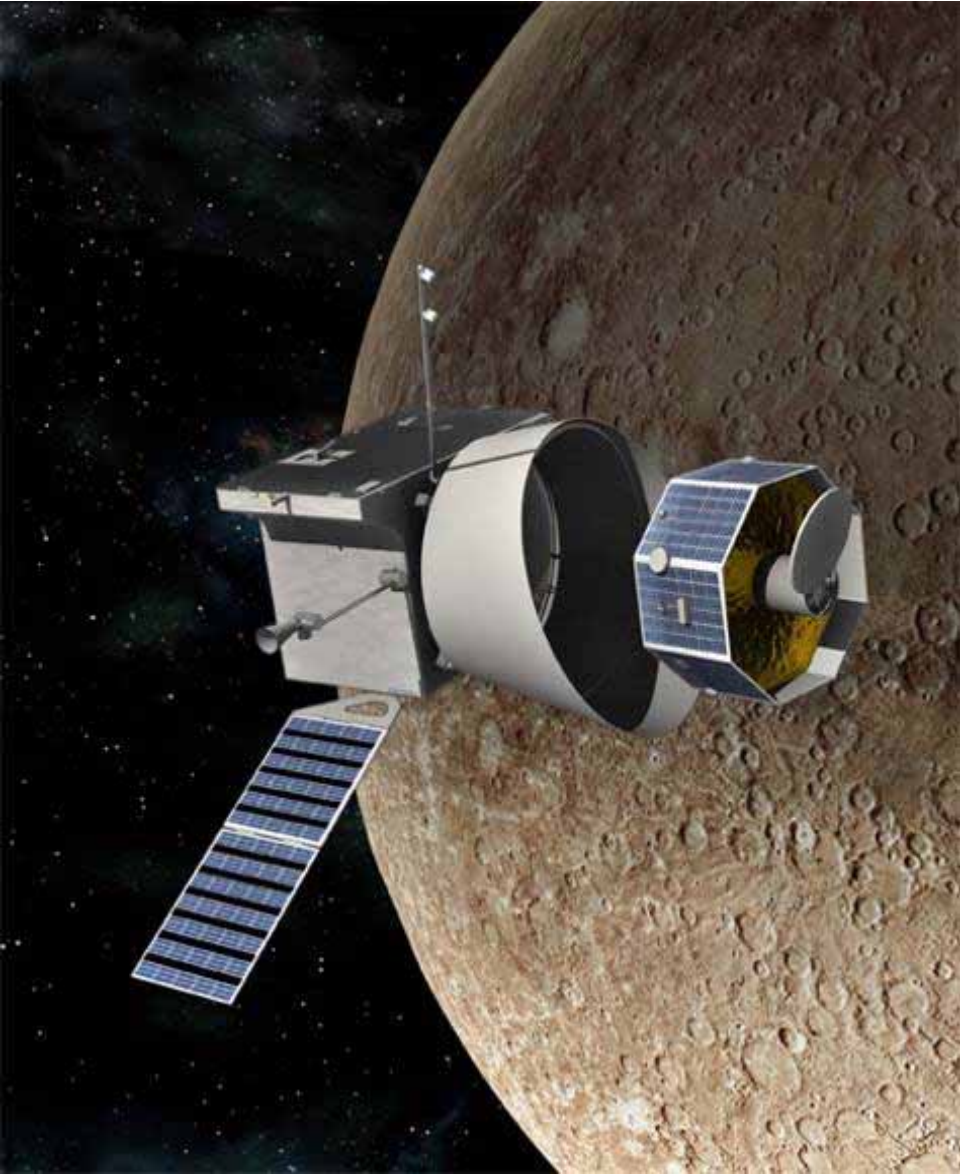
2 Surface Assets:

Russian surface platform,
European Rover



BepiColombo, 2018-2024...2026

Mission to Mercury



Collaboration between ESA/JAXA (Japan)

The mission comprises two spacecraft:

- Mercury Planetary Orbiter (MPO)
- Mercury Magnetospheric Orbiter (MMO)

Objective to study and understand the composition, geophysics, atmosphere, magnetosphere and history of Mercury.

Launch: 2018, Ariane 5

Arrival at Mercury: Late 2024

Orbits: Polar orbits

MPO 480 × 1500 km, 2.3 hr period

MMO 590 × 11 640 km, 9.3 hr period

Status: Implementation



Jupiter Icy Moons Explorer (JUICE), 2022 – 2033

Mission to Jupiter and its icy moons



~7 years interplanetary transfer to Jupiter
~3.5 years of operations around Jupiter and moons

Monitoring of Jupiters atmosphere

Various flybys of Calisto.

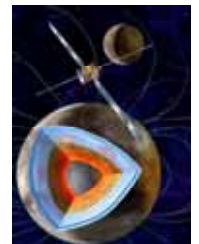
2 flybys of Europa.

9 months in order around Ganymede.

Launch: 2022 (Ariane 5)

Orbit: Tour of Jupiter,
high latitudes and orbits
around Ganymede

Status: Implementation



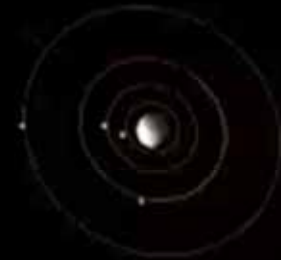
JUICE Overall Mission Profile



Launch	May/June 2022
Interplanetary transfer (Earth-Venus-Earth-Mars-Earth)	7.6 years
Jupiter orbit insertion	October 2029
2 Europa flybys	October 2030
Jupiter high-latitude phase	Dec 2030-May 2031
Transfer to Ganymede	June 2031-July 2032
Ganymede orbit insertion	August 2032
Ganymede elliptical orbit/5000 km	August-Dec 2032
Ganymede 500 km Circular Orbit	January-June 2033
End of mission	June 2033



JUICE full mission trajectory



Asteroid Impact Mission (AIM), 2020 – 2023

Detailed mapping of binary asteroid



Europe's contribution to the larger Asteroid Impact & Deflection Assessment mission: **AIDA**

NASA will contribute the Double Asteroid Redirection Test, or **DART**, which is to impact the asteroid

Launch: 2022 (Ariane 5)

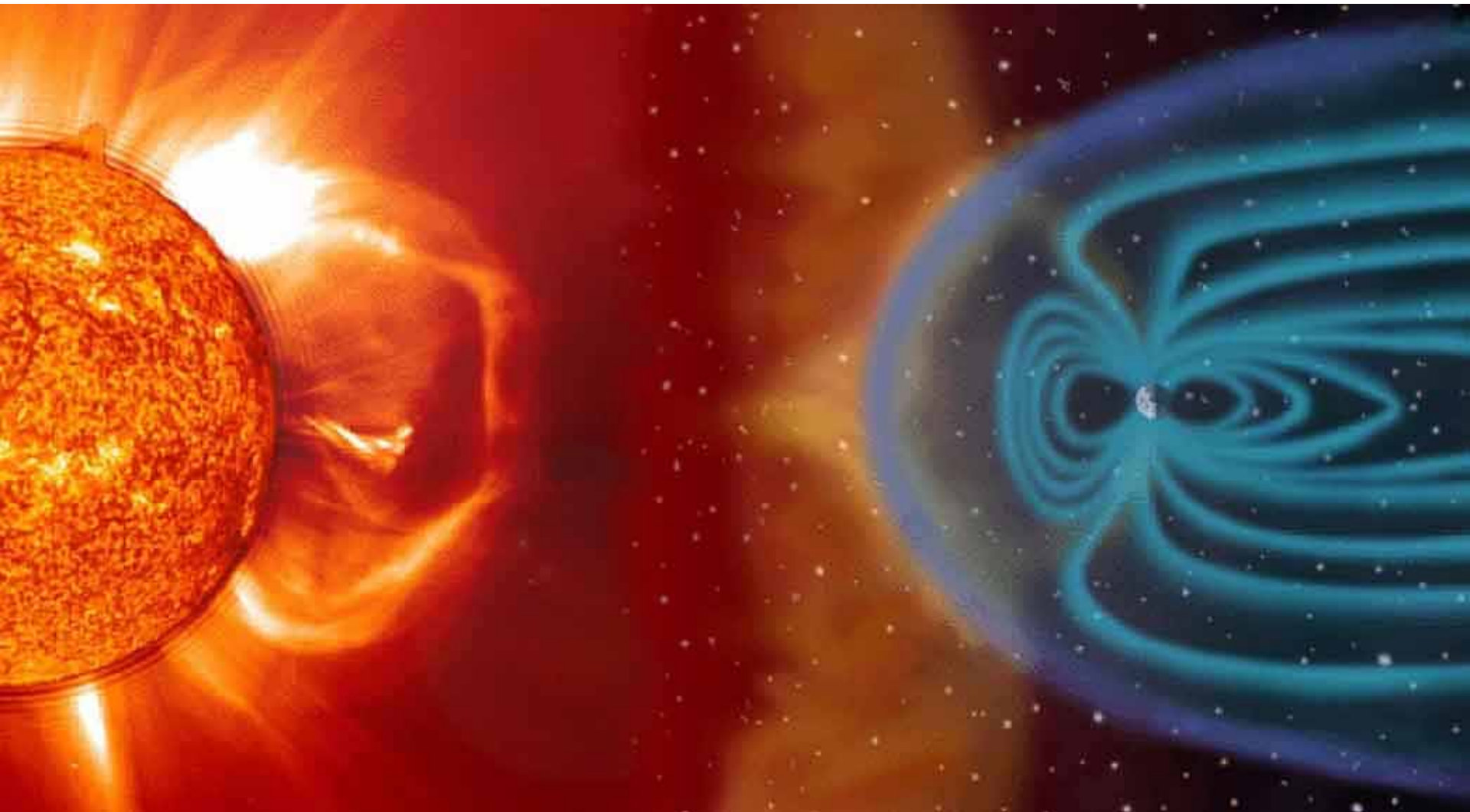
Orbit: Tour of Jupiter, high latitudes and orbits around Ganymede

Status: Implementation



Living with a star

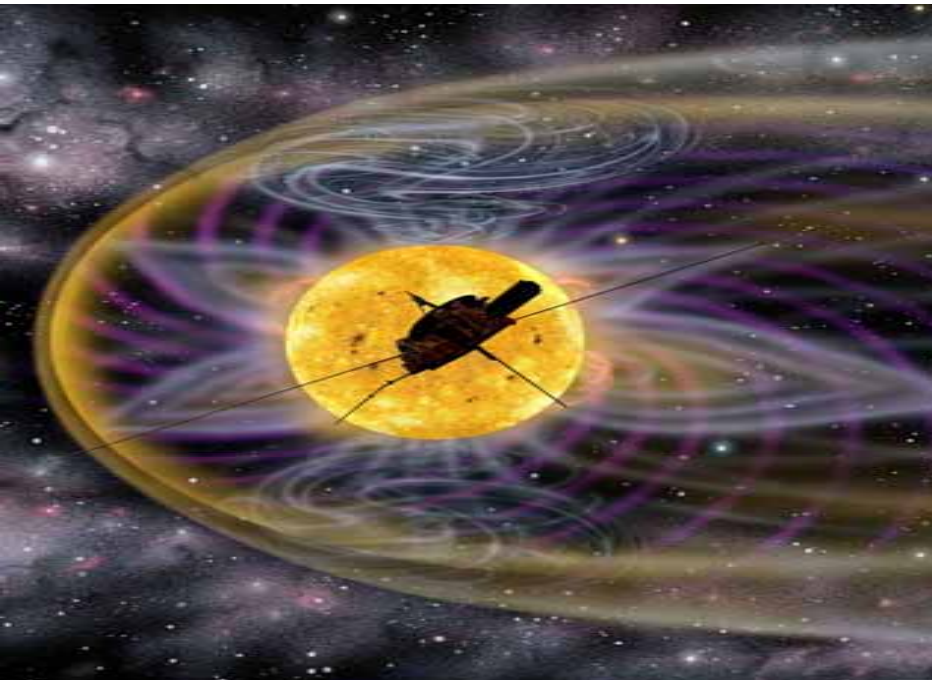
ESA Missions to study the Sun and its influence on Earth



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Ulysses, 1990-2008

over the uncharted poles of the Sun



ESA/NASA joint mission

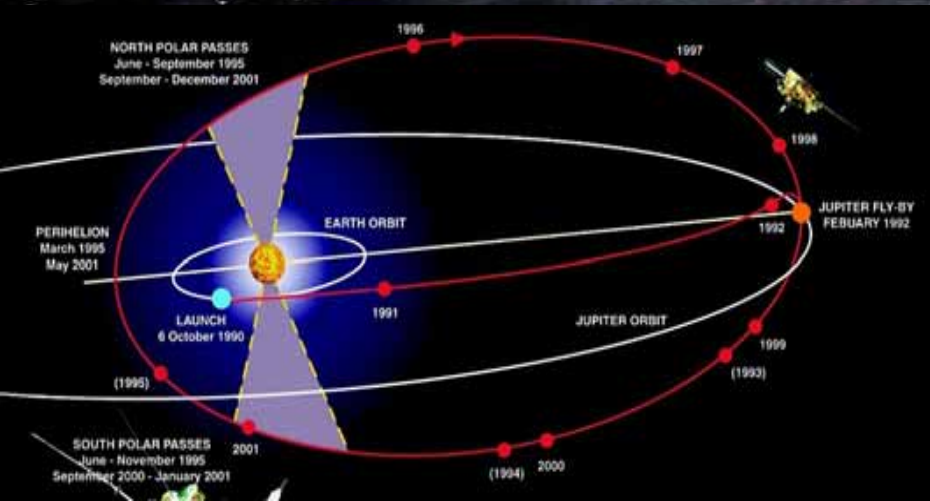
Almost 18 years of operations

First mission to fly over the Sun's poles

First 4D map of the heliosphere, its magnetic field, and the solar wind

Discovery that dangerous energetic particles can climb up to the Sun's poles and be released into space when unexpected

Study of galactic cosmic rays and of the titanic interaction between the heliosphere and the interstellar gas



Launch: 6 Oct 1990, Space Shuttle

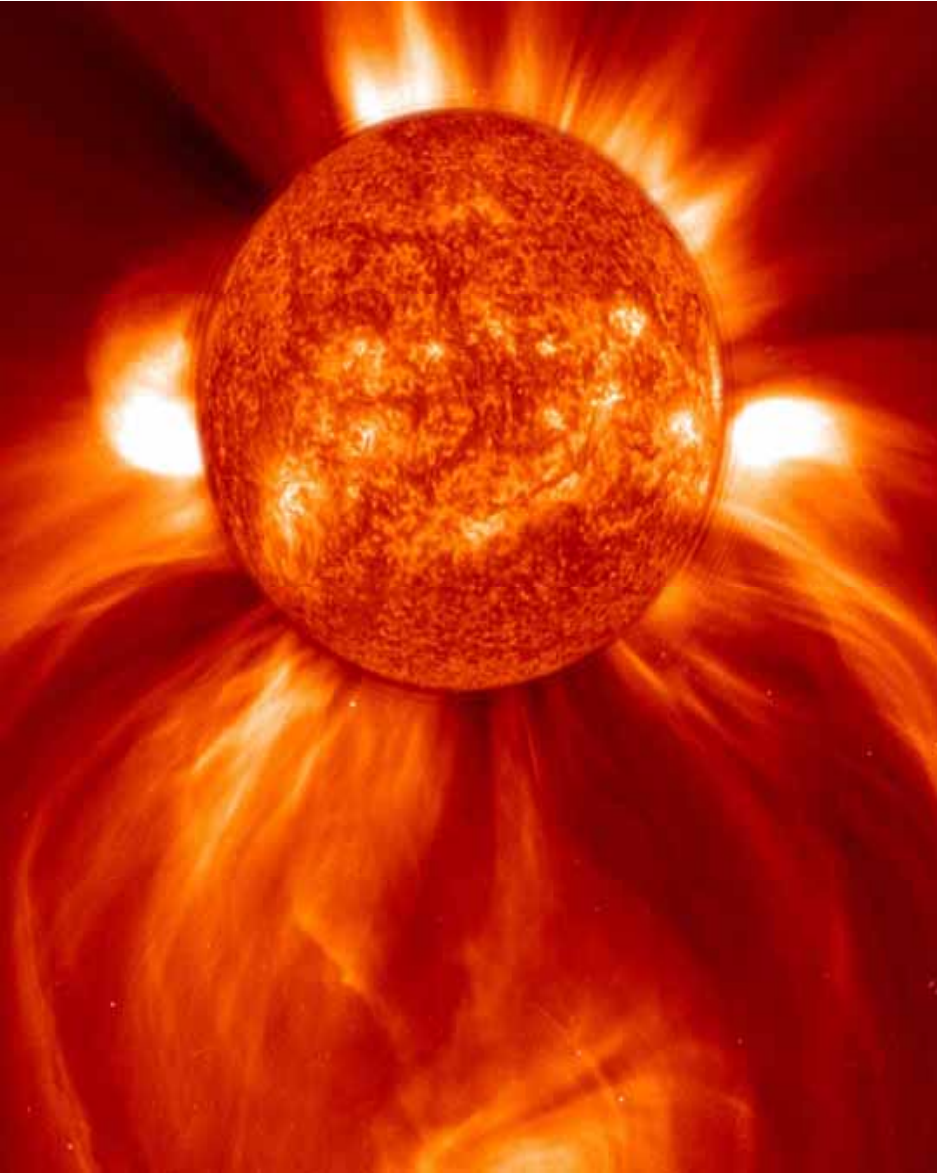
Jupiter swing-by: 8 Feb 1992

Orbit: polar, heliocentric

Status: approaching end



SOHO, 1995- the solar guardian



ESA/NASA joint mission

Unprecedented view of our star

First images ever of structures and flows below the surface

Discovering new phenomena such as coronal waves and solar tornadoes

Founder of the source of fast solar wind

Dramatically improving space-weather forecasting capability

Most prolific discoverer of comets in astronomical history - more than 1500

Launch: 2 Dec 1995, Atlas-IIAS

Orbit: around L1

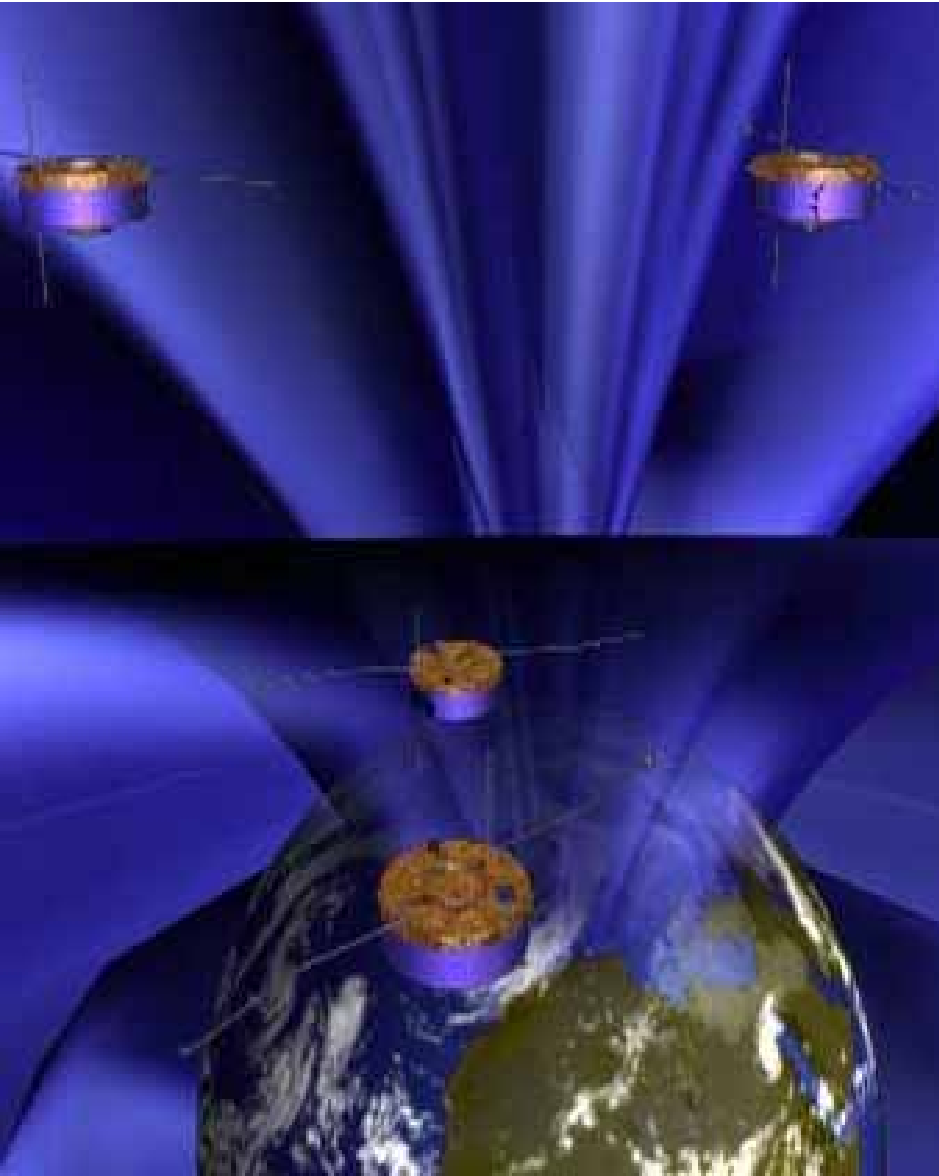
Status: operational



SOHO's 20 Years in Space: Highlights



Cluster, 2000- Sun-Earth connection in focus



Fleet of 4 identical satellites flying in formation

Unprecedented 3D study the Earth's protective bubble in space – the magnetosphere - and of its interaction with the solar wind

3D vision of magnetic reconnection in space

First measurement of electric current in space

Localization of the sources of natural plasma waves, and discovery of surface waves in the magnetotail

Explanation of the origin of black auroras

Launch: 16 Jul and 19 Aug 2000,
Soyuz-Fregat

Orbit: around Earth

Status: operational



PROBA-2, 2009 - ... testing new technologies for Sun monitoring



PROBA series of Technological Missions
PRoject for OnBoard Autonomy

Sun Observations from Earth Orbit

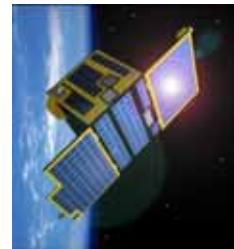
Radiometer and UV telescope I

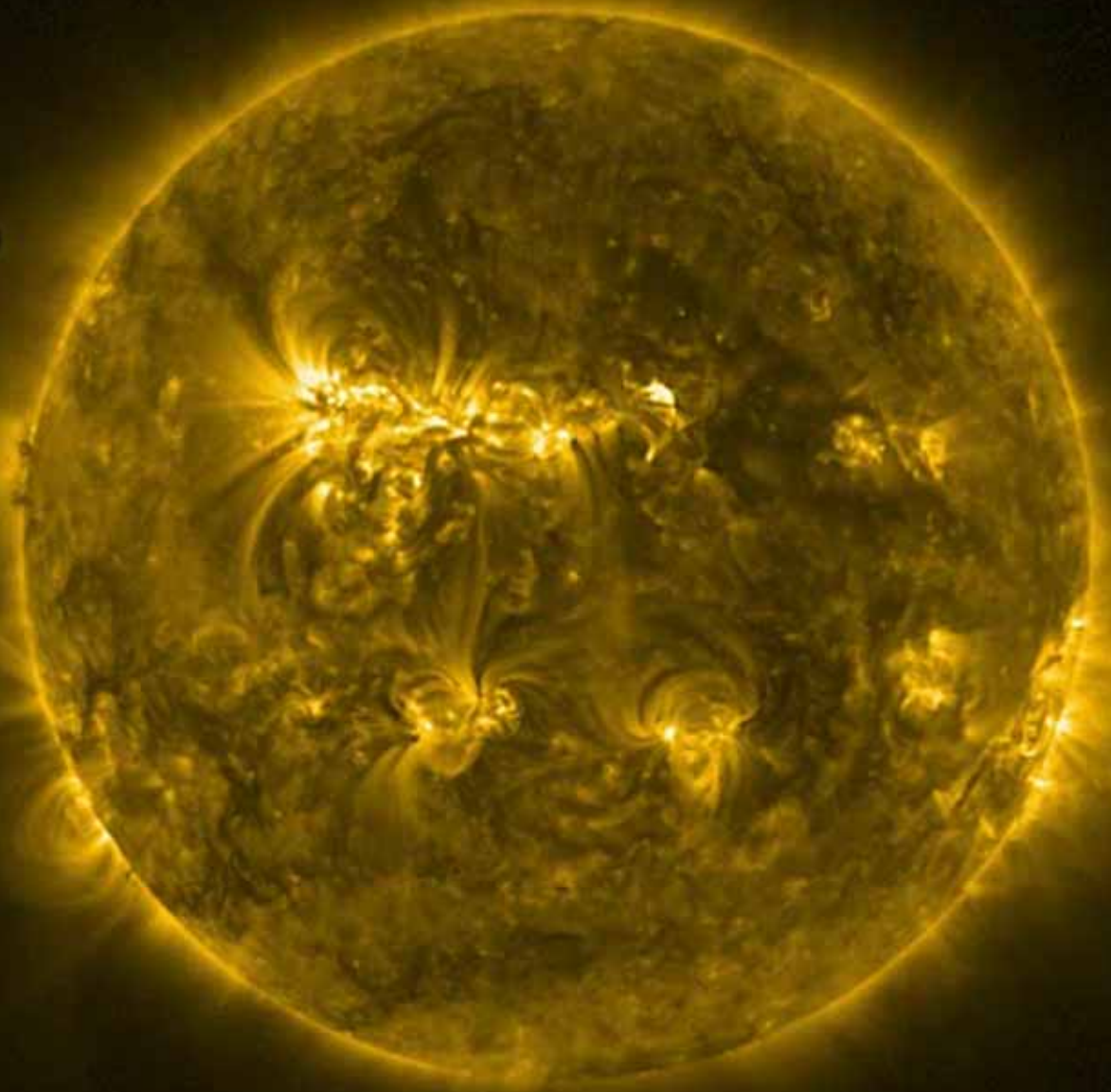
Magnetospheric and plasma measurements

Launch: Nov 2009 (Rockot)
launched with SMOS

Orbit: polar terrestrial,

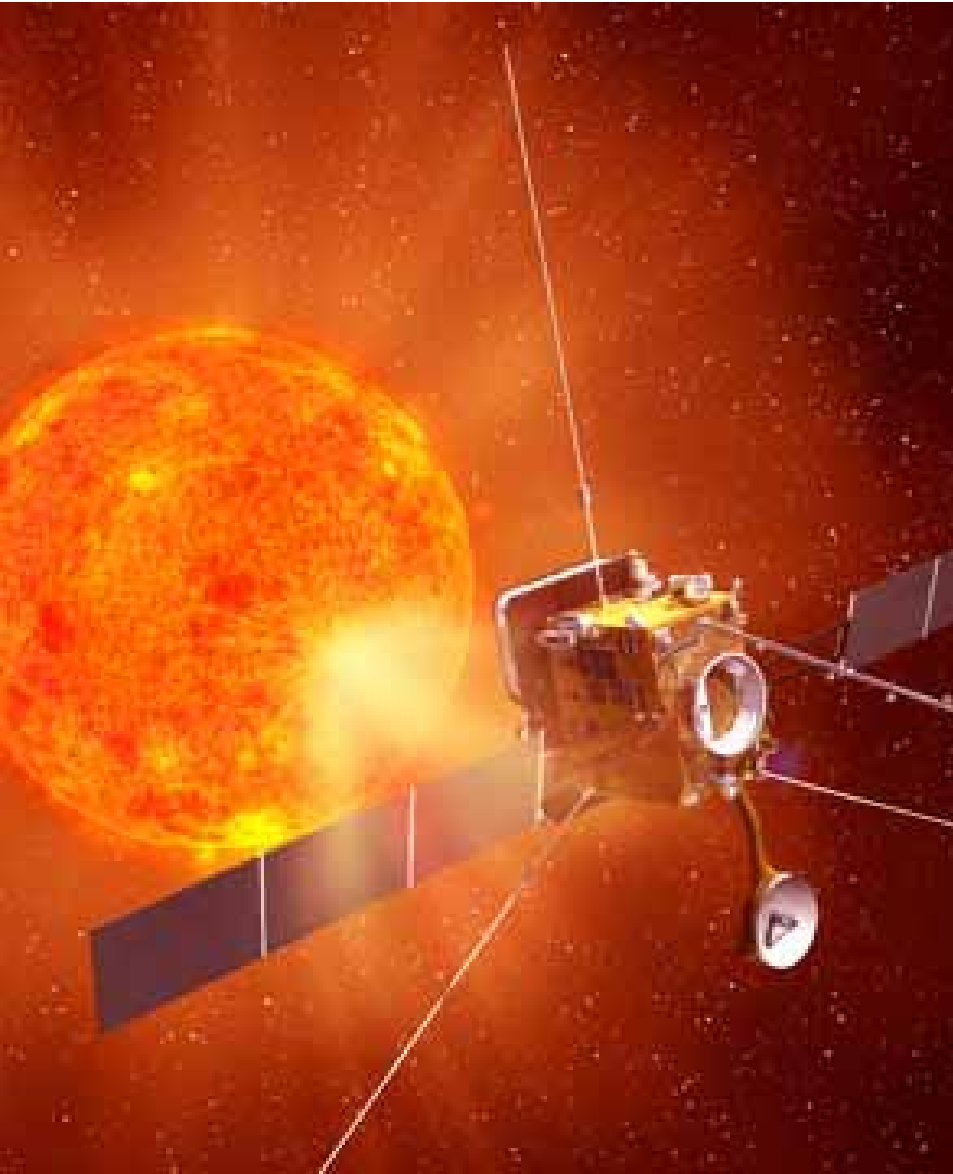
Estado: operational





Solar Orbiter, 2018 - 2025

exploring the Sun in unprecedented detail



ESA mission with important contributions by NASA.

~3 years to reach operational orbit

7 year mission around the Sun

Minimum distance to Sun, closer than Mercury.

Venus Gravity-Assist Manoeuvres used to increase inclination allowing observations of Sun Poles

Observation of Sun and Solar activity

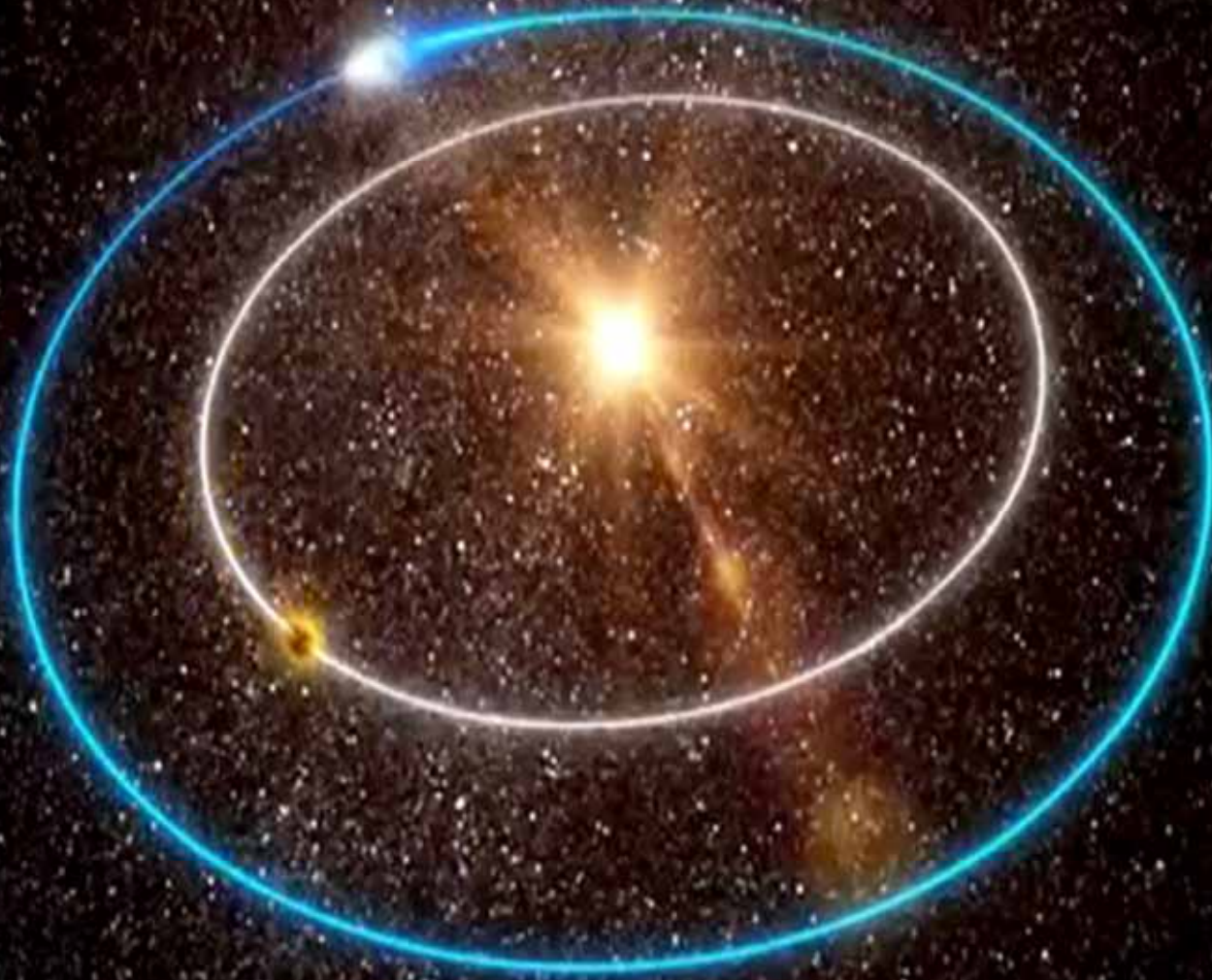
Launch: October 2018 (Atlas V)

Orbit: 168 days period orbit with minimum perihelion radius of 0.28 AU (aphelion around 0.9 AU)

Inclination: 0-34°

Status: Development





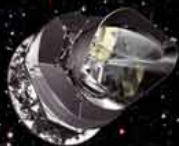
→ ESA'S FLEET ACROSS THE SPECTRUM



Thanks to cutting edge technology, astronomy is unveiling a new world around us. With ESA's fleet of spacecraft, we can explore the full spectrum of light and probe the fundamental physics that underlies our entire Universe. From cool and dusty star formation revealed only at infrared wavelengths, to hot and violent high-energy phenomena, ESA missions are charting our cosmos and even looking back to the dawn of time to discover more about our place in space.

planck

Looking back at the dawn of time



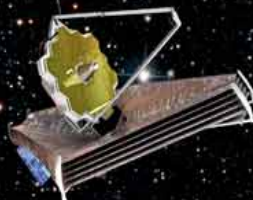
herschel

Unveiling the cool and dusty Universe



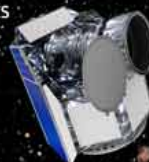
just

Observing the first light



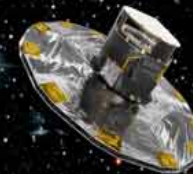
cheops

Sizing and first characterisation of exoplanets



gaia

Surveying a billion stars



euclid

Exploring the dark Universe



hst

Expanding the frontiers of the visible Universe



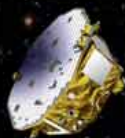
xmm-newton

Seeing deeply into the hot and violent Universe



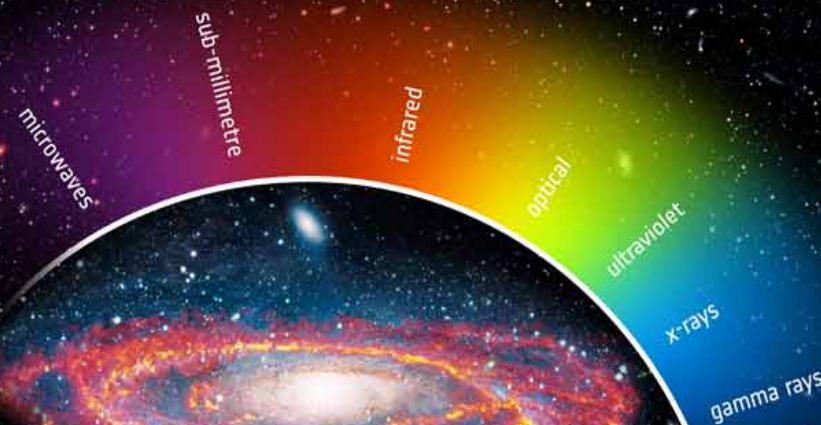
lisa pathfinder

Testing the technology for gravitational wave detection



integral

Seeking out the extremes of the Universe



ESA site in Spain since 2006.

Science Operations Centres for all
Astronomy and Solar System missions.

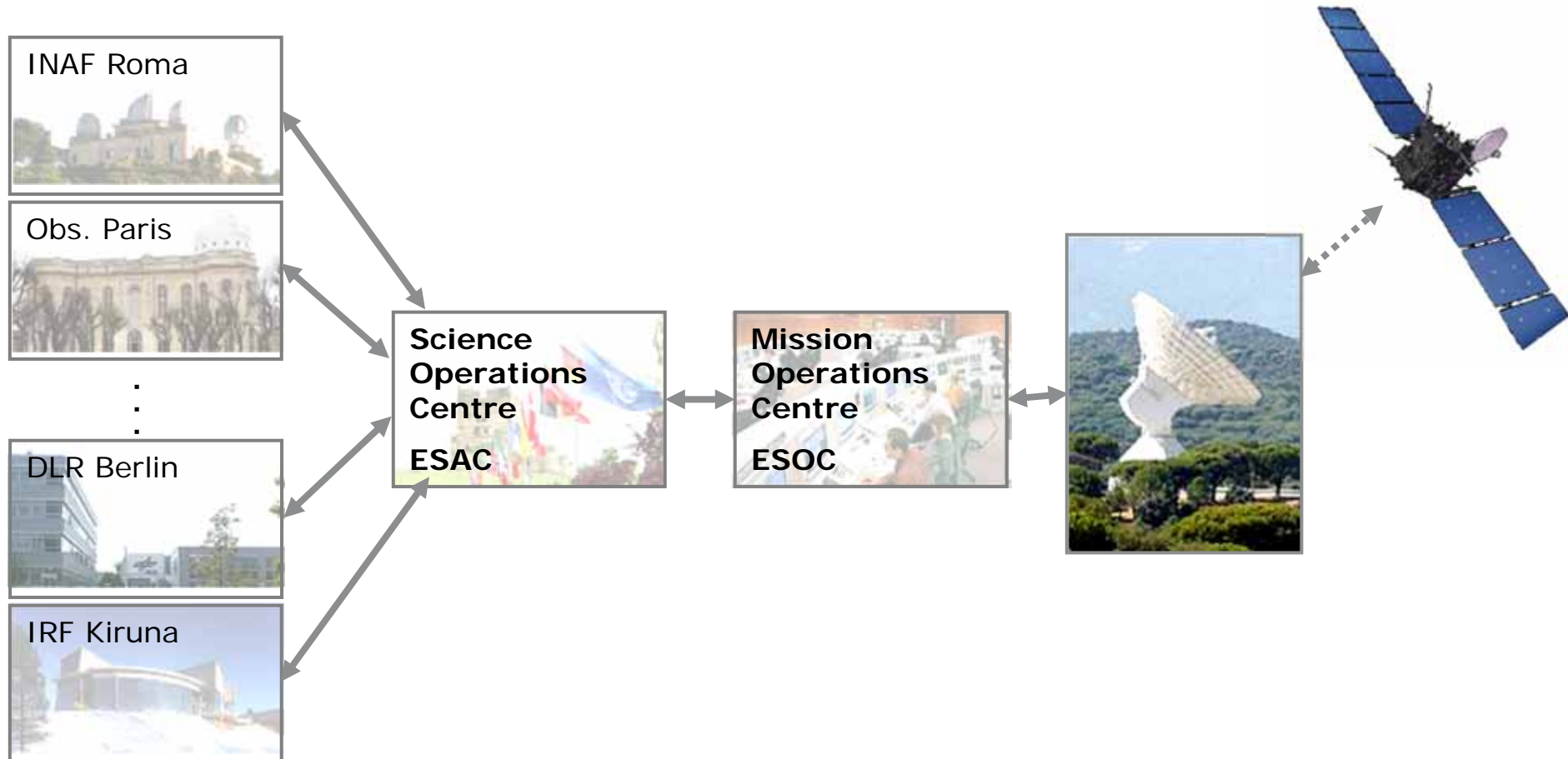
Responsible for operations,
data processing and archiving



Science Operations Centres (SOCs) at ESAC

Coordination of payloads scientific activities on all missions

- UPLINK : **Planning** of payload observations for pointing/commanding
- DOWNLINK : **Data processing** and **archiving** of all payload science

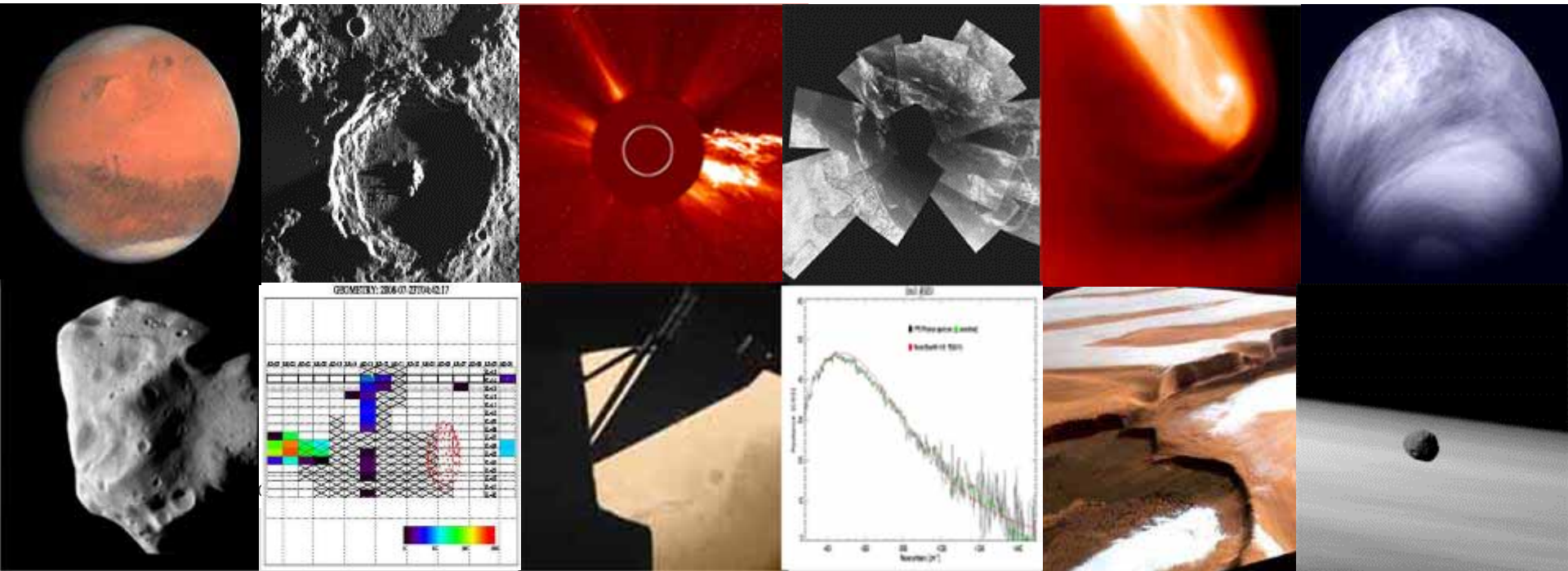


Archives: ESA Science Data Centre (ESDC) at ESAC

ESA Science Data Center (ESDC) hosts and distributes all data to the scientific community: Astronomy, Astrophysics and Solar System

Planetary Science Archive (PSA) hosts all data for ESA planetary missions: Giotto, Huygens, Mars Express, Venus Express, Rosetta and SMART-1. In the future also ExoMars, Bepi Colombo, JUICE, ...

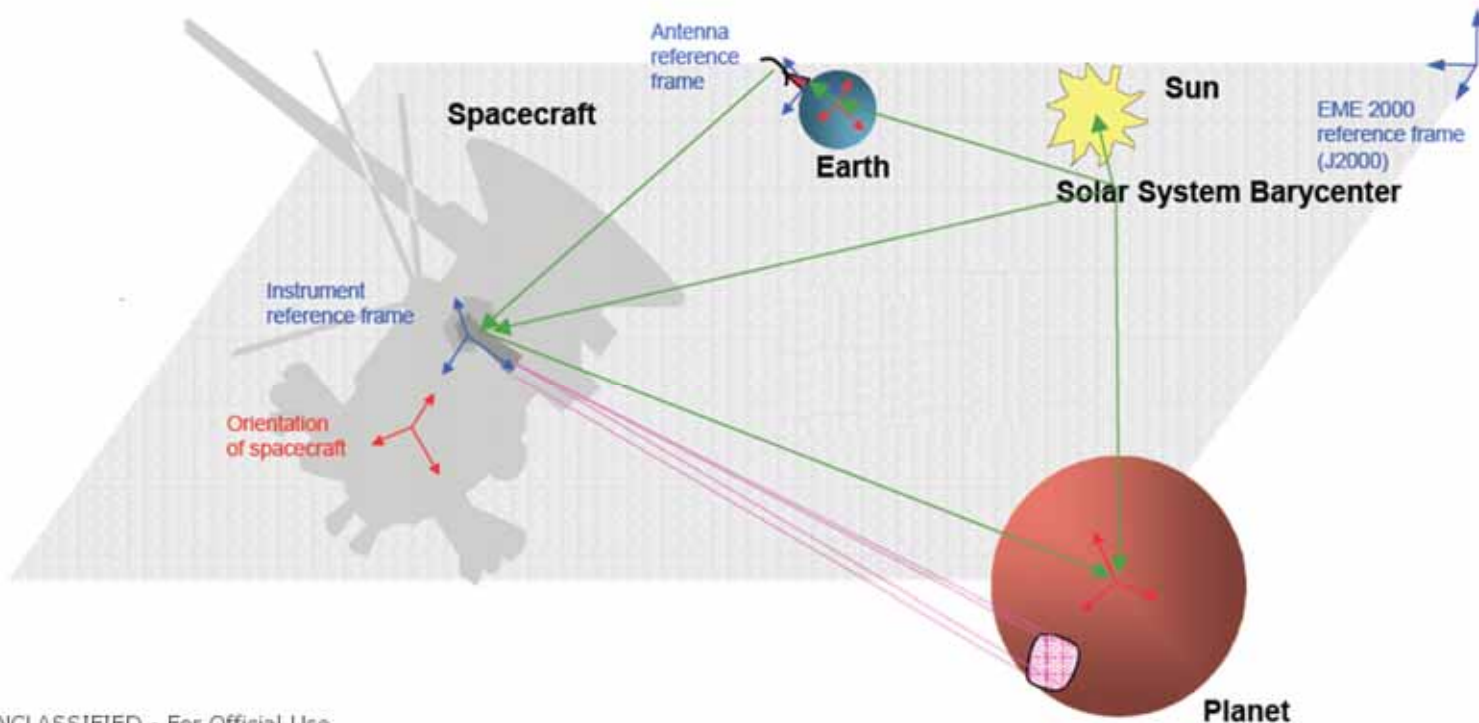
www.sciops.esa.int/PSA



SPICE Geometry Information Centre at ESAC

ESAC is the European Center responsible for SPICE :

- Auxilliary information system for planetary missions: NASA, ESA, JAXA, ...
- Information on solar system objects, ephemeris, etc
- Computation libraries for positions, velocities, angles, 3D models, ...
- Dedicated support to science operations, organization of workshops and training



Collaboration Opportunities within ESA/ESAC



Main tasks at ESAC are **operations, data processing** and **archiving**, it is **not a research institute**, however:

Science Research is strongly promoted and endorsed (*10-20% best effort*)

Direct access to all data, principal investigators and scientific community

Collaboration with Science Community is of key importance

ESAC Faculty provide **funds** for **internal** and collaborative research projects



Official ESA internship and collaboration programs:

- Students and Young scientists / engineers:
 - **Student Trainee** (3~6 months)
 - **Young Graduate Trainee** (1 year)
 - **National trainees** (German, Spanish, Portuguese)(1~3 years)
- Post-docs :
 - **Research Fellowship** (2 years + 1)



**THANK YOU!
ANY QUESTIONS...?**