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
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

Leads (8)

Working Groups (22 co-chairs)

Full Science Team (57)

Community (OPAG; EU; etc.)
Science Definition Team Working Groups

SDT Co-chairs plus community members

**Working Group 1 (Satellites)**
- Geophysics
- Composition
- Ice
- Geology
- Atmospheres/exospheres

Bruce Bills, Hauke Hussman
Federico Tosi, Tom McCord
Don Blankenship, Olivier Grasset
Ralf Jauman, Jeff Moore
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

  *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
• 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):

- 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

<table>
<thead>
<tr>
<th>Goal</th>
<th>Science Objective</th>
<th>Science Investigation</th>
</tr>
</thead>
</table>
| Explore Europa to investigate its habitability. | 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. |
| | 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.  
| | 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. |
| | 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”**  
**OPAG Feb 2010 Pre-decisional, For Planning and Discussion Purposes Only**
## JEO Traceability: Jupiter System Science

<table>
<thead>
<tr>
<th>Goal</th>
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<th>Science Investigation</th>
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| Explore Europa to investigate its habitability. | Understand Europa in the context of the Jupiter system. | 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. |
E8. Understand the sources and sinks of Io's crustal volatiles and atmosphere.  
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)  
E15. Determine how plasma and magnetic flux are transported in Jupiter's magnetosphere.  
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.  
E18. Characterize the properties 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

Pre-decisional, For Planning and Discussion Purposes Only
## Europa Science Campaigns

<table>
<thead>
<tr>
<th>JOI to EOI</th>
<th>Jul 2028</th>
<th>Aug 2028</th>
<th>Sep 2028</th>
<th>Oct 2028</th>
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</thead>
<tbody>
<tr>
<td><strong>Satellite &amp; Jupiter Science</strong></td>
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<tr>
<td><strong>Initial Europa Orbit</strong></td>
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<tr>
<td>Altitude: 200 km</td>
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<td>Inclination: 95-100° (~85° N lat)</td>
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<td>Lighting: 2:30 PM LST</td>
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<td>Repeat: 4 Eurosols</td>
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<tr>
<td><strong>After Campaign 1</strong></td>
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<td>Altitude: 100 km</td>
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<td>Repeat: 6 Eurosols</td>
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<td><strong>Europa Campaigns 1-3 total 99 days</strong></td>
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<tr>
<td><strong>Global Framework</strong></td>
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<tr>
<td>200 km altitude</td>
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<tr>
<td>(200 m/pixel WAC)</td>
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<tr>
<td>8 eurosols ≈ 28 days</td>
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<tr>
<td><strong>Regional Processes</strong></td>
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<td>100 km altitude</td>
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<tr>
<td>(100 m/pixel WAC)</td>
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<td>12 eurosols ≈ 43 days</td>
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<td><strong>Targeted Processes</strong></td>
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<td>100 km altitude</td>
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<td>8 eurosols ≈ 28 days</td>
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<tr>
<td><strong>Observing Strategies for Europa Campaigns 1-3</strong></td>
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<tr>
<td>• Always on: LA, MAG, PPI, TI, INMS (50%)</td>
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<td>• 2-orbit ops scenario permits power/data rate equalization:</td>
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<td>- Even orbits emphasize optical remote sensing</td>
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<td>- Odd orbits emphasize radar sounding to locate water</td>
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<td>• Targets collected with residual data volume</td>
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**Focused Science F4**

**Coordinated Targets**

**Europa science objectives addressed in first 100 days in orbit**

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Europa Science Campaigns: Profiling and Targeted Observations

- WAC color context frame: 100 km alt, 110 x 110 km
  - MAC: 80x20 km
  - NAC: 15x2 km
  - VIRIS: 10x10 km

- IPR + LA + TI

- ≤18 km groundtrack separation after 100 dy

- 290 Mb coordinated targets

- ~1700 coordinated targeted observations obtained after 9 mo.
### Io Science

<table>
<thead>
<tr>
<th>Satellite Encounters</th>
<th>Jupiter Monitoring</th>
<th>Io Monitoring</th>
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<tbody>
<tr>
<td>I0</td>
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<td>I1</td>
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<td>I2</td>
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<td>I4</td>
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<td>C3</td>
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### System Science

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<td>C5</td>
<td>C7</td>
<td>C10</td>
<td>C12</td>
<td>C13</td>
<td>G17</td>
<td>G19-20</td>
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- 33 perijoves during Jovian Tour
  - 23 with satellite flybys
  - 22 permit JEO-Earth radio occultations

**Rich opportunities to acquire Jupiter System Science**

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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

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

### JEO Themes:

- **Origins**
- **Evolution**
- **Processes**
- **Habitability**
- **Life**

To be modified wrt Cosmic Vision themes before June 2010

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</table>
| **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.  
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  
| **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
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<tr>
<td><strong>K. The stratosphere</strong></td>
<td>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&lt;br&gt;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).&lt;br&gt;K3. Determination of the general circulation in the stratosphere</td>
<td></td>
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<tr>
<td><strong>L. The troposphere</strong></td>
<td>L1. Determination of chemical composition: condensable species (NH3, H2O) and disequilibrium species (PH3, CO)&lt;br&gt;L2. Characterization of the strength of the vertical coupling in the atmosphere down to the troposphere&lt;br&gt;L3. Determination of the composition &amp; vertical structure of clouds and cloud size distribution&lt;br&gt;L4. Study of the relation between the upper troposphere circulation &amp; the deep circulation below the clouds &amp; processes driving the jets circulation.</td>
<td>Potential vorticity retrieval from combined dynamics and thermal measurements</td>
</tr>
<tr>
<td><strong>M. Internal structure of Jupiter</strong></td>
<td>M1. Constrain the existence and size of a core, and the nature of the H-H2 phase transition -</td>
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</table>

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

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### JGO Traceability: Magnetosphere & Jupiter System

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</table>
| 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  
**O5.** Observations of the moon auroral magnetic footprints |
| Study the interactions occurring 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 |
| Study the interactions occurring in the Jovian system | **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
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/pixel)
• Imaging (5 km/pixel WAC; 100-400 m/pixel HRC)
• Total: 120 days

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

Ganymede science objectives addressed in 300 days in orbit
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
Science Observations

Encounters
- 17 Callisto flybys
- 8 Ganymede flybys
- 33 perijove at ~15 R₉

Rich opportunities to acquire Jupiter System Science
## EJSM Synergistic Science

### Illustrative timeline

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>Notes</th>
</tr>
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<tbody>
<tr>
<td>2020</td>
<td>Launch JEO</td>
<td>Feb</td>
</tr>
<tr>
<td></td>
<td>JOI</td>
<td>Dec</td>
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<tr>
<td>2025</td>
<td>JOI</td>
<td></td>
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<tr>
<td>2026</td>
<td>GoI</td>
<td>Feb</td>
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<td>2027</td>
<td>GoI</td>
<td>May</td>
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<td>2028</td>
<td>EOI</td>
<td>Jul</td>
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<td>2029</td>
<td>EOM</td>
<td>Mar</td>
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</table>

**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)