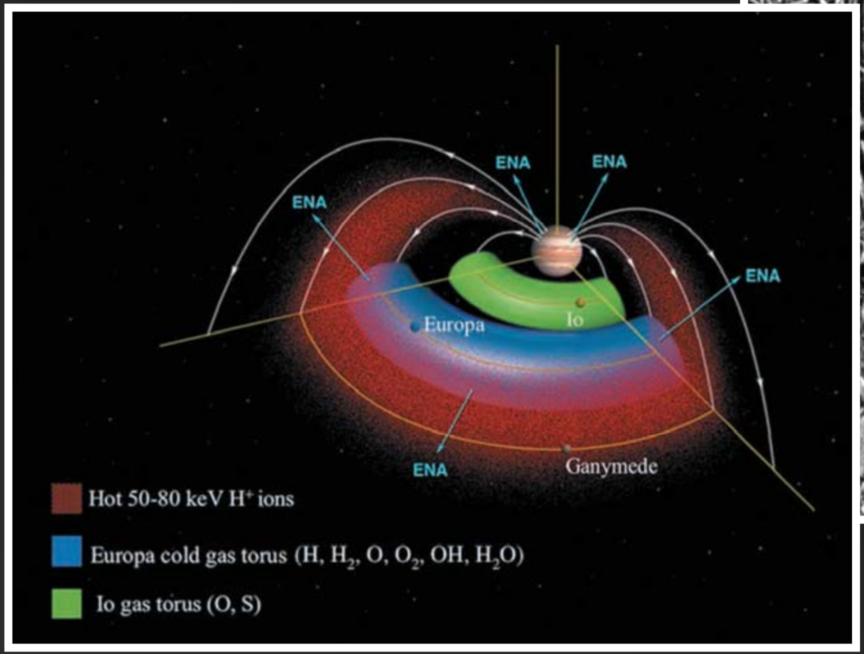
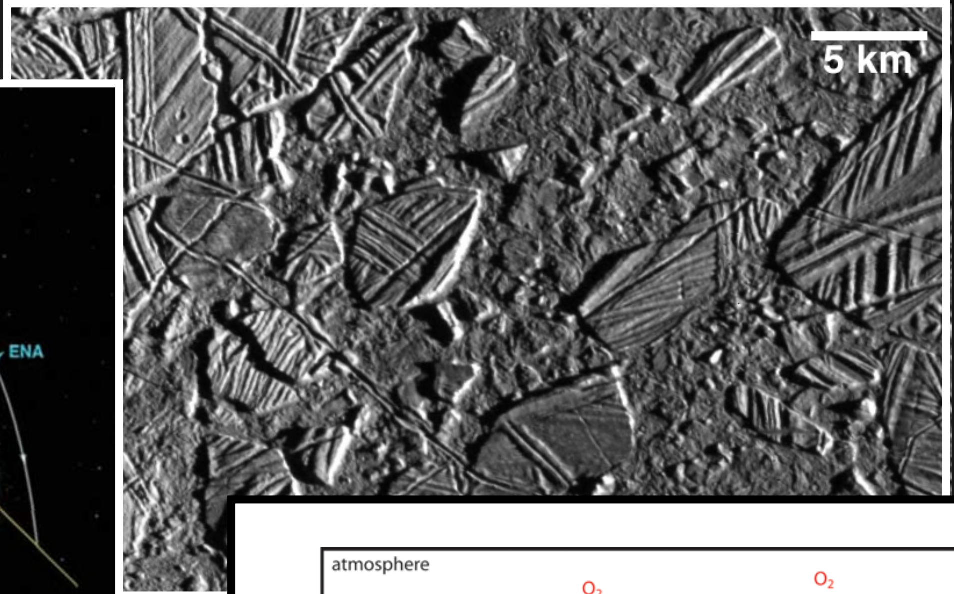
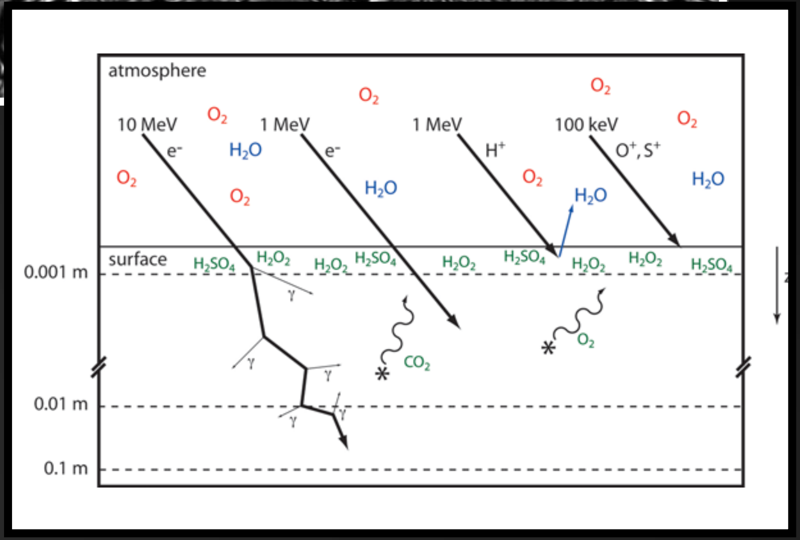
Understanding Europa's Radiation Environment and How it Influences Landing Site Characterization







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Introduction

- The surface of Europa is weathered by charged and neutral particles, micrometeroids, 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.

Background

- 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

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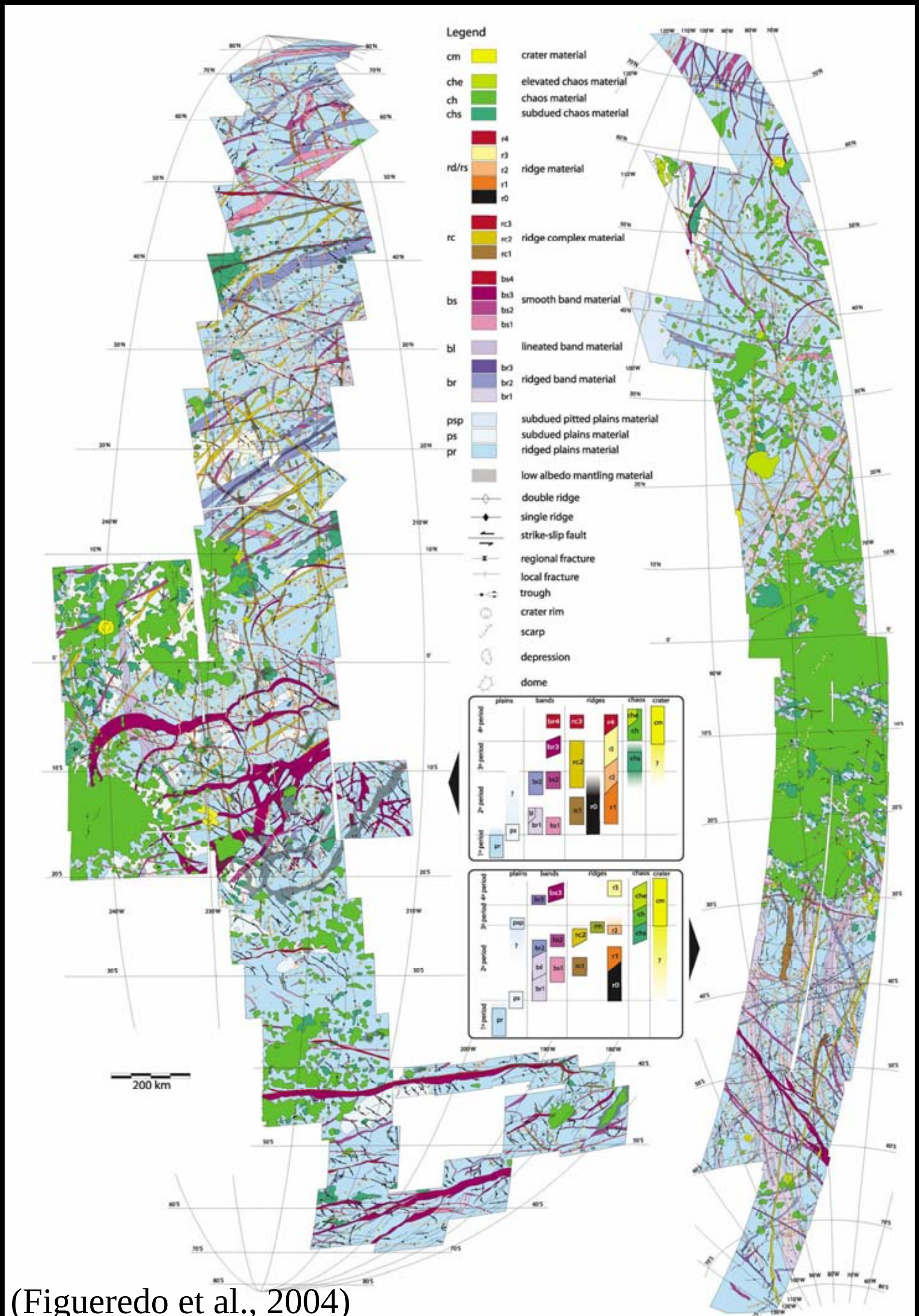

(Figueredo et al., 2004)

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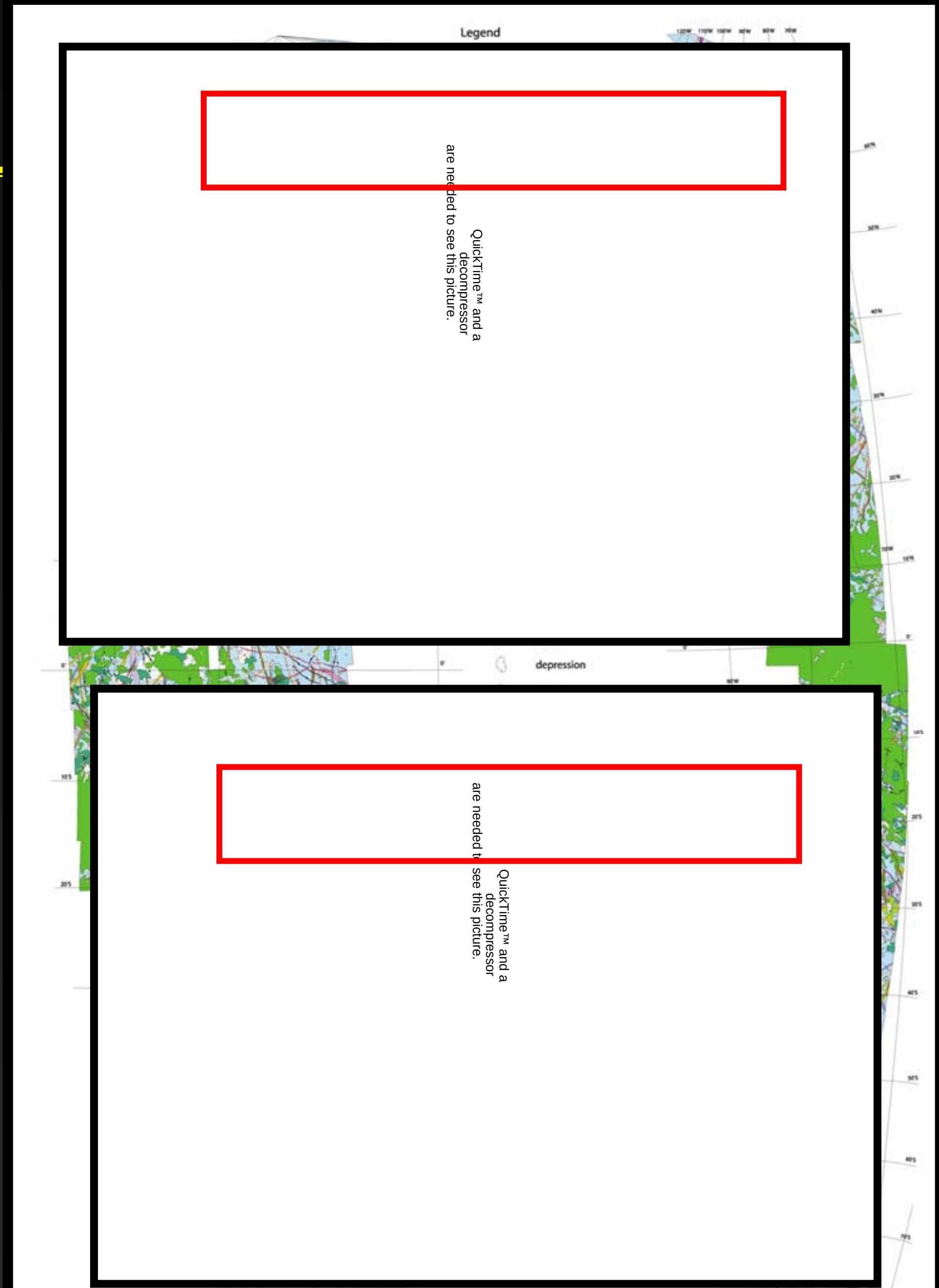

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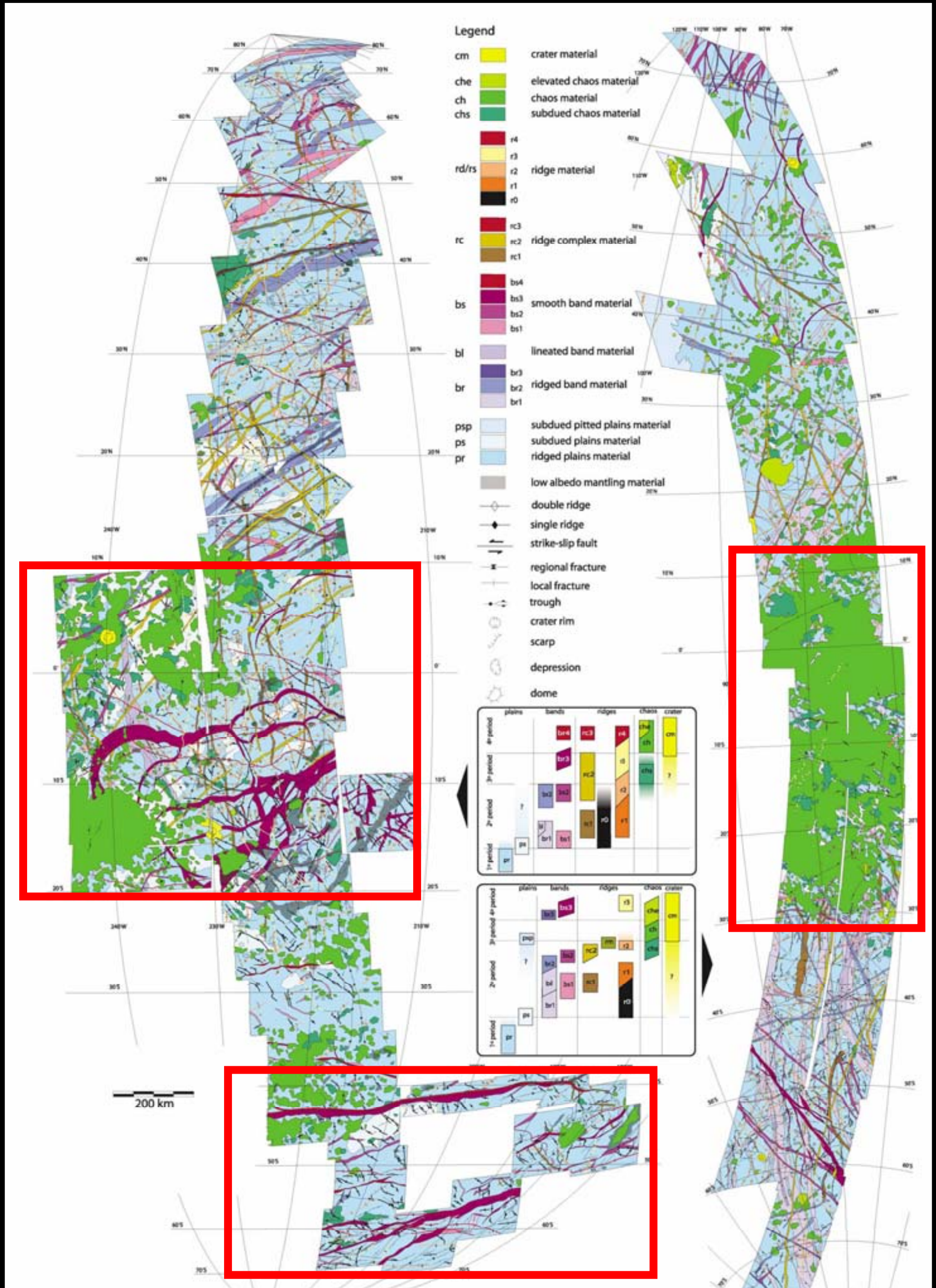

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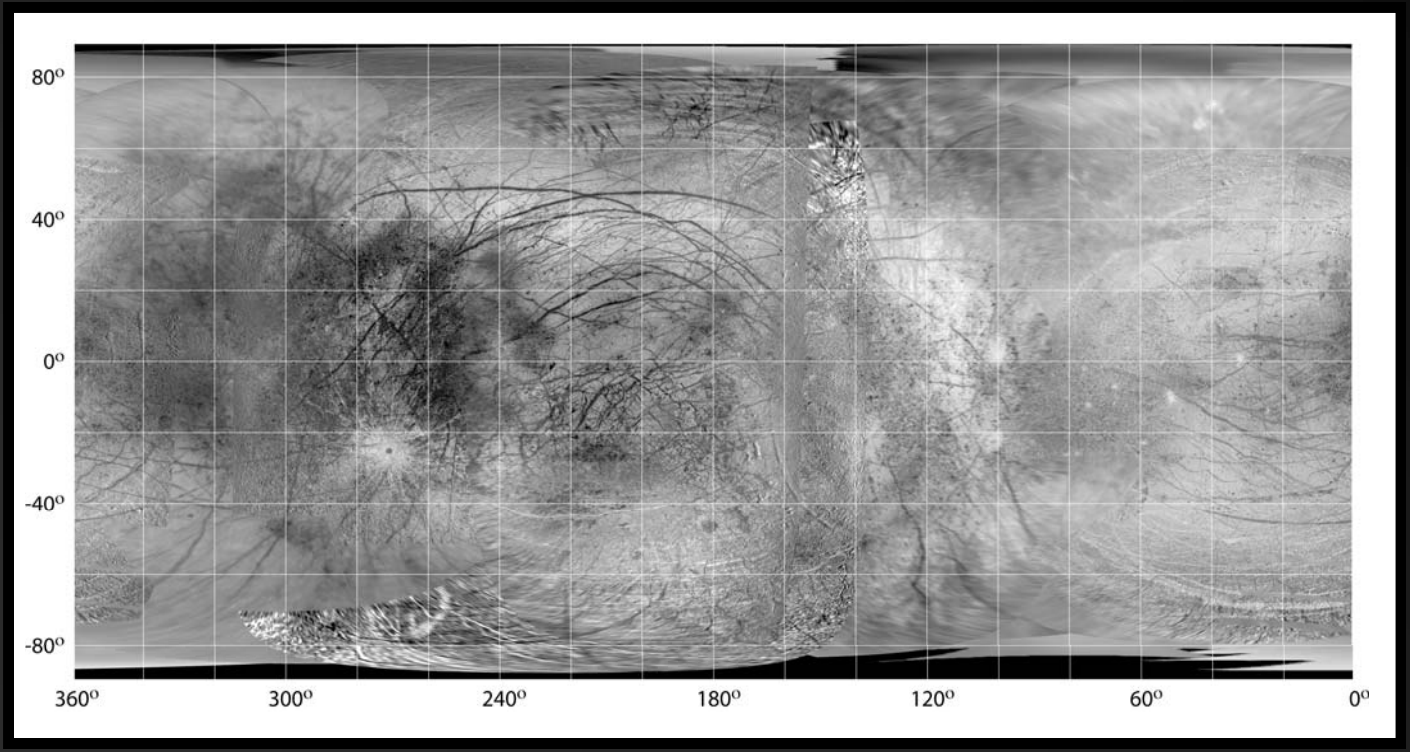

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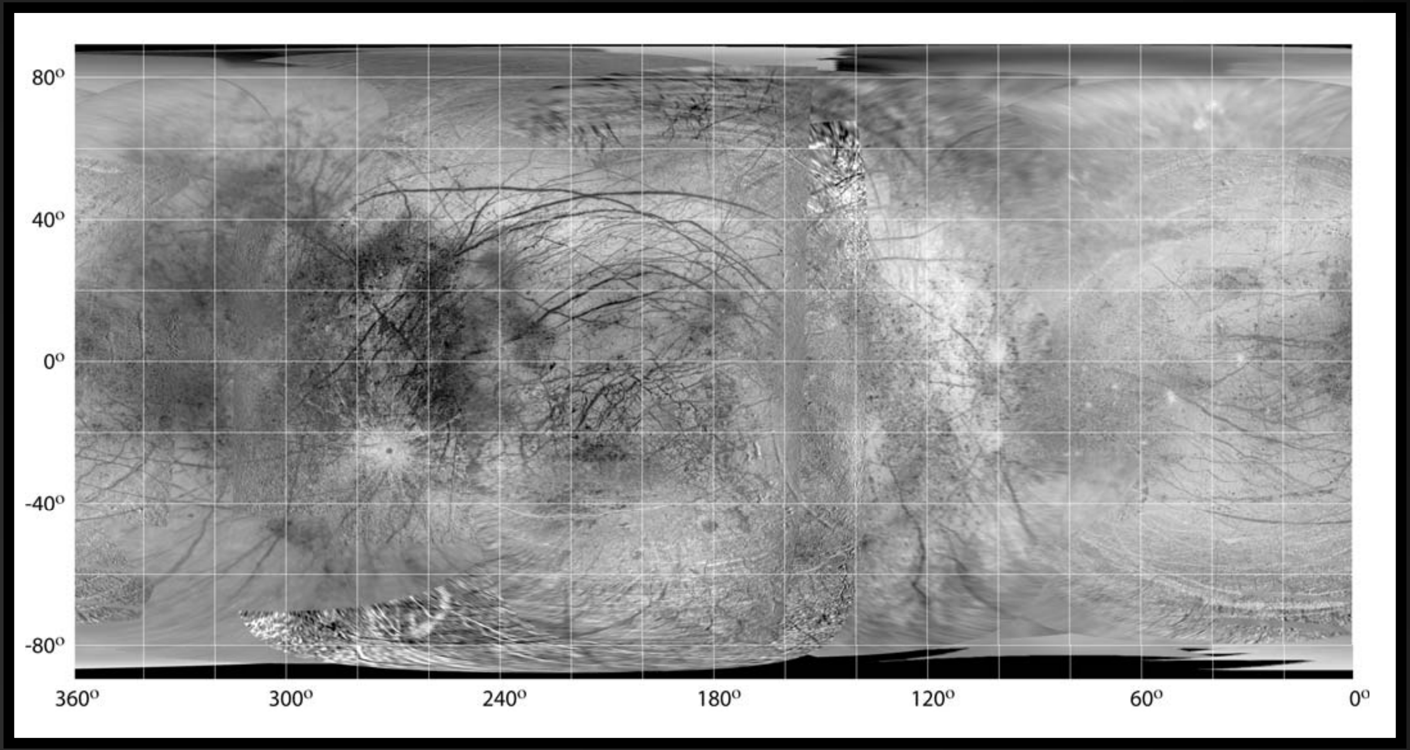

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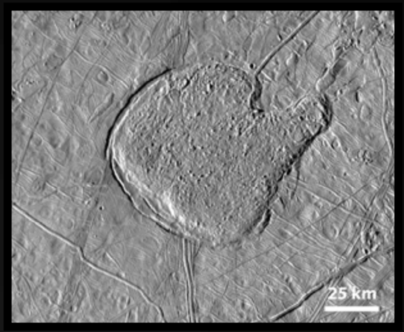
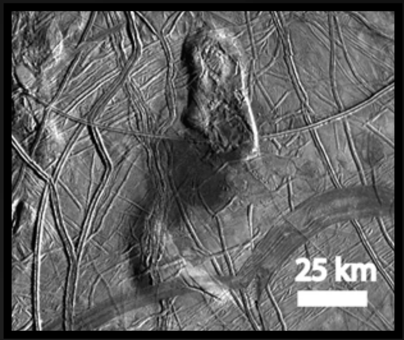
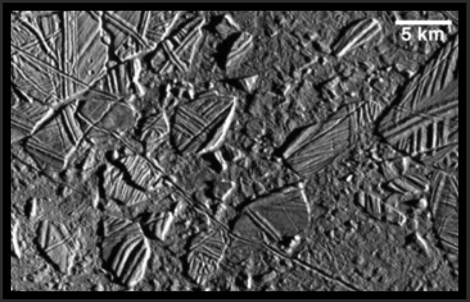


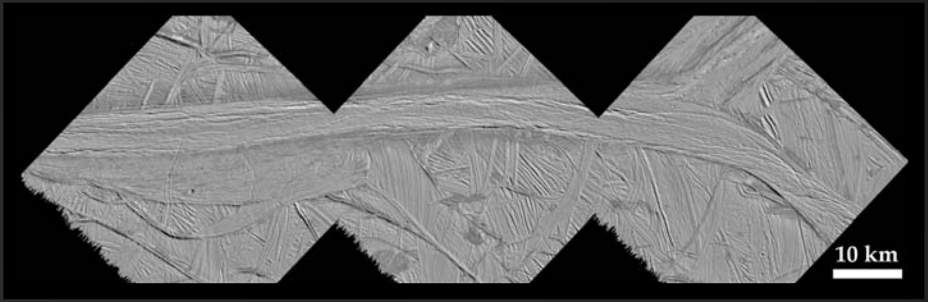
25 km



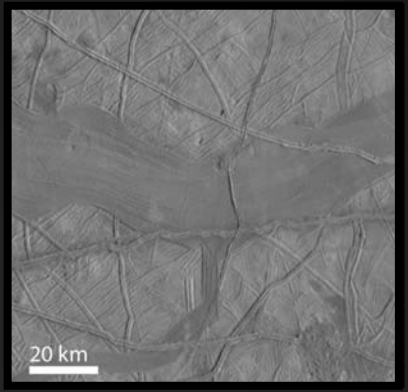
25 km



5 km

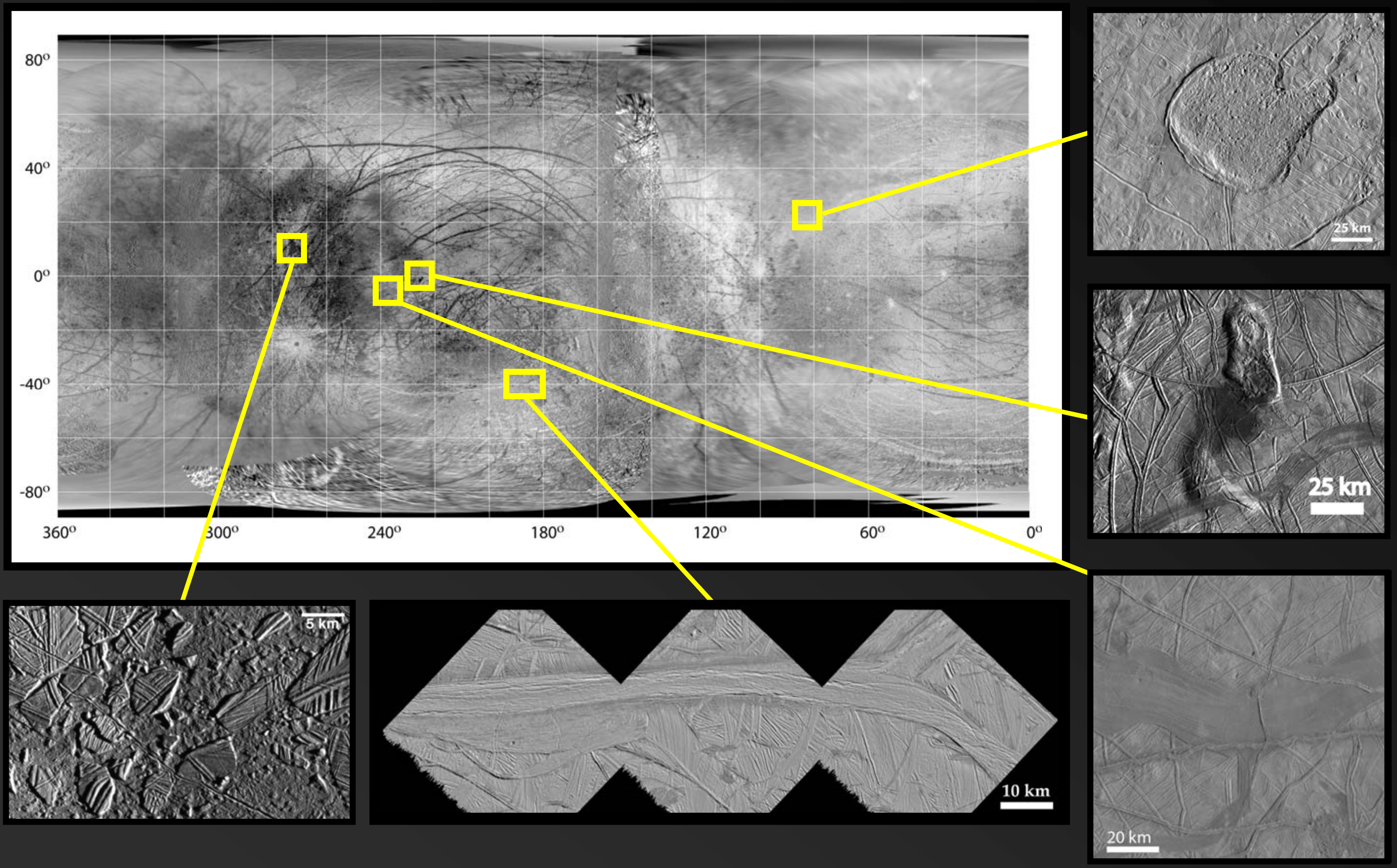


10 km



20 km

Background



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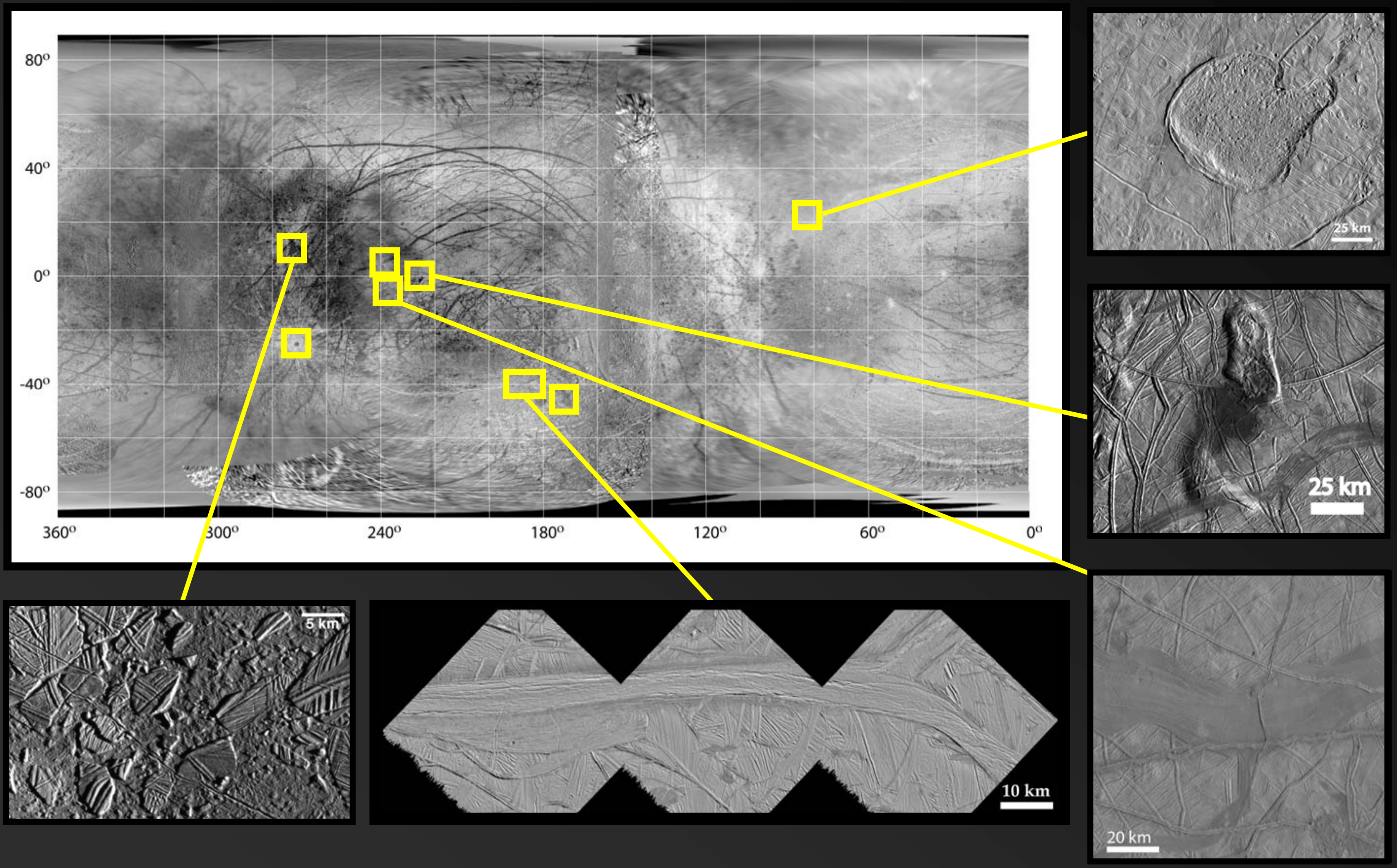

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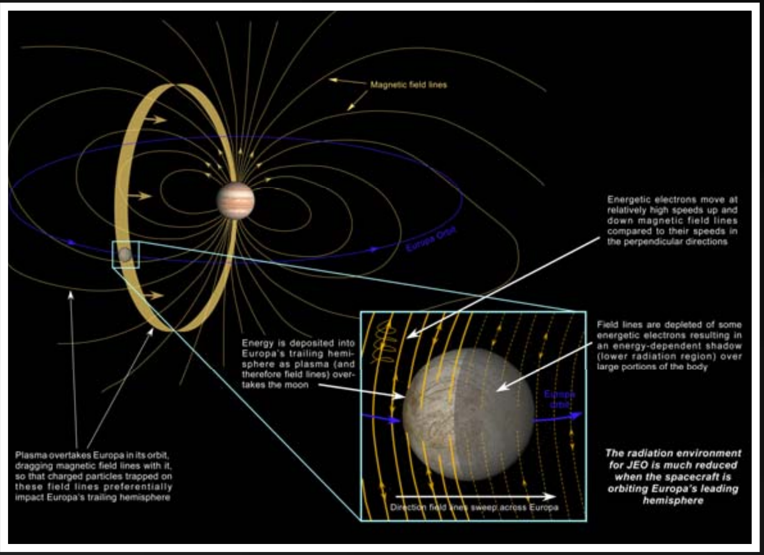
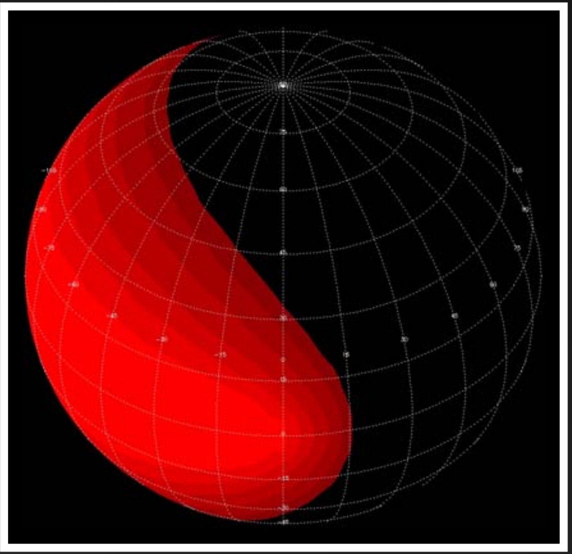
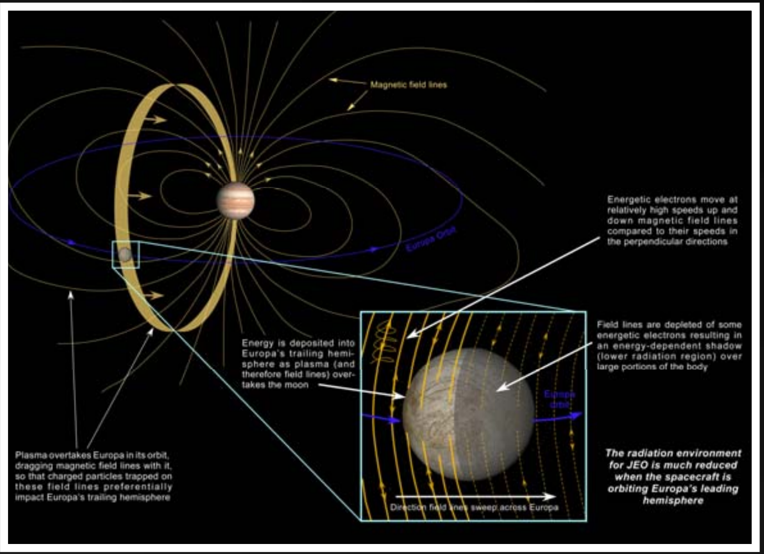
  - Evidence for material exchange between surface and subsurface
  - **External Environment**

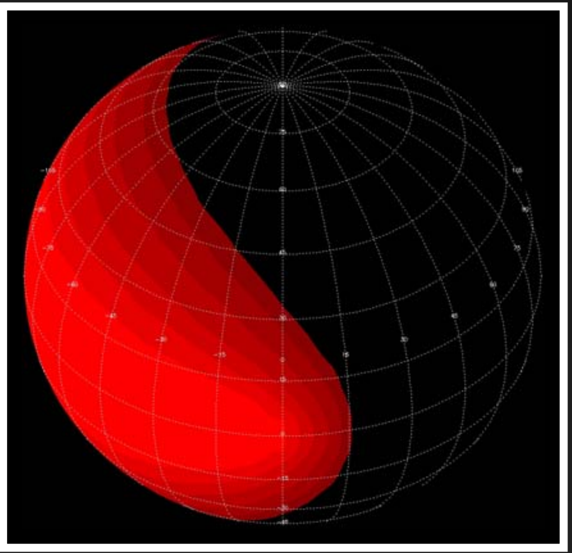




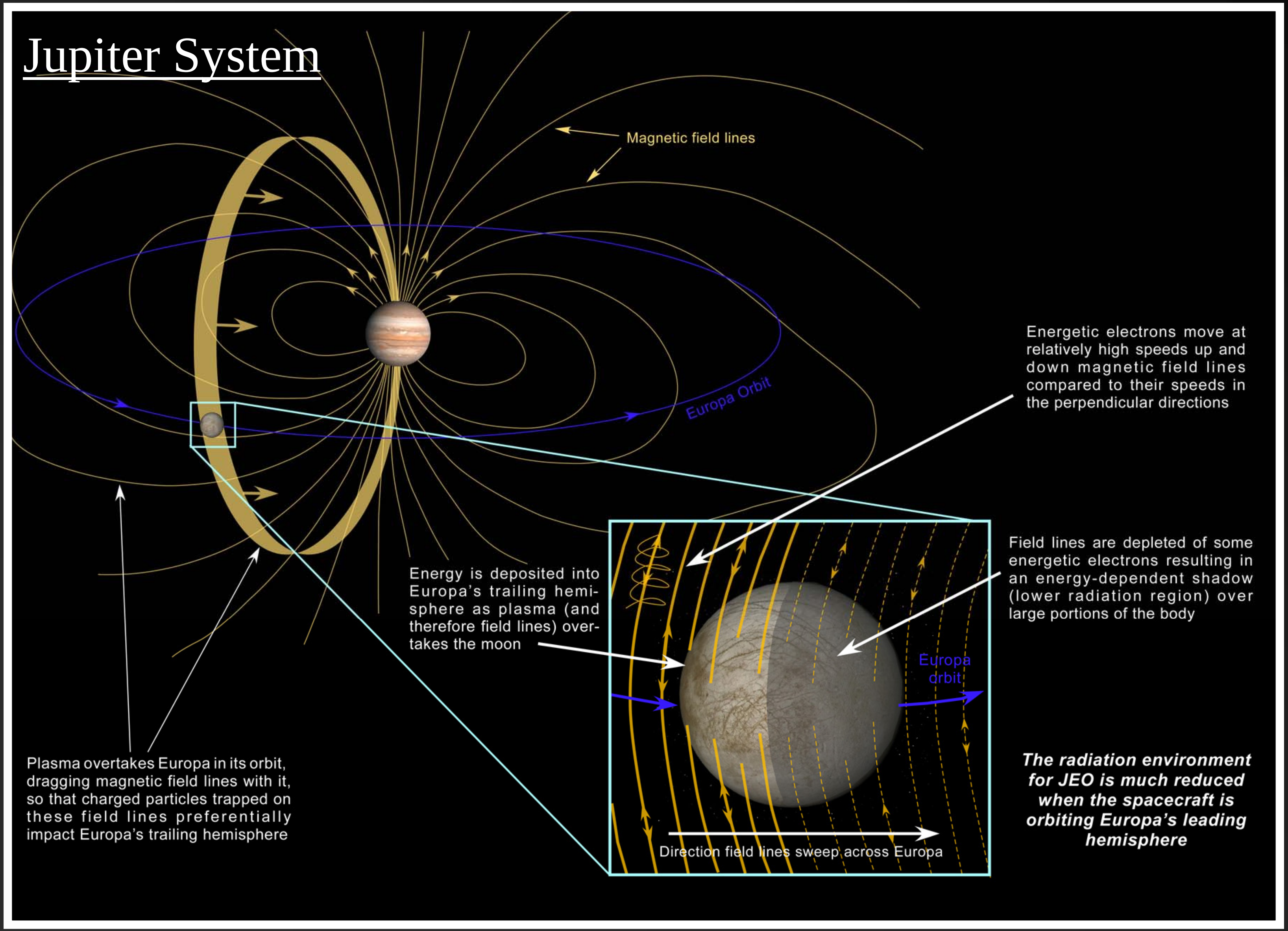
Background

- 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





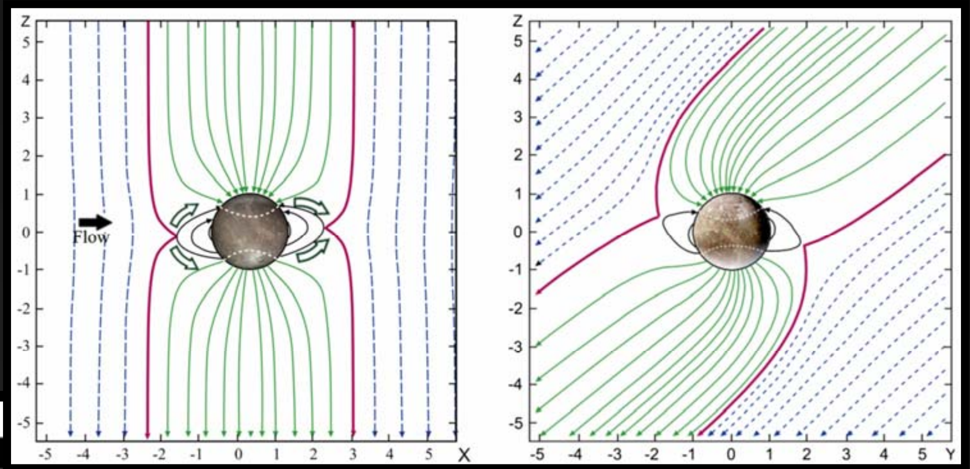
Radiation Environment



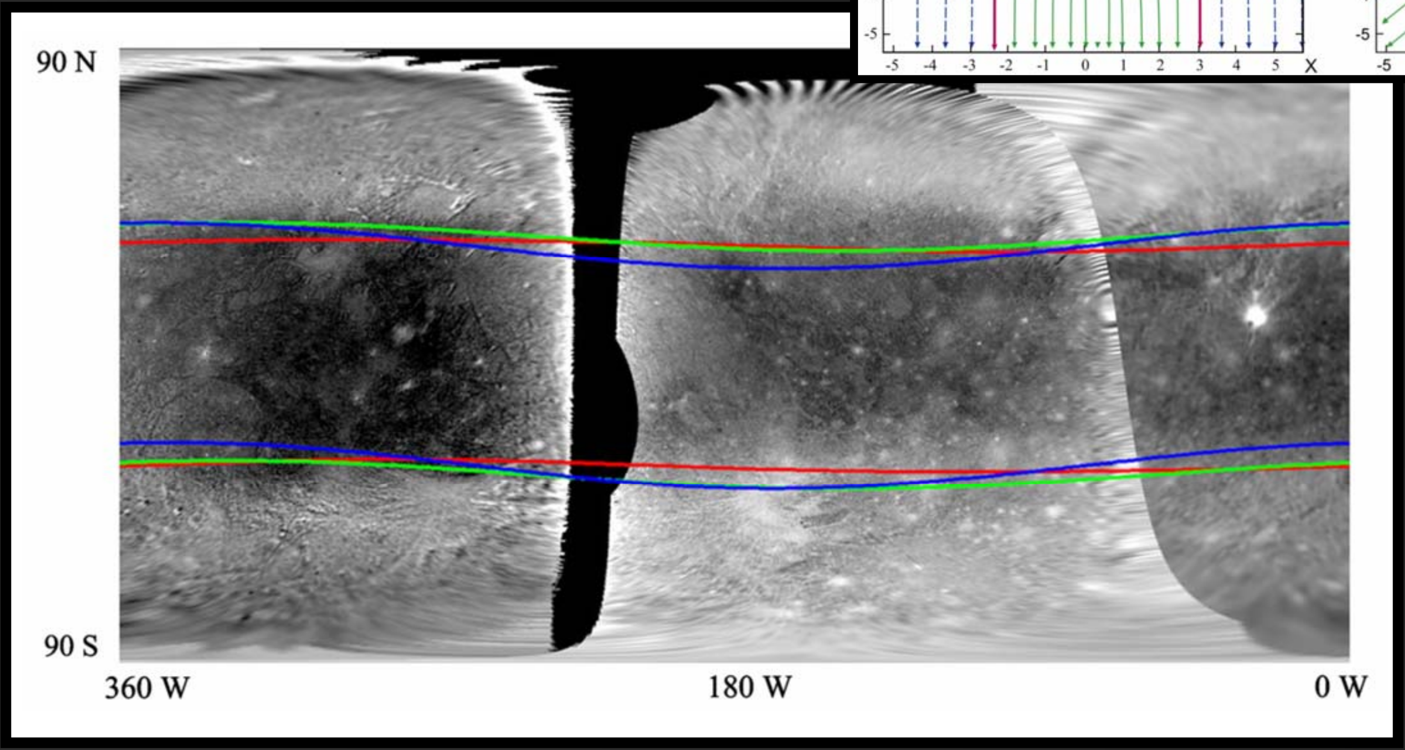
Radiation Environment

Ganymede

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



(*Khurana et al., 2007*)



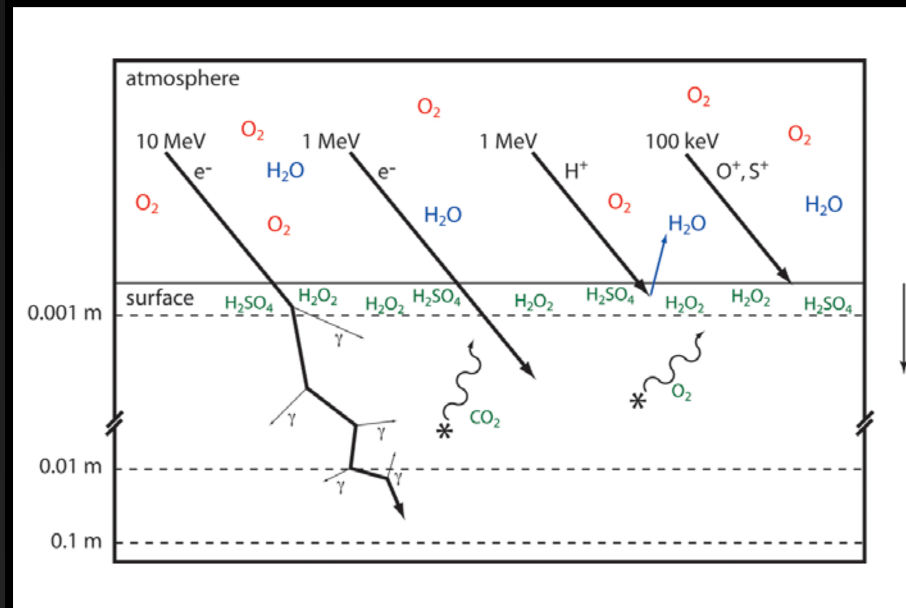
open/closed field line boundaries:

above plasma sheet

mid-plane

below plasma sheet

Radiation Environment



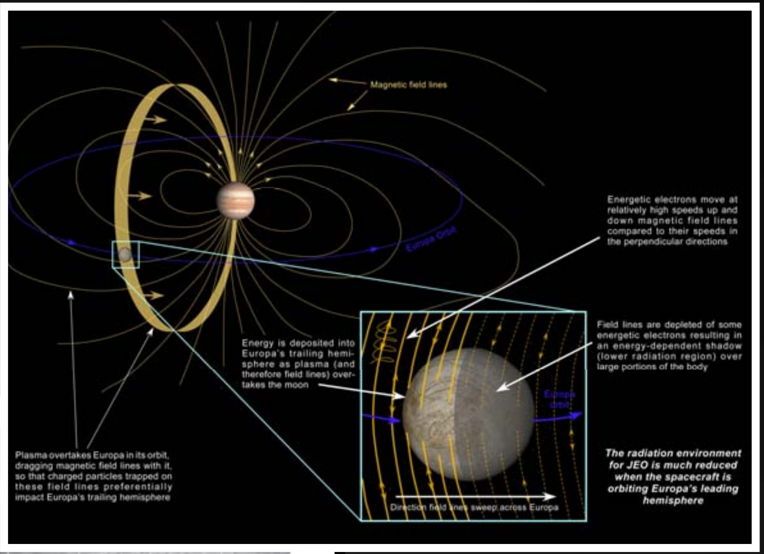
<u>Penetration Depths</u>

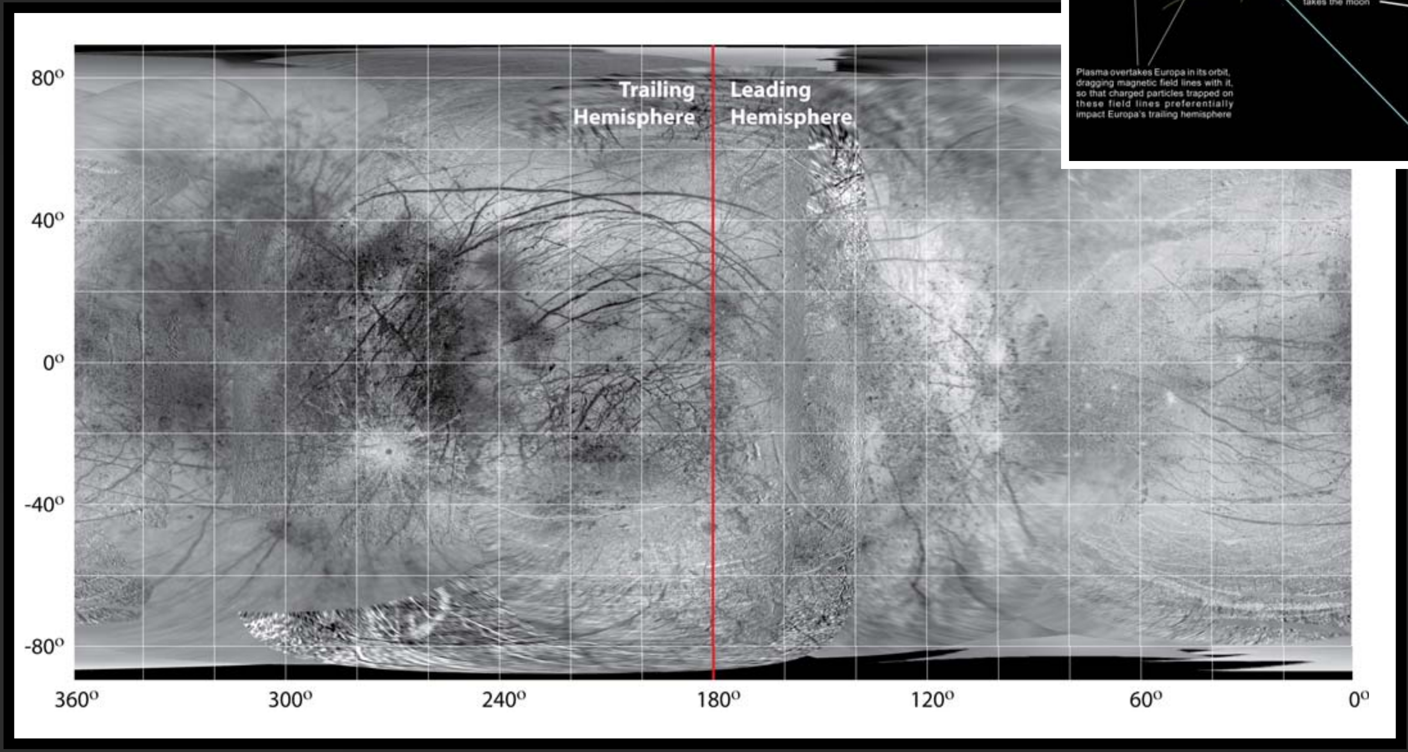
- Charged particles primarily affect the top few cm of Europa's icy shell [*Cooper et al., 2001*]
  - Ions have shallow penetration depths
  - High-energy electrons can penetrate up to a meter or more [*Paranicas et al., 2007*]
  - The significance of electron bombardment with depth is enhanced by secondaries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

Radiation Environment

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*]

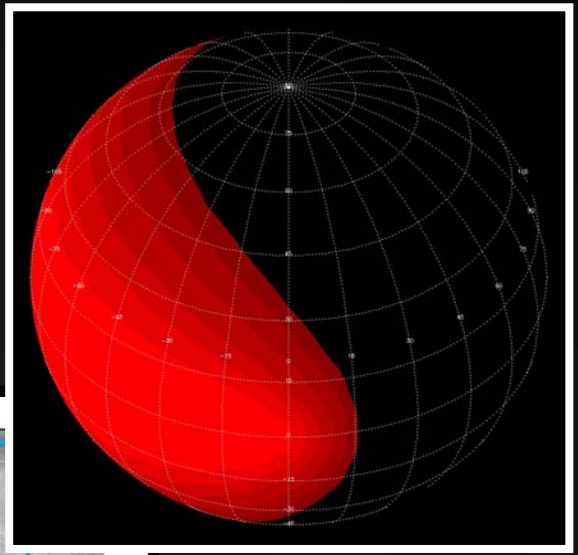


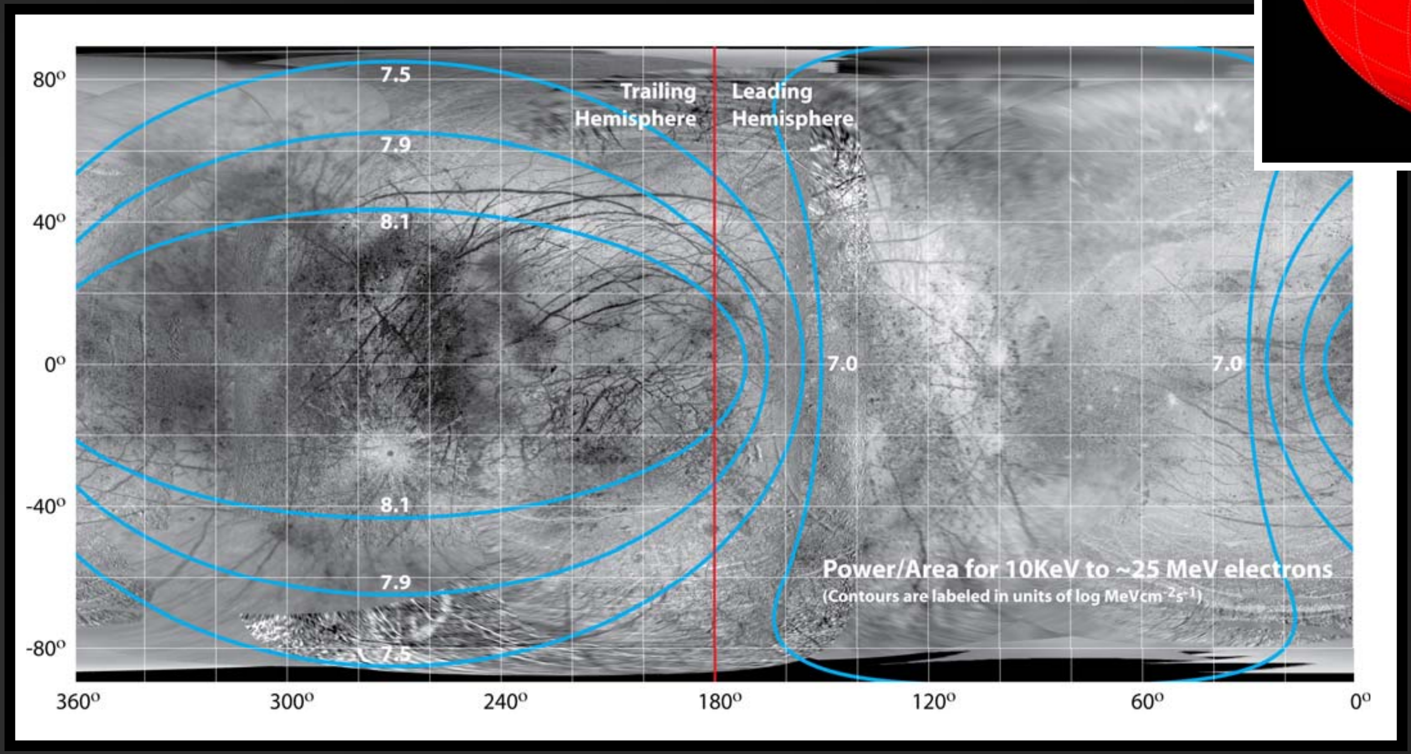


Analysis

Europa

- This suggests that Europa's leading hemisphere, particularly near the apex, is effectively shielded from a significant fraction of the radiation present





Radiation Environment

Short-term variability

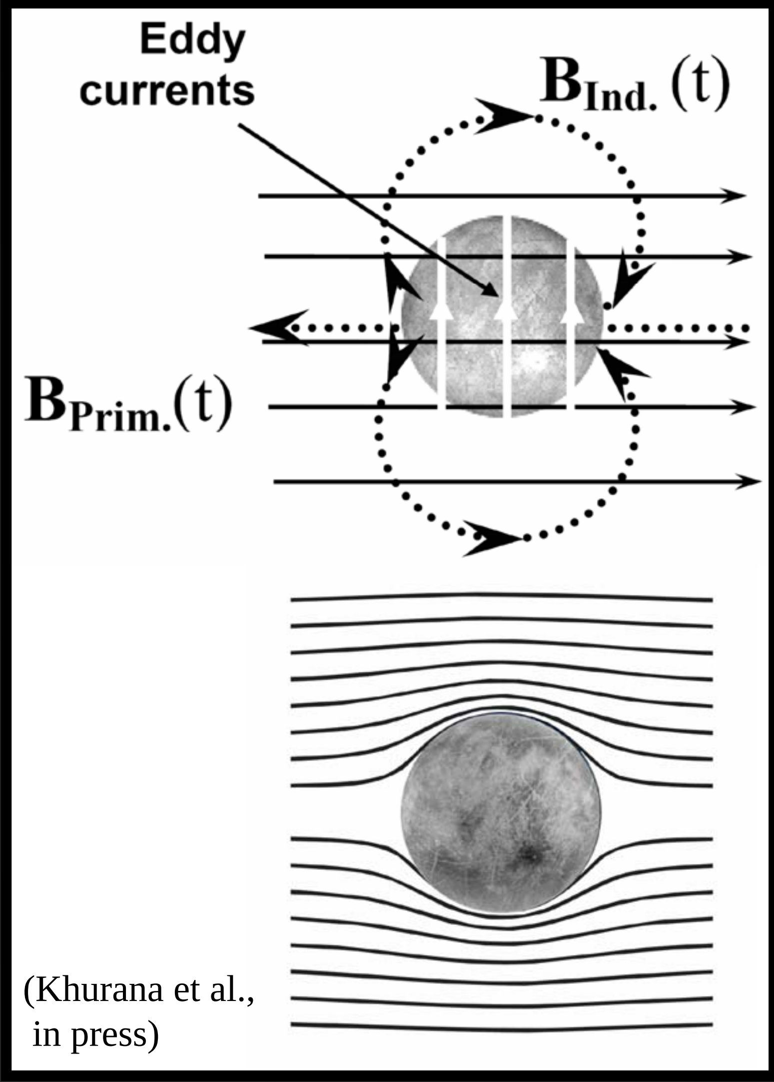
- Solar Wind variability
  - The magnetopause of Jupiter varies with solar wind dynamic pressure
  - Likely affects corotation and reconnection patterns within the magnetosphere
  - Will have some effect on the weathering of Europa

S/C	Year	Local Time	Distance BS (R_J)	Standoff BS (R_J)	Distance MP (R_J)	Standoff MP (R_J)
P 10	1973	1000	108.9	102-130	96.4-50	80-96
		0600	124-189		98-150	
P 11	1974	1000	109.7-79.5	92-100	97-64.5	80-90
		1200	90.8-95		56.6-80	
VG 1	1979	1000	85.7-55.7	77-103	67.1-46.7	62-85
		0400	199.2-258		158.3-165.4	
VG 2	1979	1000	98.8-66.5	79-95	71.7-61.9	70-101
		0300	282.3-283.3		169.1-279.4	
ULS	1992	1000	113	85-104	110-87	72-104
		1800	109-149		83-124	
GLL	1995	0600	130-214	100-130	120	90
	2000	1750			107-149	84-107
		1920	130-133	82-105	120-150	88-98
	2001	1625	108-125	82-96	102	90
CAS	2001	1900	> 450		204	111

Radiation Environment

<u>Short-term variability</u>

- 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 Jupter's magnetic equator
  - We have not yet examined the effects of this source of variability in a quantitative sense

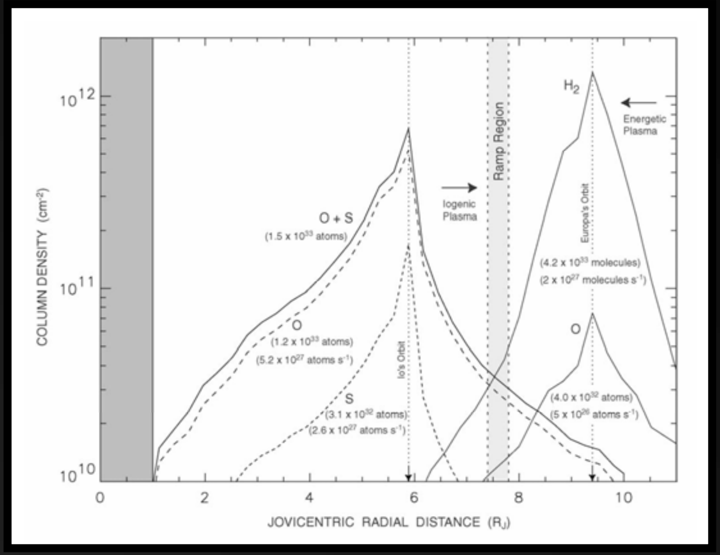


(Khurana et al., in press)

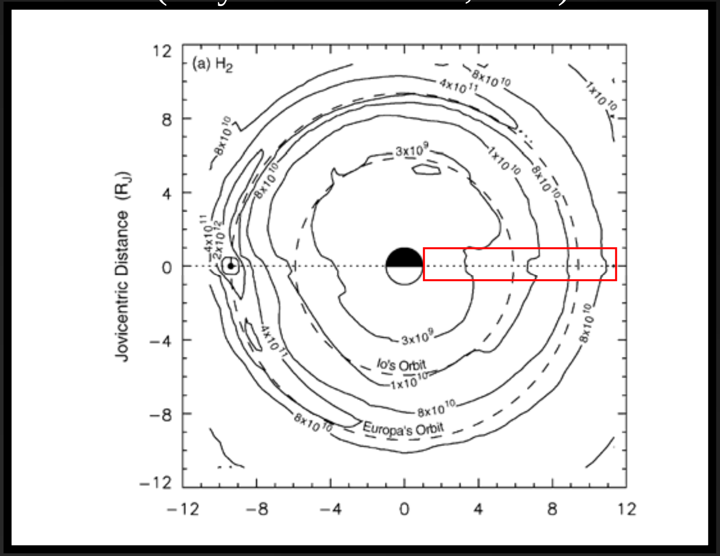
Radiation Environment

<u>Short-term variability</u>

- 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)

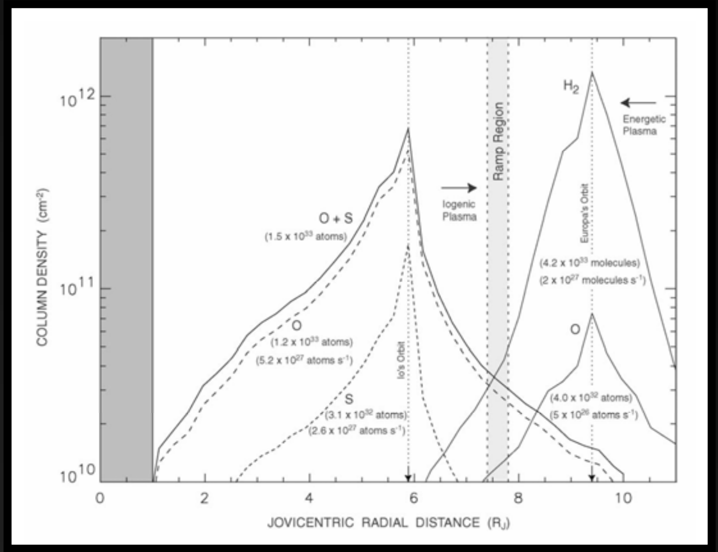


Radiation Environment

<u>Short-term variability</u>

- 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



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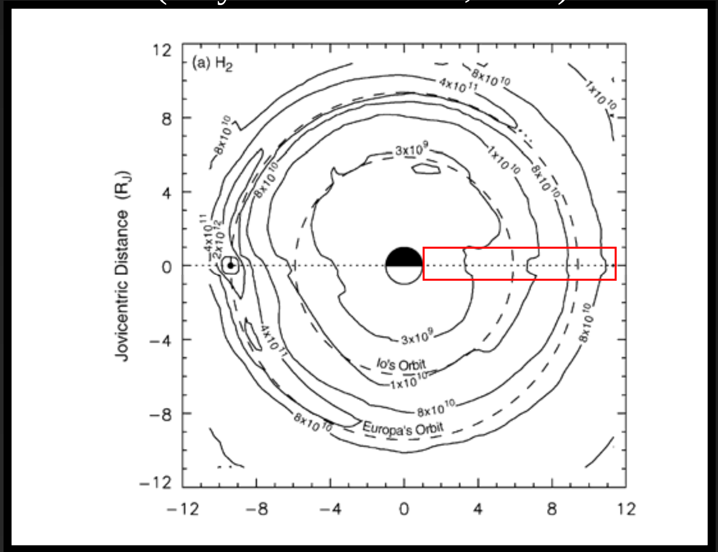
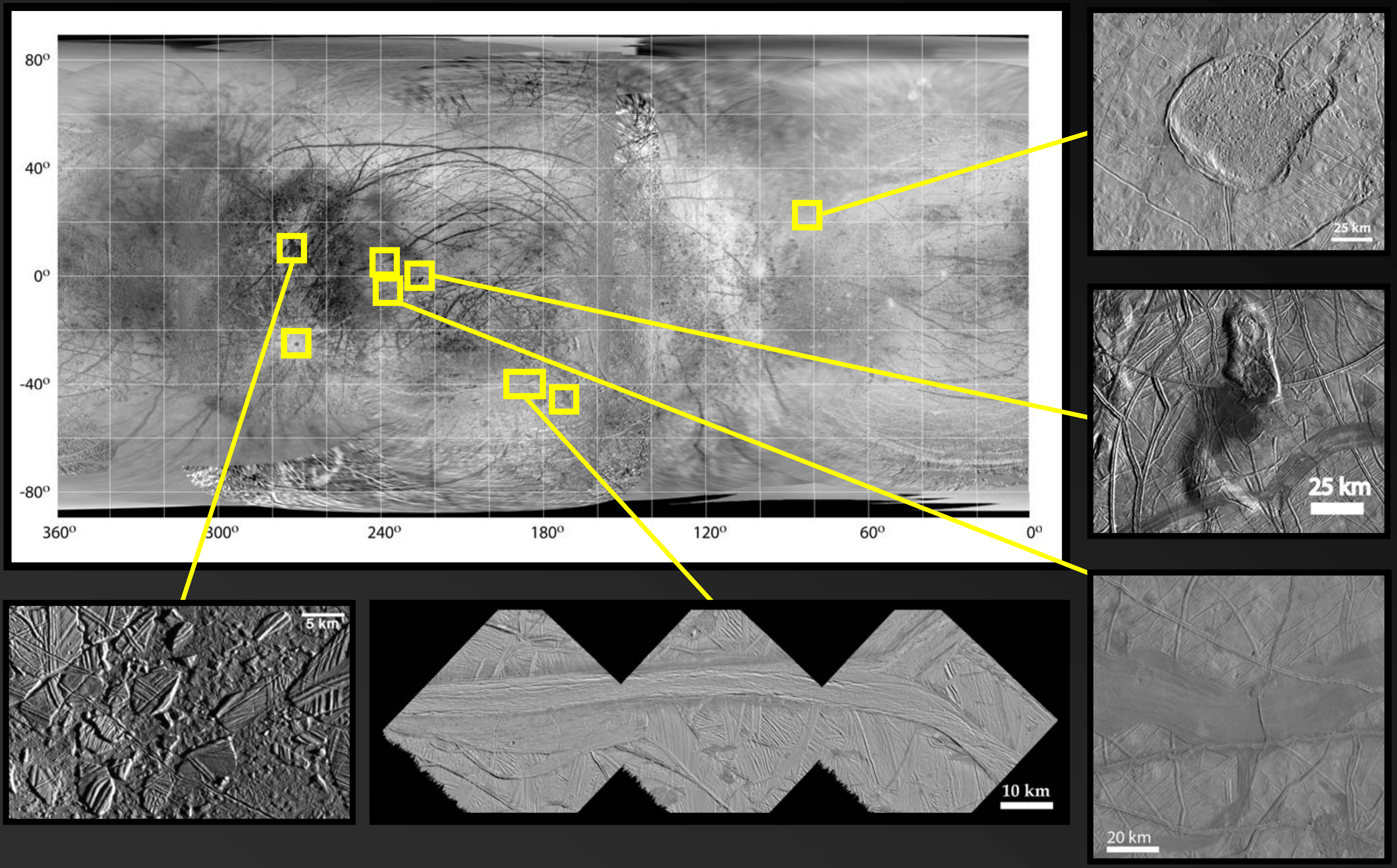


Results



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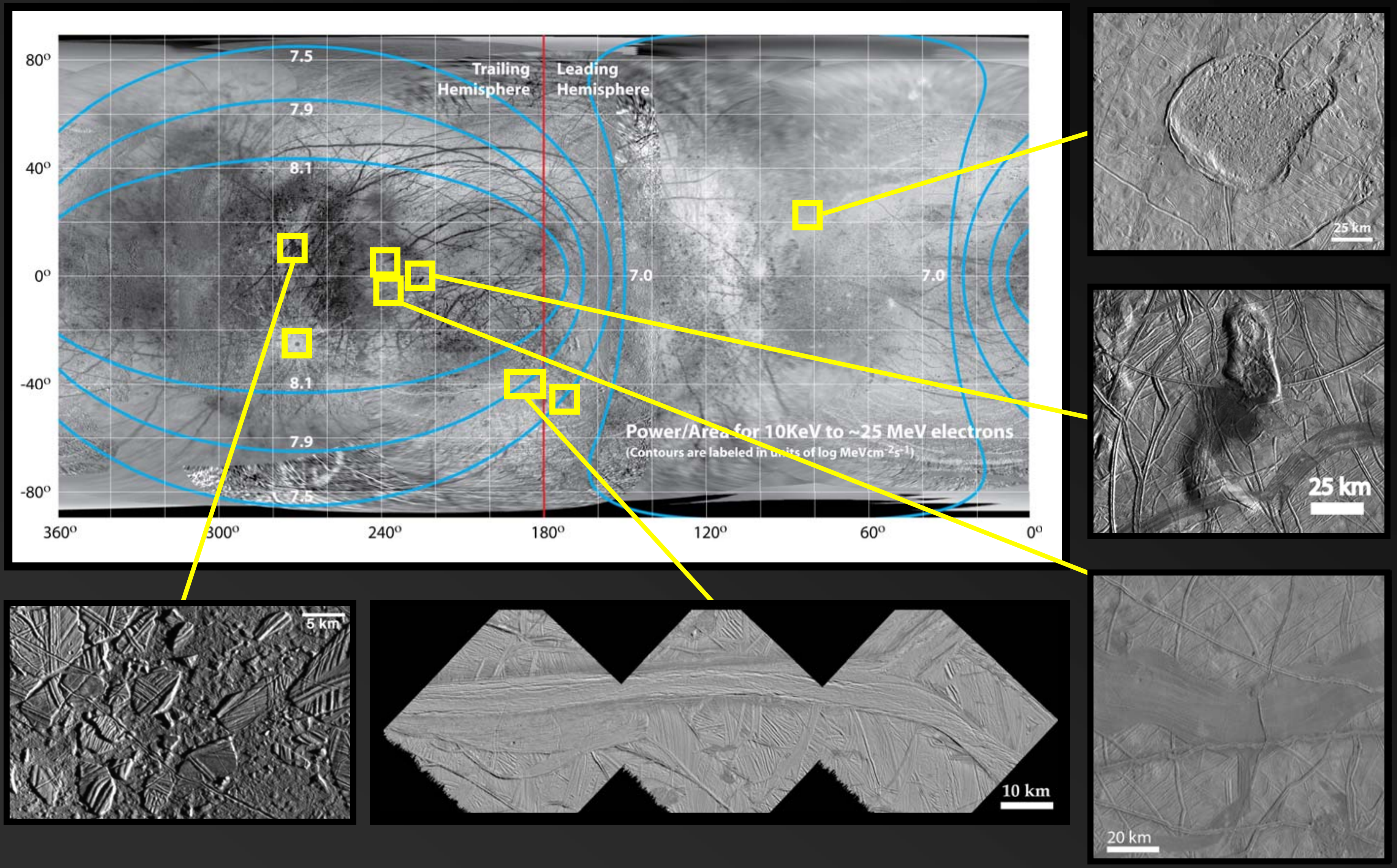


Trailing Hemisphere
Leading Hemisphere
7.5
7.9
8.1
7.0
7.0
8.1
7.9
7.5
80°
40°
0°
-40°
-80°
360°
300°
240°
180°
120°
60°
0°
Power/Area for 10KeV to ~25 MeV electrons
(Contours are labeled in units of log MeVcm-2s-1)
25 km
25 km
20 km
5 km
10 km

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 μm/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 μm/yr [*Cooper et al., 2001*].

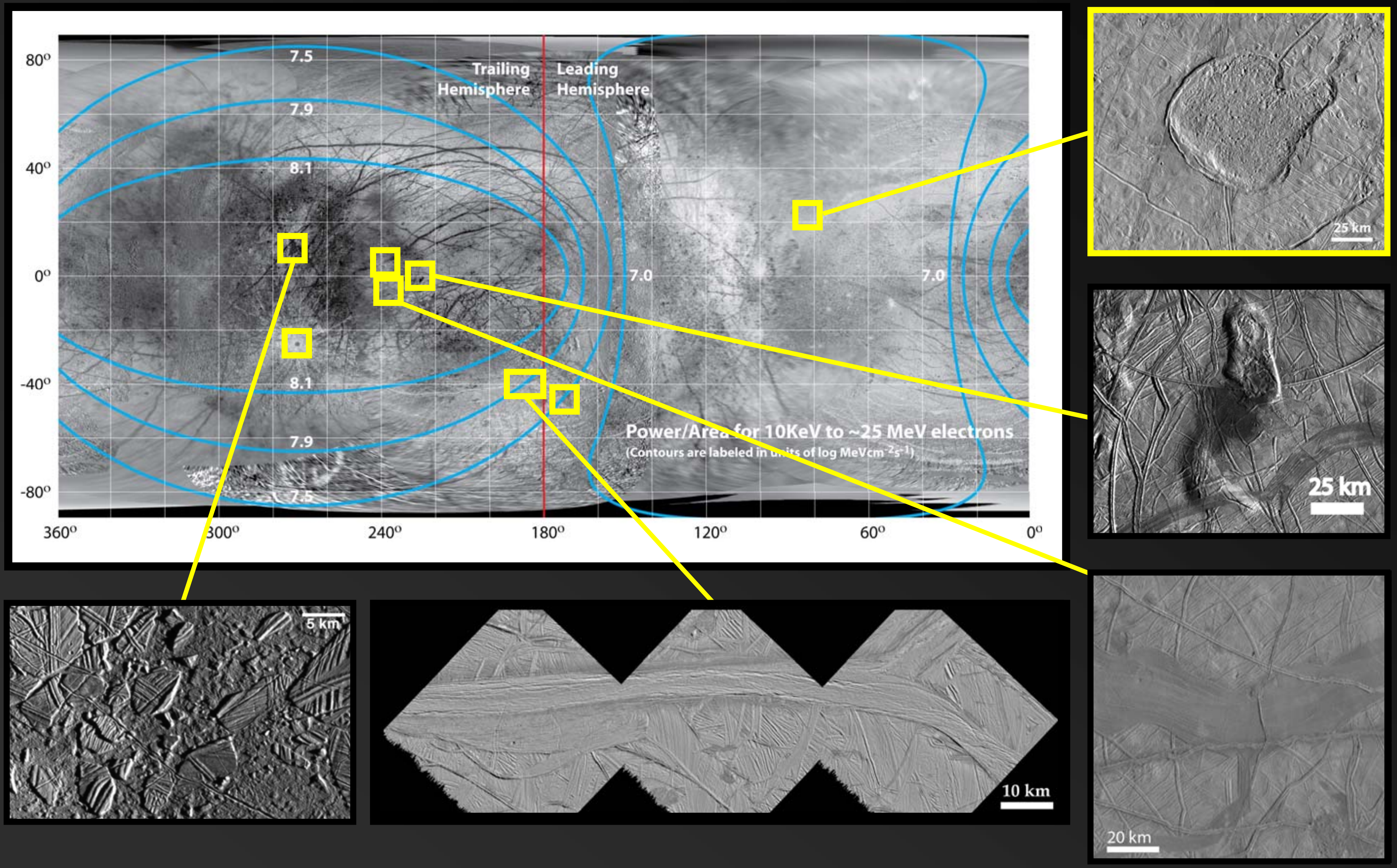
Further Considerations

- 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 Weidenshilling, 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 >10^3 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 ioniziing 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



80°
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Radiation Environment

Short-term variability

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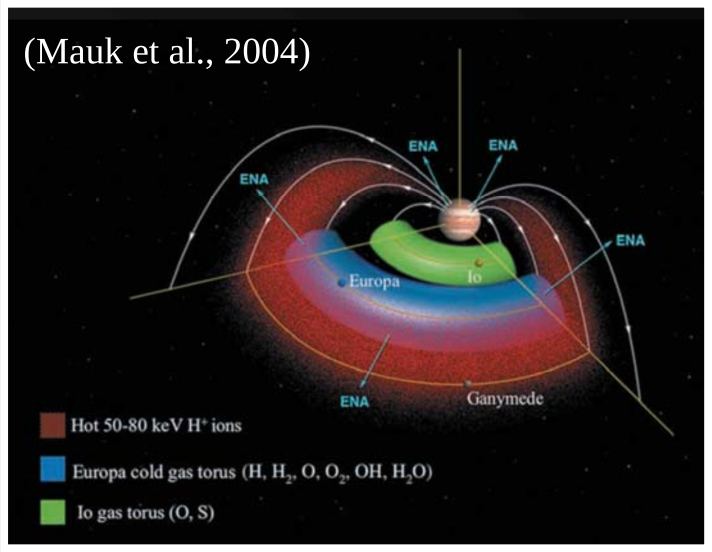
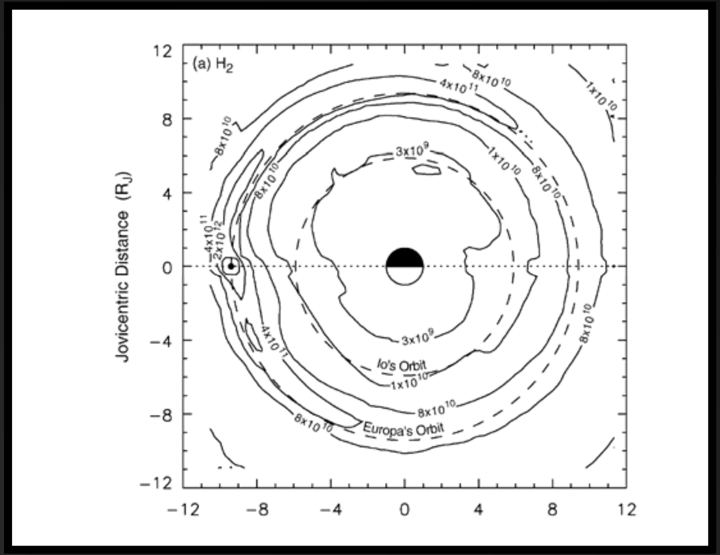
- Magnetic draping
- Flux of neutrals





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