

Unveil the microphysical properties of Europa and Ganymede surfaces

Guillaume Cruz Mermy
Research Fellow at ESAC

Aranjuez, Spain
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What are "Ices" ?

- On Earth : Solid state of water

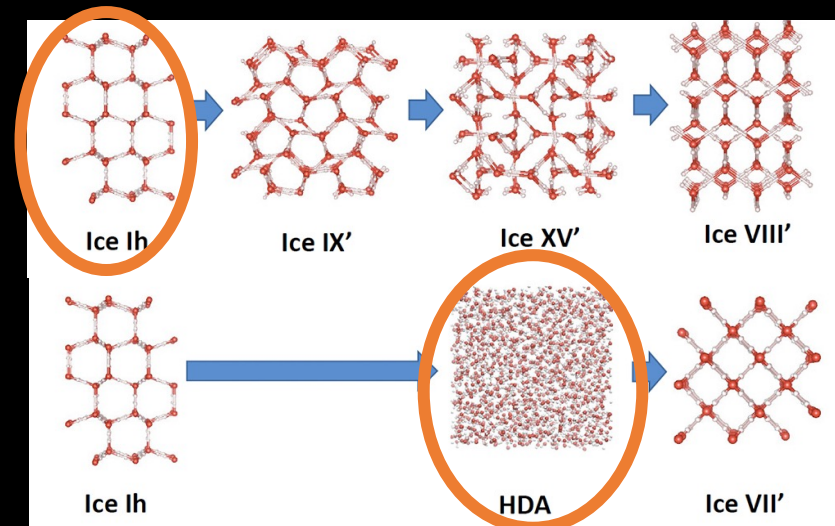
What are "Ices" ?

- On Earth : Solid state of water
- Moderately-to-highly volatile molecules in their solid state (Schmitt, 1995)

H_2O , CO_2 , CO , SO_2 , CH_4 , NH_3 , N_2



CO_2 ice also called « Dry ice »



From Tulk et al., 2019

What are "Ices" ?

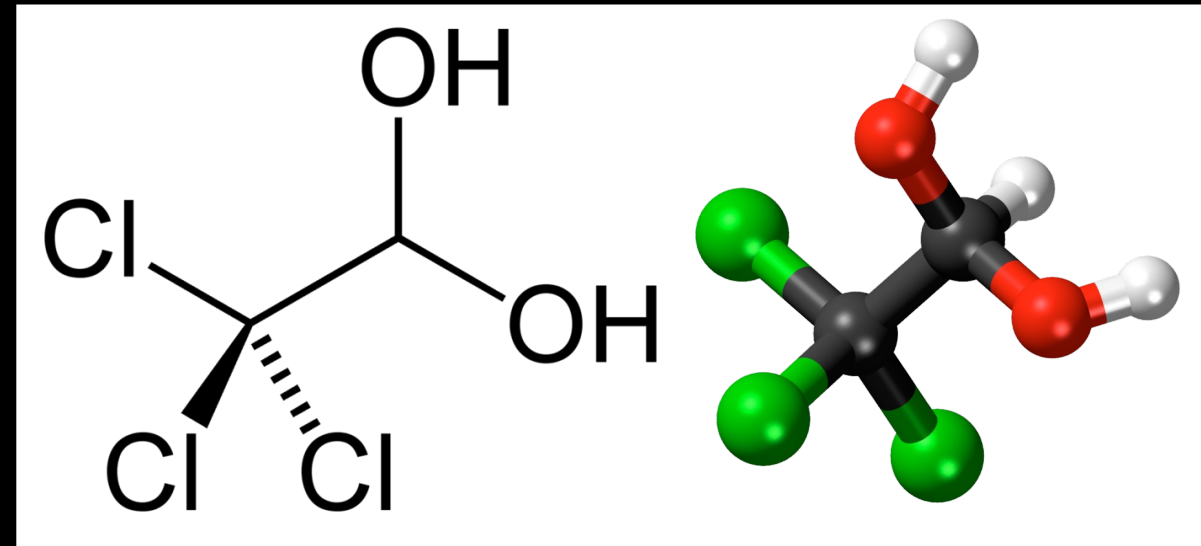
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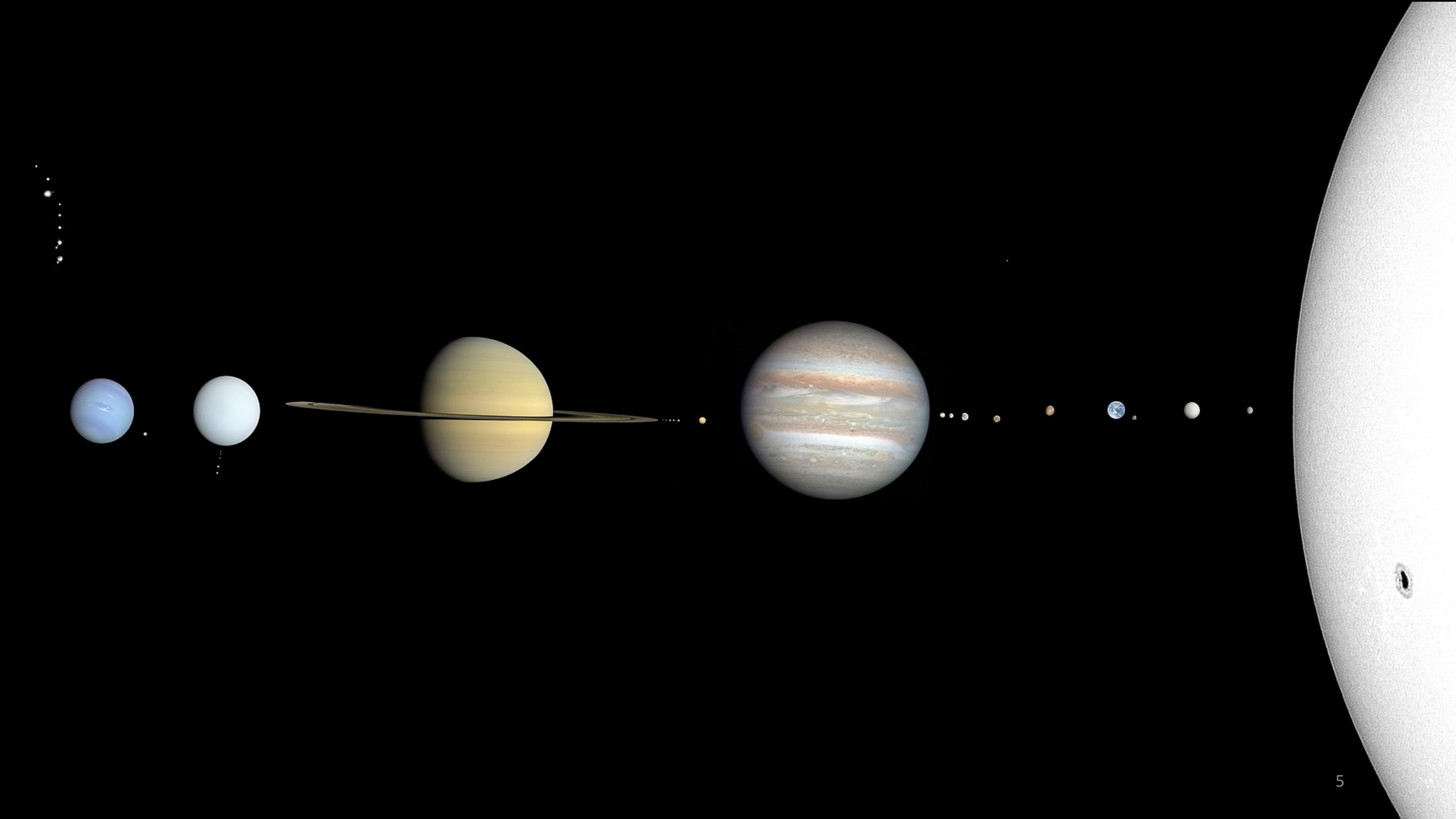
- Hydrates ($X \cdot n \text{H}_2\text{O}$)

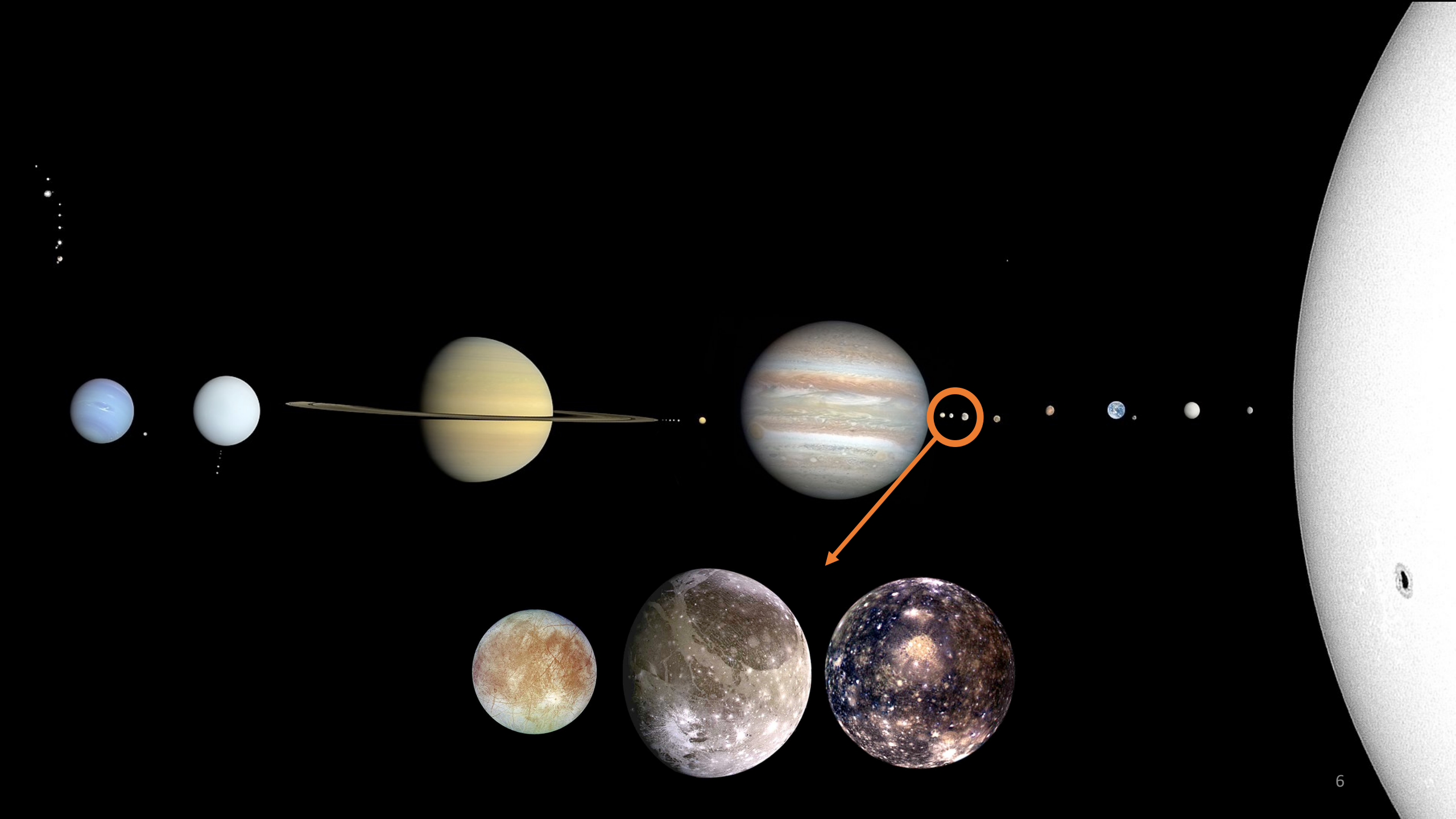
Anhydrous
compound

Hydration
state

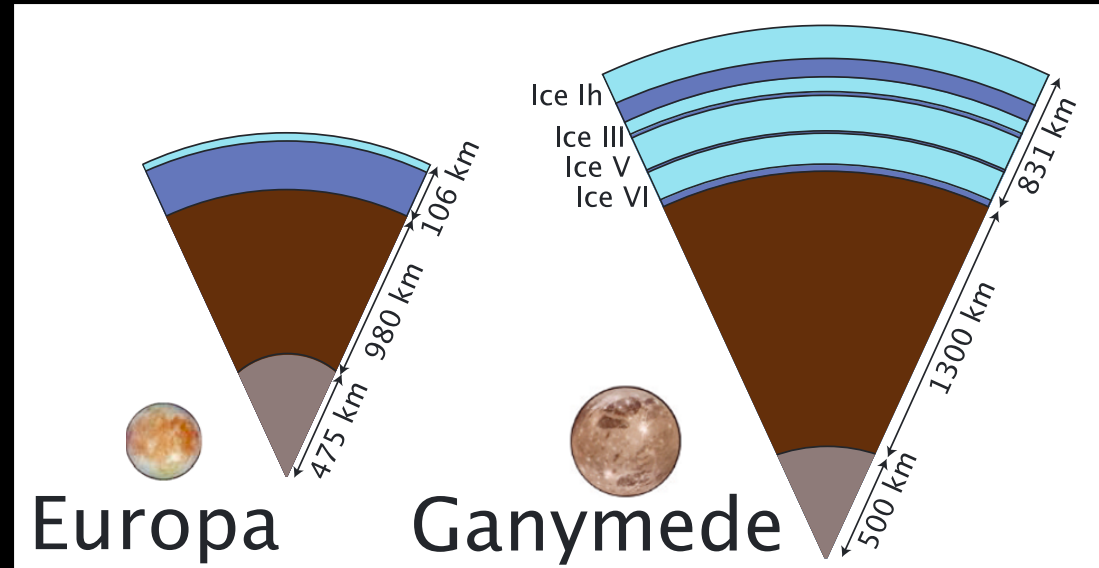


Chloral Hydrate





Why studying surface ices ?



Vance et al., 2018

Differentiated:

- Metallic Core
- Rocky interior
- Water reservoirs
- Icy surfaces

Why studying surface ices ?

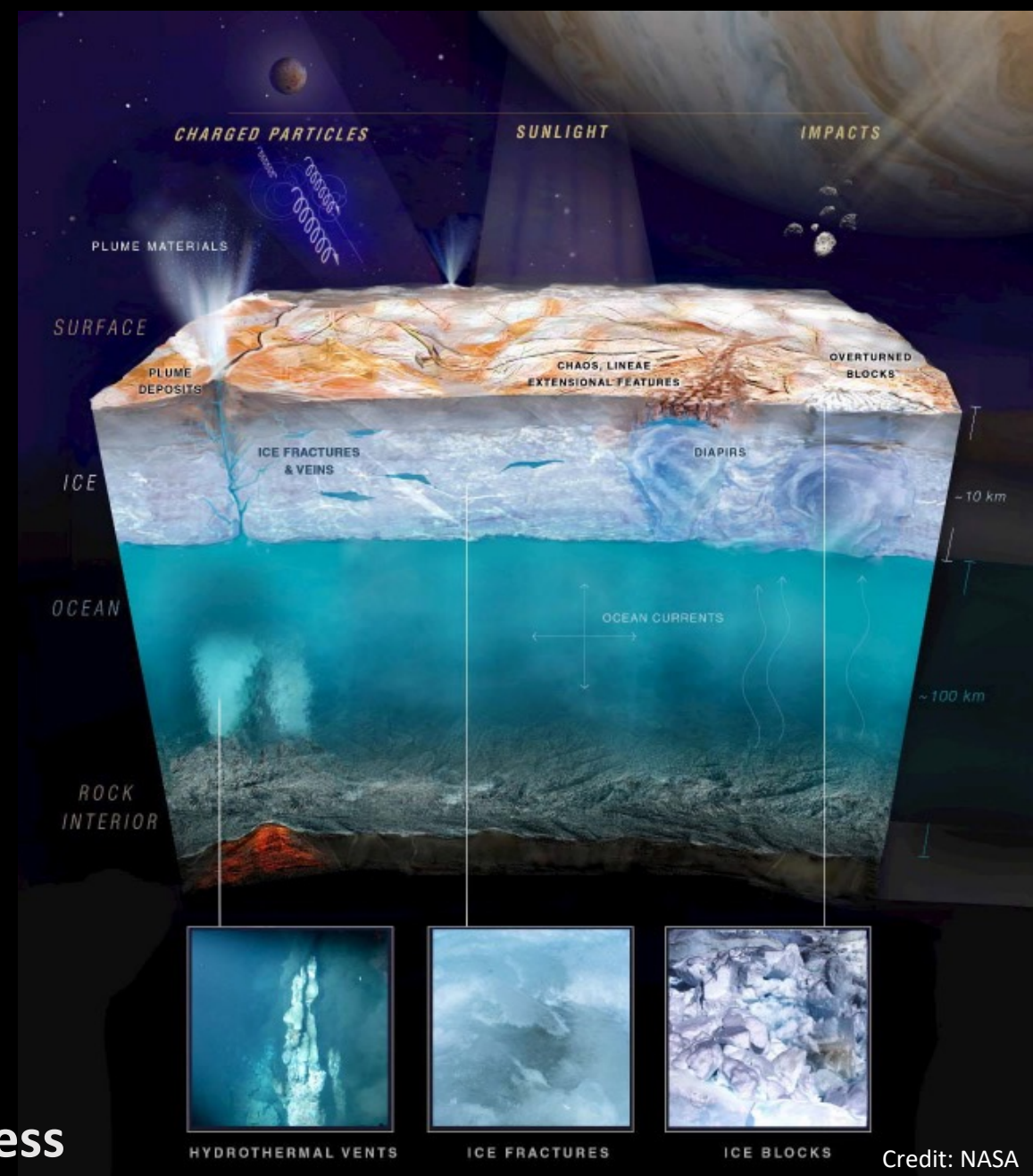
External processes

- Impacts
- Charged Particles
- Sunlight

Internal processes

- Cryovolcanism
- Diapirism
- Geyser/Plumes

Surface microphysics:
composition, grain size, porosity, roughness

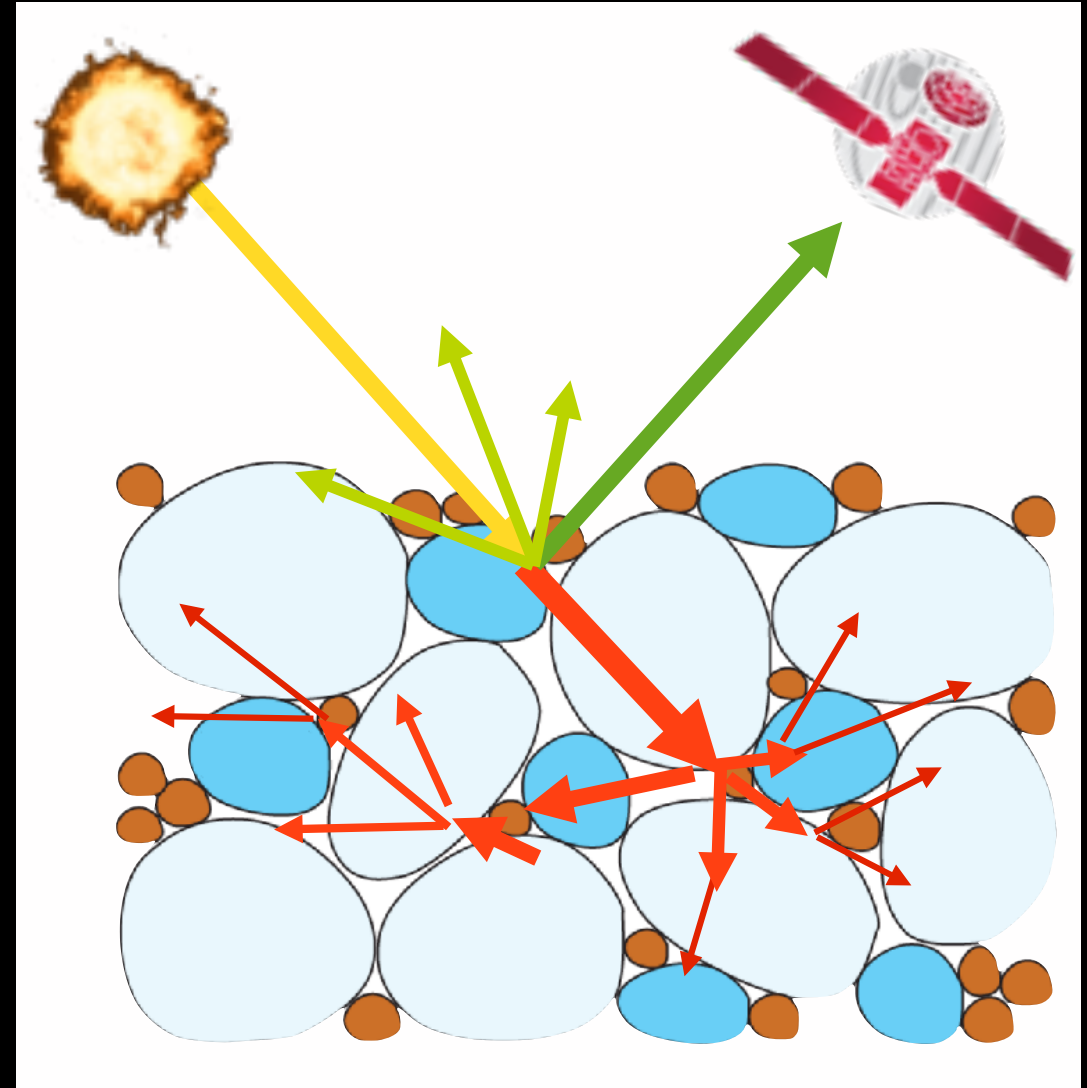


Credit: NASA

Method: reflectance spectroscopy

Complex light-matter interactions

- Reflection
- Absorption
- Transmission
- Scattering



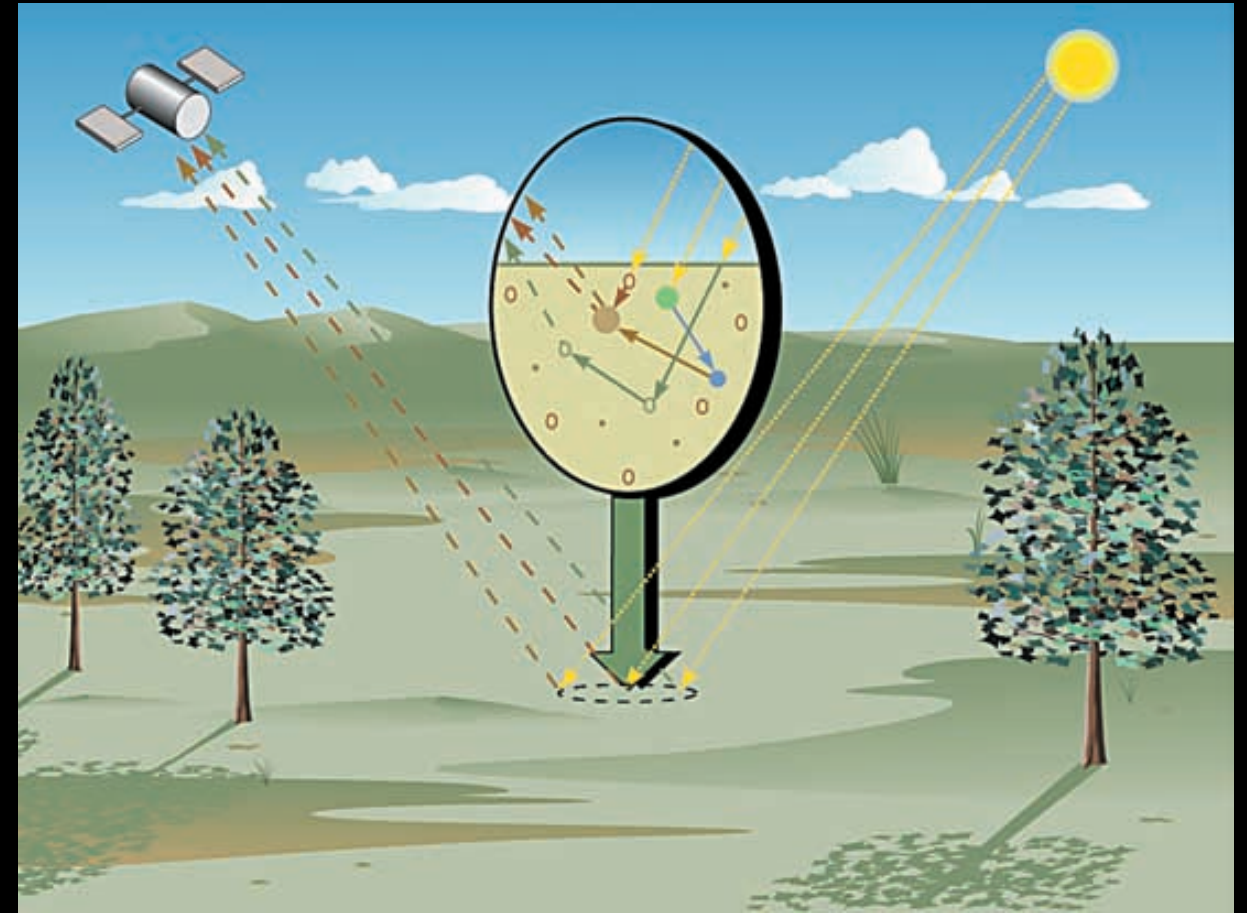
Light-matter interaction in a granular medium

Method: reflectance spectroscopy

Intimate mixing model (Hapke, 1993, 2012)

- Single scattering albedo: ω
- Particle phase function: $P(\mathbf{g})$
- Multiple Scattering: $H(\mu)$
- Opposition effect: $B(\mathbf{g})$
- Surface roughness: S

$$r(\mu_0, \mu, g) = \frac{\omega}{4\pi} \frac{\mu_0}{(\mu_0 + \mu)} \{ [1 + B(g)] P(g) + H(\mu_0)H(\mu) - 1 \} S(\mu_0, \mu, g)$$

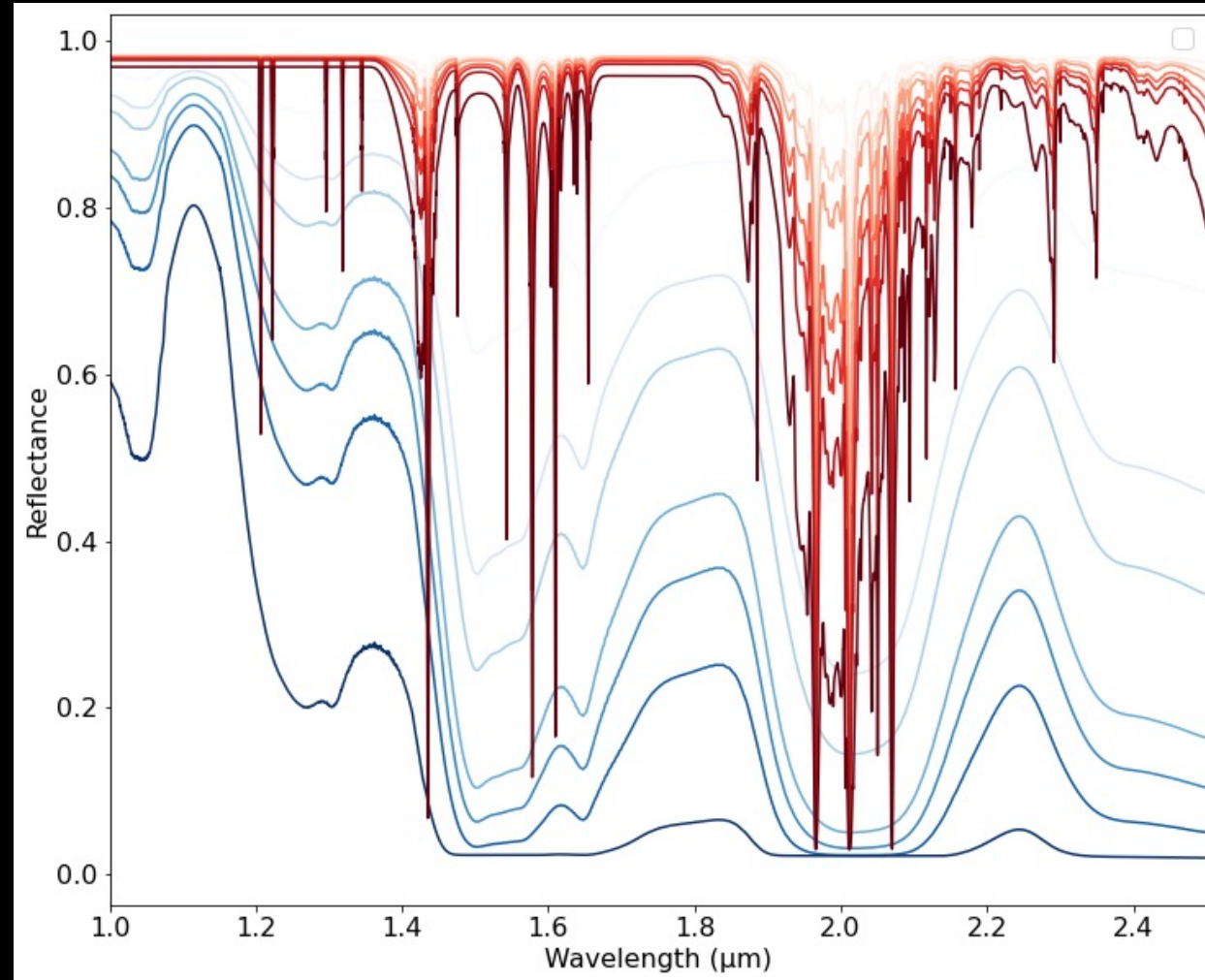


The intimate mixing (Keshava & Mustard, 2002)

Direct modelling

Reflectance spectrum:

- Volume abundance
- Grain size
- Surface roughness
- Geometry
- Phase function



Grain Size

10
μm

CO₂
ice

H₂O
ice

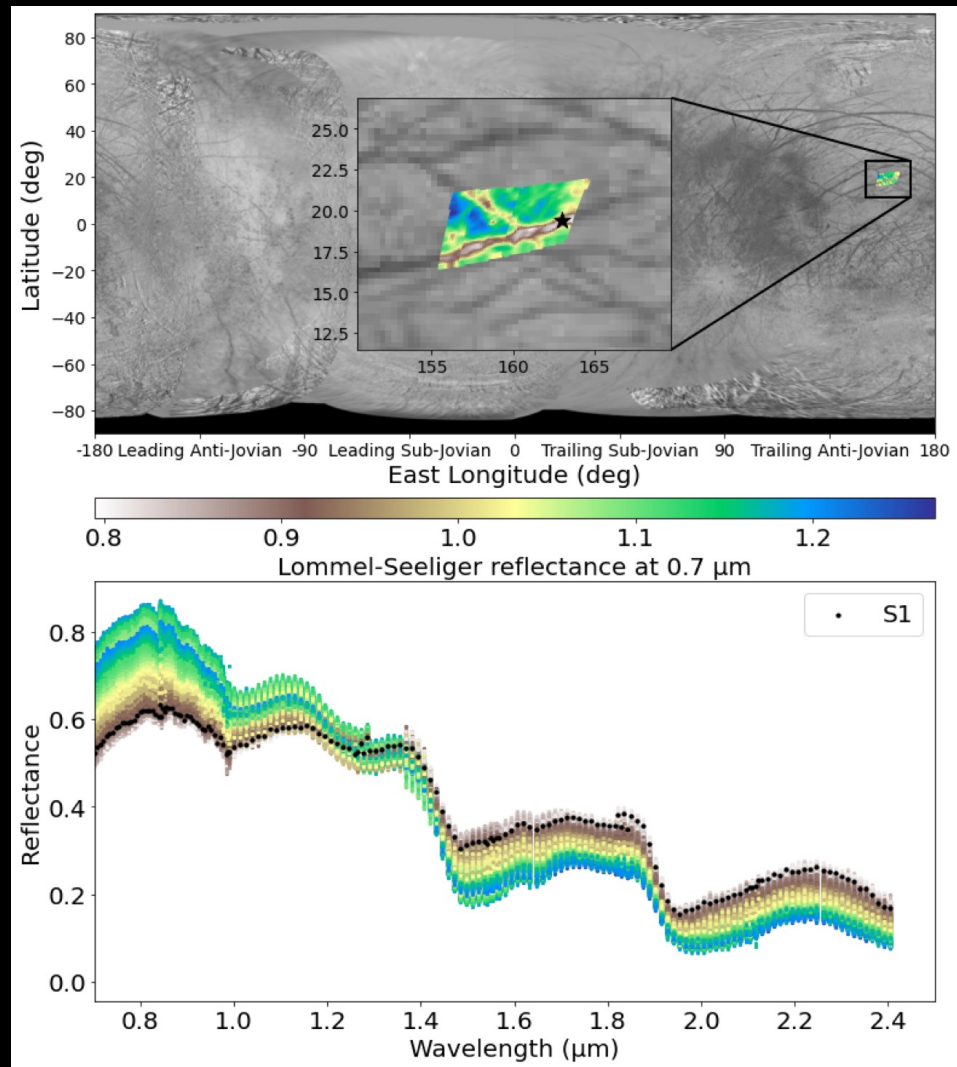
5000
μm



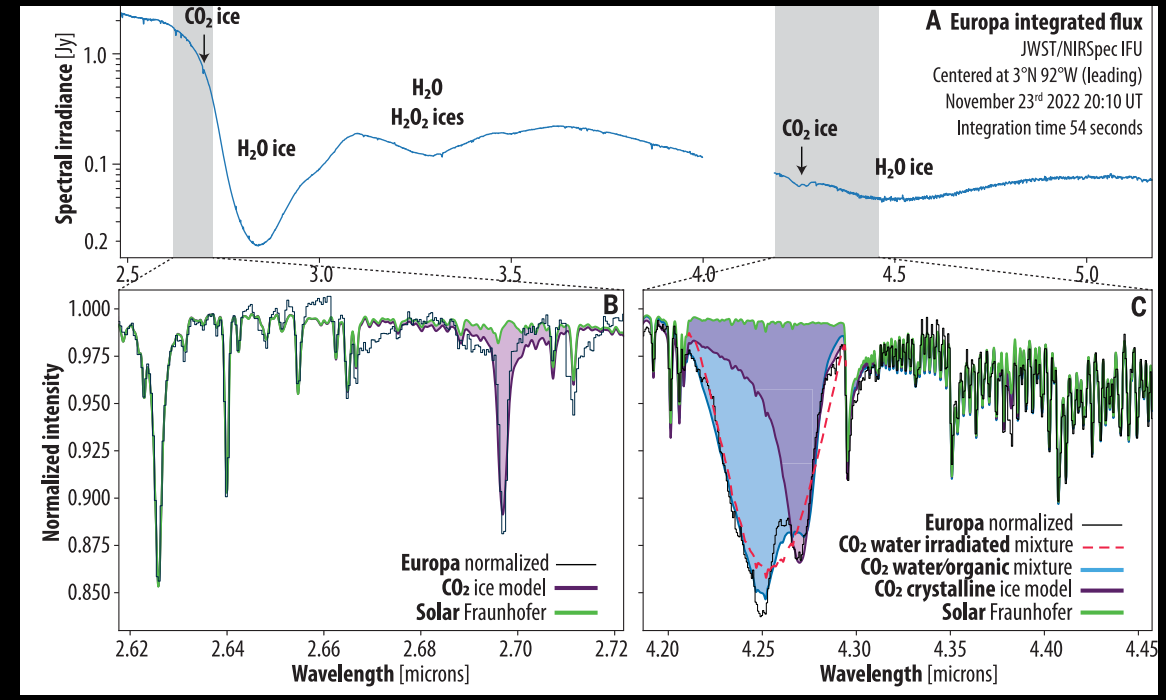
Access to these properties via inverse modelling

Datasets

Near Infrared Mapping Spectrometer (NIMS) Galileo mission, NASA



James Webb Space Telescope

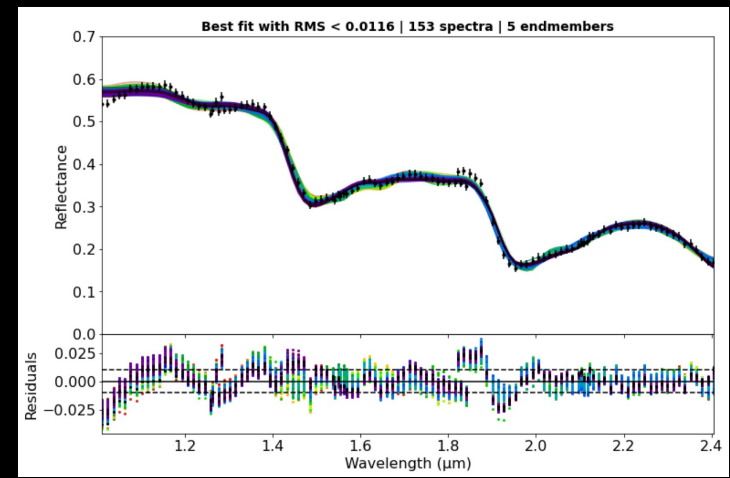
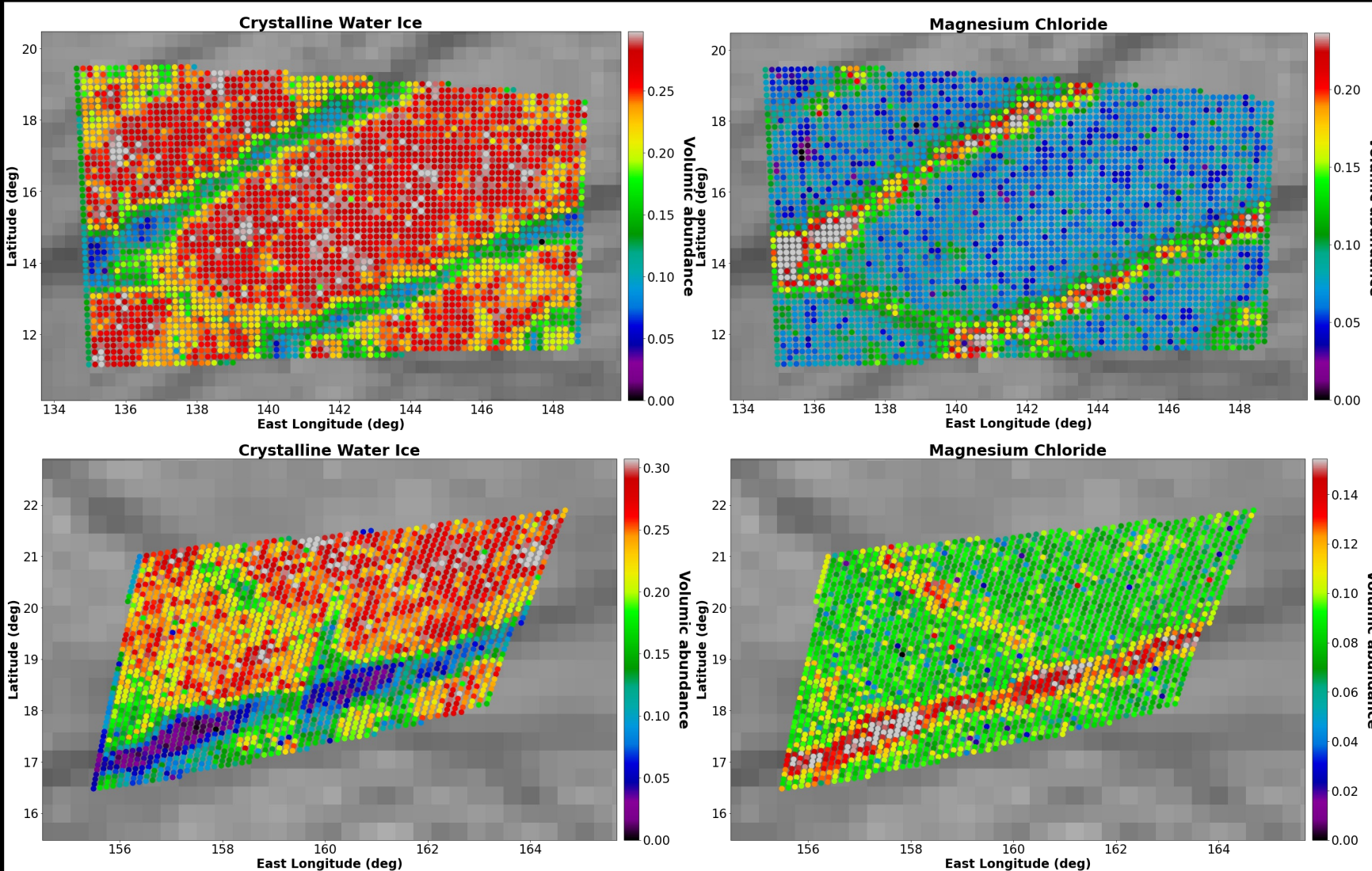


Villanueva et al. (2023)

Europa: Cycle 1, 1250, Guaranteed Time Observations (GTO), PI : Dr. Geronimo Villanueva
Ganymede: Cycle 1, 1373, Early Release Science Programs (ERS). PI : Pr. Imke de Pater

Results: NIMS

Radiative transfer (Hapke, 2012) + Bayesian MCMC framework



**Water ice drops
within lineaments**

**Magnesium Chloride
increase toward lineaments**

**Dark lineaments a
preferential location for
material exchange ?**

Results: JWST

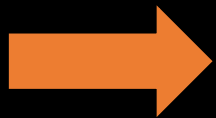
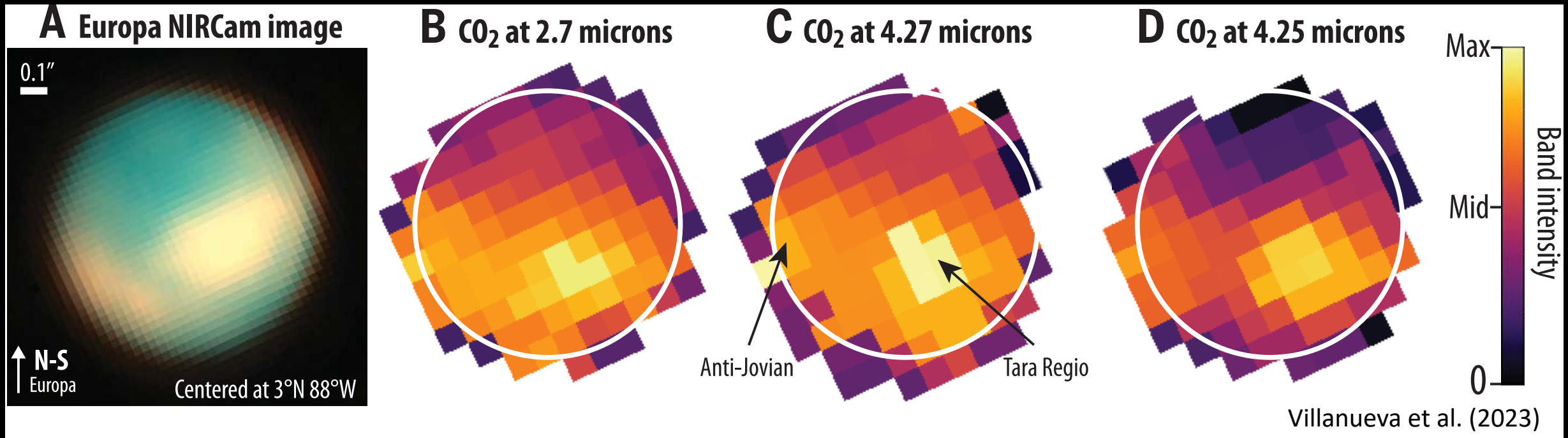
NIRSpec (band fitting) + NIRCams (mapping)

RESEARCH ARTICLE

ICY MOONS

Endogenous CO₂ ice mixture on the surface of Europa and no detection of plume activity

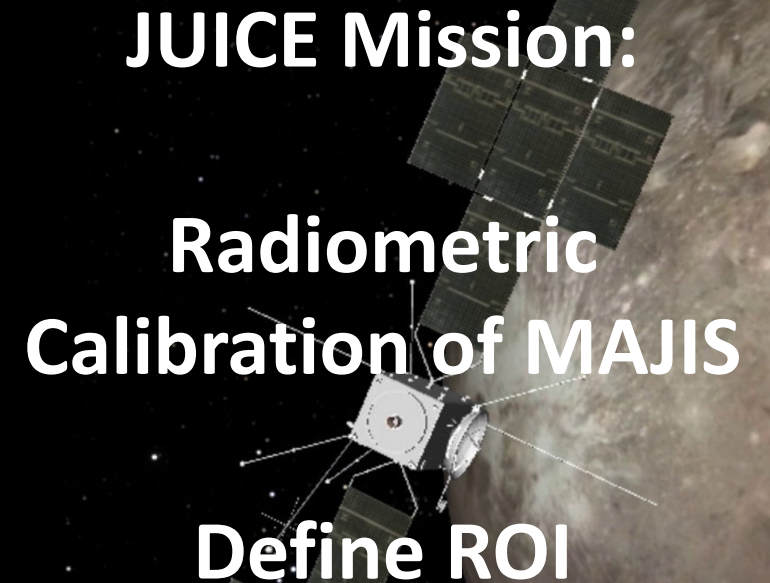
G. L. Villanueva^{1*}, H. B. Hammel², S. N. Milam¹, S. Faggi^{1,3}, V. Kofman^{1,3}, L. Roth⁴, K. P. Hand⁵, L. Paganini⁶, J. Stansberry⁷, J. Spencer⁸, S. Protopapa⁸, G. Strazzulla⁹, G. Cruz-Mermy¹⁰, C. R. Glein¹¹, R. Cartwright¹², G. Liuzzi¹³



CO₂ ice strongly correlated with chaos units !
Carbon source within Europa ?

Conclusions & Perspectives

- **Microphysical properties** accessible via Radiative Transfer modelling
- First maps of the microphysical properties of Europa !
- Combining JWST **High Spec. Res** with NIMS Spatial Res.
- Fusion of NIRSpec & NIRCам
- Proposal for future JWST observation of Ganymede



JUICE Mission:
Radiometric Calibration of MAJIS
Define ROI

The image shows the JUICE spacecraft in orbit around Europa. The spacecraft is a complex structure with multiple solar panel arrays and instruments. The planet Europa is visible in the background, showing its characteristic reddish-brown color and numerous impact craters. The text is overlaid on the right side of the image, indicating the mission's focus on radiometric calibration and defining regions of interest (ROI) for the MAJIS instrument.

On going & future collaborations:

GEOPS: F. Schmidt, F. Andrieu ; **IPAG:** B. Schmitt, E. Quirico ; **ESAC:** T. Cornet ; **OBSPM:** T. Fouchet, D. Bockelee-Morvan ; **IAS:** F. Poulet. ; **NASA-Goddard:** G. Villanueva