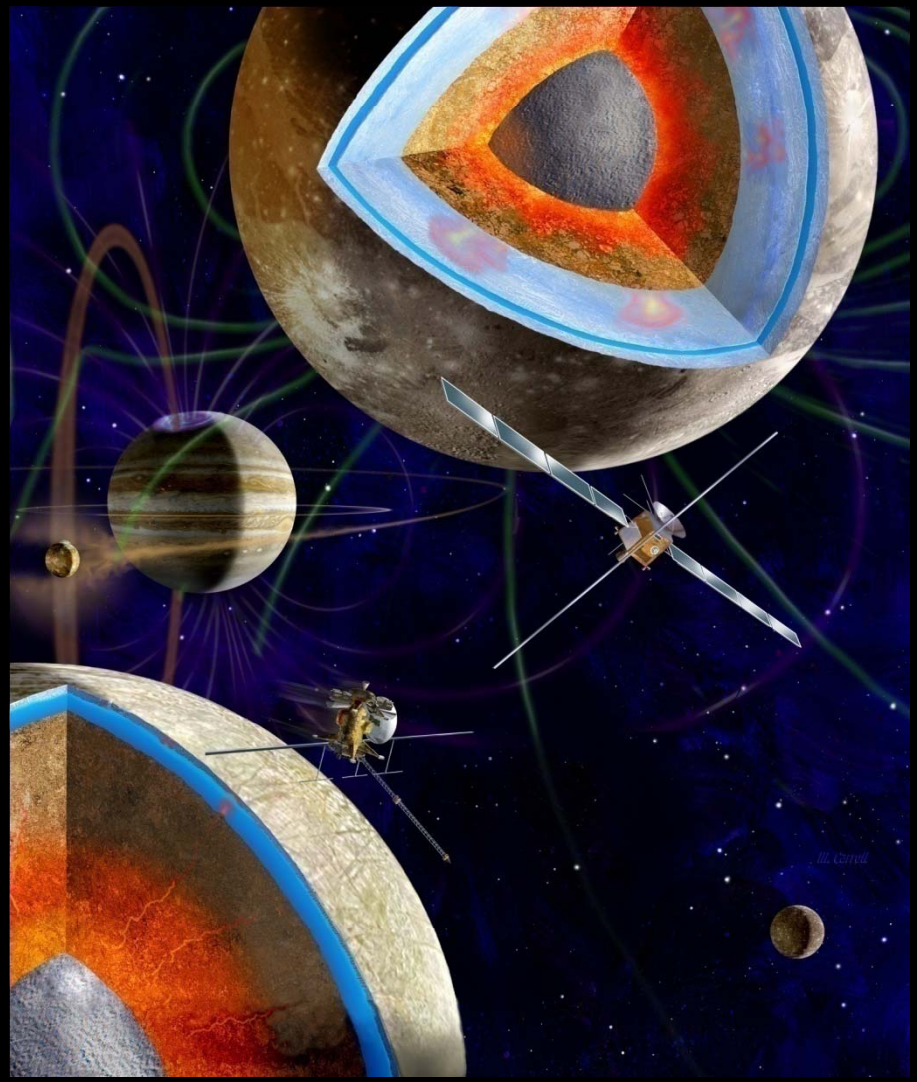
Europa Jupiter System Mission - Laplace

EJSM-Laplace

Overarching Theme: The emergence of habitable worlds around gas giant planets



Addresses two Cosmic Vision Themes:

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

Presentations by:

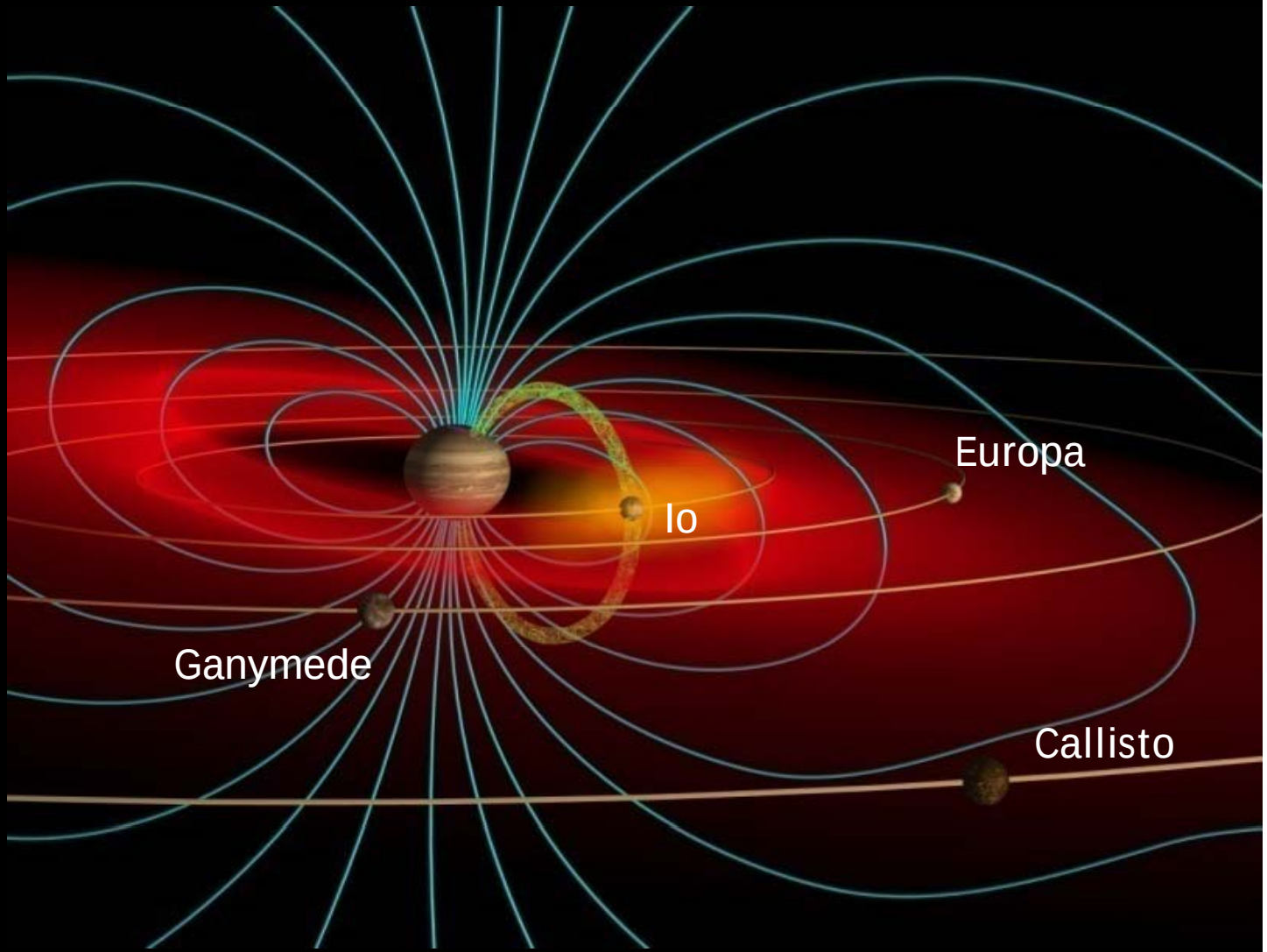
Michele Dougherty (Imperial College London)
Introduction and Summary

Olivier Grasset (Nantes University)
Habitability of the icy moons

Emma Bunce (Leicester University)
Explore the Jupiter System as an archetype for gas giants

Christian Erd (ESA)
Mission Implementation

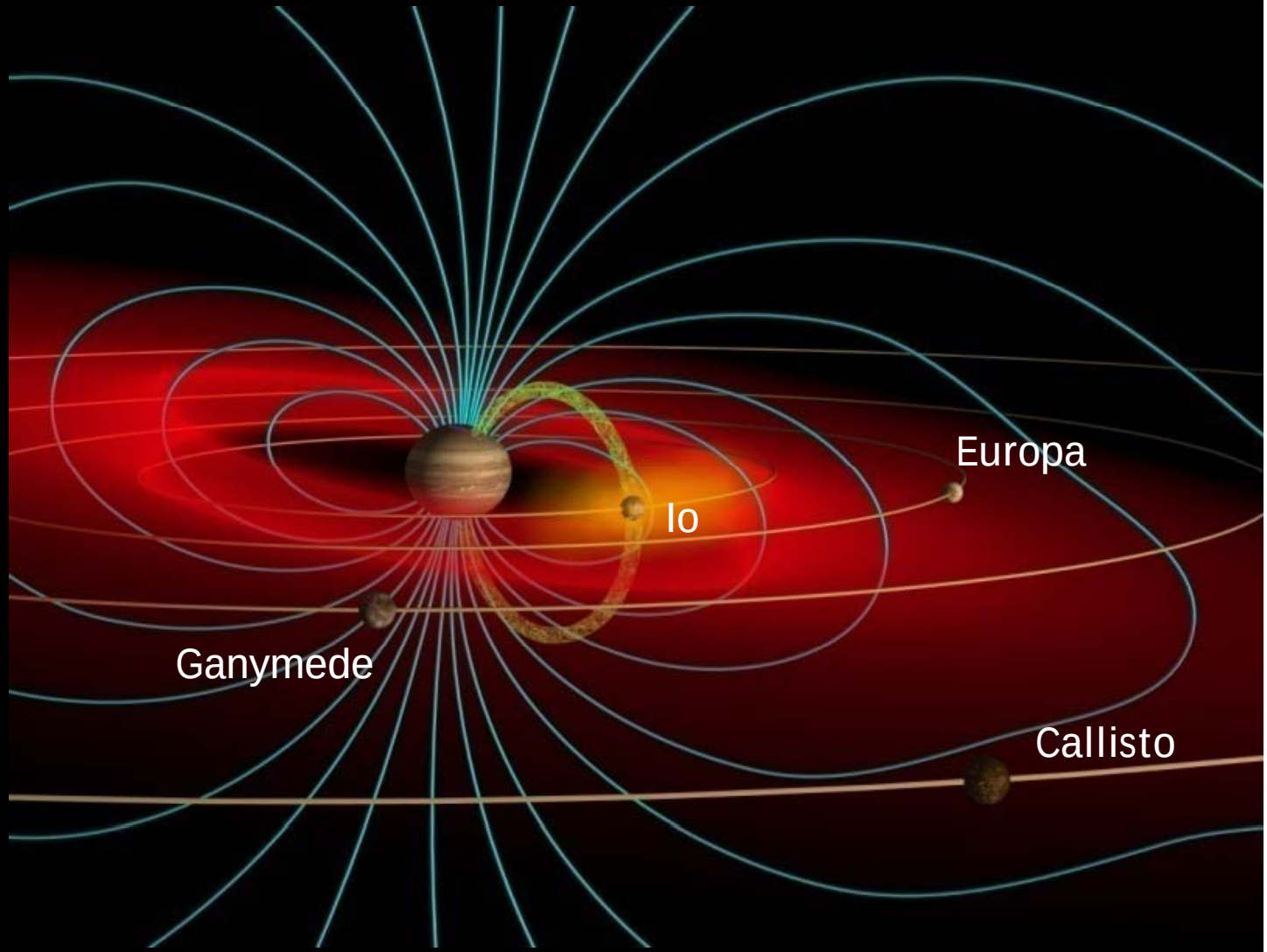
Introduction : The diverse Jupiter System



Introduction : The diverse Jupiter System

EJSM-Laplace

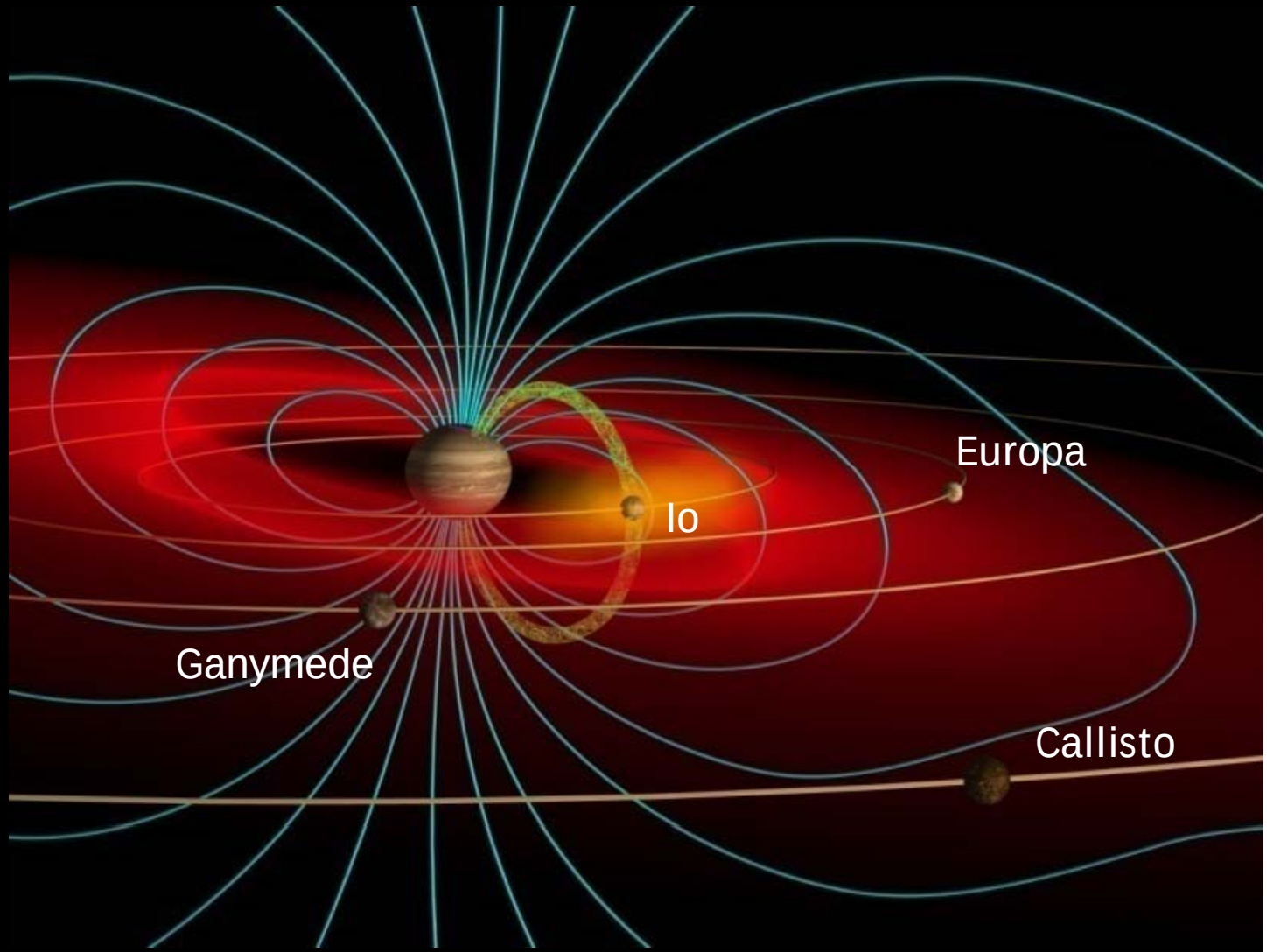
Largest planet with the largest magnetic field



Introduction : The diverse Jupiter System

Largest planet with the largest magnetic field

Most active atmosphere

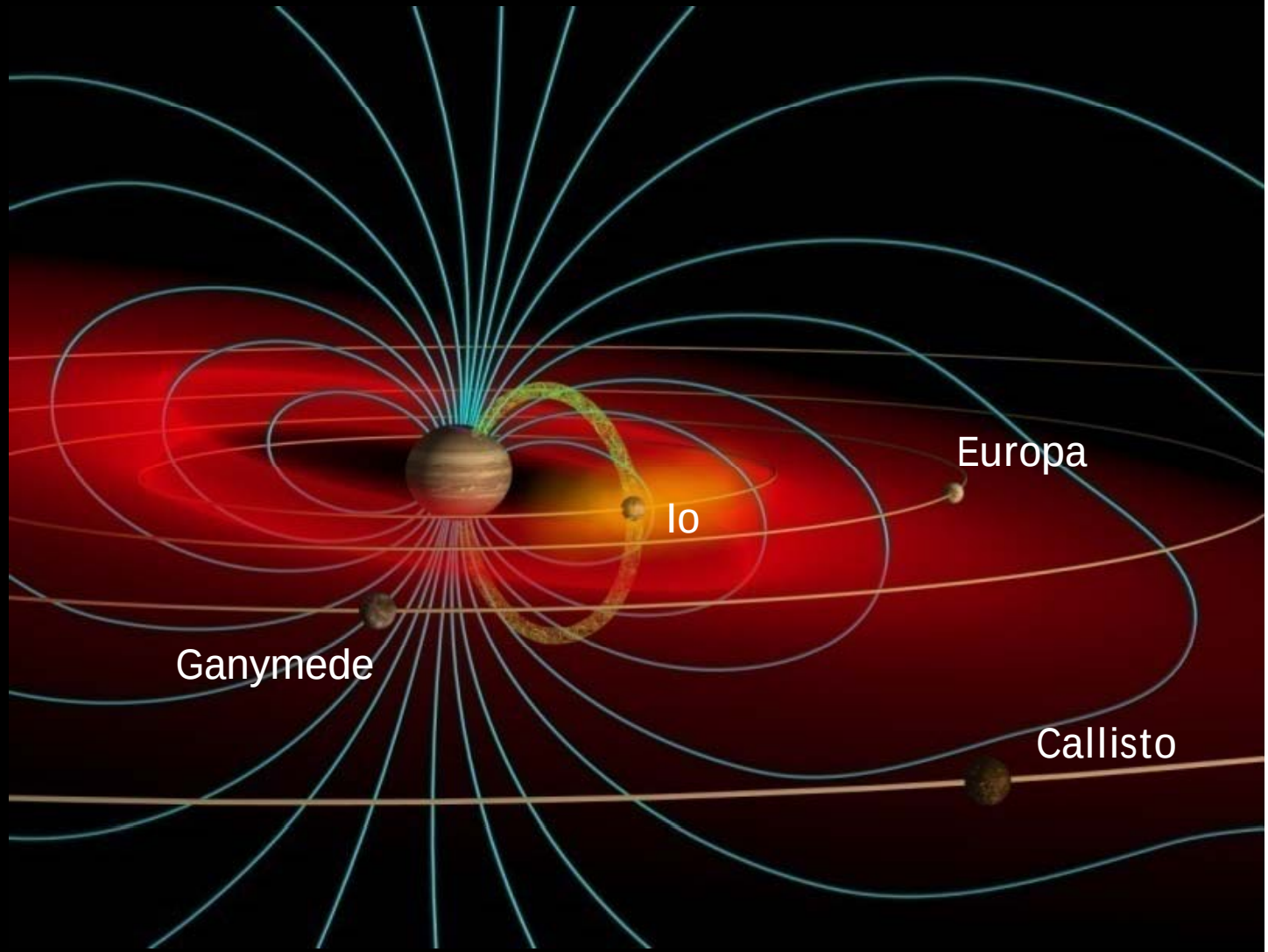


Introduction : The diverse Jupiter System

Largest planet with the largest magnetic field

Most active atmosphere

Most powerful and largest magnetosphere



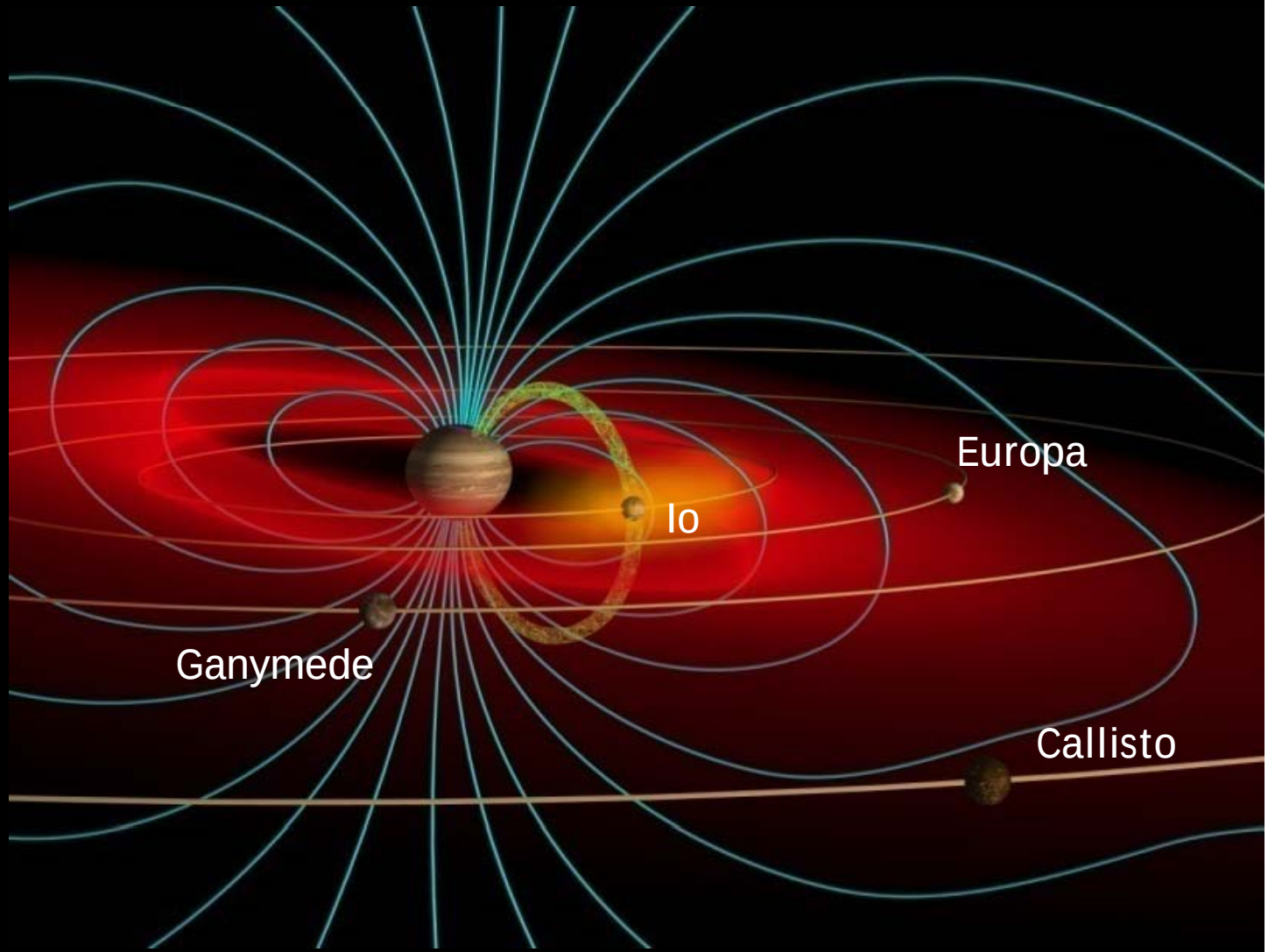
Introduction : The diverse Jupiter System

Largest planet with the largest magnetic field

Most active atmosphere

Most powerful and largest magnetosphere

63 moons, 4 large Galilean moons



Introduction : The diverse Jupiter System

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Most active atmosphere

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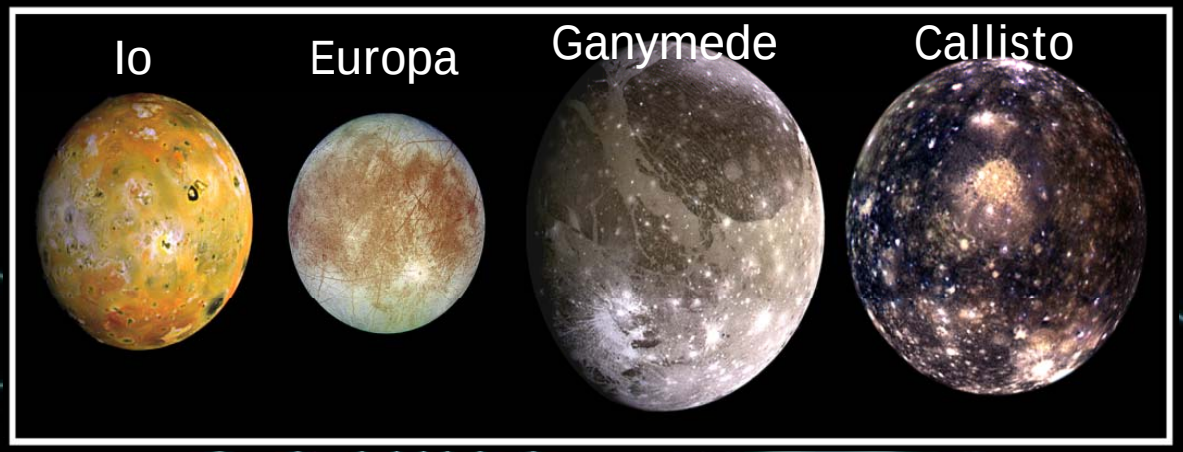
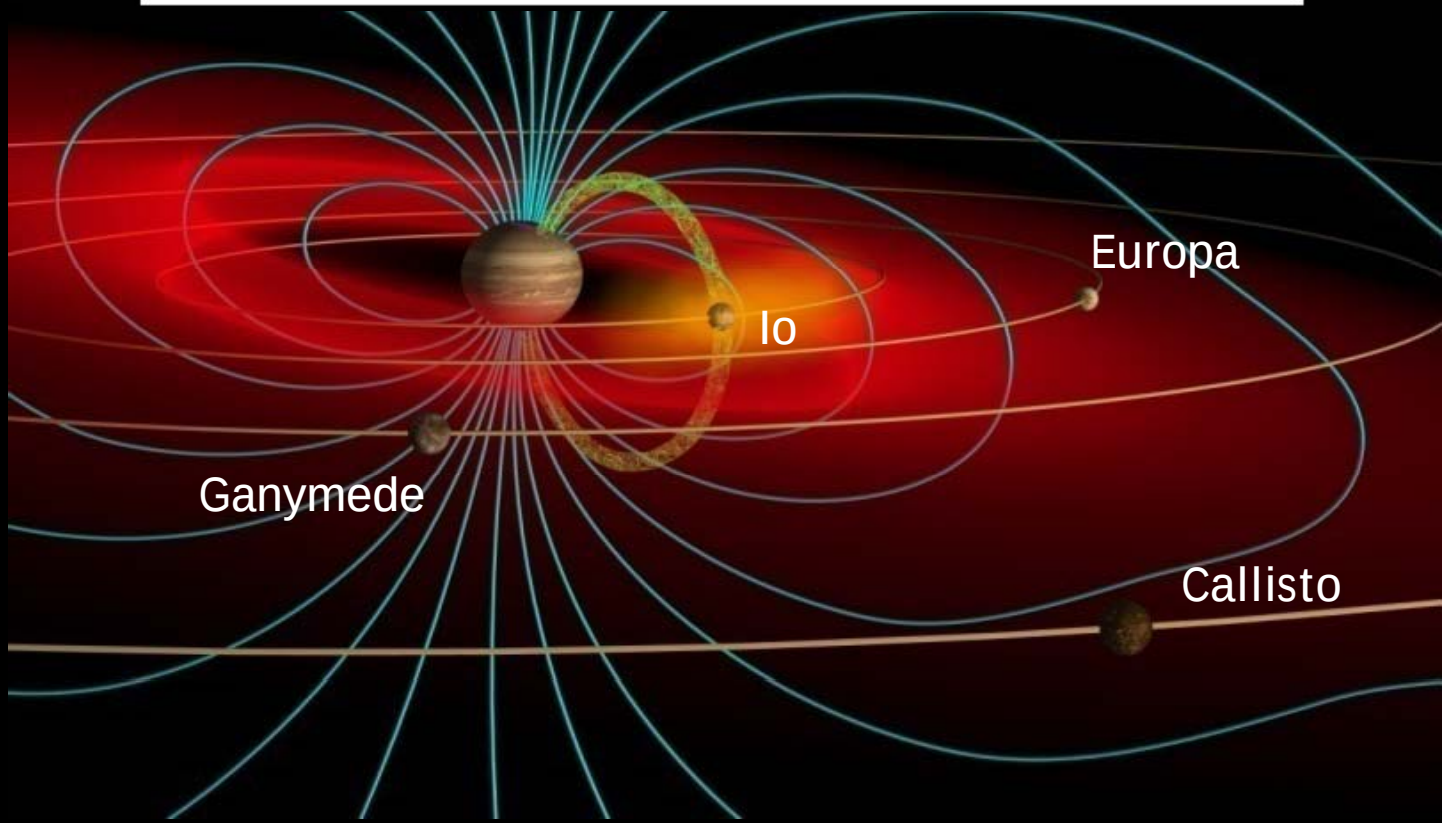
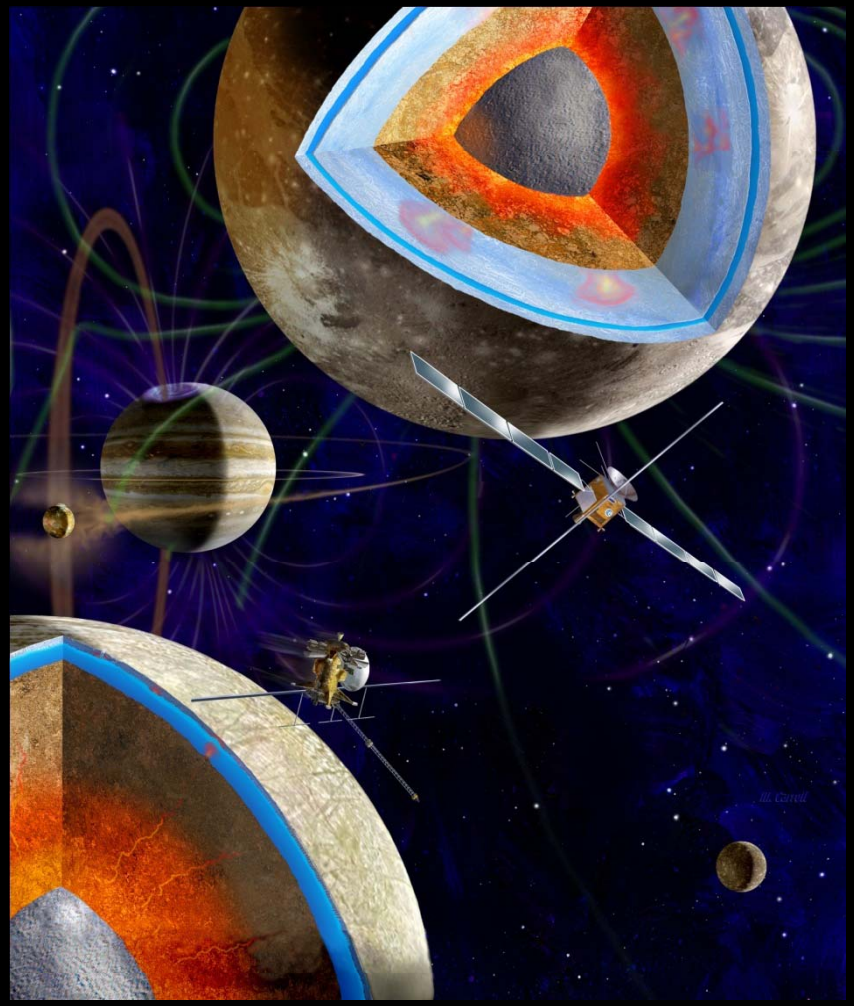






Previous studies:

- *ESA's Laplace proposal*
- *2 NASA studies*

Key Questions:

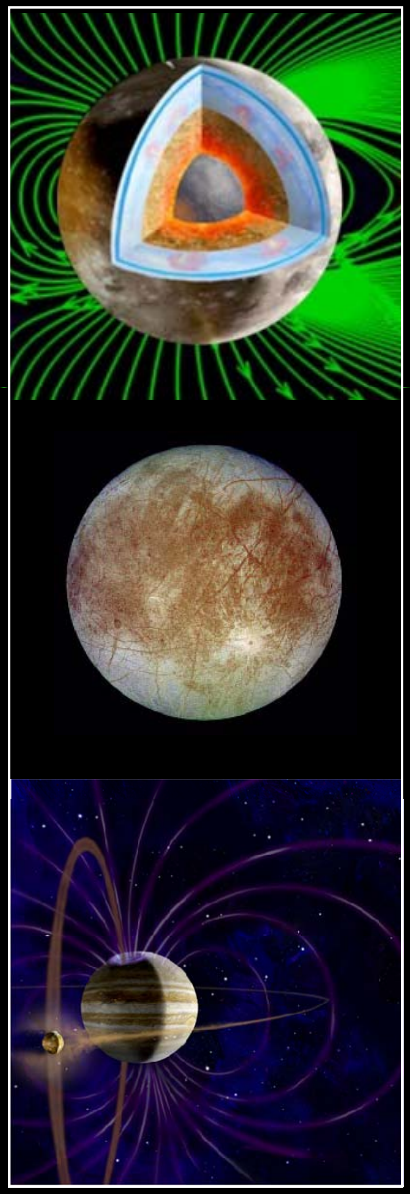
- Does the Jupiter system harbor habitable worlds?
- What are the processes operating within the Jupiter system?

EJSM-Laplace mission:

- Jupiter Ganymede Orbiter (JGO)
- Jupiter Europa Orbiter (JEO)

Introduction : Overarching Theme

The emergence of habitable worlds around gas giants



- **Ganymede (JGO-focus):** Characterise Ganymede as a planetary object including its potential habitability
- **Europa (JEO-focus):** Explore Europa to investigate its habitability
- **Jupiter System (JGO + JEO):** Explore the Jupiter system as an archetype for gas giants

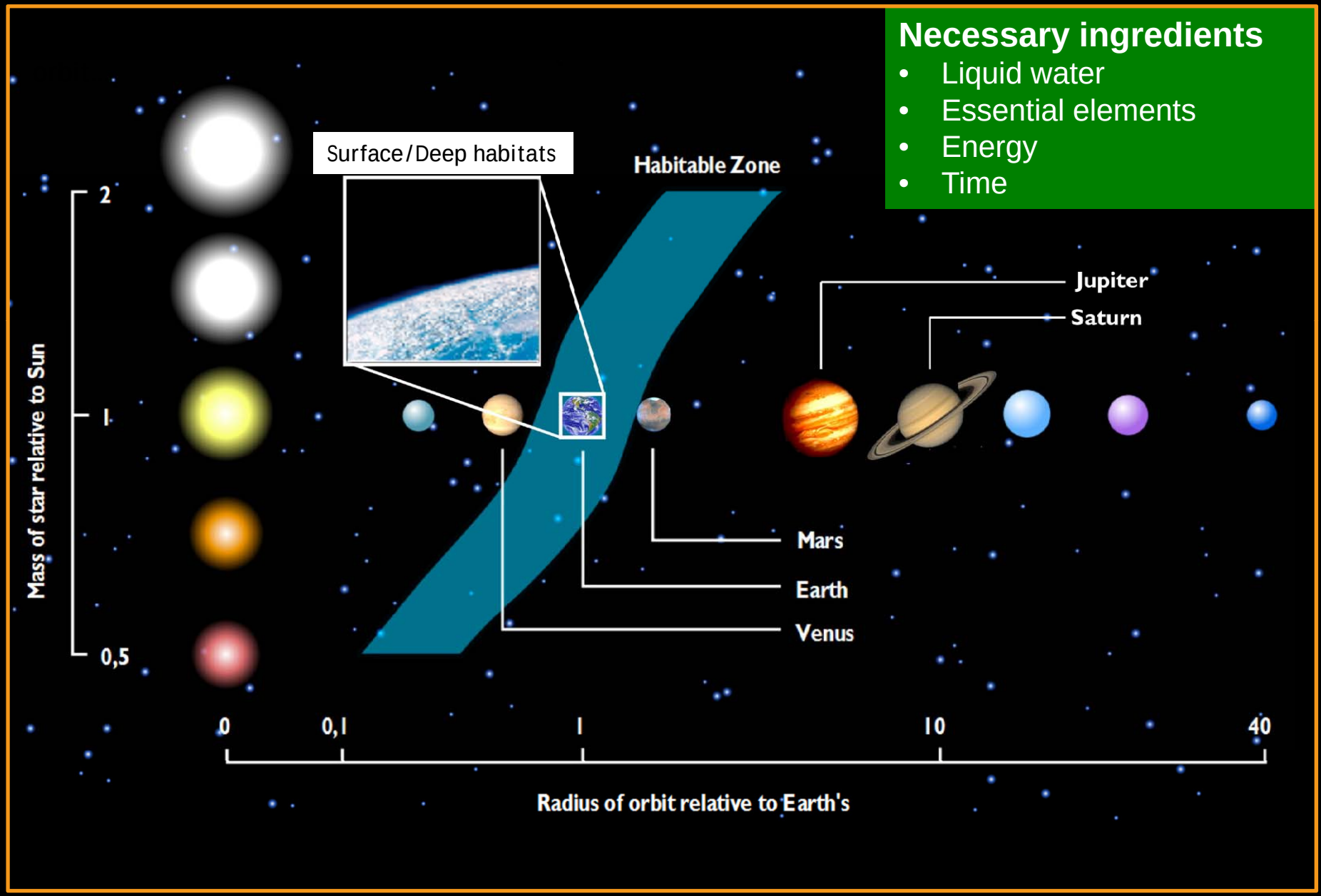
Introduction : Habitability of the icy moons

EJSM-Laplace

Are Ganymede and Europa potentially habitable worlds ?

Necessary ingredients

- Liquid water
- Essential elements
- Energy
- Time



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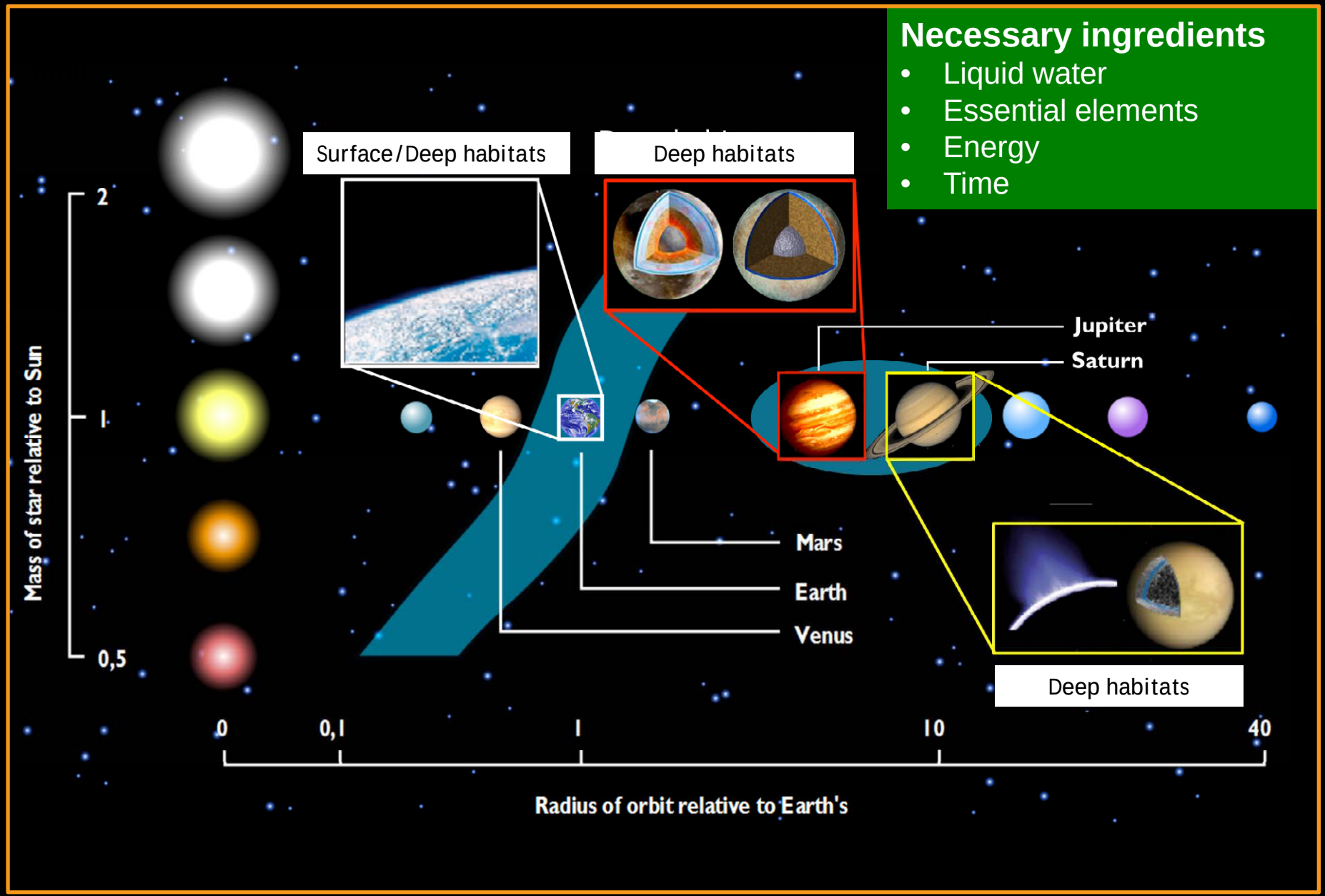
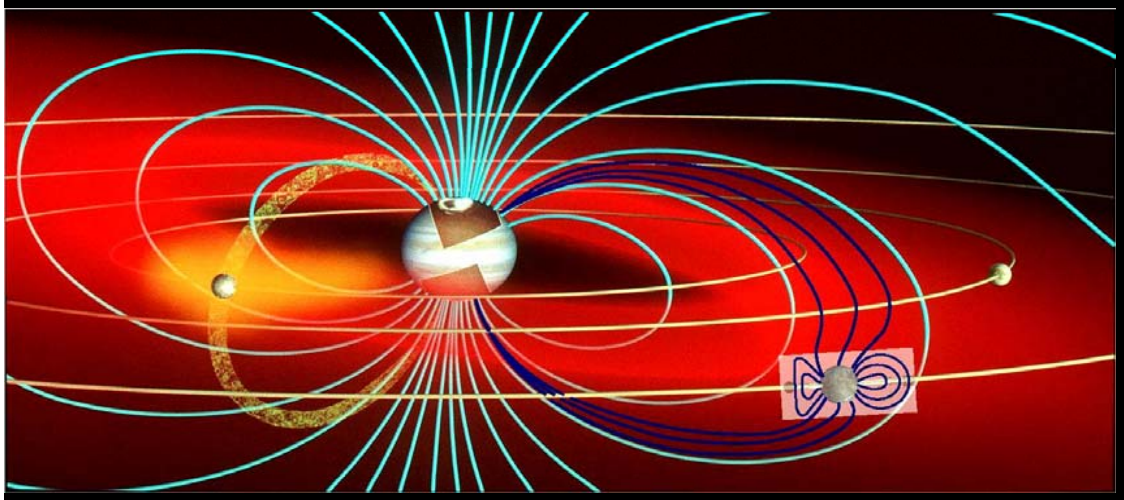


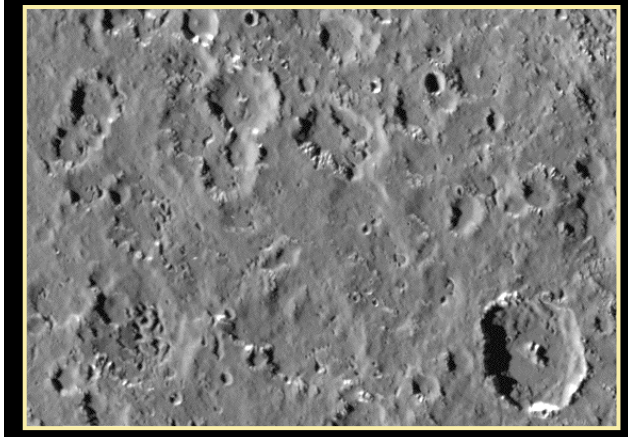
Introduction: Exploration of the Jupiter system

EJSM-Laplace

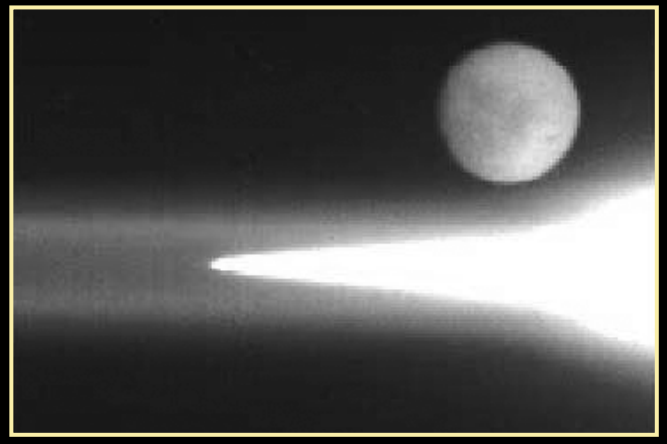


Jovian magnetosphere

Jovian atmosphere



Callisto



Rings & small satellites

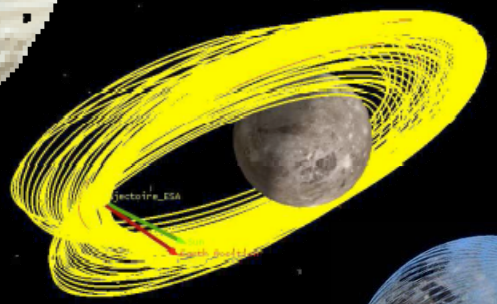
Io

The Jupiter system is rich in dynamic and coupled processes

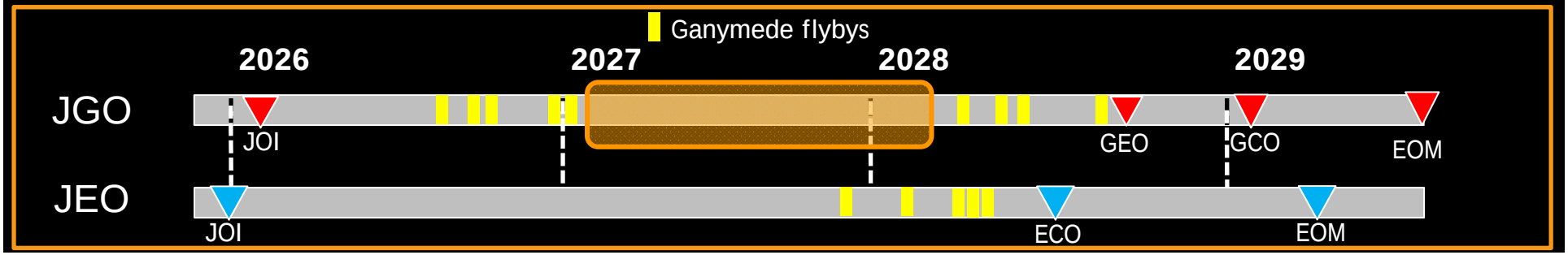
Introduction: Mission Timeline

EJSM-Laplace

- Jupiter system mission
- Including resonant orbits of Callisto
- Ganymede Elliptical Orbits (GEO)

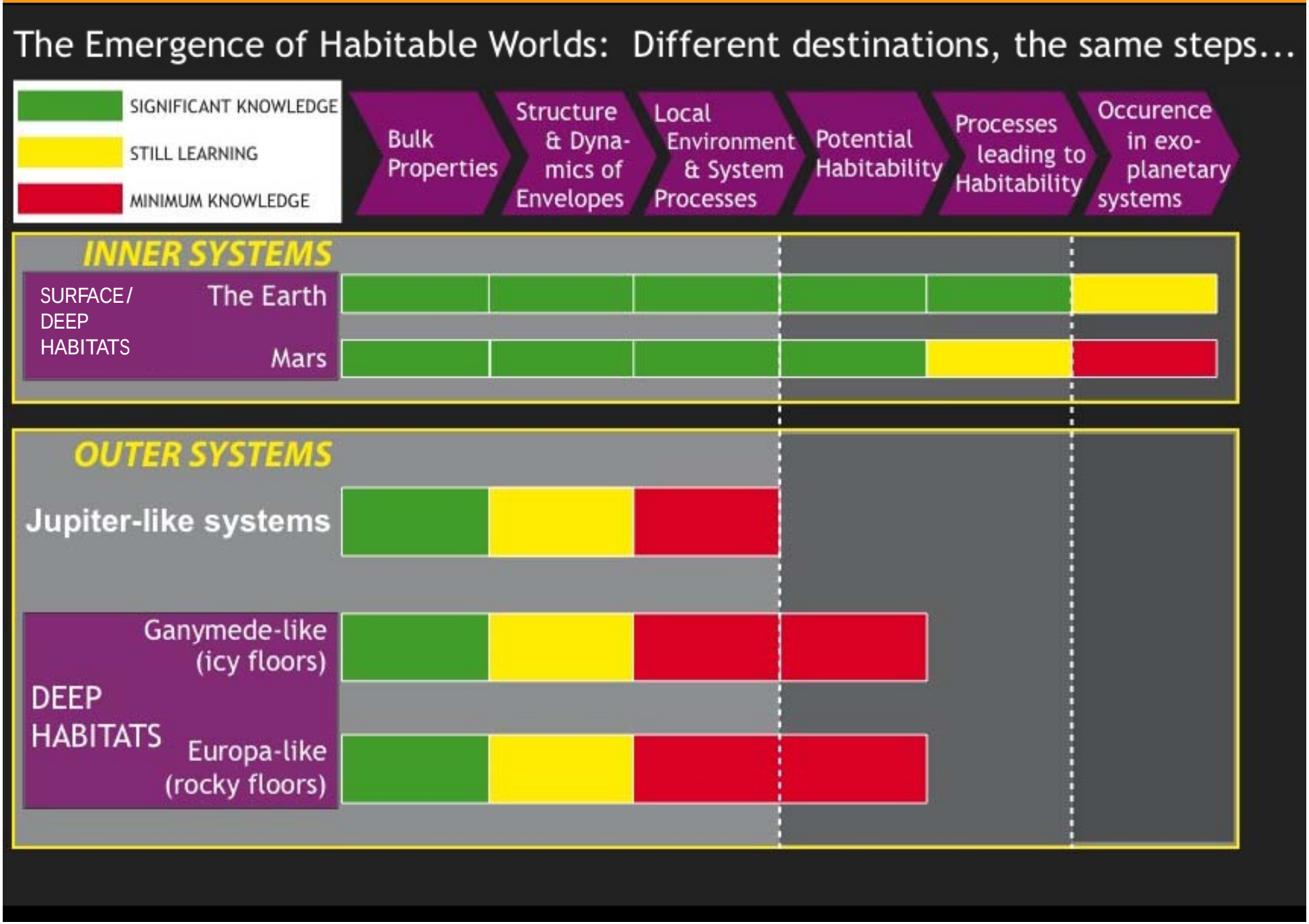


- Ganymede Circular Orbits (GCO)
  - ❑at 500km - 120 days
  - ❑at 200km – 60 days



Introduction : Our Knowledge

EJSM-Laplace



Introduction : Our Knowledge

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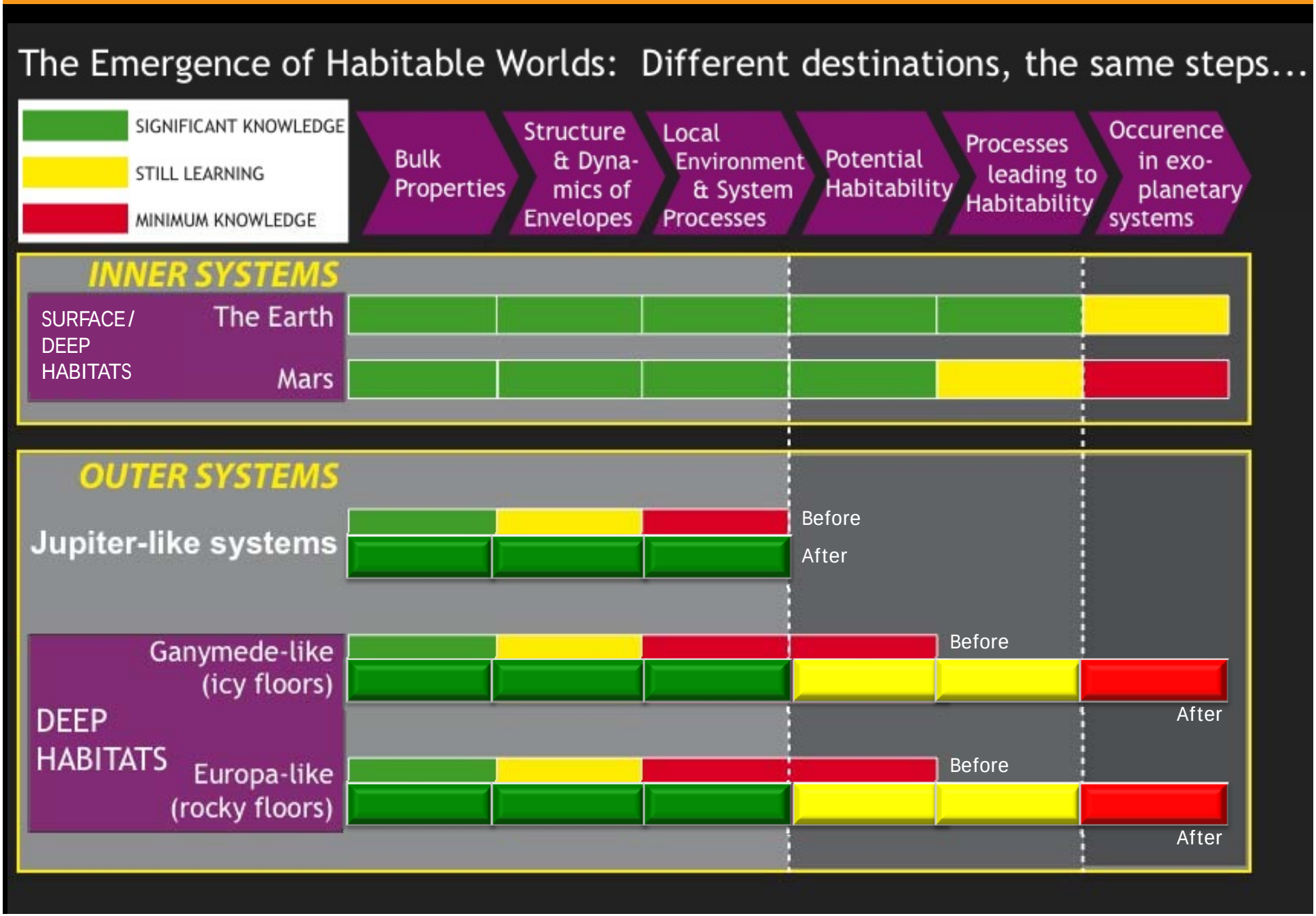


Ganymede & Europa exploration

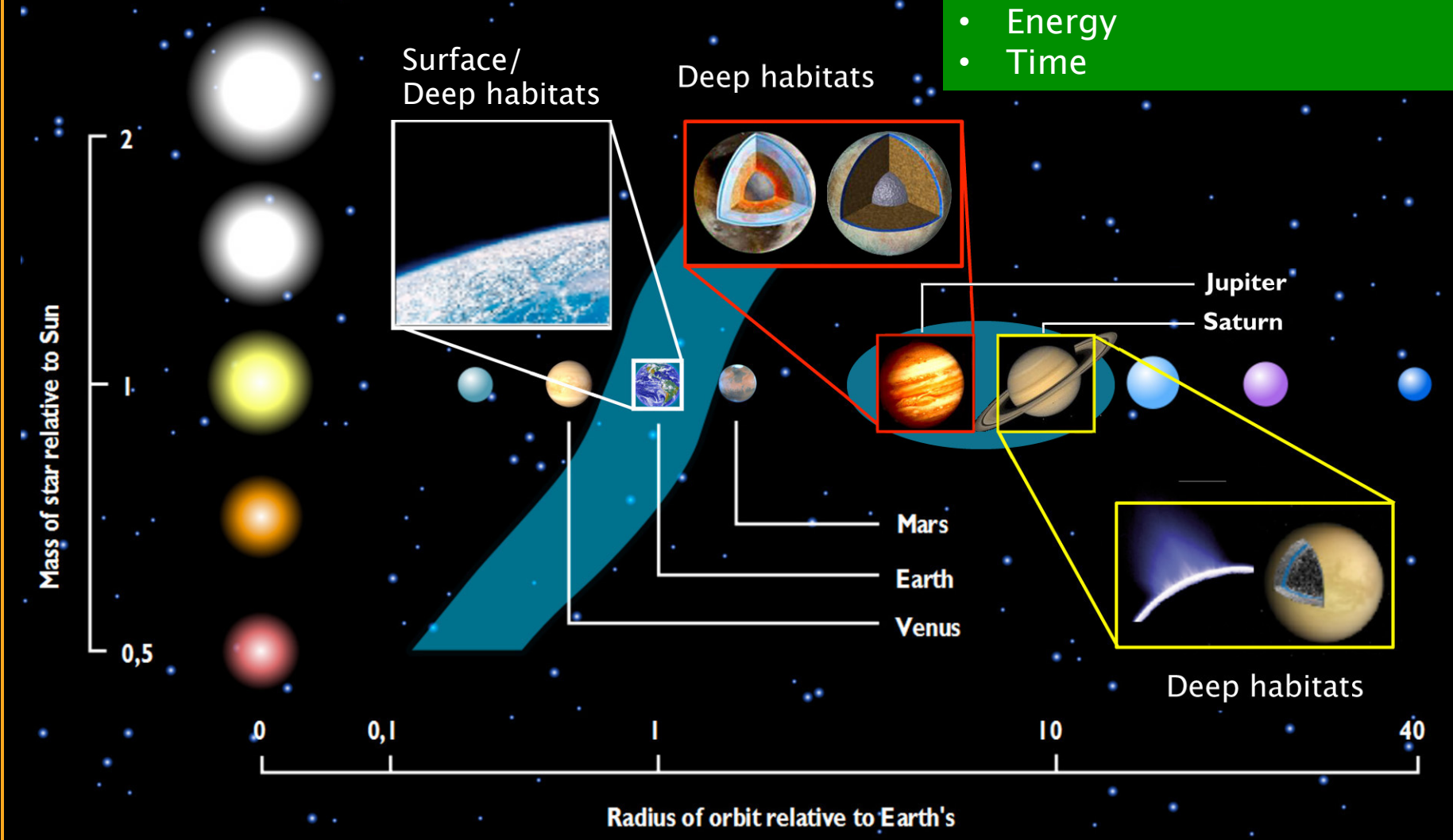
Olivier Grasset

Are Ganymede and Europa potentially habitable worlds ?

The habitable zone is not restricted to the Earth's orbit...

Necessary ingredients

- Liquid water
- Essential elements
- Energy
- Time



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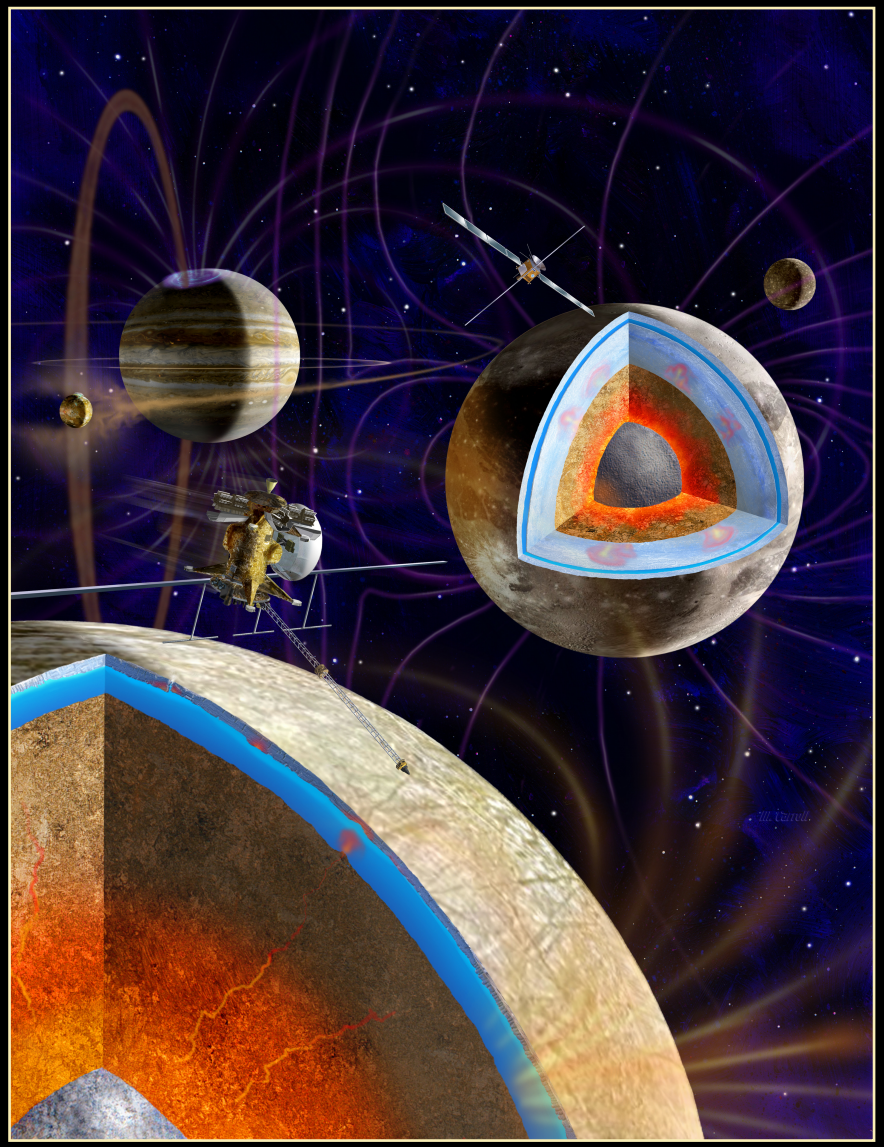


Necessary ingredients

- Liquid water
- Essential elements
- Energy
- Time

Ganymede

- Tenuous atmosphere
- Icy surface
- Two icy layers
- One liquid layer
- Silicates
- Iron core

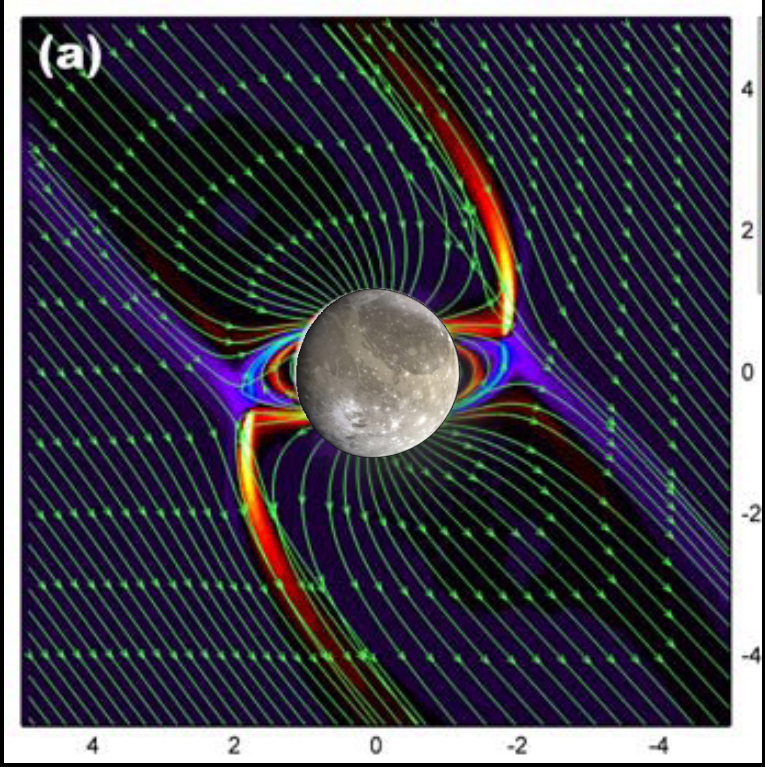
Europa

- Tenuous atmosphere
- Icy surface
- One icy crust
- One liquid layer
- Silicates
- Iron core

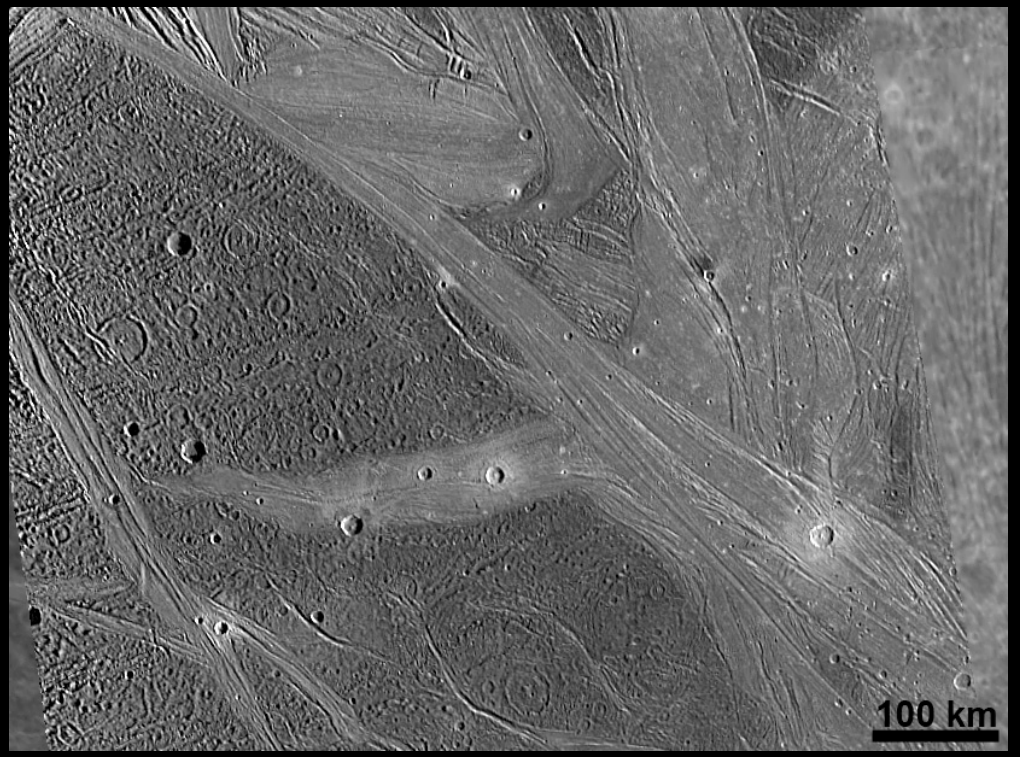
Galileo evidences of liquid layers

Induced magnetic field

Marginally demonstrated but more data needed



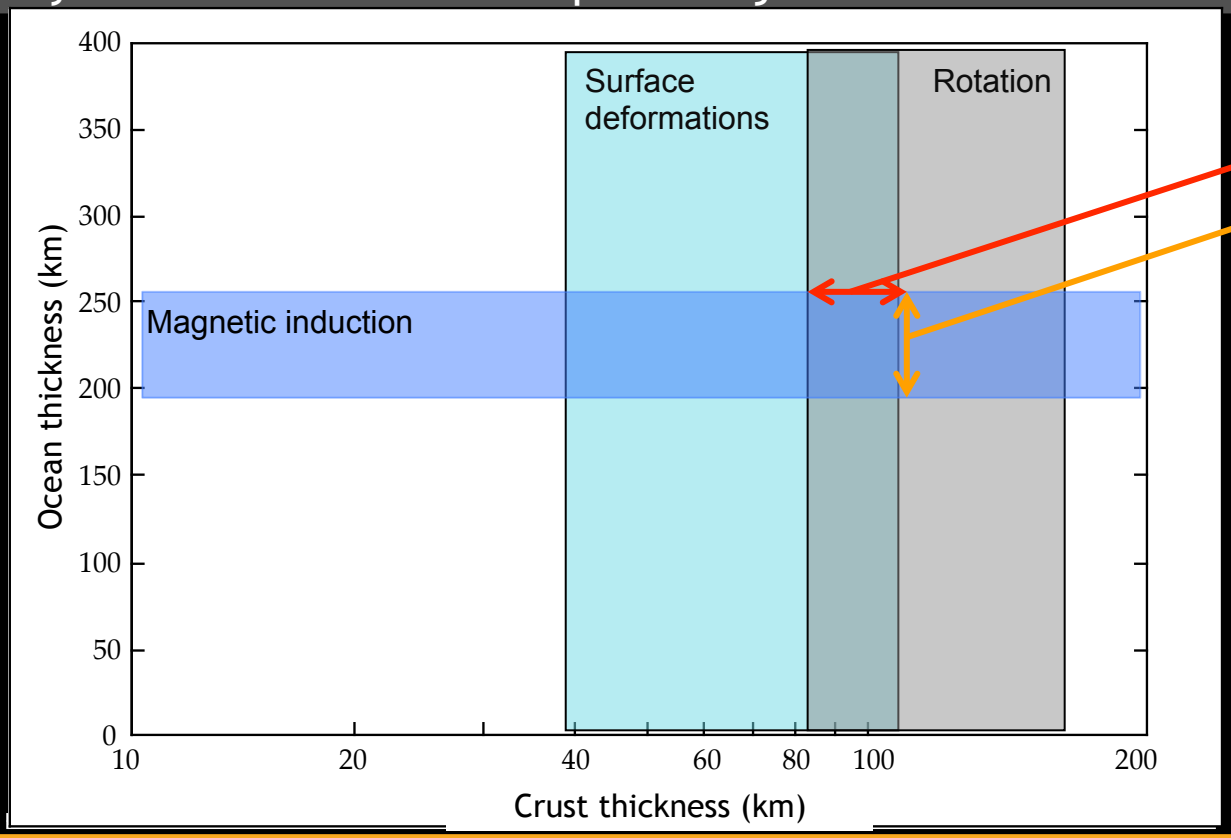
Geologic activity



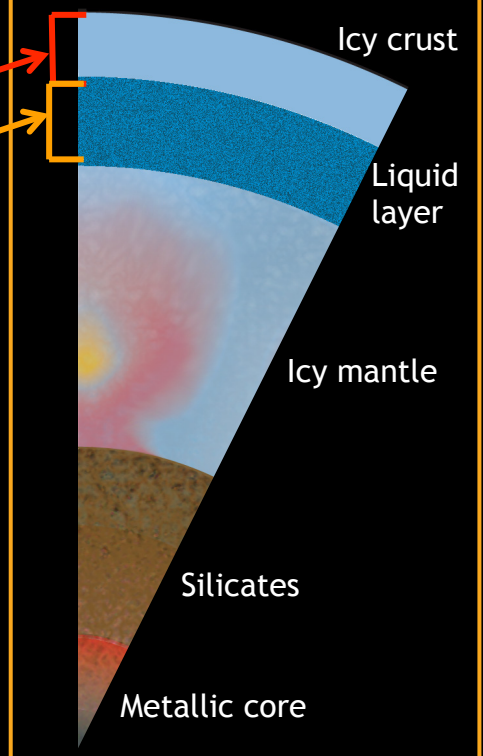
Science questions

- ✧ Existence of a liquid layer
- ✧ Location and size

Ganymede's ocean: EJSM-Laplace objectives



Internal structure



JGO measurements

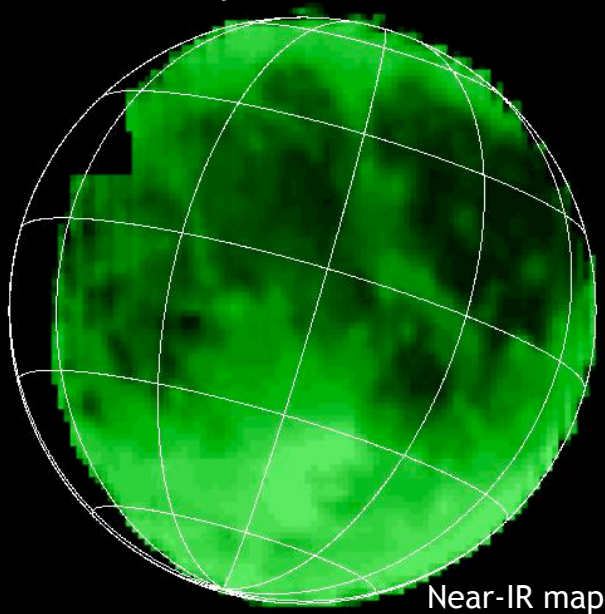
- Surface deformations
- Rotation
- Magnetic induction

Instrument Packages

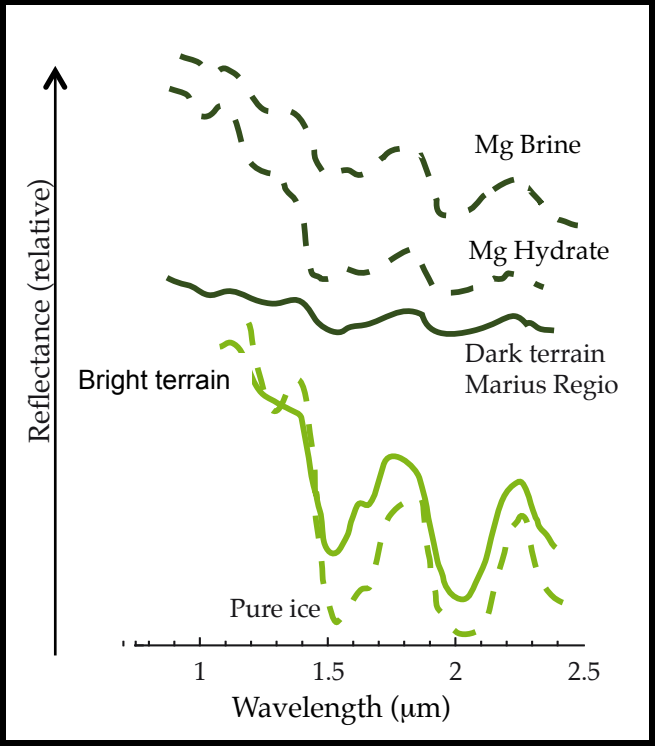
- In situ Fields and Particles
- Imaging
- Sounders and Radio Science

Galileo evidences of an outstanding complexity

Complex chemistry



Near-IR map of Ganymede

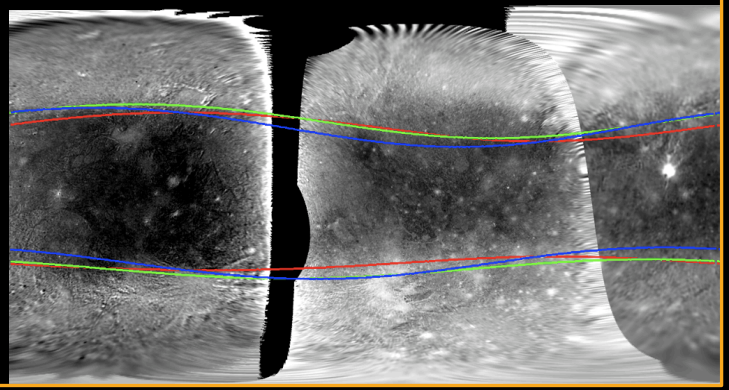


Frozen brines and hydrates ?

Complex dynamics

Specific albedo distribution

Important exogenic contribution

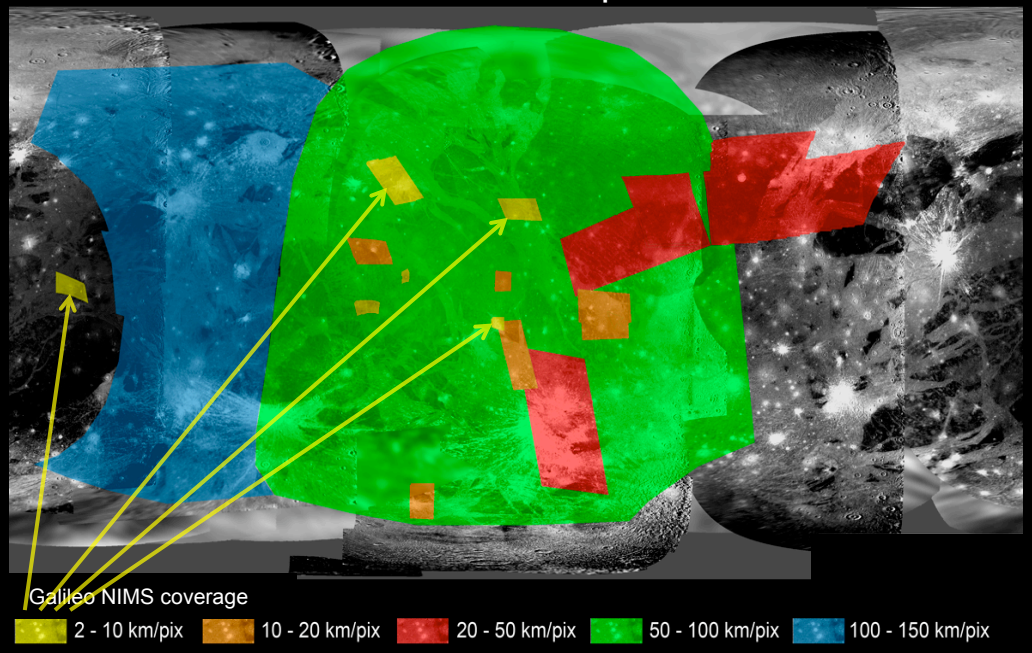


Science questions

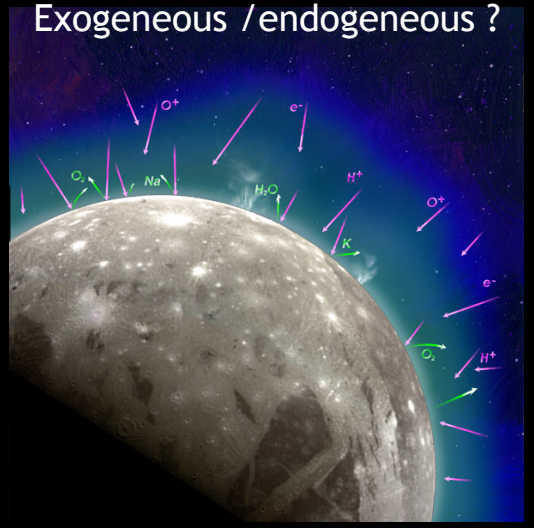
- ✧ Nature of non-ice compounds
- ✧ Surface / sub-surface correlation
- ✧ Endogeneous/exogeneous contribution

Surface composition: EJSM-Laplace objectives

What are the surface chemical compounds ?



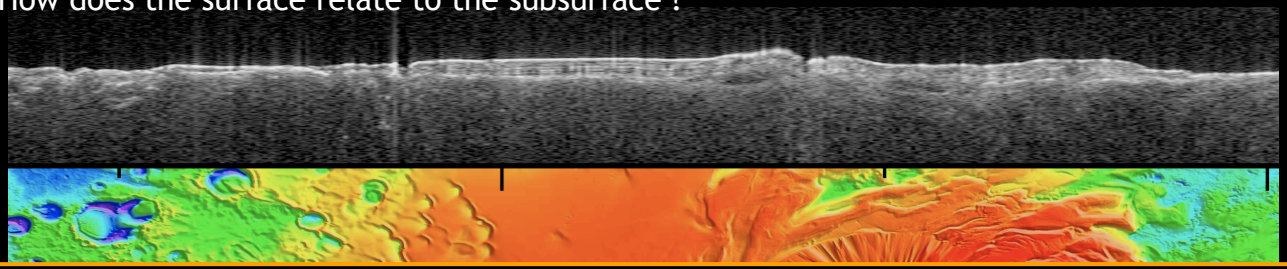
Exogeneous /endogeneous ?



Volatiles

Ions and Neutrals

How does the surface relate to the subsurface ?

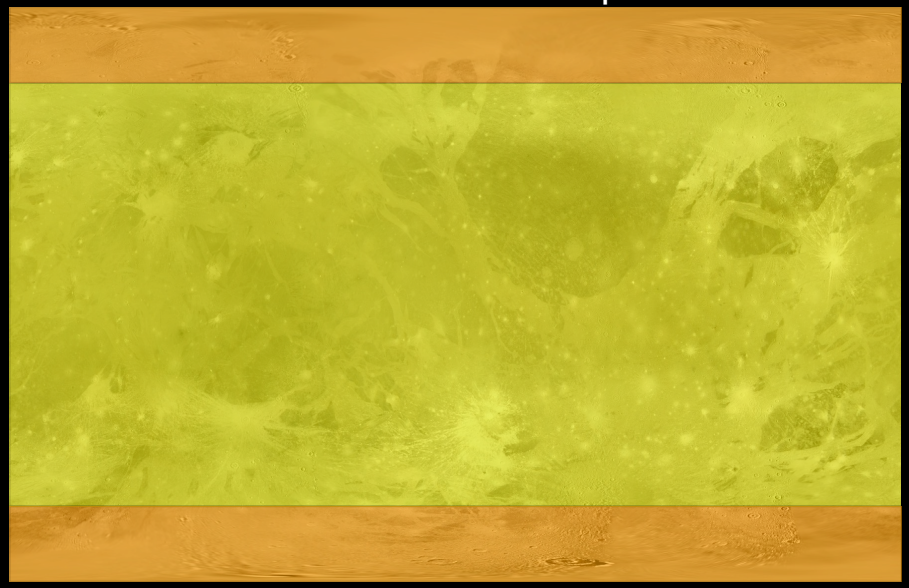


Instrument Packages

- Spectroscopy
- Imaging
- In situ Fields and Particles
- Sounders

Surface composition: EJSM-Laplace objectives

What are the surface chemical compounds ?

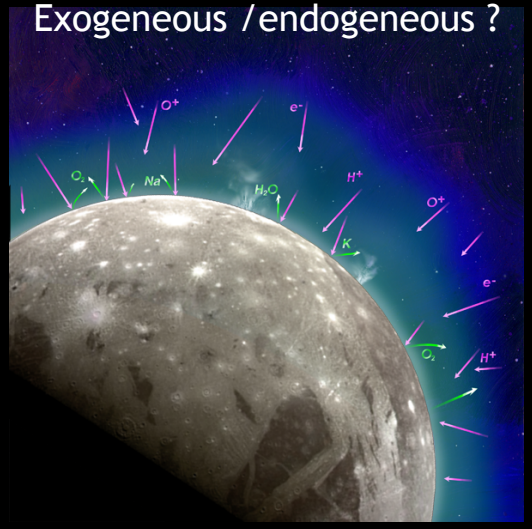


Imaging spectroscopy

Spatial coverage
- Global at a few km/px
- 100 m/px on a few %
- 10 m/px where needed

Spectral coverage
- > 5 times better than Galileo NIMS
- Close to lab data quality when needed

Exogeneous /endogeneous ?



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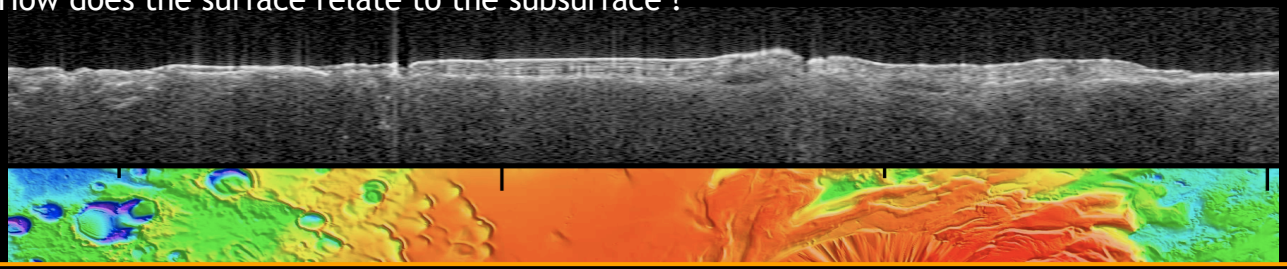

Instrument Packages

- Spectroscopy
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- In situ Fields and Particles
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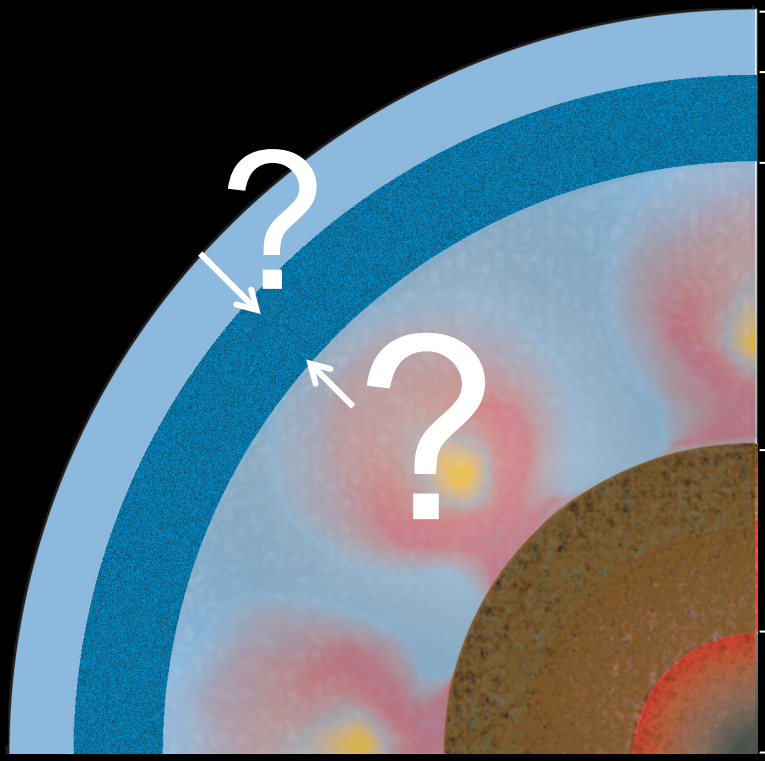
What are the energy sources?



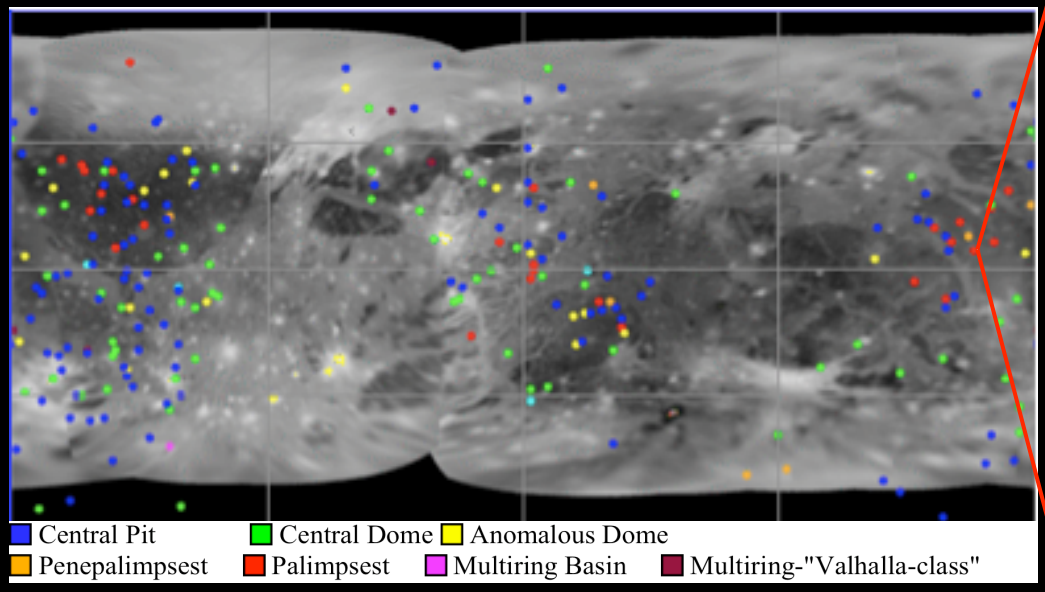
	External sources	Internal sources		
	Impactors	Tidal	Radiogenic	Secular
Ice crust	■	■		
Liquid layer		■		
Icy mantle		■		■
Silicates			■	■
Metallic core				■

Science questions

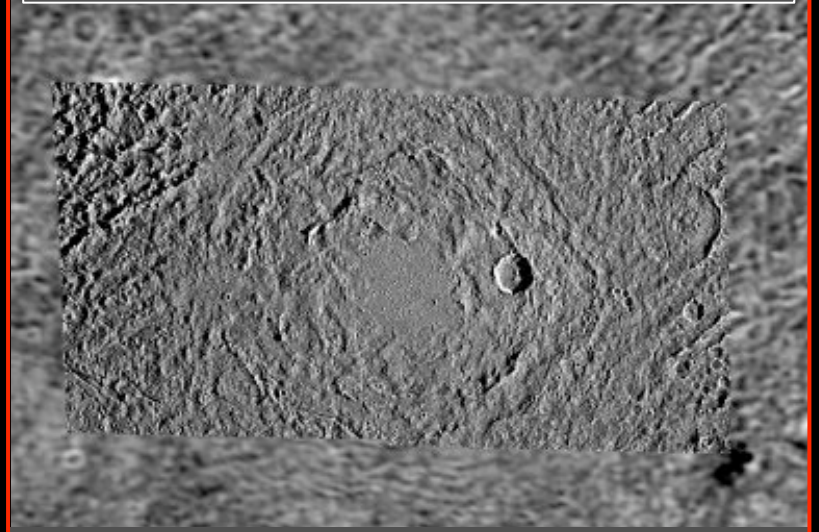
- ✧ Impacts: description, processes, chronology
- ✧ Internal structure: investigation, implications
- ✧ Energy transfer to the habitable zone

Impact cratering: description, processes, chronology

Ganymede possesses the widest range in crater morphology



Analysis requires high-resolution imaging



Palimpsest example: Buto Facula - SSI - 180 m/px

JGO measurements

- Global imaging at 200-400 m/px
- High Resolution target areas (5-50 m/px)
- Compositional relationships
- Subsurface exploration

Instrument Packages

- Imaging
- Spectroscopy
- Sounders

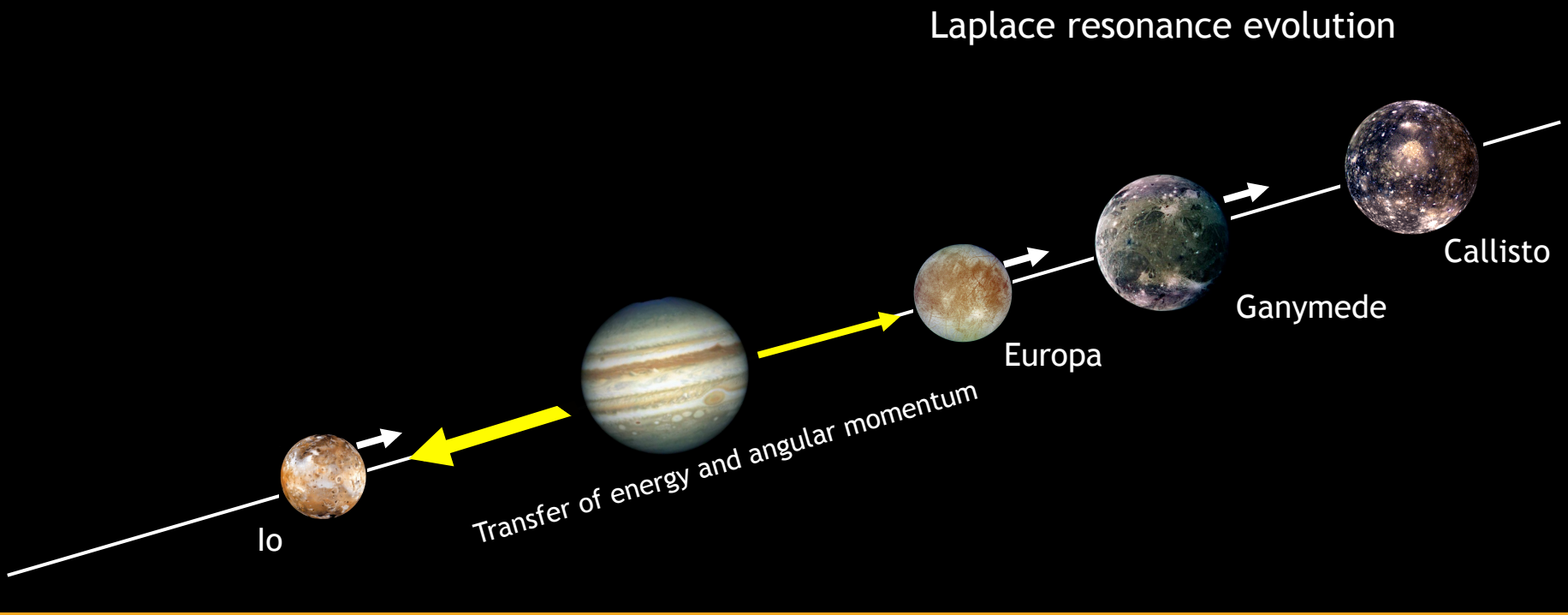
Energy for deep habitats ?

- Induced magnetic field + Surface motions → Icy crust and sub-surface ocean
- Degree 2 g-field + tidal motions → Density profile and equilibrium state
- High degree g-field → Density anomalies
- Intrinsic magnetic field → Metallic core properties

Instrument Packages

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

How stable are the present habitats ?



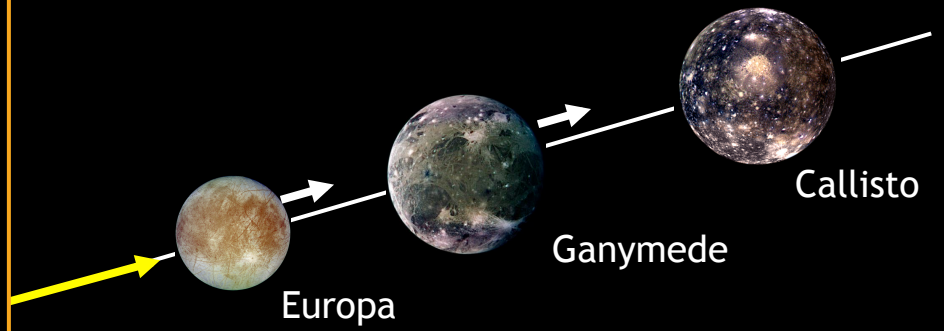
Science questions

✧ System stability: Laplace resonance

How stable are the present habitats ?

Geology as a witness of moon's evolution

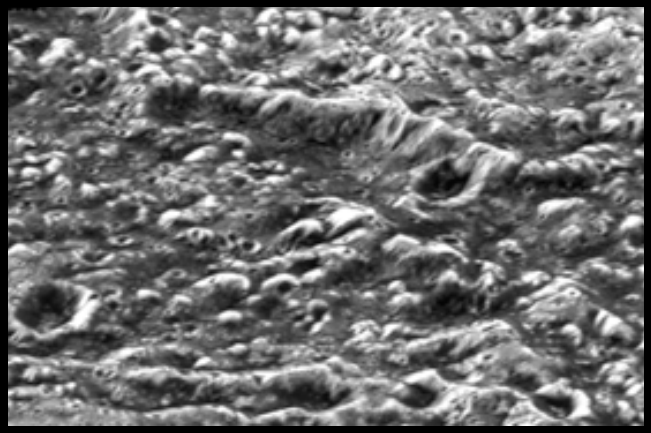
Laplace resonance evolution



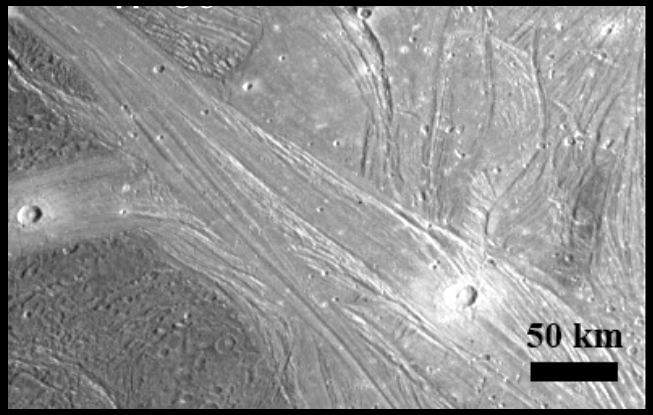
Science questions

- ✧ System stability: Laplace resonance
- ✧ Moons' histories: Geologic evidences

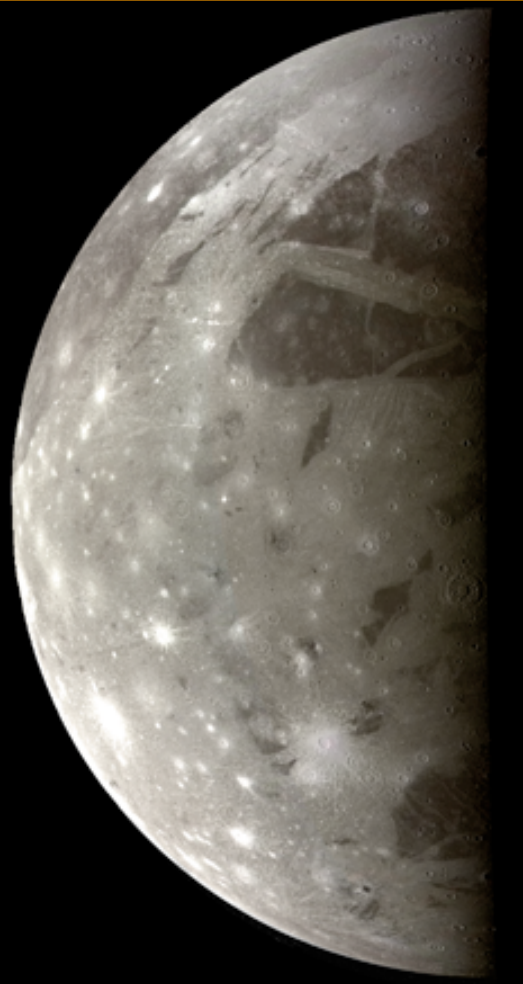
Stability of the habitats: geology as a witness of moon's activity



Dark terrain: ancient surface; furrow tectonics



Bright terrain: Rift-like tectonism, icy volcanism



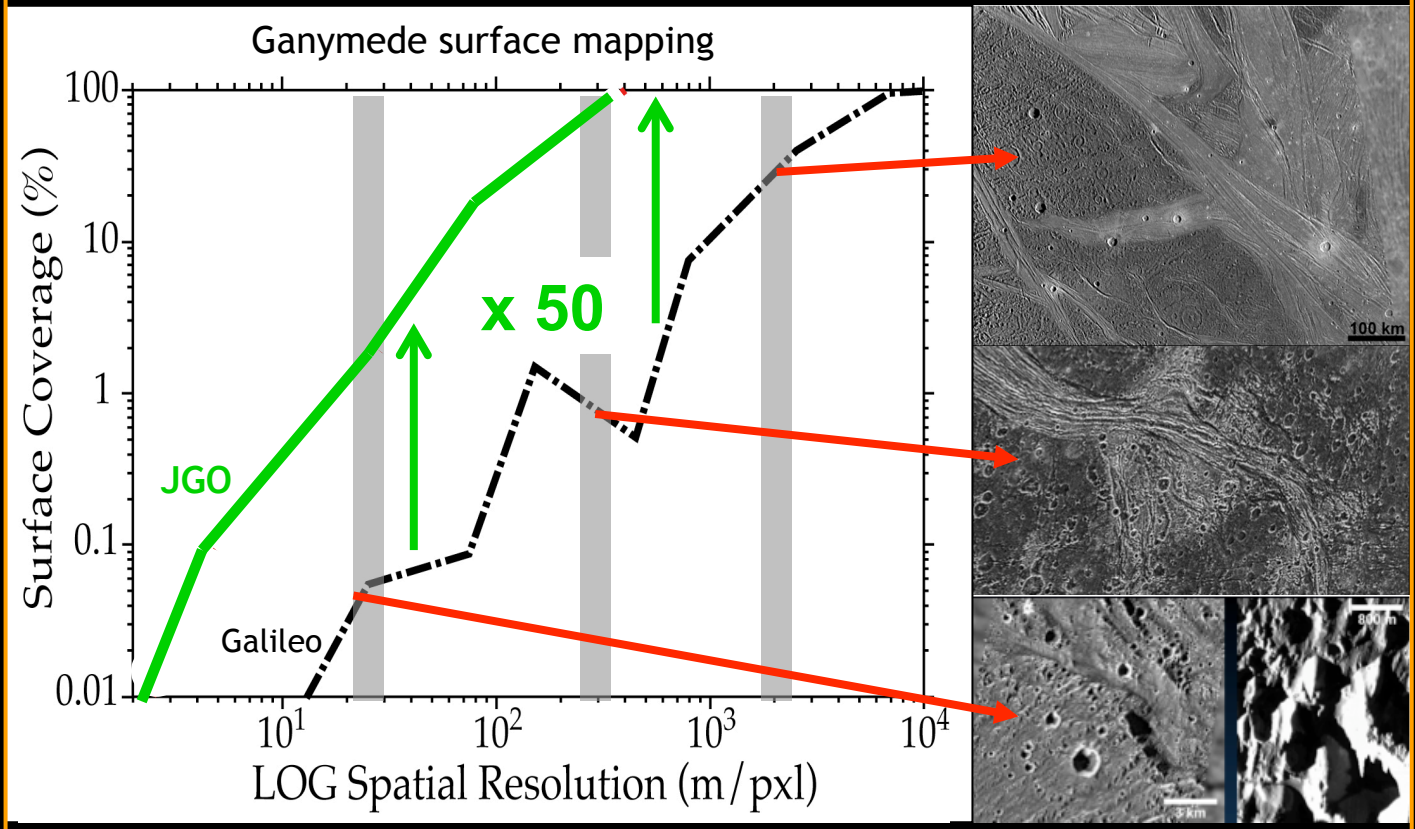
JGO measurements

- Global imaging at 200-400 m/px
- High Resolution target areas
- Topography/ morphology
- Subsurface exploration
- Compositional relationships

Instrument Packages

- Imaging
- Spectroscopy
- Sounders

Stability of the habitats: geology as a witness of moon's activity



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Instrument Packages

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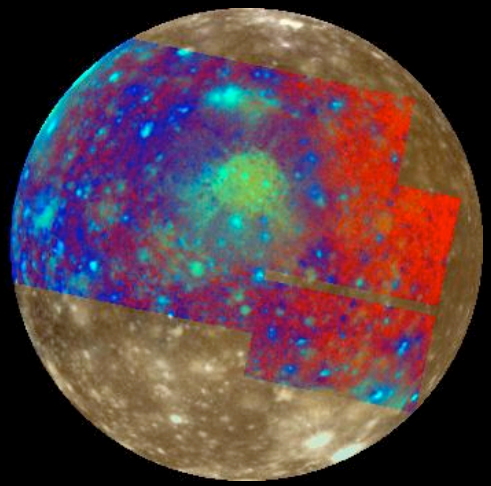
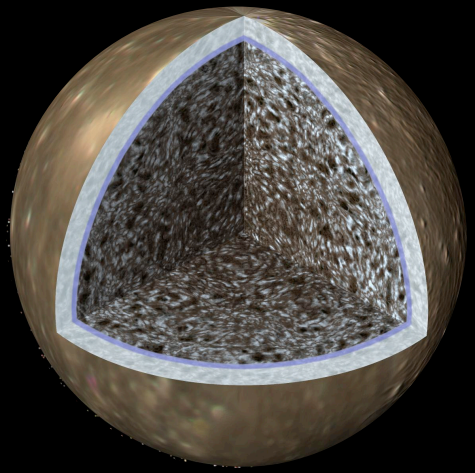
Callisto: a witness of early ages

Oldest surface of the system

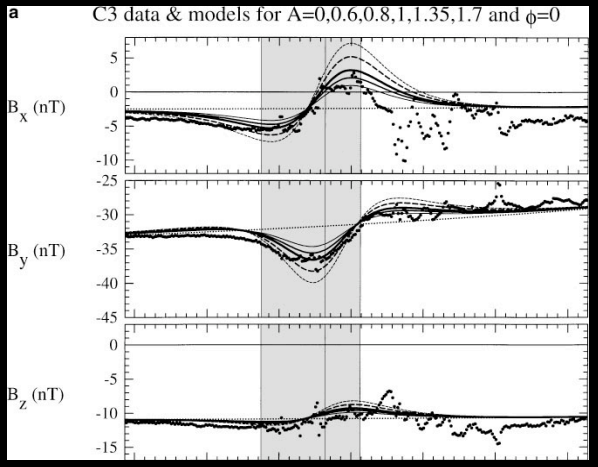
Complex chemistry



Not totally differentiated



An induced magnetic field

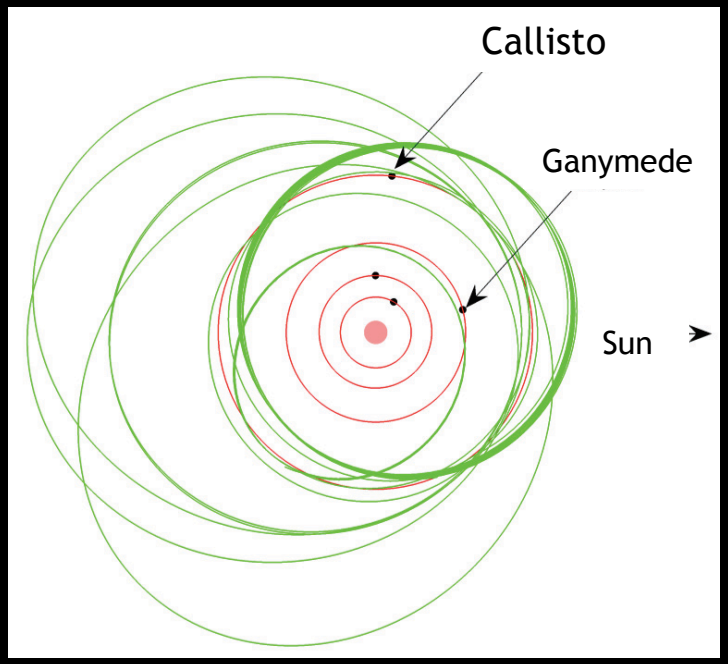


Science questions

- Presence and extent of a subsurface ocean
- Degree of differentiation
- Cratering record and early geological history
- Surface composition including organics and carbon dioxide

The oldest surface of the jovian system will be deciphered

Callisto phase

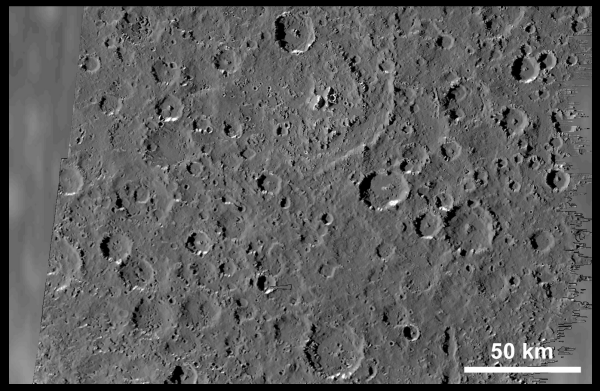


Mission profiles

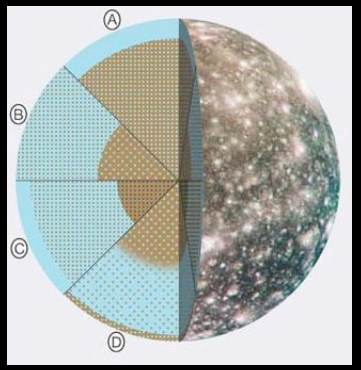
- Dedicated close flybys for JGO
- Close flybys opportunities for JEO
- JGO / JEO complementarities

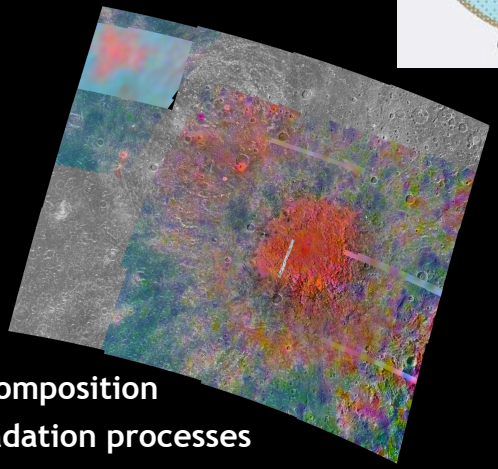
Science objectives

Cratering record and early geological history

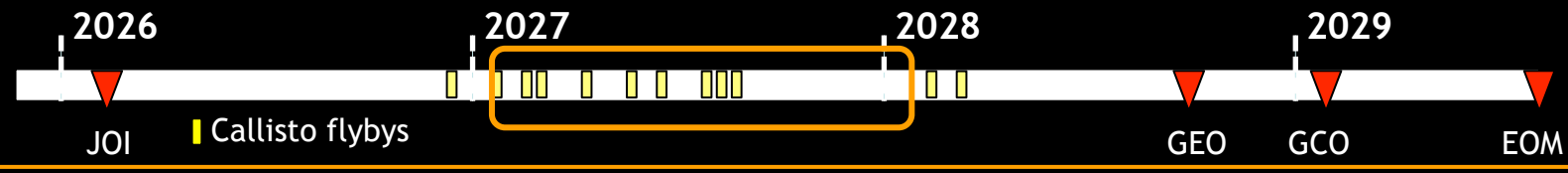


Structure and internal differentiation





Surface composition and degradation processes



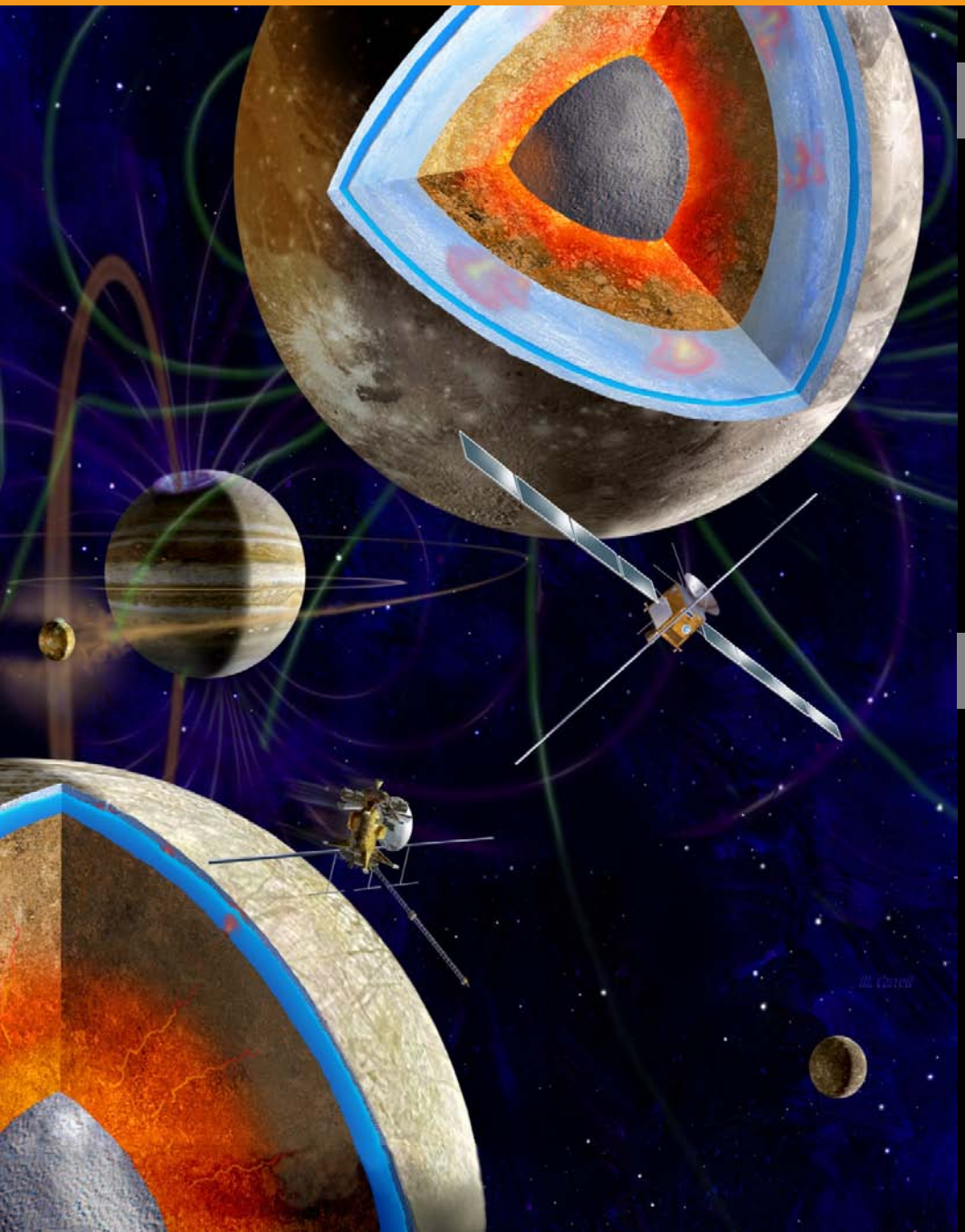
From the objectives to the measurements

	INSTRUMENT	LIQUID	CHEMISTRY	ENERGY	TIME
In situ Fields and Particles	Magnetometer (MAG)	X	X		
	Radio and Plasma Wave Instr. (RPWI)	X	X		
	Particle and Plasma Instr.– Ion Neutral Mass Spectr. (PPI-INMS)	X	X		
Imaging	Narrow Angle Camera (NAC)	X	X	X	X
	Wide Angle Camera (WAC)	X	X	X	X
Spectroscopy	Visible Infrared Hyperspectral Imaging Spectrometer (VIRHIS)		X	X	X
	UV Imaging Spectrometer (UVIS)		X	X	
	Sub-mm Wave Instrument (SWI)		X		X
Sounders & Radio Science	Laser Altimeter (LA)	X		X	X
	Ice Penetrating Radar (IPR)		X	X	X
	Radio Science Instrument (JRST+USO)	X		X	X

Jupiter System

Emma Bunce

The Jupiter System



The Jupiter system

Archetype for gas giants

Solar system in miniature

Paradigm for exoplanetary systems

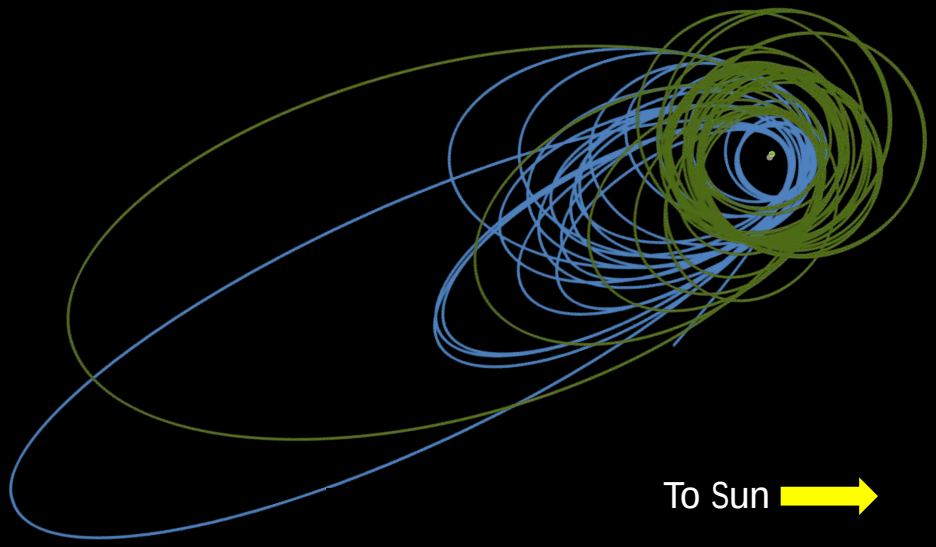
EJSM-Laplace represents…

FIRST two-spacecraft mission to a gas giant system

Significant advance in our knowledge

A major opportunity for complementary and synergistic science

Complementary and Synergistic Science: Where JEO and JGO unite



Complementary – two spacecraft extend the coverage of the system

✓ two spacecraft in orbit around Jupiter and/or a moon at the SAME TIME

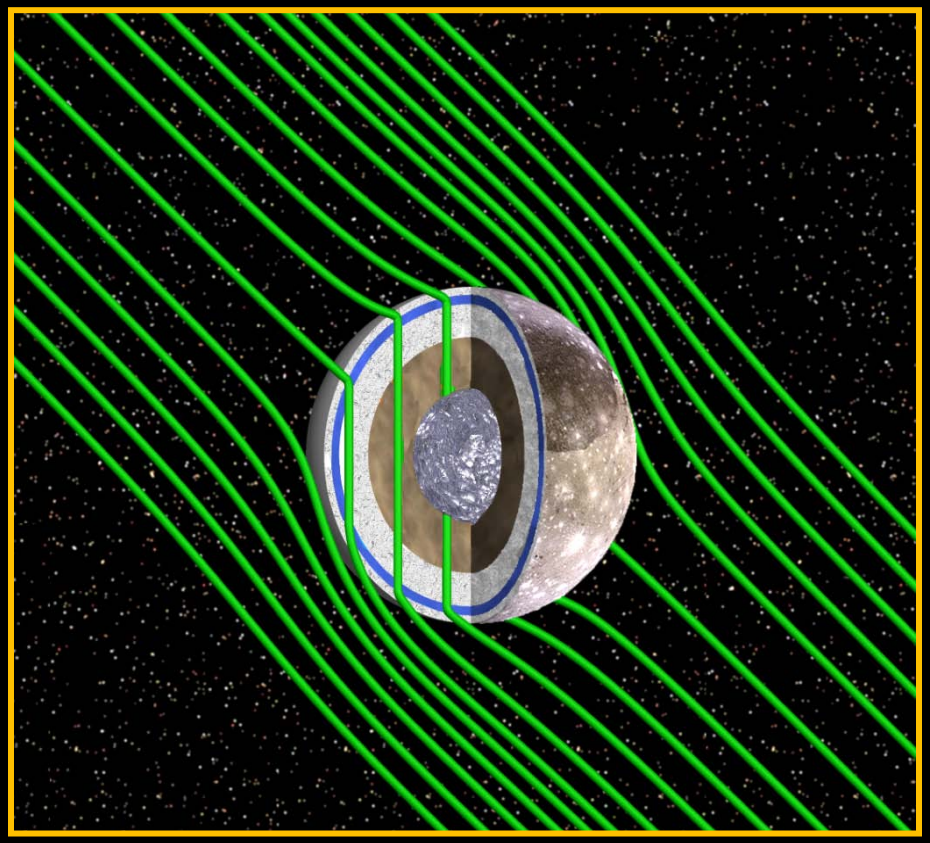
✓ trajectory of two spacecraft extends coverage in LOCAL TIME/LATITUDE

Synergistic – two spacecraft together provide new opportunities

✓ spacecraft-to-spacecraft link provided by receiving capability on JGO

✓ dual observations of spatially and temporally varying phenomena

GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE



Previous Exploration

✓ *Induced* magnetic field → sub-surface (conducting) ocean?

✓ *Intrinsic* dipole magnetic field

✓ *Mini-magnetosphere* is created

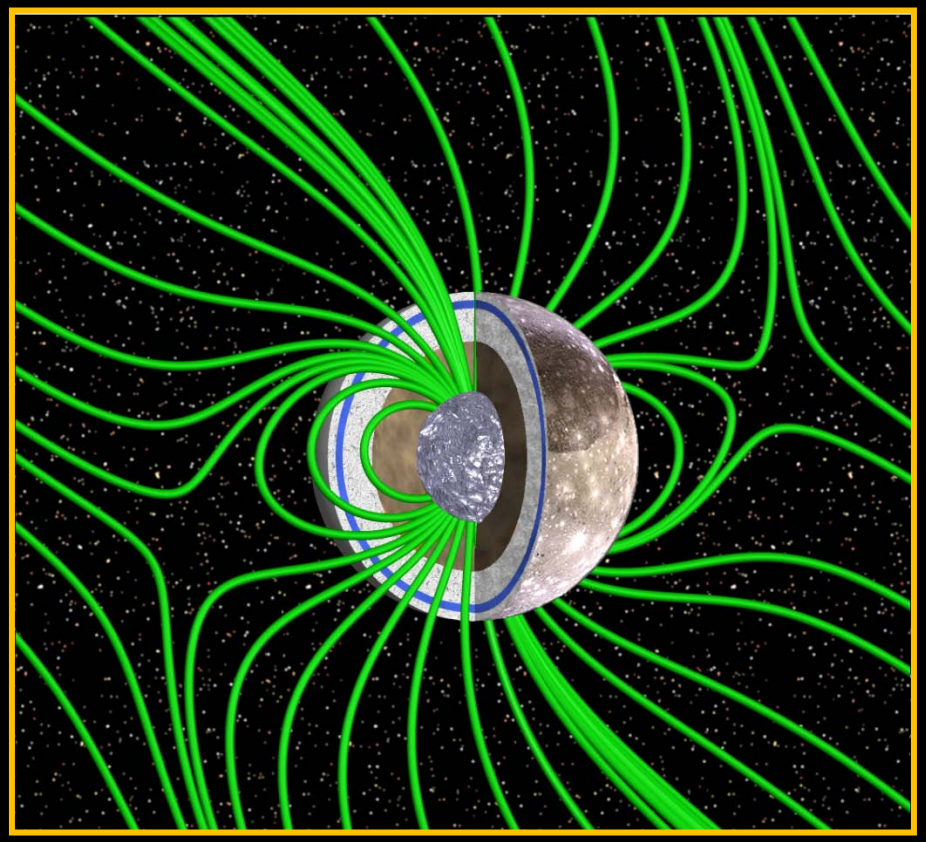
✓ Interaction is complex & highly variable

— B

Science Topics:

Ganymede's dipole magnetic field and mini-magnetosphere
Coupling to Jupiter's magnetosphere
Local plasma environment effects

GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE



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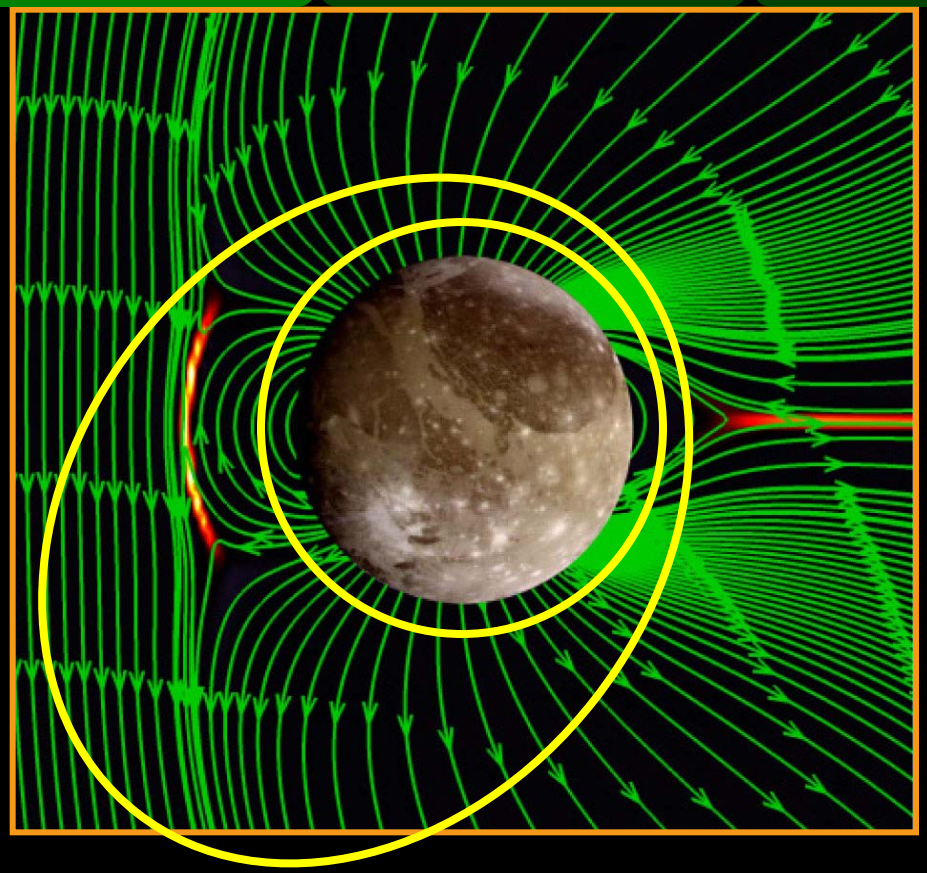
GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE



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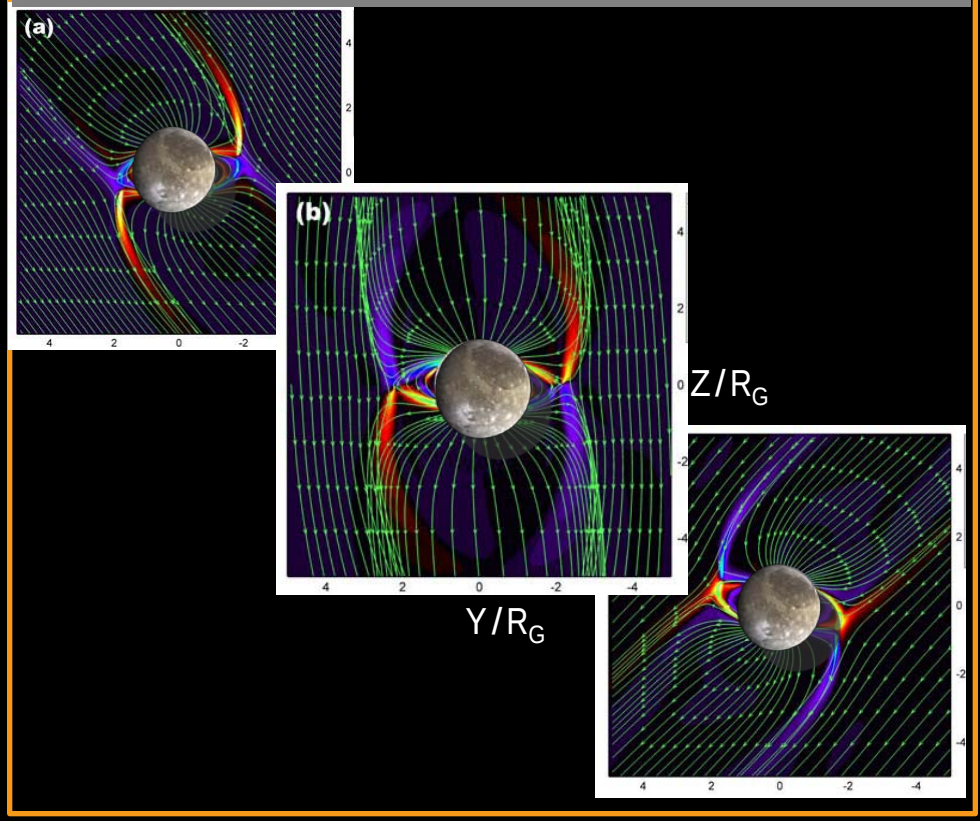
Coupling to Jupiter's magnetosphere
Local plasma environment effects

The Jupiter System

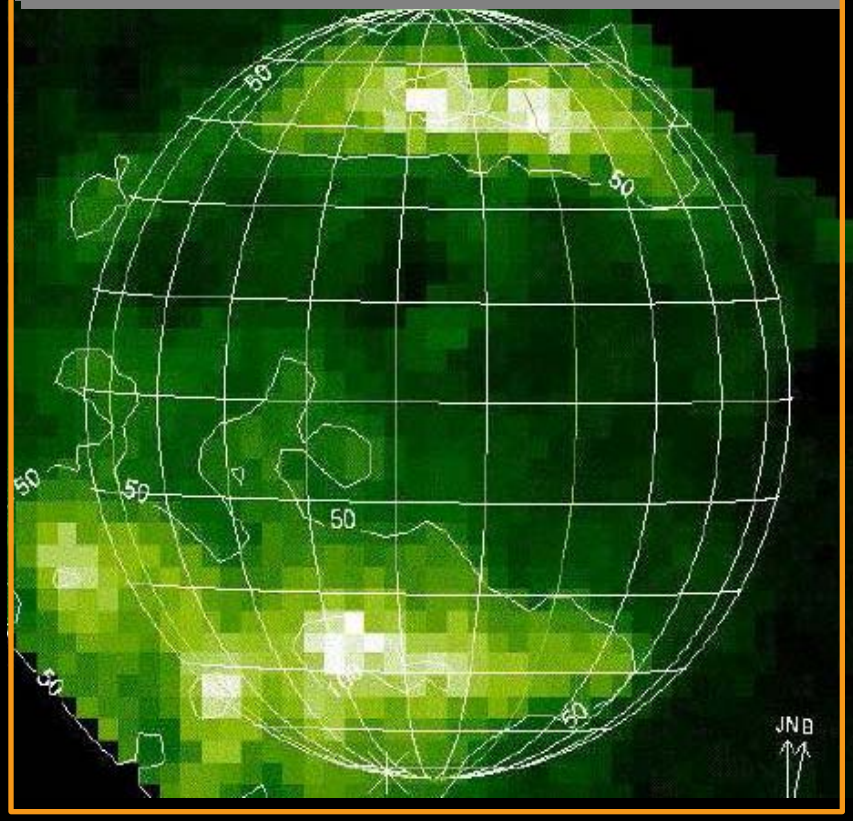
EJSM-Laplace

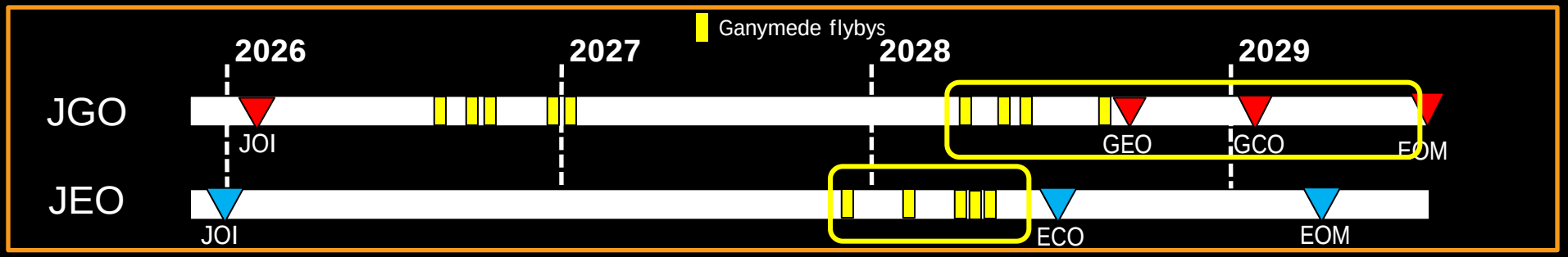
GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Dipole magnetic field and mini-magnetosphere



Coupling to Jupiter's magnetosphere



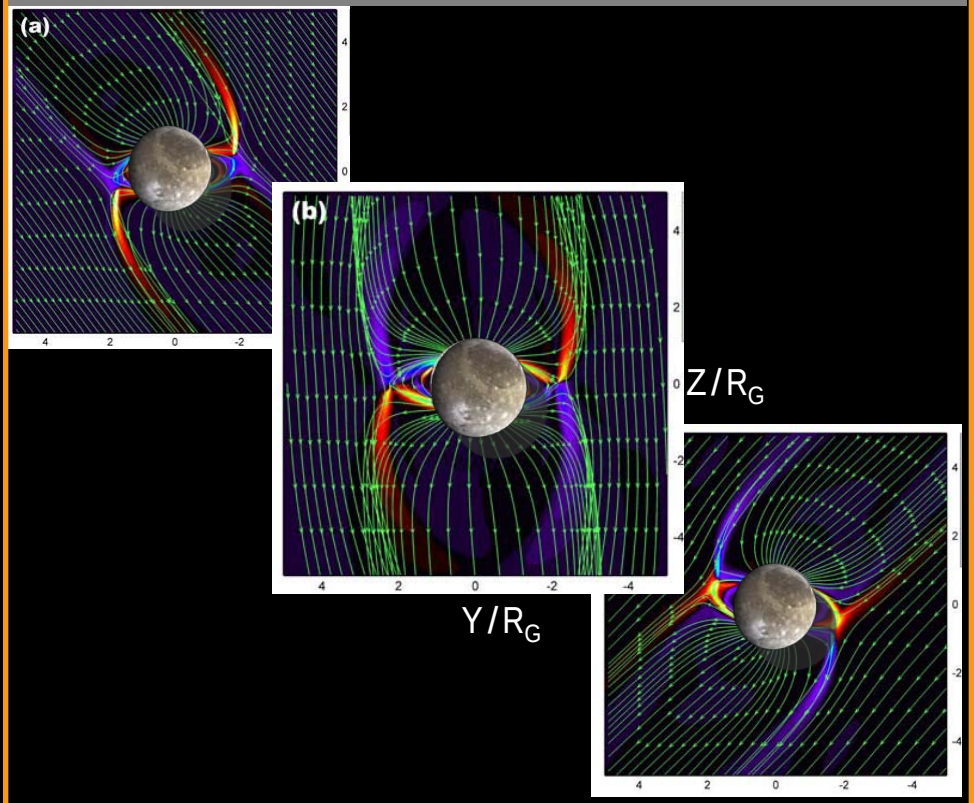


The Jupiter System

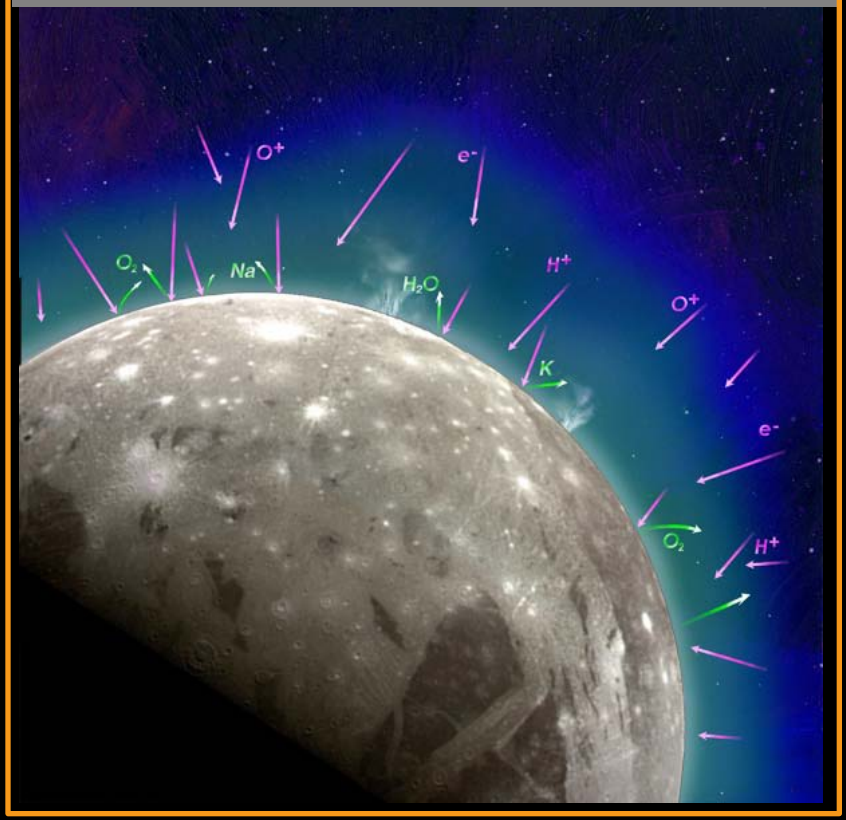
EJSM-Laplace

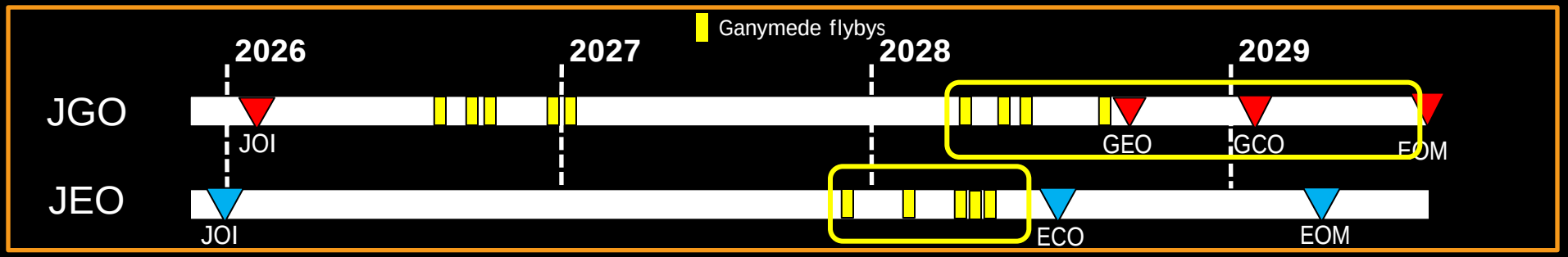
GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Dipole magnetic field and mini-magnetosphere



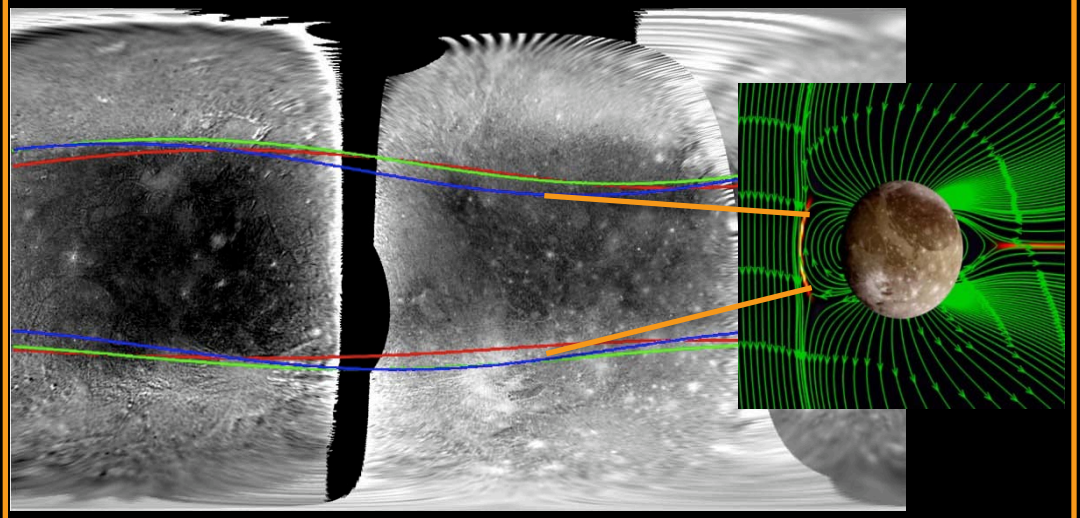
Sources and sinks of atmosphere





GANYMEDE ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Local plasma environment effects



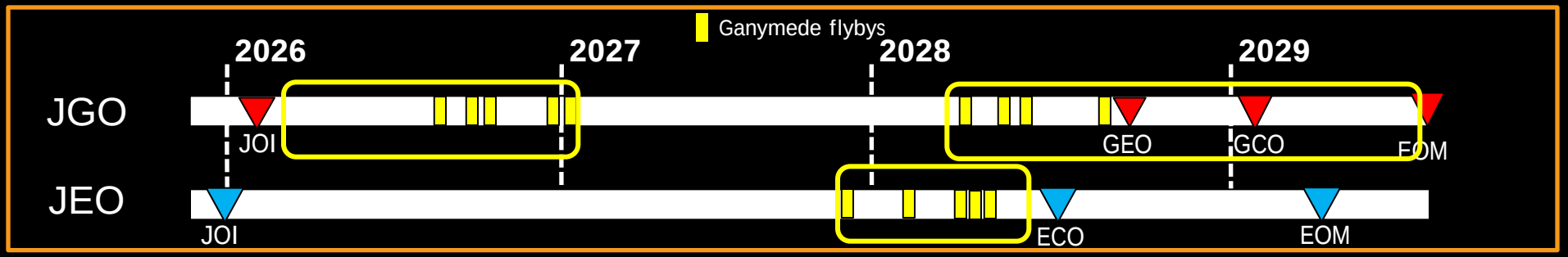
INSTRUMENT PACKAGES

In situ Fields and Particles

Imaging

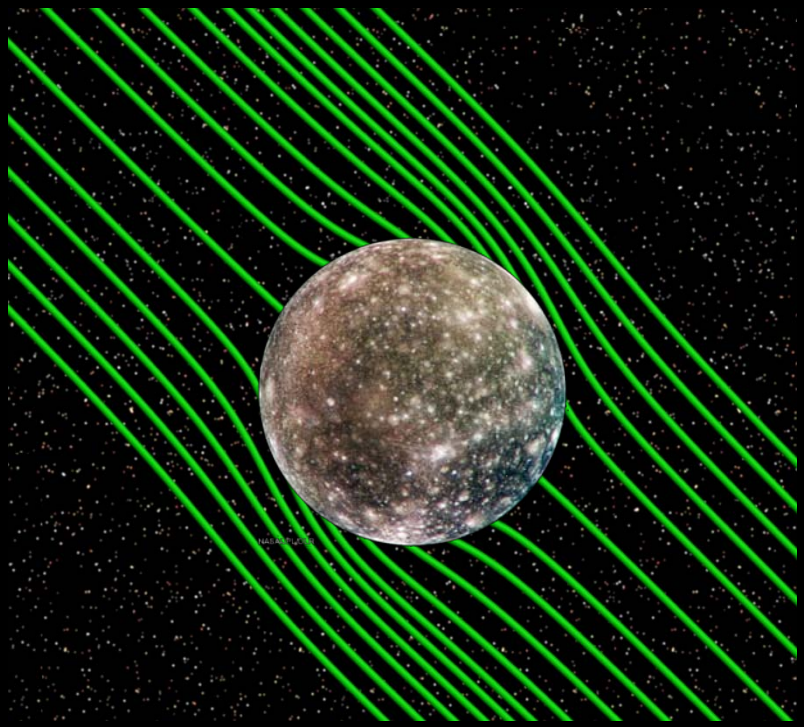
Spectroscopy

Radio science



CALLISTO ENVIRONMENT | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Local plasma environment effects



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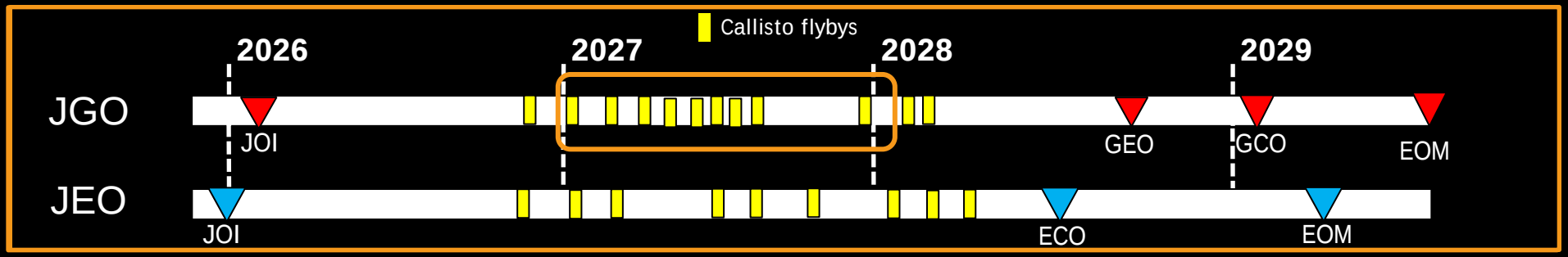


The Jupiter System

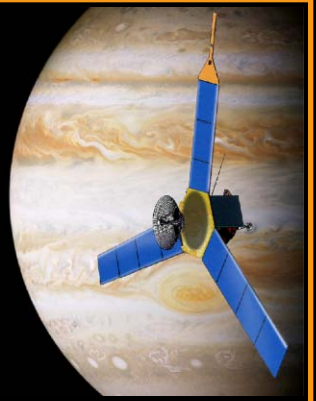
MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Previous Exploration

Previous missions (1979-2007)

- Brief fly-through observations
- Galileo completed a survey

Future Exploration



Complementary to Juno's (2016+) investigations

- Close mapping of Jovian internal field
- Polar magnetosphere

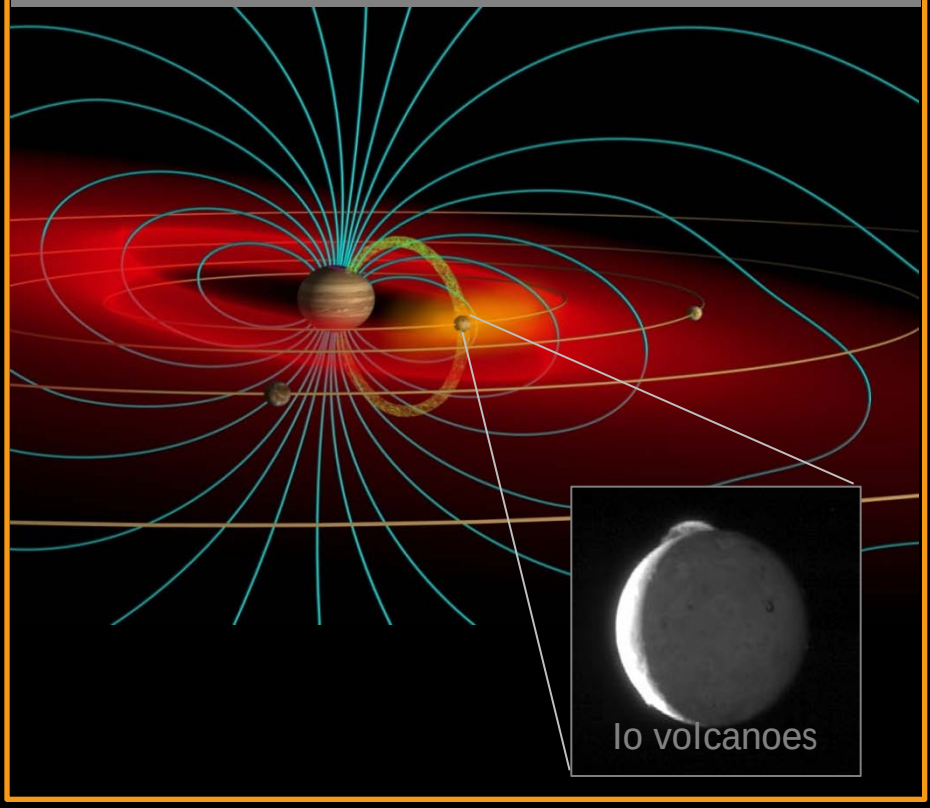
Science Topics:

Properties of the magnetodisc
Magnetospheric driving; Energy & Momentum transfer
Particle acceleration and loss
Moon-magnetosphere interactions

The Jupiter System

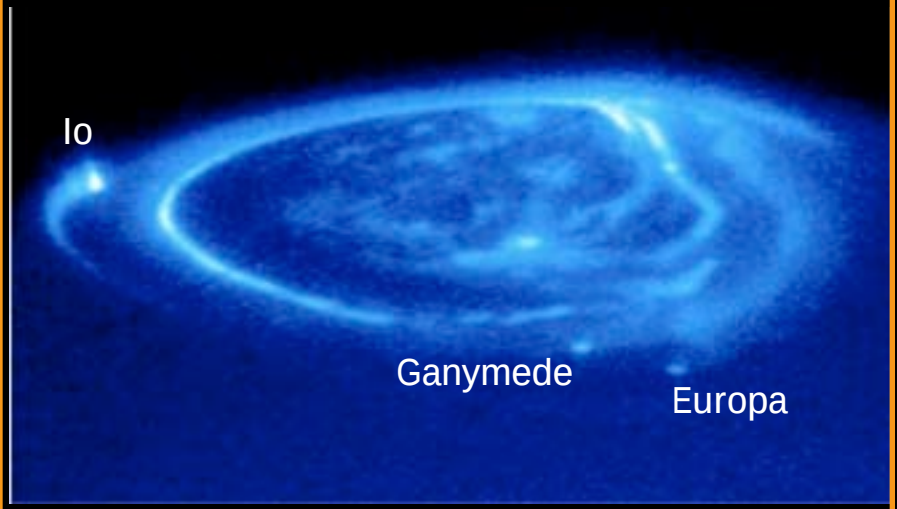
MOON ENVIRONMENTS | **JUPITER MAGNETOSPHERE** | JUPITER ATMOSPHERE

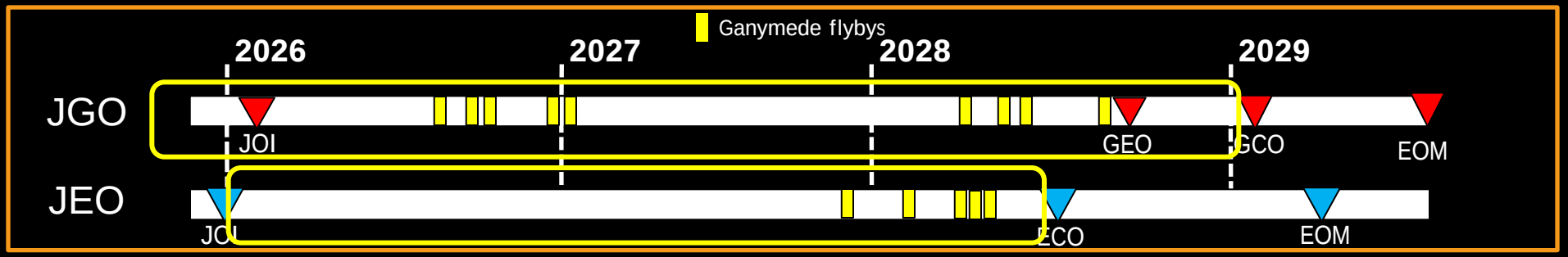
Properties of the magnetodisc



Energy transfer in the coupled system

UV aurora – main oval and moon footprints



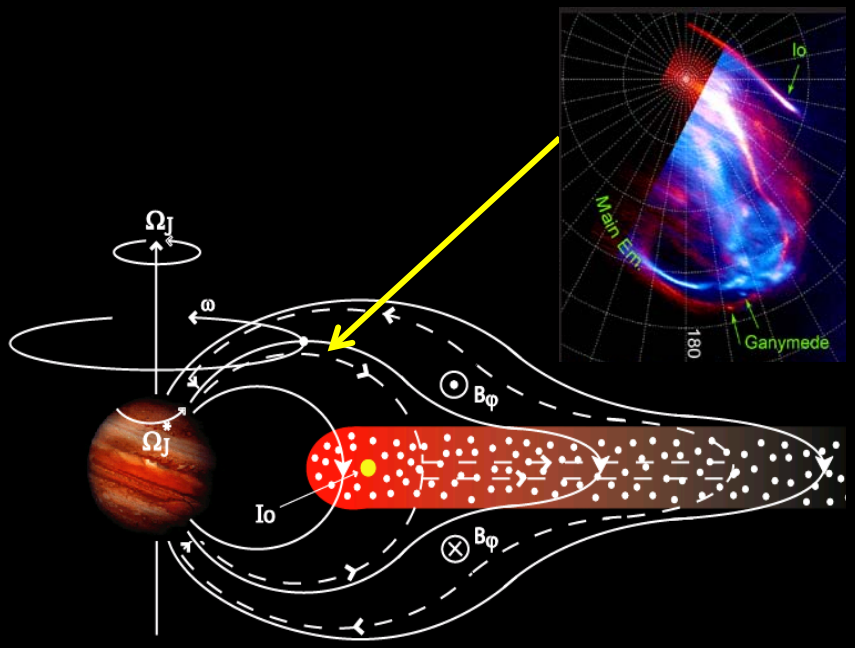


The Jupiter System

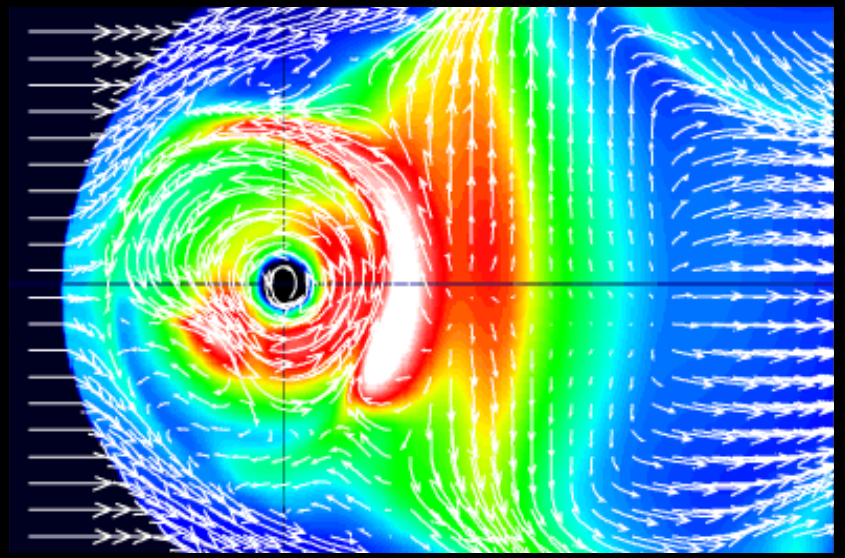
EJSM-Laplace

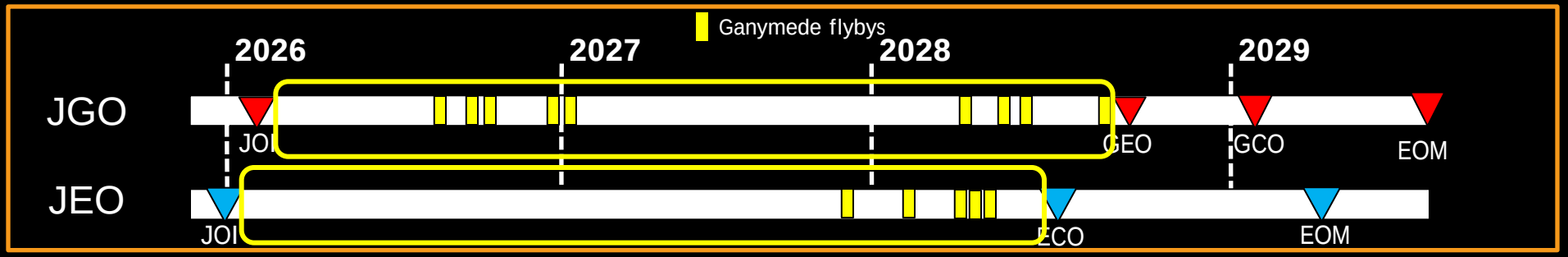
MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Particle acceleration



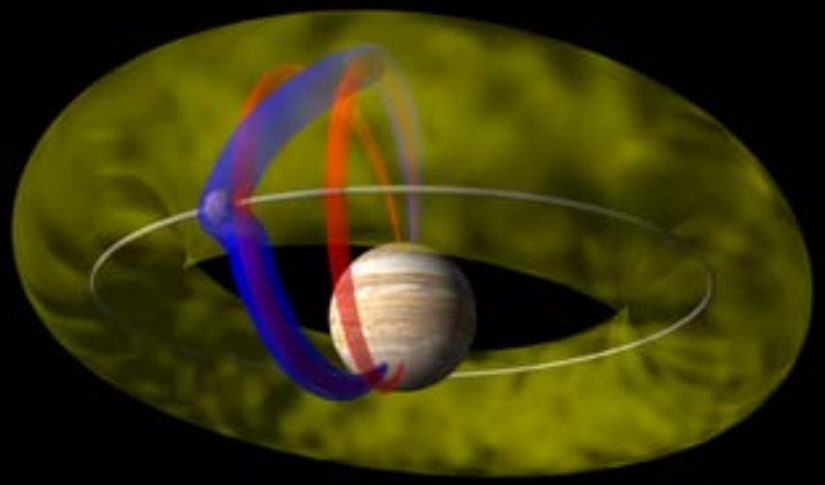
Mass loss processes





MOON ENVIRONMENTS | **JUPITER MAGNETOSPHERE** | JUPITER ATMOSPHERE

Moon-magnetosphere interactions



Io-Jupiter interaction

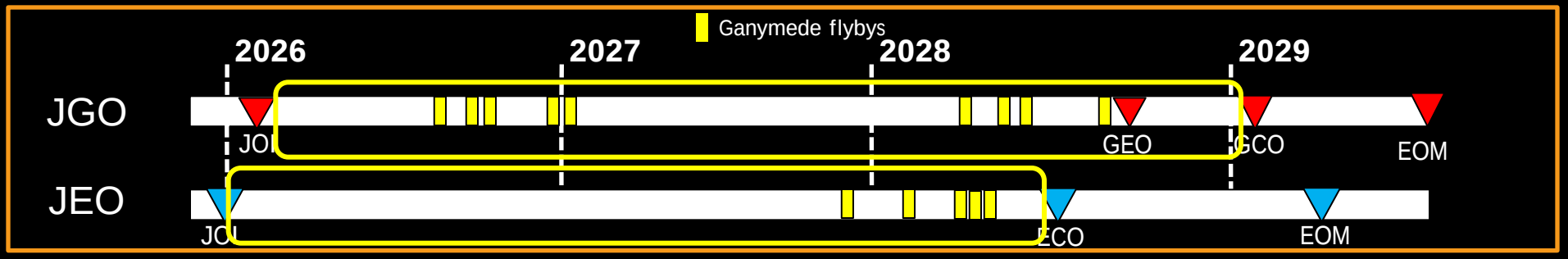
INSTRUMENT PACKAGES

In situ Fields and Particles

Imaging

Spectroscopy

Radio science

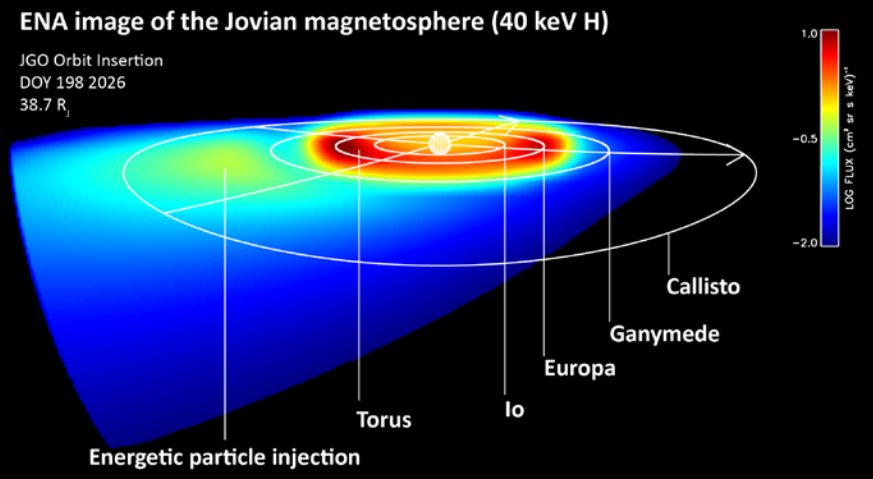


The Jupiter System

EJSM-Laplace

MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Moon-magnetosphere interactions



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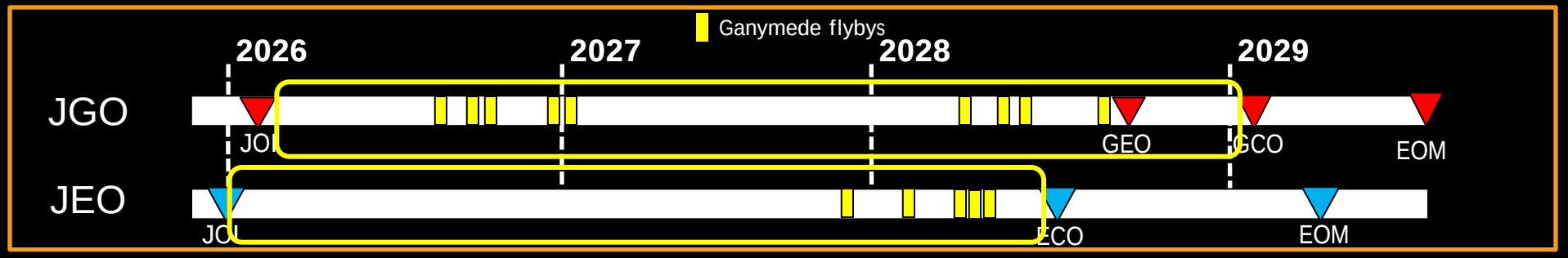
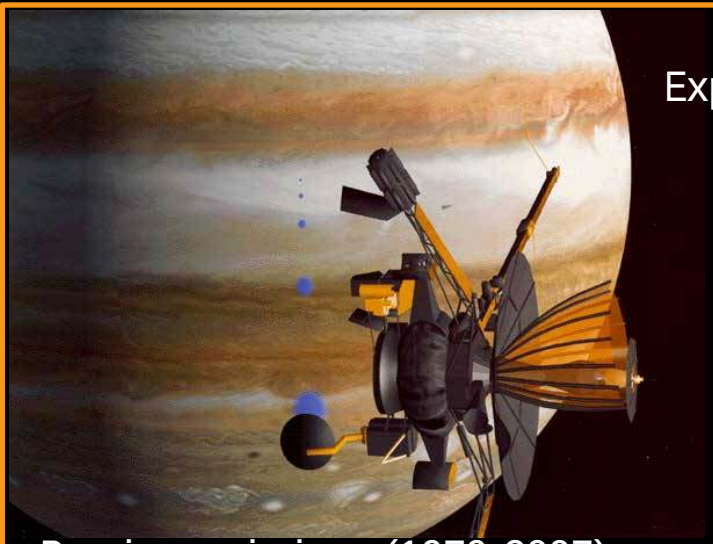


The Jupiter System

MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

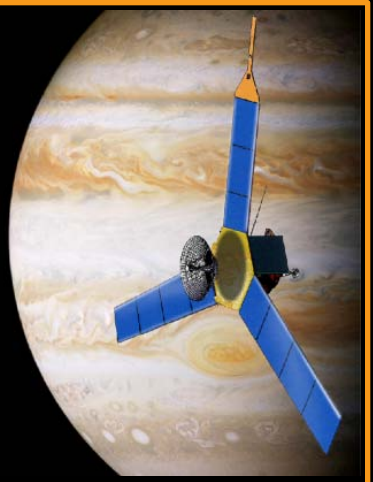
Previous Exploration



Previous missions (1979-2007)

- Snap-shot observations
- Probe findings (local measurements)

Future Exploration



Complement and extend Juno's (2016+) investigation of deep interior

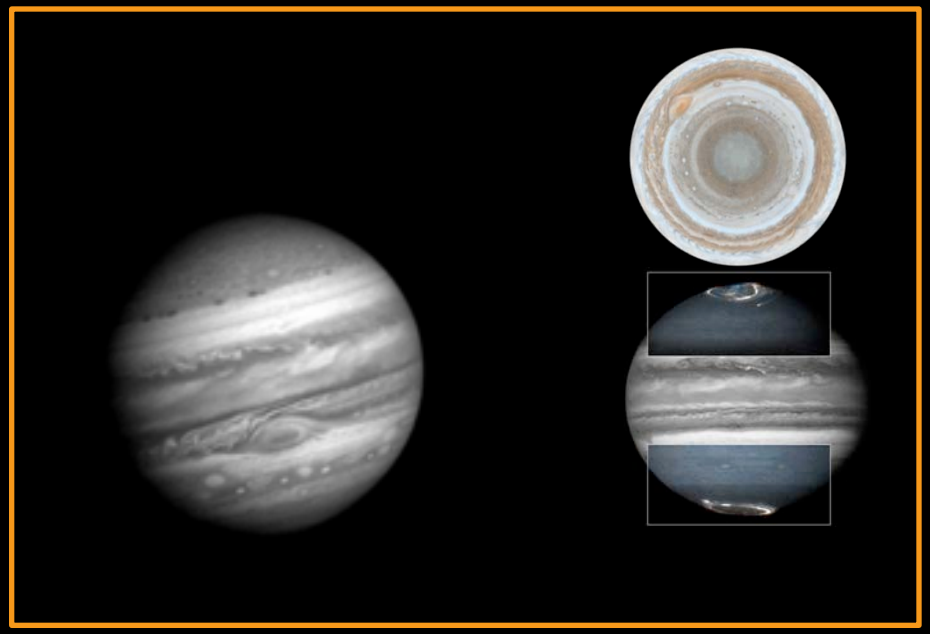
- Microwave studies of volatiles in deep interior
- Gravity mapping of Jupiter

Science Topics:

Global atmosphere dynamics and variability
Jupiter's bulk composition
Transport of energy and material tracers
Vertical coupling

The Jupiter System

MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | **JUPITER ATMOSPHERE**

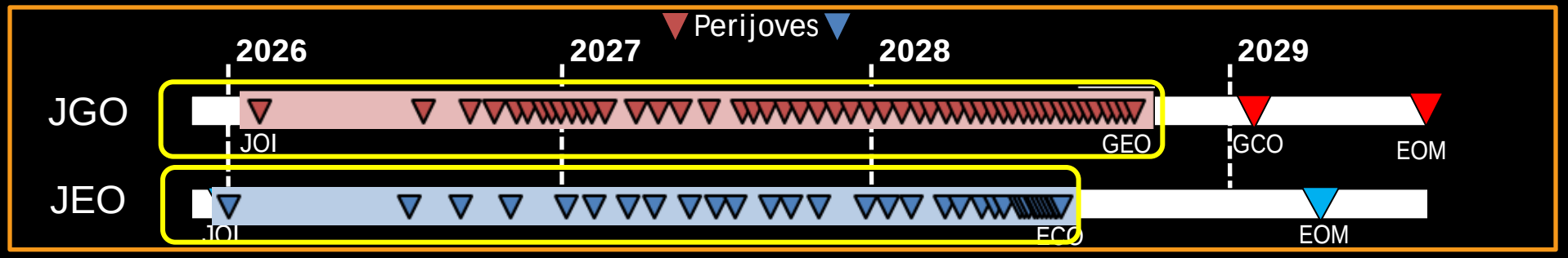


Dynamics and Circulation

Winds and thermodynamics
Lightning studies
Wave propagation
Vertical coupling
Storms, vortices, and instabilities
Variability of circulation

INSTRUMENT PACKAGES

Imaging
Spectroscopy
Radio Science



The Jupiter System

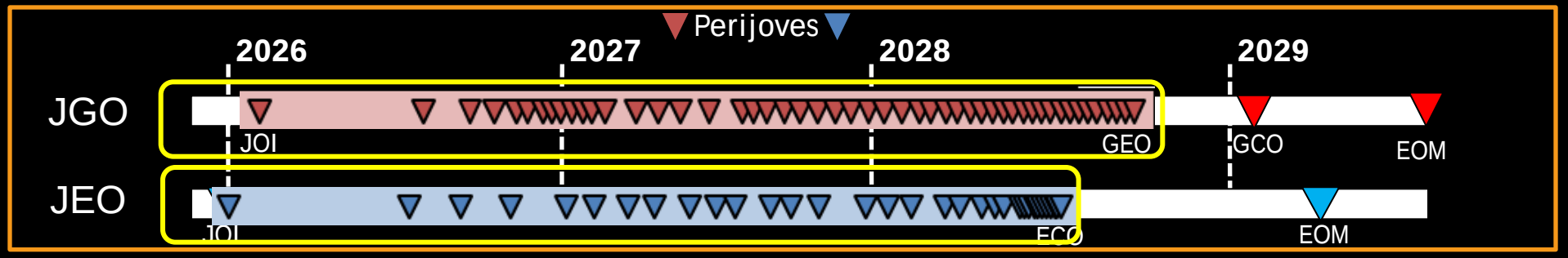
MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

Composition and Chemistry

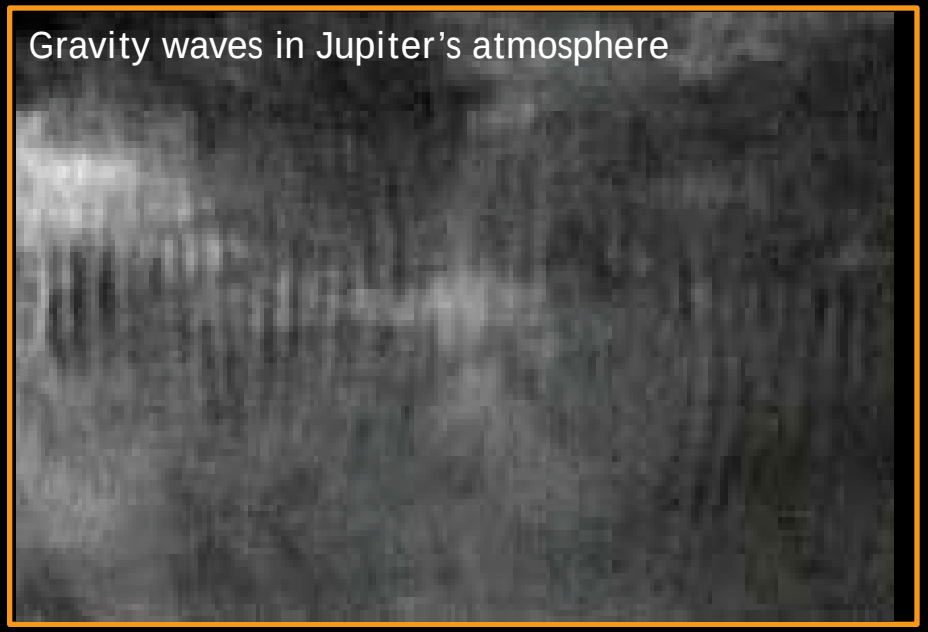
Distribution of condensible volatiles
Tracers of weather-layer dynamics
Hydrocarbon chemistry
Stratospheric trace species

INSTRUMENT PACKAGES

Imaging
Spectroscopy
Radio Science



MOON ENVIRONMENTS | JUPITER MAGNETOSPHERE | JUPITER ATMOSPHERE

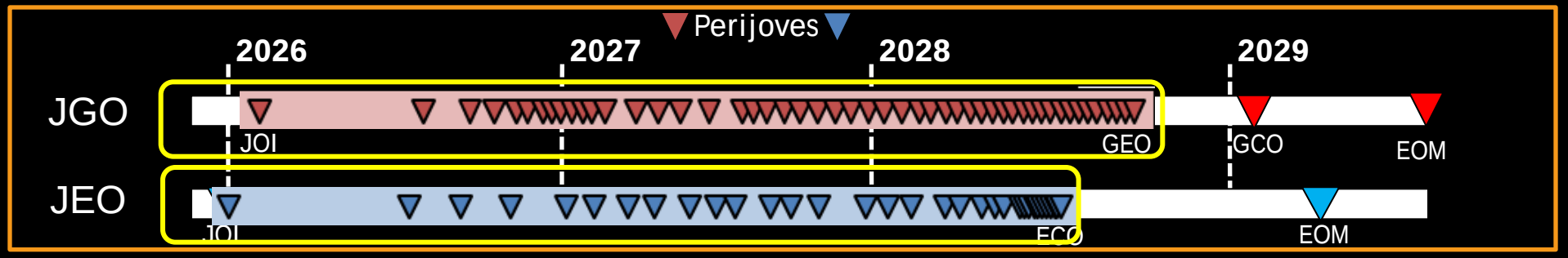


Vertical Structure and Interior

Properties of cloud and haze layers
Vertical aerosol distribution
Coupling of atmosphere to deep interior and external environment

INSTRUMENT PACKAGES

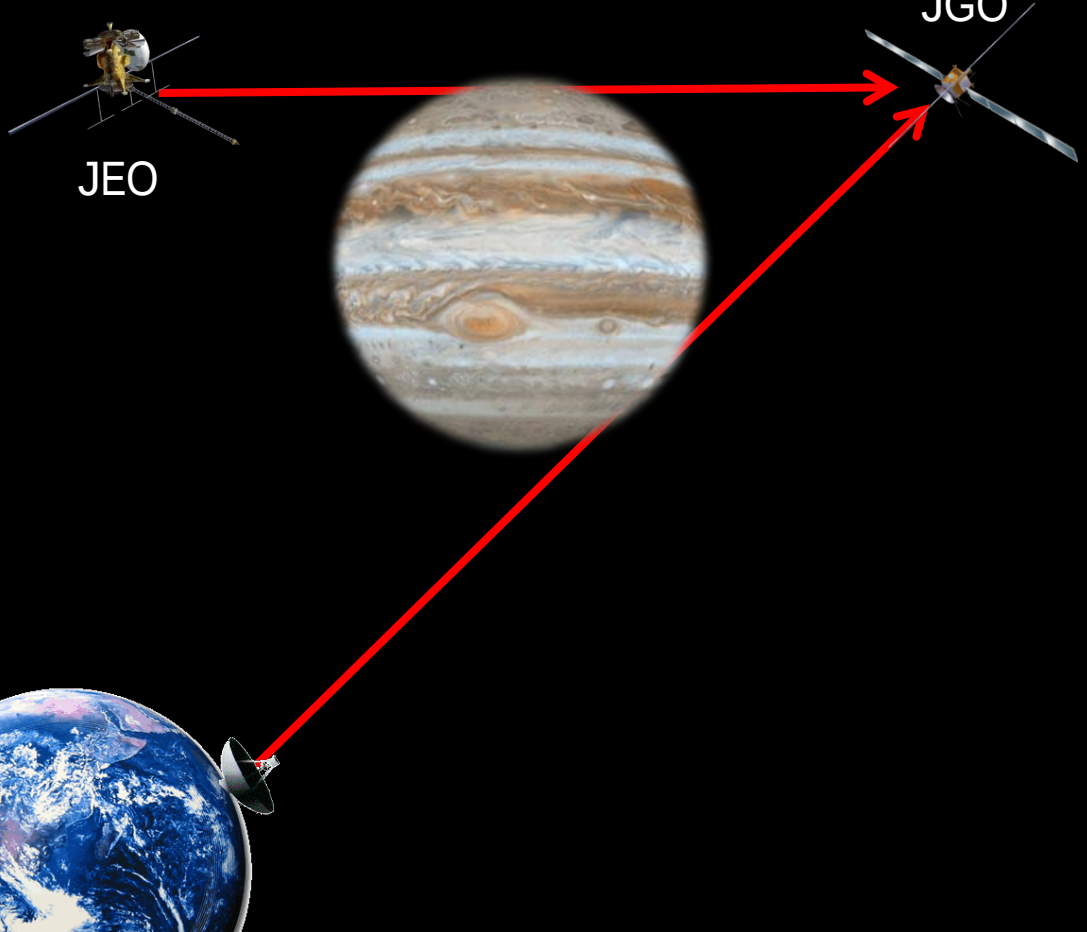
Imaging
Spectroscopy
Radio Science

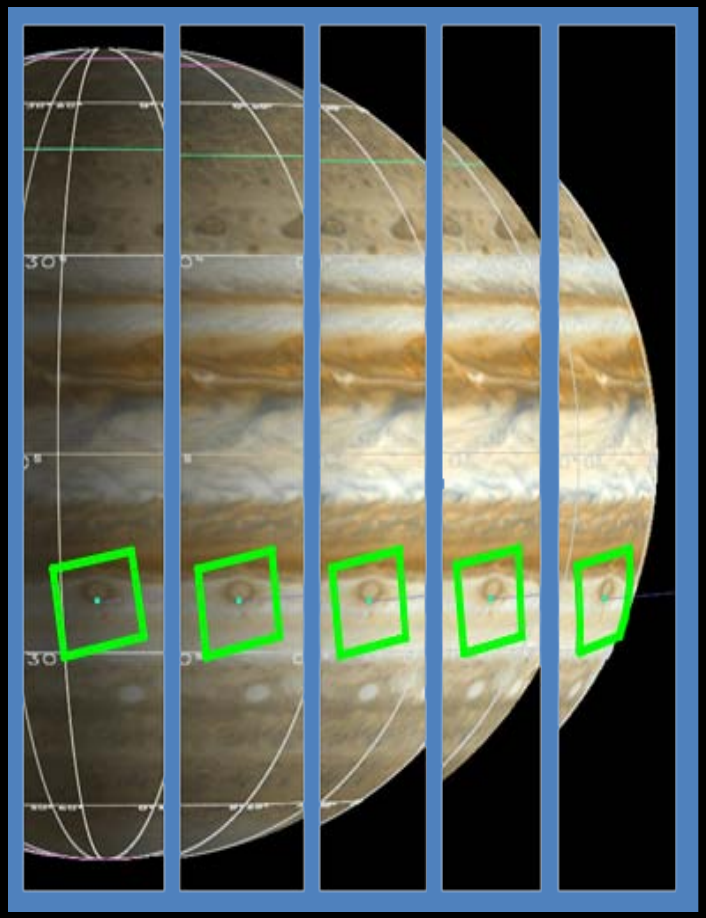


Complementary and synergistic atmosphere studies

- ✓ Radio science occultations of Jupiter/satellite atmospheres = Increased opportunities
- ✓ Dual observations of atmospheric phenomena
- ✓ Enhanced flexibility with specialised instrumentation and wavelength coverage

Spacecraft-to-spacecraft science



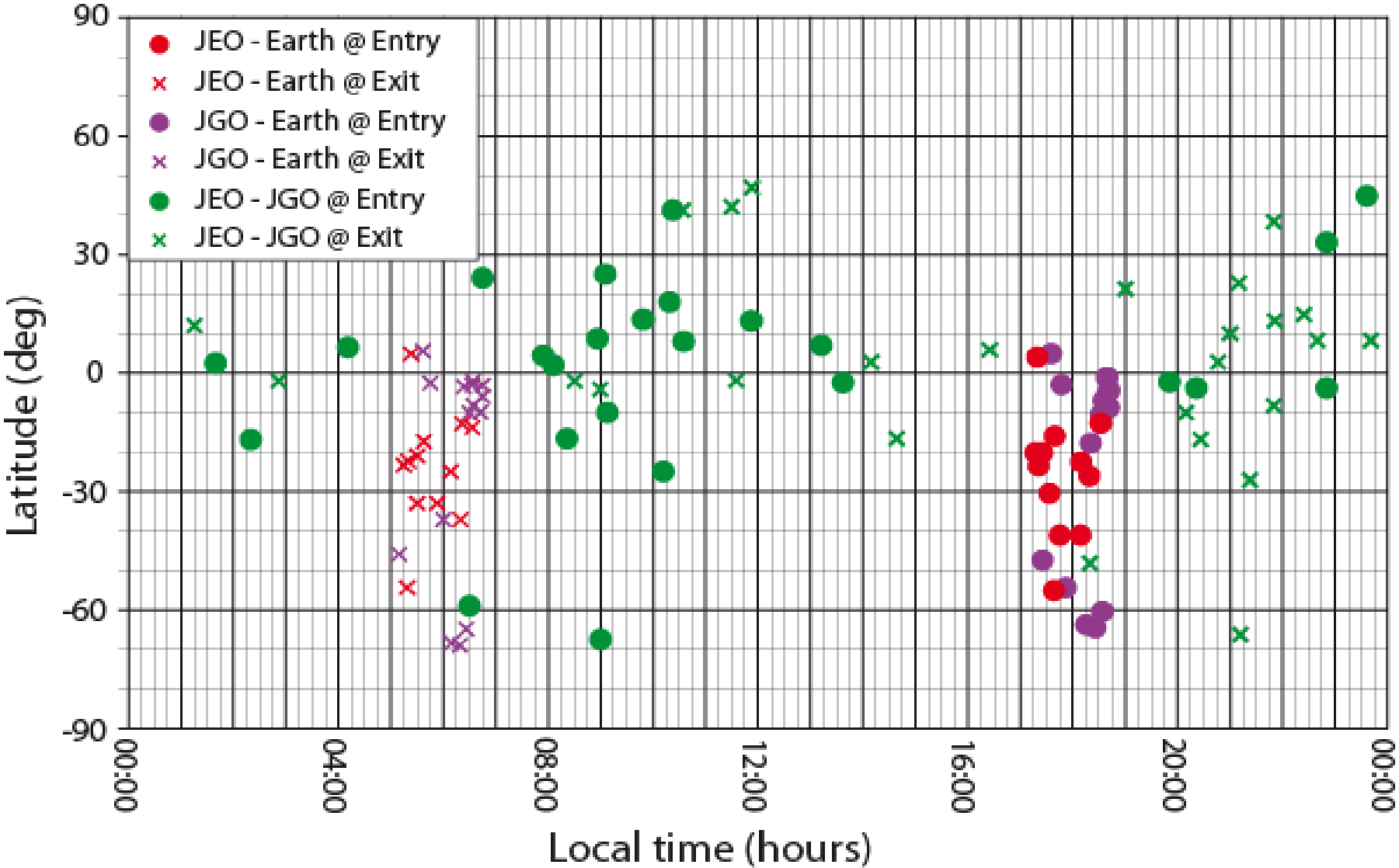


Dynamic feature tracking

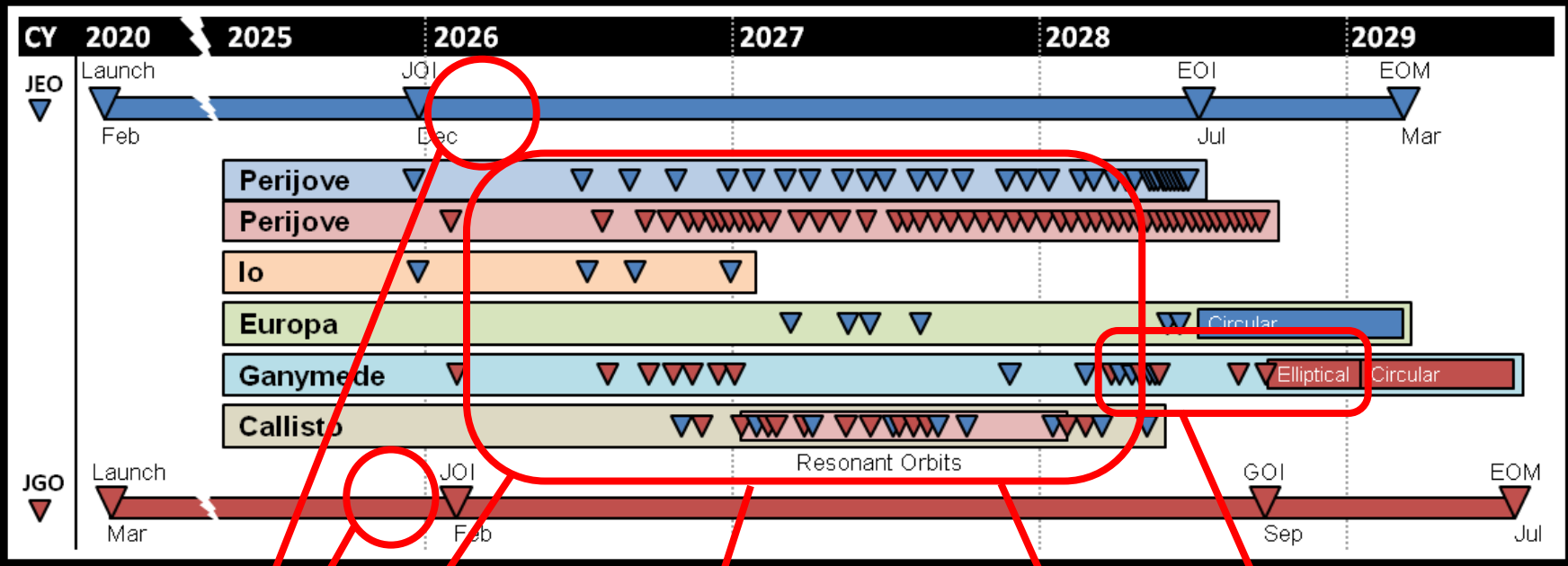
Complementary and synergistic atmosphere studies

✓ Radio science occultations of Jupiter/satellite atmospheres = Increased opportunities

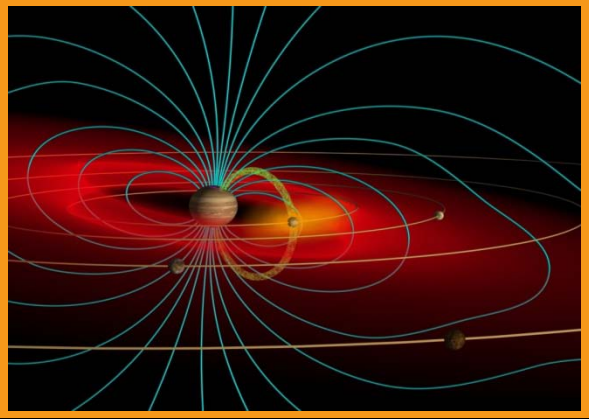
Spacecraft-to-spacecraft Radio Science Opportunities



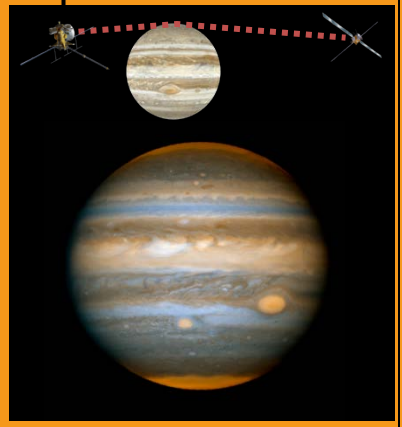
Complementary and Synergistic Science: Where JEO and JGO unite



Jupiter's Magnetosphere

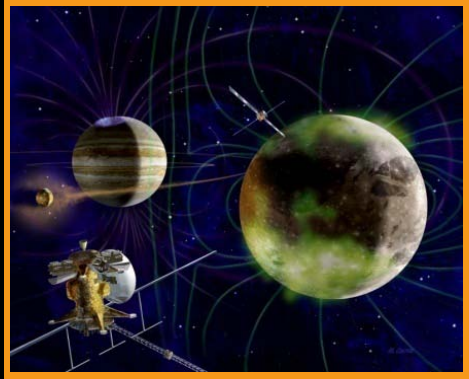


Jupiter Science



Satellite Science

Ganymede Magnetosphere Studies



From the objectives to the measurements

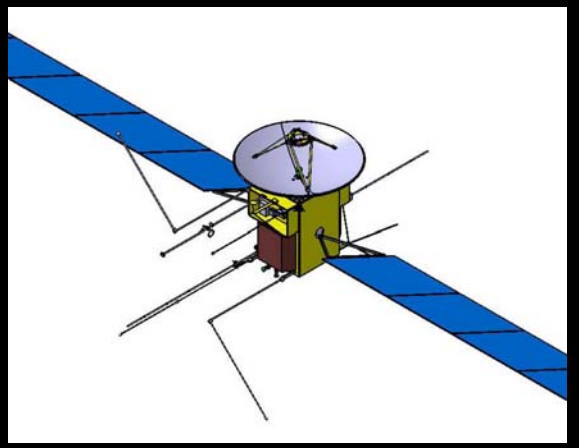
	INSTRUMENT	MOON ENVIRONMENTS	JUPITER MAGNETOSPHERE	JUPITER ATMOSPHERE
In situ Fields and Particles	Magnetometer (MAG)	X	X	
	Radio and Plasma Wave Instr. (RPWI)	X	X	
	Particle and Plasma Instr.— Ion Neutral Mass Spectr. (PPI-INMS)	X	X	
Imaging	Narrow Angle Camera (NAC)	X	X	X
	Wide Angle Camera (WAC)	X	X	X
Spectroscopy	Visible Infrared Hyperspectral Imaging Spectrometer (VIRHIS)	X	X	X
	UV Imaging Spectrometer (UVIS)	X	X	X
	Sub-mm Wave Instrument (SWI)	X		X
Sounders & Radio Science	Laser Altimeter (LA)			
	Ice Penetrating Radar (IPR)			
	Radio Science Instrument (JRST+USO)	X		X

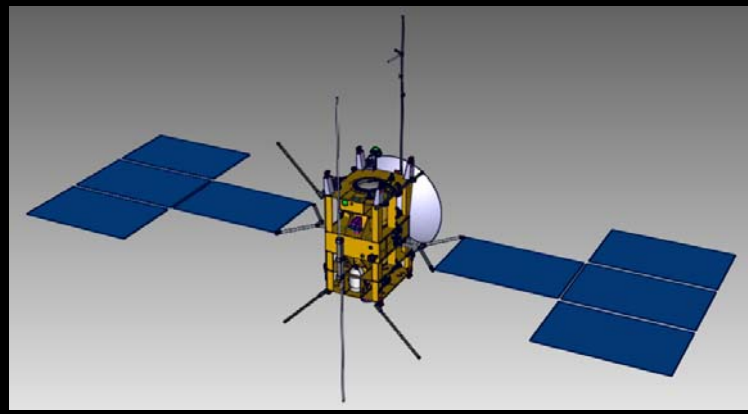
JGO Mission Implementation

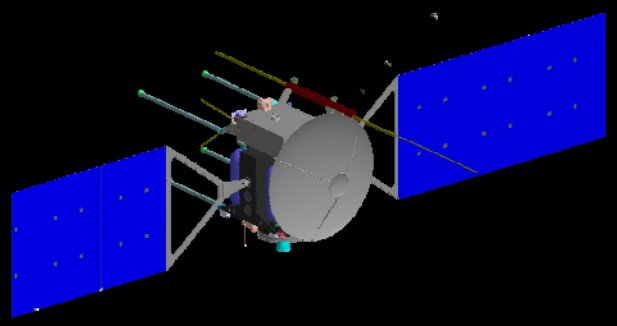
Christian Erd

JGO Spacecraft Salient Properties

- Dry mass ~1700 kg, propellant mass ~2500 kg
- High Δv required: 2350 m/s
- Model payload 104 kg, ~120 — 150 W
- 3-axis stabilized s/c
- Power: solar array 60 — 70 m^2, 640 — 700 W
- HGA: >3 m, fixed to body, X & Ka-band
- Data return >1 Gb per 8 h pass (1 ground station)





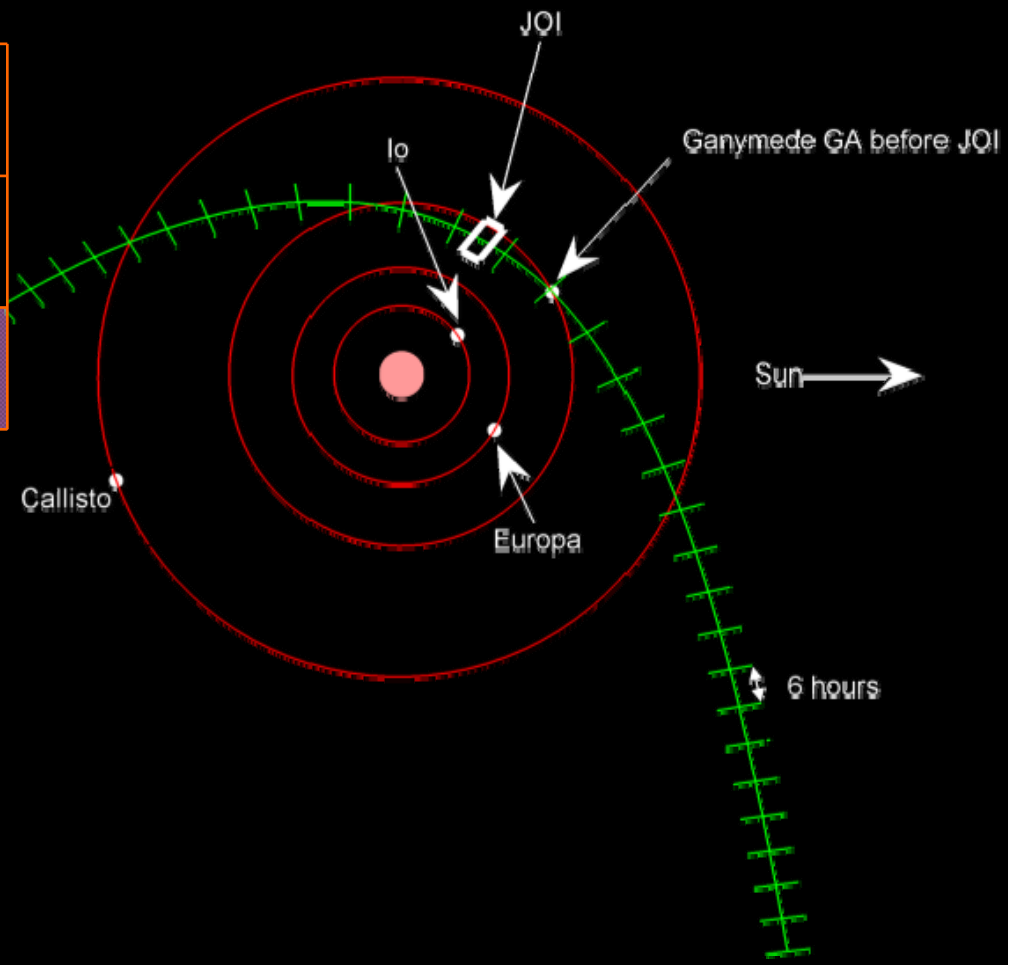


JGO Trajectory Overview

EJSM-Laplace

Mission Trajectory

Launch	March 2020 (June 2022)
Interplanetary Transfer	5.9 years (7.3 years)
Jupiter Orbit Insertion to Callisto	~11 months



JGO Trajectory Overview

EJSM-Laplace

Mission Trajectory

Launch	March 2020 (June 2022)
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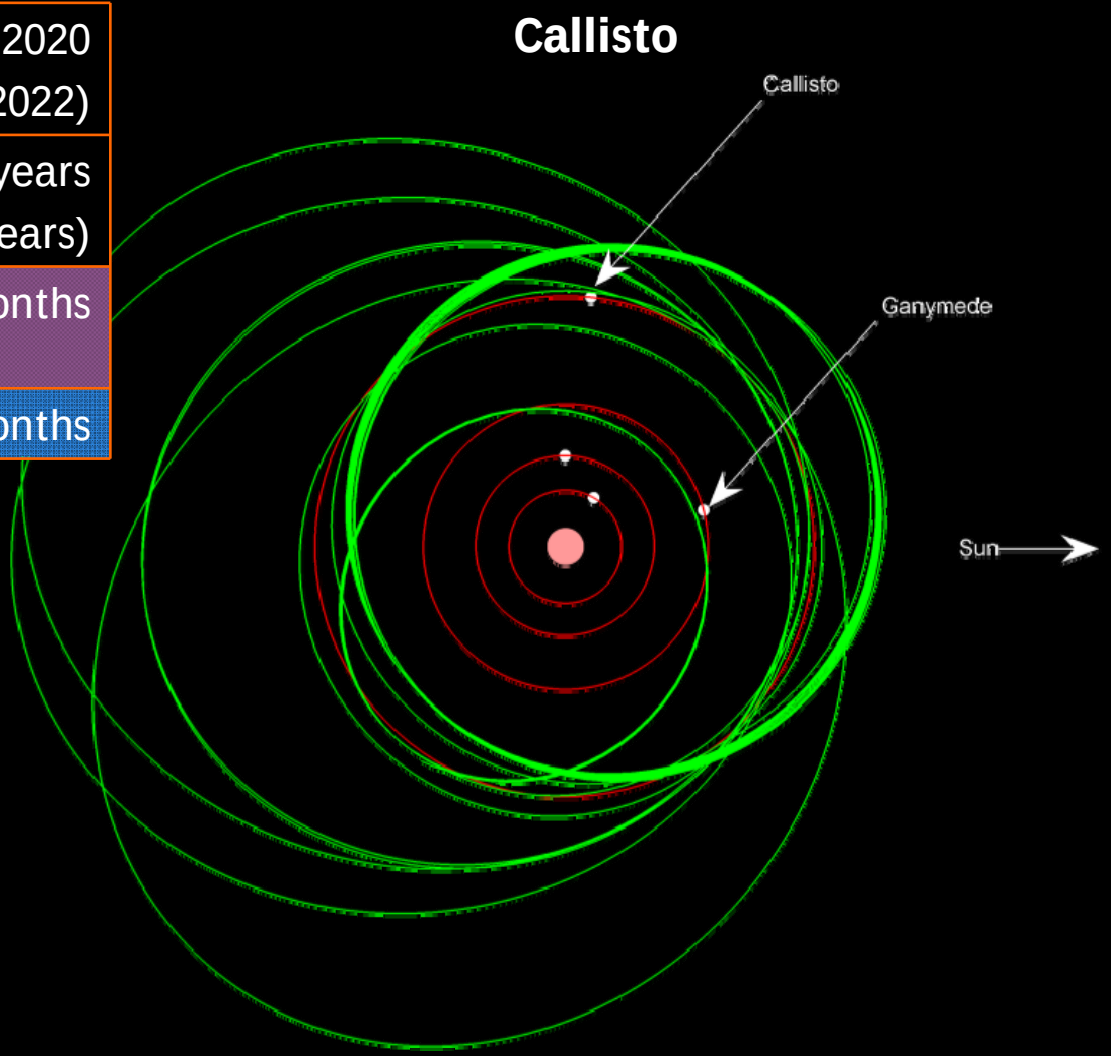


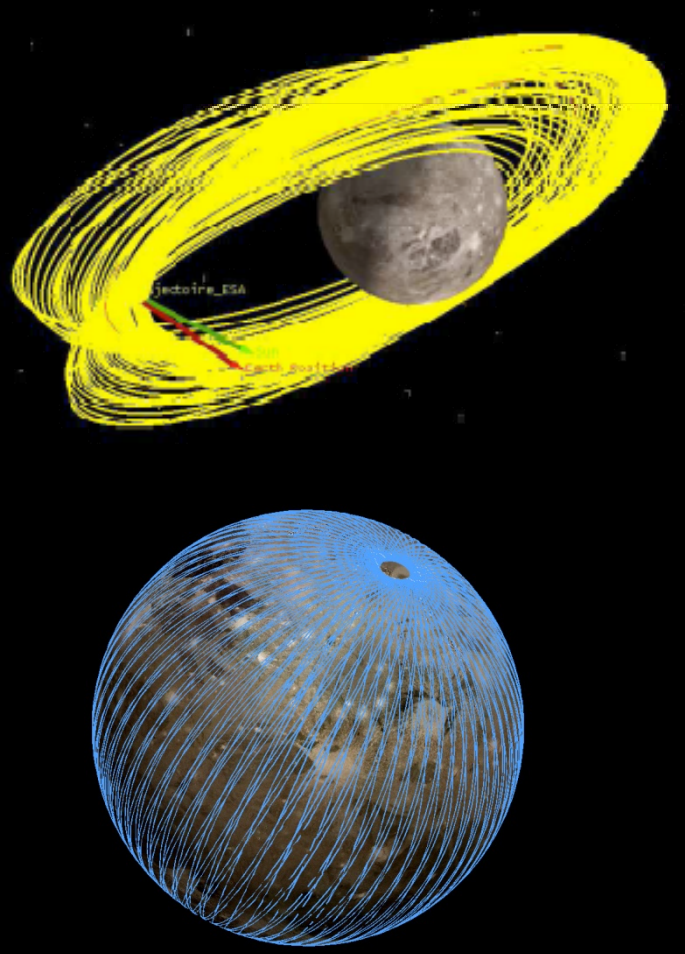
JGO Trajectory Overview

EJSM-Laplace

Mission Trajectory

Launch	March 2020 (June 2022)
Interplanetary Transfer	5.9 years (7.3 years)
Jupiter Orbit Insertion to Callisto	~11 months
Callisto flybys	~13 months
Callisto to Ganymede	6 months
Ganymede (polar) 10,000x200 km & 5000 km 500 km circular 200 km circular	 120 days 120 days 60 days
Total mission duration	9.2 years (10.6 years)

Ganymede



Model Payload

Total mass: 104 kg

Imaging	
Narrow Angle Camera (NAC)	10 kg
Wide Angle Camera (WAC)	4.5 kg

In situ Fields and Particles	
Magnetometer (MAG)	1.8 kg
Radio and Plasma Wave Instr. (RPWI)	11.2 kg
Particle and Plasma Instr.— Ion Neutral Mass Spectr. (PPI-INMS)	18.2 kg

Spectroscopy	
Visible Infrared Hyperspectral Imaging Spectrometer (VIRHIS)	17 kg
UV Imaging Spectrometer (UVIS)	6.5 kg
Sub-mm Wave Instrument (SWI)	9.7 kg

Sounders & Radio Science	
Laser Altimeter (LA)	11 kg
Ice Penetrating Radar (IPR)	10 kg
Radio Science Instrument (JRST+USO)	4 kg

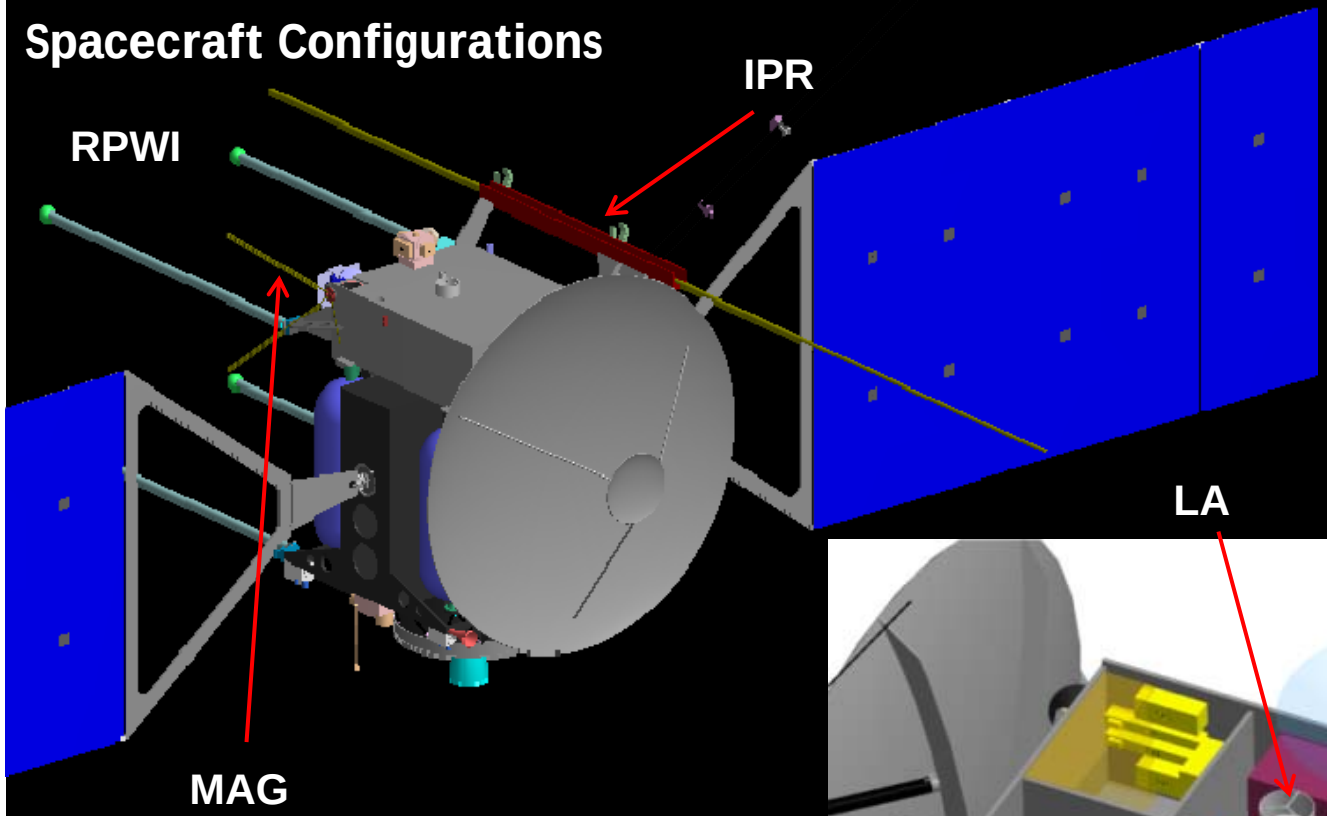
Model payload is based on heritage: BepiColombo, Juno, Mars Express, Double Star, Venus Express, Rosetta, Dawn, Cassini, etc.

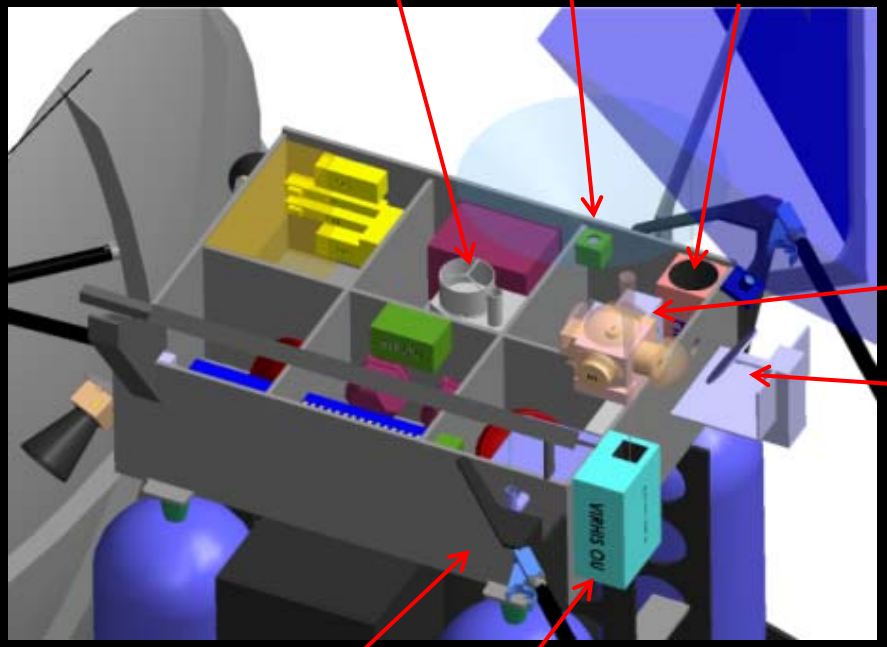
JGO Implementation

EJSM-Laplace

Spacecraft Configurations

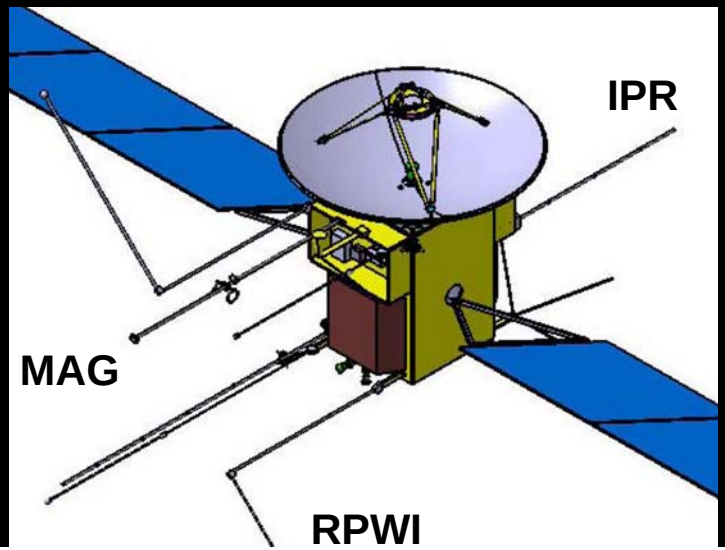
Option 1



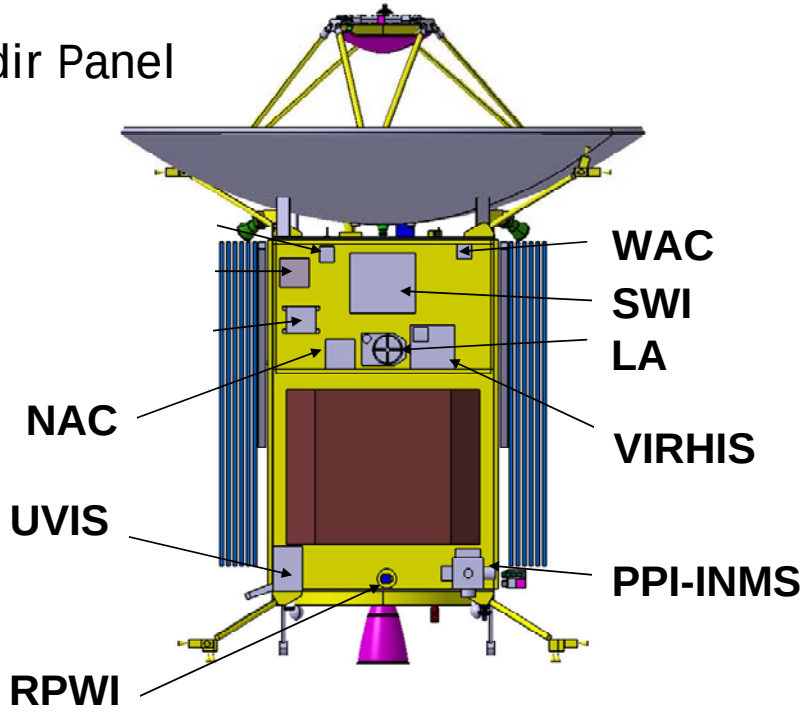


Spacecraft Configurations

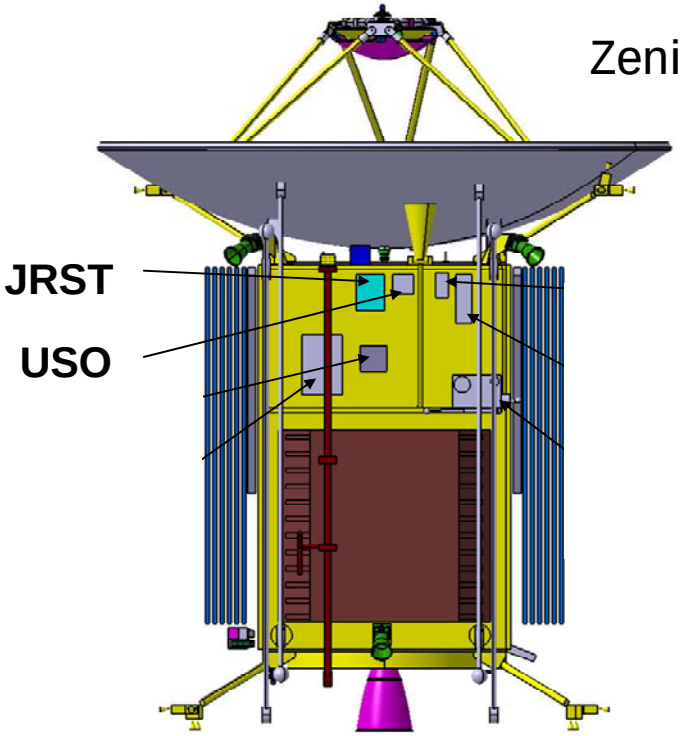
Option 2



Nadir Panel

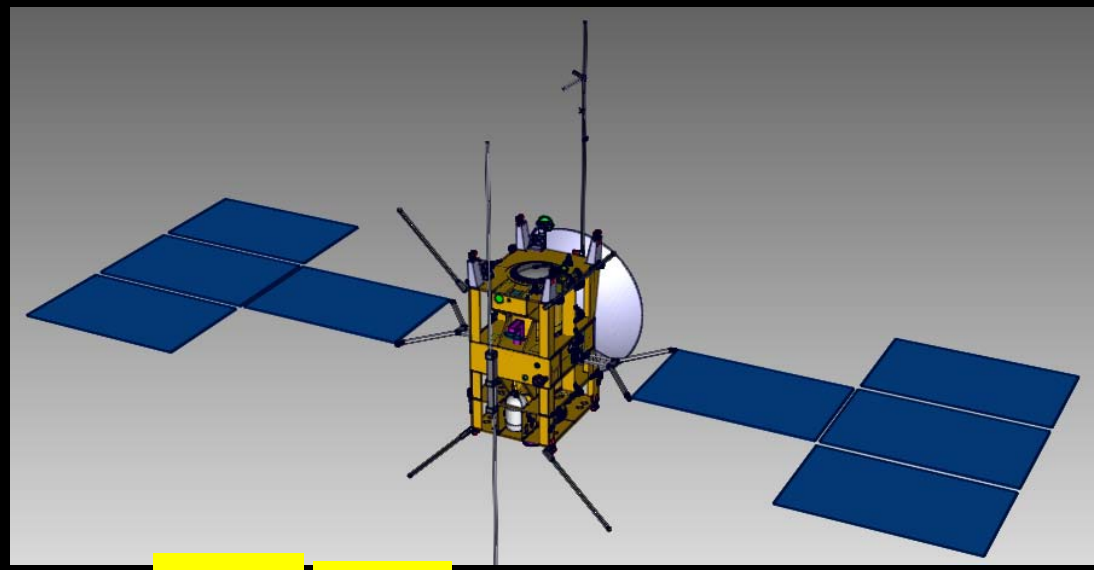


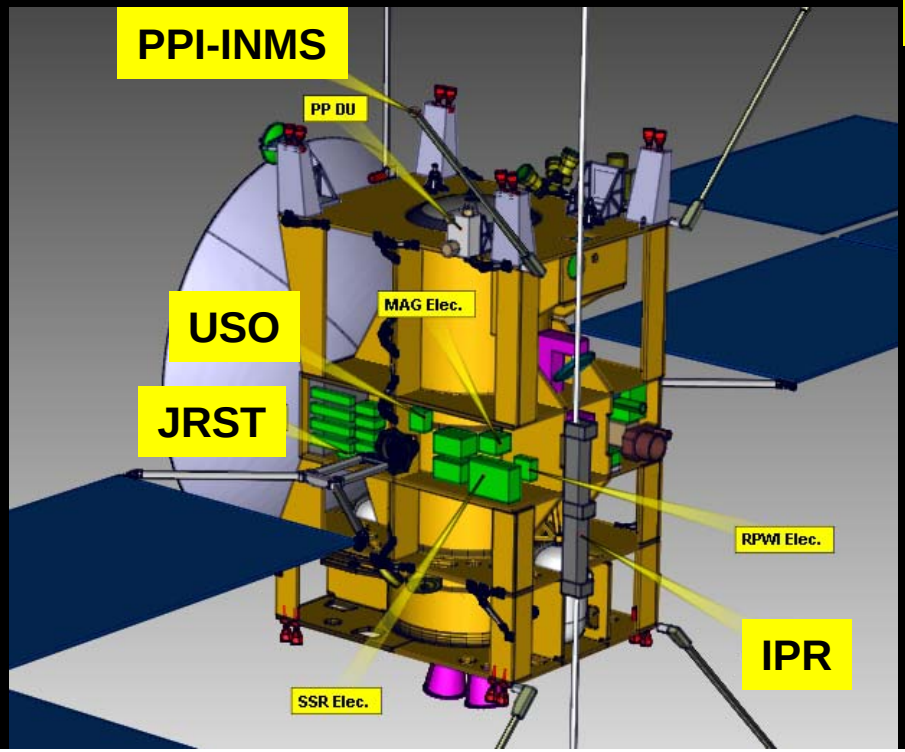
Zenith Panel

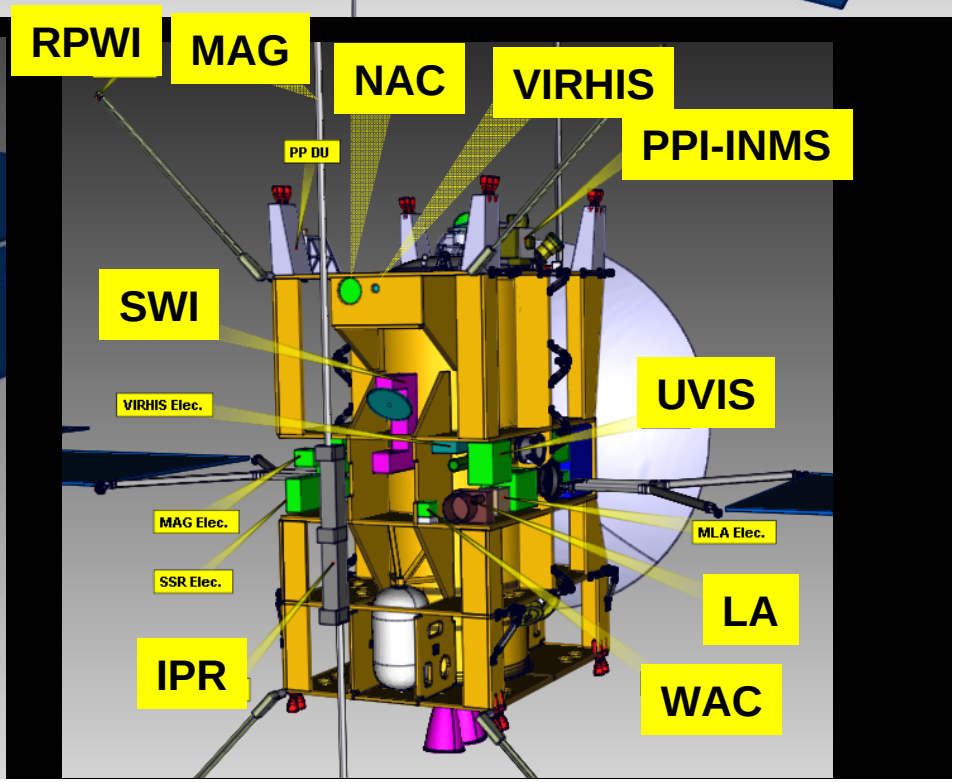


Spacecraft Configurations

Option 3







JGO Technology

- Radiation
  - 85 krad inside 10 mm Al
  - Layered shielding strategy achieving 25 krad
    - Shielded equipment compartment (“vault”)
    - Equipment housing
    - Spot shielding of components
  - Sufficient reduction, components available with tolerance of 50 krad
- Solar arrays
  - Low Intensity Low Temperature technology confirmed
  - Enhancements expected from ongoing developments
- Planetary Protection easily achievable

No need for critical technologies

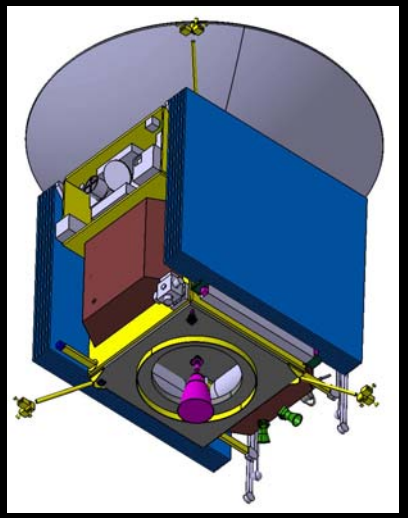
ESA Technical Review: Summary of Risk Assessment — Spacecraft

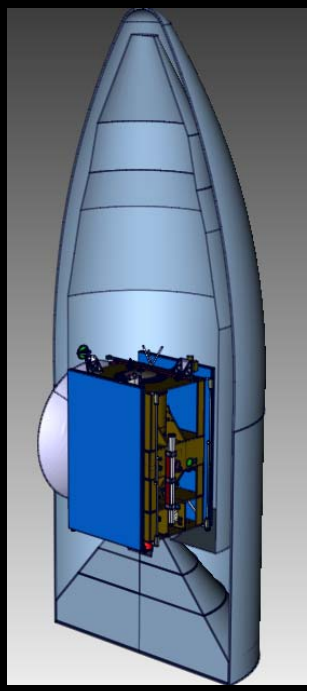
Spacecraft Risk Area	Low	Low-Medium	Medium	Medium-High	High
Mass					
Solar array					
Radiation tolerance					
Materials					
Electrostatic charging					
Magnetic cleanliness					
Communications					
Planetary Protection					
Autonomy and ops					
Technology					
Schedule				2020 launch	

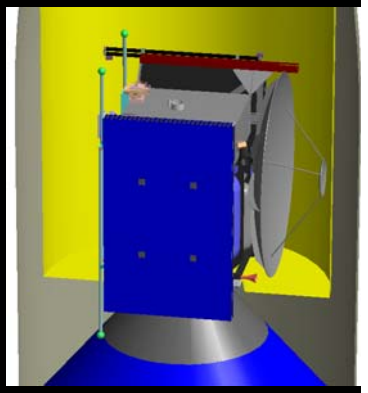
ESA Technical Review: Follow-up and way forward

- **Mass: way forward**
  - Interplanetary transfer: Δ*v*, duration
  - Launcher performance confirmed
  - Optimization of shielding feasible
  - Required system margin (20%) feasible

- **Schedule: way forward**
  - 2020 launch is feasible, but is tight and requires efficient decision process
  - 2021 launch being looked at
  - 2022 can be met comfortably







ESA Technical Review: Summary of Risk Assessment — Model Payload

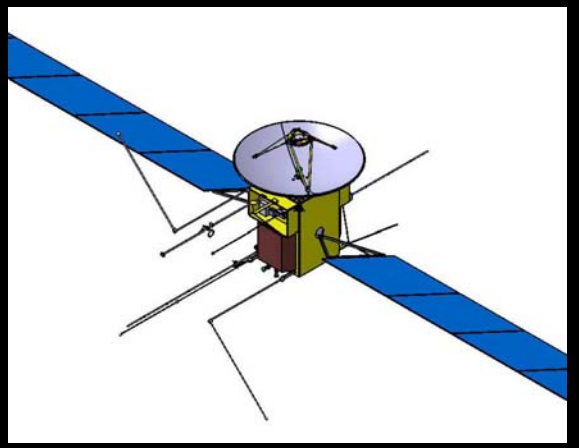
- Instrument teams should avoid single point failures (mechanisms)
- Recommendation for resource sharing, in particular for redundancy:
  - E.g. to consider sharing of p/l processors

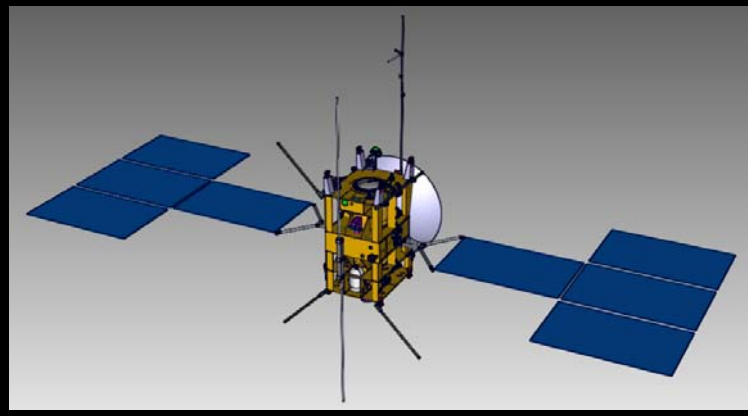
Model Payload Risk Area	Low	Low-Medium	Medium	Medium-High	High
Instrumentation for JGO					
New developments for JGO (sensors & optics)					
Schedule					

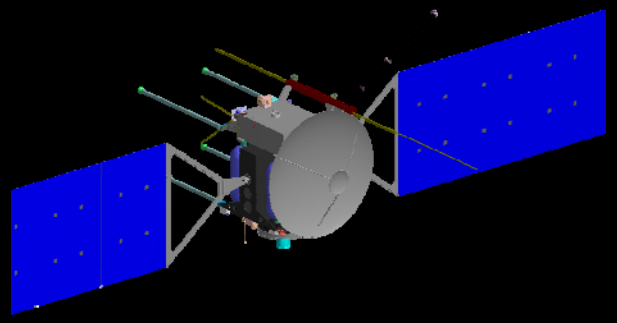
European Instrumentation for JEO					

Conclusions

- JGO is the ESA spacecraft within the EJSM-Laplace mission
- JGO is technically feasible
- JGO is ready to go: No need for critical technology identified
- JGO is compatible with programme constraints







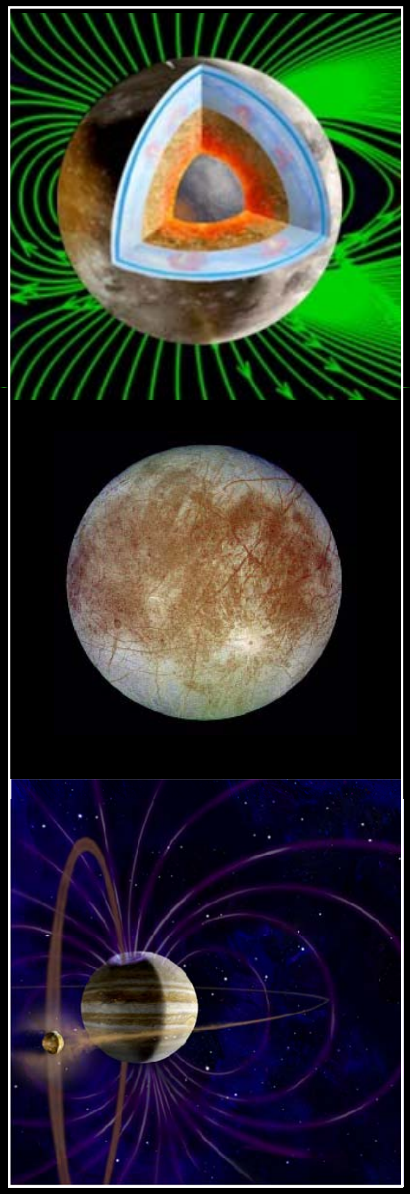
Summary

Michele Dougherty

Summary

EJSM-Laplace

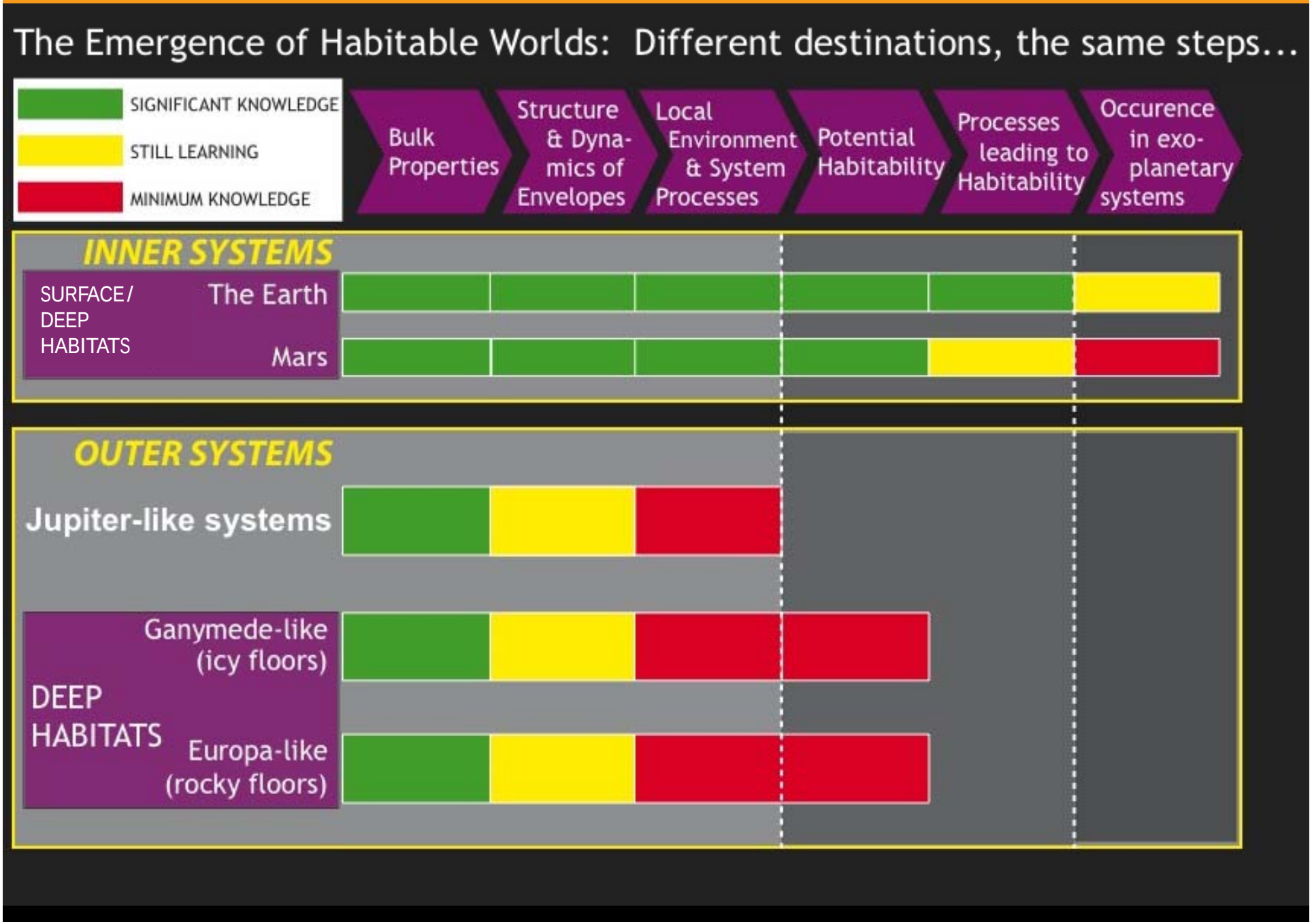
The emergence of habitable worlds around gas giants



- **Ganymede (JGO-focus):** Characterise Ganymede as a planetary object including its potential habitability
- **Europa (JEO-focus):** Explore Europa to investigate its habitability
- **Jupiter System (JGO + JEO):** Explore the Jupiter system as an archetype for gas giants

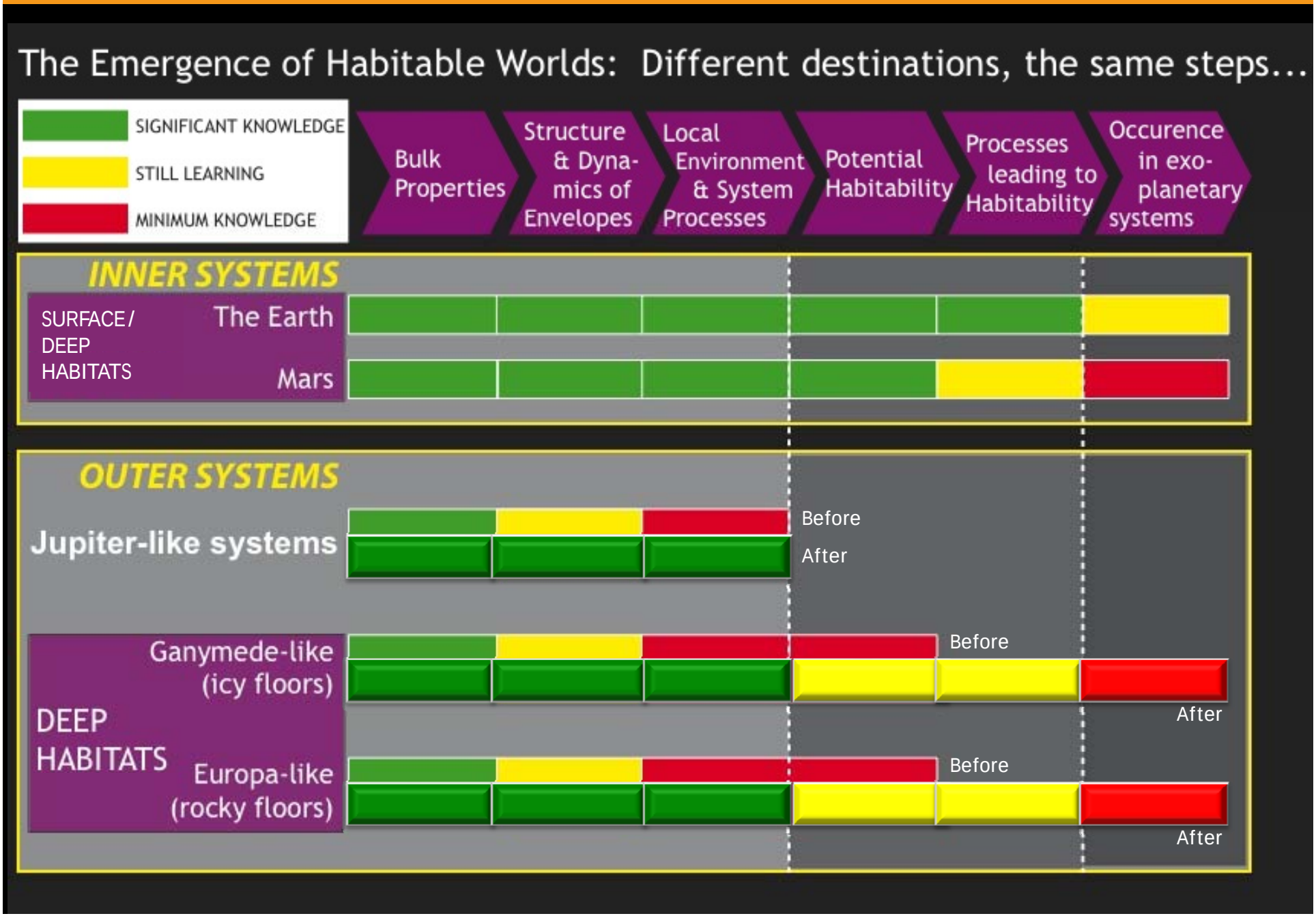
Summary : Our Knowledge

EJSM-Laplace



Summary : Our Knowledge

EJSM-Laplace



Thanks to the Joint Science Definition Team

EJSM-Laplace

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Many Credits for images and data:

Voyager, Galileo, Mars Express, New Horizons, NASA, ESA, DLR, JPL, IRTF, Jia, Kivelson, Khurana, Schenk, Clarke, Cowley, Grodent, Fukazawa, Bonfond, Reuter, Feldman, Spencer, Brandt, Carroll, Powell

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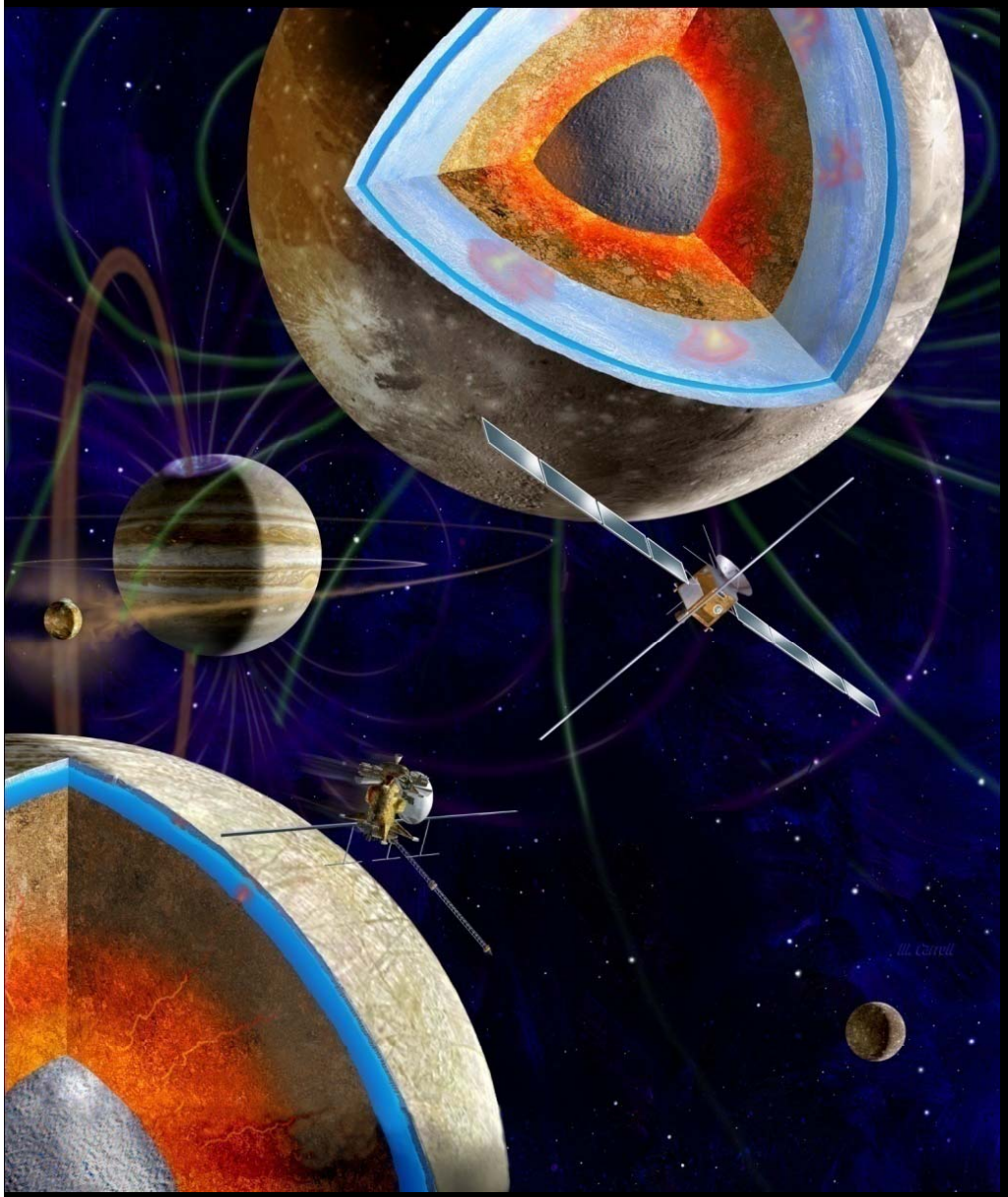
Hunter Waite (USA)

Summary: L-class Cosmic Vision Science

EJSM-Laplace



- Scientific goals and objectives are well-defined:
  - Broad appeal to different science communities
  - Flows from community priorities
  - Mature science coupled with exploration opportunities
- International cooperation:
  - JGO and JEO will offer unique scientific synergies
  - JGO and JEO each address key portions of EJSM-Laplace science
  - JGO and JEO could each stand on their own to achieve compelling icy world and Jupiter system science
- Mission is judged feasible with no need for critical technologies
- Many opportunities for public outreach

The emergence of habitable worlds around gas giant planets