Energetic charged particle instrumentation for JUICE

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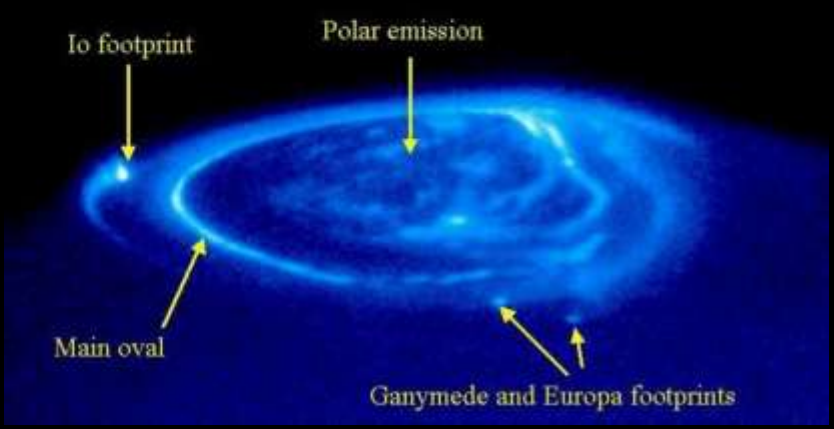
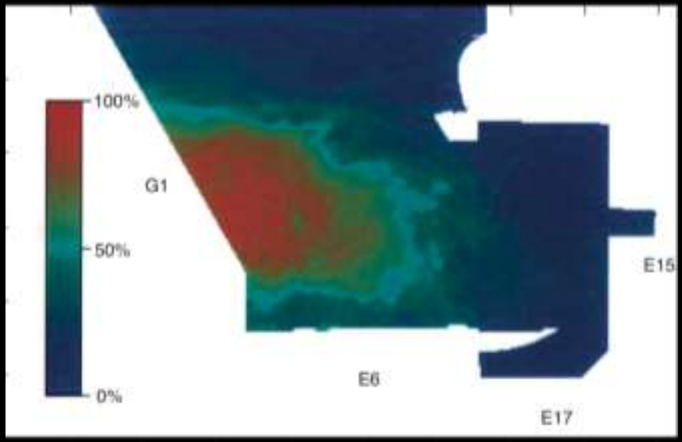
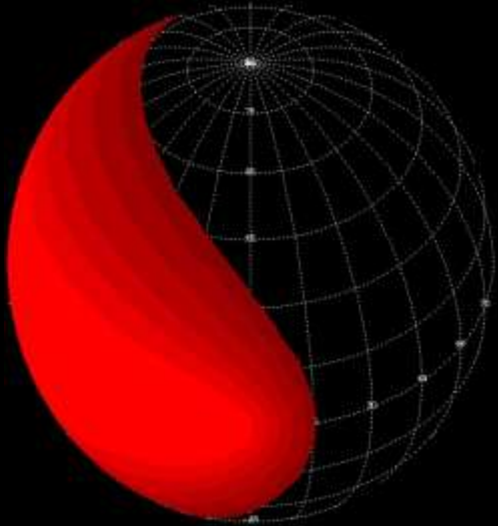






Outline of talk

Why measure energetic electrons?

Examples of processes

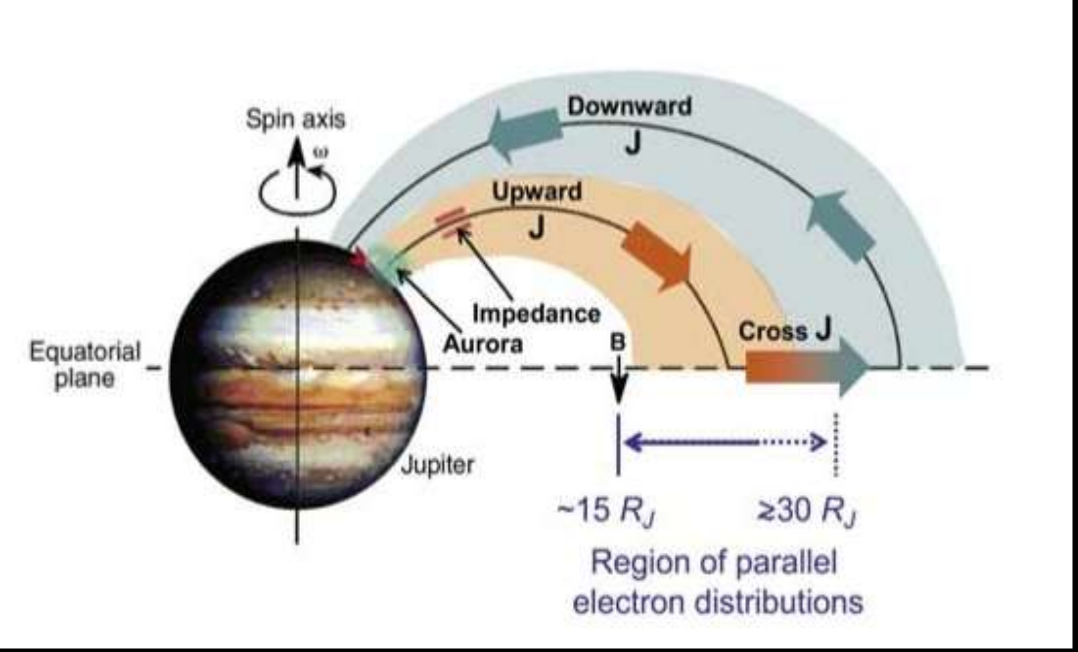
Challenges of the radiation environment

Instrumentation for a radiation environment

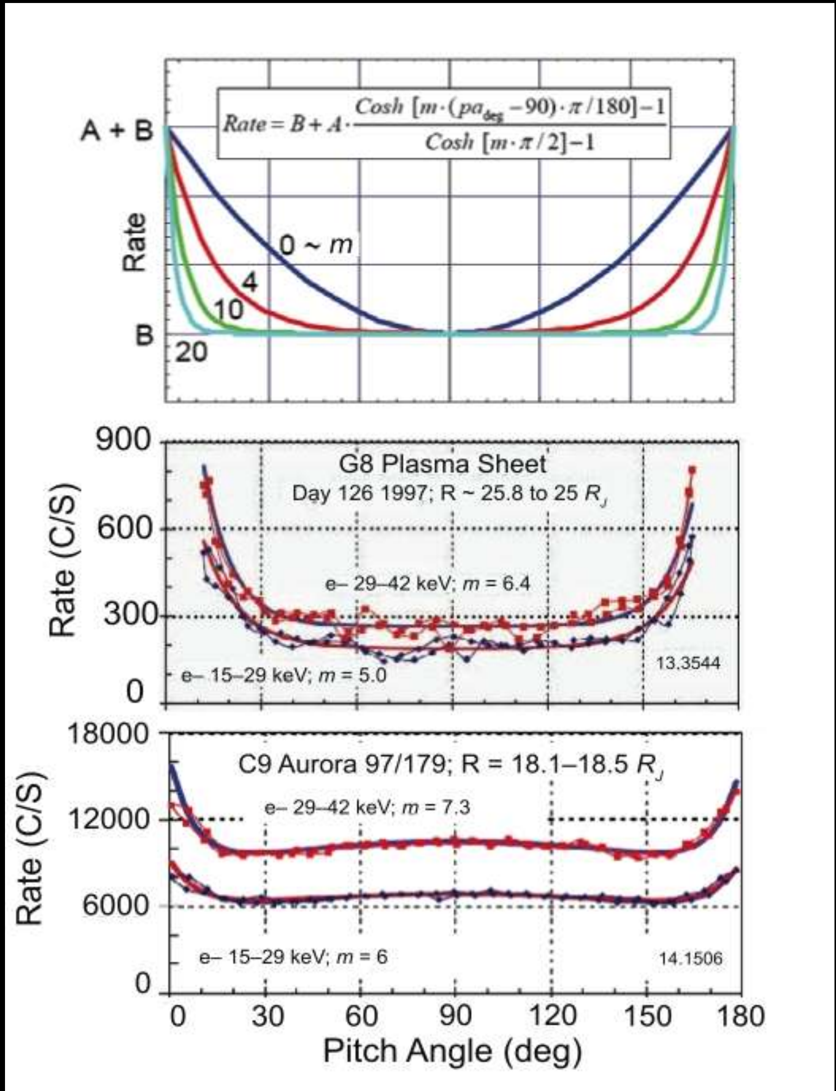
Summary and conclusions

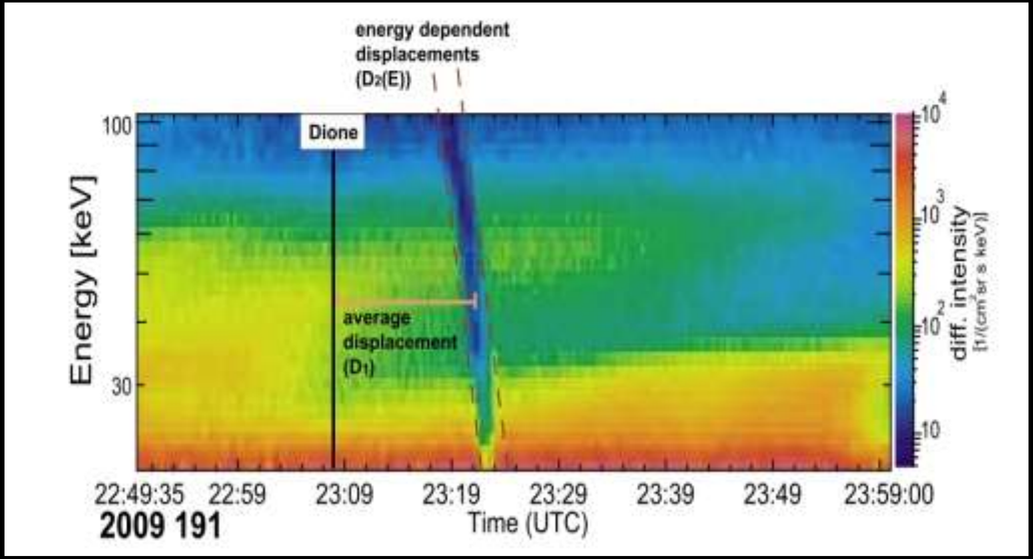
Why measure energetic electrons?

- Will go through these in this order:
- Power auroral emissions on the planet and at the satellite
- Understand magnetospheric processes: injections, satellite interactions, etc.
- Weather/modify the surface materials
- Probe topology on short timescales
- Measure magnetic fields at satellite surfaces
- Drivers of the radiation dose

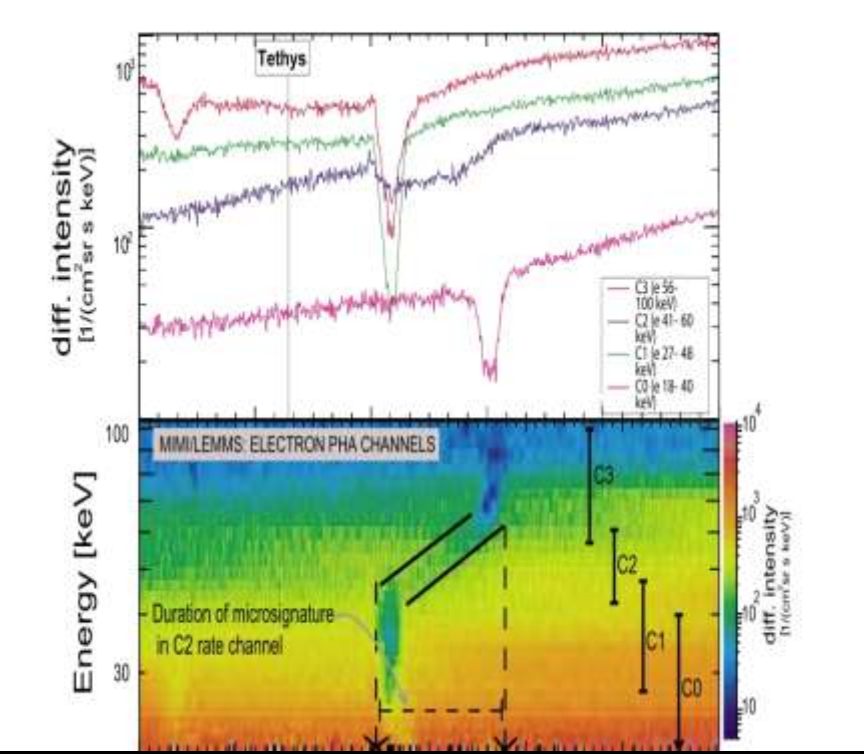


Mauk and Saur (2007) used beams detected by Galileo EPD to investigate auroral processes



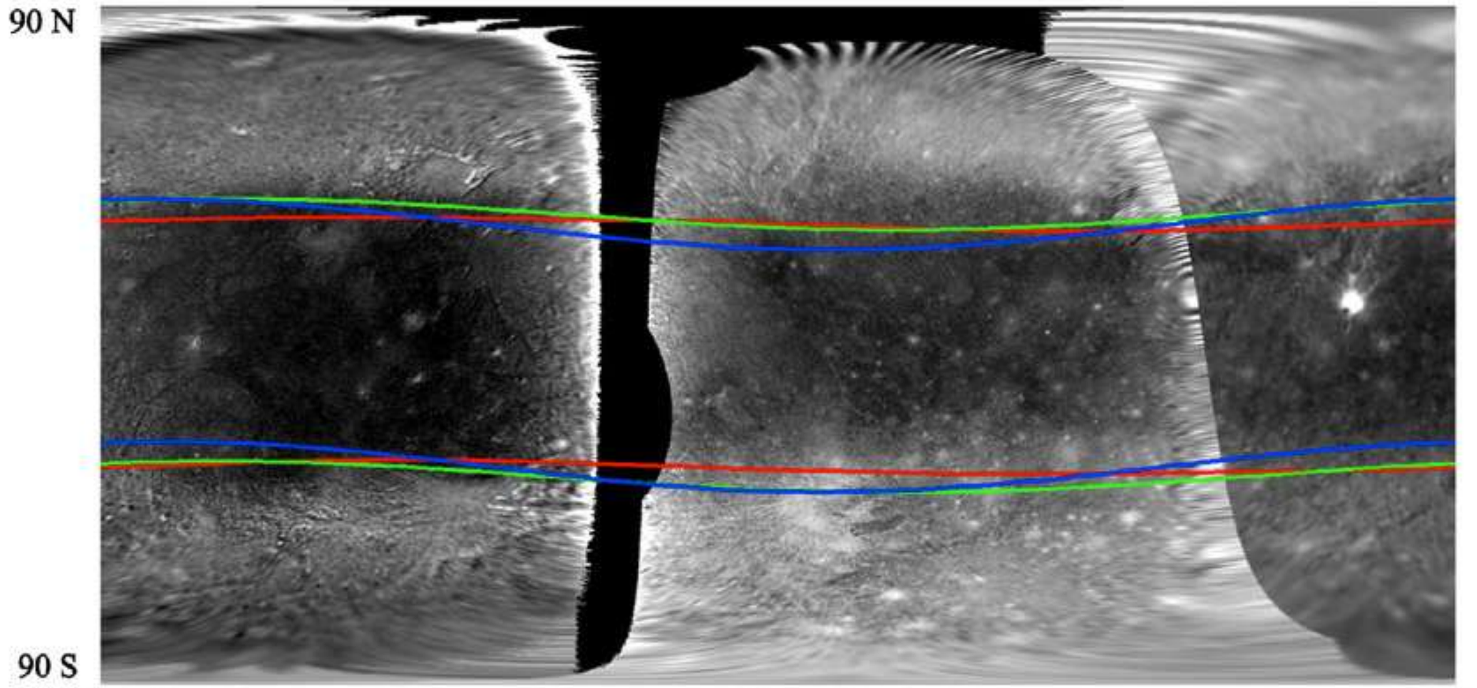


This figure from Roussos et al. (2010) shows a typical Dione microsignature (from Cassini/MIMI data) under steady-state conditions on the left and a Tethys microsignature following magnetospheric activity on the right. The authors extracted the radial speed of the plasma disturbance from these data.



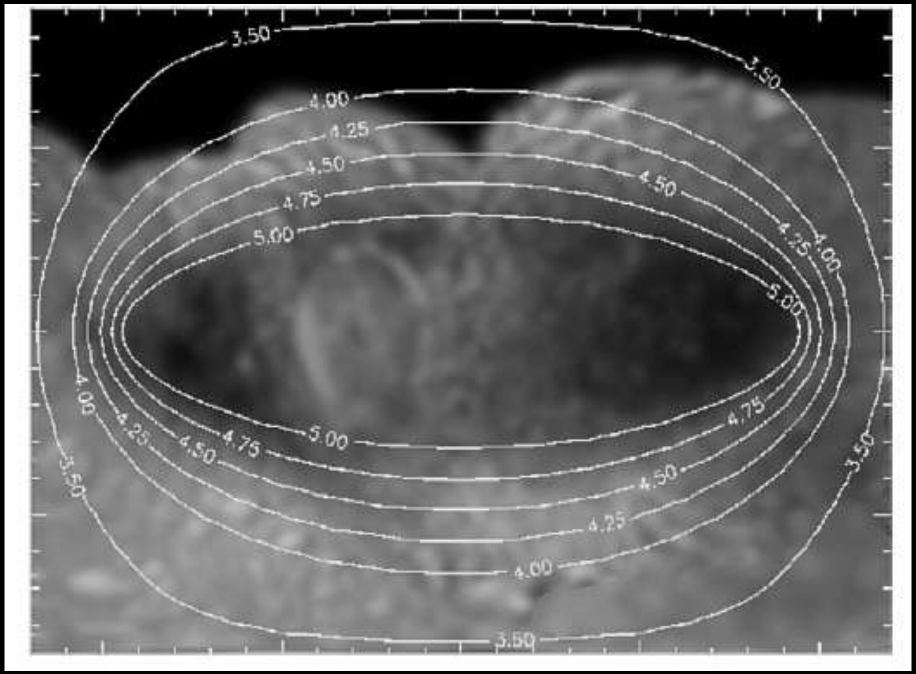
Further evidence of the importance of space environmental factors on optical remote sensing.

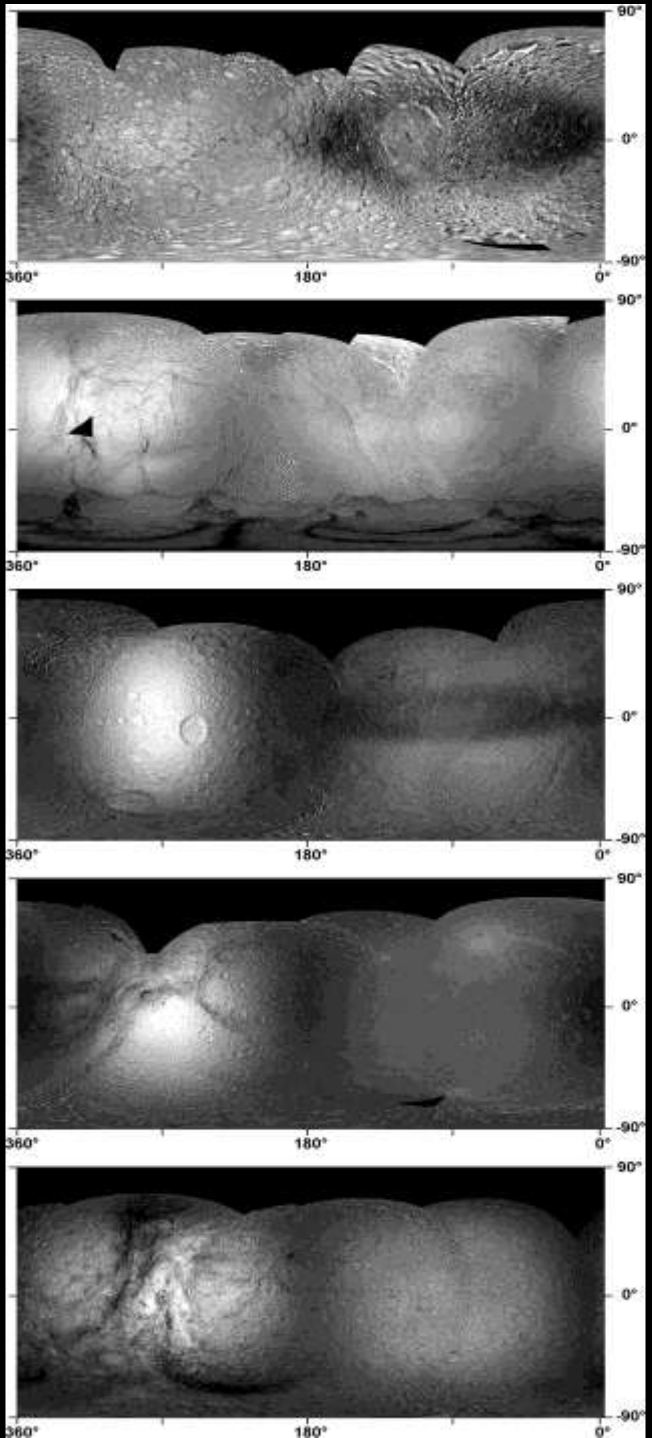
Khurana et al. (2007) relates the location of the polar caps of Ganymede to “open” magnetic field lines on that moon. Charged particles appear to brighten the surface.



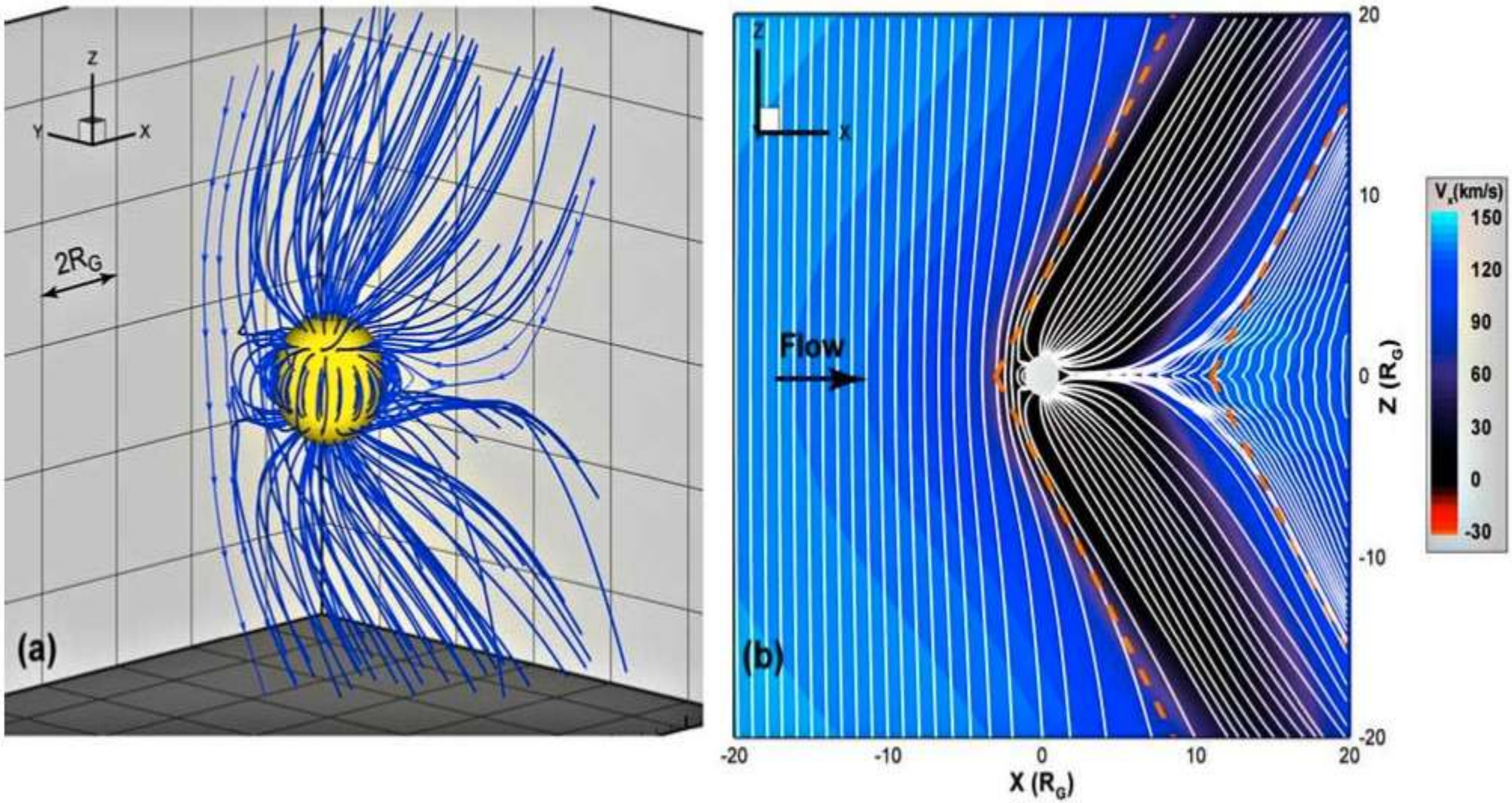
(b)

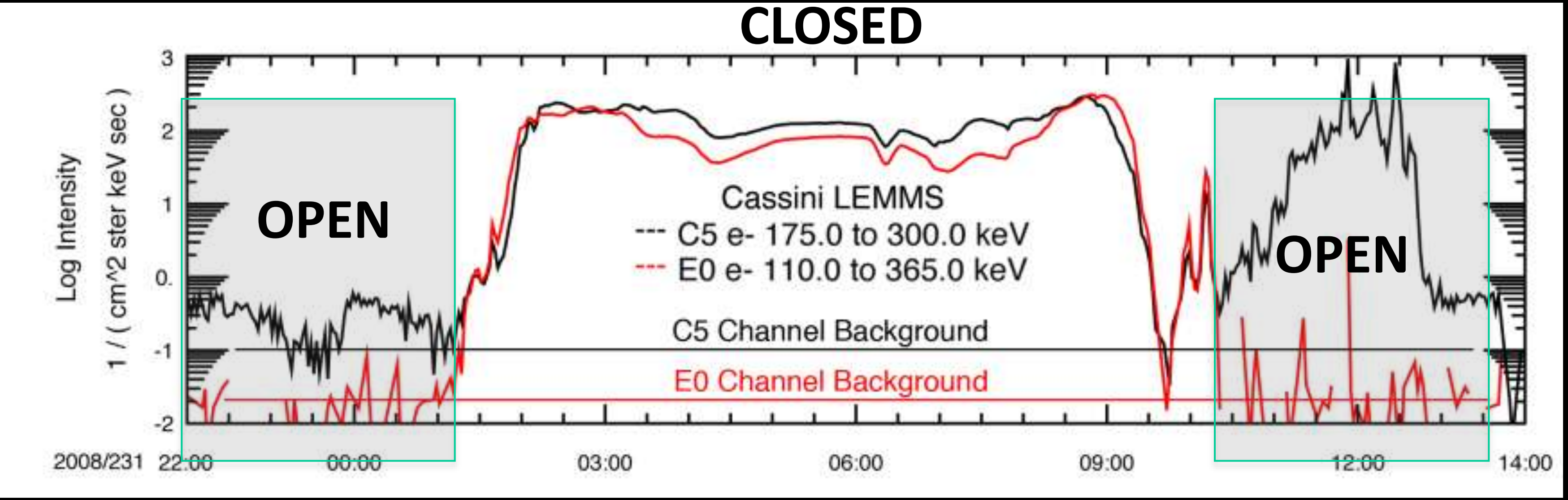
In a 2011 Icarus paper led by Schenk, we looked at how the icy surfaces of Saturn's satellites are modified or "weathered" by electrons that are precipitating onto them from the magnetosphere. Based on Cassini/MIMI data and modeling, the patterns are expected to have a lens-like shape (below). This corresponds to similar patterns in the color ratios of the surface from optical remote sensing of the 5 major inner satellites (right).





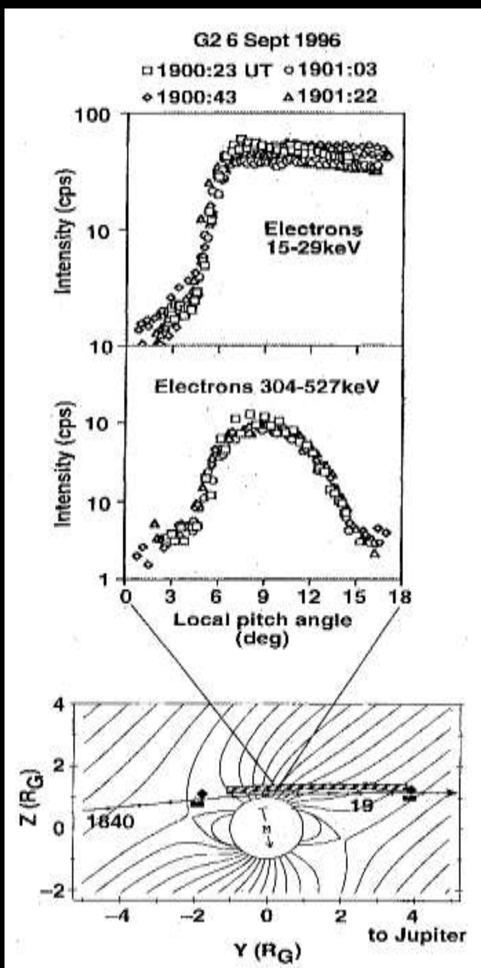
From the work of Jia et al. (2008). This figure shows a simulation of the magnetic field near Ganymede and x-component of the plasma flow. One challenge of JUICE will be to know when the s/c is on open/closed/boundary field lines to study subjects such as weathering and escape of pick-up ions revealing surface composition

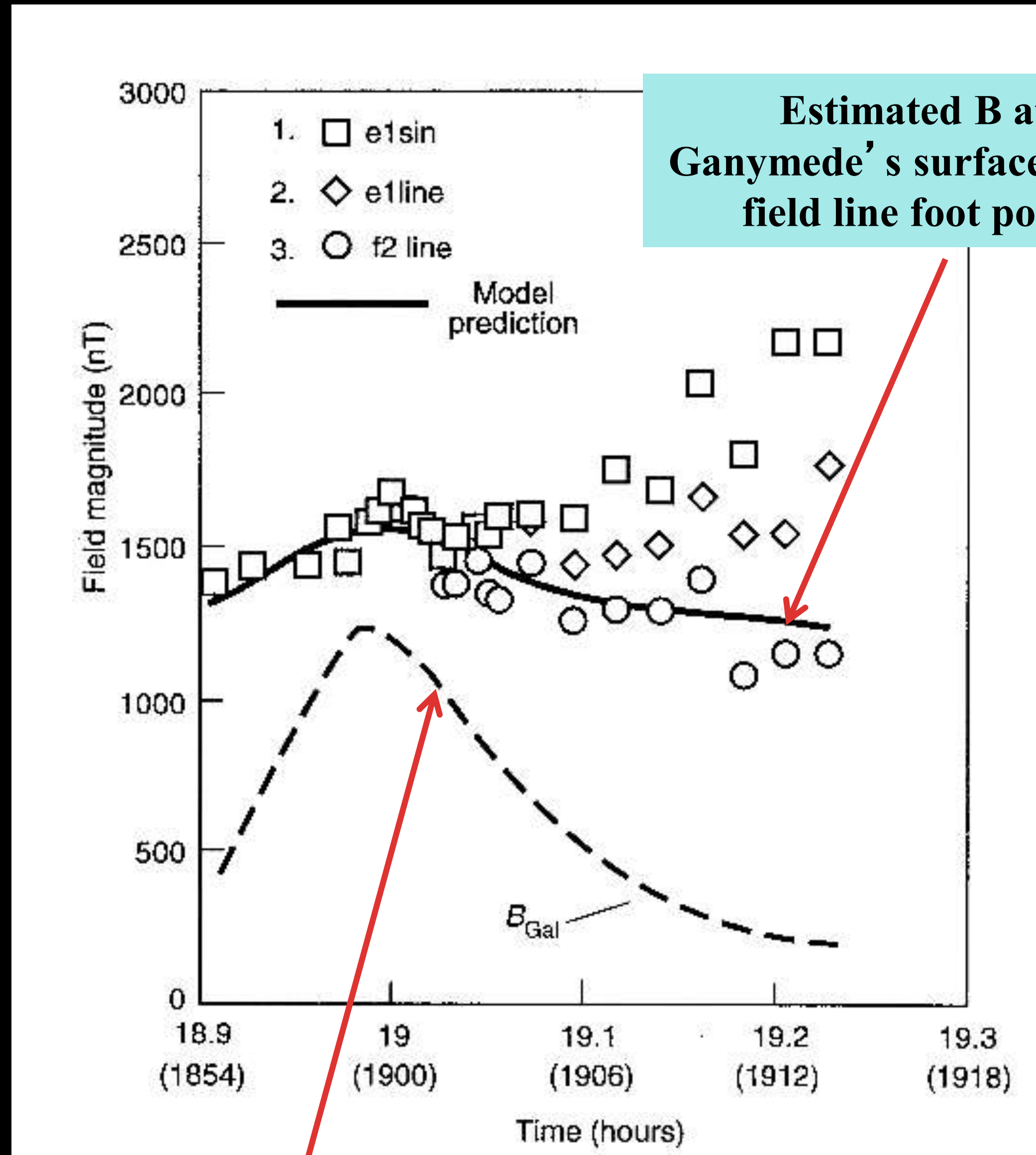




Electrons move rapidly on magnetic field lines. In this example, channels c5 and e0 measure nearly identical electrons in telescopes viewing 180° apart. When trapped flux is present (closed field lines), the two measurements are identical and the two lines fall on top of each other (Mitchell et al).

Williams et al. (1997; 1998) used EPD electron pitch angle distributions such as those below to estimate the magnetic field at the surface of Ganymede

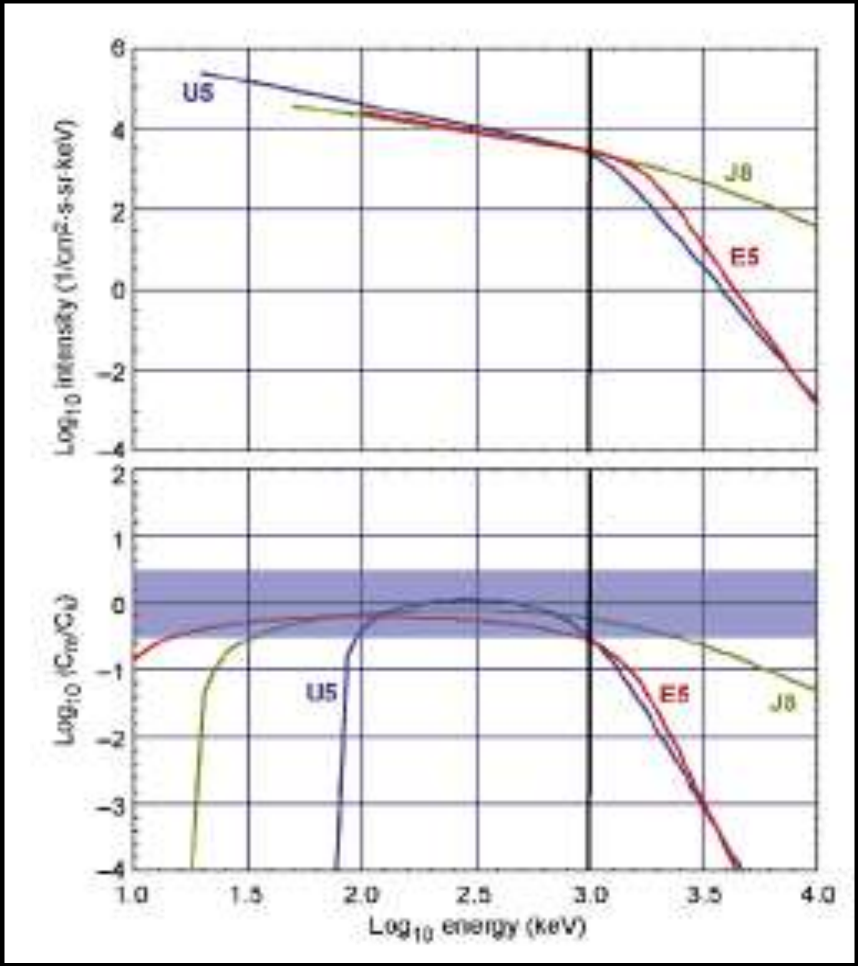




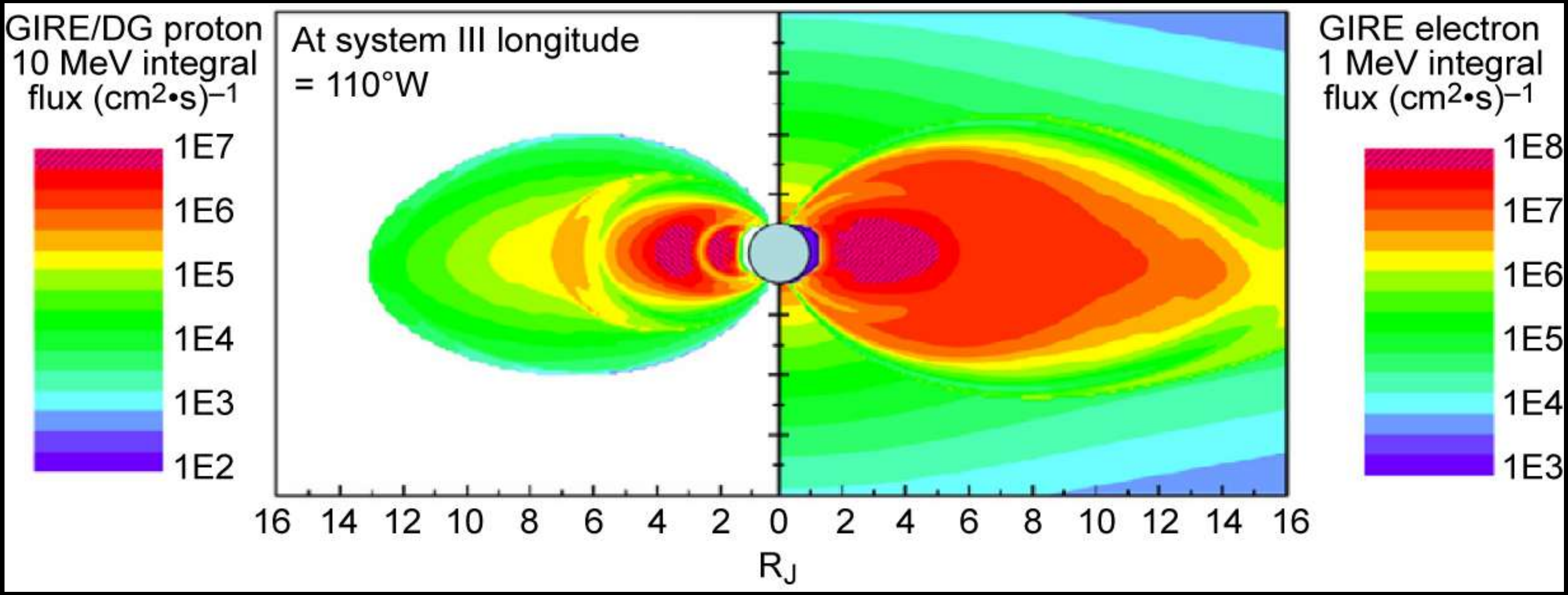
Estimated B at Ganymede's surface at the field line foot point

Magnetic field strength at Galileo

Jovian environment is a very challenging one from the point of view of radiation. This figure shows the intensities of the energetic electrons at Earth, Jupiter, and Uranus. In the important > 1 MeV electrons, see a departure of the Jovian environment. From Mauk and Fox (2010).

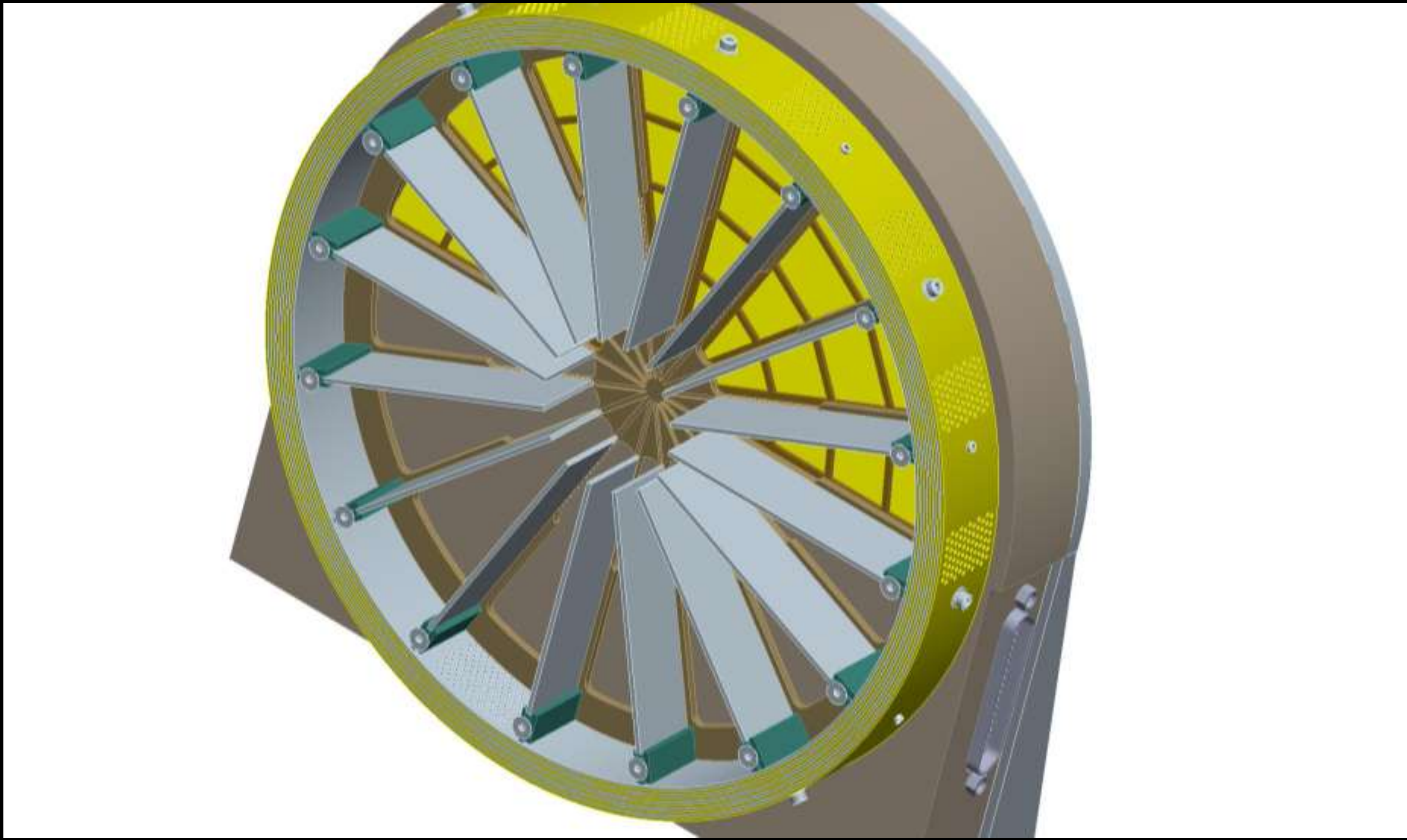


Radiation environment of Jupiter. On the right is the JPL model of > 1 MeV electrons. Europa is at about 9.4 R_J and Ganymede is at about 15 R_J.



Instrumentation

Jovian Energetic Electrons (JoEE)



See, Ho et al. (2003), Miniaturized electron magnetic spectrometer, *Adv. Space Res.*, *32*, 389-394.

Electrons pass through the collimator, are magnetically deflected downward into 4 separate SSDs, depending on energy, and anti-coincidence system operates (not shown)

Energetic electron sensor

- **Proposed sensor will be based closely on past APL sensors**
  - Electrons: 25 – 1000 keV
  - Number of energy channels will be limited by telemetry
  - FOV for each of 16 sectors: 12 degrees x 22.5 degrees (total is 12x360)
  - Will typically get good pitch angle distributions in space except at times where the magnetic field vector points perpendicular to the plane of the look sectors
  - Advantages are simultaneous measurements in all directions and very rapid accumulation of energy spectrum
- **Challenges: Radiation (dose and interference)**

  TID is manageable for the JUICE mission

  No expected pulse pile-up based on current environment models

  Use shielding for very energetic particles that can reach detectors thru sides
- **Proposed method of reducing radiation into sensor**
  - Collimator
  - Deflect electrons downward (separates them from light and ions)
  - Use a set of SSD’s and below them a second set for anti-coincidence
  - Detailed sensor modeling with GEANT4
- **Resources**
  - Low resource instruments

Electron measurements

- **One of the drivers of the design is the ability to look along the field line in both directions at the same time. Using multiple sectors are generally able to get the look direction of the sensors close to the magnetic field direction (the B field does not have to point into the sector to do this sensing)**

- **To improve e- msmnts, we also wanted a design where light cannot shine directly onto the detectors (this was a small problem with time on Cassini/LEMMS when the telescope points directly at the sun)**

- **By using magnetic deflection, there is no pathway for ions to reach the detector unless they are scattered onto it**

- **By bending the electrons based on their speed, we tend to do a good job separating by energy (we do a better job on Cassini/MIMI using the C channels for energy resolution than the E channels – which are not magnetically deflected).**

- **In contrast a stack of ssd's can be somewhat responsive to all energies (meaning the channel passband is not identically zero at various energies). Don't have the same range of non-zero efficiencies using magnetically deflection**

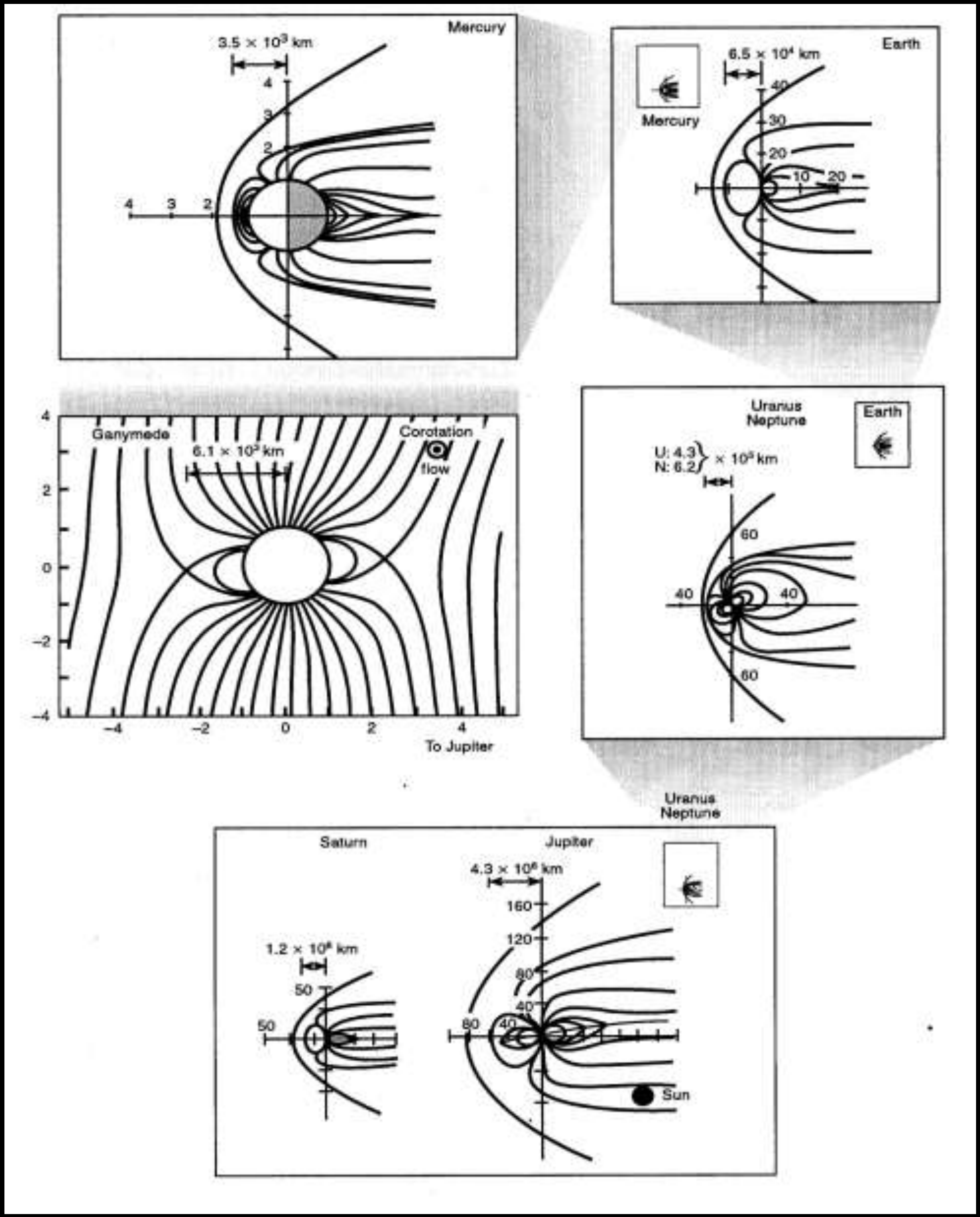
Summary and conclusions

- For JUICE, an important issue is knowing when the spacecraft is on open/closed/boundary field lines near Ganymede. By simultaneously measuring quasi-relativistic electrons in all directions, this is achieved. This will inform subjects such as the access of particles to and from the surface (including light charged dust particles, plasma, energetic charged particles)
- Where are electrons precipitating on each moon and what effect does this weathering have on their optical surfaces?
- How is the satellite aurora powered and how is the moon's footprint in the Jovian auroral region generated (and why do we measure beams near the satellites and elsewhere)?

- Use electron lossess to probe the nature of the interaction with the magnetosphere – micro and other signatures (e.g., is Callisto's interaction like a completely inert body or is Callisto/environment strongly EM?)
- Use electrons to determine the magnetic field strength at Ganymede's surface along sub-spacecraft track (for modeling induction response)
- For these investigations, need nearly instantaneous sampling of energetic electrons in all look directions, good energy coverage, and good time resolution

BACKUP

This figure from an APL Tech Digest article by Don Williams shows the known magnetospheres of the Solar System and their relative scales with respect to one another.



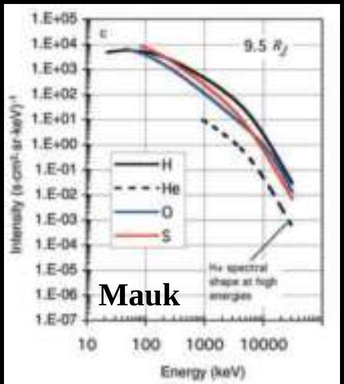
JEPPI Science Objectives

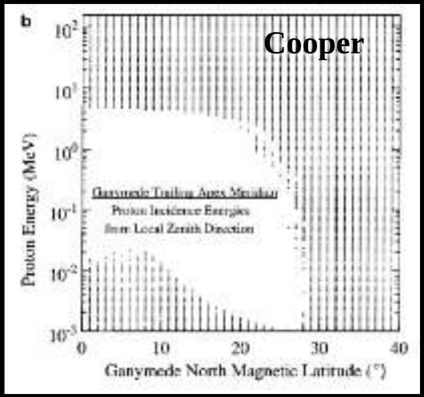
- **The JEPPI team has many science goals including traditional magnetospheric goals.**
- **But two main goals will be emphasized, specifically those that support the astrobiological thrust of JEO:**

  - Probe Europa's interior (ocean) with magnetic sounding
    - How extensive and how conducting is Europa's interior ocean?
    - Quantitative sounding of Europa's interior ocean demands understanding of the significant exterior contributions to the magnetic signatures from plasma pressure and flow.
  - Understand the physical and chemical modifications of Europa's surface
    - How much and where does sputtering re-surface Europa?
      - e.g., where is older surface exposed? where is surface buried?
    - How does Jupiter's environment otherwise modify the surface?
    - Which salts (e. g. H_2SO_4) are radiolytic and which are endogenic?
    - Our approach combines space environment measurements and modeling to make the connection to optical remote sensing.

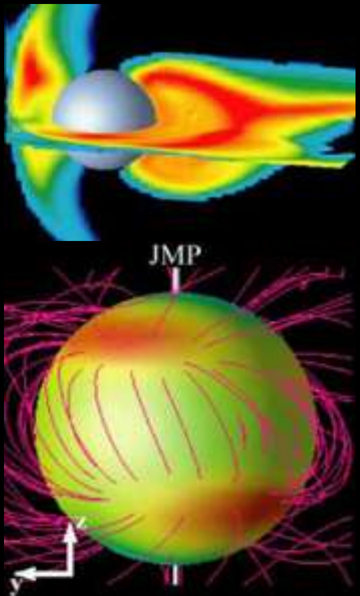
<u>Science Traceabilty</u>: Understand the physical and chemical modifications of Europa's surface

Measure particle spectra and deposition patterns at Euorpa



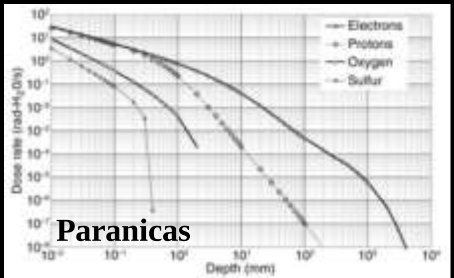


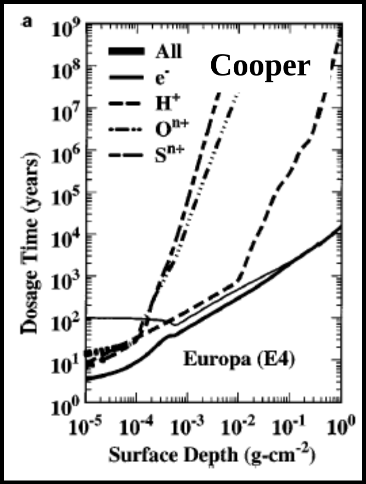
Understand observed energy / species depositions using powerful simulations



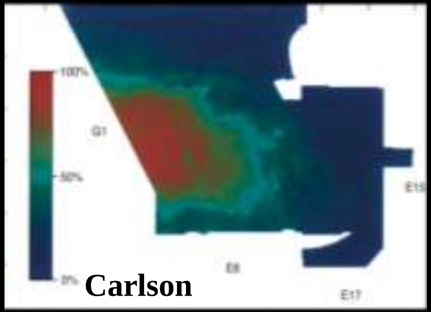
Paty: Example model from Ganymede study

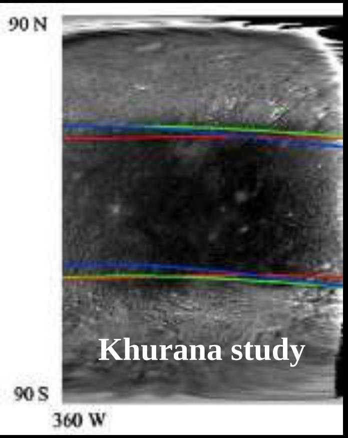
Predict consequences to surfaces base on laboratory studies and theoretical analyses





Compare measured patterns and predicted modifications to Optical Remote Sensing images





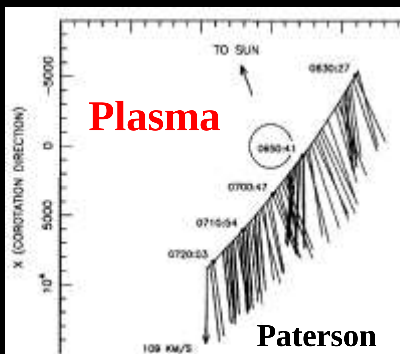
Our objective is to obtain complete closure between observed spectra and deposition patterns, our understanding of the electromagnetic interactions between Euorpa and it space environment, and the consequences of that environment to Euorpa's surface properties and appearance

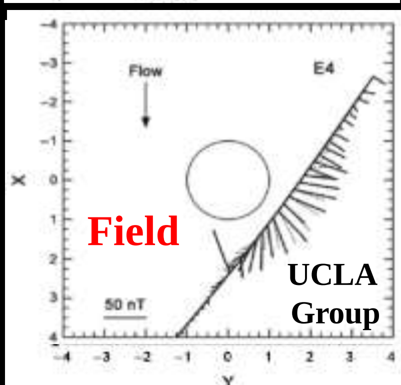
Science Traceabilty: Probe Europa's interior (ocean) with magnetic sounding

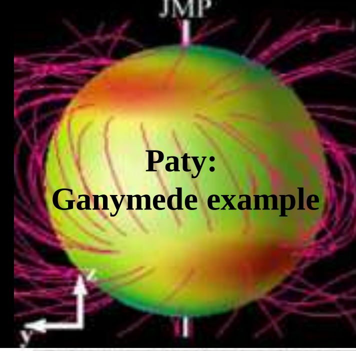
Measure distributions of ion pressure and flows in conjunction with magnetic field vectors

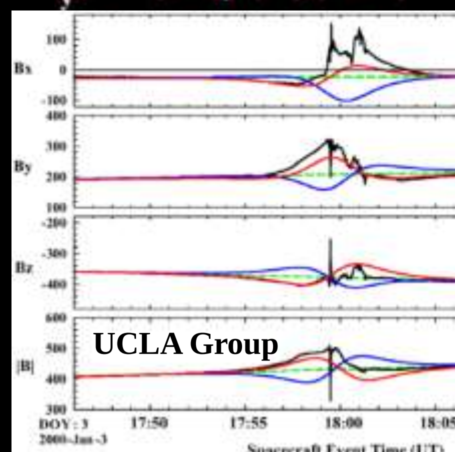
Powerful simulations sort the contributions of plasmas and internal (induced) fields to the magnetic perturbations

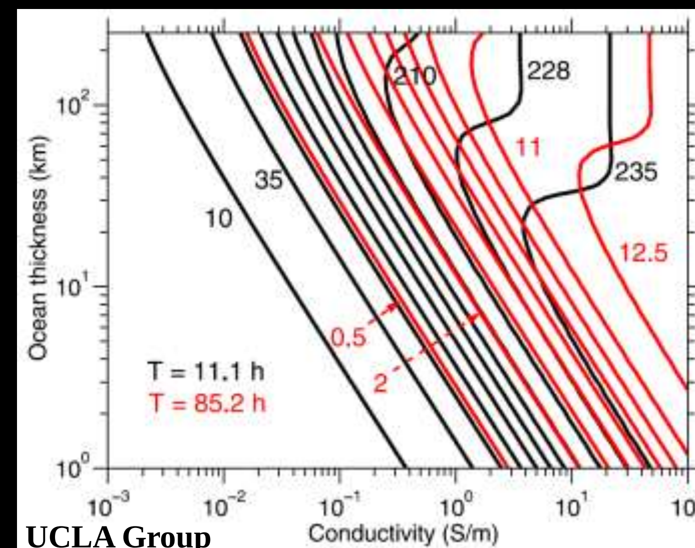
Derived internal (induced) contributions to the magnetic perturbations are used to constrain ocean configuration and conductivity



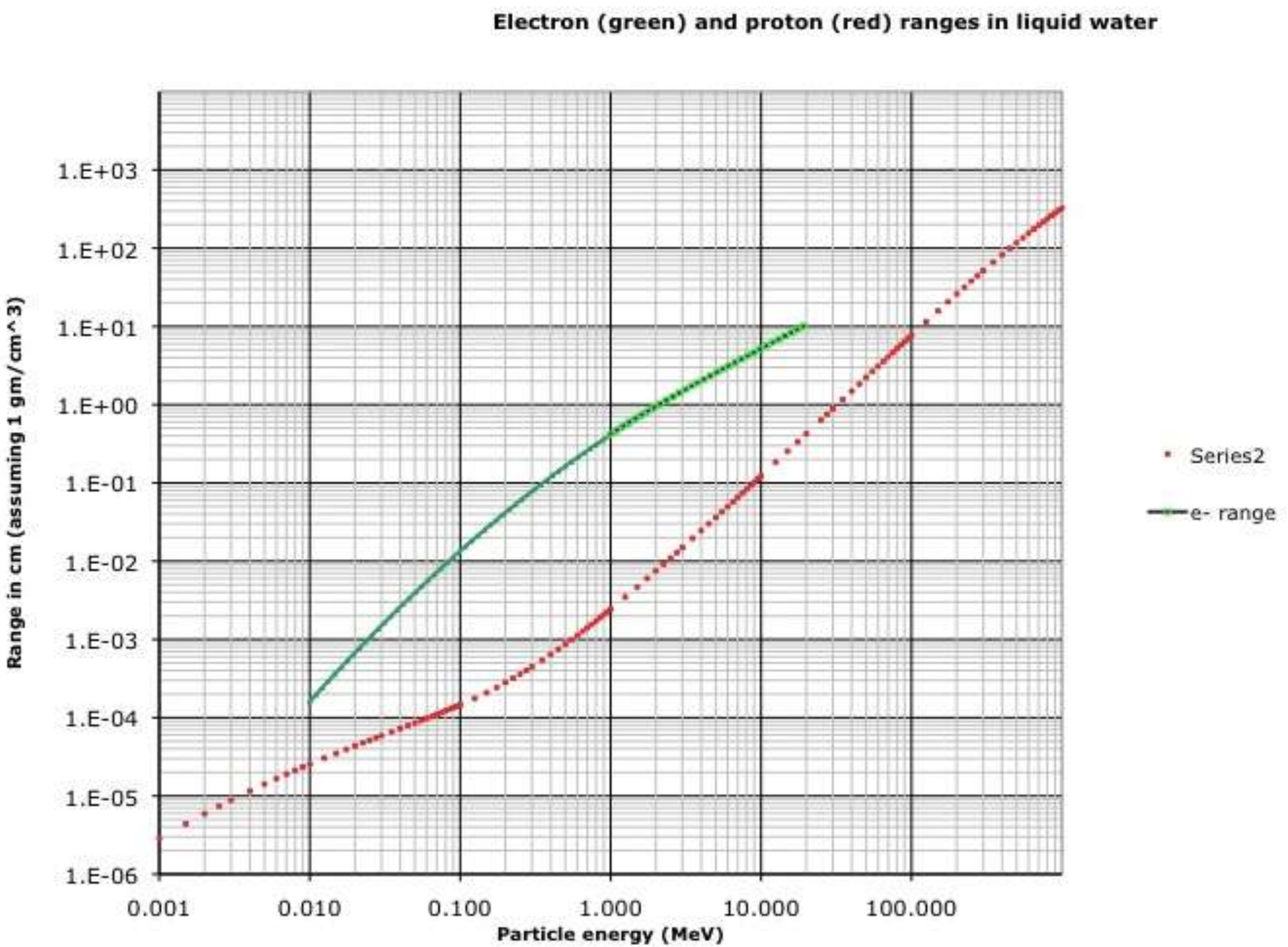


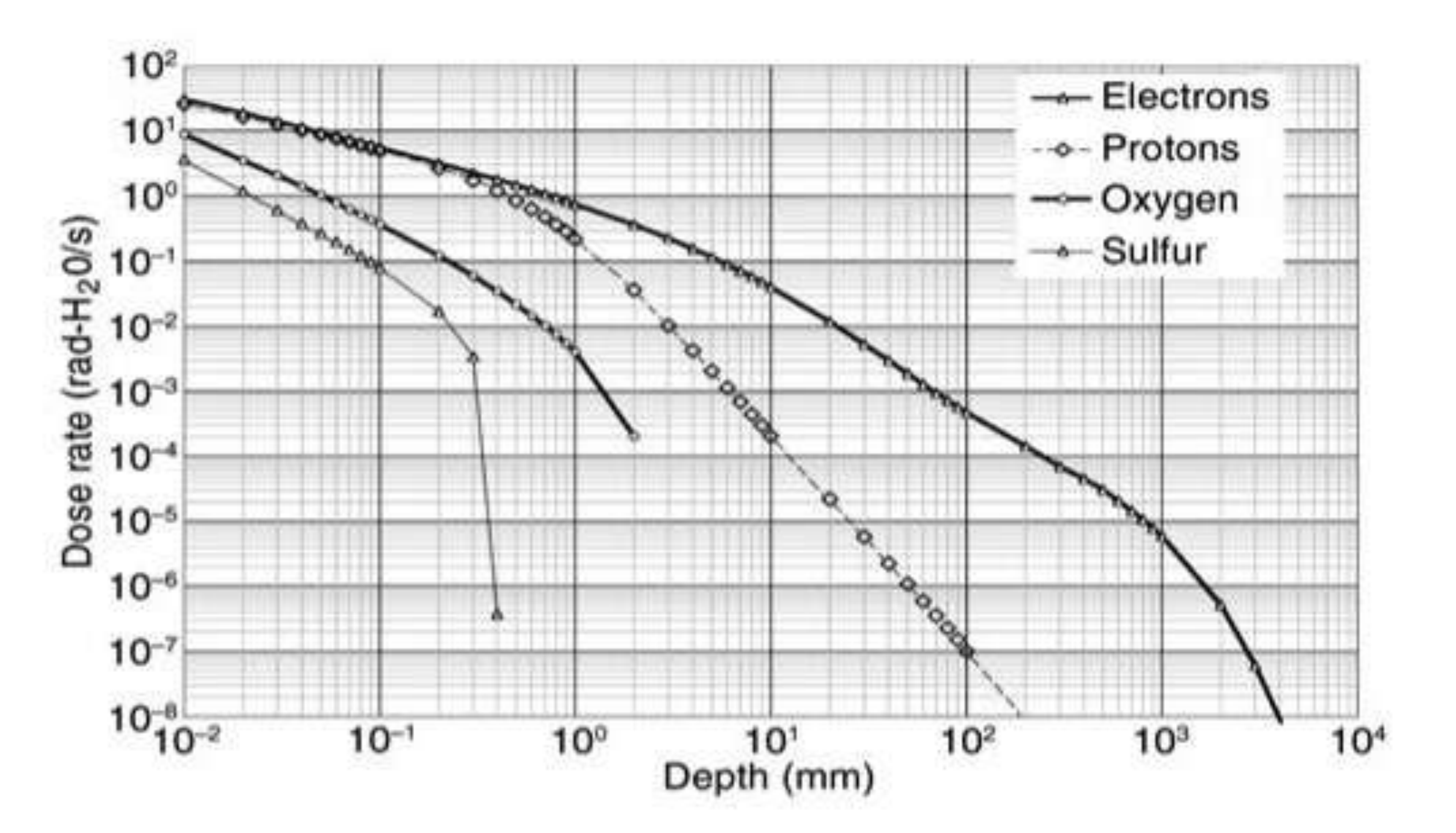






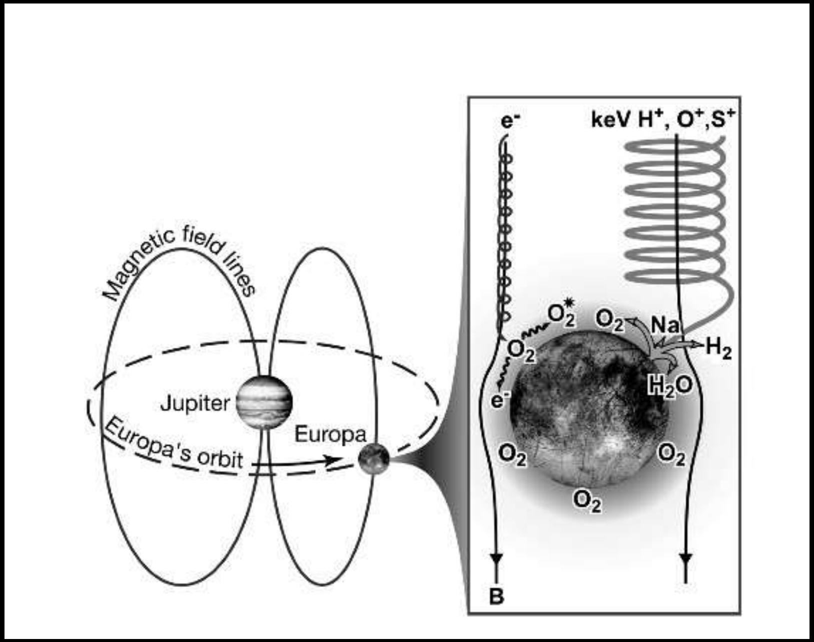
Our objective is the help probe the oceans of Europa by developing a complete understanding of the electromagnetic interactions between Euorpa and its environment. Our contribution is the plasma moments which will be combined with magnetic field measurements.


Electron (green) and proton (red) ranges in liquid water
Range in cm (assuming 1 gm/cm^3)
1.E+03
1.E+02
1.E+01
1.E+00
1.E-01
1.E-02
1.E-03
1.E-04
1.E-05
1.E-06
0.001
0.010
0.100
1.000
10.000
100.000
Particle energy (MeV)
Series2
e- range



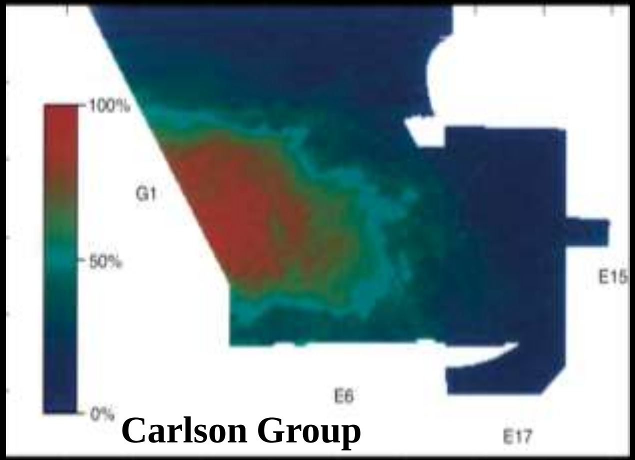
Electrons
Protons
Oxygen
Sulfur
Dose rate (rad-H$_2$0/s)
Depth (mm)
10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-2}
10^{-1}
10^0
10^1
10^2
10^3
10^4

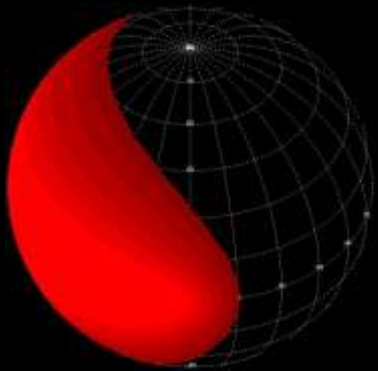
- Understand the physical and chemical modifications of surfaces

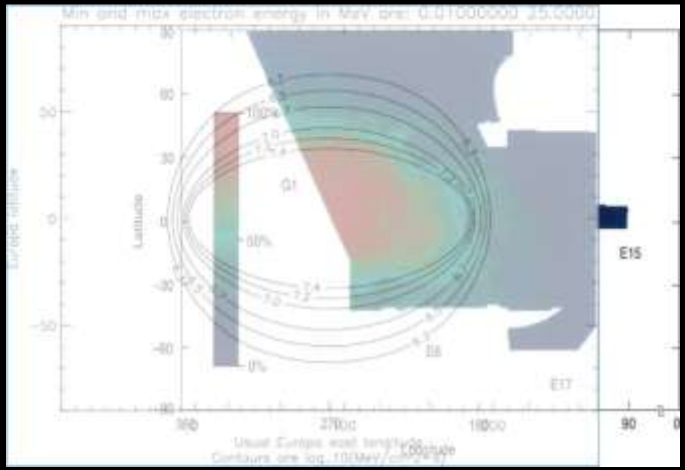


(Johnson et al. 2004)

- Understand the physical and chemical modifications of Europa's surface (2 of 3)
  - The upper panel shows Galileo/NIMS measurements of Europa's surface and relative concentrations of hydrated H_2SO_4 (Carlson Group).
  - The middle panel shows a model of energetic electron deposition onto Europa's surface.
  - The lower panel shows the electron deposition pattern projected onto the Galileo / NIMS image.
  - A main goal of this investigation is to understand the bombardment map of Europa by charged species/energy to determine how the enviornment modifies the surface and which chemicals come from the inside vs. the outside

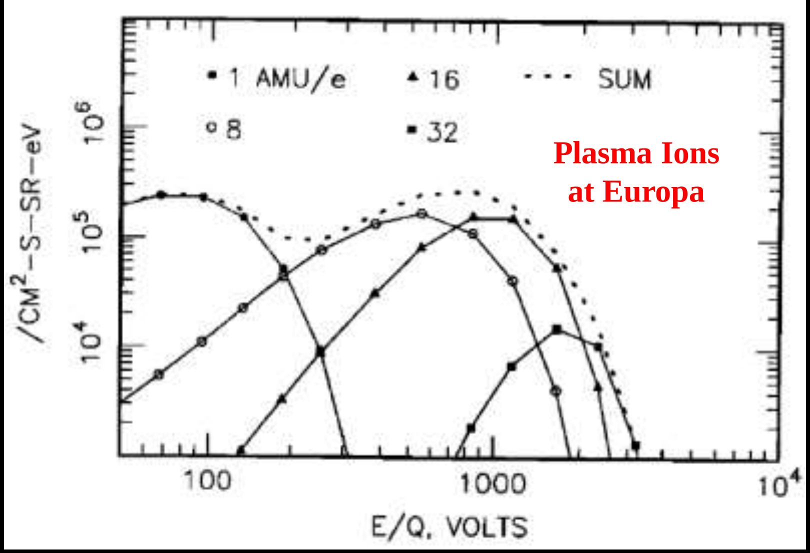




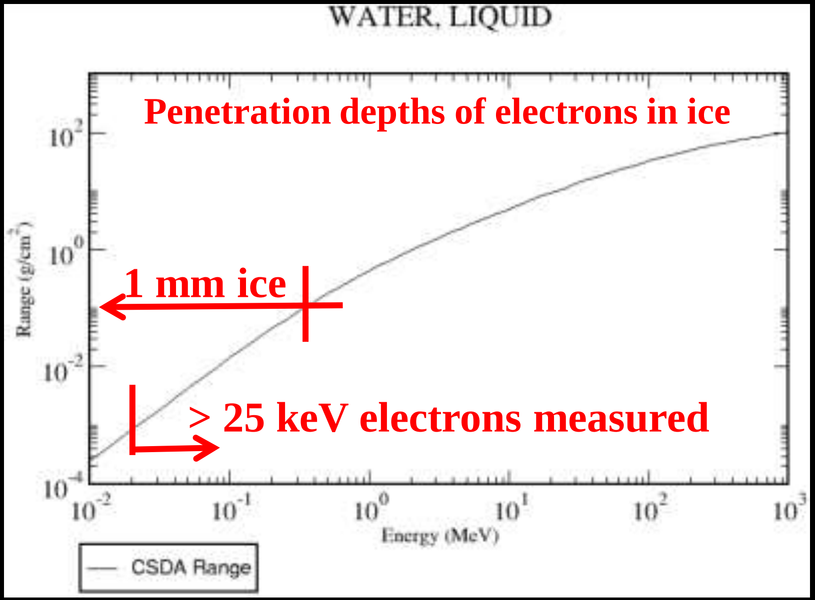


Paranicas et al., 2001

JEPPI Energy Ranges are appropriate to the target science



Paterson et al., 1999



- > 10 eV/q ion plasma measurements capture all of the ions relevant to plasma pressure and flow
- > 25 keV electron measurements capture those electrons that can modify surface features observed by optical remote sensing instruments (~ 1mm for IR imaging)