Europa Study Update

OPAG meeting, Pasadena, CA
10/19/2011
Science
Bob Pappalardo
Europa Study Scientist and SDT Chair
OPAG meeting, Pasadena, CA
10/19/2011
Ingredients for Life

• Three “ingredients” necessary for life:
  – Water: Solvent to facilitate chemical reactions
  – Chemistry: Constituents to build organic molecules
  – Energy: Disequilibrium to drive metabolism

“Because of this ocean’s potential suitability for life, Europa is one of the most important targets in all of planetary science.”

–NRC Planetary Decadal Survey 2011
Decadal Survey Recommendations

• “Both JEO and the Mars Sample Return campaign (beginning with MAX-C) were found to have exceptional science merit.”

• JEO is “second highest priority Flagship mission” relative to MAX-C, based on “pragmatic reasons associated with the required spending profiles.”

• JEO’s “cost as currently designed is so high that both a decrease in mission scope and an increase in NASA’s planetary budget are necessary to make it affordable.”

• “Possible pathways to lower cost include use of a larger launch vehicle that would reduce cost risk by shortening and simplifying the mission design, and a significant reduction in the science payload. Other possible descopes were listed in section 4.1.5 of the 2008 JEO mission study final report.”

• For plutonium savings, switch from MMRTG to ASRGs

• MAX-C was chosen over JEO foremost “to maintain programmatic balance by assuring that no one mission takes up too large a fraction of the planetary budget at any given time.”

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Pre-Decisional — For Planning and Discussion Purposes Only
• To achieve the highest priority JEO Europa science objectives, invoke a two-element approach
  – Orbiter element to perform geophysical measurements (“Ocean” science) which can only be achieved from Europa orbit
  – Multiple-flyby element to perform remote measurements (“Chemistry” and “Energy” science) which can be achieved from Jupiter orbit
• Each achieves key science objectives, and each has very high science value of its own
  – Neither science nor element cost (~$1.5B FY15) is a clear discriminator between elements
• The complementary elements would fly separately, and staggered in time
  – Anticipate the second element would be presented to the next Decadal Survey for consideration
• A landed element is now being studied by the Europa SDT at NASA’s request
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fran Bagenal</td>
<td>Univ. Colorado</td>
<td>Plasma</td>
</tr>
<tr>
<td>Amy Barr</td>
<td>SwRI</td>
<td>Geophysics</td>
</tr>
<tr>
<td>Bruce Bills</td>
<td>JPL</td>
<td>Geophysics</td>
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<td>Diana Blaney</td>
<td>JPL</td>
<td>Composition</td>
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<tr>
<td>Don Blankenship</td>
<td>Univ. Texas</td>
<td>Ice shell</td>
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<tr>
<td>Will Brinckerhoff*</td>
<td>GSFC</td>
<td>Astrobiology</td>
</tr>
<tr>
<td>Jack Connerney</td>
<td>GSFC</td>
<td>Magnetometry</td>
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<tr>
<td>Kevin Hand*</td>
<td>JPL</td>
<td>Astrobiology</td>
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<tr>
<td>Tori Hoehler*</td>
<td>Ames</td>
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<td>Bill Kurth</td>
<td>Univ. Iowa</td>
<td>Plasma</td>
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<tr>
<td>Melissa McGrath</td>
<td>MSFC</td>
<td>Atmosphere</td>
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<tr>
<td>Mike Mellon*</td>
<td>Univ. Colorado</td>
<td>Ice Physics</td>
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<td>Jeff Moore</td>
<td>Ames</td>
<td>Geology</td>
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<tr>
<td>Bob Pappalardo</td>
<td>JPL</td>
<td>Chair / Study Scientist</td>
</tr>
<tr>
<td>Louise Prockter</td>
<td>APL</td>
<td>Deputy / Geology</td>
</tr>
<tr>
<td>Dave Senske</td>
<td>JPL</td>
<td>Deputy / Geology</td>
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<tr>
<td>Everett Shock*</td>
<td>ASU</td>
<td>Geochemistry</td>
</tr>
<tr>
<td>David Smith</td>
<td>MIT</td>
<td>Geophysics</td>
</tr>
</tbody>
</table>

*Recent SDT augmentations
Europa SDT Meetings

- May 2–3, 2011, JPL
  - Considered Europa objectives and mission design trades, and converged on two-element mission concept
- June 23–24, 2011, JPL
  - Provided feedback on initial orbiter and flyby mission designs, and iterated on model payload and mission requirements
- Aug. 22–23, 2011, JPL
  - Finalized science traceability, model payloads, and mission requirements
- Oct. 17–18, 2011, JPL
  - Developed initial objectives and investigations for a landed element
  - Will develop lander element model payload and associated mission requirements
1. Europa:
Explore Europa to investigate its habitability

2. Ganymede:
Characterize Ganymede as a planetary object including its potential habitability

3. Jupiter System:
Explore the Jupiter system as an archetype for gas giants
Science Goal, Objectives, and Themes
Modified and Simplified from JEO

• **Goal:** Explore Europa to investigate its habitability

• **Objectives:**
  – *Ocean:* Characterize the extent of the ocean and its relation to the deeper interior
  – *Ice Shell:* Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange
  – *Composition:* Understand the habitability of Europa's ocean through composition and chemistry
  – *Geology:* Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities

• **Themes:**

  - water
  - habitability
  - chemistry
  - energy
Science as a Driver of Mission Architecture

Science traceability leads to a **two element** mission concept:

**Orbiter Element:**

*Geophysical measurements that can be achieved only from orbit*

- Science focused primarily to address “Ocean” objective:
  - Gravity field
  - Tidal amplitude
  - Induction signatures
  - Plasma correction
  - Stratigraphic mapping

**Flyby Element:**

*Remote measurements that can be accomplished via multiple flybys*

- Science focused primarily to address “Chemistry” and “Energy” themes:
  - Subsurface dielectric horizons
  - Surface constituents
  - Atmospheric constituents
  - Targeted landforms

- Each element achieves key Europa science objectives
- The elements are complementary, and each has very high science value of its own
# Two-Element Approach

<table>
<thead>
<tr>
<th>Objective</th>
<th>Europa Science</th>
<th>Orbiter</th>
<th>Multiple Flyby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>Gravity field</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tidal amplitude</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Induction signatures</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plasma correction</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Ice Shell</td>
<td>Subsurface dielectric horizons</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Composition</td>
<td>Surface constituents</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td></td>
<td>Atm. constituents</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Geology</td>
<td>Stratigraphic mapping</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Targeted landforms</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
## Orbiter Element Traceability
### Ocean Emphasis

<table>
<thead>
<tr>
<th>Goal</th>
<th>Objective</th>
<th>Investigation</th>
<th>Model Instruments</th>
<th>Theme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Ocean</strong></td>
<td>Explore Europa to investigate its habitability</td>
<td>Characterize the extent of the ocean and its relation to the deeper interior.</td>
<td>O.1 Determine the amplitude and phase of gravitational tides.</td>
<td>Radio subsystem, Laser altimeter</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>O.2 Determine Europa's magnetic induction response.</td>
<td>Magnetometer, Langmuir probe</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O.3 Determine the amplitude and phase of topographic tides.</td>
<td>Laser altimeter, Radio subsystem</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O.4 Determine Europa's rotation state.</td>
<td>Laser altimeter, Mapping camera</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O.5 Investigate the deeper interior.</td>
<td>Radio subsystem, Laser altimeter, Magnetometer, Langmuir probe</td>
</tr>
<tr>
<td><strong>Geology</strong></td>
<td>Explore Europa to investigate its habitability</td>
<td>Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.</td>
<td>G.1 Determine the distribution, formation, and three-dimensional characteristics of magmatic, tectonic, and impact landforms.</td>
<td>Mapping camera, Laser altimeter</td>
</tr>
</tbody>
</table>

**Themes:** W = Water, C = Chemistry, E = Energy
# Flyby Element Traceability  
## Chemistry & Energy Emphasis

<table>
<thead>
<tr>
<th>Goal</th>
<th>Objective</th>
<th>Investigation</th>
<th>ModelInstr.</th>
<th>Theme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ice Shell</td>
<td>Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange.</td>
<td>I.1 Characterize the distribution of any shallow subsurface water and the structure of the icy shell.</td>
<td>Radar sounder, Topo. Imager</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.2 Search for an ice-ocean interface.</td>
<td>Radar sounder, Topo. Imager</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.3 Correlate surface features and subsurface structure to investigate processes governing material exchange among the surface, ice shell, and ocean.</td>
<td>Radar sounder, IR spectrometer, Topo. imager</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>I.4 Characterize regional and global heat flow variations.</td>
<td>Radar sounder</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td>Composition</td>
<td>Understand the habitability of Europa's ocean through composition and chemistry.</td>
<td>C.1 Characterize the composition and chemistry of the Europa ocean as expressed on the surface and in the atmosphere.</td>
<td>IR spectrometer, INMS</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C.2 Determine the role of Jupiter's radiation environment in processing materials on Europa.</td>
<td>IR spectrometer, INMS</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C.3 Characterize the chemical and compositional pathway's in Europa's ocean.</td>
<td>IR spectrometer, INMS</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
<tr>
<td>Geology</td>
<td>Understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities.</td>
<td>G.2 Determine sites of most recent geological activity, and characterize high science interest localities.</td>
<td>Topo. Imager</td>
<td>W ✓ C ✓ E ✓</td>
</tr>
</tbody>
</table>

**Themes:** W = Water, C = Chemistry, E = Energy
## Traceability Matrix Example

<table>
<thead>
<tr>
<th>Goal</th>
<th>Objective</th>
<th>Investigation</th>
<th>Measurement</th>
<th>Example instrument</th>
<th>Mission requirements</th>
<th>Notional Instrument Specifications</th>
<th>Notional Mission Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explore Europa to investigate its habitability.</td>
<td>Characterize the extent of the ocean and its relation to the deeper interior.</td>
<td>Determine the amplitude and phase of gravitational tides.</td>
<td>Measure degree two time dependent gravity field, to recover $k_2$ amplitude at Europa's orbital frequency to 0.003 absolute accuracy, and the phase to 1 degree.</td>
<td>Radio subsystem</td>
<td>(1) Low altitude (~100+ km), circular, near-polar (within 5° to 10° of the pole) orbit, for at least 30 days (baseline), 18 days (floor); (2) Range-rate measurements with an accuracy better than 0.1 mm/s at 60 sec integration time to determine spacecraft orbit to better than 1-meter (rms) in radial direction over several tidal cycles; (3) Several “unperturbed” days for the data arcs (preferably at least one rotation of Europa) for gravity-limit spacecraft momentum dumping or thrusting to an interval of 3 to 4 days, if possible.</td>
<td>Ka and X, both up and down (closed-loop)</td>
<td>Orbiter</td>
</tr>
<tr>
<td>Instrument(s)</td>
<td>Key Accommodation Requirements</td>
<td>Element</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Radio Subsystem + Laser Altimeter</td>
<td>Low altitude (~100+ km), circular, near-polar orbit, for at least 30 days. Unperturbed orbital arcs (no thrusting) of at least 3 days.</td>
<td>Orbiter</td>
<td></td>
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</tr>
<tr>
<td>Magnetometer + Langmuir Probe</td>
<td>Low altitude (~100+ km), circular, near-polar orbit, for at least 30 days. Cover approximately 12 hours of Europa local time.</td>
<td>Orbiter</td>
<td></td>
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</tr>
<tr>
<td>Mapping Camera</td>
<td>Low altitude (~100+ km), ≥ 80% global coverage under near uniform lighting conditions, solar incidence angle &gt; 45° (70° preferred).</td>
<td>Orbiter</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Ice Penetrating Radar</td>
<td>≥ 800 km tracks in 11 of 14 globally distributed regions, intersected by at least 1 other track, with track lengths measured from ≤ 400 km alt. ~25–100 km closest approach at ≤ 6 km/s.</td>
<td>Flyby</td>
<td></td>
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</tr>
<tr>
<td>ShortWave IR Spectrometer</td>
<td>≥ 70% coverage at ≤ 10 km per pixel. Ability to target specific geologic locations with a wide range of surface locations, lighting between 9:00am and 3:00pm. Attitude stability &lt; ½ IFOV over integration time, flyby speed &lt; 6 km/s.</td>
<td>Flyby</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Topographical Imager</td>
<td>High resolution stereo imagery aligned with IPR coverage; lighting conditions solar incidence angle &gt; 20° (70° preferred).</td>
<td>Flyby</td>
<td></td>
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</tr>
<tr>
<td>Ion and Neutral Mass Spectrometer</td>
<td>Low altitude (&lt; 200 km with lower altitudes desired) at ≤ 7 km/s; long integration times and low altitudes (≤ 100 km) preferred.</td>
<td>Flyby</td>
<td></td>
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</tbody>
</table>
Orbiter Model Payload: Outline

- Model payload instruments
  - Radio Subsystem (RS)
  - Laser Altimeter (LA)
  - Magnetometer (MAG)
  - Langmuir Probe (LP)
  - Mapping Camera (MC)
- Science operations concept
- Example coverage
Orbiter Model Payload Instruments

- **Radio Subsystem (RS)**
  - X-band up and down; Ka-band down only
  - Ka Transponder

- **Laser Altimeter (LA)**
  - Nadir view, co-boresighted with camera on 2-axis gimbal platform

- **Magnetometer (MAG)**
  - Dual 3-axis fluxgate
  - Sensors on boom 5 m and 10 m from S/C

- **Langmuir Probe (LP)**
  - Two 5 cm diameter spheres mounted on 1 m long booms pointed > 90° from each other

- **Mapping Camera (MC)**
  - Pushbroom imager; 1024 pixel CMOS or CCD line array
  - 5 separate line arrays in focal plane (radiation shielded)
    - 4 nadir viewing: panchromatic + 3 color bands (color for E/PO)
    - 1 panchromatic viewing ~40° forward or aft for stereo
  - Nadir view, co-boresighted with LA on 2-axis gimbal platform

**Similar instruments**

- NEAR NLR
- Galileo MAG
- Rosetta LAP
- MPL/MSL MARDI
Orbiter Science Operations Concept

- **Gravity Science** while not occulted (Earth-pointed HGA)
- **Magnetometer** and **Langmuir Probe** on all the time
- **Laser Altimeter** on all the time (2 axis scan platform)
- **Mapping Camera** on during day with ~45% duty cycle (2 axis scan platform)
Mapping Camera
Global Stereo Map in 3 Eurosols (<11 days)

- 10% side-to-side swath overlap
- Orbit altitude of 103 km permits ground track near-repeat
- 1024-pixel line width ~100 m/pixel average resolution across FOV
- Wide gap is due to Jupiter occultation; It could be filled through off-nadir pointing
Laser Altimeter Nadir Track
Each color is 1 eurosol (3.55 days)

~25 km equatorial spacing of laser profiles after 30 days
Flyby Model Payload: Outline

- Model payload instruments
  - Ice Penetrating Radar (IPR)
  - ShortWave InfraRed Spectrometer (SWIRS)
  - Topographical Imager (TI)
  - Ion and Neutral Mass Spectrometer (INMS)
- Science operations concept
- Example coverage
Flyby Model Payload Instruments

- **Ice Penetrating Radar (IPR)**
  - Dual-frequency sounder
    - 60 MHz with 10 MHz bandwidth (shallow)
    - 9 MHz with 1 MHz bandwidth (deep)
  - Deployed dipole antenna array on 15 m boom

- **ShortWave InfraRed Spectrometer (SWIRS)**
  - Spectral Range 0.85 – 5.0 µm; Spectral Resolution 10 nm
  - Single optic, single grating spectrometer & HgCdTe detector
  - Scan mirror for Target Motion Compensation

- **Topographical Imager (TI)**
  - Pushbroom, 4096 pixels width
  - Stereo obtained through along-track overlap

- **Ion and Neutral Mass Spectrometer (INMS)**
  - Mass Range 1 – 300 Da; Mass Resolution > 500; Sensitivity 10 particles/cm³
Flyby Science Operations Concept

- **Ice Penetrating Radar** obtains primary data at \( \leq 400 \) km
- **ShortWave InfraRed Spectrometer** obtains data \( \leq 66,000 \) km
- **Topographical Imager** obtains stereo images \( \leq 1,000 \) km
- **INMS** obtains data \( \leq 1,000 \) km, including several ~25 km flybys
Flyby Ground Tracks
Altitude < 1,000 km

Altitude [km]

< 25  100  400  1000  2000  66000
SWIRS Low Resolution Coverage
Altitude 2,000 km – 66,000 km

Coverage shown for local true solar times between 9:00am and 3:00pm
SWIRS High Resolution Coverage
Altitude ≤ 2,000 km

Coverage shown for local true solar times between 9:00am and 3:00pm
IPR Ground Coverage

- 25 – 400 km (primary data collection)
- 400 – 1,000 km (extended data collection)
Topo Imager Coverage
Resolution for Altitude ≤ 1,000 km
Topo Imager Coverage
Solar Incidence Angle for Altitude ≤ 1,000 km
Science as a Driver of Mission Architecture

Science traceability leads to a two element mission concept:

**Orbiter Element:**
Geophysical measurements that can be achieved only from orbit

- Science focused primarily to address “Ocean” objective:
  - Gravity field
  - Tidal amplitude
  - Induction signatures
  - Plasma correction
  - Stratigraphic mapping

**Flyby Element:** Remote measurements that can be accomplished via multiple flybys

- Science focused primarily to address “Chemistry” and “Energy” themes:
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  - Surface constituents
  - Atmospheric constituents
  - Targeted landforms
Science as a Driver of Mission Architecture

Science traceability leads to a two element mission concept:

**Orbiter Element:** Geophysical measurements that can be achieved only from orbit
- Payload focused primarily to address “Ocean” objective:
  - Radio Subsystem (RS)
  - Laser Altimeter (LA)
  - Magnetometer (MAG)
  - Langmuir Probe (LP)
  - Mapping Camera (MC)
- Have readily accommodated those instruments that are:
  - Less massive
  - Lower power
  - Lower data rate

**Flyby Element:** Remote measurements that can be accomplished via multiple flybys
- Payload focused primarily to address “Chemistry” and “Energy” themes:
  - Ice Penetrating Radar (IPR)
  - ShortWave IR Spectrometer (SWIRS)
  - Ion and Neutral Mass Spectrometer (INMS)
  - Topographical Imager (TI)
- Have readily accommodated those instruments that are:
  - More massive
  - Higher power
  - Higher data rate
Pragmatic two-element architecture would fulfill the highest-priority Europa science objectives
  - Orbiter element concentrates on the “Ocean” objective
  - Multiple-flyby element concentrates on the “Chemistry” and “Energy” themes
Each element has very high science value on its own
Directly responsive to Decadal Survey’s recommendation for Europa
Scientific priorities drive the architecture, permitting low-cost Europa mission options
Backup Slides: Science
<table>
<thead>
<tr>
<th>Decadal Survey Theme and Key Questions:</th>
<th>Building New Worlds</th>
<th>Planetary Habitats</th>
<th>Workings of Solar Systems</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Explore Europa to investigate its habitability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>✓</td>
<td>✓✓ ✓</td>
<td>✓✓ ✓</td>
</tr>
<tr>
<td>Characterize the extent of the ocean and its relation to the deeper interior.</td>
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<td>Ice Shell</td>
<td>✓✓ ✓</td>
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<tr>
<td>Comp’tn Ice Shell</td>
<td>✓✓ ✓</td>
<td>✓✓</td>
<td>✓✓ ✓</td>
</tr>
<tr>
<td>Understand the habitability of Europa's ocean through composition and chemistry.</td>
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</tr>
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<td>Geology</td>
<td>✓✓ ✓</td>
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</tbody>
</table>

 ✓ = good, ✓✓ = very good, ✓✓✓ = excellent
Europa Science Definition Team
Subgroup Structure

Objectives subgroups:

- **Ocean & Ice:**
  - Bills, Barr, Blankenship*, Connerney, Senske, Smith

- **Composition:**
  - Blaney, Bagenal, Hoehler, Hand, Shock*, Brinckerhoff, Vance

- **Geology:**
  - Moore, Kurth, McGrath, Mellon, Patterson, Prockter*

Cross-Cutting subgroups:

- **Astrobiology:**
  - Hoehler, Blankenship, Hand*, McGrath, Senske, Shock

- **Instrumentation:**
  - Mellon, Bills, Blaney, Brinckerhoff*, Connerney, Kurth

- **Landing Sites:**
  - Prockter, Bagenal, Barr*, Moore, Patterson, Smith, Vance

**Bold** = Lead; **= Deputy Lead
Orbiter: Laser Altimeter (LA)

• **Primary Science Investigations**
  – Europa global topography and tidal deformation, rotation state, landform topography

• **Measurement Requirements**
  – Topographic differences to 1 m vertical accuracy at globally distributed crossover points at varying Europa orbital phases; implies surface ranging to 10 cm accuracy
  – Simultaneous ranging with stereo imagery desired
  – Near-polar near-circular orbit at ≤ 200 km altitude

• **Configuration for Model Payload**
  – Time-of-flight rangefinder
  – Transmits 2.7 mJ pulses at 1.064 µm
  – 50 m laser spot from 100 km altitude
  – Receiver telescope aperture of 12.5 cm diameter provides good SNR from 100 km altitude
  – Avalanche photodiode detector (radiation shielded)
  – 26 Hz pulse rate yields 50 m spot spacing
  – Nadir view co-boresighted with camera; minimize thruster contamination
  – Mounted on 2-axis gimbal platform (assuming simultaneous ranging and downlink over fixed-mounted HGA from mid-afternoon orbit)

Similar instruments

MESSENGER MLA

NEAR NLR

LRO LOLA
Orbiter: Radio Subsystem (RS)

- **Primary Science Investigations**
  - Europa static gravity field and gravitational and tides

- **Measurement Requirements**
  - Degree-2 time-dependent gravity field, to recover $k_2$ amplitude at Europa's orbital frequency to $\leq 0.003$ absolute accuracy and phase to $\leq 1^\circ$
  - Europa position wrt Jupiter to $\leq 10$ m throughout orbital mission
  - Europa static gravity field resolved to degree and order 30
    - Range-rate to $< 0.1$ mm/s at 60 s integration time
    - S/C orbit determination about Europa to accuracy of $< 1$ m (rms) in radial direction
  - Near-polar near-circular orbit at $\leq 200$ km altitude for $\geq 30$ days
  - Data arcs over several “unperturbed” days
  - Range-rate measurements over several Europa tidal cycles

- **Configuration for Model Payload**
  - X-band up and down; Ka-band down only
  - Ka Transponder/Hybrid Diplexer
  - USO not required
Orbiter: Magnetometer (MAG)

- **Primary Science Investigations**
  - Europa magnetic induction response

- **Measurement Requirements**
  - 3-axis magnetic field components at 8 Hz, 8 vectors/s
  - Sensitivity of 0.1 nT
  - Near continuous measurements
  - Near-polar near-circular orbit at ≤ 200 km altitude for ≥ 30 days

- **Configuration for Model Payload**
  - Dual 3-axis fluxgate
  - Sensitivity 0.1 nT
  - Maximum sampling rate 32 Hz; sampling resolution 0.01 nT
  - Sensors on boom 5 m and 10 m from S/C
  - Spacecraft cleanliness of 0.1 nT desired, 0.5 nT required at outboard sensor
  - Periodic S/C slow spins about two orthogonal axes for calibration
• **Primary Science Investigations**
  – Europa ionospheric plasma effects on magnetic induction response

• **Measurement Requirements**
  – Local plasma density, temperature, and flow
  – Electric field (near DC to 3 MHz)
  – Electron temperature
  – Ion currents
  – $4\pi$ coverage
  – Map approximately 12 hours of Europa local time
  – Near-polar near-circular orbit at $\leq 200$ km altitude for $\geq 30$ days

• **Configuration for Model Payload**
  – Two 5 cm diameter spheres mounted on 1 m long booms
  – Booms pointed $> 90^\circ$ from each other, desire one always free of S/C wake
  – Electronics (including pre-amp) in S/C vault $< 3$ m from sensors
  – EMI/EMC cleanliness like Rosetta and/or Cassini

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**Similar instruments**

- Rosetta LAP
- Cassini RPWS
Orbiter: Mapping Camera (MC)

• **Primary Science Investigations**
  – Landform mapping, Europa rotation state, and surface/subsurface material exchange

• **Measurement Requirements**
  – ≥ 80% global mapping at ≤ 100 m/pixel
  – 30 m vertical resolution topo, ≤ 300 m horizontal footprint resolution
  – Incidence angle > 45° (70° preferred)
  – Near-polar near-circular orbit with consistent lighting

• **Configuration for Model Payload**
  – Pushbroom imager; 1024 pixel CMOS or CCD line array
  – 5 separate line arrays in focal plane (radiation shielded)
    • 4 nadir viewing: panchromatic, 0.56, 0.76, 0.99 µm bands
    • 1 panchromatic viewing ~40° forward or aft for stereo
  – IFOV = 0.85 mrad; FOV = 50°
    • 85 m/pixel at nadir from 100-km orbit altitude
    • 94 km wide swath (~3.4° of longitude at the equator)
    • 63 ms for 1 pixel of smear in 100 km orbit, providing good SNR
  – Can elect to operate color and stereo bands, or not
  – Loose pointing requirements (~2° accuracy; 5 mrad/s stability)
  – Mounted on 2-axis gimbal platform (permits simultaneous imaging and HGA downlink)
  – Small radiator with view to dark space

Similar instruments

MRO MARCI

MPL/MSL MARDI
Flyby: Ice Penetrating Radar (IPR)

- **Primary Science Investigations**
  - Characterize distribution of shallow subsurface water and structure of ice shell
  - Search for an ice-ocean interface
  - Correlate surface features, subsurface structures, and geological processes

- **Measurement Requirements**
  - Shallow Mode: 10 m vertical resolution; 100 m to 3 km depth
  - Deep Mode: 100 m vertical resolution; 1 km to 30 km depth
  - Globally distributed intersecting and adjacent swaths, in 11 of 14 “panels”
  - Supporting requirements:
    - Nadir altimetry, 10 m vertical resolution
    - Cross-track surface topography (stereo imaging), 100 m vertical resolution

- **Configuration for Model Payload**
  - Dual-frequency sounder
    - 60 MHz with 10 MHz bandwidth (shallow)
    - 9 MHz with 1 MHz bandwidth (deep)
  - Deployed dipole antenna array on 15 m boom
  - Range compression, pre-summing, Doppler filtering, data averaging, resampling in S/C electronics

Similar instruments:
- Mars Express MARSIS
- MRO SHARAD
Primary Science Investigations
- Characterize surface composition for representative landforms
- Characterize exogenic materials

Measurement Requirements
- Spectral Range 850 nm – 5.0 µm
- Spectral Resolution 10 nm
- Spectral Channels 420
- Spatial Resolution 300 m @ 2000 km (IFOV = 150 µrad)
- Image Width 480 pixels (4.2°)
- Signal to Noise ~ 100 at 5 µm (TMC 8), 18 at 5 µm (TMC 1)
- Exposure time ~ 1 s / row (TMC 8) [7.7 min for full image], 0.12 s / row (TMC 1)

Configuration for Model Payload
- Implementation of 4 scans for each flyby: 2 @ 10 km/pixel (s/c slew) and 2 < 300 m/pixel (scan mirror, s/c tracking nadir)
- Single optic, single grating spectrometer & HgCdTe detector; TMC (scan mirror)
- Passive detector and spectrometer cooling
- Detector radiation noise (for TMC 8, 4% pixels are hit @ 9.5 cm tantalum shielding; for TMC 1, 4% pixels are hit @ ~3 cm Ta); calculation for worst case 0° inclination
Flyby: Topographical Imager (TI)

- **Primary Science Investigations**
  - Removal of radar returns from off-nadir surface topography
  - High-resolution stereo imaging of landforms for geology

- **Measurement Requirements**
  - Spectral Range: visible
  - Spectral Bands: monochromatic
  - FOV: 58° (for stereo separation)
  - Image Width @ C/A: 100 km (matches width of radar swath)
  - Signal to Noise: ≥ 100

- **Configuration for Model Payload**
  - Pushbroom operation
  - Stereo obtained through along-track overlap with ~ 50 m vertical resolution
  - Image width: 4096 pixels
  - Spatial Resolution: 25 m @ 100 km alt (250 µrad iFOV) (6.2 m @ 25 km alt)
  - SNR: ~ 100 @ 100 km alt (can increase to ~400 using TDI) ~ 27 @ 25 km alt (with TDI, can get up to ~ 100)
  - Exposure times: 5.5 ms for 1 pixel of smear @ 100 km alt
  - Radiation noise (% of pixels hit with electrons/1 cm Ta detector shielding): 0.5%
Flyby: Ion and Neutral Mass Spectrometer (INMS)

- **Primary Science Investigations**
  - Elemental, isotropic and molecular composition of Europa’s atmosphere and ionosphere

- **Measurement Requirements**
  - Mass Range: 1 – 300 Daltons
  - Mass Resolution: > 500
  - Sensitivity: 10 particles/cm³
  - Field of View: 60 degree clear input

- **Configuration for Model Payload**
  - Ram pointed inlet
  - Remote electronics
  - One-time opening cover

- **Note on Sensitivity and Resources**
  - We solicited input from INMS providers to understand the limits on sensitivity and detection of minor species during fast flybys

Similar instruments
- Rosina RTOF
- Cassini INMS