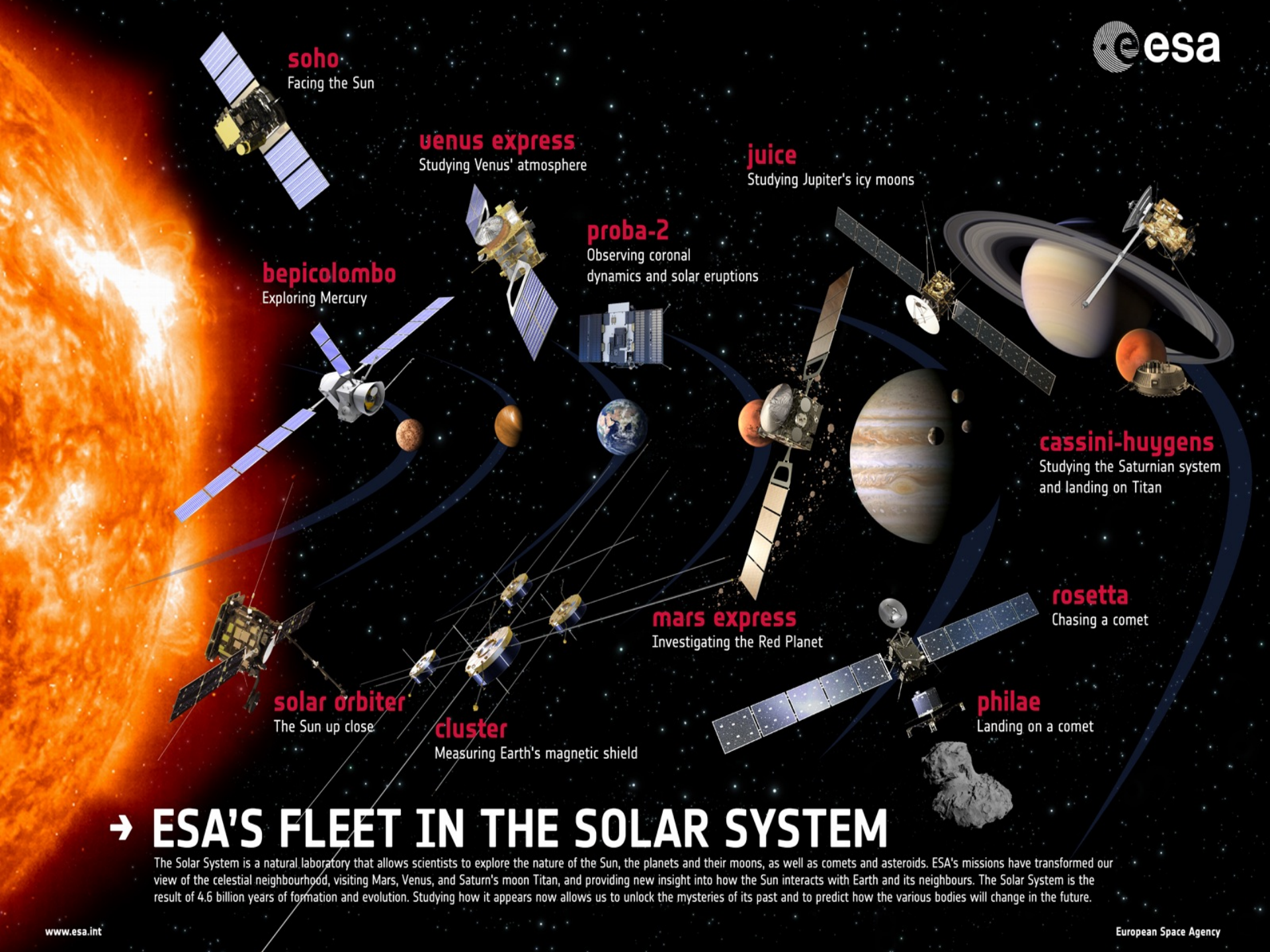
FUTURE EXPLORATION OF GANYMEDE AND EUROPA WITH JUICE AND OTHER MISSIONS

Athena COUSTENIS
LESIA, Paris Observatory
France
for the JUICE SWT

JUICE artist impression
(Credits ESA, AOES)


esa
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
rosetta
Chasing a comet
mars express
Investigating the Red Planet
solar orbiter
The Sun up close
cluster
Measuring Earth's magnetic shield
philae
Landing on a comet
→ 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.
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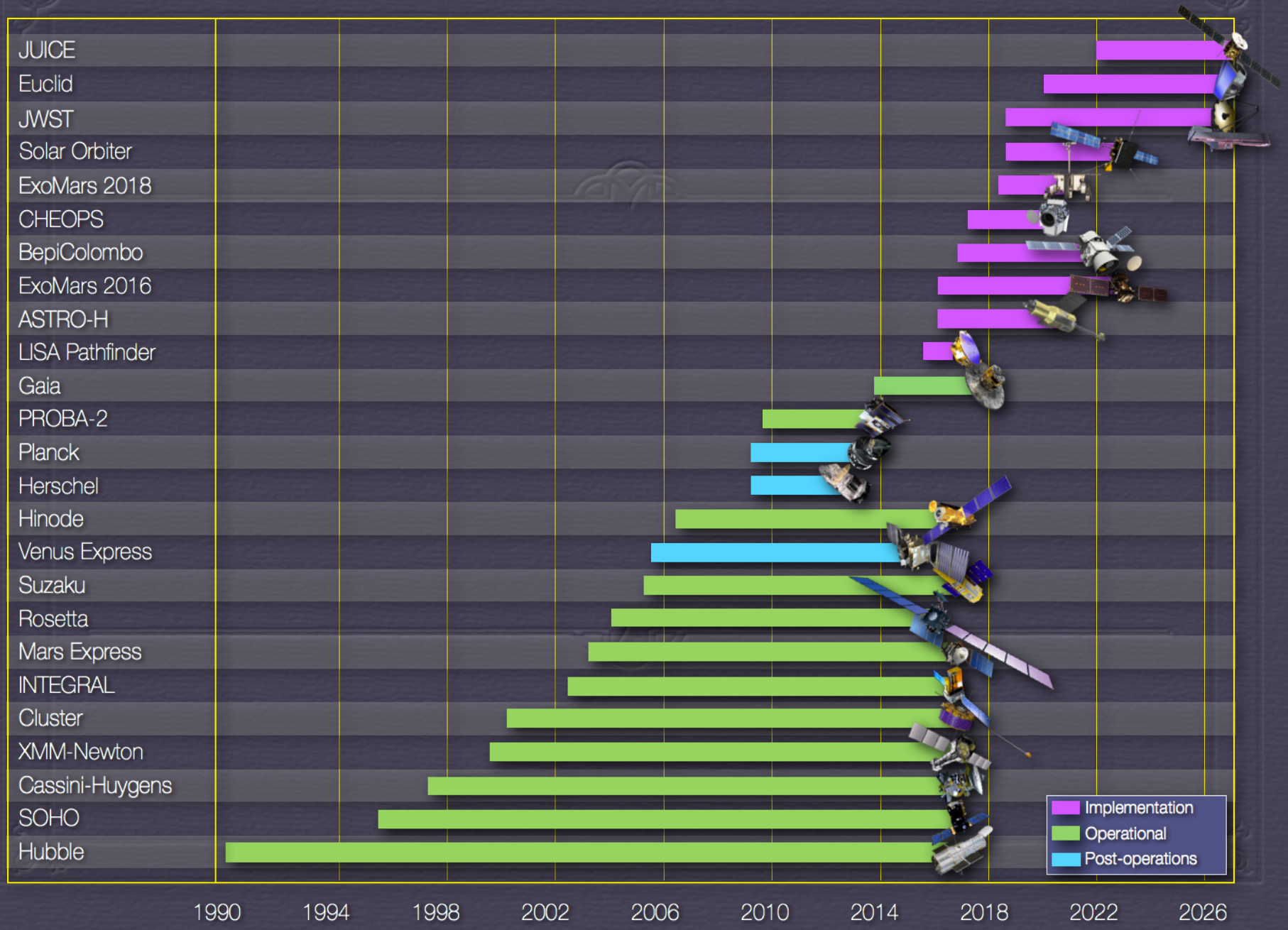
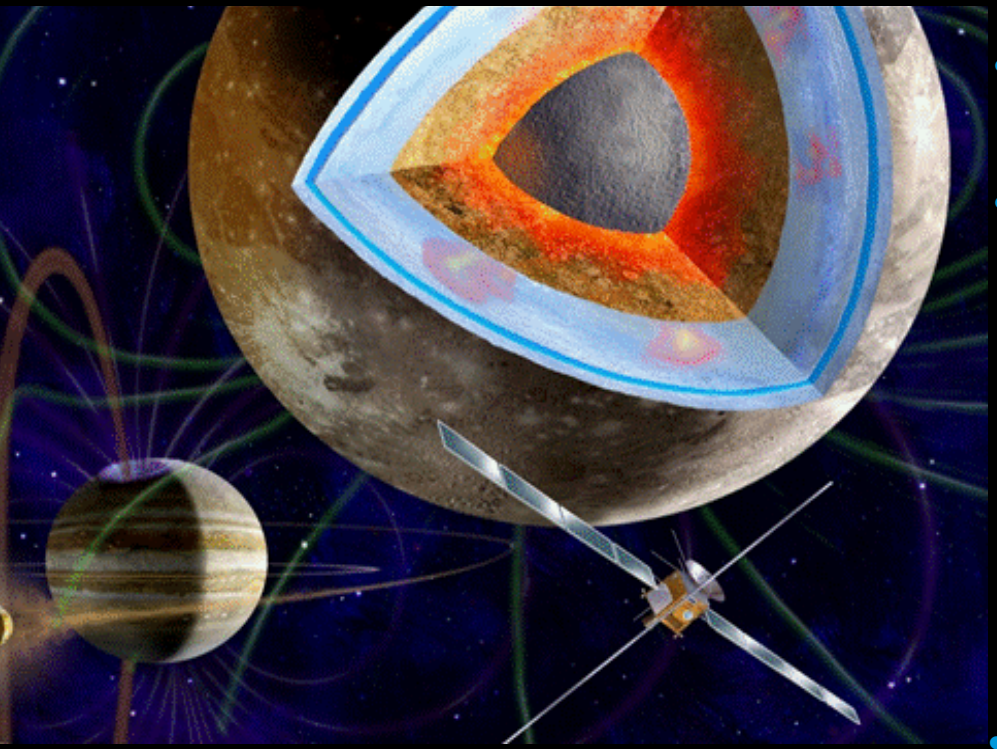
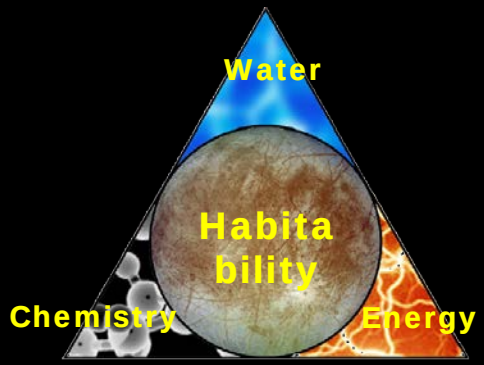


JUICE: JUpiter Icy moons Explorer



JUICE Science Goals

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



Cosmic Vision Themes

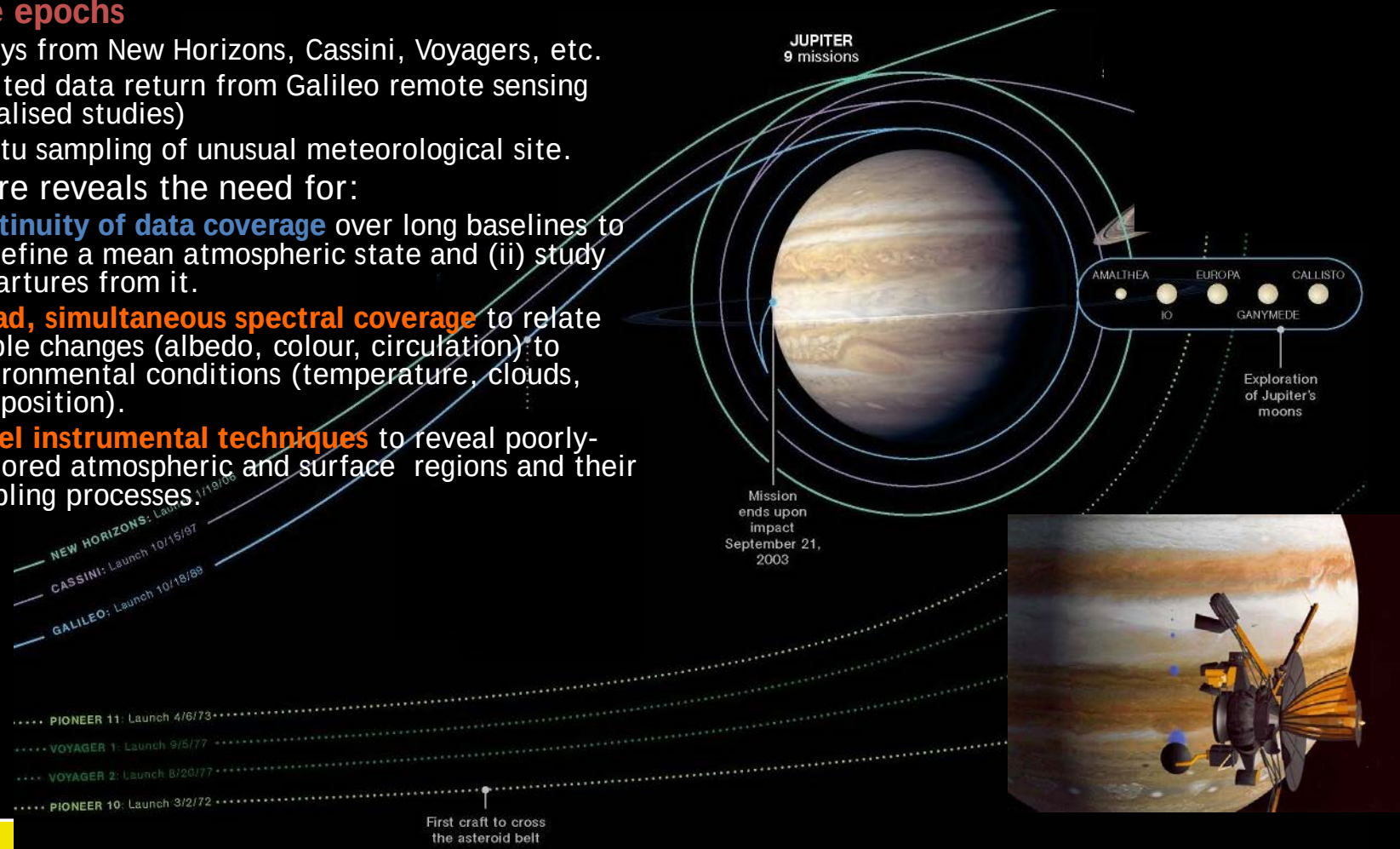
- *What are the conditions for planetary formation and emergence of life?*
- *How does the Solar System work?*

JUICE 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

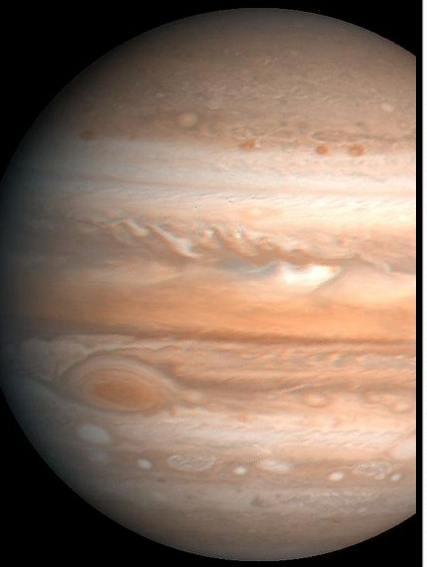
- Previous exploration provided **snapshots of discrete epochs**
  - Flybys from New Horizons, Cassini, Voyagers, etc.
  - Limited data return from Galileo remote sensing (localised studies)
  - In situ sampling of unusual meteorological site.
- Literature reveals the need for:
  - **Continuity of data 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.

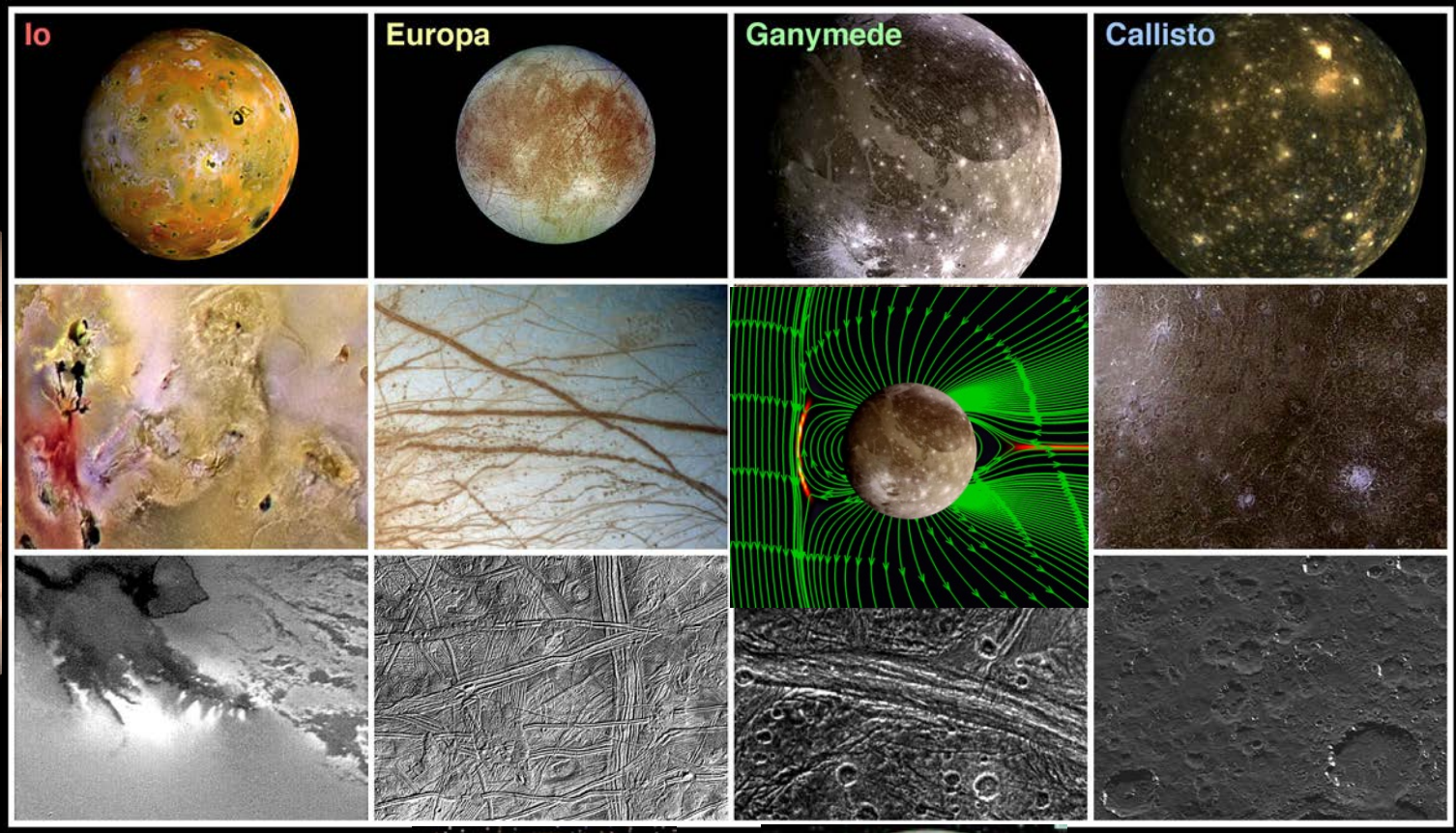


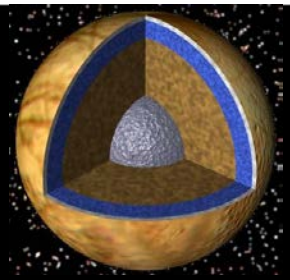
Perijoves

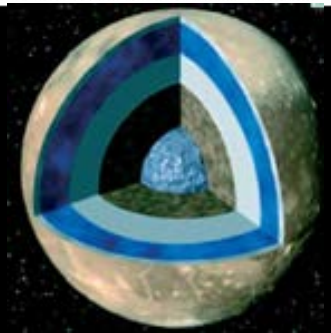
Year	2030	2031	2032	2033

Jupiter family





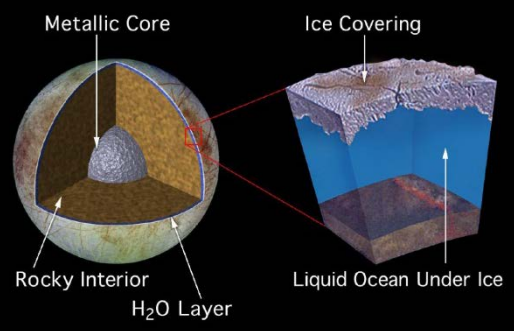


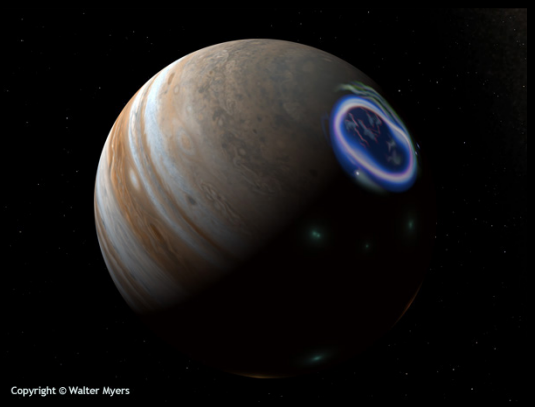


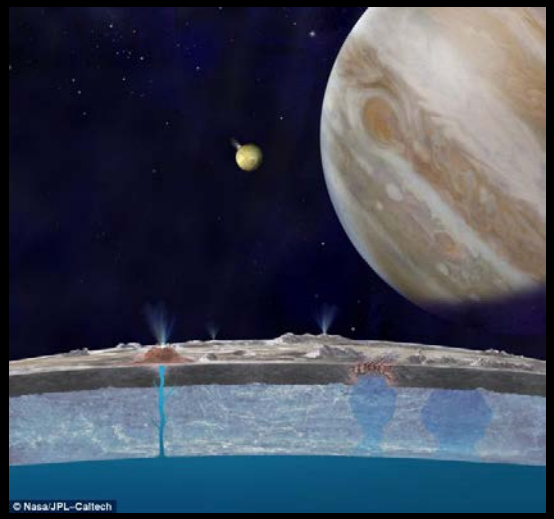
Credit NASA

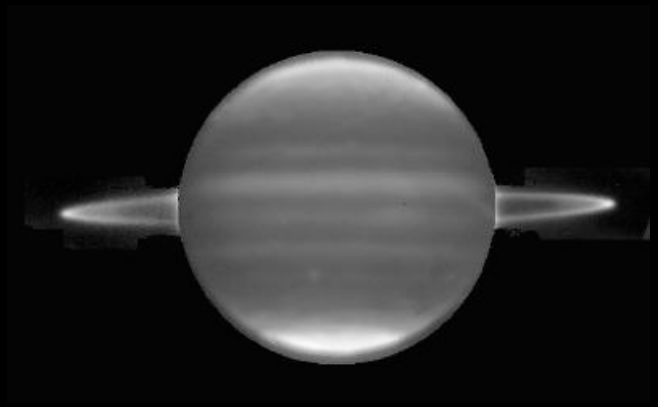
Topics:
Planet, moons, rings, magneto

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







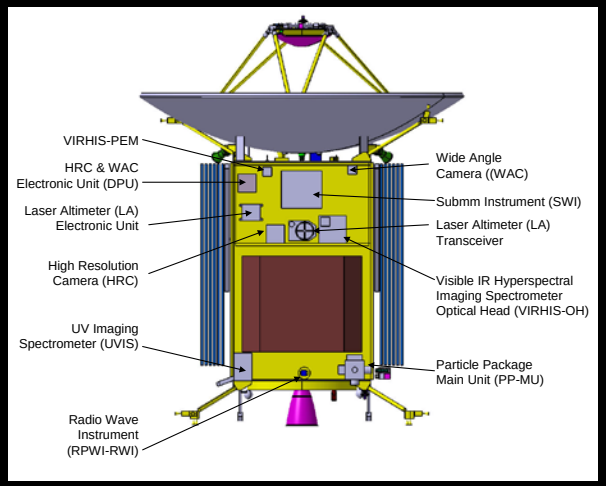


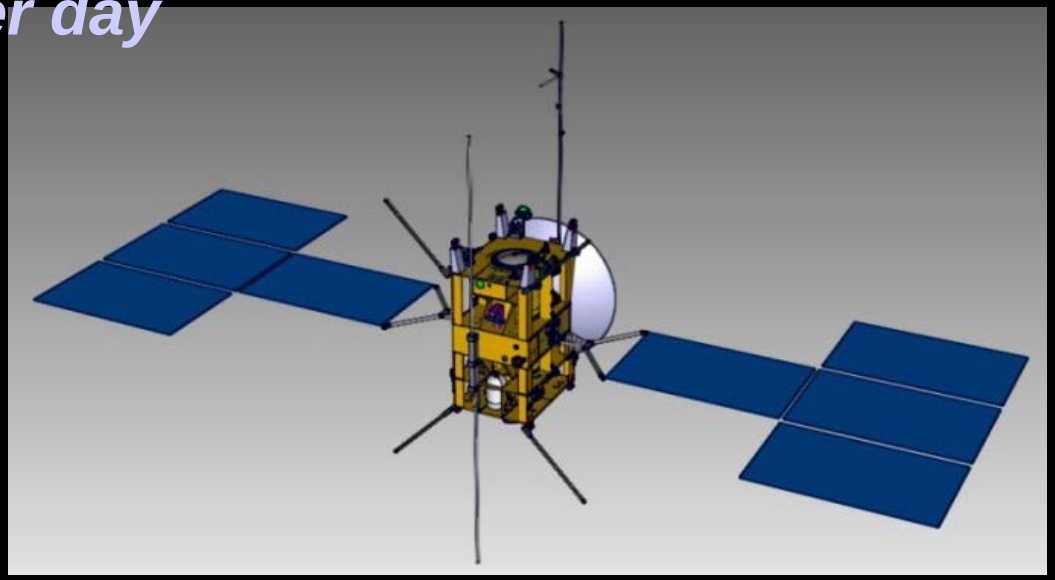
Jupiter system: largest planet, largest storm, fastest rotation, largest magnetic field, largest moon, largest moon system, most active moons

JUICE : SPACECRAFT, PAYLOAD & SCENARIO

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 ~140 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*





JUICE Payload

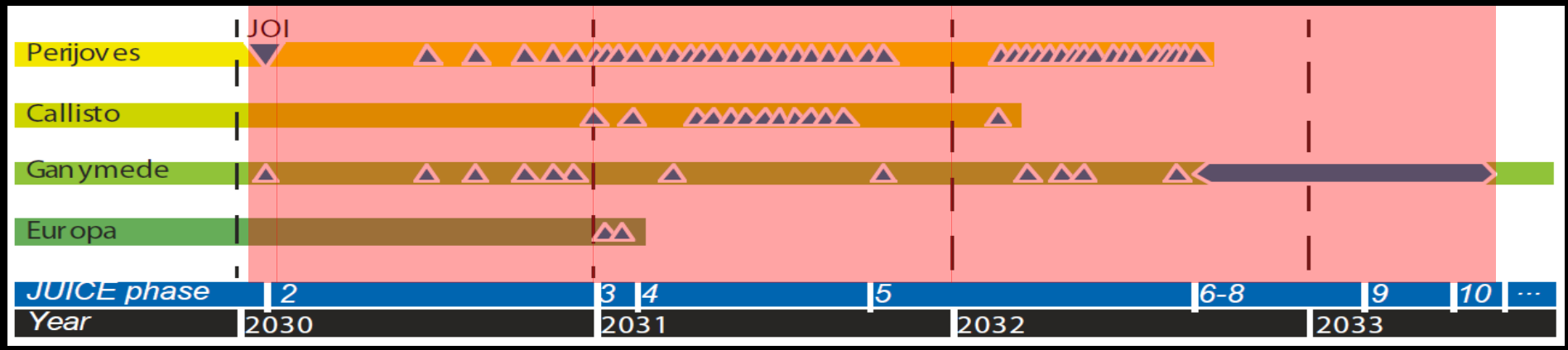
Acronym	PI	LFA	Instrument type
Remote Sensing Suite			
JANUS	P. Palumbo	Italy	Narrow Angle Camera
MAJIS	Y. Langevin G. Piccioni	France Italy	Vis-near-IR imaging spectrometer
UVS	R. Gladstone	USA	UV spectrograph
SWI	P. Hartogh	Germany	Sub-mm wave instrument
Geophysical Experiments			
GALA	H. Hussmann	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

Mission baseline scenario

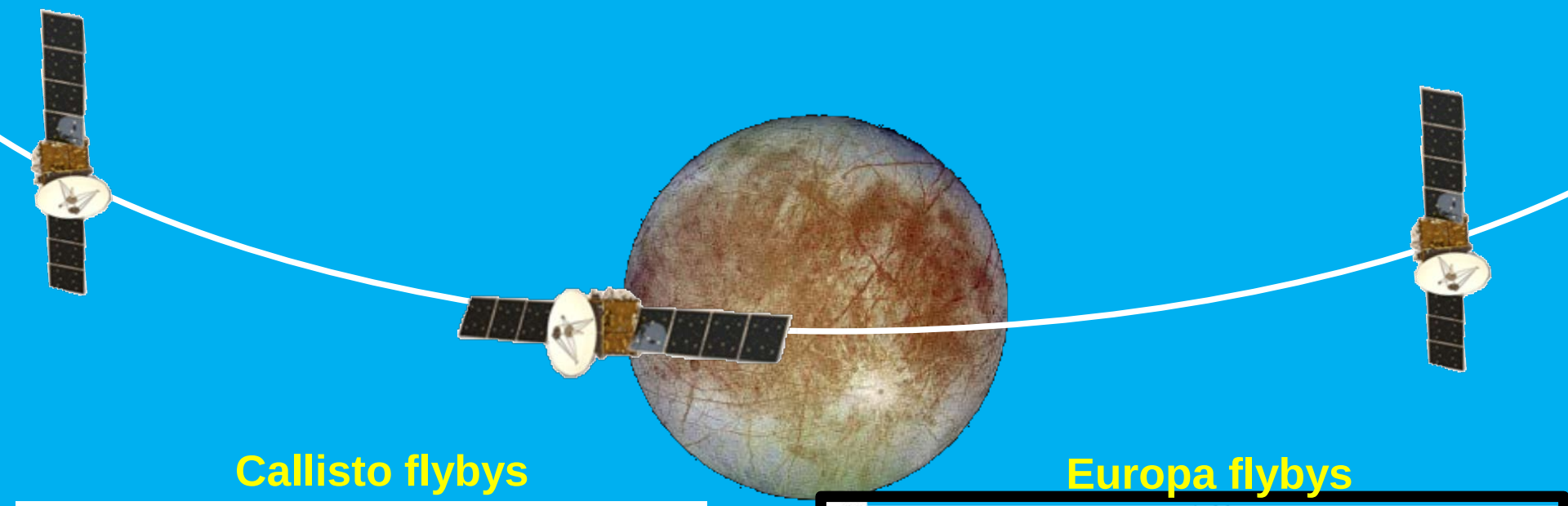
Launch (Ariane 5, Kourou)	June 2022
1. Interplanetary Transfer	7.6 years
Jupiter Orbit Insertion	Jan 2030
2. Jupiter equatorial phase #1	~11 mon
3. Two Europa flybys	36 days
4. Jupiter high-latitude phase including 14 Callisto flybys	260 days
5. Jupiter equatorial phase #2 and transfer to Ganymede	~11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

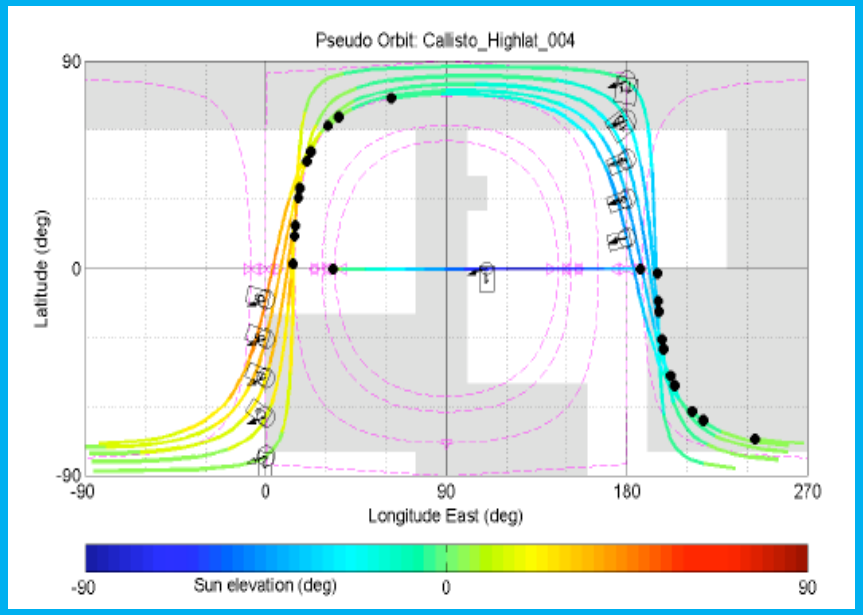
End of nominal mission : June 2033



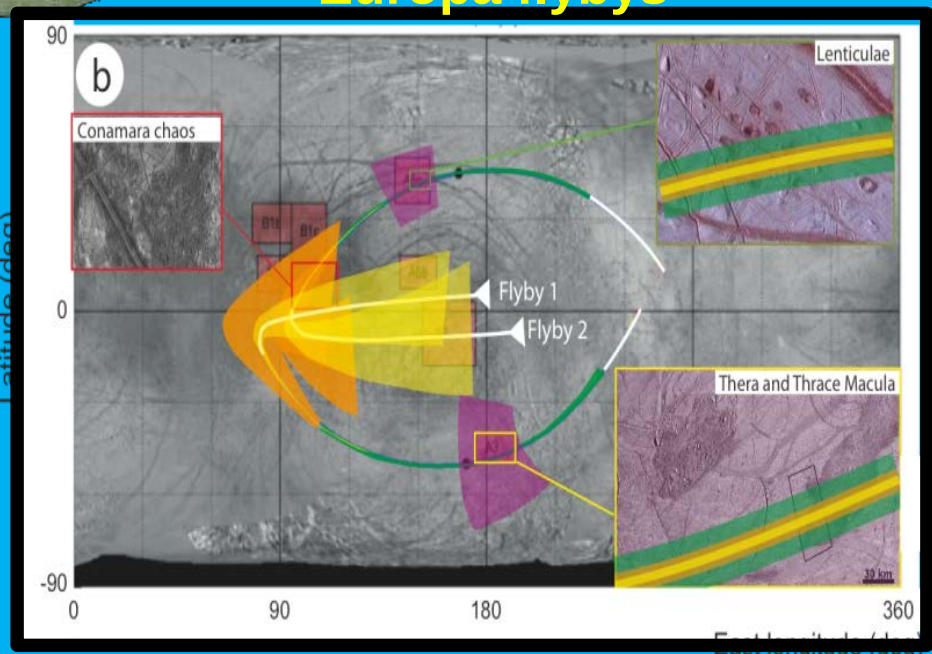
Moons' flybys



Callisto flybys



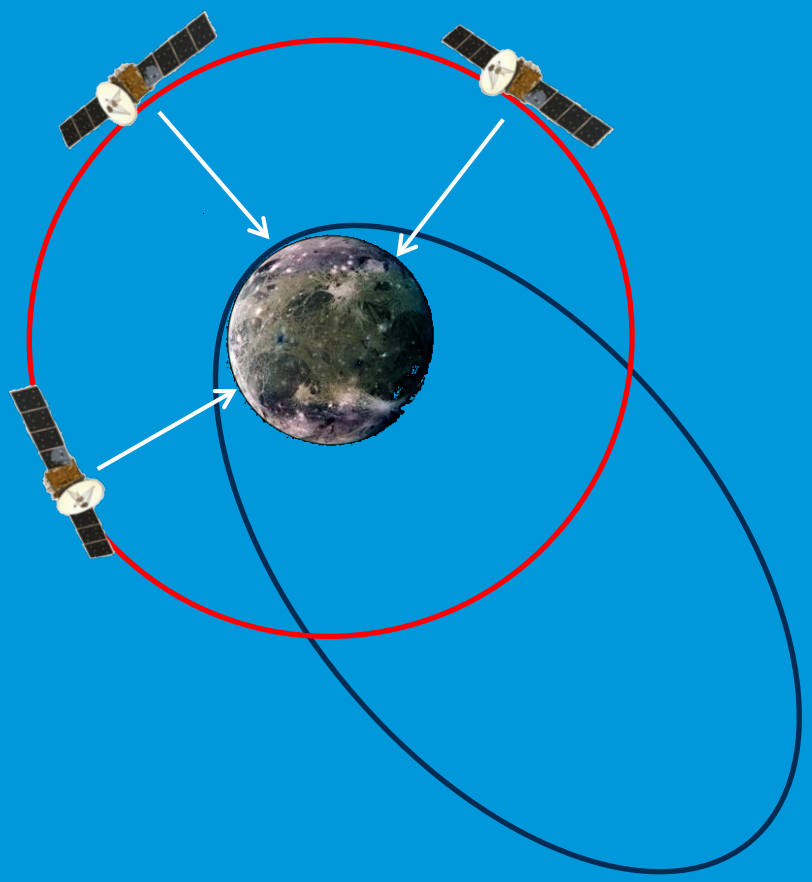
Europa flybys

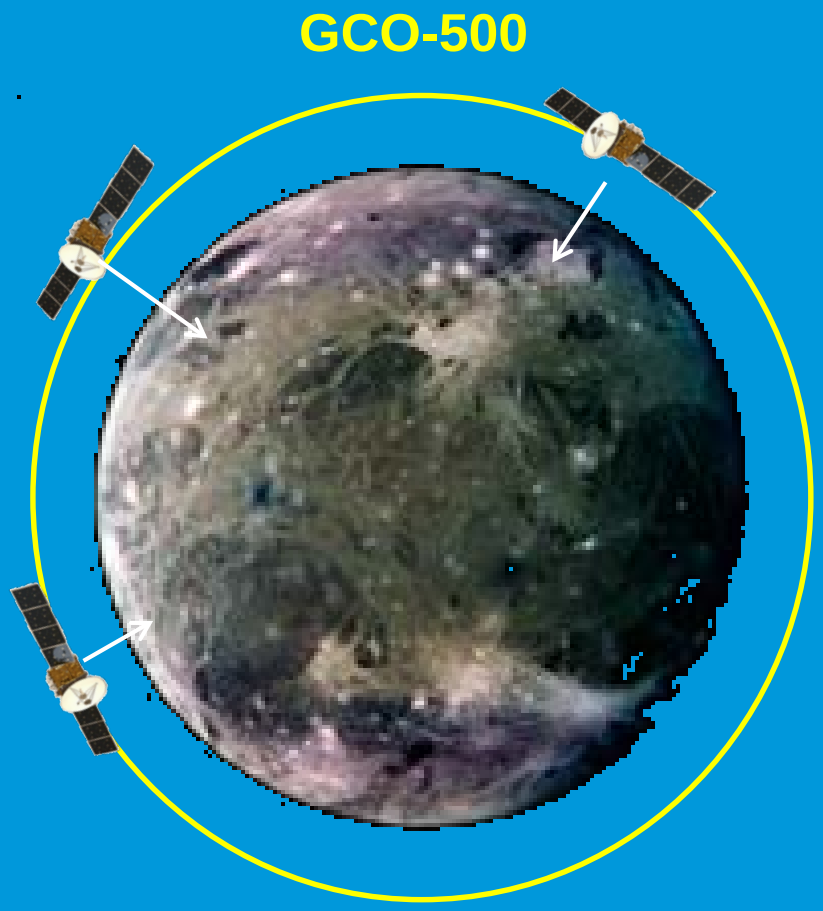


EUROPA FLYBY

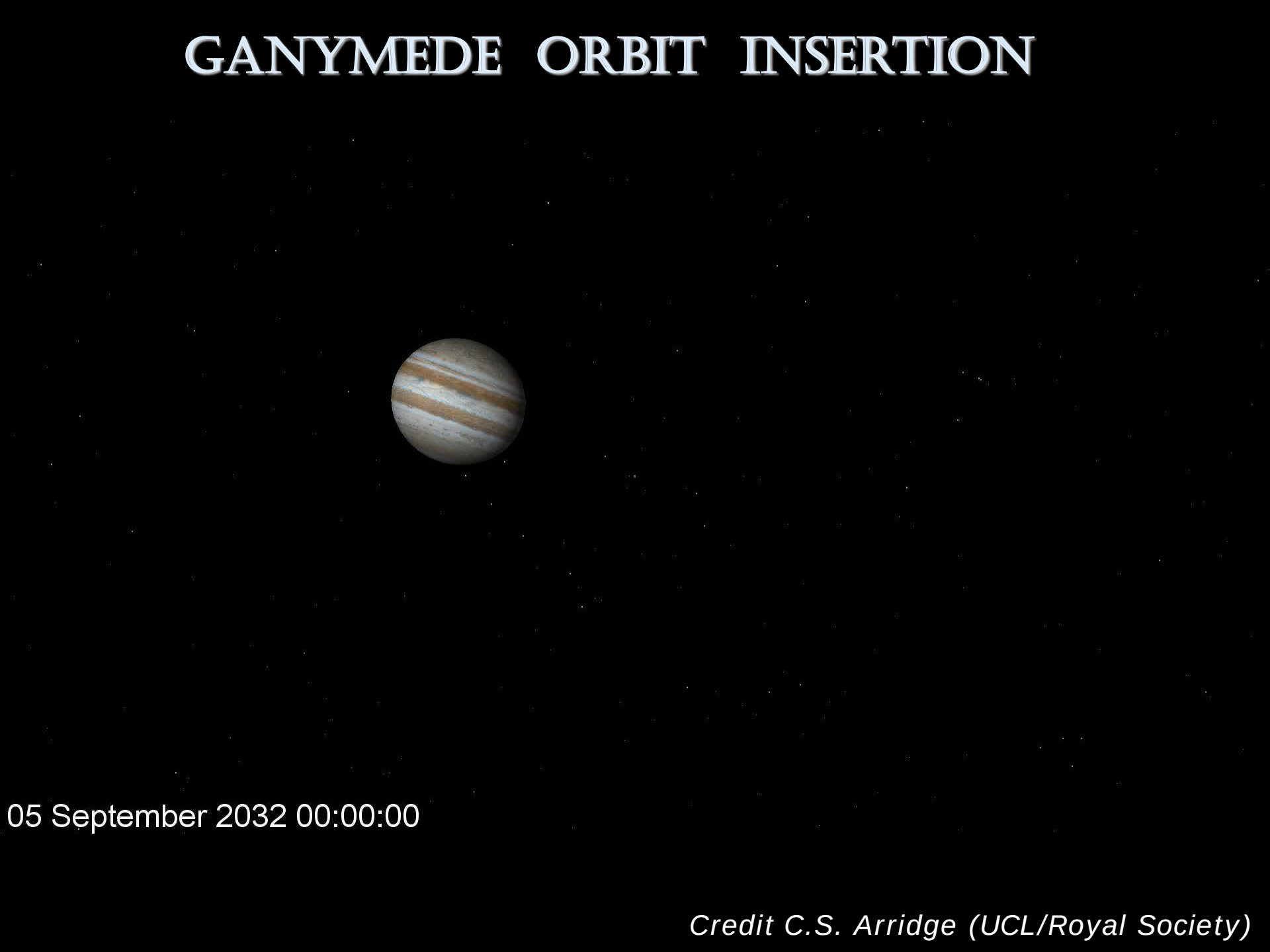
Credit C.S. Arridge (UCL/Royal Society)

Ganymede Tour





GANYMEDE ORBIT INSERTION

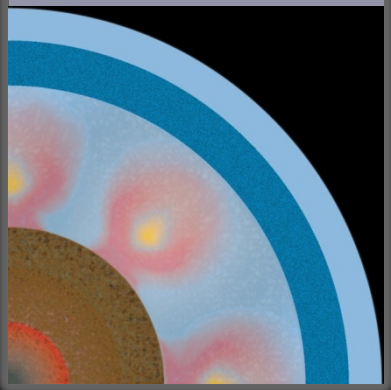


Credit C.S. Arridge (UCL/Royal Society)

JUICE : SCIENCE INVESTIGATIONS

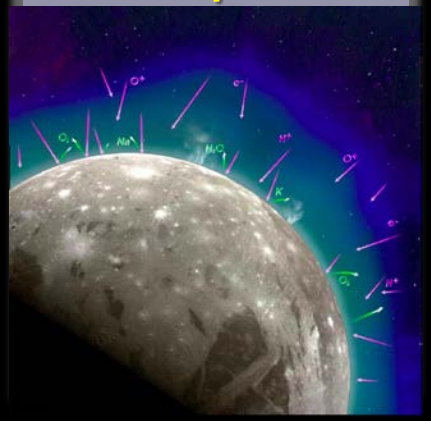
Ganymede: planetary object and potential habitat

Ice shell, ocean, deeper interiors

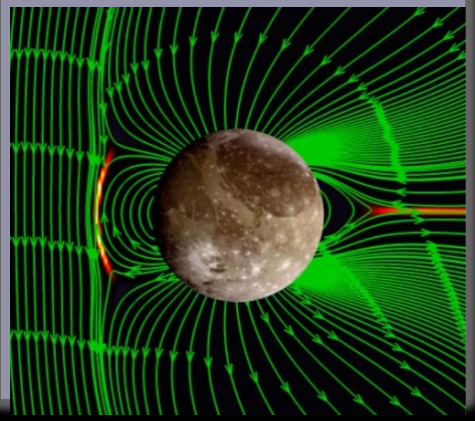


Geology, surface composition

Atmosphere, ionosphere



Magnetosphere, plasma environment



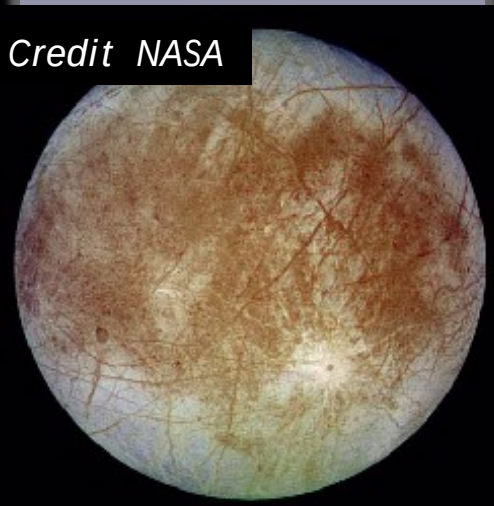
Main investigations

- 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

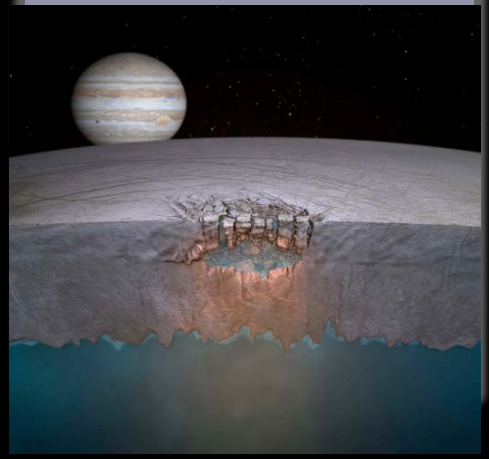
Credit NASA

Europa: study of recently active regions

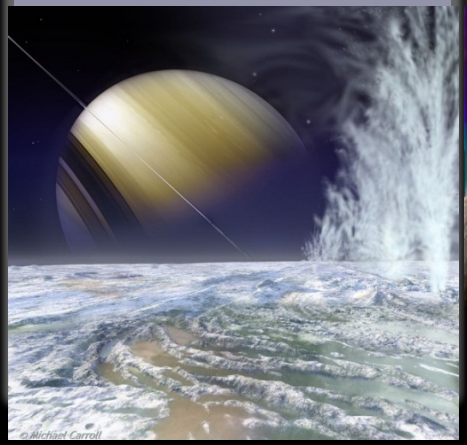
Composition of non-ice material



Liquid sub-surface water



Active processes

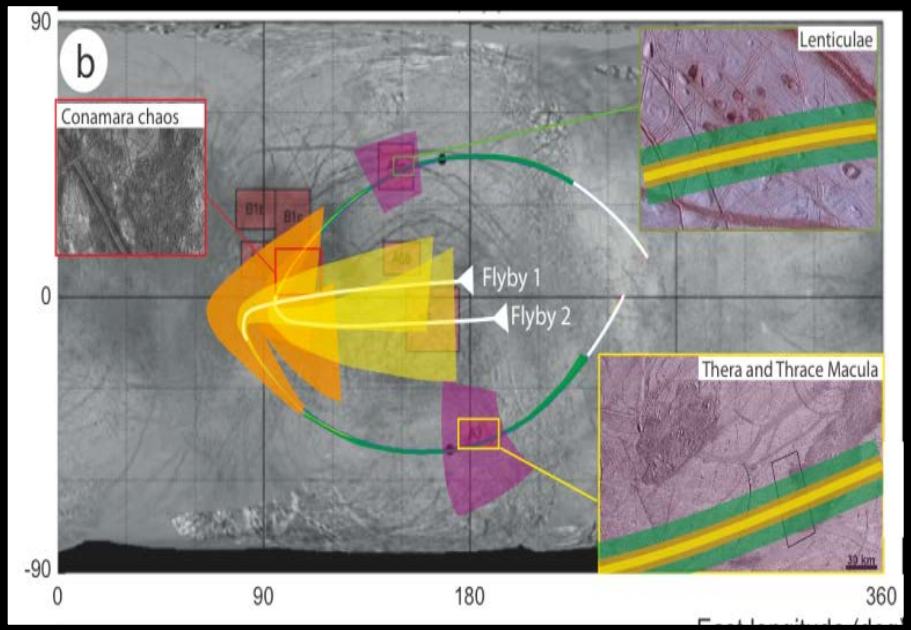


Atmosphere, ionosphere

Main investigations

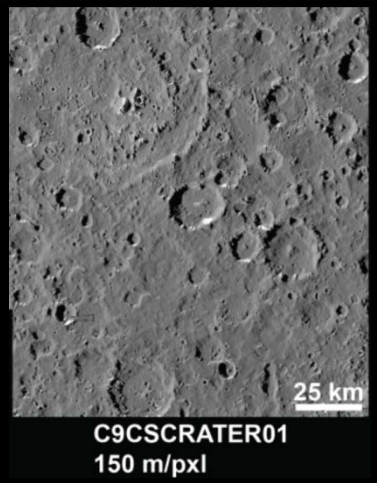
- At least 1 Europa flyby with CA <500 km over the most active regions
- Favorable illumination conditions at CA
- Anti-Jovian side at CA
- Simultaneous operations of all experiments (including 3GM as a goal)
- Non-ice materials in selected sites mapped at regional (>5 km/px) and local (<500 m/px) scales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

Geometry of two baseline Europa flybys

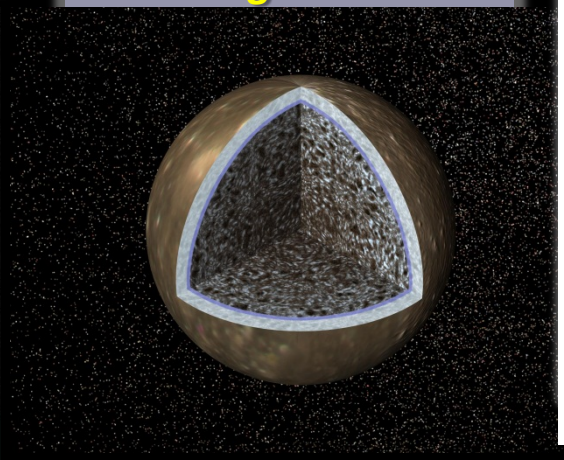


Callisto: a witness of the early Solar System

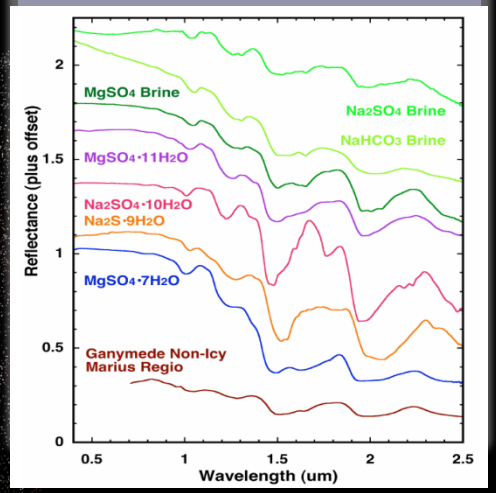
Geological history and past activity



Outer shell including ocean



Non-ice material

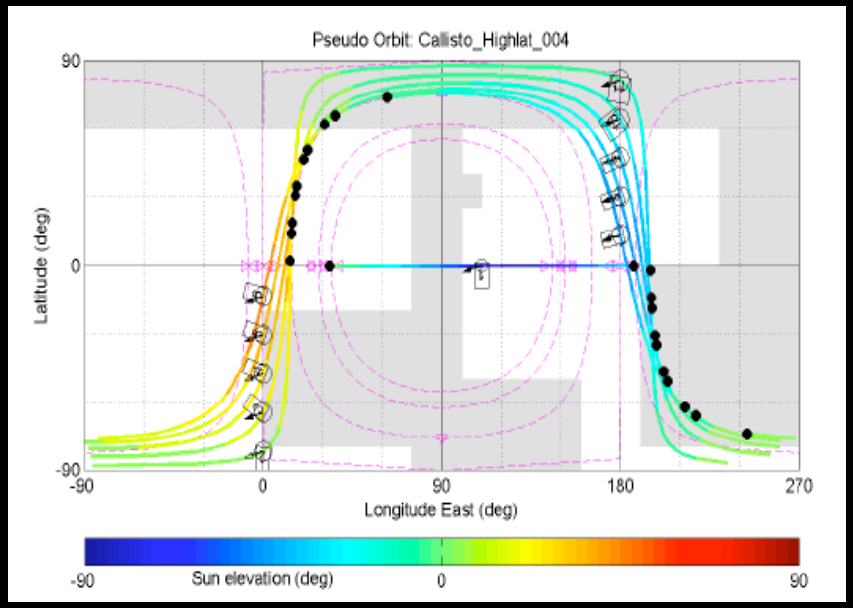


Credit NASA

Main investigations

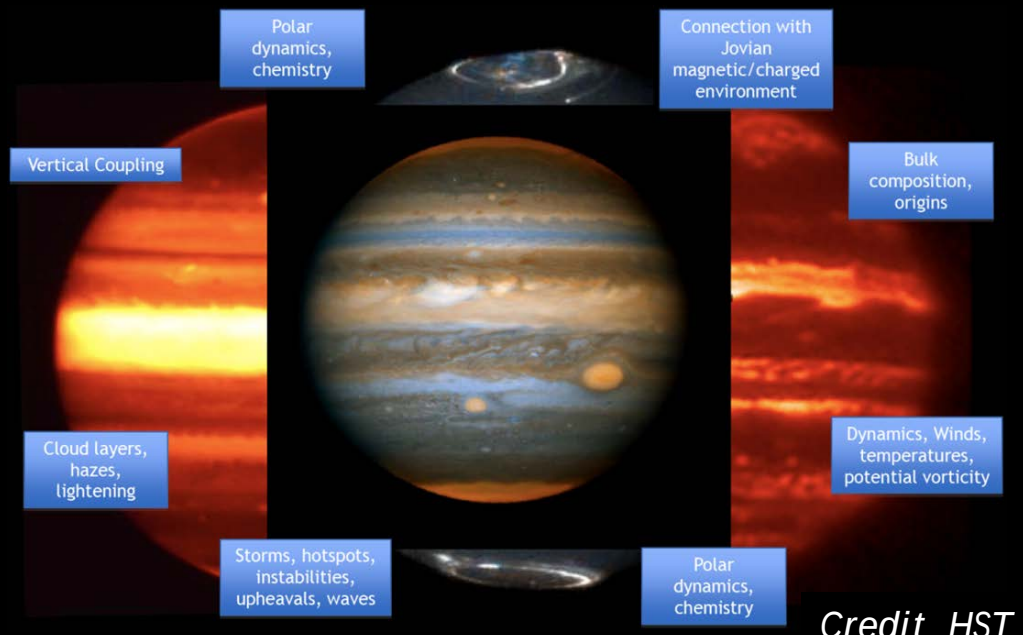
- *At least 9 Callisto flybys with CA<1000 km*
- *Several flybys with CA<500 km and good illumination conditions*
- *Flyby trajectory inclined by at least 50° to the moons equator*
- *Medium resolution imaging (<400 m/px)*
- *Regional mineralogical mapping (~5km/px)*
- *Subsurface down to few km*

Geometry of the baseline Callisto flybys



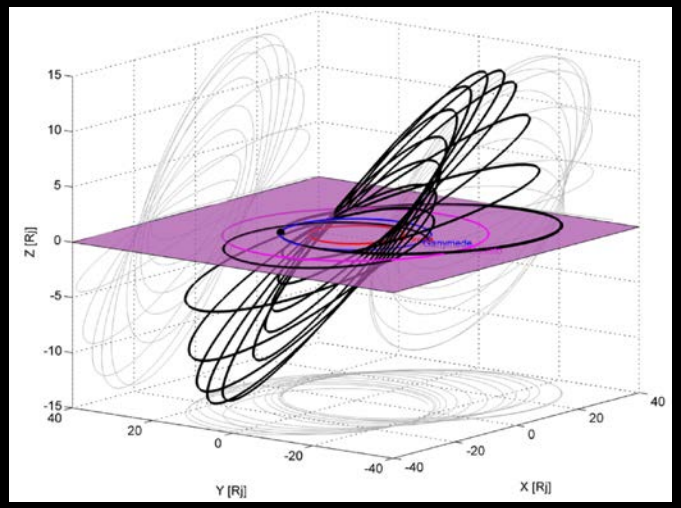
Jupiter atmosphere

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



Credit HST

High-inclination trajectories

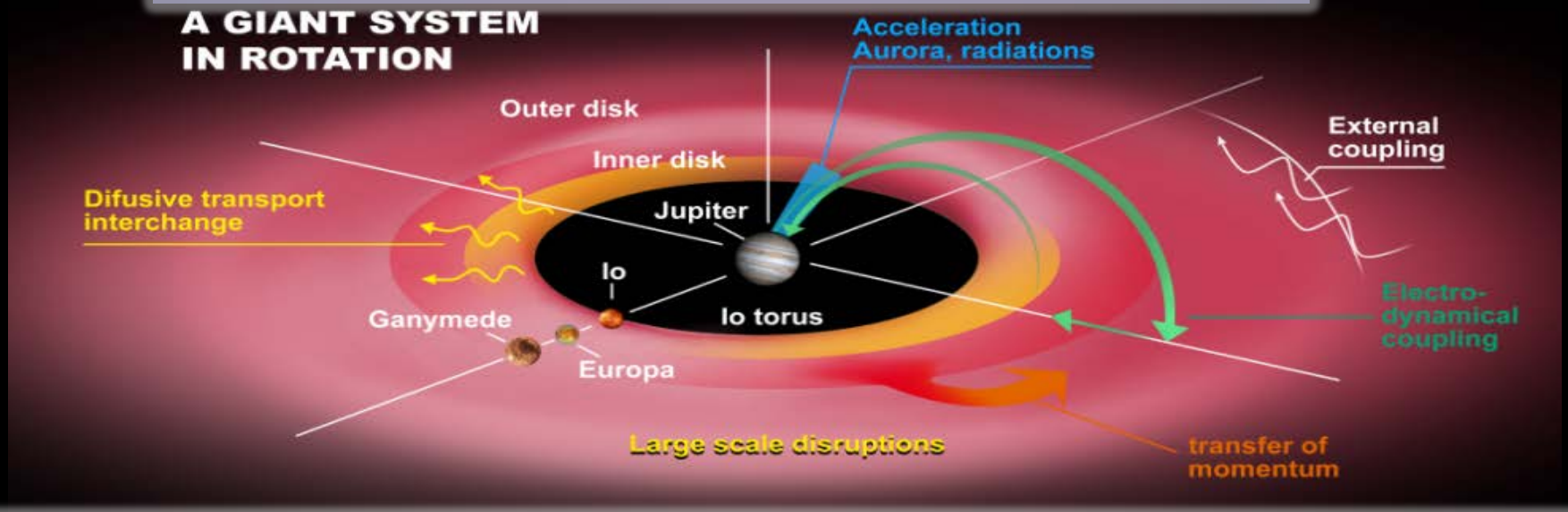


Main investigations

- *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*

Exploration of the Jupiter system

JUICE

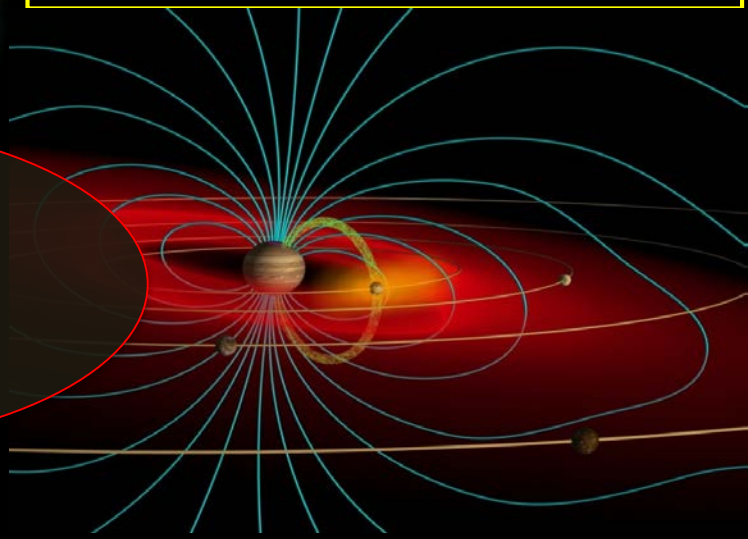
The biggest planet, the biggest magnetosphere, and a mini solar system

Jupiter

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

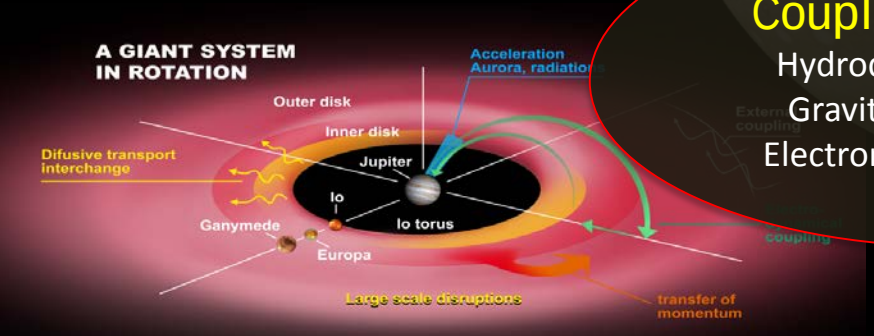
Magnetosphere

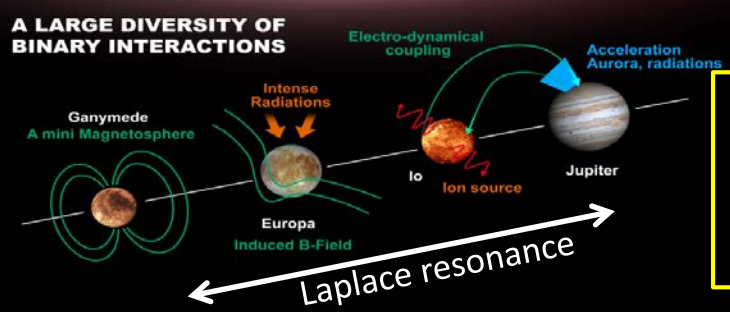
- Largest object in our Solar System
- Biggest particle accelerator in the Solar System
- Unveil global dynamics of an astrophysical object



Coupling processes

Hydrodynamic coupling
Gravitational coupling
Electromagnetic coupling





Satellite system

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

JUICE : PAYLOAD SYNERGY

Payload: Remote sensing suite

Acronym	Instrument type	Characteristics
JANUS	Imaging system	• 350-1050 nm, 13 filters • FOV: 1.72x1.29 ° • 3 m/px at Ganymede (from 200 km orbit) • 15 km/px at Jupiter (from Ganymede orbit)
MAJIS	Vis-near-IR imaging spectrometer	• 0.4-5.7 µm, 3-7 nm resolution • FOV: 3.4° • 0.025km/px at Ganymede (from 200 km orbit) • 125 km/px at Jupiter (from Ganymede orbit)
UVS	UV spectrograph	• 55-210 nm, <0.6 nm resolution • 0.5 km/px at Ganymede(200 km) • 250 km/px at Jupiter
SWI	Sub-mm wave instrument	• 530-601 GHz (500 µm) • 10^7 resolving power • 30 cm antenna, 1-2 mrad resolution

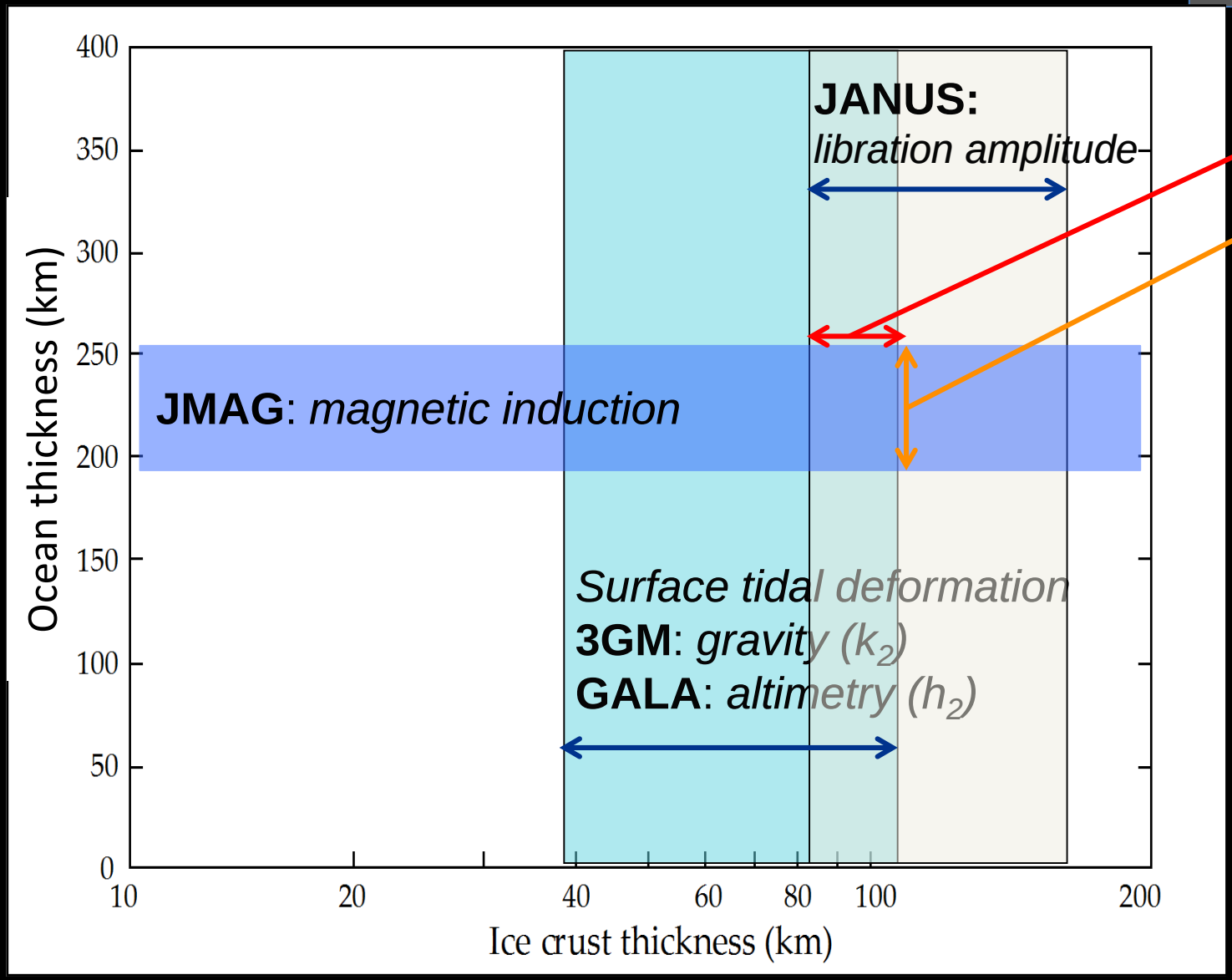
Payload: Geophysical experiments

Acronym	Instrument type	Characteristics
GALA	Laser Altimeter	• 30 & 75 shot frequency • Resolution H/V: 10 m/ 0.1 m at Ganymede (200km)
RIME	Ice Penetrating Radar	• 9 MHz (1&3 MHz band) • 10 m antenna • down to 9 km depth • 30 m resolution in ice
3GM (USO+KaT)	Radio science experiment	• Gravity field up to degree 10 at Ganymede • Structure of the Jupiter atmosphere 0.1-800 mbar
PRIDE	VLBI experiment	• Lateral position of s/c with ~25 m accuracy • Registration of weak signals

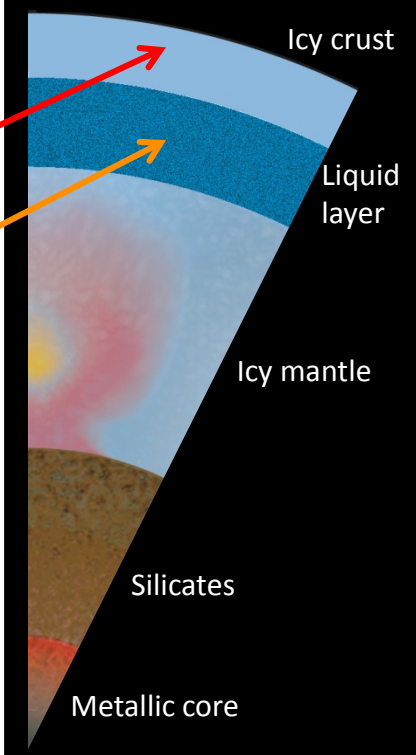
Payload: in-situ plasma & fields package

Acronym	Instrument type	Characteristics
PEP	Plasma Environmental Package	• 6 sensors • Neutrals, ions, electrons • Energy range <0.001 eV to >1 MeV • Composition with mass range 1-1000 amu and M/dM > 1100
RPWI	Radio & plasma Wave Instrument	• 4 sensors • E-field : DC - 45 MHz • B-field : 0.1 Hz – 20 kHz • Plasma properties: N_e, N_i, T_e,V_i • Dust characterization (>1 µm)
J-MAG	Magnetometer	• Measurements rate 32 Hz, 128 Hz • ±8000 nT @ 1 pT resolution • ±50000 nT @ 6 pT resolution

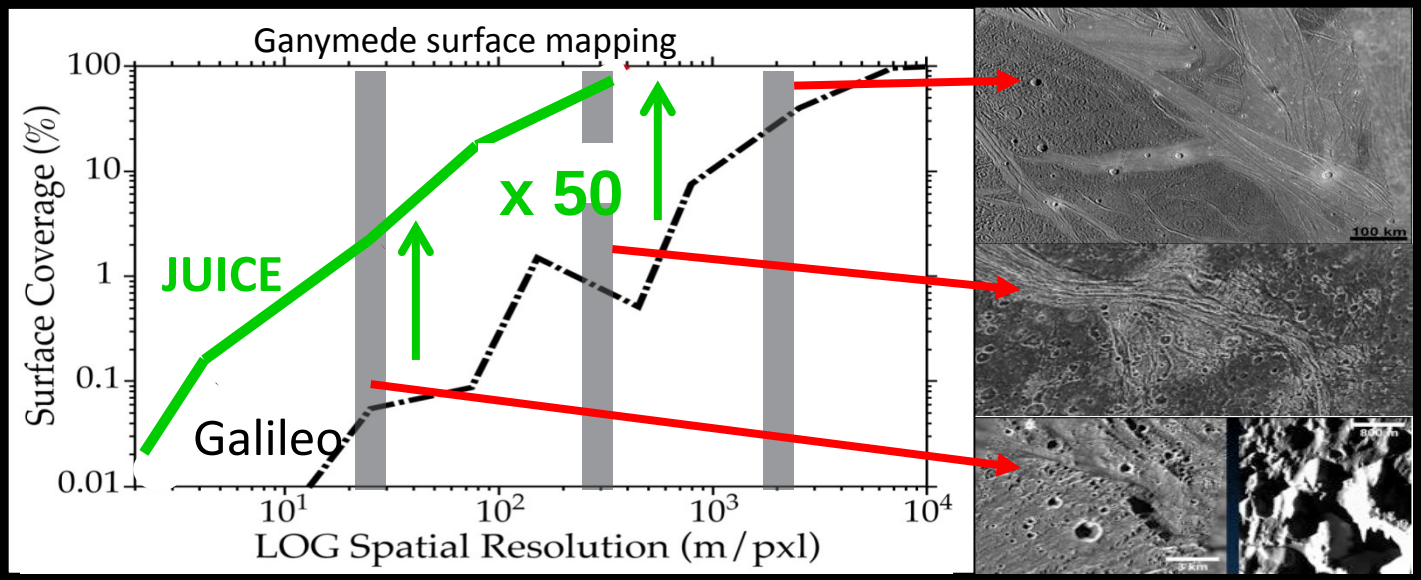
Ocean and icy crust at Ganymede



Internal structure

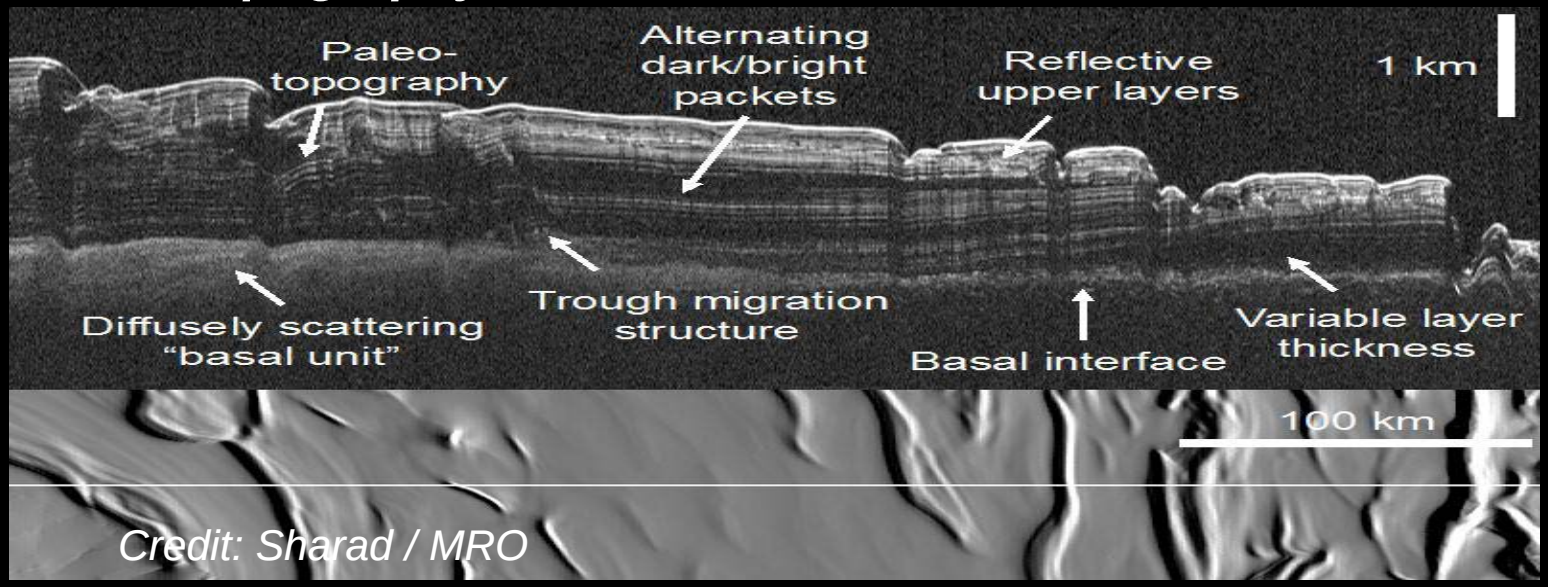


Ganymede surface and subsurface studies



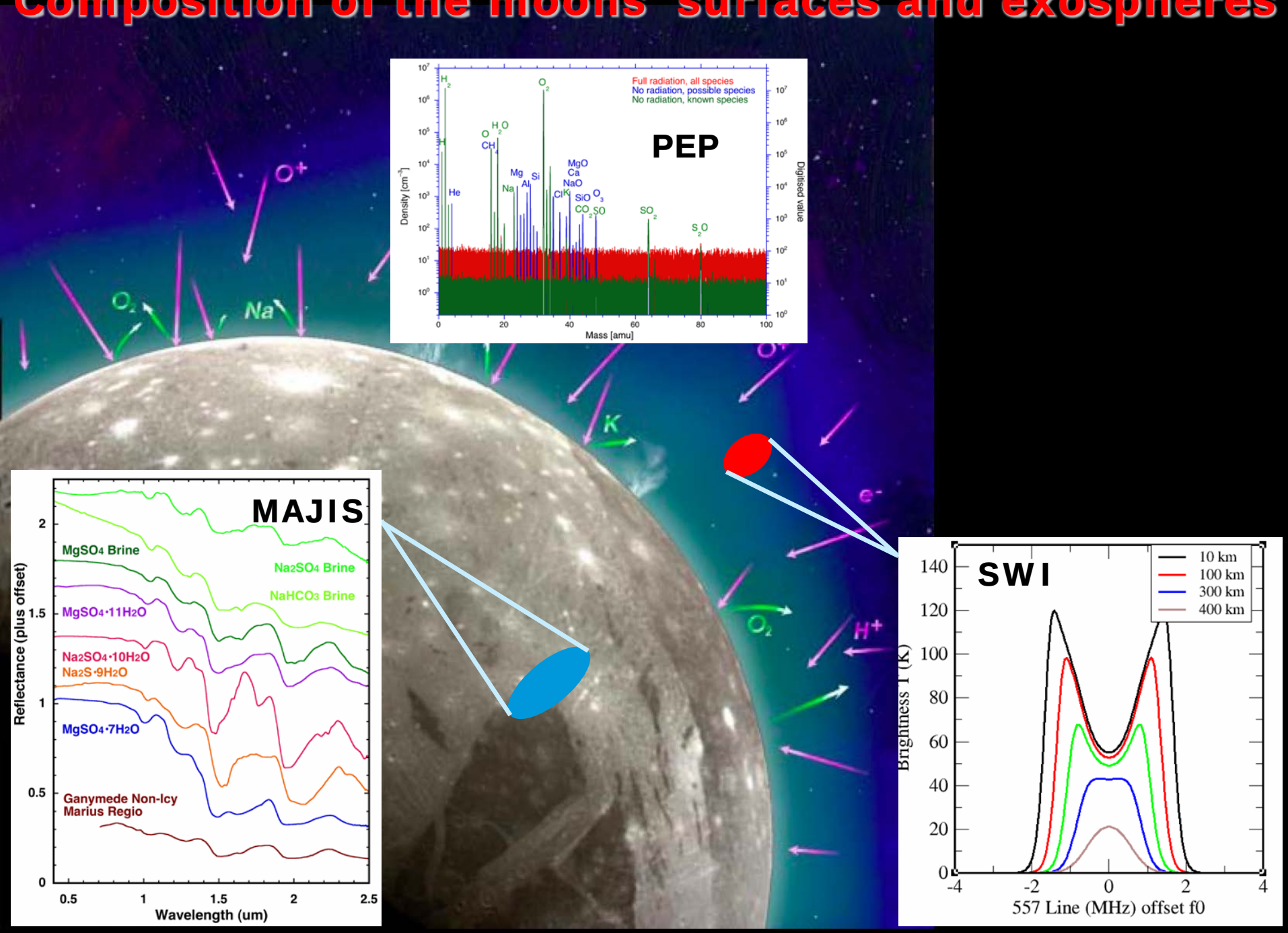
JANUS imaging

RIME subsurface sounding
GALA topography



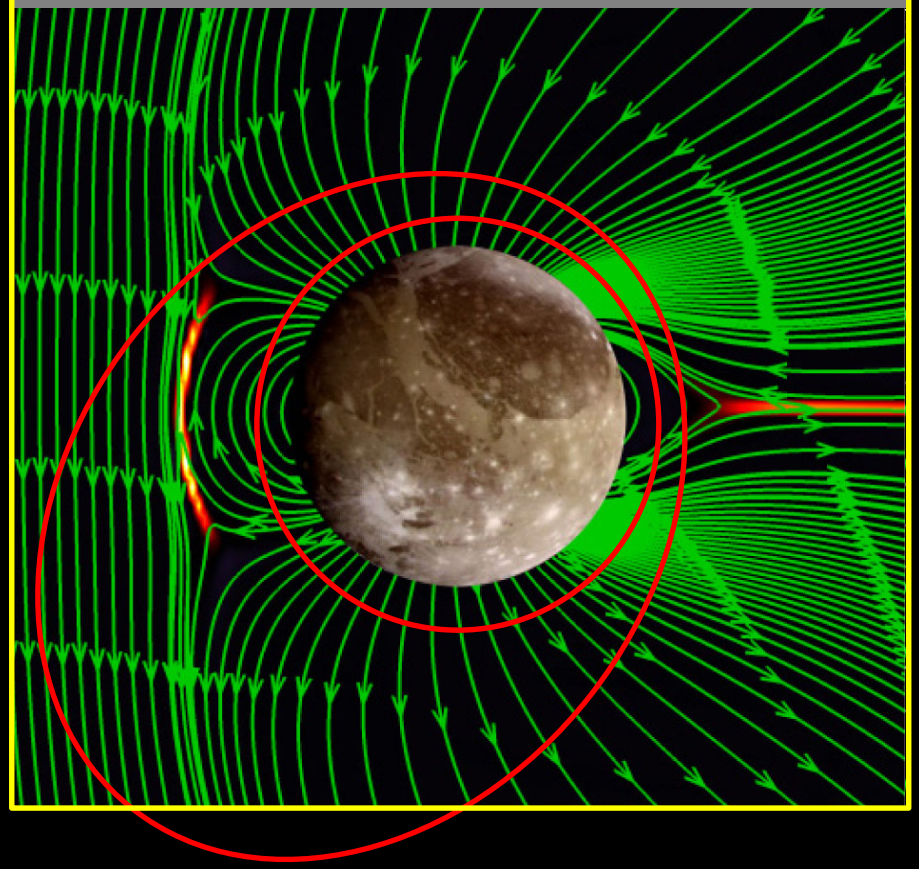
Credit: Sharad / MRO

Composition of the moons' surfaces and exospheres

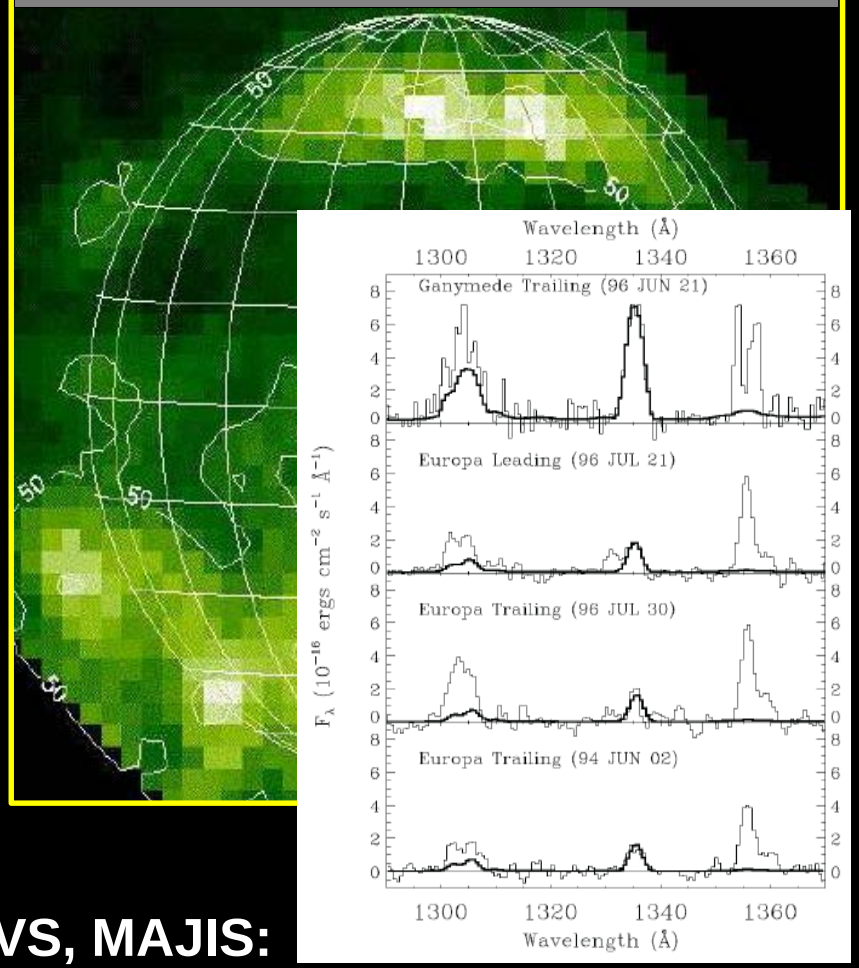


Local plasma environment at Ganymede

Dipole magnetic field and mini-magnetosphere



Coupling to Jupiter's magnetosphere



J-MAG: *magnetic field*

PEP: *neutrals, ions, electrons*

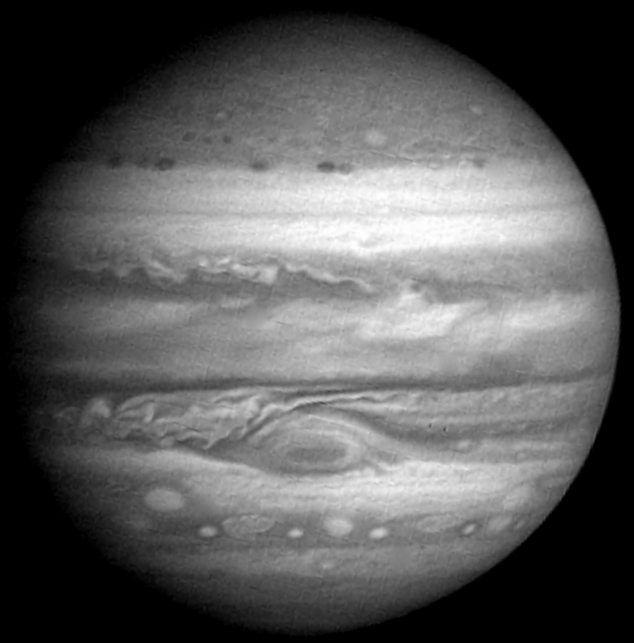
RPWI*: wave activity*

UVS, MAJIS:

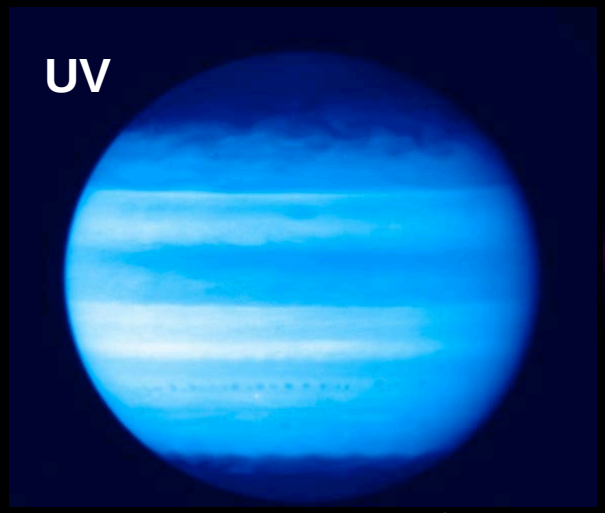
aurora spectral imaging

Dynamics of the Jovian atmosphere

Visible

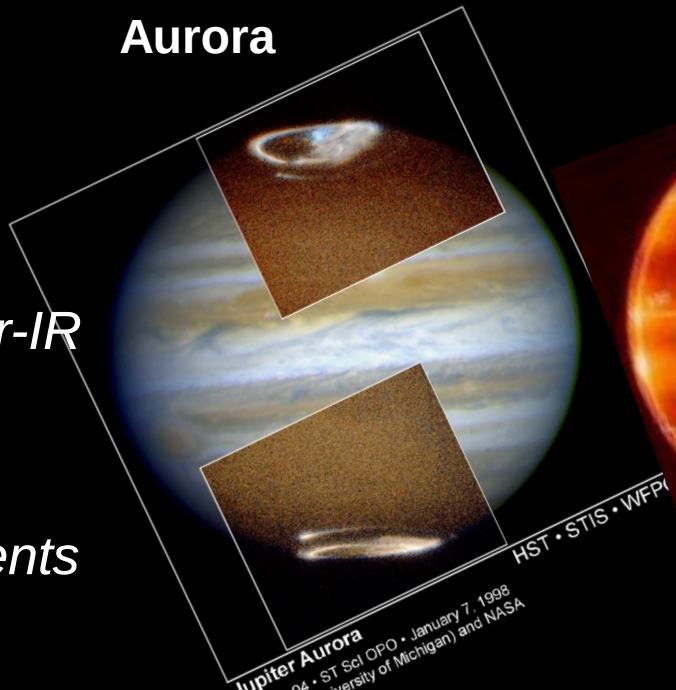


UV

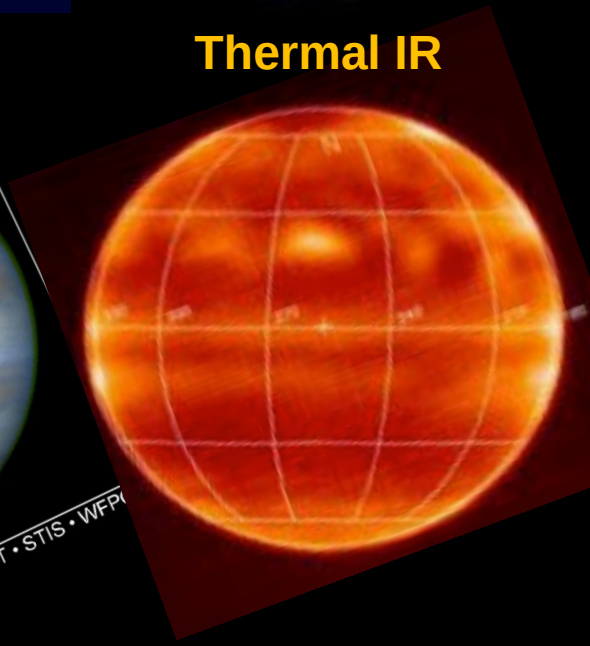


Near-IR

Aurora



Thermal IR



JANUS, MAJIS, UVS:

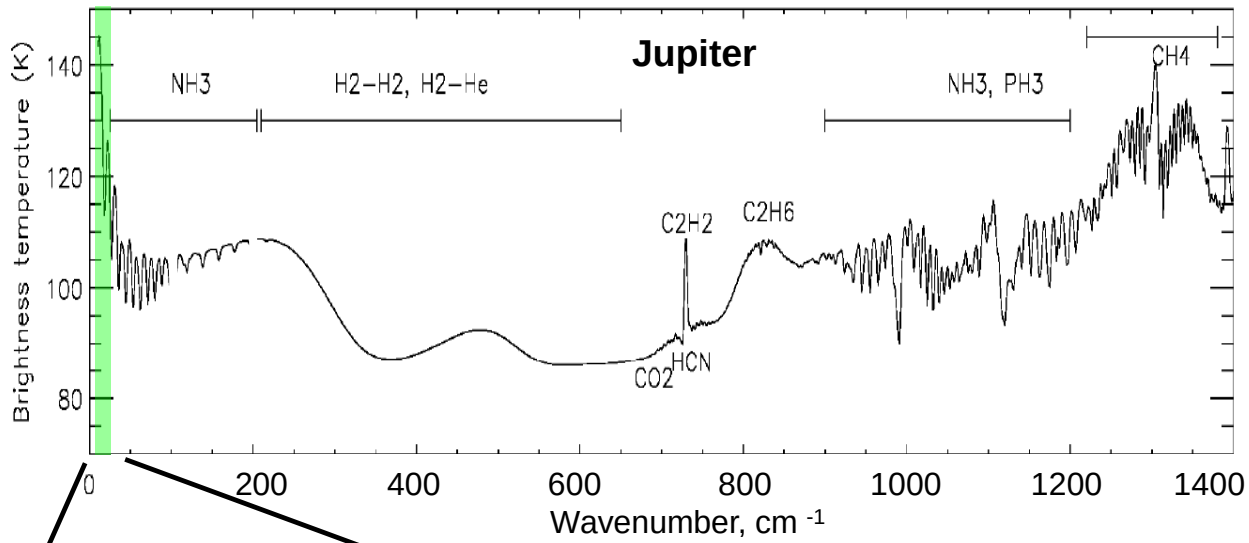
spectral imaging from UV to near-IR

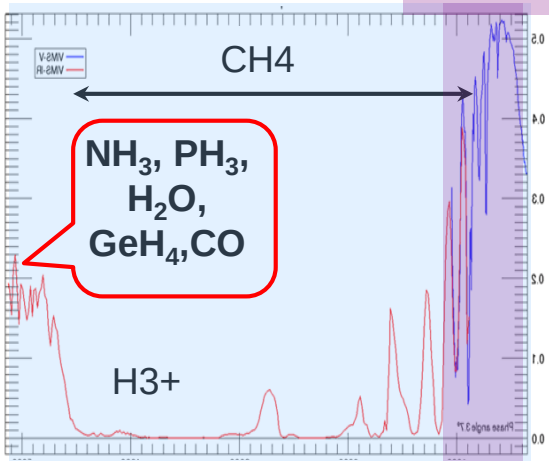
SWI:

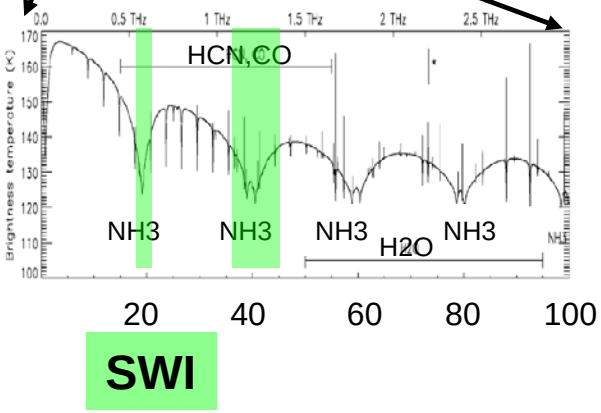
Doppler wind speed measurements

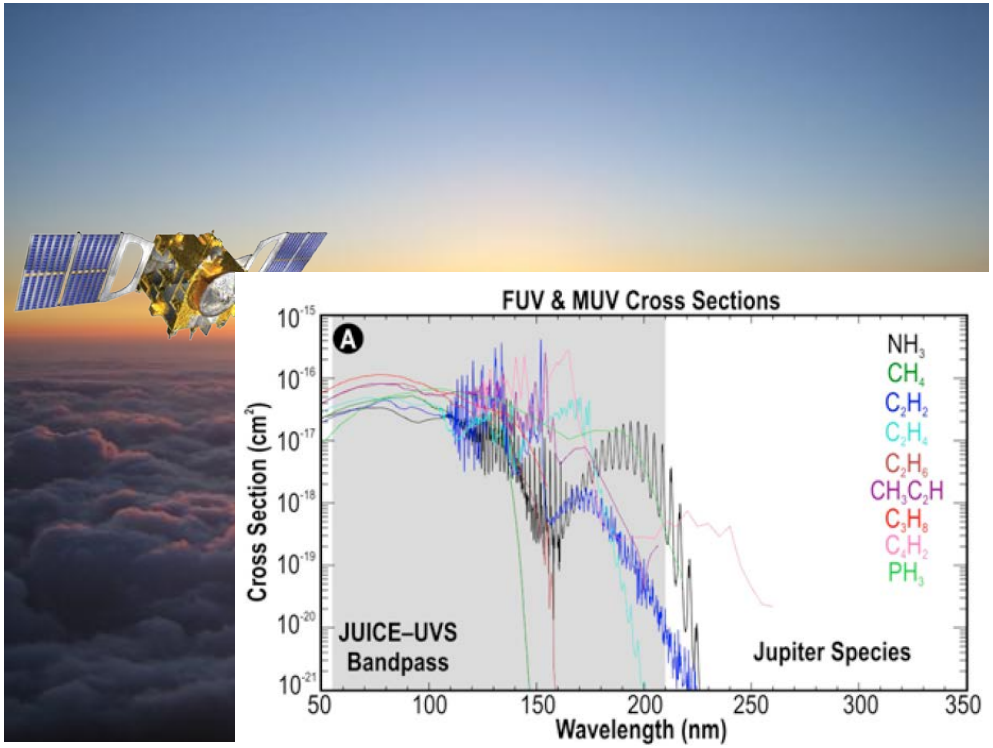
Credit HST, NASA

Composition of the Jovian atmosphere





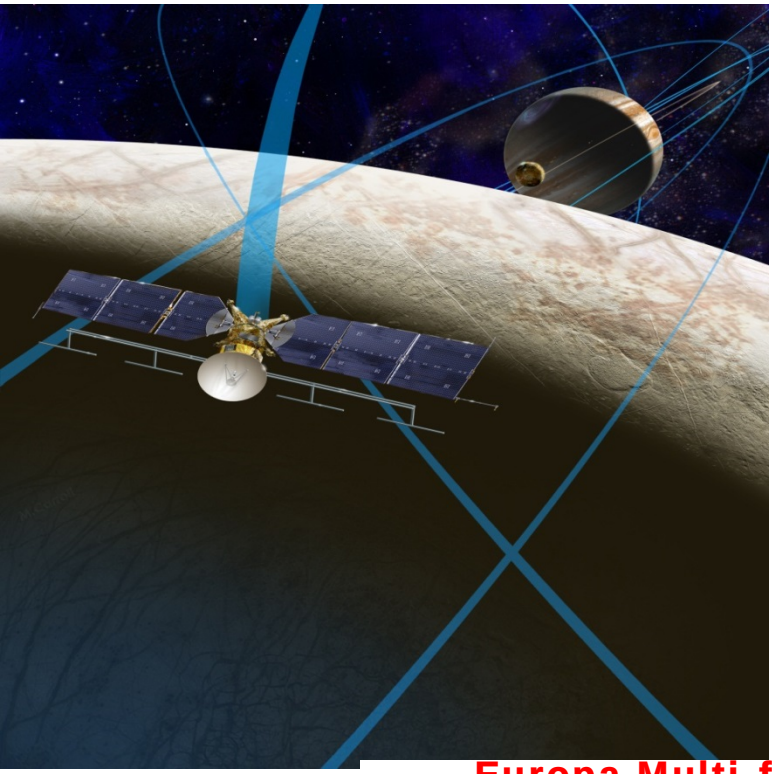




Conclusions

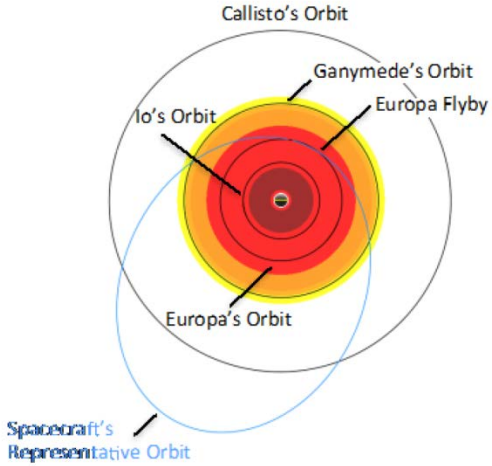
- **Highly capable spacecraft with synergistic and multi-disciplinary payload**
- **Detailed study of two classes of planetary objects**
  - *a gas giant*
  - *several icy moons with focus on Ganymede*
- **Comparative study of the icy moons family**
- **Investigations of two classes of planetary atmospheres**
  - *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**
- **Conjunction with ground-based support**
- **Precursor for future missions**

NASA Europa "Clipper" mission



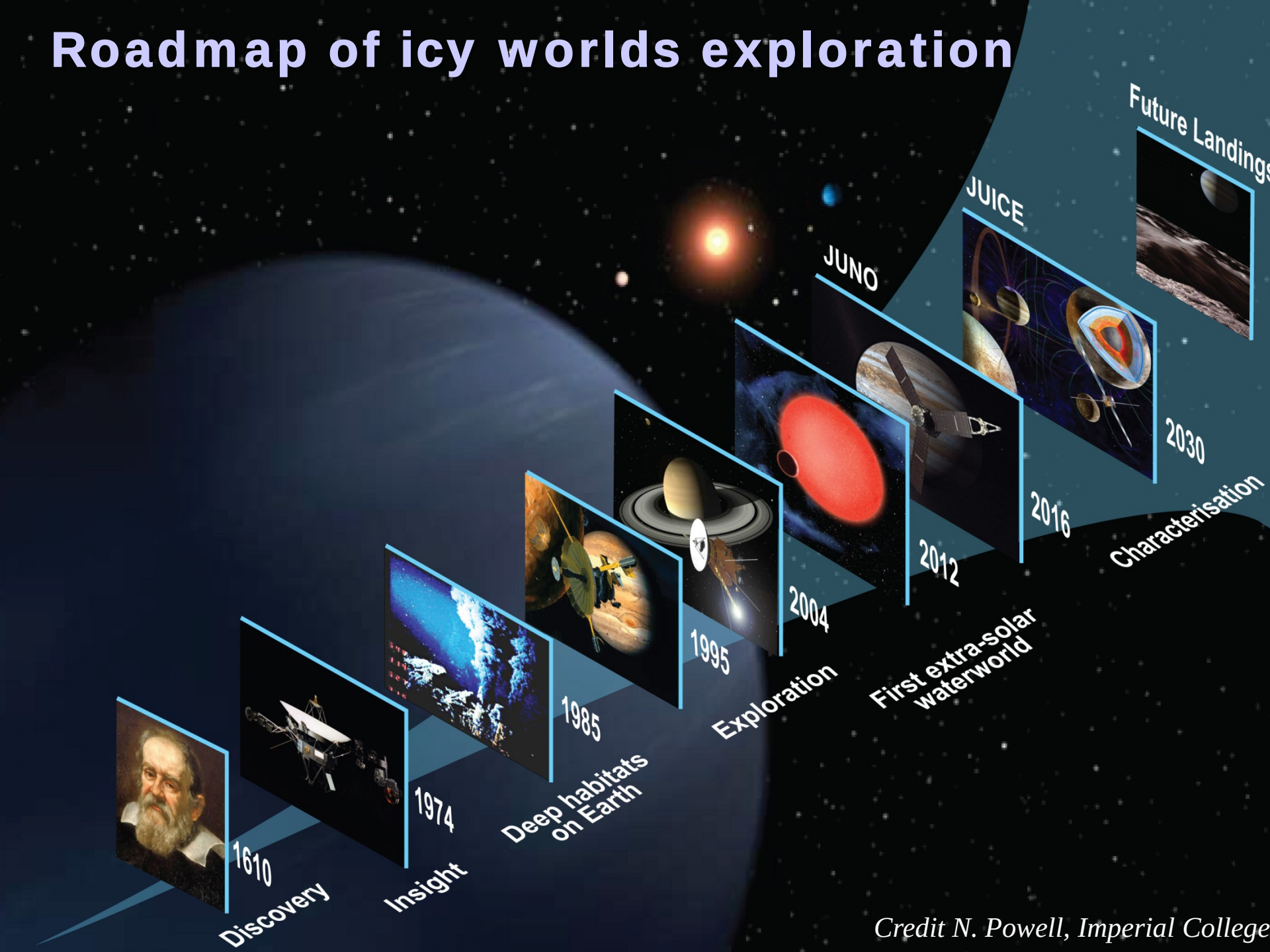
- Spacecraft in orbit around Jupiter
- Science goal: Europa's habitability
- Multiple (45) flybys of Europa
  - Altitudes: 25 – 2700 km
- 9 instruments selected: cameras, magnetometers, radar, dust analyser, spectrometers, plasma + mass spectrometer
- Schedule
  - Start formulation phase in Oct. 2016
  - Launch 2020-2025
  - Cruise: 2 or 7 years
  - Nominal mission: 3-4 years

Europa Multi-flybys



Possible extra probe, penetrator or lander provided by ESA is being discussed

Roadmap of icy worlds exploration

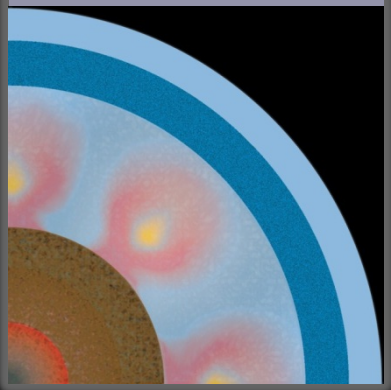


Credit N. Powell, Imperial College

ADDITIONAL SLIDES

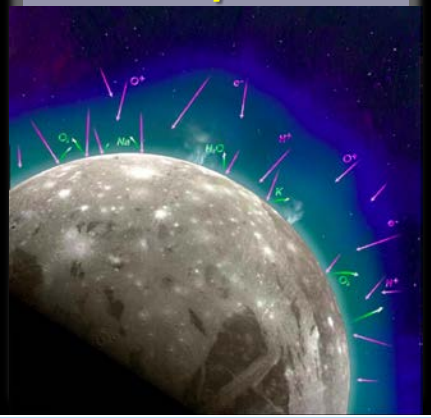
Ganymede: planetary object and potential habitat

Ice shell, ocean, deeper interiors

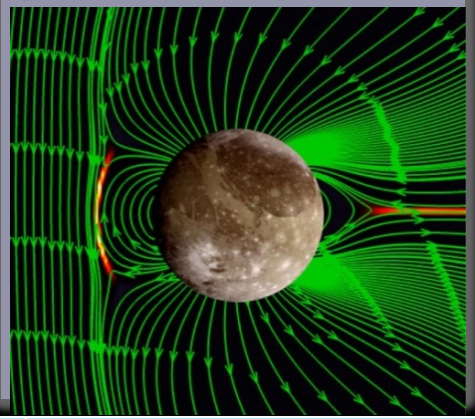


Geology, surface composition

Atmosphere, ionosphere



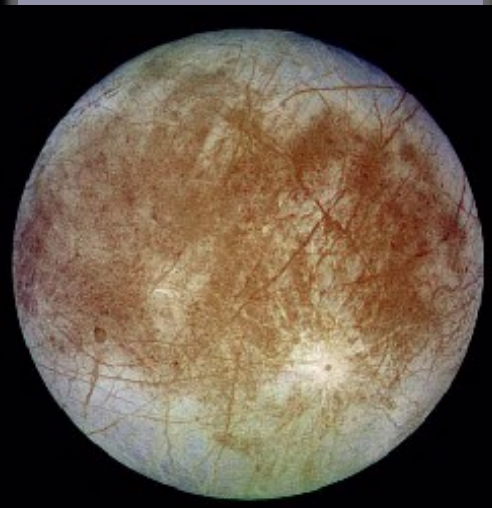
Magnetosphere, plasma environment



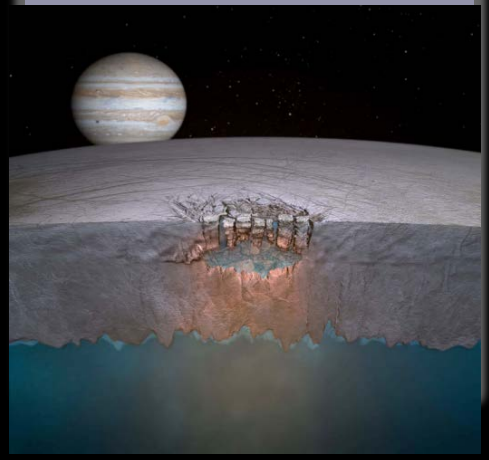
Main investigations	Instruments
Thickness of the icy crust, ocean depth and conductivity	J-MAG, 3GM, GALA, JANUS
Sub-surface sounding down to ~9 km depth	RIME
Imaging: global ~400 m/px, selected targets ~3 m/px	JANUS
Mineralogical mapping (especially of non-ice materials): globally 1-5 km/px , selected targets ~25 m/px	MAJIS, UVS
Composition and dynamics of the atmosphere	PEP, SWI, UVS
Magnetosphere, plasma environment, and interaction with the surface and the Jovian magnetosphere	PEP, RPWI, JMAG, UVS, MAJIS

Europa: study of recently active regions

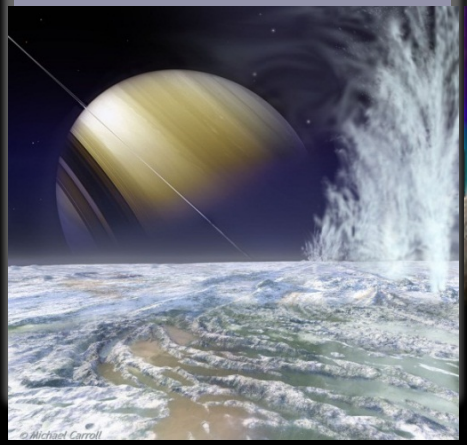
Composition of non-ice material



Liquid sub-surface water



Active processes



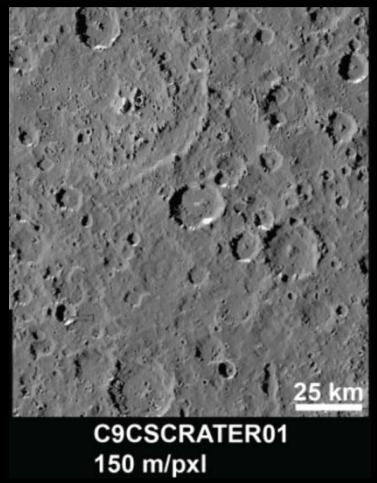
Atmosphere, ionosphere

Main investigations	Instruments
Non-ice materials in selected sites mapped at regional (>5 km/px) and local (<500 m/px) scales	MAJIS, UVS
Search for liquid water in the shallow (few km) subsurface	RIME
Processes in active sites	JANUS, MAJIS, UVS
Atmosphere and plasma environment	PEP, RPWI, JMAG, SWI, UVS

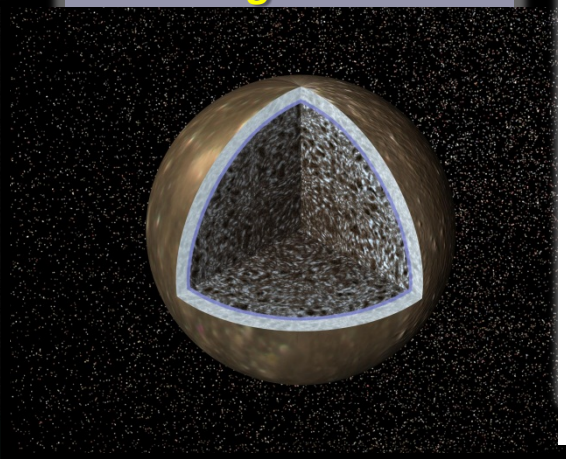
Callisto: a witness of the early Solar System

Geological history and past activity

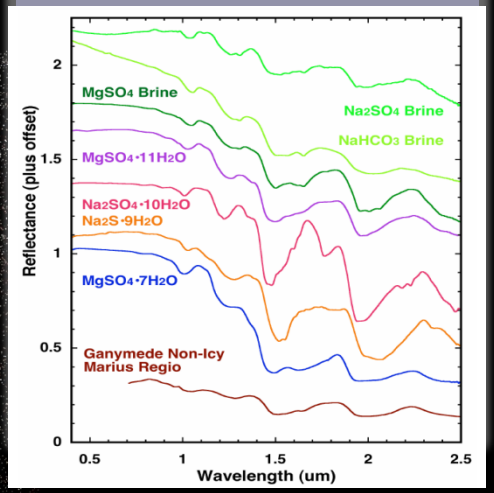
Credit NASA



Outer shell including ocean



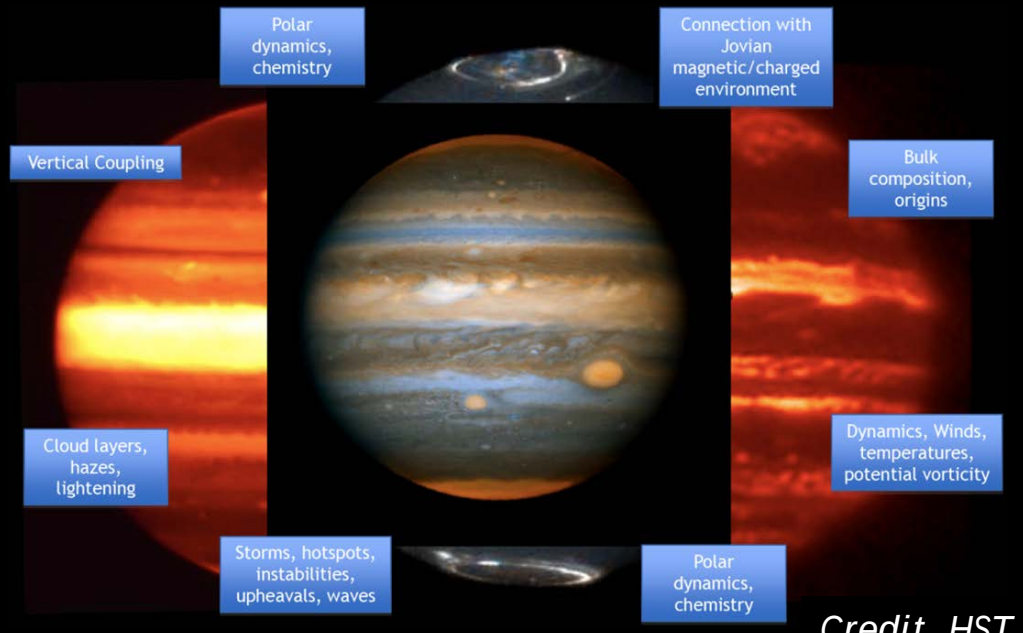
Non-ice material



Main investigations	Instruments
Medium resolution imaging (<400 m/px)	JANUS
Regional mineralogical mapping (~5 km/px)	MAJIS
Outer shell including ocean	3GM, JMAG
Subsurface down to few km	RIME
Exosphere and weathering processes	PEP, SWI, UVS, MAJIS, RPWI

Jupiter atmosphere

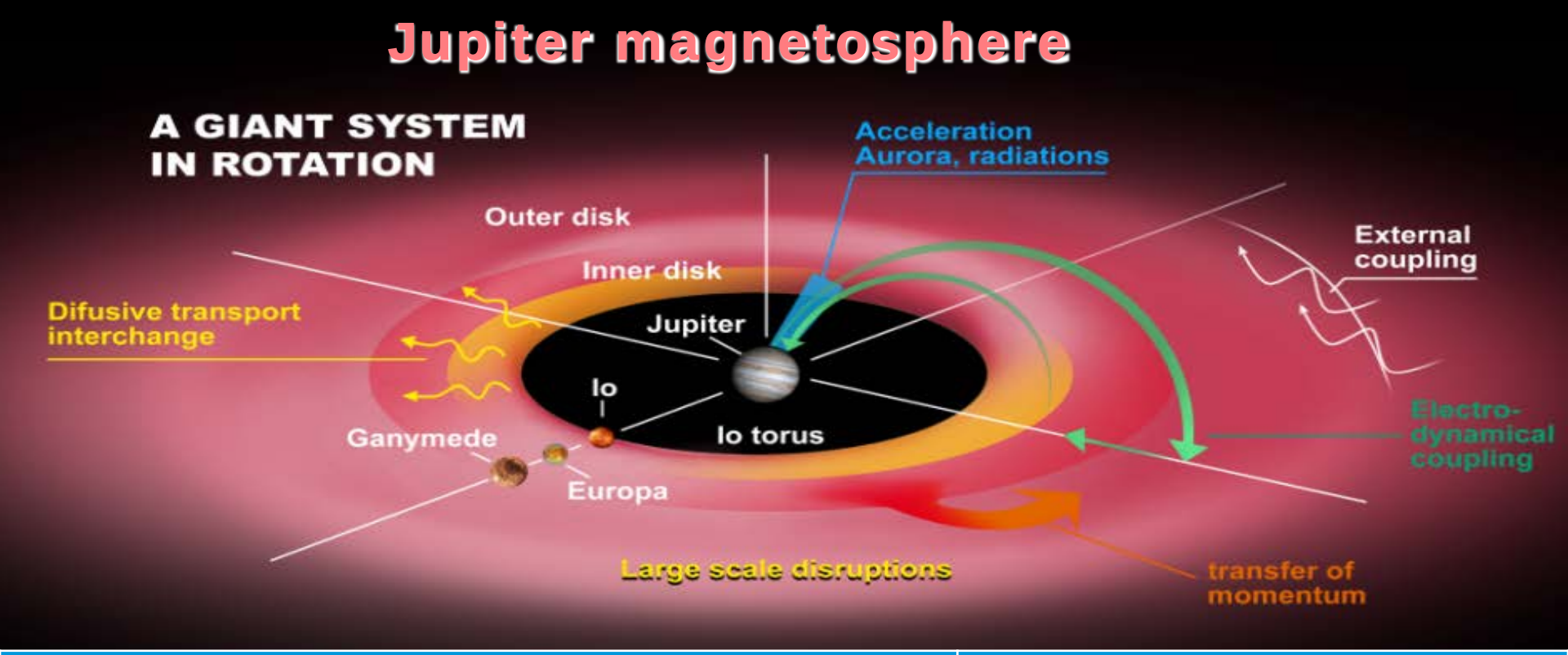
- *Atmospheric structure, composition and dynamics*
- *Coupling between troposphere, stratosphere and thermosphere*



Credit HST

Main investigations	Instruments
Structure of the atmosphere	UVS, 3GM, SWI, MAJIS, PRIDE
Composition and chemistry	MAJIS, UVS, SWI
Dynamics and meteorology	SWI, JANUS, MAJIS

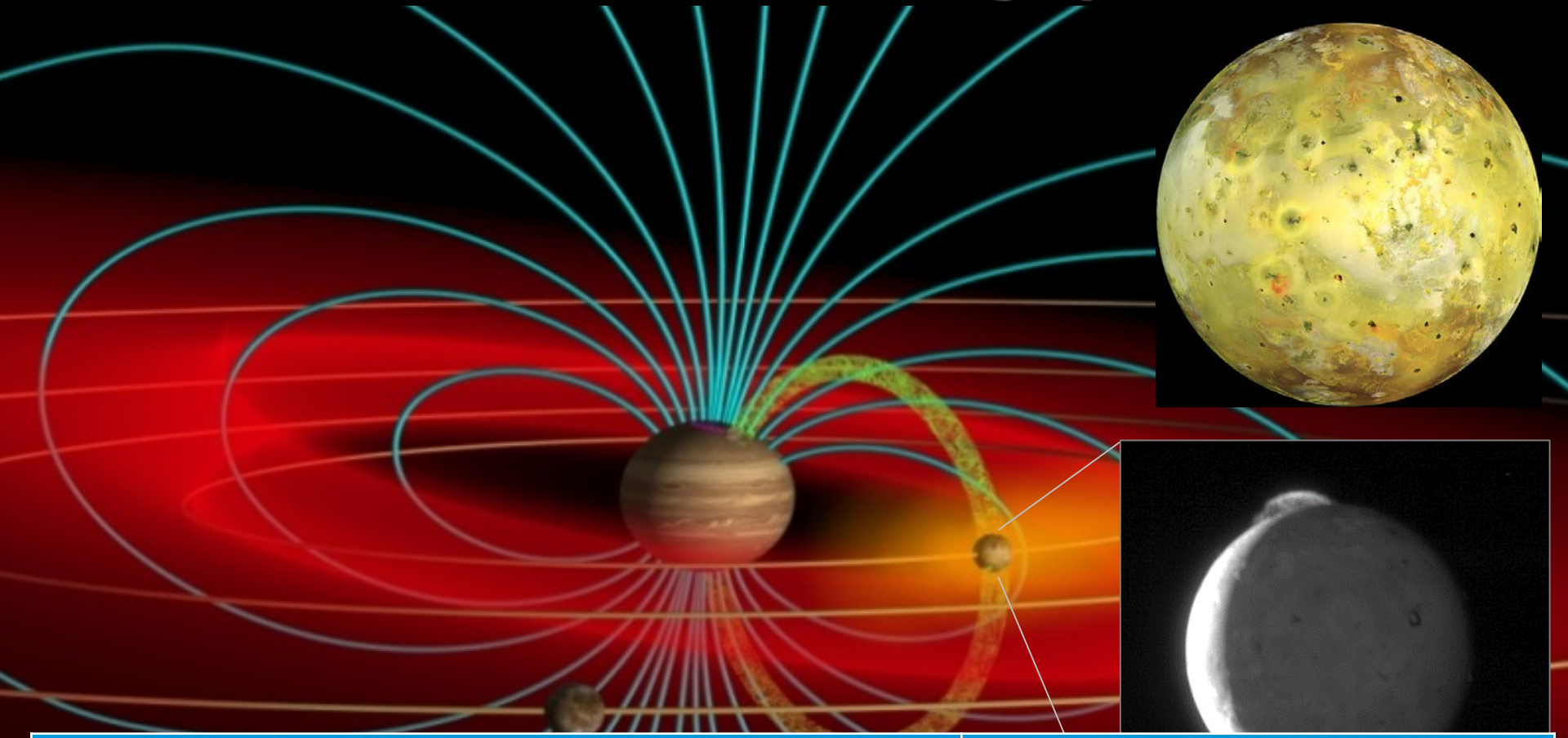
Jupiter magnetosphere



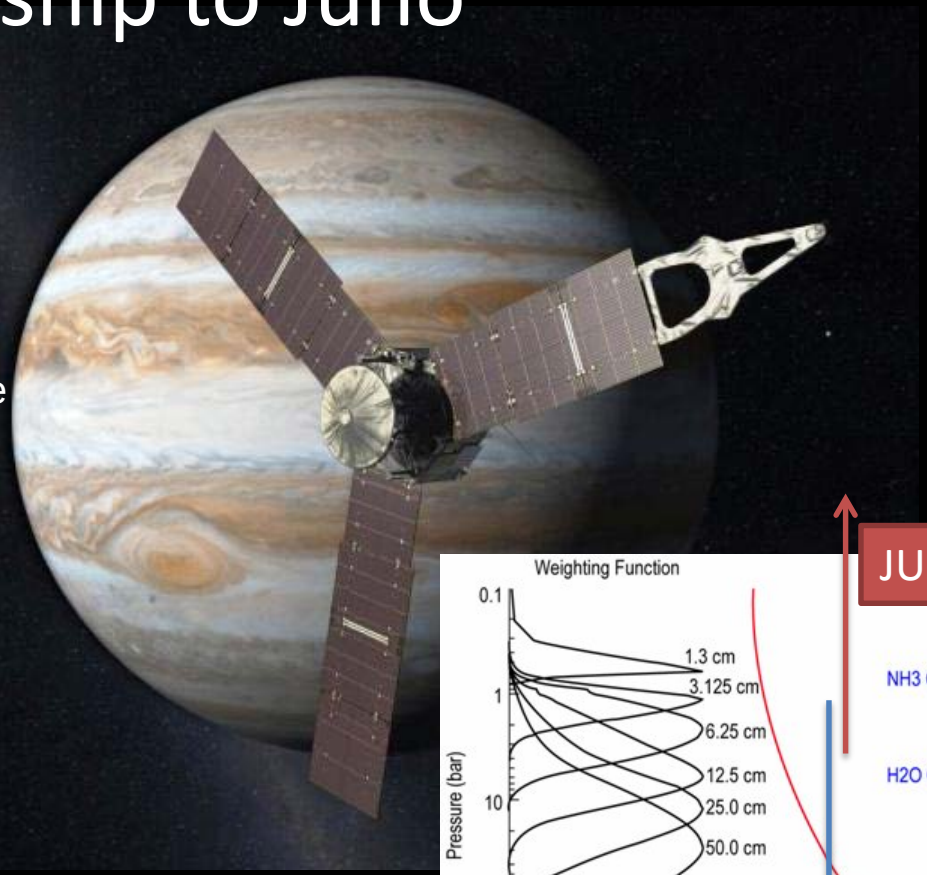
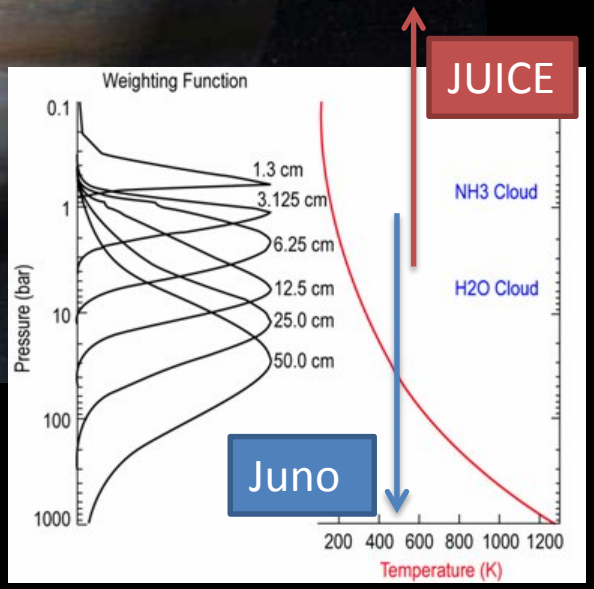
Main investigations	Instruments
Magnetosphere as a fast magnetic rotator	JMAG, RPWI, PEP
Magnetosphere as a giant particle accelerator	PEP, RPWI, JMAG
Moons as sources of magnetospheric plasma	UVS, PEP, MAJIS, JANUS

Credit ESA/ NASA

Jovian satellite and ring system



Main investigations	Instruments
Io activity and surface composition	JMAG, RPWI, PEP
Rings and moons	PEP, RPWI, JMAG
Ephemerides in the Jovian system	PRIDE, 3GM

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.