Laboratory Simulation of Europa's Surface Properties under Radiation Environment

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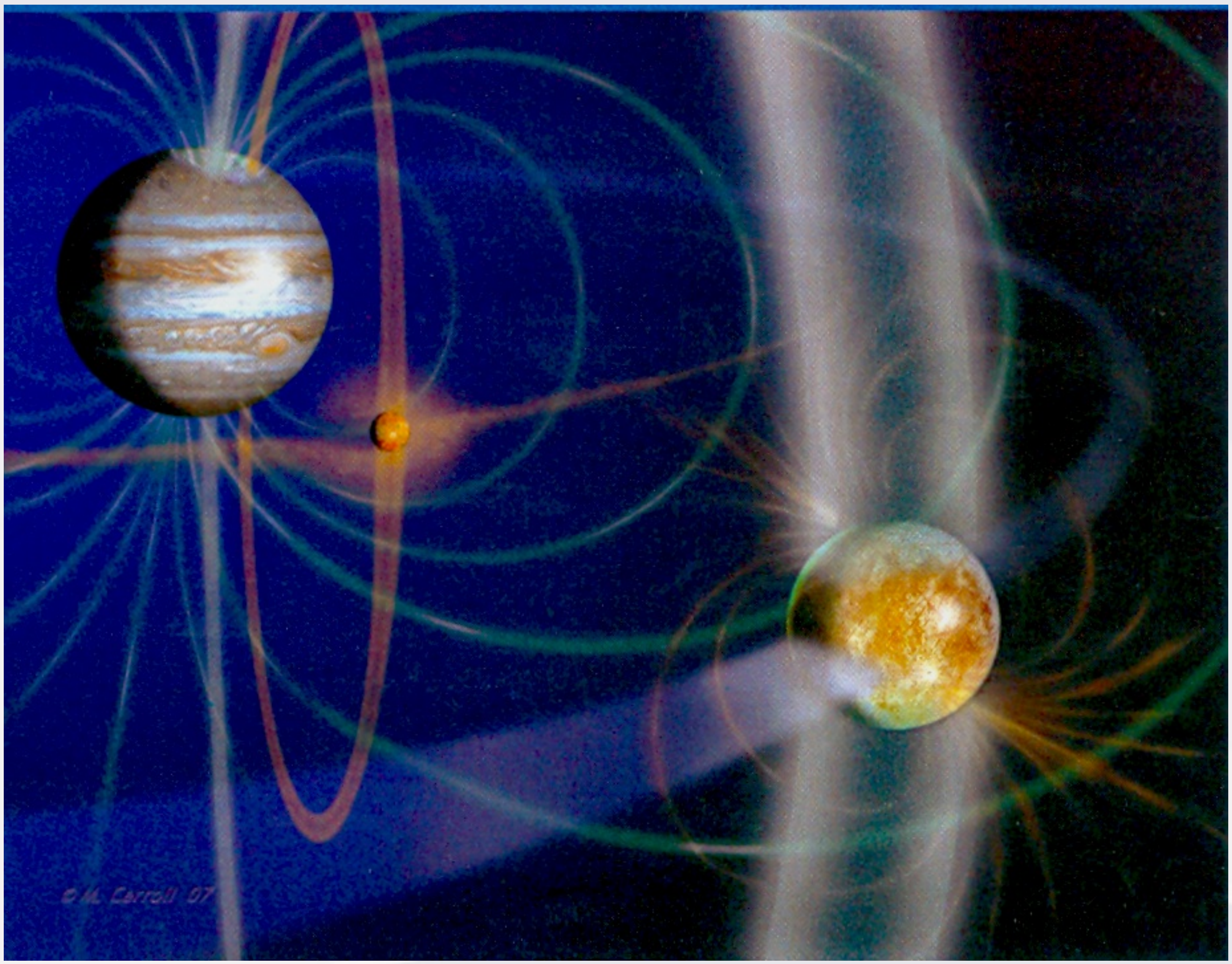
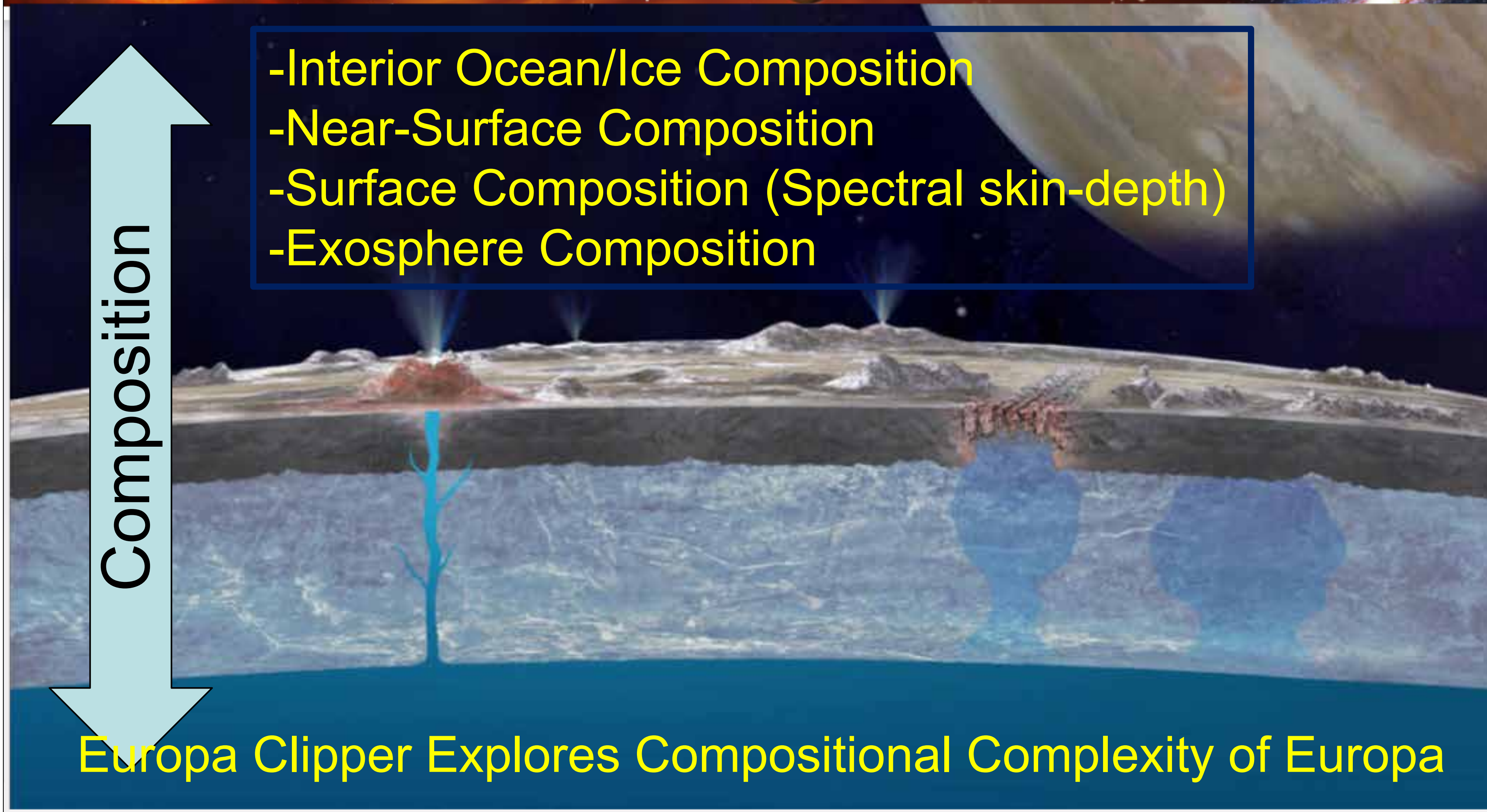
Radiation Environment of Europa

Electrons Reaching Europa's Surface: Trailing (colored) Hemisphere: **<25 MeV**; Leading Hemisphere: **>25 MeV**



Composition of Europa

- Interior Ocean/Ice Composition
- Near-Surface Composition
- Surface Composition (Spectral skin-depth)
- Exosphere Composition



Europa Clipper Explores Compositional Complexity of Europa

Surface Properties of Europa

Surface hardness and topography dictate future explorations involving lander and drilling

Europa Lander. Artist's Concept. Predecisional information, for planning and discussion only.

Europa – Surface & Radiation

Surface – upper few millimeters

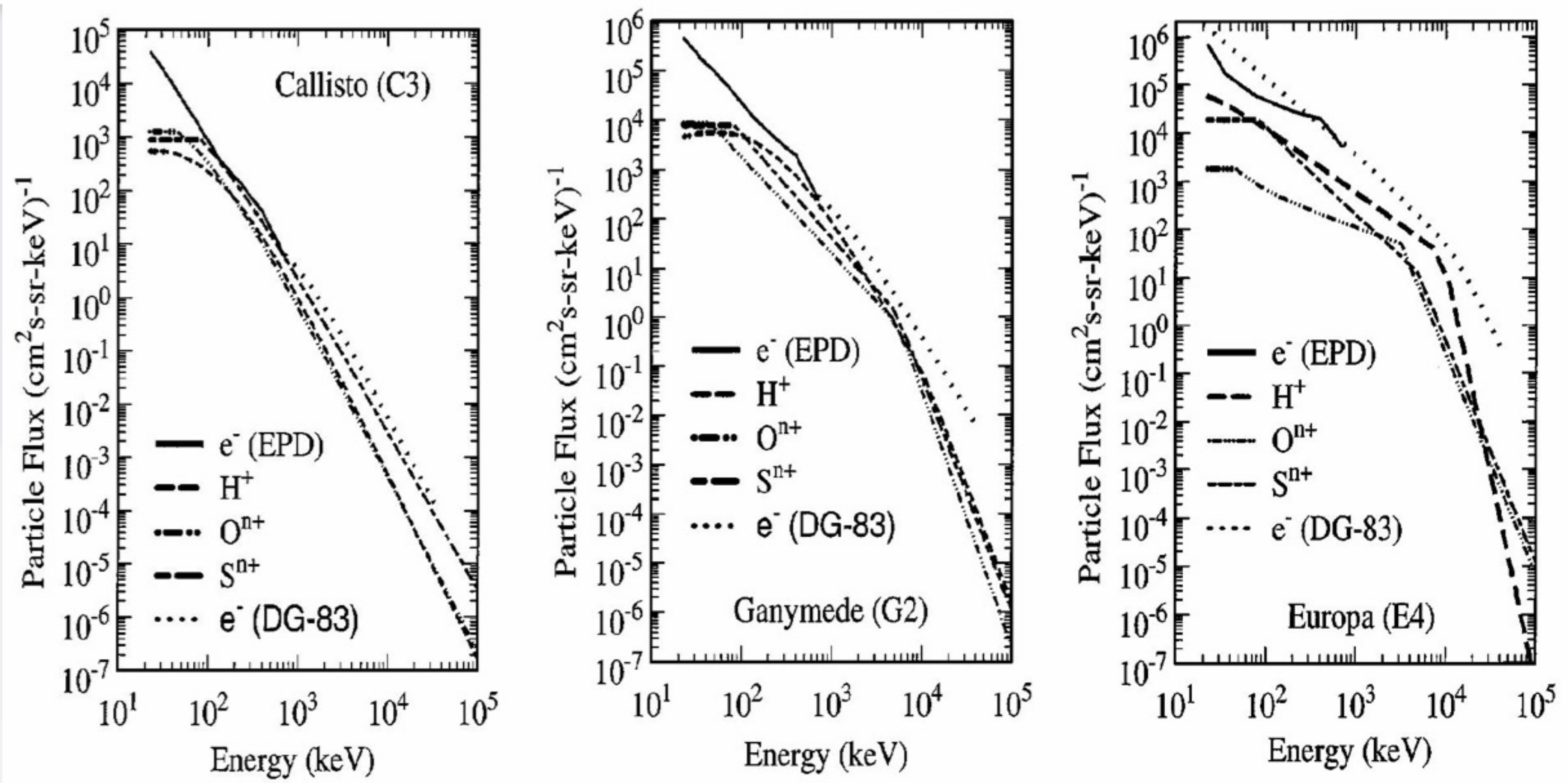
- Leading Hemisphere Surface – Ice Abundant
- Trailing Hemisphere Surface – Ice Depleted

Surface – upper few meters and below

Frequency of upwelling/renewing the surface - Unknown.

Radiation & Surface Properties of Europa are Inseparable!

Europa Radiation Environment



Galileo Orbiter measurements of energetic ions (20 keV to 100 MeV) and electrons (20–700 keV) in Jupiter's magnetosphere are used in conjunction with the JPL electron model (<40 MeV) to compute irradiation effects in the surface layers of Europa, Ganymede, and Callisto. Significant elemental modifications are produced on unshielded surfaces to approximately centimeter depths in times of 10^6 years, whereas micrometer depths on Europa are fully processed in <10 years.

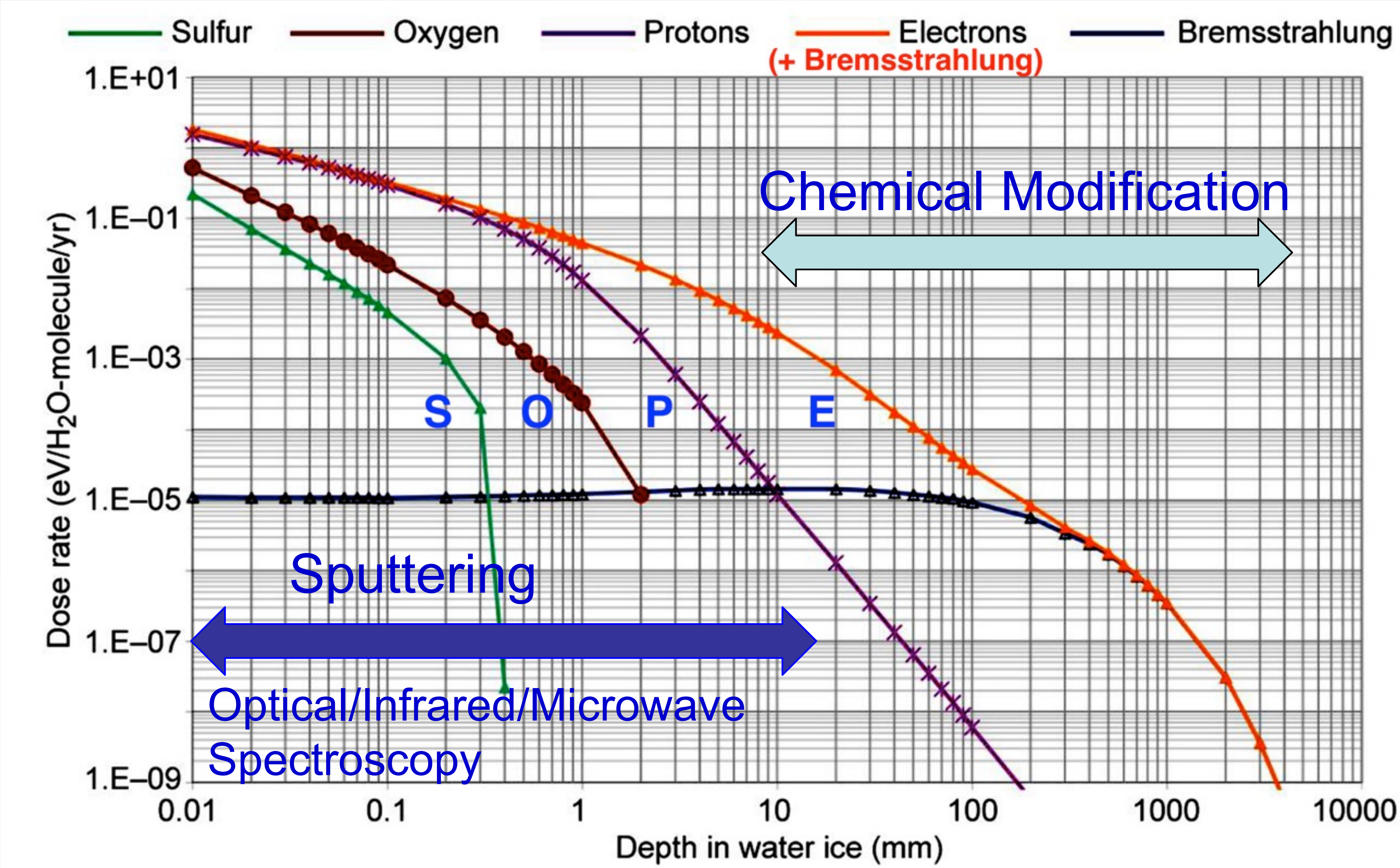
John Cooper et al. Icarus (2001)

Modeling Radiation Environment of Europa

Present Models are Based on Galileo Data (JUNO??)
No Laboratory Data of Europa Surface Analogs

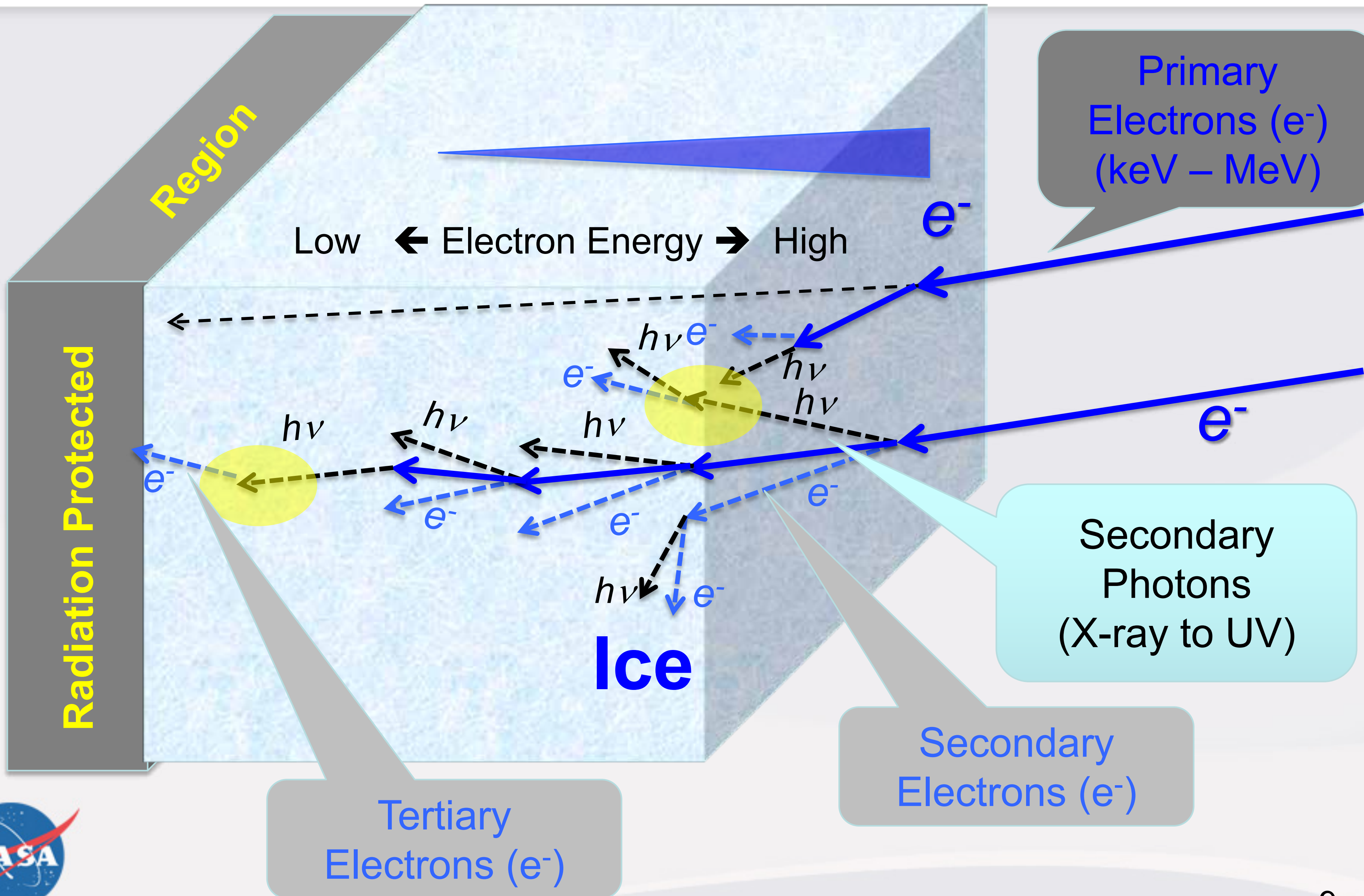
Modeling Europa's Radiation Dose

Based on liquid water or empirical data – no lab data YET published



Plot from: Paranicas et al. (2002)

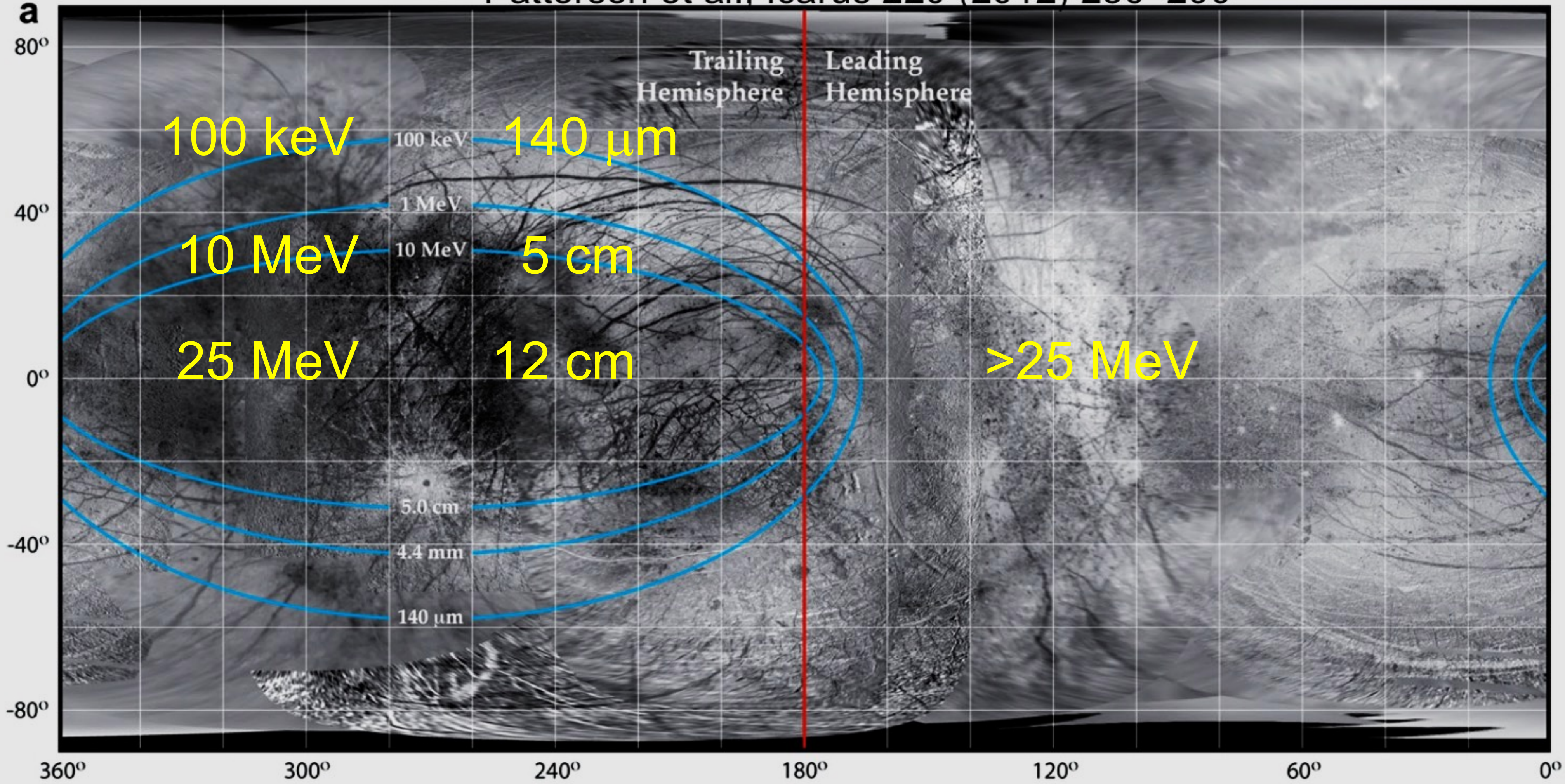
Electron Impact on Matter: Primary and Secondary Radiation



Electron Radiation on Europa's Surface: Models

IMPORTANT: These numbers are 50% Probability (cutoff)

Patterson et al., Icarus 220 (2012) 286–290

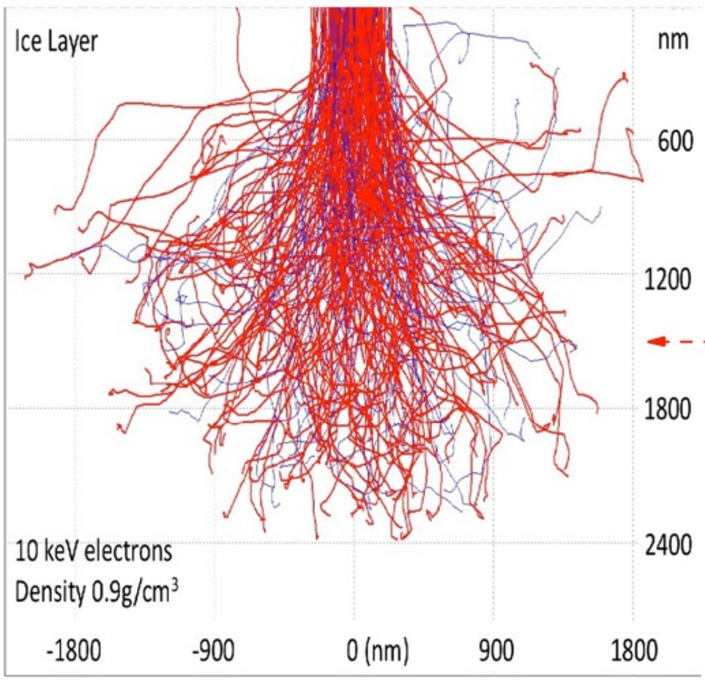


100 keV ~140 μm; 1 MeV ~4.4 mm; 10 MeV ~ 5 cm
Bremsstrahlung penetrates ~20 times deeper

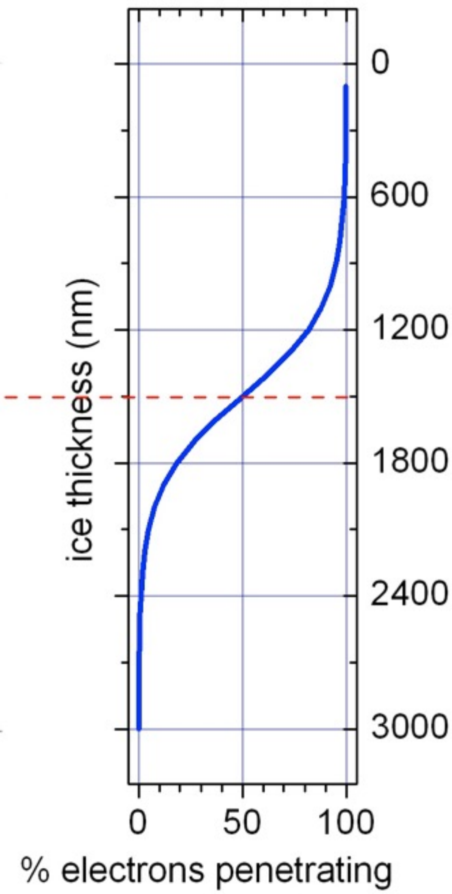
Penetration of Electrons in Ice is Statistical: Modeling

CASINO:
Hovington et al. Scanning 19 (1997) 29

Li Barnett, Lignell, Gudipati ApJ 747:13 (11pp), 2012



CASINO simulations for penetration paths of 10 keV electrons through ice of 0.9 g/cm^3



Sigmoidal not a Delta Function

Electron penetration into ice is a statistical phenomenon – that can be approximated by a sigmoidal equation (probability):

$$y = \frac{A_1 - A_2}{1 + e^{(x - x_0)/dx}} + A_2$$

Penetration depths must have percentile qualifier.

The default is 50% of the particles (electrons).

The rest of the 50% make to further depths.

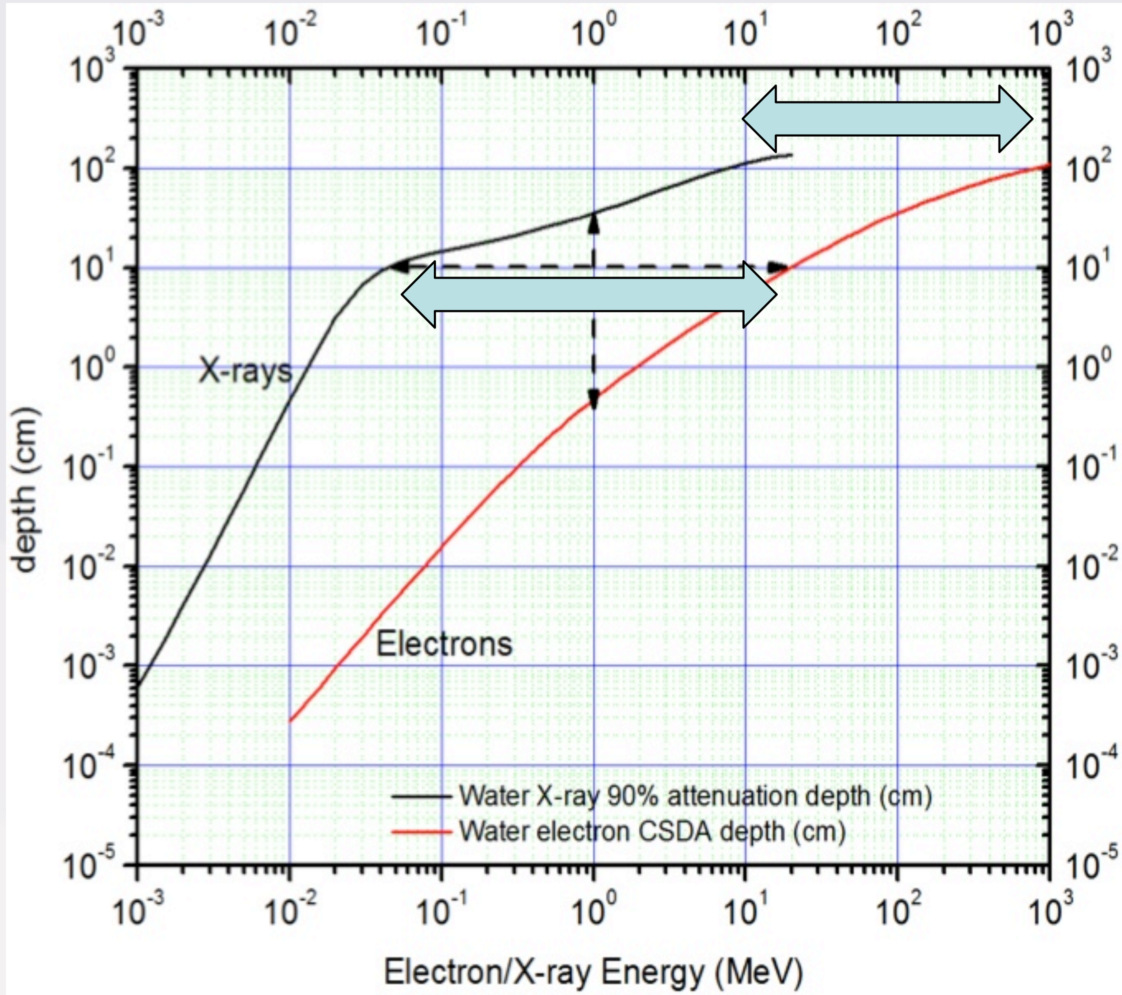
e.g.: 50% of 25 MeV electrons penetrate deeper than 12 cm

Penetration of Bremsstrahlung (X-rays) vs. Electrons

	100 keV	1 MeV	10 MeV
Electrons:	~140 μm	~4.4 mm	~ 5 cm
X-rays:	~15 cm	~30 cm	~100 cm

Electrons = 50% Attenuation
X-rays = 90% Attenuation

100 cm
10 cm

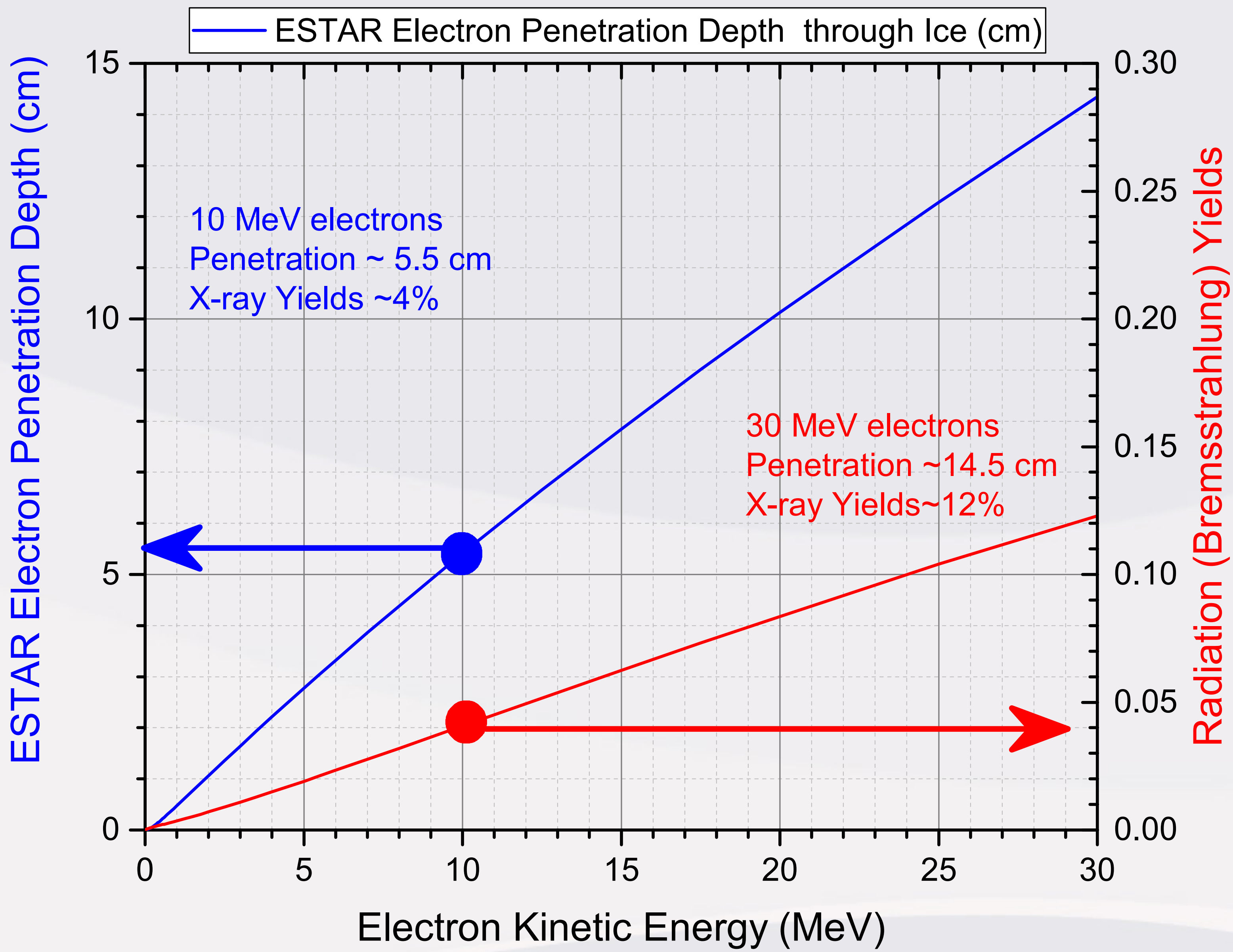


10 cm penetration:
20 MeV electrons or
50 keV X-rays

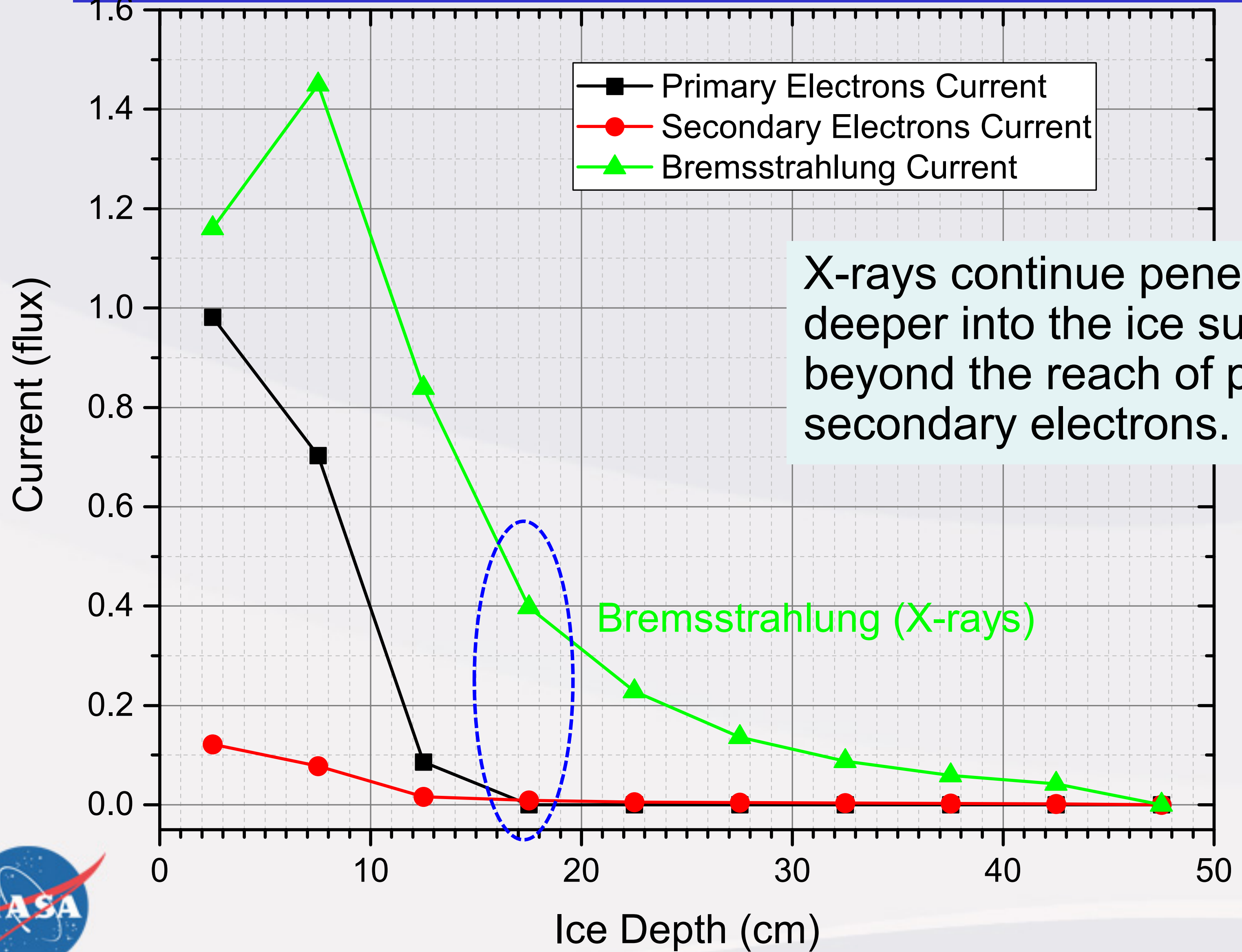
100 cm penetration:
1000 MeV electrons or
10 MeV X-rays

Electrons: http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html
X-rays: http://www.nist.gov/pml/data/xraycoef/index.cfm

Empirical Models: Bremsstrahlung (X-ray) Yields



GEANT Simulation of 30 MeV Primary Electron yields of Secondary Electrons and Bremsstrahlung (X-rays) at various Depths through Ice



X-rays continue penetrating deeper into the ice surface beyond the reach of primary and secondary electrons.

How Good are Models without realistic Experiments?

Modeling Studies were based on:

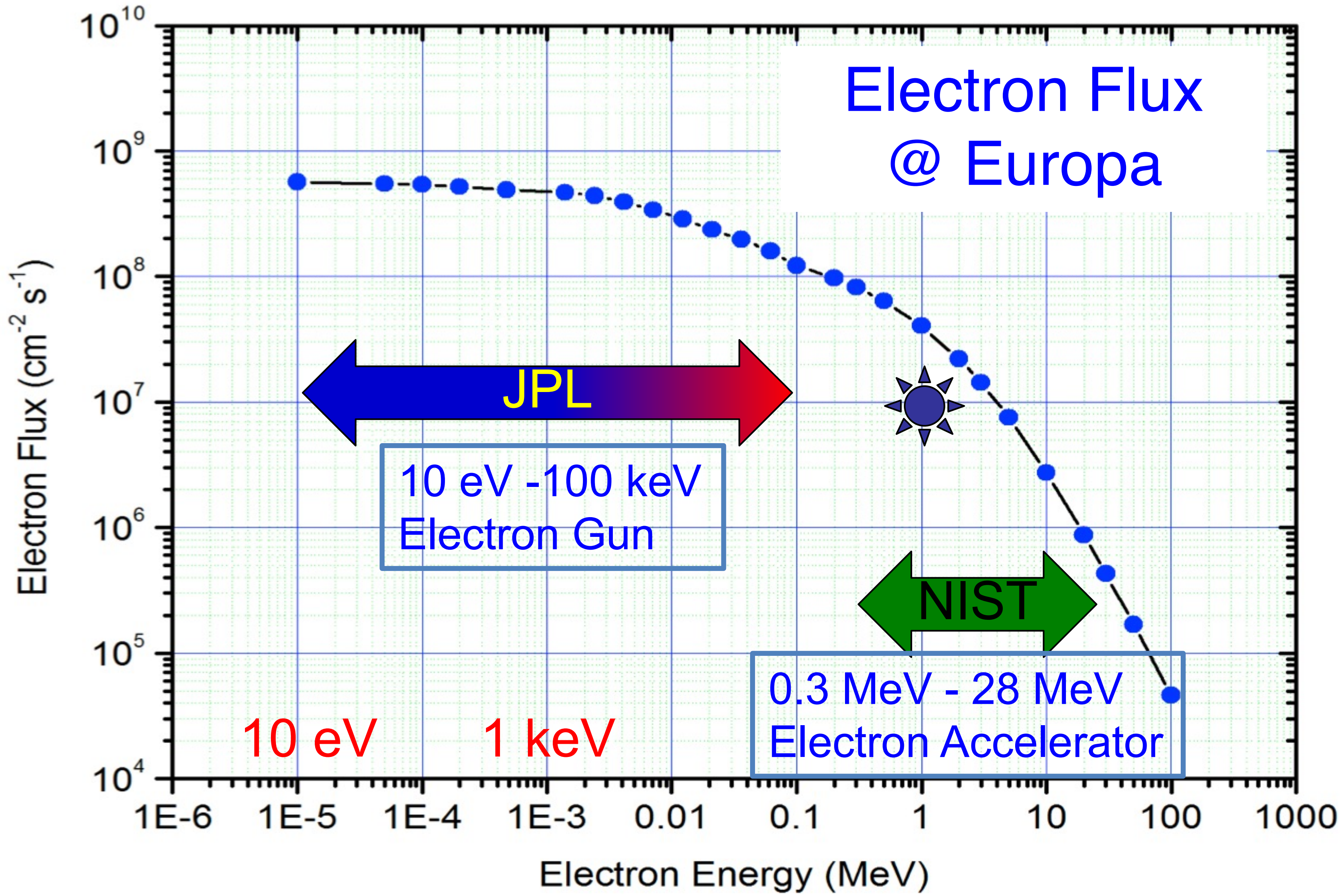
Liquid water and other non-ice targets.

Energies different from Europa's surface.

Extrapolations were done to estimate under Europa's conditions.

Until We Started Our Laboratory Studies At the Ice Spectroscopy Lab (ISL) of JPL

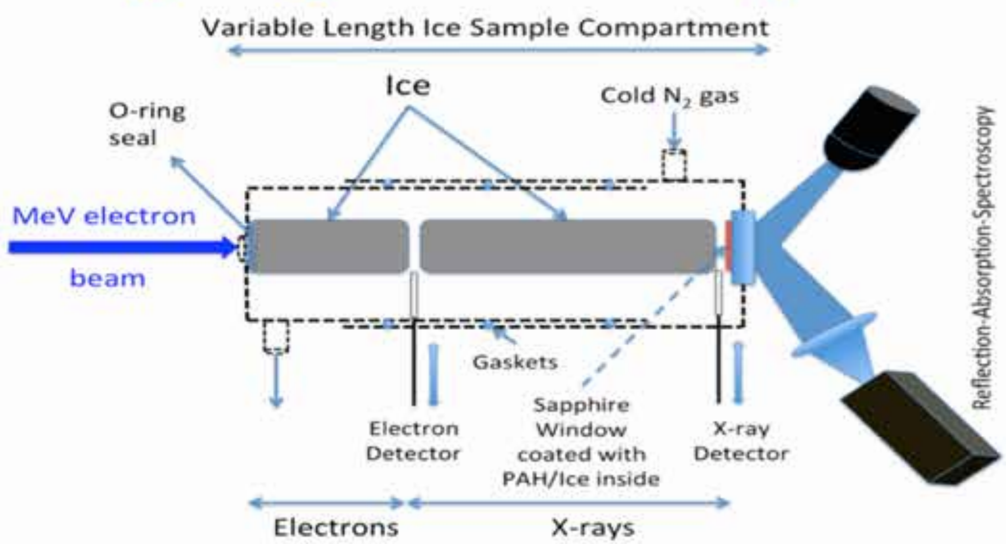
Present Capabilities of the ISL @ JPL

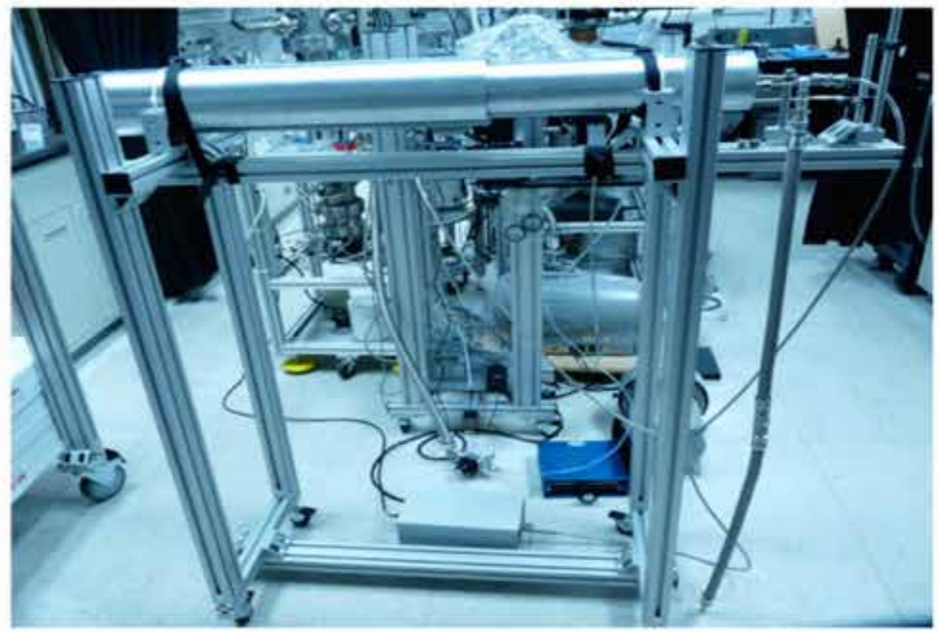


ICE-HEART @ ISL

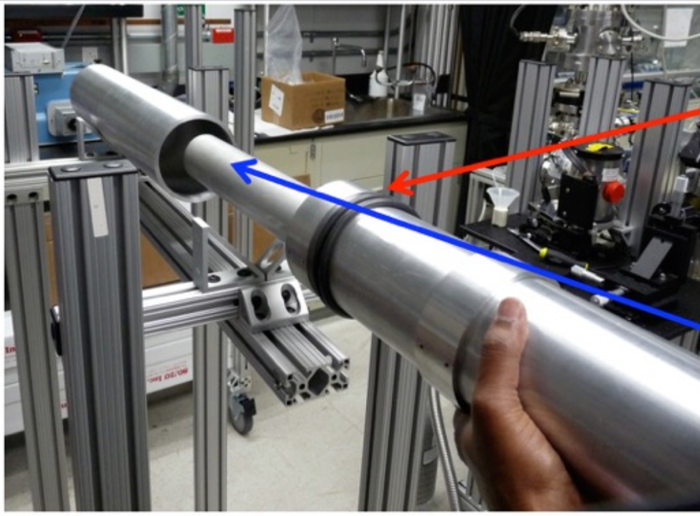
(Ice Chamber for Europa's High-Energy Electron And Radiation-Environment Testing)

Designing and building ICE-HEART for Europa



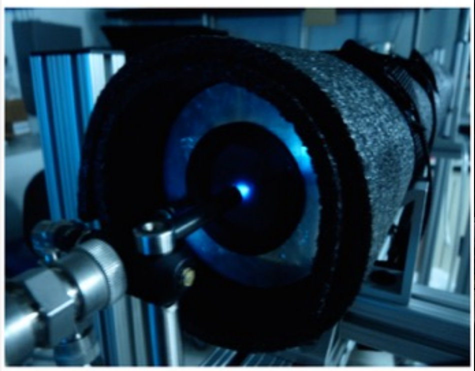


ICE-HEART

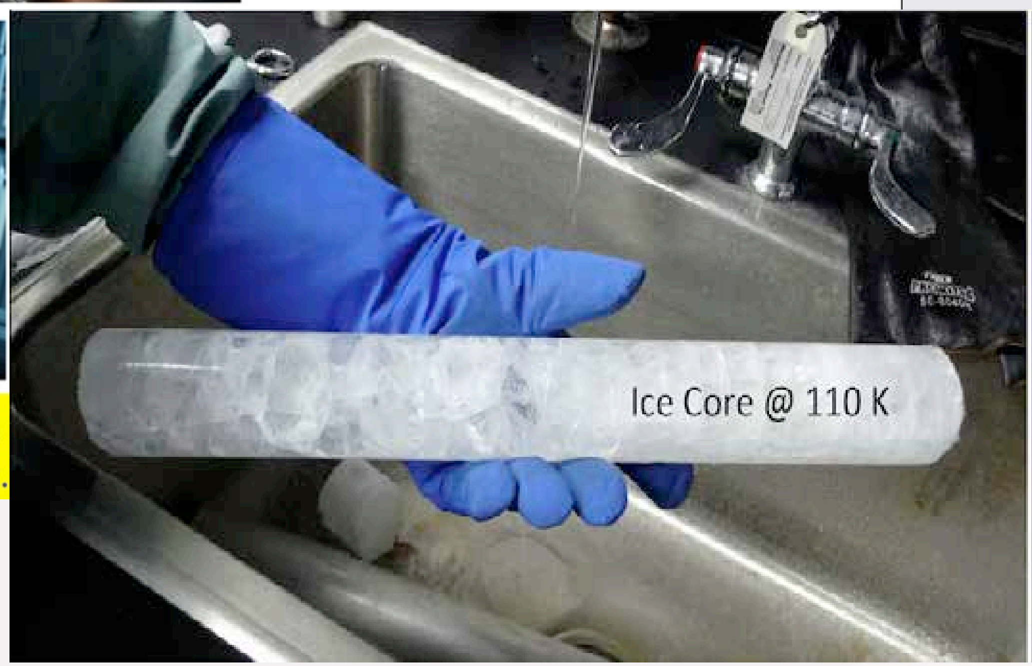


Outer Telescope with vacuum seal O-rings.

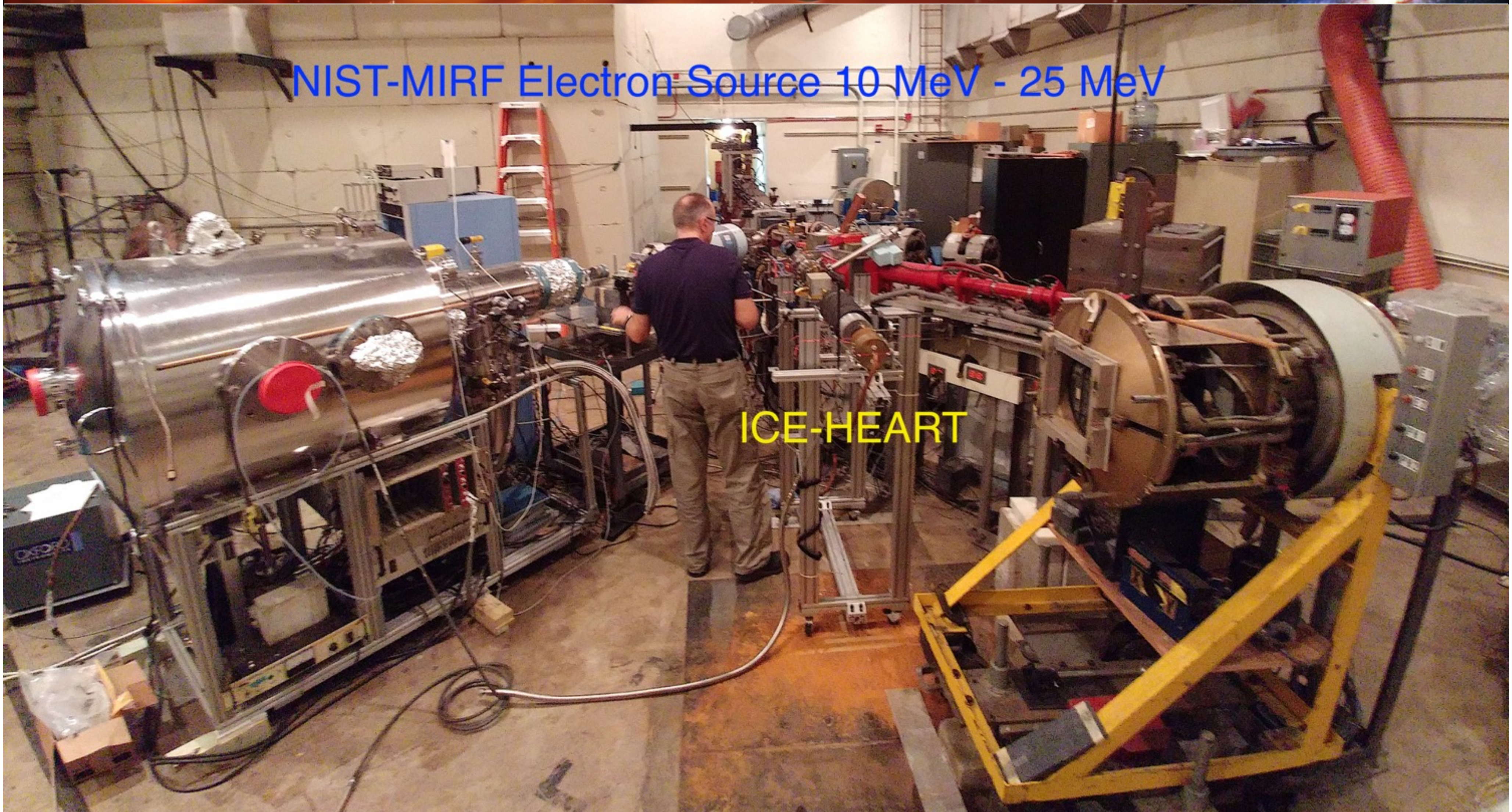
Inner 2.5-inch diameter tube for water ice frozen in the tube or loaded as crushed powder.



Insulated for 100 K operation
Using liquid nitrogen cooling.



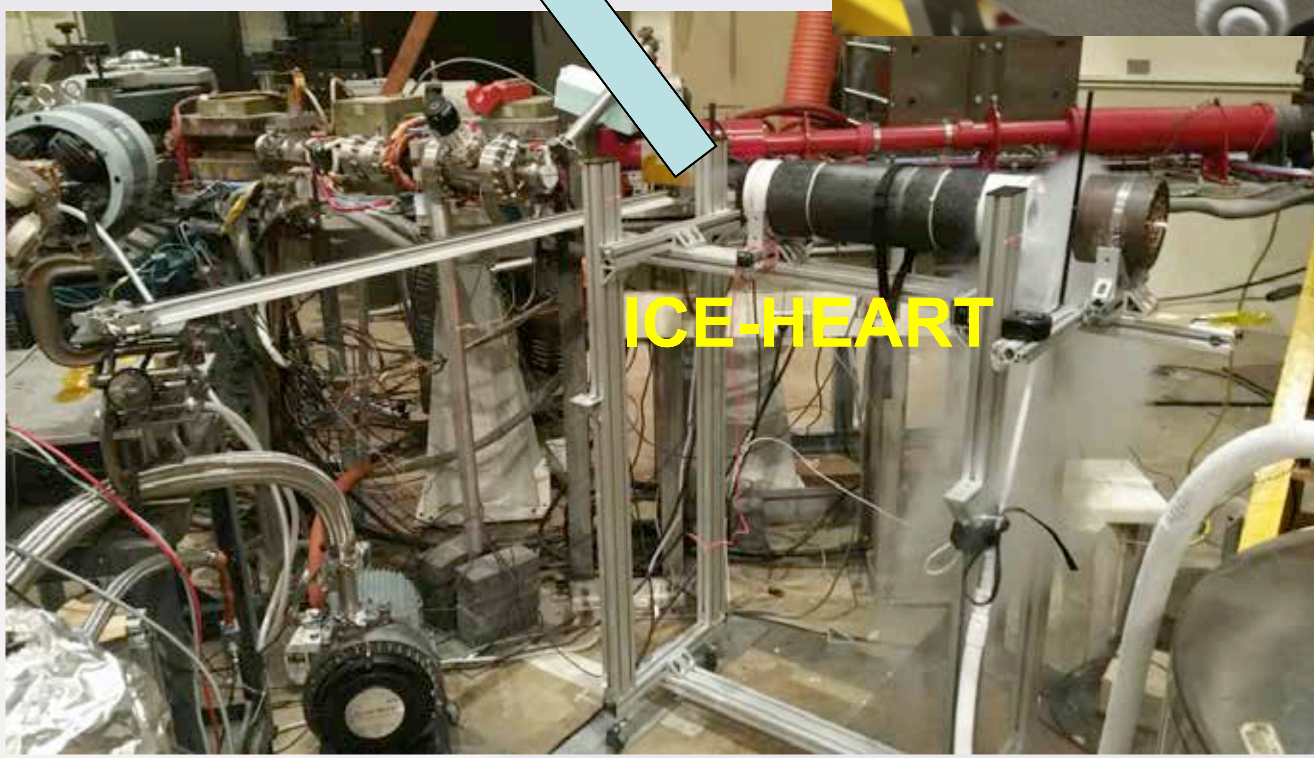
NIST Electron Sources Cover 300 keV to 28 MeV



ICE-HEART in Action @ NIST

Front

~90 K



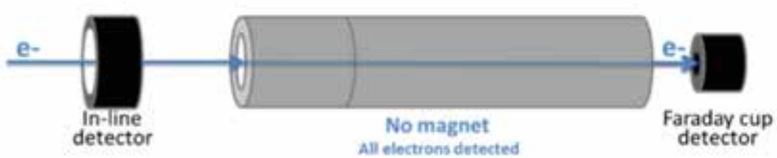
ICE-HEART Crew in Action @ NIST MIRF

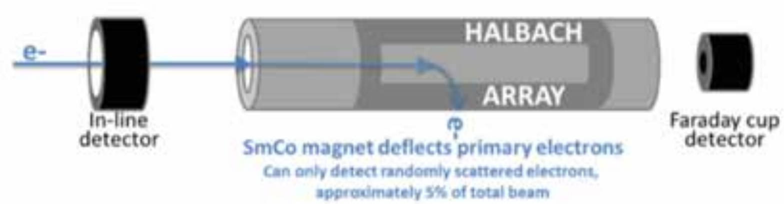
Ice Sample Handling in (subsequent to) High-Radiation Environment

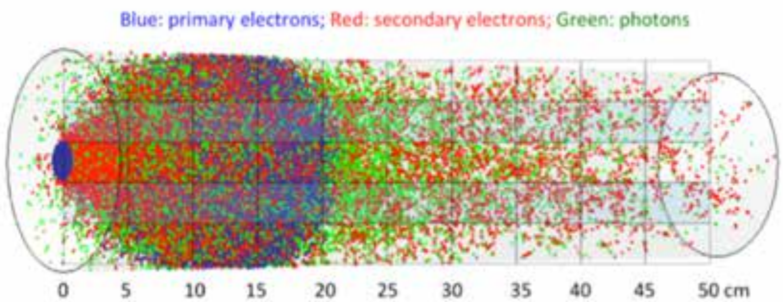
How to Quantify Bremsstrahlung (X-rays)?

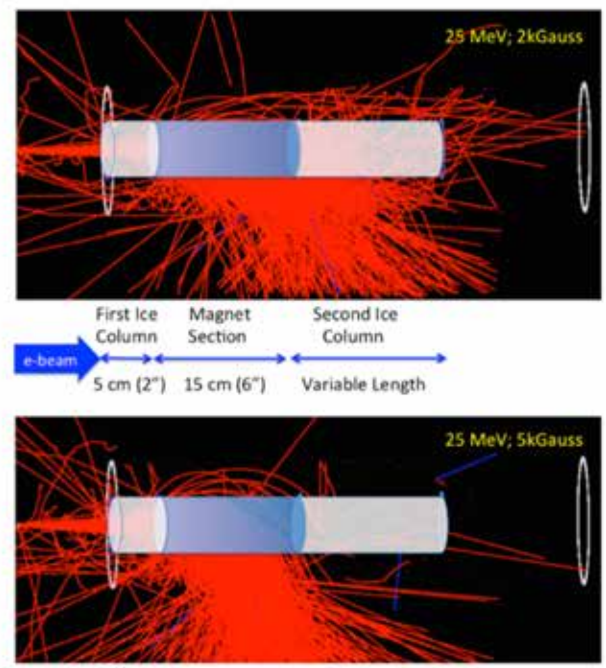
By Removing Secondary Electrons

**5kG Halbach Cylindrical Magnet @ 80 K
Deflecting Primary and Secondary Electrons Enables Quantification of X-ray Yields and Penetration Depths**







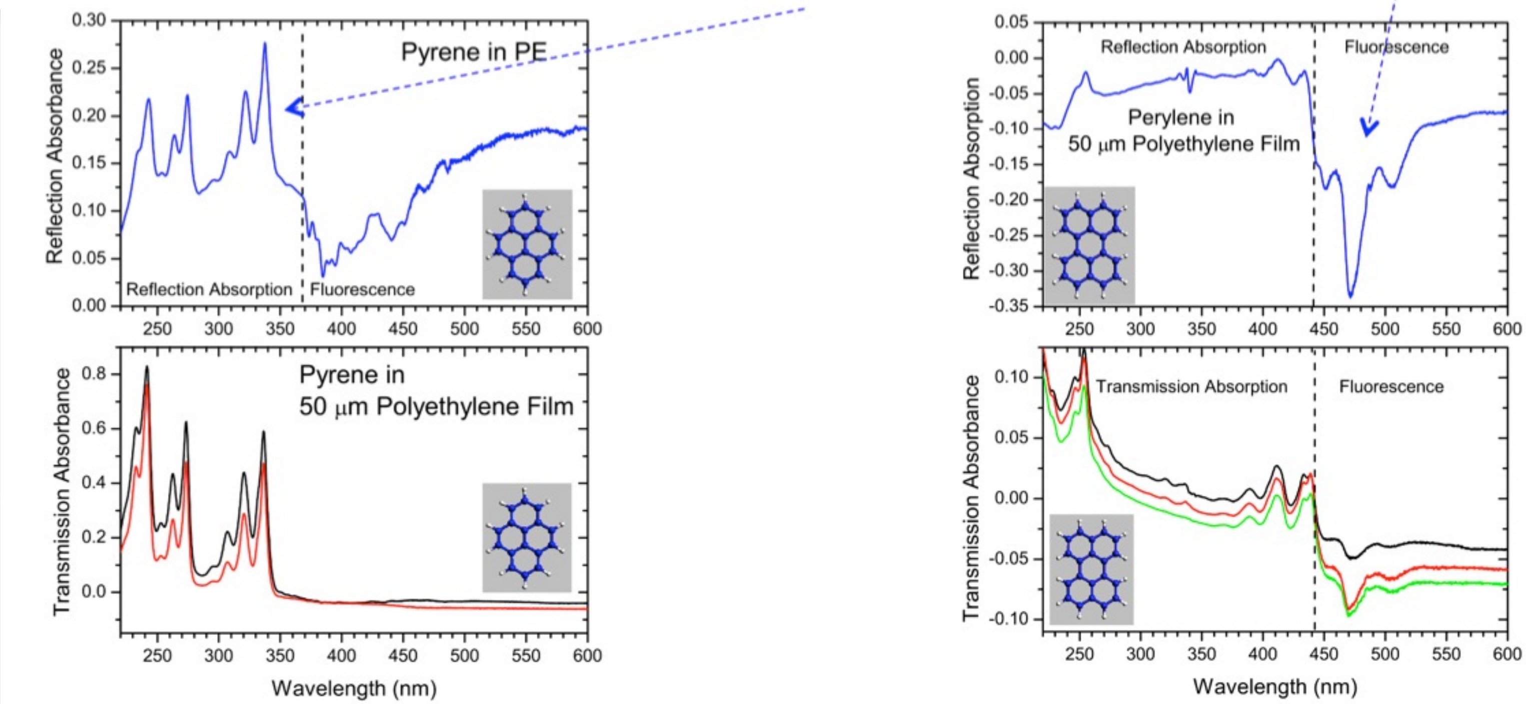


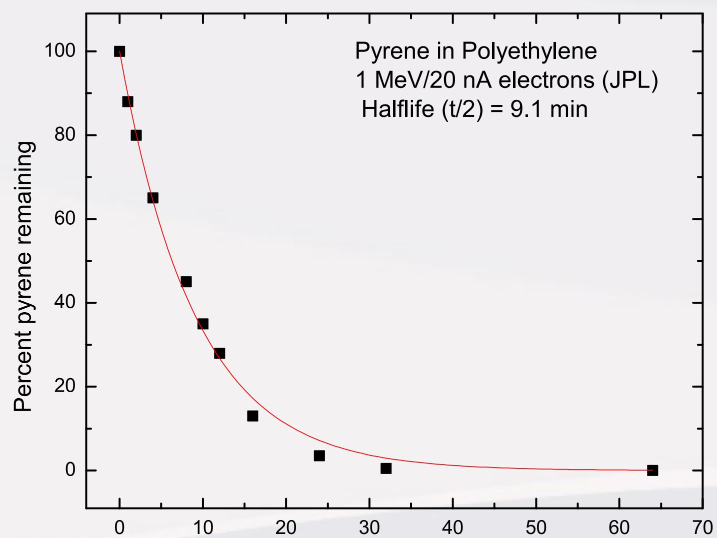
Above: typical secondary particle generation in the ICE-HEART when high energy electrons impinge upon ice with no magnet.

Right: Inserting a strong SmCo magnet (5 kGauss) into the chamber causes electrons to be deflected to the side, so that they no longer impinge upon the detector.

Organic Damage by 1MeV Electrons

Two Organic Probes: Strongly Absorbing (Pyrene); Strongly Fluorescent (Perylene)

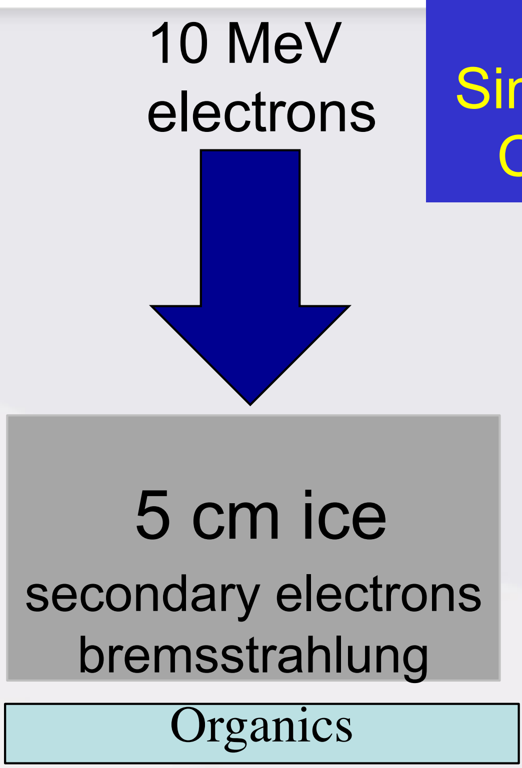




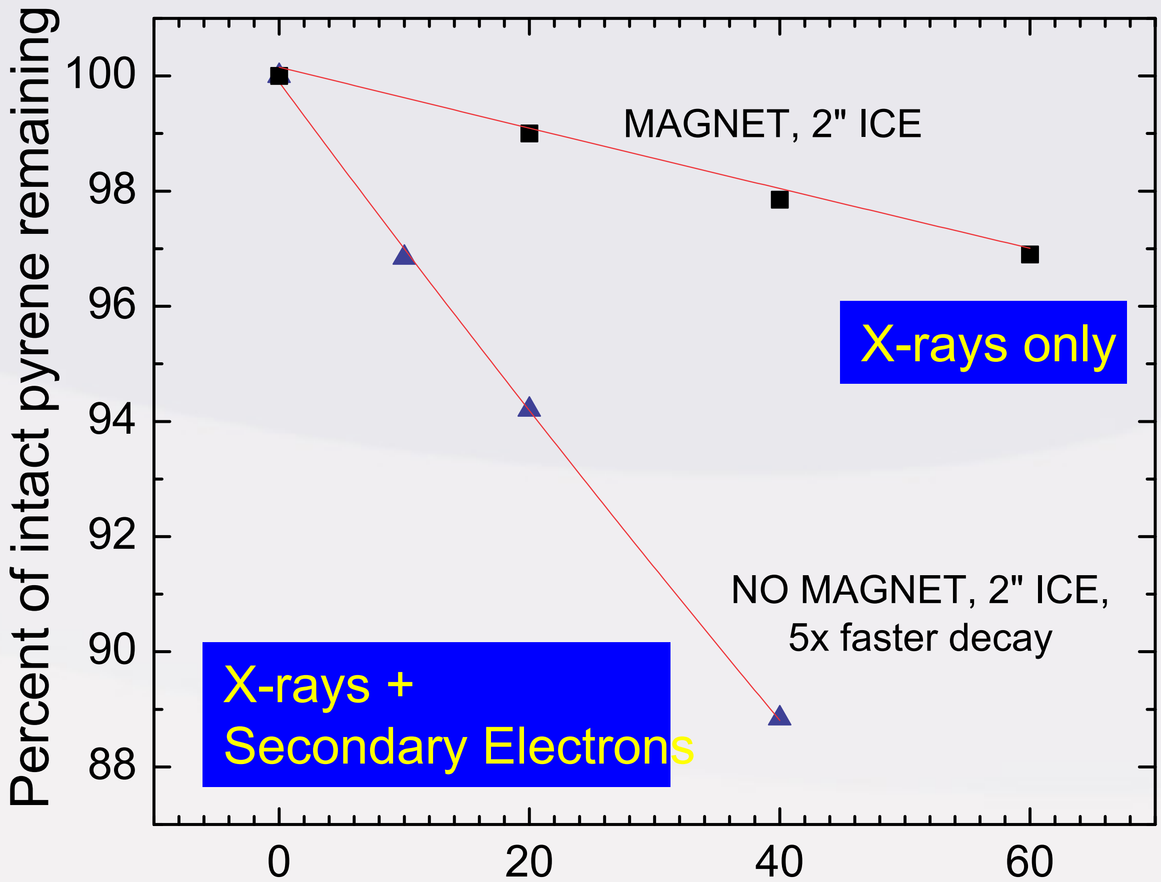
Secondary Radiation (Bremsstrahlung)

Secondary Electrons vs. X-rays

First JPL-NIST MIRF Data for 10 MeV Primary Electrons
bombarding 5 cm thick ice targets at 100 K
Simulating Europa's Surface Radiation Damage of Organics
Critical for Future Lander Missions & Surface Habitability



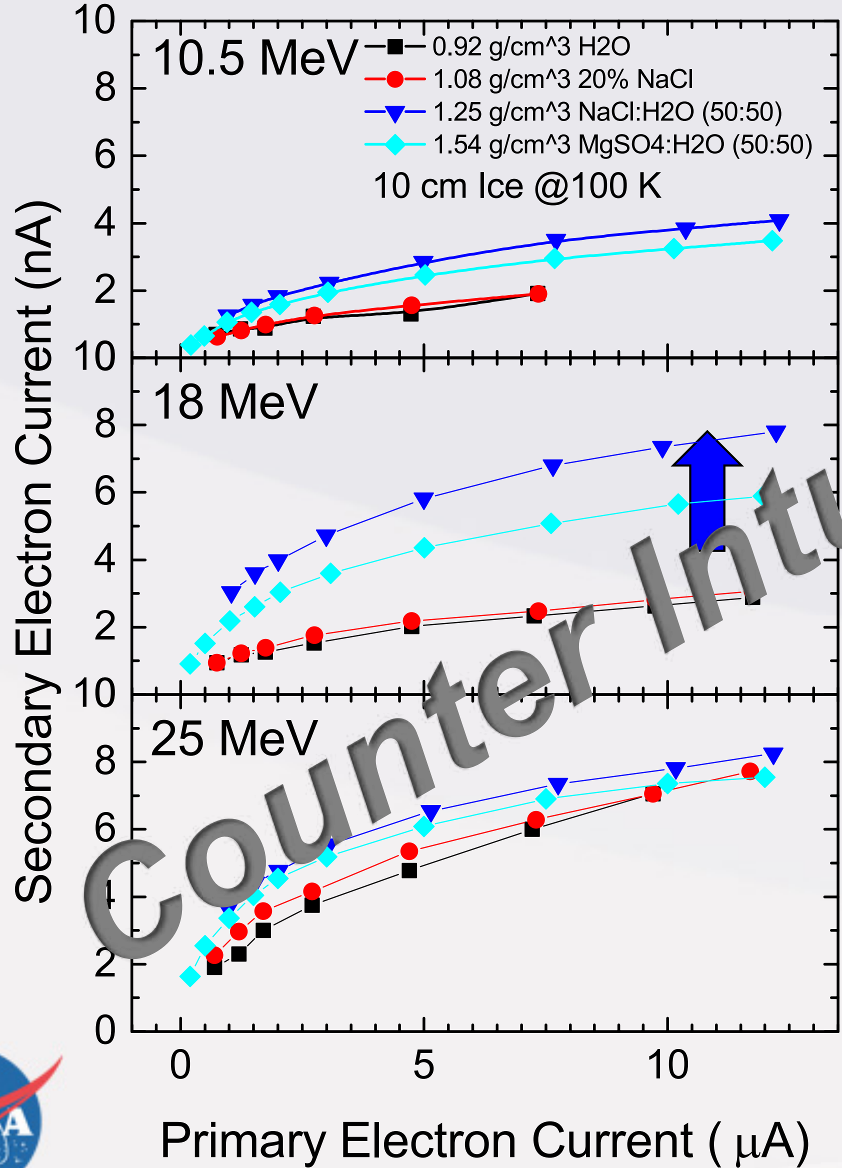
Damage through
sec. ele. 80%; X-rays 20%

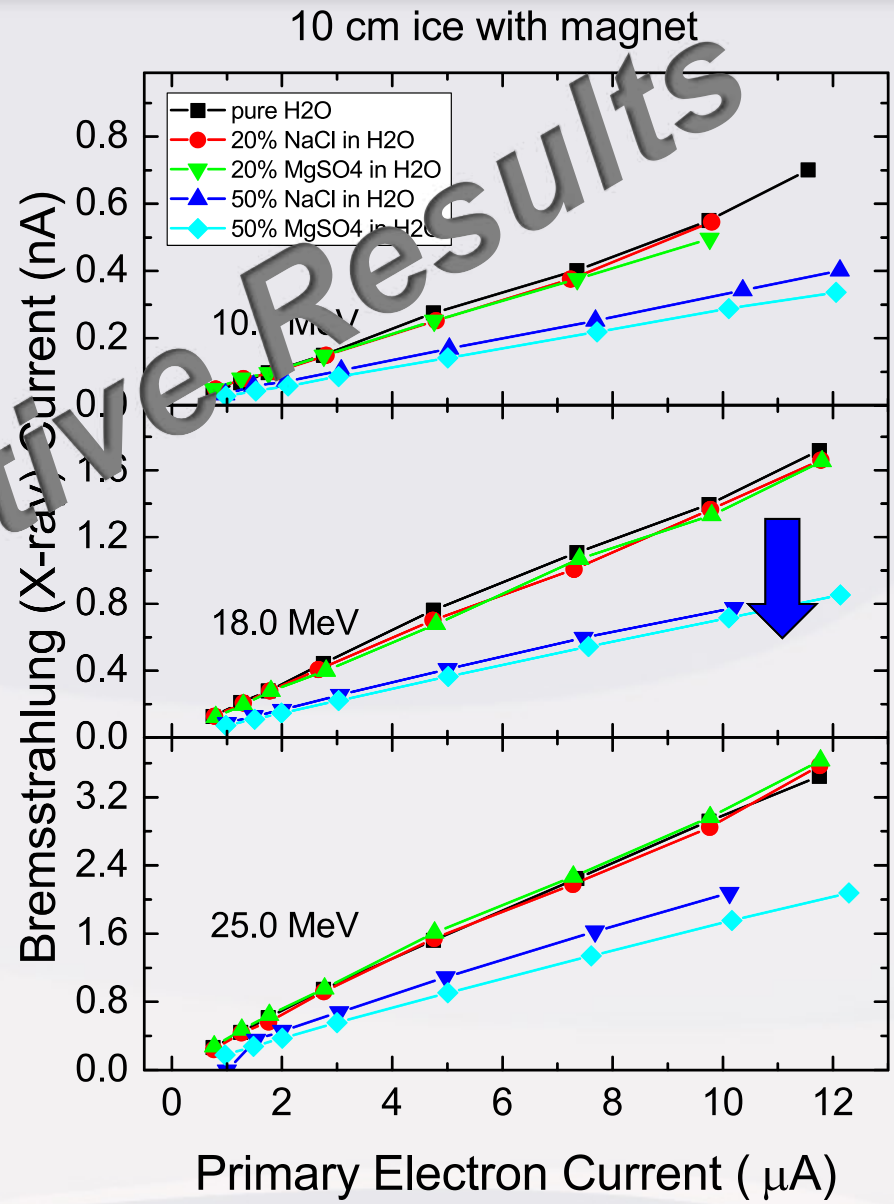


Irradiation time (minutes) at 10.5 MeV and a dose of 0.43 nA

Europa Ice Analogs (10 cm) with NaCl & $MgSO_4$

Secondary Electrons / Bremsstrahlung





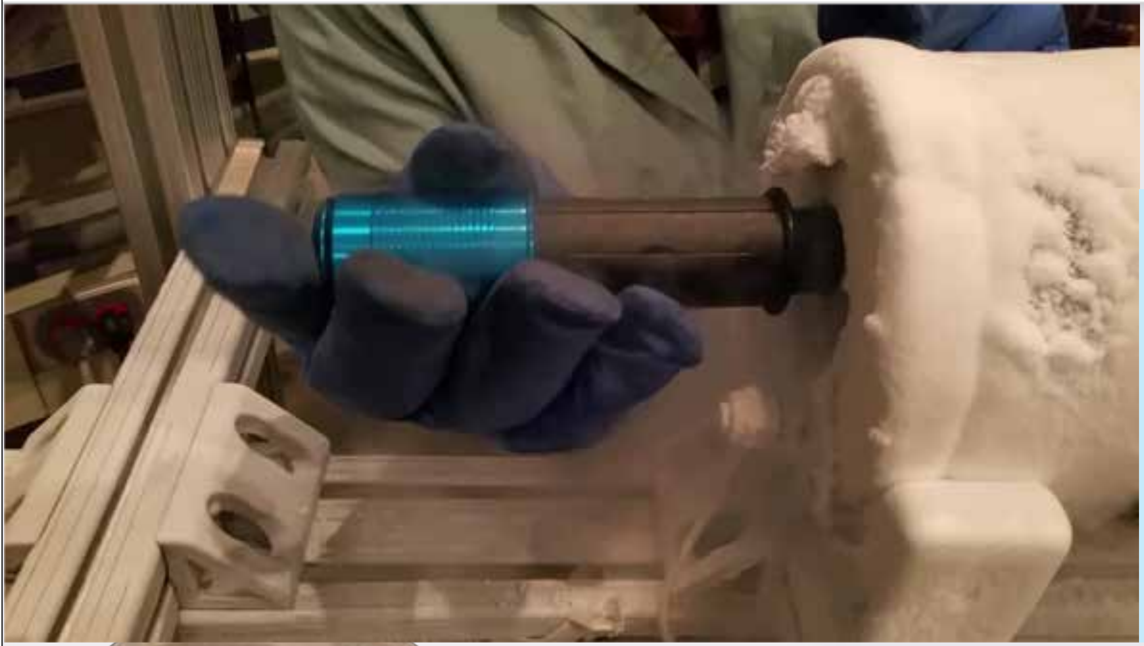
Counter Intuitive Results

Europa Surface Hardness

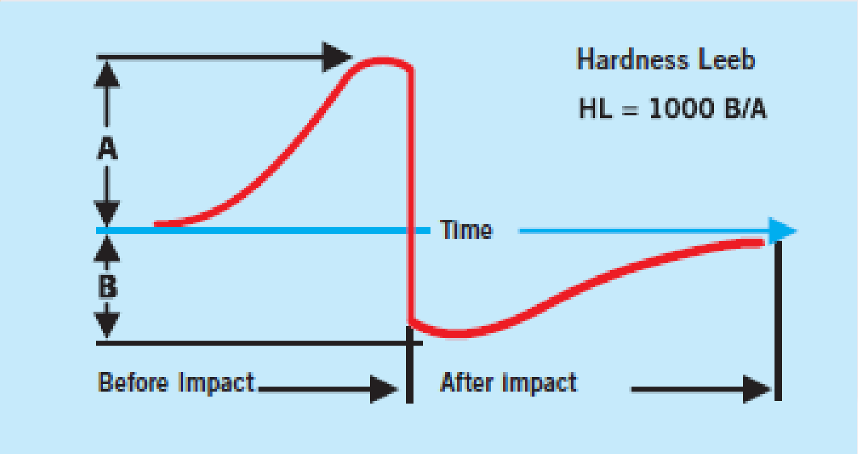
Surface Hardness of Europa's Trailing Hemisphere

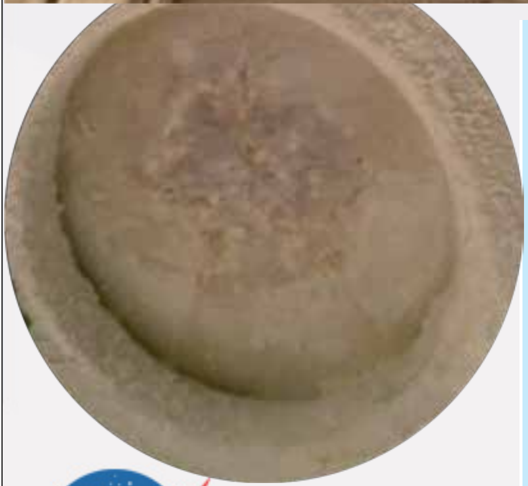
Testing Surface Hardness of Irradiated Sample

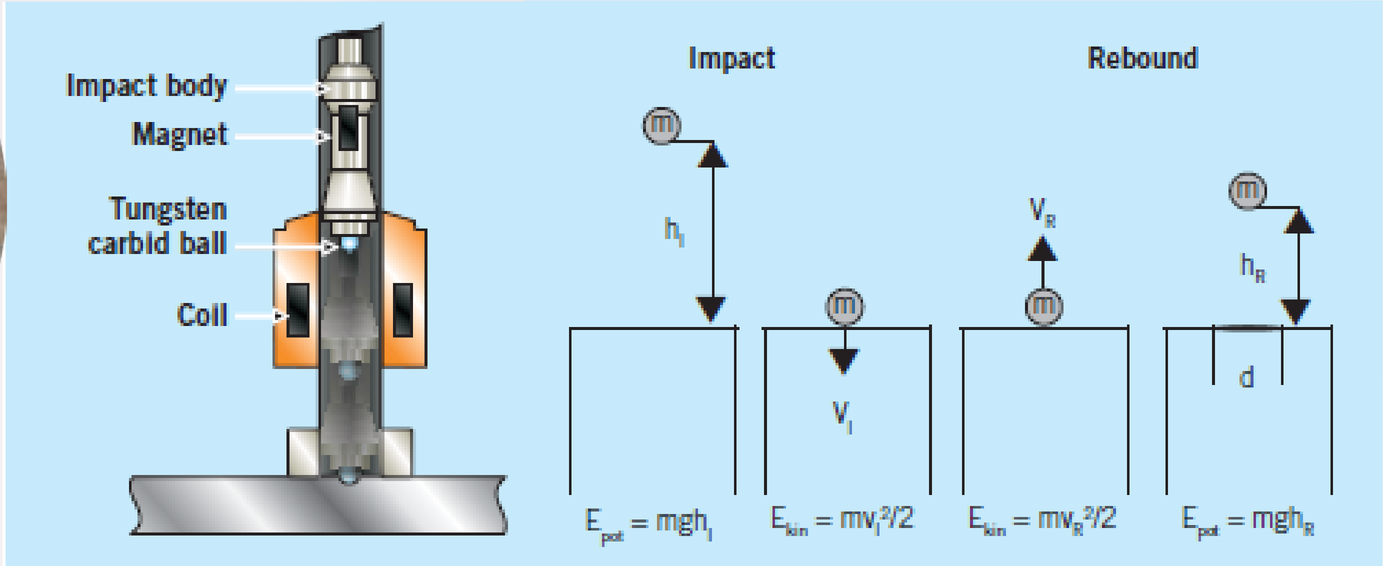
Choice: Rebound methods (e.g. Leeb Hardness)



Works Horizontal or Vertical



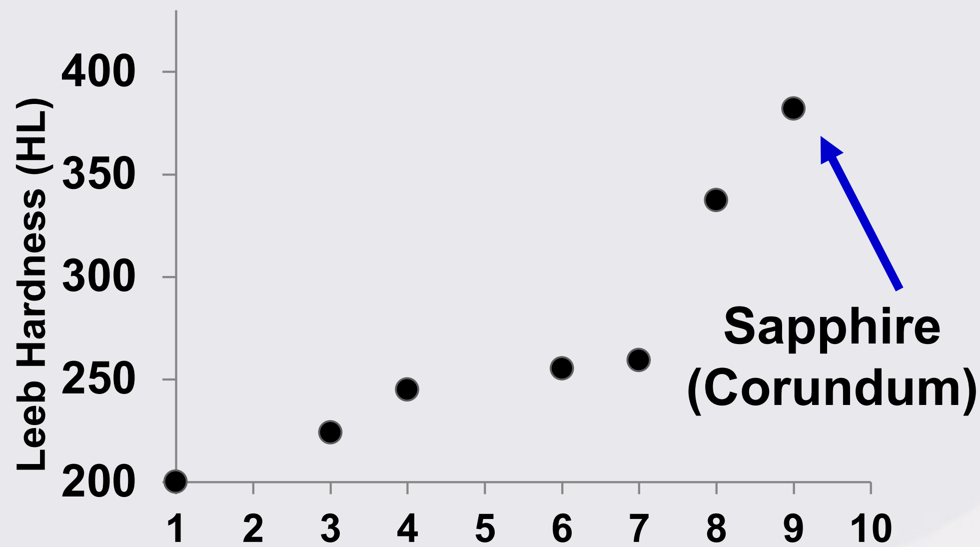


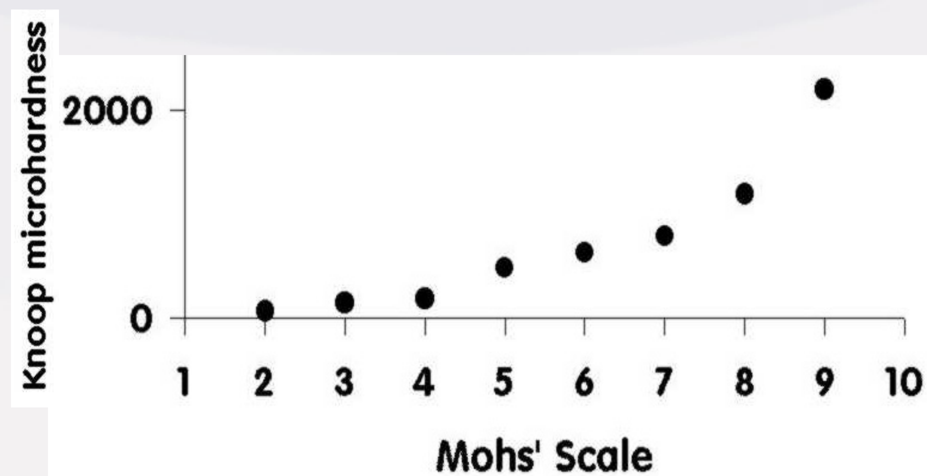


Hardness Scale – Leeb vs. Moh's

Since diamond is the hardest, it is given Number 10; talc is the softest, so it is given Number 1. Quartz, Number 7, is often used as a division in the scale, and all those above 7 are called hard minerals.

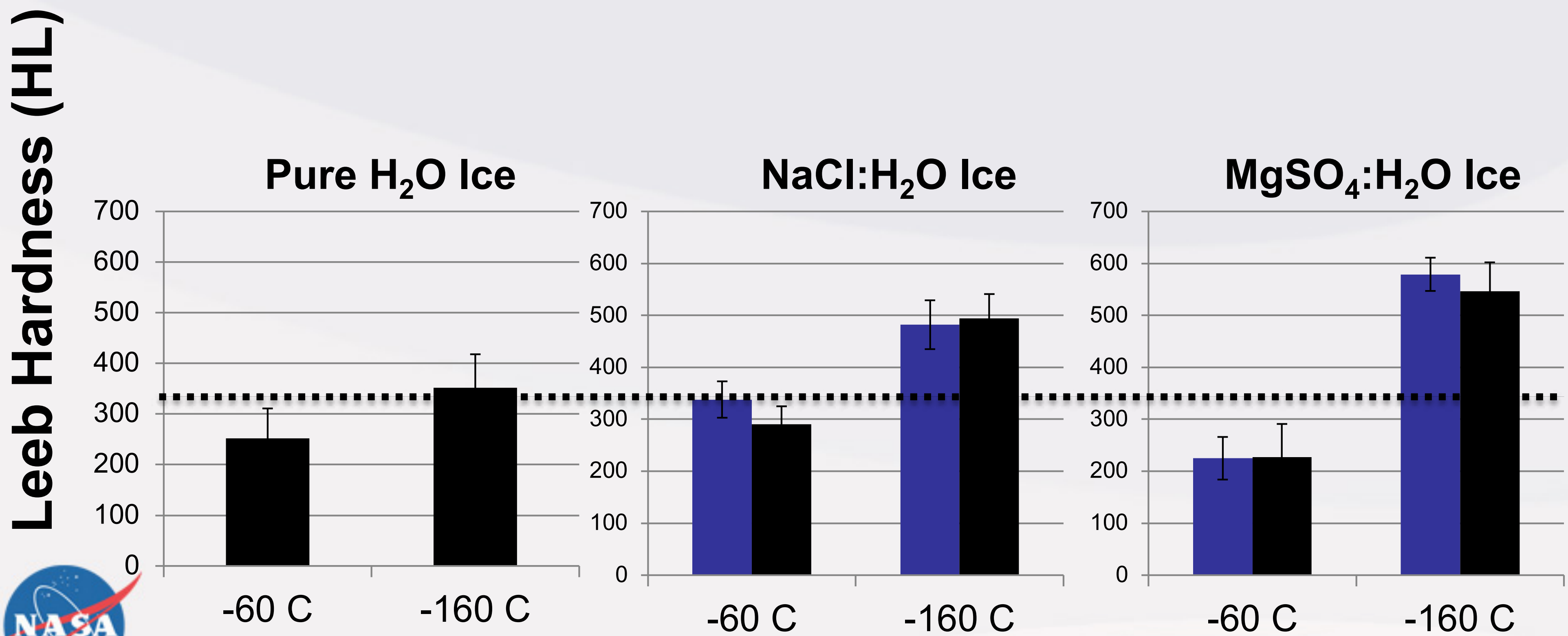
10. DIAMOND
9. CORUNDUM
8. BERYL-TOPAZ
7. QUARTZ
6. FELDSPAR
5. APATITE-TRIPHYLITE
4. FLUORITE
3. CALCITE
2. GYPSUM
1. TALC





Hardness of Unirradiated Europa Ice Analogs

- Salt-rich ices are harder than pure water ices
- $MgSO_4$-containing ices are the hardest.
- Lower the Temperature, Higher the Hardness
- Exact salt concentration (25% or 50%) has no significant effect

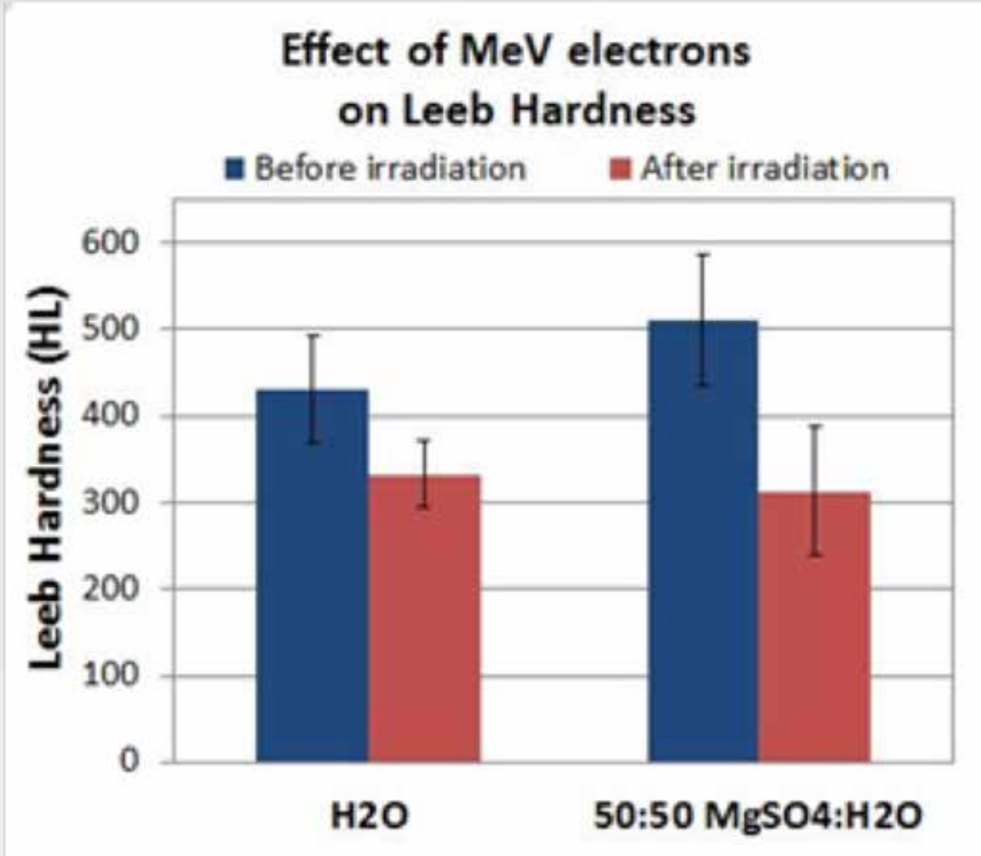


Radiation-induced changes in Leeb Hardness

Radiation-Softening Occurred in All Ice Analogss.

Physical Changes:
- Crystallinity
- Grain-Size and Boundaries

Chemical Changes:
- Ionization
- Dissociation
- Diffusion of Atoms/Ions



Bombardment at 90 K with 10.5-25 MeV electrons. Dose for the 50:50 $MgSO_4$:H_2O sample was $6x10^{16}$ MeV cm^{-2} and for H_2O was $8x10^{16}$ MeV cm^{-2} (~25 years of radiation on Europa's trailing hemisphere). Error bars represent one standard deviation of the measured values.

Conclusions & Future Work

Conclusions

- Secondary Photons (Bremsstrahlung) penetrate deeper (up to 1m) on trailing hemisphere of Europa (close to the equator).
- Bremsstrahlung damage to organics is NOT INSIGNIFICANT (~20%)
- Secondary Electron Yields are HIGH in Salts (vs. pure ice)
- Bremsstrahlung Yields are LOW in Salts (vs. pure ice)
- Surface composition of Europa would be dictated by the altitude dependent geological activity. Geologically inactive regions are expected to be heavily processed.
- Trailing hemisphere of Europa is expected to be radiation-softened, but still much harder than pure water-ice, particularly should $MgSO_4$ were to present..

Future Work & Acknowledgments

- Systematic Data on Wide Range of Europa Surface Analogs (Including Sulfuric Acid Hydrates)
- Quantification of Secondary X-rays and their Yields
- Quantification of X-ray damage to Organics

Thank You for Your Time!

Funding:
JPL R&TD Funds
JPL Technology Enabling Funds

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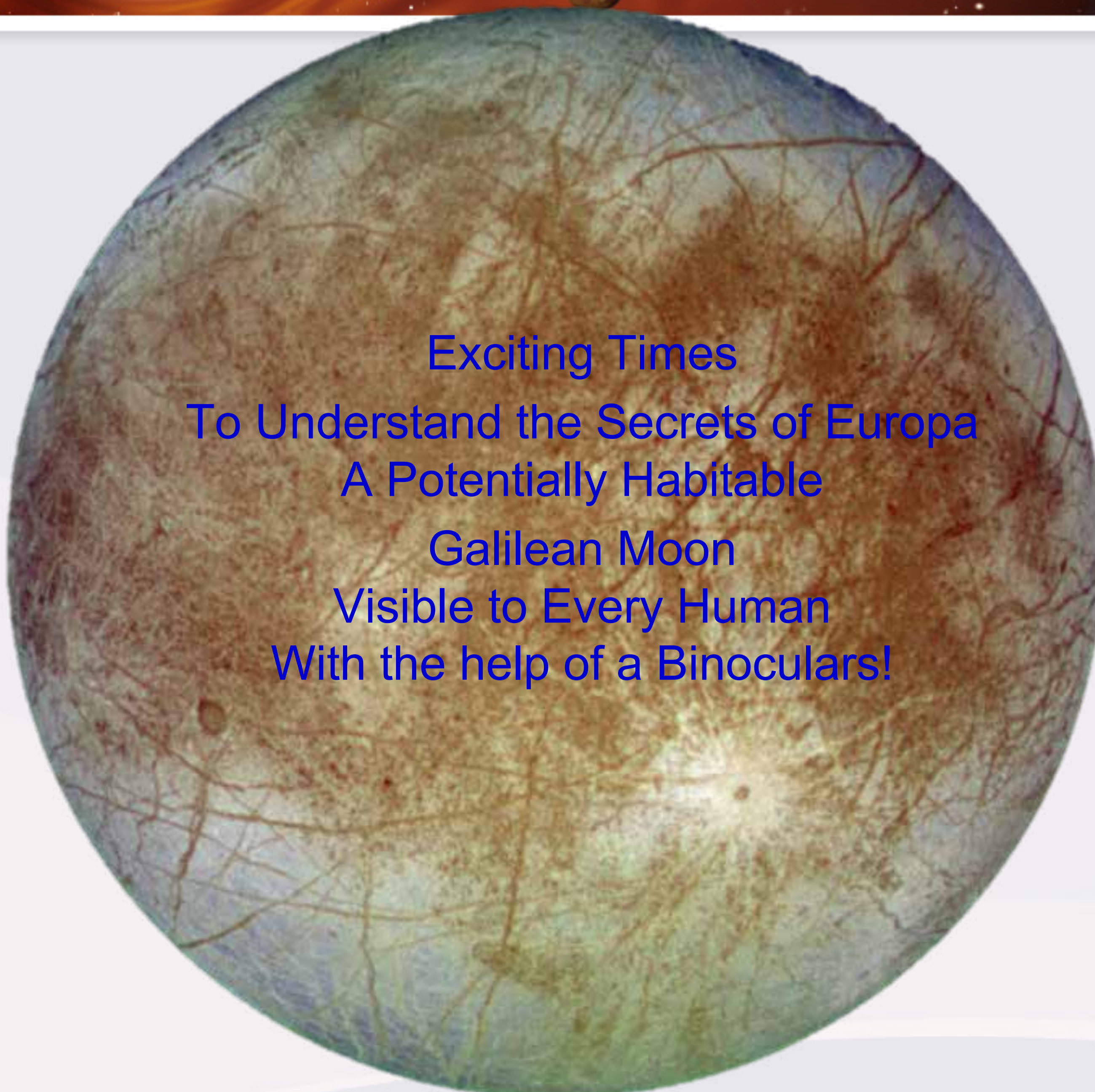

Exciting Times

To Understand the Secrets of Europa
A Potentially Habitable
Galilean Moon
Visible to Every Human
With the help of a Binoculars!