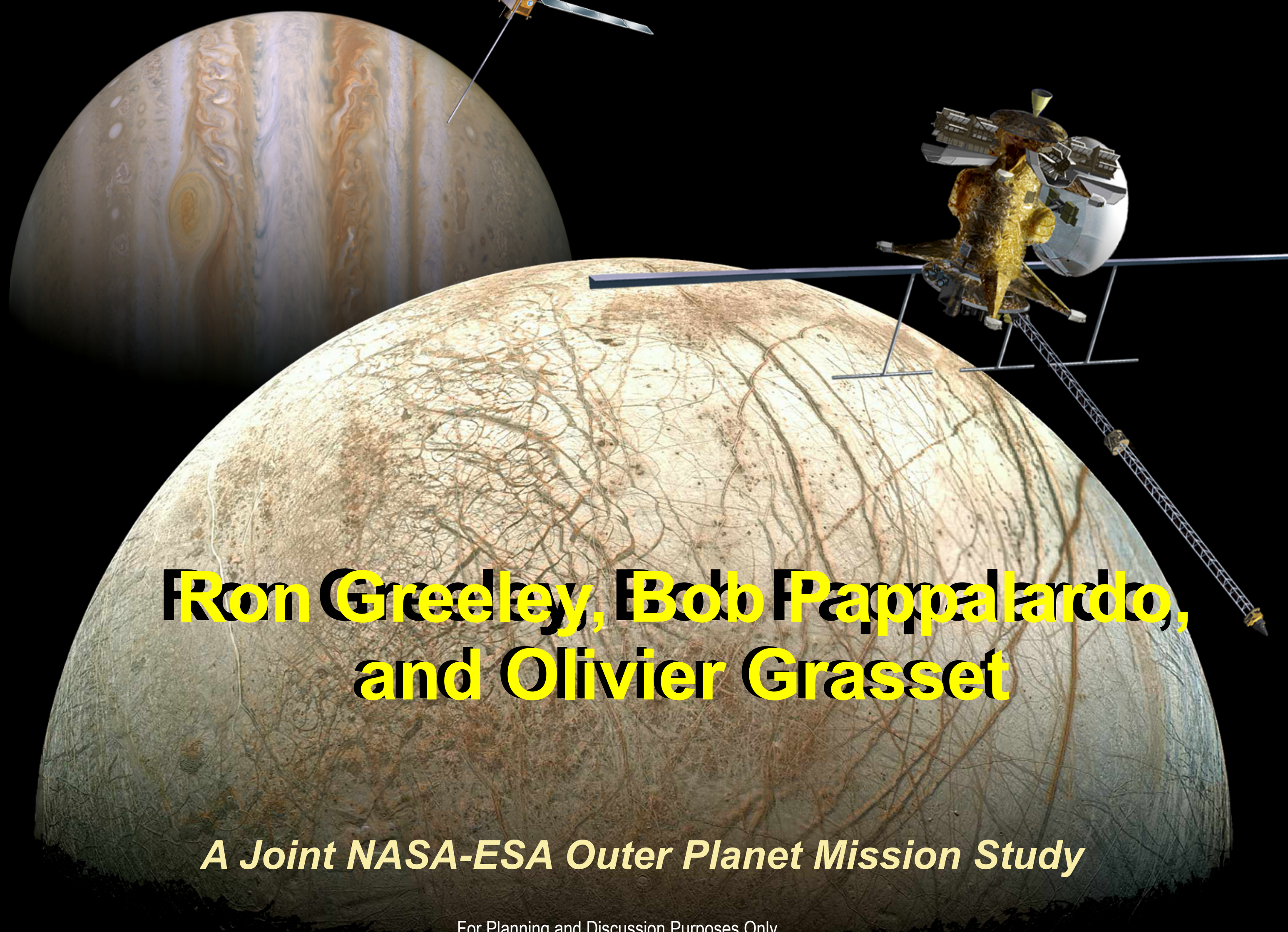
Exploring the Habitability of Icy Worlds:

The Europa Jupiter System Mission



Ron Greeley, Bob Pappalardo, and Olivier Grasset

A Joint NASA-ESA Outer Planet Mission Study

For Planning and Discussion Purposes Only

OPAG Review

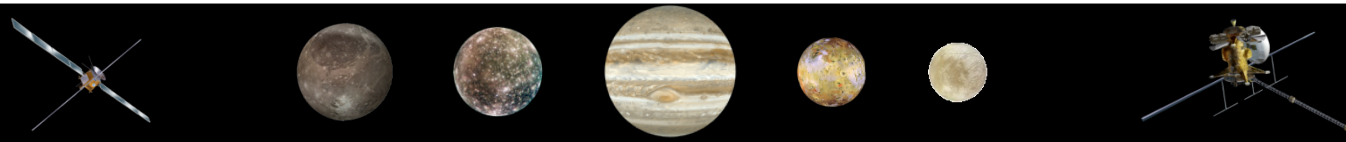
- Strategic Science Plan Status
- Europa Jupiter System Mission
  - Overview
  - Jupiter Europa Orbiter
  - Jupiter Ganymede Orbiter
- OPAG review and input

Strategic Science Plan

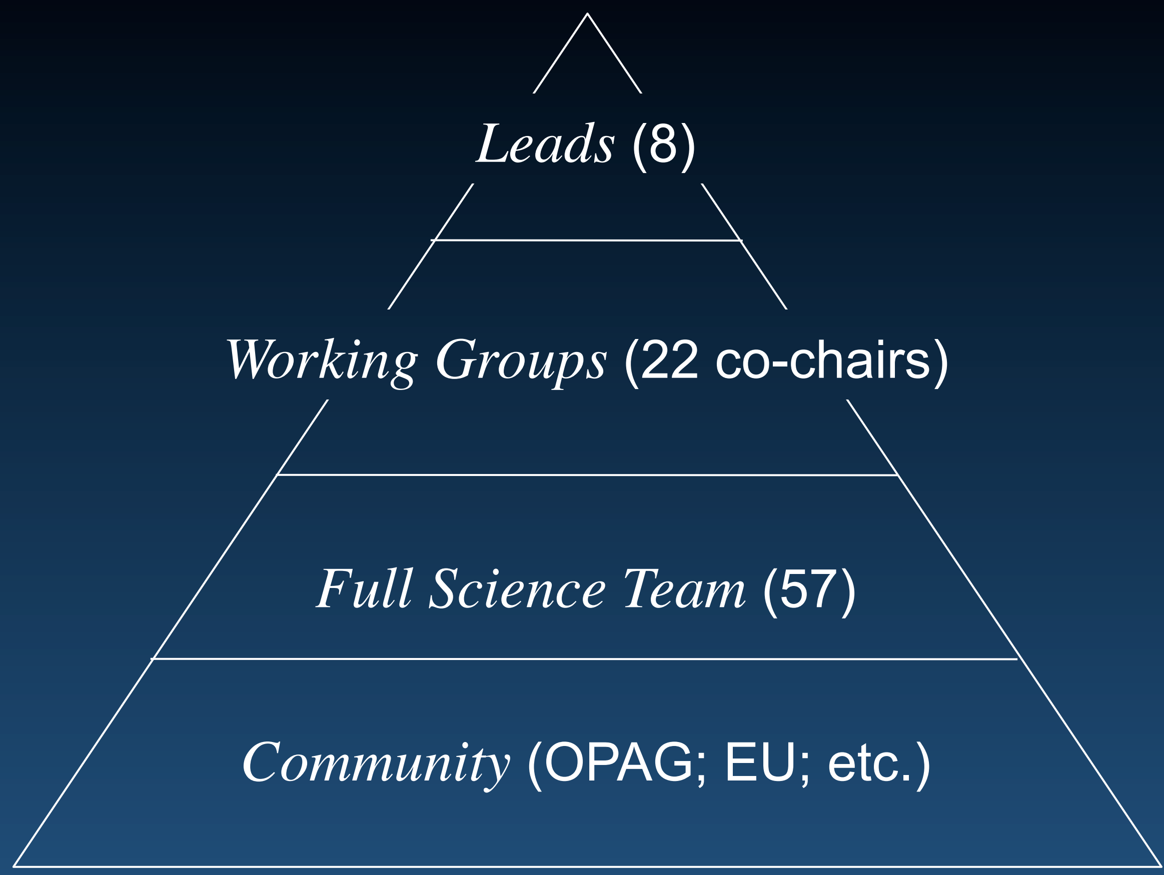
Europa Jupiter System Mission (EJSM)

Objectives

- Continue direct science involvement with JEO, JGO Projects
- “Retire” weaknesses identified in the NASA and ESA reviews
- Build the case for JGO to be an ESA “L” class mission
- Refine joint aspects of EJSM (JEO, JGO)
- Incorporate the best aspects from the Europa and Titan studies
- Engage broad science community and public support



EJSM Study Science Structure



Science Definition Team Working Groups

SDT Co-chairs plus community members

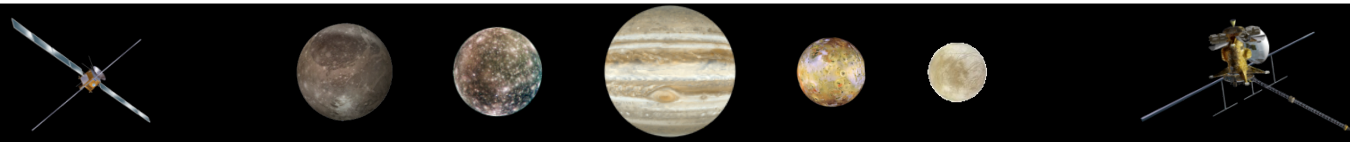
Working Group 1 (Satellites)

Geophysics	Bruce Bills, Hauke Hussman
Composition	Federico Tosi, Tom McCord
Ice	Don Blankenship, Olivier Grasset
Geology	Ralf Jauman, Jeff Moore
Atmospheres/exospheres	Melissa McGrath, Andrew Coates

Working Group 2 (Jupiter)	Pierre Drossert, Leigh Fletcher, Amy Simon-Miller
Working Group 3 (Magnetospheres)	Krishan Khurana, Norbert Krupp
Working Group 4 (Jupiter System)	Tim Van Hoolst, Melissa McGrath

Transverse/cross-cutting Working Groups

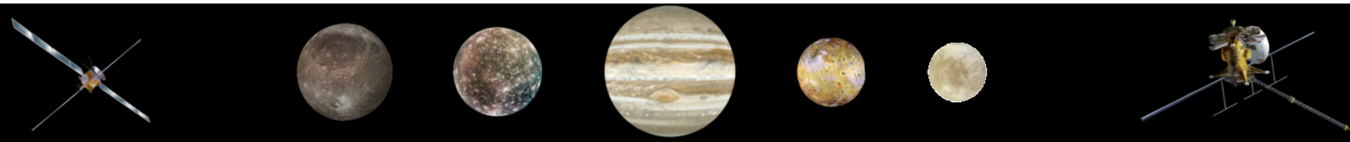
Working Group 5 (Origin and Formation)	Angioletta Coradini, Bill Moore, Hunter Waite
Working Group 6 (Astrobiology)	Kevin Hand, Olga Prieto-Ballesteros
Working Group 7 (Cosmic Connections)	Athena Coustenis, Masaki Fujimoto
Working Group 8 (Radio Science)	Paolo Tortora, Essam Marouf
Working Group 9 (Education Public Outreach)	Athena Coustenis, Ron Greeley, Michel Blanc, Louise Prockter



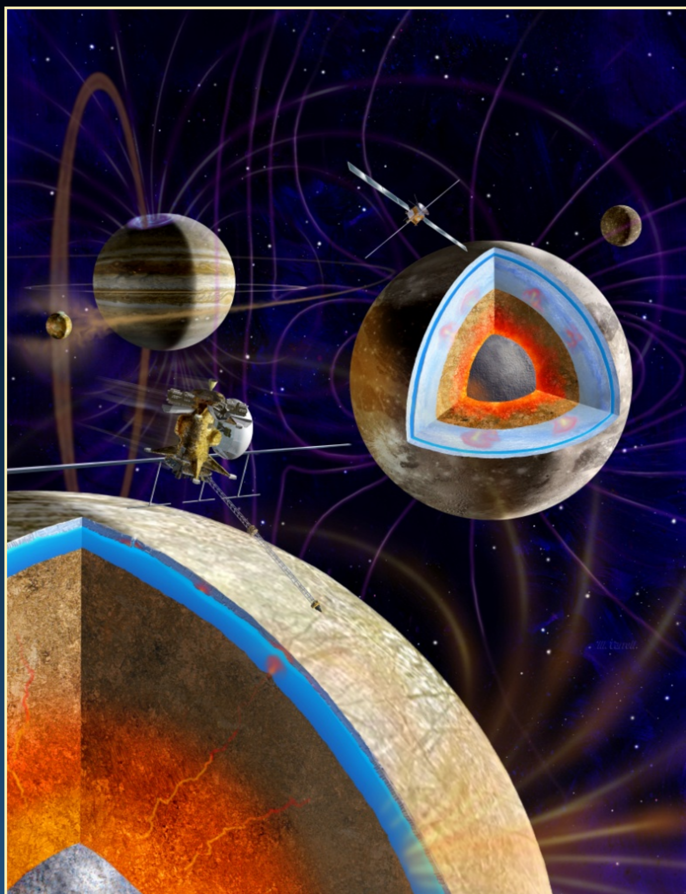
Community Engagement: Special Sessions

- *Lunar and Planetary Science Conference* (Houston, 23-27 Mar. 2009)
  Two sessions
- *European Geoscience Union* (Vienna, 19-24 Apr. 2009)
  Four sessions
- *EJSM Instrument Workshop* (Maryland, 15-17 Jul. 2009)
- *European Planetary Science Congress* (Potsdam, 13-18 Sep. 2009)
  Four sessions and two workshops
- *Division of Planetary Science* (Puerto Rico, 4-9 Oct. 2009)
  Several relevant sessions
- *Geological Society of America* (Portland, 18-21 Oct. 2009)
  Cryovolcanism in the Solar System
- *American Geophysical Union* (San Francisco, 14-18 Dec. 2009)
  The Galilean Satellites: 400 years of Discovery
- *Galileo 400th* (Padua, 6-9 Jan. 2010)
- *EJSM Instrument Workshop* (Noordwijk, 18-20 Jan. 2010)

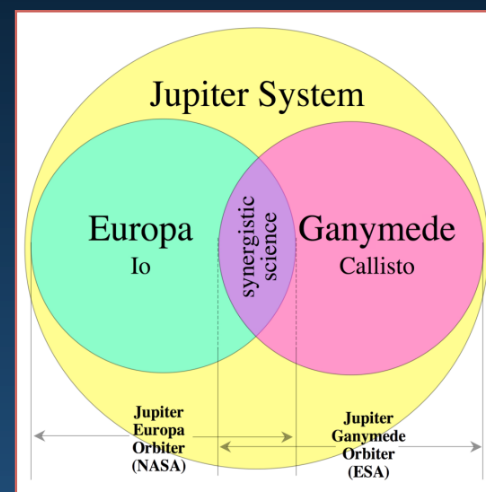
Similar sessions and activities will be held throughout 2010



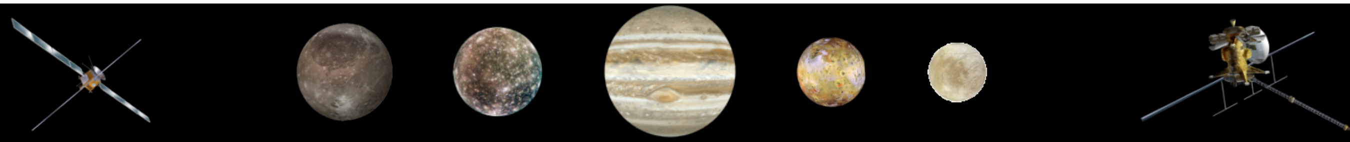
Europa Jupiter Science Mission (EJSM)



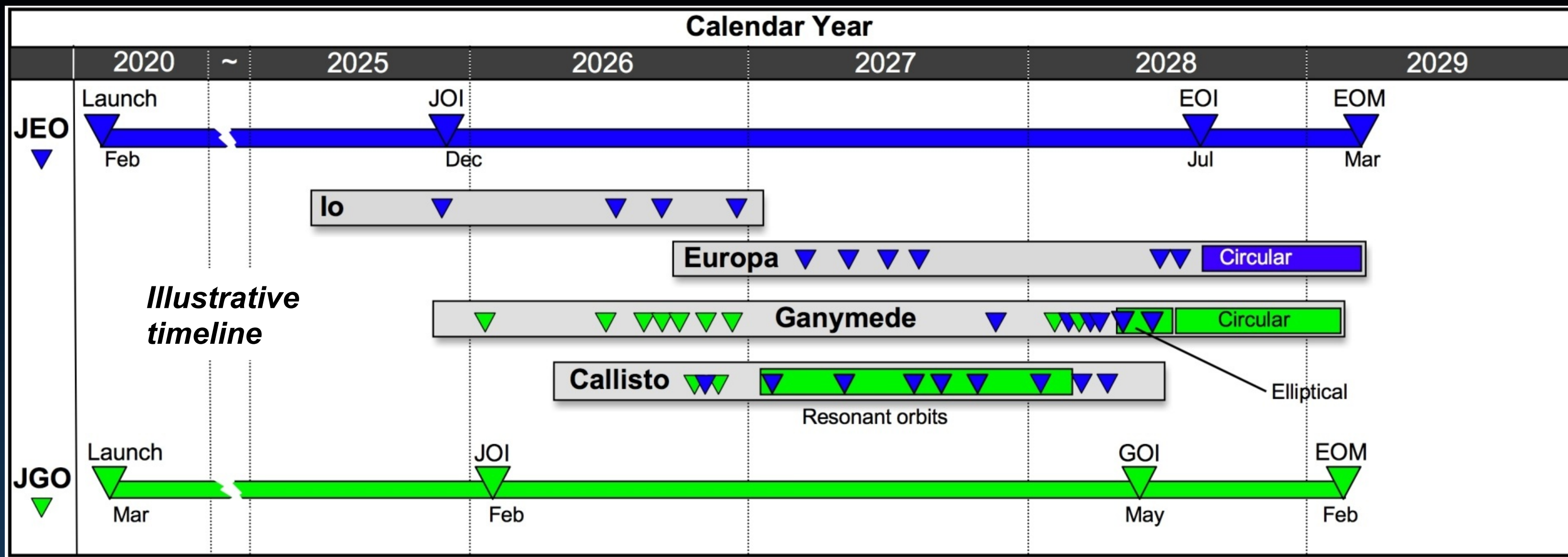
- NASA and ESA: Shared mission leadership
- Independently launched and operated orbiters
  - NASA-led Jupiter Europa Orbiter (JEO)
  - ESA-led Jupiter Ganymede Orbiter (JGO)
- Complementary science and payloads
  - JEO concentrates on Europa and Io
  - JGO concentrates on Ganymede and Callisto
  - Synergistic overlap
  - 11-12 instruments each
- Science goals:
  - Icy world habitability
  - Jupiter system processes



Synergistic science: The sum of JEO + JGO is greater than the parts



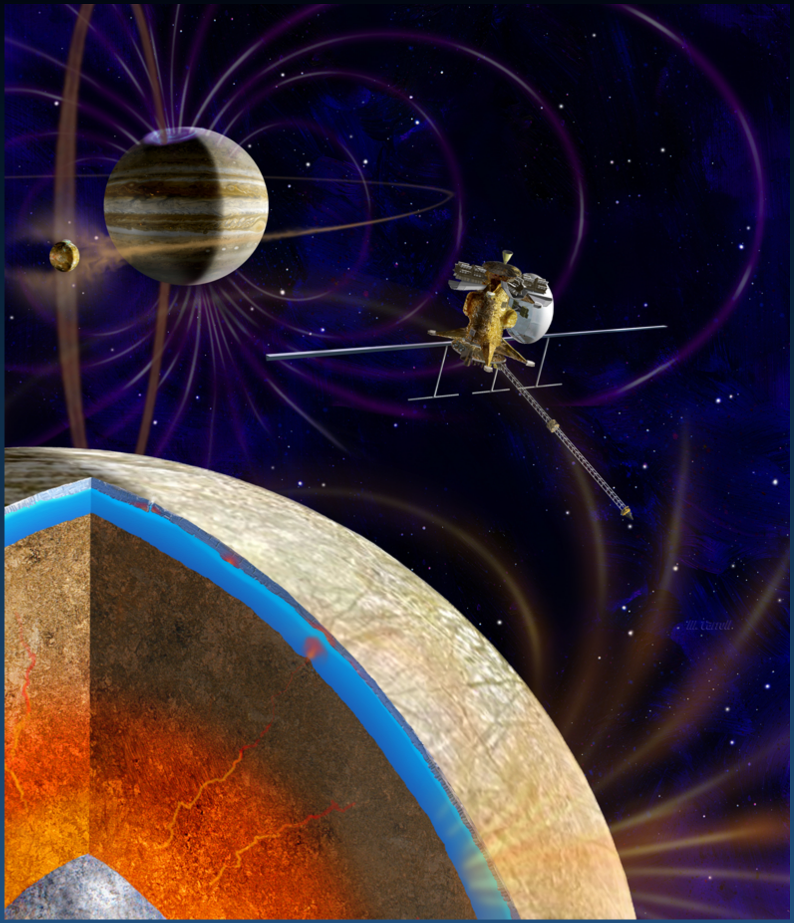
Nominal EJSM Timeline



- Launches: 2020
- Jovian system tour phases: 2–3 years
- Moon orbital phases: 6–12 months
- End of Prime Missions: 2029
- Flexibility if either flight element is delayed or advanced

Coordinated timelines ensure synergistic science

JEO Goal:
Explore Europa to Investigate Its Habitability

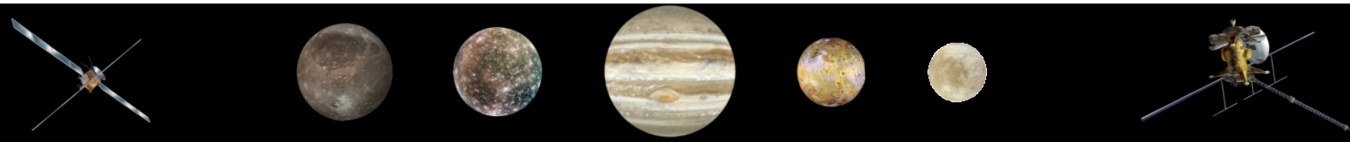


Objectives (prioritized):

Habitability

- Ocean and Interior
- Ice Shell
- Chemistry and Composition
- Geology and Landing Sites
- Jupiter System
  - Satellite surfaces and interiors
  - Satellite atmospheres
  - Plasma and magnetospheres
  - Jupiter atmosphere
  - Rings

Characterizing the archetype of icy world habitability

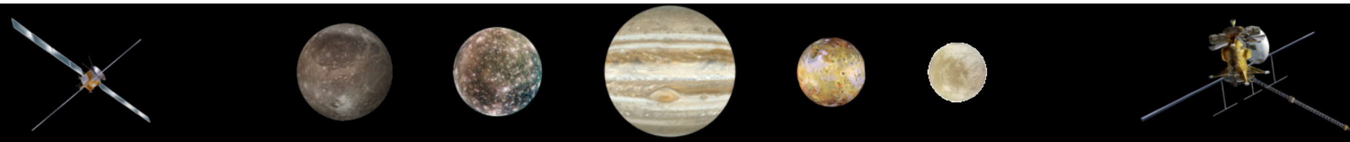


JEO Traceability: Europa

Goal		Science Objective	Science Investigation
Explore Europa to investigate its habitability.	A. Ocean	**Characterize the extent of the ocean and its relation to the deeper interior.**	A1. Determine the amplitude and phase of the gravitational tides.
			A2. Characterize the magnetic environment (including plasma) to determine the induction response from the ocean over multiple frequencies.
			A3. Characterize surface motion over the tidal cycle.
			A4. Determine the satellite's dynamical rotation state.
			A5. Investigate the core, rocky mantle, and rock-ocean interface.
	B. Ice	**Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.**	B1. Characterize the distribution of any shallow subsurface water.
			B2. Search for an ice-ocean interface.
			B3. Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.
			B4. Characterize regional and global heat flow variations.
	C. Chemistry	**Determine global surface compositions and chemistry, especially as related to habitability.**	C1. Characterize surface organic and inorganic chemistry, including abundances and distributions of materials, with emphasis on indicators of habitability and potential biosignatures.
			C2. Relate compositions to geological processes, especially material exchange with the interior.
			C3. Characterize the global radiation environment and the effects of radiation on surface composition, atmospheric composition, albedo, sputtering, sublimation, and redox chemistry.
			C4. Characterize the nature of exogenic materials.
	D. Geology	**Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future *in situ* exploration.**	D1. Determine the formation history and three-dimensional characteristics of magmatic, tectonic, and impact landforms.
			D2. Determine sites of most recent geological activity, and evaluate future landing sites.
			D3. Investigate processes of erosion and deposition and their effects on the physical properties of the surface debris.

JEO Themes: Origins | Evolution | Processes | Habitability | Life

Based on 2002 Decadal's "objectives of solar system exploration" esa



NASA

JEO Traceability: Jupiter System Science

Goal	Science Objective		Science Investigation
Explore Europa to investigate its habitability.	E. Jupiter system science **Understand Europa in the context of the Jupiter system.**	Satellite surfaces and interiors	E1. Investigate the nature and magnitude of tidal dissipation and heat loss on the Galilean satellites, particularly Io
			E2. Investigate Io's active volcanism for insight into its geological history and evolution (particularly of its silicate crust)
			E3. Investigate the presence and location of water within Ganymede and Callisto.
			E4. Determine the composition, physical characteristics, distribution and evolution of surface materials on Ganymede.
			E5. Determine the composition, physical characteristics, distribution and evolution of surface materials on Callisto.
			E6. Identify the dynamical processes that cause internal evolution and near-surface tectonics of Ganymede and Callisto.
		Satellite Atms.	E7. Characterize the composition, variability and dynamics of Europa's atmosphere and ionosphere
			E8. Understand the sources and sinks of Io's crustal volatiles and atmosphere.
			E9. Determine the sources and sinks of the Ganymede and Callisto atmospheres.
	Giant Planets Panel	Plasma and magnetospheres	E10. Characterize the neutral atoms and molecules escaping Europa's gravity.
			E11. Characterize the composition of and transport in Io's plasma torus.
			E12. Study the pickup and charge exchange processes in the Jupiter system plasma and neutral tori.
			E13. Study the interactions between Jupiter's magnetosphere and Io, Ganymede and Callisto (incl. characterize Ganymede's magnetic field)
			E14. Understand the structure, composition and stress balance of Jupiter's magnetosphere.
			E15. Determine how plasma and magnetic flux are transported in Jupiter's magnetosphere.
		Jupiter atm.	E16. Characterize the abundance of minor species (especially water and ammonia) in Jupiter's atmosphere to understand the evolution of the Jovian system, including Europa.
			E17. Characterize Jovian atmospheric dynamics and structure.
		Rings	E18. Characterize the properites of the small moons, ring source bodies and dust
			E19. Identify the dynamical processes that define the origin and dynamics of ring dust.

JEO Themes: Origins | Evolution | Processes | Habitability | Life

Europa Science Campaigns

JOI to EOI	Jul 2028	Aug 2028	Sep 2028	Oct 2028

Satellite & Jupiter Science

Initial Europa Orbit
Altitude: 200 km
Inclination: 95-100° (~85° N lat)
Lighting: 2:30 PM LST
Repeat: 4 Eurosols

After Campaign 1
Altitude: 100 km
Repeat: 6 Eurosols

Checkout (6 days)

Observing Strategies for Europa Campaigns 1-3
- Always on: LA, MAG, PPI, TI, INMS (50%)
- 2-orbit ops scenario permits power/data rate equalization:
  - Even orbits emphasize optical remote sensing
  - Odd orbits emphasize radar sounding to locate water
- Targets collected with residual data volume

1A **1B**

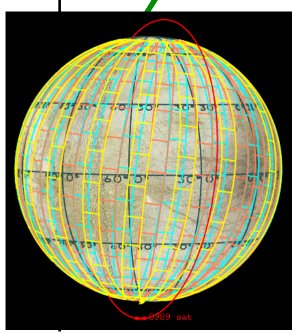
2A **2B**

3

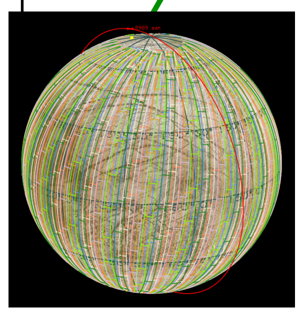
Focused Science

4

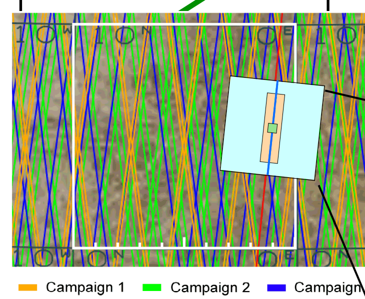
Europa Campaigns 1-3 total 99 days



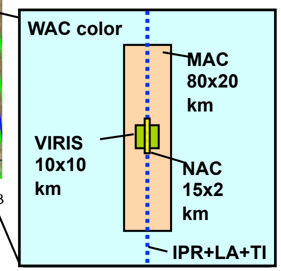
Global Framework
200 km altitude
(200 m/pixel WAC)
8 eurosols ≈ 28 days



Regional Processes
100 km altitude
(100 m/pixel WAC)
12 eurosols ≈ 43 days



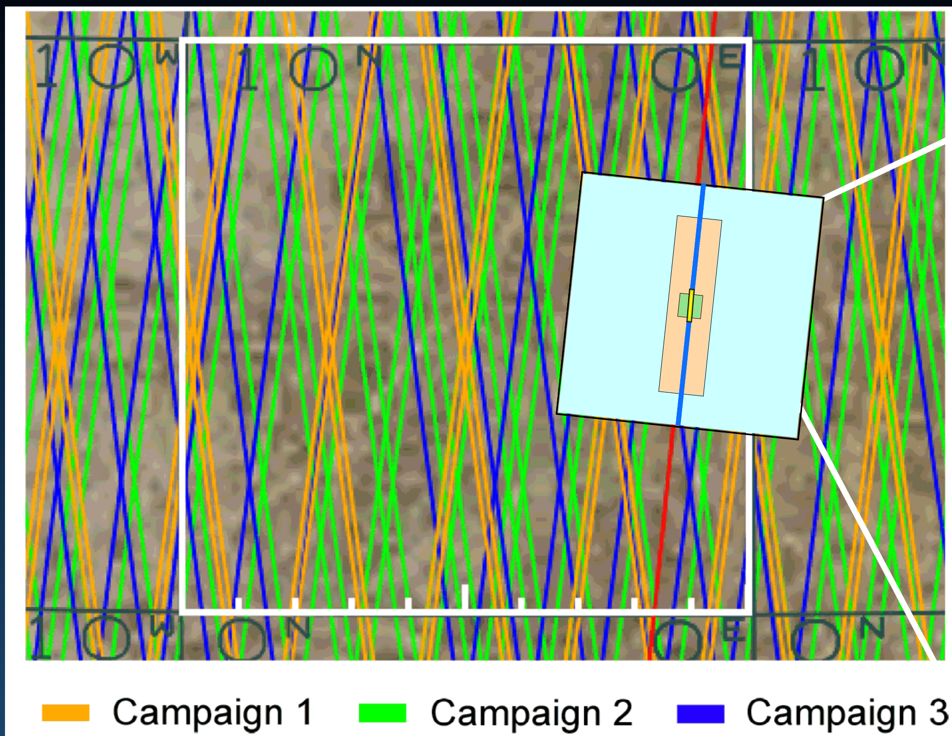
Targeted Processes
100 km altitude
8 eurosols ≈ 28 days



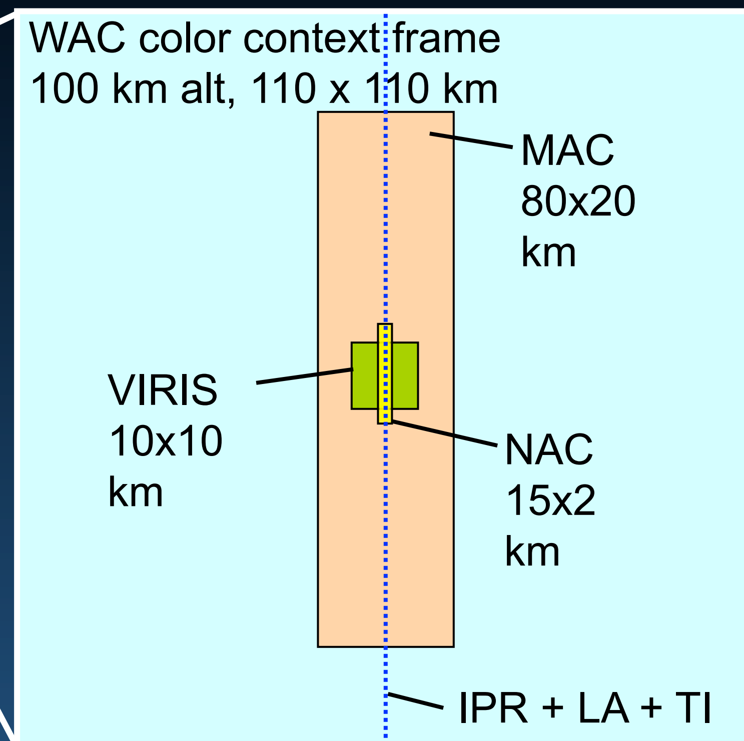
Coordinated Targets

Europa science objectives addressed in first 100 days in orbit

Europa Science Campaigns: Profiling and Targeted Observations

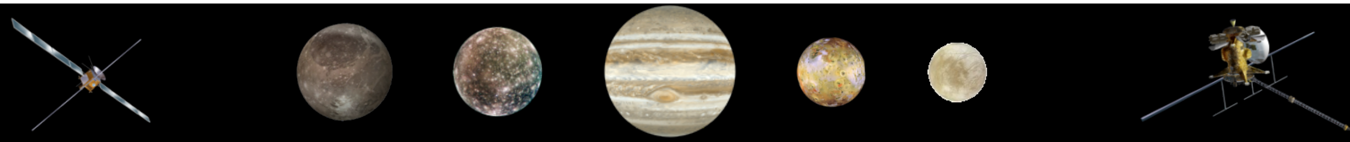


≤18 km groundtrack separation after 100 dy

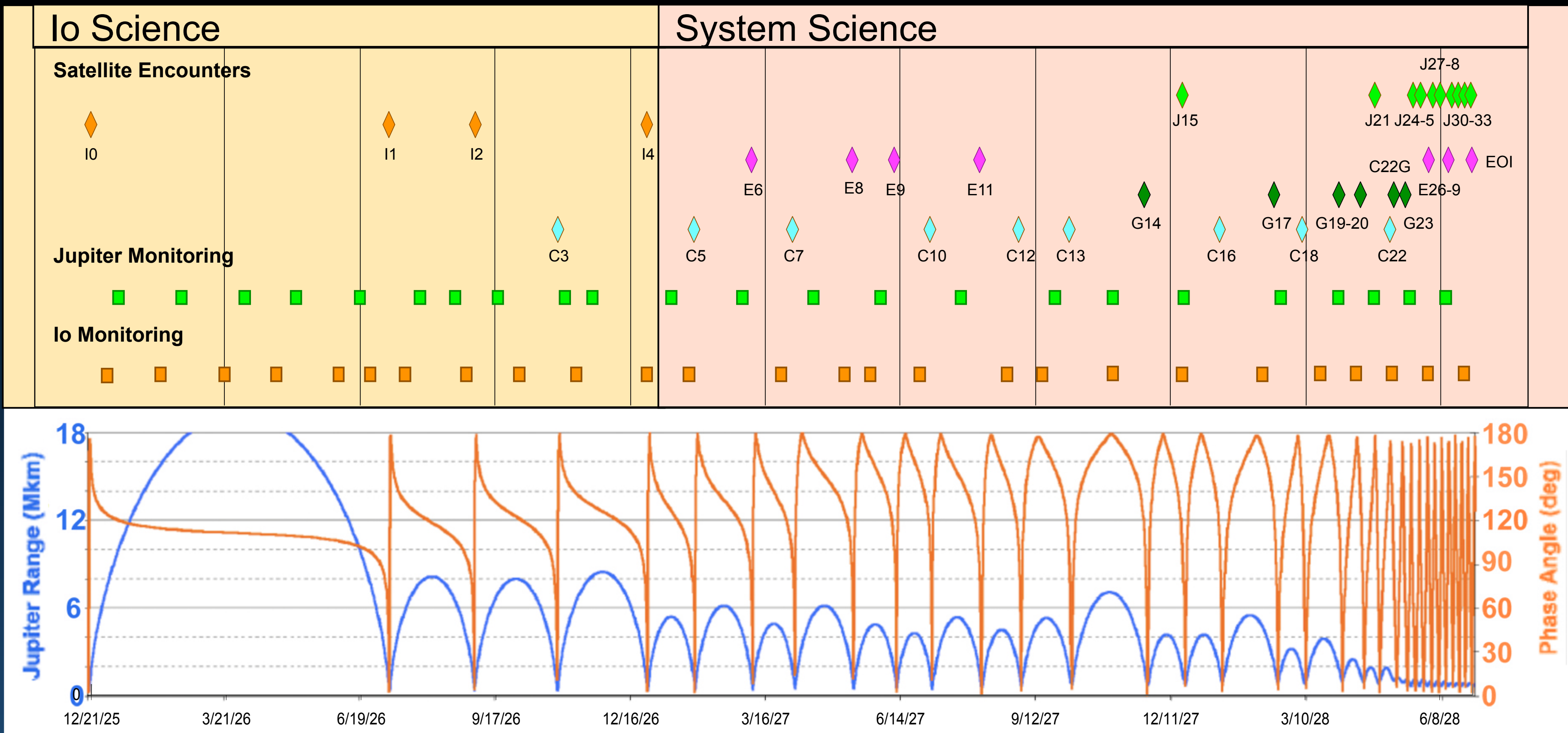


290 Mb coordinated targets

~1700 coordinated targeted observations obtained after 9 mo.



JEO Jovian Tour Example

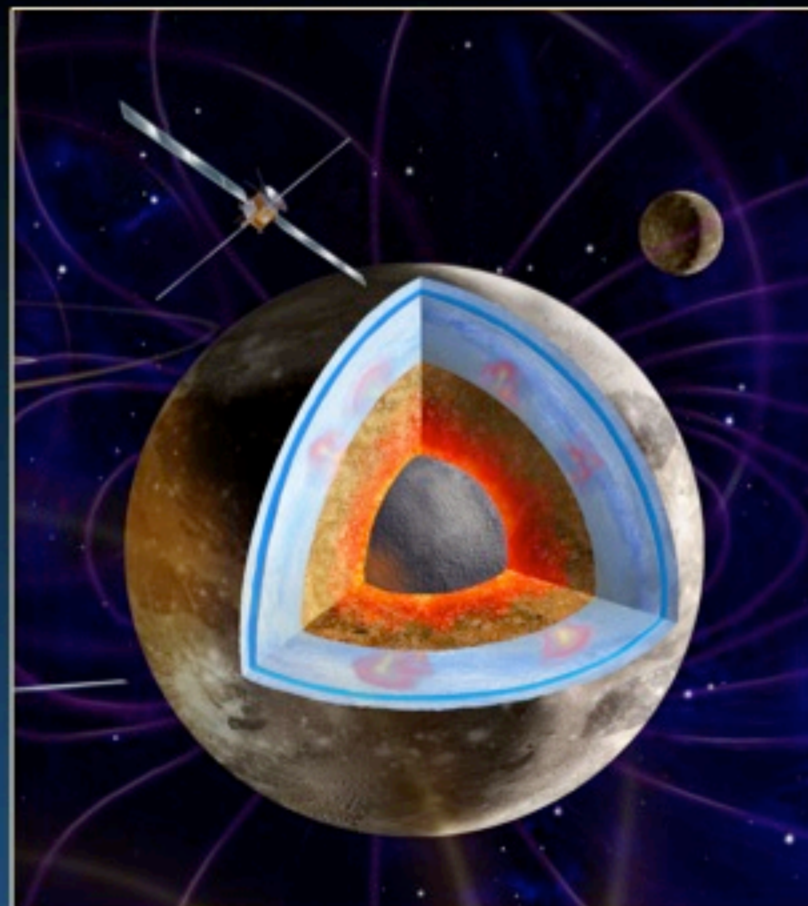


- 33 perijoves during Jovian Tour
  - 23 with satellite flybys
  - 22 permit JEO-Earth radio occultations

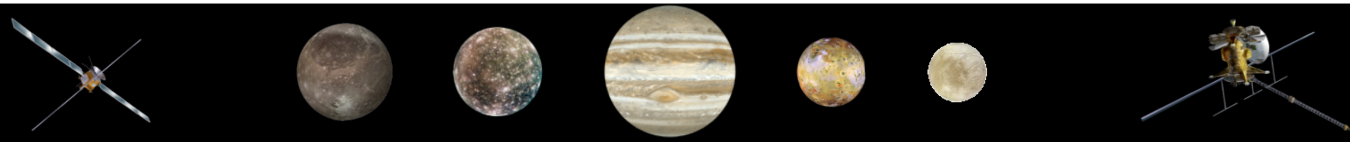
Rich opportunities to acquire Jupiter System Science

JGO Goals and Objectives

- Key JGO science phases
  - **Jupiter system:** In-depth exploration
    - From Jupiter orbit, synergistically with JEO
  - **Callisto:** In-depth study and mapping
    - Multiple flybys using a resonant orbit
  - **Ganymede:** Detailed orbital study
    - Elliptical orbit first, then circular orbit
- Science Objectives:
  - **Ganymede:** Characterize Ganymede as a planetary object, including its potential habitability
  - **Satellite System:** Study the Jovian satellite system
  - **Jupiter:** Study the Jovian atmosphere
  - **Magnetosphere:** Study the Jovian magnetodisk / magnetosphere
  - **Jupiter system:** Study the interactions occurring in the Jovian system



Characterizing the Jupiter system and its outer Galilean moons

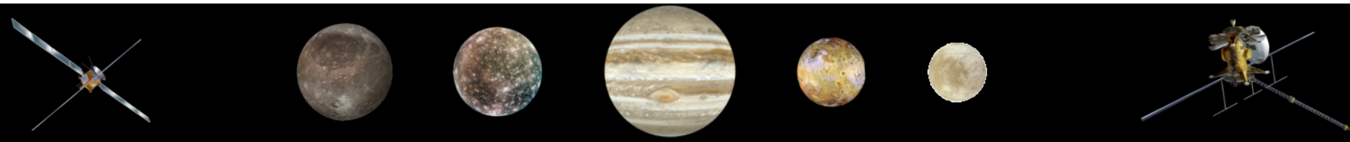


JGO Traceability: Ganymede

Goal	Science objective		Science investigation
Characterize Ganymede as a planetary object including its potential habitability	**A. Ice shell and ocean**	A1.	Time dependent altimetry and gravity to determine Love numbers h2 and k2.
		A2.	Study the magnetic field at multiple frequencies
		A3.	Subsurface characterization - Determine the properties of the icy shell and the presence and location of shallow liquid water.
		A4.	Constrain the amplitude of forced libration and obliquity and non-synchronous rotation
	B. Induced and intrinsic magnetic fields	B1.	Globally characterize Ganymede's intrinsic magnetic field (to accuracy of 0.1nT).
		B2.	Characterize particle population within Ganymede's magnetosphere and its interaction with Jupiter's magnetosphere
		B3.	Investigate the generation of Ganymede's aurora
		B4.	Study of the ionosphere and exosphere of Ganymede
		B5.	Investigate surface composition and structure on open vs. closed field line regions
	C. Geology and search for past and present activity	C1.	Improve global and regional mapping
		C2.	Topographic mapping of large fractions of the surface.
		C3.	Subsurface characterization
		C4.	Constrain global and regional surface ages
	D. Surface comp. and physical properties of subsurface layers	D1.	Nature and location of non-ice and organic compounds
		D2.	Constrain the existence and rate of mass transfer processes
	E. Deep interior	E1.	Precise determination of low-degree static gravity field and shape
		E2.	Detailed study of the intrinsic magnetic field
		E3.	Search for deviations from hydrostatic equilibrium and for mass anomalies

JEO Themes: **Origins** | **Evolution** | **Processes** | **Habitability** | **Life**

To be modified wrt Cosmic Vision themes before June 2010

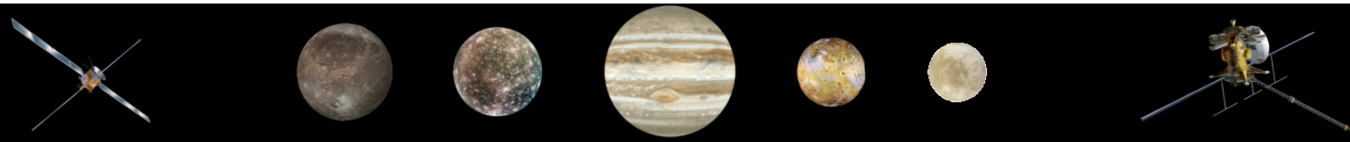


JGO Traceability: Satellites

Goal	Science objective	Science investigation
Study the Jovian satellite system	**F. Callisto: Study its surface composition, physical properties, putative ocean, and internal structure**	F1. Constrain the tidally varying potential and shape - Time dependent altimetry and gravity to determine Love numbers
		F2. Study the induced magnetic field at multiple frequencies
		F3. Subsurface characterization
		F4. Nature and location of non-ice and organic compounds
		F5. Constrain the amplitude of forced libration and obliquity and non-synchronous rotation
		F6. Precise determination of low-degree static gravity field and shape
		F7. Topographic mapping of large fractions of the surface.
		F8. Characterization of Callisto ionosphere and exosphere.
		F9. Constrain the existence and rate of mass transfer processes between a) leading vs trailing hemispheres (role of impactors and dust); b) north vs south hemispheres.
		F10. Constrain global and regional surface ages
		F11. Improve imaging coverage of Callisto's surface .
	G. Io and Europa	G1. Study of pick-up & charge-exchange processes in plasma/neutral tori
		G2. Monitor Io's activity at a wide range of longitudes and local times
		G3. Characterization of satellite's exospheres.
	H. Study the irregular satellites (if close flybys are feasible)	H1. Characteristics and chemical composition of the surfaces of outer irregular satellites
		H2. Astrometric observations and mass determination of irregular satellites
		H3. Search for new outer irregular satellites
	I. Investigate the inner region of the Jupiter system including the ring system	I1. Physical characterization and chemical composition of the ring system in 3D and over different timescales and search for new associated satellites
		I2. Characteristics and chemical composition of the surfaces of Thebe, Amalthea and other small inner satellites
		I3. Provide improved ephemerides and mass estimates for small inner satellites

JEO Themes:	Origins	Evolution	Processes	Habitability	Life

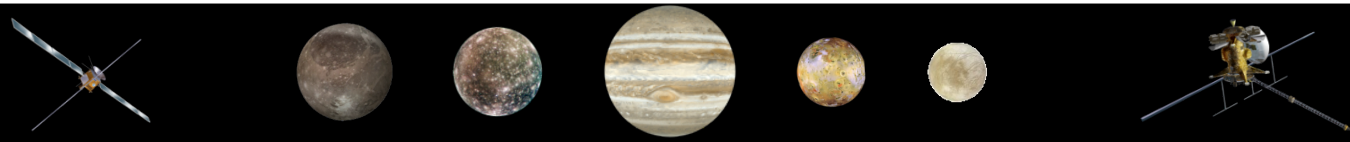
To be modified wrt Cosmic Vision themes before June 2010



JGO Traceability: Jupiter

Goal	Science objective		Science investigation
Study the jovian atmosphere	**J. The upper atmosphere**	J1.	Determination of general circulation & composition in the upper atmosphere
		J2.	Characterization of the vertical coupling in the atmosphere & of its drivers , ion drag or wave activity)
		J3.	Temperature structure retrieval from upper atmosphere to the troposphere
	EJSM	J4.	Characterization of ionospheric total electron densities & variations
		J5.	Characterization of the wave activity at low- to mid-latitudes and eddy activity and eddy meridional transport
	K. The stratosphere	K1.	Determination of the composition : H2O (characterisation of latitudinal variations, dynamics, role in atmospheric chemistry); HCN (dispersion following the SL9 impact), hydrocarbons (stratospheric chemistry) and haze; characterization of the strength of vertical mixing
		K2.	Determination of temperature structure from stellar and solar occultations over a wide range of latitudes in the upper stratosphere (1-km at 20 K per measurement).
		K3.	Determination of the general circulation in the stratosphere
	L. The troposphere	L1.	Determination of chemical composition : condensable species (NH3, H2O) and disequilibrium species (PH3, CO)
		L2.	Characterization of the strength of the vertical coupling in the atmosphere down to the troposphere
		L3.	Determination of the composition & vertical structure of clouds and cloud size distribution
		L4.	Study of the relation between the upper troposphere circulation & the deep circulation below the clouds & processes driving the jets circulation. Potential vorticity retrieval from combined dynamics and thermal measurements
	M. Internal structure of Jupiter	M1.	Constrain the existence and size of a core, and the nature of the H-H2 phase transition -

JEO Themes: | Origins | Evolution | Processes | Habitability | Life | To be modified wrt Cosmic Vision themes before June 2010



JGO Traceability: Magnetosphere & Jupiter System

Goal	Science objective		Science investigation
Study the Jovian magnetodisk/magnetosphere	**N. The magnetosphere as a fast magnetic rotator**	N1.	Characterize the properties of the magnetodisk with nearly 3D coverage in order to obtain good and reliable plasma moments (density, pressure, bulk flow velocity)
		N2.	Improve our understanding of the plasma processes acting in the magnetodisk
		N3.	Investigate the plasma sources, mass loading variability, composition, transport modes, and loss processes in the magnetosphere
		N4.	Study of the dust - plasma interactions
		N5.	Characterize the large-scale coupling processes between the magnetosphere, ionosphere and thermosphere
		N6.	Magnetospheric response to solar wind variability
		N7.	Look for direct evidence of the effects of the solar wind and planetary rotation on driving magnetospheric dynamics
	O. The magnetosphere as a giant accelerator	O1.	Characterize the time evolving Jovian radiation environment
		O2.	Improve our understanding of the particle bombardment of the surfaces of the moons
		O3.	Detail the particle acceleration processes
		O4.	Study the loss processes of charged energetic particles
		O6.	Observations of the moon auroral magnetic footprints
Study the interactions occuring in the jovian system	**P. Satellite / mag. interactions: the magnetosphere as a magnetized binary system**	P1.	Study of pick-up & charge-exchange processes in plasma/neutral tori
		P2.	Search for plasma effects on satellites (including irregular)
		P3.	Analysis of absorption signatures by moons, rings and dust
	Q. Tidal coupling among Jupiter and the satellites	Q1.	Determine short-term and long-term changes of the orbits of the Galilean satellites and the inner satellites
		Q2.	Study the coupled evolution of Io Europa and Ganymede by determining internal structures, heat flows, and tidal responses (including tidal phase lags) of the moons.

JEO Themes: Origins | Evolution | Processes | Habitability | Life — To be modified wrt Cosmic Vision themes before June 2010

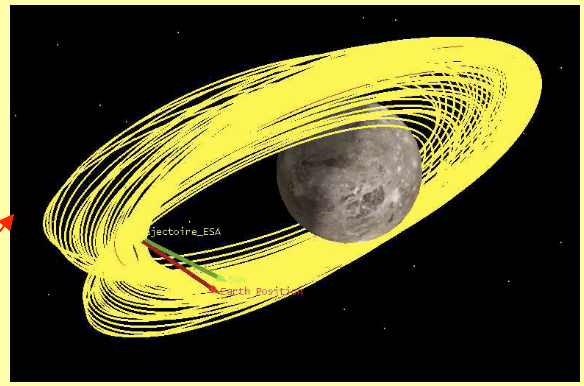
Around Ganymede in 300 Days

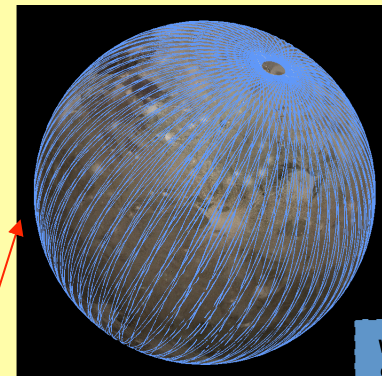
09 - 28 | 01 - 29 | 07 - 29

Phases 2-6 | Phase 7 - Total 300 days | …

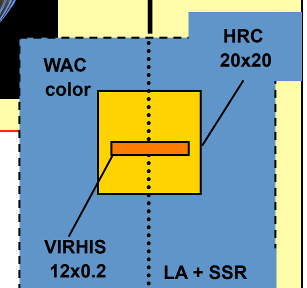
Satellite & Jupiter Science

7 A | 7 B | 7 C | 7 D | 8





Extended mission?

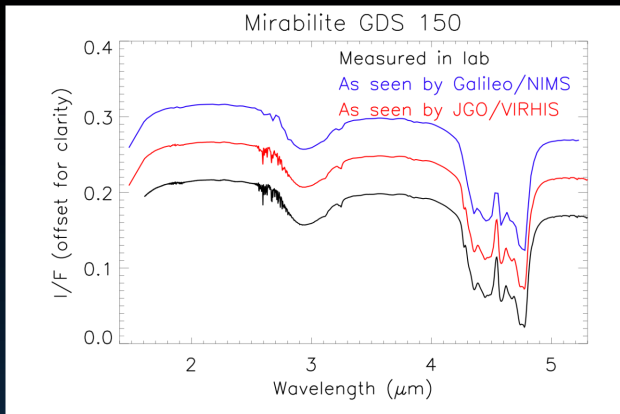


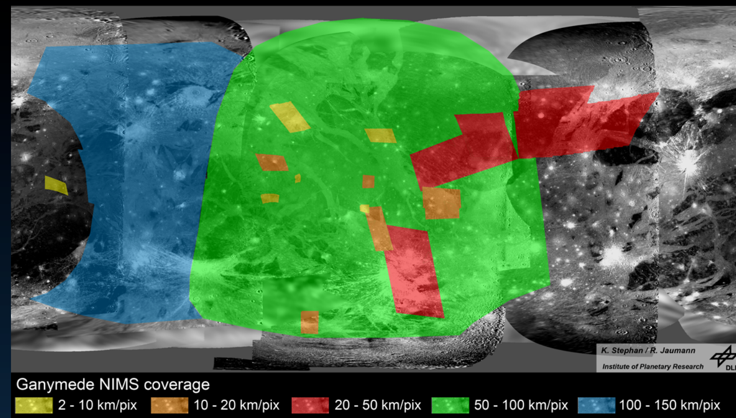
Global Framework
26 days of highly elliptical orbits (7A; 7C)
94 days at 5000 km altitude (7B)
•Study of the Ganymede's magnetospheric field
•Nearly global VIS-IR spectral mapping (2-2.5 km/pxl)
•Imaging (5 km/pxl WAC; 100-400 m/pxl HRC)
•Total: 120 days

Regional Framework
180 days circular
200 km altitude
•IR spectral mapping at 200 m/pxl
•Imaging (400 m/pxl WAC; 2-20 m/pxl HRC)
•Study of the Ganymede's intrinsic & induced magnetic field
•Altimetry, gravimetry, sub-surface sounding…

Ganymede science objectives addressed in 300 days in orbit

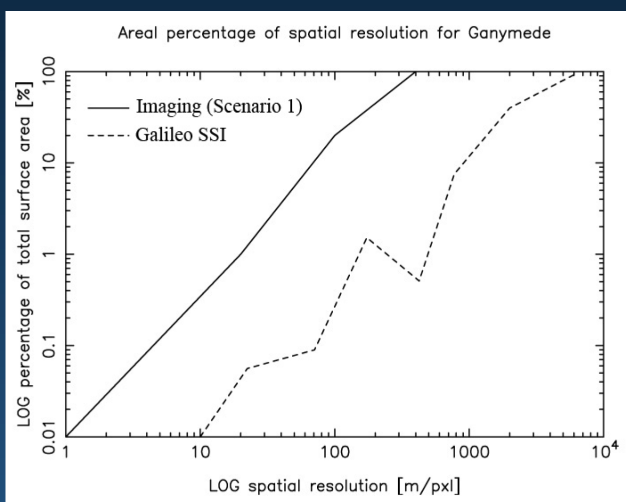
Around Ganymede in 300 Days: Some Examples

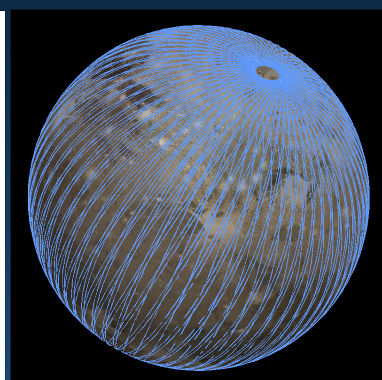




Remote sensing

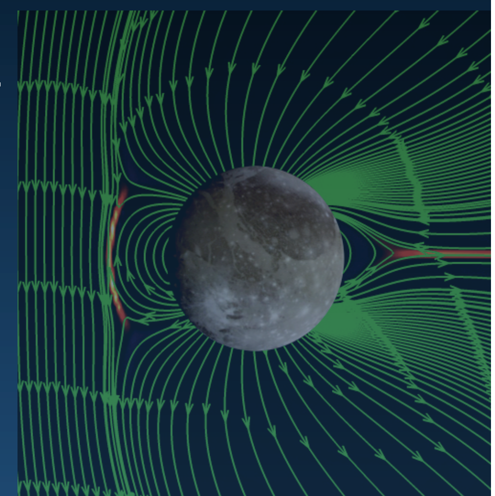
Significant improvement in spectral (x5) and spatial (80% at 2-2.5 km/pxl) resolution.





In situ continuous acquisition

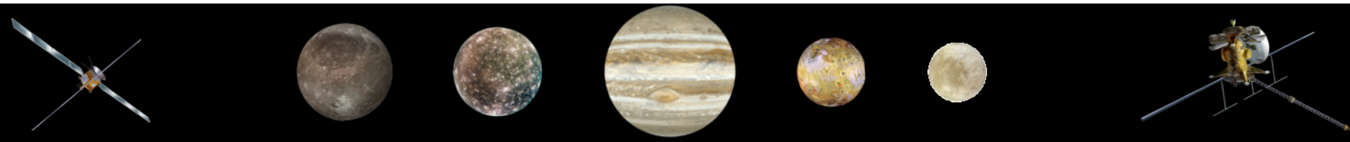
Full investigation of intrinsic and induced magnetic fields



Imaging & Topography

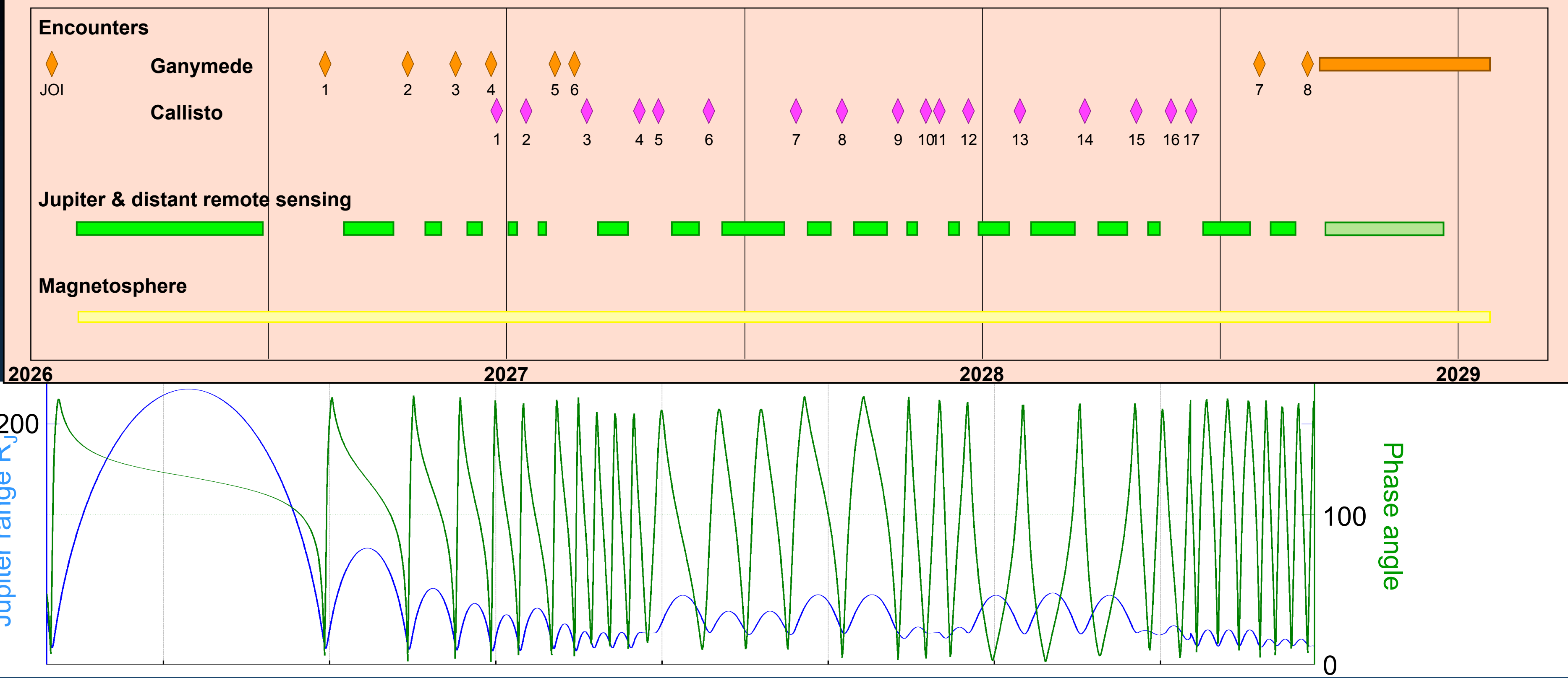
Significant improvement in spatial coverage

> 400 Gb of compressed data



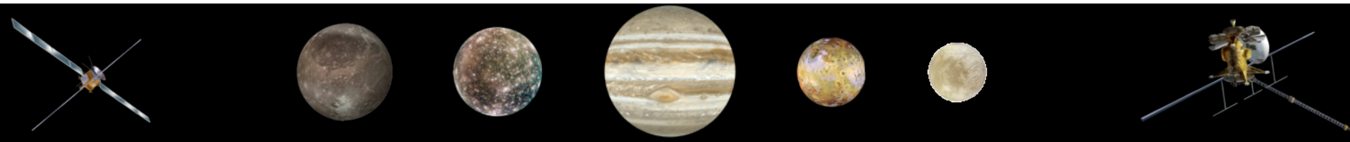
JGO Jovian Tour Example

Science Observations

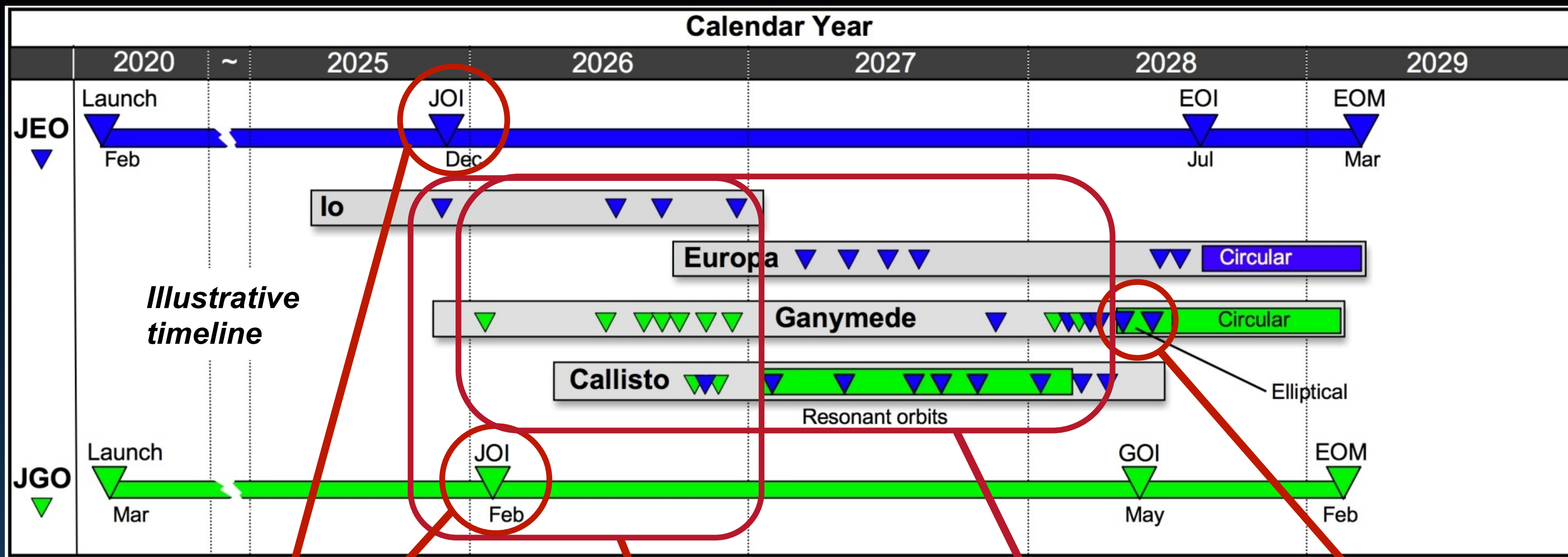


- 17 Callisto flybys
- 8 Ganymede flybys
- 33 perijove at ~15 R_J

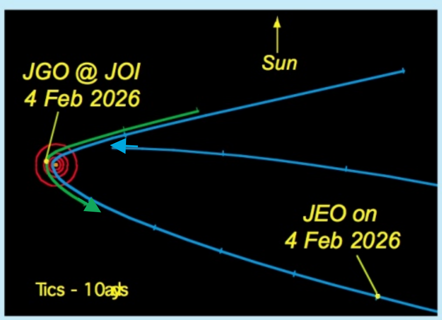
Rich opportunities to acquire Jupiter System Science



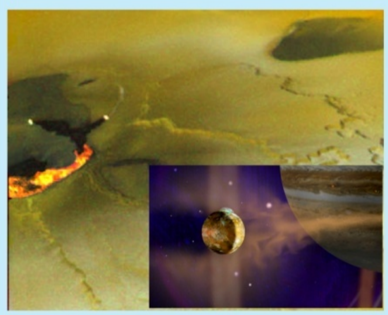
EJSM Synergistic Science



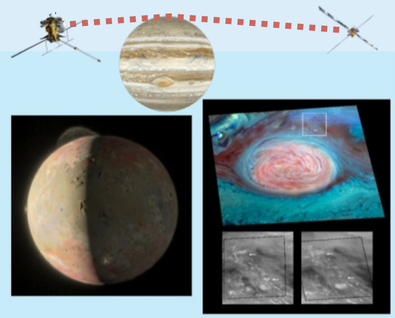
Jupiter Magnetosphere Studies



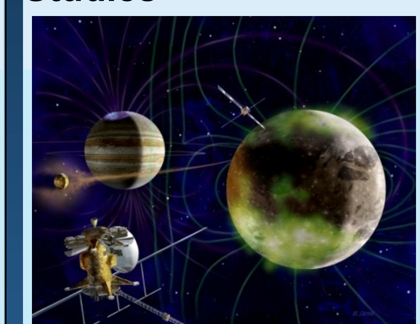
Io Volcanism & Io Torus Dynamics



Satellite & Jupiter Monitoring; Radio Occultation Science?



Ganymede Magnetosphere Studies



OPAG Feb 2010: What's Needed?

- Discussion sessions (Tues. morning)
  - Satellites (Dave Senske, Olivier Grasset)
  - Jupiter (Amy Simon-Miller, Leigh Fletcher, Bob Pappalardo)
  - Review the science
  - "Walk through" the example Jovian Tour
  - Make recommendations
- Jupiter System Science (Melissa McGrath)
  - Synergistic Magnetospheric Science (Norbert Krupp)
  - General Discussion (all)