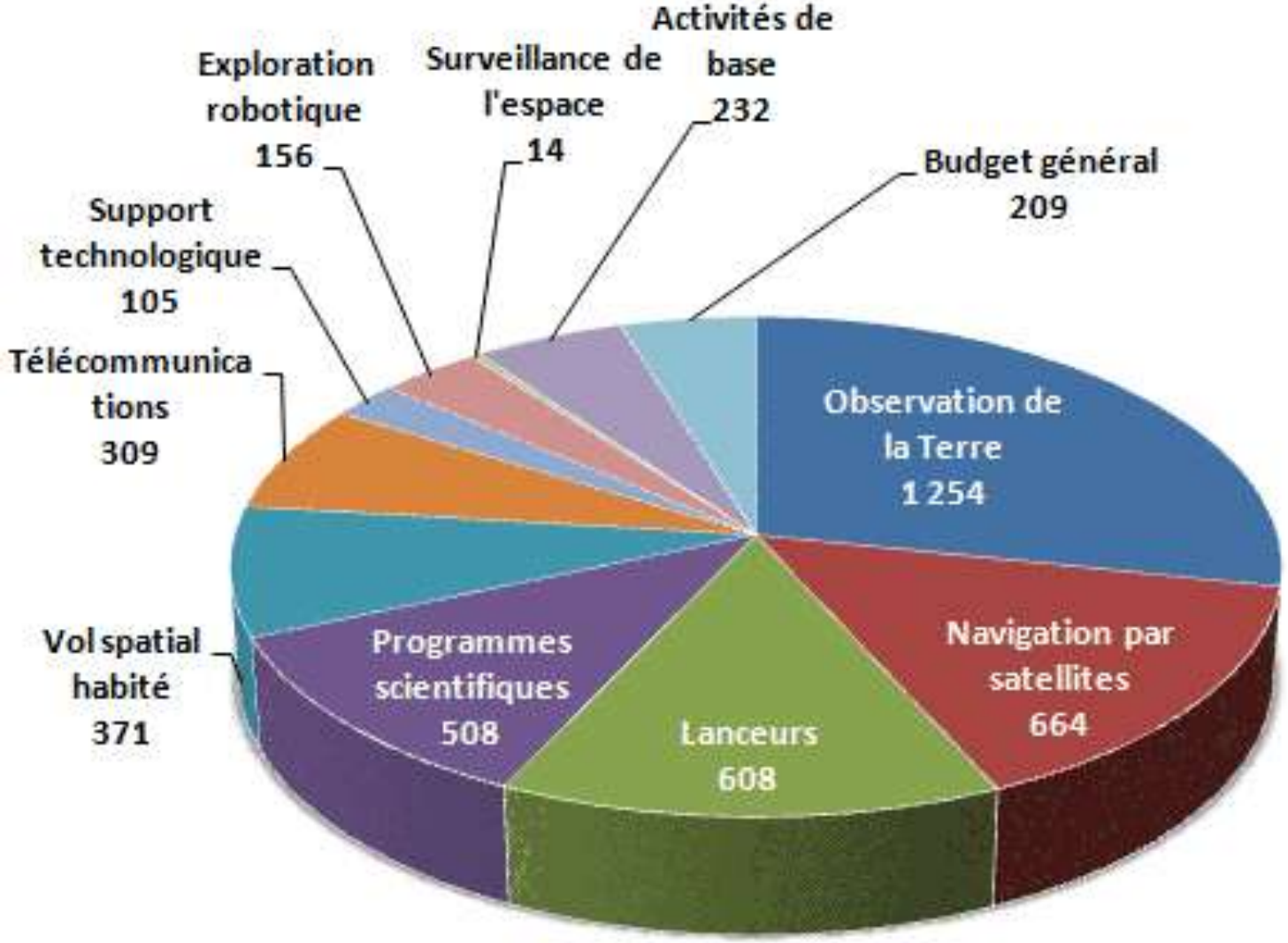
ESA past, present and future Space Science Program

Roger-Maurice Bonnet
International Space Science Institute
Bern

APSCO-ISSI-BJ Summer School 18/10/16

ESA Programs and respective Budgets (Billions €)



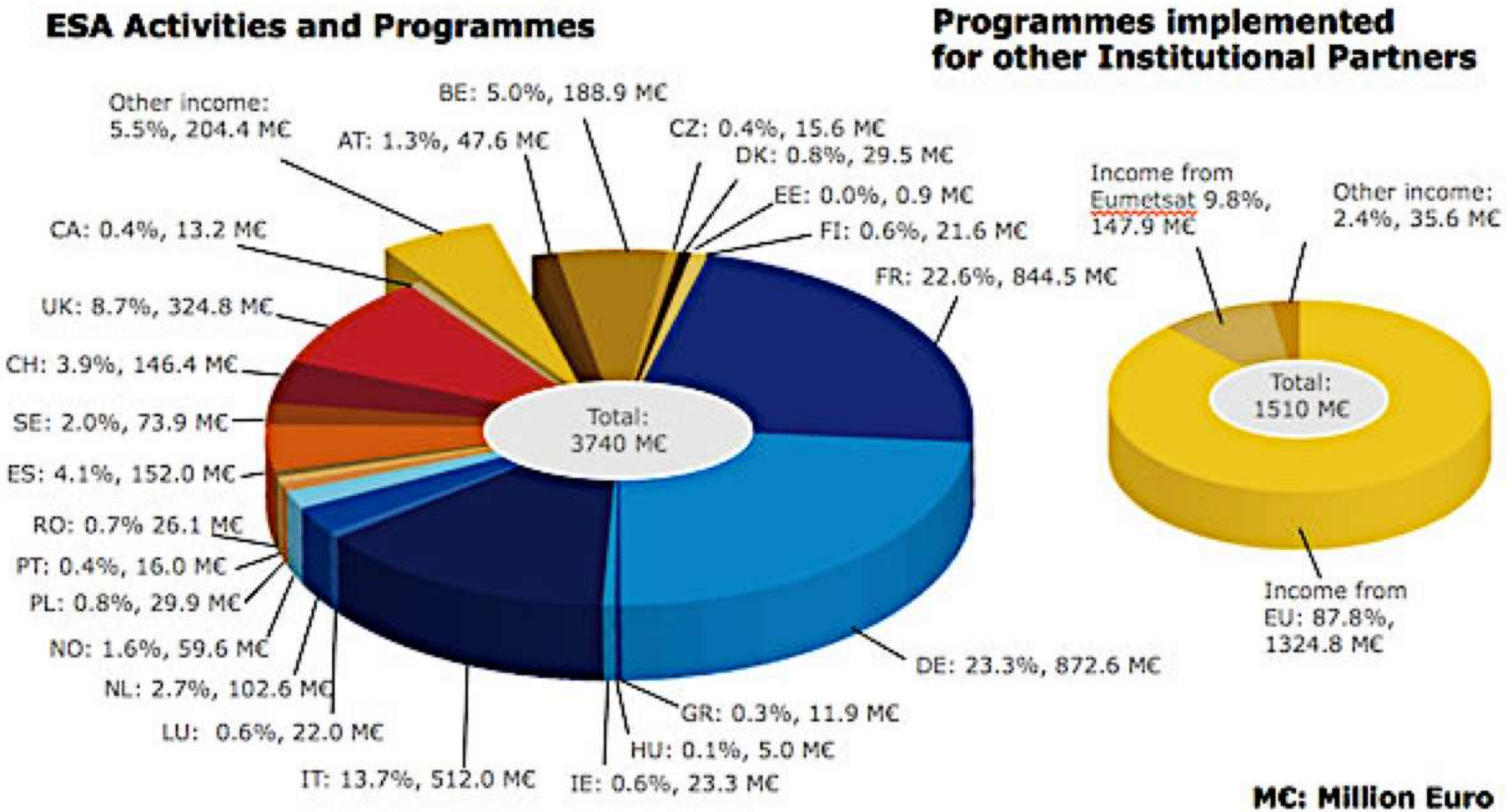
What is space science at ESA?

A Mandatory Program that all Member States contribute to in proportion of their respective GNP and composed of:

- Astronomy and Fundamental Physics,
- Planetary and solar System robotic exploration
- Solar Physics

Earth Sciences not part of mandatory activities

ESA Budget for 2016



TOTAL ESA BUDGET FOR 2016: 5250 M€

In Space Sciences, Europe is number 2!
Why not number 1?

- Not enough overall resources devoted to space!
- Too much political/industrial interest in the Member states!
- The vicious effect of “shared competences” between all the partners

Fundaments of ESA/ESRO

- An organization dedicated to scientific research, essentially controlled by the scientific community in the definition of the program and following the fundamental principle of a Bottom-up approach;
- All scientific work - planning of experiments, design and construction of instruments, results interpretation, remain the responsibility of research groups in the Member States, and not within ESRO laboratories.
- Importance of national programs in the parallel development of each nation's technical and scientific expertise;

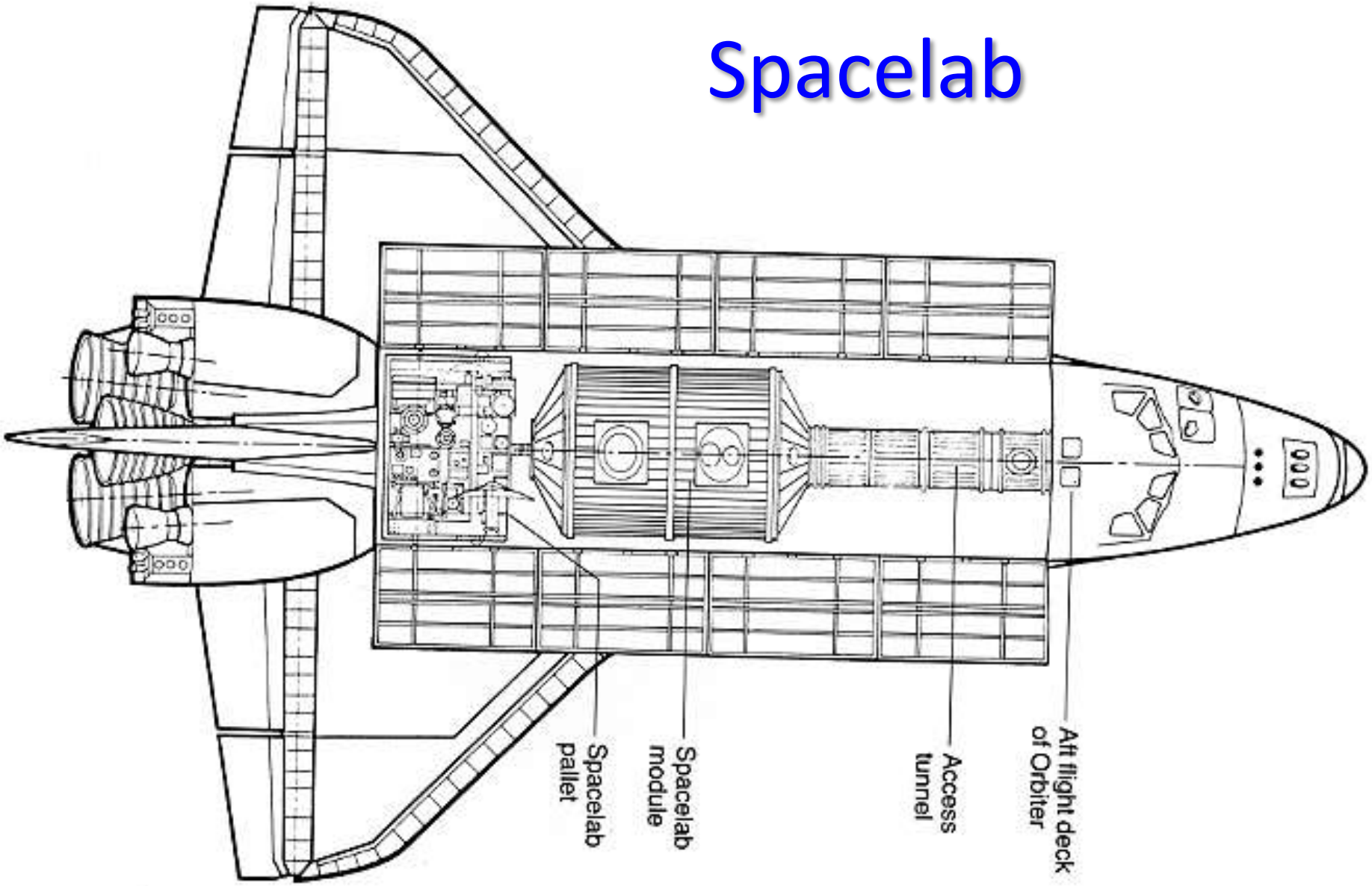
The Early Unrealistic ambitions 1964-1972

- Foresaw the firing of some 435 sounding rockets and the launching of 17 satellites over the 8 years covered by the ESRO Convention.
- Of these, at the end of that phase:
  - 168 sounding rockets had launched, as well as
  - Five small satellites, and 3-axis stabilized TD-1 medium-size satellites

Transition Phase
1964-1972

- The Launching Program Advisory Committee in 1970 rules out UV astronomy, Solar Physics, Planetary science considered to be too expensive.
- Cooperation with NASA (and USSR) was the only option for scientists interested in these disciplines.

Spacelab


Spacelab pallet
Spacelab module
Access tunnel
Aft flight deck of Orbiter

Status of ESA science program in1975

- GEOS, HEOS-A, COSB, EXOSAT, in development illustrating the ambitions and capabilities of Europe in **magnetospheric and heliospheric physics, and high energy astronomy**
- Spacelab utilization generated studies on infrared astronomy (LIRST) and Solar Physics (GRIST) enabling European astronomers to deepen their expertise in these two scientific fields
- Under consideration: **participation in the Large Space Telescope (HST) and the Out-of-Ecliptic mission (ISPM)**

Characteristics of ESA Science Program in 1975

- **A modest science program** (excluding Earth sciences and microgravity) made of medium-class missions;
- **A rapidly growing dependence upon NASA**;
- **An increasing set of substantial national programs** (some of them in cooperation with NASA and USSR), especially in the fields of Solar Physics (OSOs), Heliospheric physics (HELIOS), Plasma and magnetospheric physics (AMPTE), infrared and high-energy astronomy.
- **A budget capped at 76 MAU in 1978 price levels**

1973-1983
Europe dependence upon NASA

- ESRO/ESA missions even though predominantly European were dependent of the US to launch
- ESA science program adopted the line of an Increased cooperation with NASA:
  - Space Shuttle and Spacelab
  - Large Space Telescope (ST, Hubble)
  - OOE mission (ISPM, Ulysses)
- The ISPM (Ulysses) crisis was a waking-up call for a new approach of ESA's space science policy

The Ulysses Crisis

Europe,
from dependent became leader!

From Dependence to Autonomy!

- Only in 1980, with the successful development of the Ariane rocket entirely under European control, could ESA consider becoming autonomous for launching its satellites

Ariane 1
24/12/1979

Independence and international cooperation

Ariane 1
04/07/1985

The Giotto satellite made the first image of a comet's nucleus (Halley) at the short distance of 600km on 13 March 1986

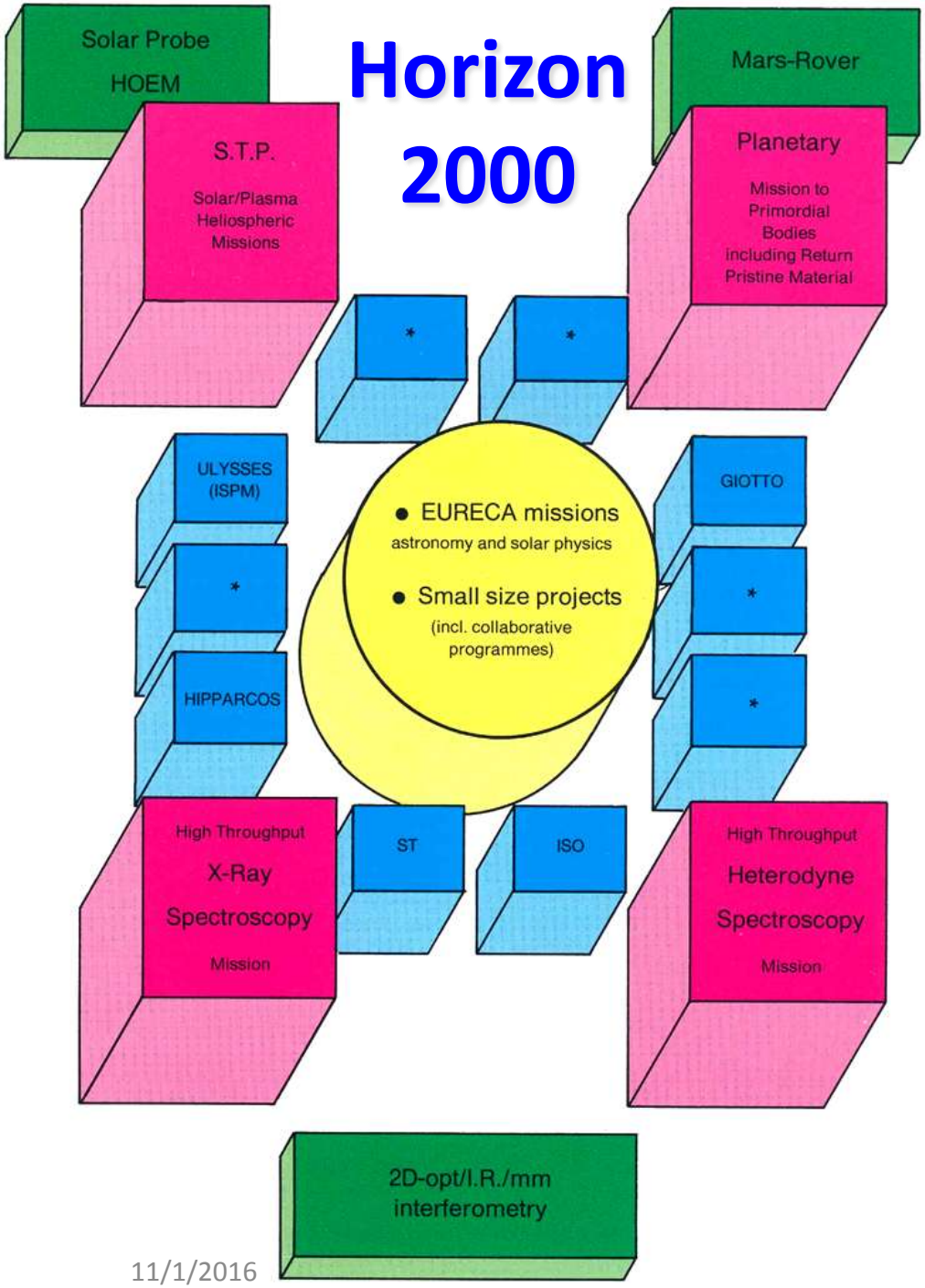
The revolutionary step

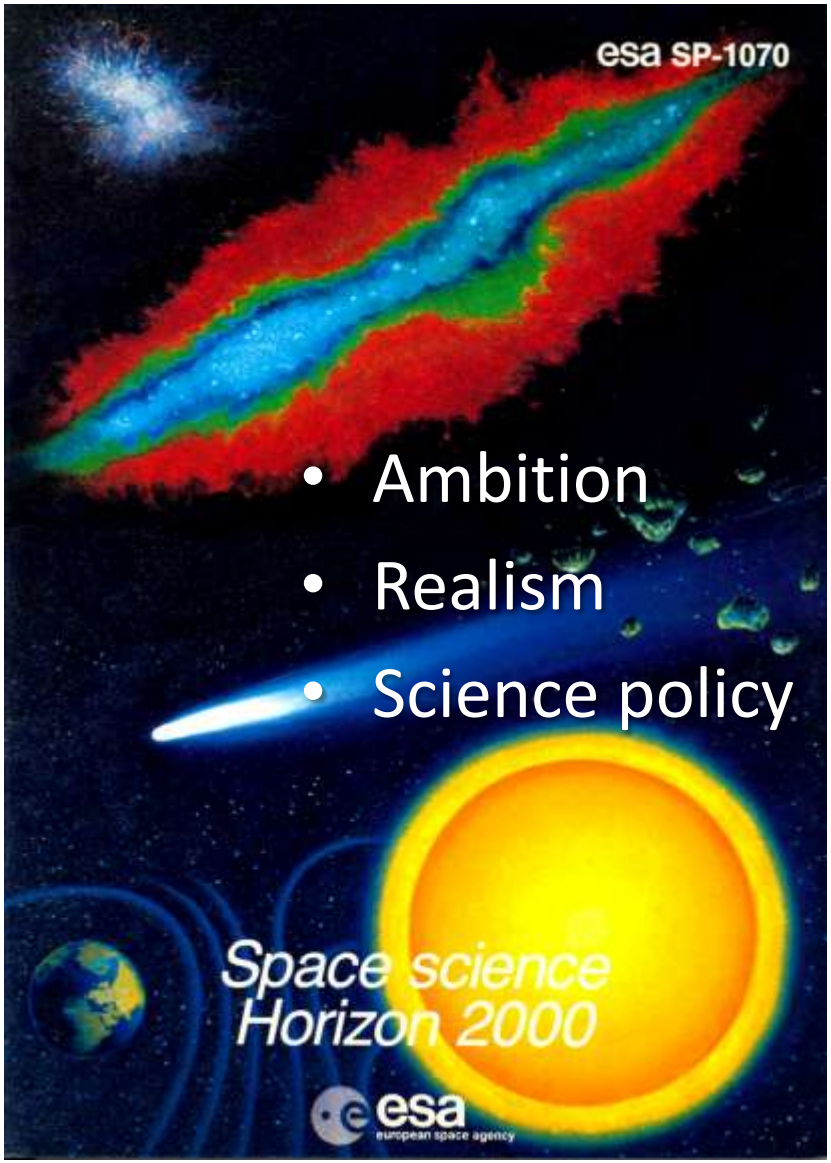
H2000 Survey Committee meeting Venice June 1984

Horizon 2000

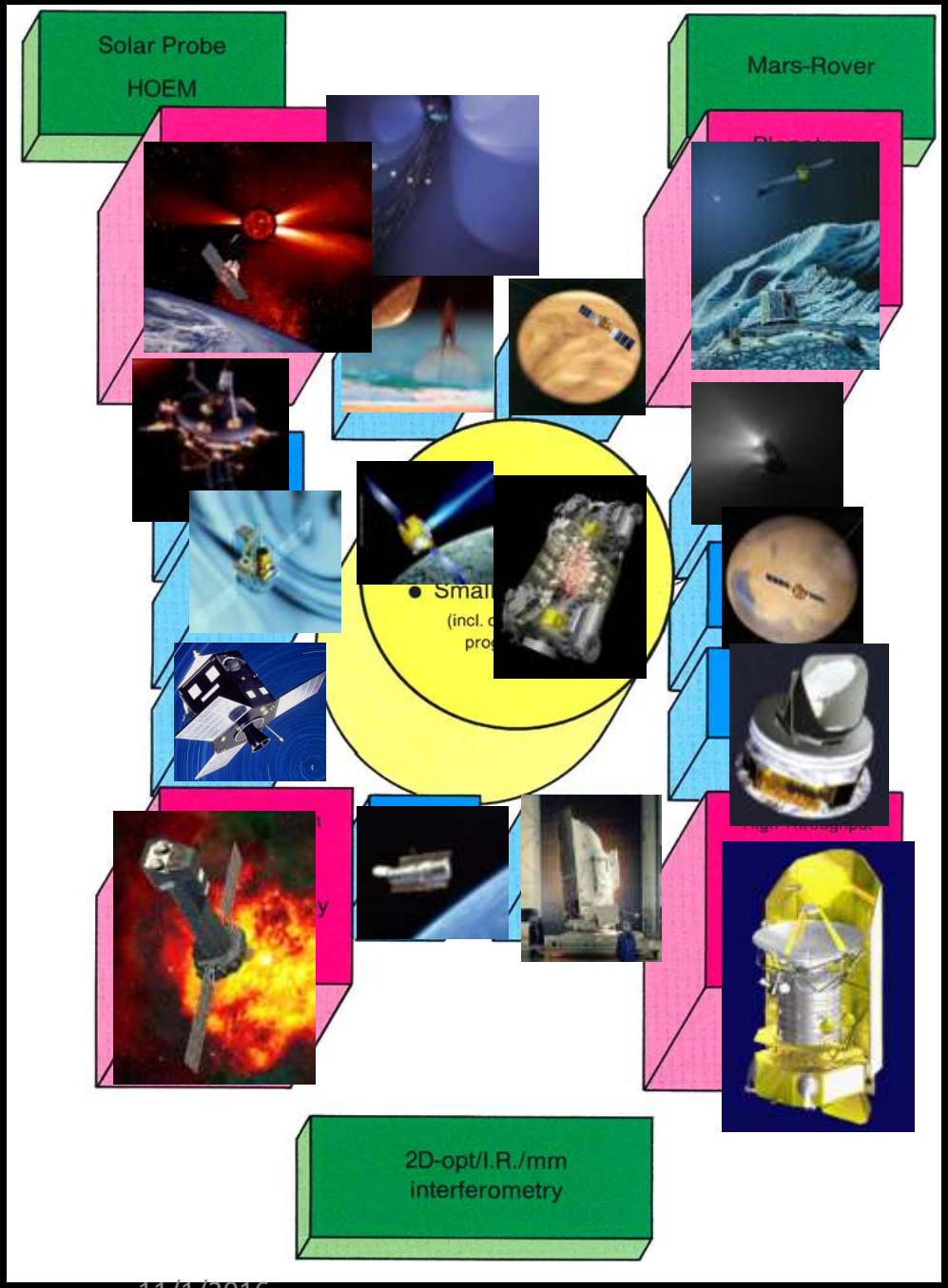
- A European program in space science for 20 years
- Established from a consultation of more than 3000 scientists in all Member states and outside
- Independent, but opened to International Cooperation, with other agencies thereby increasing the basic scientific capabilities of the missions
- Cooperation between ESA and its Member states at the level of scientific payloads, but **MORAL agreement** that H 2000 had priority above national projects

Horizon 2000





Venice June 1984

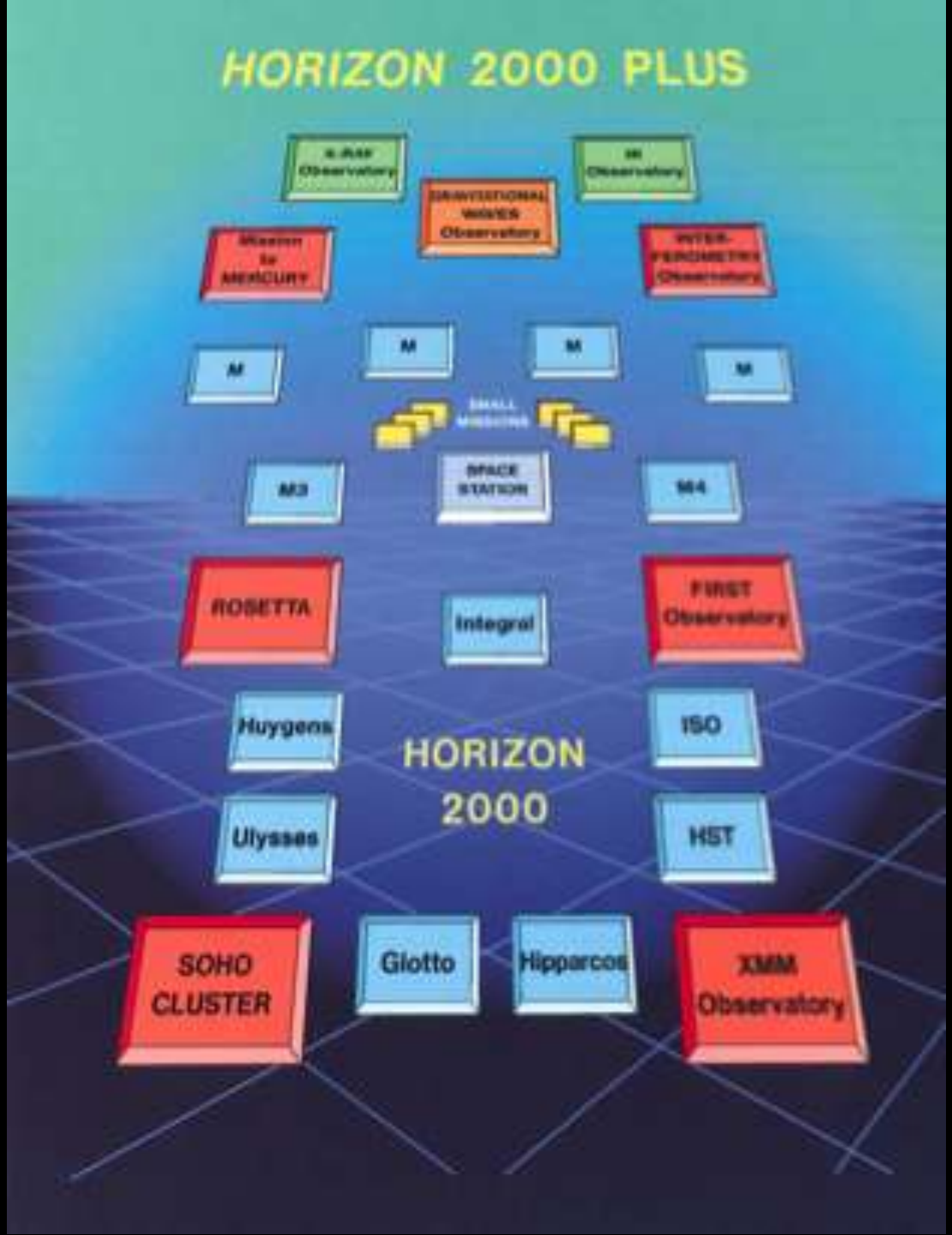


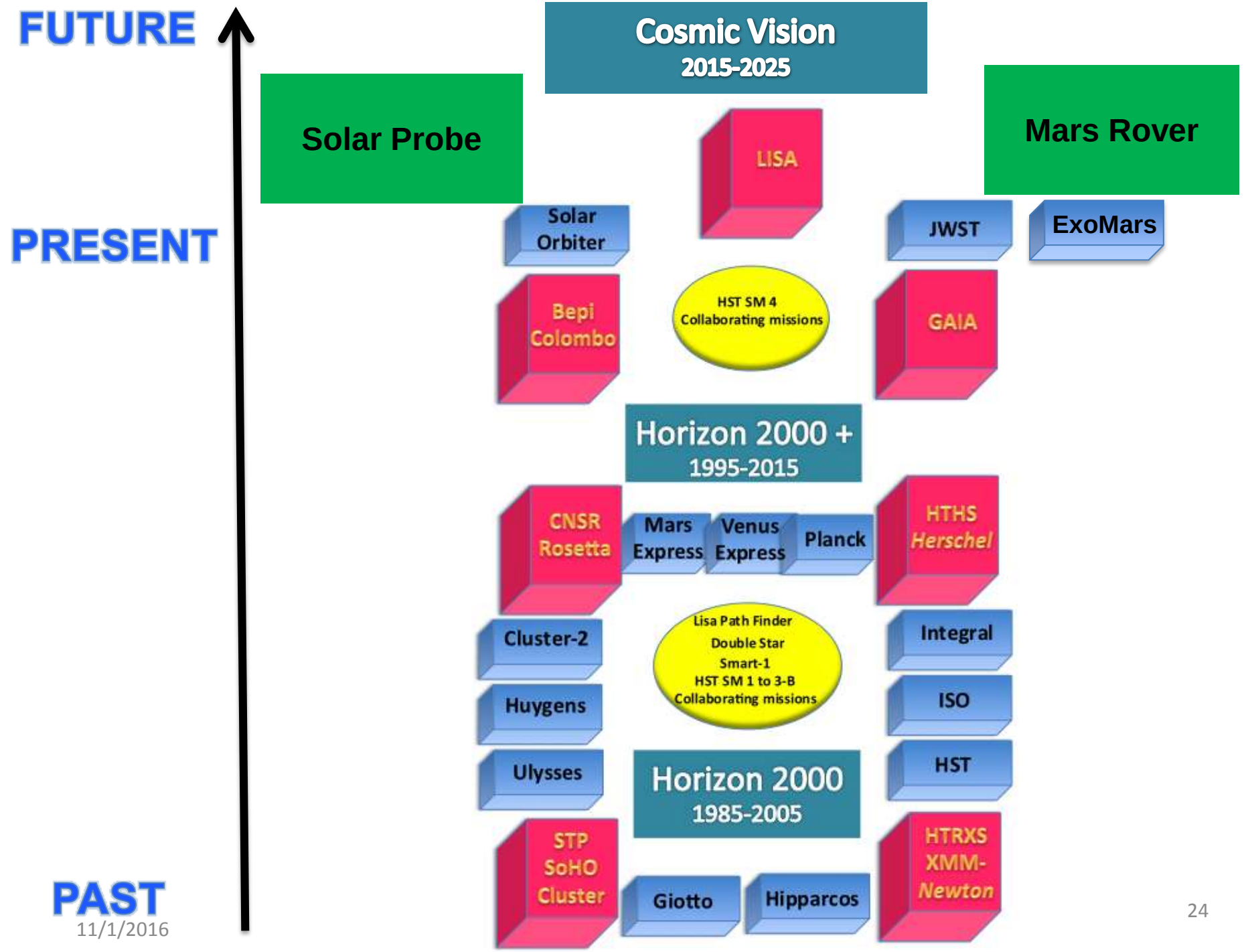
Horizon 2000
1985-2009

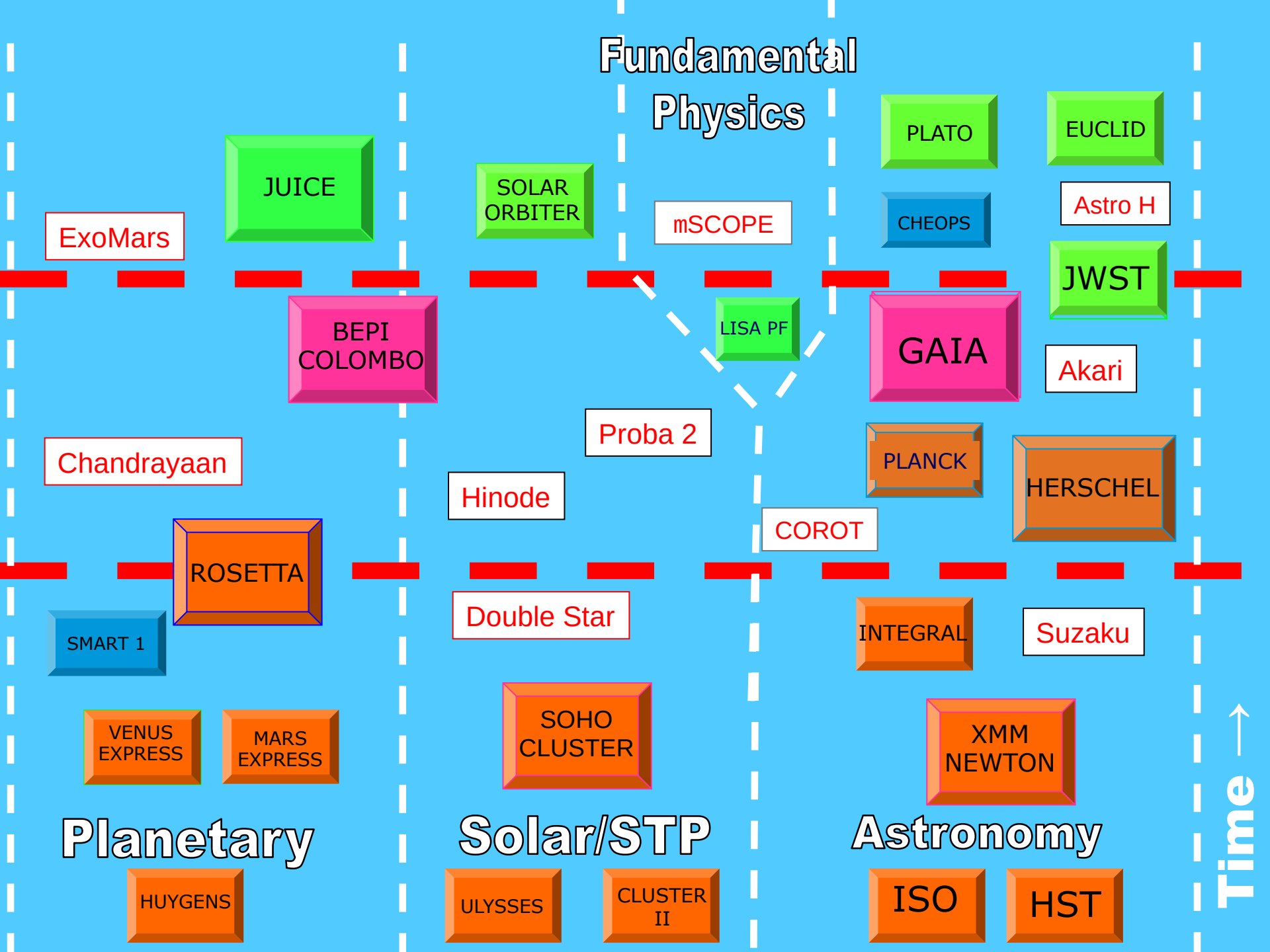
- Four cornerstones launched, in orbit and operational
- Nineteen medium size satellites launched
- Two small missions lanched SMART-1 and SMART-2 renamed LISA Pathfinder (2015)
- Despite of two major and one moderate accidents (propulsion problems)

- Strict policy of design to cost!
- Became a model for Earth sciences at ESA

Ariane 501 04/06/96


HORIZON 2000 PLUS
Observatory
Observatory
Observatory
Observatory
MERCURY
M
M
M
M
SMALL
SPACE
STATION
M3
M4
ROSETTA
Integral
FIRST
Observatory
Huygens
ISO
HORIZON
2000
Ulysses
HST
SOHO
CLUSTER
Giotto
Hipparcos
XMM
Observatory


FUTURE
PRESENT
PAST
Cosmic Vision
2015-2025
Solar Probe
Mars Rover
LISA
Solar Orbiter
JWST
ExoMars
Bepi Colombo
HST SM 4
Collaborating missions
GAIA
Horizon 2000 +
1995-2015
CNSR Rosetta
Mars Express
Venus Express
Planck
HTHS Herschel
Cluster-2
Lisa Path Finder
Double Star
Smart-1
HST SM 1 to 3-B
Collaborating missions
Integral
Huygens
ISO
Ulysses
Horizon 2000
1985-2005
HST
STP SoHO Cluster
Giotto
Hipparcos
HTRXS XMM-Newton

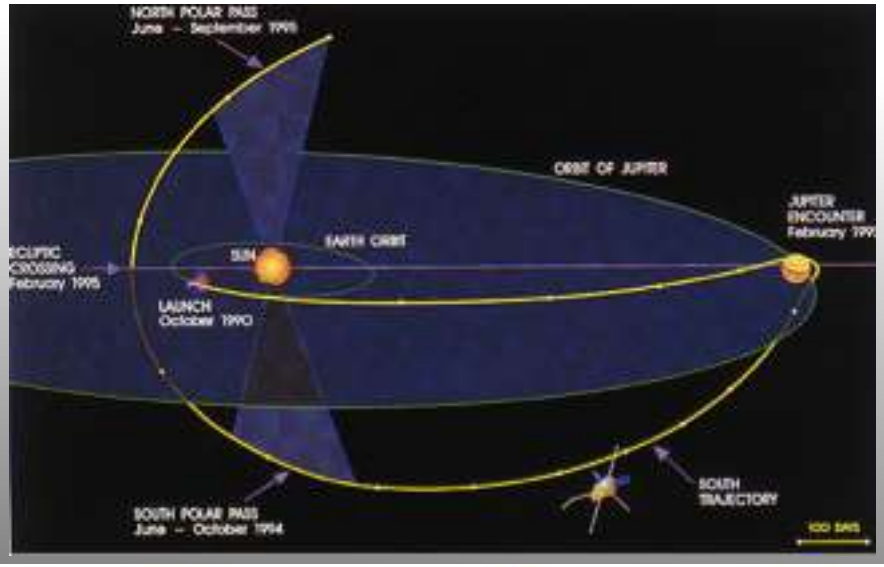

Fundamental Physics
JUICE
SOLAR ORBITER
PLATO
EUCLID
ExoMars
mSCOPE
CHEOPS
Astro H
JWST
BEPI COLOMBO
LISA PF
GAIA
Akari
Proba 2
PLANCK
Chandrayaan
HERSCHEL
Hinode
COROT
ROSETTA
Double Star
SMART 1
INTEGRAL
Suzaku
SOHO CLUSTER
VENUS EXPRESS
MARS EXPRESS
XMM NEWTON
Planetary
Solar/STP
Astronomy
HUYGENS
ULYSSES
CLUSTER II
ISO
HST
Time

Domains of excellence of ESA Space Science

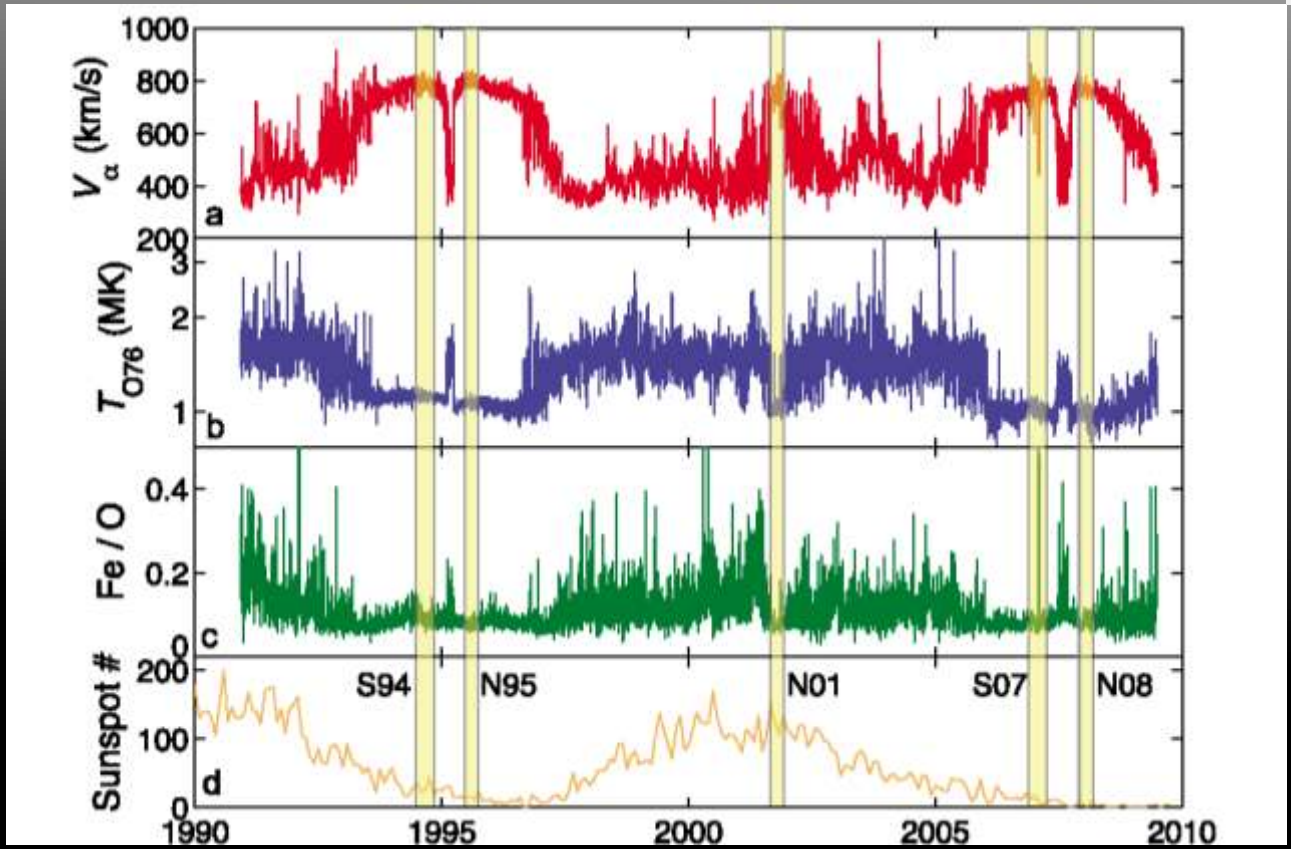
Solar Physics

- Ulysses
- SoHO
- Solar Orbiter

Solar Physics

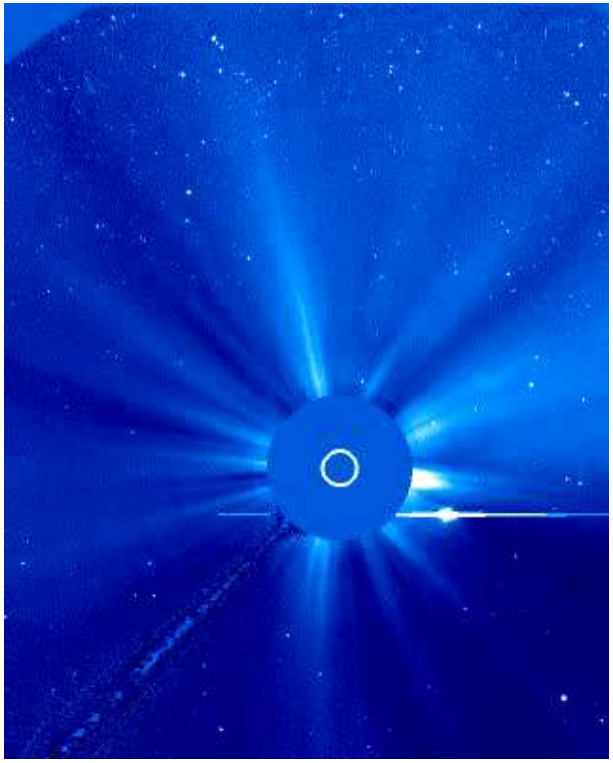


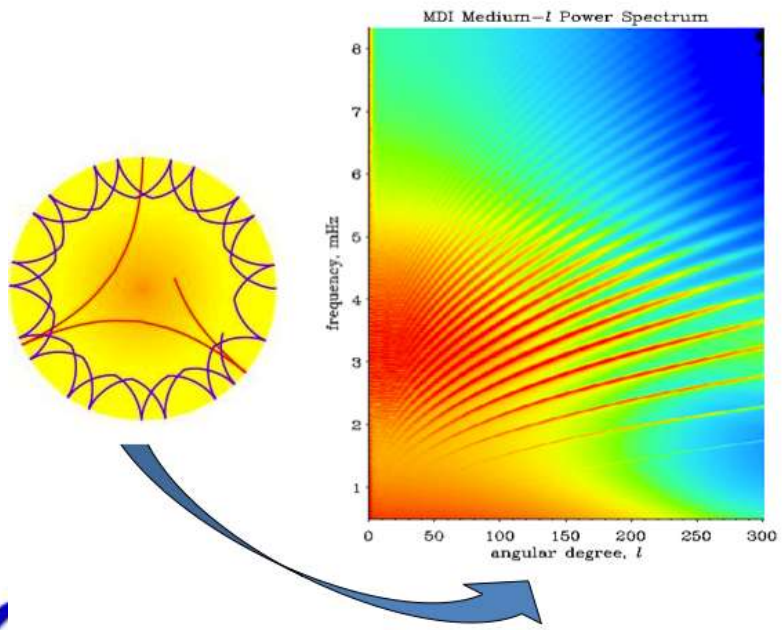
Unique view of the Sun's poles over 2 complete cycles

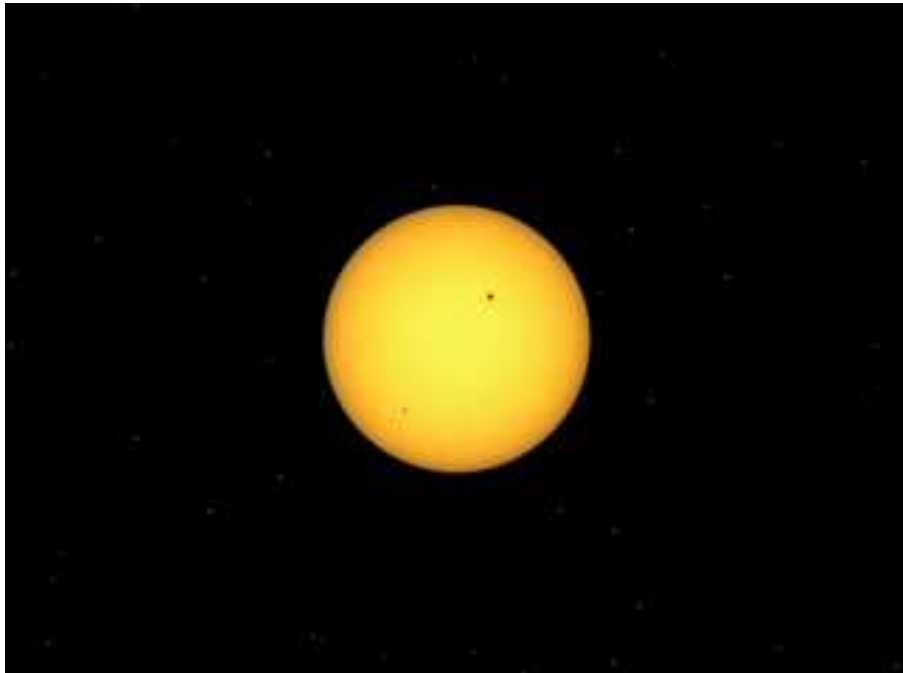


Credit: R. von Steiger, and T. Zurbuchen, 2011,

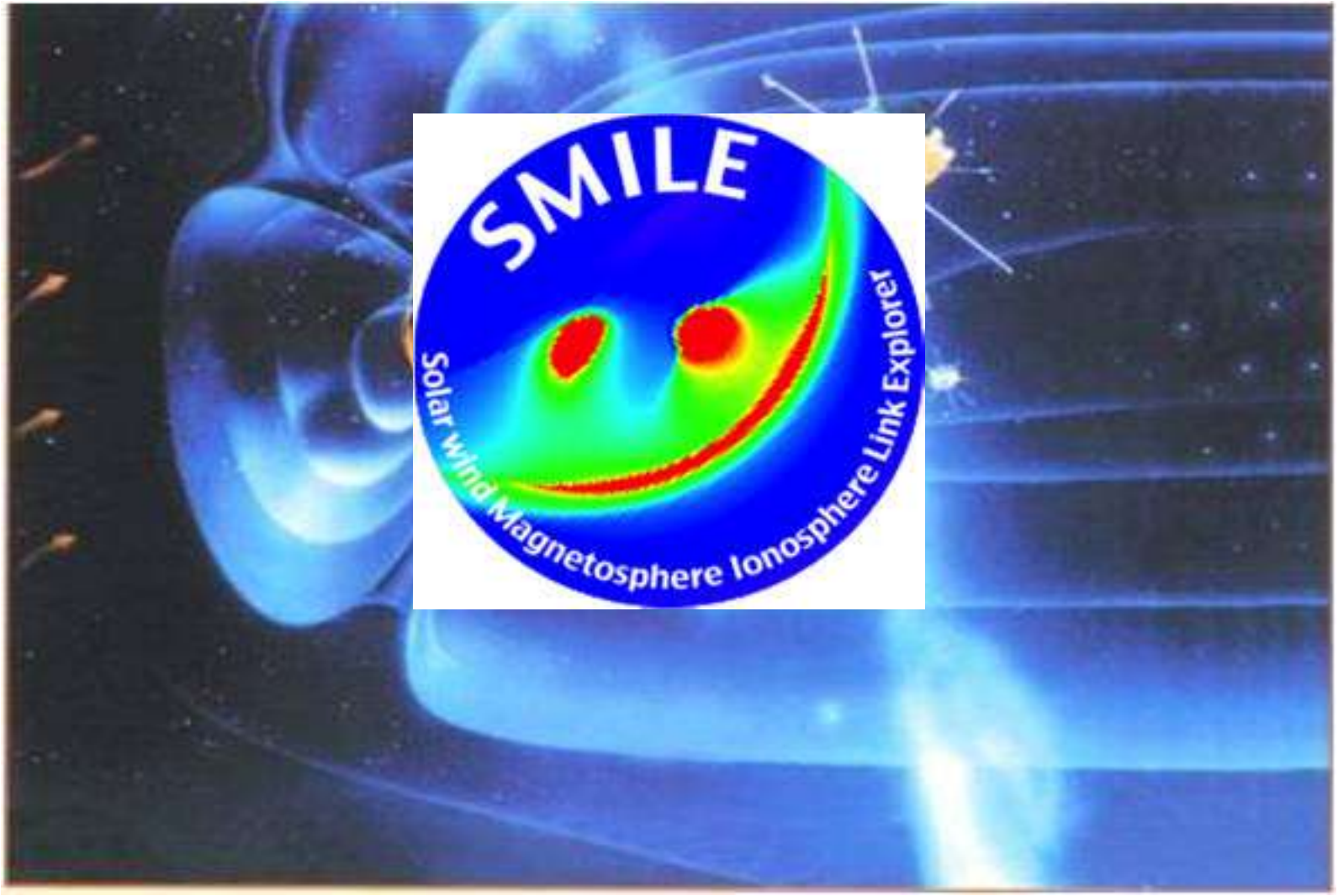

SOHO




MDI Medium−l Power Spectrum
frequency, mHz
angular degree, l
0
50
100
150
200
250
300
1
2
3
4
5
6
7
8



Plasma and Magnetospheric Research



Astronomy

- Visible and Near IR astronomy: Hubble Space Telescope
- Astrometry
- Far Infrared

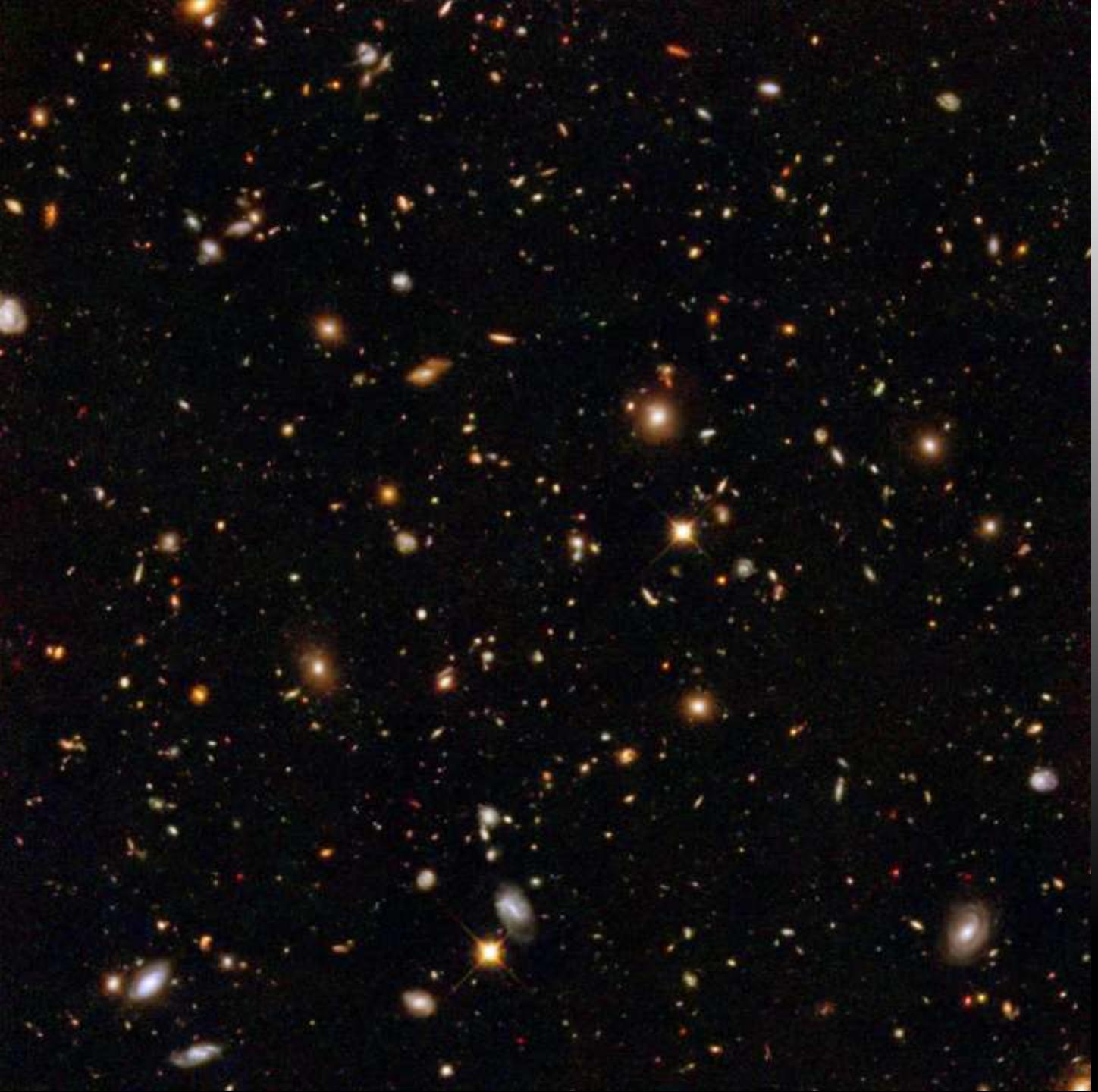
1990-2010:
Hubble 20 years in orbit

SM1: Dec. 2-13, 1993

Messier 100

Before SM-1

After SM-1

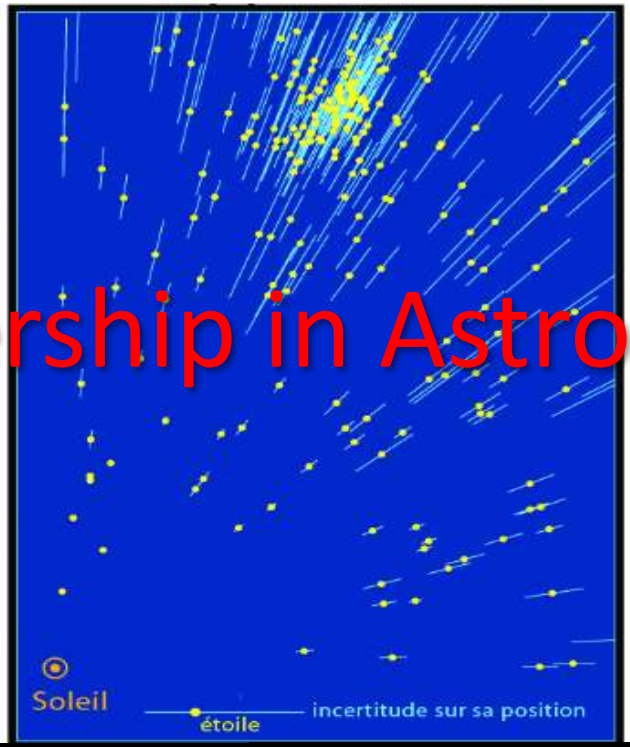


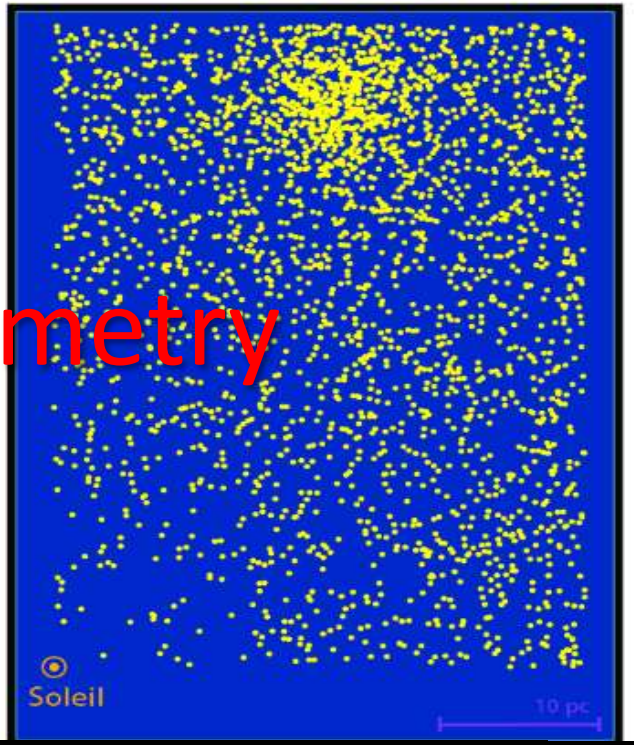
Hubble Space Telescope Ultra-Deep Field

Sol

Hipparcos (1990)

Gaia (2020)



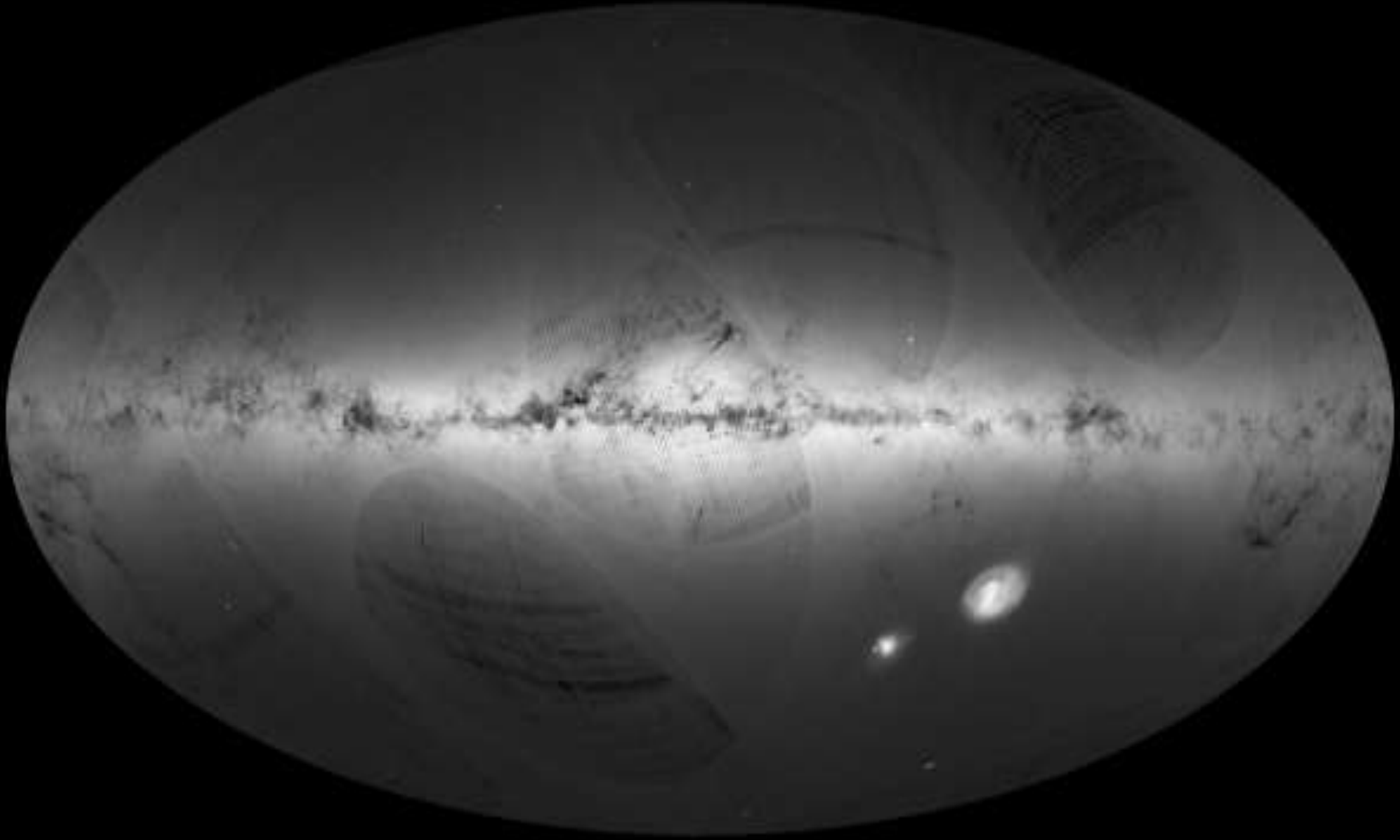


Leadership in Astrometry

HIPPARCOS
1989-1997

GAIA
DEC. 2013

GAIA



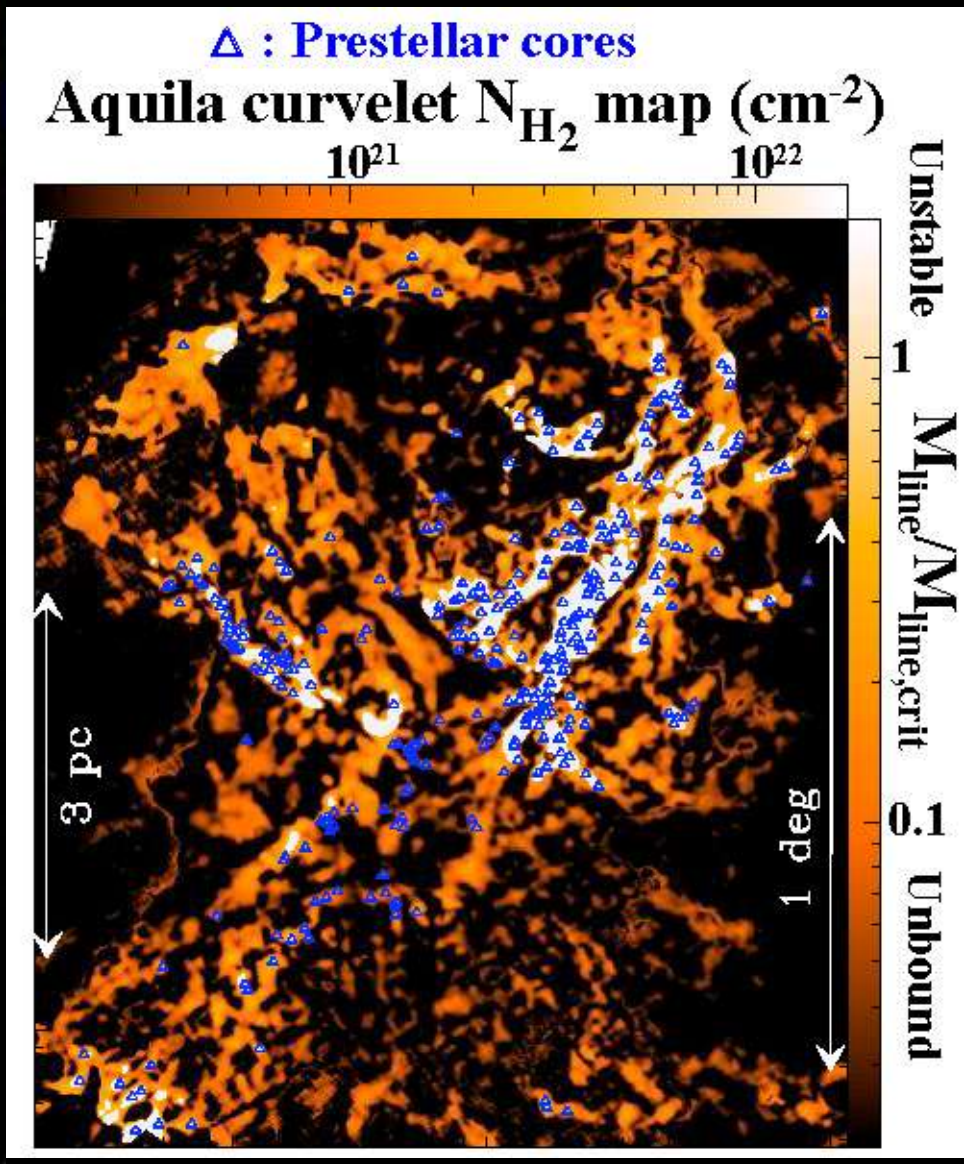
Far Infrared Astronomy
From ISO to Herschel

Herschel Results

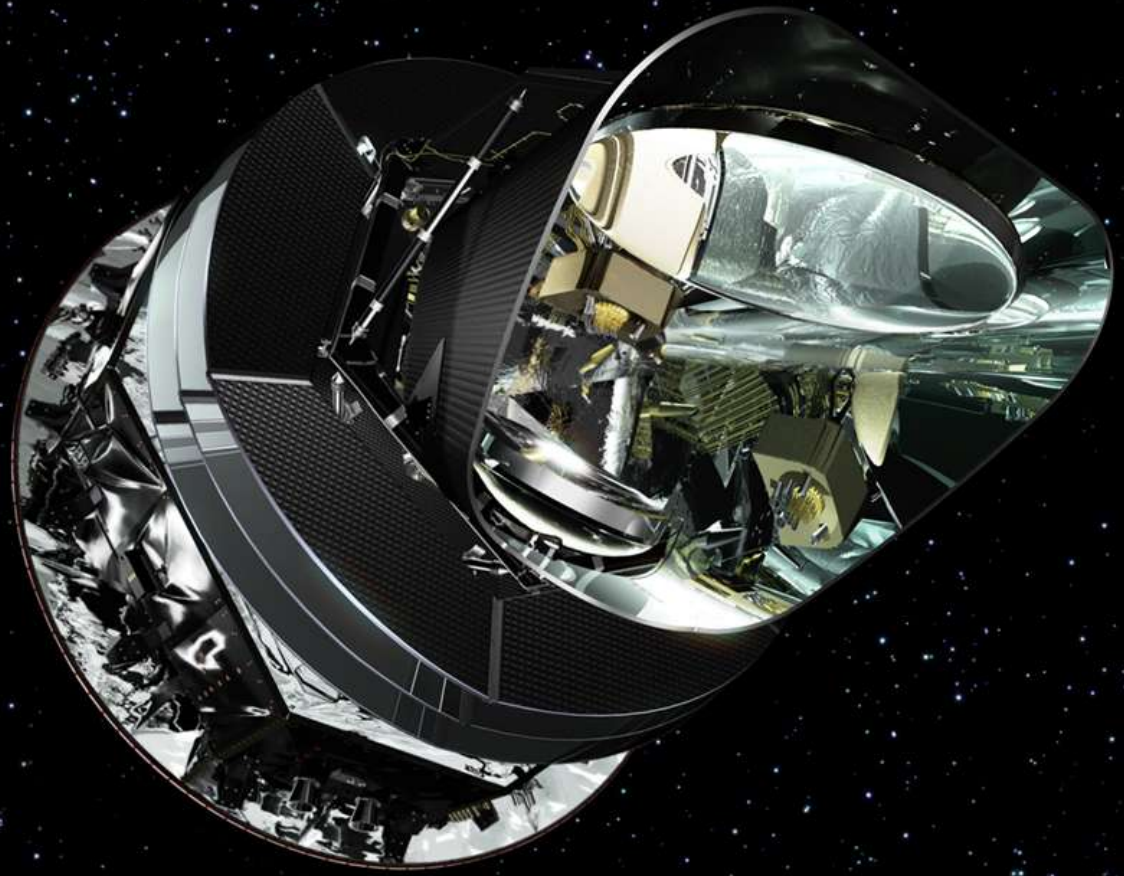
- Observations of ‘filaments’ in detail in relatively nearby molecular clouds revealing a two-stage scenario for the birth of stars like our own sun.
- Observations of infrared dominated galaxies and the resulting implications for galaxy evolution and the history of star formation across more than 90% of the age of the universe.
- Observations of water vapour and the associated ‘water trail’ from pre-stellar cores to planetary bodies, and the origin of the water on earth today.

Orion as seen by Herschel

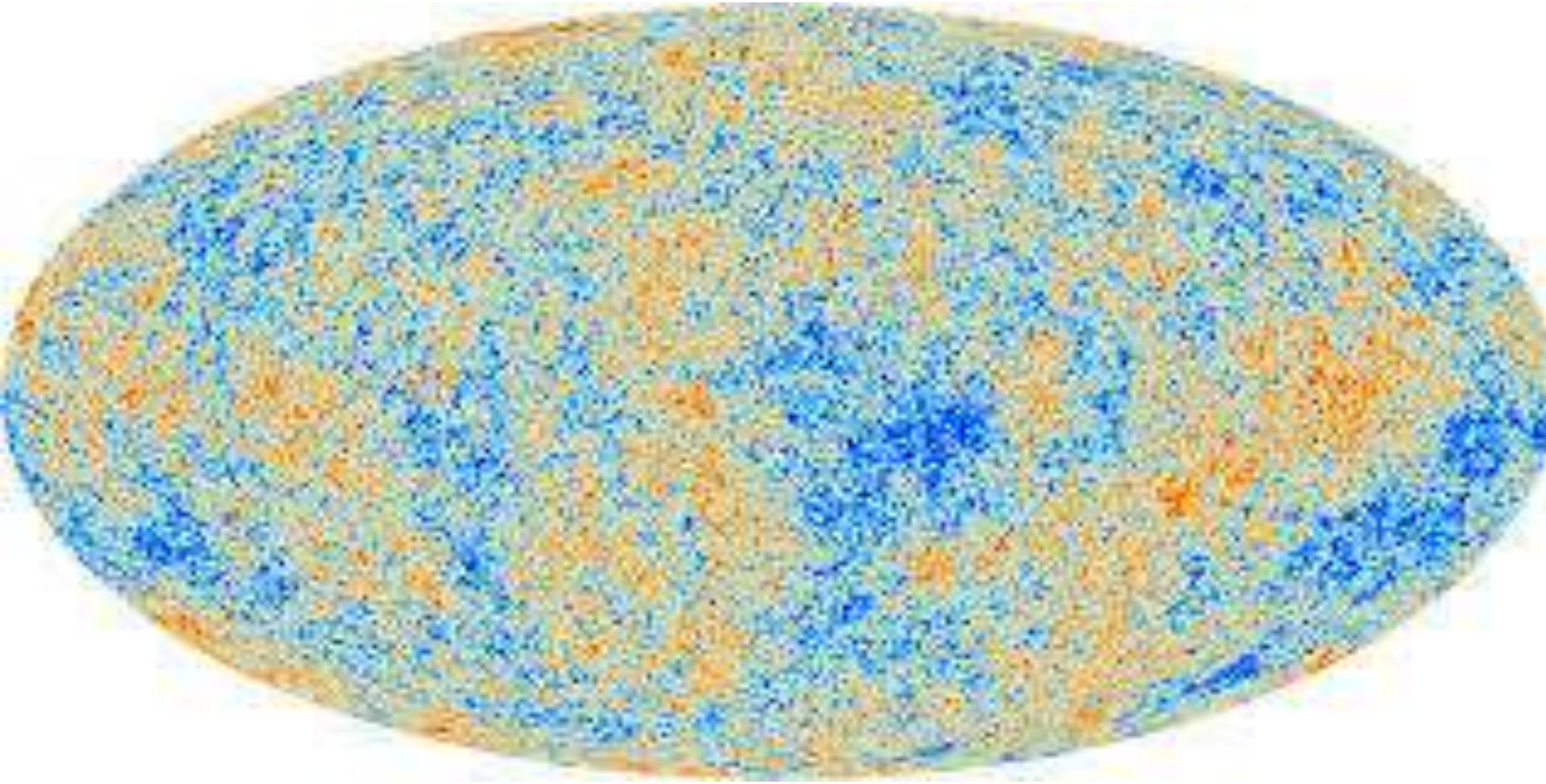
Filaments

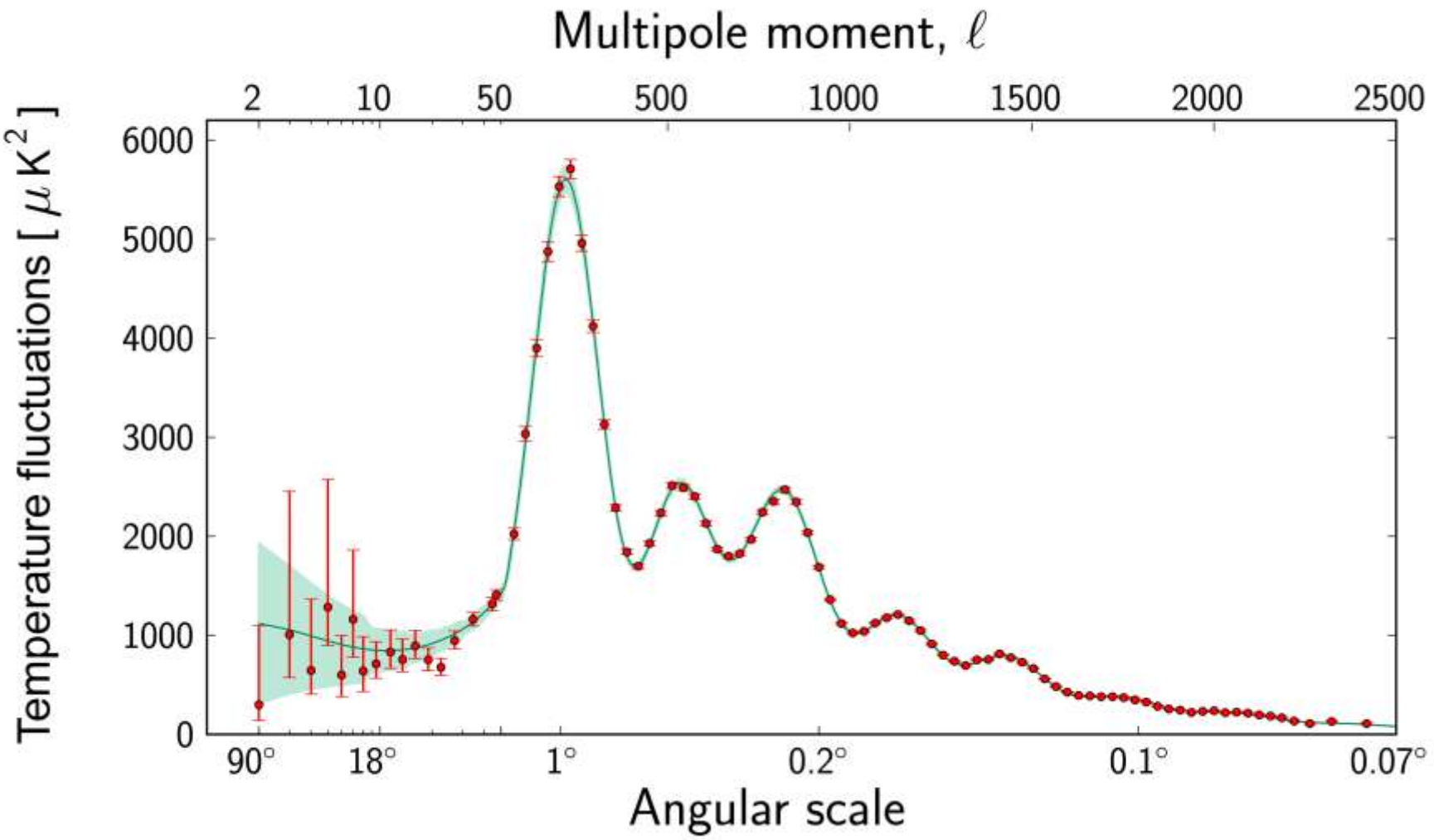

Δ : Prestellar cores
Aquila curvelet N_{H_2} map (cm^{-2})
10^{21}
10^{22}
3 pc
1 deg
Unstable
1
$M_{line}/M_{line,crit}$
0.1
Unbound

Planck



Planck observes the Universe at 300,000 years of age

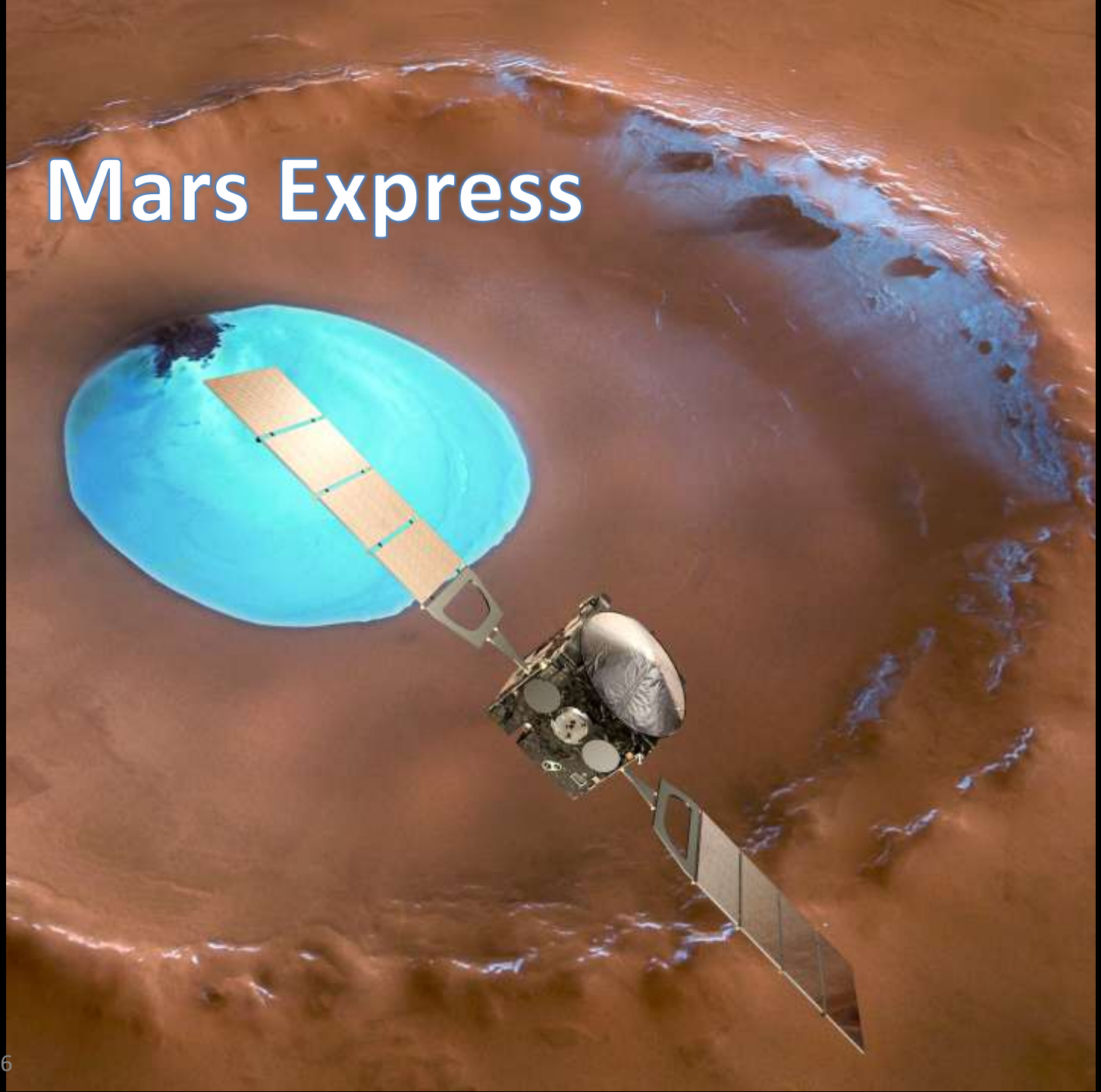



Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μ K^2]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale

Solar System Exploration

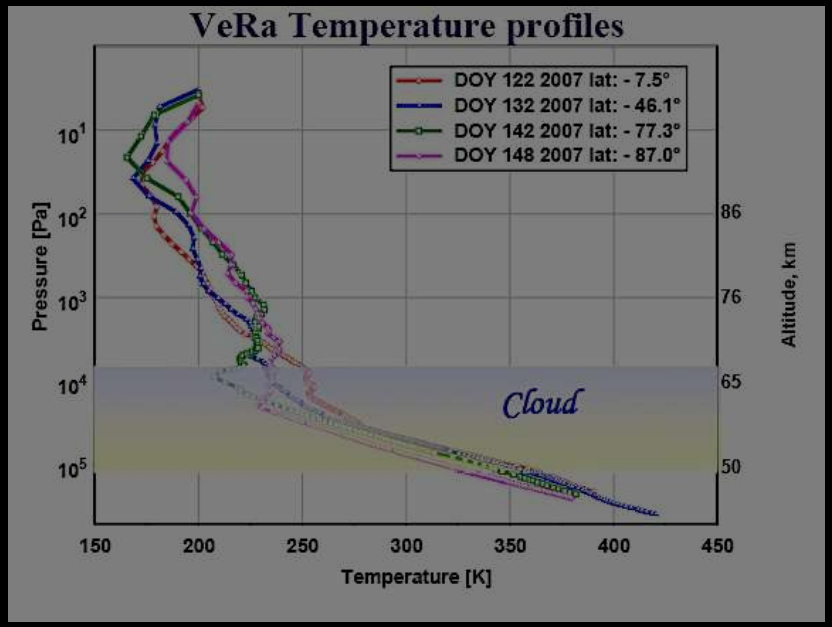
- Mars
- Venus
- Saturn and Titan
- The Moon
- Comets
- Mercury
- Jupiter

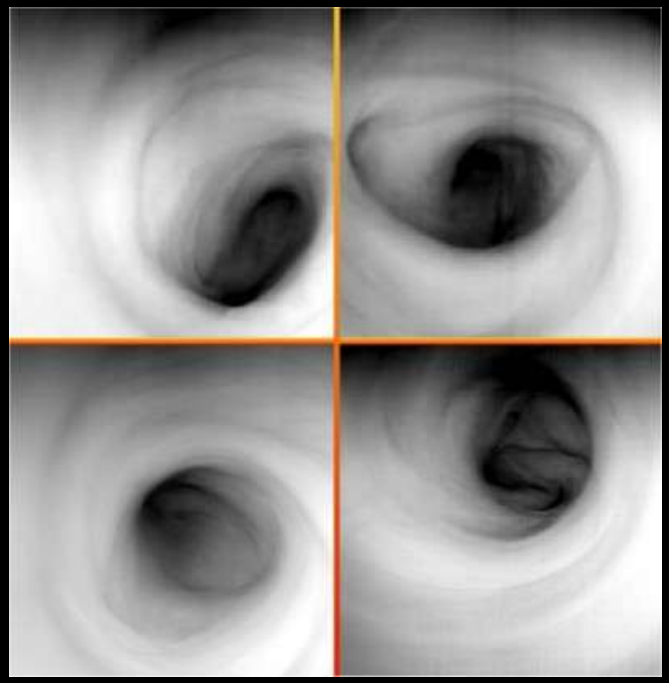
Mars Express



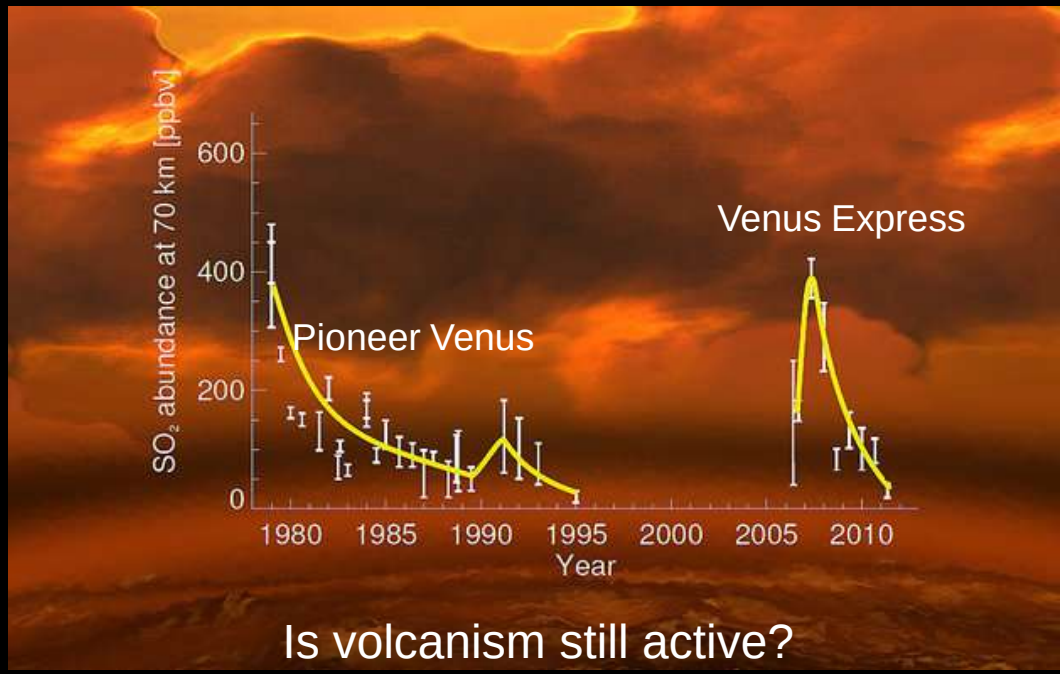
Mars Express:
Glacier on Mars

Venus science

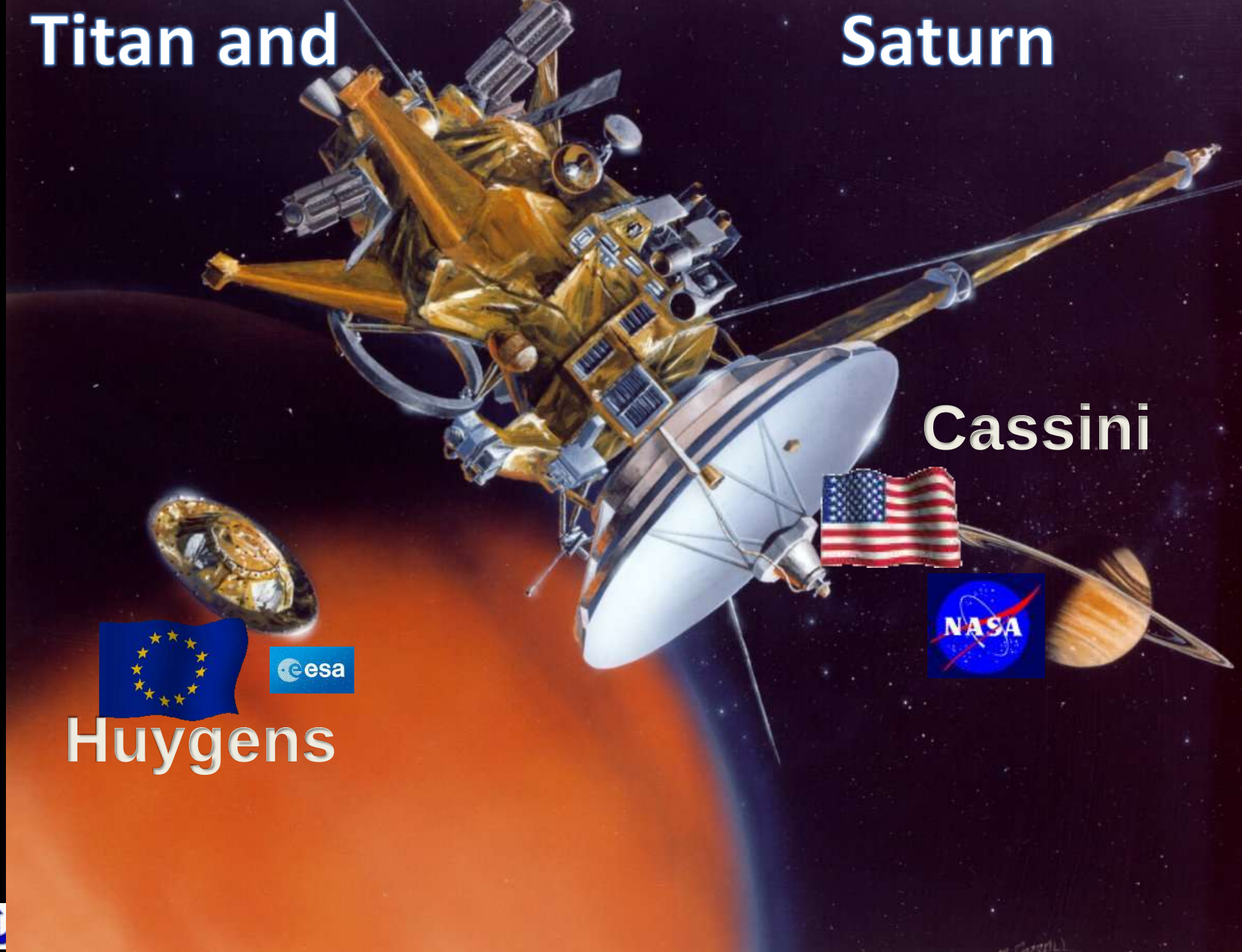




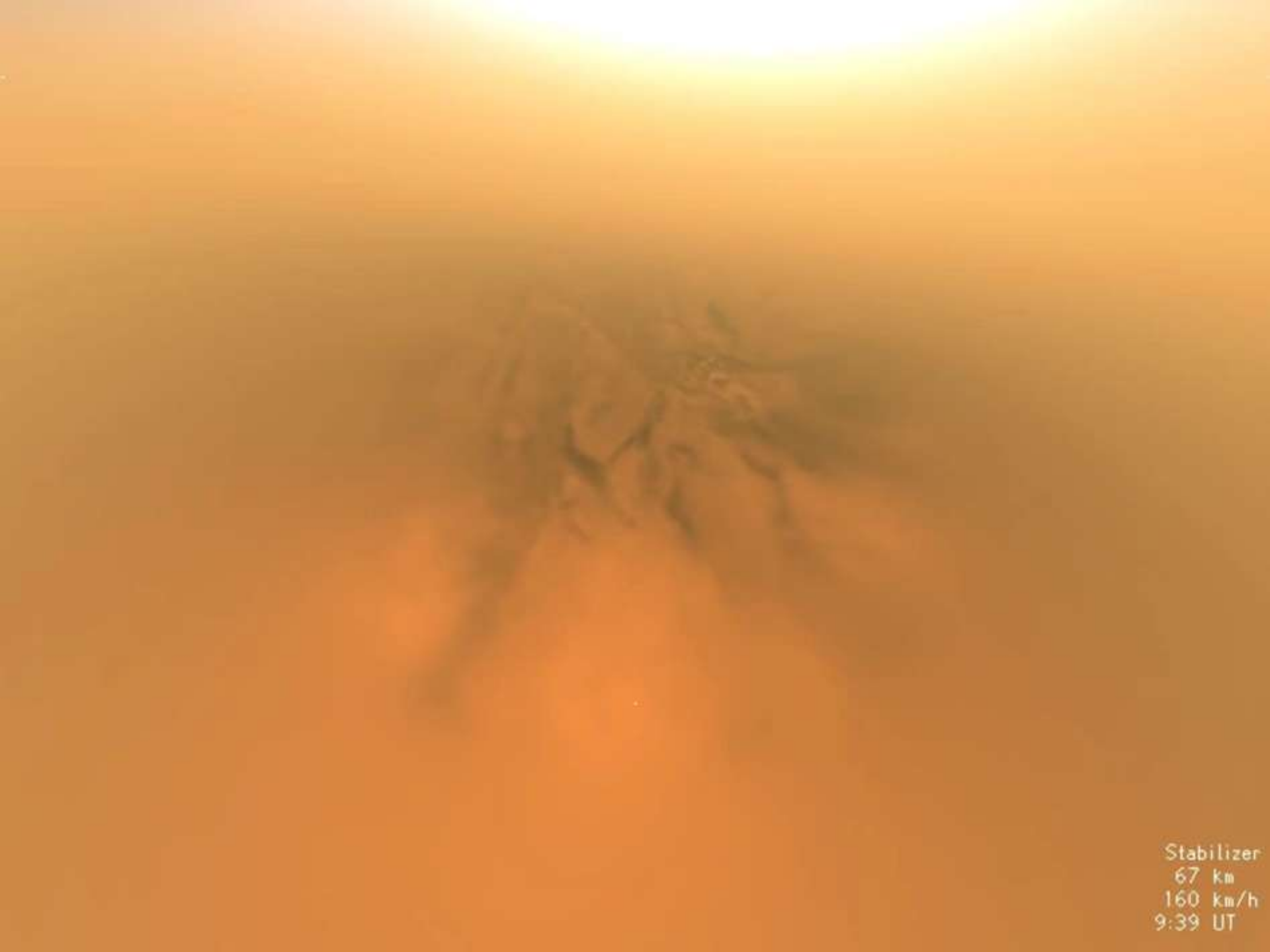
Venus South Pole strange vortex



Is volcanism still active?


Titan and
Saturn
Cassini
NASA
esa
Huygens

Most distant landing ever

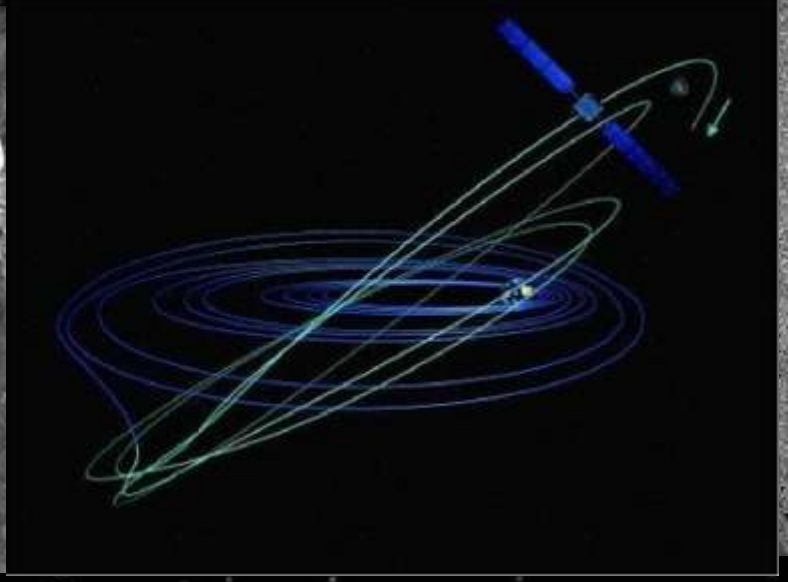

Stabilizer
67 km
160 km/h
9:39 UT

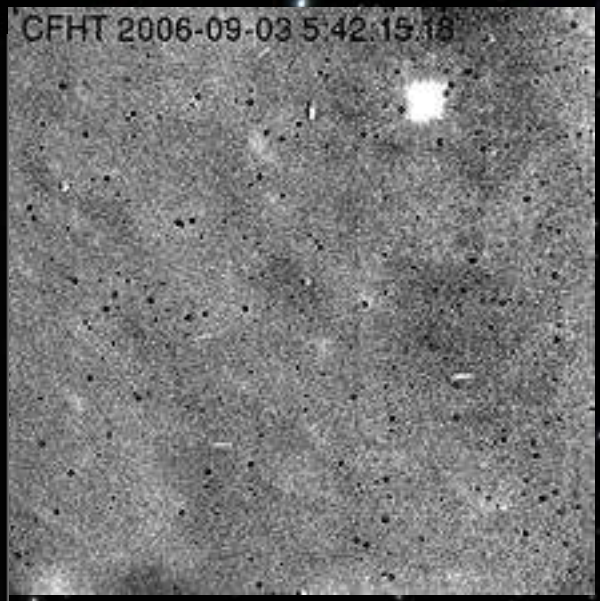
South West North East South

Most distant landing ever

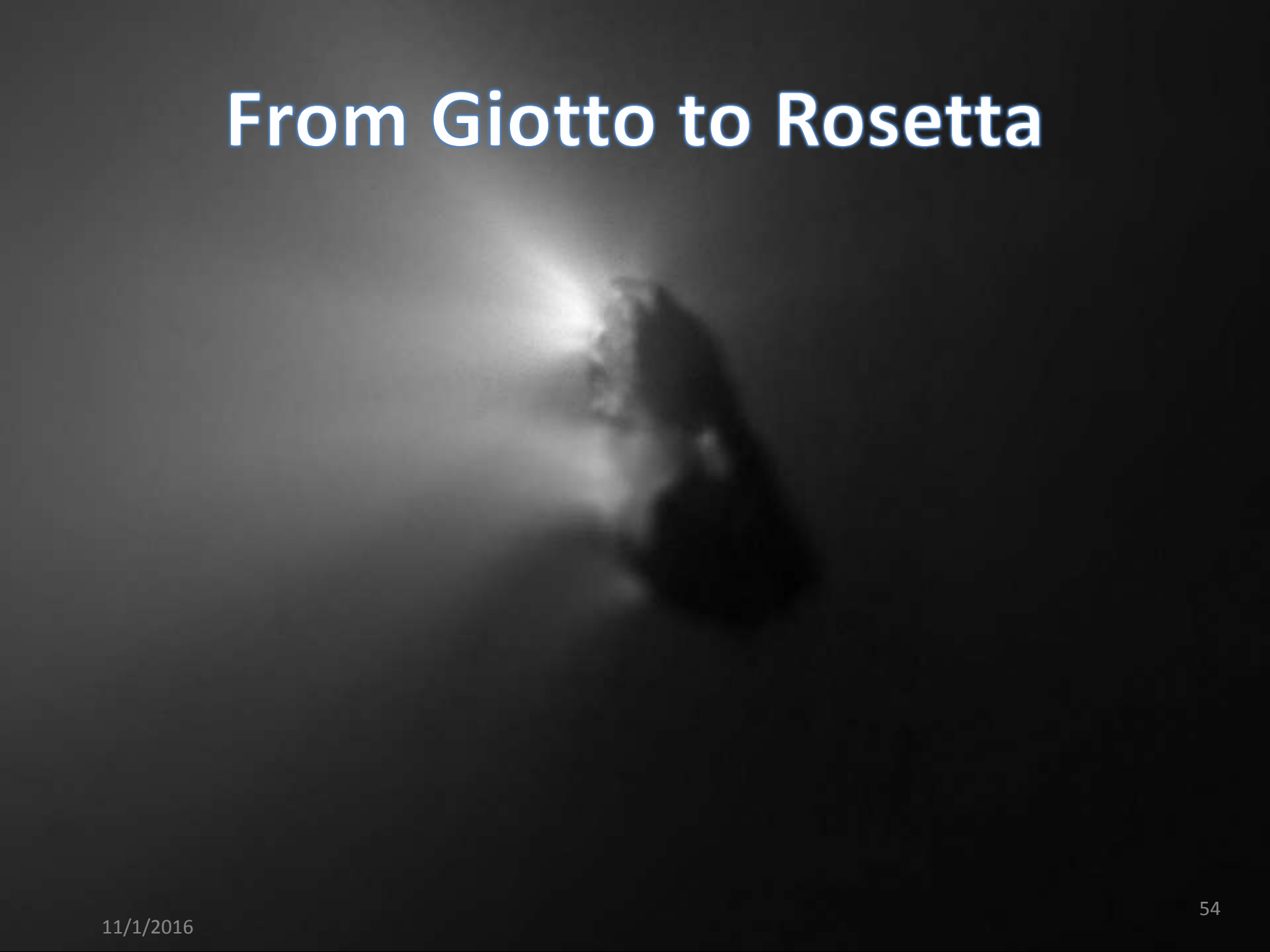
SMART-1


SMART-1 view of
Glushko crater
ESA / SPACE-X, Space Exploration Institute




CFHT 2006-09-03 5:42:15.18

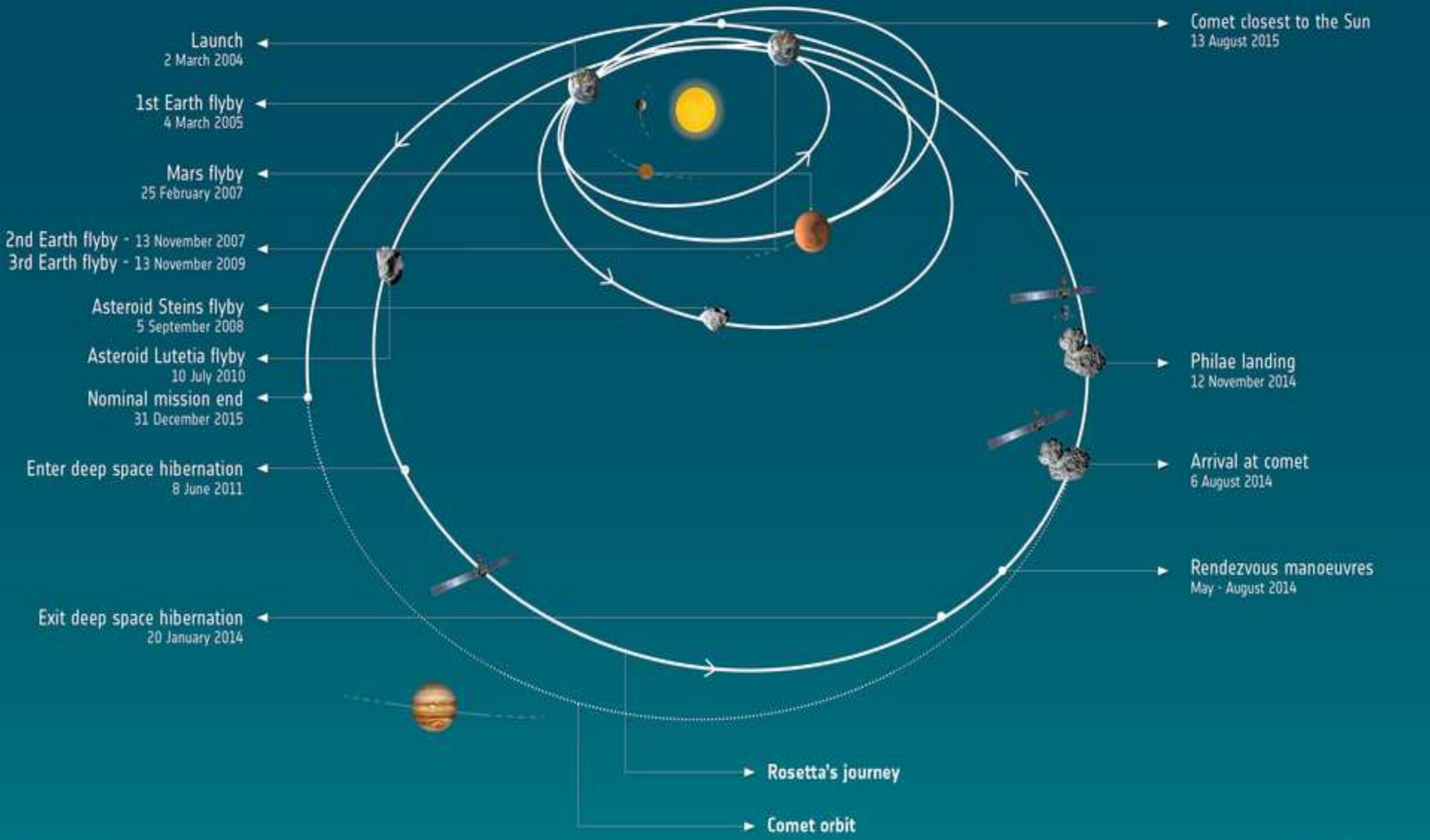
From Giotto to Rosetta



8 months journey through the Solar System

Giotto

A 12y journey through the Solar System



Rosetta's decade-long journey

After a ten-year journey, the European Space Agency's Rosetta spacecraft will arrive at its destination on Wednesday for an unprecedented mission to orbit a comet and dispatch a lander to the surface.

Rosetta orbiter
Carries 11 science experiments

After entering orbit with the **Comet 67P/Churyumov-Gerasimenko** in November, the spacecraft will release a small lander onto the comet's icy nucleus.

Philae lander
Carries 10 science instruments

KEY SPECS:
Launch date: **March 2, 2004**
Orbiter mass: **3,000 kg**
Lander mass: **100 kg**
Cost of mission: **1.3 billion EUR**
Mission lifetime: **Until Dec. 2015**

CLOSE ENCOUNTERS

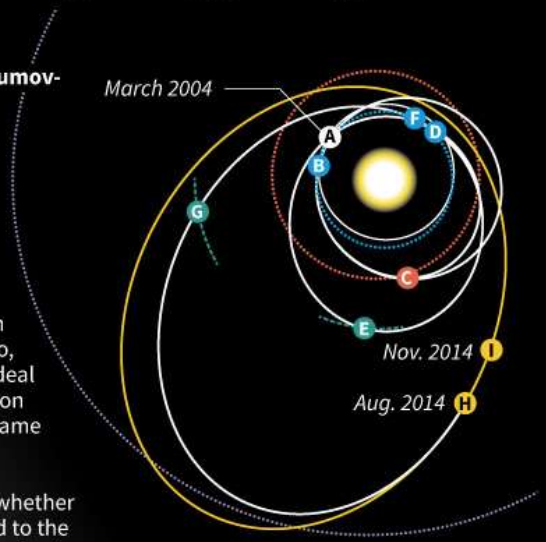
During its long journey, Rosetta had flybys with two asteroids: Steins, with its closest approach at 802.6 km in September 2008, and Lutetia, with its closest at 3,162 km in July 2010.

Note: Spacecraft and comet not to scale.

ROSETTA'S TIMELINE

Comet's diameter is about 4 km

ORBITS
- **Rosetta**
- **Comet 67P/Churyumov-Gerasimenko**
- Mars
- Earth
- Jupiter

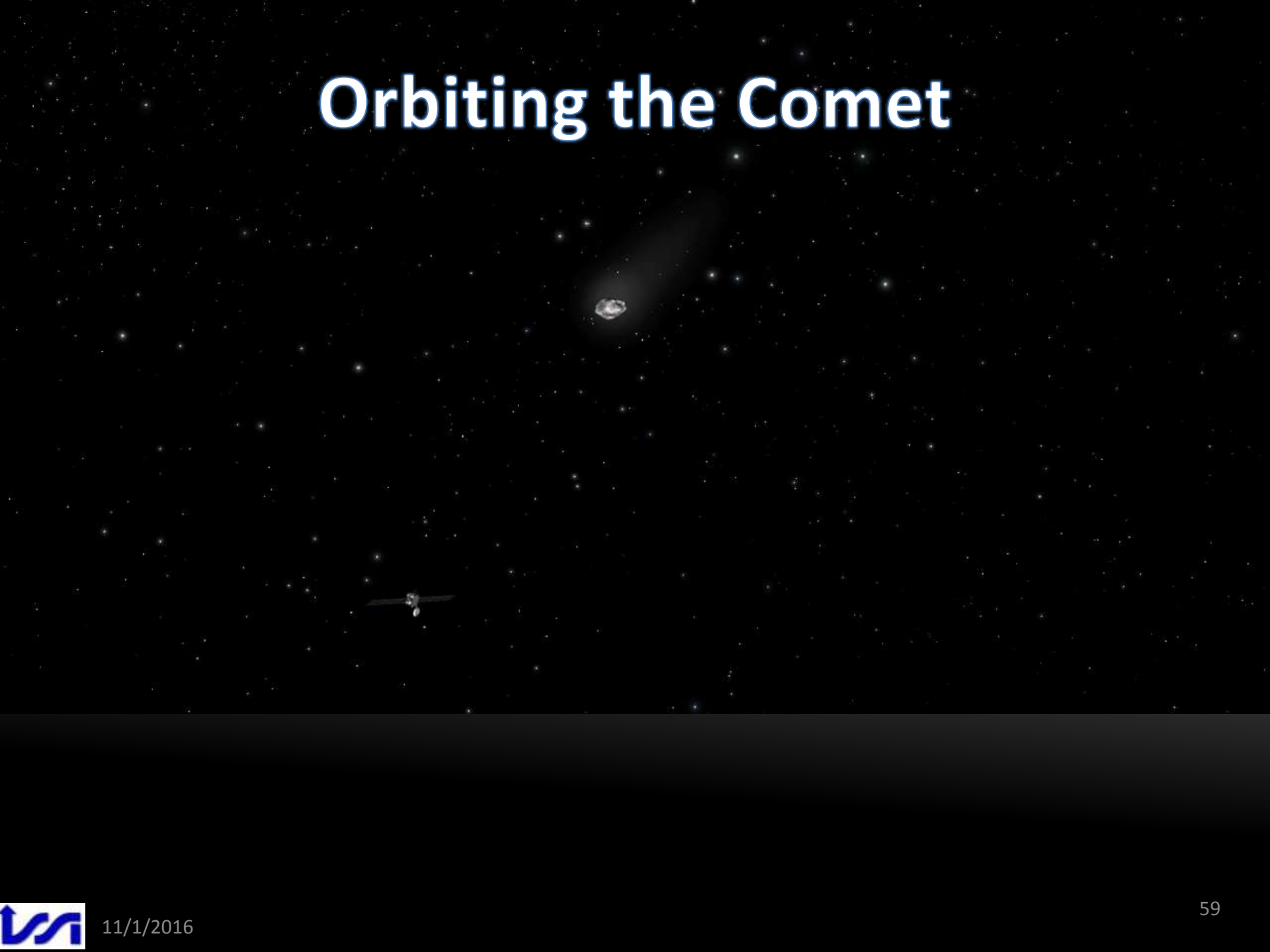


Comets have not changed much since the Solar System's formation 4.6 billion years ago, making them the ideal specimen to study on how the universe came into existence.

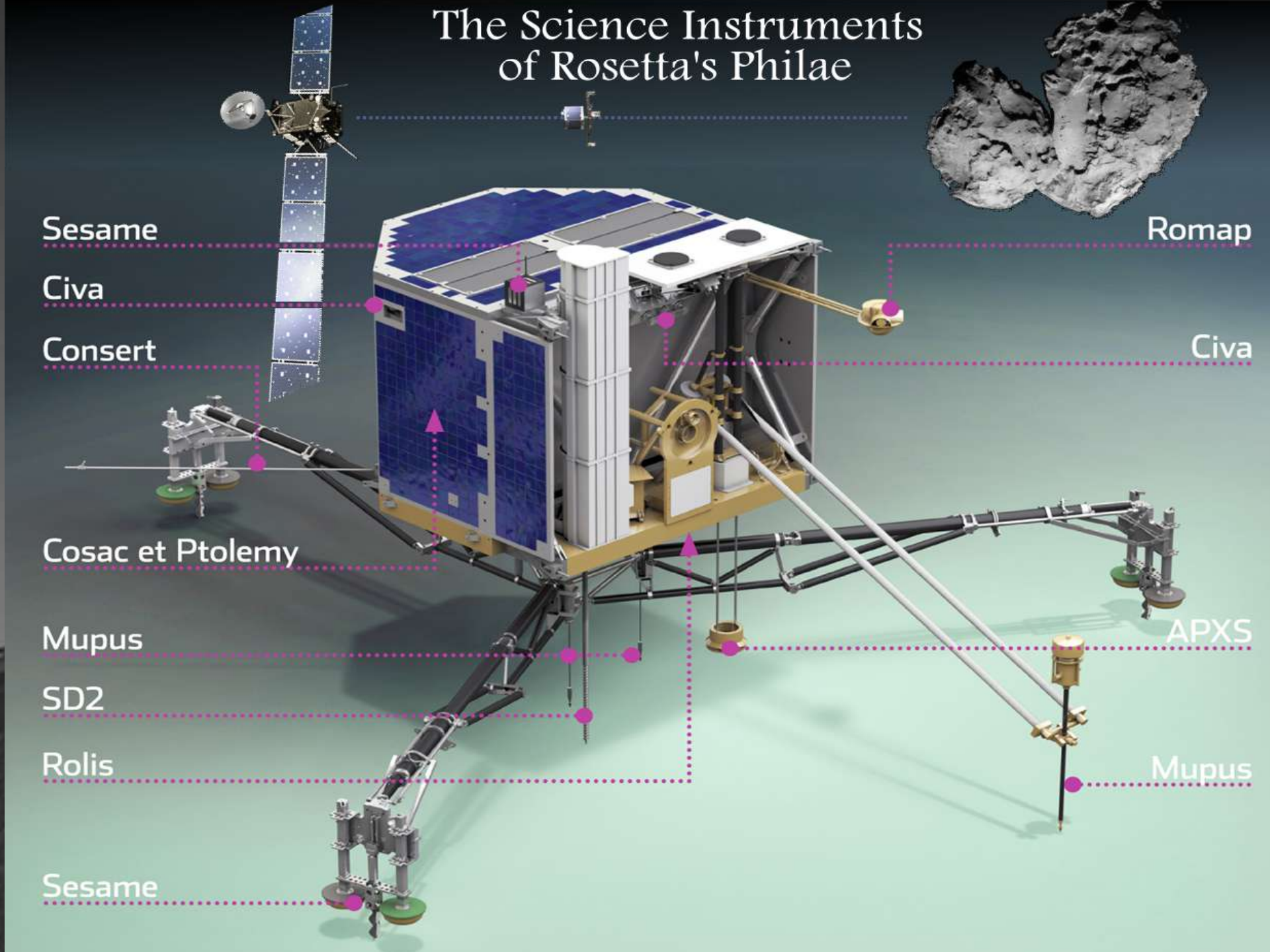
Rosetta will study whether comets contributed to the beginnings of life on Earth.

Sources and images: ESA; NASA, JPL

Orbiting the Comet

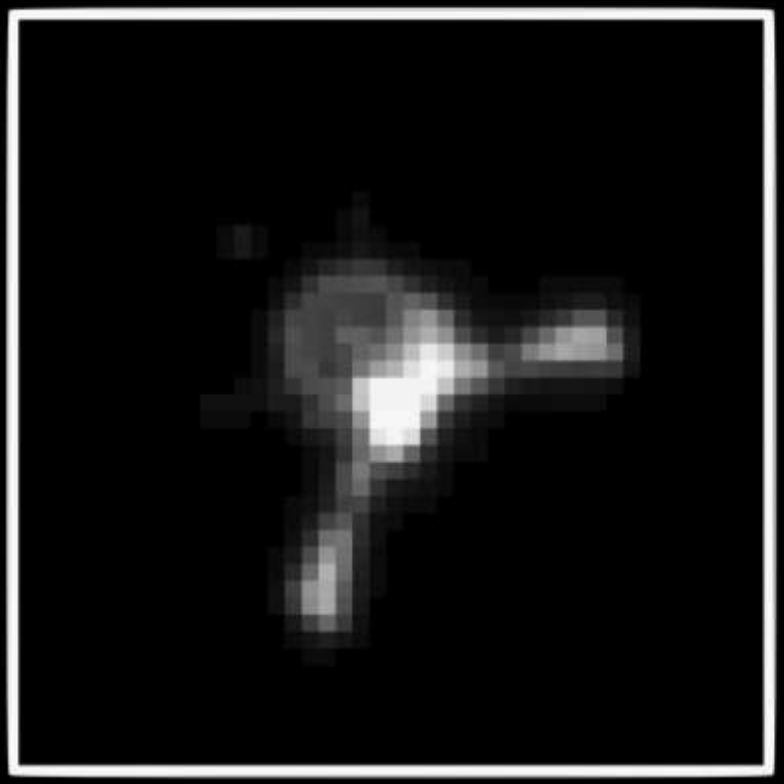


The Science Instruments of Rosetta's Philae

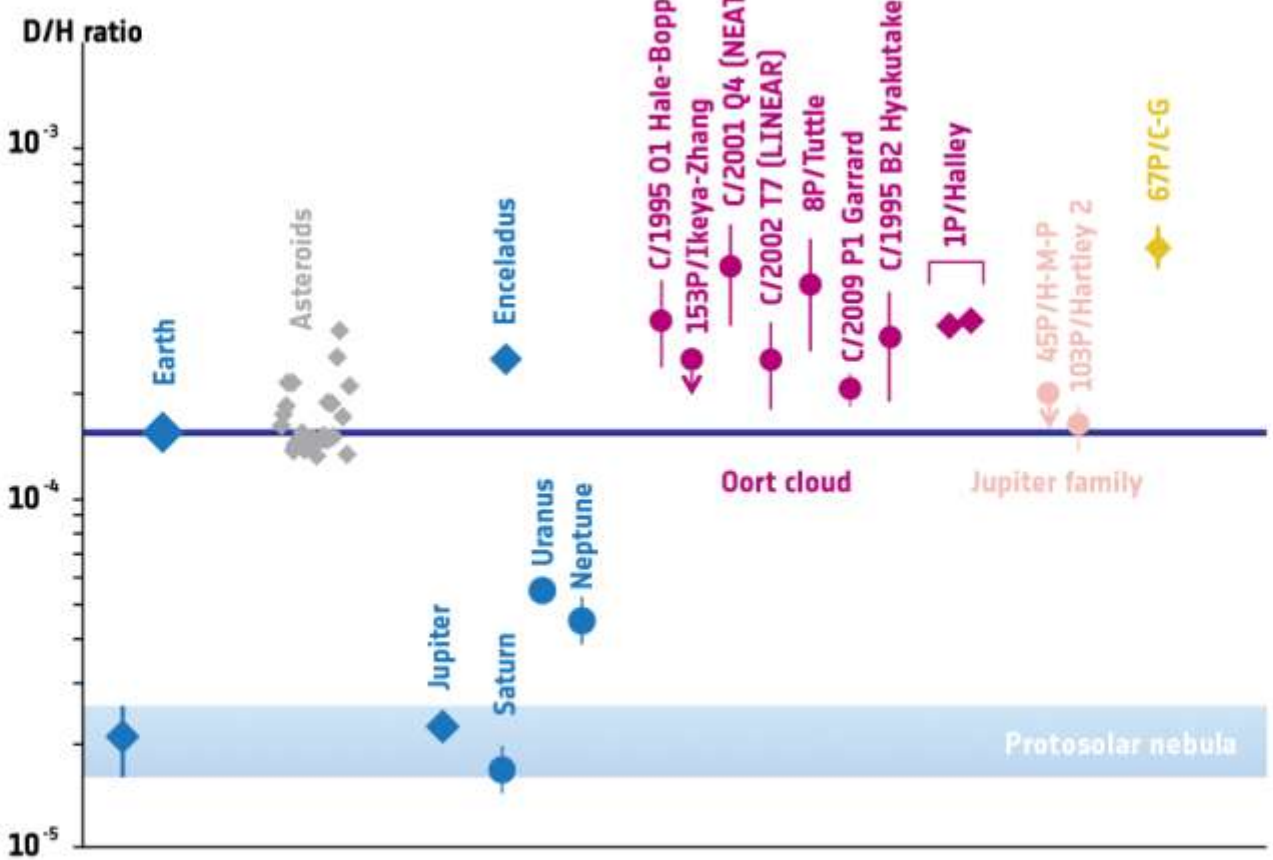


Klim Churyumov watches Philae's separation

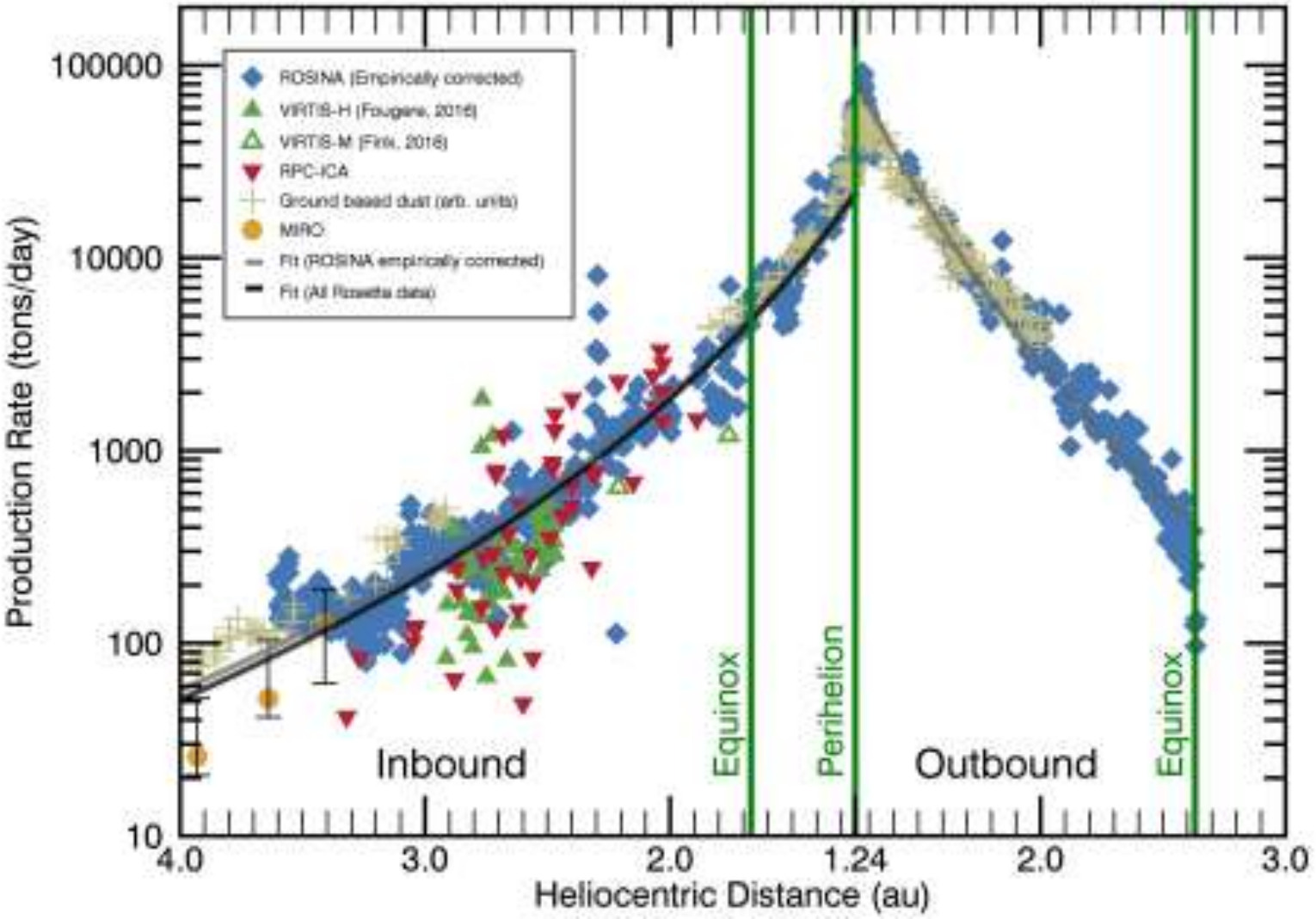
Philae 12 November 2014



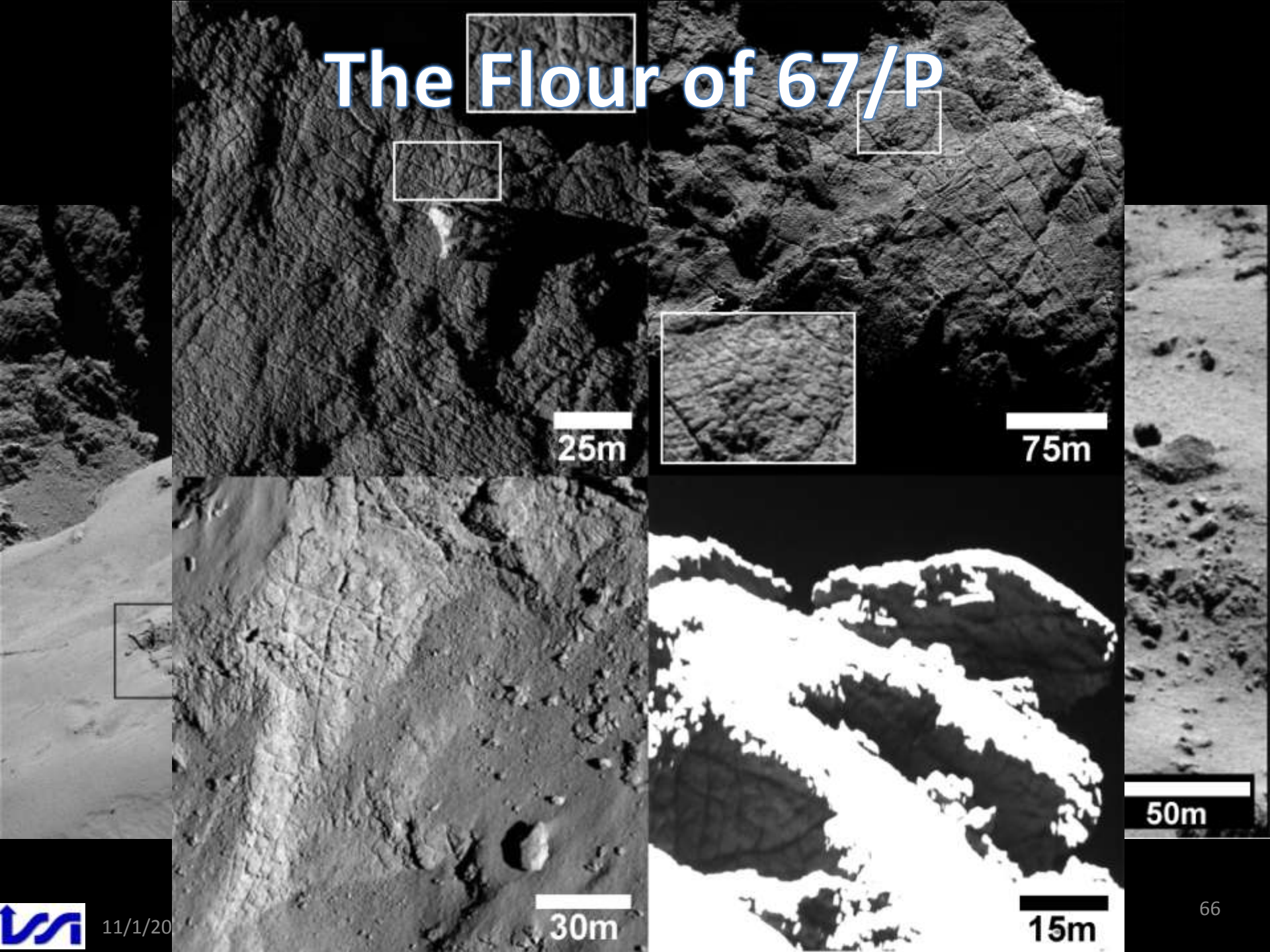
Ratio D/H in the Solar System



Water

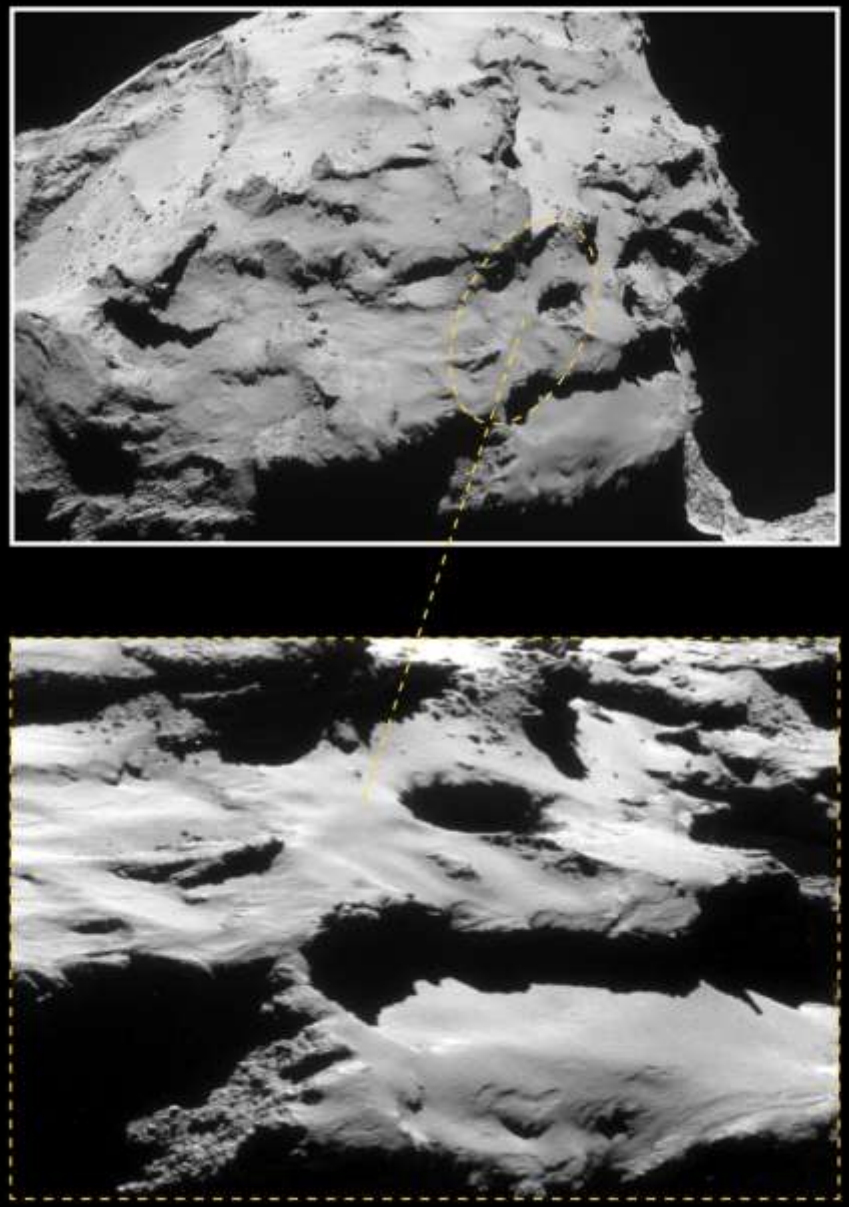

ROSINA (Empirically corrected)
VIRTIS-H (Fougere, 2016)
VIRTIS-M (Fink, 2016)
RPC-ICA
Ground based dust (arb. units)
MIRO
Fit (ROSINA empirically corrected)
Fit (All Rosetta data)
Production Rate (tons/day)
100000
10000
1000
100
10
Inbound
Equinox
Perihelion
Outbound
Equinox
4.0
3.0
2.0
1.24
2.0
3.0
Heliocentric Distance (au)

The Flour of 67/P

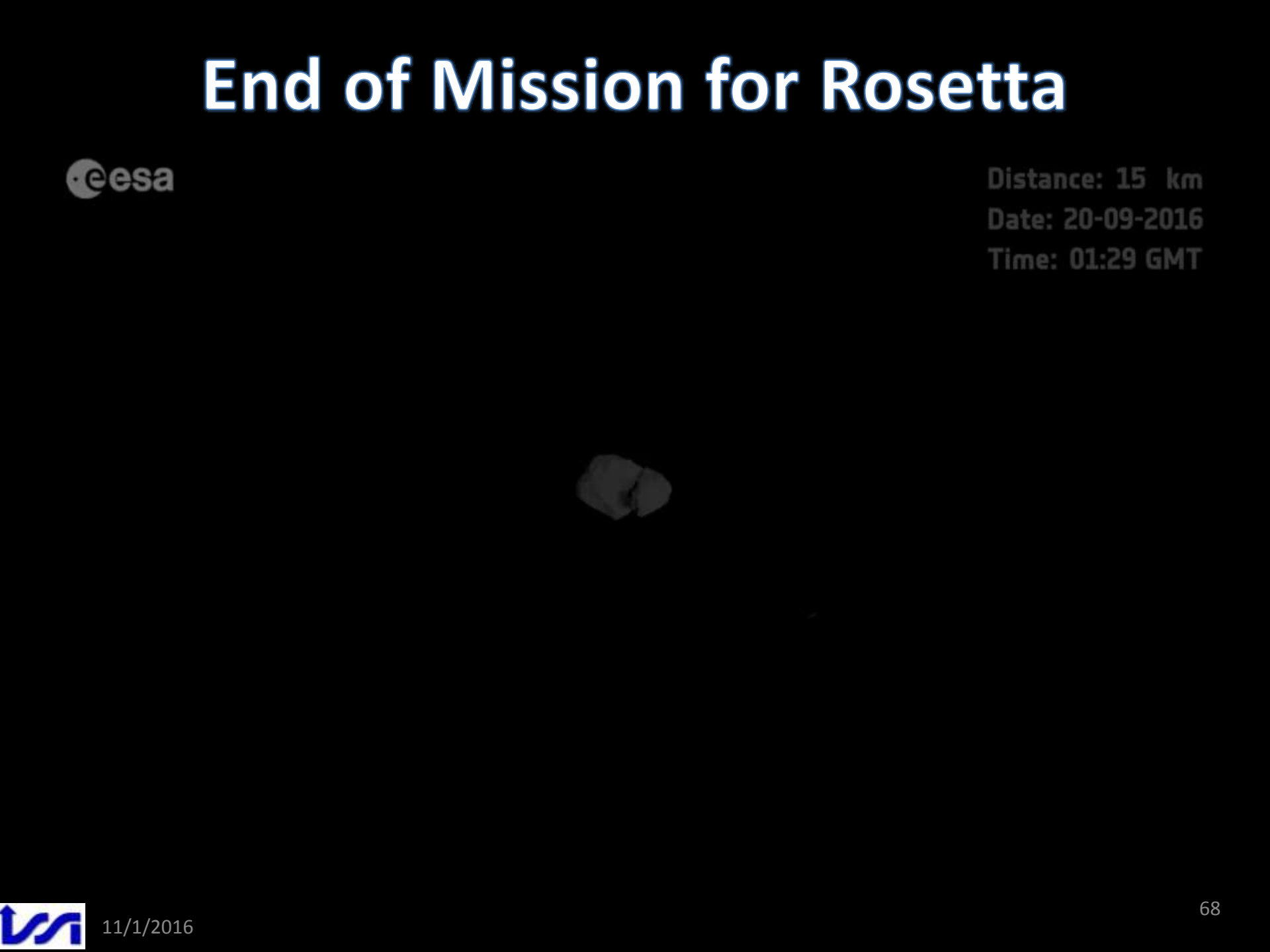


→ ROSETTA'S PLANNED IMPACT SITE

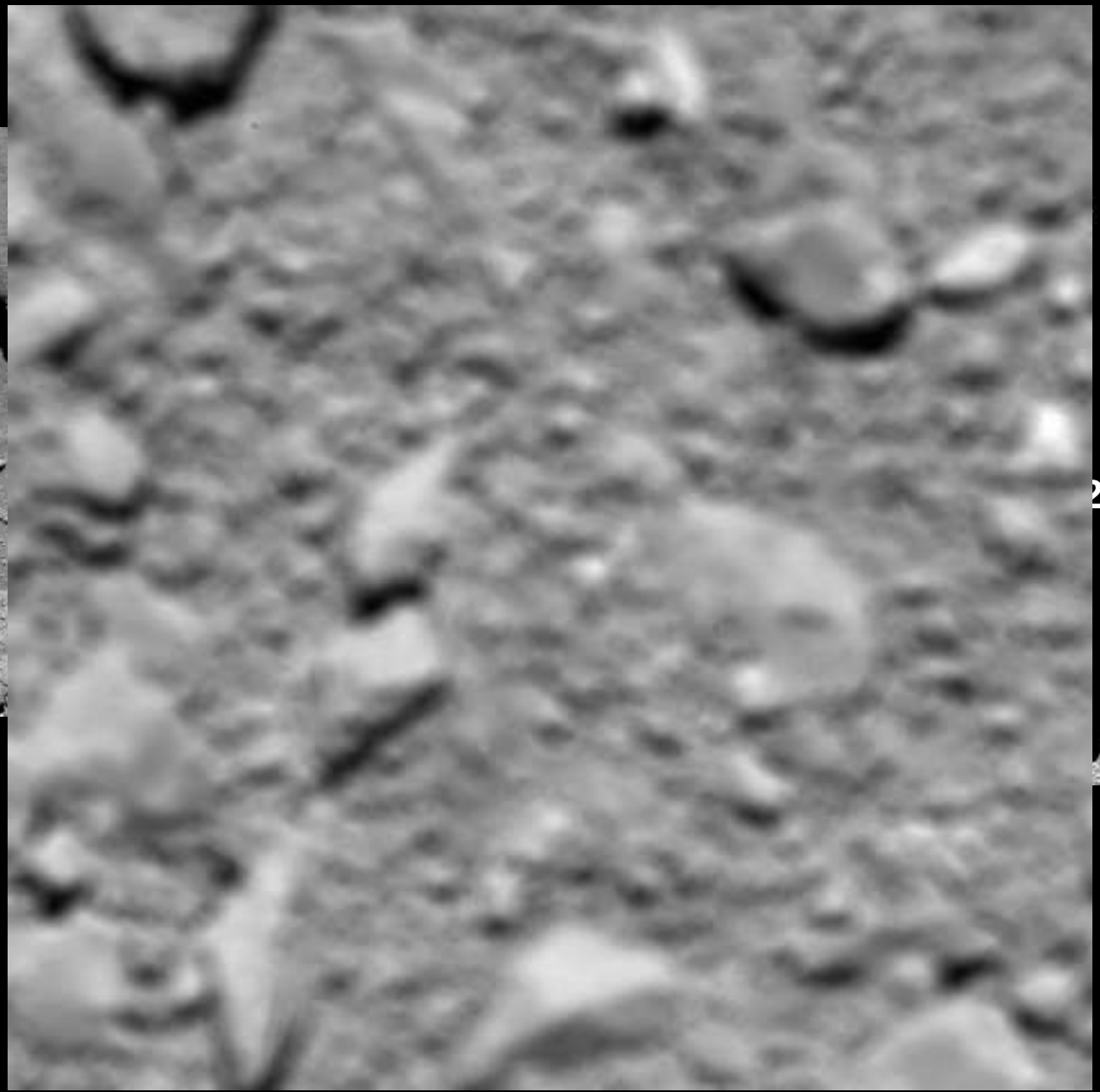
esa



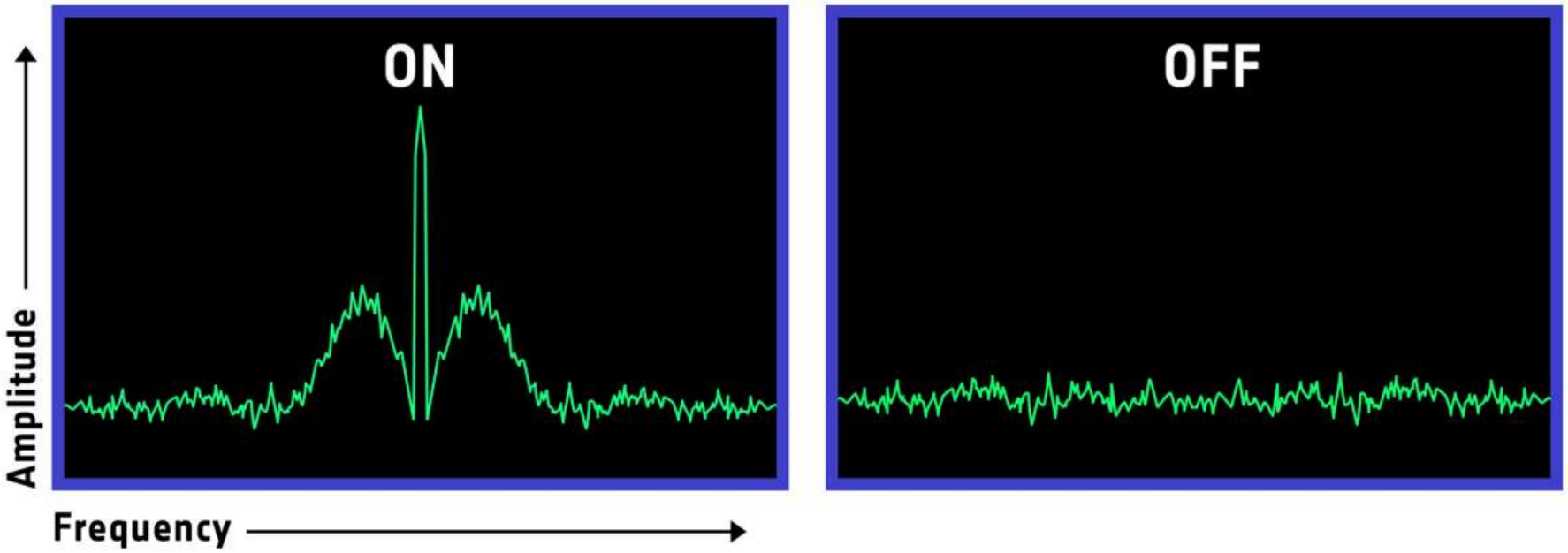
End of Mission for Rosetta



Last touchdown 30/09/2016



Rosetta spacecraft signal

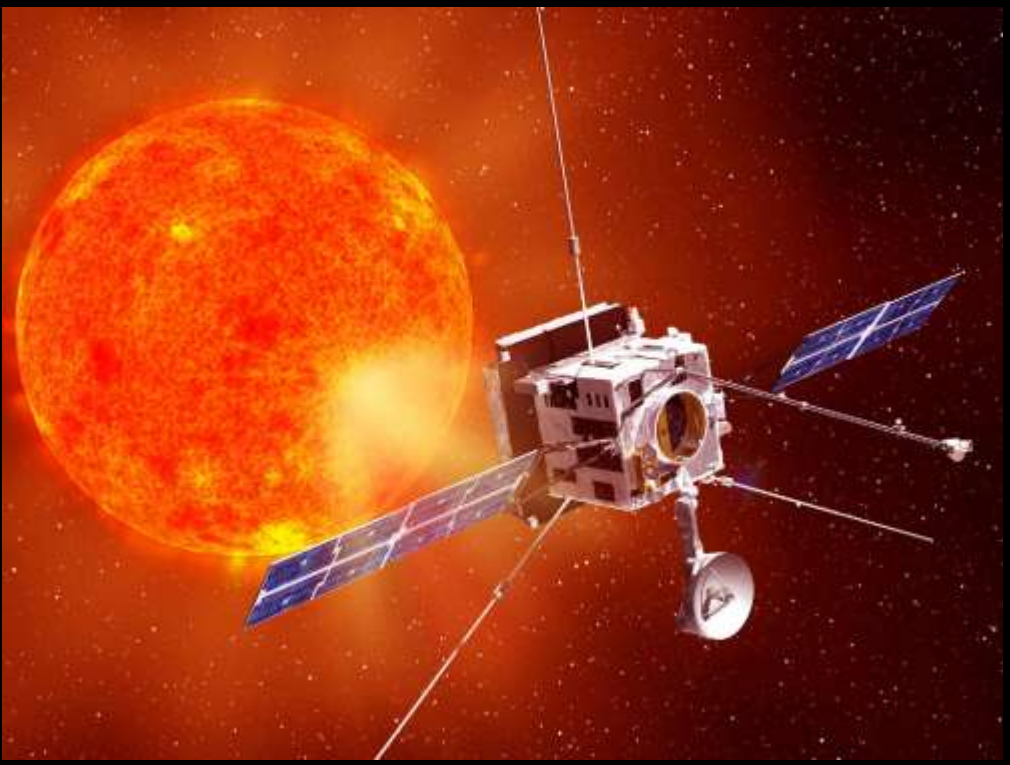


Last touchdown 30/09/2016

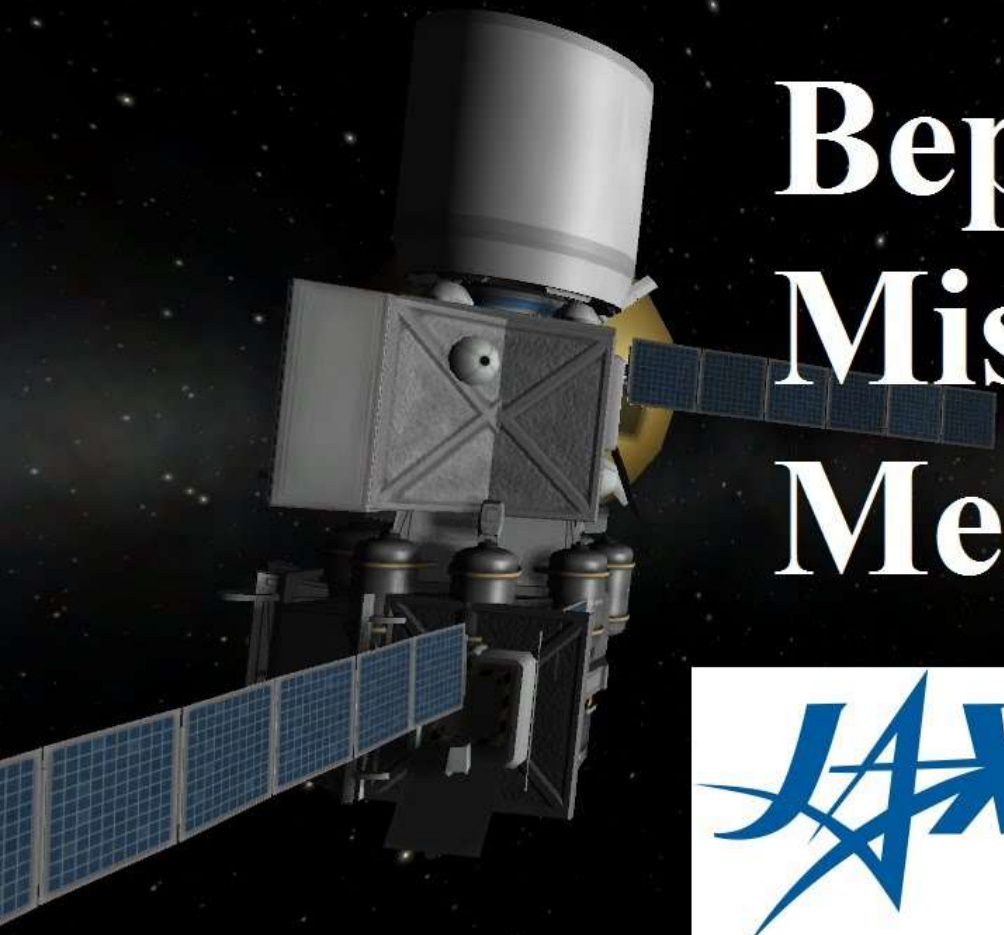
The Future

- Solar System
  - Solar Orbiter (2018)
  - Bepi Colombo (2018)
  - JUICE (2022)
- Astronomy
  - CHEOPS (2018)
  - JWST (2018)
  - Euclid (2020

Solar Orbiter



- **Solar Orbiter aims to make significant breakthroughs in our understanding both of how the inner heliosphere works, and of the effects of solar activity on it. The spacecraft will take a unique combination of measurements: *in situ* measurements will be used alongside remote sensing close to the Sun to relate these measurements back to their source regions and structures on the Sun's surface. It will operate both in and out of the ecliptic plane. Solar Orbiter will measure solar wind plasma, fields, waves and energetic particles close enough to the Sun to ensure that they are still relatively pristine.**



BepiColombo Mission To Mercury

JUICE

The **JUpiter ICy moons Explorer** (**JUICE**) is the L1 ESA Cosmic Vision science program mission designed to visit the Jovian system, focused on studying three of Jupiter's Galilean moons:

- Ganymede
- Calisto,
- Europa.

It will characterize these three worlds, all of which are thought to have significant bodies of liquid water beneath their surfaces.

Planned for launch in 2022 and arrival at Jupiter in 2030.

JWST

The
James Webb
Space Telescope

Secondary mirror
Reflects gathered light from the primary mirror into the science instruments

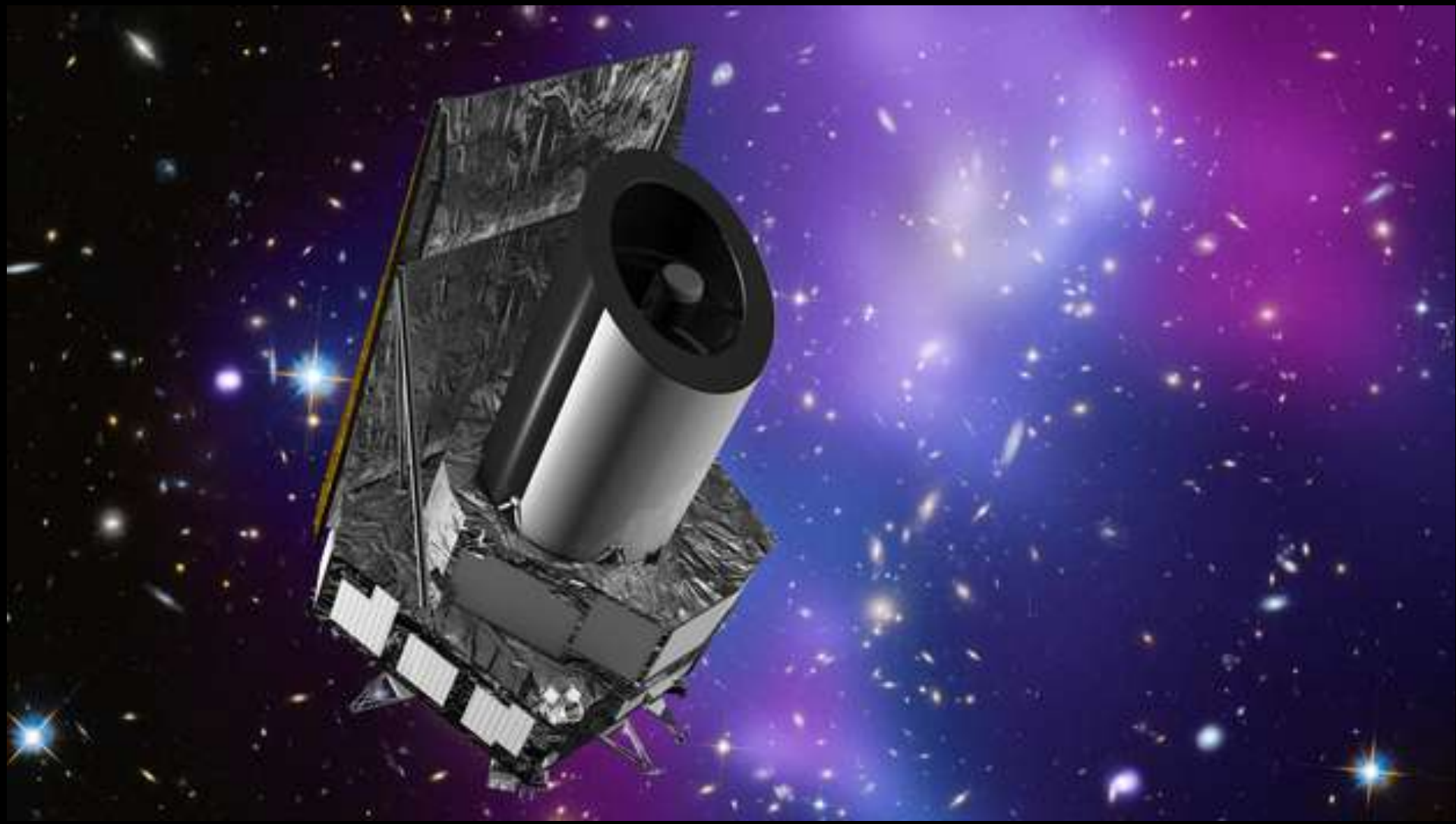
the metal beryll
with gold to cap

Science instrument module
Houses all of cameras and instruments

Spacecr
control s

CHEOPS

Euclid



Athena

The **Advanced Telescope for High-ENergy Astrophysics** – will be an X-ray telescope designed to study the Hot and Energetic Universe'.Responding to two key astrophysical questions:

How does ordinary matter assemble into the large-scale structures we see today? and
How do black holes grow and shape the Universe?

The long-term Future

SMART-2
LISA Pathfinder

Figure 2.11.1. The LISA Technology Package Core Assembly, with two inertial sensors and the optical bench interferometer between. In the interferometer, a set of 22 mirrors and beam-splitters, directs two laser beams across the bench. One beam (shown in red) reflects off the two free-falling masses, while the other (blue) is confined to the bench. (ESA–ATG medialab)

Conclusions 1/2

Europe through the ESA science program is now beating records:

- Largest mirrors ever launched for IR and X-ray astronomy;
- Most distant landing ever accomplished on an extraterrestrial object;
- True revolution in solar observations;
- First multi-points studies of the Earth magnetosphere;
- Orbiting a comet.

Conclusions 2/2

- ESA Science program through H 2000, H 2000+ and Cosmic Vision, has given European scientists a leading role in super-high resolution astrometry, X and infrared astronomy, in cosmology, solar physics, magnetospheric physics, Solar System exploration, including comets, Mars, Venus, Titan, Saturn, and soon Jupiter. The European space science community is now considered as an essential unavoidable partner on the worldwide scene.

My advice to the new generation

- **Remain at the central core of progress by jumping above the barriers that you will find in front of you!**
- **Evaluate your constraints!**
- **Fight!**
- **Resist!**
- **Never think that you can do everything alone!**
- **Learn how to work with colleagues and collaborators!**
- **Learn how to make shine the golden nugget that everyone in your team of collaborators, be they the top level scientist, the best manager or just the house keeper, possess in him/herself and will, through their talent and sense of responsibility at any level of contribution, make you the future leaders of the winning teams!**


Thanks

What is ESA?

- A truly international organization
- 22 Member States:Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, The Netherlands, Norway, Poland, Portugal, Romania, Spain, Sweden, Switzerland and the United Kingdom.
- Canada takes part in some projects under a Cooperation Agreement.
- Other EU states also have Cooperation Agreements with ESA, such as Bulgaria, Cyprus, Lithuania and Malta. Latvia, Slovenia and Slovakia are participating in the Plan for European Cooperating States (PECS).

ESA Facilities

- ESA Head Quarters are located in Paris
- ESA facilities are distributed among the following 5 research centres:
- ESTEC in Noordwijk (Netherlands): science missions, technology, integration facilities;
- ESRIN in Frascati, Italy: Earth Observation missions;
- ESA Mission Control (ESOC) in Darmstadt, Gernany;
- European Astronaut Center that trains astronauts for future missions (EAC) Cologne, Germany;
- European Space Astronomy Center (ESAC) in, Spain.
- ESA has a worldwide staff of about 2,000

Hipparcos in large simulator at ESTEC