Europa Deep Dive 2: Chemical Composition of Europa and the State of Laboratory Data

Murthy S. Gudipati (JPL/Caltech)
With inputs from the Workshop Participants

A White Paper is in Preparation

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Workshop Format

Each topic will have three parts as pertinent: Observations, Modeling, and Laboratory Work

Surface Composition and Variability

- Current state of knowledge from spacecraft and ground-base
- Influx of exogenic material to Europa
- Radiation effects on surface composition

Active Exchange Processes

- Exchange between subsurface and surface
- Exchange between surface and exosphere
- Plumes and other potential regions of recent activity

Organizers

Institutional Support

Lunar and Planetary Institute
Universities Space Research Association

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To assess present status of our understanding of Europa's Chemical Composition.

To have community feed back on "Critical Laboratory Work" that is necessary for improving our understanding of Europa's Chemical Composition.

To encourage collaboration among observers, modelers, and laboratory researchers.

To work beyond "on-going or future mission needs".

To keep unbiased focused on Science, "mission-related talks were not invited".

Attendees: 58
Oral Presentations: 25
Poster Presentations: 13

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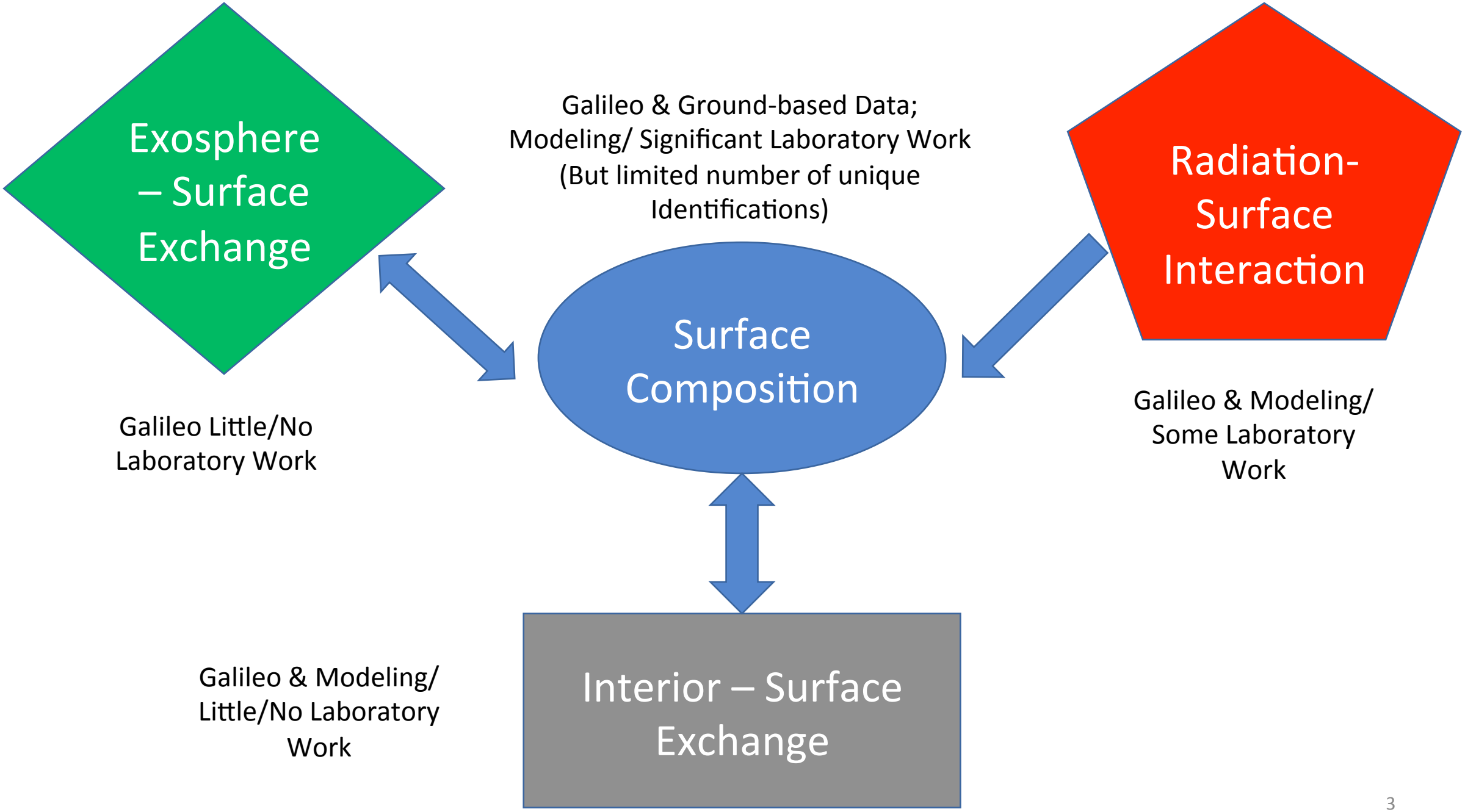

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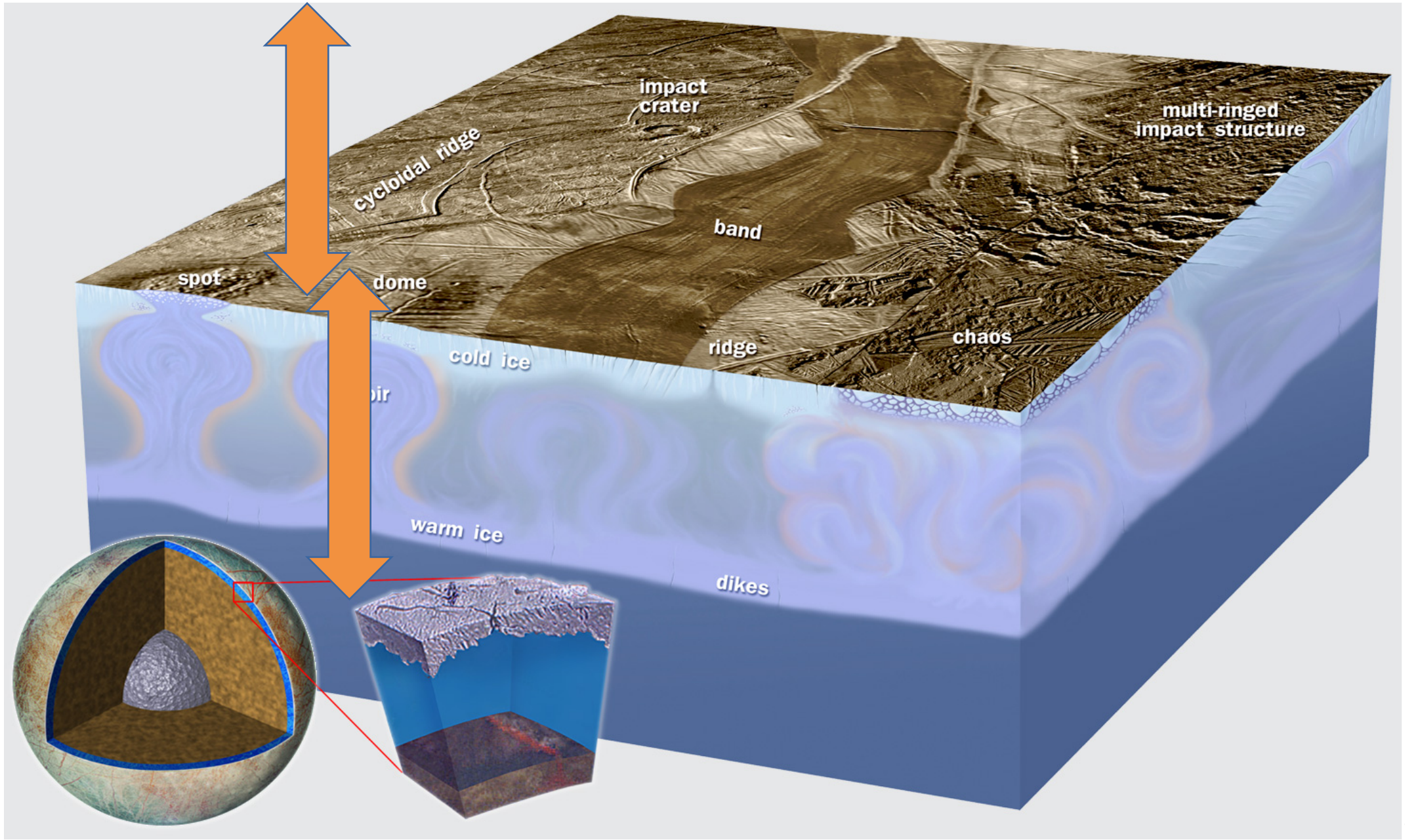
Europa Composition: Interior – Surface - Exosphere



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Europa Deep Dive 2 – Composition: Summary

Interior Composition

Mohit Melwani Daswani et al.,

1. **If Europa has been in its current Laplace resonance since accretion, a large amount of tidal energy (~10^3 kJ/kg) needs to go somewhere. This amount of energy is comparable to the latent heat required to vaporize and remove much or all of Europa's water.**
2. Tides caused by orbital evolution can change the composition of the ocean.
3. **Oxidants and organics useful for habitability can be supplied from tides melting the rocky interior, and water-rock interaction at the seafloor.**
4. We can make these predictions based on thermodynamics and orbital models, but we have poor constraints on all of these processes actually occurring because we lack direct observations. **(How about Lab Data??)**

Sam Howell et al.,

1. **How, where, and on what timescales do geologic processes enable ocean-surface and surface-ocean interaction?**
2. Is the ice shell interior compositionally homogeneous, or does it vary in non-ice components spatially and with depth?
3. Can remote sensing of non-ice materials constrain geologic mechanisms within the ice shell?

Laboratory Data: The relationships between non-ice incorporation, freezing rate, grain size, porosity, and time will all have significant impacts on the thermo-mechanical evolution of the ice shell.

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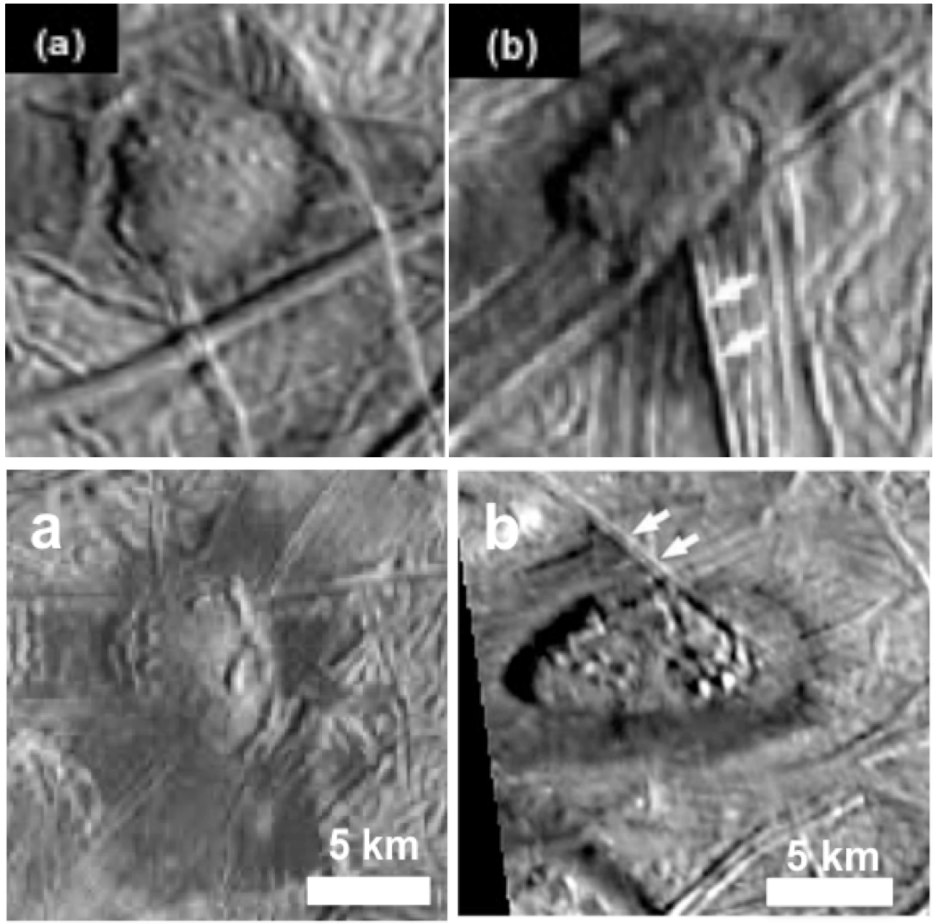
Europa Deep Dive 2 – Composition: Summary

Interior-Surface Active Exchange: Cryovolcanism

Lynnae Quick:

Are Low-Albedo Moats Signs of Surface-Subsurface Exchange on Europa?



For Cryovolcanism Modeling, we need:

- Experiments that show us how briny, aqueous solutions behave at the temperatures and pressures we find on Europa's surface. **We need experiments that will help us to understand the rheology of these fluids better.**
- We also need laboratory work that can help us better understand the **crystallization sequences or "cryo-petrology" of cryogenic solutions in Europa's interior.** These crystallization sequences will affect the composition of the fluids after they erupt onto the surface.

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Europa Deep Dive 2 – Composition: Summary

Interior – Surface Active Exchange (Plumes) & Habitability

Ngoc Truong et al.,

Key findings: All 14 proteinogenic amino acids considered decompose to a great extent (>99.9%) over relatively short lengths of time in hydrothermally active oceans. As a rule of thumb, we suggest that if amino acids are detected at Enceladus, Europa, or other hydrothermally active ocean worlds above a concentration of 1 nM, they should have been formed recently **(less than 1 Billion Years)** and not be relicts of early processes. **In particular, the detection of aspartic acid (Asp) and threonine (Thr) would strongly suggest active production within the ocean, as these amino acids cannot persist beyond 1 billion years even at the freezing point temperature of 273K.**

Recommendation: We should have more kinetics data for the decomposition of amino acids at different pH, oxidation state levels to asses fully details the evolution of amino acids in these ocean worlds.

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Europa Deep Dive 2 – Composition: Summary

Near-Surface Habitability: Biosystems vs. Biosignatures

Kumkum Ganguly et al.,

Preservation of potential biosignatures in the shallow subsurface of Europa: exploring a potentially habitable ocean world

Conclusion: We have produced survival curves for the bacteria at different exposure levels and isolated the DNA of the cells to perform Raman spectroscopy to detect the signatures. This will help us to build the training data sets for developing Organicam, an instrument similar to Chemcam by Los Alamos National Laboratory.

Discussion and key questions: Our preliminary analysis of the data showed that the organic materials could be identified by Raman spectroscopy. Major question was on form of life materials. (i) Will it be a single cell or mass of organic matters? **(ii) What would be the effect of extreme radiation and cold temperature on microbial life?** (iii) Will there be a cosmic drive to self-organize biomaterials?

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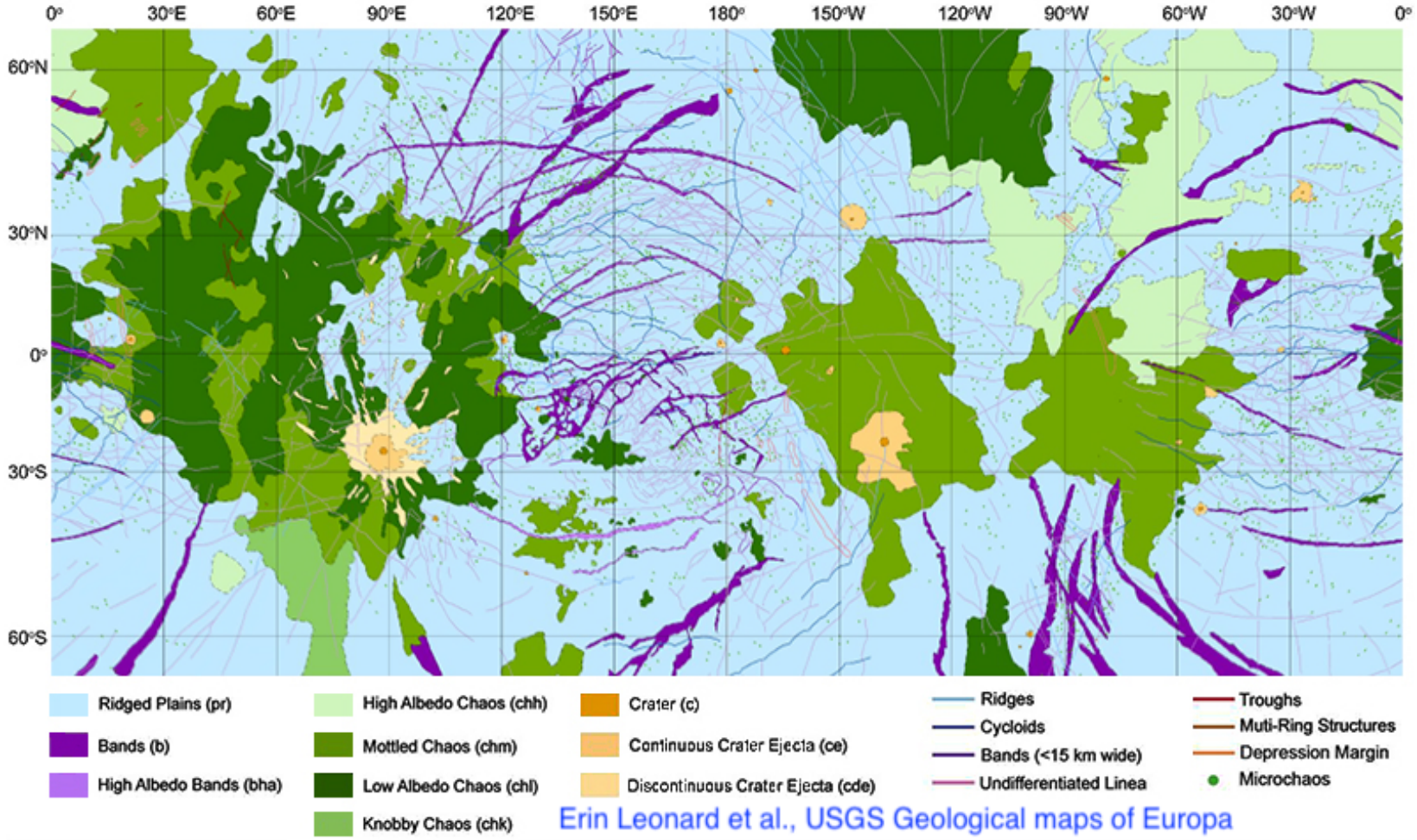
Europa Deep Dive 2 – Composition: Summary

Interior – Surface Exchange: Composition &Geology

Murthy Gudipati:

Europa's Surface Age:
Maximum of ~60 million years (from cratering geology);
Otherwise: Recent, Not-so-Recent, and Ancient

We need to better constrain the surface age w.r.t. surface geology/composition in order to better understanding **chemical composition through interior-surface exchange and radiation-processing**.



Erin Leonard et al., USGS Geological maps of Europa

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Europa Deep Dive 2 – Composition: Summary

Surface Physical Properties

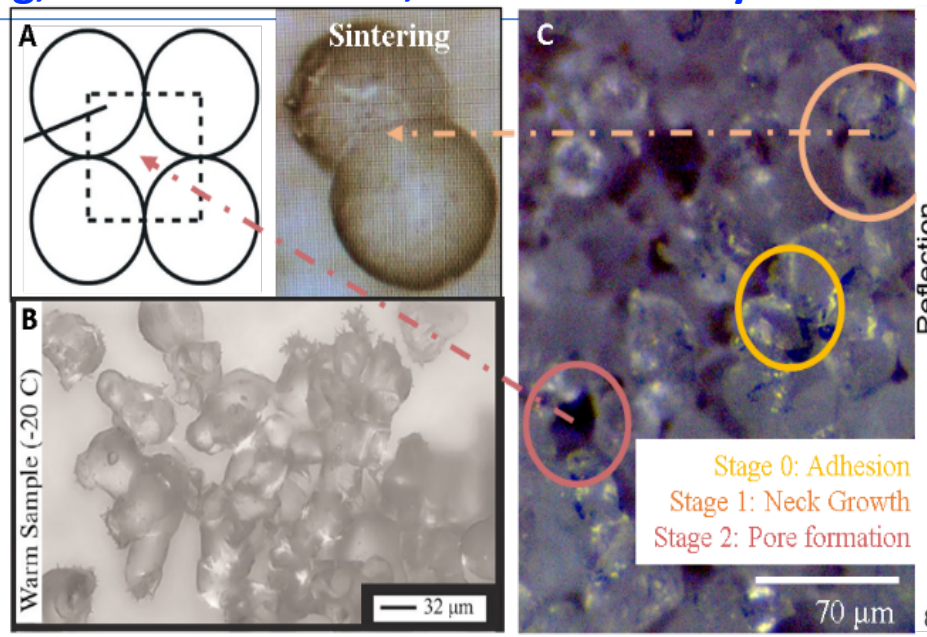
Vishaal Singh, Bryana Henderson, & Murthy Gudipati:

Microphysics could have information on Surface Geological Processes:

- Grain-size and sintering could provide direct information on the age of Europa's surface.
- Both effect on surface spectral depths and albedo.
- However, it is a model developed based on the principle of single scattering from a sphere/grain.
- We do not have grain-size dependent spectral data taken in the laboratory covering a wide range of grain-sizes.

Future laboratory work needs on physical properties of Europa's surface analogs include:

- **Grain-size; Sintering; Surface Hardness; Surface Porosity**



Modified from Molaro et al., 2017,2019

Singh et al., 2019 (*in prep*)

Singh et al., 2019 (*in prep*)

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Europa Deep Dive 2 – Composition: Summary

Surface Composition – VUV Spectroscopy

Tracy Becker et al., (Inputs from Roger Clark & Murthy Gudipati):

UV Spectroscopy and Non-Icy component of Europa

Non-ice surface material is very absorbing in the UV and obscuring the otherwise very strong and easily identifiable water ice absorption feature near 165 nm. Europa therefore has a very difference spectrum than Enceladus in the UV-Visible. **It appears that this 165 nm water-ice absorption feature is lacking on all hemispheres, including the leading hemisphere, whereas strong ice absorption features are clearly seen in the near-infrared (1 – 5 microns) on the leading hemisphere.**

This could be due to:

- The non-icy component of the surface?
- A thin layer of lag deposit from the irradiated non-icy component?
- Variations in relative grain size of the ice and non-ice material?
- Small amounts of nano-phase iron?

More laboratory studies at these UV wavelengths, especially with irradiated materials, would be very helpful. Correlated laboratory measurements in the UV and NIR spectral region can uniquely identify chemical and physical properties of Europa's surface materials.

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Europa Deep Dive 2 – Composition: Summary

Surface Chemical Composition

Thermal Chemistry & Linear Mixing of Spectra

Reggie Hudson; Bryana Henderson; Murthy Gudipati

Thermal Chemistry:
Effect of temperature from 70 K (in the polar regions) on the surface to ~300 K at the ice-ocean interface: **Thermally induced chemistry is important to understand long-term up- and down-welling of oxidants and other material exchange between liquid interior and surface.**

Limited Inventory and Linear Mixing Limitations:

- Most approaches have involved fitting of observed spectra to linear mixtures (or intimate mixtures) of species from spectral databases –typically obtained from non-irradiated samples, which are iterated until the spectra match relatively well and plausible combinations are achieved.
- **Linear mixing models can suffer when the amount of species in the spectral catalogs is small, but adding species to the catalog indiscriminately can lead to non-unique spectral fitting results.**
- **Linear mixing models can also go wrong when components interact chemically (such as H_2O and NH_3 mixed-ice)**
- **VUV to mid-IR laboratory spectra will be needed** to properly analyze future returned data from observations of Europa's surface. Fitting spectra with a wide spectral range improves the accuracy of the model results and the likelihood of obtaining unique matches.

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Europa Deep Dive 2 – Composition: Summary

Surface Chemical Composition

Since Galileo, Ground Based Studies helped significantly

Mike Brown
Samantha Trumbo
Kevin Hand
Bryana Henderson
Murthy Gudipati
Reggie Hudson
James Shirley
(Bradly Dalton)

Certain:
H_2O, H_2O_2, O_2, CO_2, H_2SO_4
Likely:
NaCl, ??
Tentative:
$MgSO_4$, Na_2SO_4, $NaHSO_4$, $MgCl_2$, Hydrocarbons.
Expected:
S-containing intermediates: H_2S, SO, SO_2, SOCl, etc. (from S^+ bombardment).
Need to Understand:
Exogenic (impacts) vs. Endogenic (upwelling) material and its radiation processing.
Puzzling Issues:

- **H_2O_2 laboratory data (low stability at higher temperatures) is in contradiction to observations – higher concentration at equatorial leading hemisphere than in higher latitudes with lower temperatures.**
- **The 450 nm absorption (attributed to pure NaCl color centers) is more prevalent in icy parts (leading) than non-icy parts (trailing) surface.**

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Europa Deep Dive 2 – Composition: Summary

Surface Composition - Laboratory Work Needed

Mike Brown
Samantha Trumbo
Kevin Hand
Bryana Henderson
Murthy Gudipati
Reggie Hudson
James Shirley
(Bradly Dalton)

Physical Parameters:
Grain-size, Sintering, Hardness, Porosity, & Thermal Conductivity.

Chemical Composition – An Inventory of Potential Material on Europa:
Salts (anions, cations), Salt hydrates, Sulfuric acid hydrates, Organics, and Exogenic Material Composition.

Chemical Evolution under Radiation:
Radiation Processing of fresh materials, sputtering/implantation by ions (H^+, O^+, S^+)

Multi-Wavelength Spectroscopy:
Chemical identification cannot be with a single absorption band in one wavelength, but need multiwavelength (VUV – UV – IR) spectroscopy as well as mass spectrometry in the laboratory - to enable better identification by spacecrafts/landers instruments.

Amorphous vs. Crystalline Ice on Europa:
How Temperature and Radiation on Europa could lead to amorphous frosting or amorphization of crystalline ice.

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Europa Deep Dive 2 – Composition: Summary

Europa's Radiation Environment

John Cooper:

- Europa radiation has multiple scales from the local magnetosphere to the atmosphere-ionosphere to the hemispheric megasurface of generally flat terrain to the regional surface and local microsurface with topographic features and smaller scale-texture.
- **The simplified models of electron interaction confirm the highest energy fluxes on the trailing hemisphere below 20 MeV and the lowest energy fluxes above 20 MeV on the leading side. But the magnetic field models have not yet included the distorted local environment of the magnetosphere-ionosphere interaction zone, for example the pileup of magnetic field on contact with the trailing ionosphere could significantly the simple leading-trailing anisotropy of surface energy flux.**
- Various groups are working on MHD and hybrid-kinetic models of the magnetosphere-ionosphere interactions **but not yet a realistic field and plasma interaction model that tracks energetic particle motions to the surface**.

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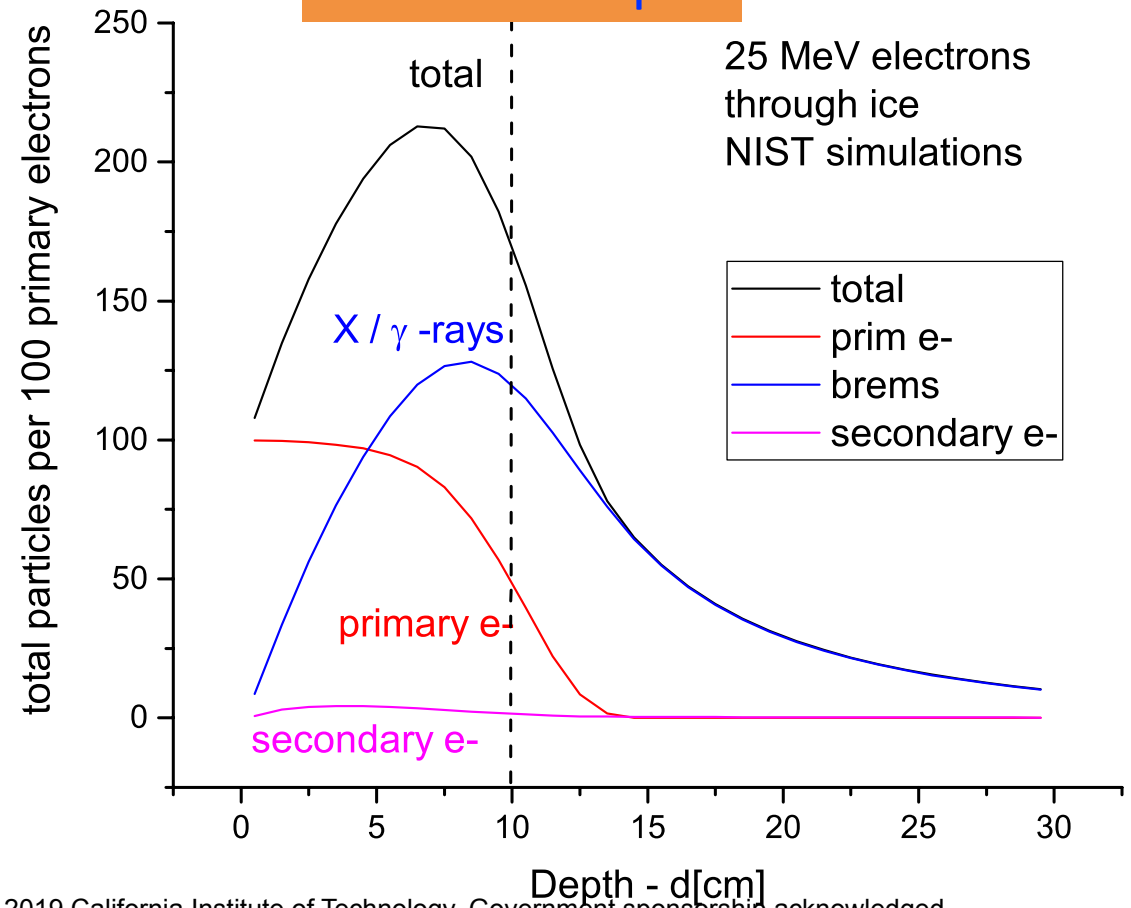
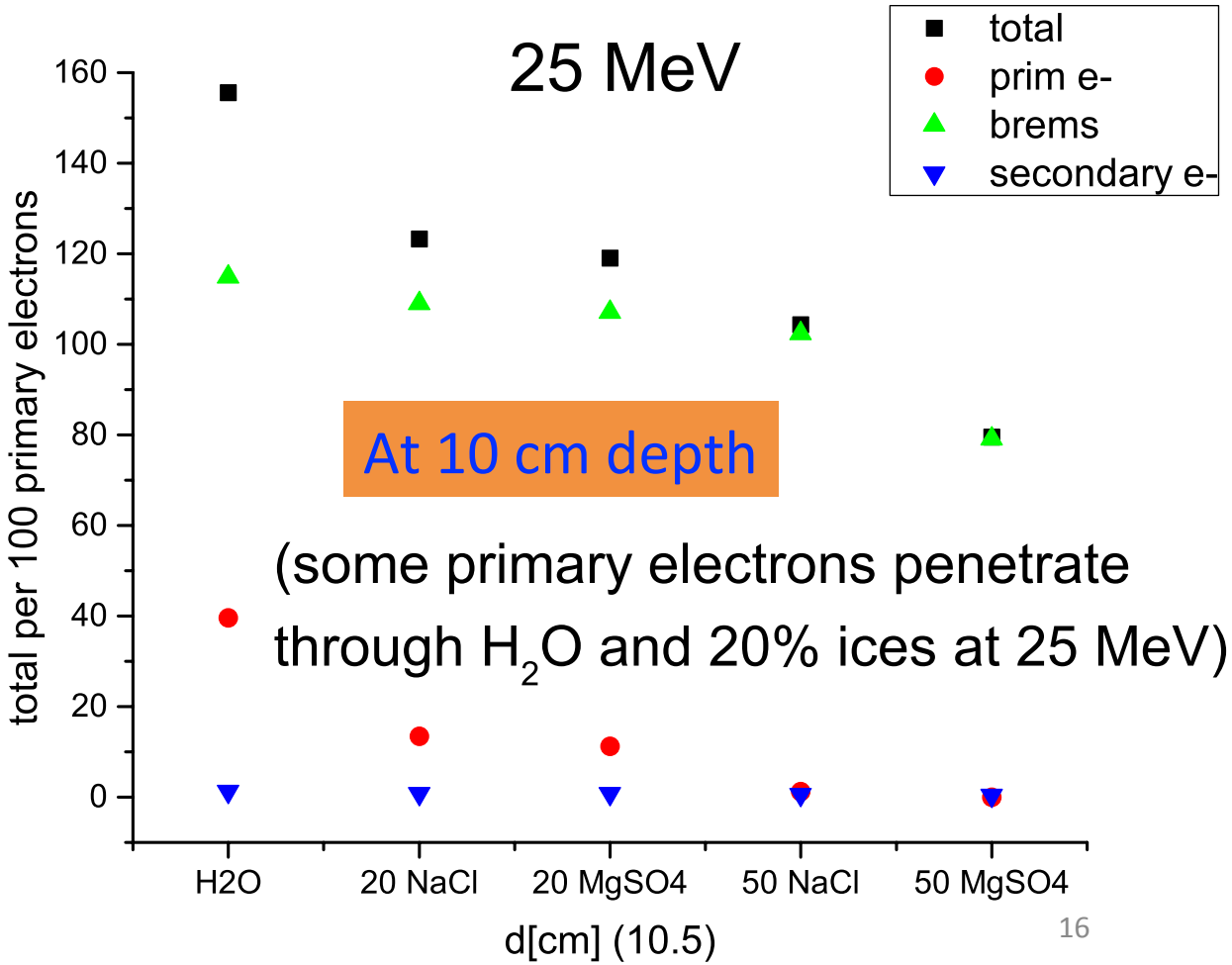
Europa Deep Dive 2 – Composition: Summary

Europa's Radiation Environment

Radiation vs. Surface Depth: NIST full Monte Carlo simulations (GAMOS/GEANT4) Gudipati, Henderson, Bateman (to be published)

At 10 cm depth





At 10 cm depth

(some primary electrons penetrate through H_2O and 20% ices at 25 MeV)

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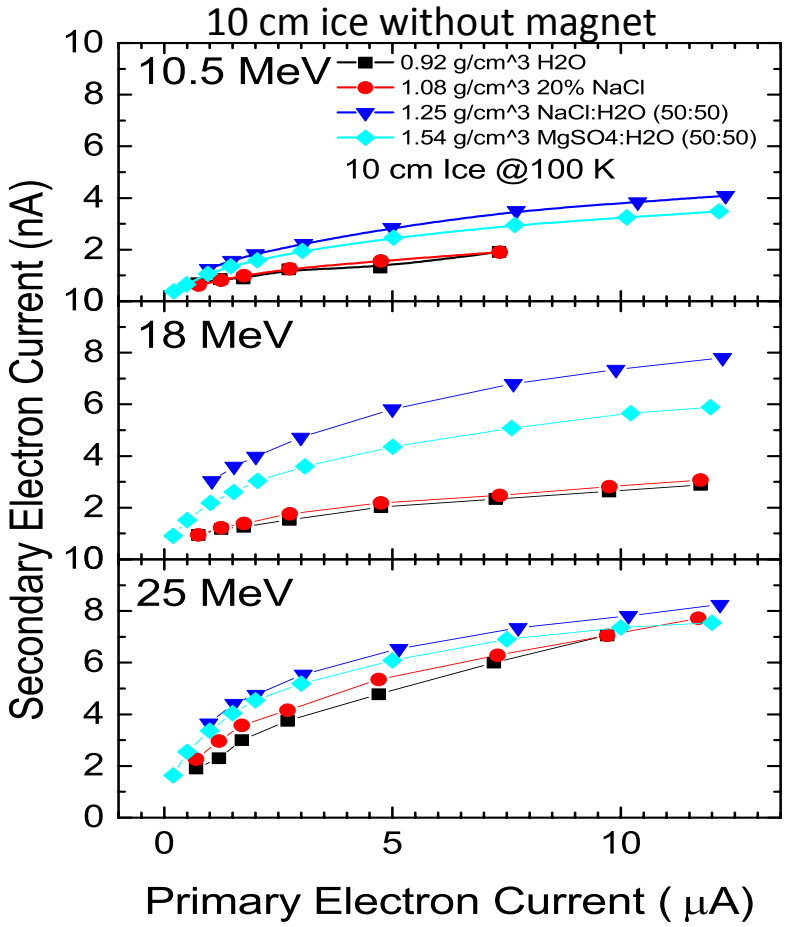
Europa Deep Dive 2 – Composition: Summary

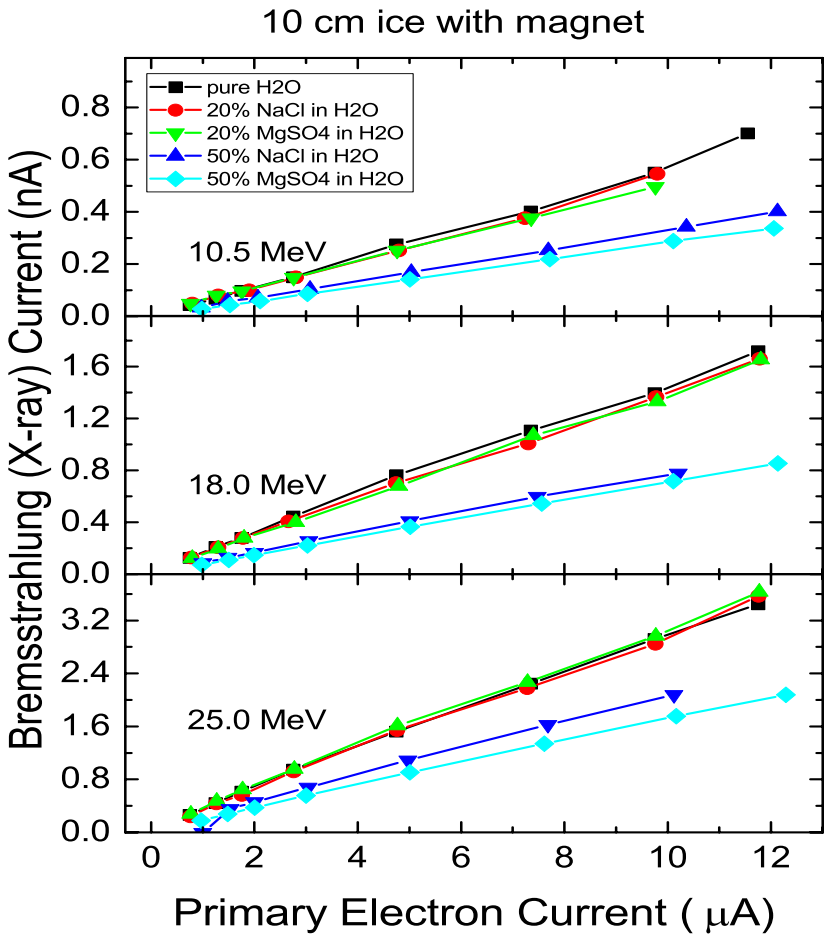
Europa's Radiation Environment

Radiation vs. Surface Depth: NIST MIRF Experiments with 10 cm thick ice
Gudipati, Henderson, Bateman (to be published)

Secondary Electrons + Photons



Photons (Bremsstrahlung) only



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Europa Deep Dive 2 – Composition: Summary

Europa's Radiation Environment: Modeling Uncertainties vs. Observations

Trailing Hemisphere maximum electron energy:
25 MeV or 20 MeV – what is the uncertainty?

GEOPHYSICAL RESEARCH LETTERS, VOL. 34, L15103, doi:10.1029/2007GL030834, 2007

Click Here for Full Article

Europa's near-surface radiation environment

C. Paranicas,[1] B. H. Mauk,[1] K. Khurana,[2] I. Jun,[3] H. Garrett,[3] N. Krupp,[4] and E. Roussos[4]

Received 29 May 2007; revised 27 June 2007; accepted 11 July 2007; published 4 August 2007.

motion. Electrons drift opposite to corotation and therefore move slower than the cold plasma. Above about 25 MeV, the electron gradient-curvature drift becomes about equal and opposite to the rigid corotation speed of plasma at Europa. This means that the guiding center field lines of all charged particles except >25 MeV electrons sweep past Europa from its trailing hemisphere to its leading hemisphere and for >25 MeV electrons, the electrons sweep over Europa from its leading to its trailing hemisphere.

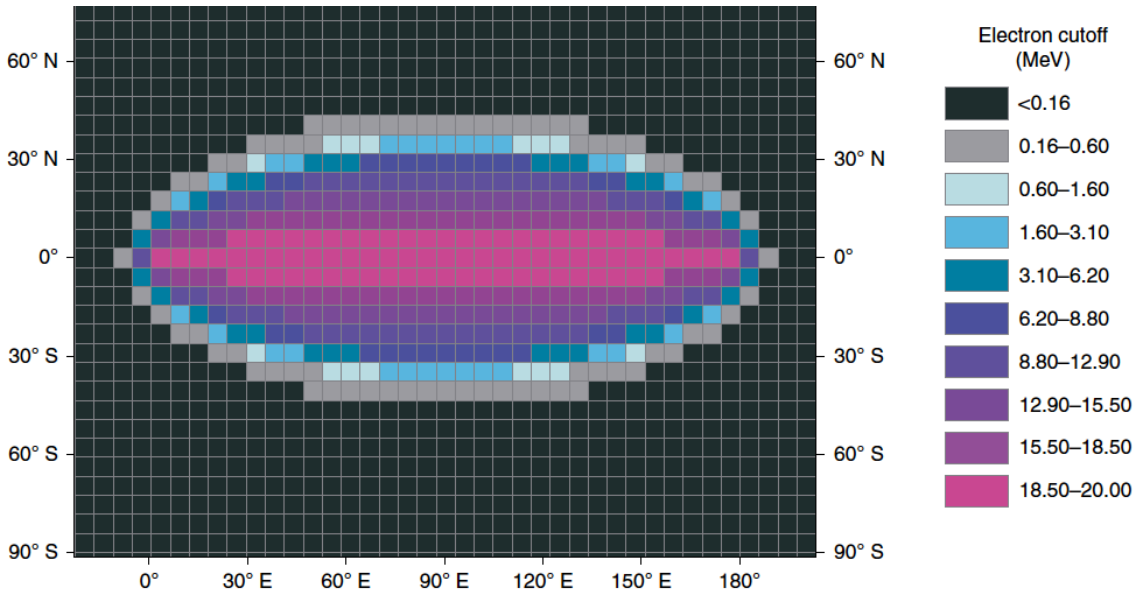
nature astronomy

ARTICLES

https://doi.org/10.1038/s41550-018-0499-8

Preservation of potential biosignatures in the shallow subsurface of Europa

T. A. Nordheim[1]*, K. P. Hand[1] and C. Paranicas[2]



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Europa Deep Dive 2 – Composition: Summary

Europa's Radiation Environment

Tom Nordheim
John Cooper
Murthy Gudipati
Bryana Henderson
Karl Hibbitts
Reggie Hudson
Robert Johnson
Ujjwal Raut
Abi Rymer
Benjamin Teolis

- Still some open questions regarding the Jovian radiation environment
- For example, we do not have direct measurements of the very high energy end of the energetic electron population (about >40 MeV). This could affect surface dose estimates, particularly on the leading hemisphere.
- **Need better constraints on maximum energy of electron reaching trailing hemisphere (25 MeV or 20 MeV with error margins).**
- Need a better understanding of variability in Europa's radiation environment over both short (throughout an orbit) and long (over geological timescales).
- Need better understanding of spatial and energy distribution of charged particles close to Europa's surface (e.g. within one O_2 scale height).

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Europa Deep Dive 2 – Composition: Summary

Europa's Radiation Environment

Modelling

- Models need to include more realistic local electromagnetic fields that take into account both Europa's ionosphere and ocean-induced field, as well as ion pick-up and the possible presence of plumes.
- Modeling efforts to examine the effect of different surface compositions (e.g. salts, H_2SO_4) and structures (e. g. amorphous vs crystalline ice, porosity) on charged particle interactions.
- Need to better understand the effect of local surface topography and roughness on charged particle flux and received radiation dose.

Lab work

- Investigate the effects of radiation on surface and near-surface composition and structure over a wide spectral range (FUV to mid-IR). Extend to multi-component ices, salt and acid hydrates and organics.
- Investigate effect of grain-size, porosity, sintering, and radiation-processing on FUV to IR (0.1 – 20 microns) spectral properties of Europa surface analogs.
- Investigate sputtering of single components and mixtures (e.g. $H_2O + CO_2$), salts and acid hydrates to constrain inputs to exospheric models. Characterize the surface-exosphere connection at Europa.
- Investigate radiation stability and sputtering of potential biosignatures.
- Further investigation of secondary particle (e.g. bremsstrahlung and secondary electron) characteristics of candidate Europa surface analog materials.

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Europa Deep Dive 2 – Composition: Summary

Europa's Exosphere – Surface Interaction

Bob Johnson

O_2 near-surface (exosphere) number density does not directly correlate with plasma (radiation) flux/energy, indicating other parameters such as surface temperature and porosity playing a significant role that alters otherwise expected direct correlation. **Is it likely that the O_2 seen in the gas phase is dominated by thermal desorption from the regolith?**

Murthy Gudipati

We need more laboratory work – working closely with modelers to better understand the exchange between surface and exosphere

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Europa Deep Dive 2 – Composition: Summary

Europa's Exosphere – Surface Interaction

Zachary E. Ulibarri et al., (Edited by Murthy Gudipati) – Hypervelocity Dust Impact Experiments

- Long-term chemical evolution of many airless icy bodies is affected by hypervelocity micrometeoroid bombardment
- **There has been little experimental investigation into these impact phenomena, especially at the impact speeds seen on airless icy bodies or in fly-by spacecraft.**
- Using the cryogenic ice target at the NASA SSERVI Institute for Modeling Plasma, Atmospheres, and Cosmic Dust (IMPACT) dust accelerator, these types of dust impacts have been studied in a controlled environment under highly realistic conditions. Dust particles of up to a micron in size are impacted at velocities of 3-50 km/s onto ice surfaces. The plume of ejecta particles, and ions within this plume are accelerated towards a Time of Flight (TOF) mass spectrometer.

  Experiments have shown that lysine, histidine, and the di-peptide amino acid chain lysine-glycine that were doped into the ice survive the impact process and are measured by the TOF.
- **Experiments were performed by doping water ice with CO_2. Observations of CO_2H were made from impacts above 3.5 km/s. However, in high velocity (>15 km/s) spectra, CO, elemental C, and an unknown mass line at 32 were also observed, which could be either O_2 or methanol (CH_3OH). If the line is indeed methanol, this would show that dust-impact-induced organic chemistry can be an important pathway for the chemical evolution of airless icy surfaces.**
- Future experiments will gradually step up complexity to determine which, if any, prebiotic molecules can be synthesized through dust impact. In the event of detecting such organics in plumes/dust on Europa, it is important to understand whether they represent surface composition or made during the impact process.

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Europa Deep Dive 2 – Composition: Summary

Europa's Exosphere – Icy Dust Impacts

Zoltan Sternovsky et al., (edited by Murthy Gudipati):

- Europa's (and other Icy Worlds') composition can be assesses through particulates in the exosphere (or potentially plumes)
- These particulates are ejected to flyby altitudes by the continual micrometeoroid bombardment and characterized by Galileo for Europa
- The capabilities of a dust impact ionization mass spectrometer were demonstrated by Cassini's Cosmic Dust Analyzer
- Today we have much more capable instruments to take more sensitive measurements with much higher mass resolution
- Currently there is limited capabilities for simulating the impact ionization process in the laboratory. These include:
  - Laser dispersion mass spectrometry using water microbeams (Frie University, Berlin)
  - Laser distortion mass spectrometry using icy surfaces (JPL)
  - Dust impact generated mass spectrum from icy surfaces (CU Boulder)
- **There is a need for icy dust accelerators to simulate realistic analog experiments of exosphere icy-dust impact on spacecraft-born instruments**
- **The thorough understanding of the icy dust impact ionization process would allow direct determination of the organic and inorganic compounds embedded in exospheric ice particles, which would inform usabout the Europa's geochemical conditions and habitability.**

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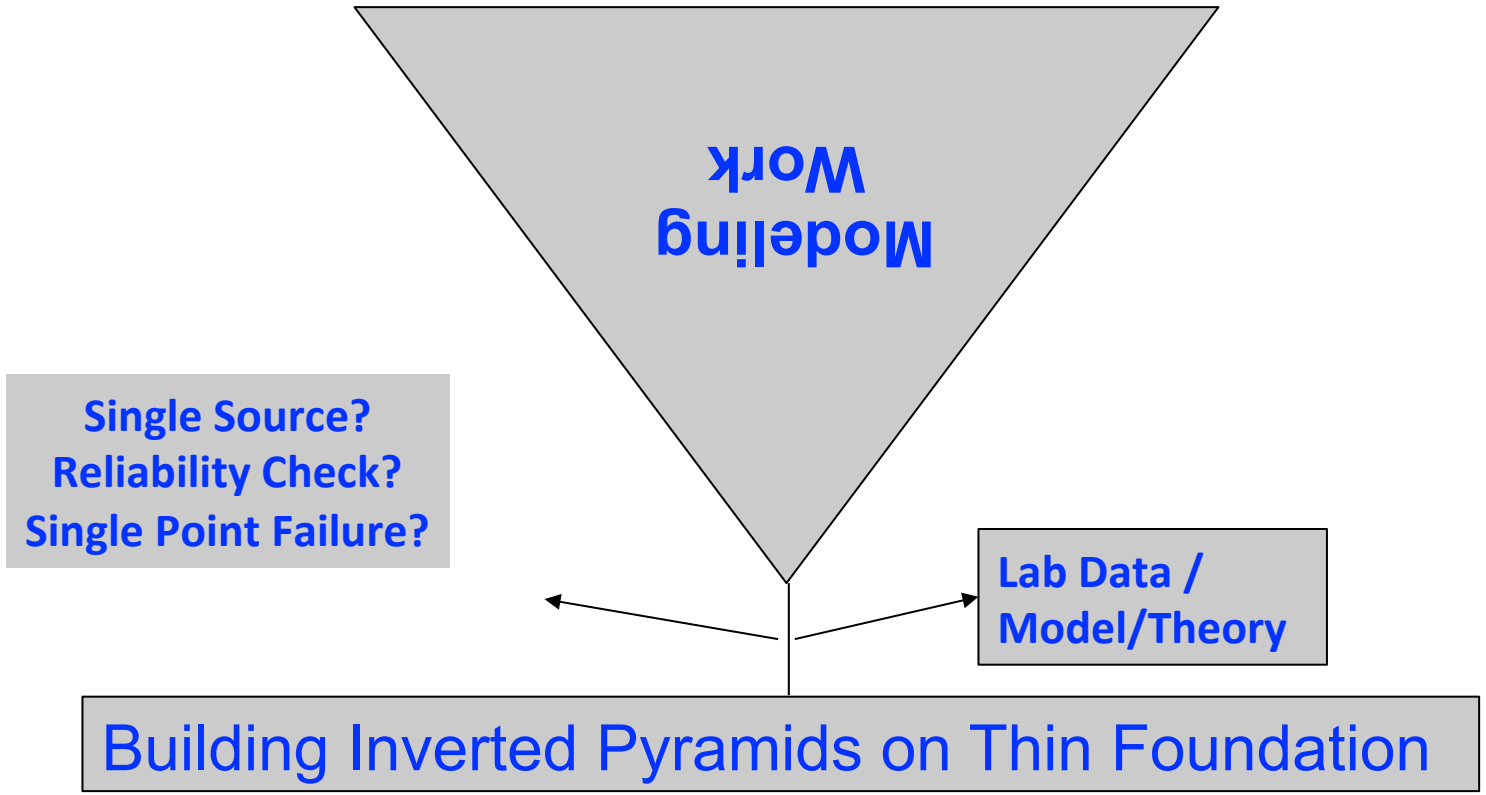
Europa Deep Dive 2 – Composition: Summary

Single Point – Inverted Pyramid of Models

Murthy Gudipati:

- How Reliable is the Lab or Modeling Work Data?
- What are the Errors?
- Is this a Single Source or Multiple Independent Publications?
- Is the original publication based on “modeling only” or has accurate lab data?
- How reliable are your parameters?



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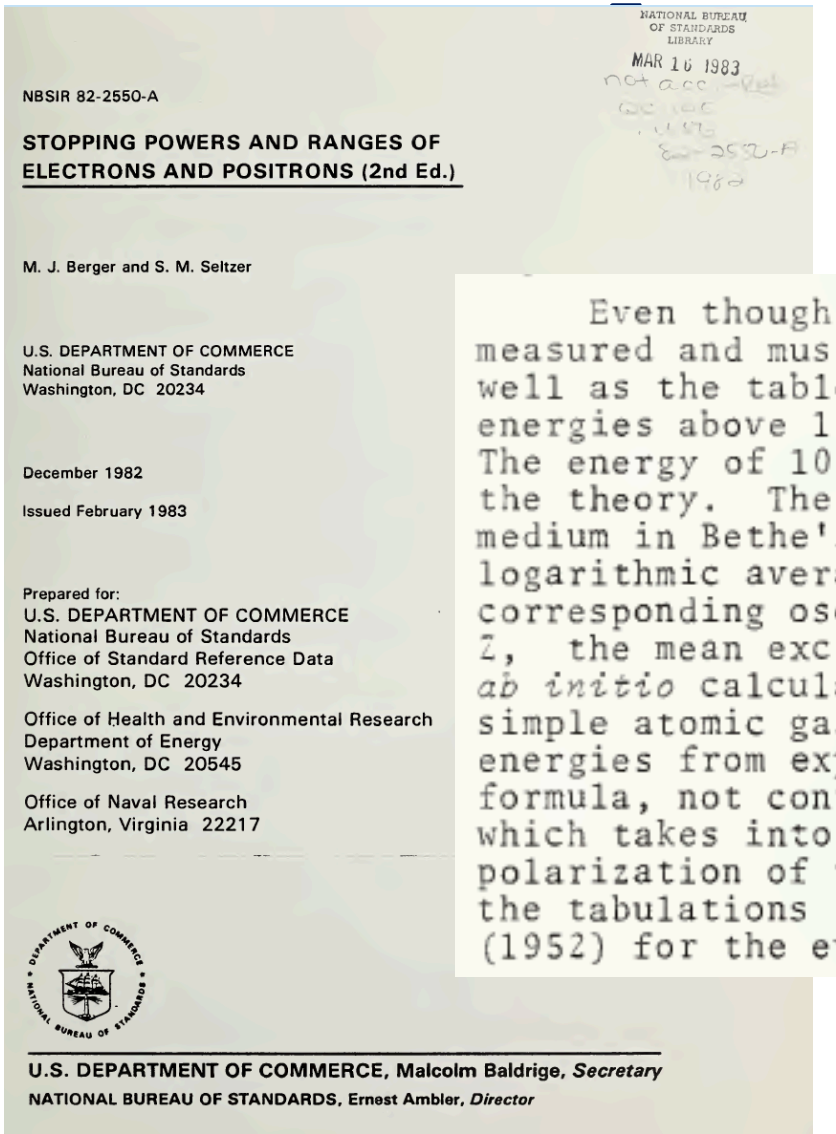
Europa Deep Dive 2 – Composition: Summary

Murthy Gudipati:

Modeling ONLY – Accepted as

Electron Stopping through Materials



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STOPPING POWERS AND RANGES OF ELECTRONS AND POSITRONS (2nd Ed.)

M. J. Berger and S. M. Seltzer

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
Washington, DC 20234

December 1982

Issued February 1983

Prepared for:
U.S. DEPARTMENT OF COMMERCE
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Office of Standard Reference Data
Washington, DC 20234

Office of Health and Environmental Research
Department of Energy
Washington, DC 20545

Office of Naval Research
Arlington, Virginia 22217

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Even though electron stopping powers and ranges are widely used, they are rarely measured and must be obtained from stopping-power theory. All previous tables as well as the tables in this report contain collision stopping powers for electrons at energies above 10 keV evaluated according to the theory of Bethe (1930, 1932, 1933). The energy of 10 keV is a commonly accepted lower limit for the applicability of the theory. The principal non-trivial quantity describing the properties of the medium in Bethe's stopping-power formula is the mean excitation energy, which is a logarithmic average of the excitation energies of the medium weighted by the corresponding oscillator strengths. Except for elements with very low atomic number Z, the mean excitation energies in eV are approximately equal to $10 \cdot Z$. Accurate *ab initio* calculations of mean excitation energies are possible at present only for simple atomic gases. For most materials it is necessary to determine mean excitation energies from experimental data. Another important quantity in the stopping-power formula, not contained in Bethe's original theory, is the density-effect correction, which takes into account the reduction of the collision stopping power due to the polarization of the medium by relativistic charged particles (Fermi, 1940). All of the tabulations including the present one have relied on the method of Sternheimer (1952) for the evaluation of the density-effect correction.

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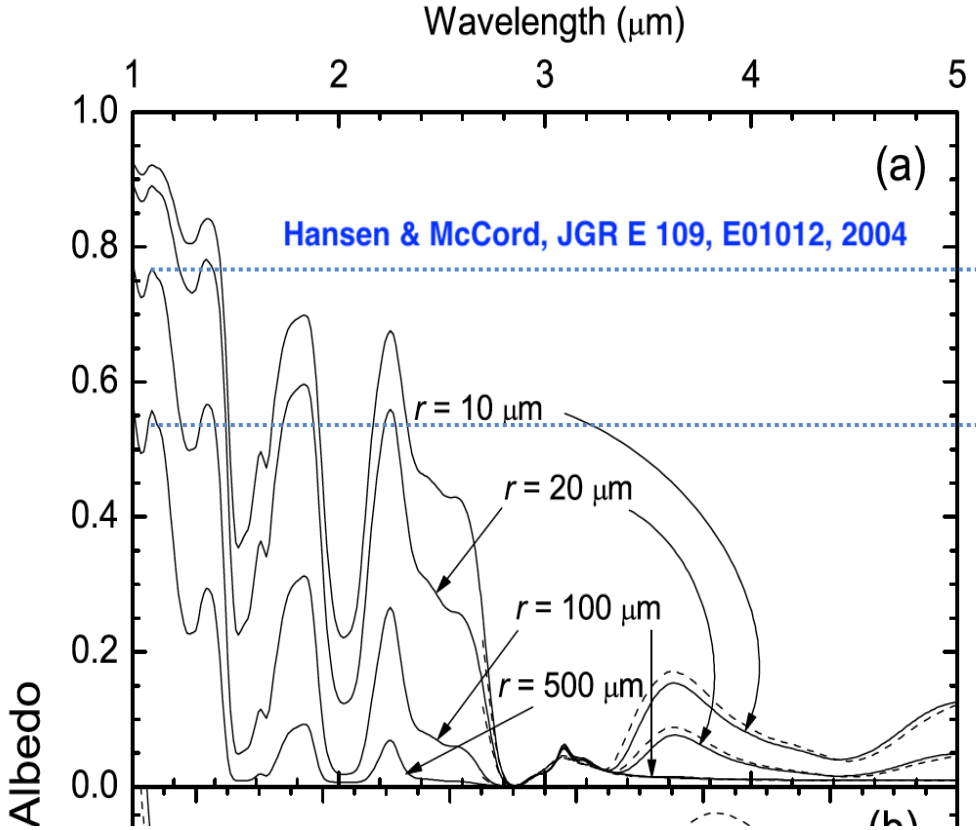
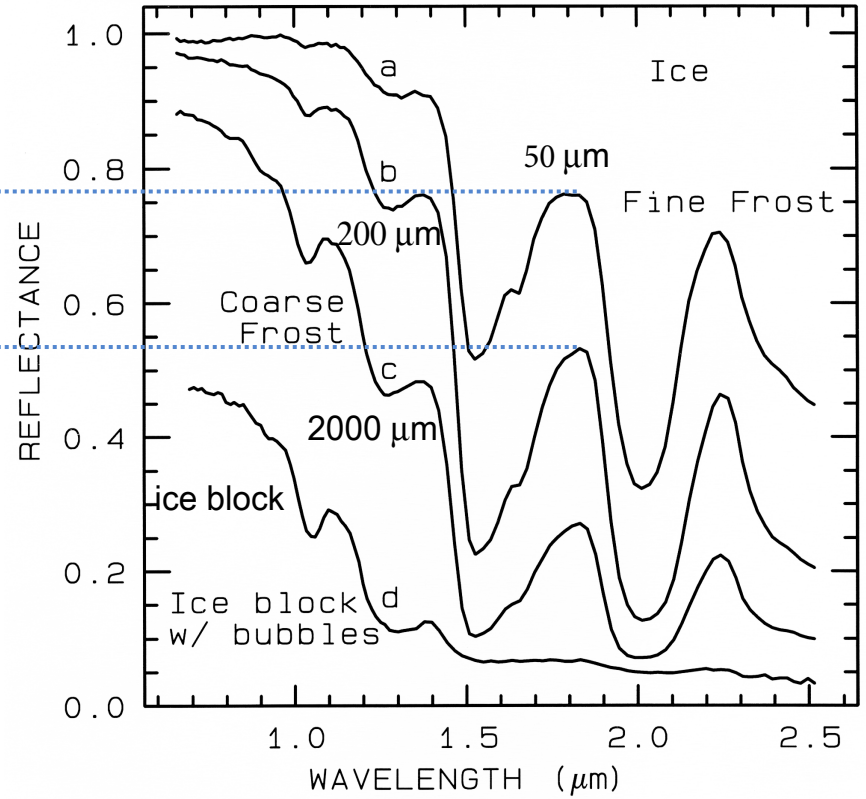
Europa Deep Dive 2 – Composition: Summary

Modeling ONLY – Accepted as

Grain-Size Dependent Spectral Albedo: Qualitative but not Quantitative





Only a few Laboratory Spectra are available for grain-size dependent spectral albedo.

We need:

1) **Quantitative Models**
2) **Grain-size dependent laboratory data at various temperatures**
3) **Phase-angle dependence**
4) **Effect of sintering/annealing on spectra**
5) **Effect of Composition**
6) **Effect of Radiation**

Modeling

Experimental: Roger Clark USGS

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Conclusions – I

- There is a difference between "**qualitative**" data vs. "**quantitative**" data.
- **As of Now, for Europa's chemical composition, the data is qualitative.**
- Key Science Questions and Goals such as "Detection of Life" or "Habitability" are tough to be answered with qualitative data on hand.
- Quantitative data needs to be confirmed by multiple independent works – to avoid single-source error and single-point failure.
- **Laboratory experimental work needs 3-5 years of incubation before getting the science results.**

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Conclusions – II

- **Like the ROSES DAPs, we need LEAP (Laboratory Experimental-Data Acquisition Program) to start with any new selection of a mission (Discovery, New-Frontier or Flagship) in order to be ready when missions need laboratory data for analysis or assessment.**
- **Each of my previous slides have highlighted details of laboratory data critical for modeling and spectral analysis.**

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Thank you!

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Note:
The Presentation is NOT YET Cleared by JPL for Public Release

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Critical Laboratory Data – For Europa

1. Material transport through ICE
2. Cryovolcanism & Other Active Processes.
3. Surface Spectroscopy – VUV - IR (0.1 - 20 microns)
4. Surface Composition – Geology Correlations.
5. Radiation Models – Wetted (or give the error margins of present models)
6. Radiation Penetration & Processing – Physical and Chemical Properties of Top Meters.
7. Exosphere – Exogenic vs. Endogenic

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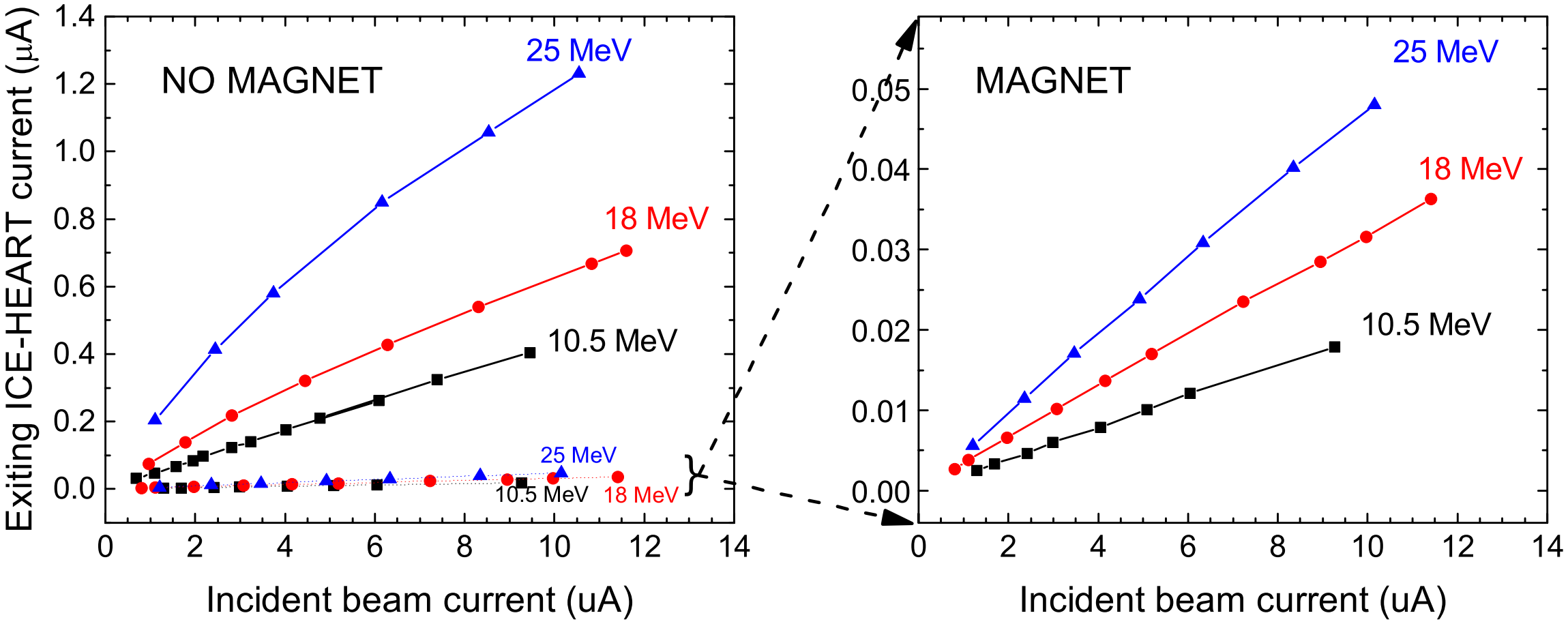
12% of incident arrive at the detector

0.5% of incident arrive at the detector



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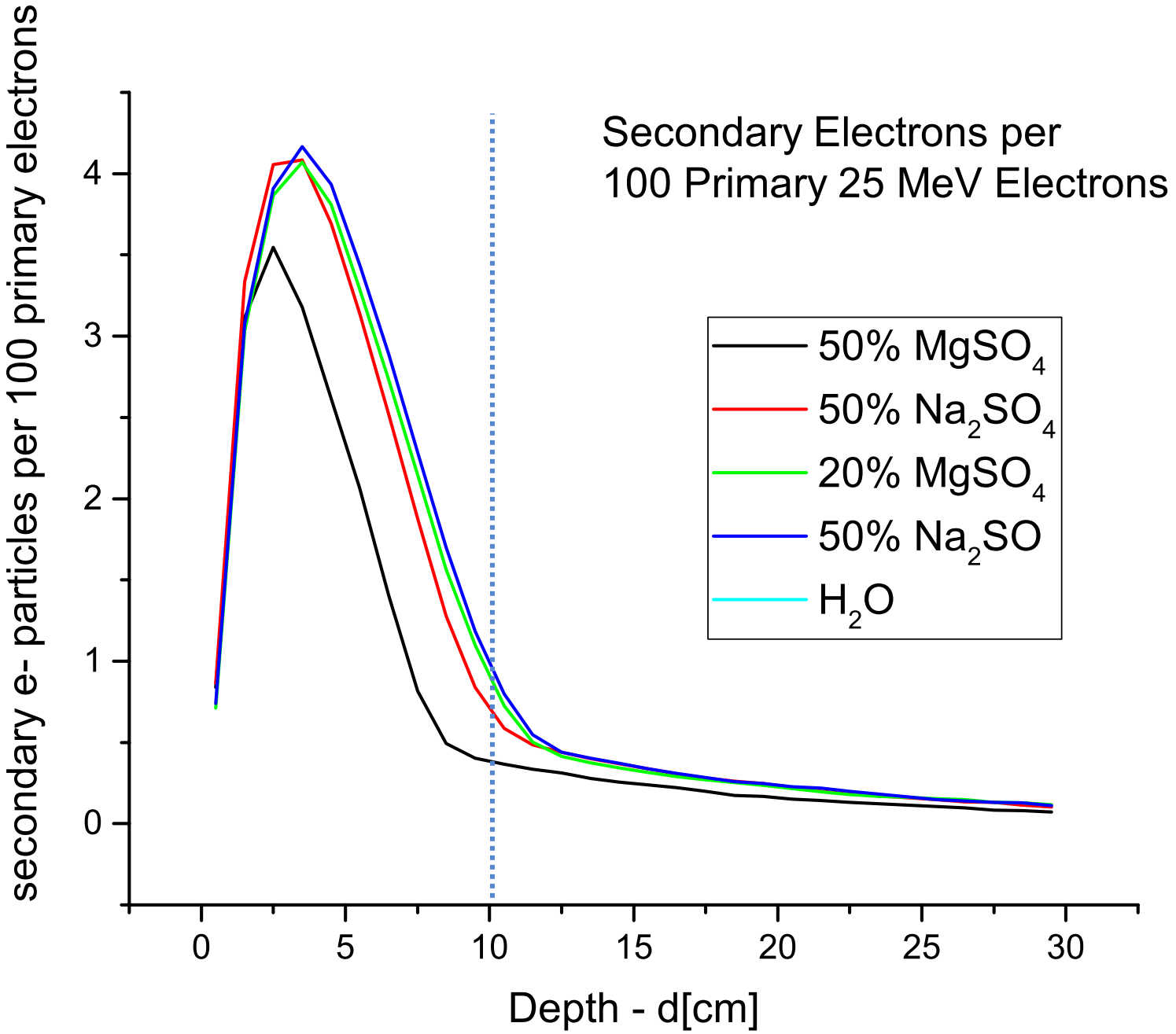

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