The Surface Composition of Europa: Implications for Landed Missions

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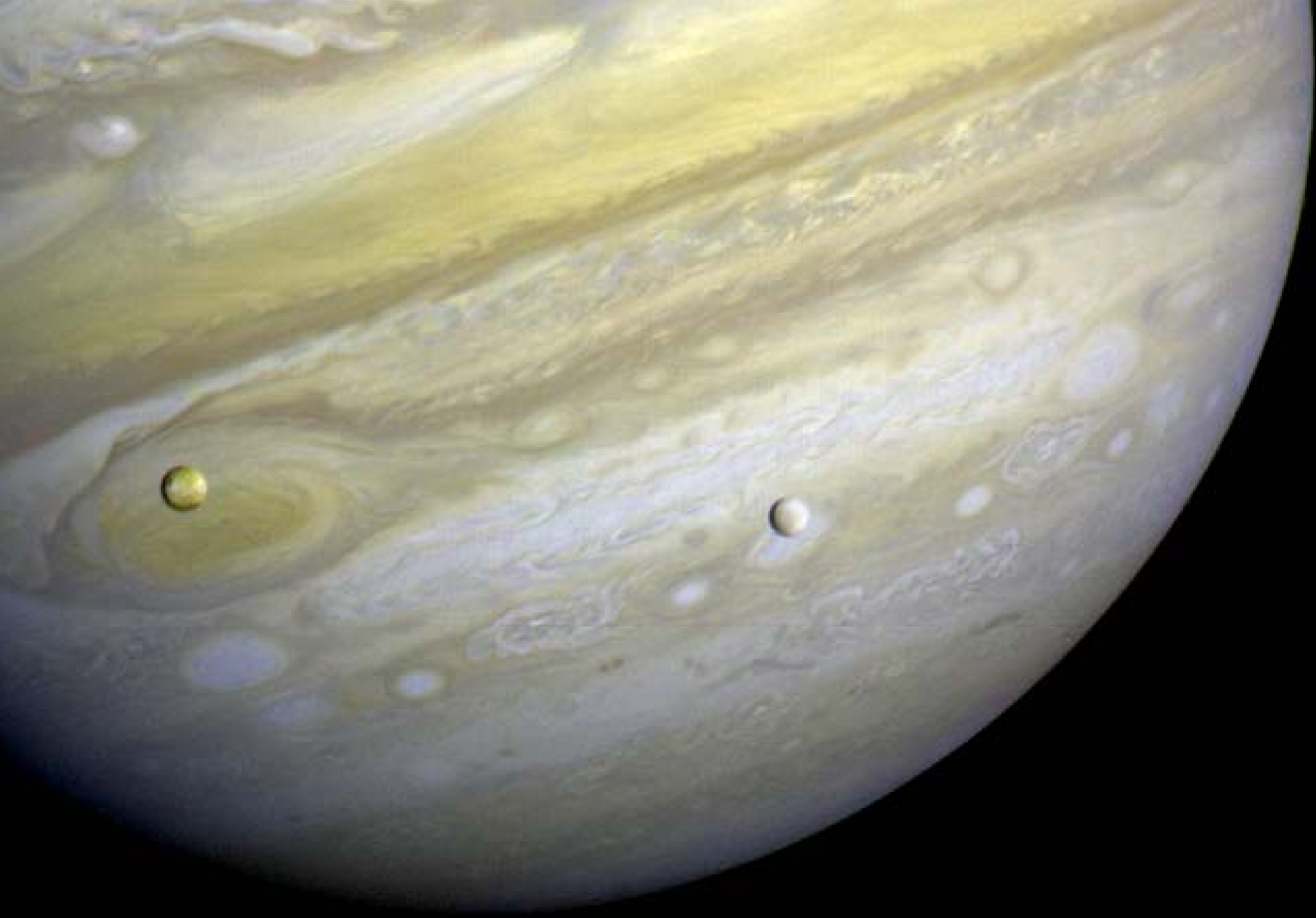
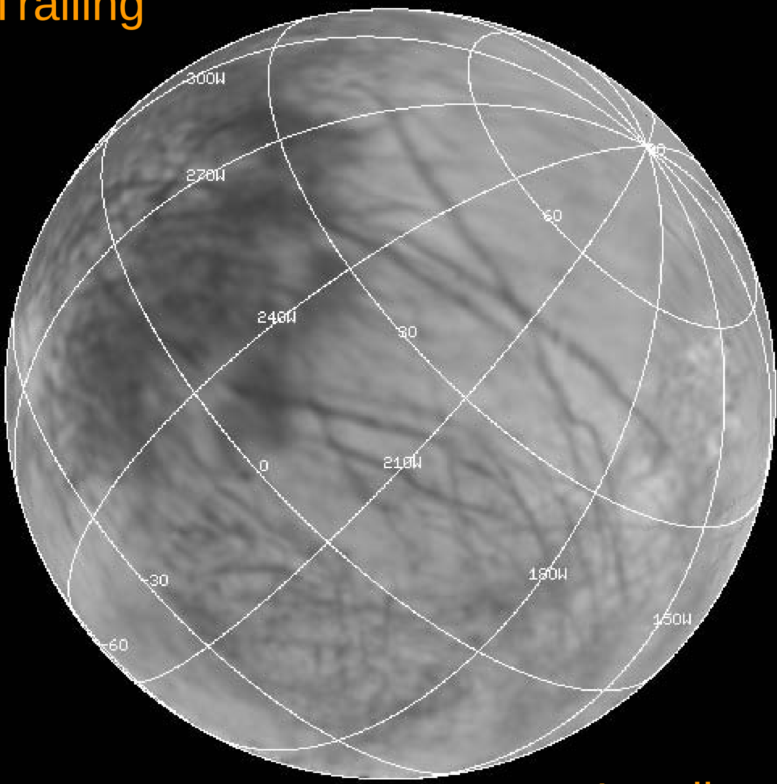
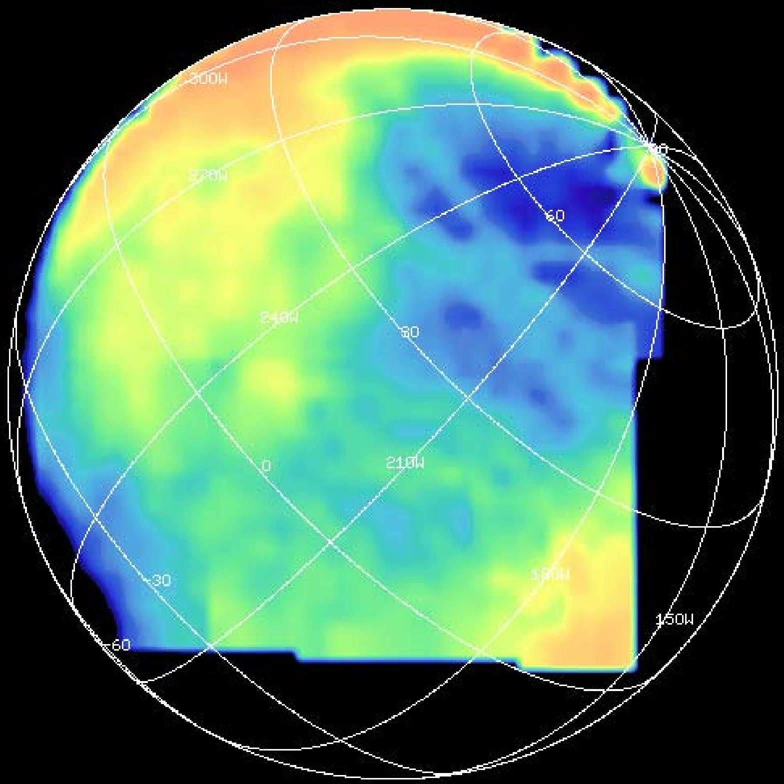


Remote Sensing from Galileo NIMS

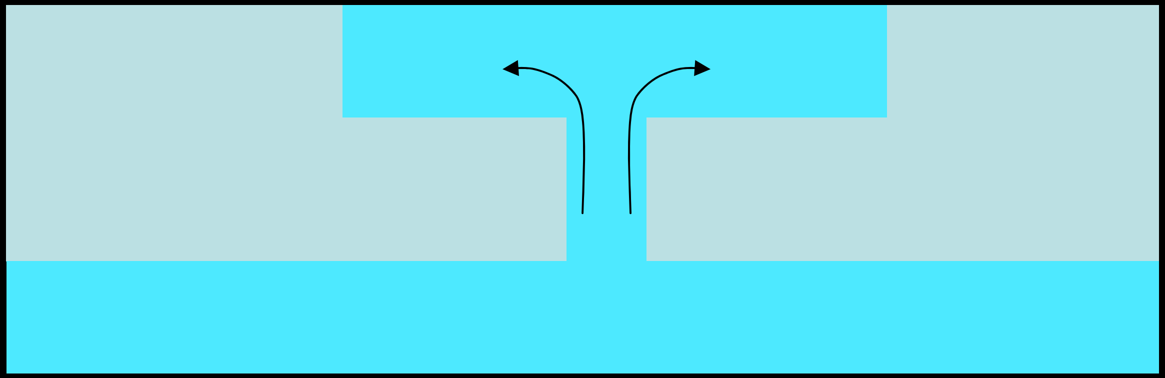
Trailing



Leading



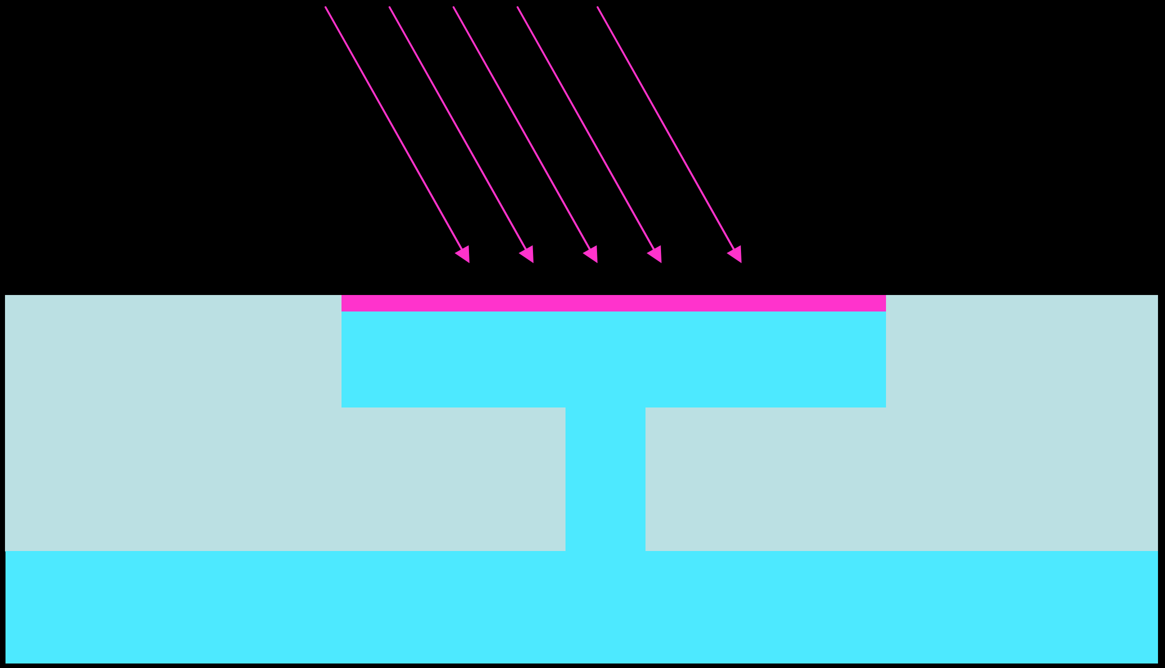
Surface Modification Processes



1. Emplacement

Endogenic material placed at the surface by geologic processes

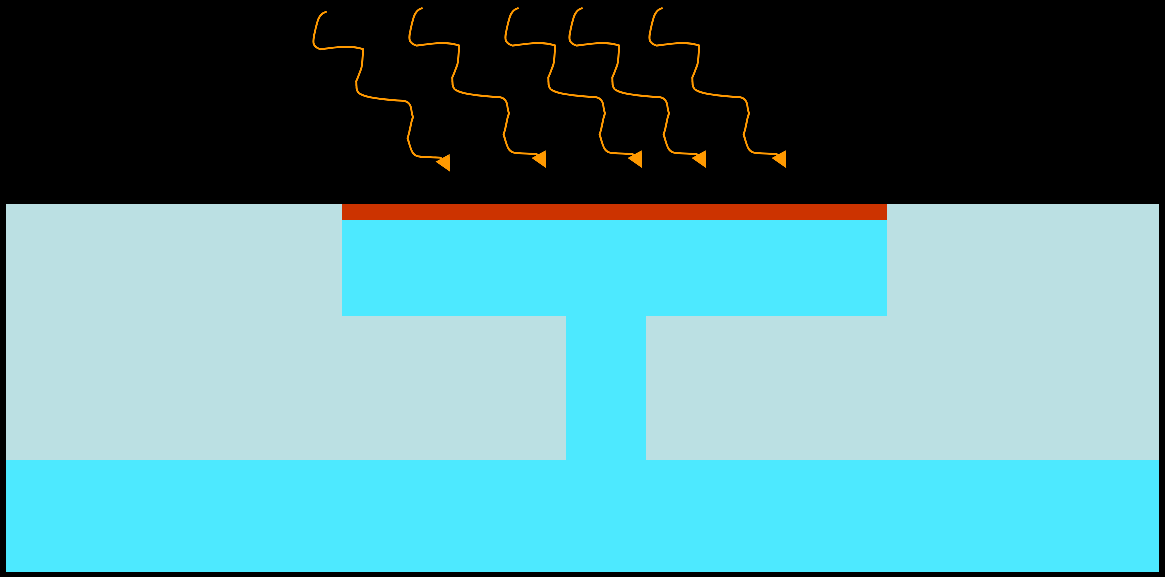
Surface Modification Processes



2. Implantation

Ions (H, Na, K, Cl, S, O… Mg?) implanted into the surface ice

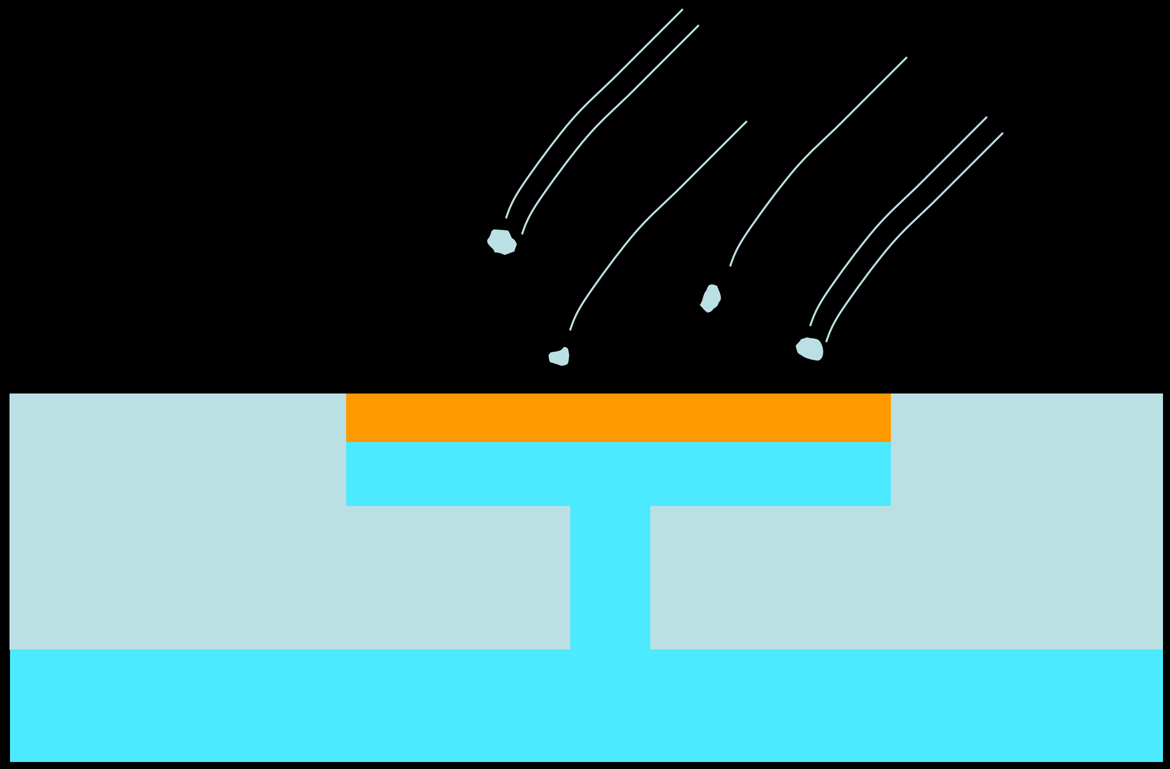
Surface Modification Processes



3. Radiolysis and photolysis

Radiation-driven chemistry alters surface composition

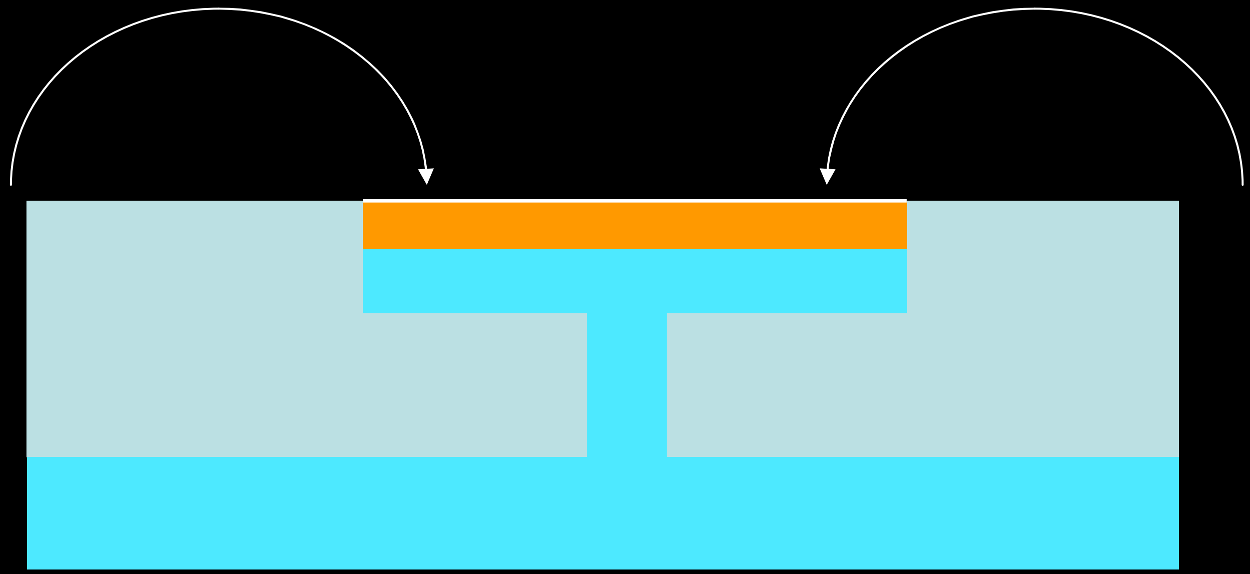
Surface Modification Processes



4. Impact Gardening

Micrometeoritic bombardment mixes the upper ~1-2 m

Surface Modification Processes

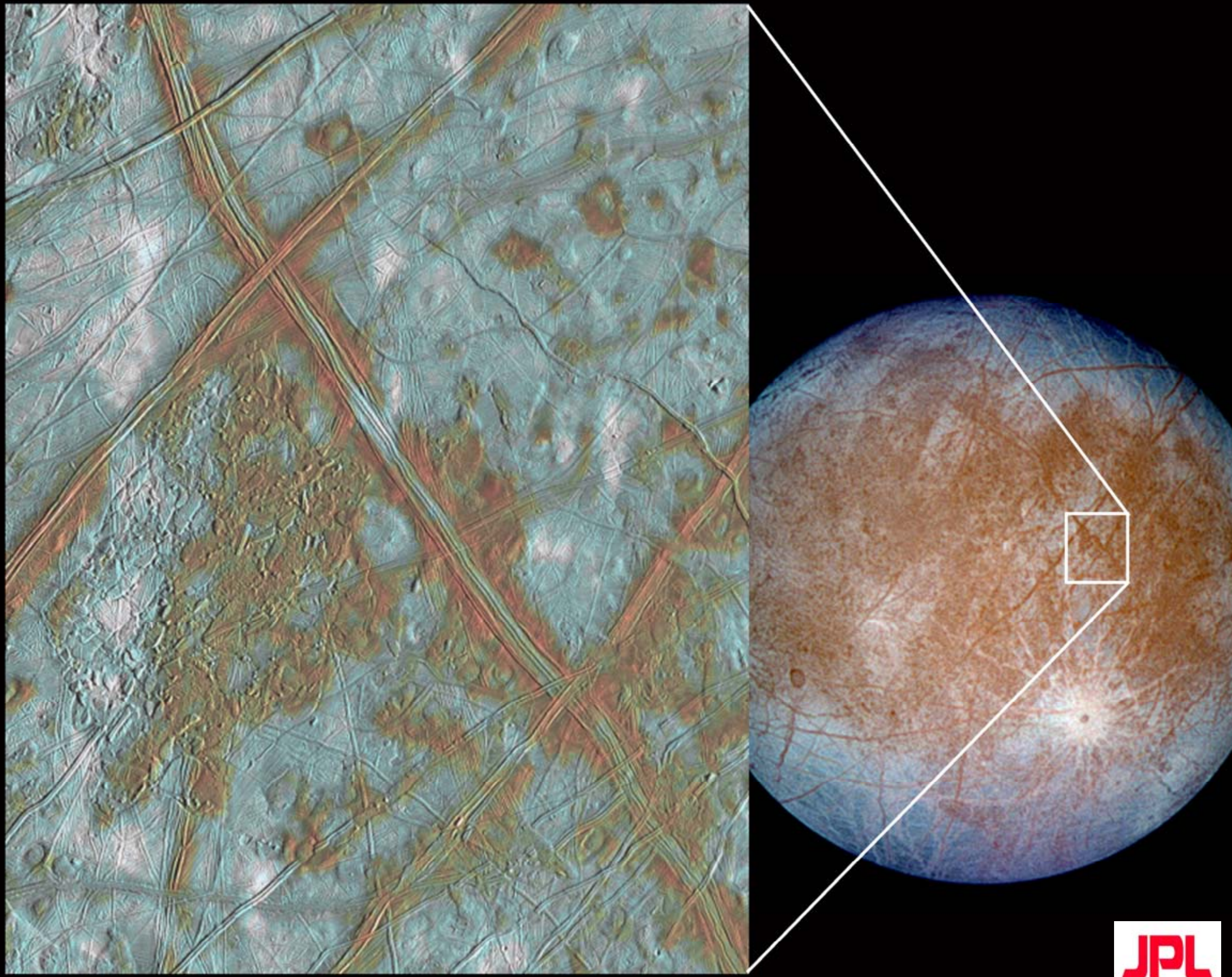


5. Frost (re-)Deposition

Linea brighten over time as water ice is vapor-deposited on surface

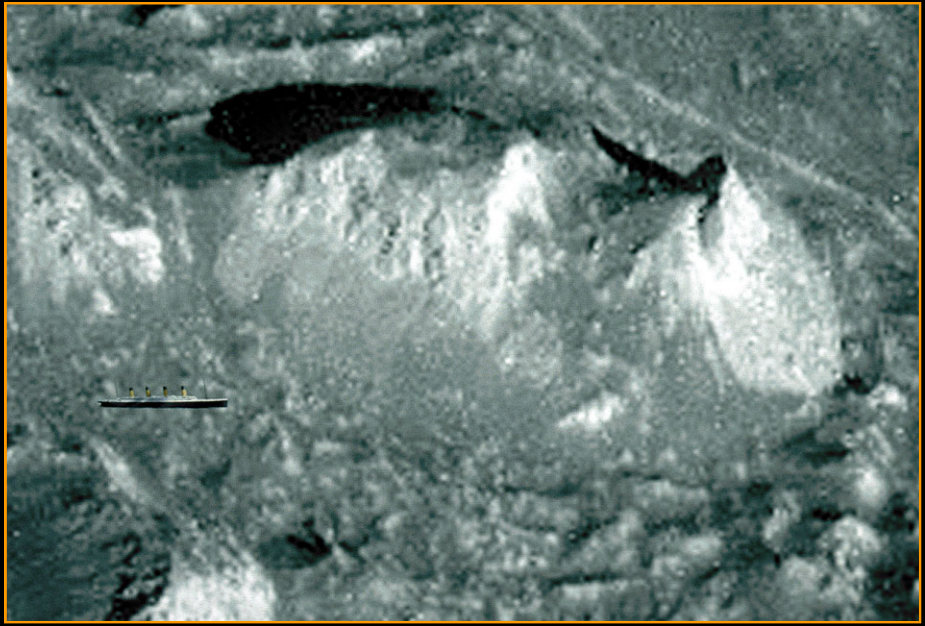
Surface Modification Processes

Material emplaced at the surface has been modified by radiation, impact gardening, and the re-deposition of sputtered and/or excavated frost

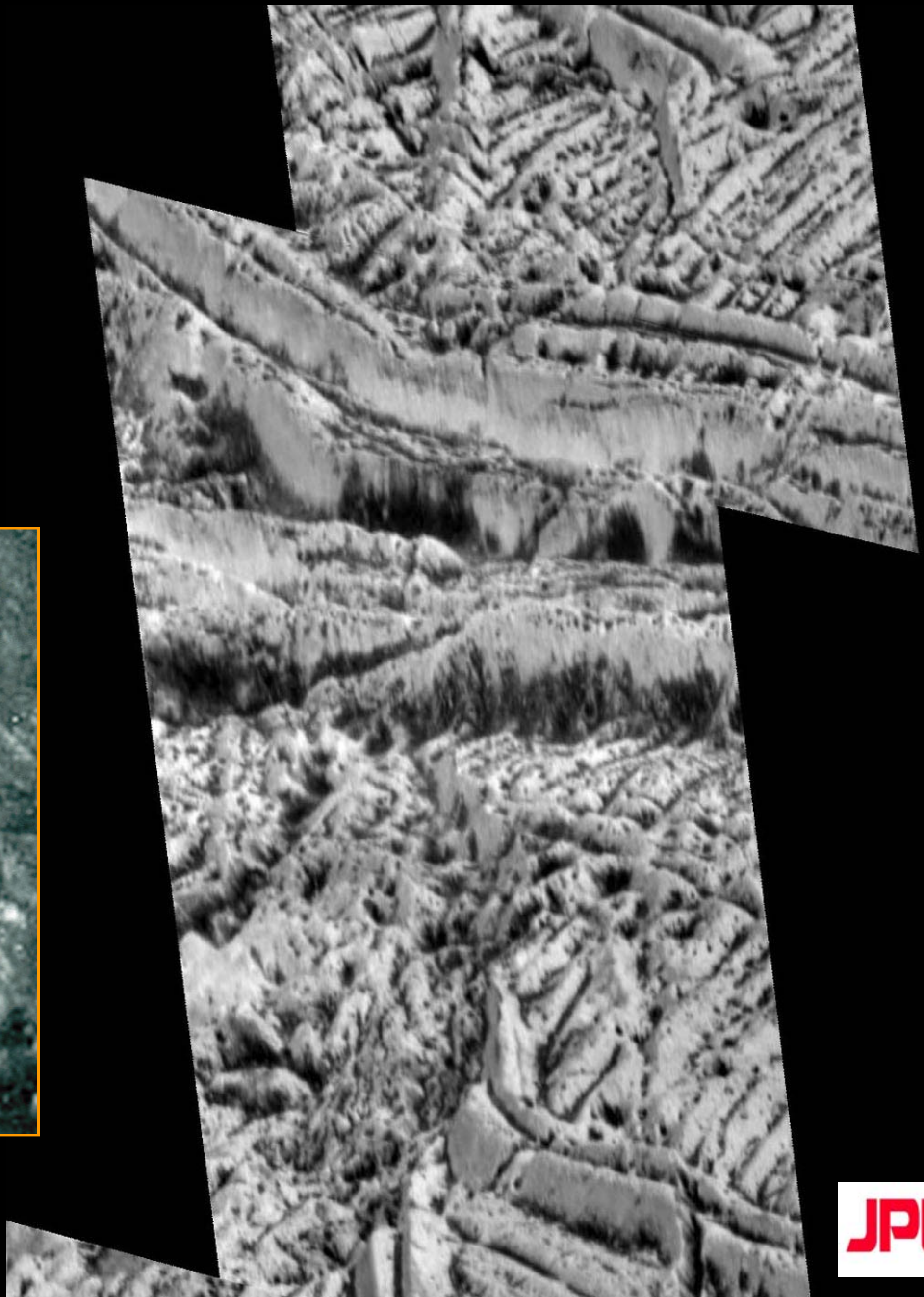


Europa Surface Character

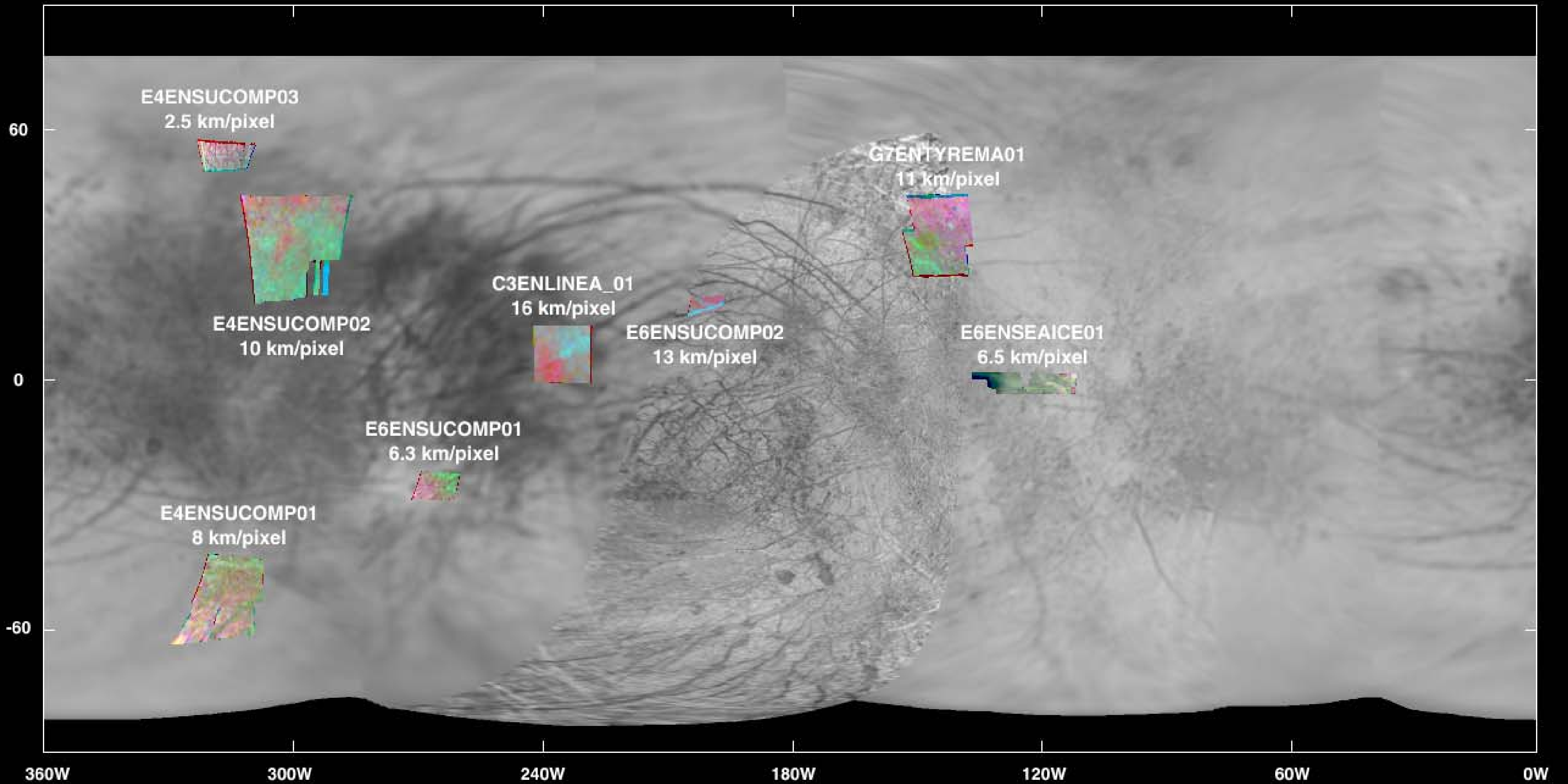
- Highly variable surface topography
  - Typical ~100-300m
  - Up to > 1250 m
- Many scarps and vertical cliffs
- Ridges of ~30-35 degree slope
- Exposed faces
- Lag deposits

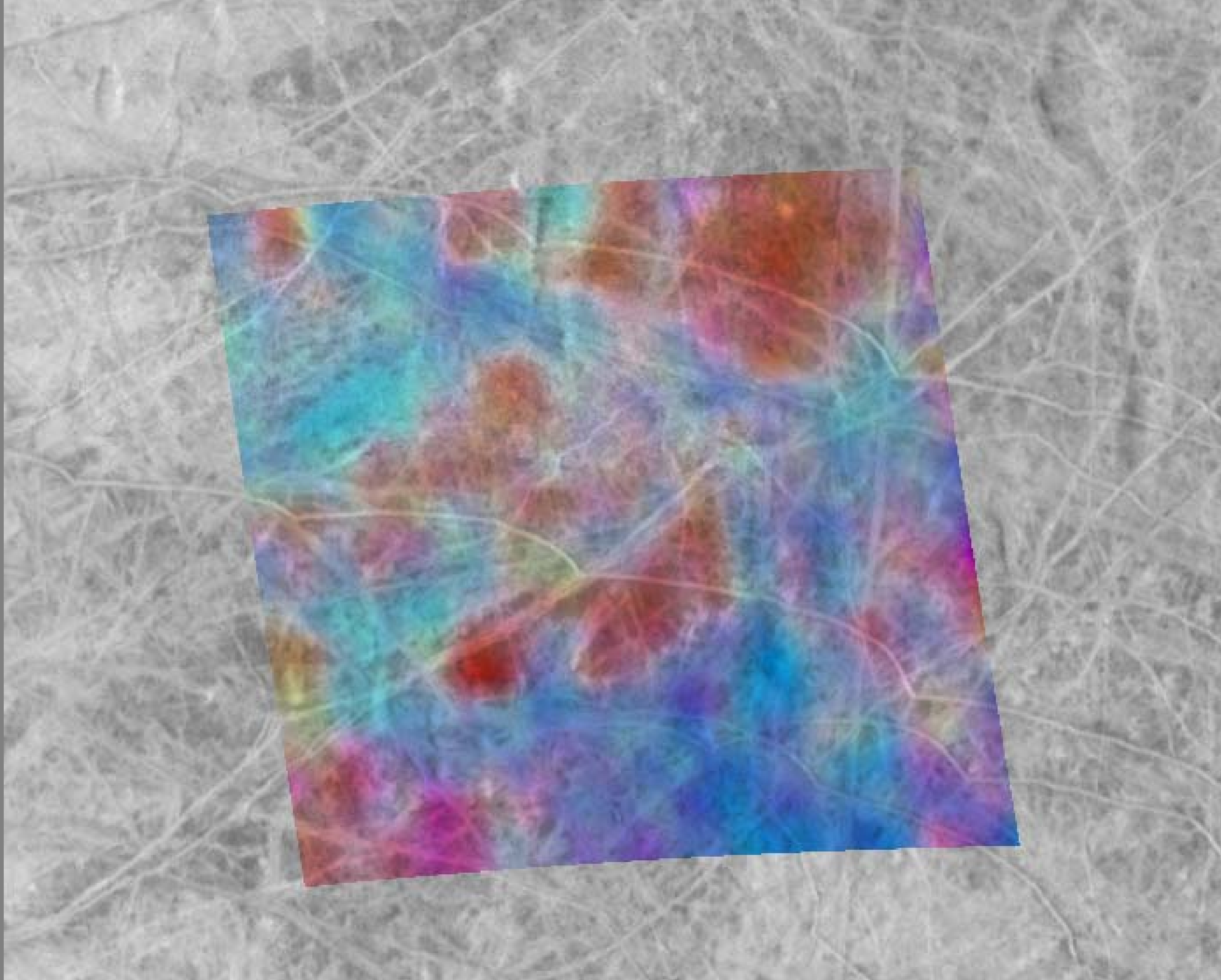


(Titanic Courtesy of Patricio Figueredo)



NIMS Europa High Resolution Coverage





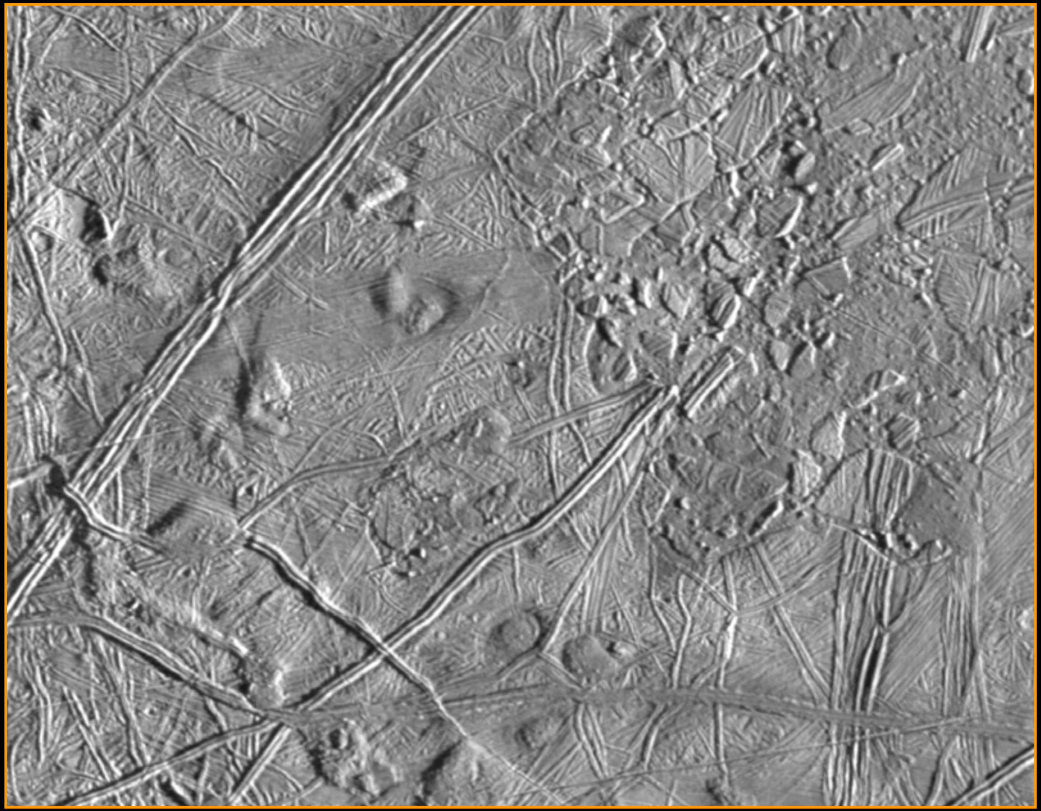
Surface Composition of Europa

Known:

- Water Ice
- Carbon Dioxide Ice
- Sulfur Dioxide Ice
- Hydrogen Peroxide
- Hydronium Ion (H_3O^+)

Expected:

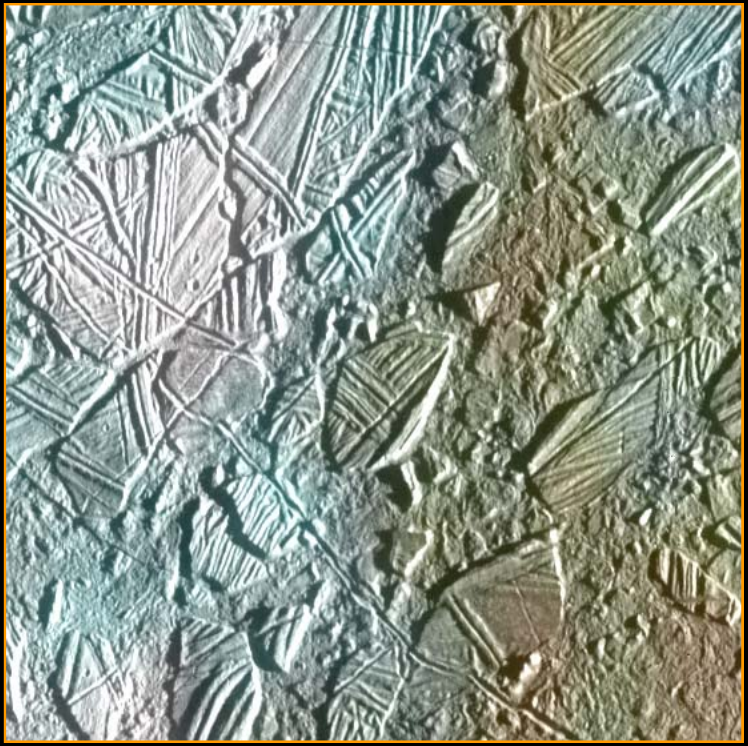
- Hydrogen sulfide (H_2S)
- Formaldehyde (H_2CO)
- Hydrochloric Acid (HCl)
- Carbon Monoxide (CO)
- Oxygen (O_2), Ozone (O_3)



Surface Composition of Europa

"Non-Ice" Material:

- Sulfuric Acid Hydrate
- Hydrated Sulfate Salts
- Irradiated Material
- Organic Material?
- Clathrate Hydrates?



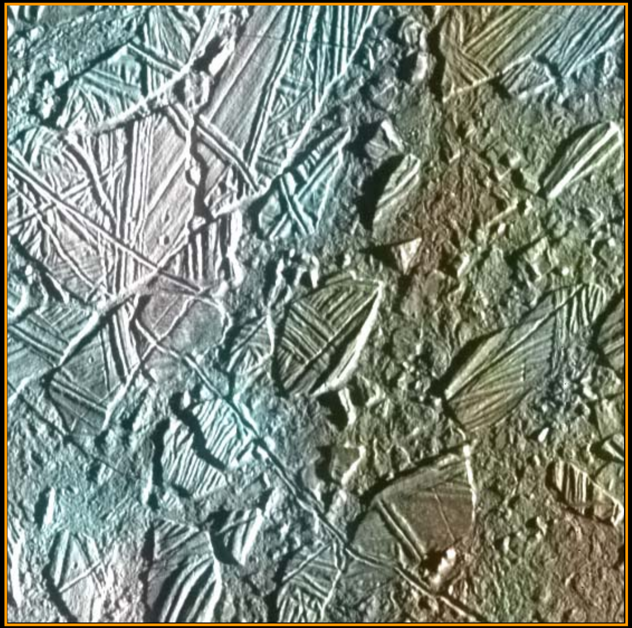
Hydrated Sulfur Compounds

Magnesium Sulfate Hydrates

$MgSO_4 \cdot 1H_2O$	Kieserite
$MgSO_4 \cdot 2H_2O$	Sanderite
$MgSO_4 \cdot 4H_2O$	Starkeyite
$MgSO_4 \cdot 5H_2O$	Pentahydrite
$MgSO_4 \cdot 6H_2O$	Hexahydrite
$MgSO_4 \cdot 7H_2O$	Epsomite
$MgSO_4 \cdot 11H_2O$	Undecahydrite

Sodium Sulfate Hydrates

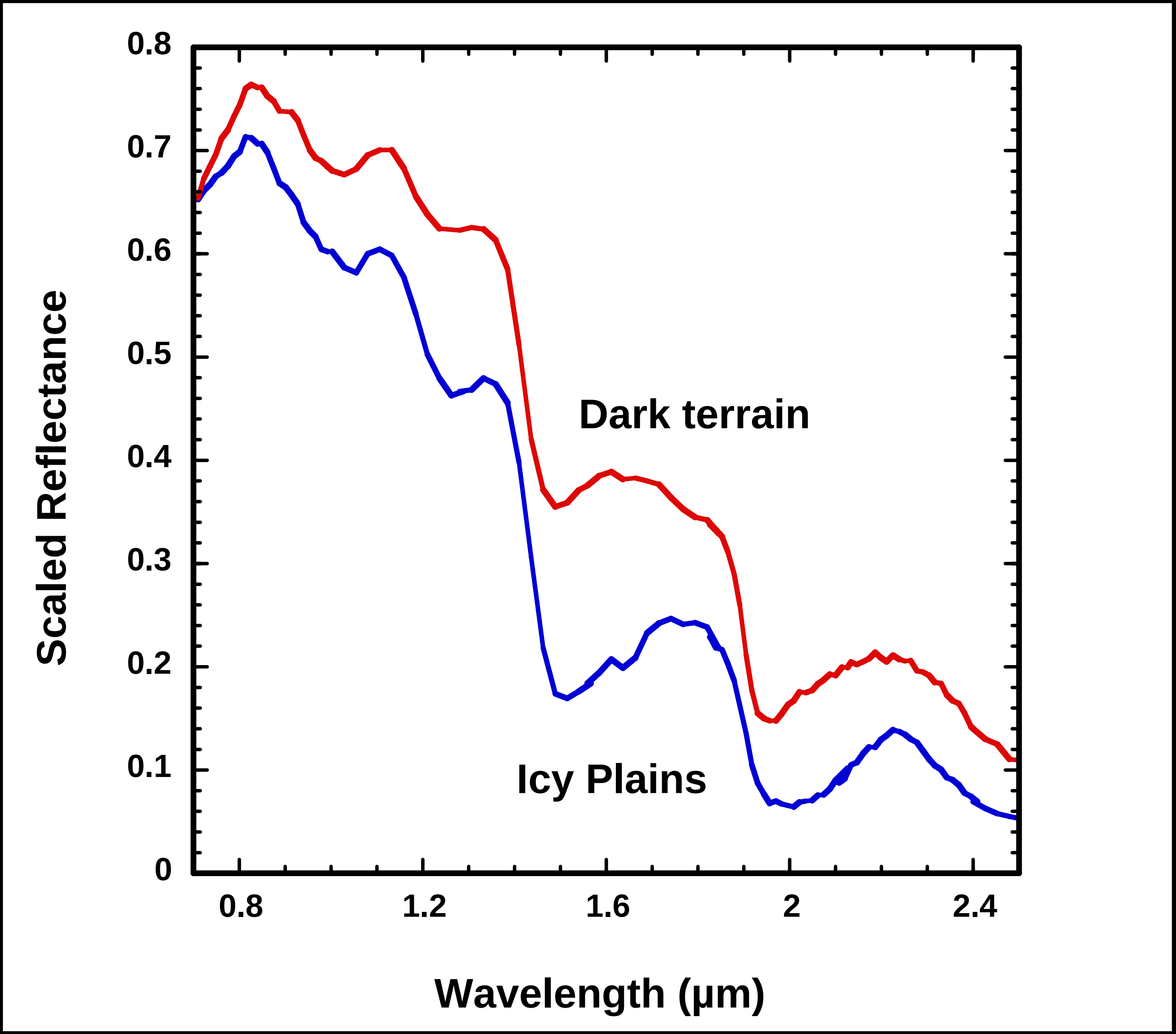
$Na_2SO_4 \cdot 10H_2O$	Mirabilite
$Na_2Mg(SO_4)_2 \cdot 4H_2O$	Bloedite



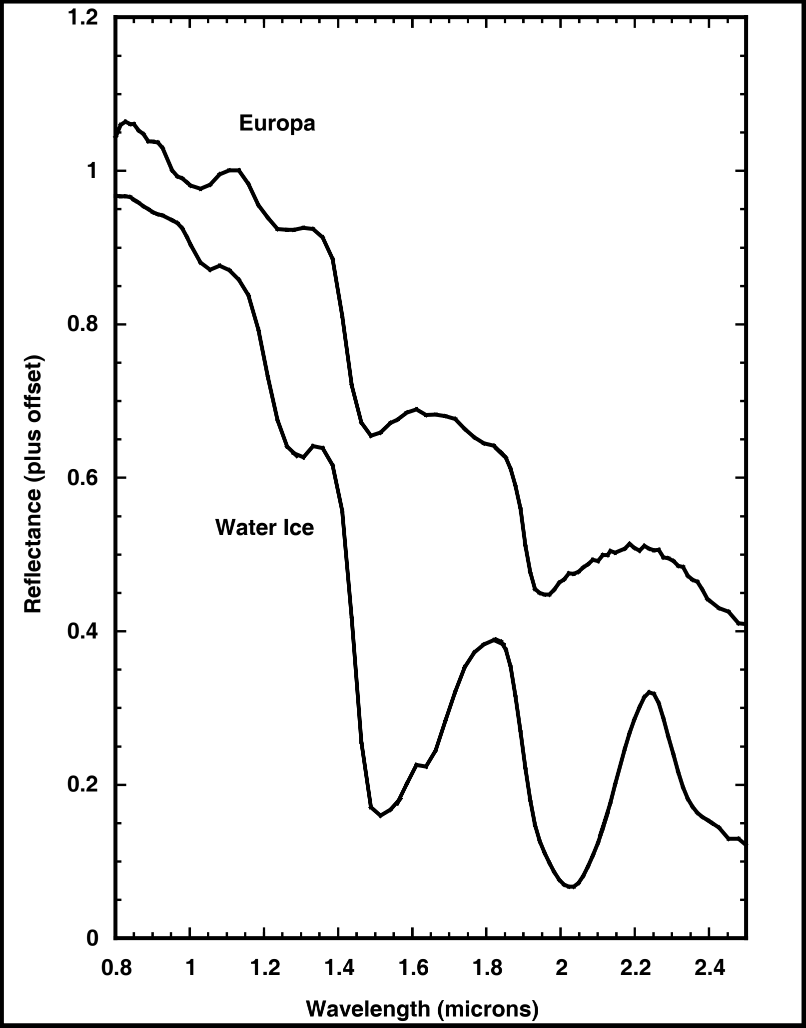
Other Sulfur Compounds

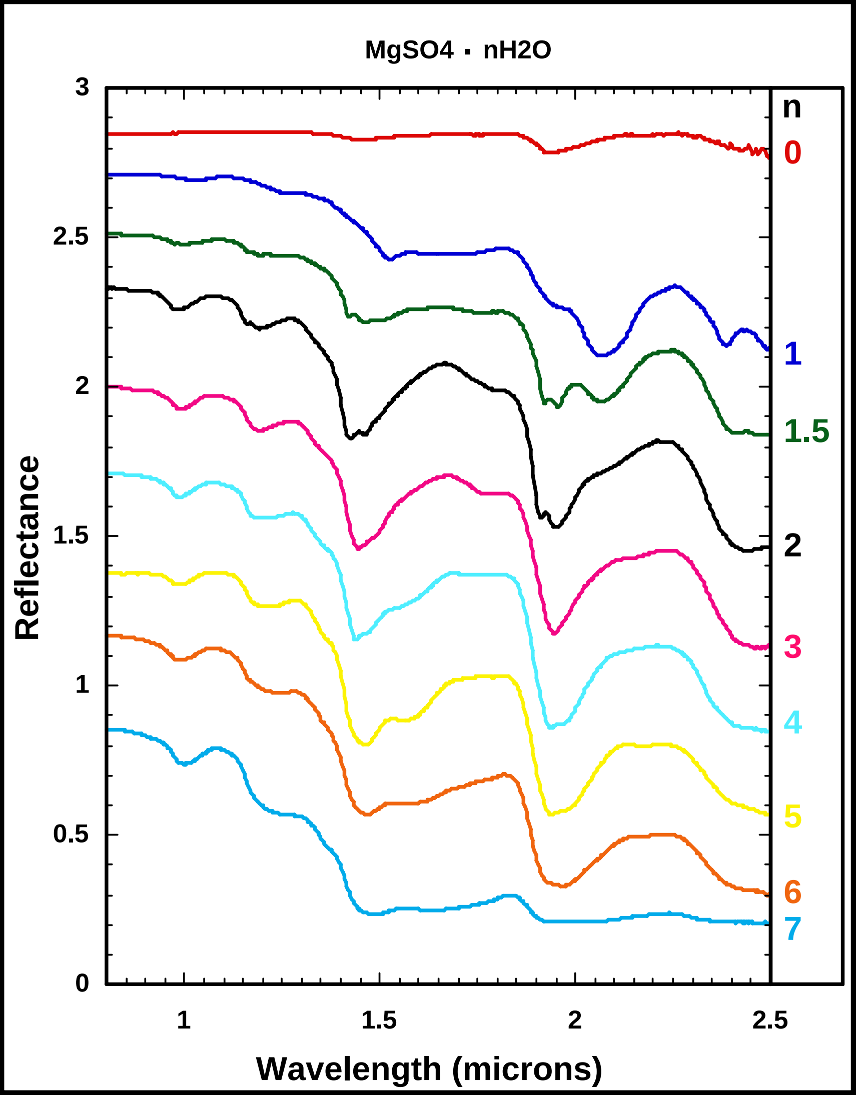
$Na_2S \cdot 9H_2O$	Sodium Sulfide Nonahydrate
$H_2SO_4 \cdot 8H_2O$	Sulfuric Acid Hydrate
$MgSO_4 + H_2O(l)$	Magnesium Sulfate Brine

Galileo NIMS spectroscopy of Europan surface units

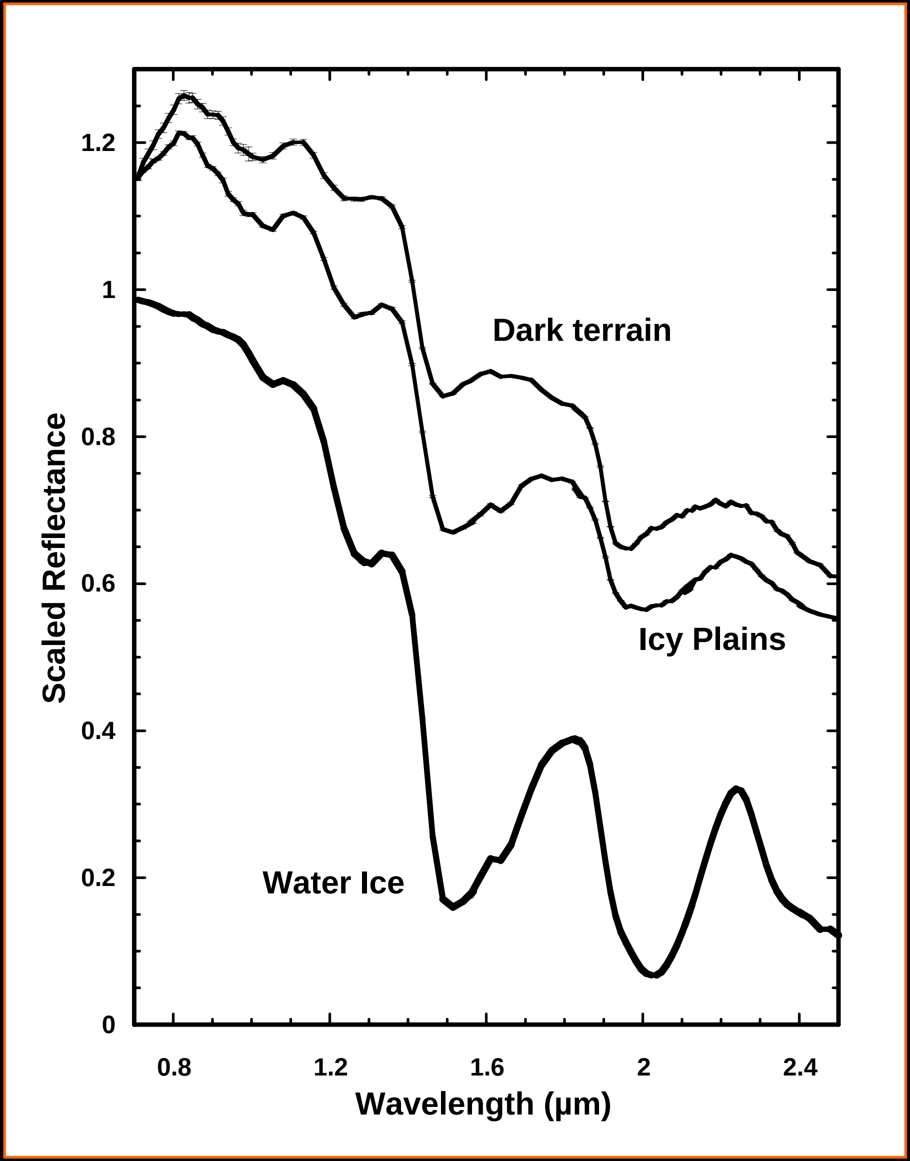


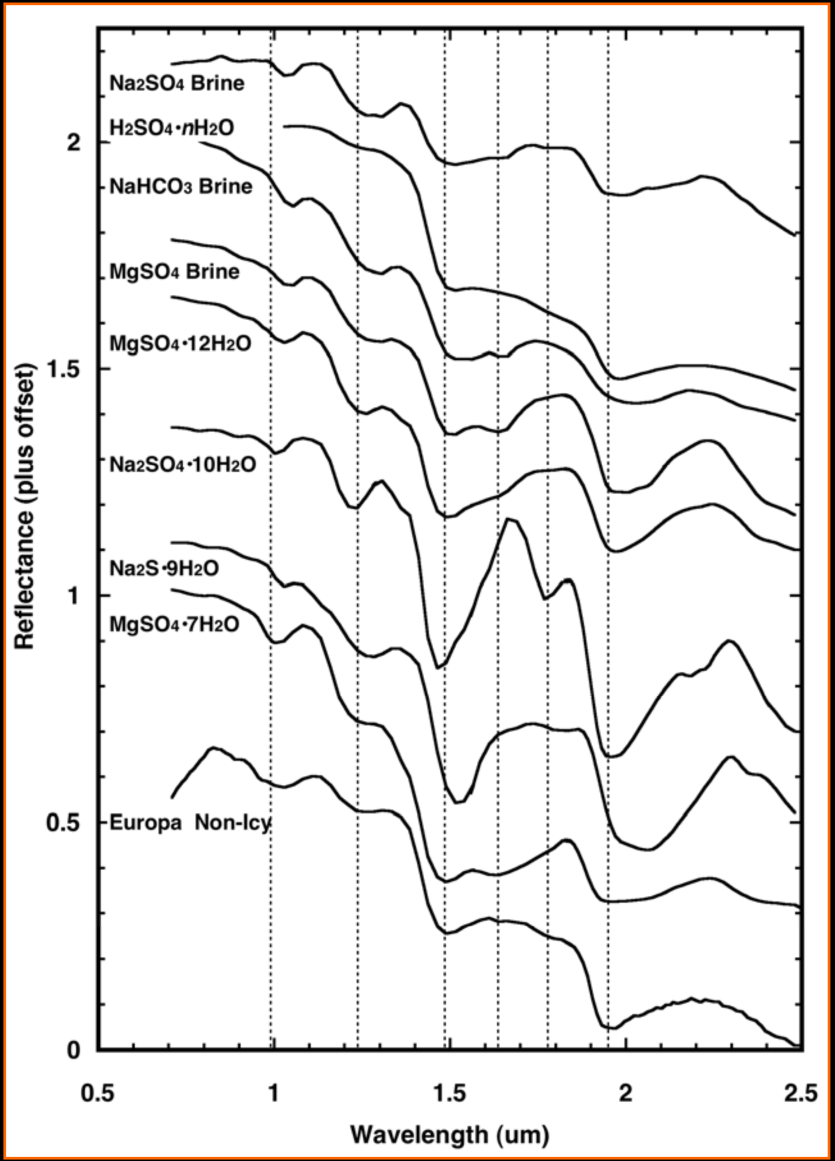
Spectral Effects: Water of Hydration





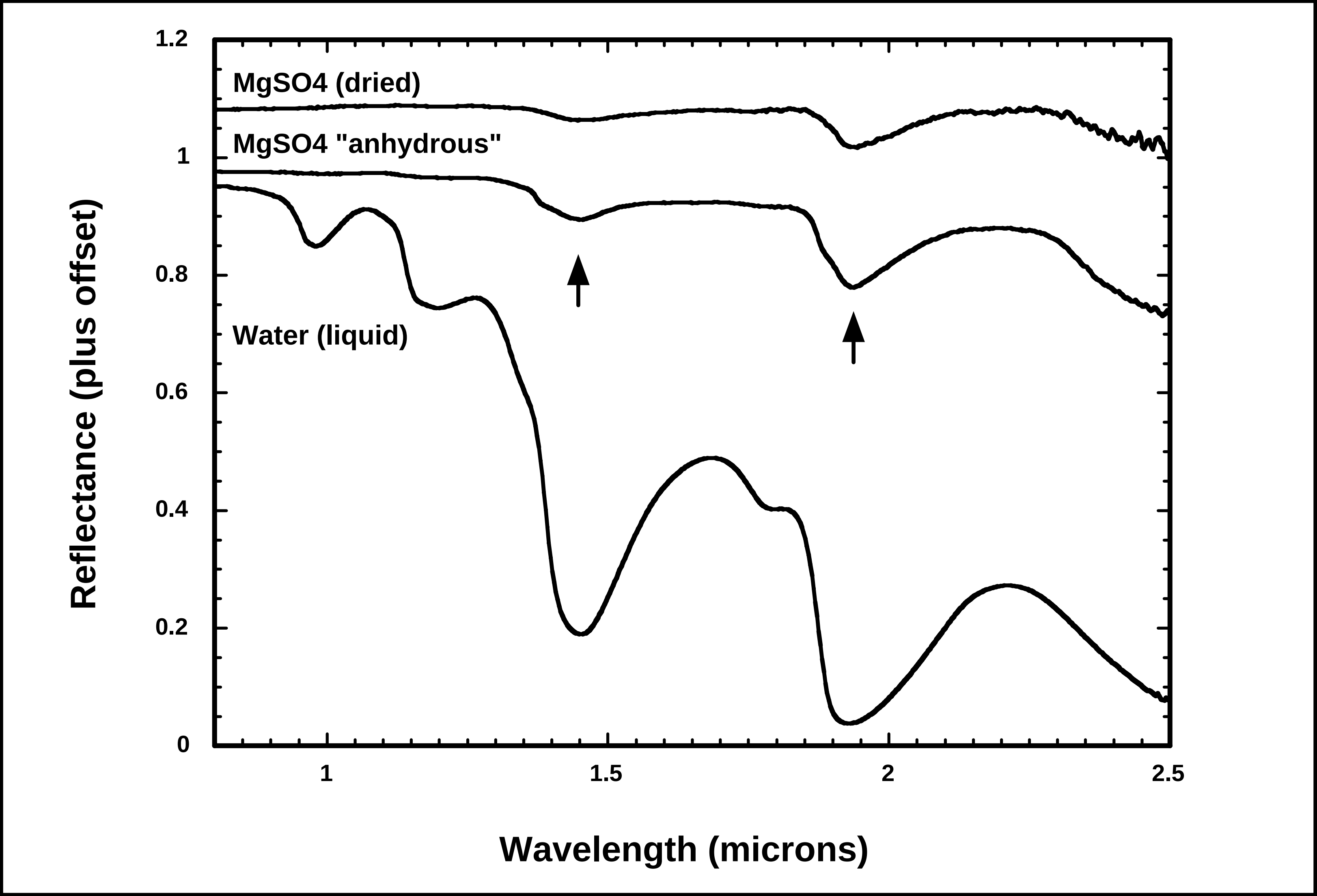
Europa Spectrum and Hydrated Materials





Hydrated sulfates all exhibit Europa-like spectral characteristics

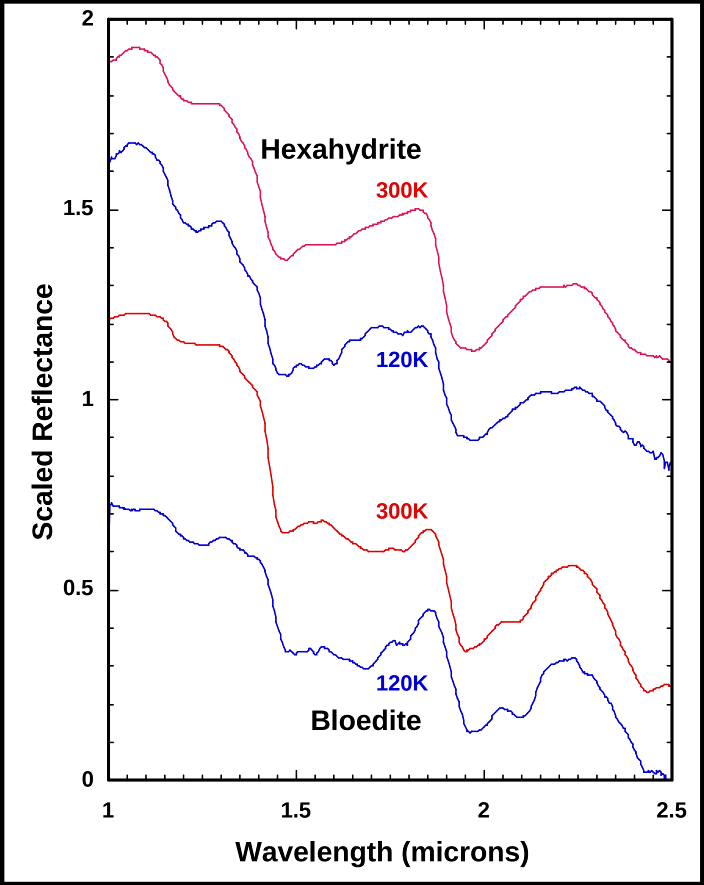
Spectral Effects: Water of Hydration

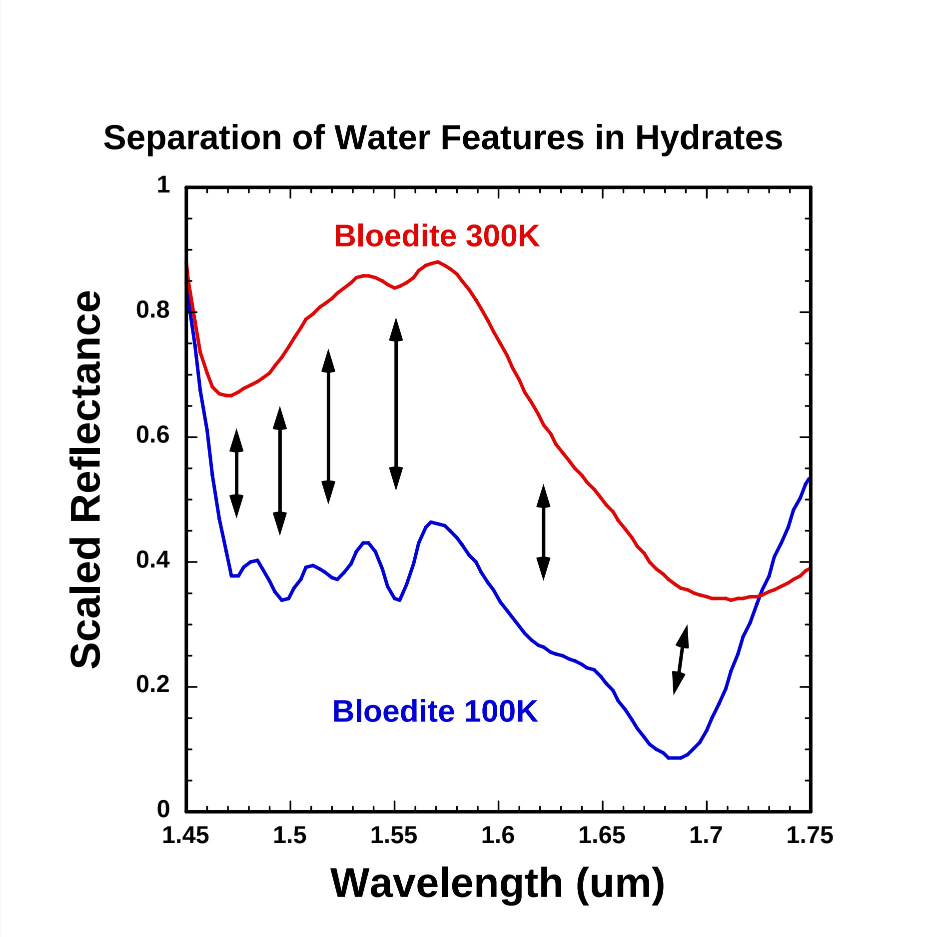


These absorptions are *not* intrinsic to the host molecule!

Temperature-dependent Effects

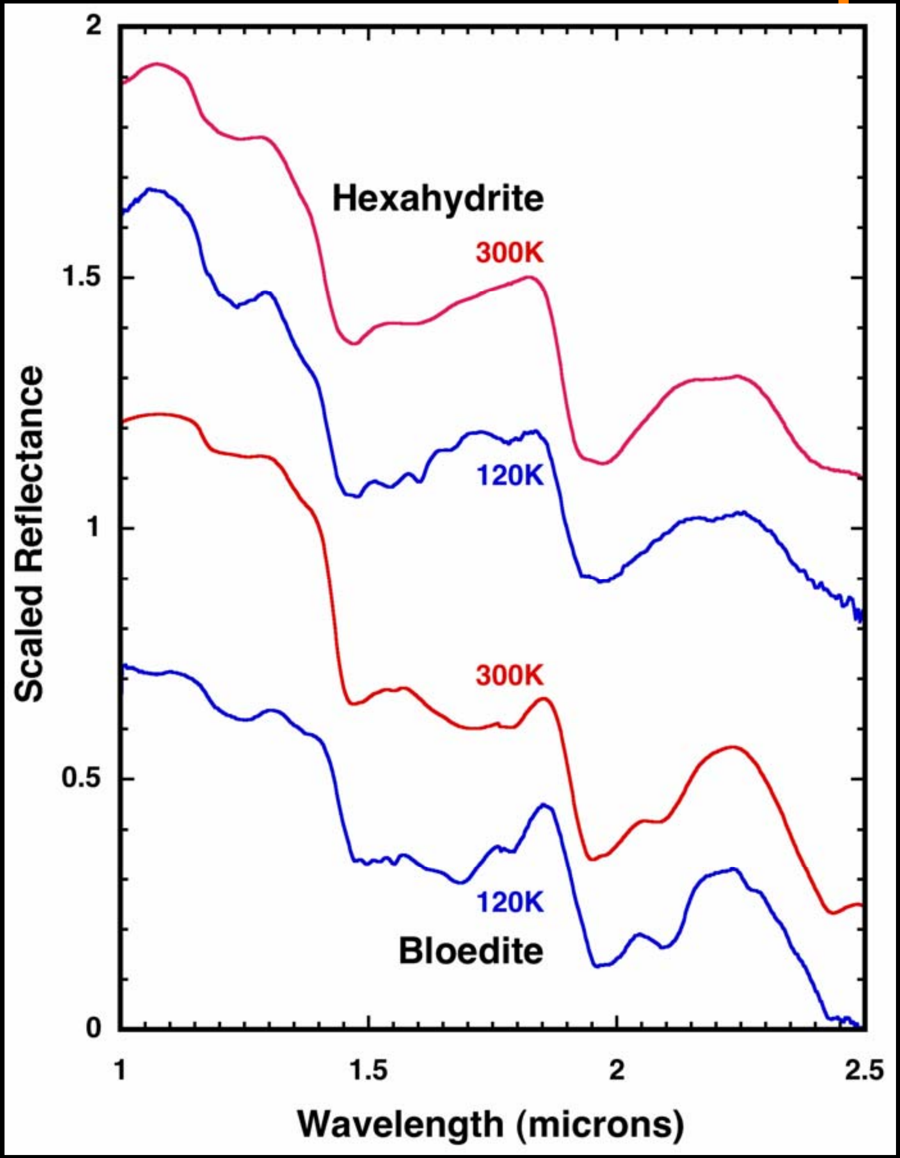
Hexahydrite ($MgSO_4 \cdot 6H_2O$) and Bloedite ($MgNa_2(SO_4)_2 \cdot 4H_2O$) suggested to comprise 80% of surface material (McCord et al., 1999)





BUT… Spectral behavior at cryogenic temperatures may differ markedly from that at room temperature (Dalton and Clark, 1999; Dalton, 2000, 2003, 2005)

Temperature Dependence of Spectral Properties



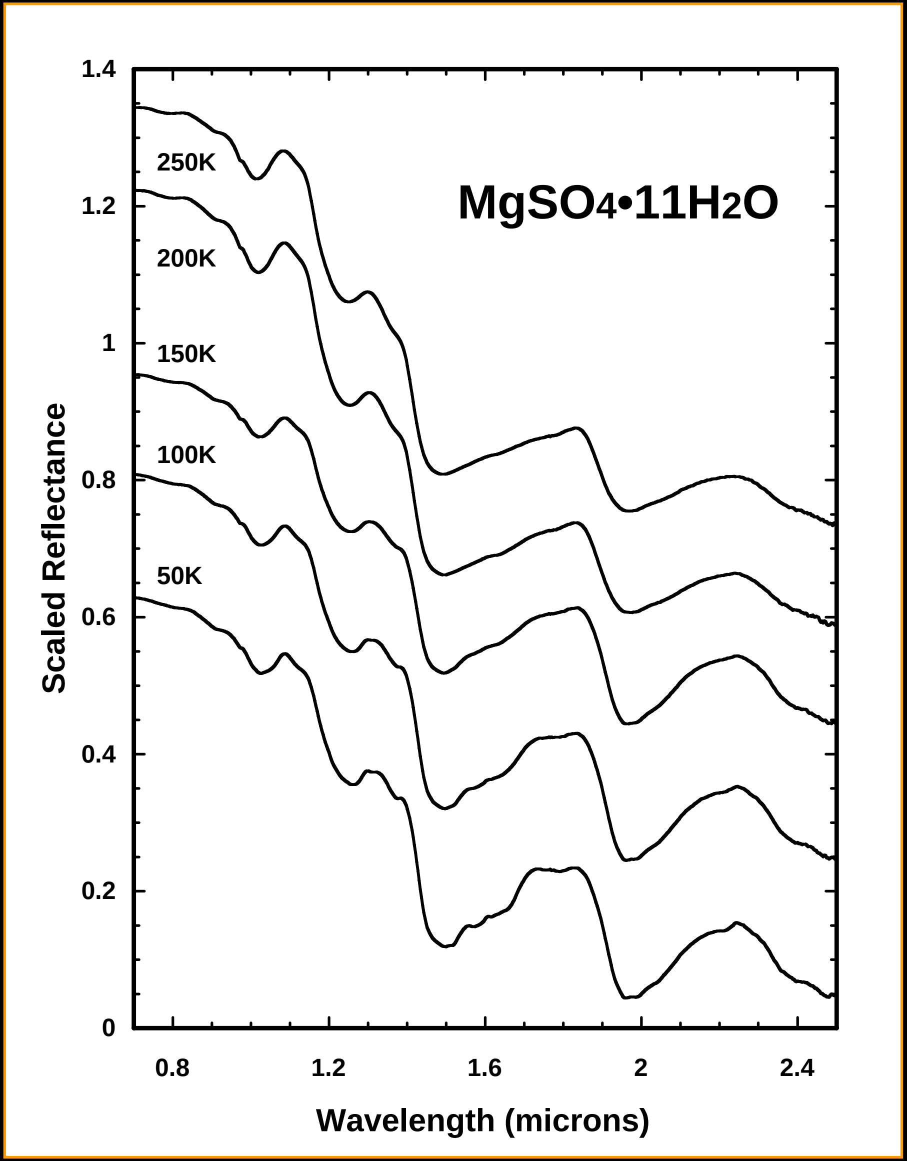
Hexahydrite ($MgSO_4 \cdot 6H_2O$) and Bloedite ($MgNa_2(SO_4)_2 \cdot 4H_2O$) suggested to comprise >70% of surface material (McCord *et al*., 1999) based on available room temperature spectra

Subsequent cryogenic spectra (eg., Dalton et al., 2000, 2003, 2005) demonstrated strong temperature dependence of spectral absorption ba strengths, shapes, positions

Spectral models utilizing cryogenic spectroscopy thus have the potential to provide realistic constraints on surface composition of icy satellites

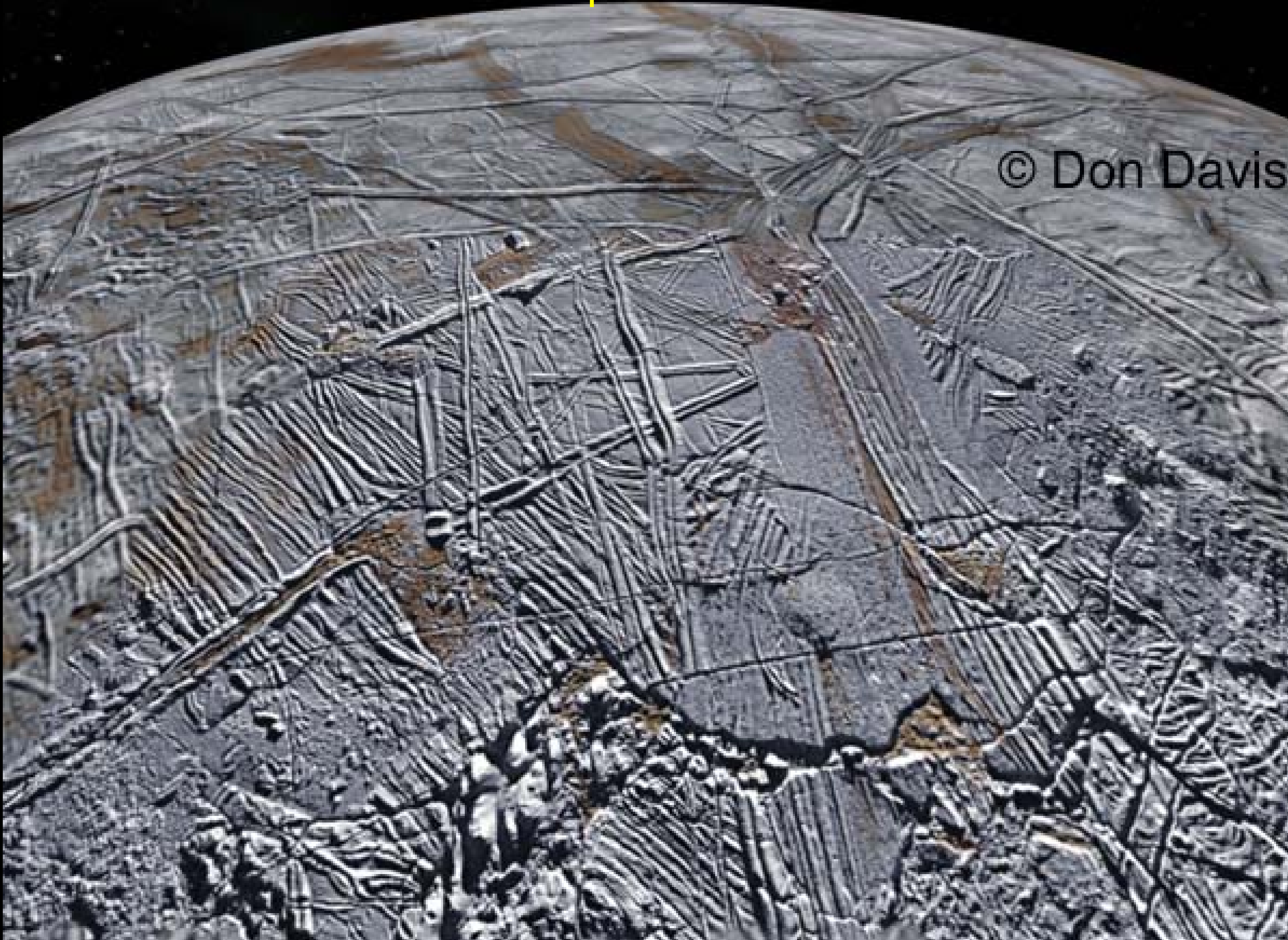
Magnesium Sulfate Undecahydrate

As temperature is reduced below 200K, individual absorption features separate and narrow, producing fine structure that can be used to discriminate between materials



Dalton et al., 2005

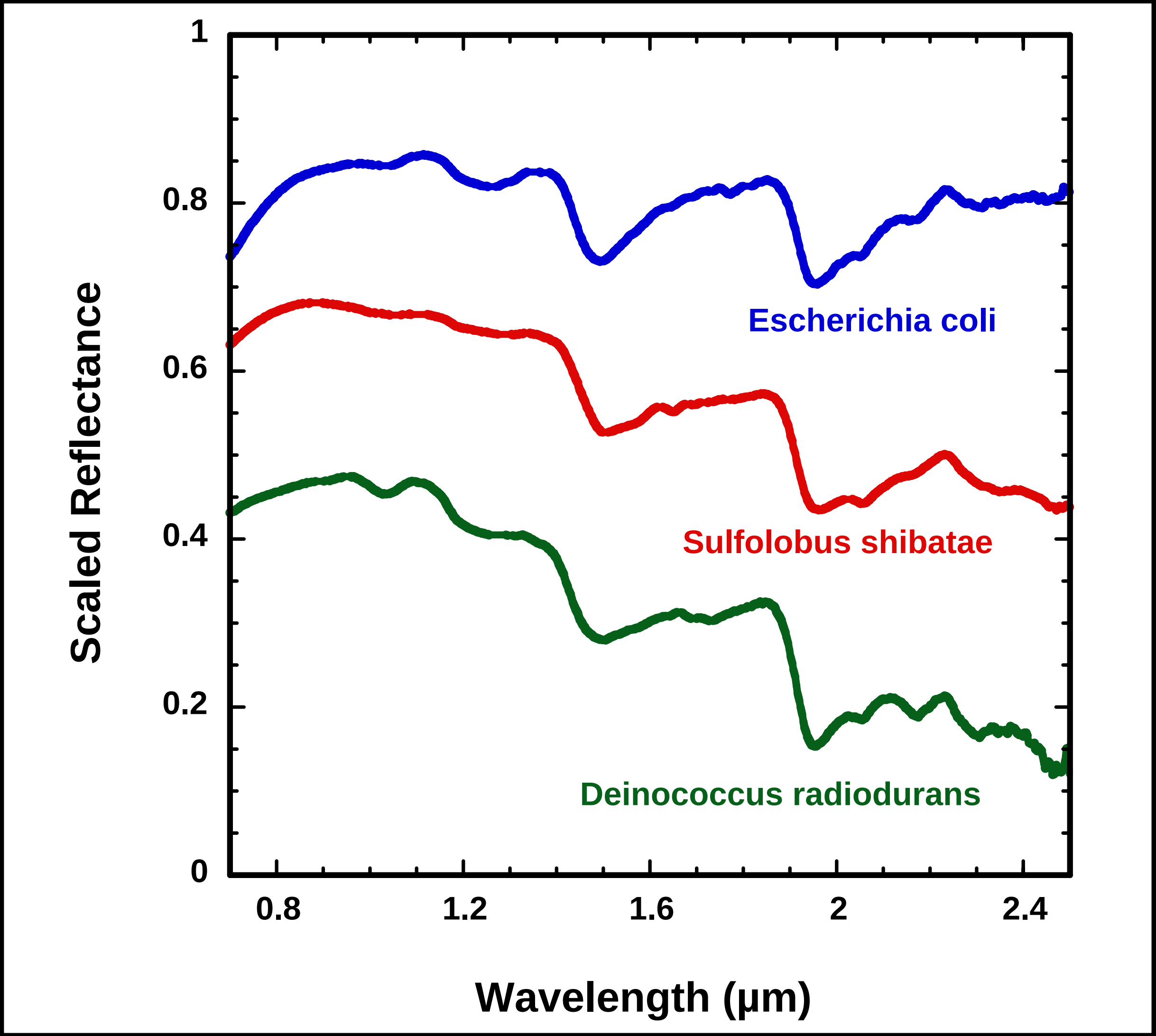
The Search for Life on Europa….



Psychrophiles at bottom edge of sea ice core near Barrow, Alaska

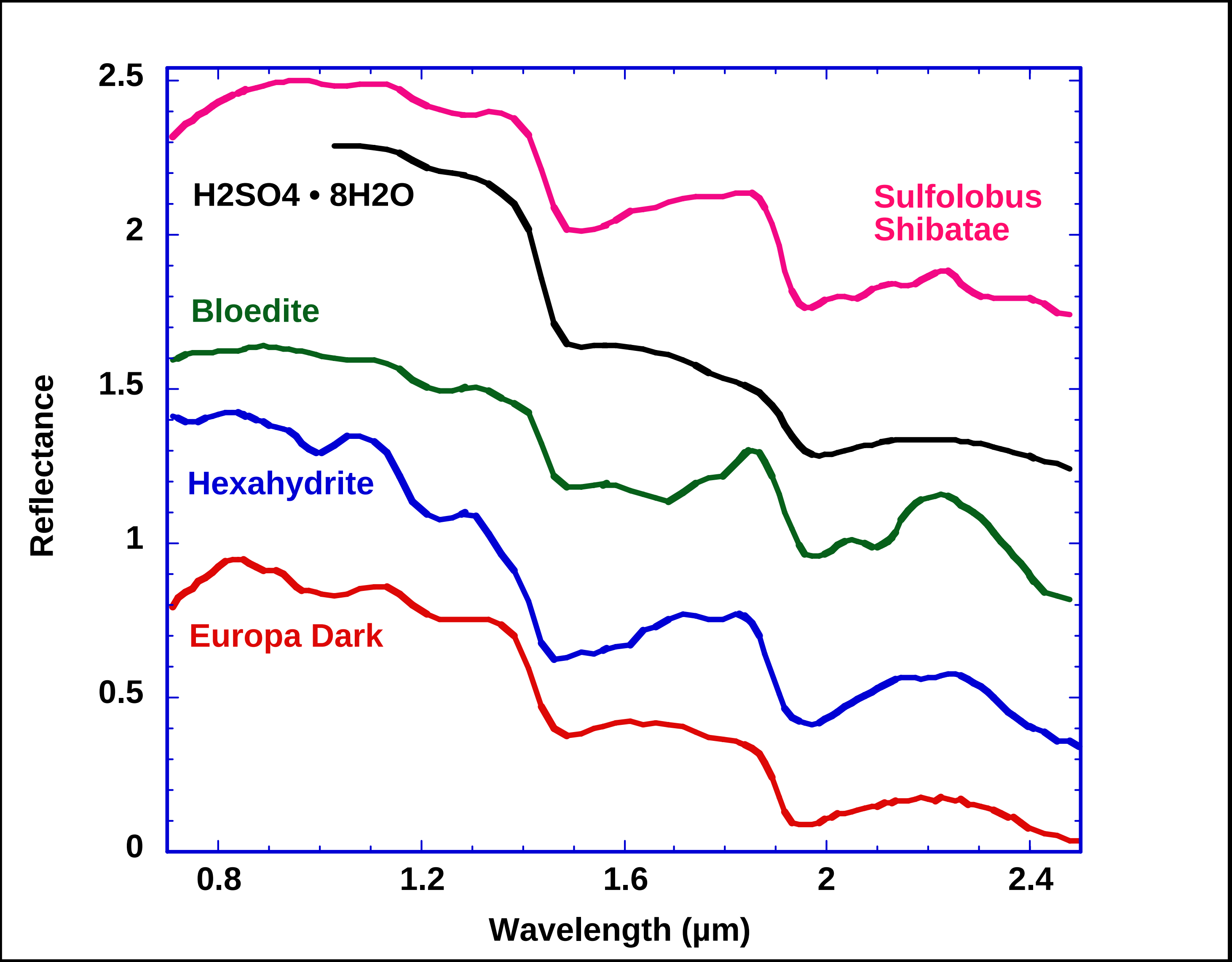
Halophiles and salt crust at San Francico Bay (salinity >300 ppt)

Spectra of extremophiles at 120 K



- Life contains many things
- Life contains hydrates
- Life contains amides

Some Popular Hydrated Materials

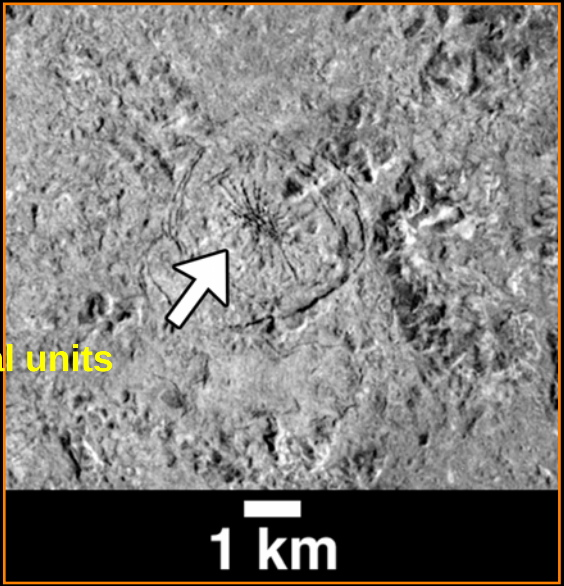


Spatial Considerations for Interpretation of Surface Composition

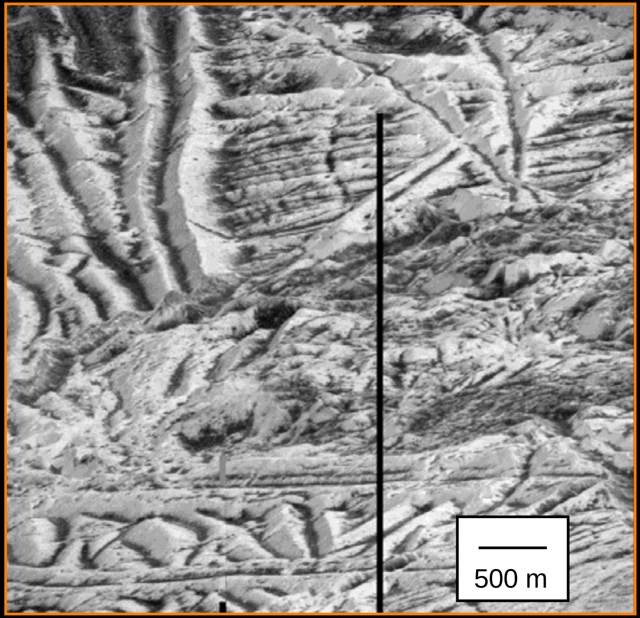
Discrimination of surface constituents requires high spectral AND high spatial resolution

Surface heterogeneous at small spatial scales
Spectra are mixtures of adjacent surface units
∴ large footprint reduces detectability of constituents

Identification of surface materials requires spectral imaging of individual units



Galileo SSI image of unique crater with apparent subsurface material flowing onto surface from radial fractures.

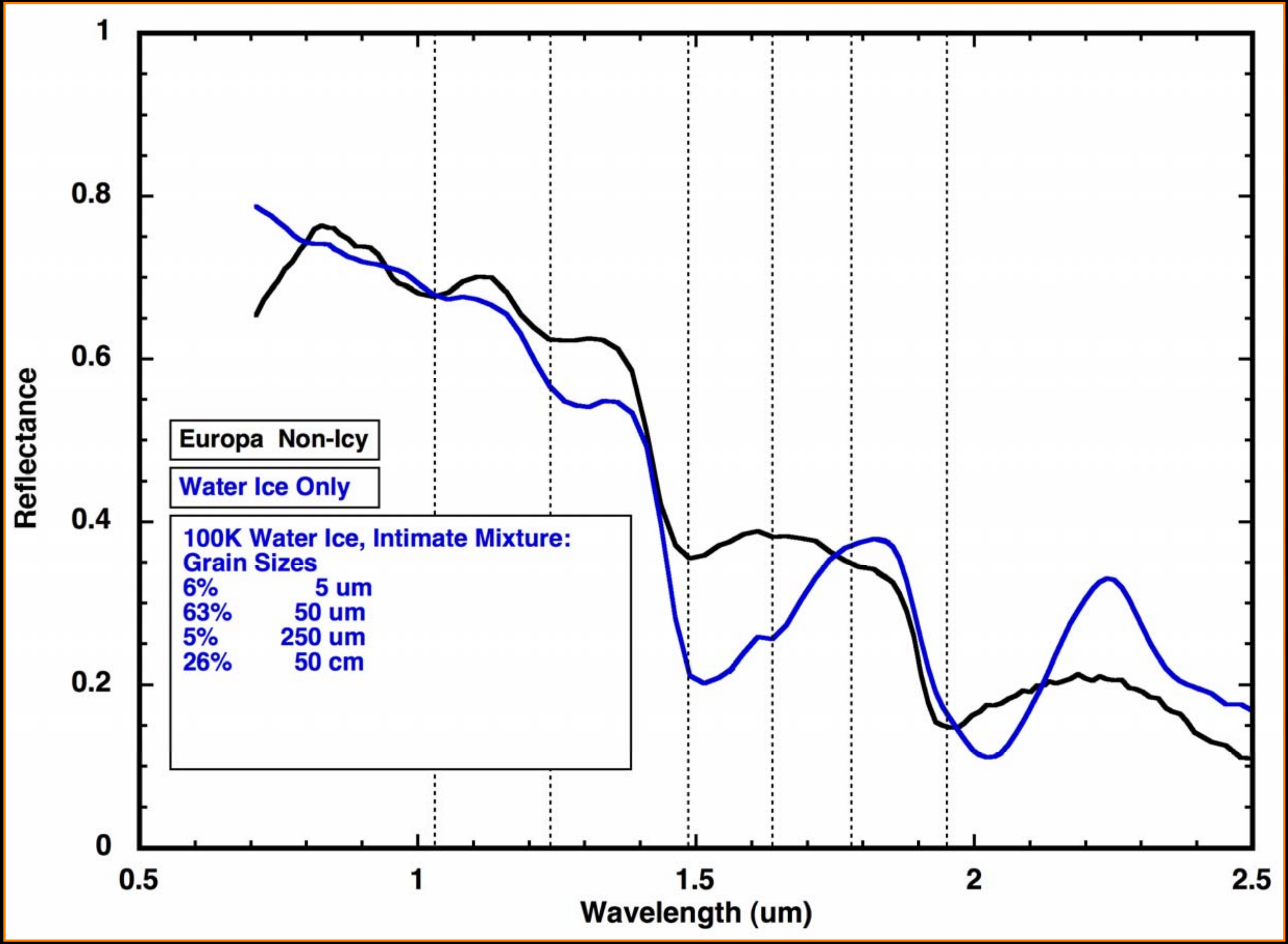


Galileo SSI image of ridged plains at 6 m/pixel. Linear troughs containing dark material are about 100 m wide.

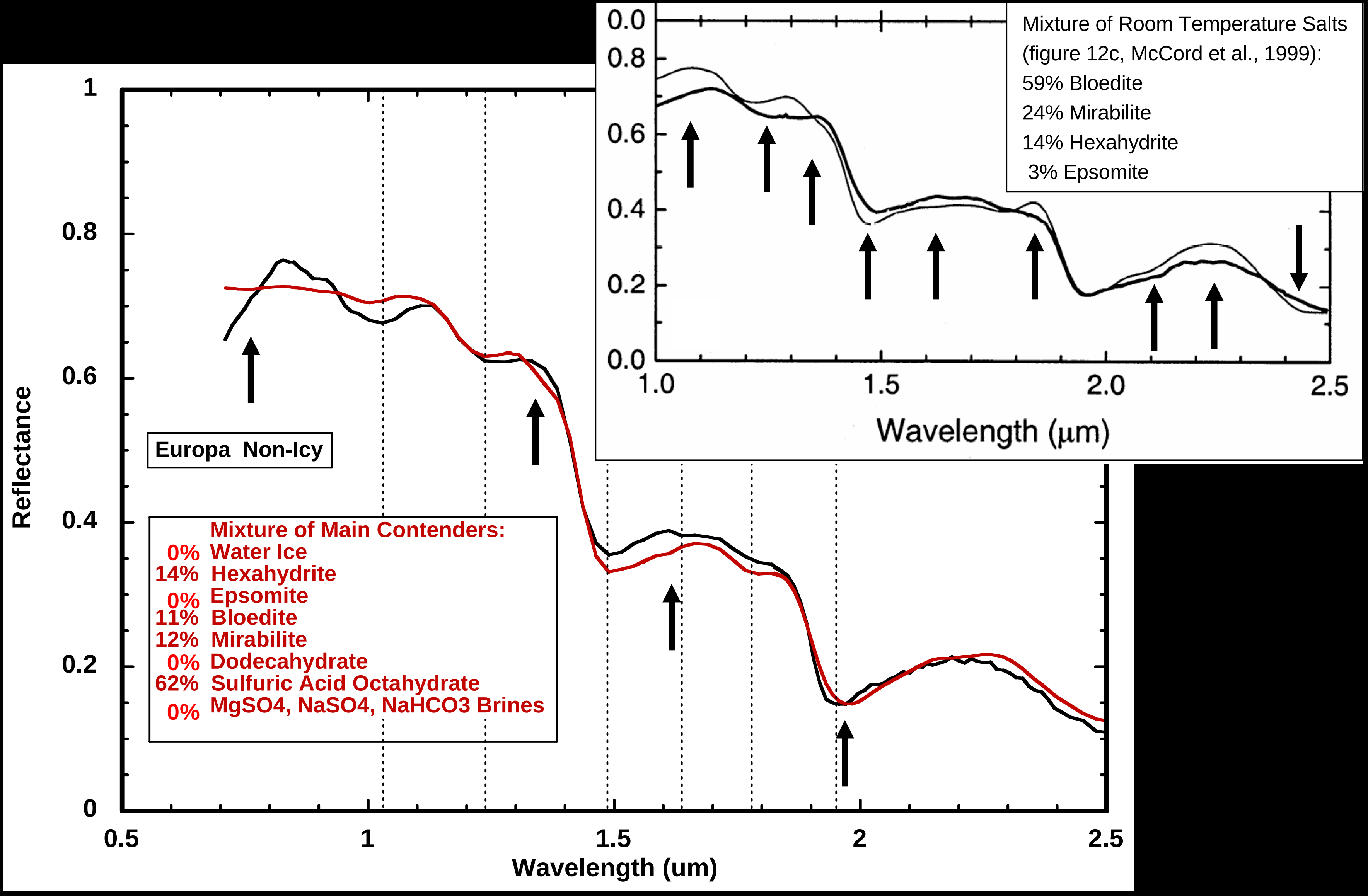
Spatial Resolution:
Surface heterogeneous at 25 - 100 m scales

Signal to Noise:
Sampling statistics and radiation noise require multipl pixels across contiguous surface units

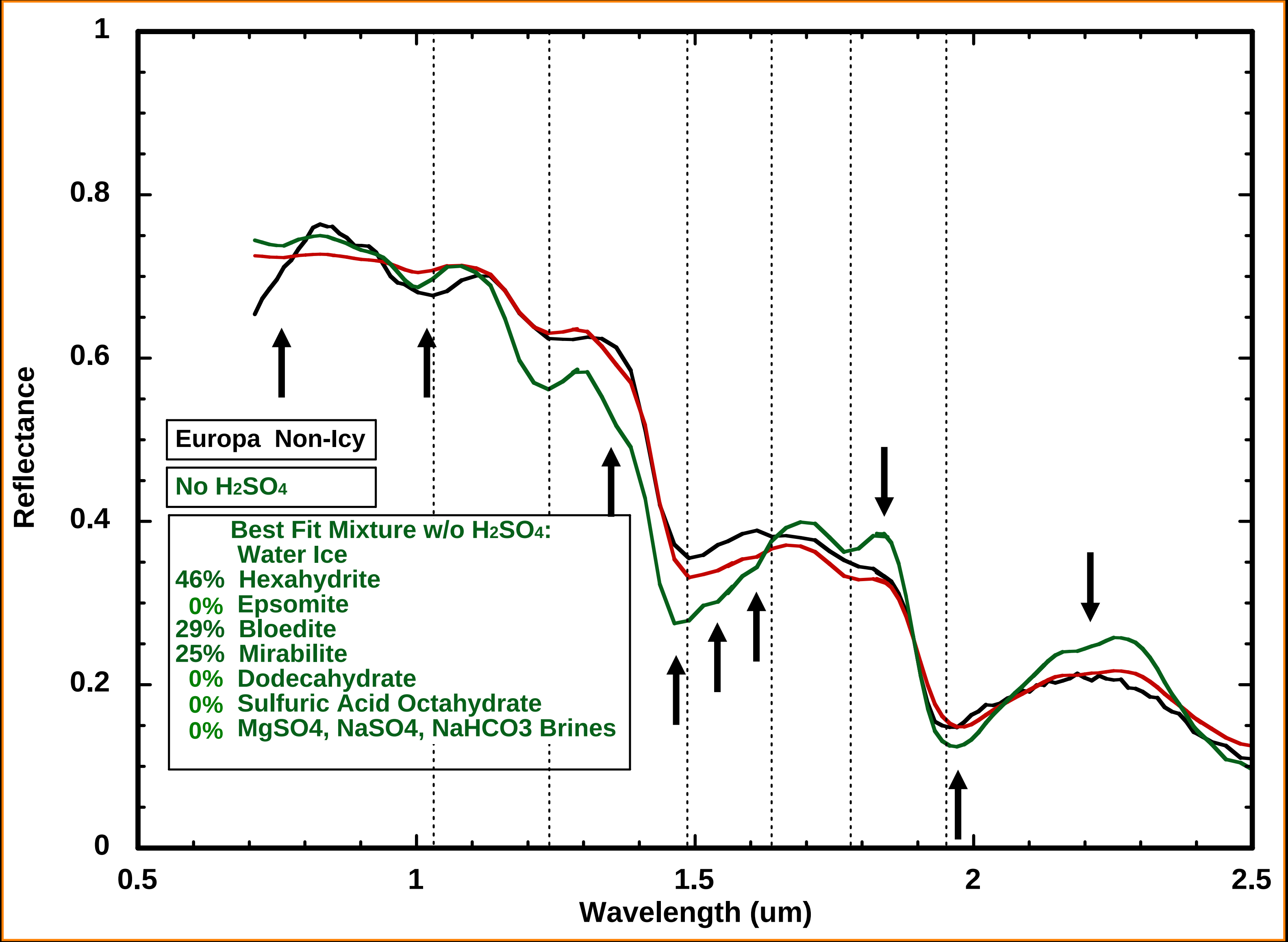
Fit to Europa “Non-Icy” Spectrum



Fit to Europa “Non-Icy” Spectrum



Fit to Europa "Non-Icy" Spectrum



Future investigations such as a Europa Flagship Mission may shed light on these mysteries…given sufficient spatial and spectral resolution, and the availability of relevant laboratory data.

Conclusions:

- Highly hydrated sulfate salts exhibit more Europa-like spectral behavior than those of lower hydration states.
- Best spectral models include BOTH hydrated salts and hydrated sulfuric acid.
- Fine structure at low temperatures can be exploited to discriminate between candidate materials.
- Lab spectra are needed for all candidate surface compounds.

Conclusions:

- Detritus of emplaced organisms is consistent with the observed spectral signature.

- Microbes are capable of surviving the low surface temperatures at Europa.

- Consideration should be given to a landed package that can confirm the presence of sulfate salts and acids, as well as search for evidence of biologically-derived material in the near subsurface.

- It is important to “look before we leap” in determining landing sites.

Recommendations:

- **The extreme surface roughness, and character of the upper surface layers need to be considered in developing a lander concept.**
- **Unraveling surface composition requires a concerted, collaborative effort that includes laboratory simulations.**
- **A lander must be prepared to encounter sulfuric acid, hydrogen peroxide, and a variety of salts.**
- **Access to the subsurface has the *potential* to acquire direct evidence of past or even recent biological activity.**