Europa Exploration: Challenges and Solutions

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Arctic Ice Sounds: courtesy of Nick Makris, Ocean Engineering, MIT
ALL THESE WORLDS ARE YOURS EXCEPT EUROP A ATTEMPT NO LANDING THERE

NO PROBLEM: ARTHUR GAVE HIS OK
Exploring Europa is .... HARD!

- Long trip times, low delivered mass fractions ..... “It’s the rocket equation, stupid”
- RADIATION (BOO!)

But ..... POSSIBLE!

Pre-decisional, for planning purposes only
History

• Galileo – we did operate successfully in the Europa environment in flyby mode
• Europa Orbiter (BFC to Europa)
  – Direct trajectory (dry mass ~ 1000 kg)
  – Limited payload - ~ 20 kg
  – Radiation tolerant electronics development needed – computers, avionics, memory
  – Limited time in orbit – 30 days
  – Cancelled 2001
• JIMO (a bridge too far)
  – Nuclear Electric Propulsion
  – Large payload - ~ 1500 kg
  – Science requirements developed by JIMO SDT (R. Greeley, T. Johnson et al.)
  – ‘Deferred’… indefinitely… in 2005
History\textsuperscript{cont'd}

- Europa Geophysical Explorer – JPL Study for NASA
  - Science: OPAG Europa subgroup – R. Greeley \textit{et al.}
  - Explored indirect trajectories, larger payloads
  - Studied options for radioisotope power in 2012 period
- This study: Europa Explorer Concept
  - JPL funded study
  - Science based on previous SDT and OPAG input organized by an \textit{ad hoc} science team (\textit{i.e.} some of the usual suspects)
  - Goal: Take advantage of previous investments in radiation hardening and mission concepts to develop an exciting Europa mission with \textbf{existing technology} that could be done in the next decade.
Key Factors

• Indirect trajectories
  – Mass margin available for science payload, shielding, power, possible surface science

• Radiation Tolerant Electronics
  – Current technology is sufficient
  – 2 yr mission at Jupiter – 1.5 yr Jupiter system, 3 months + on orbit at Europa

• Communications
  – 400 Kbps real-time mission with rad-hard buffer
  – Europa data volume = ~ 3 yrs of Cassini data return

• Planetary Protection: End-of-mission impact
  – Radiation sterilization of surfaces and unshielded components combined with pre-launch sterilization of shielded areas
The Mission

Indirect trajectories – the key to reasonable mass margins

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The rocket equation can be beaten ....
or at least cheated ....
by stealing energy from the planets!

Direct trajectory: ~ 1 Ton spacecraft
Earth GA trajectory: ~ 2 Ton spacecraft
Venus-Earth GA trajectory: ~ 3 Ton spacecraft

Cost – trip time to target (e.g. Galileo, Cassini)
Representative VEEGA Options
Representative Jupiter Arrival

Time ticks:
- S/C: 3 hrs
- Io: 2 hrs
- Europa: 3 hrs
- Ganymede: 6 hrs
- Callisto: 12 hrs

GO flyby at 500 km altitude

Position of Galilean satellites denoted at time of Perijove 0.
Sun direction fixed toward top of page

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Example Science Orbit at Europa

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Lifetime of Science Orbit

Europa Science Orbit Duration vs Eccentricity
Arg of Periapse = -90°, Inclination = 110°
Created on 09-13-2004 at 03:13PM

J₃ Values
- 0
- +3.0E-06
- +5.0E-06
- +7.0E-06
- +7.0E-05
- +5.21E-05
- +7.04E-05

Duration (days)

Initial Eccentricity

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Occultations in Science Orbit

- Earth occulted by Europa
  - Max ~37% of the time for 100 km orbit (2.1 hour period)
  - Max ~33% of the time for 200 km orbit (2.3 hour period)
- Earth occulted by Jupiter ~2.5 hours every Europa rev (3.55 days)
  - ~3% of the time
- Solar eclipses have similar duration
The Spacecraft

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EE Spacecraft Configuration

Main Engines (2x 900N)

MMRTGs (8)

3-m, 2 DOF, X-band HGA

Nadir-pointed instruments

Ice Penetrating Radar

10-m mag boom

Conceptual Illustration

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Science Instrument View

MeV Ion Spectrometer
Ice Penetrating Radar
KeV Ion Spectrometer
Ion and Neutral Mass Spectrometer
Wide Angle Camera
Medium Angle Camera
Laser Altimeter
10 m Mag Boom

Thermal Imager
IR Mapping Spectrometer

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EE Reference Mission Capability

The reference Europa Explorer mission concept has the following capabilities:

- **Launch mass capability:** 7230 kg
- **Spacecraft wet mass:** 6888 kg
- **Spacecraft dry mass:** 2608 kg
- **Power available (EOM):** 823 W
- **Number of MMRTGs:** Eight
- **Data rate (@5.5 AU):** 400 kb/s

This leaves an **additional 340 kg** of unallocated mass that may be used for greater spacecraft margin and/or mission enhancements.
EE Functional Description Summary - 1

- **General**
  - 3-axis stabilized
  - MMRTG powered, with battery
  - 10 body-fixed instruments
  - Deployed appendages: HGA, MAG, IPR antenna array

- **Communications**
  - X-band; 50 W(RF); gimbaled 3m HGA
  - Ka up/down for science; 3.5 W transmitter

- **Data Handling**
  - RAD750 processors
  - 1553 bus + LVDS interfaces
  - Separate science computer and mass memory
  - Small mass data memories: 300 Mbit

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• **Attitude and Propulsion**
  - Reaction wheels
  - Star sensor/TRU/sun sensors
  - 900 N bipropellant main engine
  - 4.5 and 32.5 N monoprop thrusters
  - Translational thrusting in 6 directions

• **Thermal Control, using:**
  - RTG waste heat
  - 140 Radioisotope Heater Units (RHUs)
    - 120 used on Galileo
    - 117 used on Cassini
    - 8 used on each MER rover
  - Electrical heaters, blankets, louvers, etc.

Notional bi-prop thruster

Radioisotope Heater Unit (RHU)
Lander Concepts

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Mass, kg

Impactor | Airbag Landers | Soft Landers

Europa Explorer Unallocated Mass – 340Kg

Lander Concepts

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Pre-decisional, for planning purposes only

Data
Data Return Solution

- Continuous coverage by the Deep Space Network
- Science memory of only 300 Mb stores data when the spacecraft is behind Europa
- Mission returns 21 Gb/day at the start of the mission increasing to 35 Gb/day after 90 days
- Mission acquires ~3 Tb total data in the 90 day Prime Mission

CHANGES
NOT HEALTHY: FOR CARBON OR SILICON BASED LIFE FORMS

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Radiation Hardening: Progress

- Galileo design standard: 150,000 rad Si
- Current situation: NASA and DOD radiation hardening development in last decade has yielded:
  - Flight computers (Pentium class): 1,000,000 rad Si
  - Many avionics and flight parts: > 300,000 rad Si
- Better characterization of environment by Gaileo
- Bottom Line: With mass for shielding, a Europa mission can now be done with current technology
Radiation Design and Mitigations

- More Rad hard electronics are available
  - Rad 750 is now in use – it is on MRO
  - Power electronics developed by JIMO before cancellation
  - DOD work has led to more parts being available

- Galileo experience and knowledge base
  - Radiation environment model – significantly refined with Galileo data
  - Failure history – what failed, when and why
  - Mitigation methods – annealing, operational work-arounds
  - Fault handling – how quickly can the spacecraft recover

- A new operational strategy
  - Real time data transmission from Europa
  - Minimal data storage – feasible with current rad hard technology
  - Minor compromises in data types acquired
Galileo Radiation Failures vs Time in Orbit about Jupiter

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Europa Explorer Concept

Probability that Actual Radiation Environment Seen is Below Selected Design Point

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Europa Explorer – Operating Lifetime

Radiation Dose (Prime Mission =1)

- 700 krads
- Galileo – End of Mission
- Europa Orbit Insertion
- Europa Explorer – End of Mission?
- 360 day Extended Mission
- 225 day Extended Mission
- 90 day Prime Mission in Europa Orbit

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# Concept Comparison

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Europa Orbiter</th>
<th>Europa Geophysical Explorer</th>
<th>Europa Explorer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instrument Mass</td>
<td>27 kg</td>
<td>180 kg</td>
<td>180 kg</td>
</tr>
<tr>
<td>Instrument Power (Orbital Average)</td>
<td>27 W</td>
<td>154 W</td>
<td>100 W</td>
</tr>
<tr>
<td># Instruments</td>
<td>4</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Lander</td>
<td>Not Possible</td>
<td>850 kg</td>
<td>340 kg</td>
</tr>
</tbody>
</table>

**Prime Mission**

<table>
<thead>
<tr>
<th>Duration</th>
<th>30 Days</th>
<th>30 days</th>
<th>90 Days</th>
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</thead>
<tbody>
<tr>
<td>Data Return</td>
<td>100 Gbits</td>
<td>1000 Gbits</td>
<td>3000 Gbits</td>
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</table>

**Extended Mission**

<table>
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<tr>
<th>Duration</th>
<th>0 Days</th>
<th>70 Days</th>
<th>135 Days</th>
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</thead>
<tbody>
<tr>
<td>Data Return (Assumes 24/7 DSN coverage)</td>
<td>N/A</td>
<td>2333 Gbits</td>
<td>4500 Gbits</td>
</tr>
</tbody>
</table>

* Expect some degradation in performance
Europa Data Comparison

Relative Data Volume Returned

Relative Observation Time

Galileo  Europa Orbiter  Europa Explorer  Galileo  Europa Orbiter  Europa Explorer
Summary

Europa Explorer Orbiter would

- be fully operational in Europa orbit for at least 90 days with significant data return expected for up to a year

- produce 1000 times more close-up observations of Europa as the Galileo mission performed in six years of flybys

- carry 180 kg of instruments (including shielding and contingency)

- have \( \sim 340 \text{ kg} \) of unallocated mass that could be used for additional margin, an enhanced science payload, and/or a Europa lander

- return approximately \( \sim 3.0 \text{ Tbits} \) of Europa data in first 90 days

- use existing technology

Europa Explorer - A Capable Mission - Now
RETURN TO EUROPA