Space Weathering Impact on Solar System Surfaces

Community White Paper

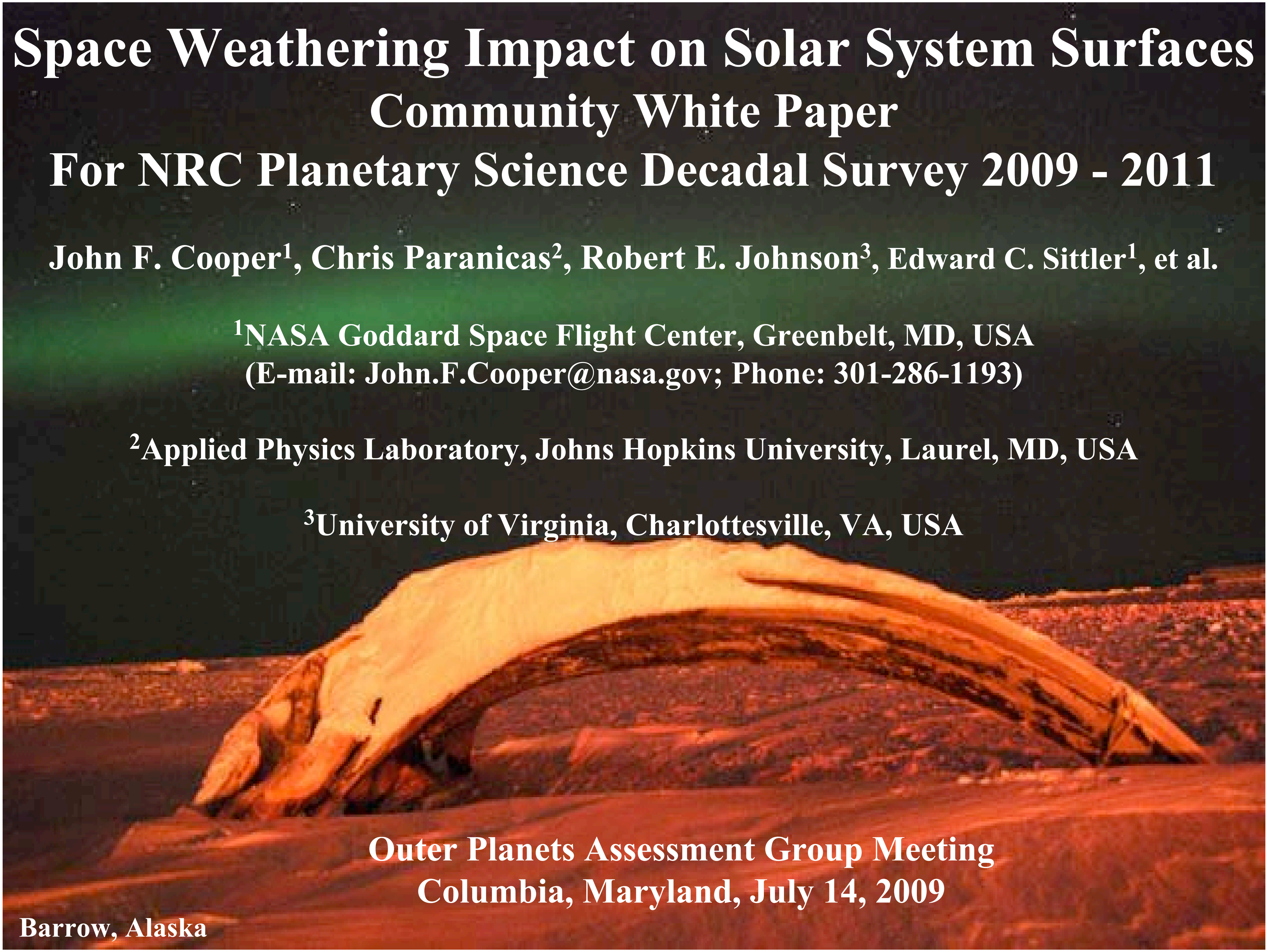
For NRC Planetary Science Decadal Survey 2009 - 2011

John F. Cooper[1], Chris Paranicas[2], Robert E. Johnson[3], Edward C. Sittler[1], et al.

[1]NASA Goddard Space Flight Center, Greenbelt, MD, USA
(E-mail: John.F.Cooper@nasa.gov; Phone: 301-286-1193)

[2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, USA

[3]University of Virginia, Charlottesville, VA, USA



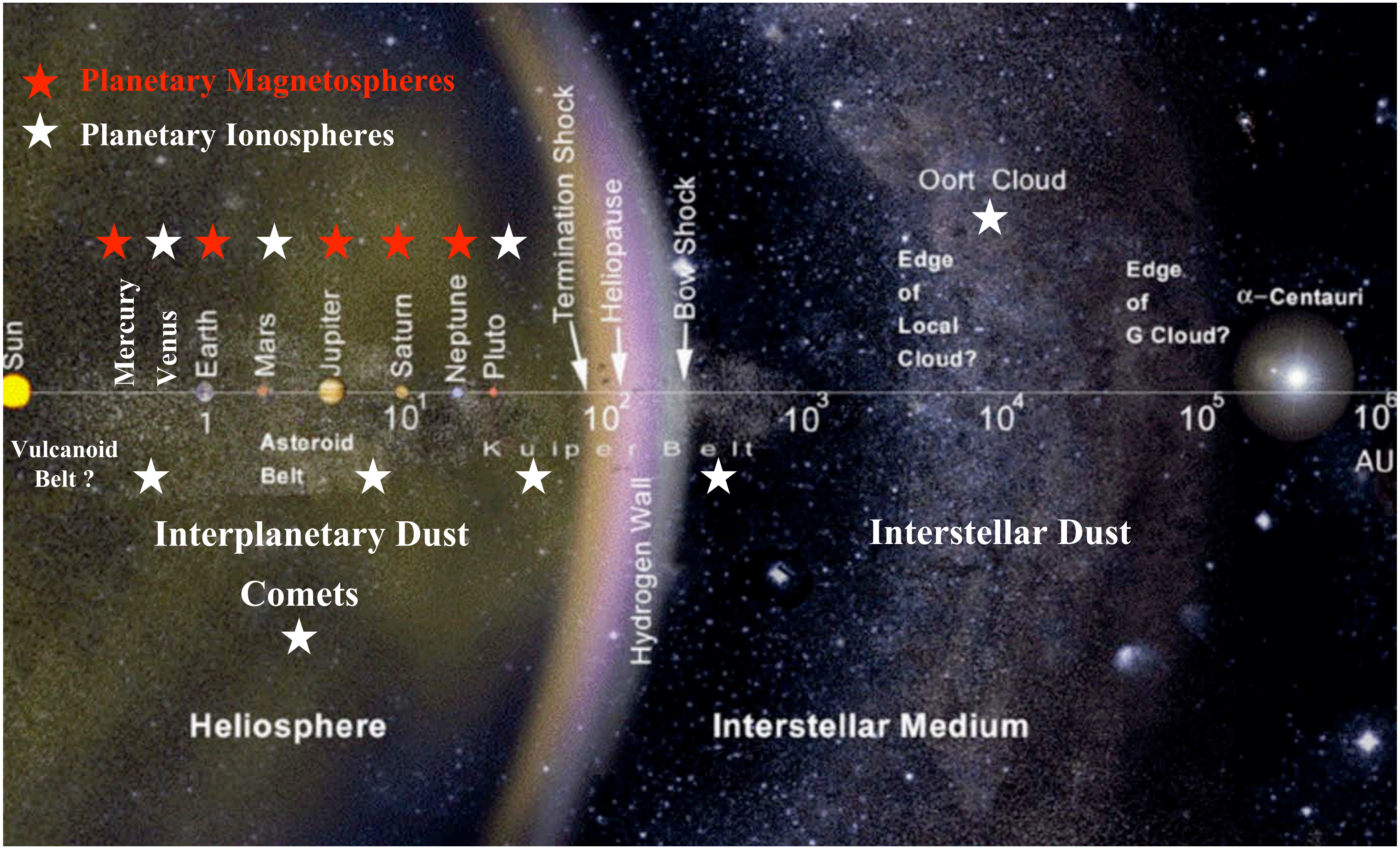
Outer Planets Assessment Group Meeting
Columbia, Maryland, July 14, 2009

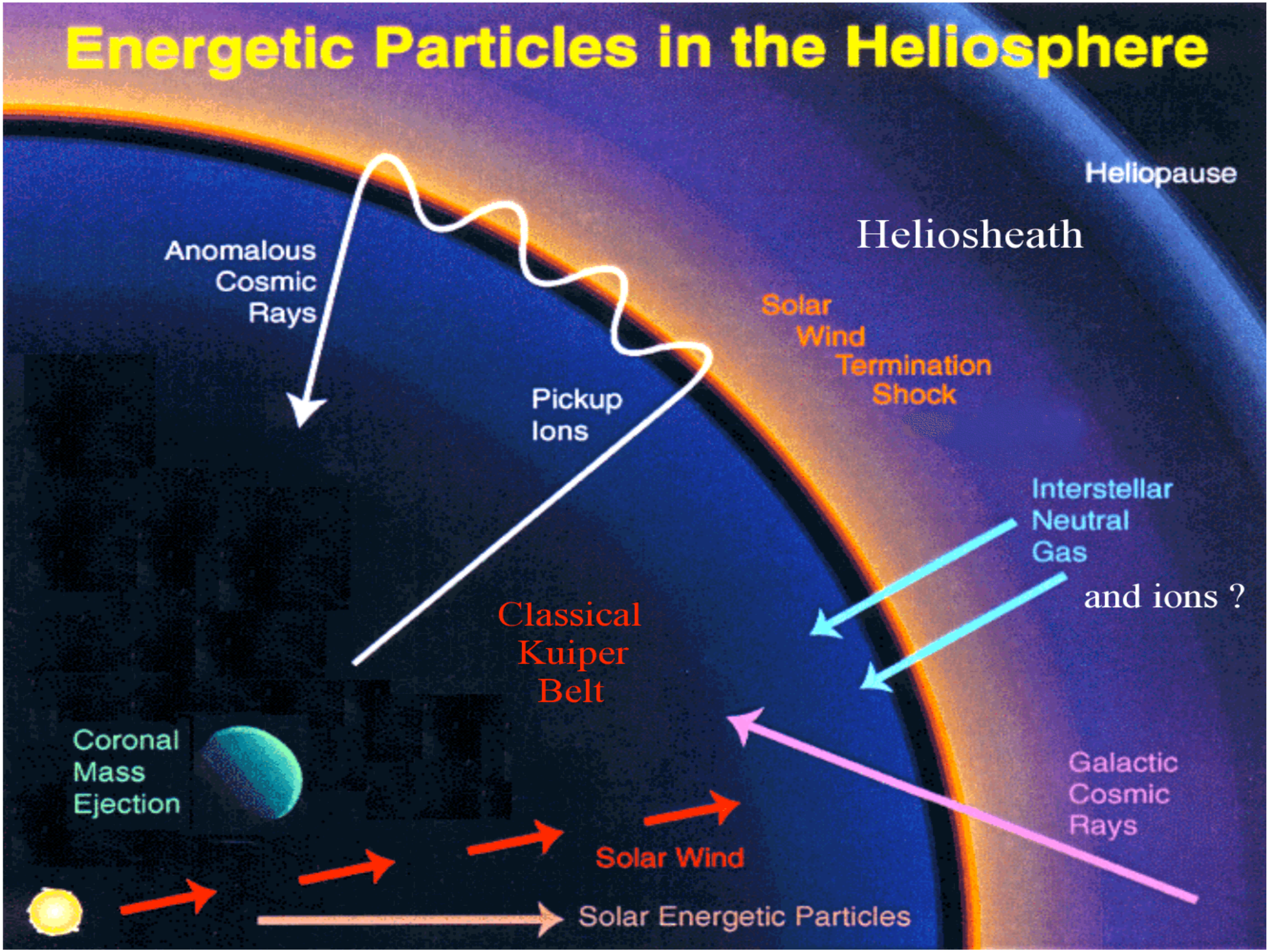
Barrow, Alaska

Universal Processes of Space Weathering

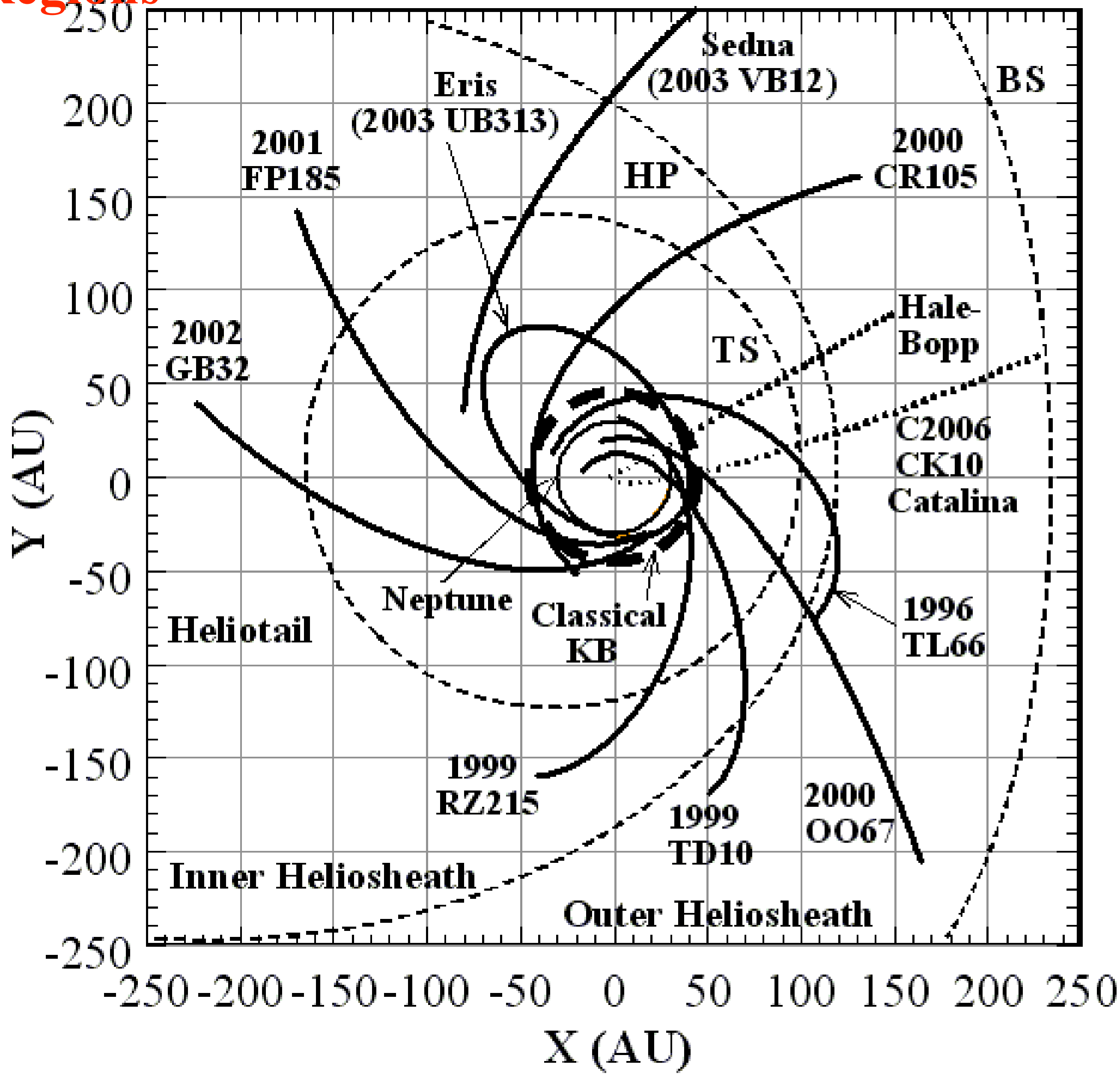
- Plasma ion implantation into surfaces
- Plasma & energetic ion surface sputtering
- Surface volume ionization by energy loss
- Radiolytic chemistry evolved from radiation products
- Micro-ionospheric environments (partly ionized gas, solid)
- Regolith formation by micrometeroid and larger impacts
- Regolith porosity impact on radiation chemistry
- Plasma source for space environment from impact ejecta
- Exchange of impact ejecta in planetary moon systems
- Exchange of impact ejecta in heliocentric belts (asteroid, KBO)
- Impact of surface irradiation environments on survival and sensibility of astrobiological materials, organic and inorganic
- Mitigating factors of surface topography on radiation exposure

Magnetospheric, Heliospheric, Interstellar Plasma & Energetic Particles Interact with Solar System Surfaces & Atmospheres on Huge Range of Spatial and Energy Scales




Energetic Particles in the Heliosphere
Heliopause
Heliosheath
Anomalous Cosmic Rays
Solar Wind Termination Shock
Pickup Ions
Interstellar Neutral Gas
and ions ?
Classical Kuiper Belt
Coronal Mass Ejection
Galactic Cosmic Rays
Solar Wind
Solar Energetic Particles

Many Natural 'Voyagers" Cross the Heliospheric Boundary Regions



Object trajectories for last 400 years since time of Galileo

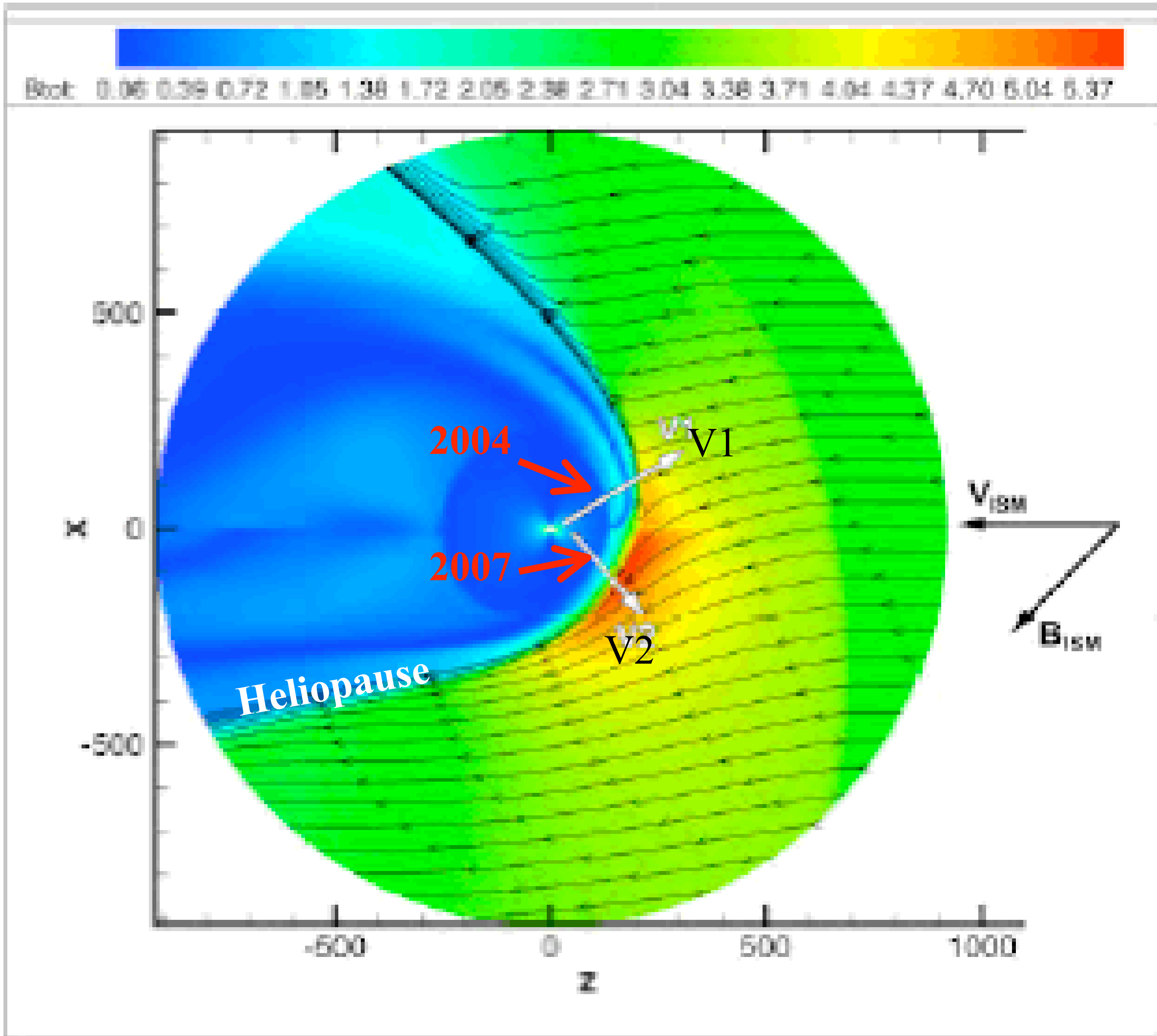
Over 30 TS-crossing Scattered Disk Objects from the Kuiper Belt

Over 300 TS-crossing Oort Cloud comets

Largest known dwarf planet, Eris (2003 UB_{313}), always stays within the supersonic heliosphere inside TS

How do radiation dosage profiles change in different heliospheric regions

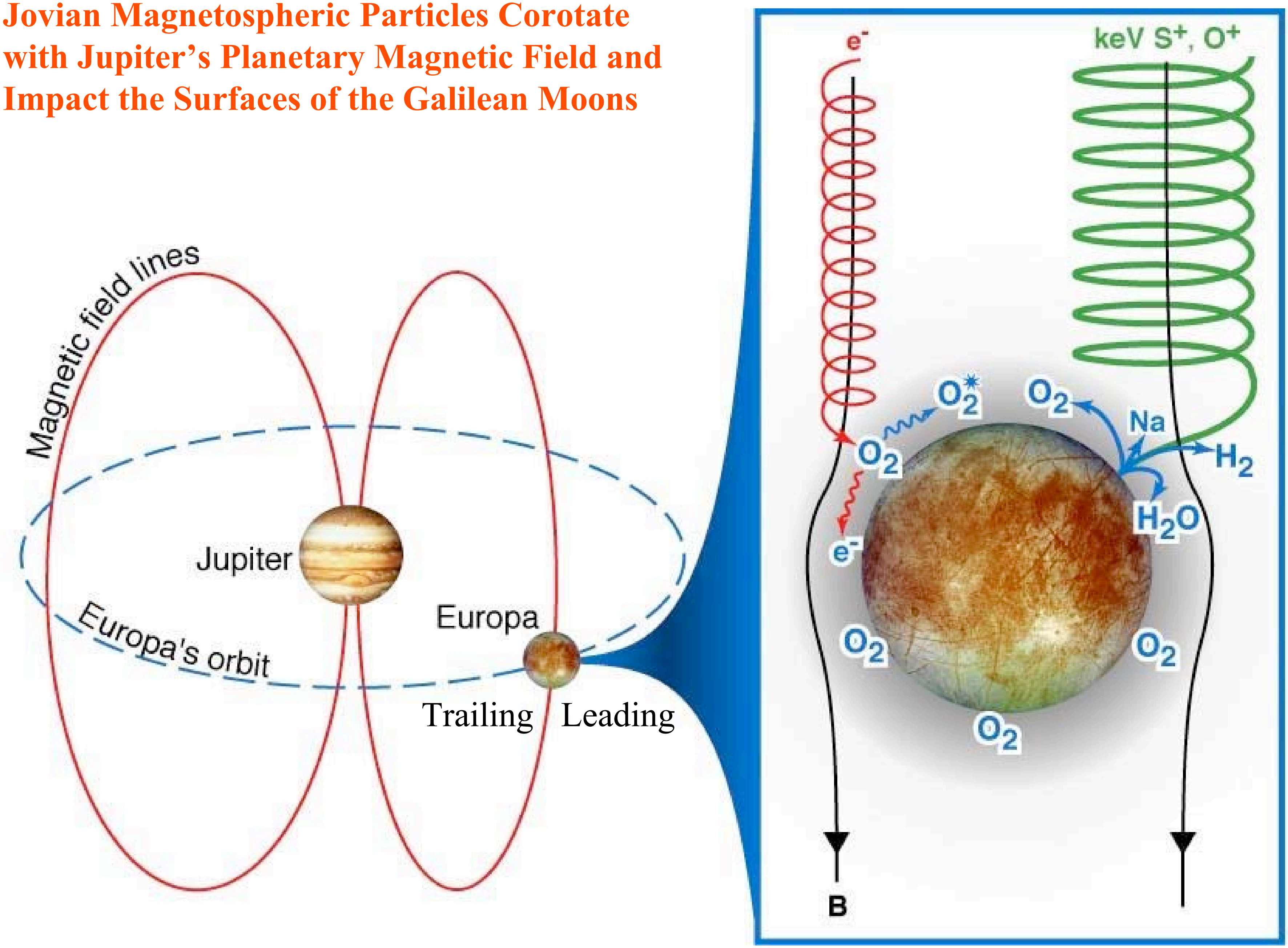
A New View of the Outer Heliosphere from Voyager



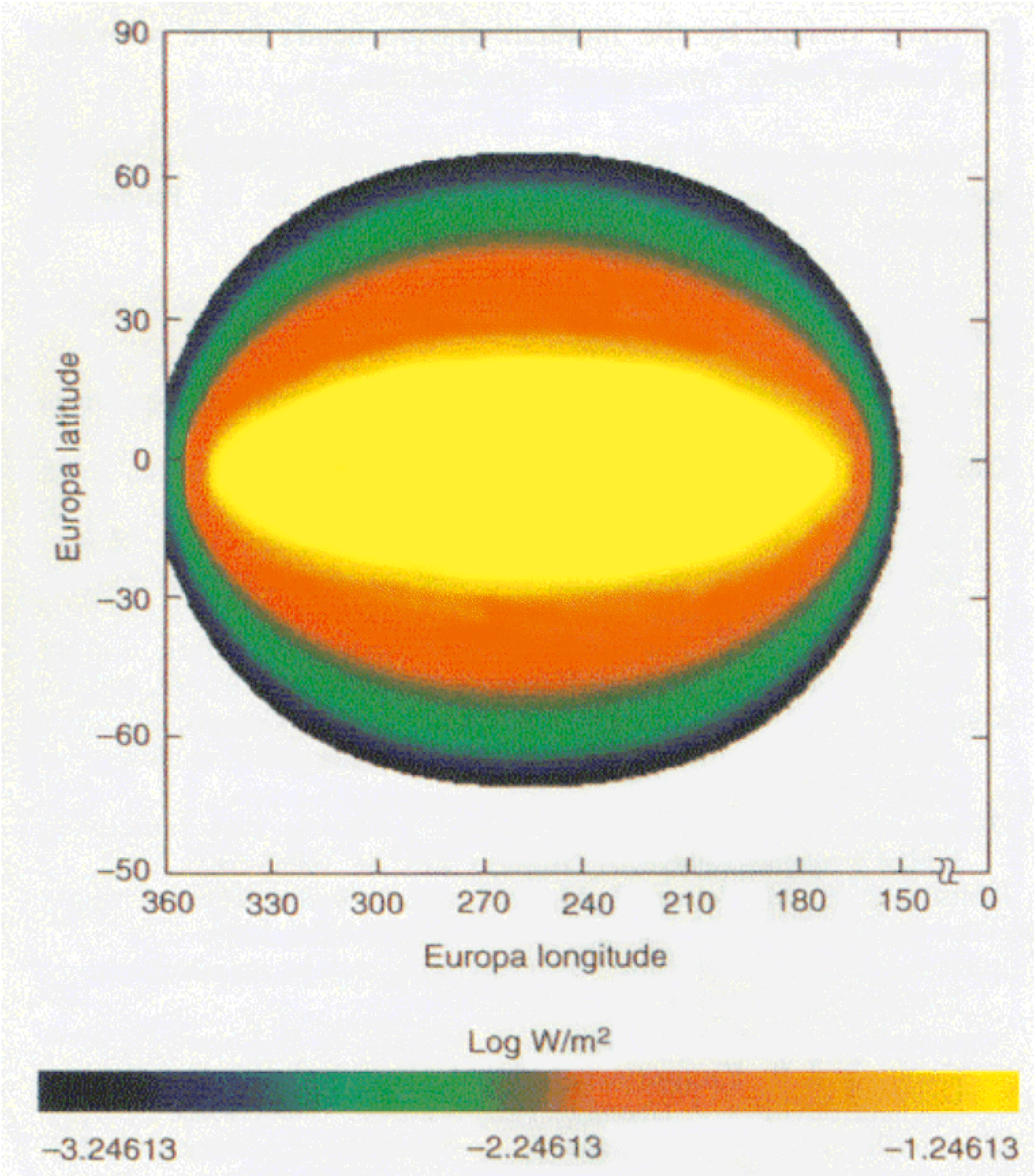
Model from Pogorelov et al. 2004

Both Voyagers now exploring the heliosheath boundary region since 2004 for V-1 (2007 for V-2) in search of heliopause boundary to local interstellar medium

Jovian Magnetospheric Particles Corotate with Jupiter's Planetary Magnetic Field and Impact the Surfaces of the Galilean Moons



Johnson et al. (2004)



Paranicas et al., Geophys. Res. Lett. 28(4), 673-676, 2001

Paranicas et al (2001) Model for Electron Energy Flux into the Trailing Hemisphere of Europa

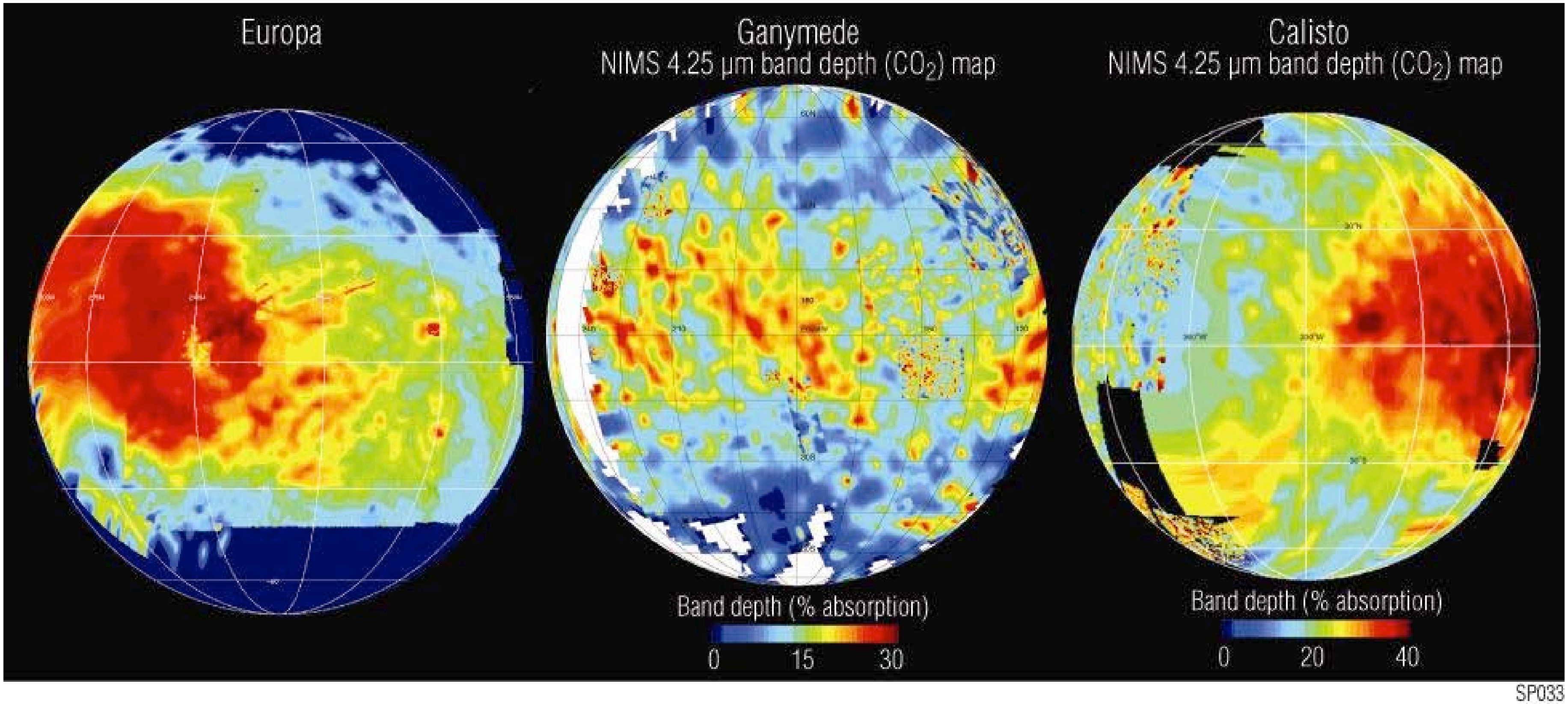
Highest energy fluxes at initial points of contact for corotating magnetic field lines with moon surface

Two order of magnitude decrease from apex center of initial impact region

Roughly correlates to sulfate distribution

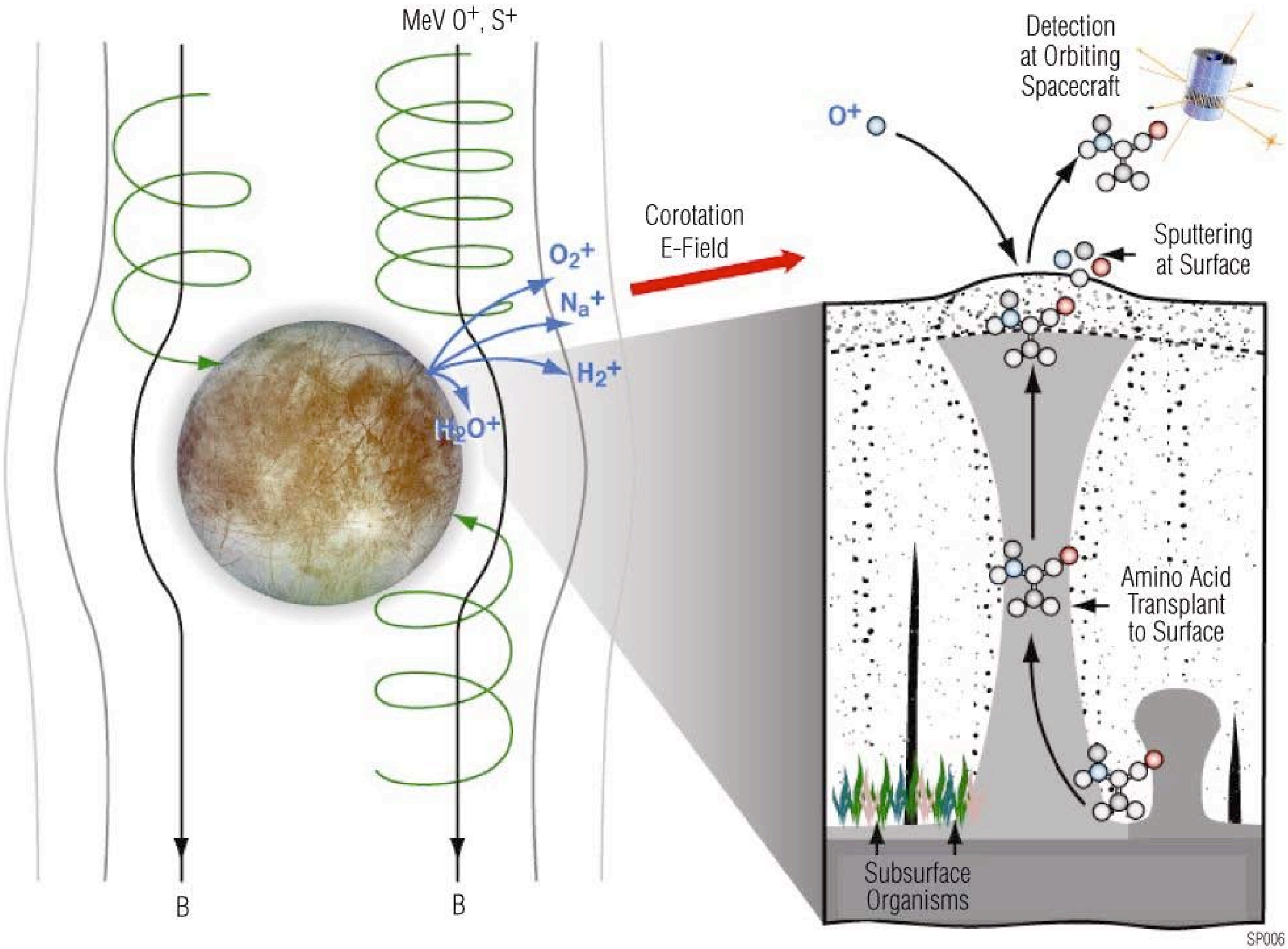
Leading hemisphere is far less irradiated by "killer" electrons, more conducive to survival and detection of near-surface biosignatures

Comparative Space Weathering Effects on the Icy Galilean Moons

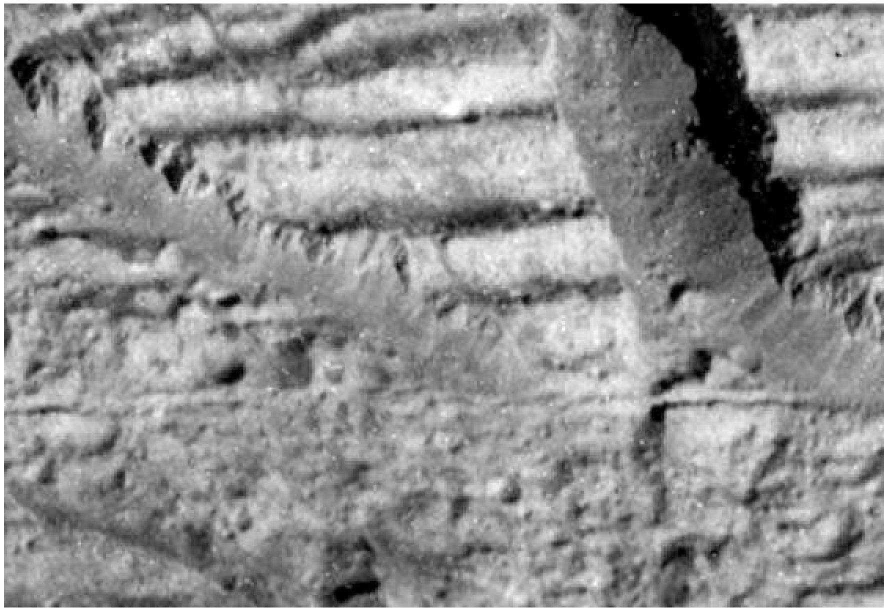
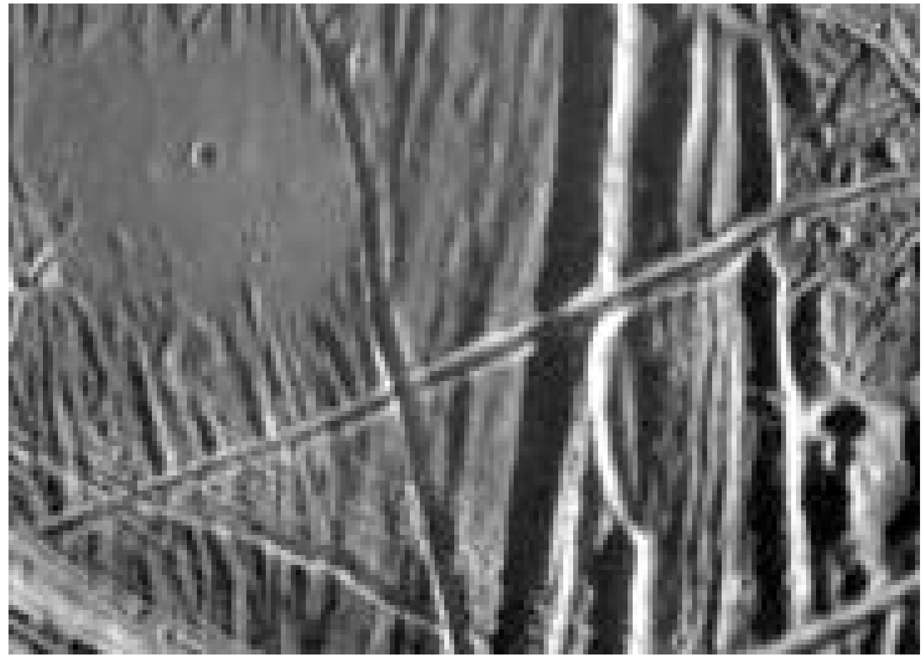
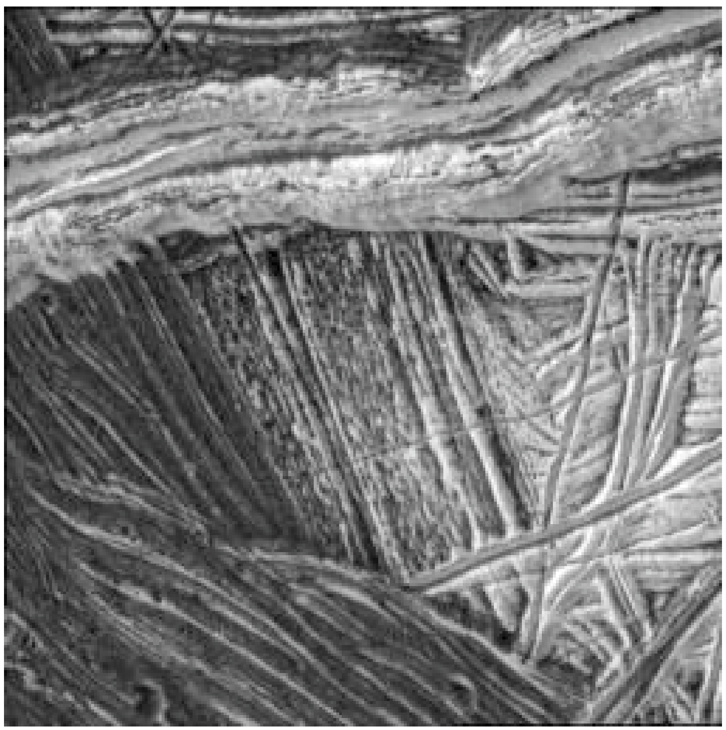
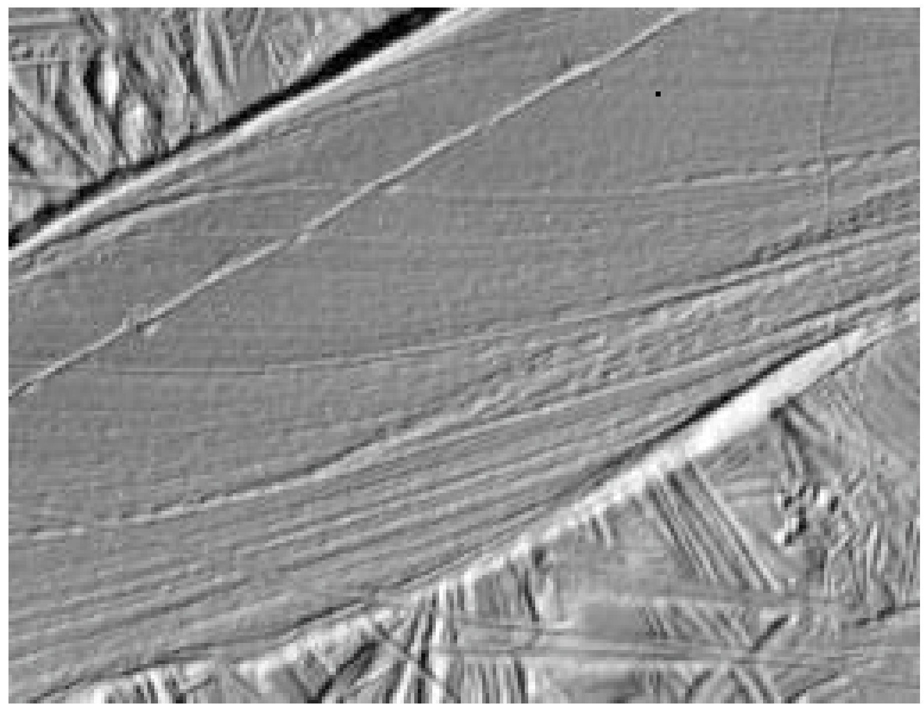


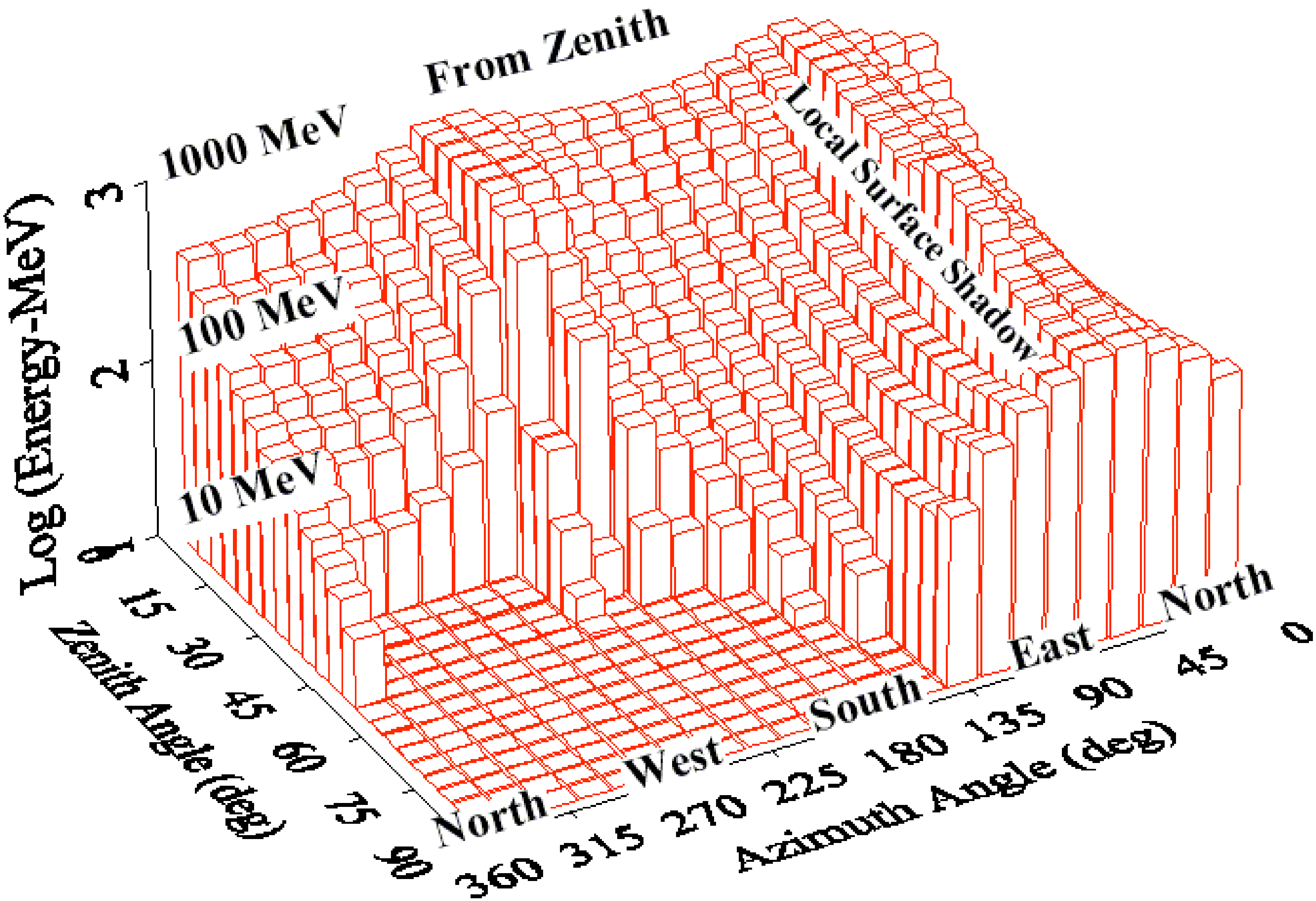
NIMS images of global surface distributions on Europa (left), Ganymede (middle), and Callisto (right) show different responses in hydrated sulfate (Europa) and CO_2 (Ganymede, Callisto) to chemical weathering by the Jovian magnetospheric environment. Highest concentrations, in red, are centered on trailing hemispheres for Europa and Callisto, consistent with magnetospheric irradiation effects. The Ganymede CO_2 appears confined to the equatorially-centered band of this moon's intrinsic dipole magnetic field, possibly indicative of filtering effects on magnetospheric particles penetrating the field to the surface.

Europa Magnetospheric Sputtering Could Enable Astrobiology from Orbit



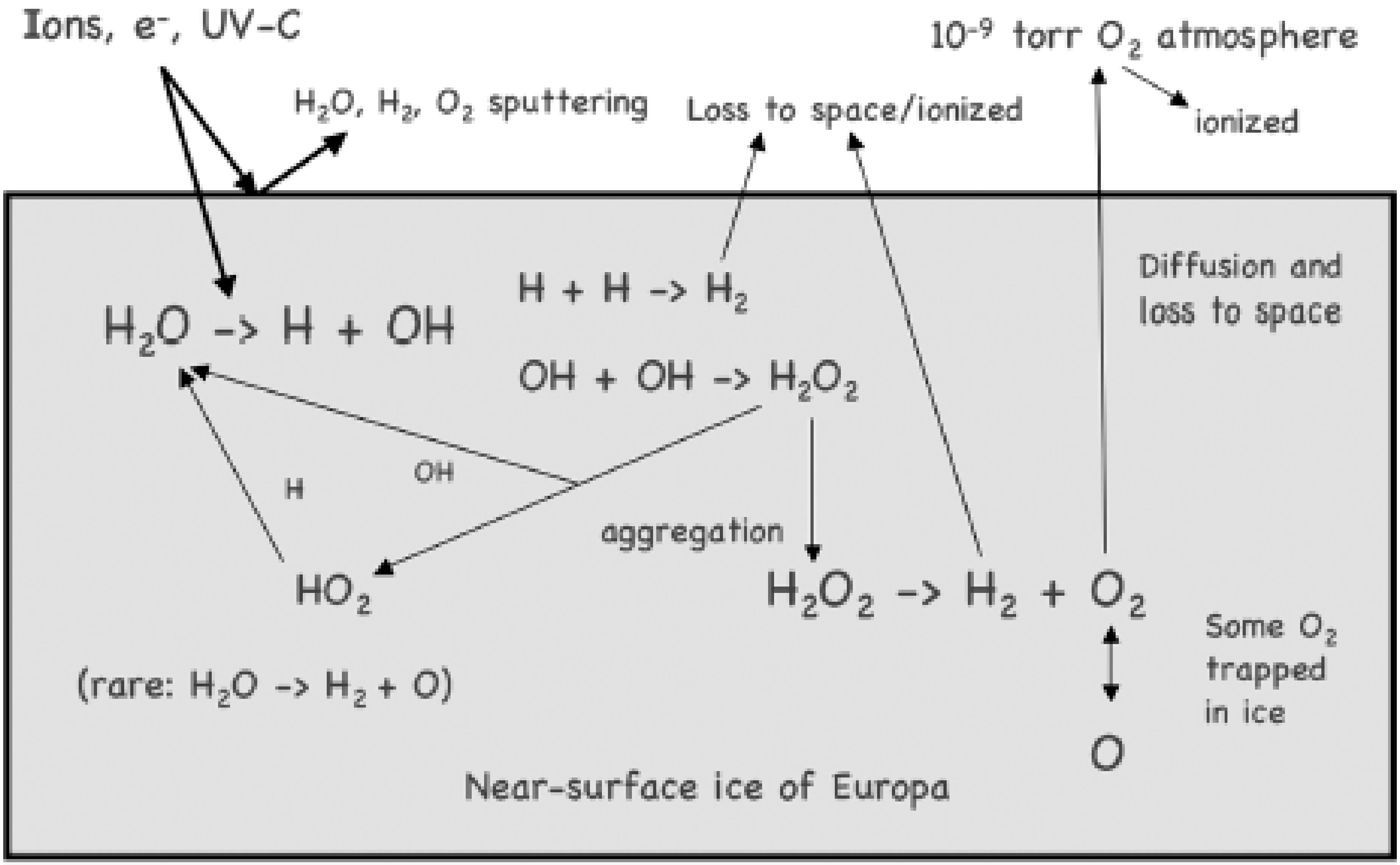
Detection and mass analysis of biomolecules by a Europa orbital spacecraft is potentially facilitated by high-yield sputtering of the surface ice matrix by high energy (MeV) heavy ions from the Jovian magnetosphere. These biomolecules may originate via upward liquid flow or rheological transport from subsurface liquid water reservoirs, e.g., Europa's ocean.



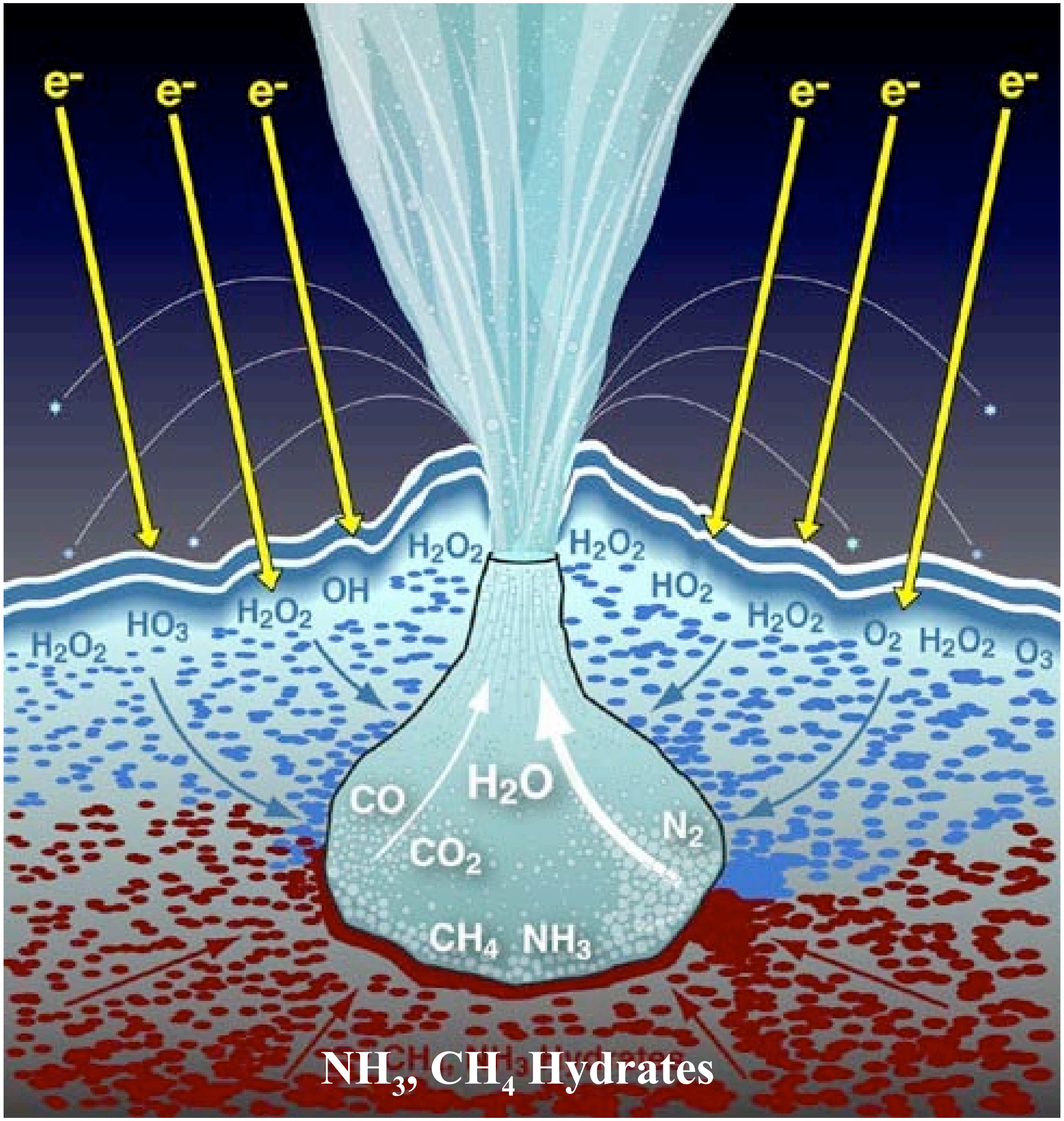
Surface Electron Energy Cutoffs at Europa Leading Apex in Europa Total Magnetic Field

Water Ice Surfaces Are Heavily Oxidized by Radiolytic Processes



→ Oxygen and mixed gas clathrates (Hand et al., 2006), icy moon cryovolcanism ?

Icy Moon Radiolytic Gas-Driven Cryovolcanism ?



Radiolytic oxidants arise in saturated upper layer from surface irradiation

Organics, NH_3, other fuels upwell from primordial sources in deep interior

Tidal dissipation, friction, radioisotope decay, and/or exothermic chemistry provide heat sources to maintain aquatic H_2O subsurface reservoirs

High thermal gradients at reservoir margins drive enhanced redox chemistry

Cryovolcanic gases arise from abiotic, and any biotic, oxidation processes

Recommendations

- **Measure full elemental and key isotope composition**
  - **Remote surface sample analysis without return**
  - **Spacecraft and propulsion contamination issues?**
- **Composition & radiation aging correlations to surface geology and topography, protected refugia of organics**
  - **Measuring & modeling global & local interactions**
- **Comparative compositional analysis of system bodies**
  - **Io and Enceladus volcanic output to their systems**
  - **Surface impacts exchange material within system**
- **Analyze surface regoliths for records of planetary atmospheric evolution via pickup ion implantation**
  - **Earth/Moon, Mars/Phobos-Deimos, Jup/Ganymede**