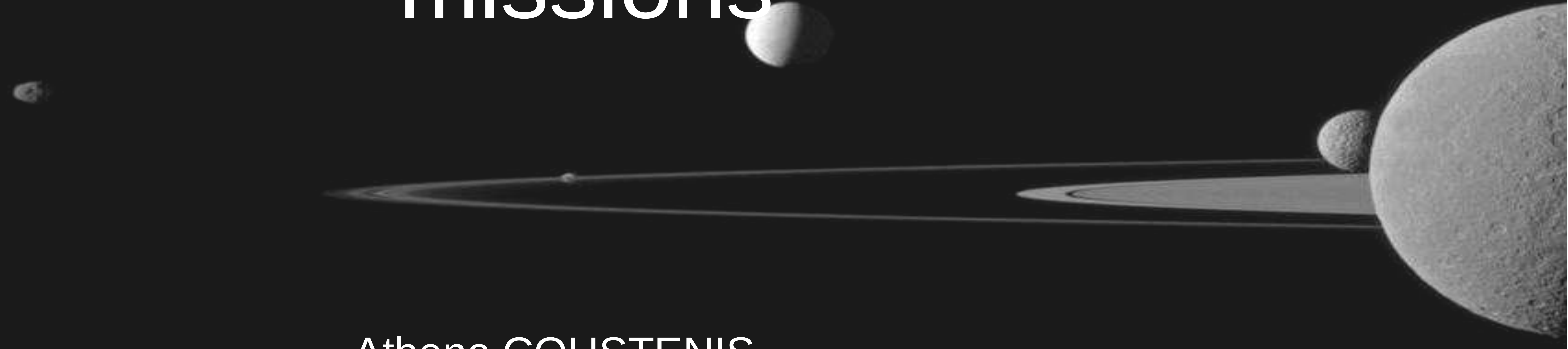
# Overview of ESA’s current and future planetary science missions



Athena COUSTENIS
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athena.coustenis@obspm.fr

# The European Space Agency Current Scientific Programmes

- Science Mandatory Programme
- Human Spaceflight and Robotic Exploration Programme
- Earth Observation Programme

# The European Space Agency Current Scientific Programmes

- **Science Mandatory Programme (SCI)**
- **Human Spaceflight and Robotic Exploration Programme (HSRE): Mars & the Moon**
- Earth Observation Programme

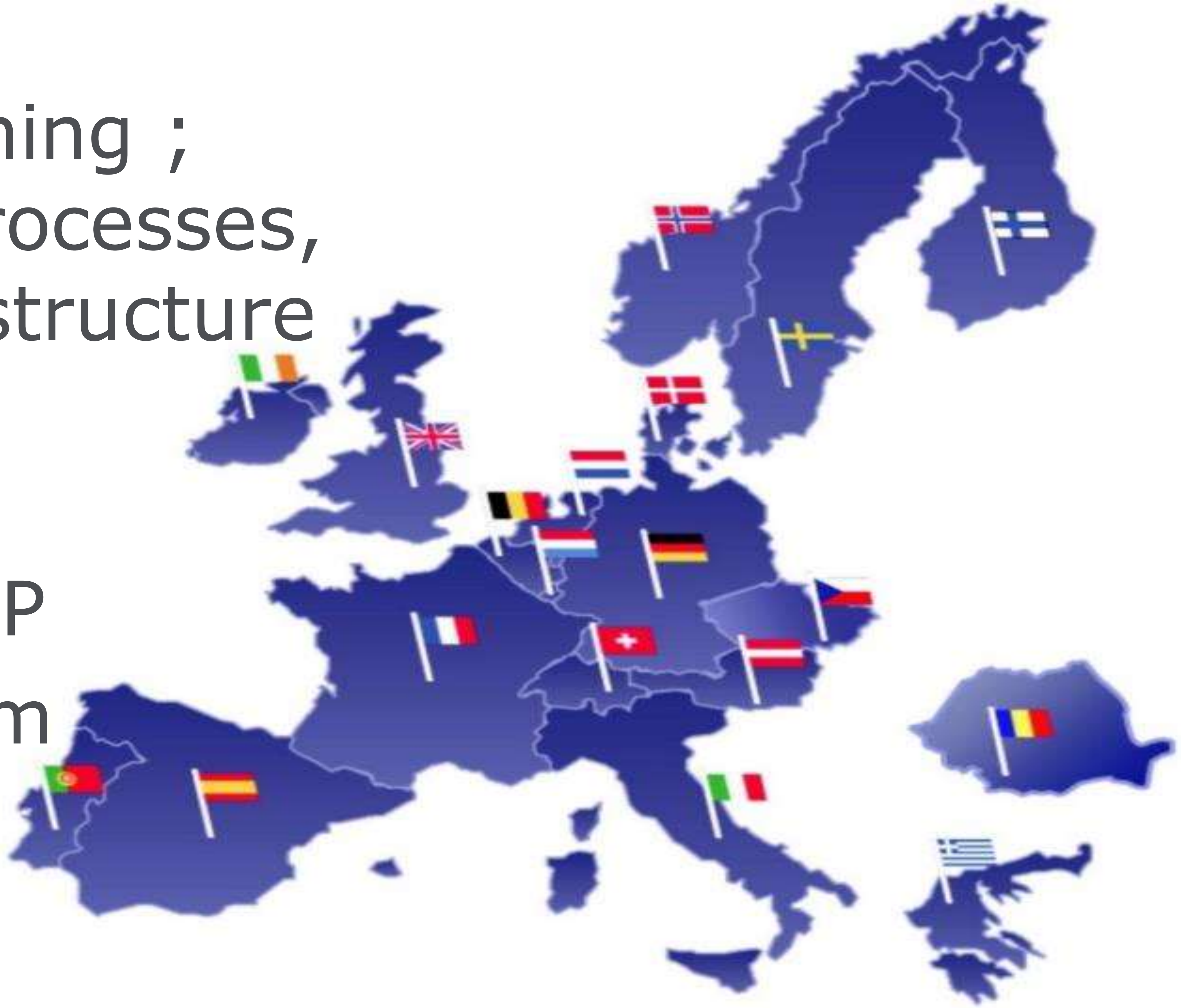
# Basics of the SCI and HSRE Programmes

- **The Programmes are Science-driven and exploratory:**

  both long-term science and exploratory planning ; mission or experiment calls are bottom-up processes, relying on broad community input, advisory structure and peer review.

- **The Science Programme is Mandatory:**

  all member states contribute pro-rata to GDP providing budget stability, allowing long-term planning of its scientific goals and being the backbone of the Agency.



- **The Human Spaceflight and Robotic Exploration Programme is optional:**

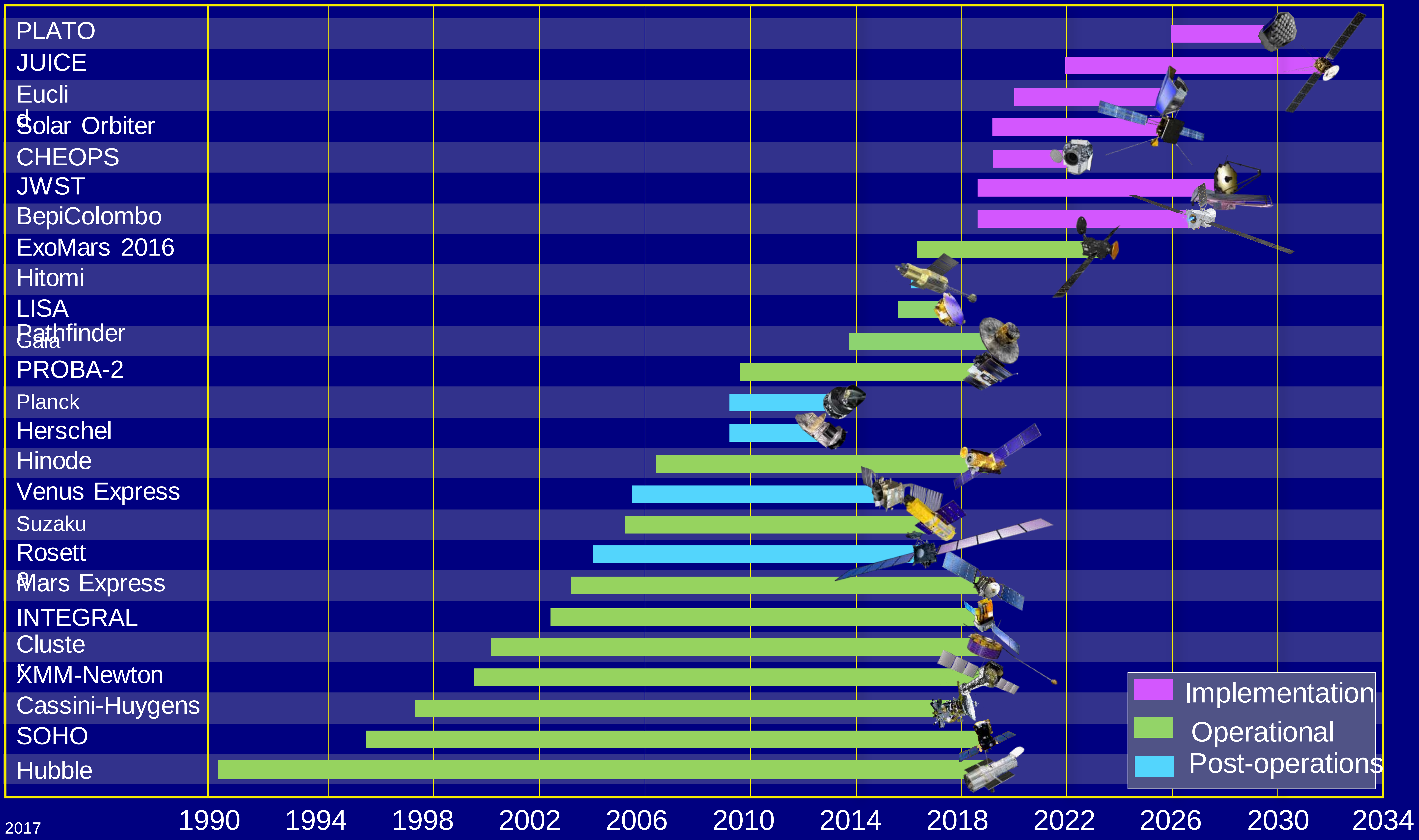
  17 countries and Canada contribute. E3P encompasses ISS, astronauts, Orion, Moon and Mars

# ESA science programme

## Successes and objectives of the science mandatory programme

- Based on peer-reviewed selection of missions on the basis of scientific excellence following an open call. The content of the Programme (which missions?) is decided by the SPC (national delegates).
- Long-term planning to service a broad community with the annual budget over 4-5 years decided at ESA Council at Ministerial level.
- Regular sequence of launches based on a balance of mission sizes (Small, Medium, Large), fostering both ambitious, high-return missions and faster, smaller missions.
- Solid partnership with National programmes in Member States.
- Open to broad international cooperation

# ESA space science missions




Last update: June 2017


soho
Facing the Sun
venus express
Studying Venus' atmosphere
juice
Studying Jupiter's icy moons
proba-2
Observing coronal dynamics and solar eruptions
bepicolombo
Exploring Mercury
cassini-huygens
Studying the Saturnian system and landing on Titan
exomars
Europe's new era of Mars exploration
mars express
Investigating the Red Planet
solar orbiter
The Sun up close
cluster
Measuring Earth's magnetic shield
rosetta
Chasing a comet
esa
→ ESA'S FLEET IN THE SOLAR SYSTEM
The Solar System is a natural laboratory that allows scientists to explore the nature of the Sun, the planets and their moons, as well as comets and asteroids. ESA's missions have transformed our view of the celestial neighbourhood, visiting Mars, Venus, and Saturn's moon Titan, and providing new insight into how the Sun interacts with Earth and its neighbours. The Solar System is the result of 4.6 billion years of formation and evolution. Studying how it appears now allows us to unlock the mysteries of its past and to predict how the various bodies will change in the future.
www.esa.int
European Space Agency


ESA'S FLEET ACROSS THE SPECTRUM
esa
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.
jwst
Observing the first light
gaia
Surveying a billion stars
herschel
Unveiling the cool and dusty Universe
planck
Looking back at the dawn of time
cheops
Chasing and sizing exoplanets
euclid
Probing dark energy, dark matter and the expanding 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
microwaves
sub-millimetre
infrared
optical
ultraviolet
x-rays
gamma rays
integral
Seeking out the extremes of the Universe
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# Science Mandatory Programme

## Highlights :
## current planetary missions

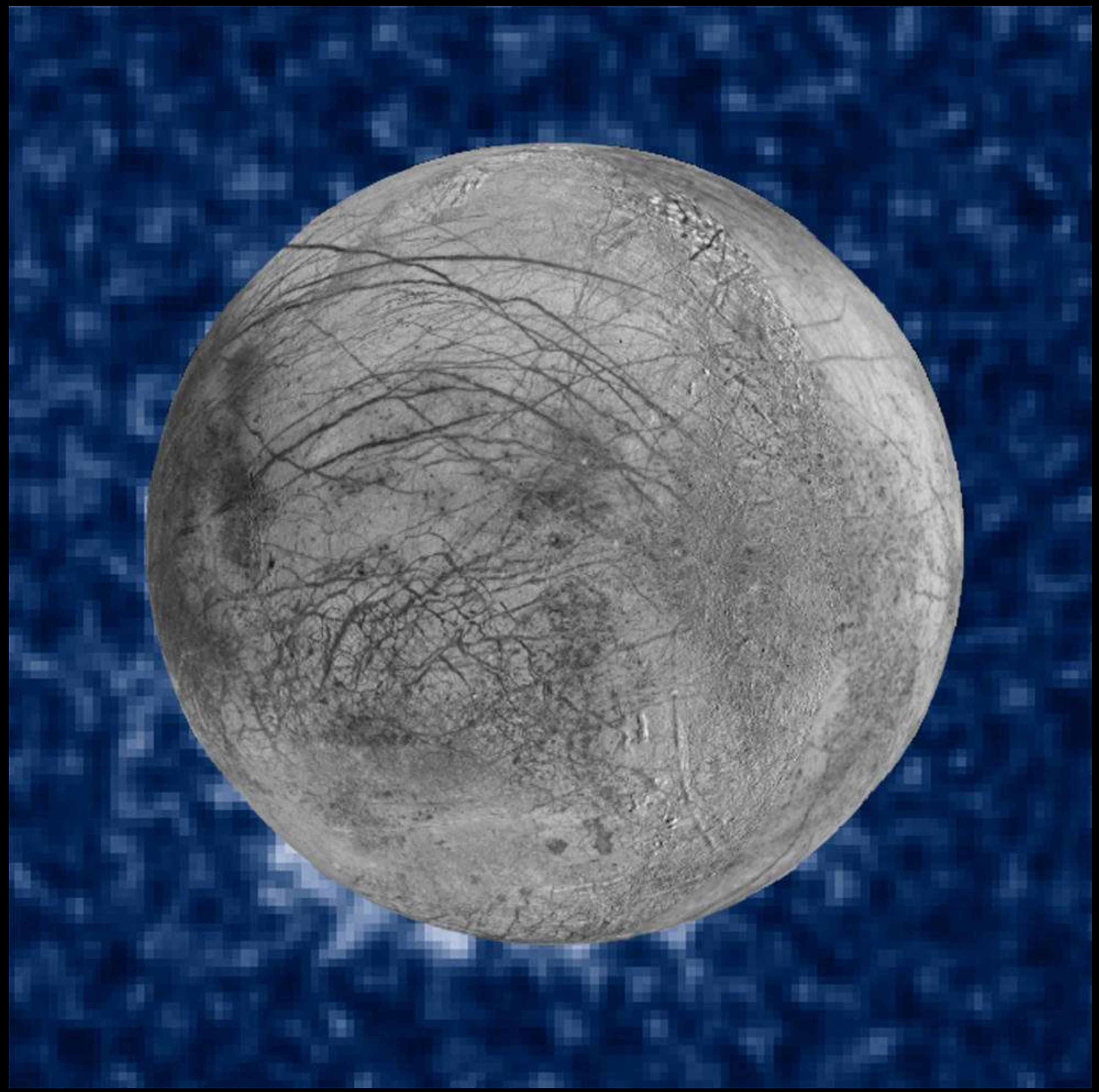
# Hubble Space Telescope

**Hubble Space Telescope, launched 1990 / NASA, ESA**

# HST Planetary result

## About the existence of deep liquid layers : EUROPA

**Water plumes on Europa with HST in 2012**



*Credits: NASA/ESA/W. Sparks (STScI)/USGS Astrogeology Science Center*

*Roth et al., 2012*

# MARS EXPRESS :

Mars Express: Mars planetary physics mission, launched 2003 / ESA

1. Hydrated minerals – evidence of liquid water on Mars

#2. Possible detection of methane in the atmosphere

#3. Identification of recent glacial landforms

#4. Probing the polar regions

#5. Recent and episodic volcanism

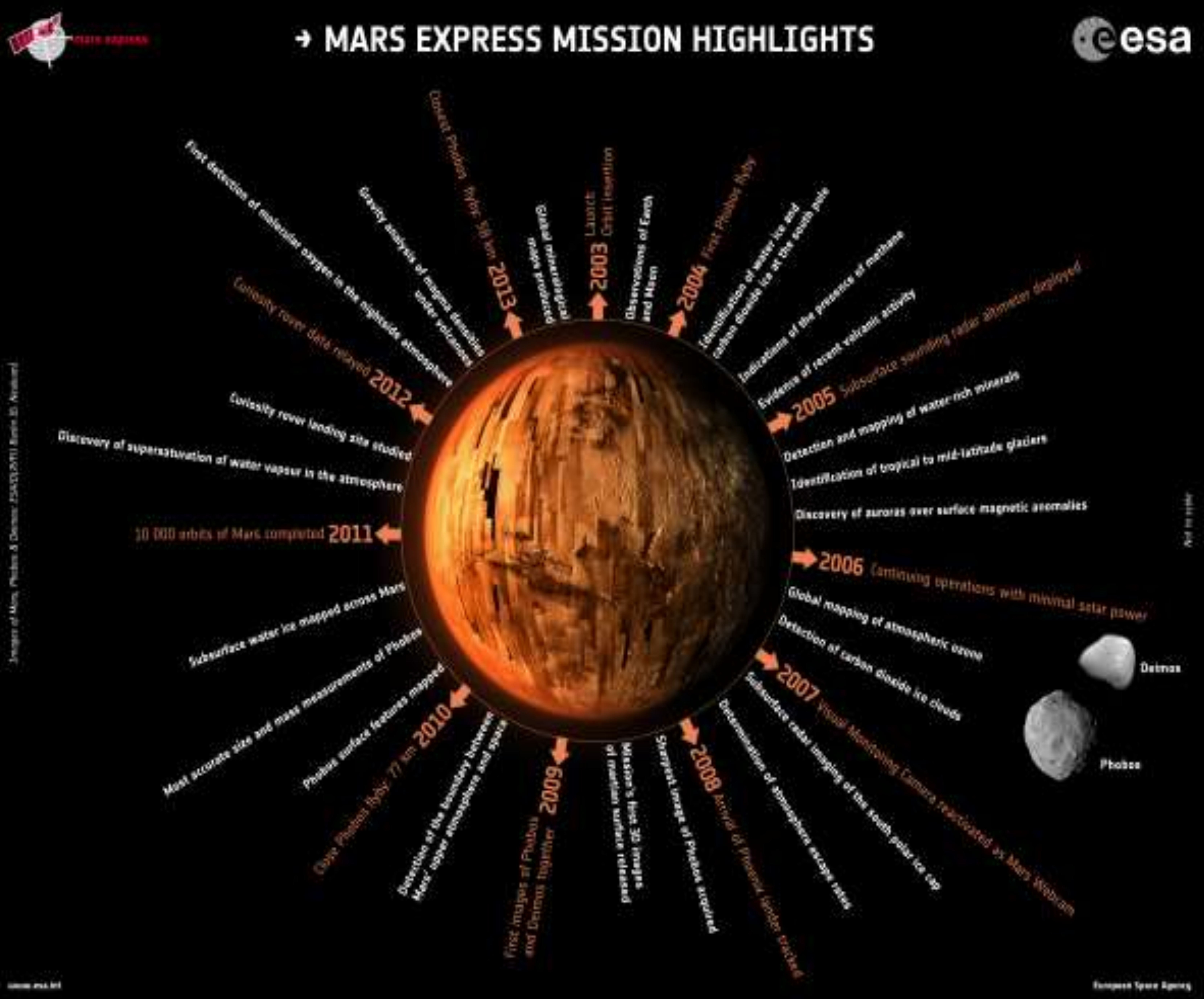
#6. Estimation of the current rate of atmospheric escape

#7. Discovery of localised auroras on Mars

#8. Mars Express discovers new layer in Martian ionosphere

#9. Unambiguous detection of carbon dioxide clouds

#10. Mapping and measuring Phobos in unprecedented detail

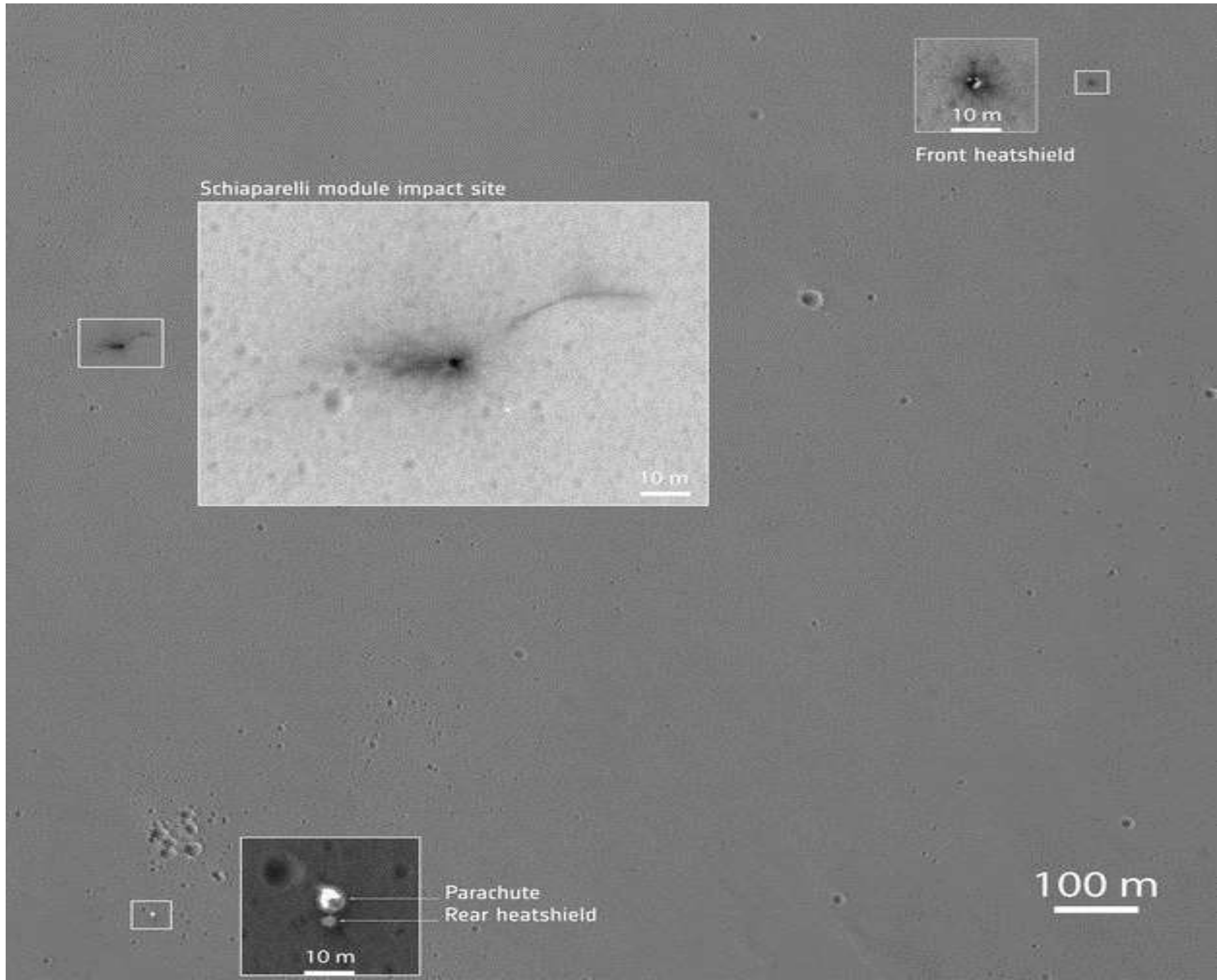



MEX HRSC 67-frame mosaic / ESA / DLR / FU Berlin / CC BY-SA IGO 3.0
© ESA/DLR/FU Berlin (G. Neukum)
N
200 km

Worcester Crater in Kasei Valles / MEX HRSC / ESA / DLR / FU Berlin / CC BY-SA IGO 3.0

# EXOMARS : Trace Gas Orbiter and EDLM

The EDLM Schiaparelli module has provided technology validation for entry and descent but not for landing …due to premature end of the descent sequence following software problem




•TGO: Launched on 14 March 2016. Effective mission from December 2017 until end of 2022. Orbiter will serve as relay for the 2020 rover mission

- will study the Martian atmosphere for evidence of biological gases (CH4, etc)
- A year later it had completed another set of important science calibration tests before embarking on a year of aerobraking until March 2018.

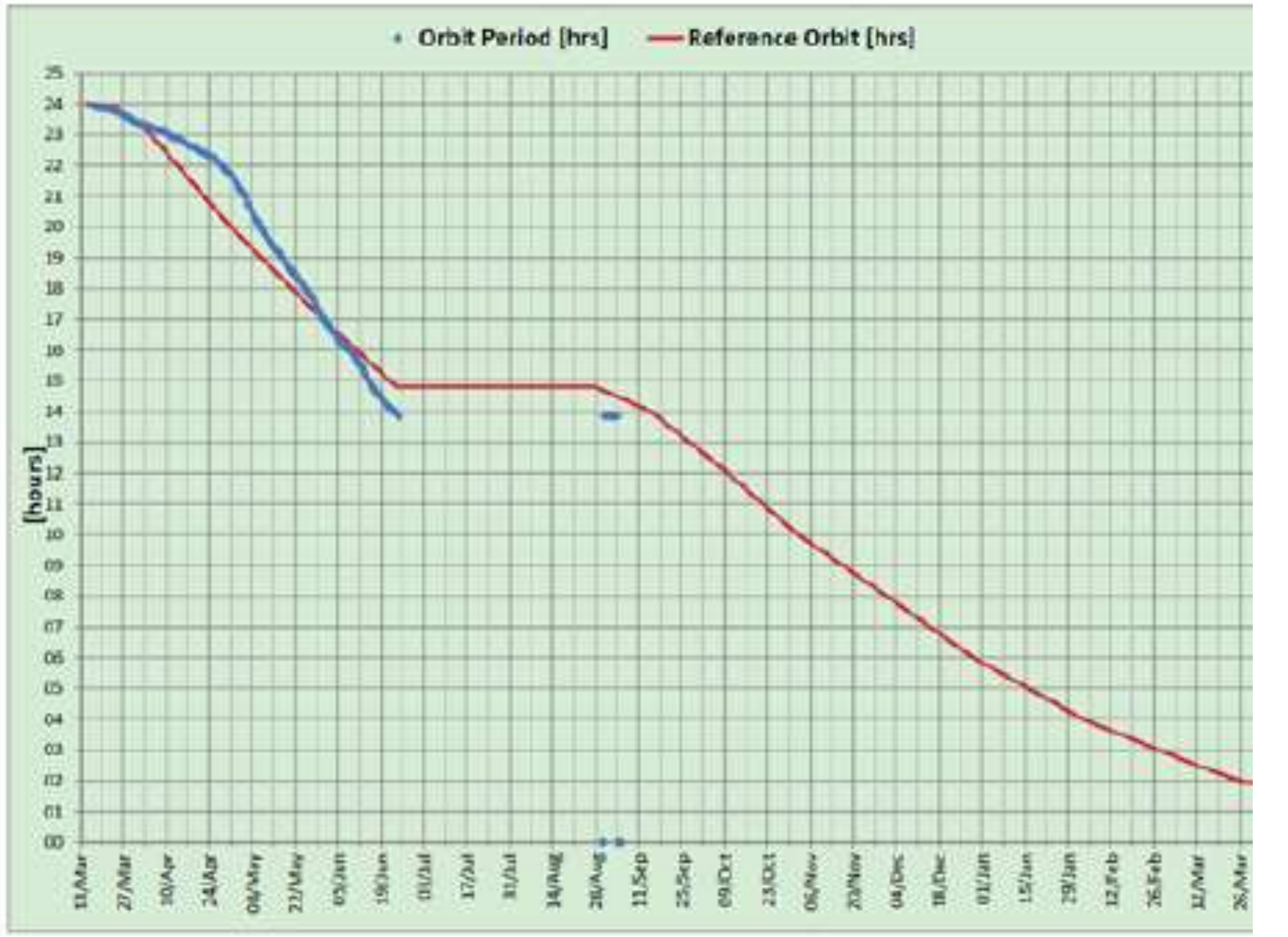
# ExoMars – STATUS UPDATE

## ExoMars MISSION 2016

- 2nd and 3rd aero-braking operational phases authorized

- Authorization to terminate the aero-braking near an apo-centre of 1000Km to reach the operational data relay orbit. Using limited fuel, TGO will reach the frozen quasi circular data relay/science orbit 410/370KM in April 2018.

- Large amount of fuel are secured for routine operations after aero-braking, even when considering contingency scenarios with multiple safe modes and aero-braking suspensions.



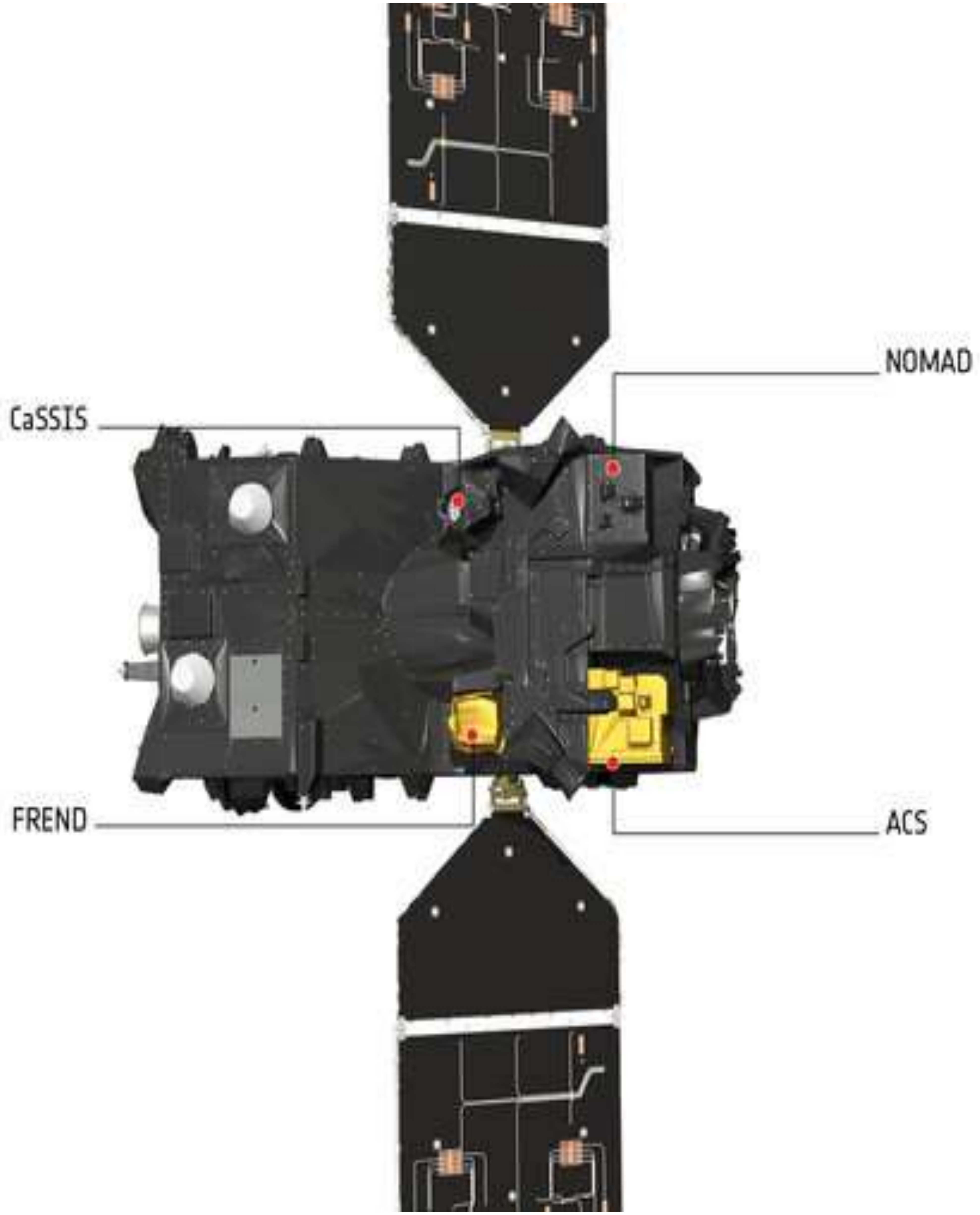
# EXOMARS : Trace Gas Orbiter

## TGO Payload :

- ***ACS*** (Atmospheric Chemistry Suite),
- ***CaSSIS*** (Colour and Stereo Surface Imaging System)
- ***NOMAD*** (Nadir and Occultation for MArs Discovery).
- ***FREND*** (Fine Resolution Epithermal Neutron Detector)

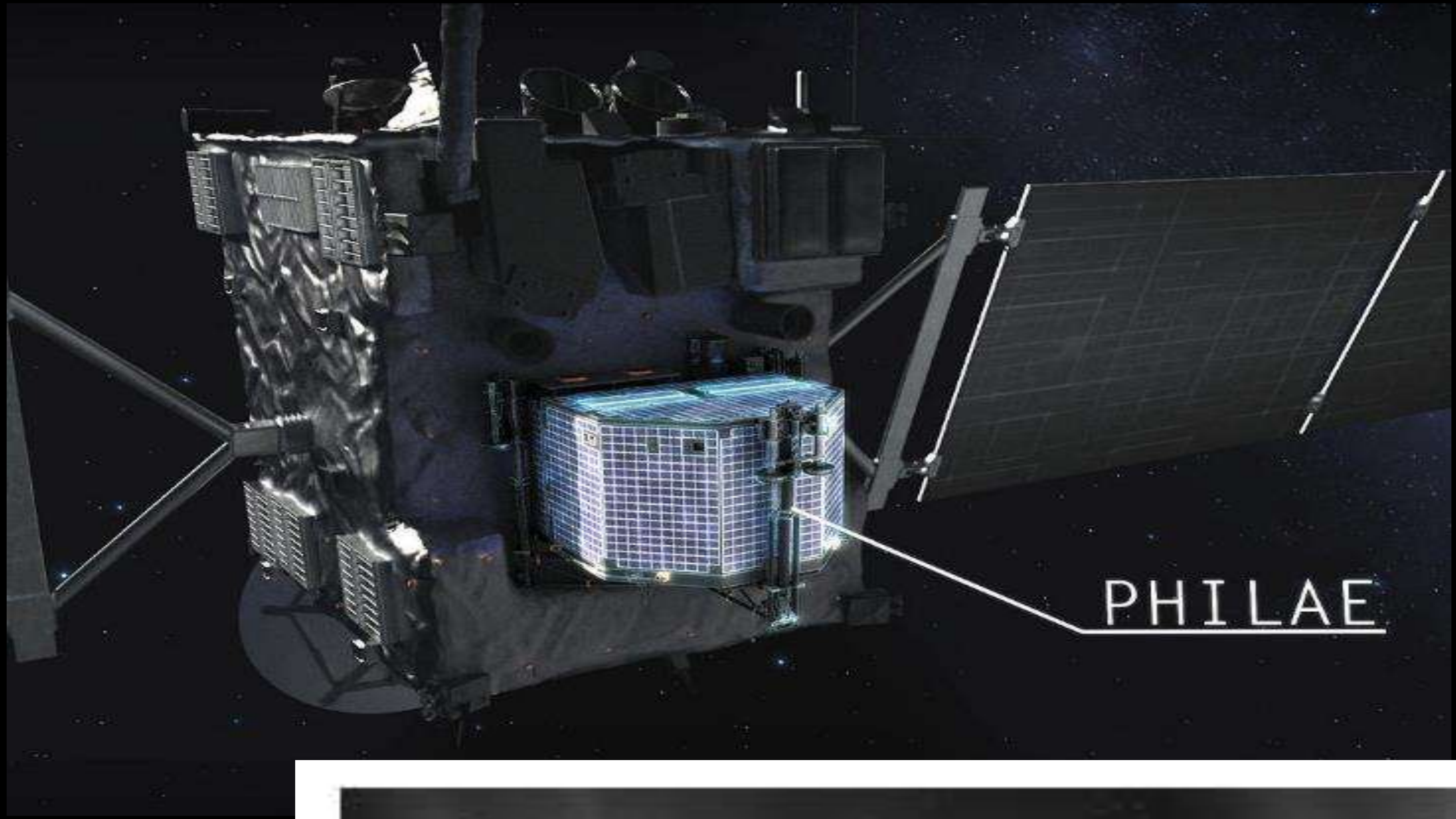
## Science :

- ***ACS*** and ***NOMAD*** spectrometers with complementary frequency range will provide for the atmosphere:
  - Inventory of Mars trace gases
  - monitor seasonal changes in the composition and temperature
  - detect minor constituents
- ***CaSSIS*** will image and characterise features on the martian surface that may be related to trace-gas sources such as volcanoes.
- ***FREND*** will map subsurface hydrogen to a depth of 1m to reveal deposits of water-ice hidden just below the surface,



# Rosetta:

Comet rendezvous, escort, & landing mission, launched 2004 / ESA

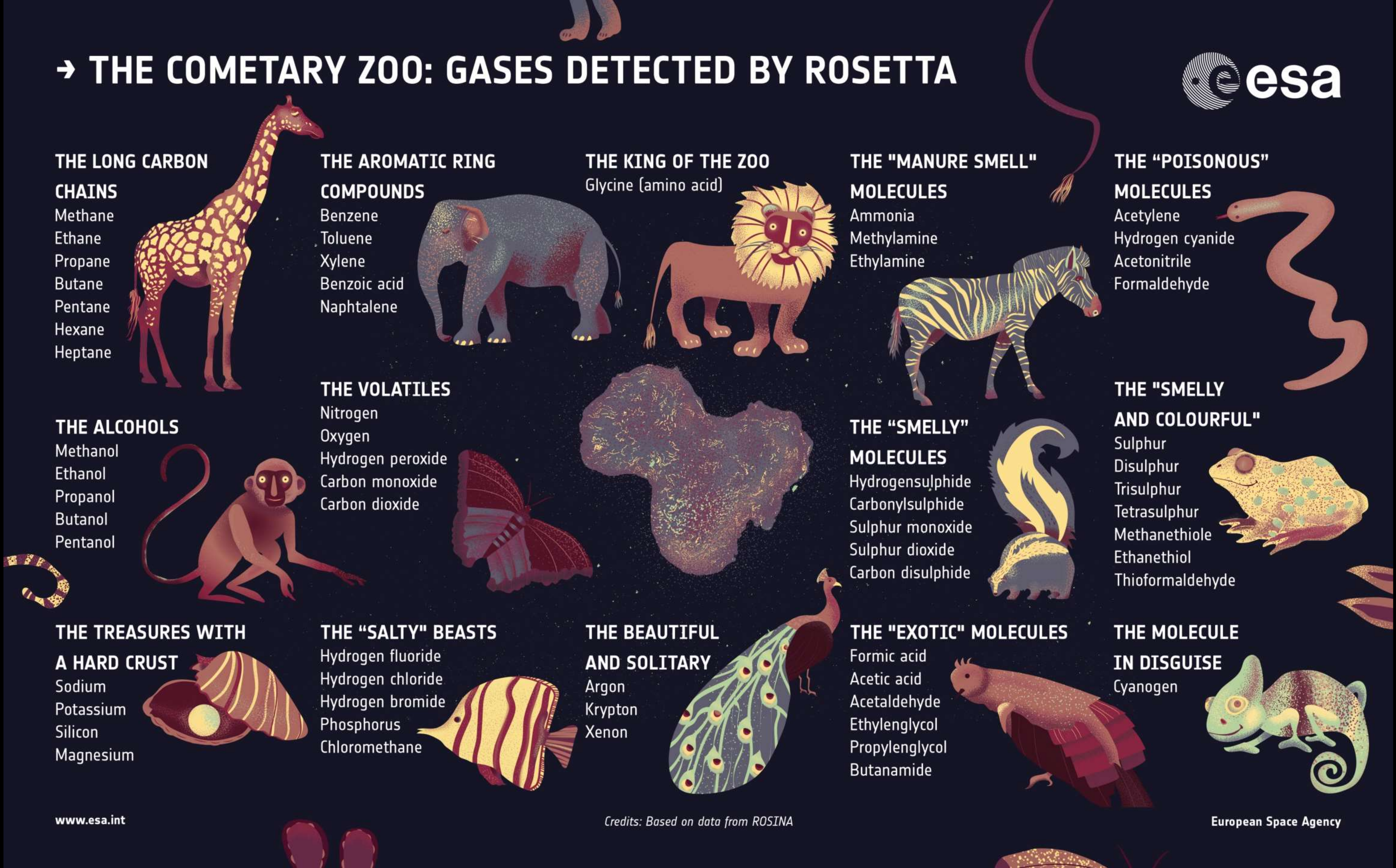


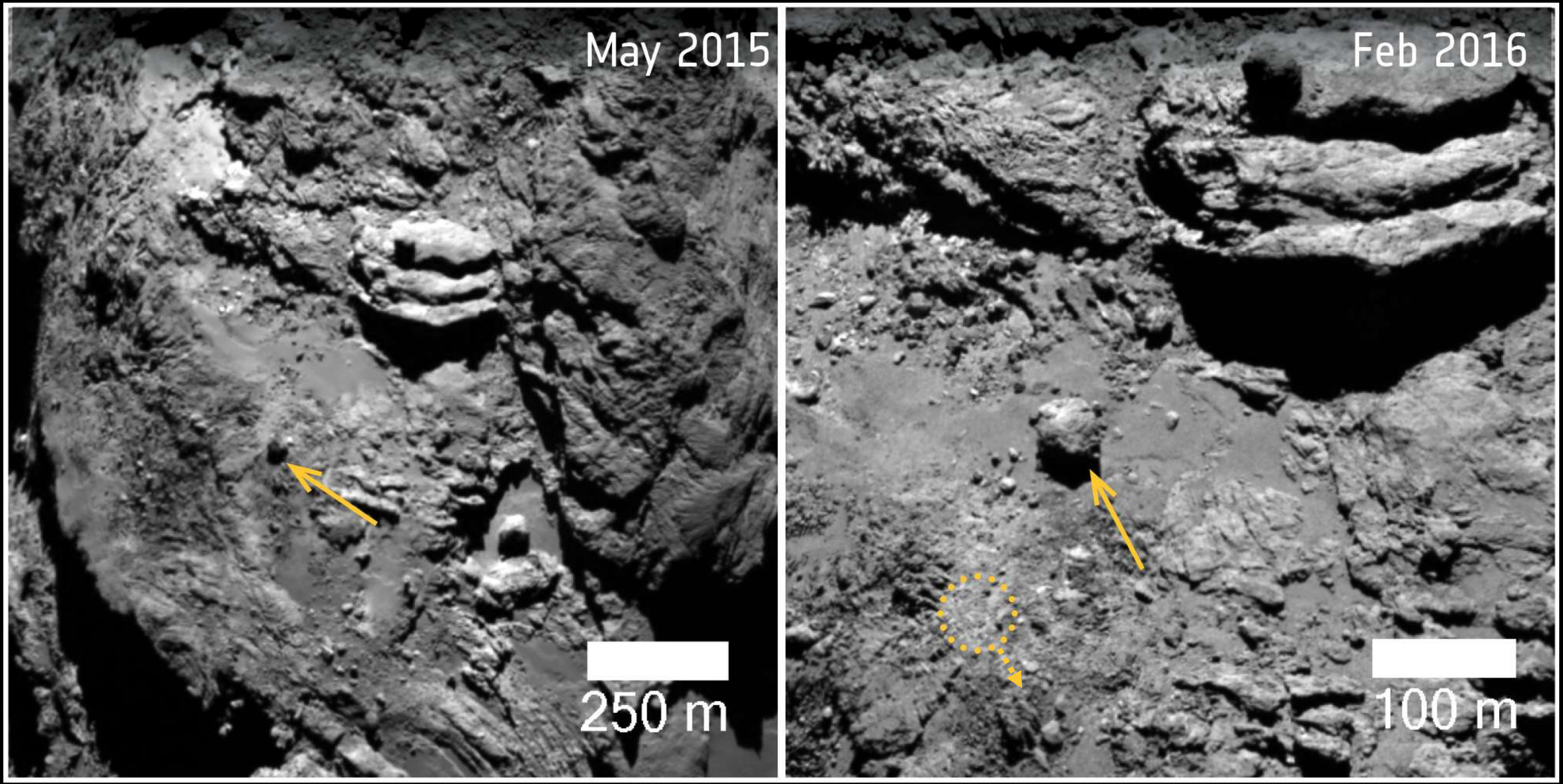

# ROSETTA

*ESA PR March 2016*

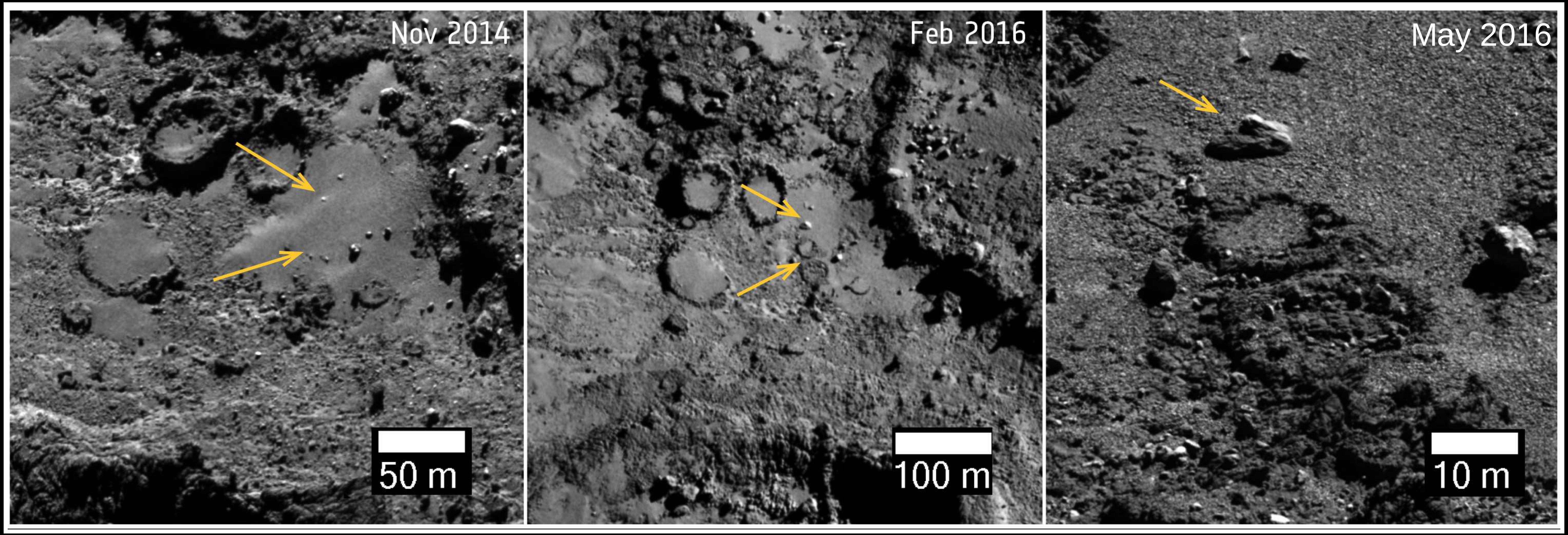
OSIRIS images of Comet 67P/C-G taken on 26 July 2015, before, during and after the detection of the diamagnetic cavity. *Credit: ESA/Rosetta/MPS for OSIRIS Team MPS/UPD/LAM/IAA/SSO/INTA /UPM/DASP/IDA*


67P/C-G activity on 10 Sep 2014 / E
IS Team / Herobrine

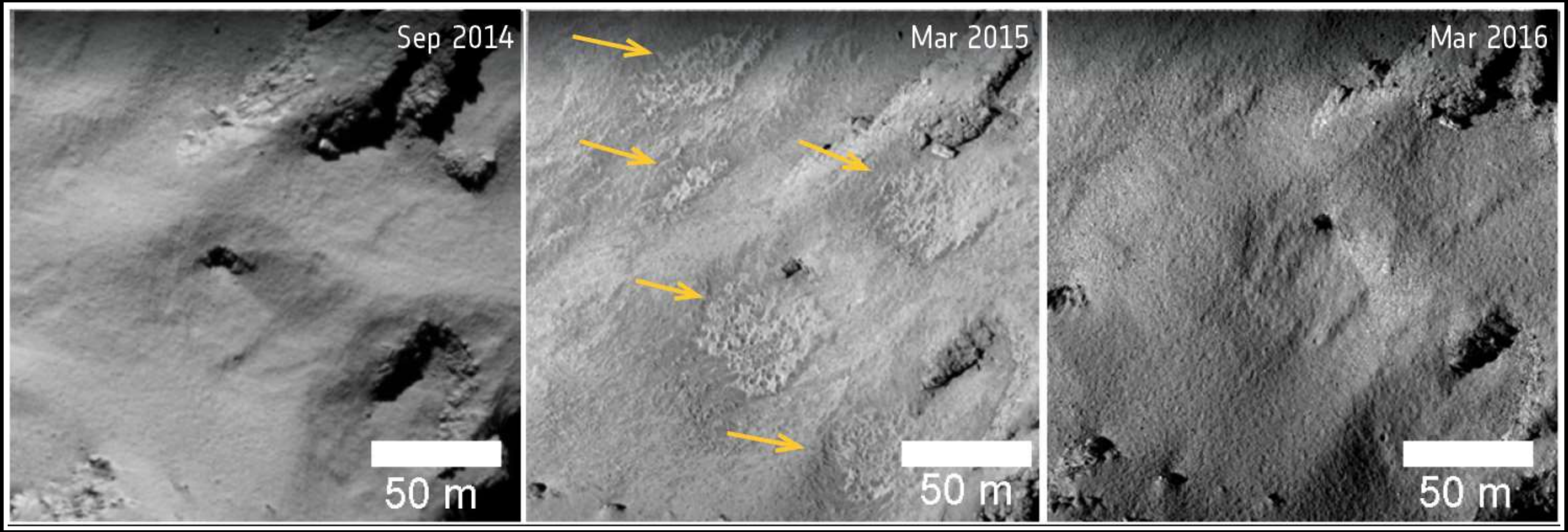

→ THE COMETARY ZOO: GASES DETECTED BY ROSETTA
esa
THE LONG CARBON CHAINS
Methane
Ethane
Propane
Butane
Pentane
Hexane
Heptane
THE AROMATIC RING COMPOUNDS
Benzene
Toluene
Xylene
Benzoic acid
Naphtalene
THE KING OF THE ZOO
Glycine (amino acid)
THE "MANURE SMELL" MOLECULES
Ammonia
Methylamine
Ethylamine
THE "POISONOUS" MOLECULES
Acetylene
Hydrogen cyanide
Acetonitrile
Formaldehyde
THE ALCOHOLS
Methanol
Ethanol
Propanol
Butanol
Pentanol
THE VOLATILES
Nitrogen
Oxygen
Hydrogen peroxide
Carbon monoxide
Carbon dioxide
THE "SMELLY" MOLECULES
Hydrogensulphide
Carbonylsulphide
Sulphur monoxide
Sulphur dioxide
Carbon disulphide
THE "SMELLY AND COLOURFUL"
Sulphur
Disulphur
Trisulphur
Tetrasulphur
Methanethiole
Ethanethiol
Thioformaldehyde
THE TREASURES WITH A HARD CRUST
Sodium
Potassium
Silicon
Magnesium
THE "SALTY" BEASTS
Hydrogen fluoride
Hydrogen chloride
Hydrogen bromide
Phosphorus
Chloromethane
THE BEAUTIFUL AND SOLITARY
Argon
Krypton
Xenon
THE "EXOTIC" MOLECULES
Formic acid
Acetic acid
Acetaldehyde
Ethylenglycol
Propylenglycol
Butanamide
THE MOLECULE IN DISGUISE
Cyanogen
www.esa.int
Credits: Based on data from ROSINA
European Space Agency




Surface changes on Comet 67P/C-G / ESA/Rosetta/MPS for OSIRIS team / El-Maarry et al. 2017, Science

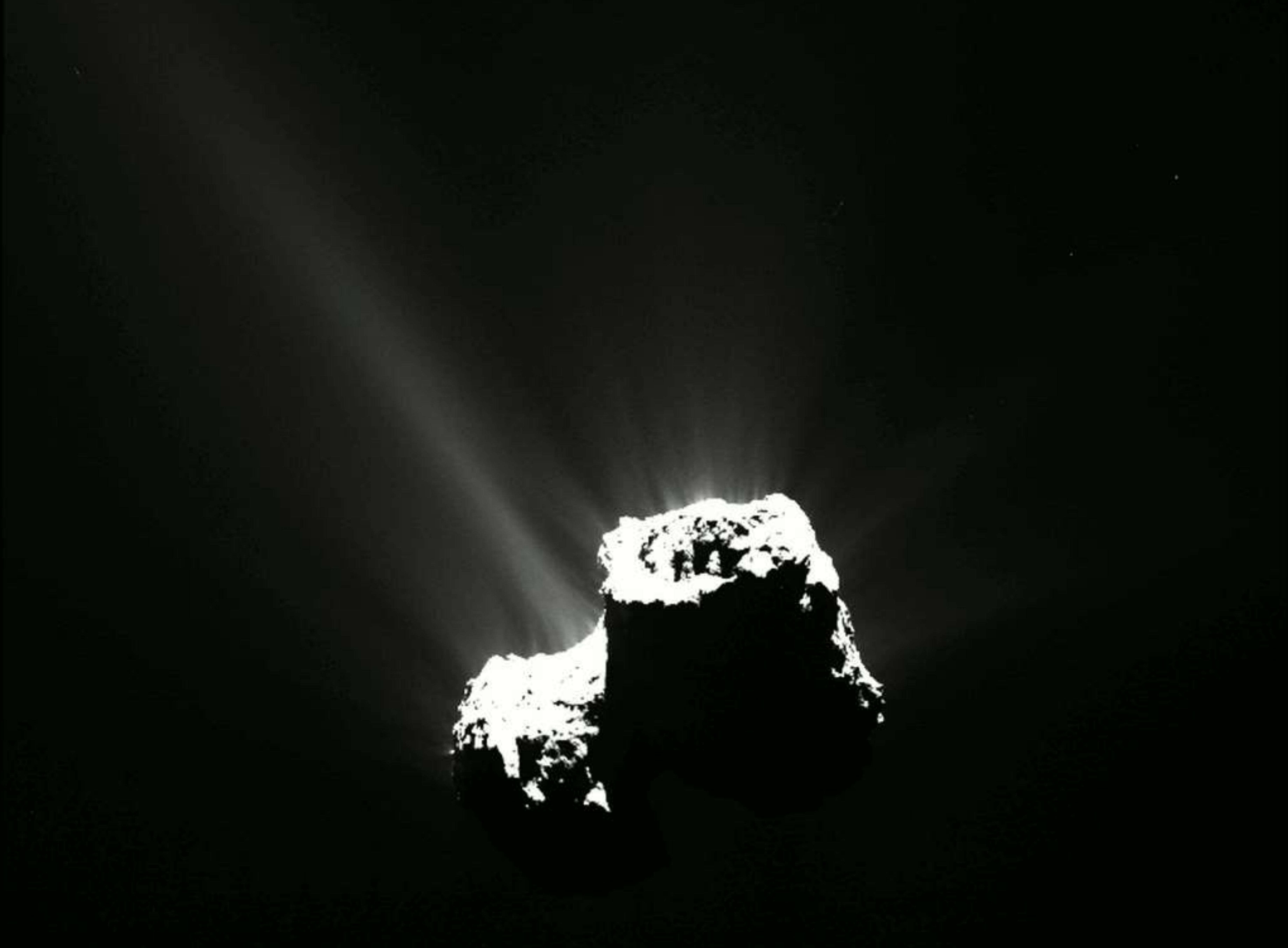



Surface changes on Comet 67P/C-G / ESA/Rosetta/MPS for OSIRIS team / El-Maarry et al. 2017, Science

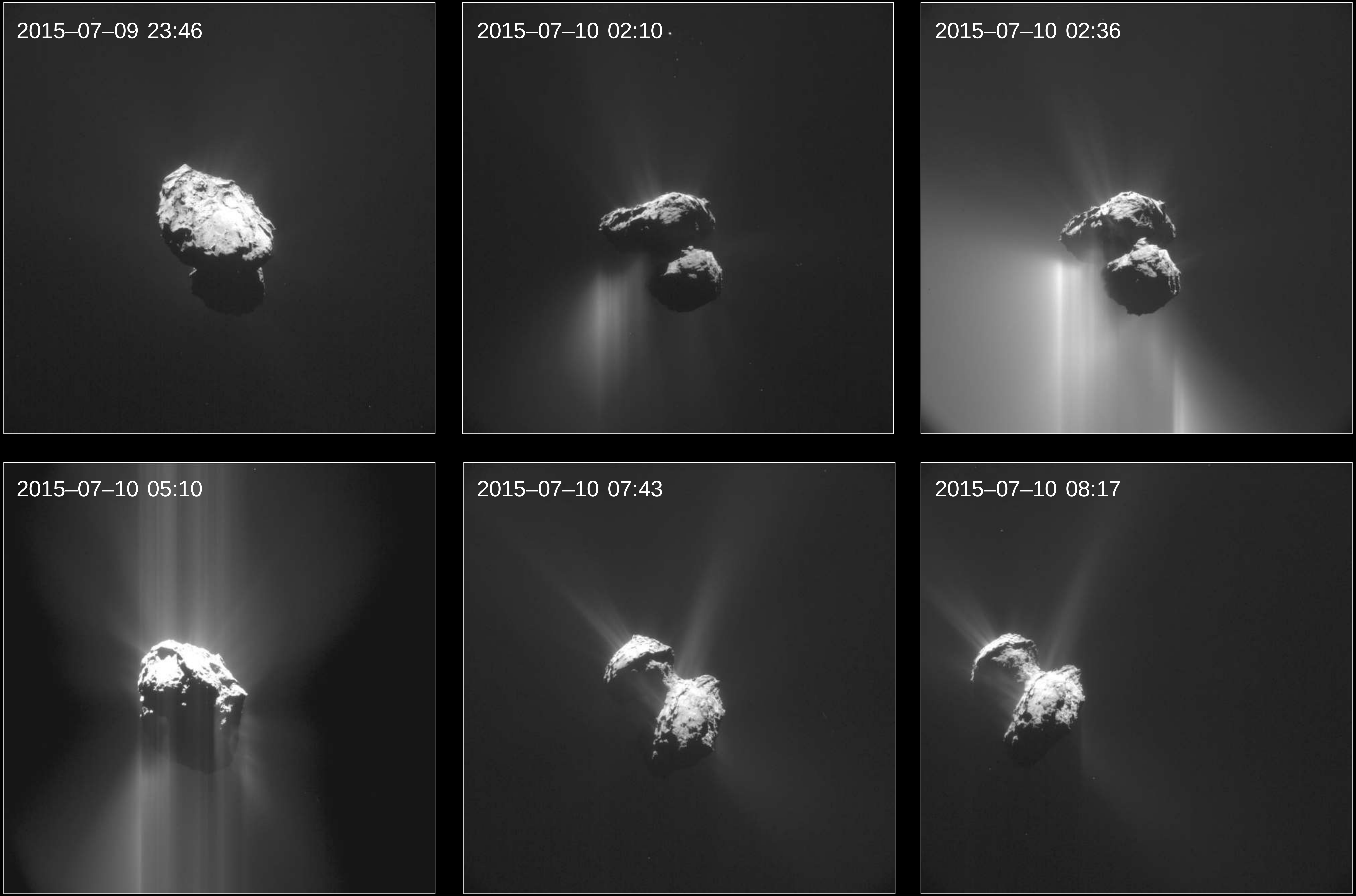



Surface changes on Comet 67P/C-G / ESA/Rosetta/MPS for OSIRIS team / El-Maarry et al. 2017, Science

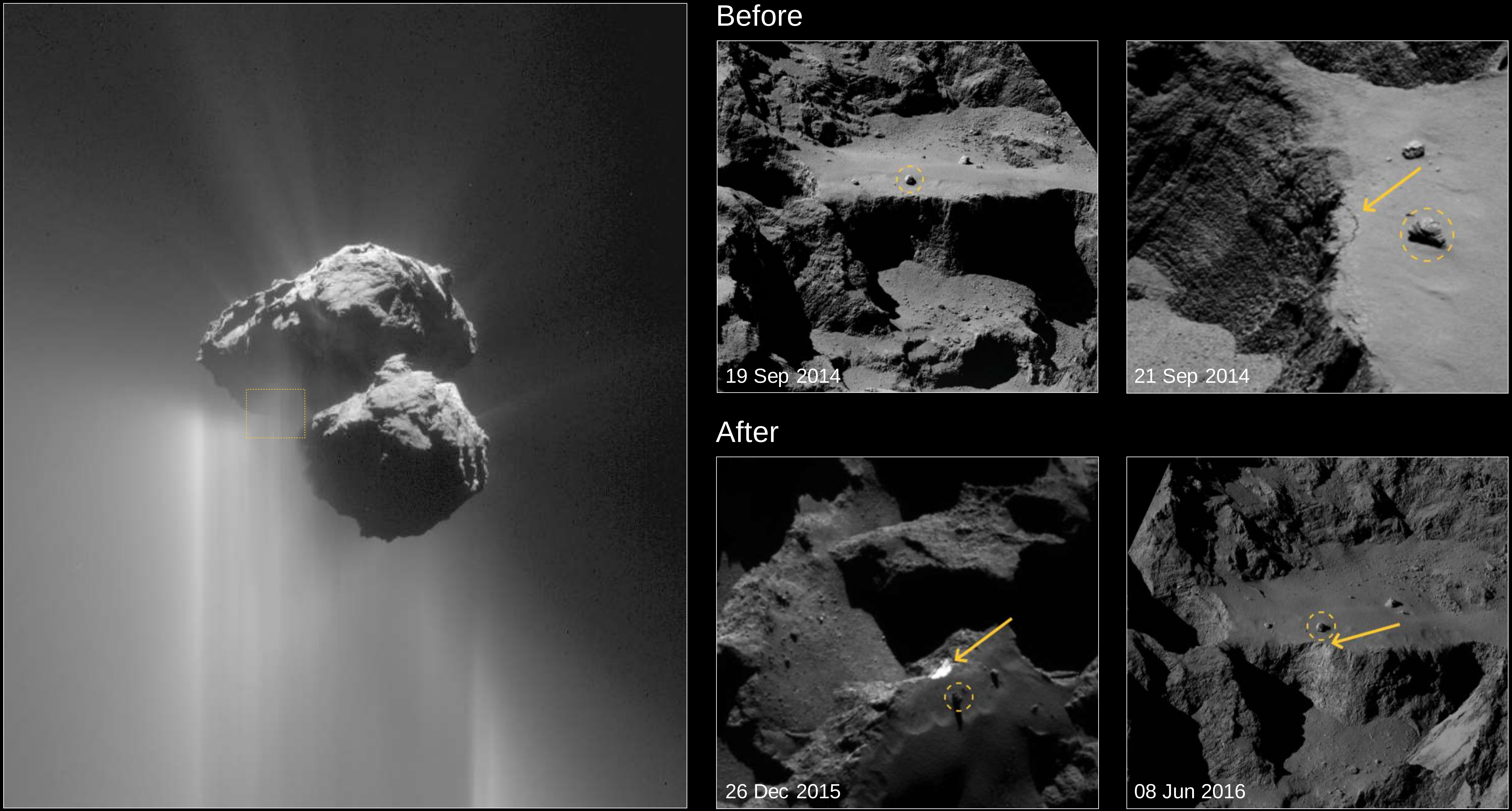
Comet 67P/C-G at 140km on 11 April 2015 / ESA/Rosetta/MPS for OSIRIS / Justin Cowart



Activity on 67P/C-G over roughly 8 hr period just before perihelion on 13 August 2015 / ESA/Rosetta/MPS for OSIRIS team




10 July 2015 outburst sequence from 155km / ESA/Rosetta/NAVCAM CC BY-SA 3.0 IGO




Aswan cliff-collapse driven outburst on Comet 67P/C-G on 10 July 2015 / Pajola et al. 2017, Nature

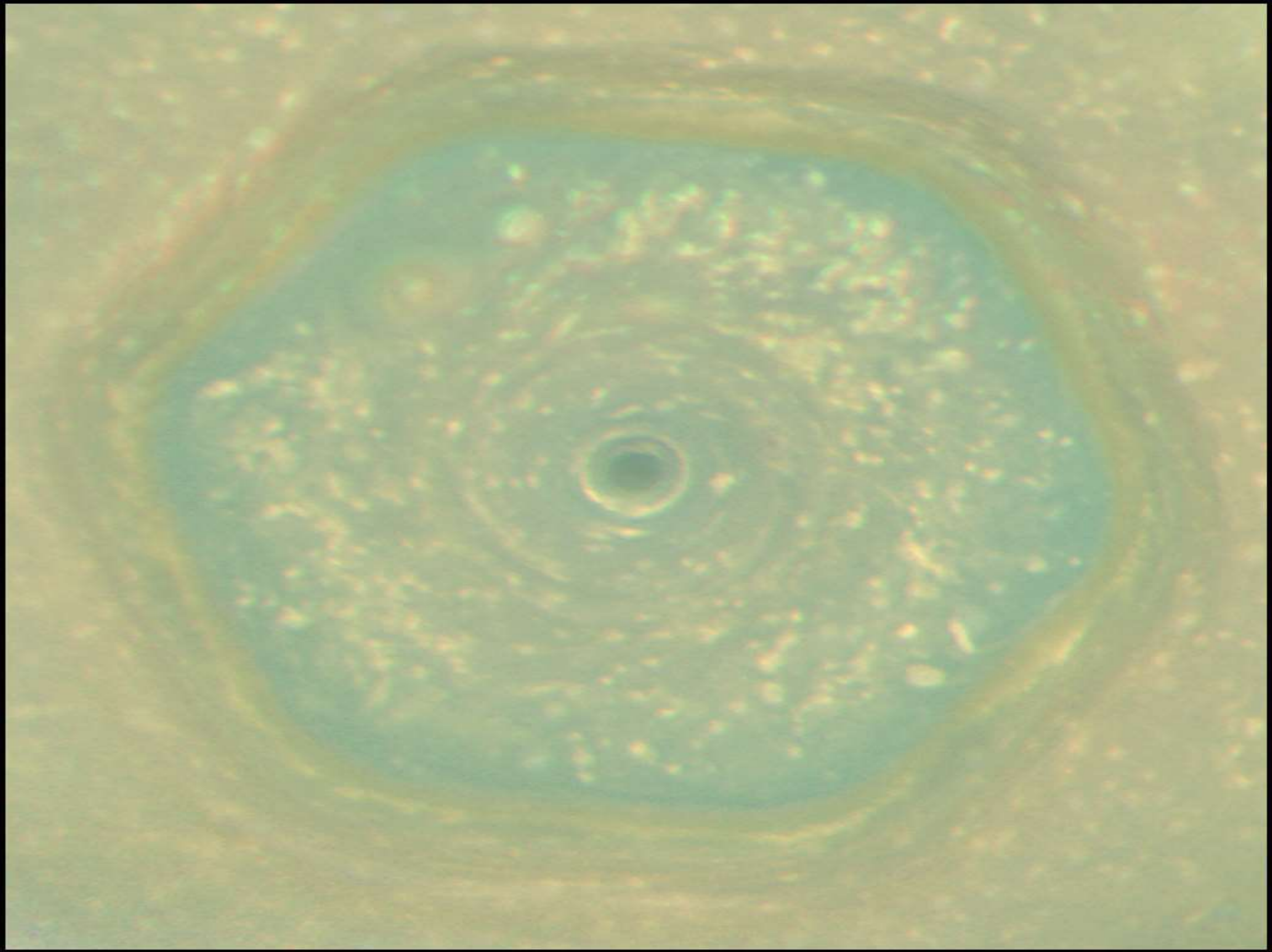
Aswan cliff collapse, before and after / Pajola et al. 2017, Nature

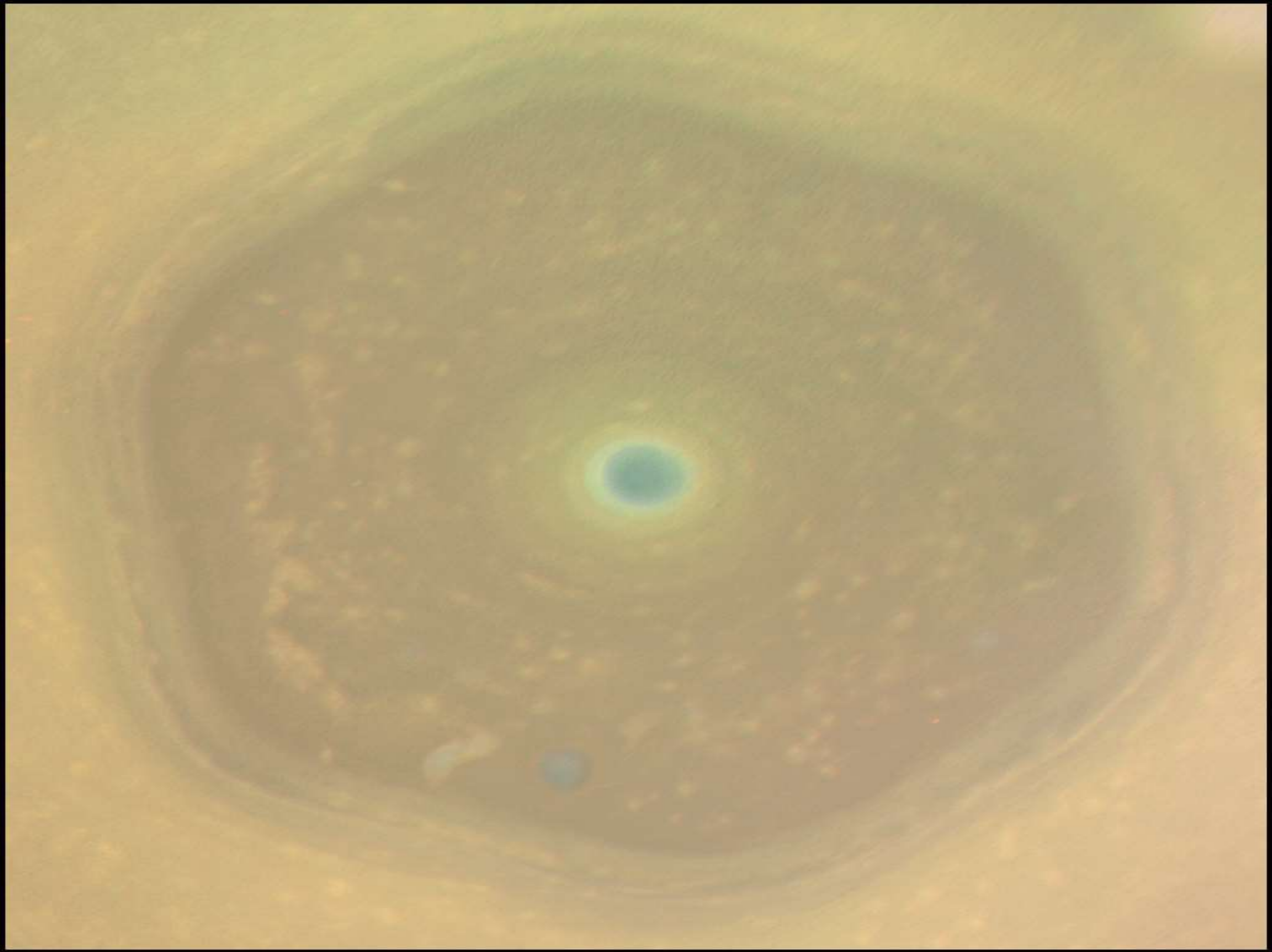
ESA/Rosetta/MPS for OSIRIS team/Scholten & Preusker

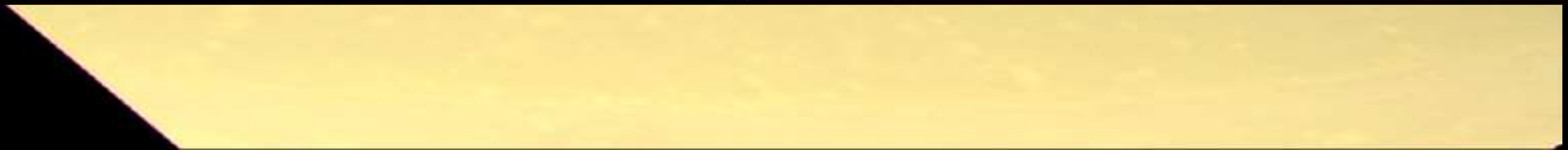
# Cassini Science Highlights:
# Ring Grazing & Grand Finale Orbits

# Hazy Days Ahead Within the Hexagon

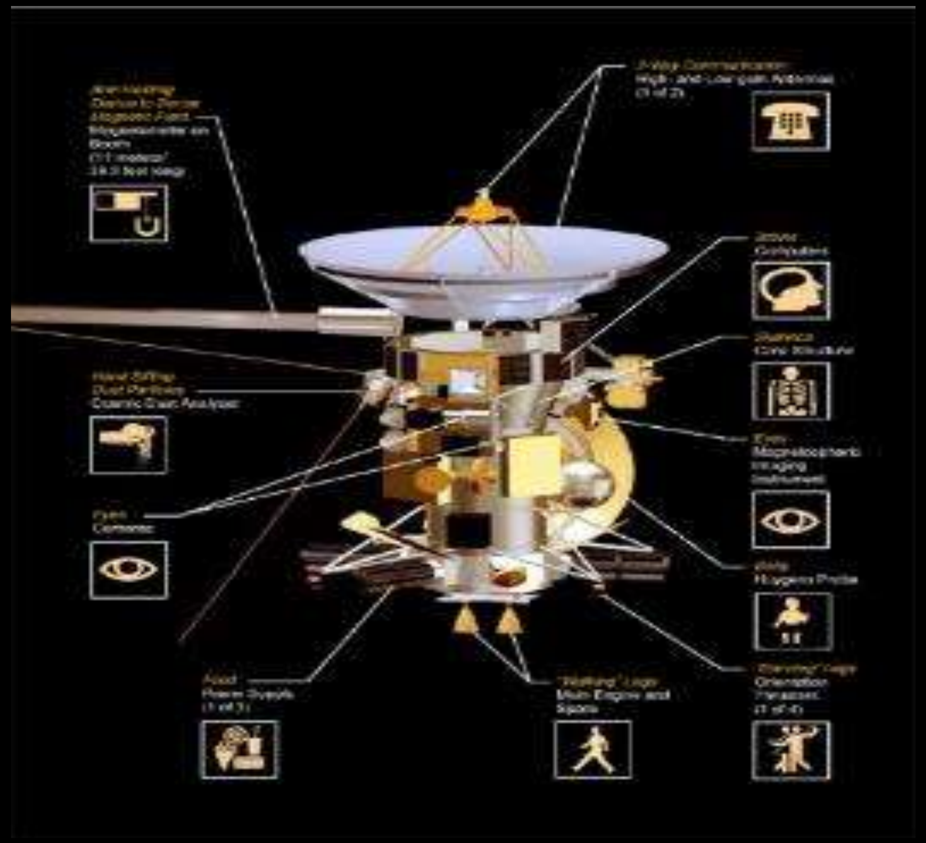
November 2012

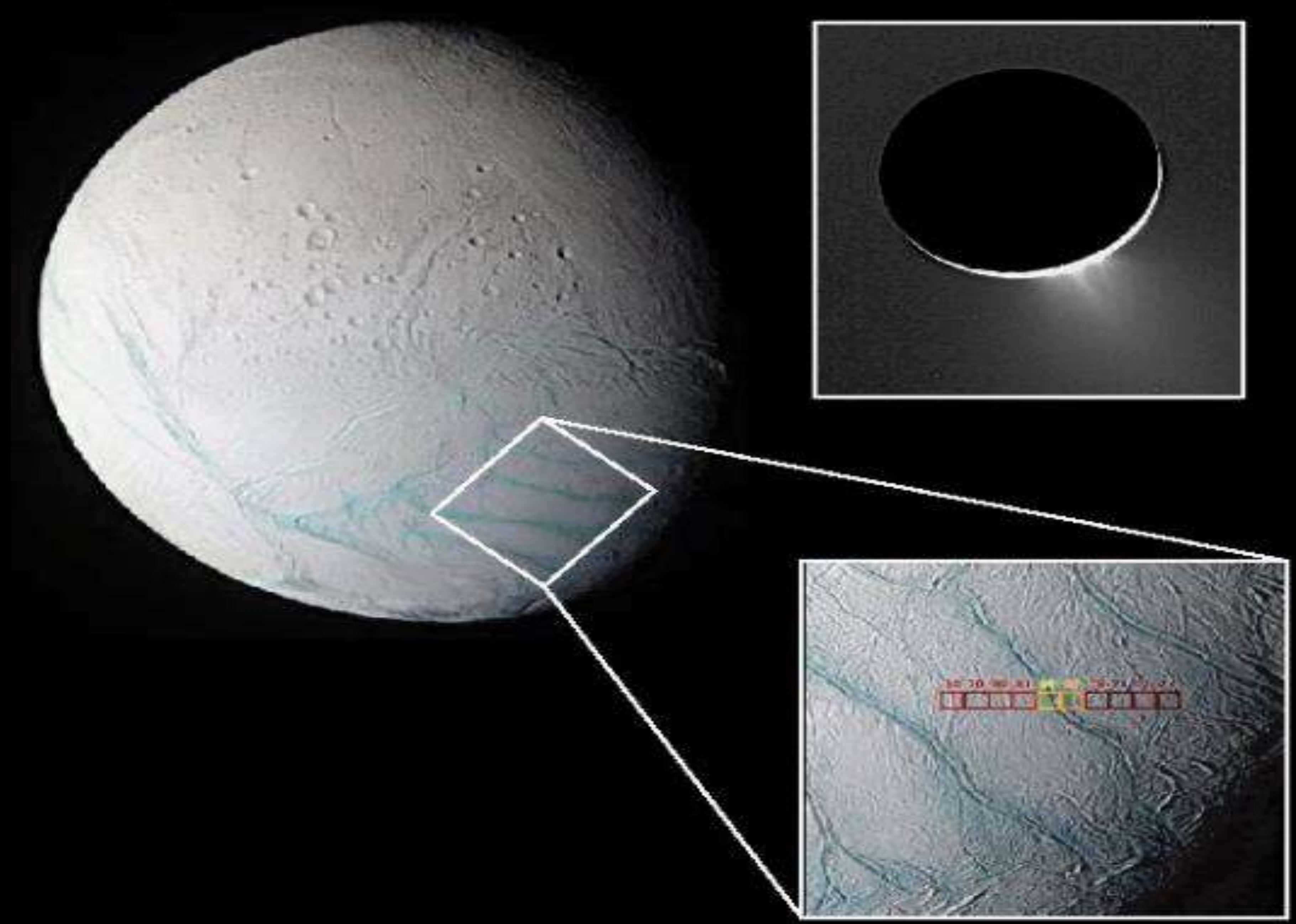




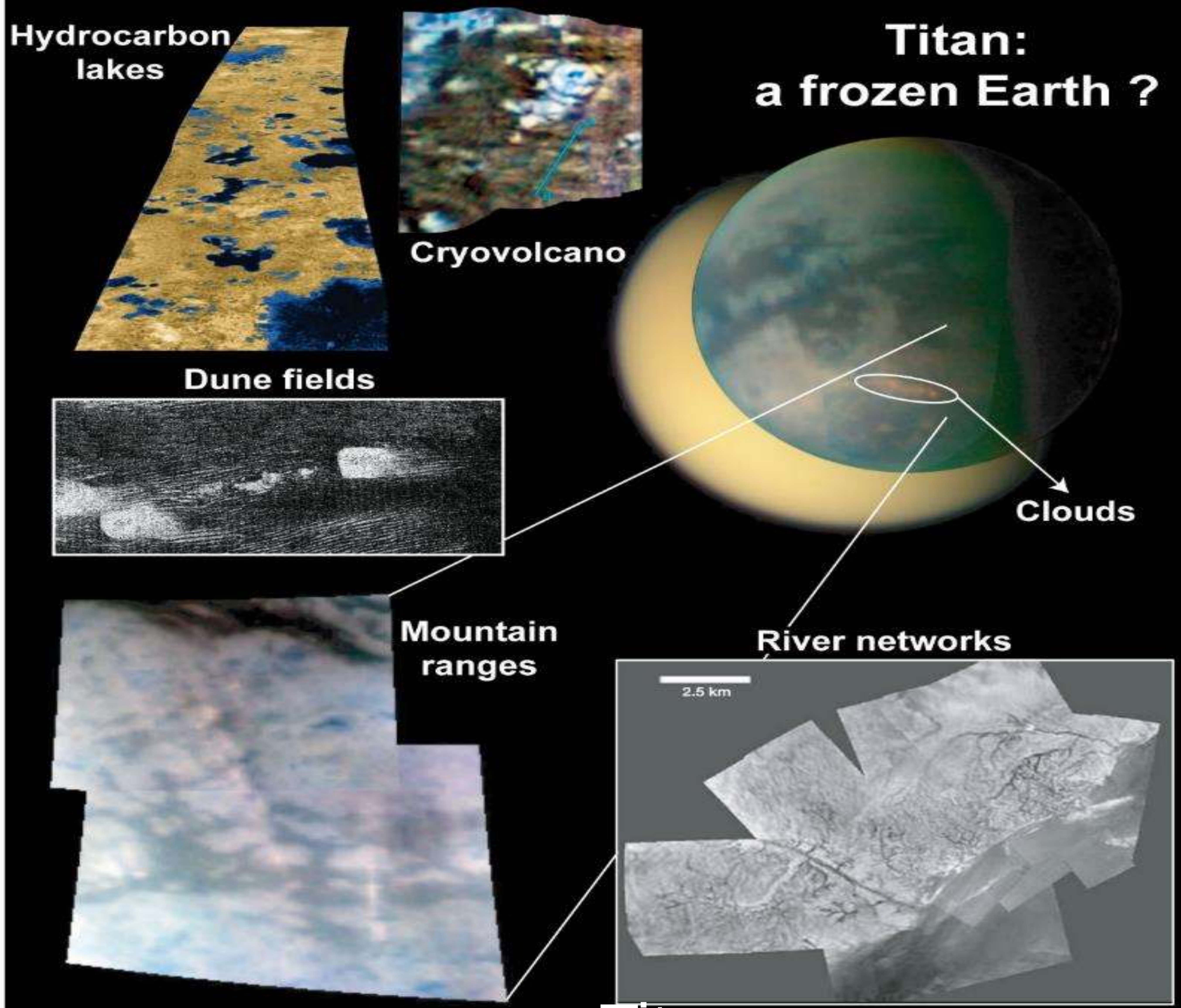


# Cassini-Huygens (2004-2017) reveals Titan and

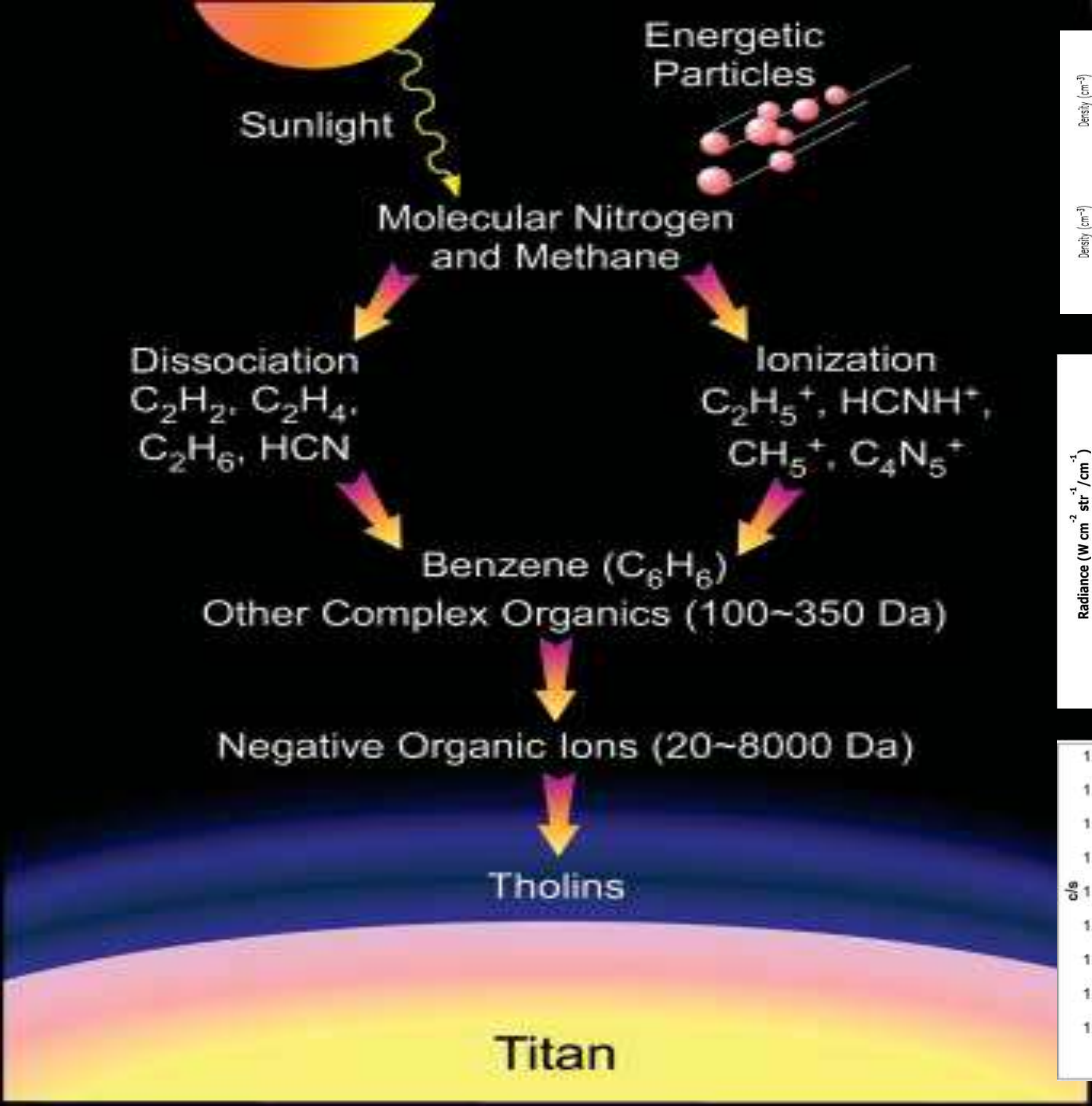




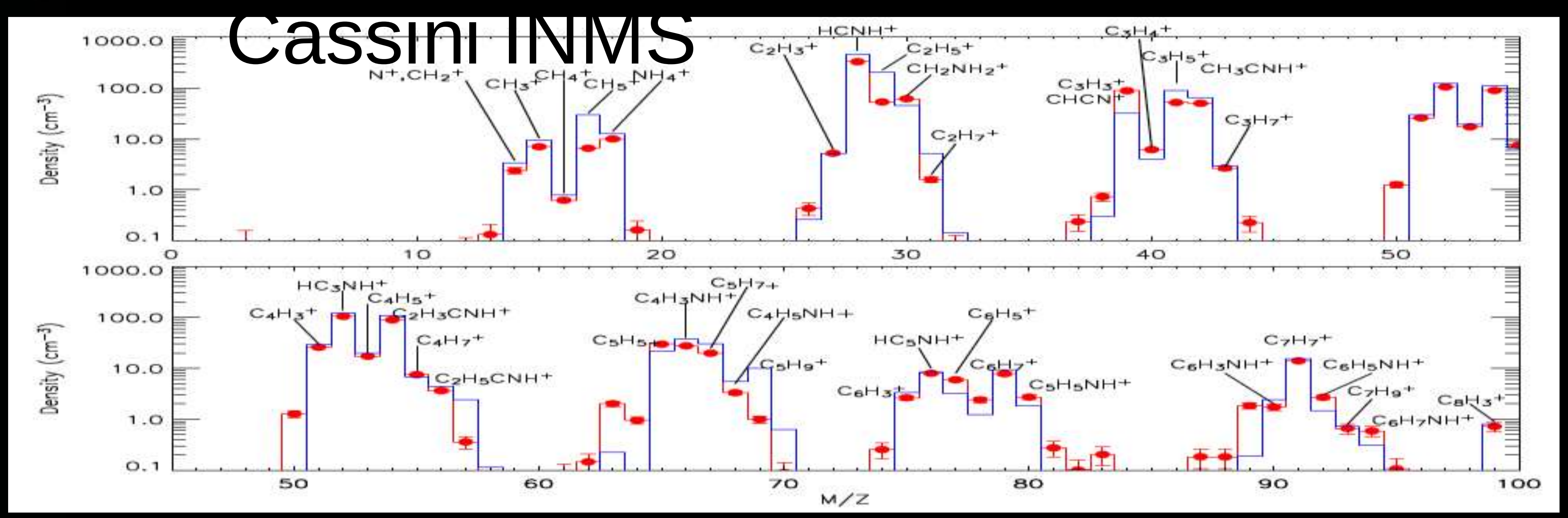
Enceladus



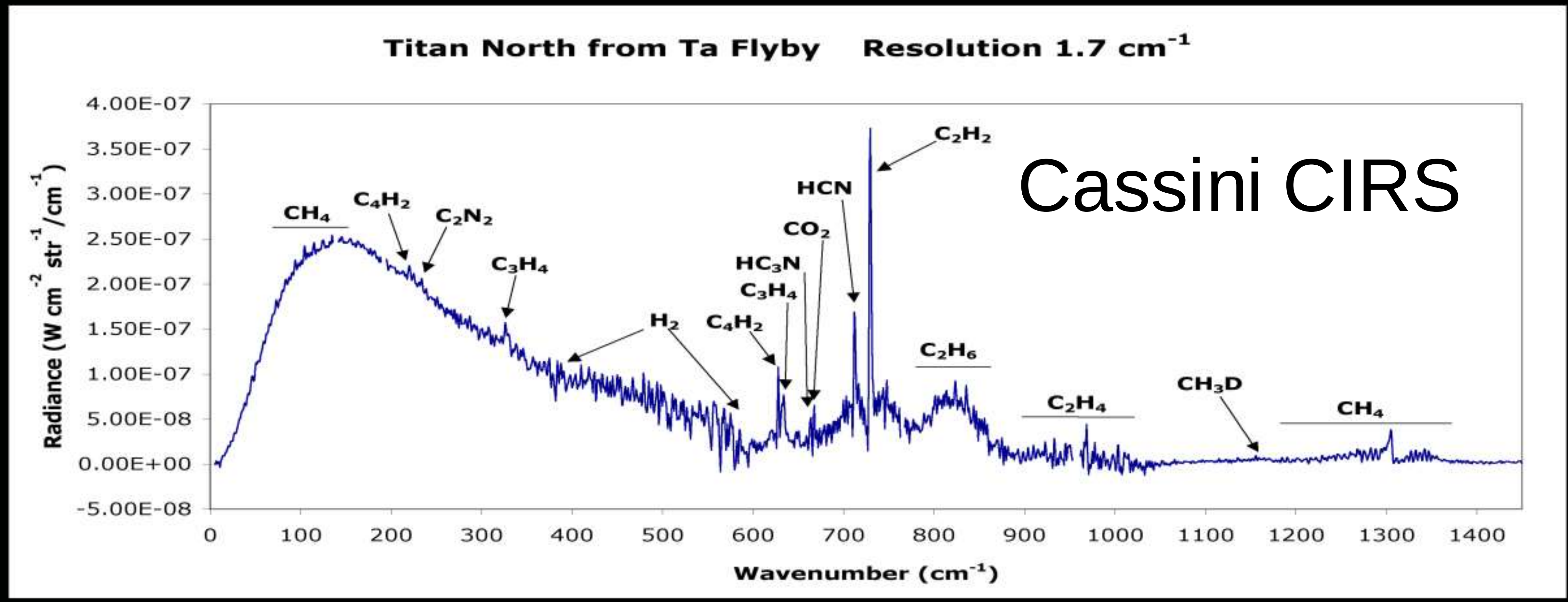

Titan



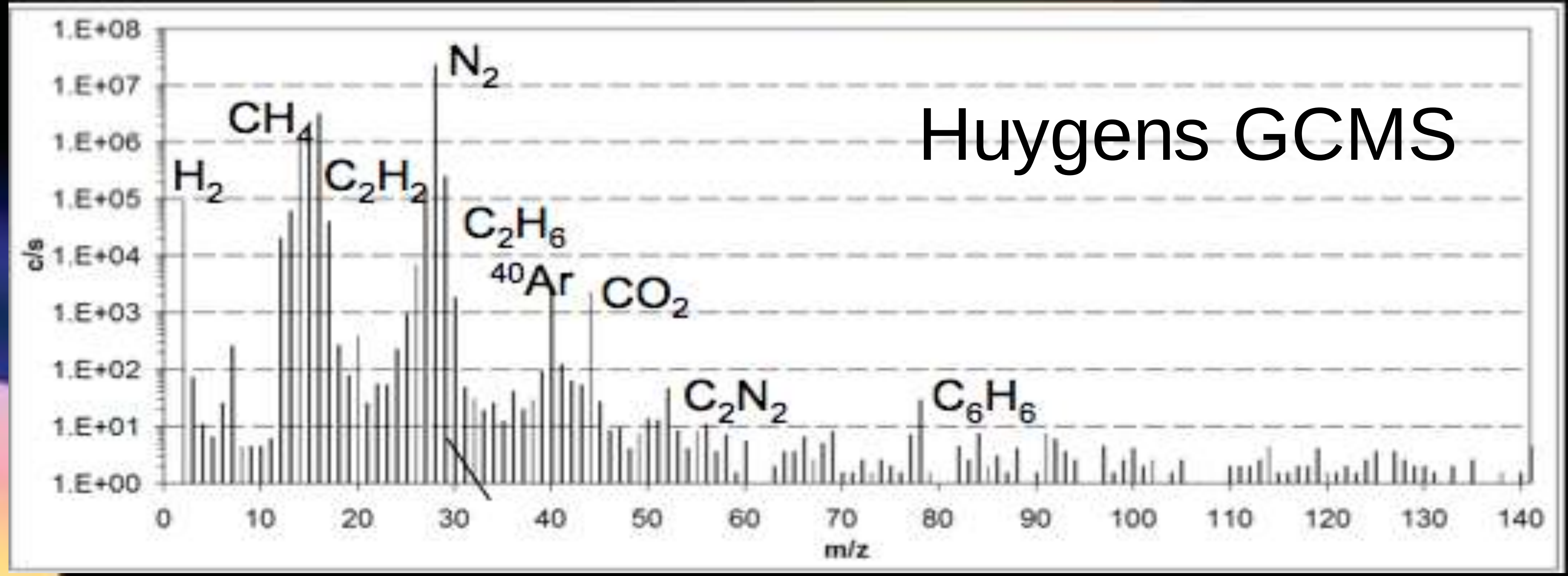
Sunlight
Energetic Particles
Molecular Nitrogen and Methane
Dissociation
$C_2H_2$, $C_2H_4$, $C_2H_6$, HCN
Ionization
$C_2H_5^+$, $HCNH^+$, $CH_5^+$, $C_4N_5^+$
Benzene ($C_6H_6$)
Other Complex Organics (100~350 Da)
Negative Organic Ions (20~8000 Da)
Tholins
Titan

Cassini INMS
Density ($cm^{-3}$)
M/Z

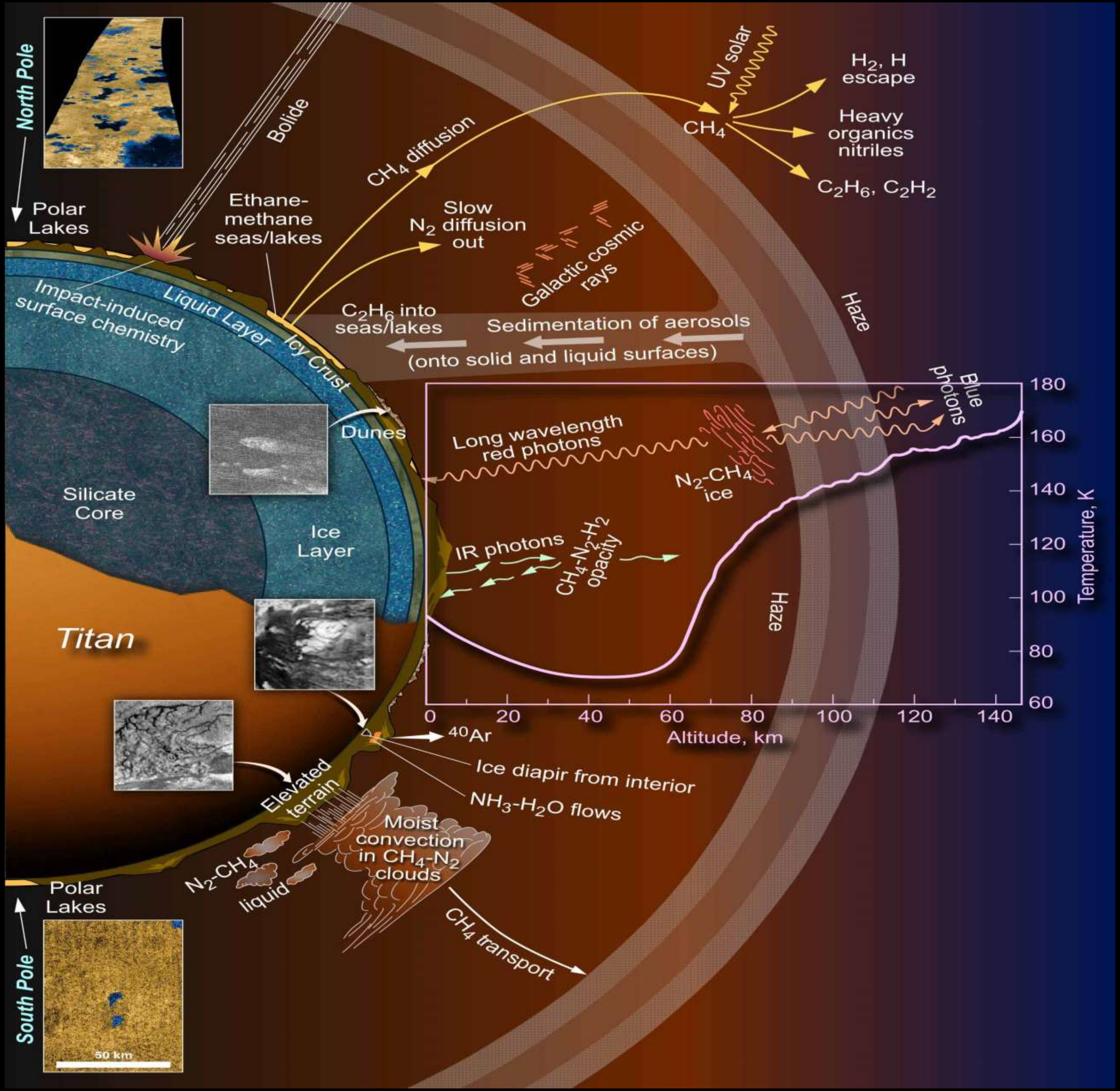
Titan North from Ta Flyby Resolution 1.7 $cm^{-1}$
Cassini CIRS
Radiance (W $cm^{-2}$ $str^{-1}$/$cm^{-1}$)
Wavenumber ($cm^{-1}$)
$CH_4$
$C_4H_2$
$C_2N_2$
$C_3H_4$
$H_2$
HCN
$CO_2$
$HC_3N$
$C_2H_2$
$C_2H_6$
$C_2H_4$
$CH_3D$

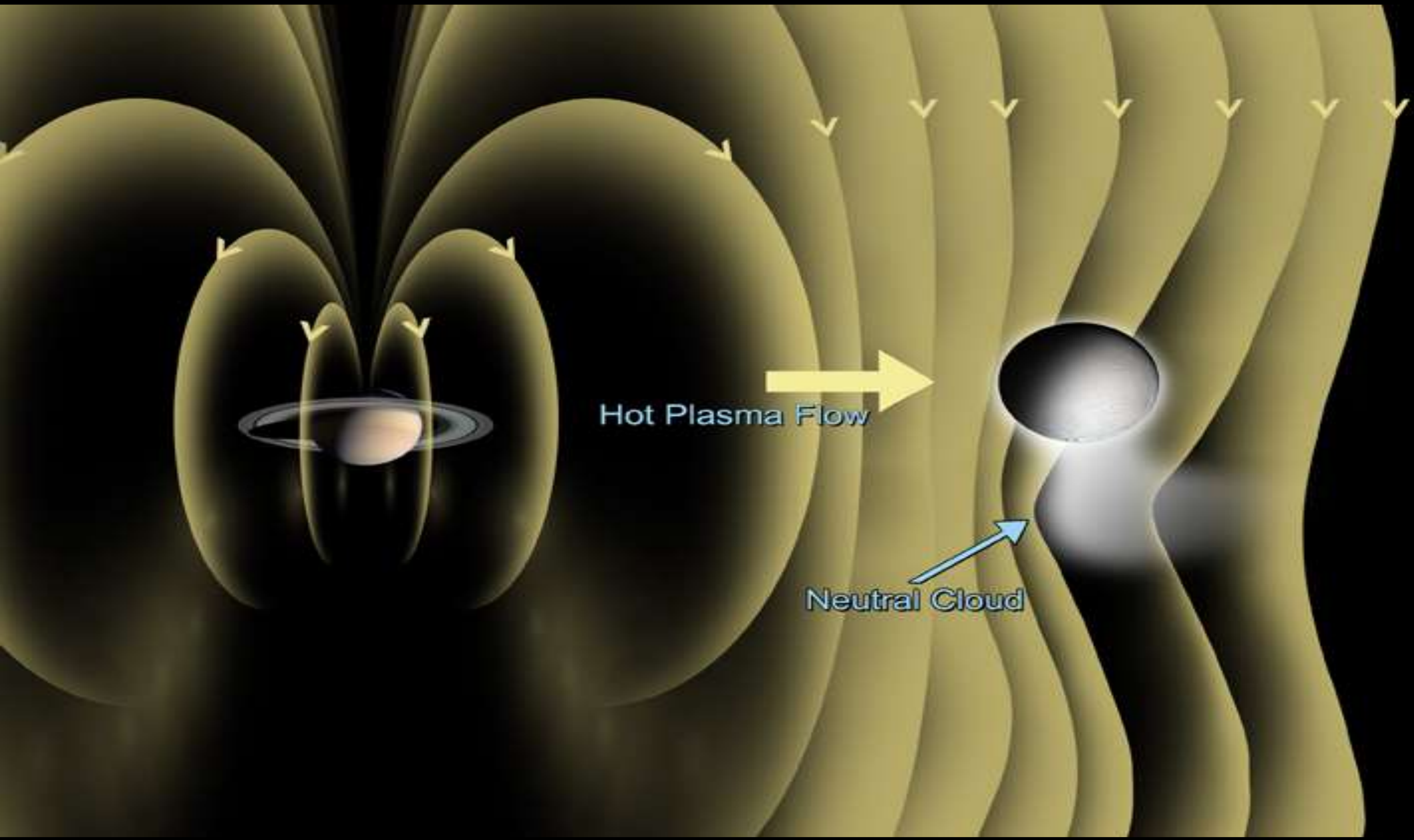
Huygens GCMS
c/s
m/z
$H_2$
$CH_4$
$C_2H_2$
$N_2$
$C_2H_6$
$^{40}Ar$
$CO_2$
$C_2N_2$
$C_6H_6$

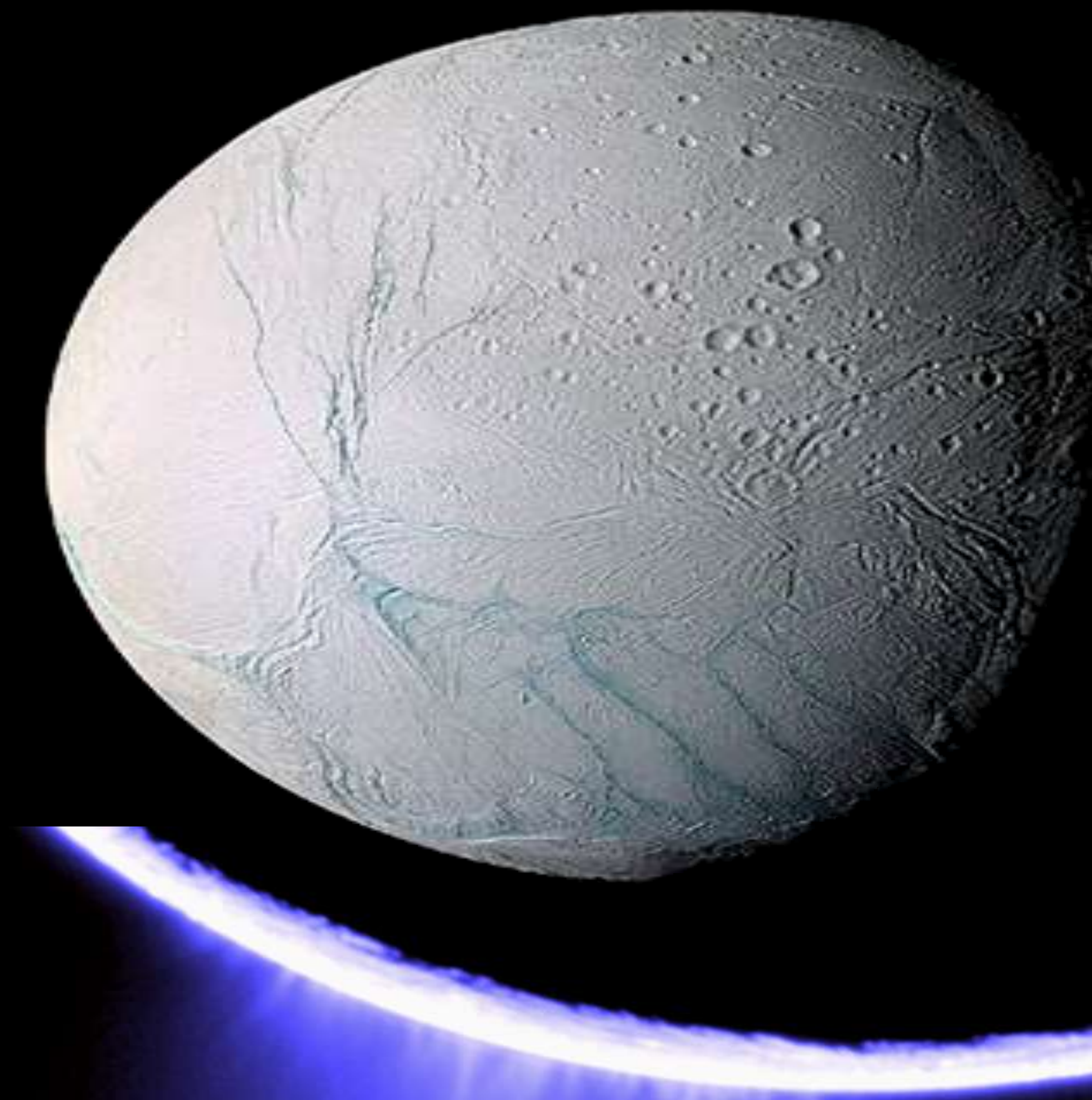
# Titan as an astrobiological object

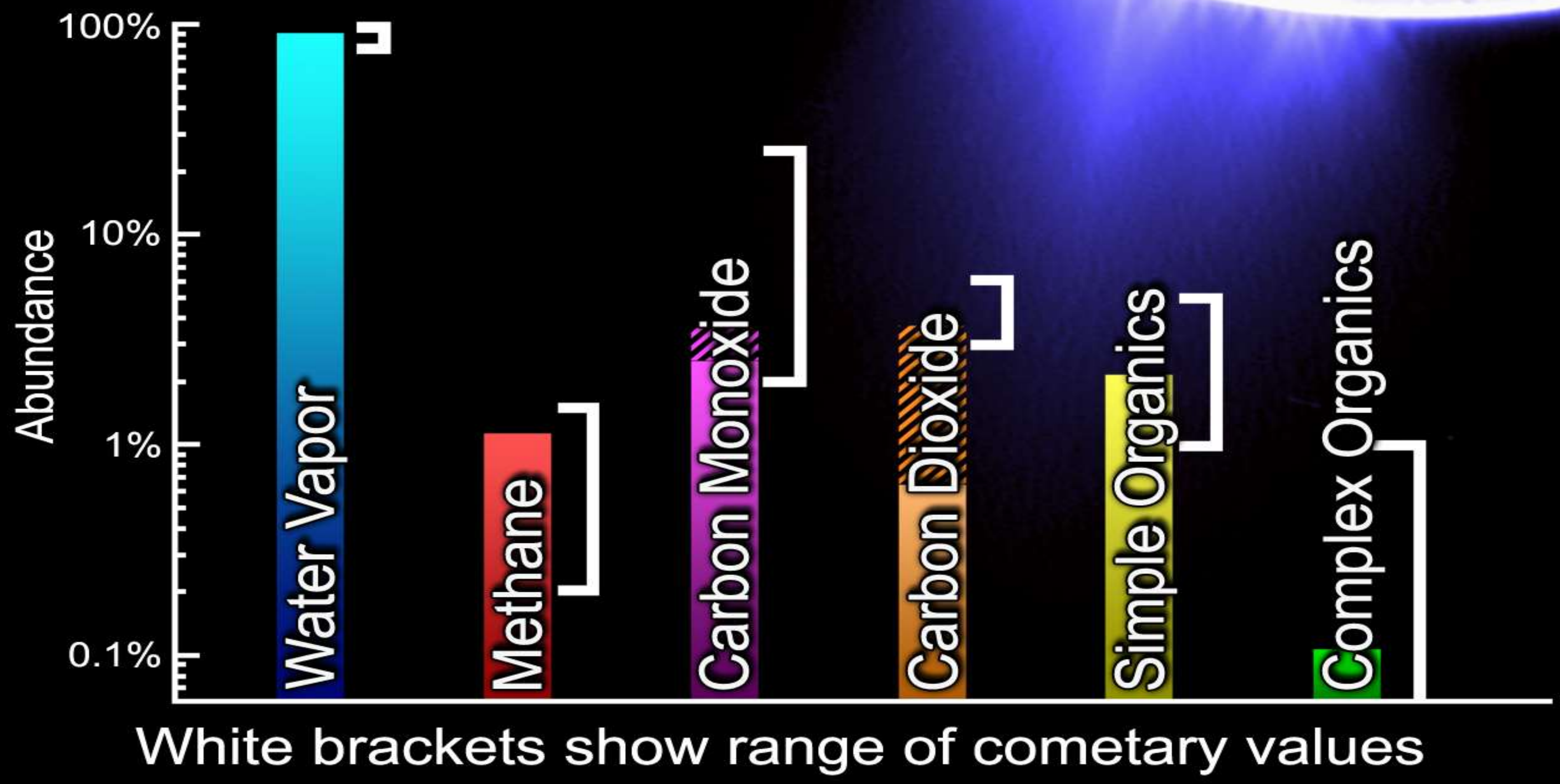
- The physical conditions
- The organic chemistry
- The methane cycle
- The undersurface water ocean
- Climatology/seasonal effects



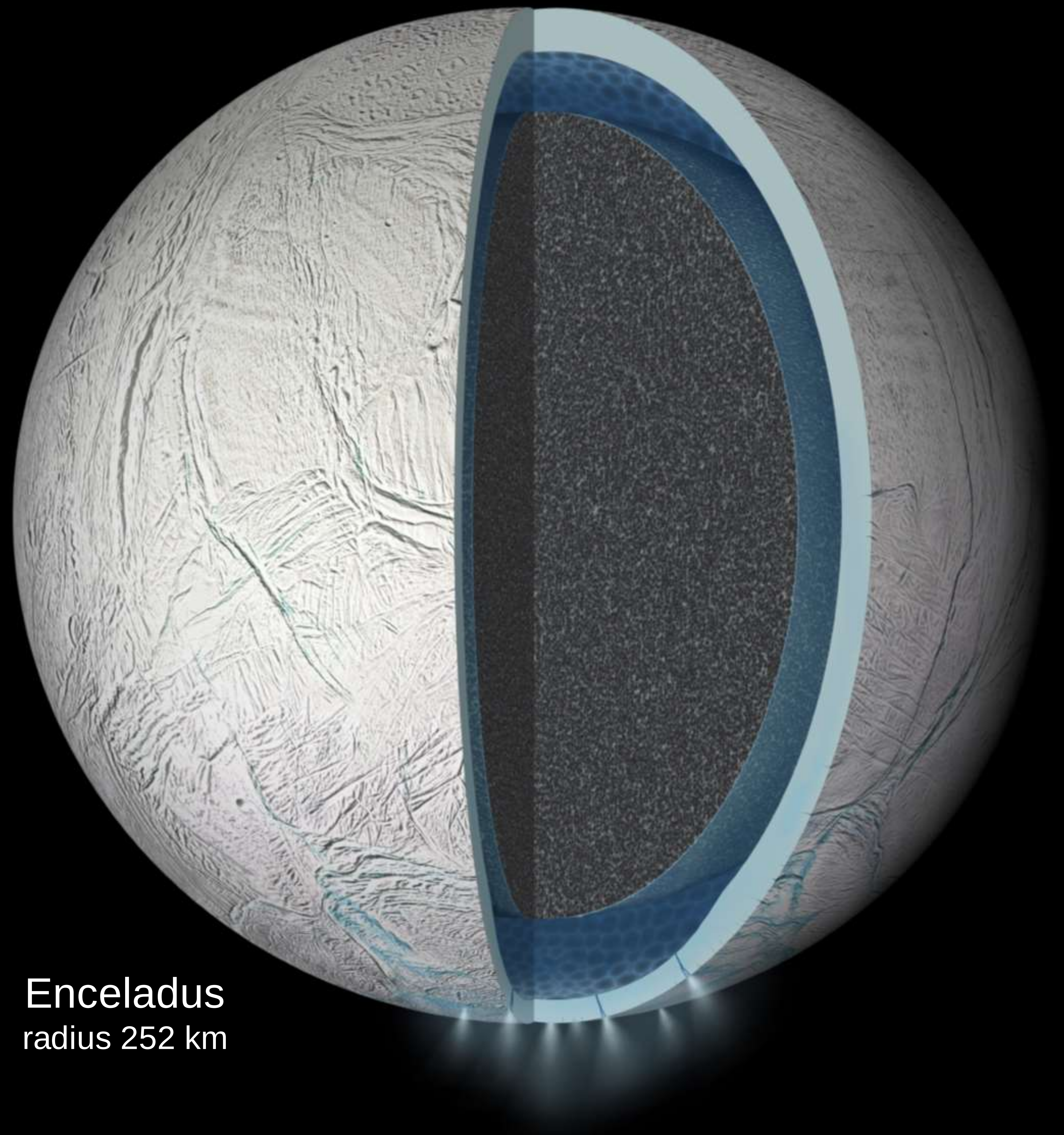
# Enceladus plumes

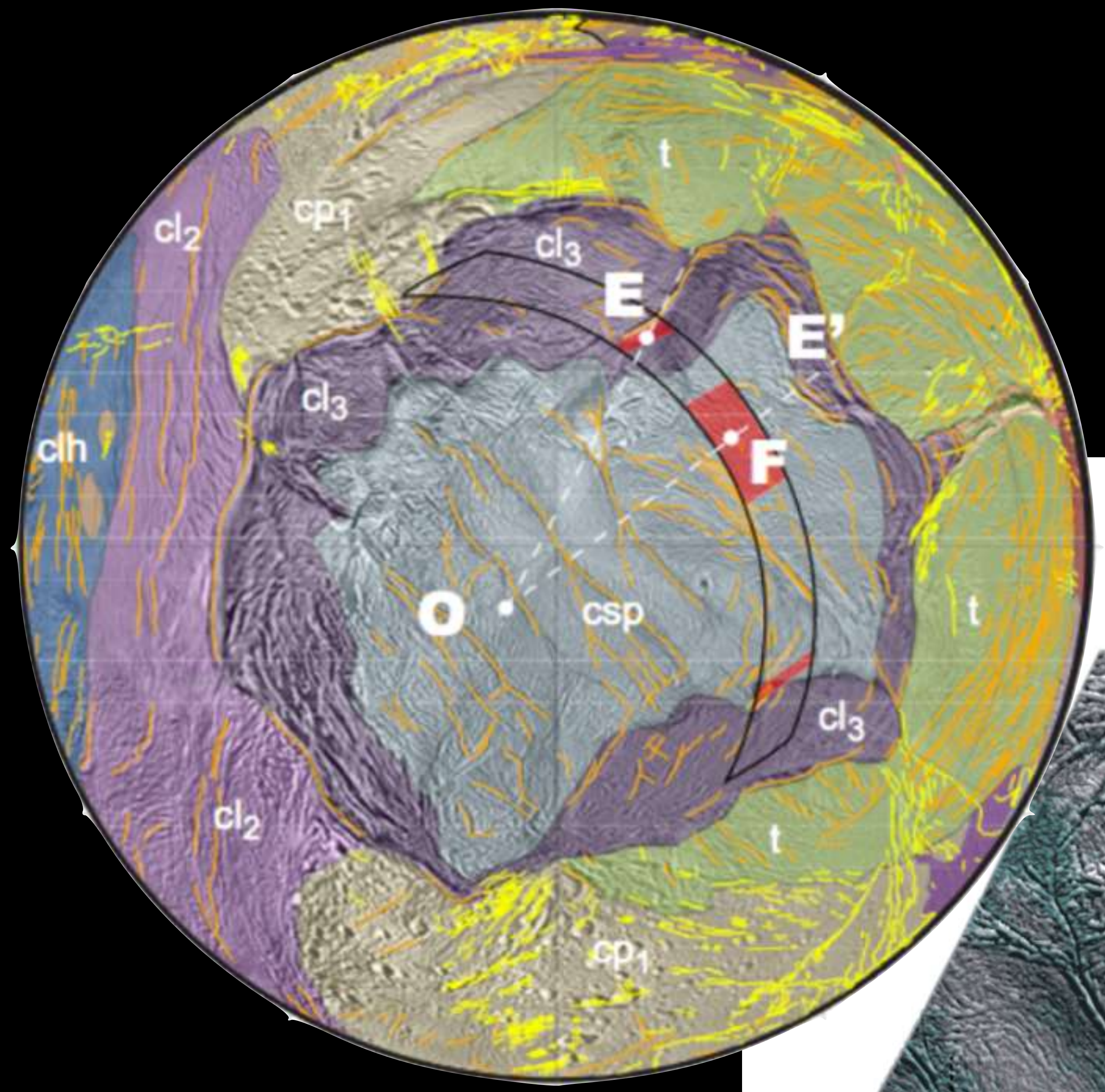


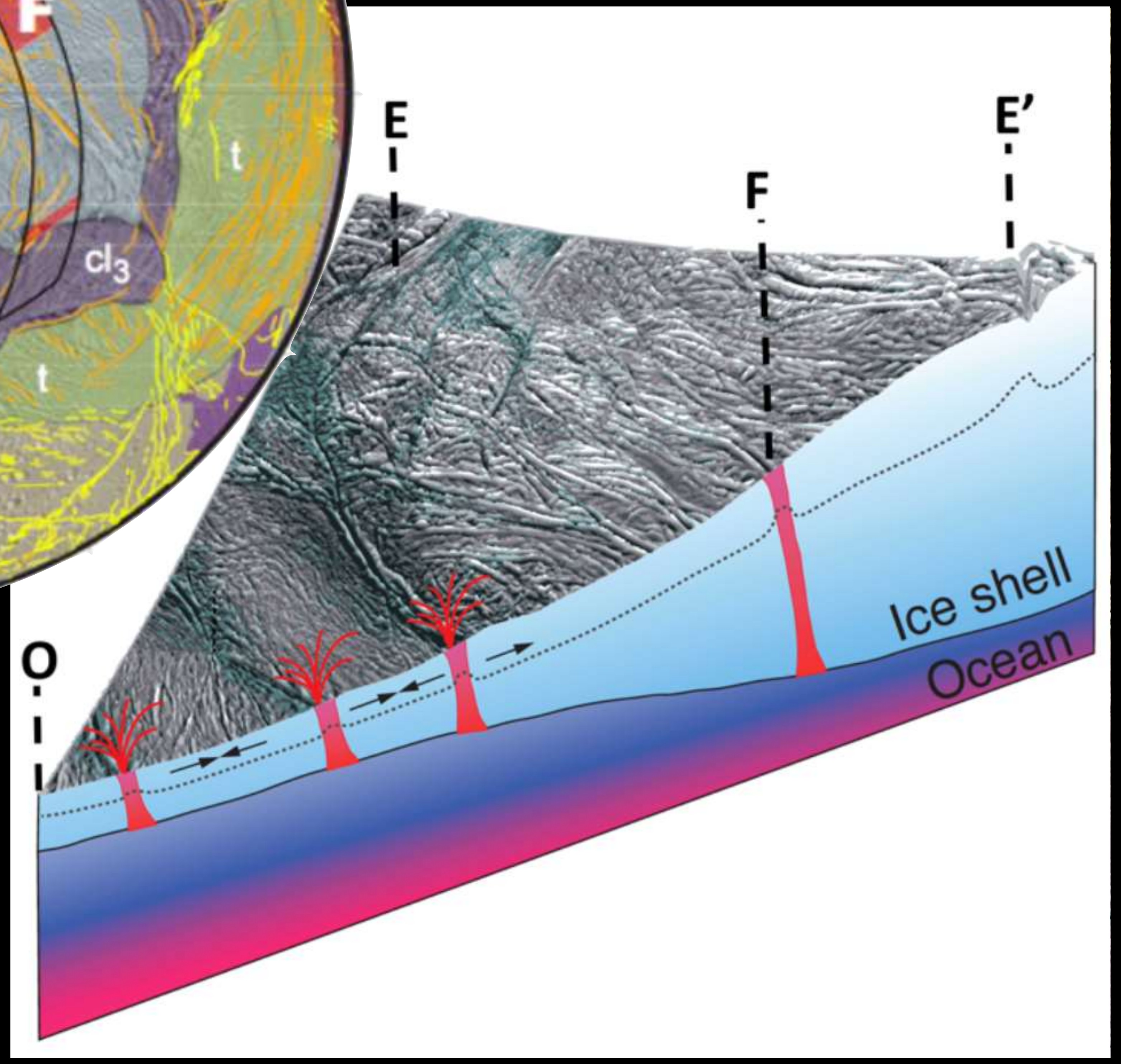






- **What is the origin of the plumes**
- **Replenishment of E-ring?**
- **Water vapor ejecta far away from the Sun** (strong implications for the habitability zones)
- **Indications for the presence of organic chemistry**



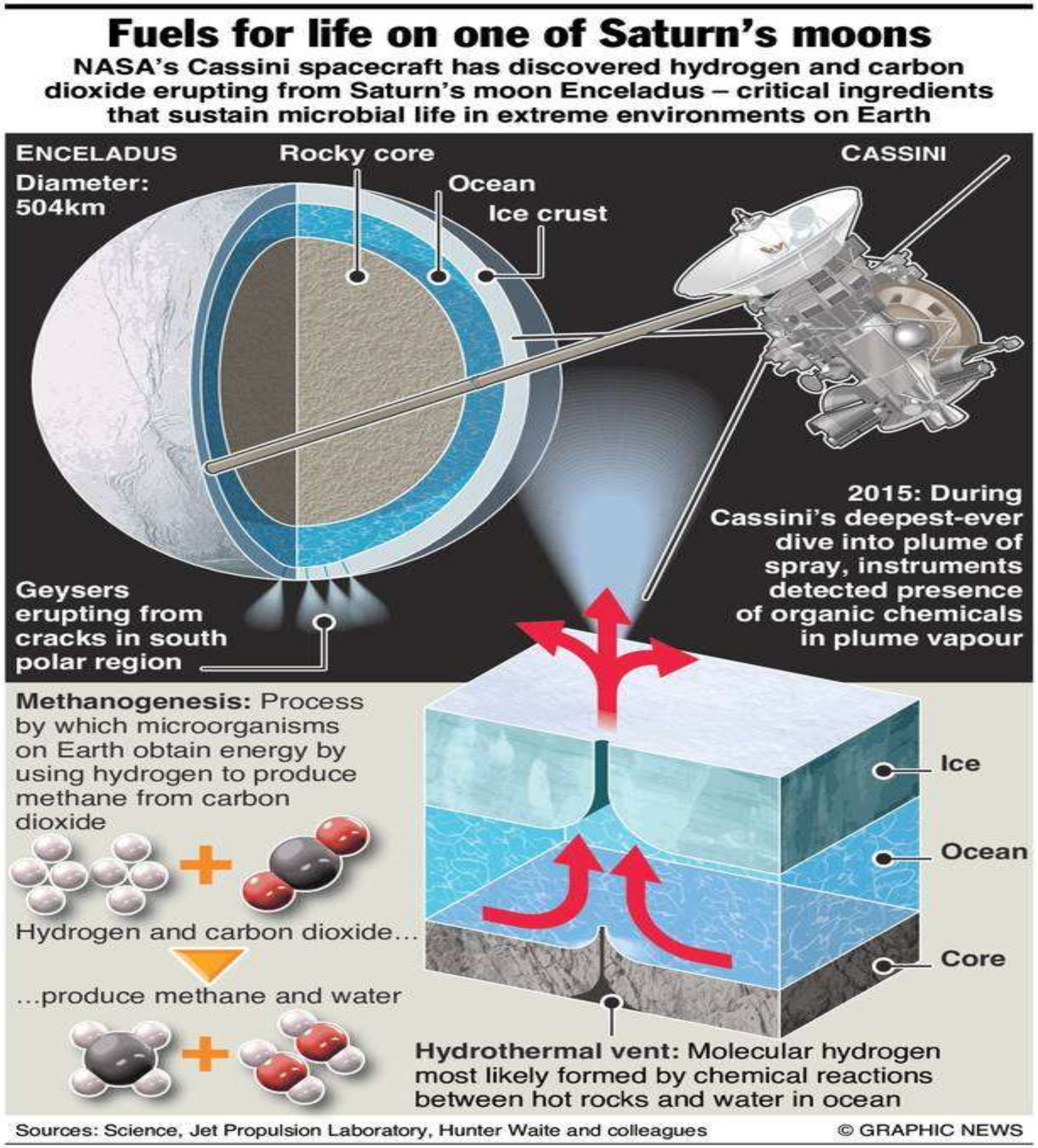




Radar scans of Enceladus south pole & fractures at 2.2cm

Thermal anomalies revealed associated with fractures: brightness temperature 32–60K

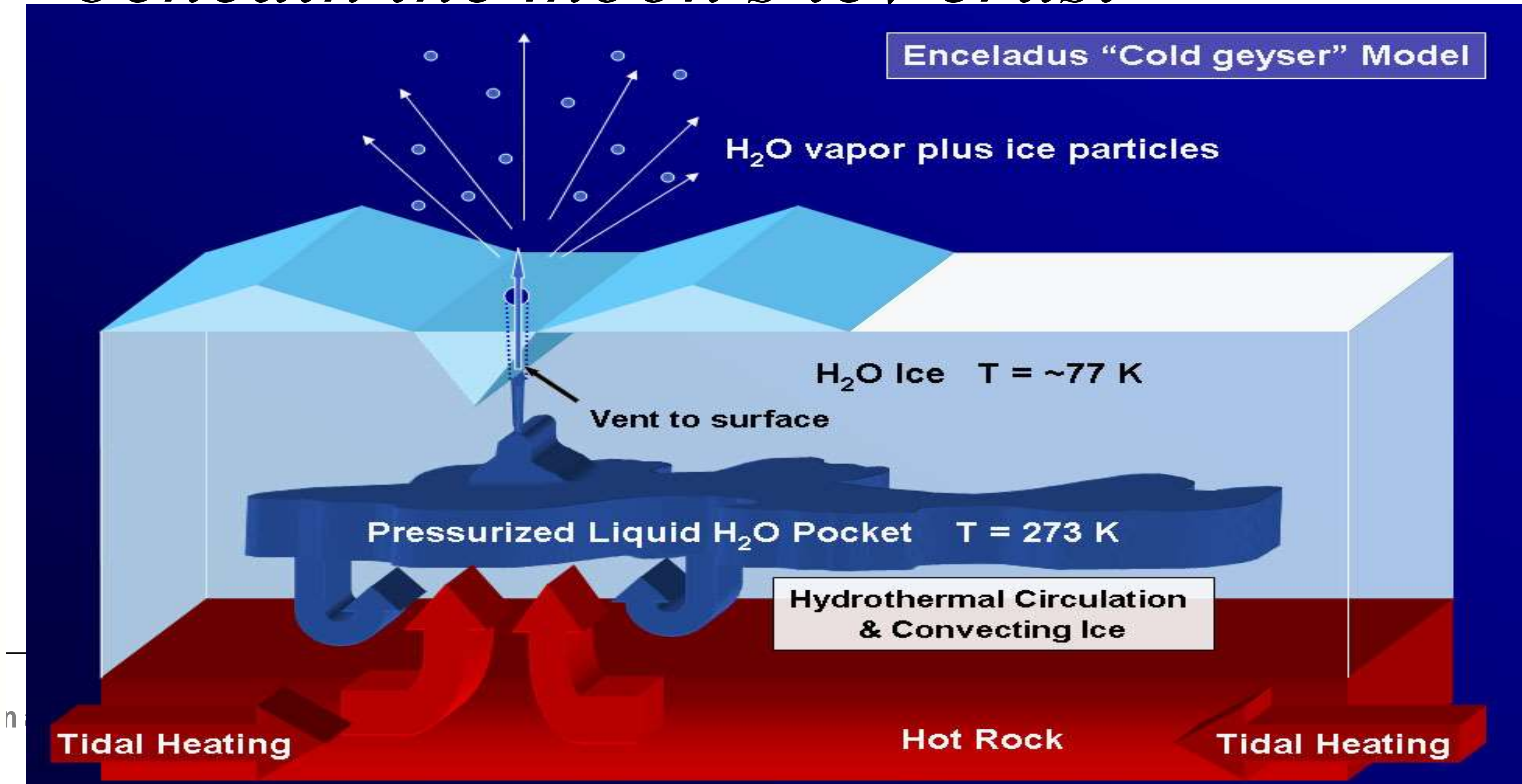
Suggests warm water even closer to surface than before: 2–5km thick ice only

Thermal anomalies on Enceladus / Cassini/NASA/ESA/ASI / Le Gall et al. 2017, Nature Astronomy

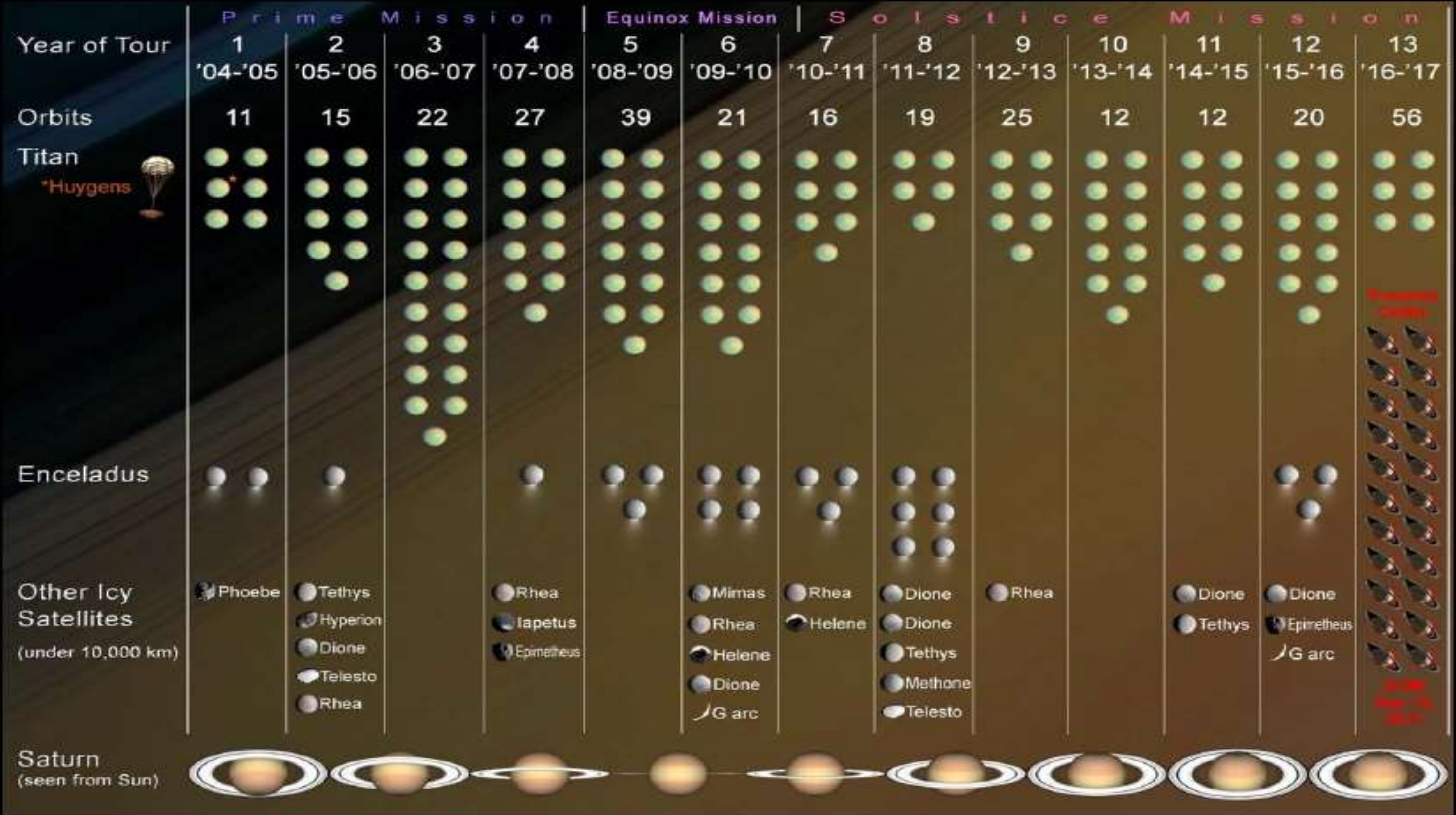



# Activity in Enceladus

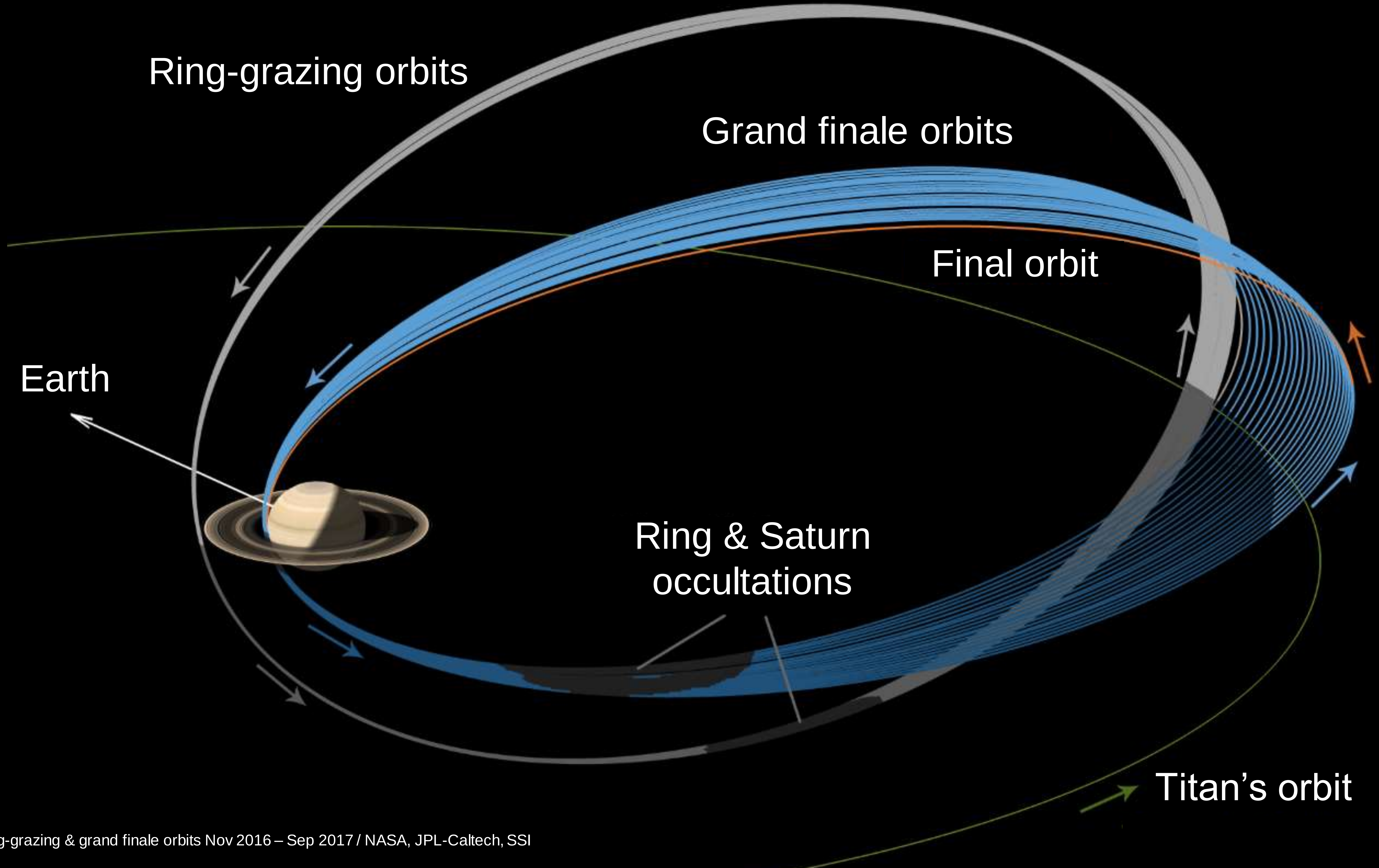
*April 2017 : The discovery of* <u>*hydrogen gas*</u> *and the evidence for ongoing hydrothermal activity on Enceladus, along with the other organics and the water, suggest that habitable conditions could exist beneath the moon's icy crust*



# Cassini-Huygens Mission Timeline

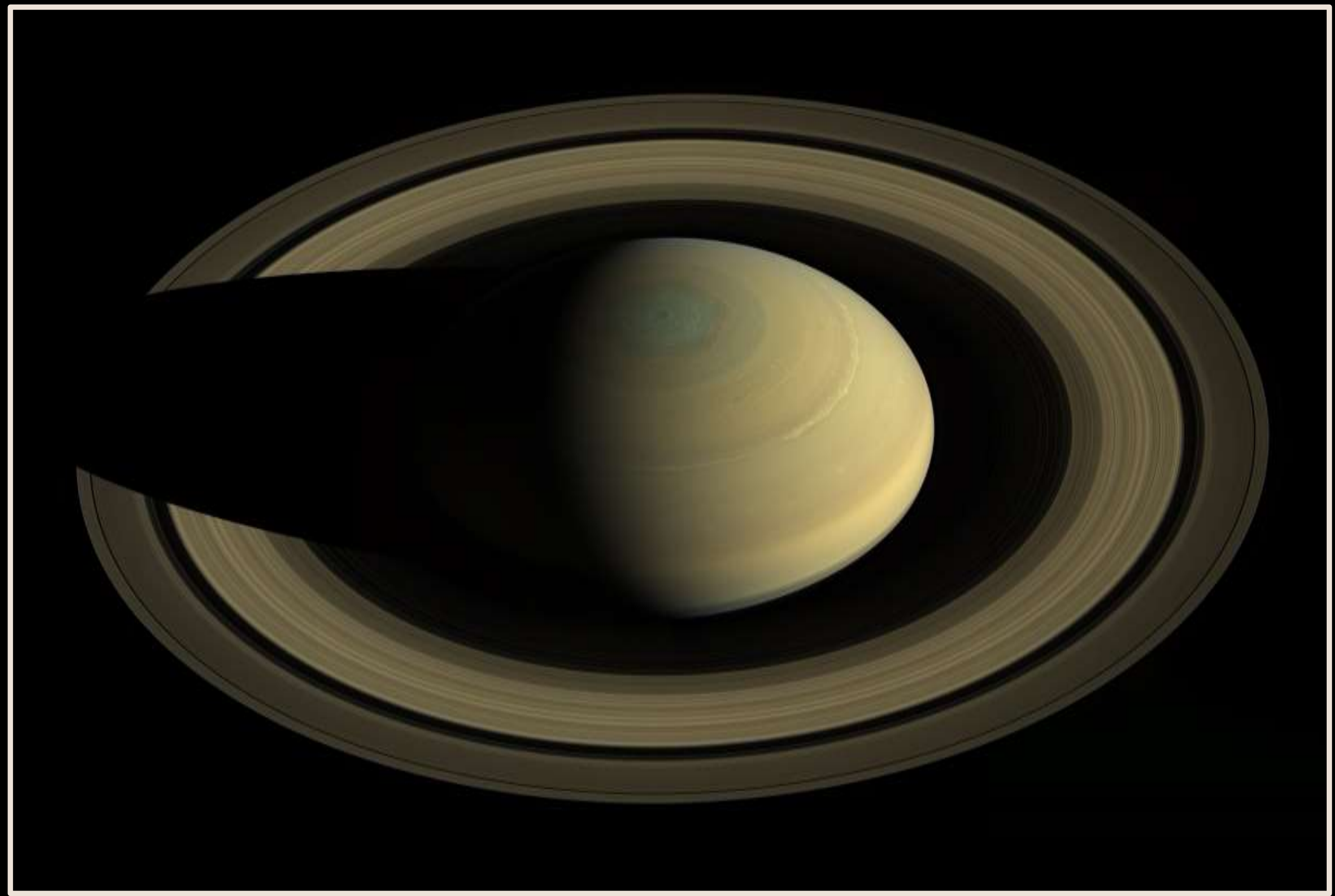


Prime Mission
Equinox Mission
Solstice Mission
Year of Tour
1 '04-'05
2 '05-'06
3 '06-'07
4 '07-'08
5 '08-'09
6 '09-'10
7 '10-'11
8 '11-'12
9 '12-'13
10 '13-'14
11 '14-'15
12 '15-'16
13 '16-'17
Orbits
11
15
22
27
39
21
16
19
25
12
12
20
56
Titan
*Huygens
Enceladus
Other Icy Satellites (under 10,000 km)
Phoebe
Tethys
Hyperion
Dione
Telesto
Rhea
Rhea
Iapetus
Epimetheus
Mimas
Rhea
Helene
Dione
G arc
Rhea
Helene
Dione
Dione
Tethys
Methone
Telesto
Rhea
Dione
Tethys
Dione
Epimetheus
G arc
Saturn (seen from Sun)




Cassini ring-grazing & grand finale orbits Nov 2016 – Sep 2017 / NASA, JPL-Caltech, SSI

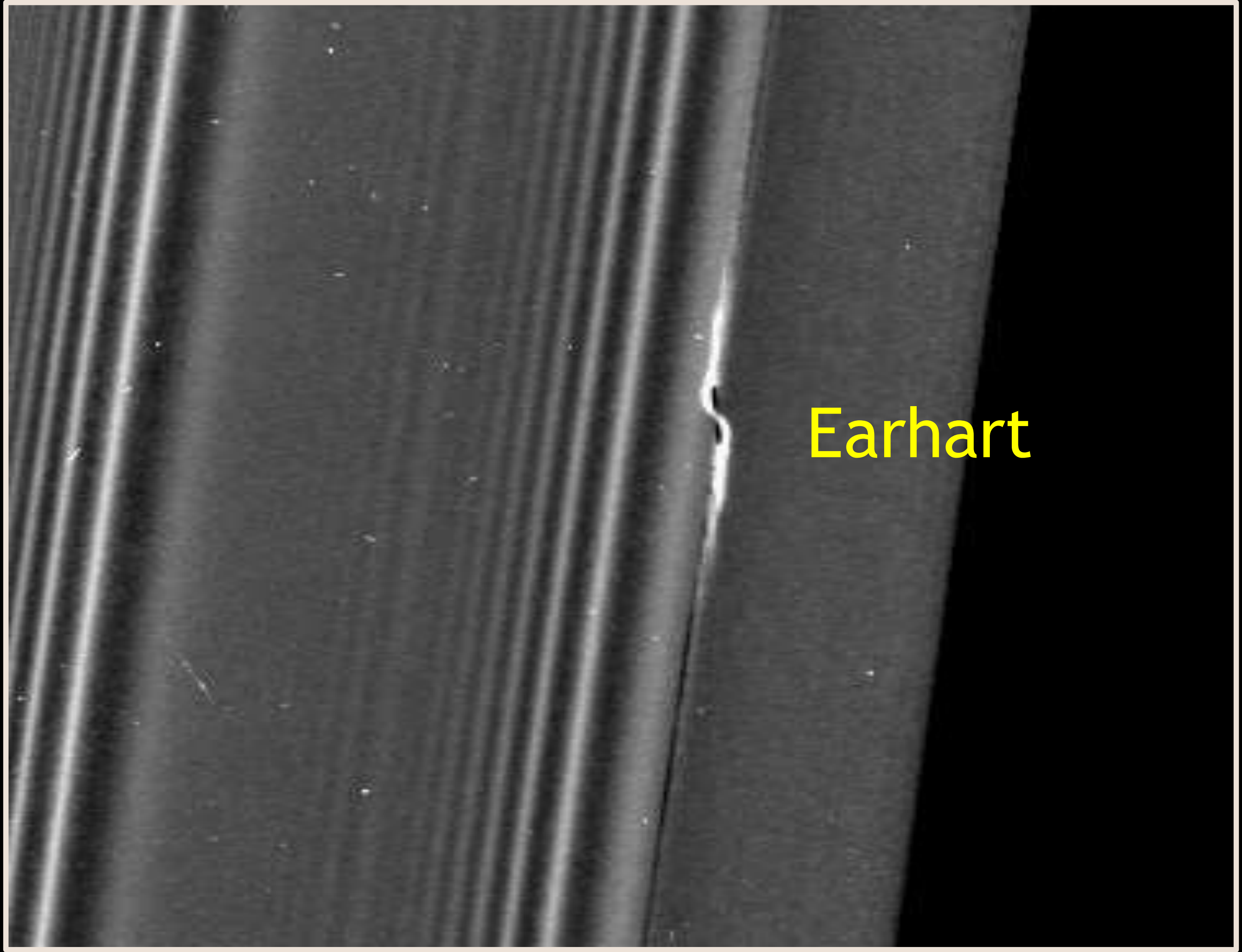
# Cassini's Final Days



Saturn and Rings

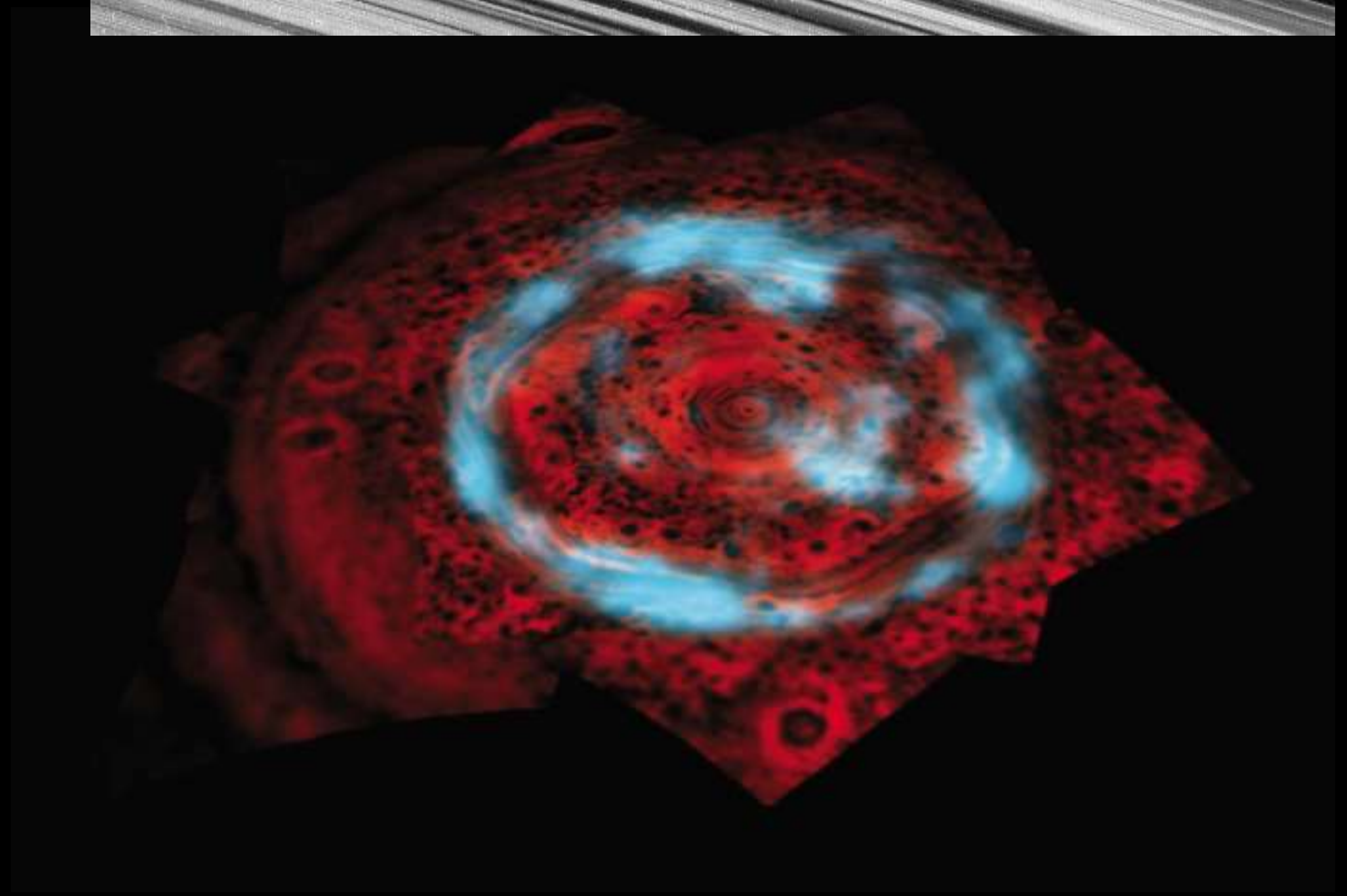
Titan


Enceladus setting behind Saturn




Propellers

# Final Orbits Science: Unique Observations



- First ever direct measurements of ring particle composition
- Highest resolution main ring observations
  - Radio occultation, imaging
  - First active Radar
- Highest resolution Saturn polar observations and aurora

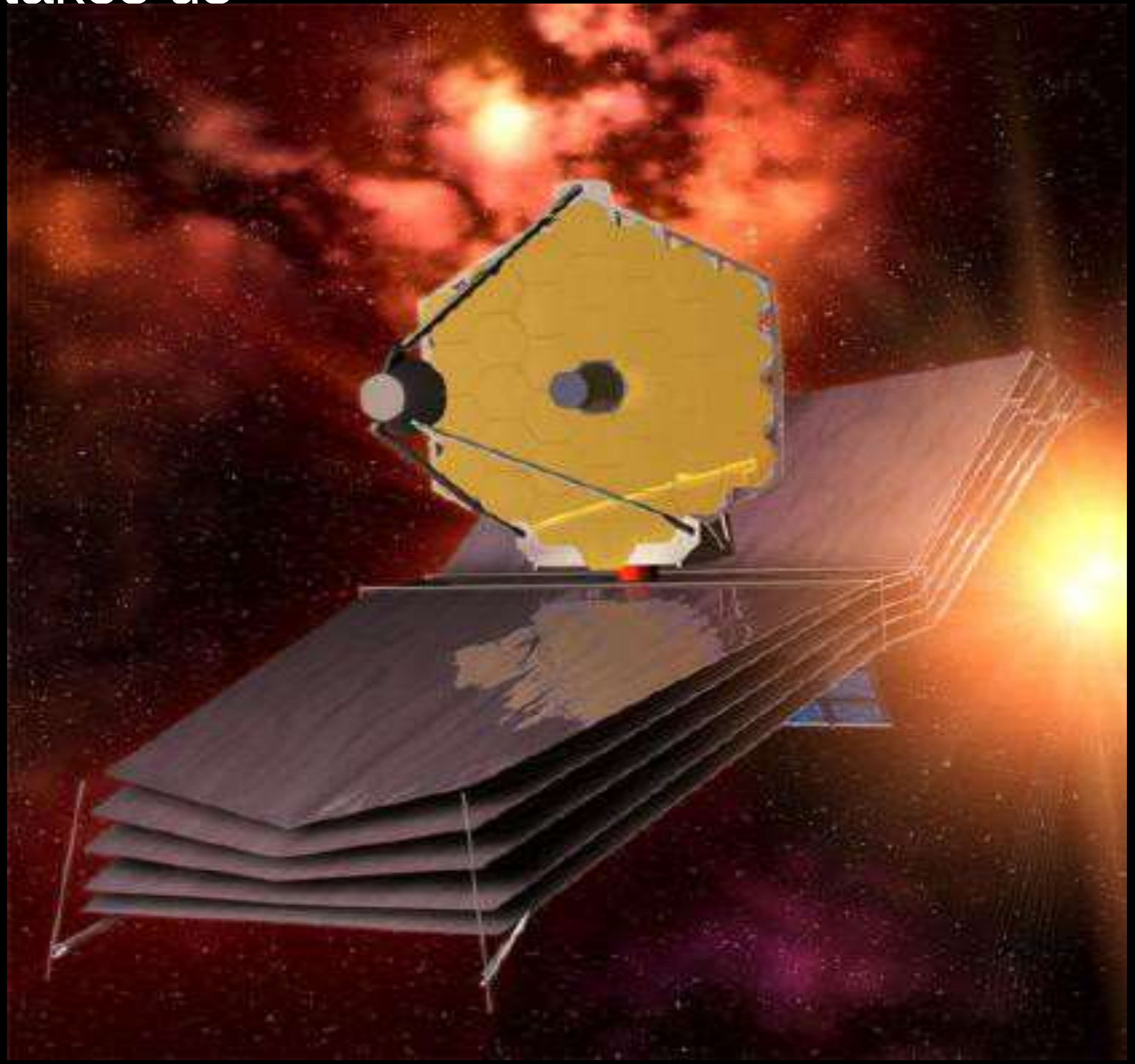
# Direct sampling of Saturn’s atmosphere

# ESA Science Planetary Programme

## Future plans

## James Webb Space Telescope

As far as our imagination takes us

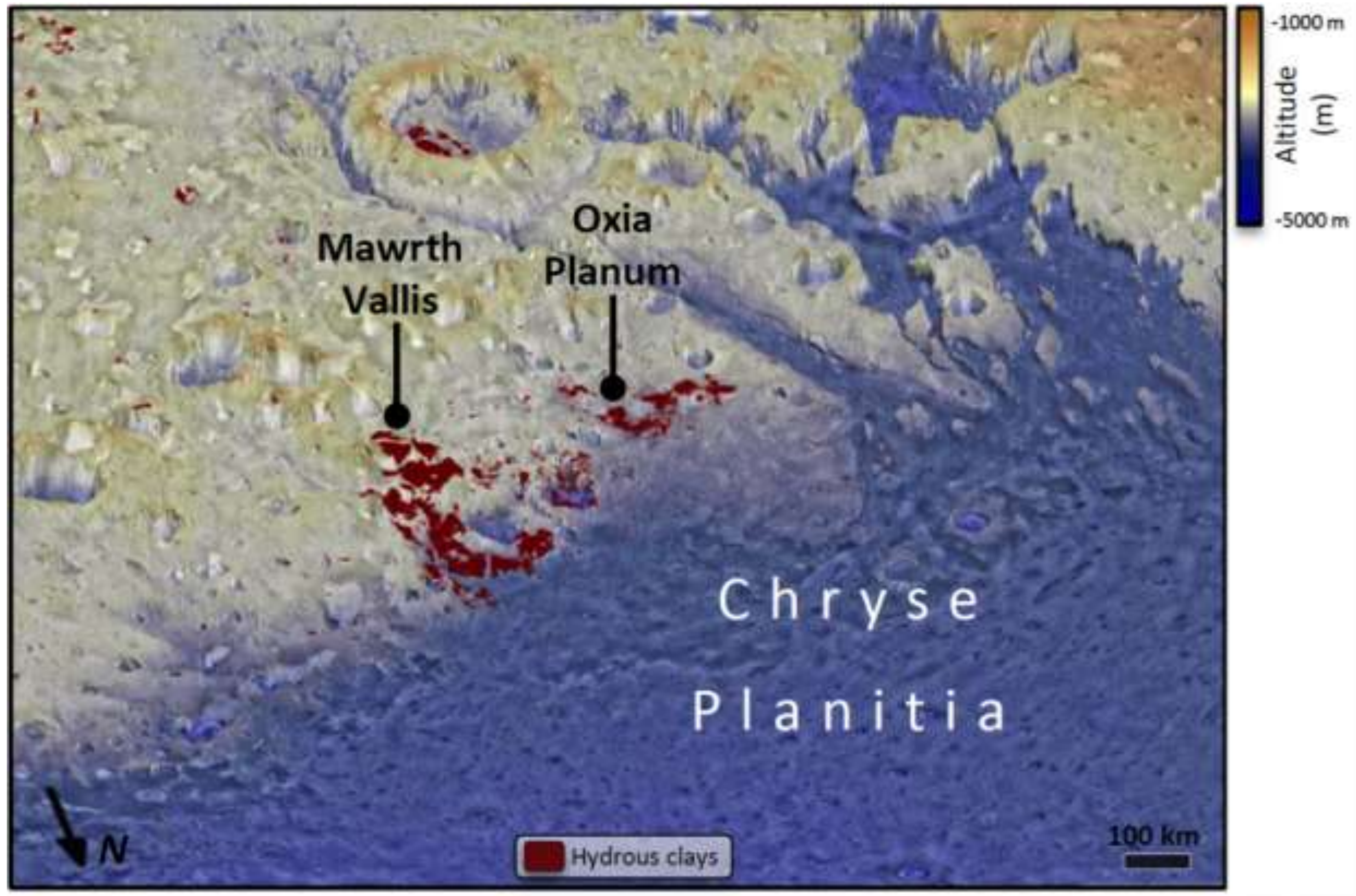


# Outcome of ESA C-MIN Dec. 2016

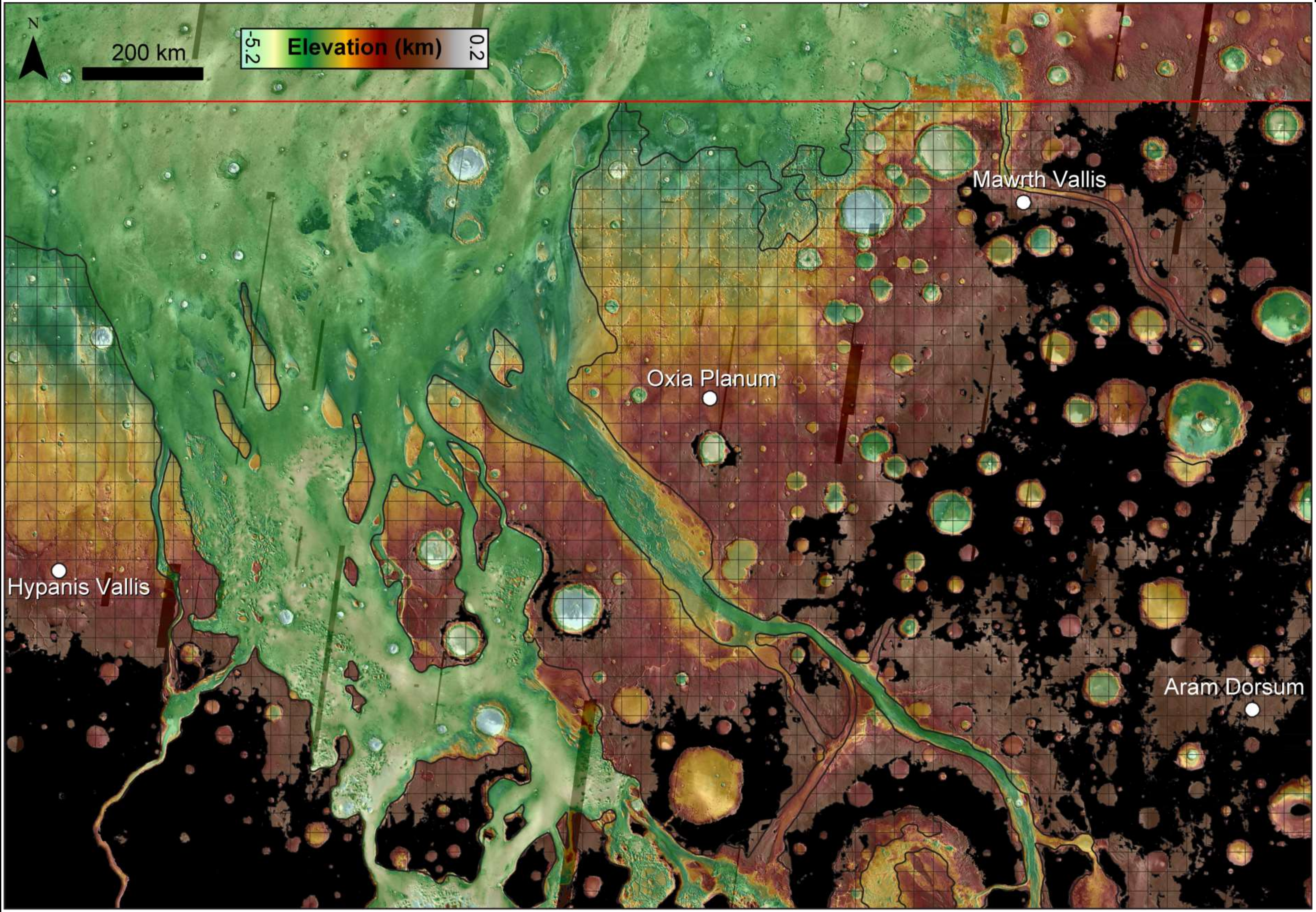
- ESA DG *Towards Space 4.0 for a United Space in Europe.* calls for a united and collaborative spirit across Europe and embraces a holistic approach to foster European Identity, spirit and cohesion through excellence in space sciences and technology. It also sets the scene for an improved coordination between ESA and the European Union institutions
- ExoMars is secured - the benefits of separate budgets between mandatory and optional activities is highlighted
- Although rather high overall subscription level, there is a concern about the fact that the interplay between the 1% increase and the contribution to ExoMars will not allow for the scientific programme to compensate the inflation over the 2017-2021 period.
- The European Exploration Envelop Programme (E3P) concept is approved, however regrettably the SciSpacE element undersubscribed

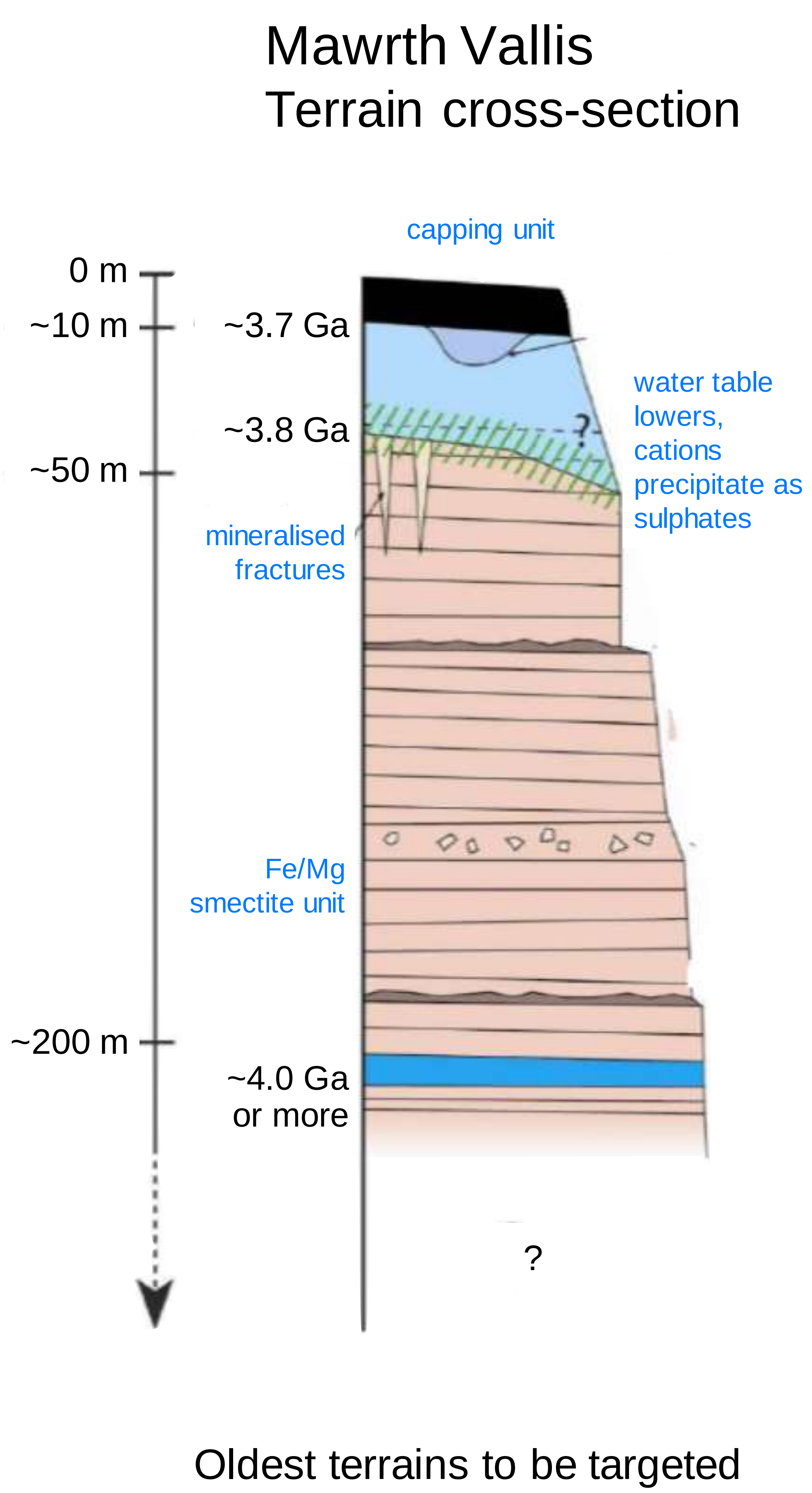
# EXOMARS :
# 2020 ExoMars rover and surface science platform

2020 Rover advanced rover that will carry out the first sub-surface investigations of Mars in order to answer questions about whether life could or ever did exist on the Red Planet




•Two low-level ancient landing sites have been selected in March 2017 for the 2020 ExoMars rover and surface science platform: Oxia Planum and Mawrth Vallis.




ExoMars 2020 rover landing site candidates / NASA/MGS/MOLA/THEMIS/Peter Grindrod

# LUNAR EXPLORATION
## EXPLORATION

ESA contribution to Roscosmos lunar missions

- Luna-Glob (Luna-25) lander : launch confirmed end 2019, to launch in 2025…
- Luna-Resurs lander (or Luna 27), a south polar lunar lander, launch now end 2022.
- Towards a fully robotic lunar base
- For eventually a lunar human base (« Moon Village »)

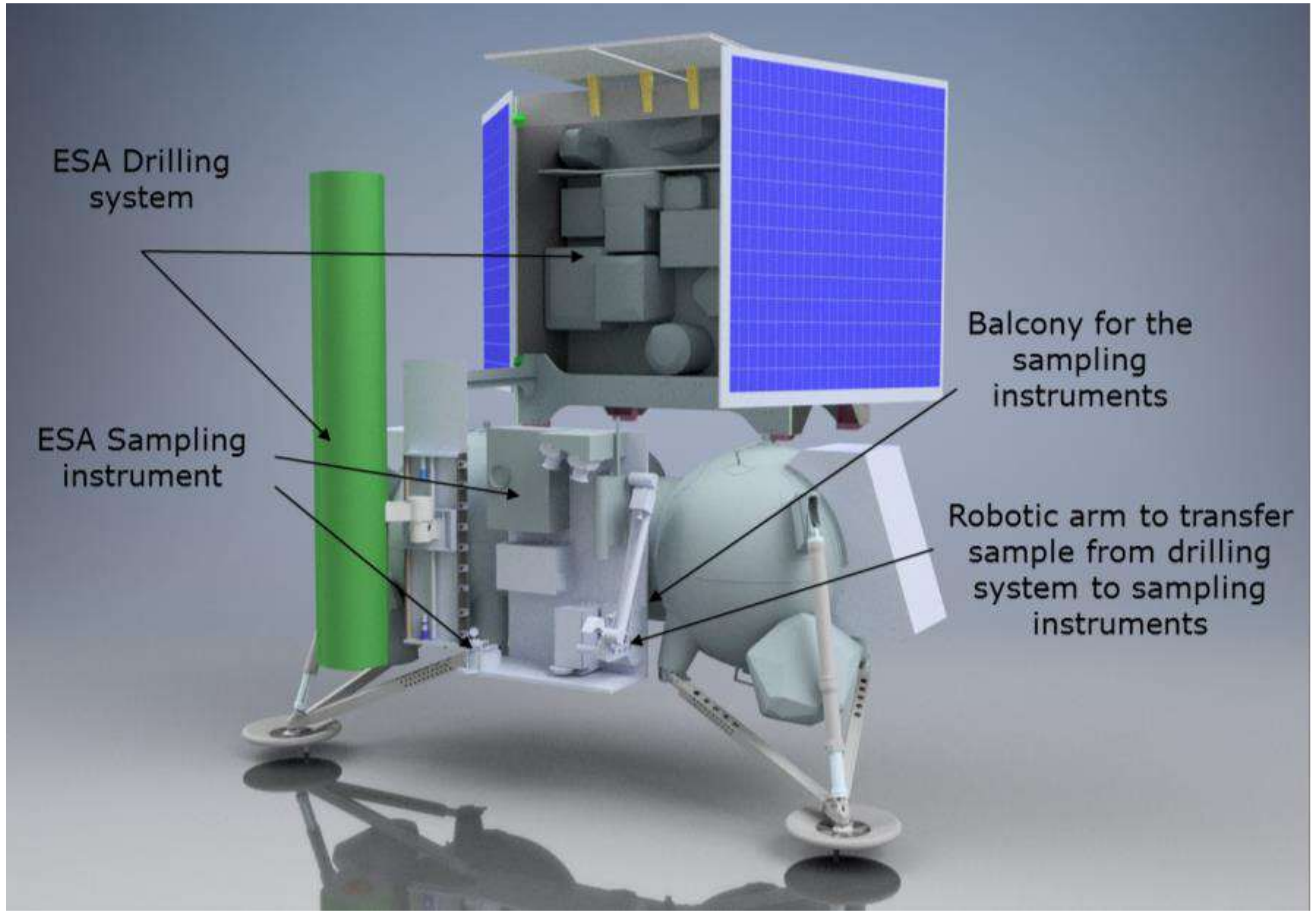
PROSPECT is a drilling, sampling, sample handling, processing and analysis package under development by ESA for the Russian Luna-27 mission; scheduled for flight to the Lunar South Polar region in 2020.


*Group picture at the PROSPECT Operational*

# LUNAR EXPLORATION

## EXPLORATION

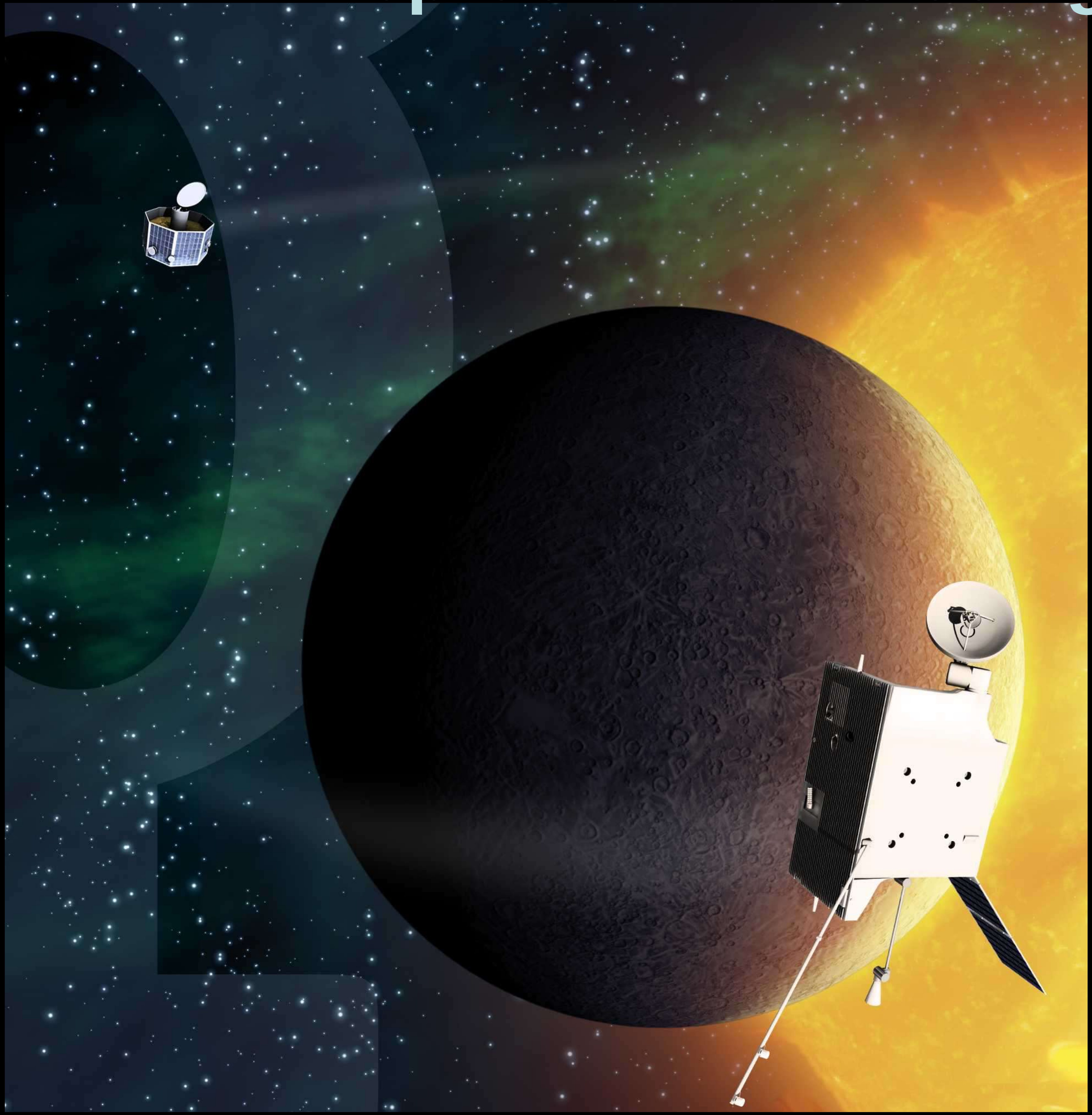
*Luna-Glob Model, picture taken during ESA DG visit at Lavochkin during MAKS in July 2017*




*PROSPECT accommodation onboard the Luna-Resource Lander*

# Possible E3P Mission Roadmap (detailed version)

# BepiColombo: Closing in on Mercury



**Jo**int ESA/JAXA mission, and first dual-satellite enterprise to Mercury. First European mission to orbit a planet in the hot regions of the Solar System.

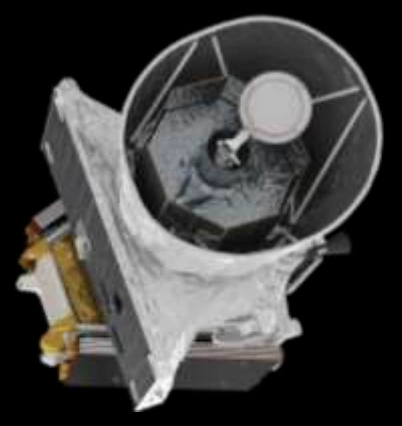
Consists of two individual orbiters:

- the Mercury Planetary Orbiter (MPO) to map the planet, and
- the Mercury Magnetospheric Orbiter (MMO) to investigate its magnetosphere developed by JAXA.

*Launch in October 2018 with 9 planetary flybys and arrival to Mercury in December 2025.*

Mercury / MESSENGER / NASA

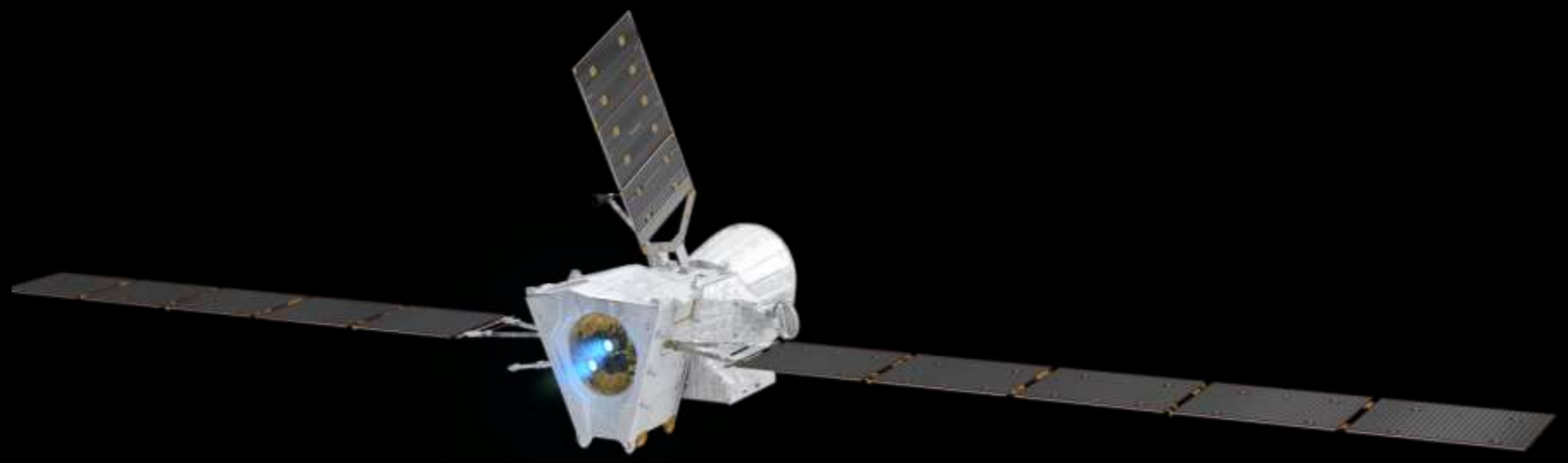
## Launch phase

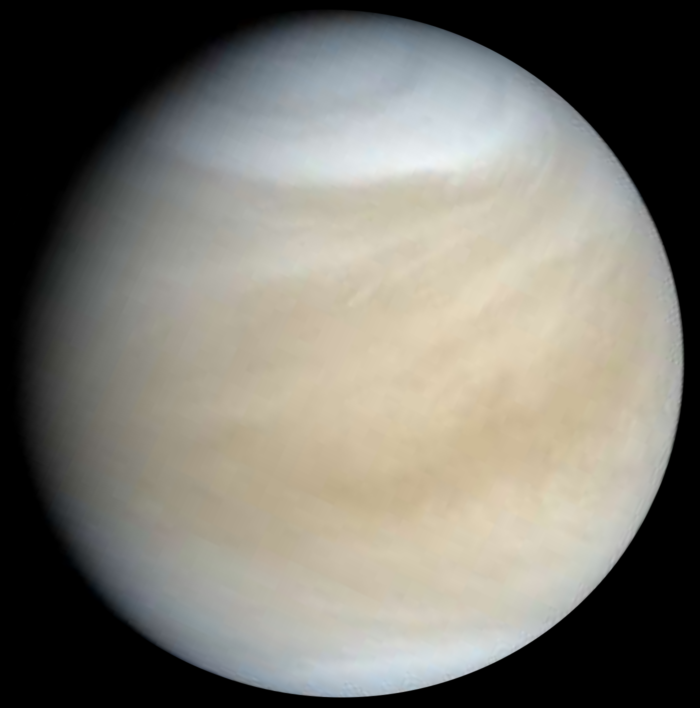


Launch: 2018–10–05

♁flyby : 2020–04–06

## Cruise phase

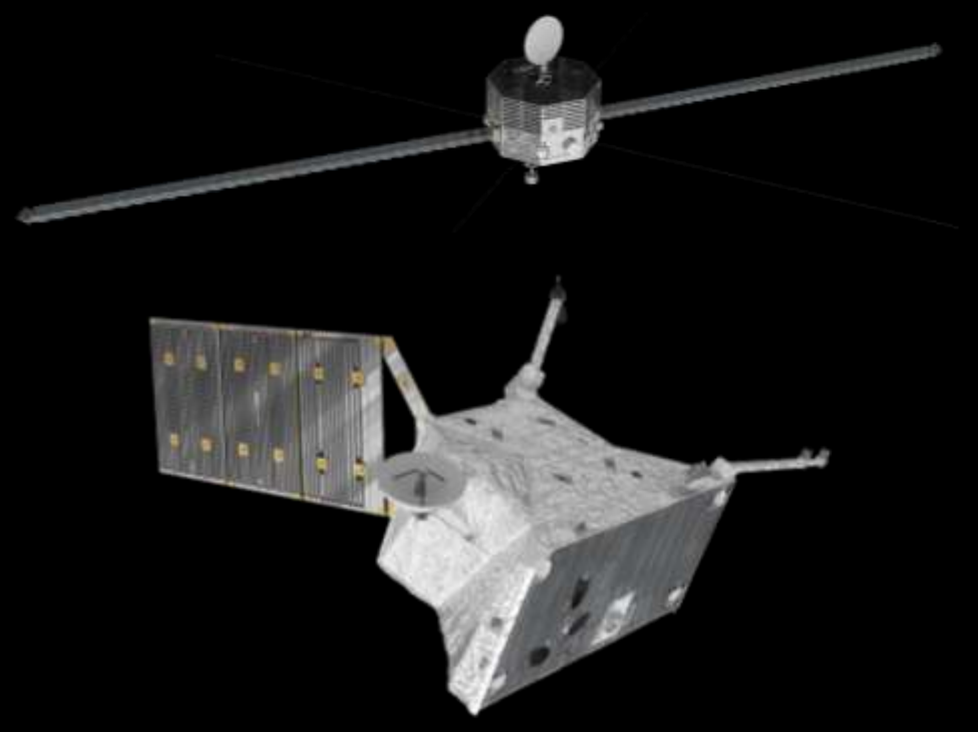




♀flyby 1: 2020–10–12

♀flyby 2: 2021–08–11

## Mercury phase



☿flyby 1: 2021–10–0

☿flyby 2: 2022–06–2

☿flyby 3: 2023–06–2

☿flyby 4: 2024–09–0

☿flyby 5: 2024–12–0

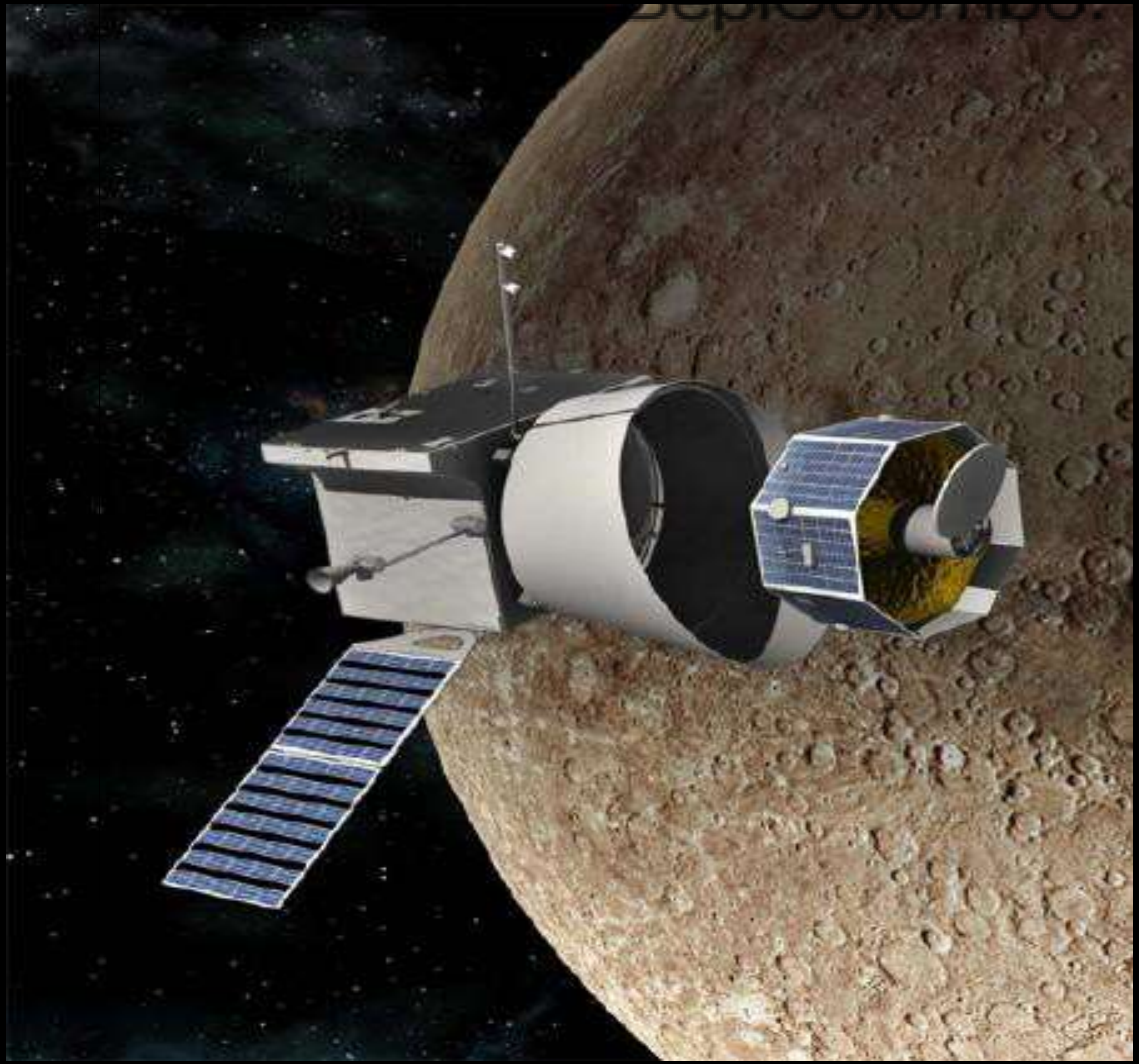
☿flyby 6: 2025–01–0

Arrival : 2025–12–

*BepiColombo journey to Mercury (nominal, May 2017)*

*ESA / JAXA / Planetary & solar images: NASA*

# BepiColombo: Science planned



**Science :**

- Make the most extensive study of Mercury – from the interior to the exosphere
- Reveal the evolution of Mercury and the formation of the inner planets, and understand the origin of Mercury’s global magnetic field – the only one of a rocky planet other than Earth
- Test Einstein’s theory of General Relativity

BepiColombo mission to Mercury, due for launch in 2018 / ESA, JAXA

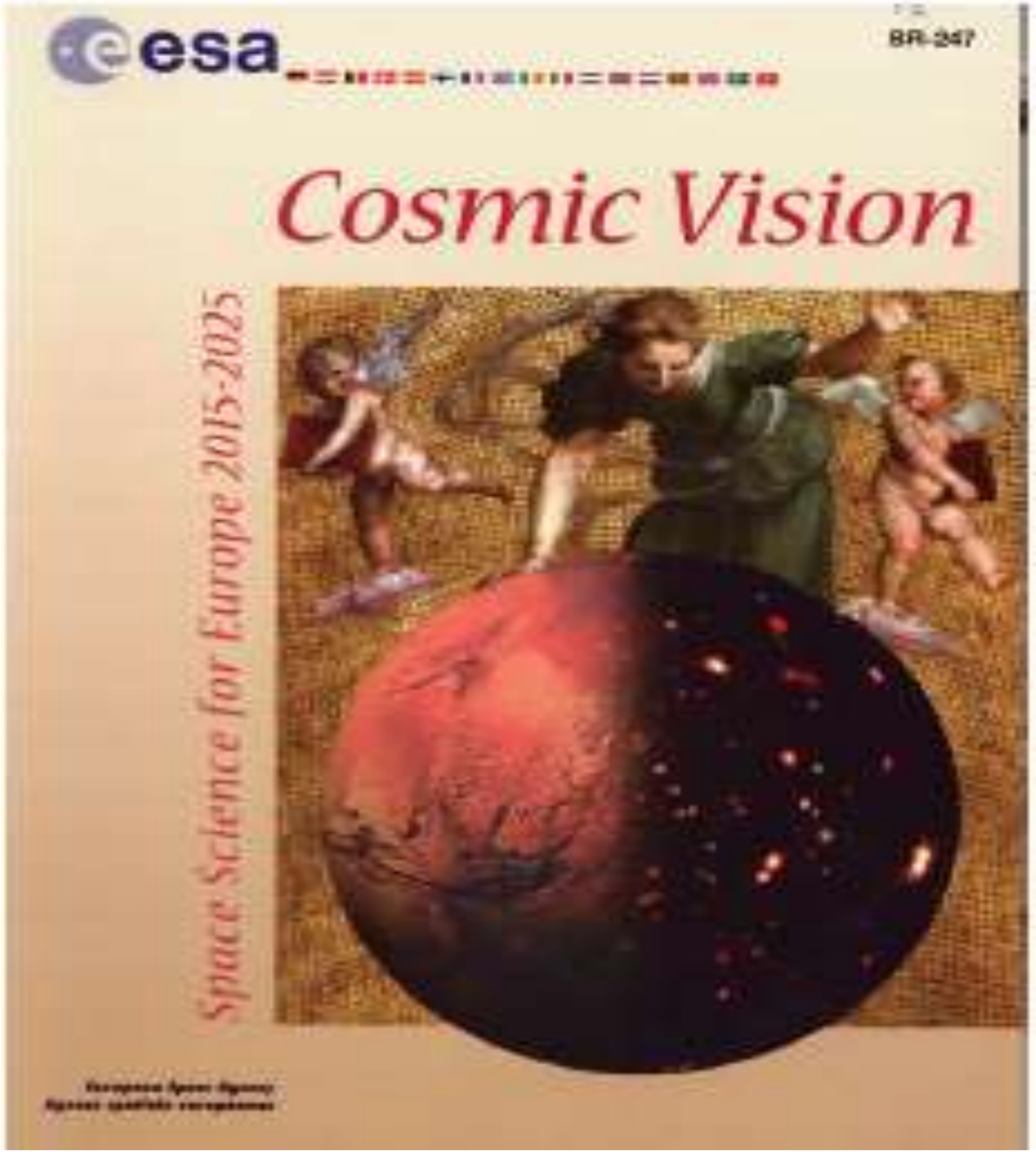
Mercury / MESSENGER / NASA


Mercury / MESSENGER / NASA

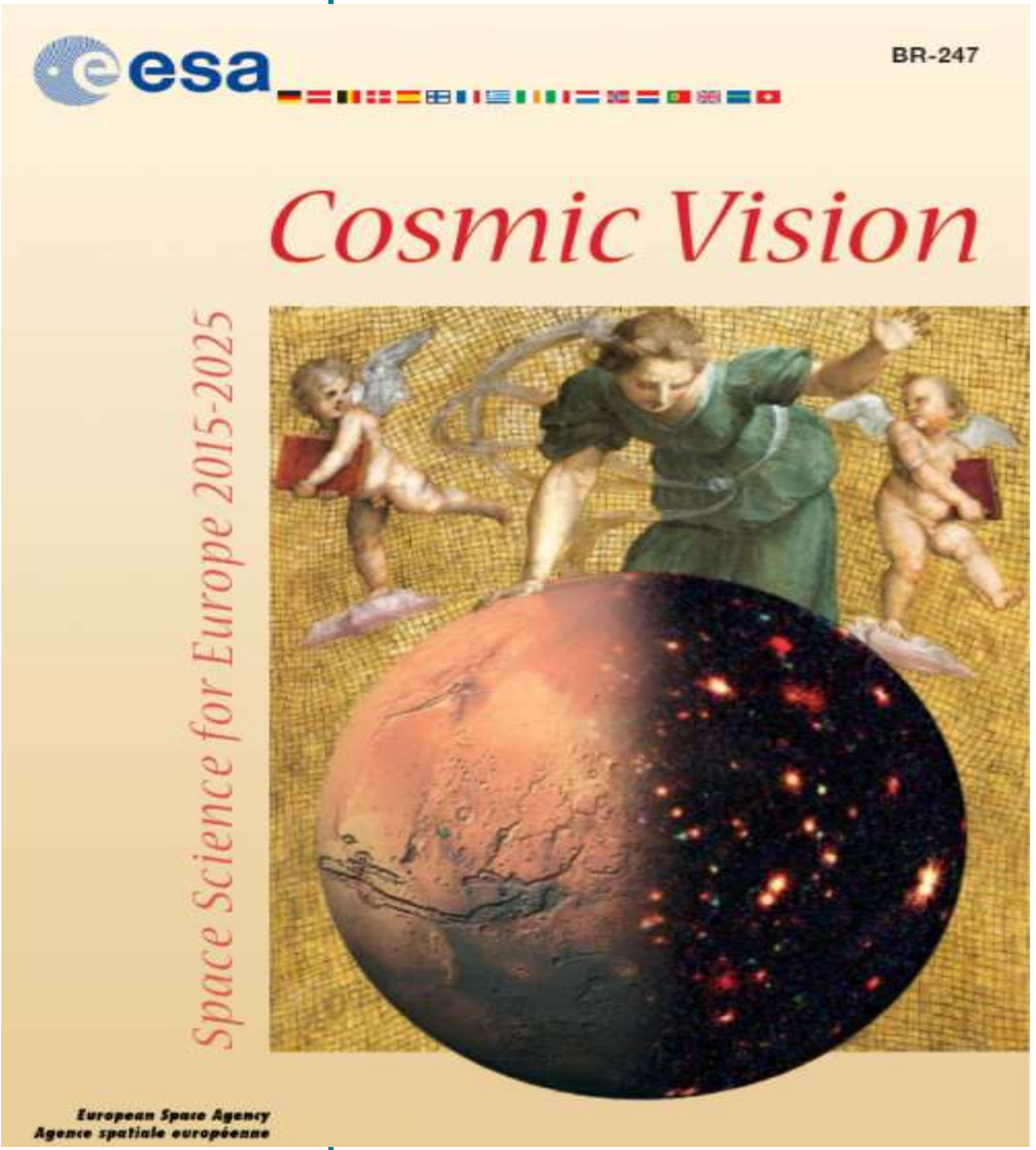
First flight MTM solar wing deployment at ESTEC, May 2017 / ESA

# COSMIC VISION

In 2005, a new programme was introduced to replace H2000+, for one more decade (until 2025) with the name Cosmic Vision (2015-2025, now 2035).

# Cosmic Vision 2015-2025




2005, 15 October: Document «Cosmic Vision: Space Science for Europe 2015-2025 »

**Themes:**

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

M-class : medium-sized missions with a budget < 450 Meuros without main technological challenges

L-class : large missions with a budget < 650 M€, with possible international contribution and need for technological development

**Timeline**:

- 2007, March = first call for mission ideas M1, M2 (launch 2017, 2020, 2022)
- 2010, July= call for missions M3 (launch 2022-2024)
- 2011, May= call for the S1 missions (launch 2018)
- 2013, March = call for the science themes of L2/L3 (launch 2028 & 2035)
- 2014, August = call for missions M4 (launch 2025)
- 2016, May = call for missions M5 (launch 2029)

# COSMIC VISION (2015-2025)
# Step 1

- **Selections of Cosmic Vision missions**
  - **Selection of Solar Orbiter as M1 and Euclid as M2 in 2011.**
  - **Selection of CHEOPS as S1 in 2012**
  - **Selection of JUICE as L1 in 2012.**
  - **Selection of PLATO as M3 in 2014**
  - **Participation to SMILE with China**



# Selected M1/M2-class missions


*Launch : February 2019*

**Solar Orbiter** (theme 2), a mission intended to produce images of the Sun at an unprecedented resolution and perform the closest-ever measurements of local, near-Sun phenomena. Solar Orbiter was carried over from Horizon 2000 Plus.


*Launch : end 2018*

**Euclid** (theme 4) – to map the geometry of the dark Universe, measuring the distance-redshift relation and the growth of structure by using two complementary dark energy probing methods, baryonic acoustic oscillations and weak gravitational lensing.

# ESA S1 MISSION  CHEOPS (To launch in late 2018)

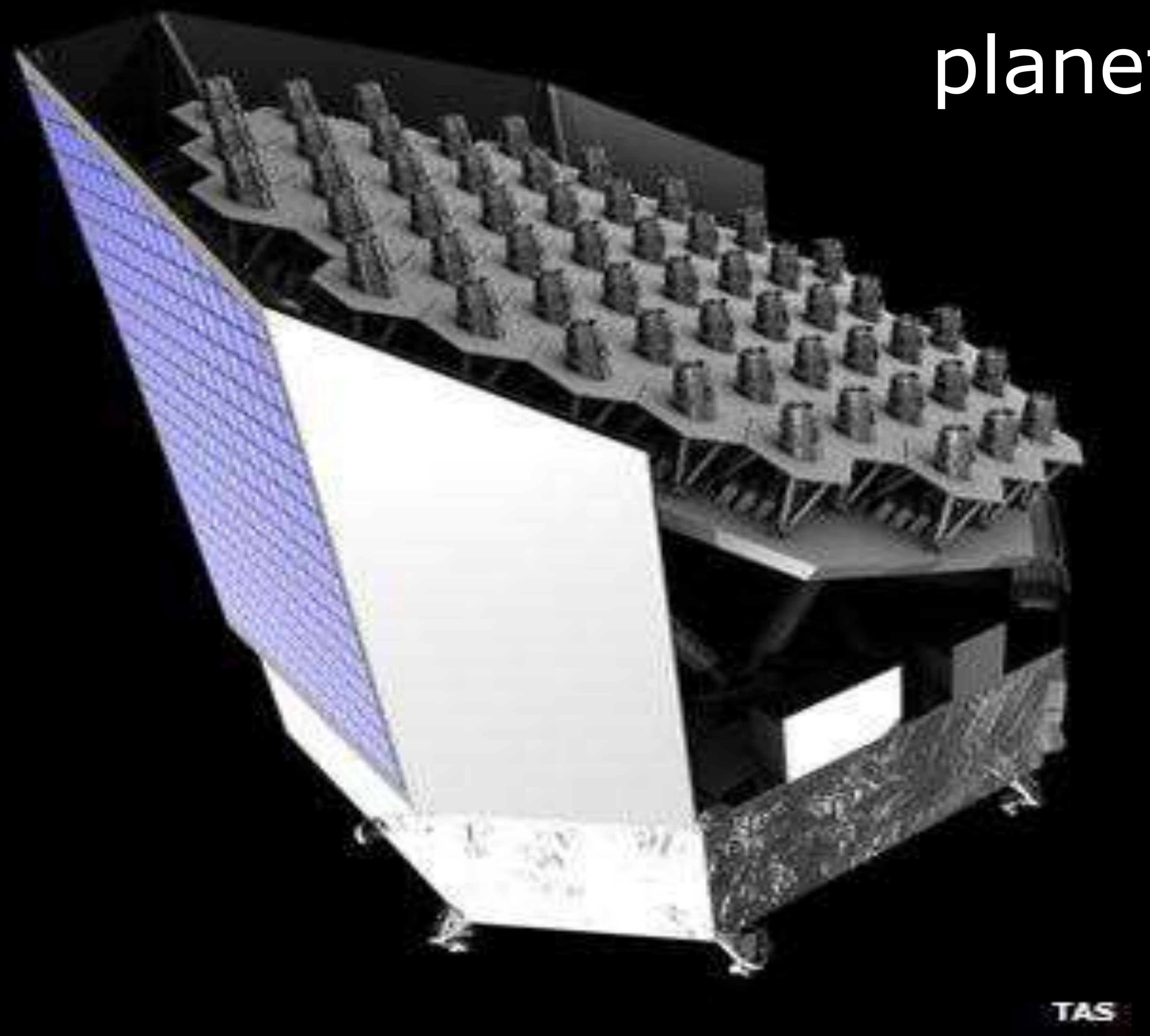
**CHEOPS has been selected as the S1 mission, with targeted launch date in 2018.**

**A technical screening was carried out by ESA on all proposals received in response to the call for S-class missions. The Science Programme Committee selected CHEOPS at their meeting on 19 October 2012.**

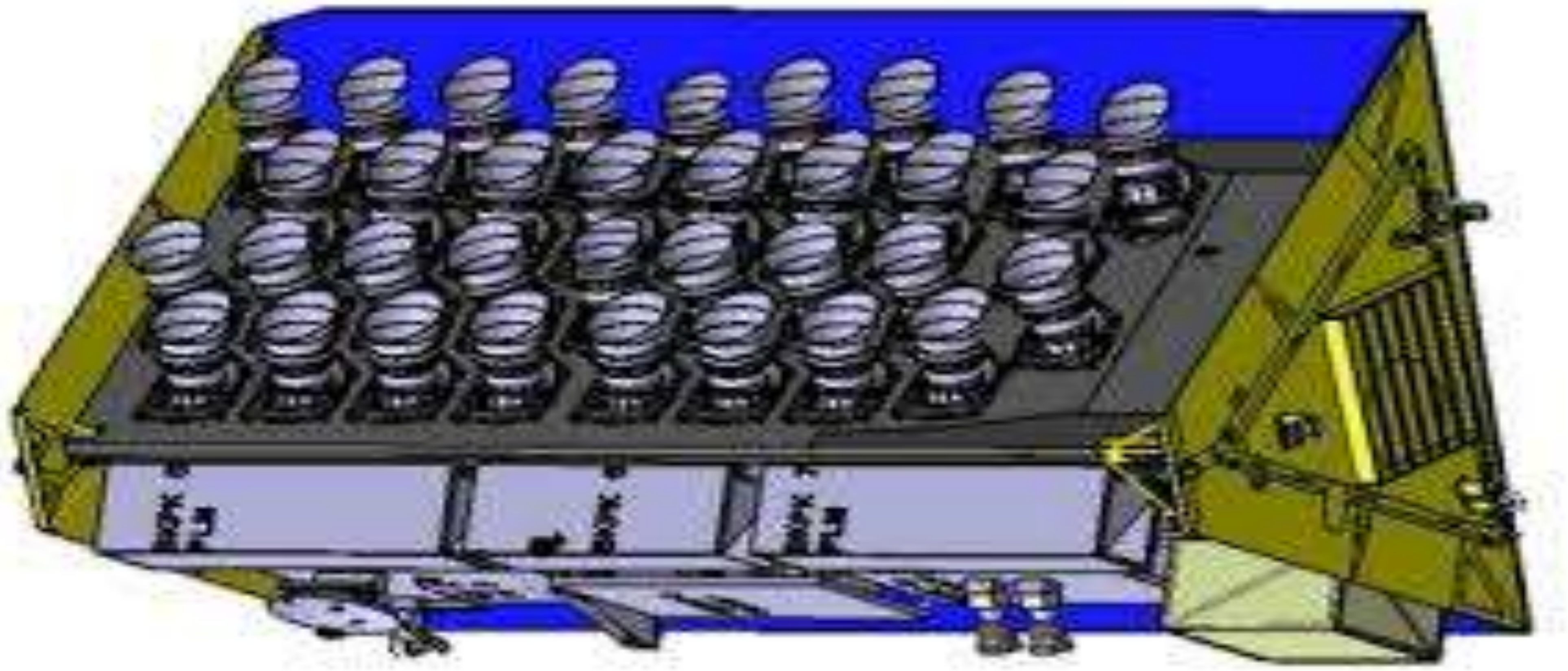
**CHEOPS - *CH*aracterizing *Ex**OP*lanets *S*atellite - will be the first mission dedicated to searching for exoplanetary transits by performing ultrahigh precision photometry on bright stars already known to host planets. It will provide the unique capability of determining accurate radii for a subset of those planets, in the super-Earth to Neptune mass range, for which the mass has already been estimated using ground-based spectroscopic surveys. CHEOPS will also provide precision radii for new planets of Neptune-size and smaller that are discovered by the next generation of ground-based**

# PLATO (M3)

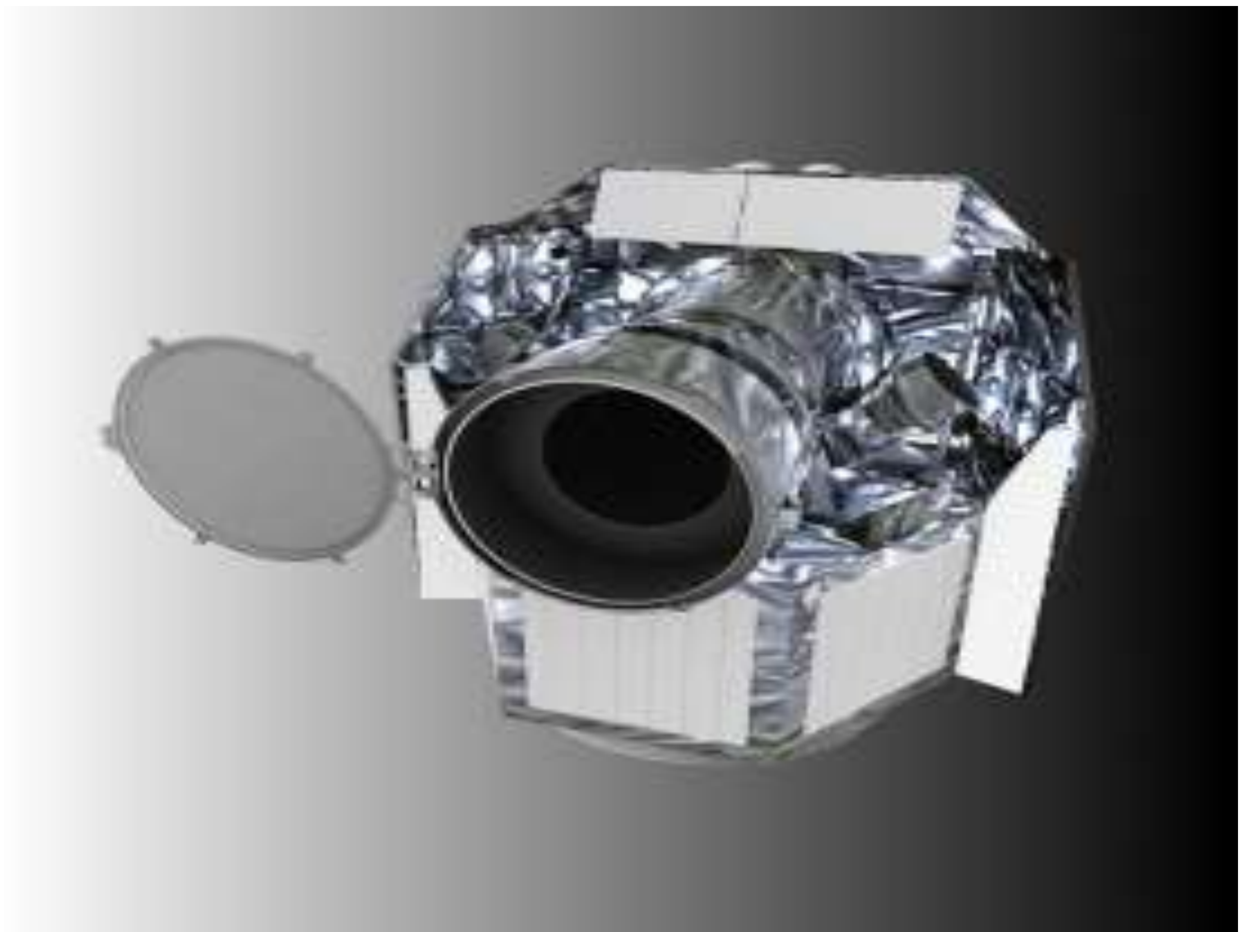
Detection and characterisation of terrestrial exoplanets around bright solar-type stars, with emphasis on planets orbiting in the habitable zone.



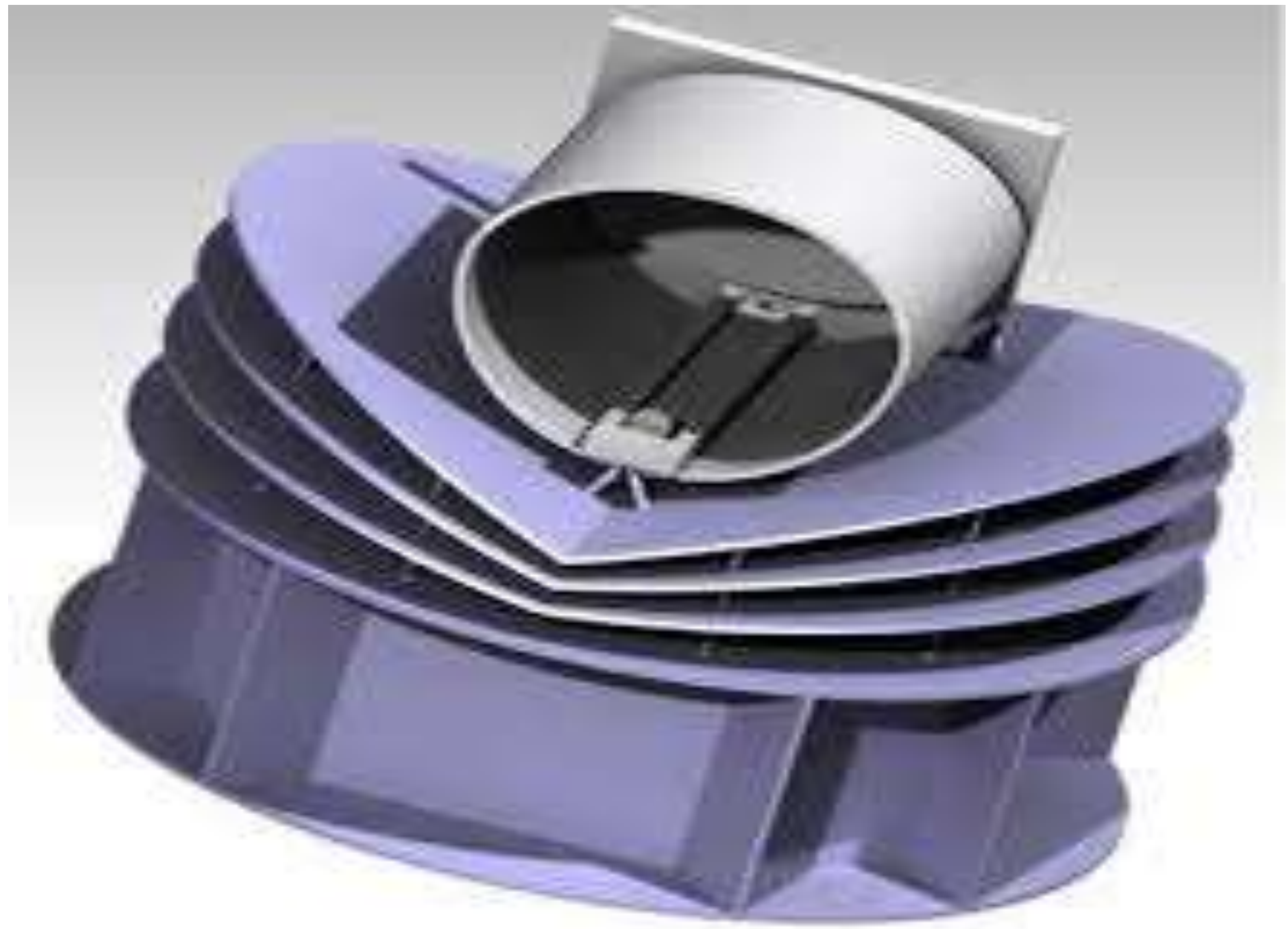

# Ideas/studies for exoplanet exploration

PLATO (M3)

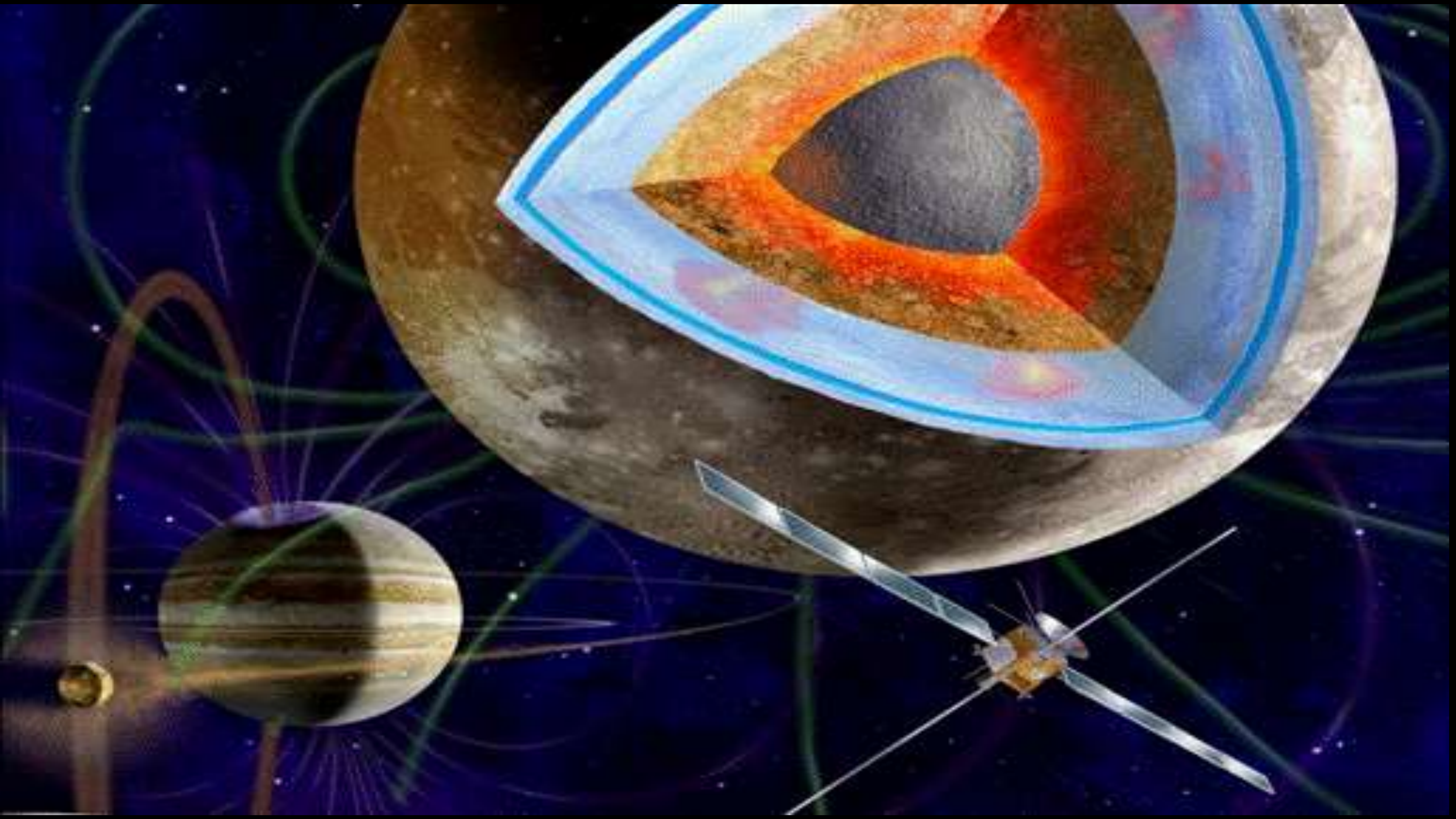


CHEOPS (S1)



ARIEL (M4)

# JUICE: JUpiter Icy moons Explorer



## JUICE Science Goals

- *Emergence of habitable worlds around gas giants*
- *Jupiter system as an archetype for gas giants*


## Cosmic Vision Themes

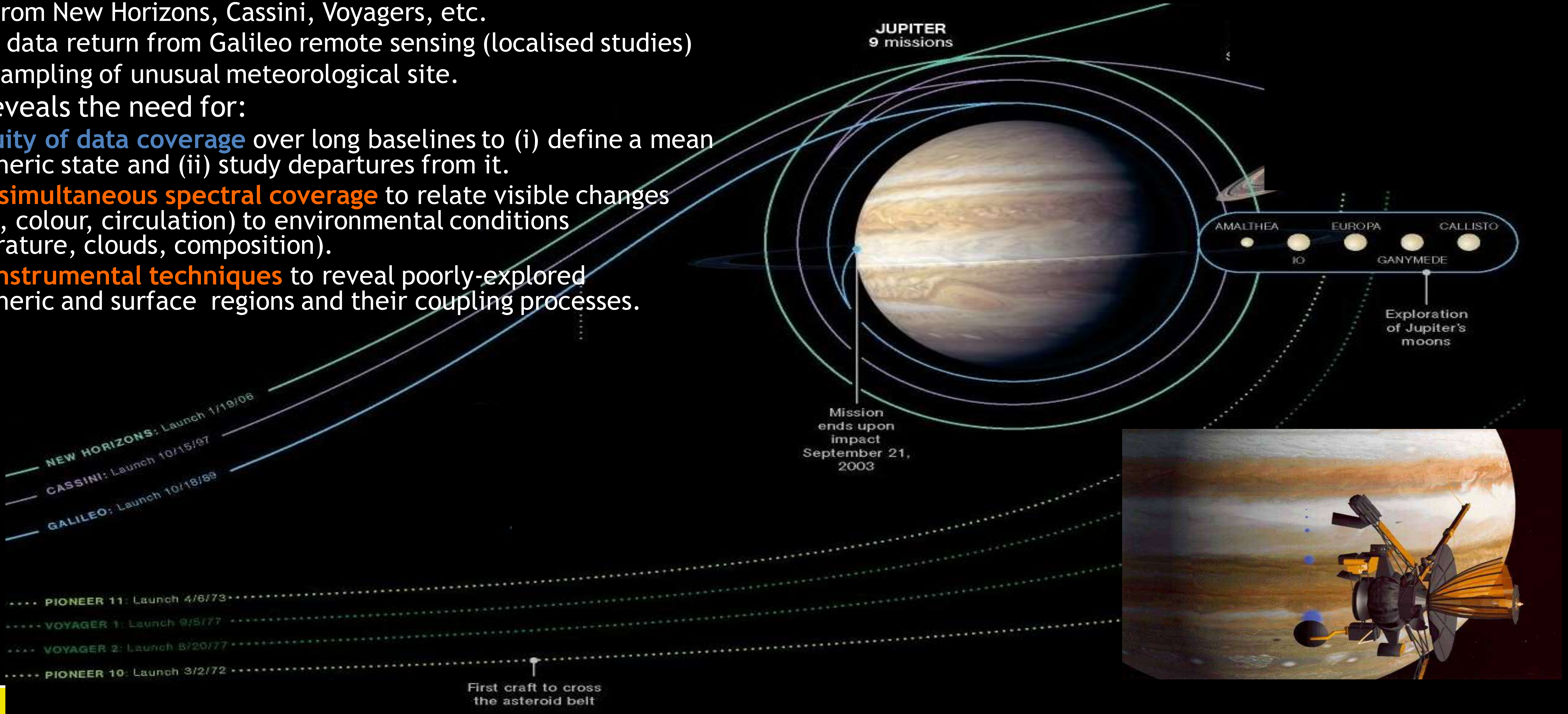
- *What are the conditions for planetary formation and emergence of life?*
- *How does the Solar System work?*

## JUICE : the 1st Large CV mission concept

- *Single spacecraft mission to the Jovian system*
- *Investigations from orbit and flyby trajectories*
- *Synergistic and multi-disciplinary payload*
- *European mission with international participation*

# Relationship to Past Exploration

- Previous exploration provided snapshots of discrete epochs
  - Flybys from New Horizons, Cassini, Voyagers, etc.
  - Limited data return from Galileo remote sensing (localised studies)
  - In situ sampling of unusual meteorological site.
- Literature reveals the need for:
  - Continuity of data coverage over long baselines to (i) define a mean atmospheric state and (ii) study departures from it.
  - Broad, simultaneous spectral coverage to relate visible changes (albedo, colour, circulation) to environmental conditions (temperature, clouds, composition).
  - Novel instrumental techniques to reveal poorly-explored atmospheric and surface regions and their coupling processes.

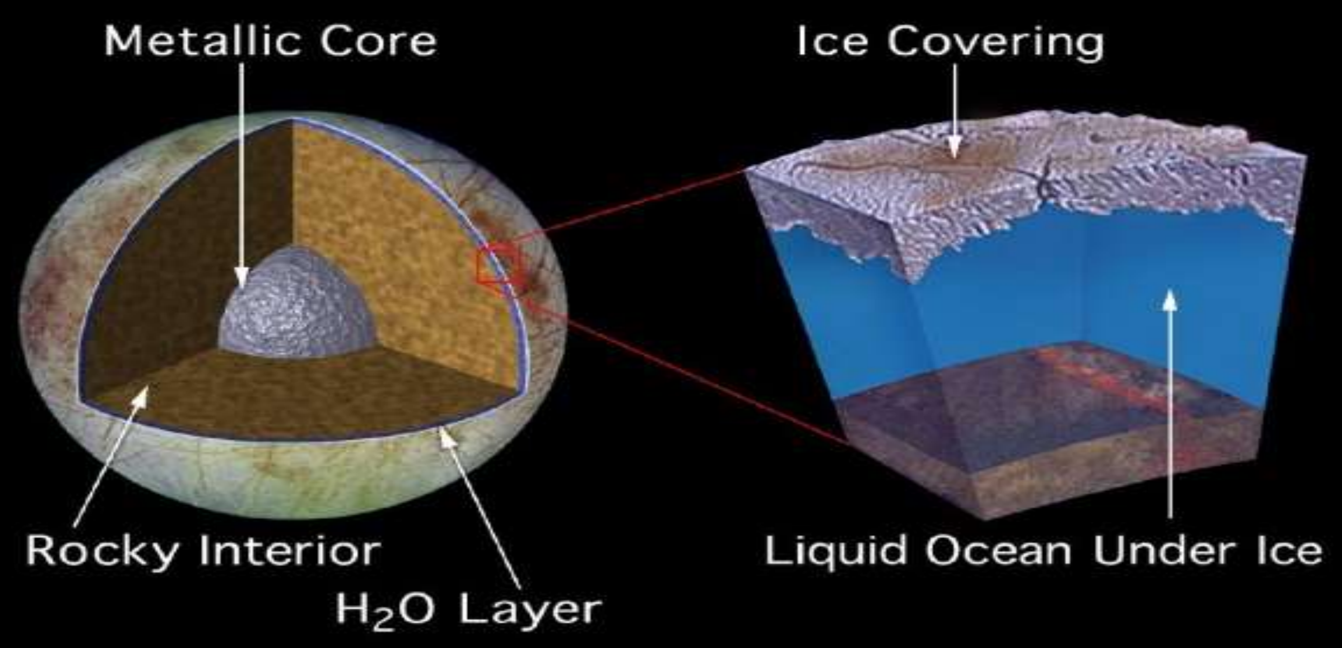



Perijoves

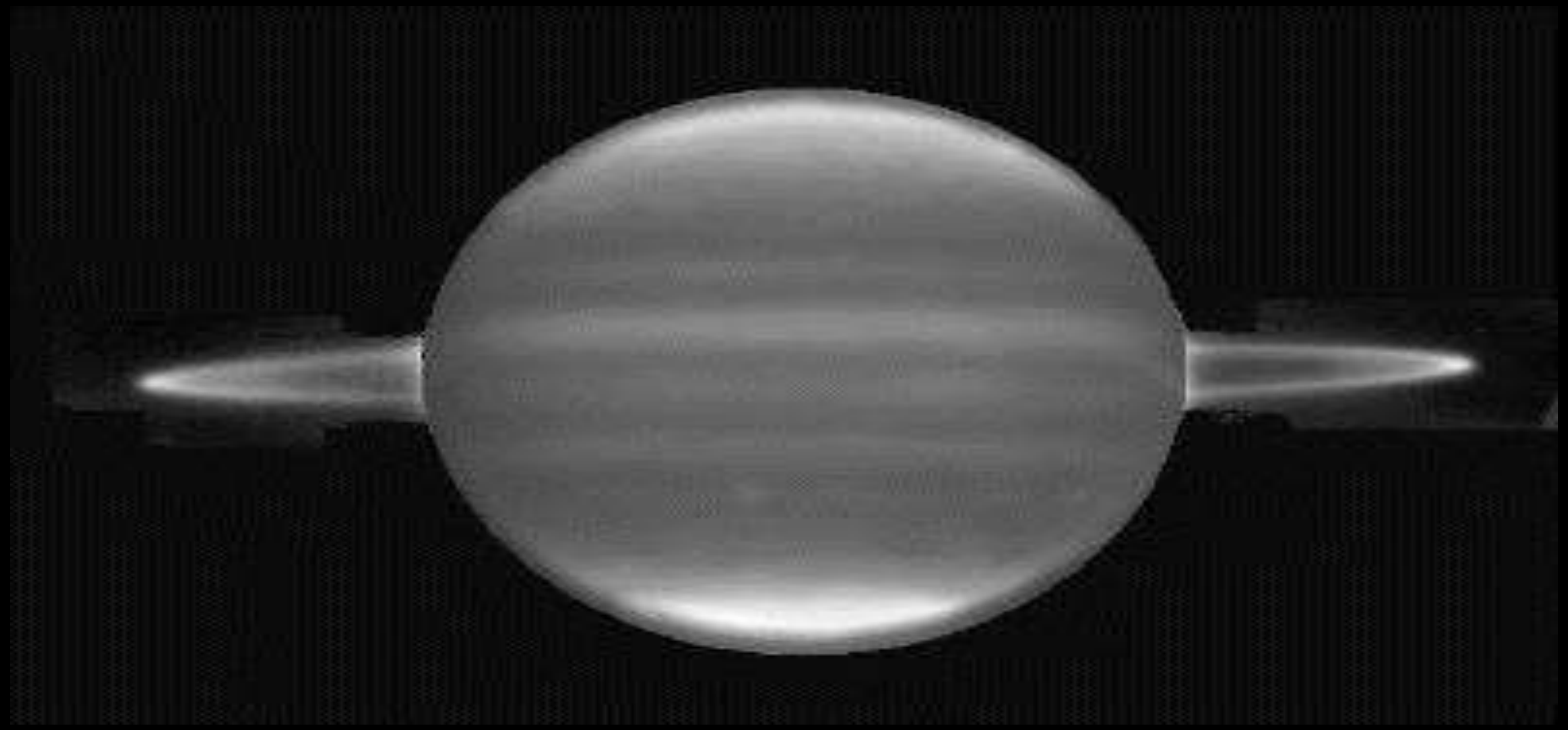
Year | 2030 | 2031 | 2032 | 2033

Topics:
Planet, moons, rings, magneto

- Interior
- Subsurface
- Geology
- Atmosphere
- Plasma
- Habitability
- Link to exoplanets





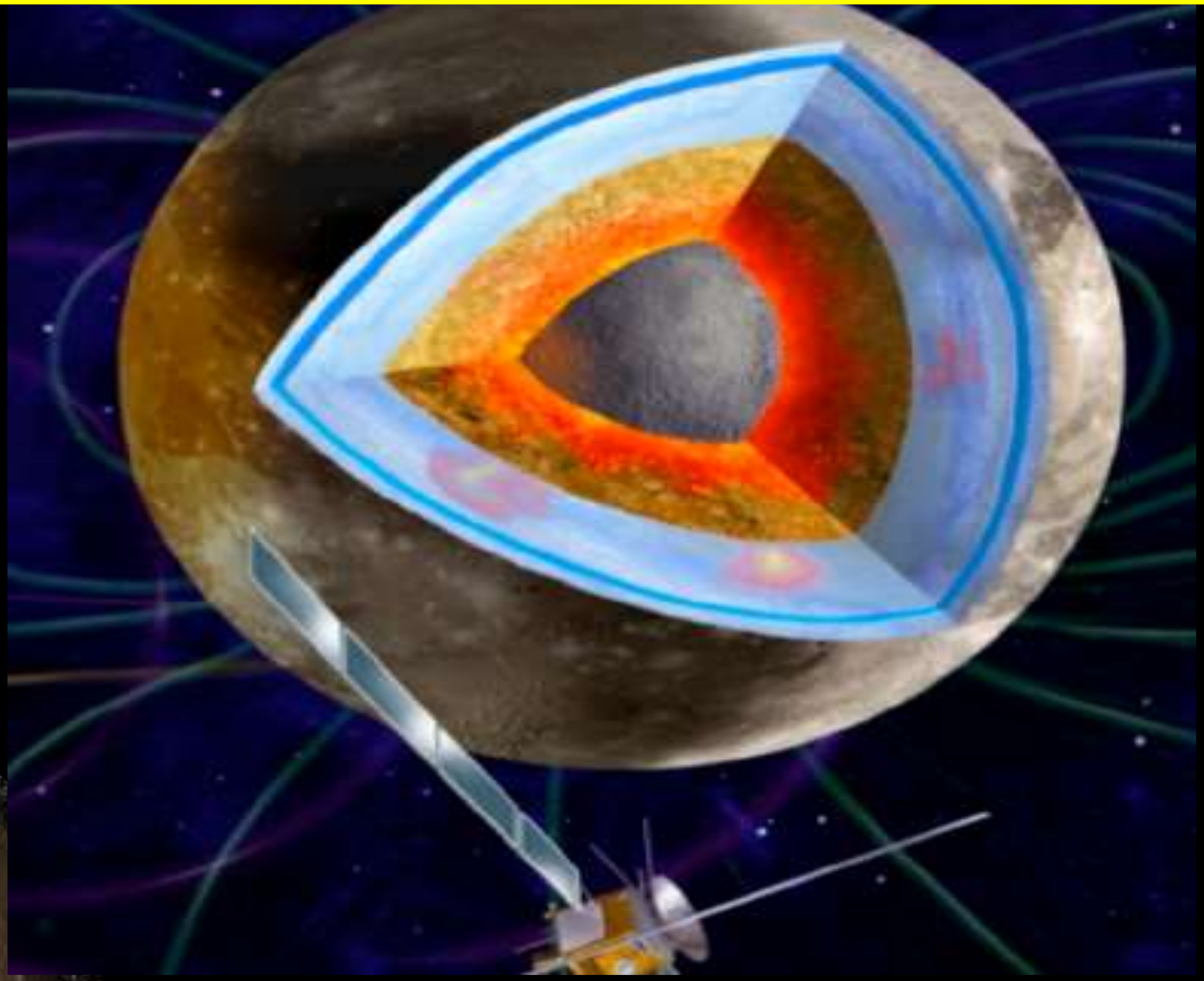
Jupiter system: largest planet, largest storm, fastest rotation, largest magnetic field, largest moon, largest moon system, most active moons

# The habitable zone around Jupiter

## Three large icy moons

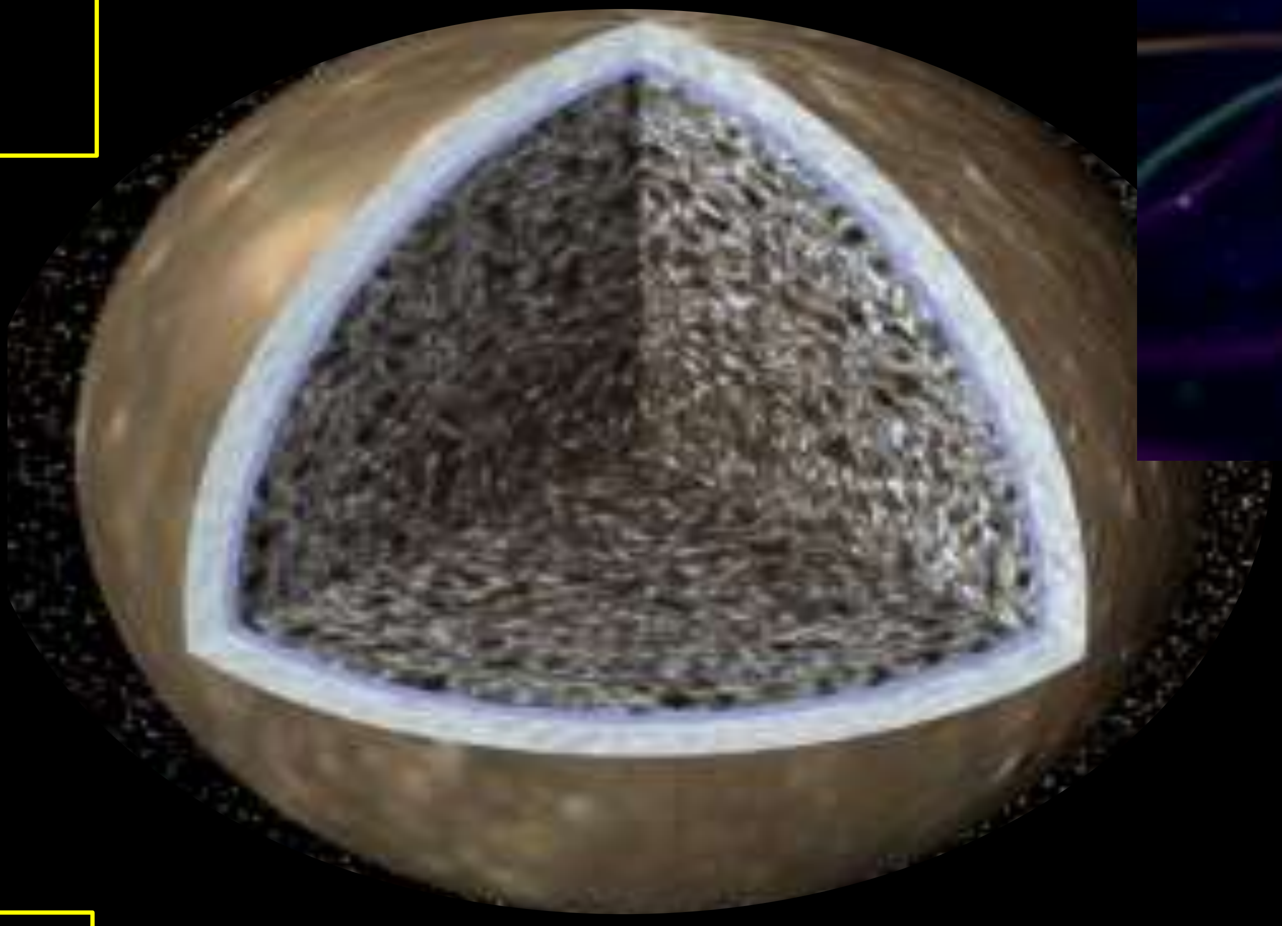
### Ganymede - class IV

- Largest satellite in the solar system
- A deep ocean
- Internal dynamo and an induced magnetic field – unique
- Richest crater morphologies
- Archetype of waterworlds
- Best example of liquid environment trapped between icy layers



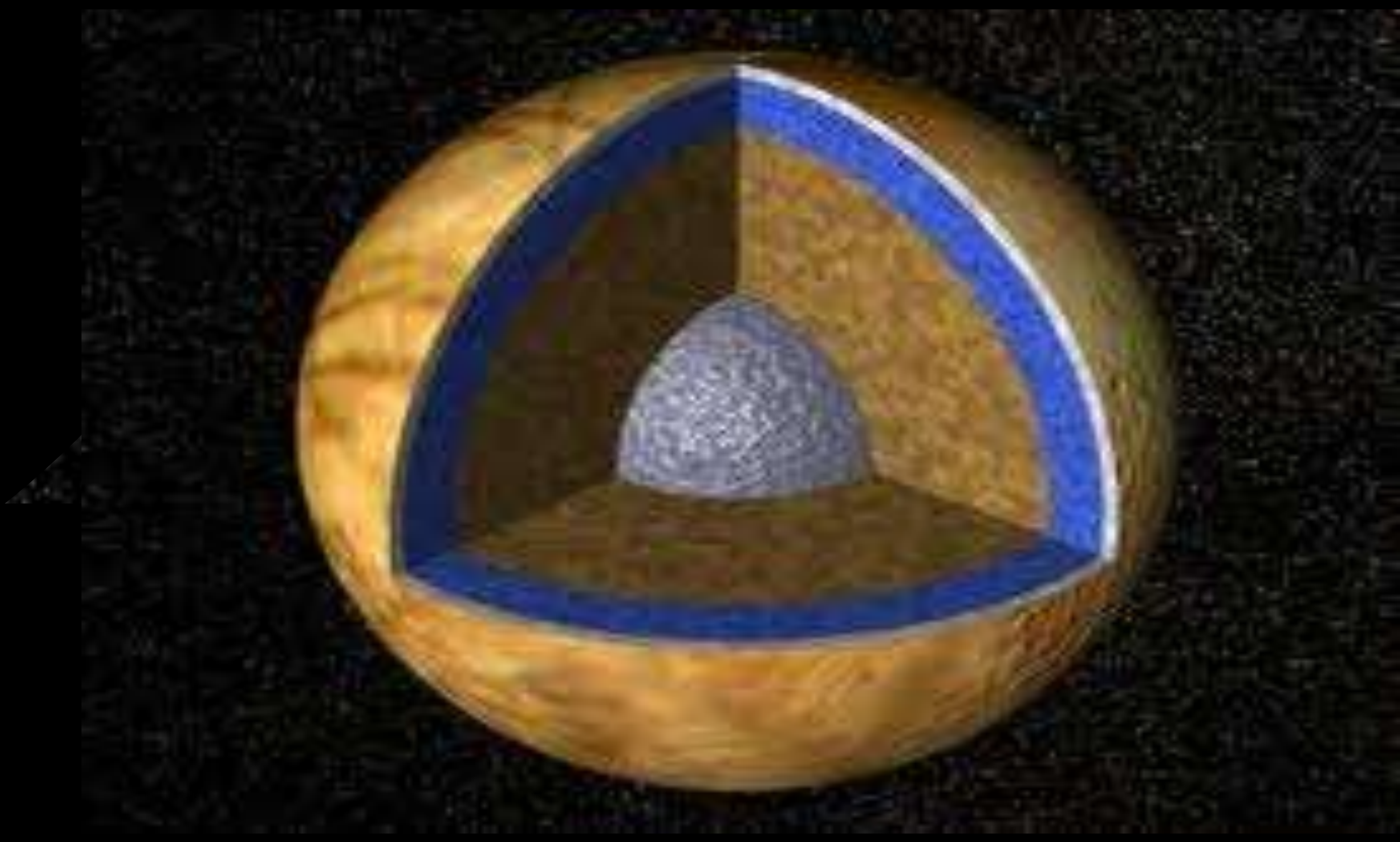
### Callisto - class IV

- Best place to study the impactor history
- Differentiation – still an enigma
- Only known example of non active but ocean-bearing world
- The witness of early ages



### Europa - class III

- A deep ocean
- An active world?
- Best example of liquid environment in contact with silicates

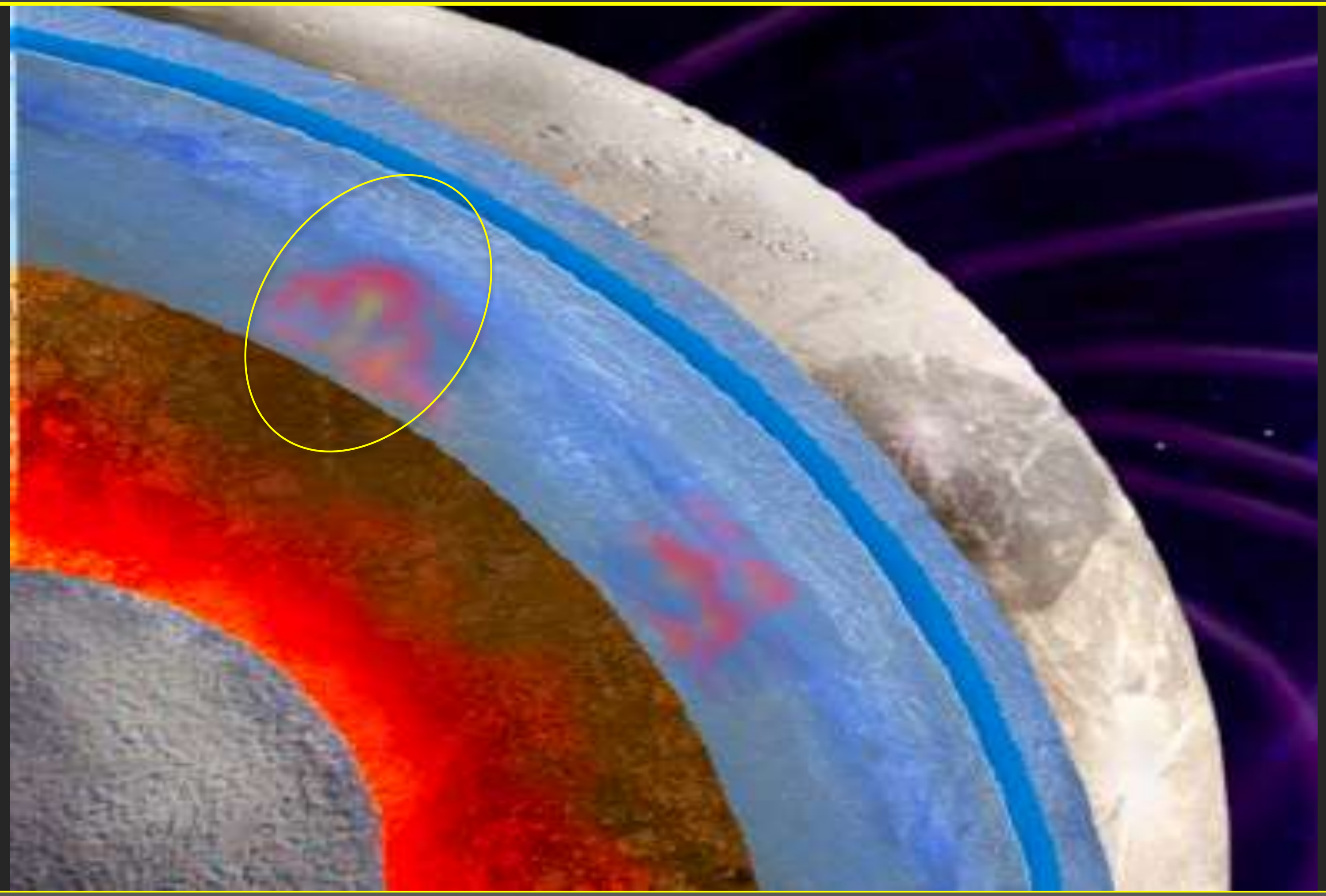


# From the Jupiter system to extrasolar planetary systems





## Waterworlds: If habitable, the liquid layers are trapped between two icy layers

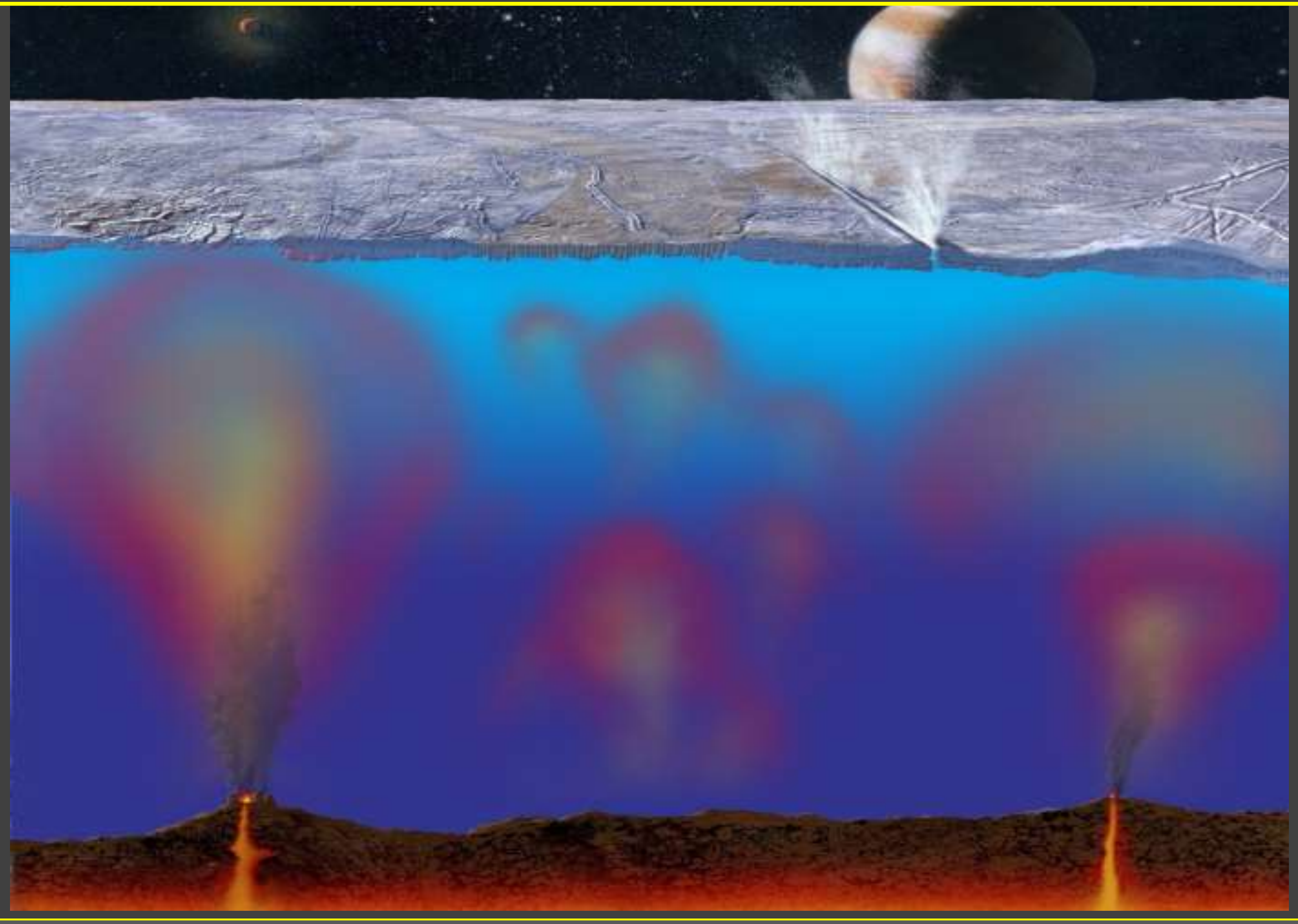


**Occurrence:**
Largest moons, hot ice giants, ocean-planets…
Most common habitat in the universe ?

**Key question:**
Are these waterworlds habitable ?

**What JUICE will do:**
Via characterisation of Ganymede, will constrain the likelihood of habitability in the universe

## Europa-like: If habitable, the liquid layers may be in contact with silicates as on Earth



**Occurrence:**
Europa, Enceladus
Only possible for very small bodies

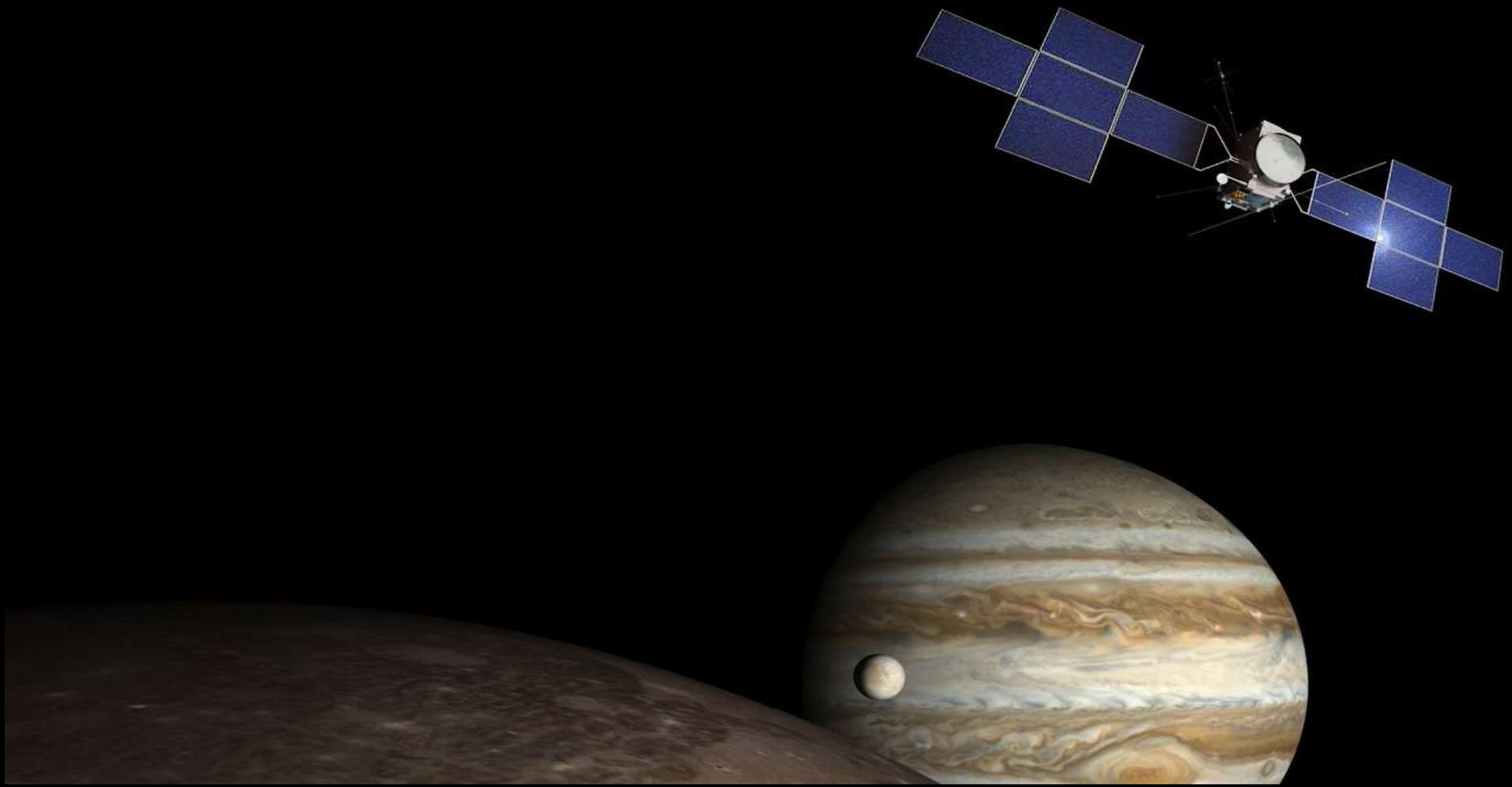
**Key question:**
How are the surface active areas related to potential deep habitats?

**What JUICE will do:**
Pave the way for future landing on Europa
Better understand the likelihood of deep local habitats

# Mission contractor

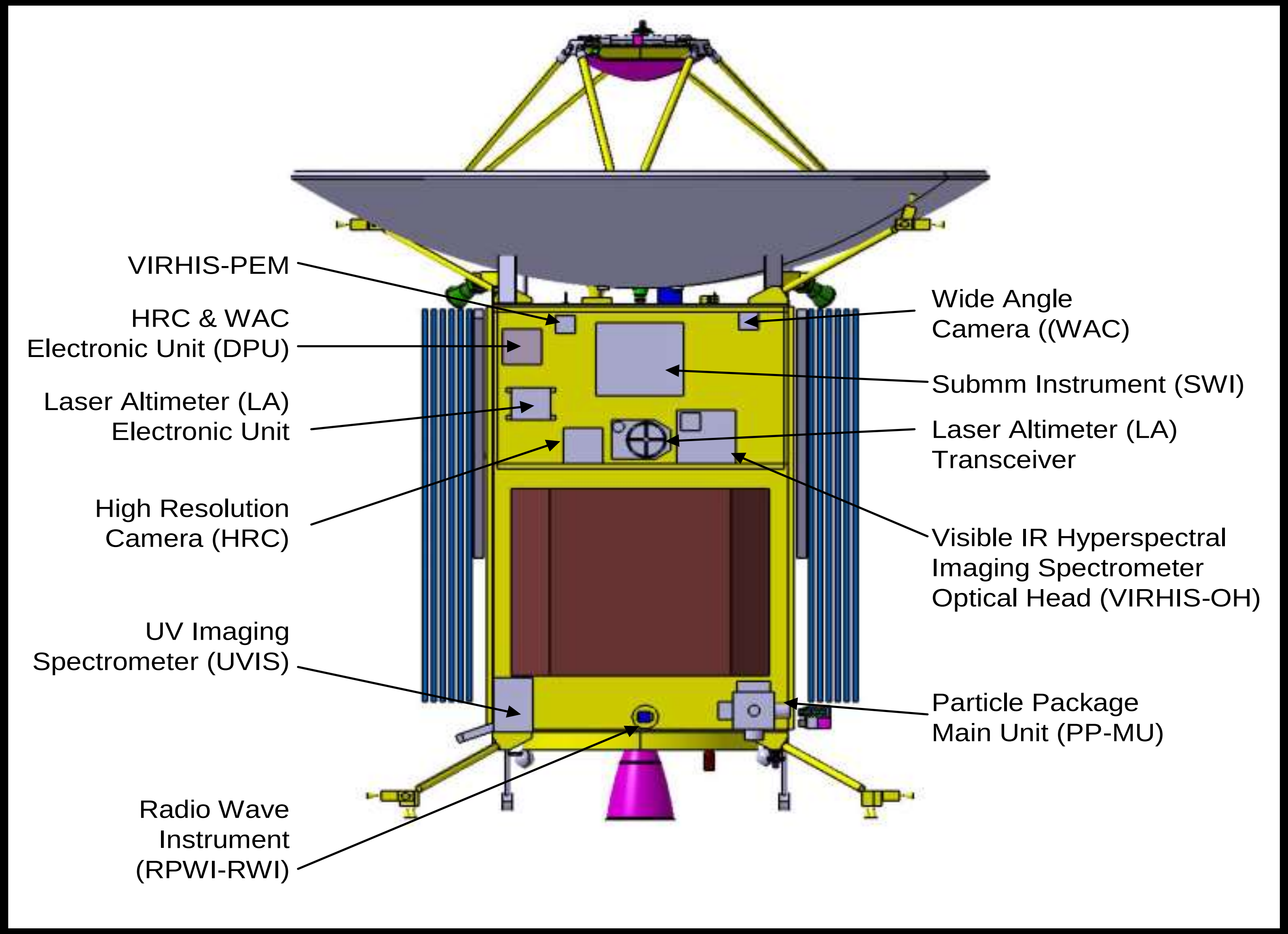
***AIRBUS DEFENCE AND SPACE :***

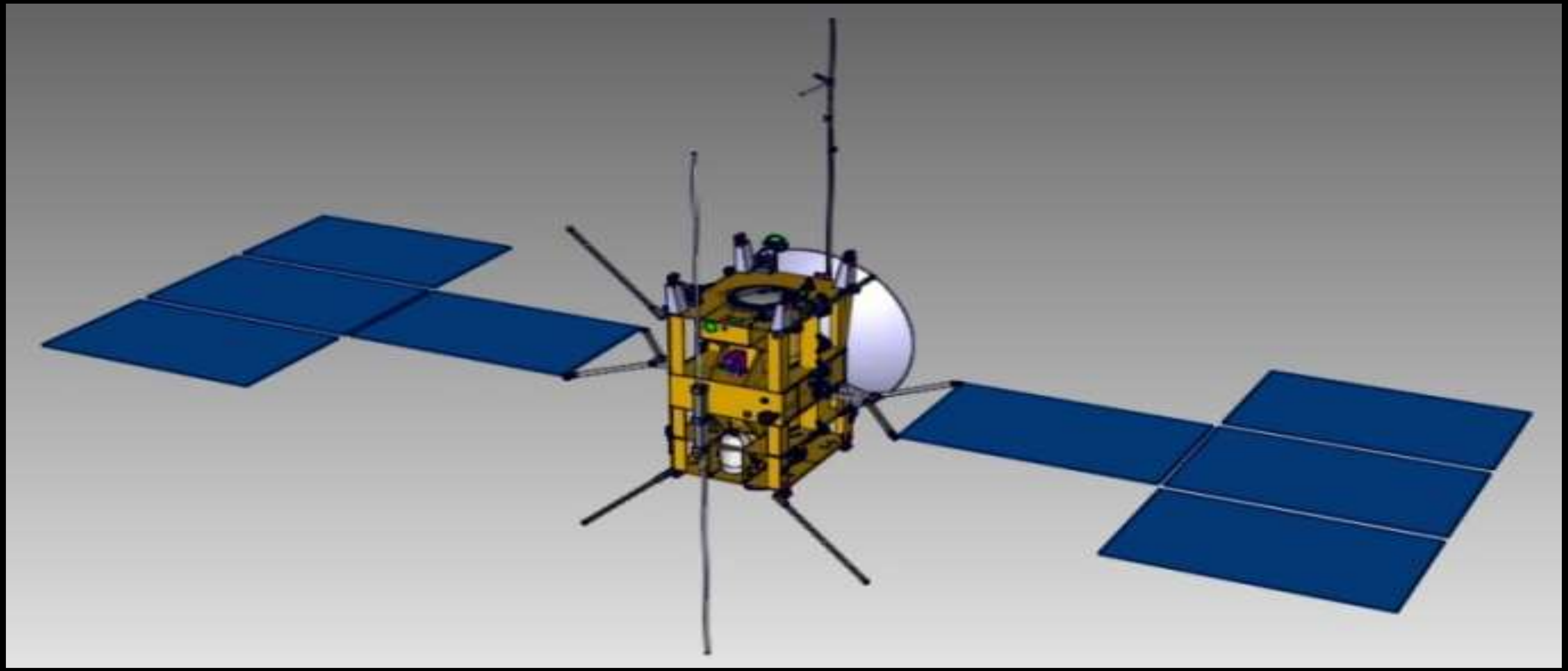
*the prime contractor to develop and build the JUICE spacecraft*



# Main features of the spacecraft design

- *Dry mass ~1900 kg, propellant mass ~2900 kg*
- *Launcher - Ariane 5 ECA (mass : 4.8 tons), High Δv required:  2600 m/s*
- *Payload ~104 kg, ~ 150 W*
- *3-axis stabilized s/c*
- *Power: solar array ~ 100 m², ~ 800 W*
- *HGA: ~3 m, fixed to body, X & Ka-band*
- *Data return >1.4 Gb per day*



# Mission baseline scenario

| | |
|---|---|
| Launch (Ariane 5, Kourou) | June 2022 |
| 1. Interplanetary Transfer | 7.6 years |
| Jupiter Orbit Insertion | Jan 2030 |
| 2. Jupiter equatorial phase #1 | ~11 mon |
| 3. Two Europa flybys | 36 days |
| 4. Jupiter high-latitude phase including 14 Callisto flybys | 260 days |
| 5. Jupiter equatorial phase #2 and transfer to Ganymede | ~11 mon |

| Ganymede phases | OI: Sep 2032 |
|---|---|
| 6. Elliptic #1 | 30 days |
| 7. High altitude (5000 km) | 90 days |
| 8. Elliptic #2 | 30 days |
| 9. Low-altitude circular orbit (500 km) | 132 days |
| Total mission duration | 11 years |

End of nominal mission : June 2033

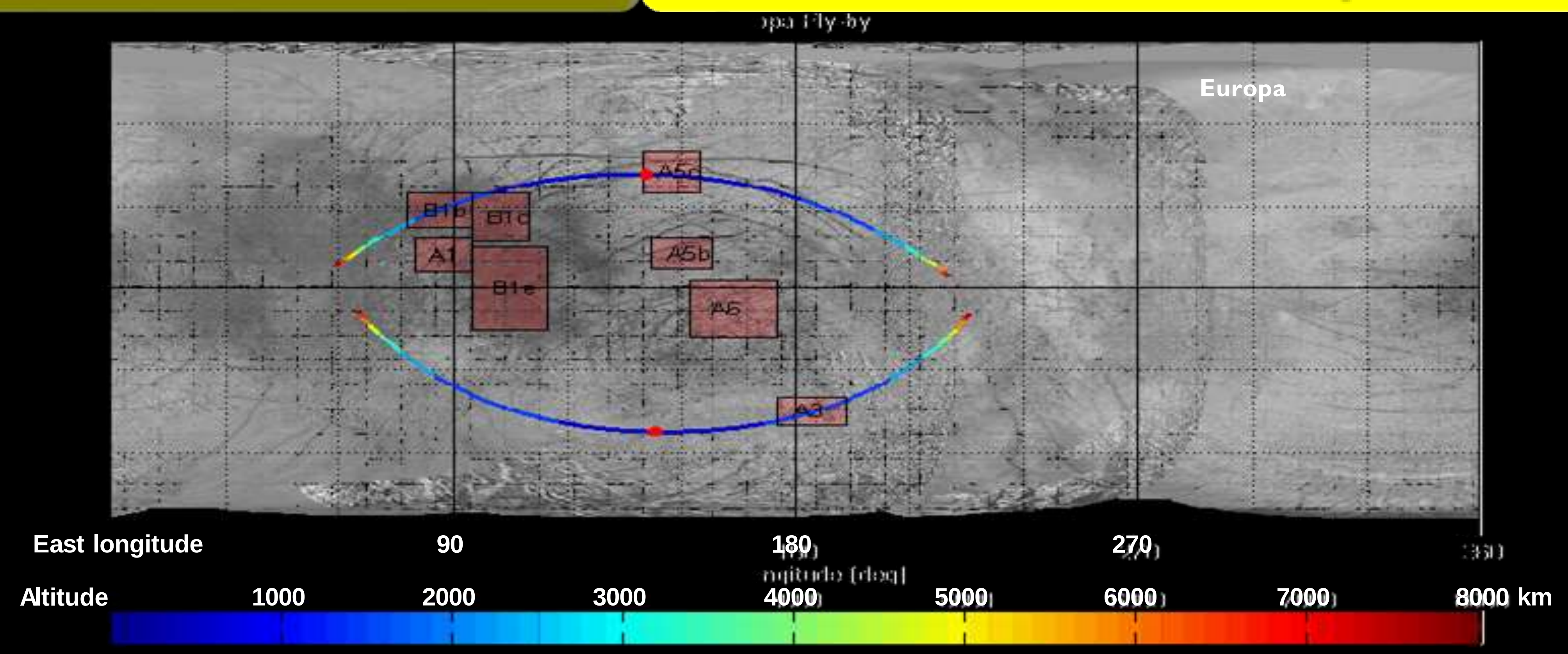
**Development**:
Phase C: March 2017-March 2019
Phase D: March 2019-September 2021
6 months margin
Launch campaign: March-May 2022
Launch 1st June 2022

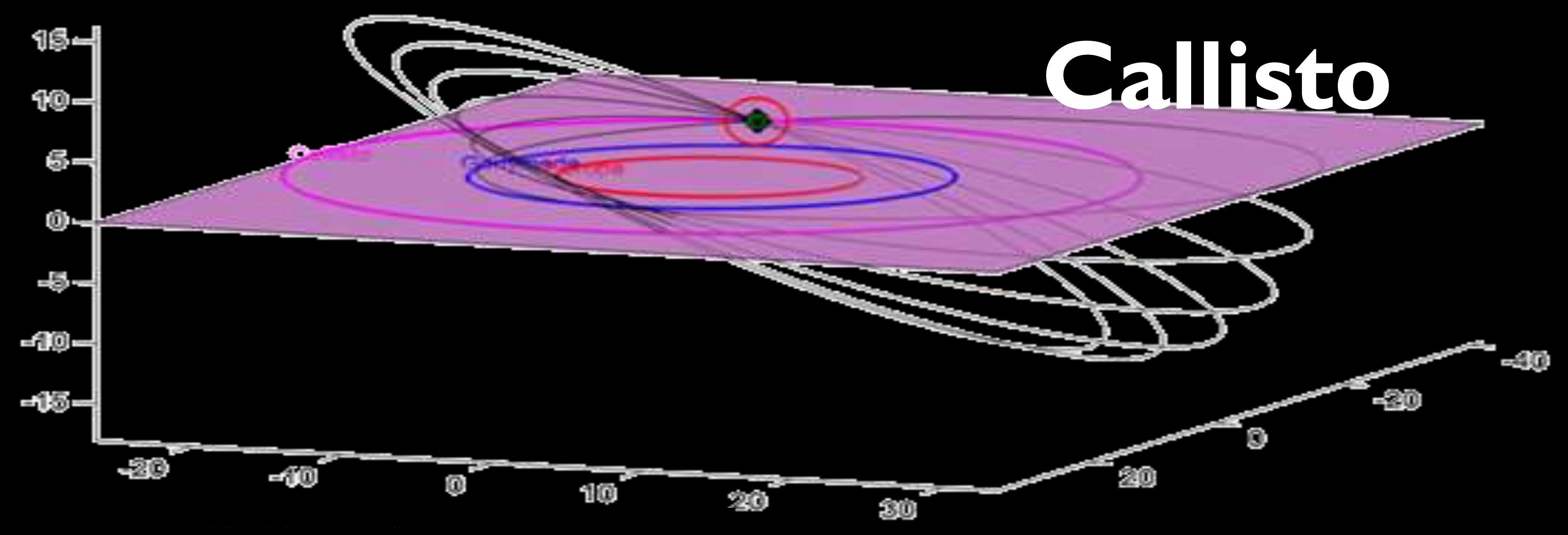
| CRUISE | Nominal mission phases |
|---|---|
| • Launch 1st June 2022<br>• Earth flyby: June 2023<br>• Venus flyby: October 2023<br>• Earth flyby: September 2024<br>• Mars flyby: February 2025<br>• Earth flyby: November 2026<br>• Jupiter orbit insertion: October 2019 | • Phase "Energy reduction" : October 2029-September 2030: 4 Ganymede flybys<br>• Phase "Europa flybys": September-October 2030: 2 Europa, 1 Ganymede, 1 Callisto flybys<br>• Phase "high-latitude": November 2030-July 2031: excursion up to 29 degrees Jupiter latitudes; 9 Callisto and 1 Ganymede flybys<br>• Phase "Transfer to Ganymede": July 2031-September 2032: 9 Ganymede and 2 Callisto flybys, and Ganymede orbit insertion.<br>• Phase "orbit around Ganymede": September 2032-June 2033.<br>• End of nominal mission June 2033 |

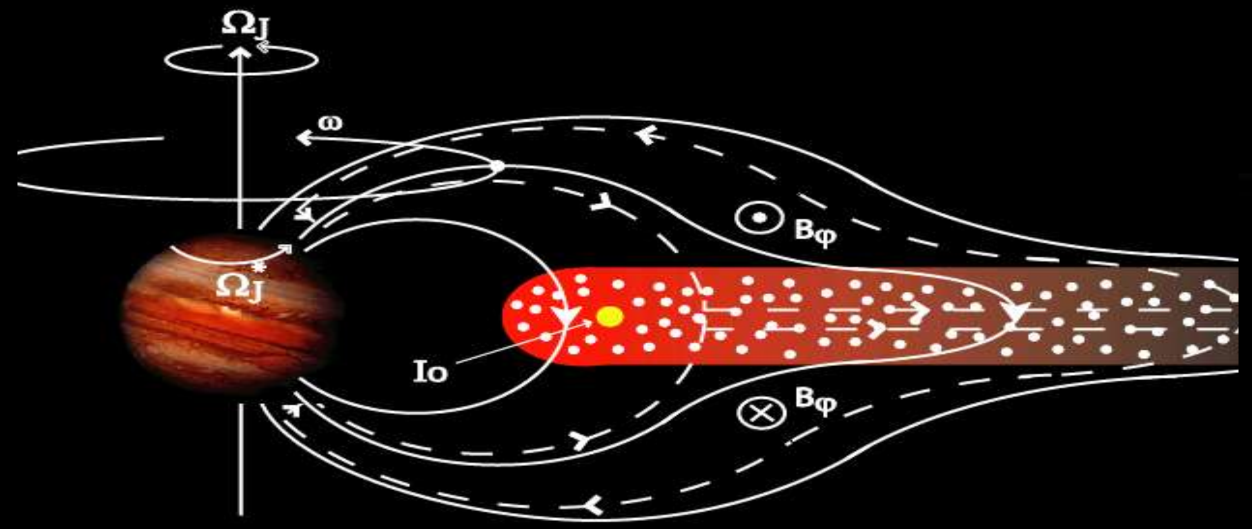
# Mission design

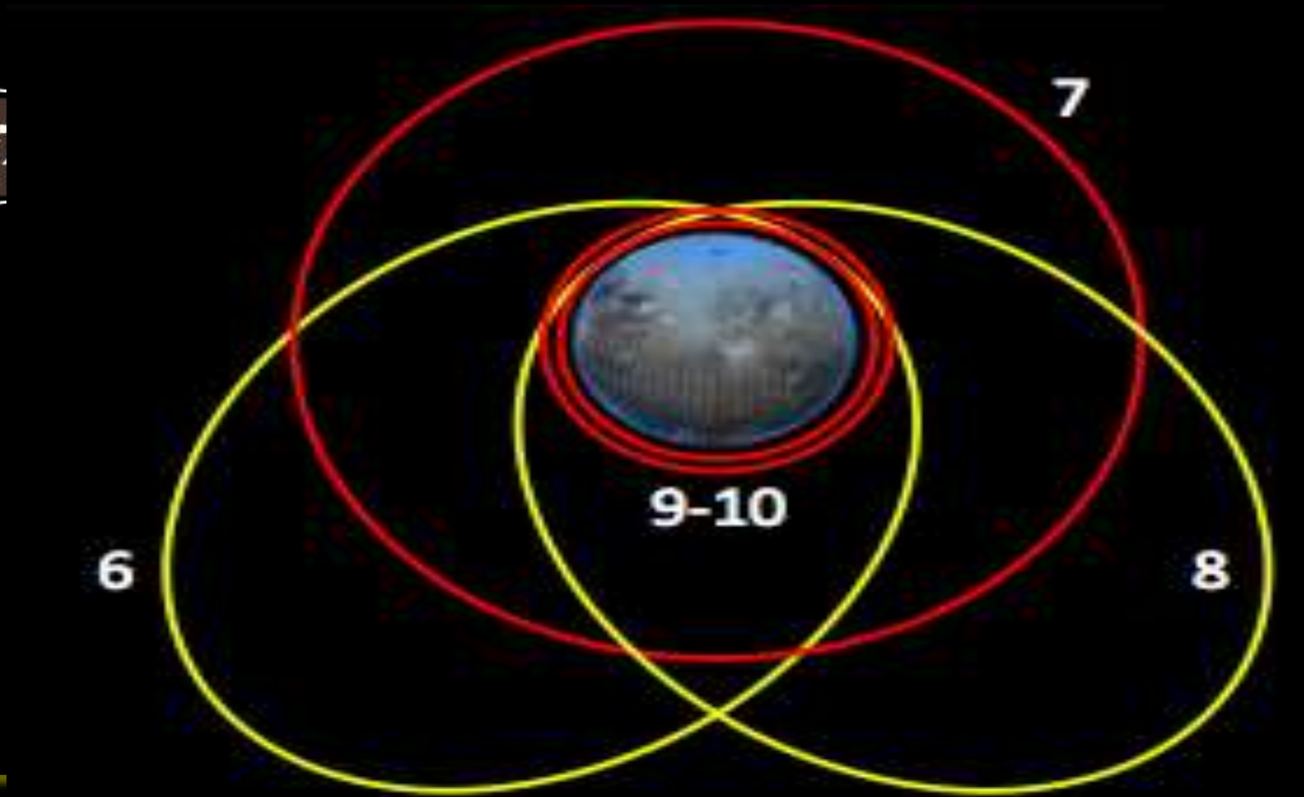
Spacecraft Design | Model instruments | **Mission phases**

| | |
|---|---|
| Launch | June 2022 |
| Interplanetary transfer (Earth-Venus-Earth-Earth) | 7.6 years (8 years) |
| Jupiter orbit insertion and apocentre reduction with Ganymede gravity assists | 11 months |
| 2 Europa flybys | 36 days |
| Reduction of $v_{inf}$ (Ganymede, Callisto) | 60 days |
| Increase inclination with 10 Callisto gravity assists | 200 days |
| **Callisto to Ganymede** | **11 months** |
| **Ganymede (polar)**<br>**10,000x200 km & 5000 km**<br>**500 km circular**<br>**200 km circular** (TBC) | <br>**150 days**<br>**102 days**<br>**30 days** |
| **Total mission at Jupiter** | **3 years** |



# JUICE : PAYLOAD

# JUICE Payload

| Acronym | PI | LFA | Instrument type |
|---|---|---|---|
| **Remote Sensing Suite** | | | |
| **JANUS** | P. Palumbo | Italy | Narrow Angle Camera |
| **MAJIS** | Y. Langevin<br>G. Piccioni | France<br>Italy | Vis-near-IR imaging spectrometer |
| **UVS** | R. Gladstone | USA | UV spectrograph |
| **SWI** | P. Hartogh | Germany | Sub-mm wave instrument |
| **Geophysical Experiments** | | | |
| **GALA** | H. Hussmann | Germany | Laser Altimeter |
| **RIME** | L. Bruzzone | Italy | Ice Penetrating Radar |
| **3GM** | L. Iess | Italy | Radio science experiment |
| **PRIDE** | L. Gurvits | Netherlands | VLBI experiment |
| **Particles and Fields Investigations** | | | |
| **PEP** | S. Barabash | Sweden | Plasma Environmental Package |
| **RPWI** | J.-E. Wahlund | Sweden | Radio & plasma Wave Instrument |
| **J-MAG** | M. Dougherty | UK | Magnetometer |

# JUICE Payload

## JANUS: Visible Camera System

**PI:** Pasquale Palumbo, Parthenope University, Italy.
**Co-PI:** Ralf Jaumann, DLR, Germany

- ≥7.5m/pixel
- Multiband imaging, 380 - 1080 nm
- Icy moon geology
- Io activity monitoring and other moons
- Jovian atmosphere dynamics

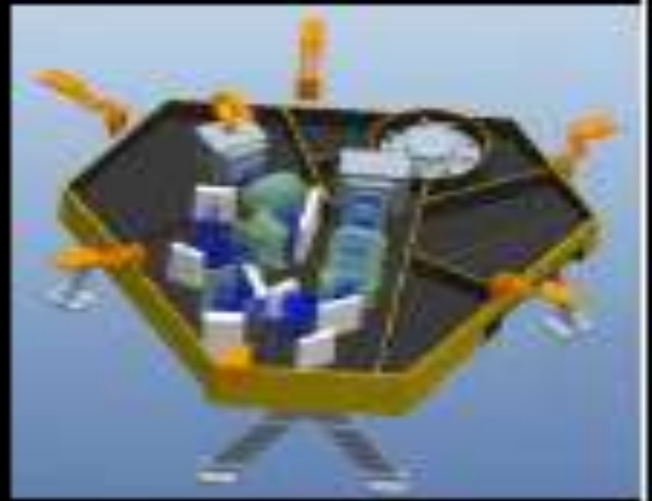
## SWI: Sub-mm Wave Instrument

**PI:** Paul Hartogh, MPS, Germany

- 600 GHz
- Jovian Stratosphere
- Moon atmosphere
- Atmospheric isotopes

## MAJIS: Imaging VIS-NIR/IR Spectrograph

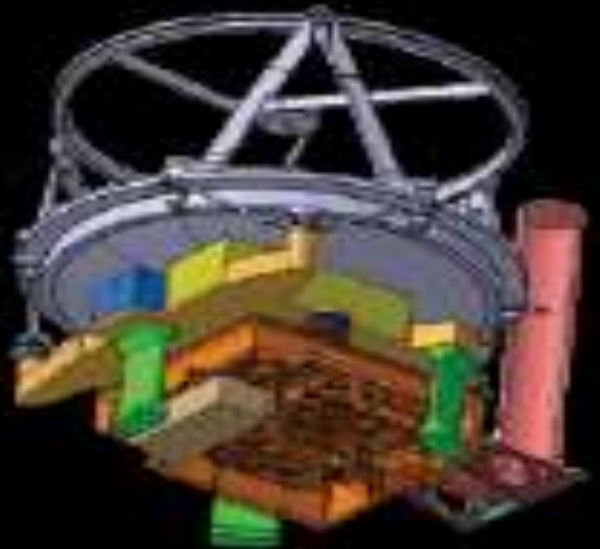
**PI:** Yves Langevin, IAS, France
**Co-PI:** Guiseppe Piccioni, INAF, Italy



- 0.9-1.9 μm and 1.5-5.7 μm
- ≥62.5 m/pixel
- Surface composition
- Jovian atmosphere

## GALA: Laser Altimeter

**PI:** Hauke Hussmann, DLR, Germany



- ≥40 m spot size
- ≥0.1 m accuracy
- Shape and rotational state
- Tidal deformation
- Slopes, roughness, albedo

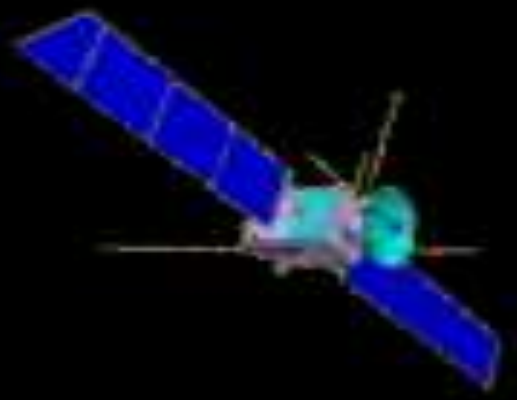
## UVS: UV Imaging Spectrograph

**PI:** Randy Gladstone, SwRI, USA

- 55-210 nm
- 0.04°-0.16°
- Aurora and Airglow
- Surface albedos
- Stellar and Solar Occultation

## RIME: Ice Penetrating Radar

**PI:** Lorenzo Bruzzone, Trento, Italy
**Co-PI:** Jeff Plaut, JPL, USA



- 9 MHz
- Penetration ~9 km
- Vertical resolution 30 m
- Subsurface investigations

# JUICE Payload

## JMAG: JUICE Magnetometer

PI: Michele Dougherty, Imperial, UK

- Dual Fluxgate and Scalar mag
- ±8000 nT range, 0.2 nT accuracy
- Moon interior through induction
- Dynamical plasma processes

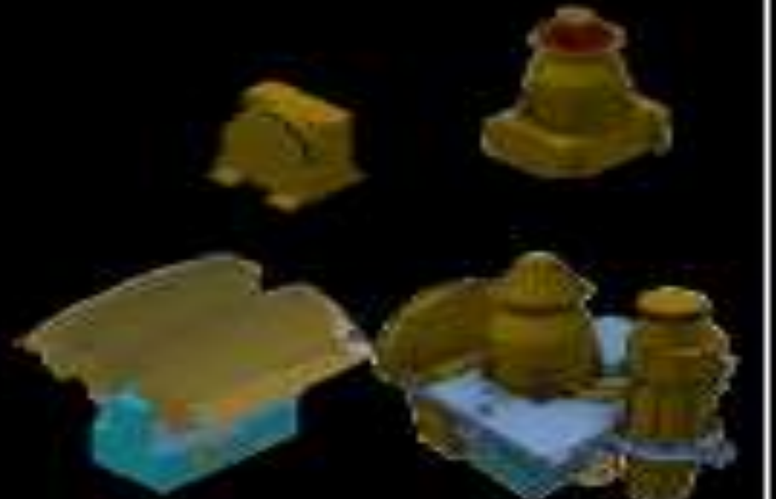
## 3GM: Gravity, Geophysics, Galilean Moons

PI: Luciano Iess, Rome, Italy
Co-PI: David J. Stevenson, CalTech, USA

- Ranging by radio tracking
- 2 μm/s range rate
- 20 cm range accuracy
- Gravity fields and tidal deformation

## PEP: Particle Environment Package

PI: Stas Barabash, IRF-K, Sweden
Co-PI: Peter Wurz, UBe, Switzerland



- Six sensor suite
- Ions, electrons, neutral gas (in-situ)
- Remote ENA imaging of plasma and torus

## PRIDE: Planetary Radio Interferometer & Doppler Experiment

PI: Leonid Gurvits, JIVE, EU/The Netherlands

- S/C state vector
- Ephemerides
- bi-static and radio occultation experiments

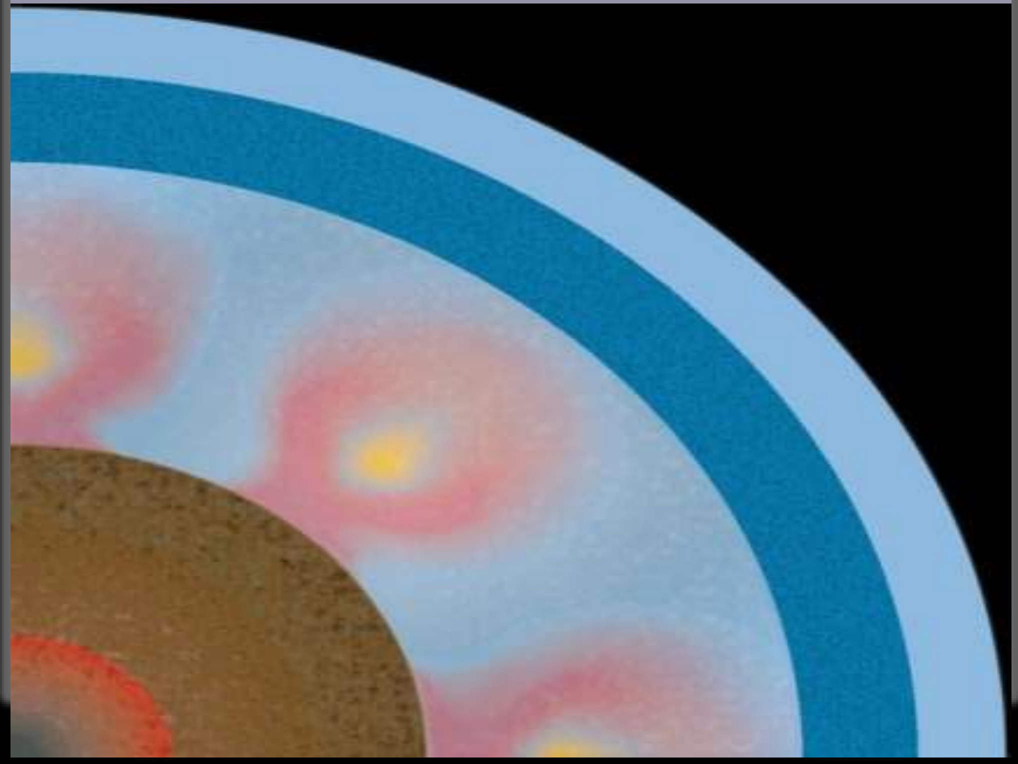
## RPWI: Radio and Plasma Wave Investigation

PI: Jan-Erik Wahlund, IRF-U, Sweden

- Langmuir Probes
- Search Coil Magnetometer
- Tri-axial dipole antenna
- E and B-fields
- Ion, electron and charged dust parameters

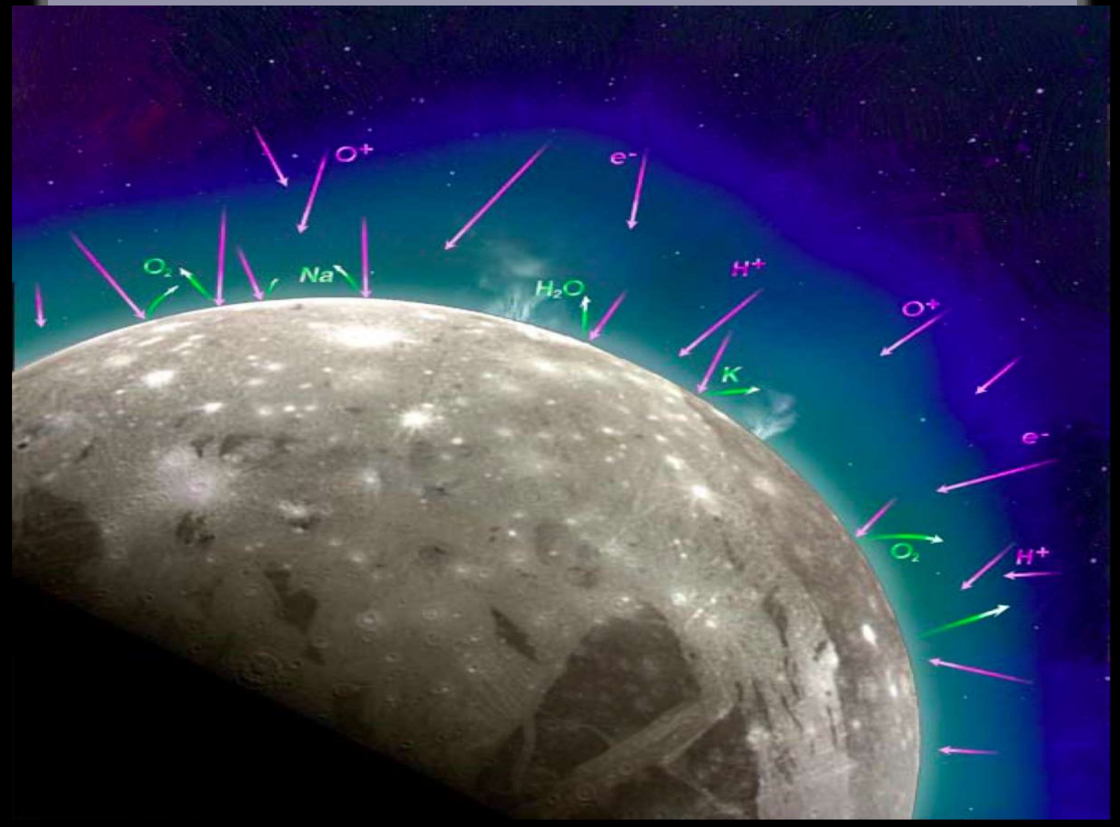
# Ganymede: planetary object and potential habitat

**Ice shell, ocean, deeper interiors**

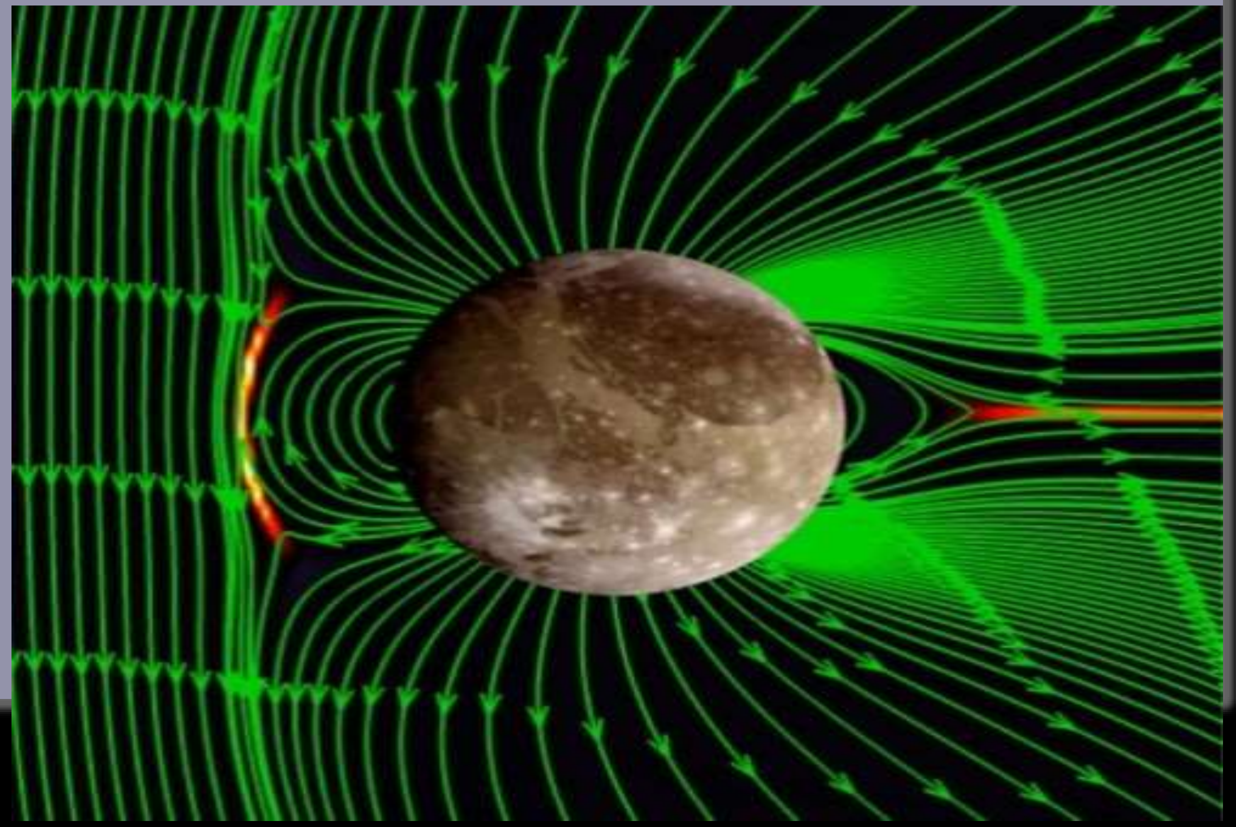


**Geology, surface composition**

**Atmosphere, ionosphere**

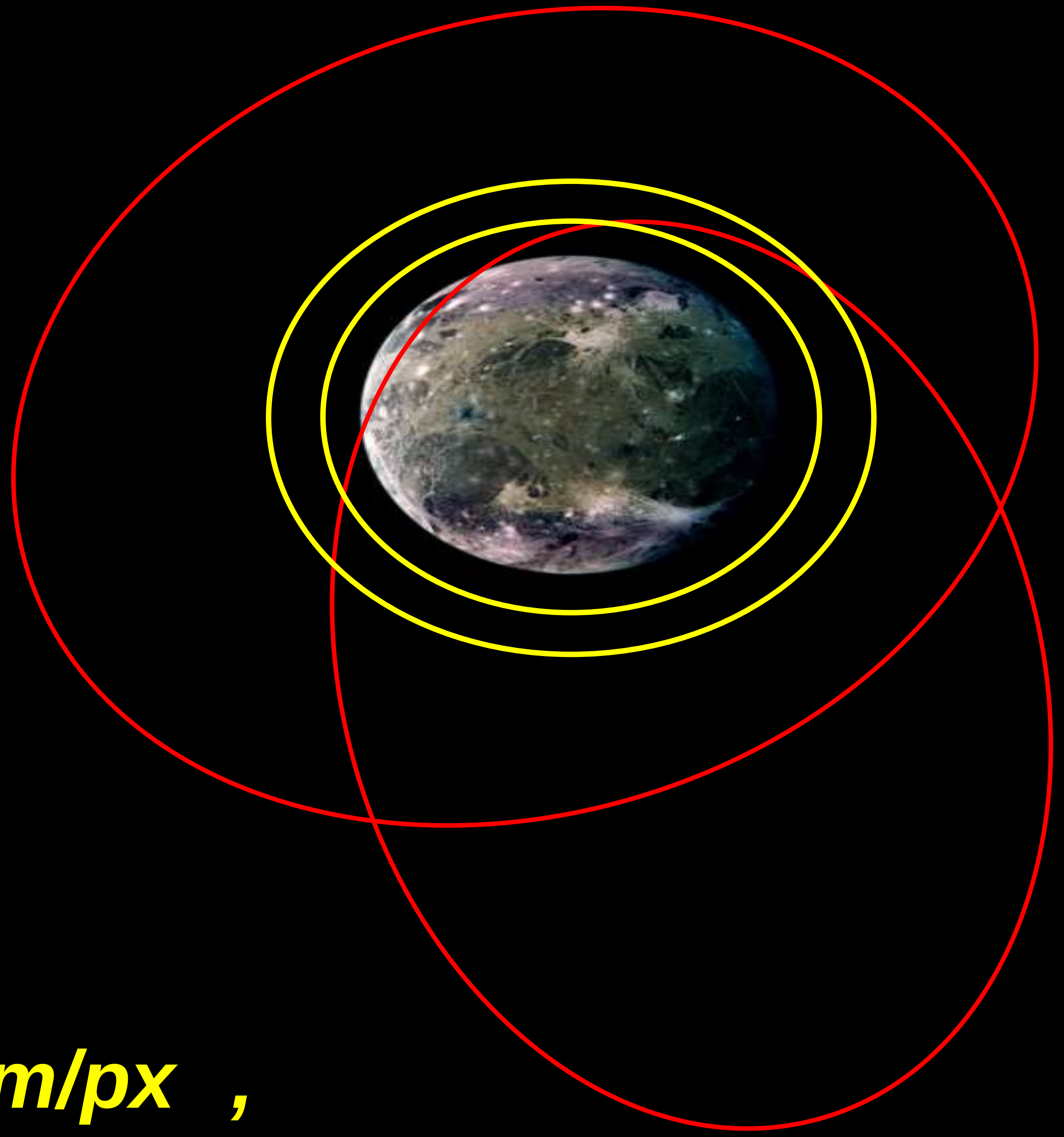


**Magnetosphere, plasma environment**



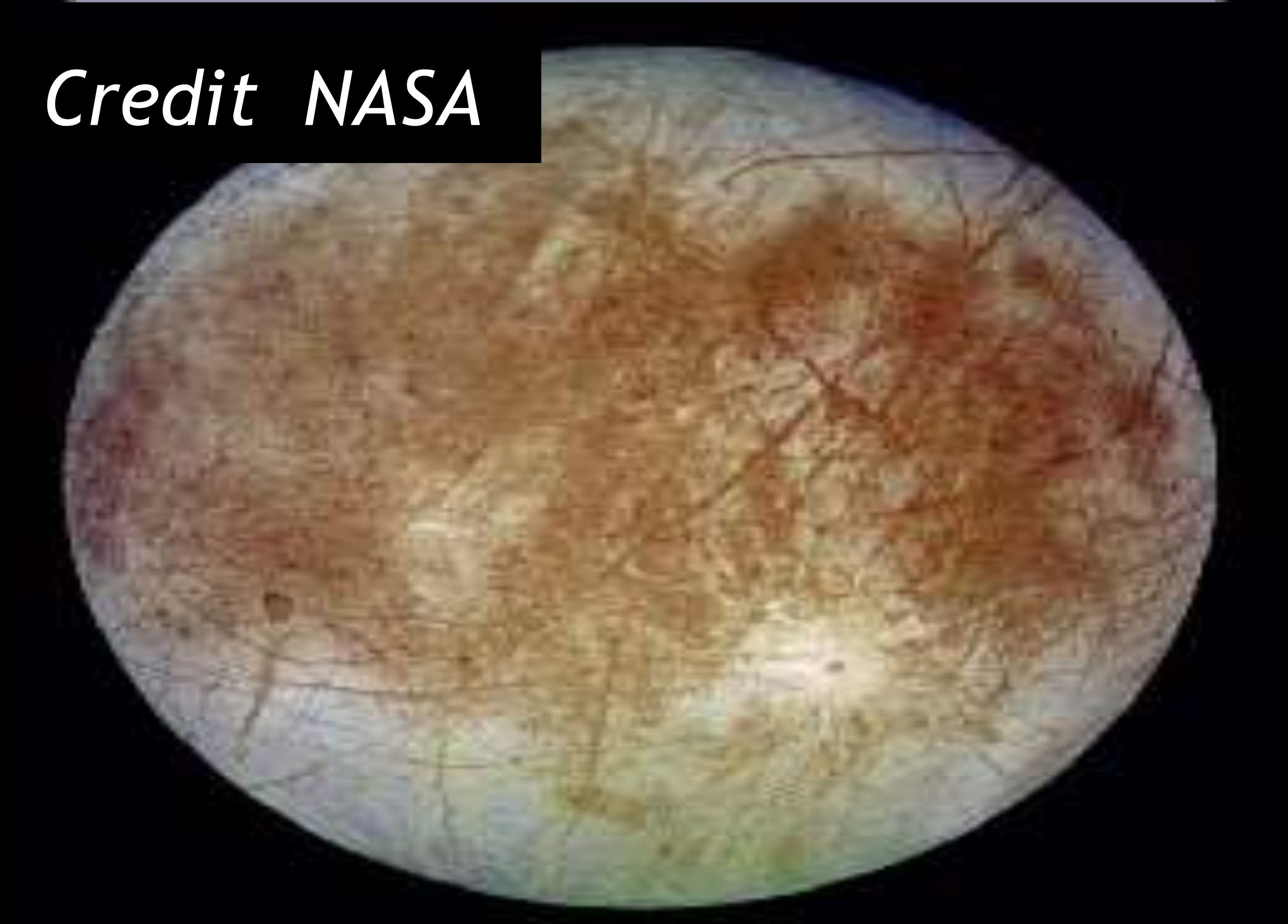
## Main investigations

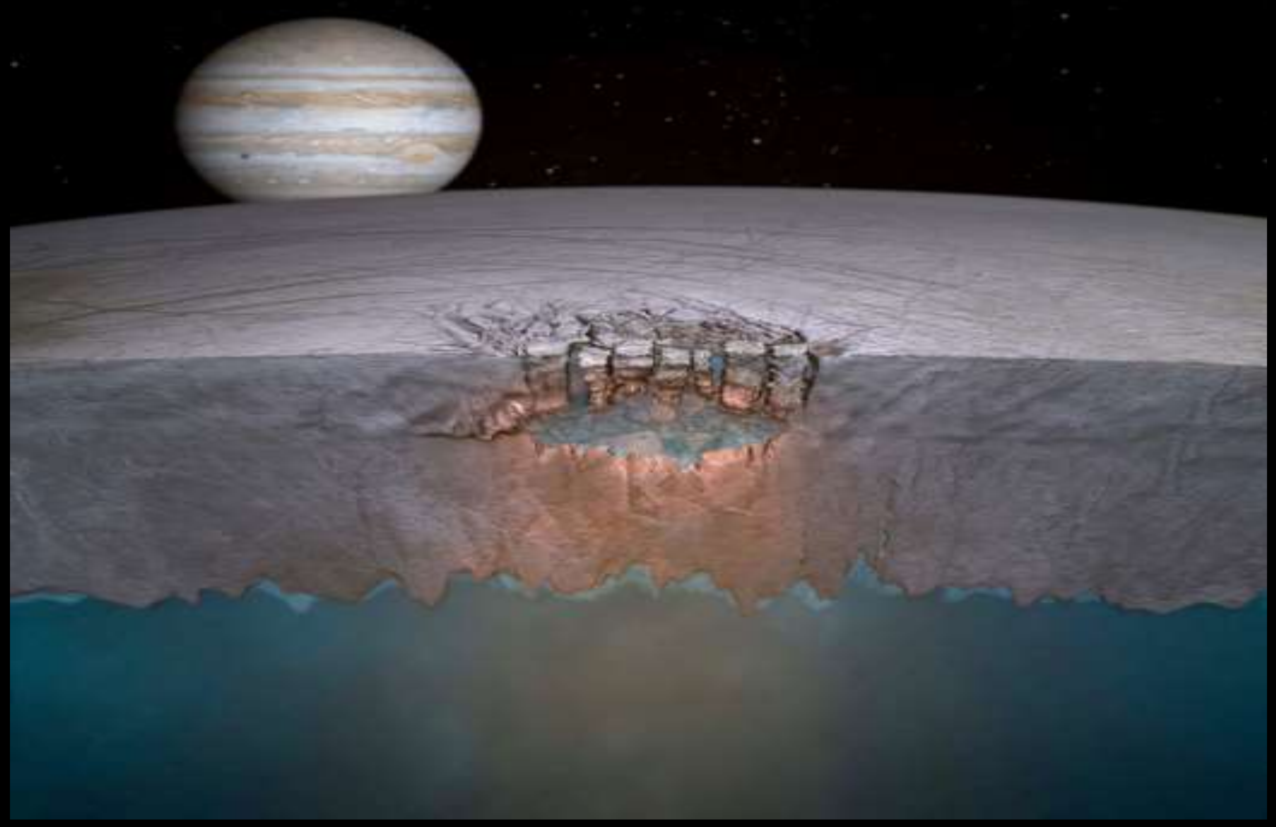
- Elliptical (1000x10000 km) & high (~5000 km) circular orbit
- Medium (500 km) circular orbits
- Favorable illumination conditions (β-angle 30°-70°)
- Dedicated pointing modes
- Sub-surface sounding down to ~9 km depth
- Imaging: global ~400 m/px, selected targets ~3 m/px
- Mineralogical mapping (especially of non-ice materials): globally 1-5 km/px , selected targets ~25 m/px

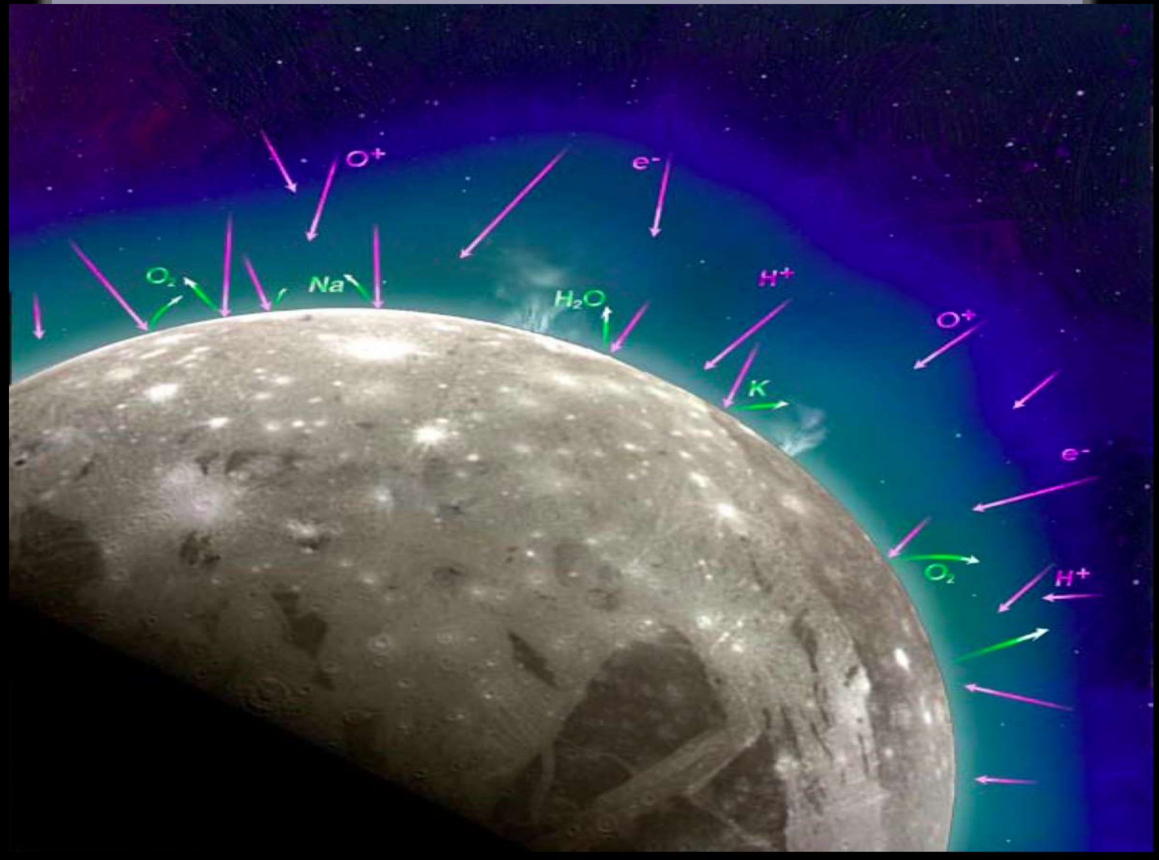


# Europa: study of recently active regions

| Composition of non-ice material | Liquid sub-surface water | Active processes | Atmosphere, ionosphere |
| --- | --- | --- | --- |



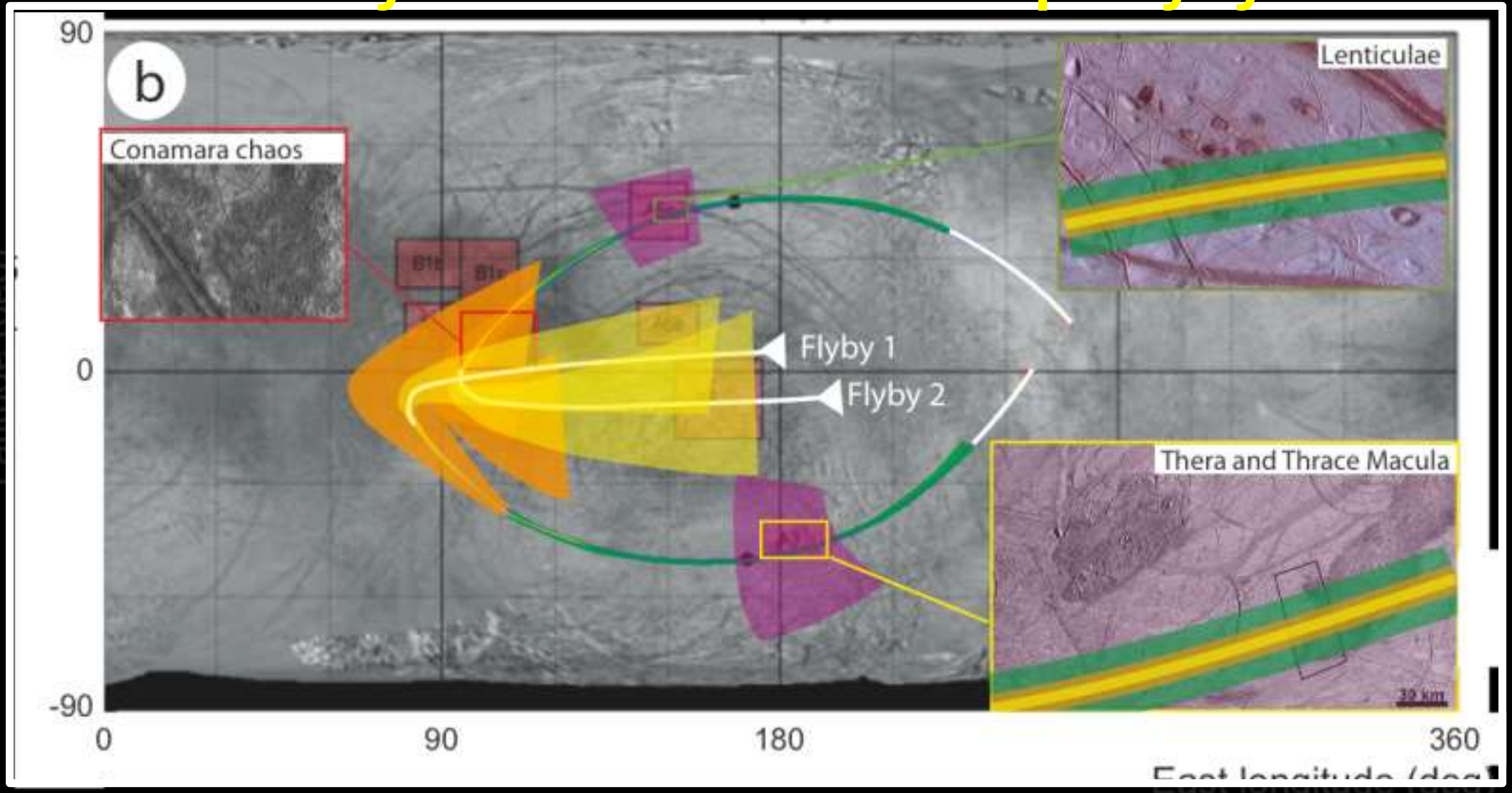





Main investigations

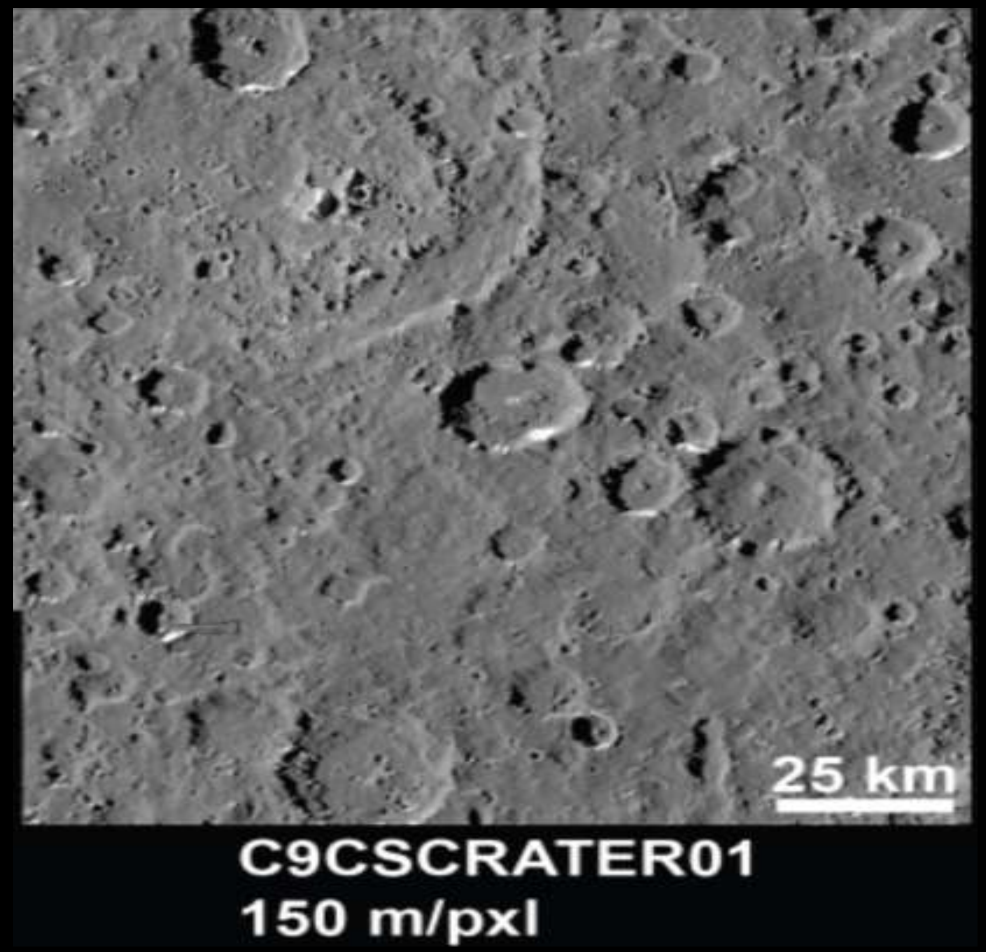
- *At least 1 Europa flyby with CA ~400 km over the most active regions*
- *Favorable illumination conditions at CA*
- *Anti-Jovian side at CA*
- *Simultaneous operations of all experiments (including 3GM as a goal)*
- *Non-ice materials in selected sites mapped at regional (>5 km/px) and local (<500 m/px) scales & processes in active sites*

## Geometry of two baseline Europa flybys

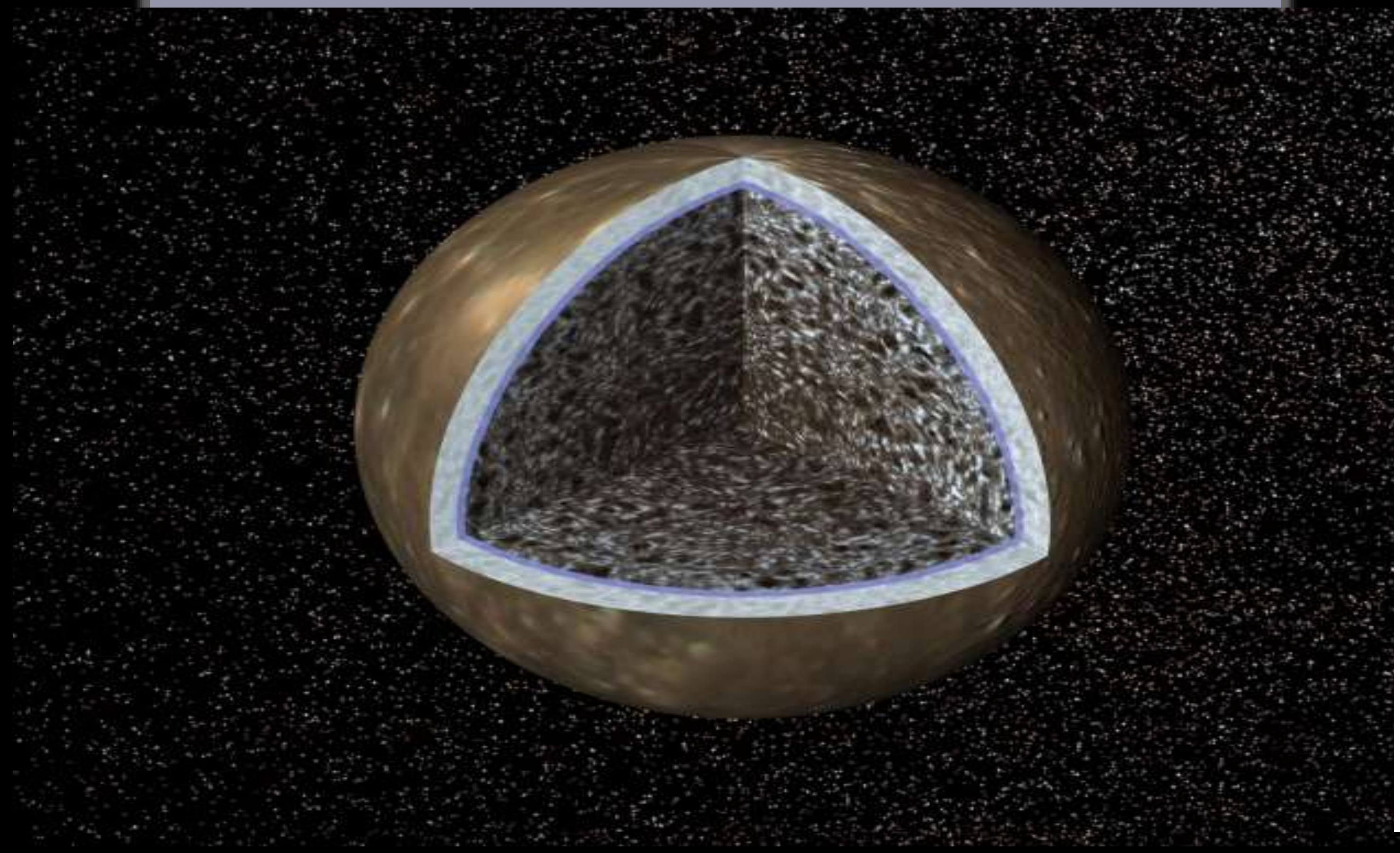


# Callisto: a witness of the early Solar System

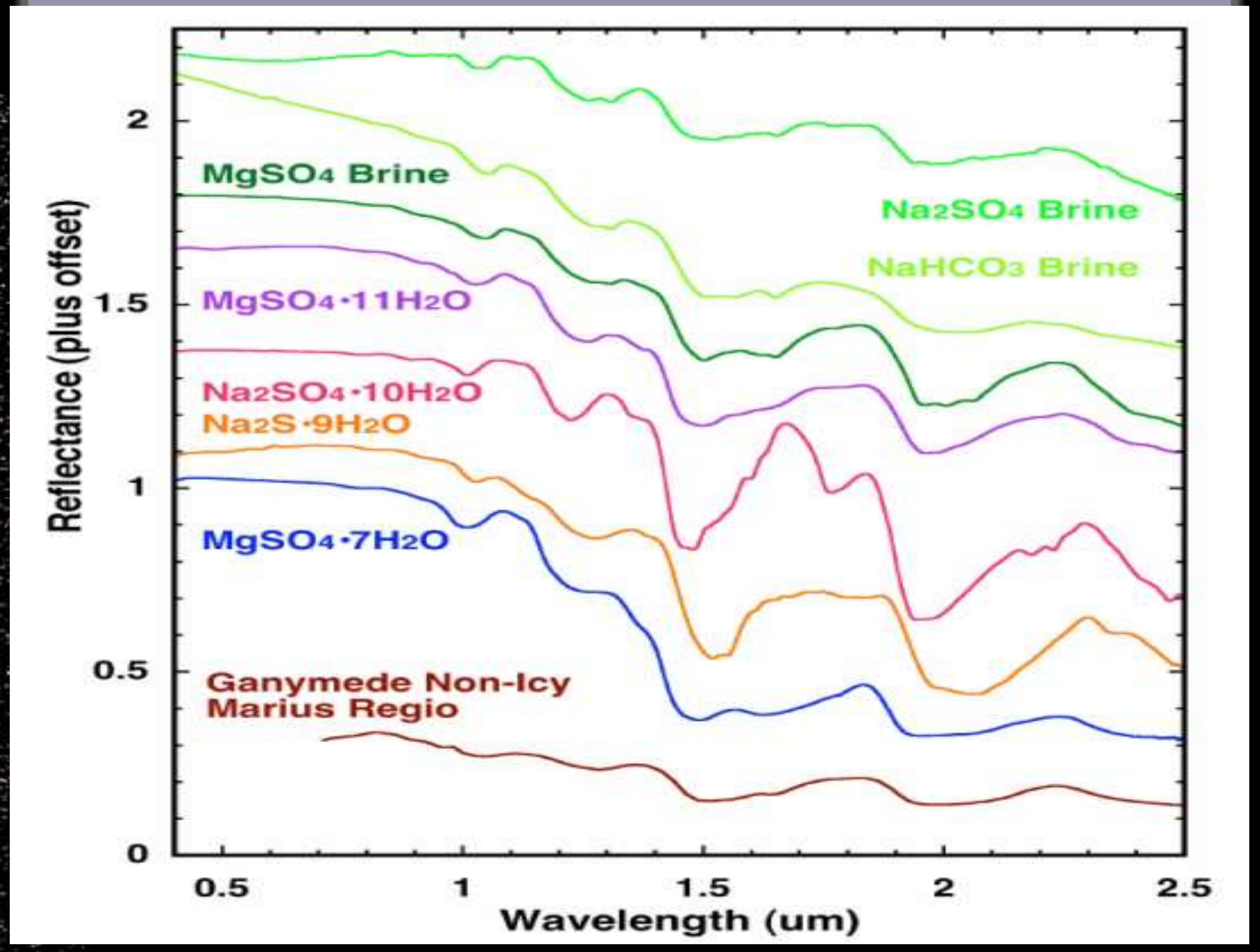
## Geological history and past activity




## Outer shell including ocean



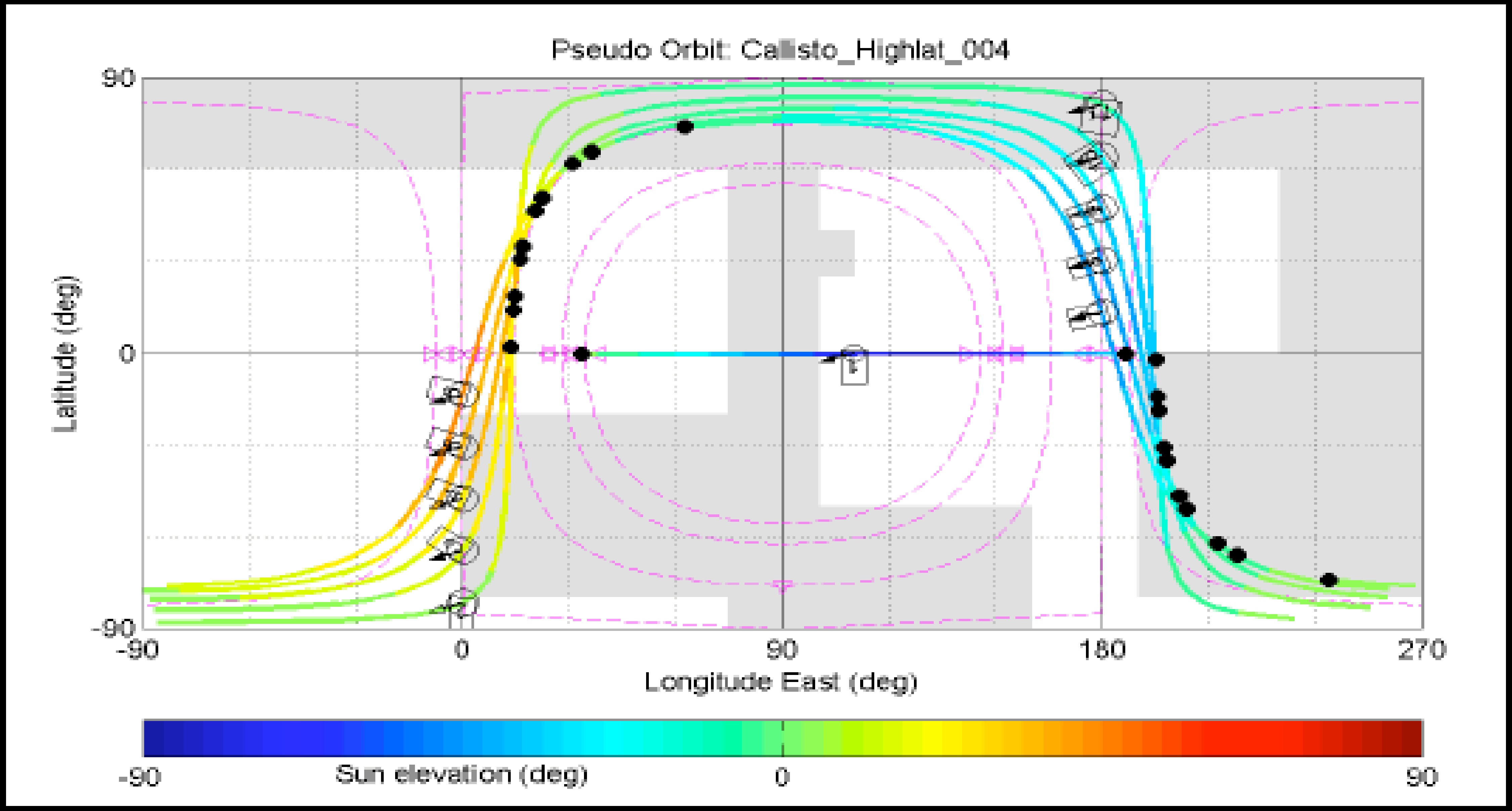
## Non-ice material




### Main investigations

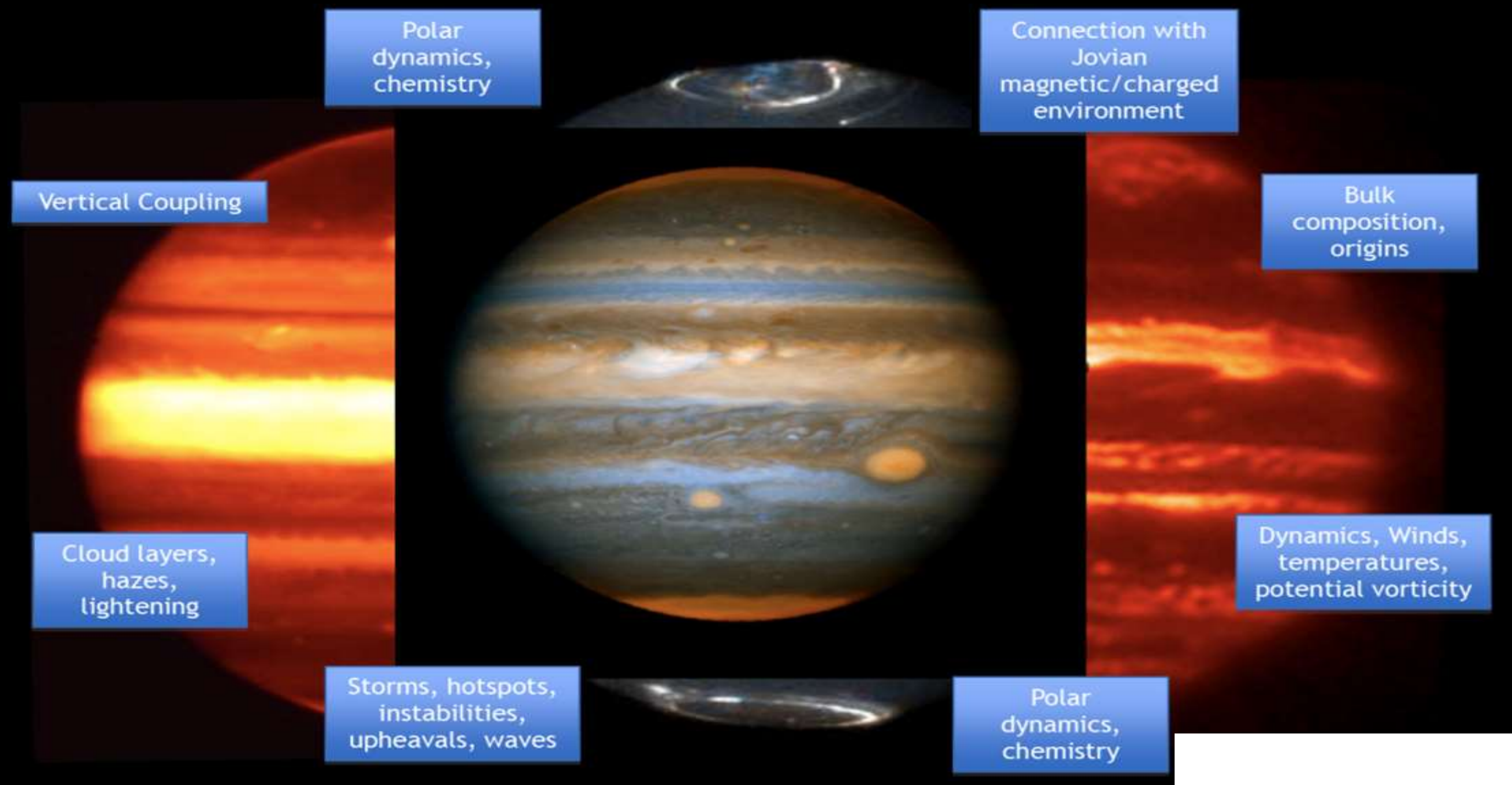
- *At least 9 Callisto flybys with CA<1000 km*
- *Several flybys with CA<500 km and good illumination conditions*
- *Flyby trajectory inclined by at least 50° to the moons equator*
- *Medium resolution imaging (<400 m/px)*
- *Regional mineralogical mapping (~5km/px)*
- *Subsurface down to few km*

### Geometry of the baseline Callisto flybys



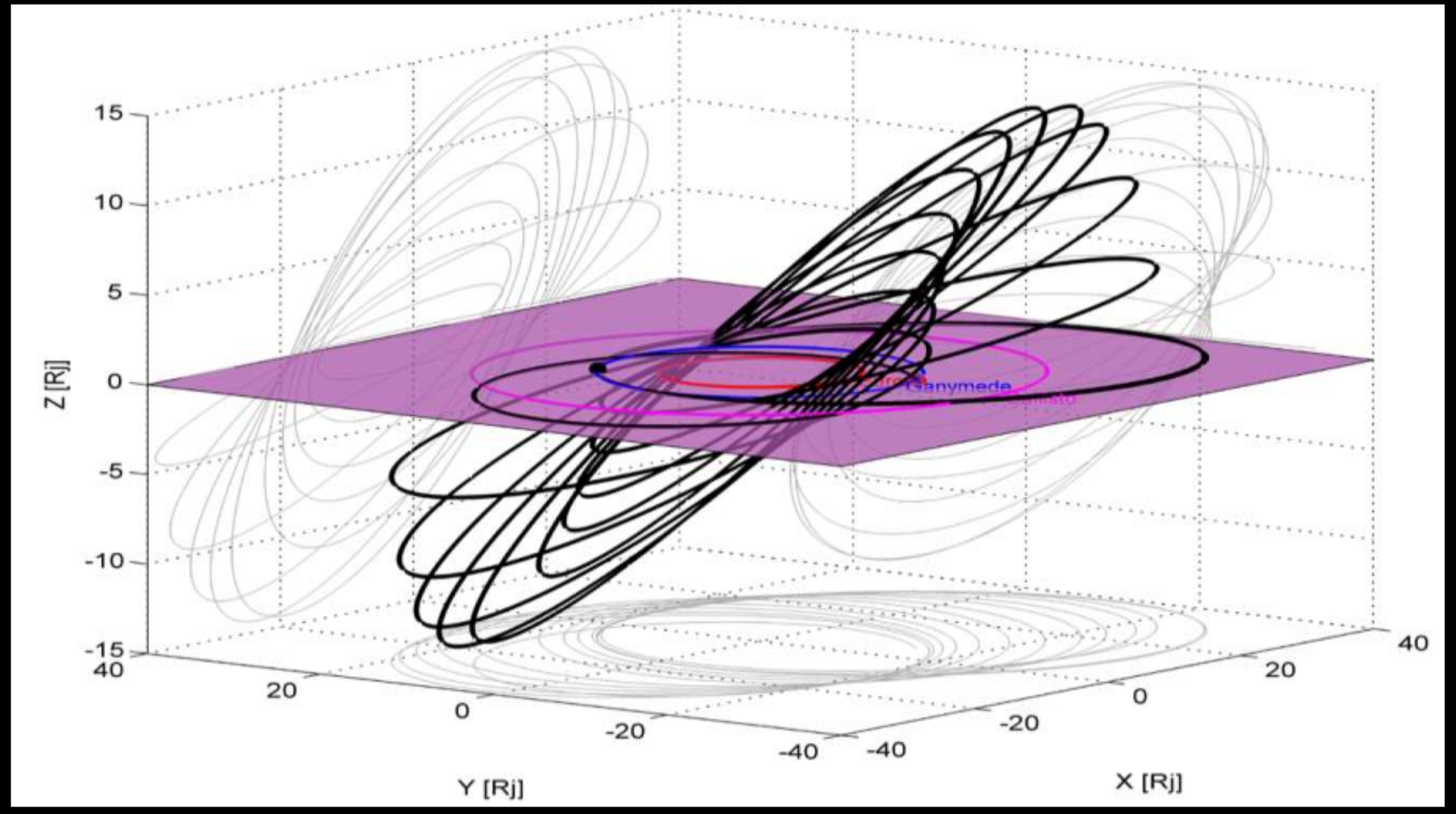
# Jupiter atmosphere

- *Atmospheric structure, composition and dynamics*
- *Coupling between troposphere, stratosphere and thermosphere*





## High-inclination trajectories

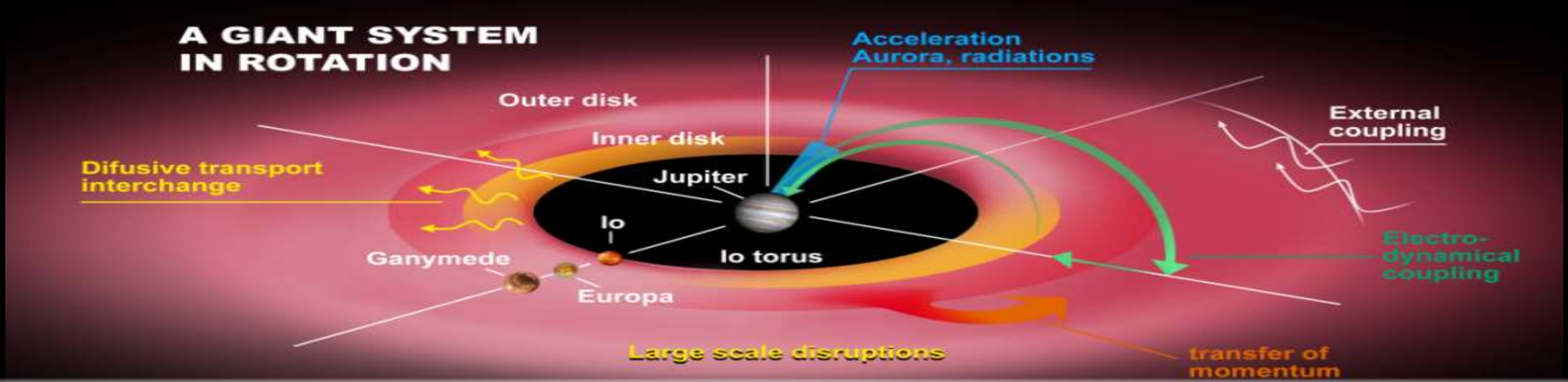



## *Main investigations*

- *Multi-wavelength observations from UV to sub-mm*
- *Imaging ~15 km/px, spectro-imaging 100-200 km/px*
- *Complete latitude, phase angle, local time coverage*
- *Repeated observations with time scales from hours to months*
- *Extended period of time (3 years in total)*

# Jupiter magnetosphere

- *Magnetosphere as a fast rotator*
- *Magnetosphere as a giant particle accelerator*
- *Interaction of the Jovian magnetosphere with the moons*
- *Moons as sources and sinks of magnetospheric plasma*



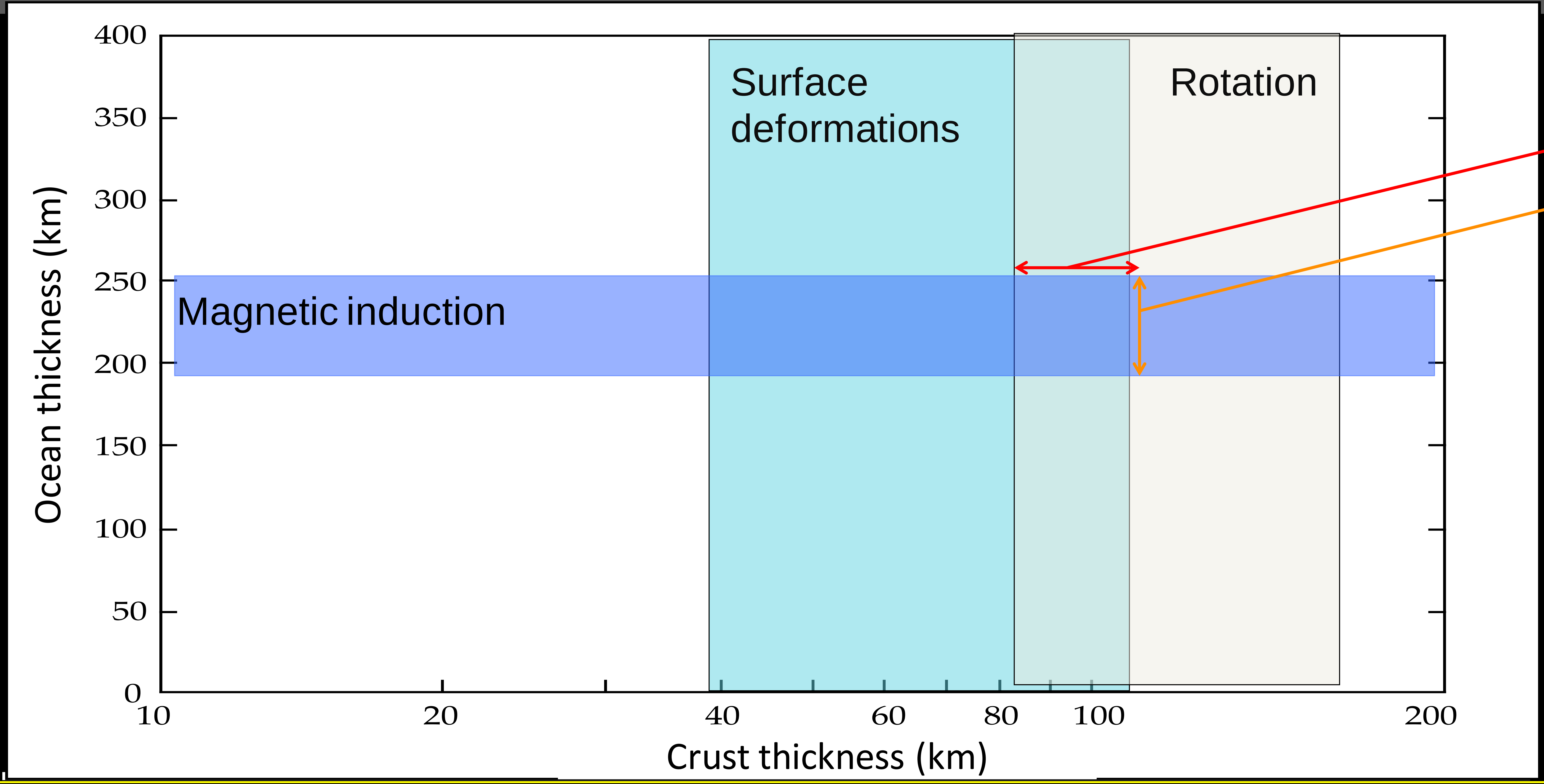

## *JUICE features*

- *Equatorial magnetosphere at R ~ 10 - 30 $R_J$ and out to at least 100 $R_J$*
- *High-inclination orbit (up to at least 22°)*
- *Simultaneous remote sensing and in-situ observations*

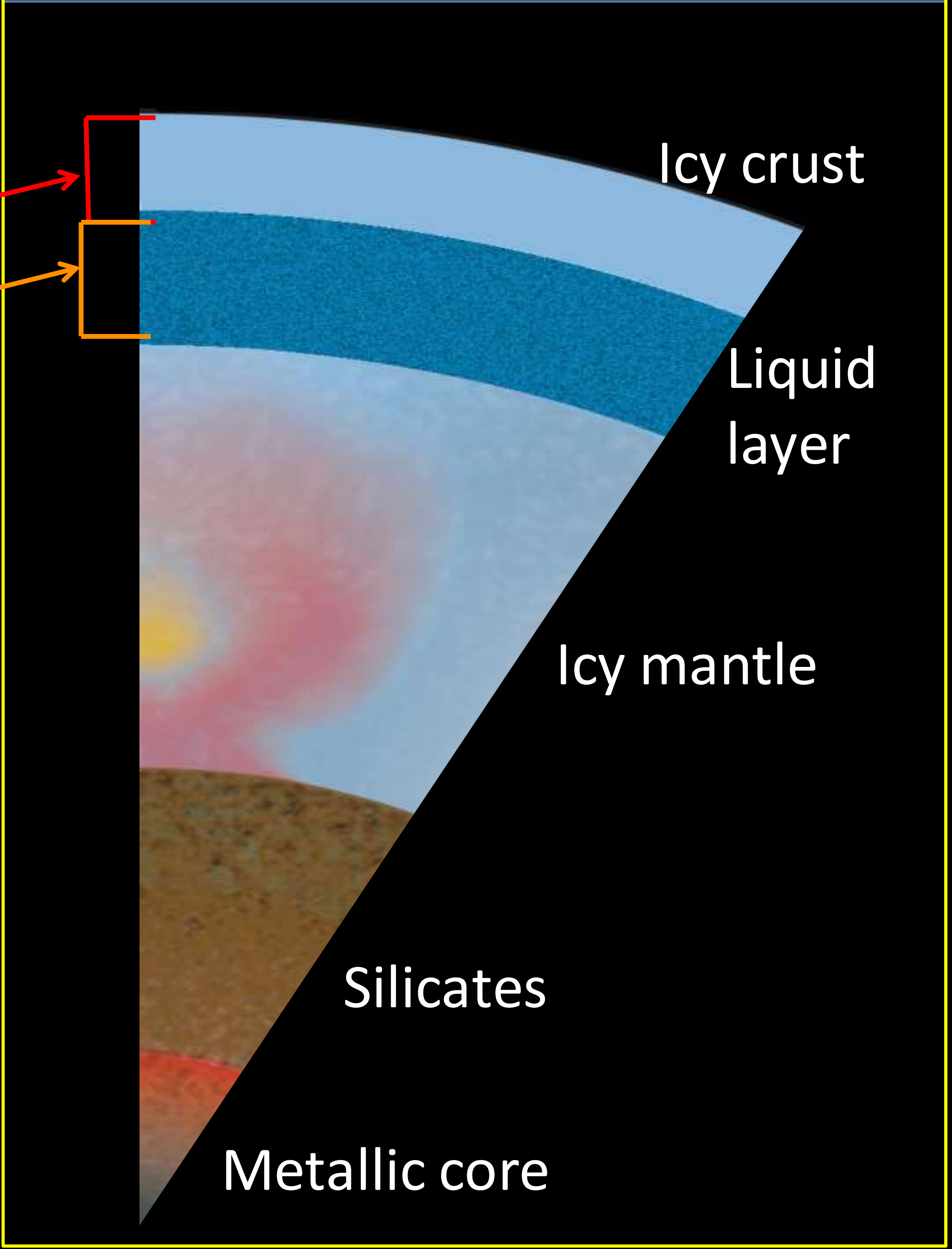
# JUICE : PAYLOAD SYNERGY

# Characterise Ganymede and Europa as planetary objects and possible habitat

## 1. Extent of the ocean and its relation to the deeper interior




## Internal structure



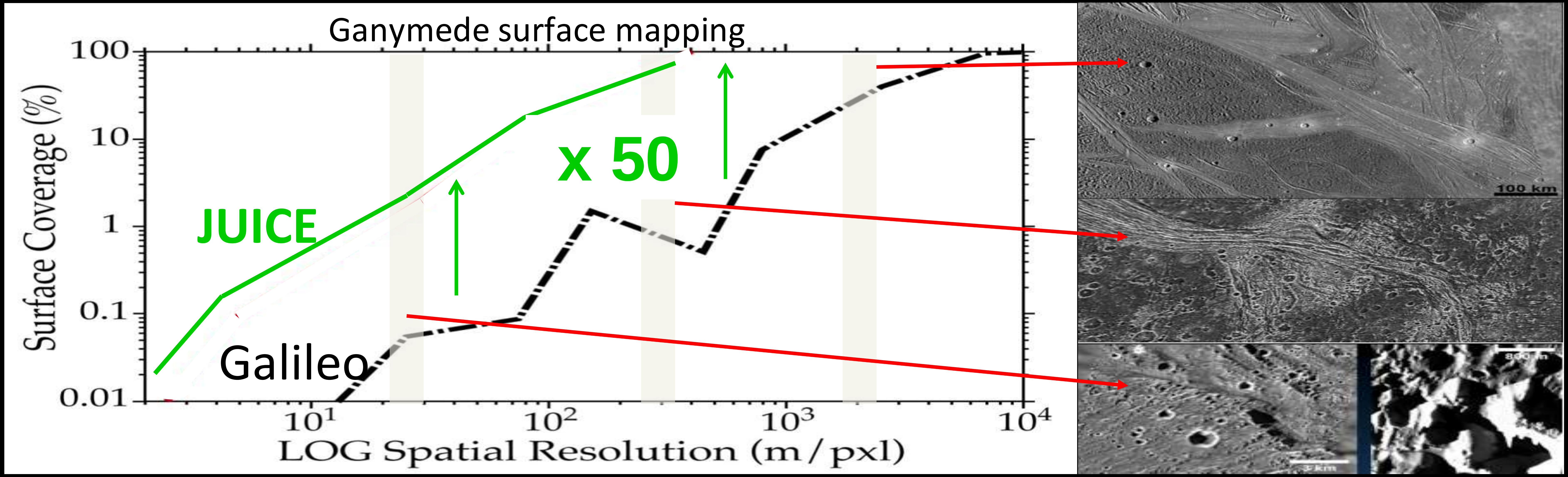

## JUICE measurements

- Eccentric orbit ->Surface deformations
- Periodic variations in the rotation (librations)
- Magnetic induction from the field vector

## Instrument Packages

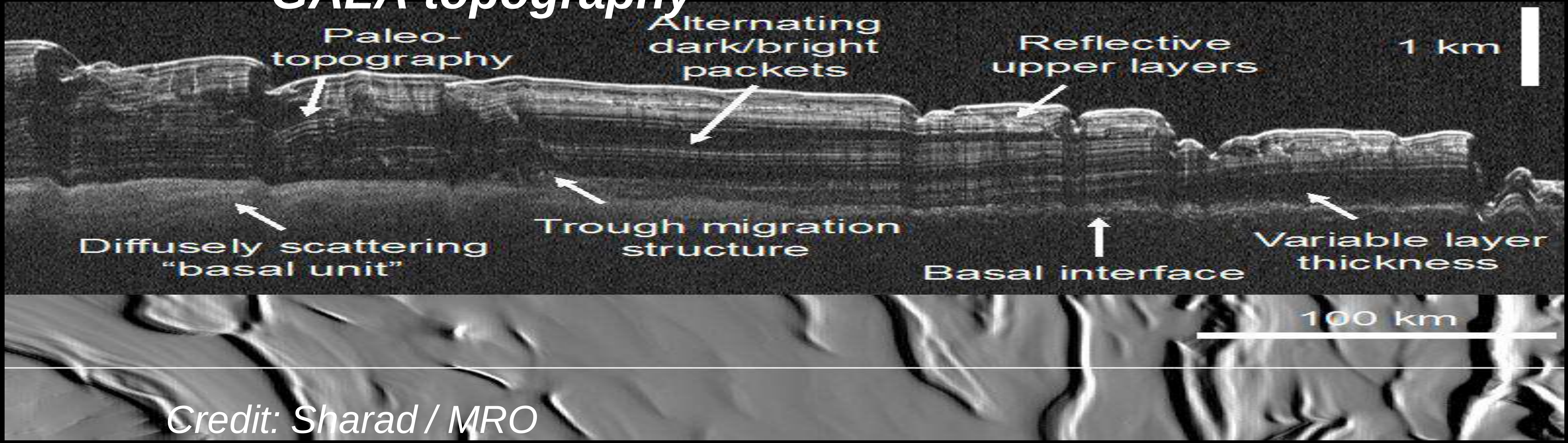
- In situ Fields and Particles
- Imaging
- Sounders and Radio Science

# Ganymede surface and subsurface studies




***JANUS imaging***

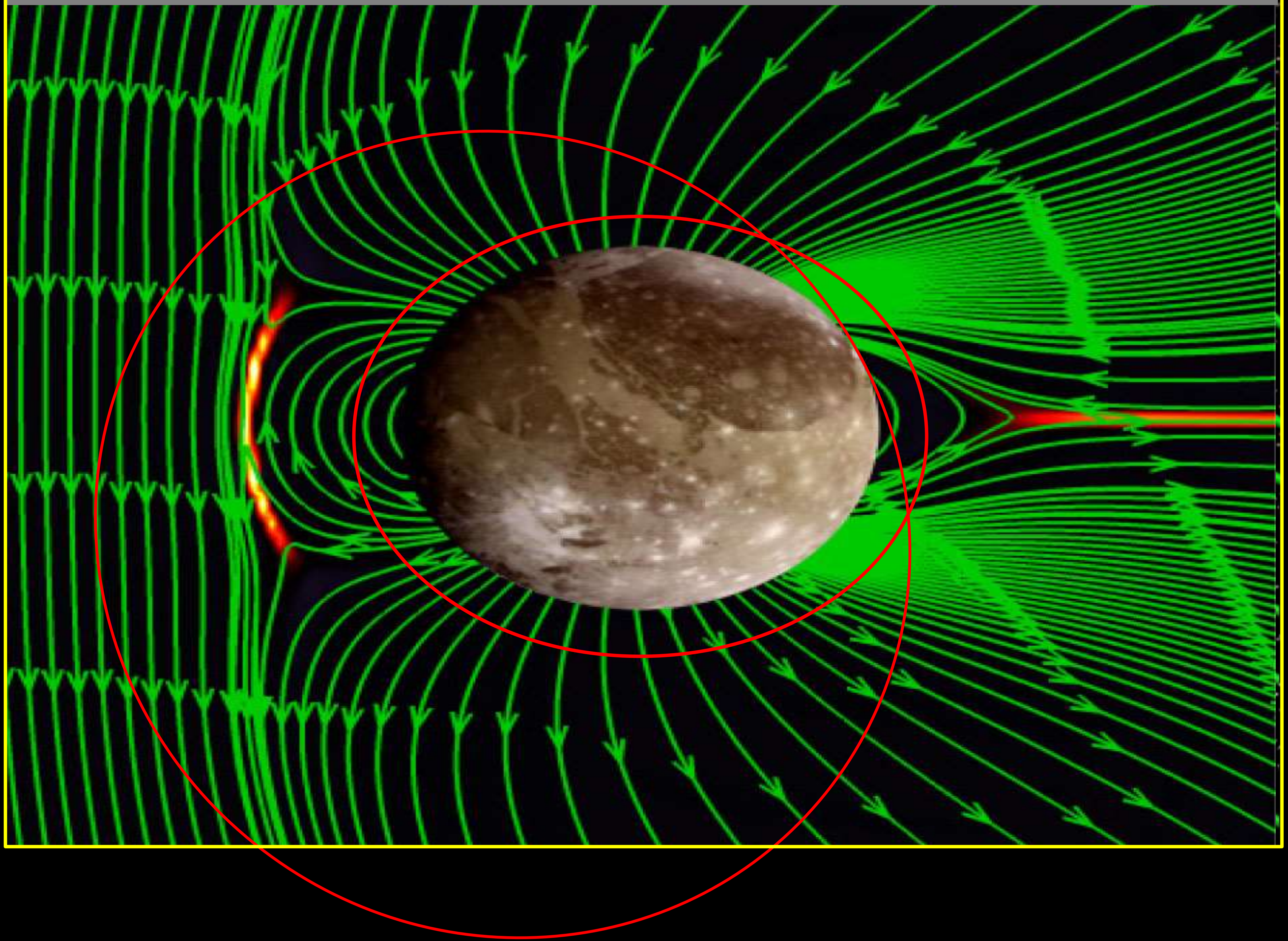
***RIME subsurface sounding***
***GALA topography***



# Composition of the moons' surfaces and exospheres

# Local plasma environment at Ganymede

Dipole magnetic field and mini-magnetosphere

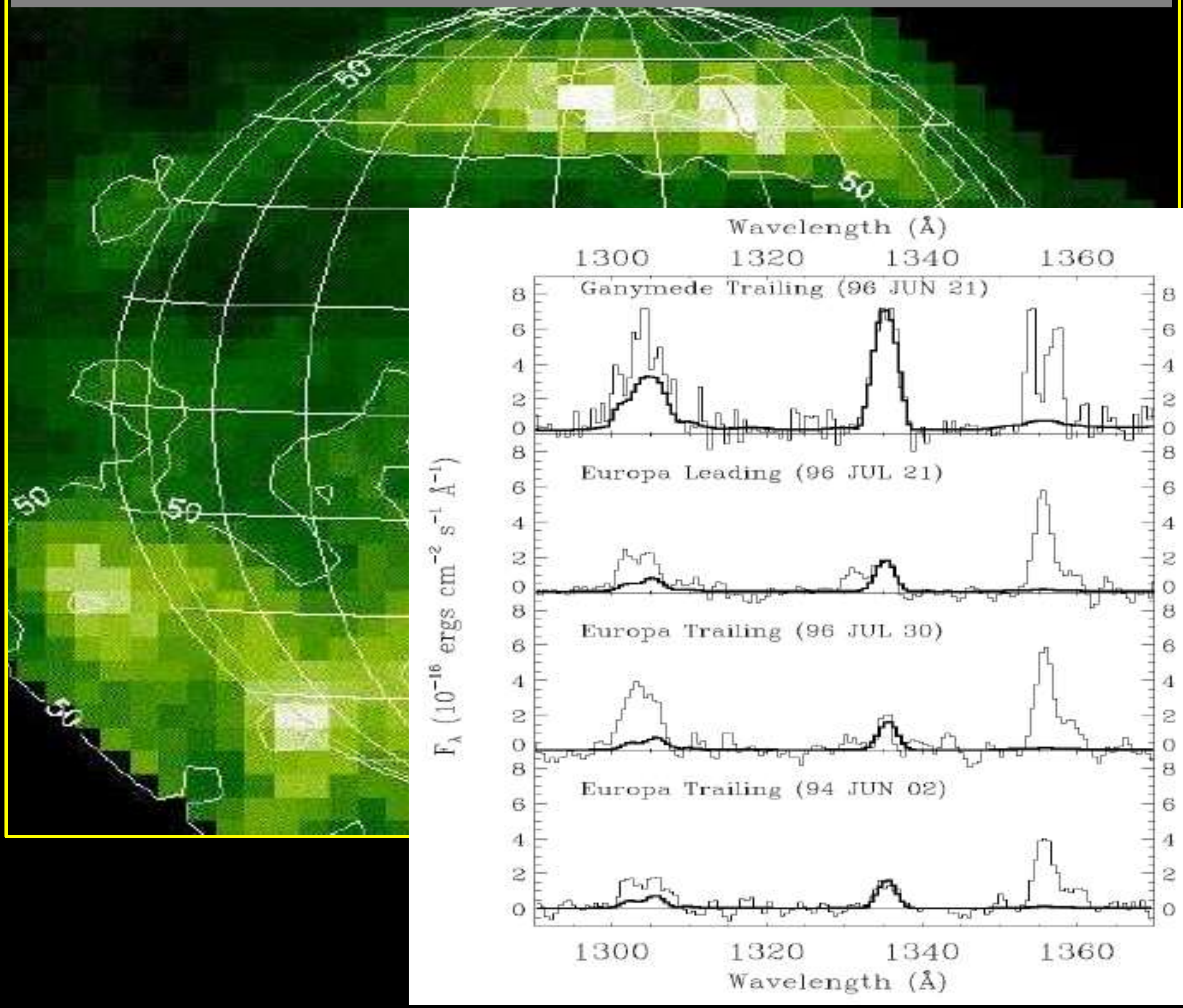


**J-MAG:** *magnetic field*

**PEP:** *neutrals, ions, electrons*

**RPWI**: *wave activity*

Coupling to Jupiter's magnetosphere




**UVS, MAJIS:**

*aurora spectral imaging*

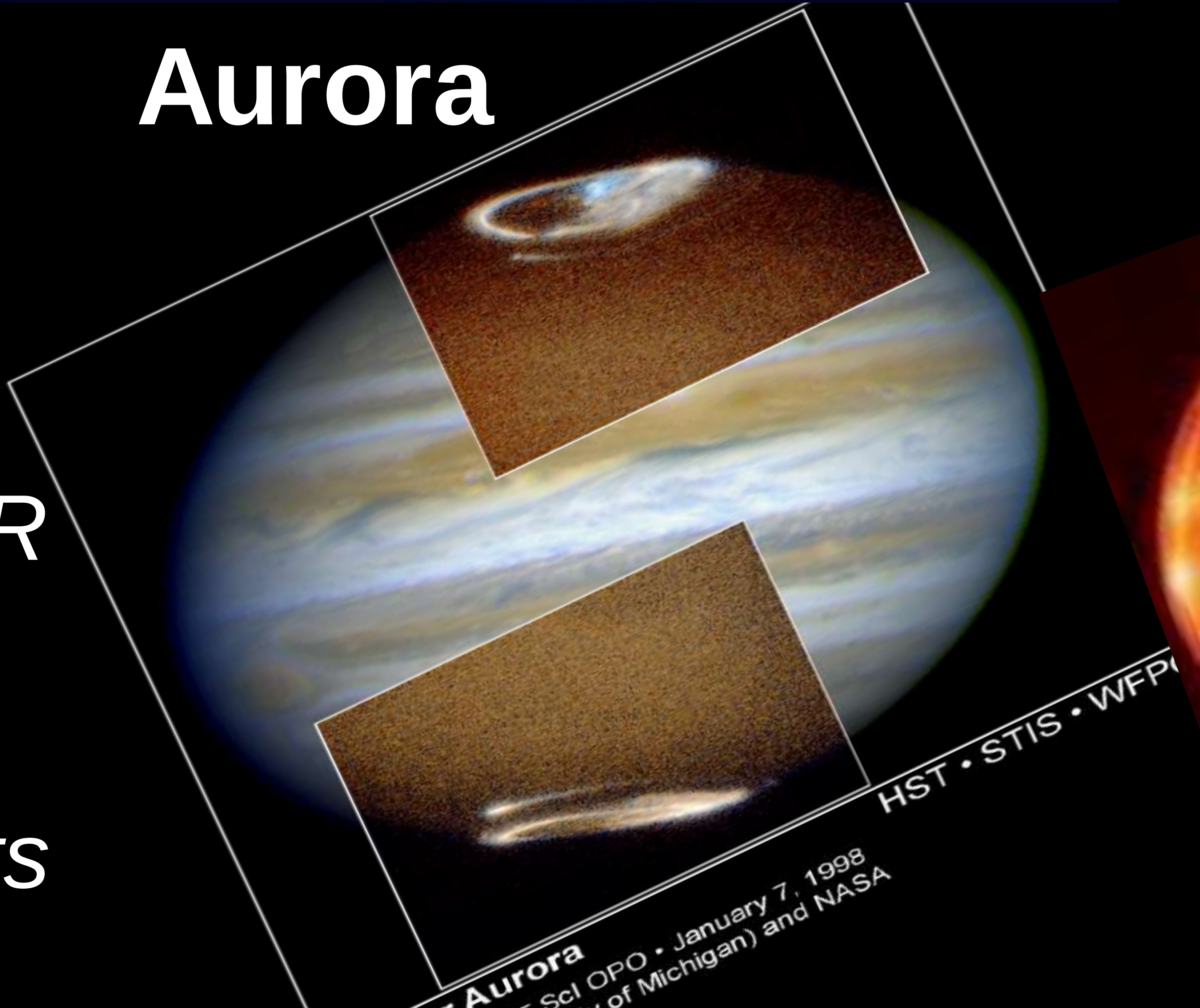
# Dynamics of the Jovian atmosphere

Visible

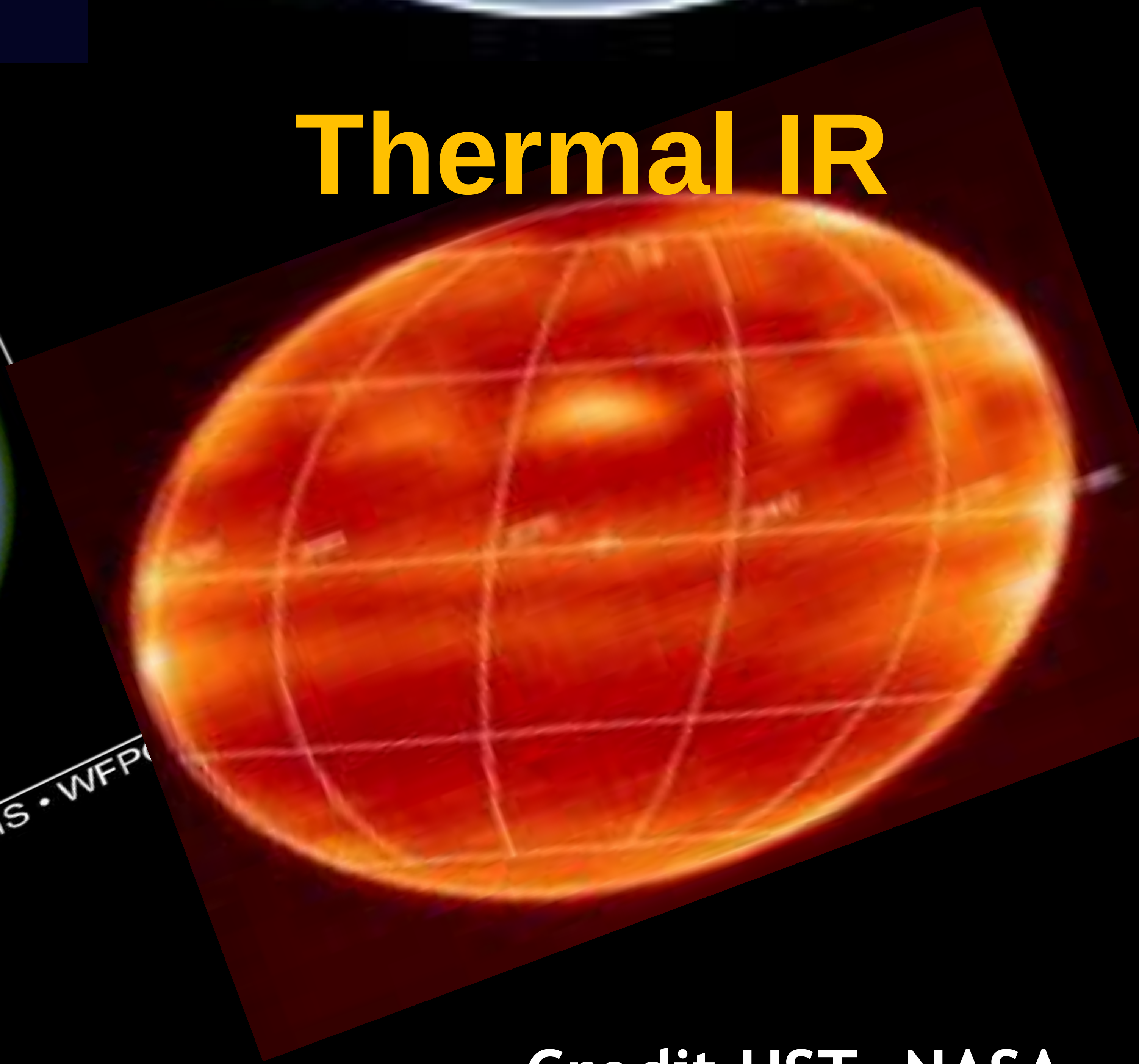
UV

Near-IR

Aurora



Thermal IR



**JANUS, MAJIS, UVS:**

*spectral imaging from UV to near-IR*

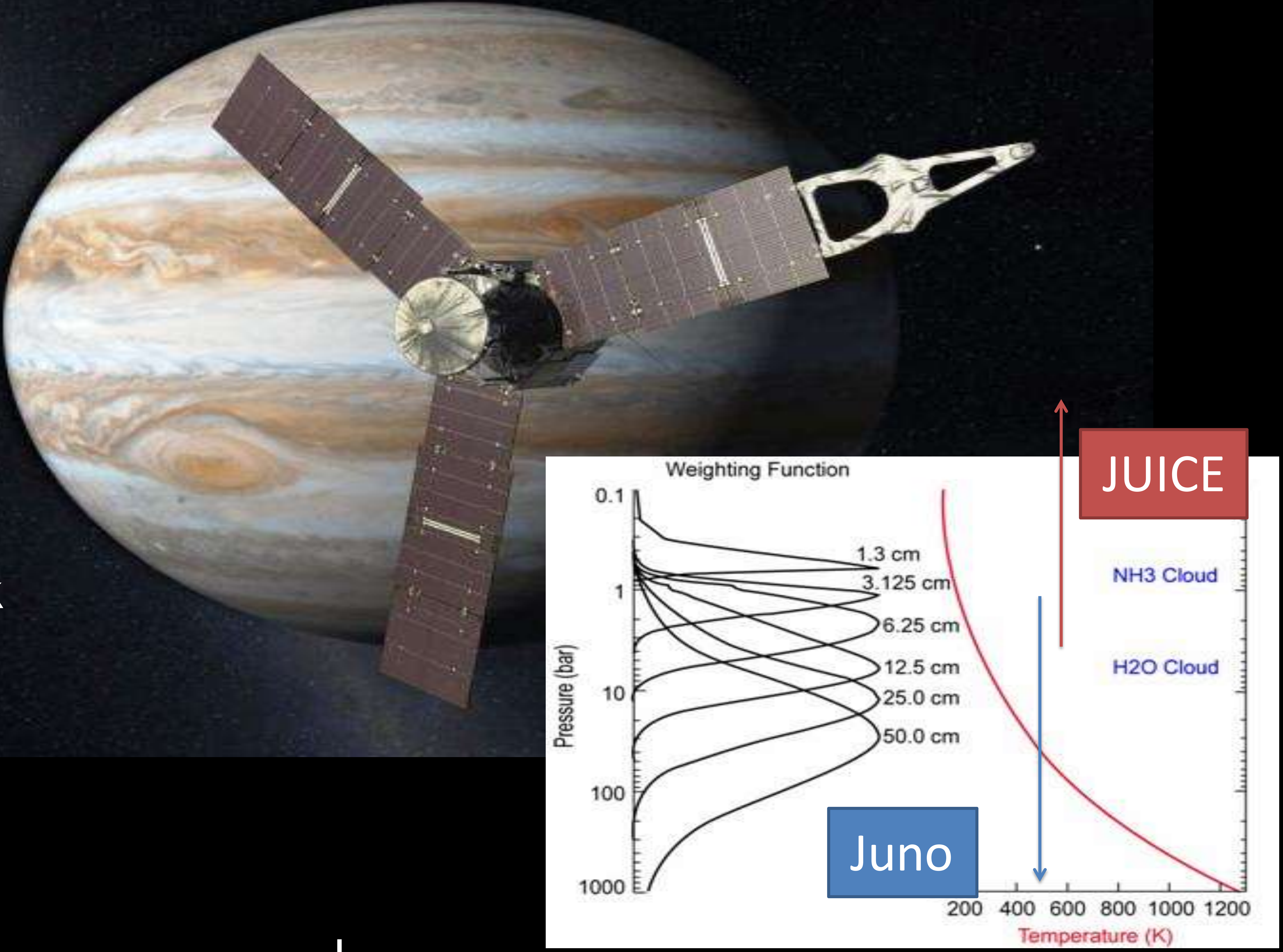
**SWI:**

*Doppler wind speed measurements*

Credit HST, NASA

# Relationship to Juno

- JUICE will complement and extend **Juno's deep atmosphere investigation**:
  - Gravitational mapping to probe density structure
  - Microwave sounding for deep volatile distribution and bulk O/H ratio.
  - High resolution close-in IR mapping (JIRAM) and UV studies (UVS).
- Juno will operate for one year only, and close-in polar orbits limits ability to (i) track meteorological features; (ii) perform global spectroscopy; (iii) study temporal variability
  - JUICE high latitude phase will greatly enhance our understanding of polar dynamics.




JOI

| Perijoves | | | | |
|---|---|---|---|---|
| Year | 2030 | 2031 | 2032 | 2033 |

# Exploration of the Jupiter system

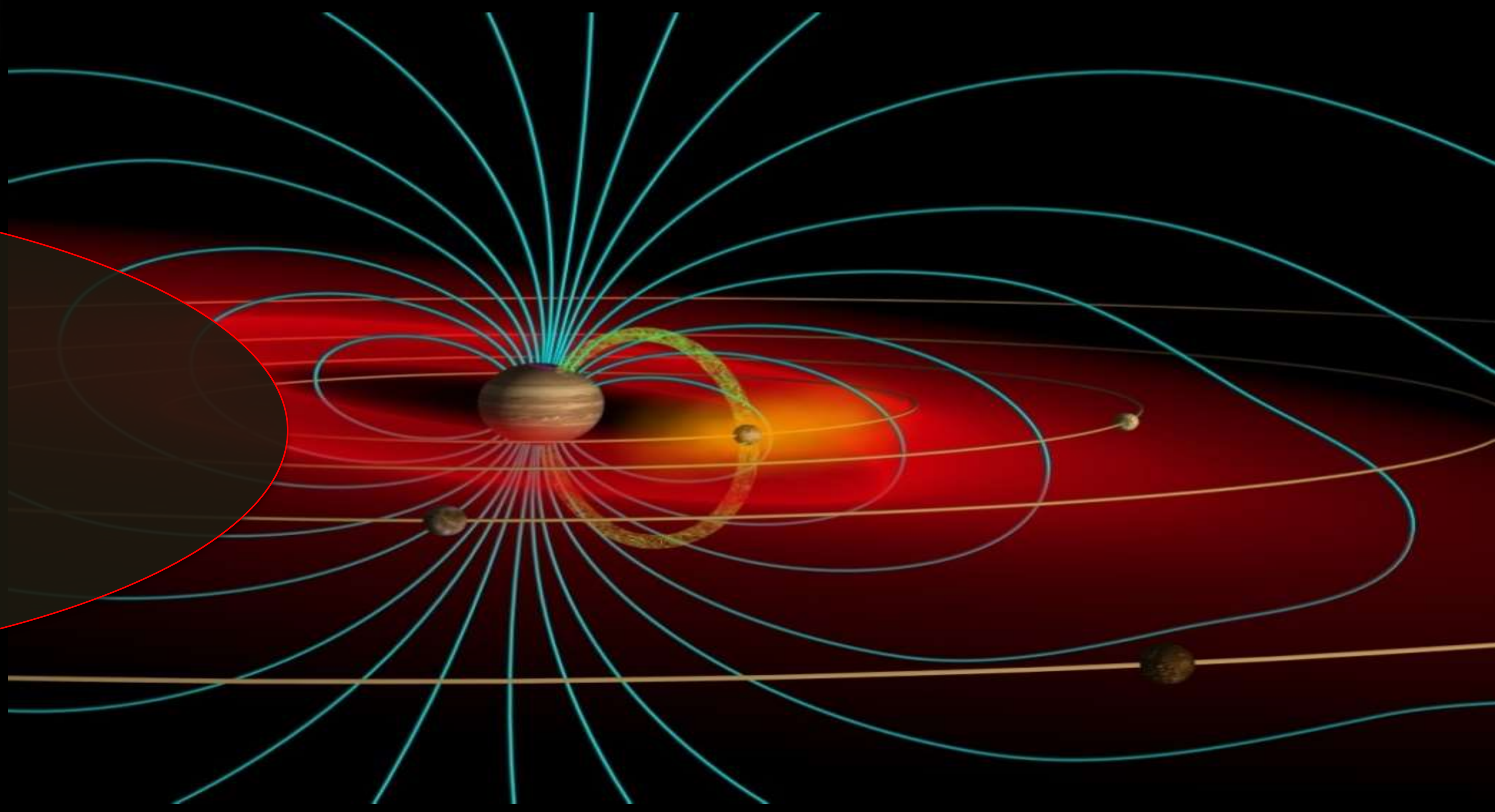
## The biggest planet, the biggest magnetosphere, and a mini solar system

## Jupiter

- Archetype for giant planets
- Natural planetary-scale laboratory for fundamental fluid dynamics, chemistry, meteorology,…
- Window into the formational history of our planetary system

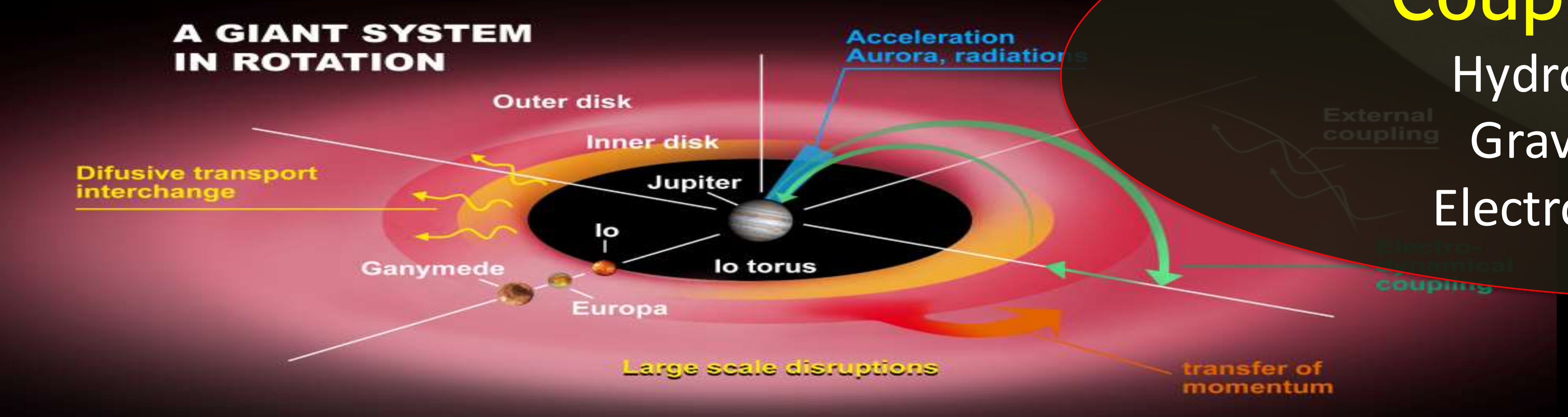
## Magnetosphere

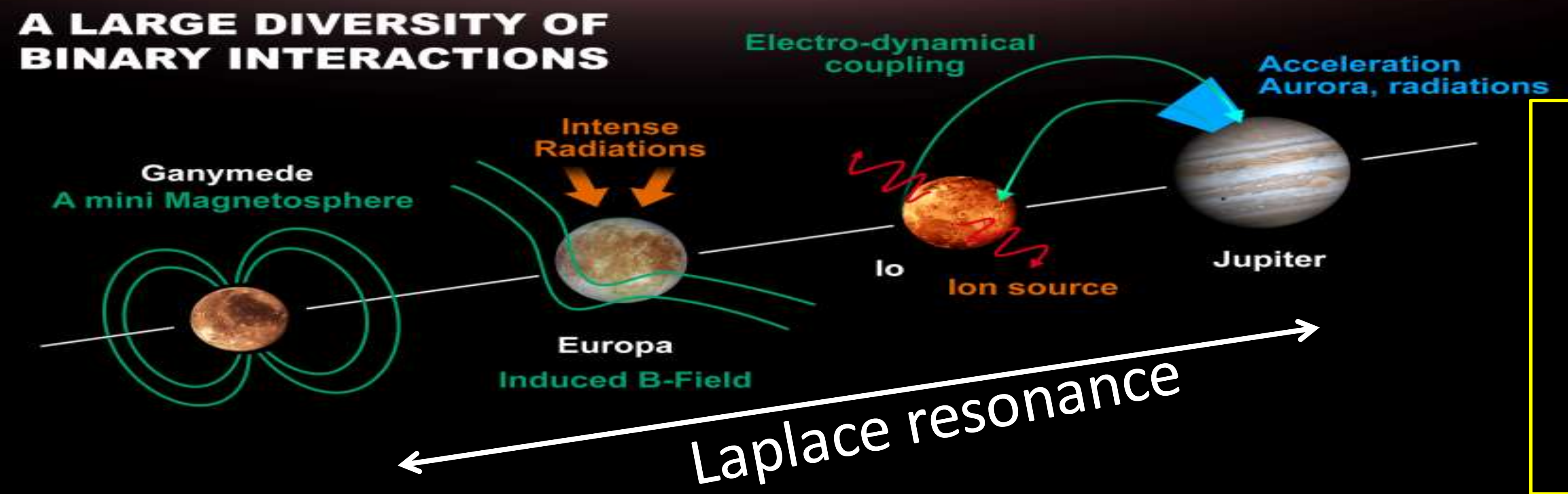
- Largest object in our Solar System
- Biggest particle accelerator in the Solar System
- Unveil global dynamics of an astrophysical object



## Coupling processes

Hydrodynamic coupling
Gravitational coupling
Electromagnetic coupling



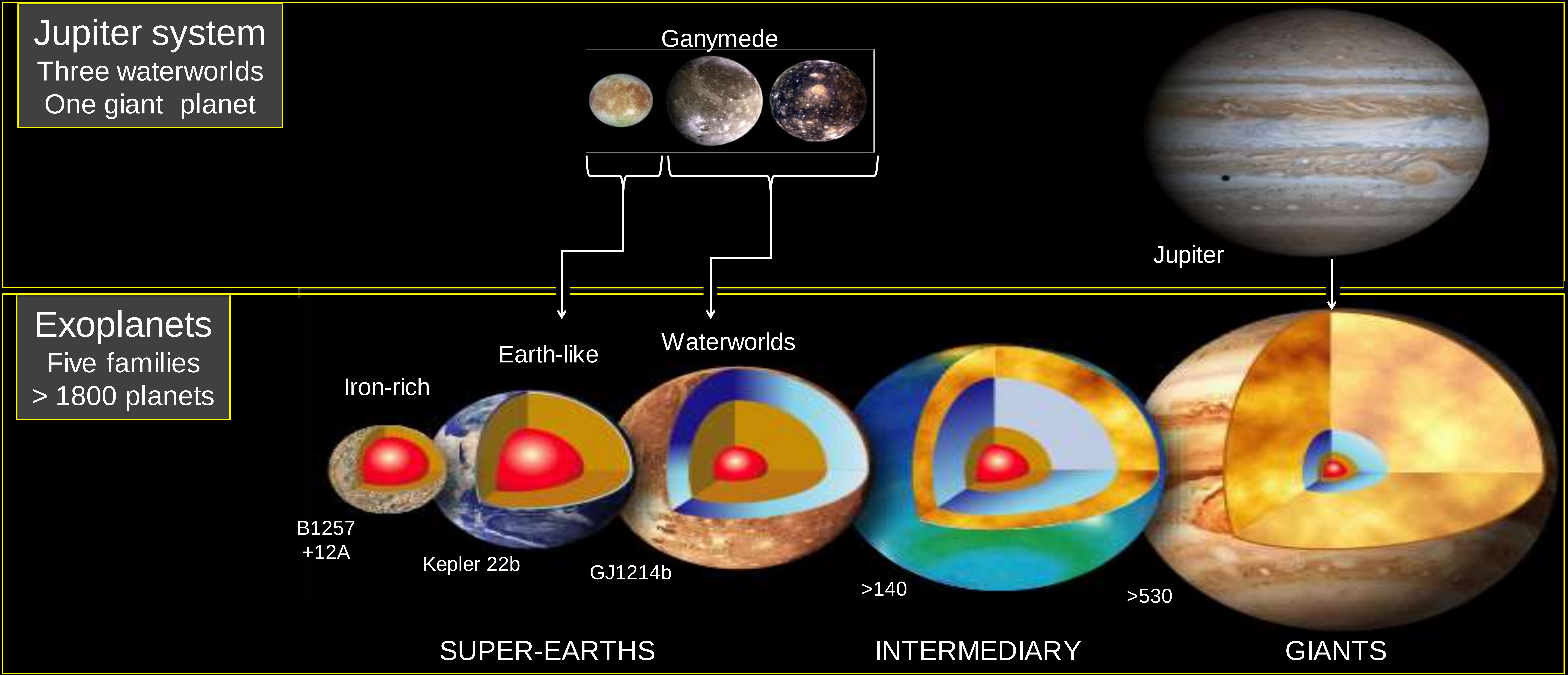

## Satellite system

- Tidal forces: Laplace resonance
- Electromagnetic interactions to magnetosphere and upper atmosphere of Jupiter

# From the Jovian system to extrasolar planetary systems

**Waterworlds and giant planets** | Habitable worlds | Astrophysics Connection

By studying Ganymede, we can characterise an entire family of exoplanets: the waterworlds.



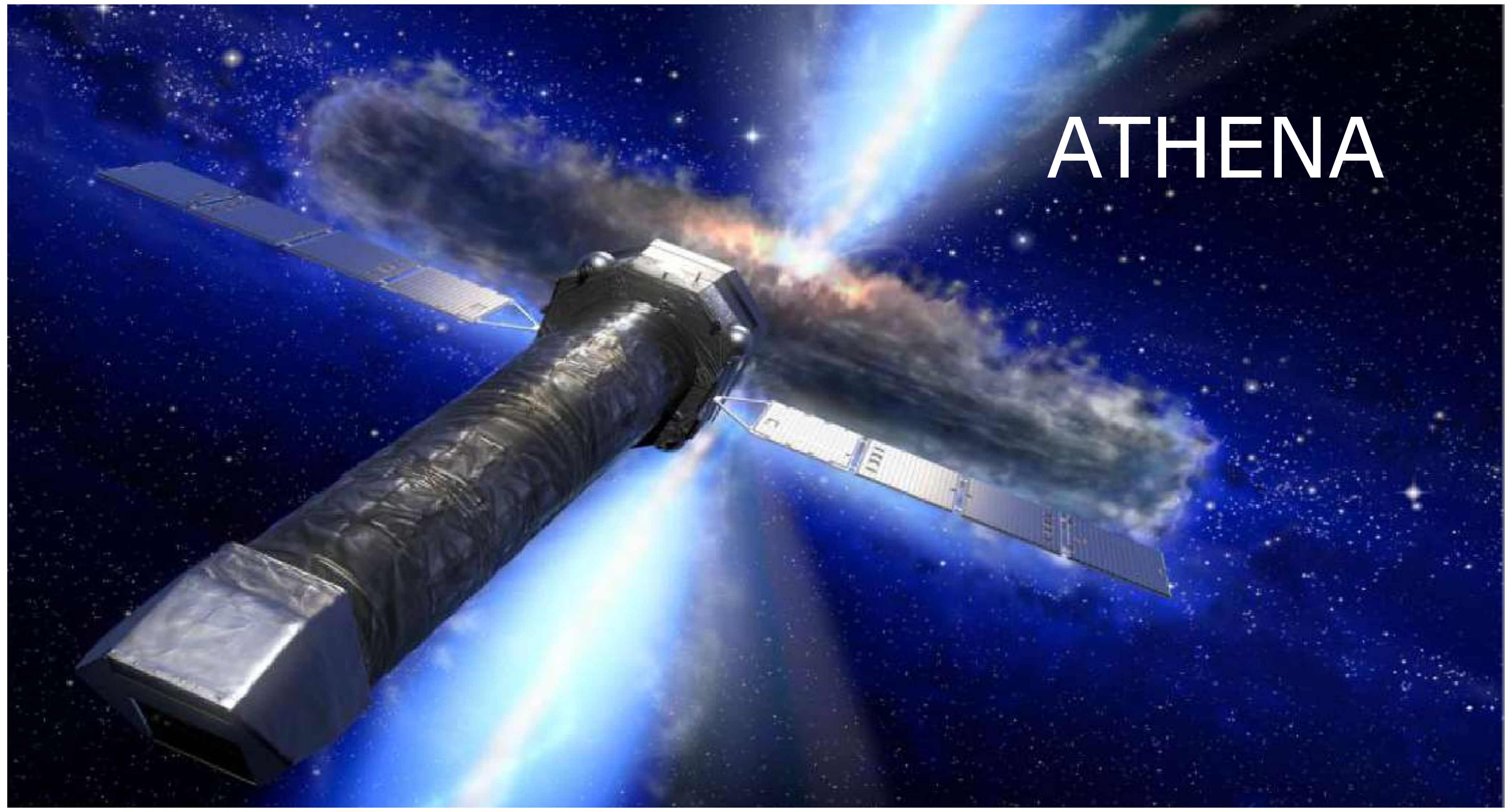
# Conclusions

- **Highly capable spacecraft with synergistic and multi-disciplinary payload**
- **Detailed study of two classes of planetary objects**
  - *a gas giant*
  - *several icy moons with focus on Ganymede*
- **Comparative study of the icy moons family**
- **Investigations of two classes of planetary atmospheres**
  - *well developed atmosphere of the gas giant*
  - *tenuous exospheres of the icy moons*
- **Magnetosphere and plasma environment of the gas giant and its interaction with its moons**
- **Couplings within the Jovian system**

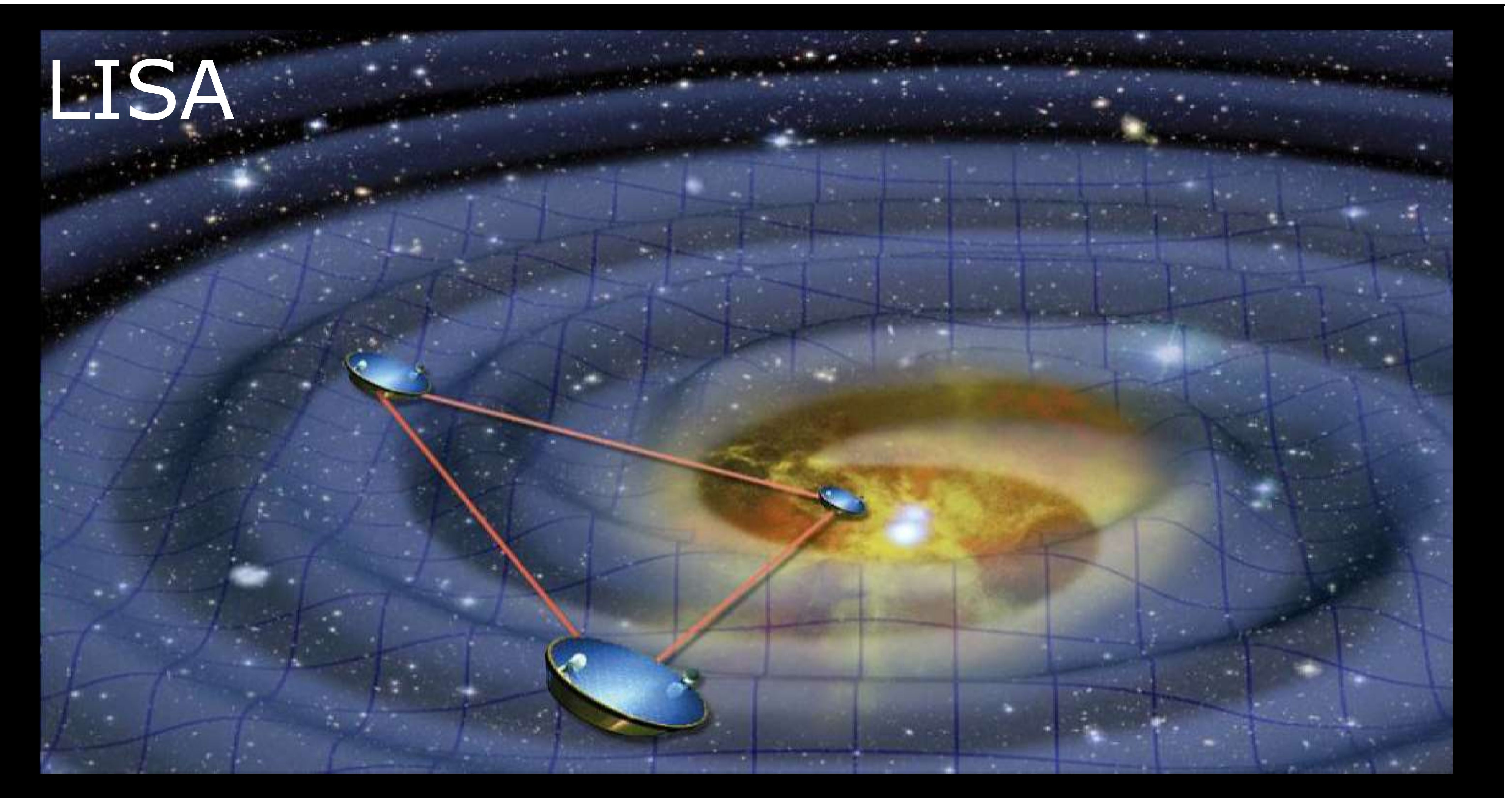
# COSMIC VISION (2015-2025)
# Step 2

- **Pre-selected M4 missions for study**

# FUTURE L2 and L3 ESA CV MISSIONS

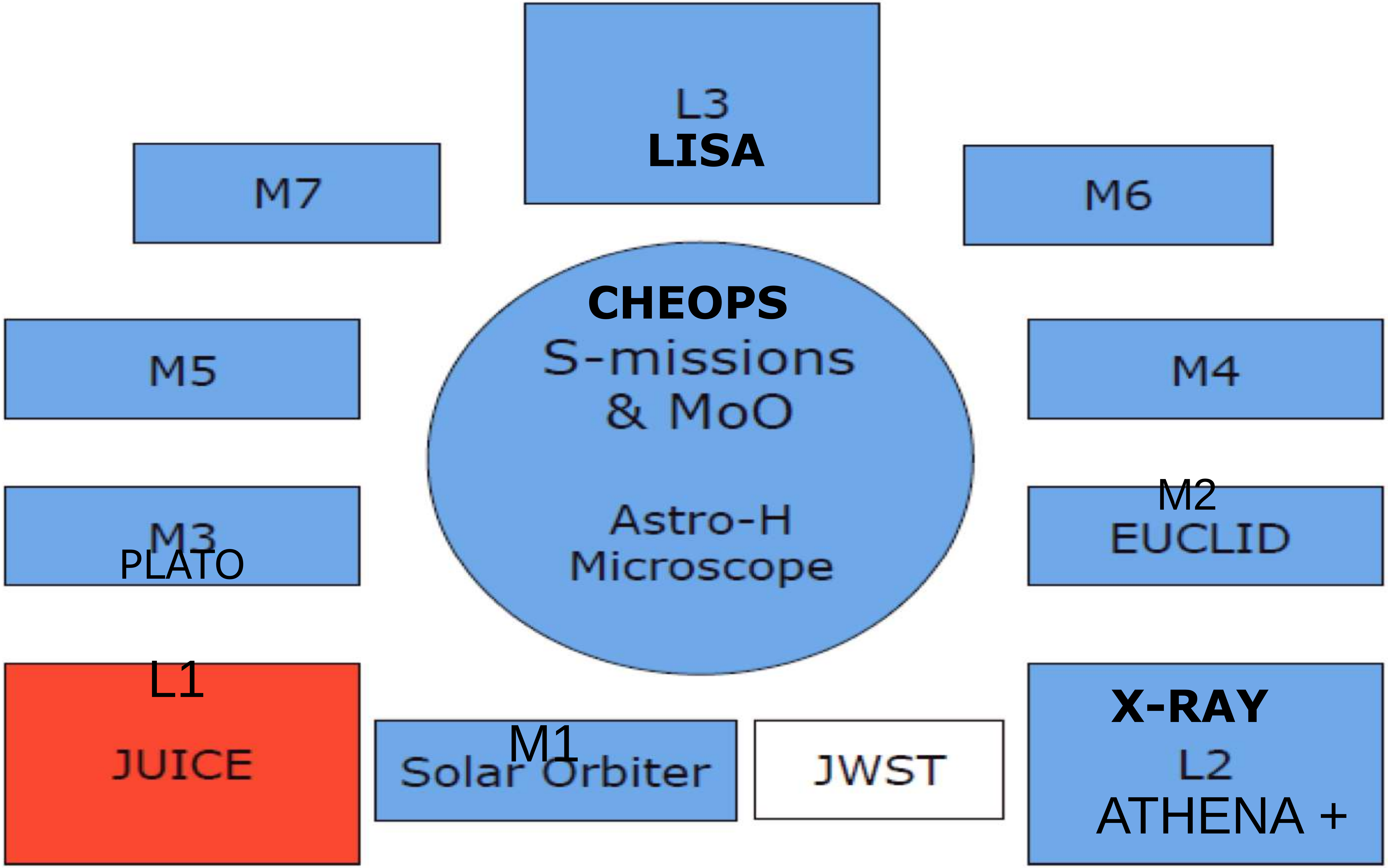



**ATHENA** is a next-generation facility to address some of the most fundamental questions in astrophysics and cosmology by investigating black holes and matter under extreme conditions, the formation and evolution of galaxies, clusters and the large scale structure, and the lifecycles of matter and energy. Launch in 2028.




**The LISA Gravitational wave Observatory is a space mission designed to measure gravitational radiation over a broad band at low frequencies, from about 100 μHz to 1 Hz, a band where the Universe is richly populated by strong sources of gravitational waves. It will benefit from the results of the LISA Pathfinder mission. Launch in 2035.**

# COSMIC VISION (2015-2035)




ARIEL
THOR
XIPE

+

Junior
Partnership
In Europa
Clipper