

ENERGETIC PROCESSING OF THE SURFACES OF THE ICY MOONS

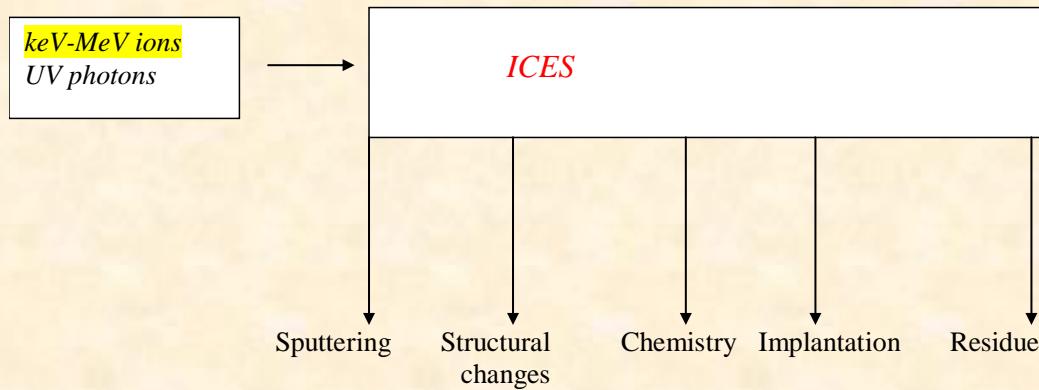
Giovanni Strazzulla

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Experimental study of the effects induced by fast ions on solids of astrophysical interest have been performed in several laboratories in the world

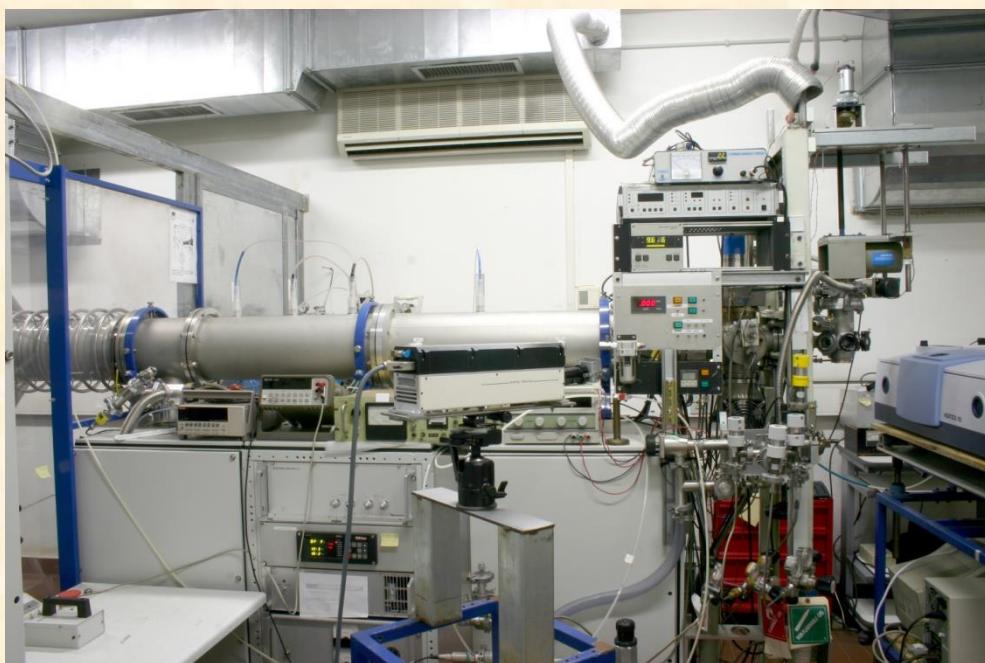


Techniques of analysis :

IR Spectroscopy

Raman Spectroscopy

Mass Spectrometry



LASp (Catania, Italy)



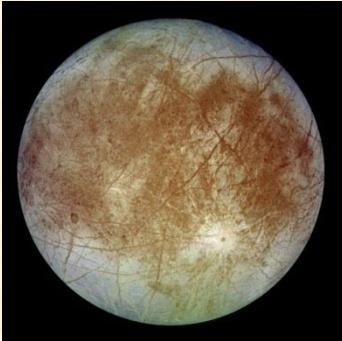
GANIL Laboratories (Caen, France)



Sackler Laboratory for Astrophysics (Leiden, The Netherlands)



Keck Research Laboratory in Astrochemistry (Honolulu, USA)



Europa



Ganymede



Callisto

Near IR observations made by the NASA *Galileo* spacecraft showed that:



- ▶ On Io SO_2 ice is dominant
- ▶ On Europa, Callisto and Ganymede H_2O ice is dominant
- ▶ Other absorption features (*) and their prime candidates are:

3.4 μm (~2940 cm^{-1})	C-H
3.5 “ (~2857 cm^{-1})	H_2O_2
3.88 “ (~2580 cm^{-1})	S-H, H_2CO_3 **
4.05 “ (~2470 cm^{-1})	SO_2
4.25 “ (~2350 cm^{-1})	CO_2
4.57 “ (~2190 cm^{-1})	CN

* McCord *et al.*, 1997a,b

** Hage *et al.* 1998.

A still open question is to understand if those species are **native** from the satellites or are **synthesized** by exogenic processes such as ion implantation.

Ion fluxes

	Energy	input (%)	Flux ($\text{cm}^{-2}\text{s}^{-1}$)
Solar Photons	2 eV	Visible (50%)	2.0×10^{17}
	4 eV	NUV (10%)	1.5×10^{16}
	6 eV	FUV (0.02%)	3.0×10^{13}
Solar Wind (1 AU)	1 keV	H ⁺ (95%)	3.0×10^8
	4 keV	He ²⁺ (5%)	
Solar Flares (1 AU)	> 1 MeV	H ⁺ (95%)	10^{10} ($\text{cm}^{-2}\text{yr}^{-1}$)
	> 1 MeV	He ²⁺ (5%)	
Galactic cosmic rays	> 1 MeV	H ⁺ (87%)	≤ 10
	> 1 MeV	He ²⁺ (12%)	

In the laboratory

Ion Energy	Fluxes $\text{cm}^{-2}\text{s}^{-1}$
< 1 MeV	10^{11} - 10^{13}
> 1 MeV	10^8 - 10^{10}

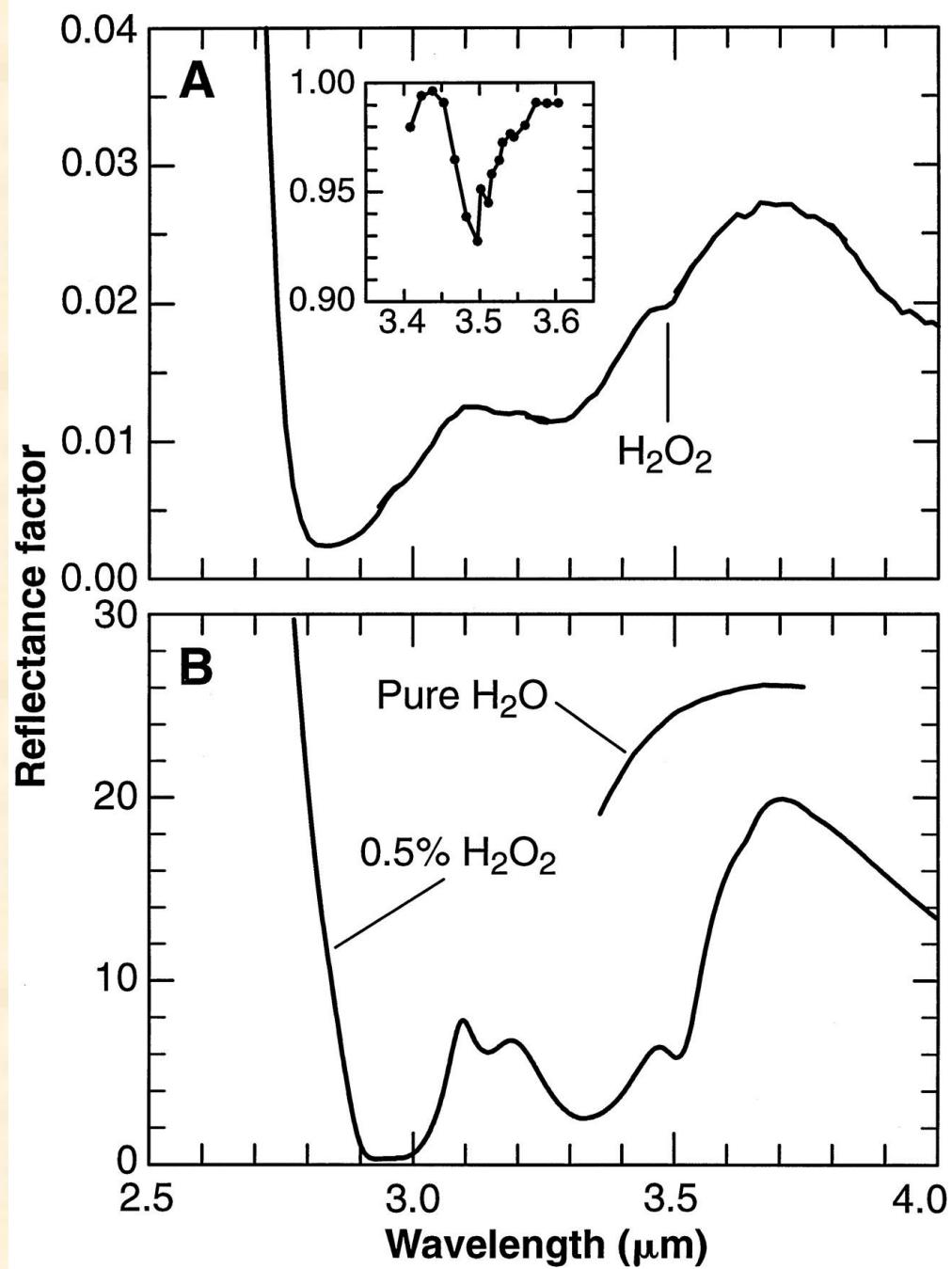
Global Average Energy Flux
in $\text{keV}/(\text{cm}^2\text{s})$

Io	1×10^9
Europa	4×10^{10} 8×10^{10}
Ganymede	5×10^9 poles 2×10^8 equator
Callisto	2×10^8

After Johnson et al. 2004. In: Bagenal et al. (Eds.), Jupiter: Planet, Satellites, and Magnetosphere. Cambridge Univ. Press, Cambridge, UK, p. 485

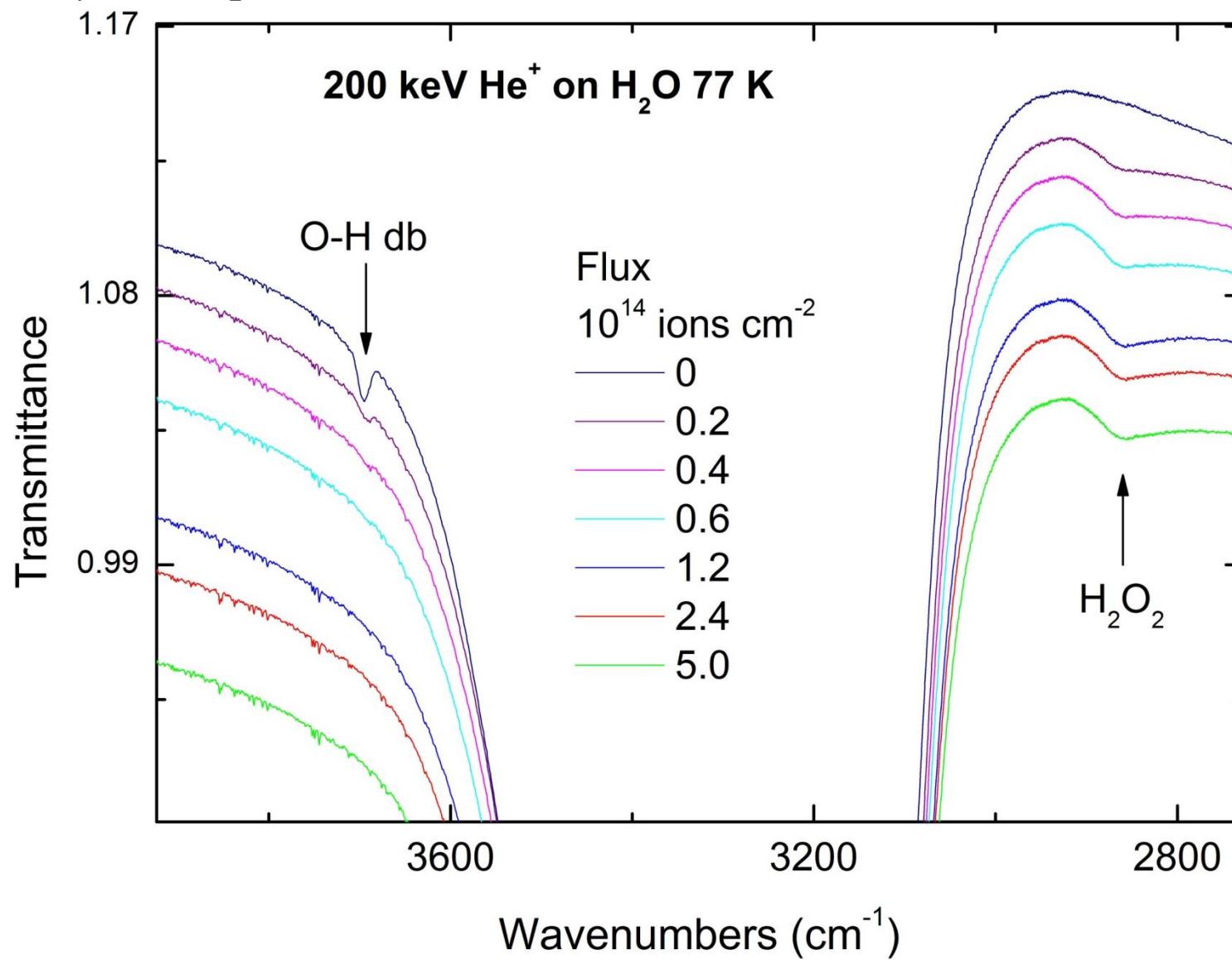
Carlson *et al.*
(Science 283, 2062, 1999)

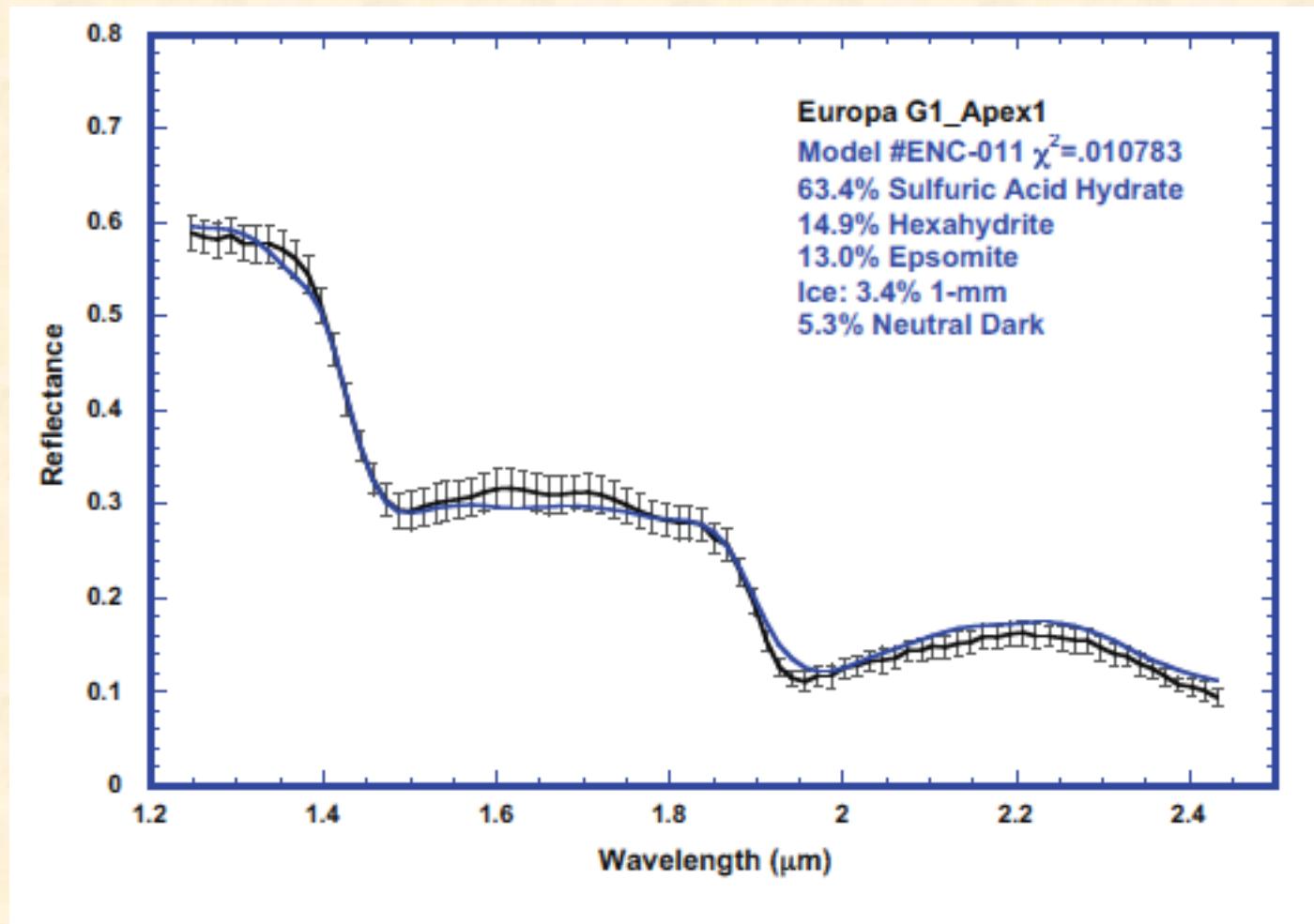
- H_2O_2 found on the surface of Europa by Galileo NIMS spectra
- Radiolysis is supposed to be
The formation mechanism



O. Gomis, M. A. Satorre, G. Strazzulla, G. Leto

Planetary and Space Science 52, 371 (2004)

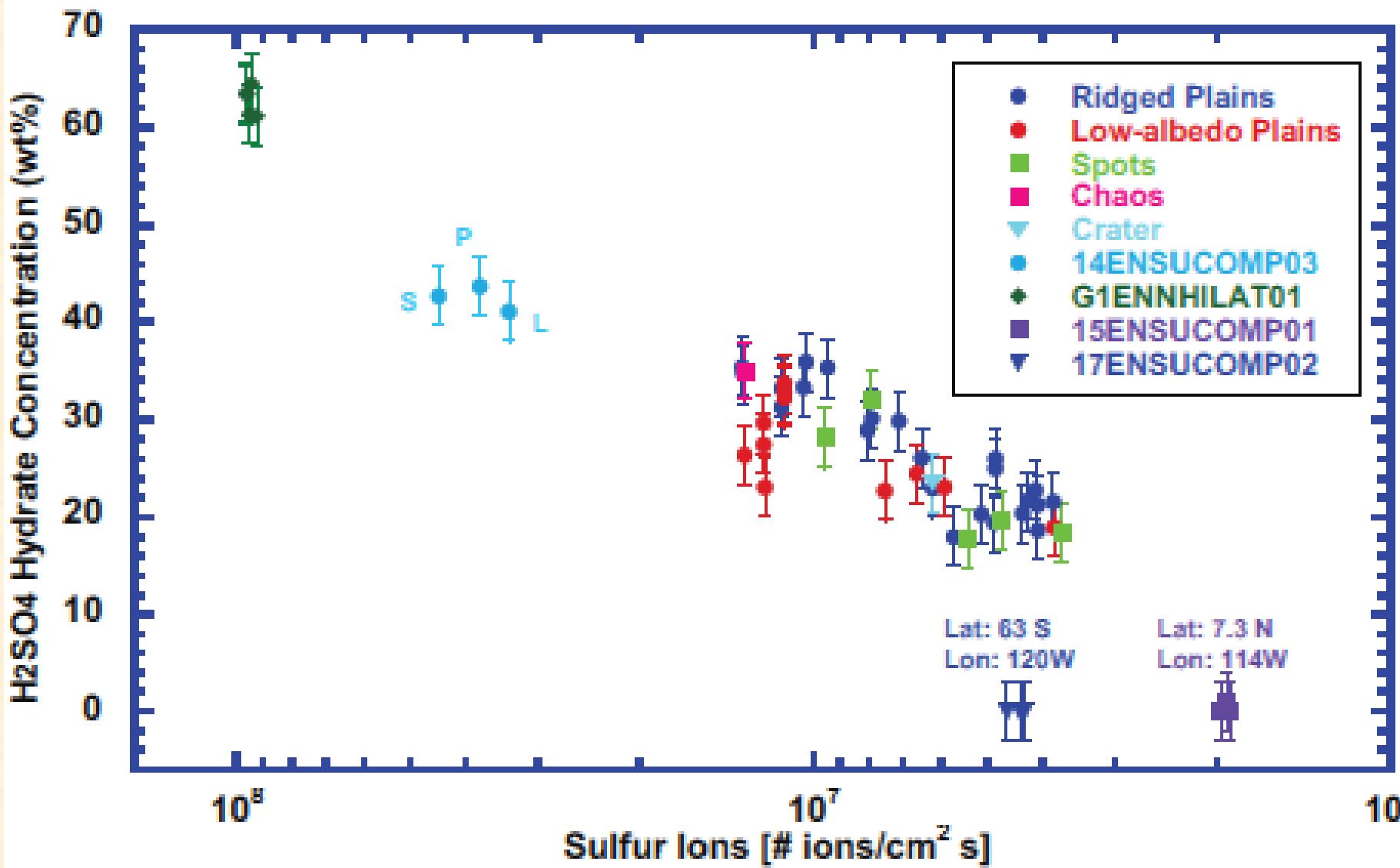




Sulfuric acid (H_2SO_4) Hydrate

Hexahydrite: $\text{MgSO}_4 \cdot 6(\text{H}_2\text{O})$

Epsomite: $\text{MgSO}_4 \cdot 7(\text{H}_2\text{O})$





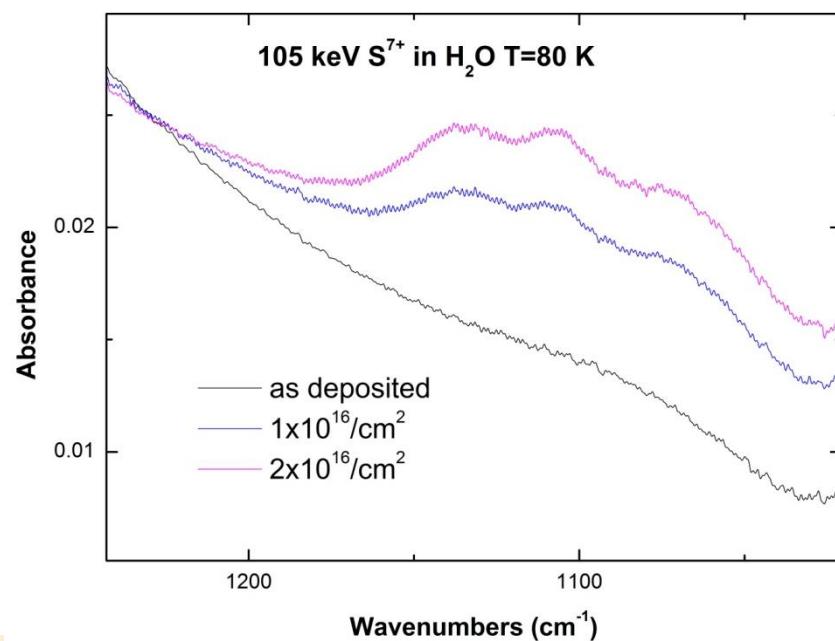
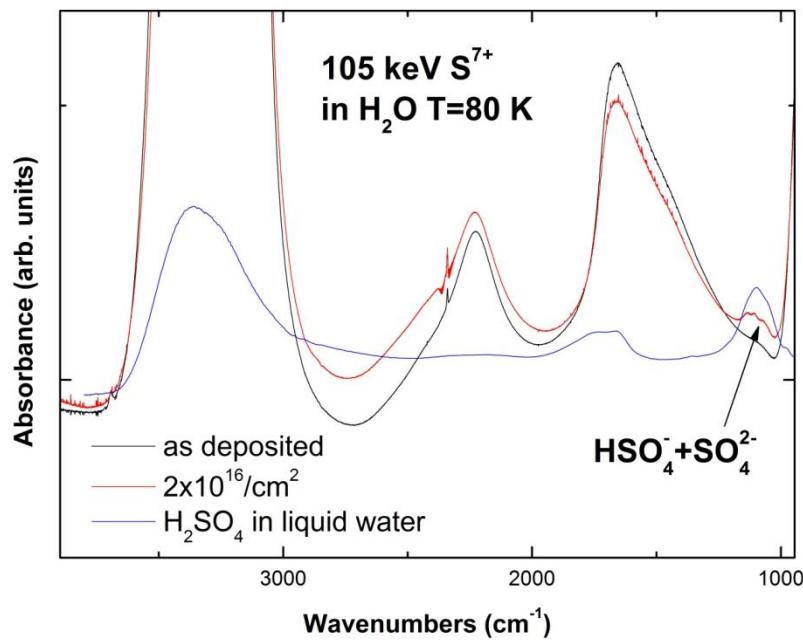
Implantation of multiply charged sulfur ions in water ice



J.J. Ding ^{a,*}, P. Boduch ^a, A. Domaracka ^a, S. Guilloux ^a, T. Langlinay ^a, X.Y. Lv ^a, M.E. Palumbo ^b, H. Rothard ^a, G. Strazzulla ^b

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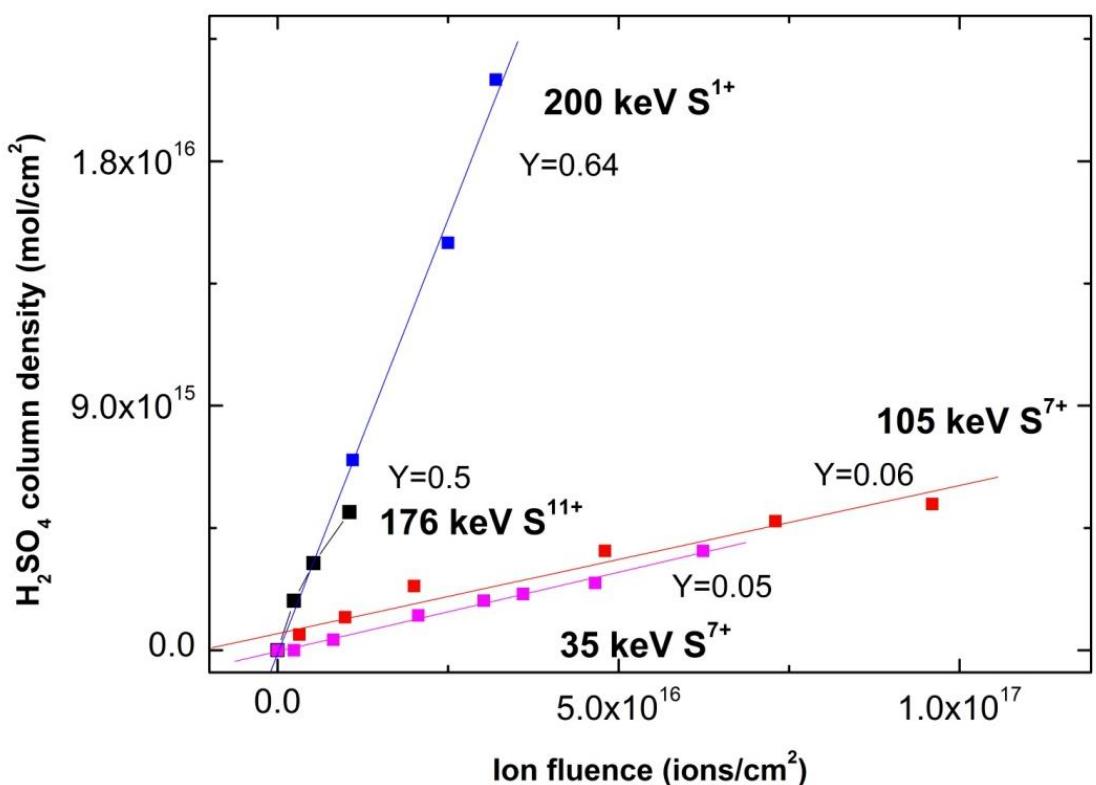
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We demonstrate that S -implantation efficiently forms hydrated sulfuric acid whose observed abundance is explained as caused by an exogenic process.

EUROPA: A NEW LOOK AT GALILEO UVS DATA. A. R. Hendrix¹ and R. E. Johnson², ¹Jet Propulsion Laboratory/California Institute of Technology, 4800 Oak Grove Dr., MS 230-250, Pasadena, CA, 91109 hendrix@jpl.nasa.gov, ²University of Virginia, Thornton Hall B103, PO Box 400238, Charlottesville, VA 22904, rej@virginia.edu.

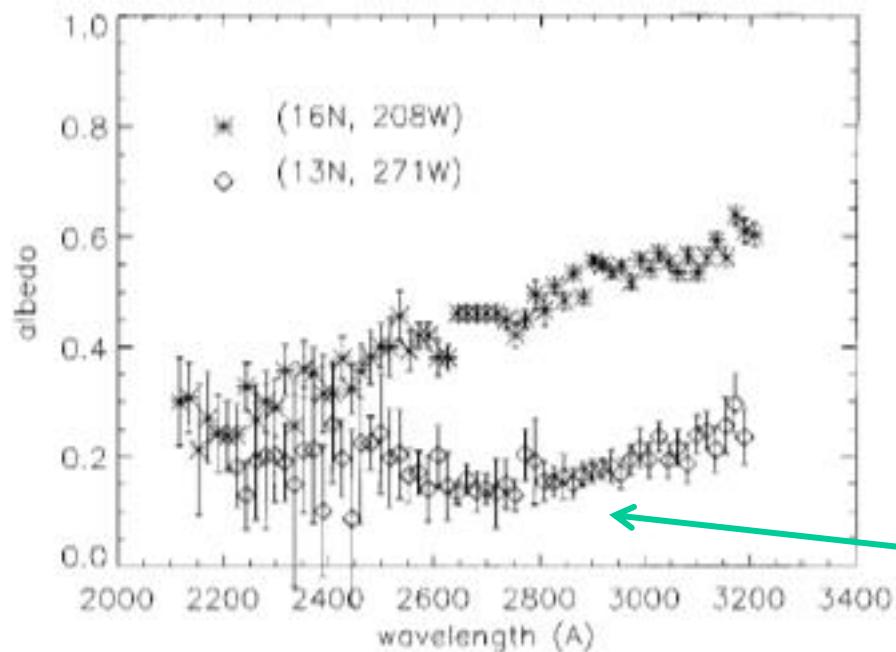


Fig. 1. Ultraviolet spectra for two disk-resolved regions on Europa, from the Galileo UVS [8]. At the apex of the trailing hemisphere (270° W), the 280 nm absorption band is prominent.

Frozen SO₂?

Endogen or Exogen?

UV-VIS, INFRARED, AND MASS SPECTROSCOPY OF ELECTRON IRRADIATED FROZEN OXYGEN AND CARBON DIOXIDE MIXTURES WITH WATER

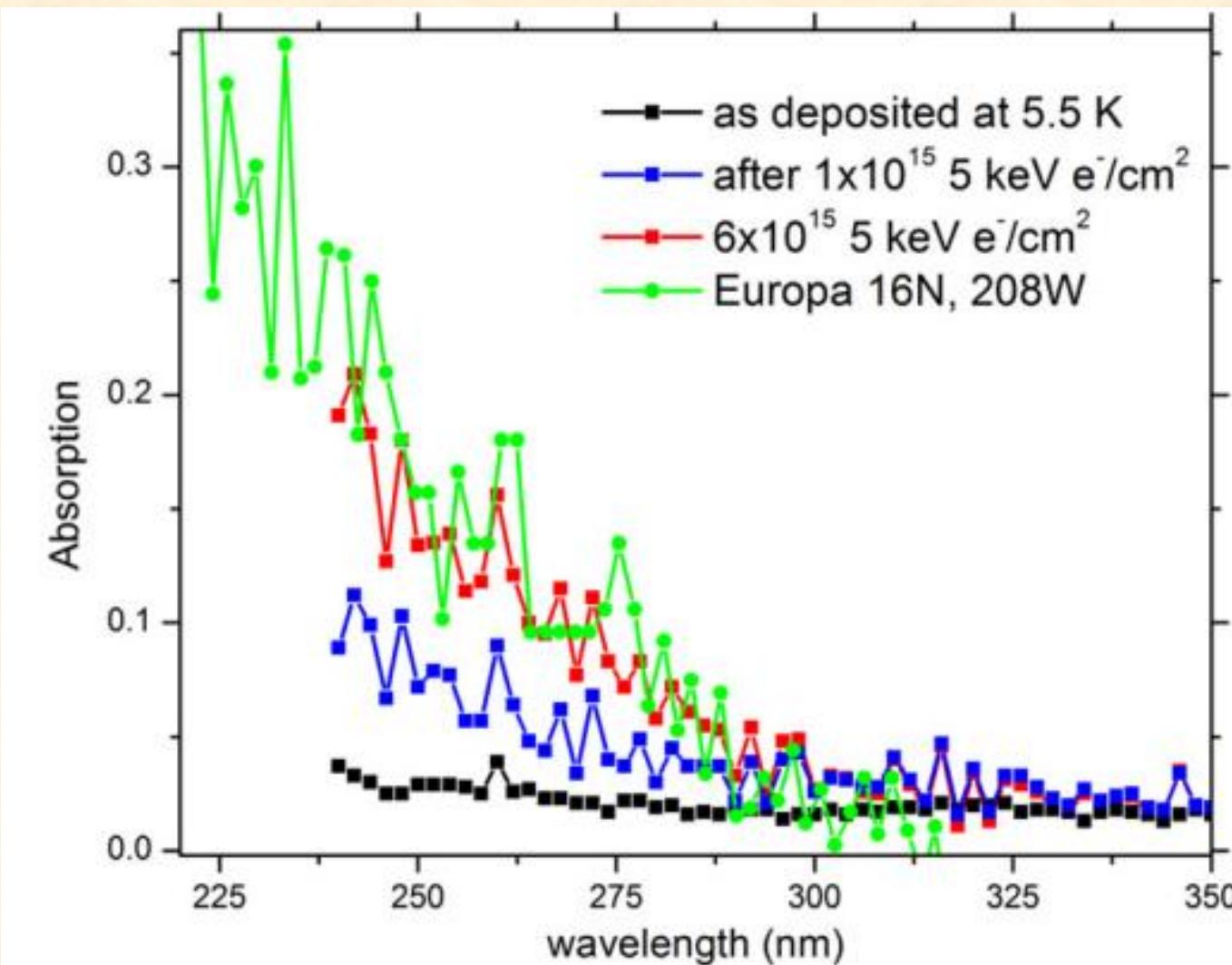
BRANT M. JONES^{1,2}, RALF I. KAISER^{1,2}, AND GIOVANNI STRAZZULLA³

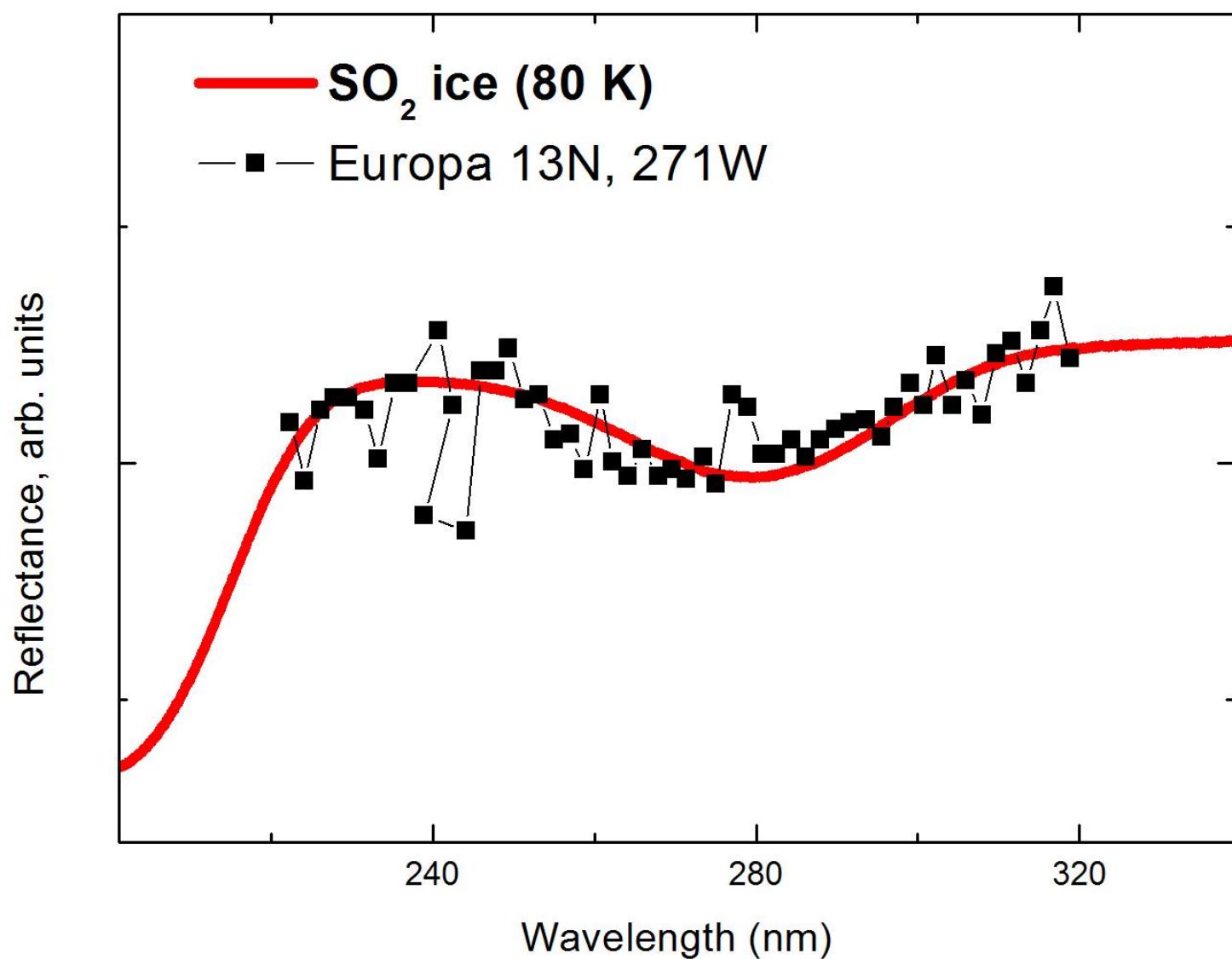
¹ W. M. Keck Research Laboratory in Astrochemistry, Department of Chemistry,
University of Hawaii at Manoa, Honolulu, HI 96822, USA

² NASA Astrobiology Institute, University of Hawaii at Manoa, Honolulu, HI 96822, USA

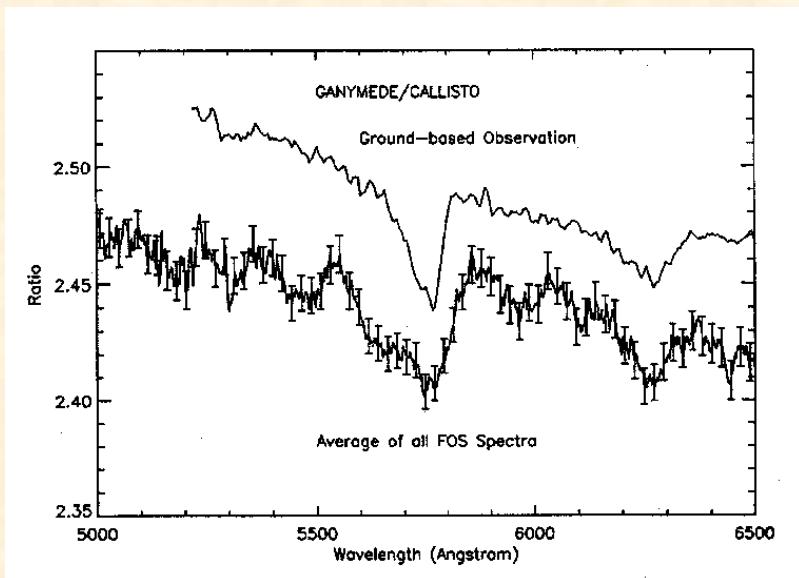
³ INAF-Osservatorio Astrofisico di Catania, Via S. Sofia 78, I-95123 Catania, Italy

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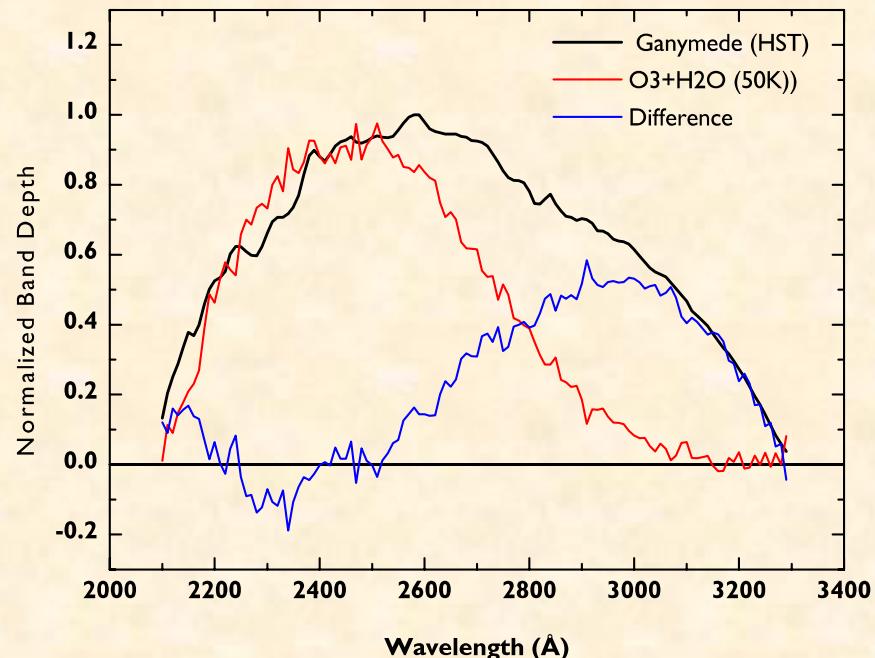




Ozone on Ganymede



Vidal, Bahr, Baragiola, Peters,
Science 276, 1839 (1997)



Teolis, Loeffler, Raut, Famà, Baragiola,
ApJ 644, L141 (2006)

UV-VIS, INFRARED, AND MASS SPECTROSCOPY OF ELECTRON IRRADIATED FROZEN OXYGEN AND CARBON DIOXIDE MIXTURES WITH WATER

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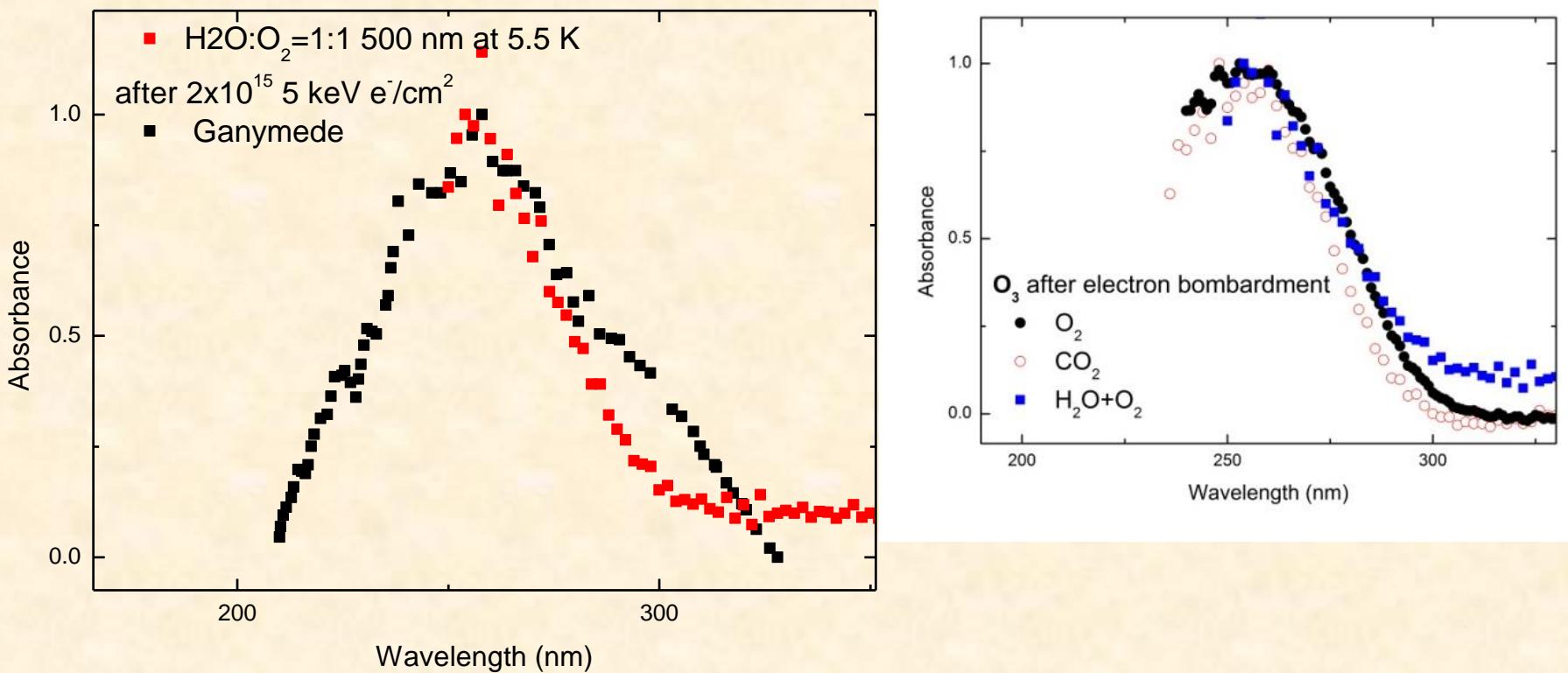
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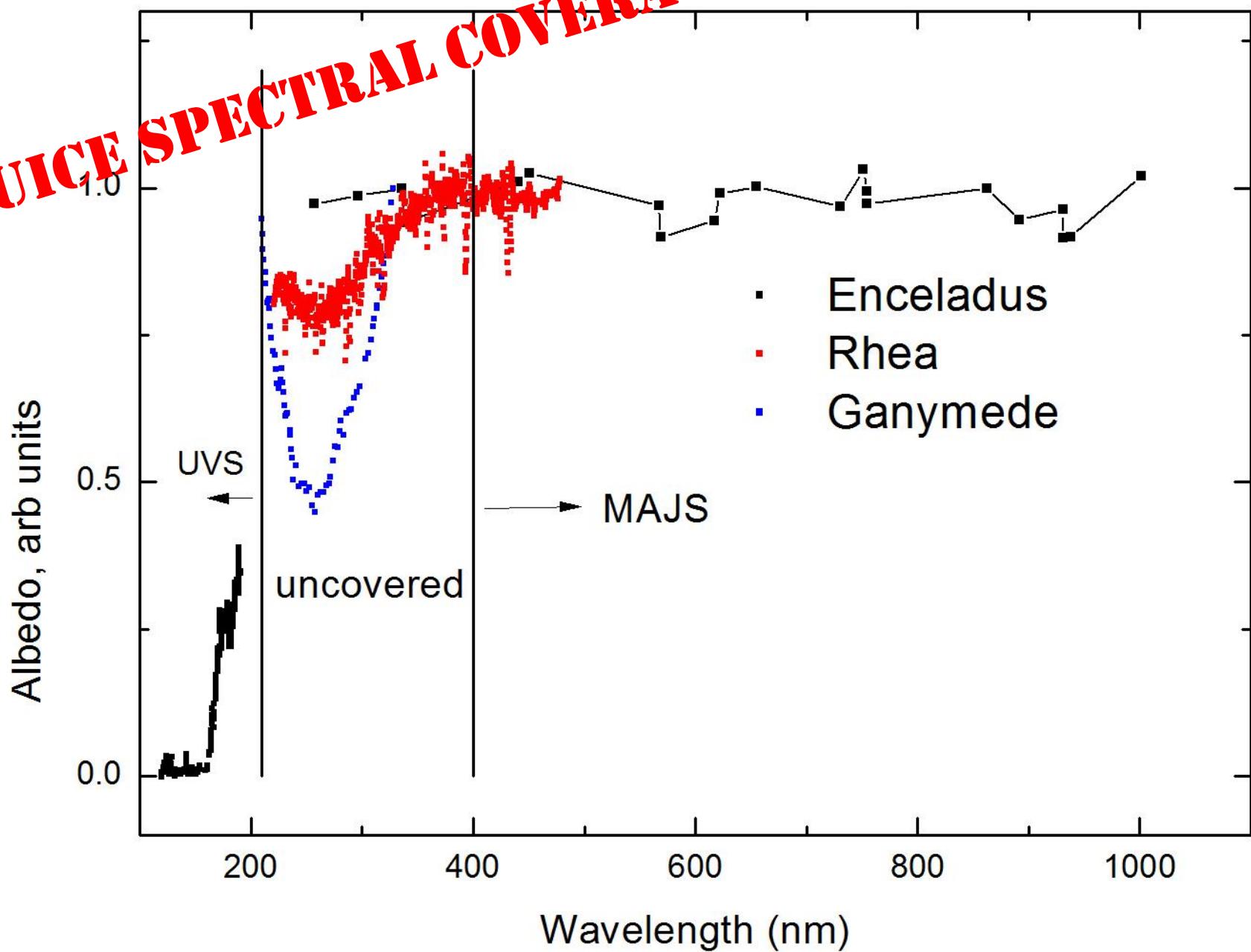
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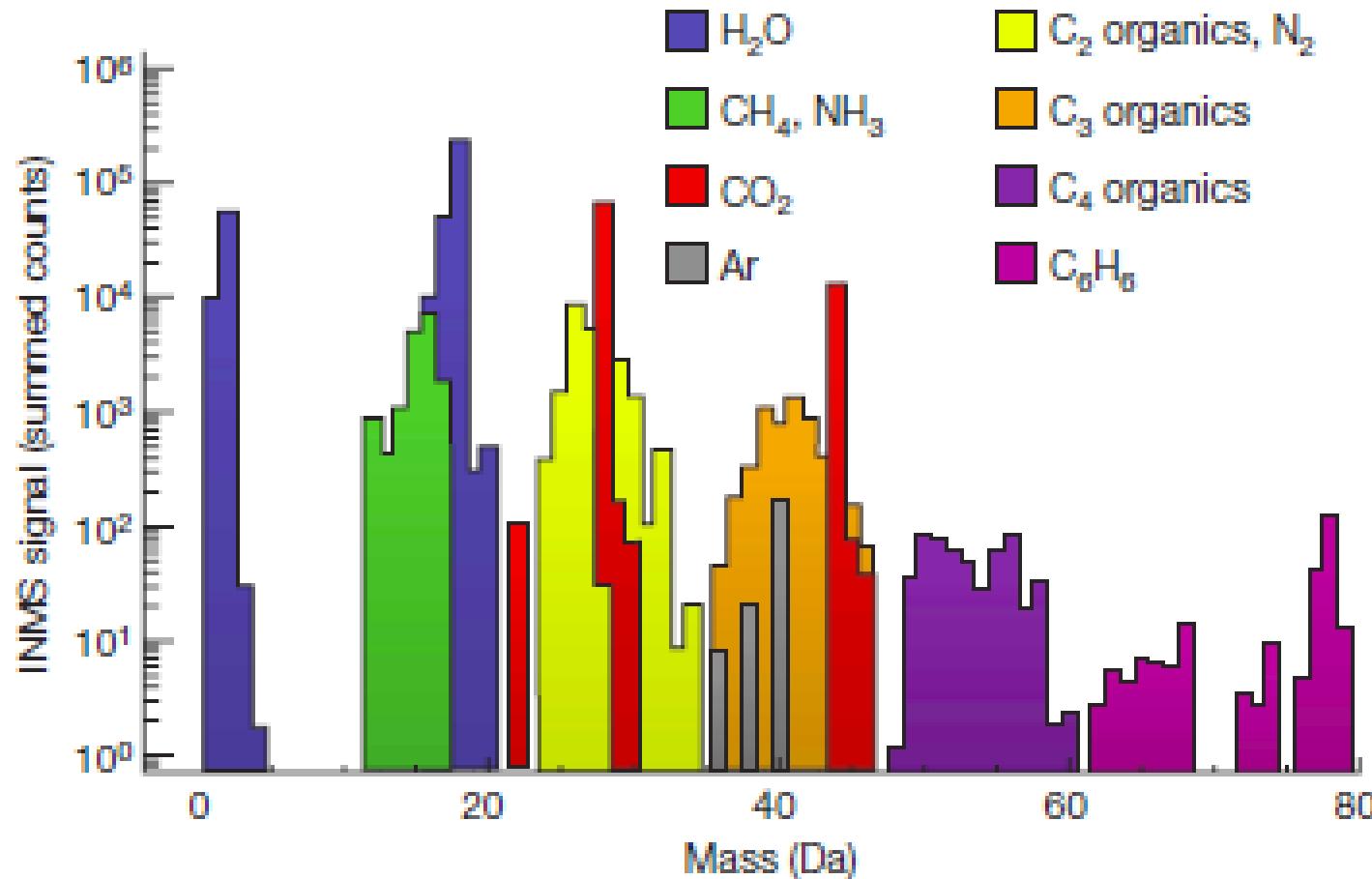


JUICE SPECTRAL COVERAGE



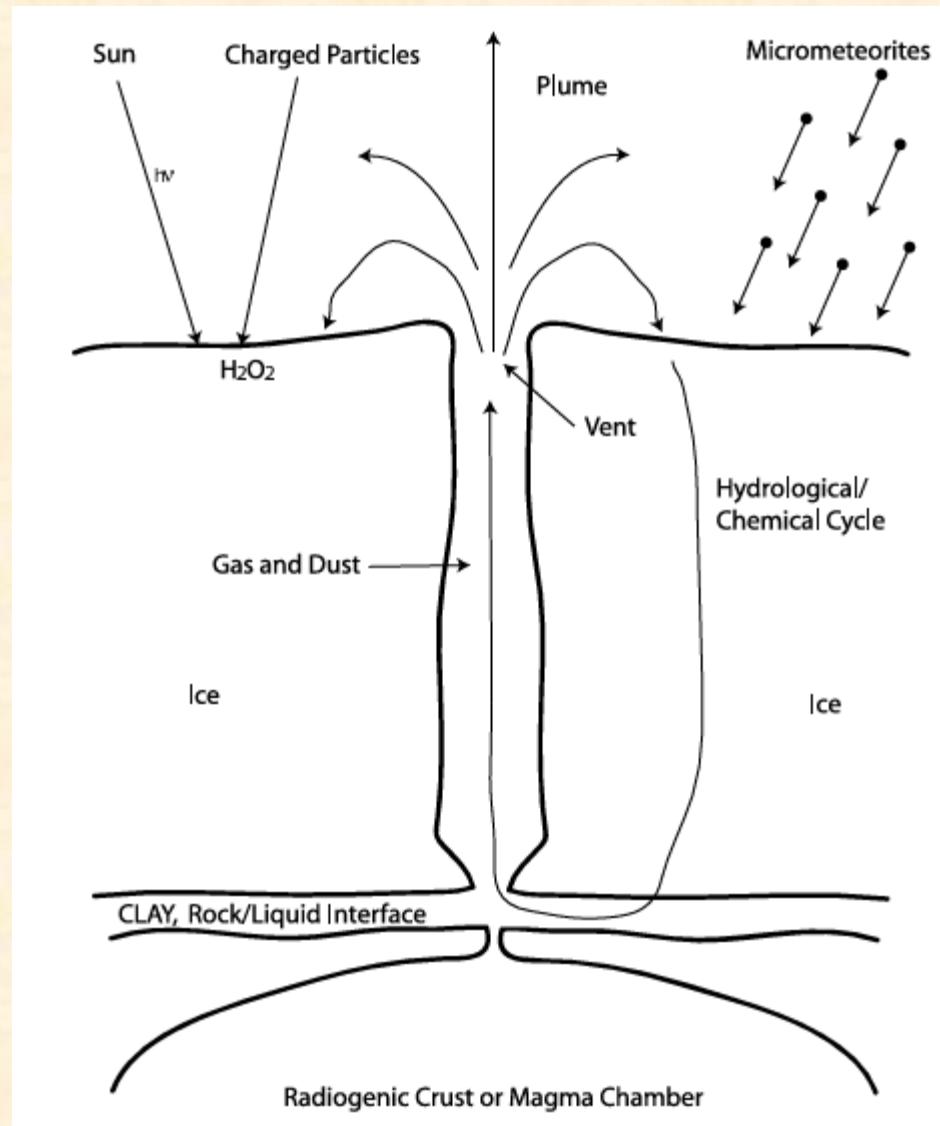
Liquid water on Enceladus from observations of ammonia and ^{40}Ar in the plume

J. H. Waite Jr¹, W. S. Lewis¹, B. A. Magee¹, J. I. Lunine², W. B. McKinnon³, C. R. Glein⁴, O. Mousis^{2,5}, D. T. Young¹, T. Brockwell¹, J. Westlake¹, M.-J. Nguyen¹, B. D. Teolis¹, H. B. Niemann⁶, R. L. McNutt Jr⁷, M. Perry⁷ & W.-H. Ip⁸



Parkinson, et al. “Enceladus: Cassini observations and implications for the search for life” A&A 463, 353-357, 2007.

Molecules	Column Density ^a
N ₂	6.0×10^{14}
H ₂ O	1.5×10^{16}
CO	$<1.3 \times 10^{14}$
CO ₂	$<1.8 \times 10^{17}$
O ₂	$<2.5 \times 10^{18}$
CH ₄	$<5.6 \times 10^{15}$
C ₂ H ₂	$<1.6 \times 10^{15}$
C ₂ H ₆	$<4.0 \times 10^{15}$
HCN	$<2.7 \times 10^{15}$
NH ₃	$<1.3 \times 10^{16}$
SO ₂	$<2.2 \times 10^{15}$
dust	$\sim 0.1 \text{ m}^{-3}$
electron	$\sim 100 \text{ cm}^{-3}$
N ⁺	$\sim 3\%$ of total ion
Organics	Detected in ice
CO ₂	Detected in ice



*We need more
experiments!*

What next?

- Irradiation of Ices: to use more sensitive techniques to evidence the formation of complex molecules and/or fragments that are of primary relevance for Astrochemistry/Astrobiology.
- SUPPORT the JUICE ESA Mission

Acknowledgments

INAF

ISTITUTO NAZIONALE DI ASTROFISICA
OSSERVATORIO ASTROFISICO DI CATANIA

Thank you!



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Rosario Brunetto (IAS-Orsay, France)

Daniele Fulvio (PUC Univ, Rio de Janeiro, Brazil)

Sergio Ioppolo (Open Univ, Milton Keynes, England)

Giuseppe Leto (INAF-Catania)

