Understanding Europa’s Radiation Environment and How it Influences Landing Site Characterization

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The surface of Europa is weathered by charged and neutral particles, micrometeoroids, and photons.

- It has been demonstrated that these weathering processes are not uniform with respect to location and depth [Cooper et al., 2001; Paranicas et al., 2007].

We have begun an effort to characterize the variability of weathering processes with location and depth globally for Europa.

- With this information, we can identify regions on Europa that provide greater protection against the harsh Jovian radiation environment and/or have high science value.
• Criteria for characterizing potential landing sites [e.g., *Figueroedo et al., 2003*]:
  
  – Relative surface age
  
  – Surface roughness
  
  – Evidence for material exchange between surface and subsurface
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  – External Environment
• Criteria for characterizing potential landing sites [e.g., Figueredo et al., 2003]:
  – Relative surface age
  – Surface roughness
  – Evidence for material exchange between surface and subsurface
  – External Environment
    • Important from an engineering and science standpoint
Radiation Environment

Jupiter System

Energy is deposited into Europa's trailing hemisphere as plasma (and therefore field lines) overtakes the moon.

Energetic electrons move at relatively high speeds up and down magnetic field lines compared to their speeds in the perpendicular directions.

Field lines are depleted of some energetic electrons resulting in an energy-dependent shadow (lower radiation region) over large portions of the body.

The radiation environment for JEO is much reduced when the spacecraft is orbiting Europa's leading hemisphere.

Plasma overtakes Europa in its orbit, dragging magnetic field lines with it, so that charged particles trapped on these field lines preferentially impact Europa's trailing hemisphere.
Radiation Environment

Ganymede

- Polar caps related to differences in plasma-induced brightening in polar and equatorial regions

(Khurana et al., 2007)

open/closed field line boundaries:
- above plasma sheet
- mid-plane
- below plasma sheet
Radiation Environment

Penetration Depths

- Charged particles primarily affect the top few cm of Europa’s icy shell [Cooper et al., 2001]
  - Ions have shallow penetration depths
  - High-energy electrons can penetrate up to a meter or more [Paranicas et al., 2007]
  - The significance of electron bombardment with depth is enhanced by secondaries
    - These photons have a wide range of frequencies and can add energy deep in the layer
Europa

- Electrons in the 100s of keV to 10s of MeV range, which dominate the radiation dose at Europa, preferentially get deposited into the trailing hemisphere [Paranicas et al. 2007]
Analysis

Europa

- This suggests that Europa’s leading hemisphere, particularly near the apex, is effectively shielded from a significant fraction of the radiation present.
Short-term variability

- **Solar Wind variability**
  - The magnetopause of Jupiter varies with solar wind dynamic pressure
  - Likely affects corotation and reconnection patterns within the magnetosphere
  - Will have some effect on the weathering of Europa

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Radiation Environment

Short-term variability

• Solar Wind variability

• Magnetic draping
  – Europa’s induced field can impact the flow of cold plasma on the satellite
  – The strength of Europa’s induced field varies as it passes in and out of Jupiter’s magnetic equator
  – We have not yet examined the effects of this source of variability in a quantitative sense

(Khurana et al., in press)
Radiation Environment

Short-term variability

• Solar Wind variability

• Magnetic draping

• Flux of neutrals
  
  – Neutrals act as a ‘buffer’, effectively cooling energetic particles
  
  – Volcanic activity on Io can effect the population of neutrals around Europa

(Smyth and Marconi, 2006)
Radiation Environment

Short-term variability

- Solar Wind variability
- Magnetic draping
- Flux of neutrals

These sources of variability effect the radiation dose at Europa but we do not believe they greatly effect the strong asymmetry present

(Smyth and Marconi, 2006)
Results
Further Considerations

• Impact gardening by micrometeorite bombardment results in vertical mixing of the surface of Europa

  – This mechanism is expected to preferentially affect the leading hemisphere [Schenk et al., 2004].

  – Given a mean surface age for Europa of \(~10^7\) yr [Zahnle et al., 1998], gardening should extend to a depth of 1.3 m [Cooper et al., 2001].

  – Mixing rates at Europa can be as high as 1.2 \(\mu\)m/yr for a fresh surface while it has been suggested that the sputtering rate due to radiolytic processes is more than an order of magnitude less at \(~0.02\) \(\mu\)m/yr [Cooper et al., 2001].
Further Considerations

- Modeling suggests that the decoupled outer ice shell of Europa should undergo nonsynchronous rotation with respect to its interior due to torques imposed by tidal forces [Greenberg and Weidenschilling, 1984; Ojakangas and Stevenson, 1989]
  
  - Comparisons of Voyager and Galileo images [Hoppa et al., 1999] suggest that this mechanism would lead to rotations of 1° in longitude over timescales >10³ yr
  
  - Such a process would ‘smear’ the effects of radiolysis and impact gardening in the near-term
Summary

• Electrons in the 100s of keV to 10s of MeV range, which dominate the radiation dose at Europa, preferentially get deposited into the trailing hemisphere.
  – Their bombarding fluxes systematically decrease across the remainder of the satellite as a function of longitude and latitude.
  – This is important to consider when determining where to land (i.e. total ionizing dose (TID), single event upsets, etc.).

• Impact gardening and nonsynchronous rotation also effect the surface and will need to be characterized

• These processes are ongoing and interact with each other to produce a complex and global cycle of chemical alteration and surface erosion

• Understanding how this cycle works can provide essential information for assessing the science value and risk associated with potential landing sites
Results
Radiation Environment

Short-term variability

- Solar Wind variability
- Magnetic draping
- Flux of neutrals

(Mauk et al., 2004)

(Smyth and Marconi, 2006)