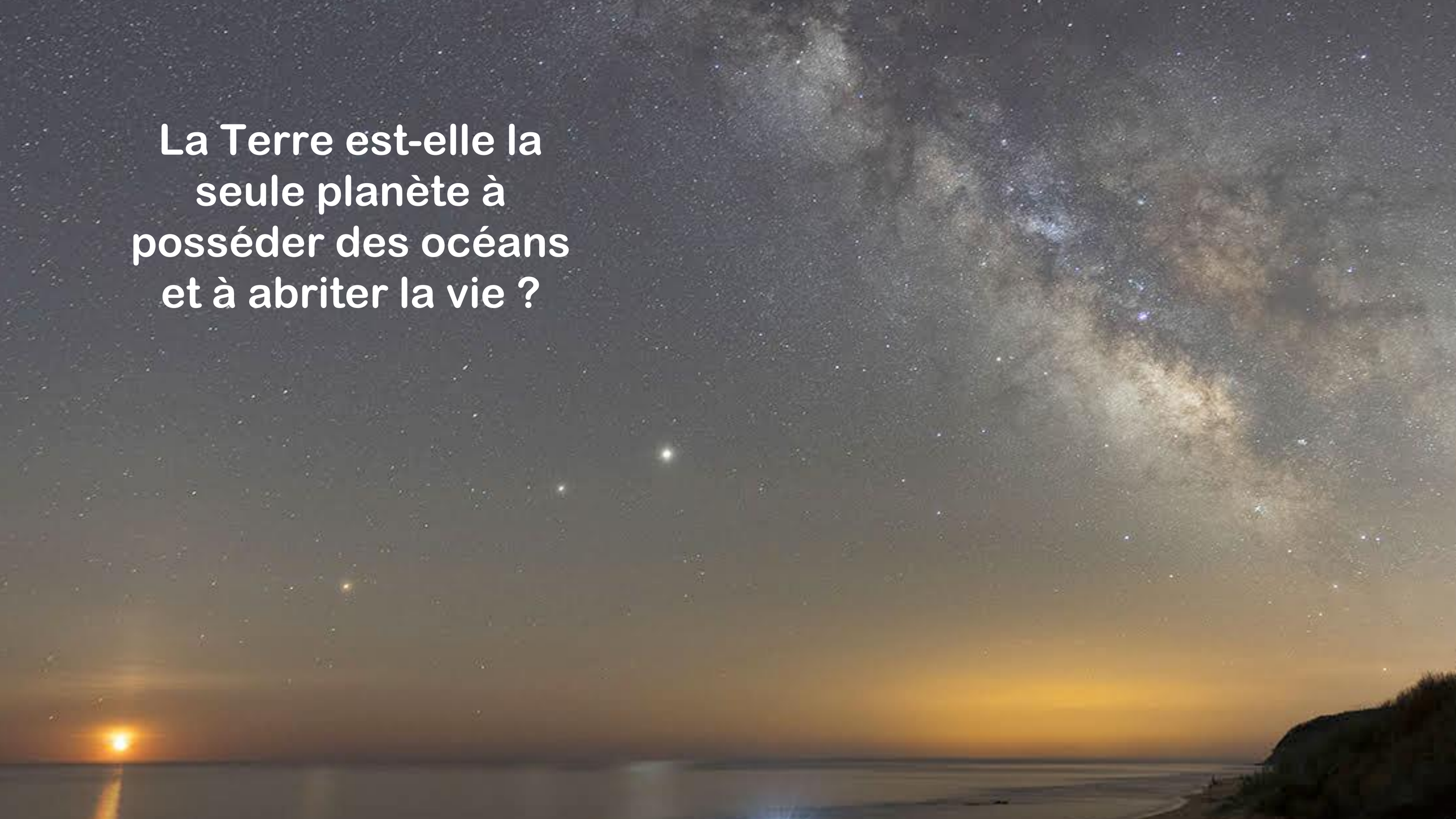
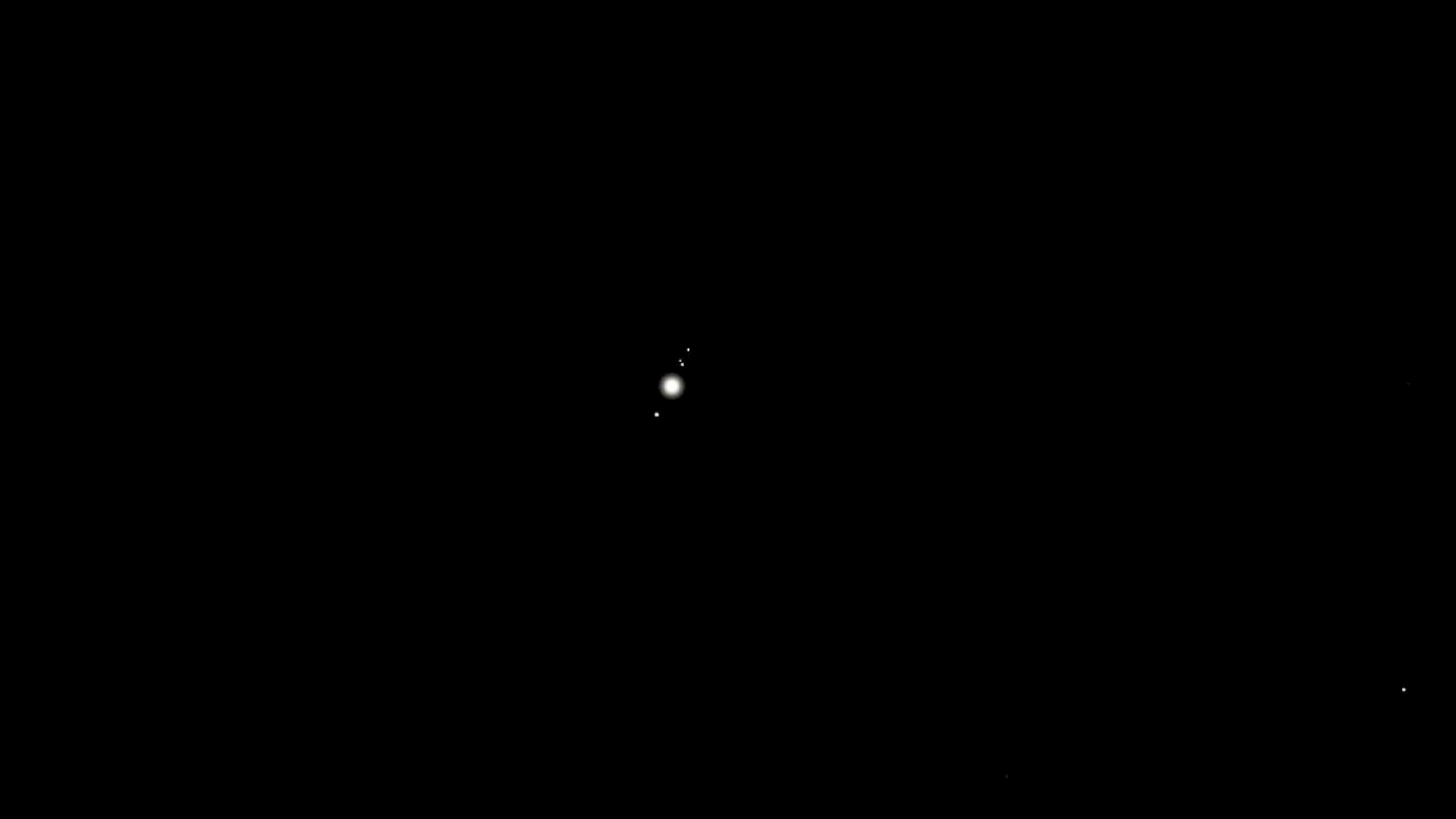
Les océans cachés des lunes de Jupiter et de Saturne

Gabriel TOBIE
Laboratoire de Planétologie et Géosciences
(CNRS, Nantes Université)


La Terre est-elle la seule planète à posséder des océans et à abriter la vie ?



Christiaan Huygens
Découverte de la lune principale de Saturne en 1655

Titan

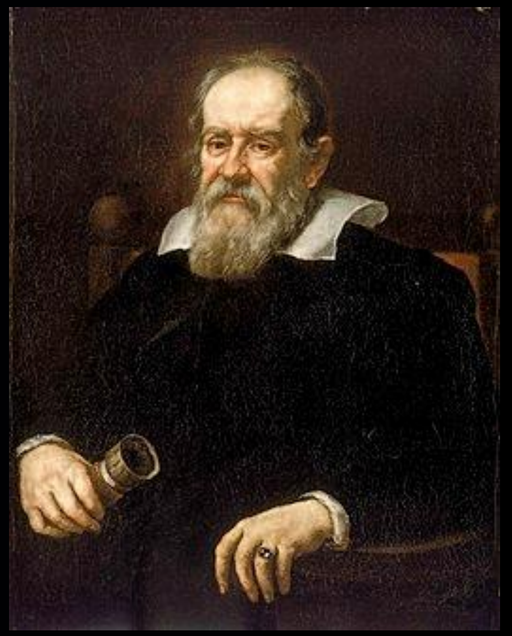
HIP 99314

Europa

Io

Ganymede

Callisto



Galilée
Découverte des lunes de Jupiter en 1610

Système de Saturne

Titan > C. Huygens, 1655

Encelade, Mimas > W. Herschel, 1789

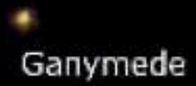
Méthane atmosphérique sur Titan > G. Kuiper 1944

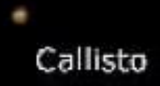
Système de Jupiter

Lunes galiléennes > Galilée, 1610

Résonance orbitale > Laplace 1805

Glace à la surface > Moroz 1965,
Pilcher et al. 1972





Premier modèle d'intérieur des lunes glacés

ICARUS 15, 174–185 (1971)

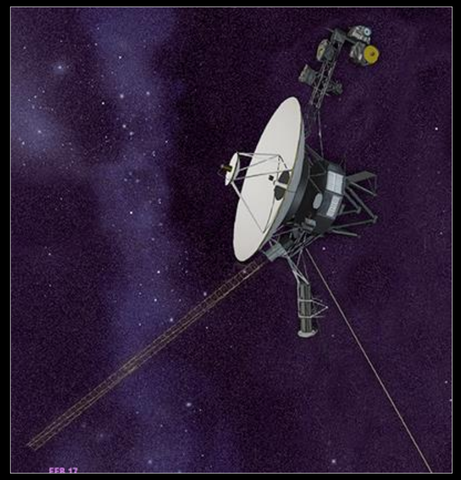
Satellites of the Outer Planets: Their Physical and Chemical Nature[1]

JOHN S. LEWIS

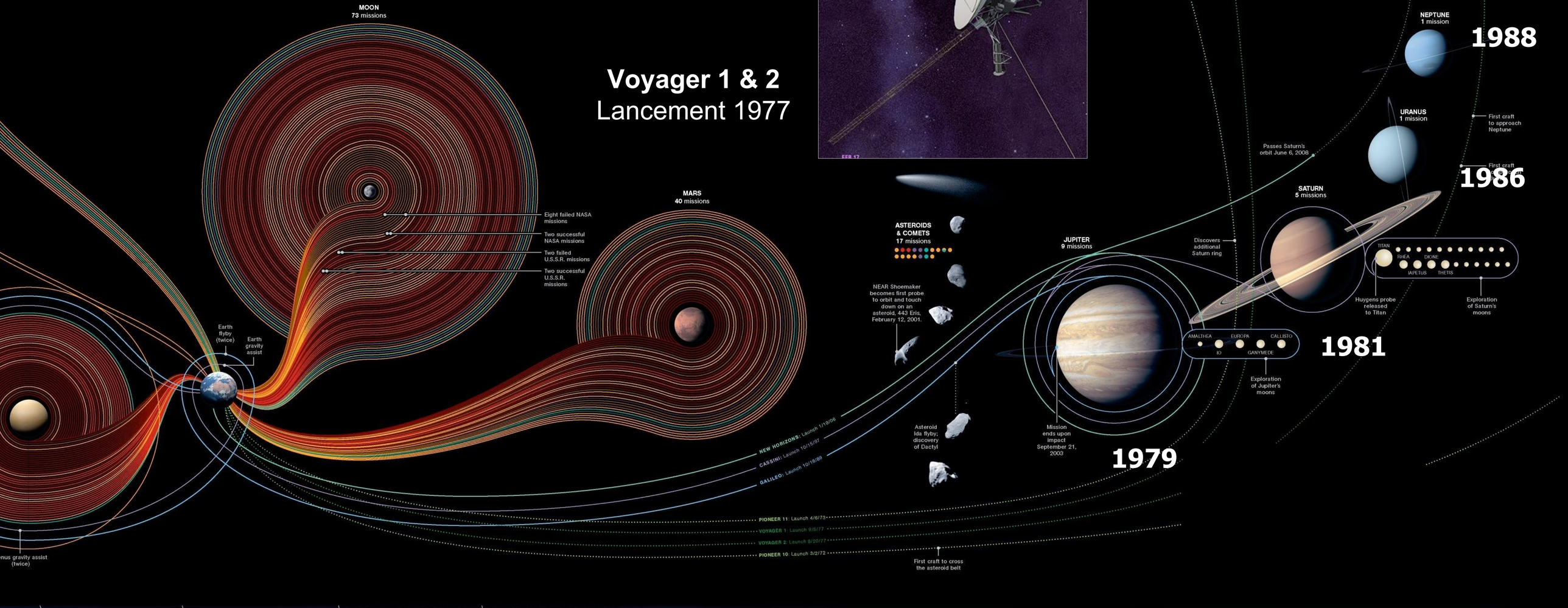
Planetary Astronomy Laboratory, Department of Earth and Planetary Sciences and Department of Chemistry, Massachusetts Institute of Technology, Cambridge 02139

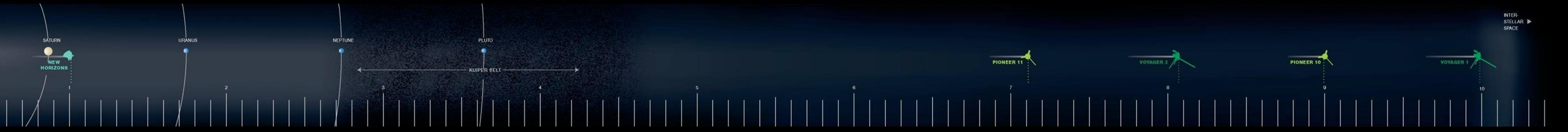
Received February 16, 1971; revised April 9, 1971

Premiers survols rapprochés des planètes géantes et de leurs lunes



Voyager 1 & 2
Lancement 1977





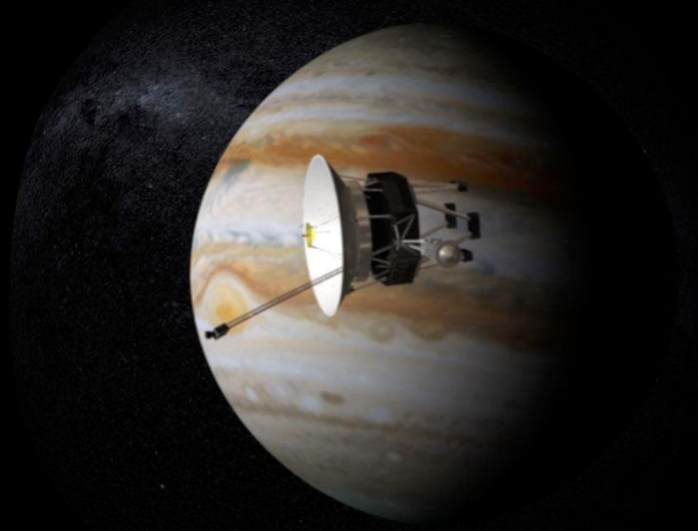
1979

Premiers survols des lunes de Jupiter par Voyager 1 & 2

Activité tectonique intense sur Europe

Eruptions volcaniques sur Io

Europe: un océan sous sa croûte de glace ?



VOL. 6, NO. 9 GEOPHYSICAL RESEARCH LETTERS SEPTEMBER 1979

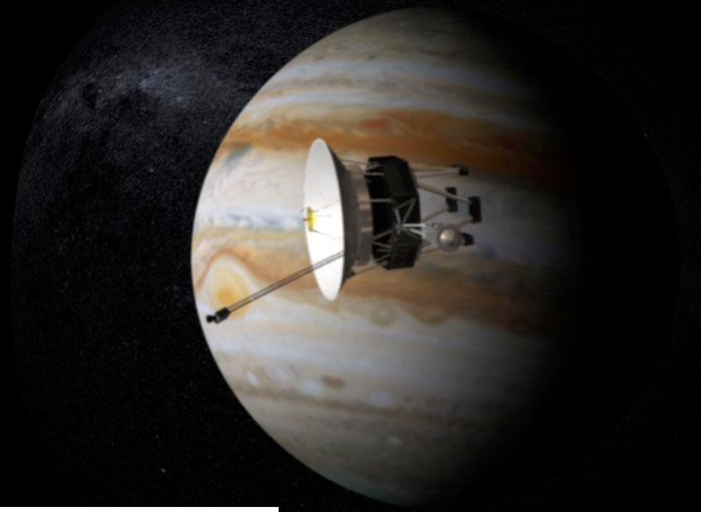
IS THERE LIQUID WATER ON EUROPA?

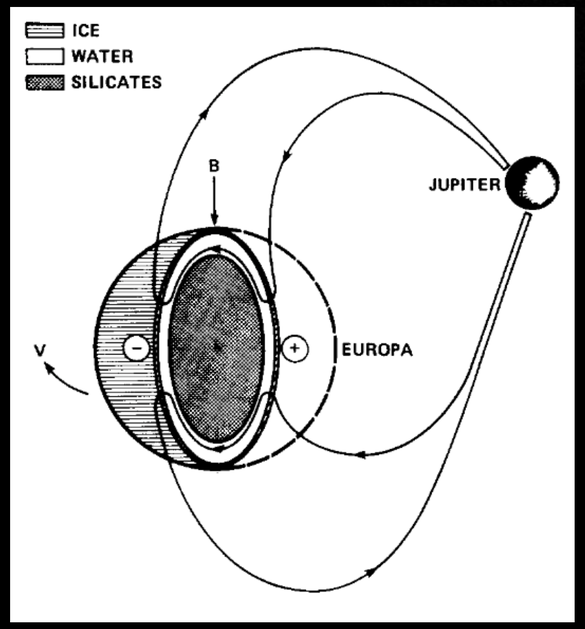
P. Cassen and R. T. Reynolds
Theoretical and Planetary Studies Branch, Ames Research Center, NASA
Moffett Field, California 94035

and

S. J. Peale
Department of Physics, University of California, Santa Barbara, California 93106

Europe: un océan habitable sous sa croûte de glace ?





« [...] there may be regions on Europa, very limited in both space and time, with physical conditions that are within the range of adaptation of life on Earth. »

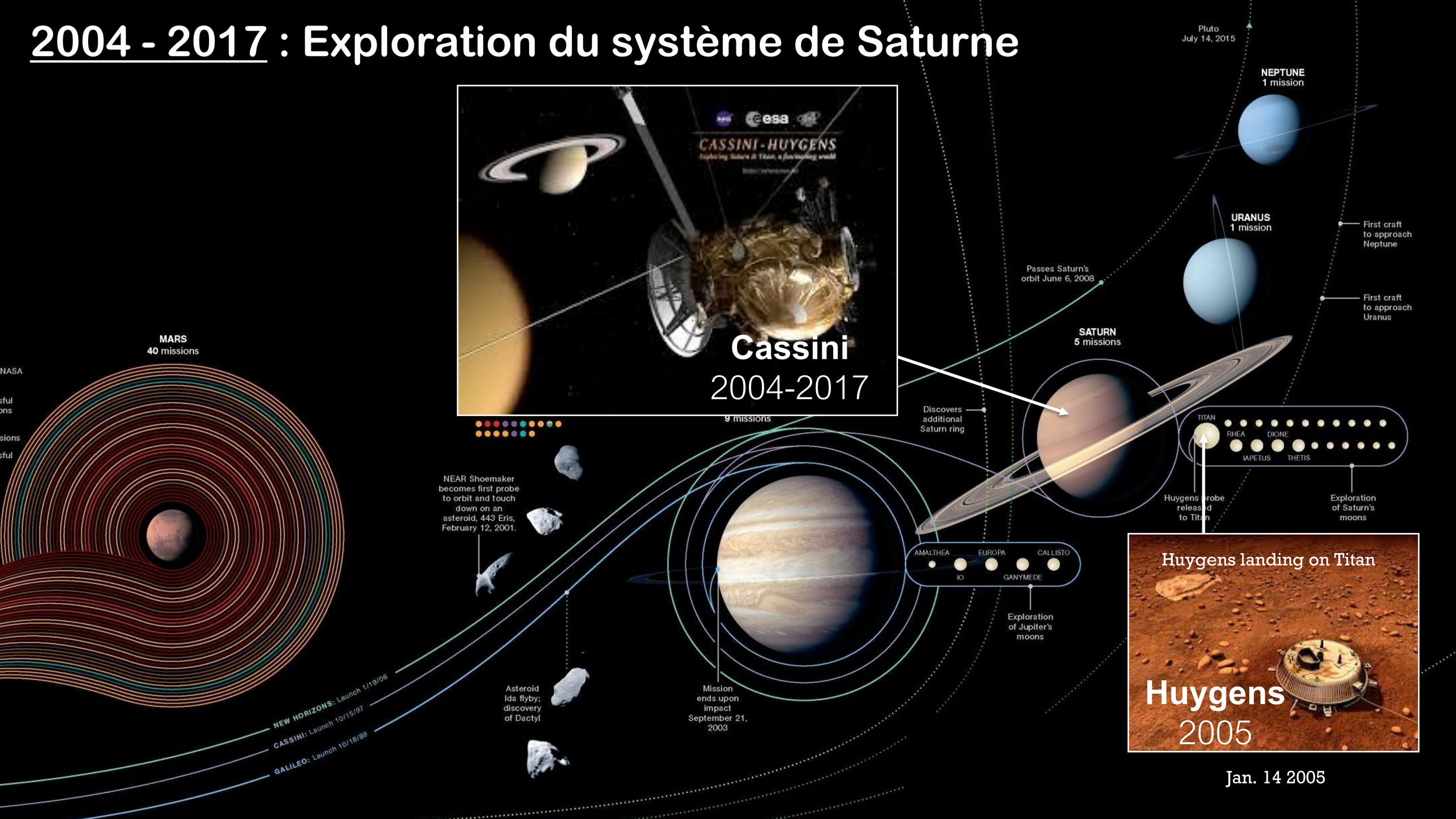
Reynolds et al. 1983

1995 - 2025 : Exploration du système de Jupiter

Galileo
1995-2003

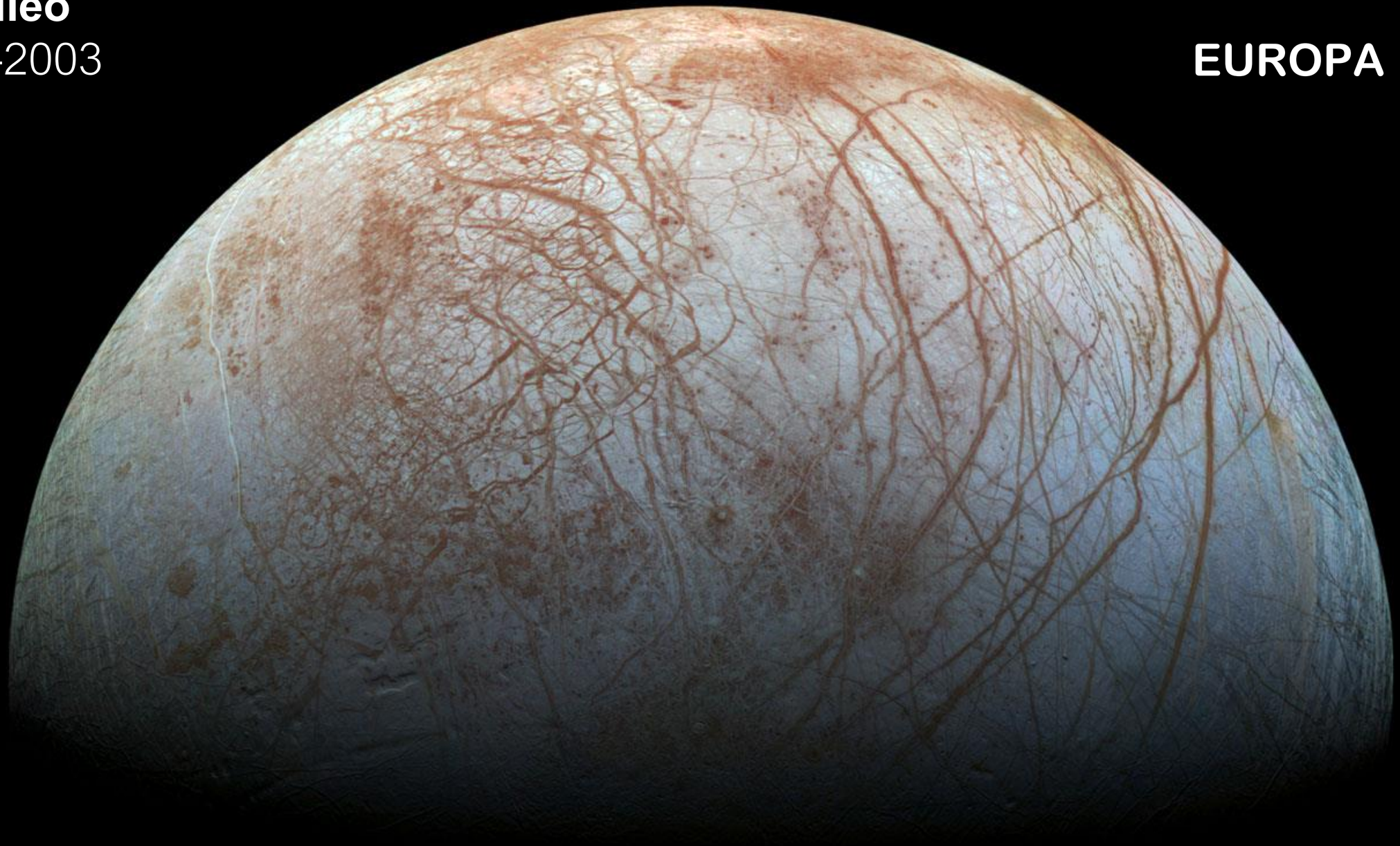
JUNO
2016-2025

2004 - 2017 : Exploration du système de Saturne



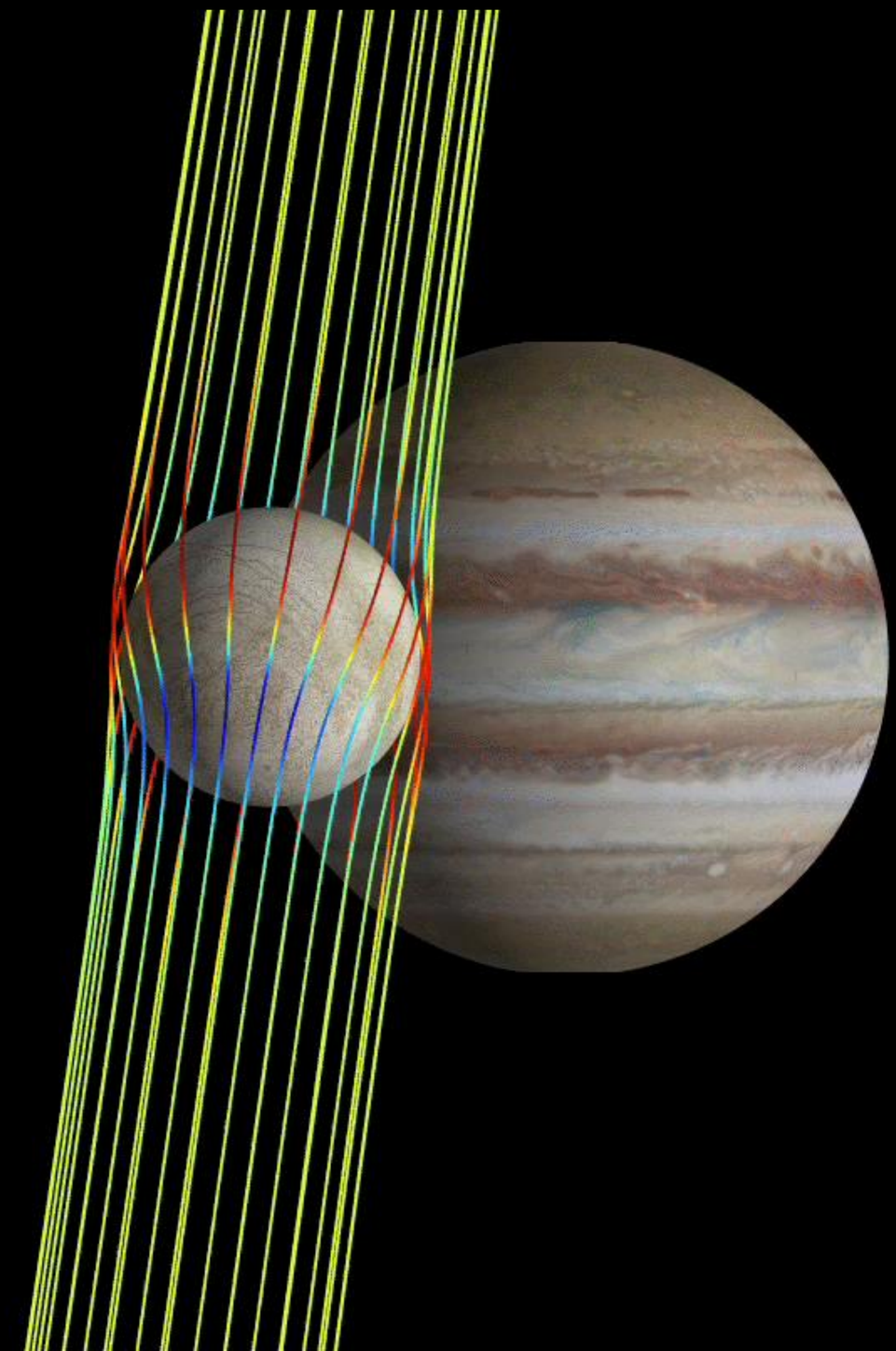
Jan. 14 2005

Galileo
1995-2003



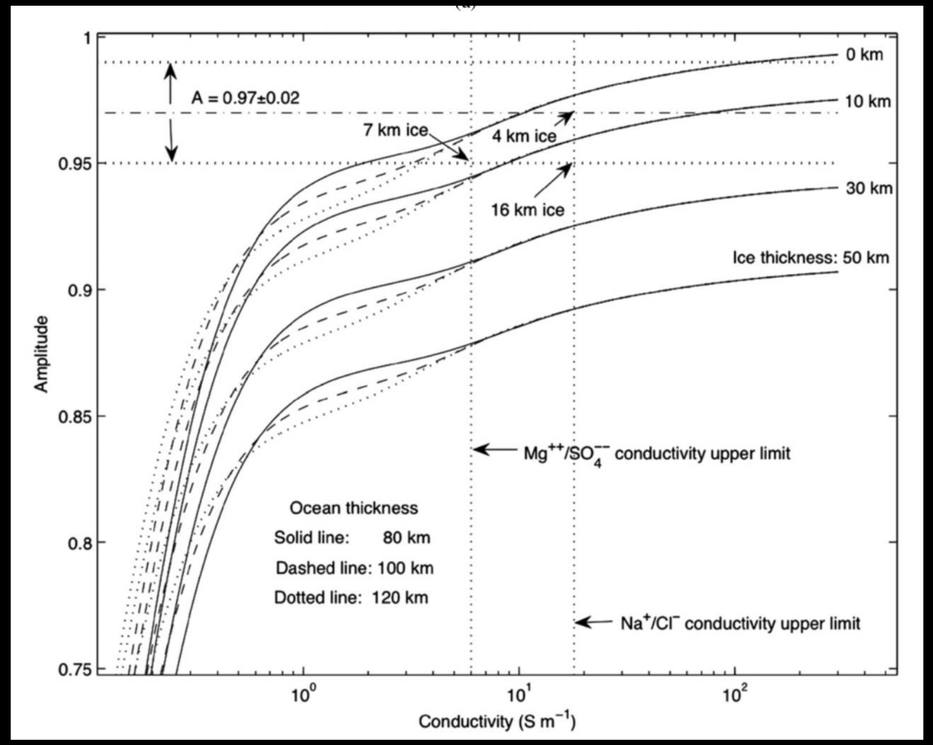
EUROPA

Détection d’un océan 10 à 30 km sous la surface d’Europe



Galileo 1998

Détection d'un océan 10 à 30 km sous la surface d'Europe



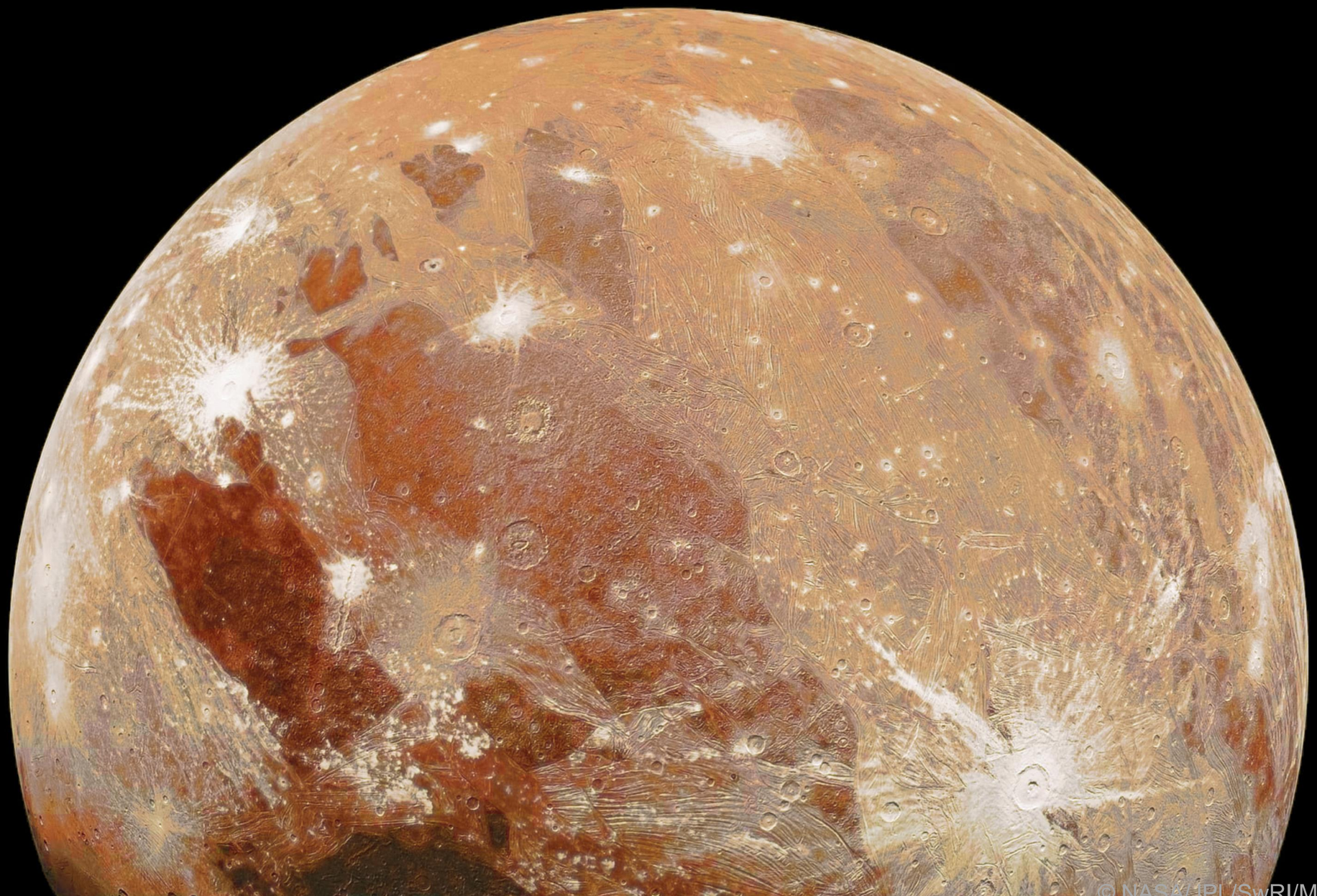
Hand & Chyba (2007)

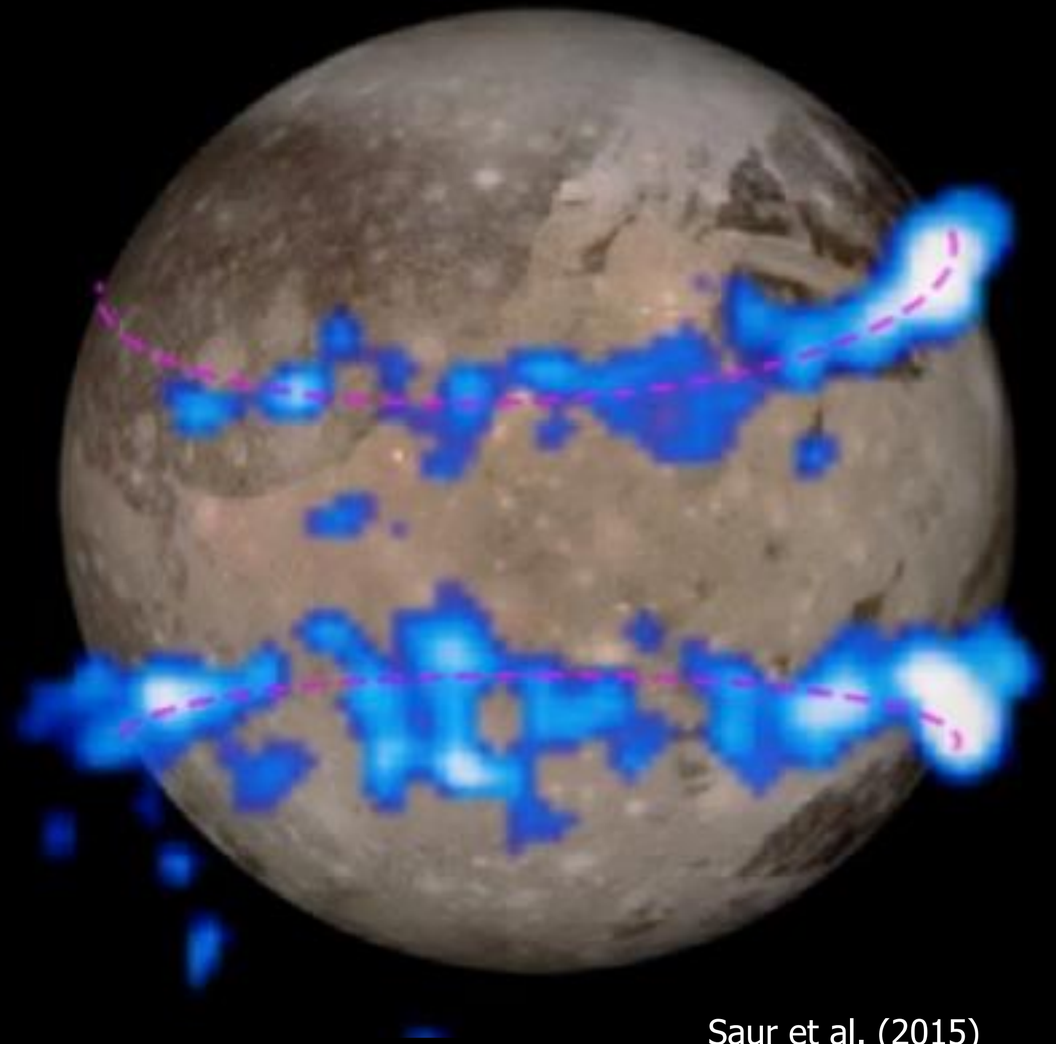
	$A = 0.97 \pm 0.02$		$A = 0.92 \pm 0.02$	
	Ice Thickness [km]	Ocean Depth [km]	Ice Thickness [km]	Ocean Depth [km]
Seawater	4^{+8}_{-3}	133^{+21}_{-34}	24^{+11}_{-12}	111^{+21}_{-30}
MgSO4	3^{+7}_{-2}	134^{+21}_{-30}	13^{+11}_{-9}	119^{+23}_{-28}
Carbonates	3^{+7}_{-2}	136^{+22}_{-32}	20^{+12}_{-9}	114^{+24}_{-29}

Petricca et al. (2023)

JUNO
07/06/2003

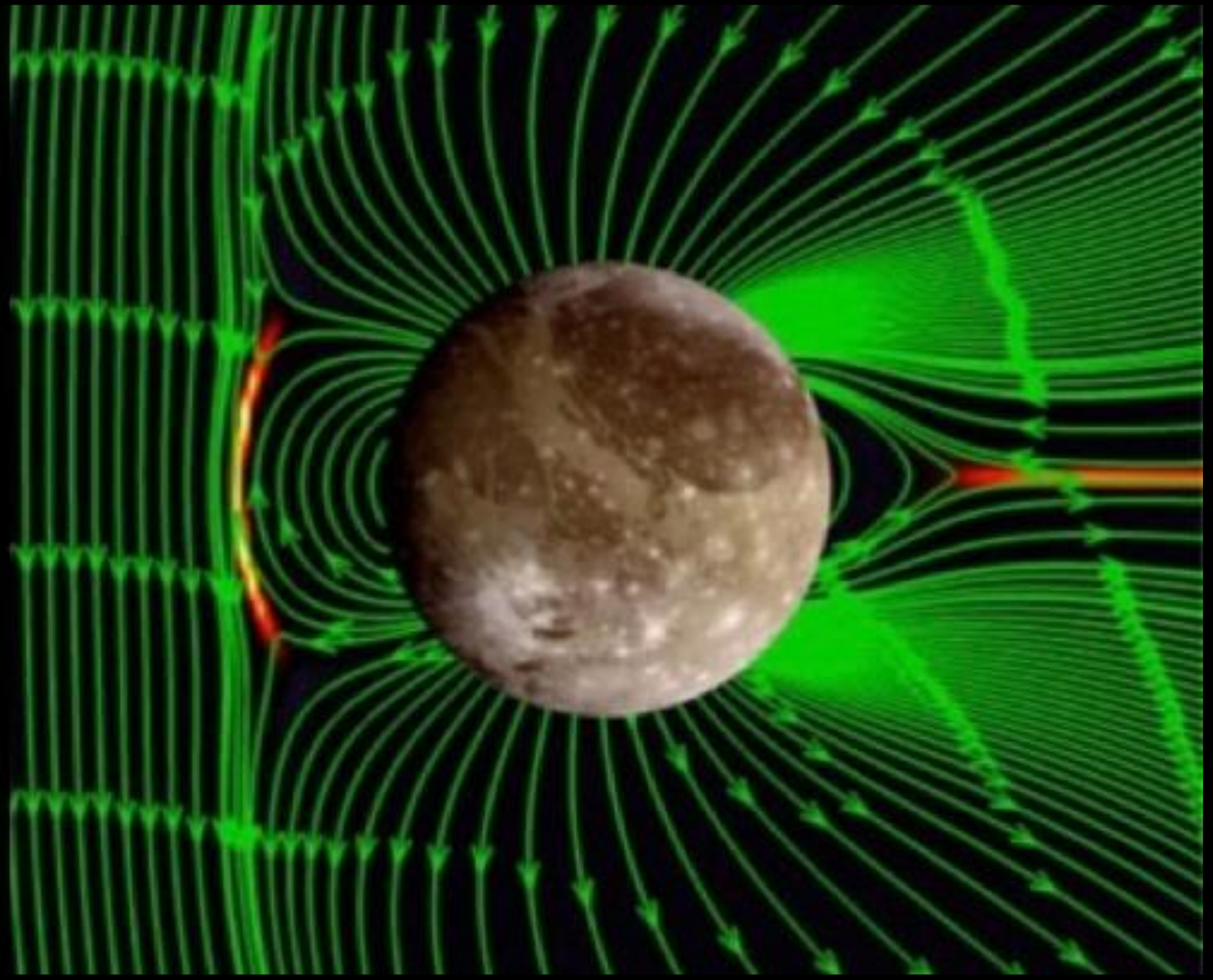
GANYMEDE





Saur et al. (2015)

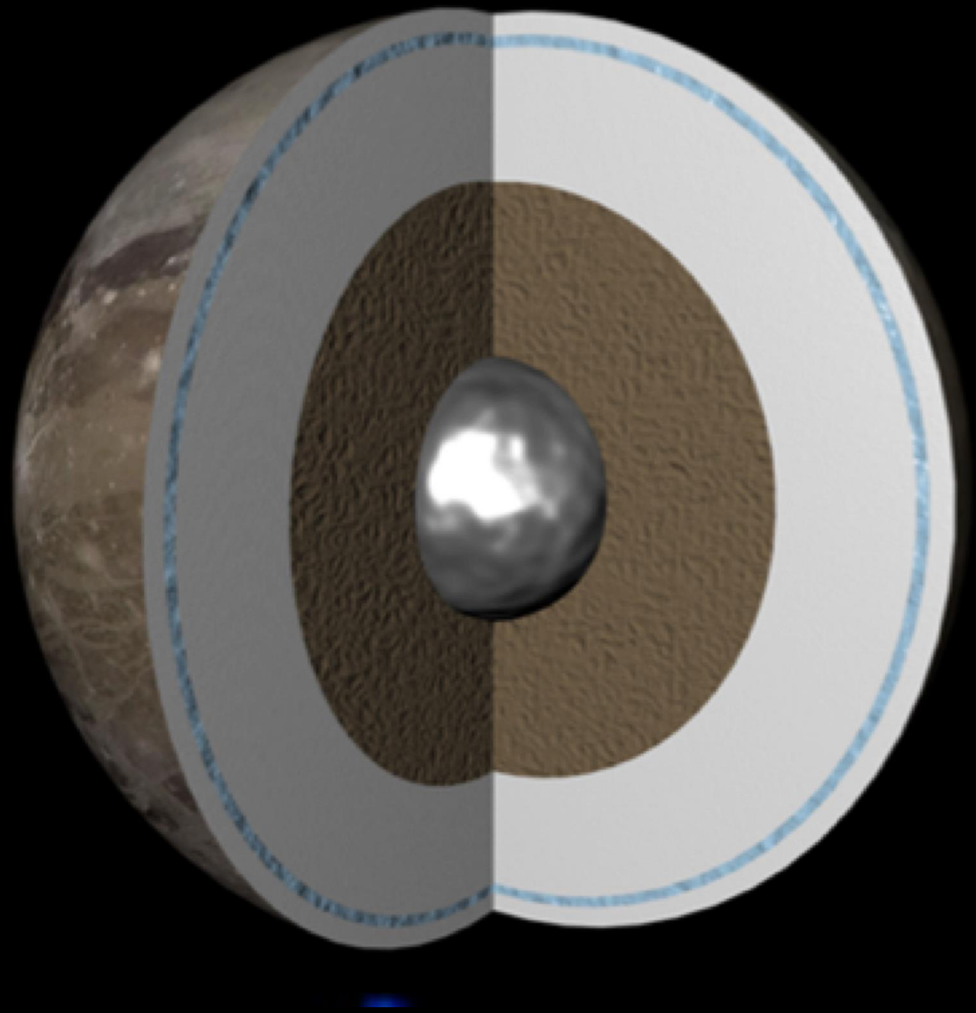
Hubble
2015

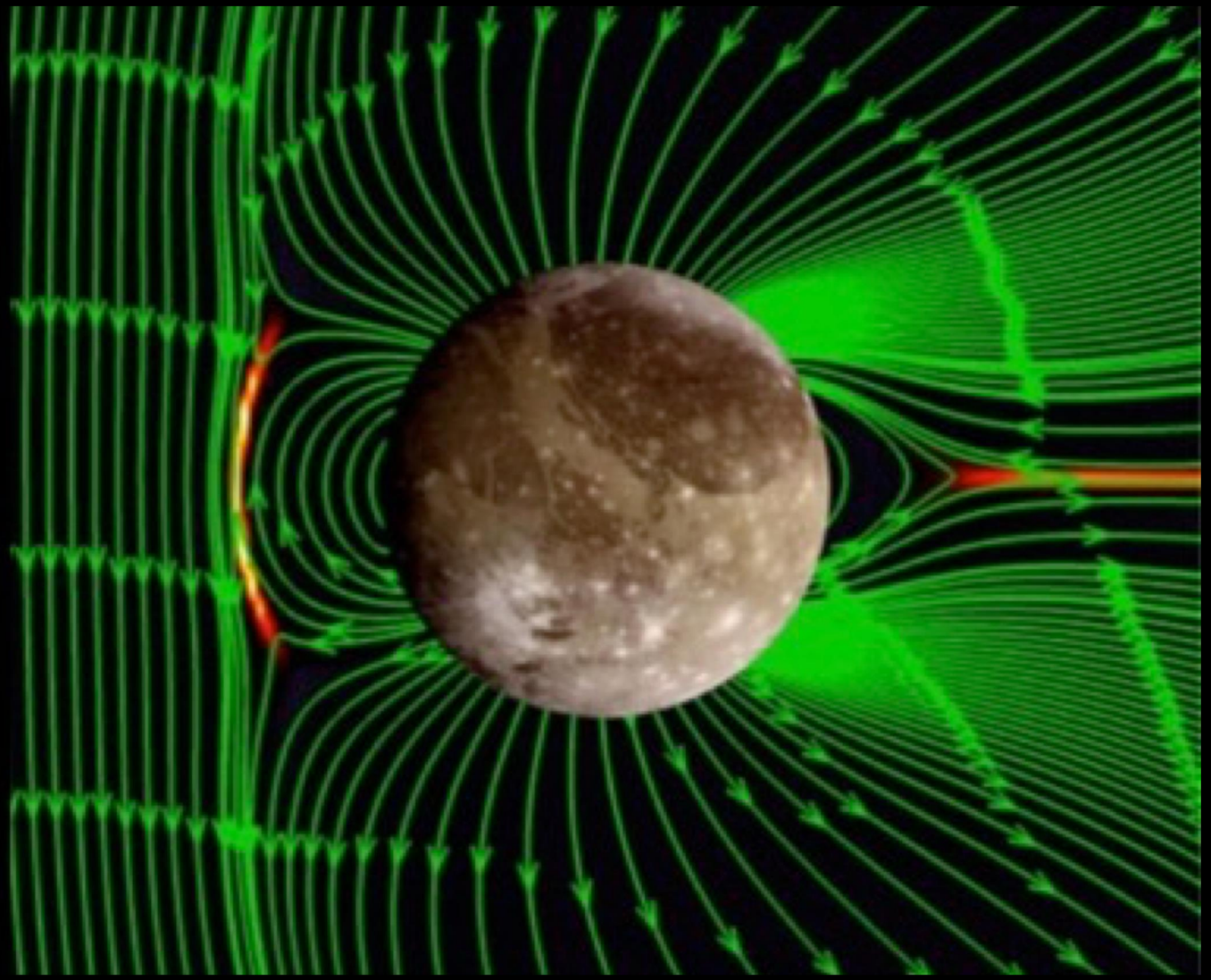


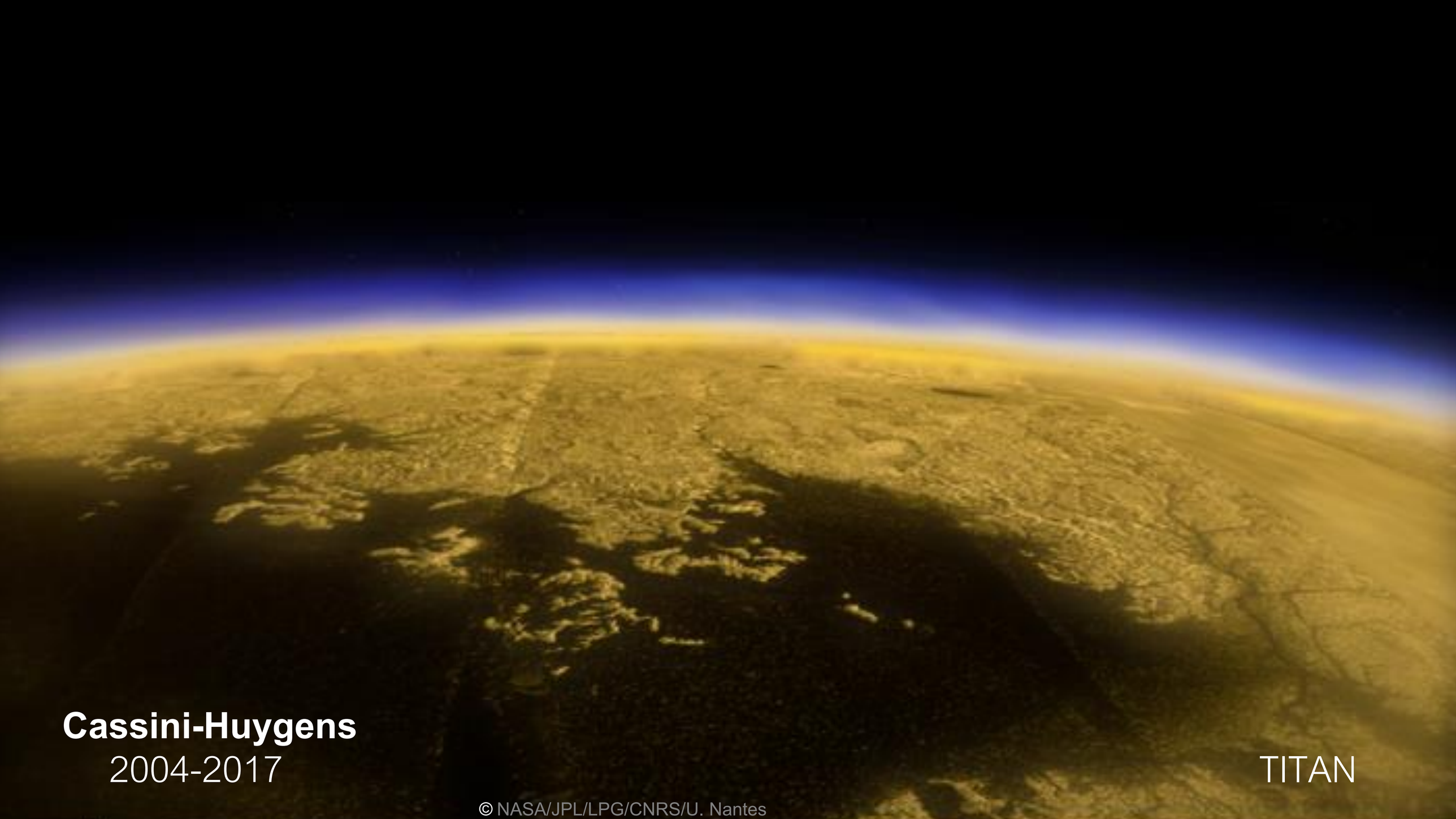
Galileo
1995-2003

GANYMEDE

Ganymède: la seule lune avec un champ magnétique actif



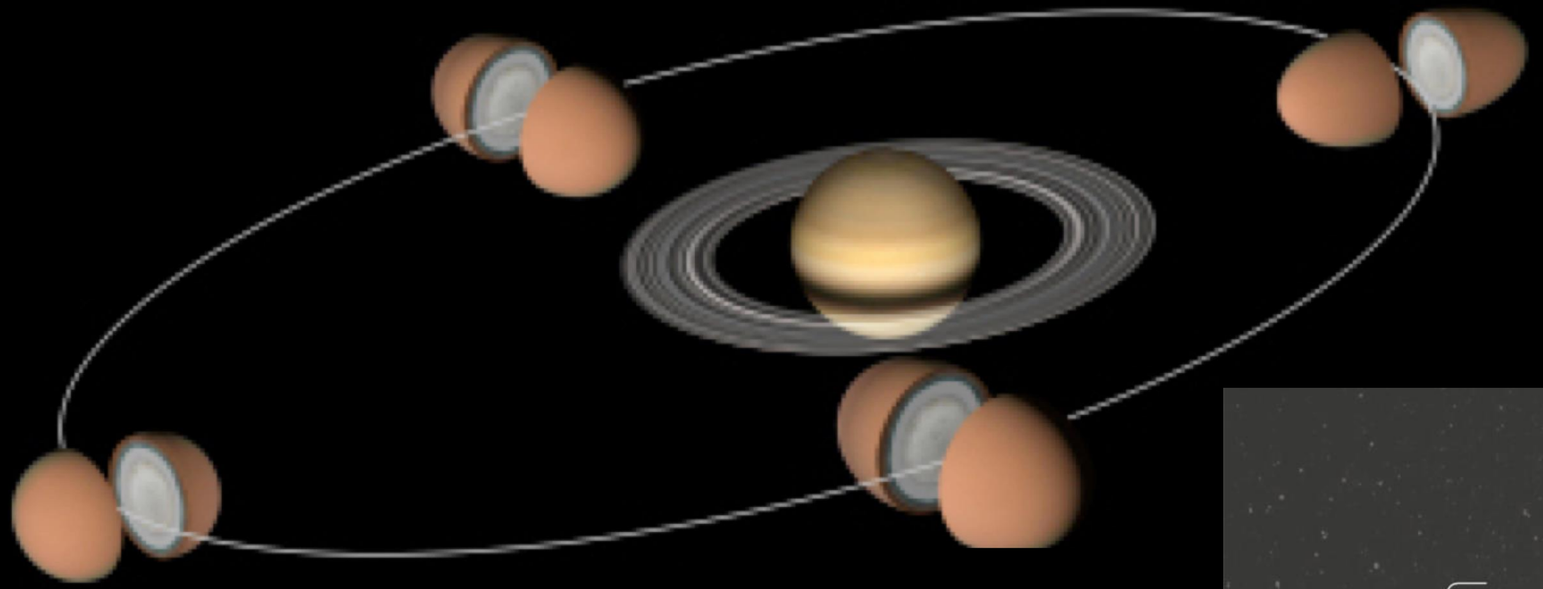




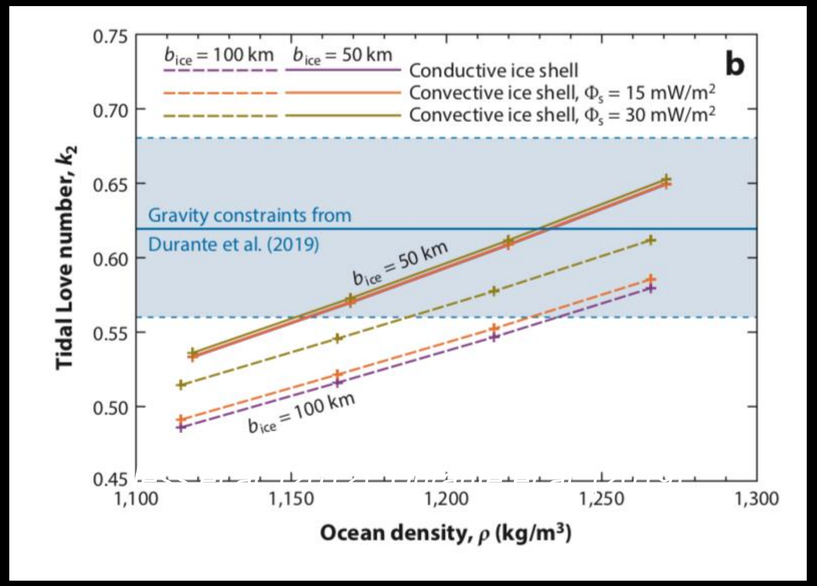
Cassini-Huygens
2004-2017

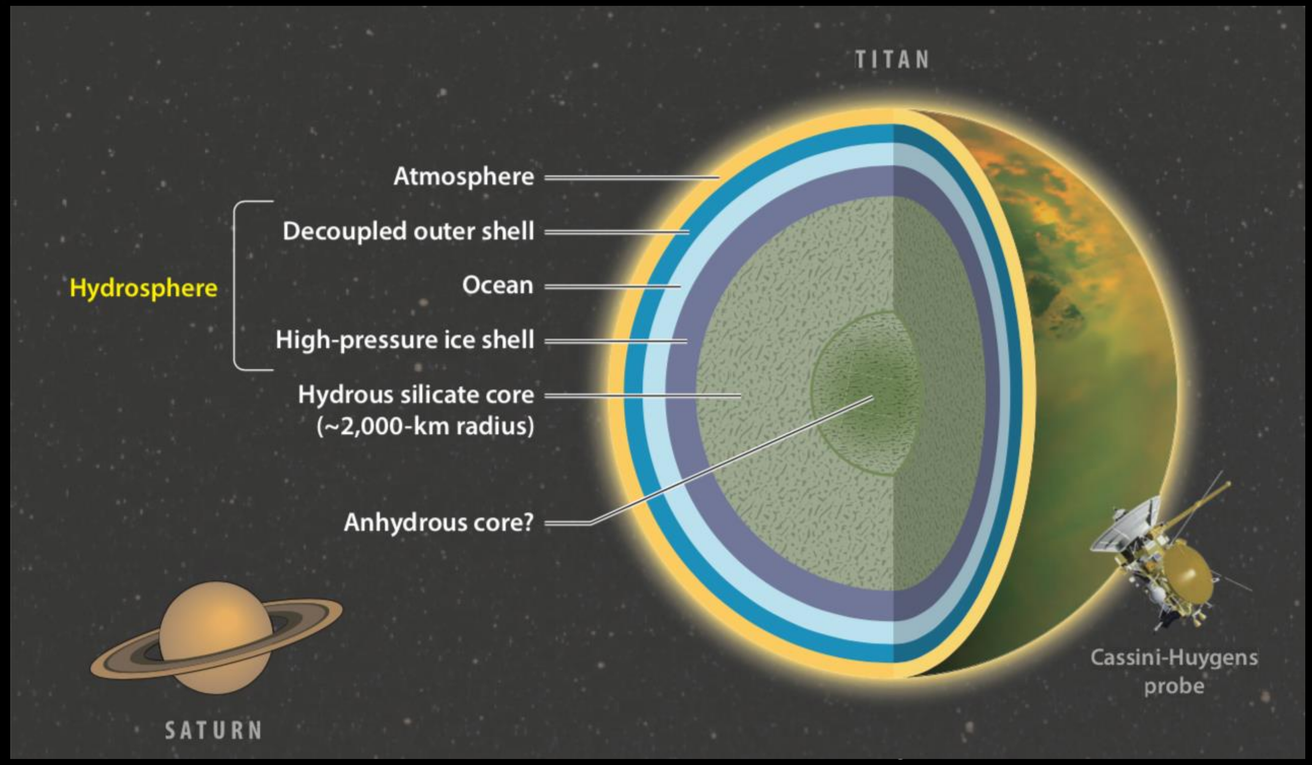
TITAN

Indice d’un océan d’eau salée sous un croûte glacée riche en hydrocarbures



Indice d’un océan interne à partir de la mesure du changement de champ de gravité liées aux marées induites par Saturne et de l’obliquité de Titan



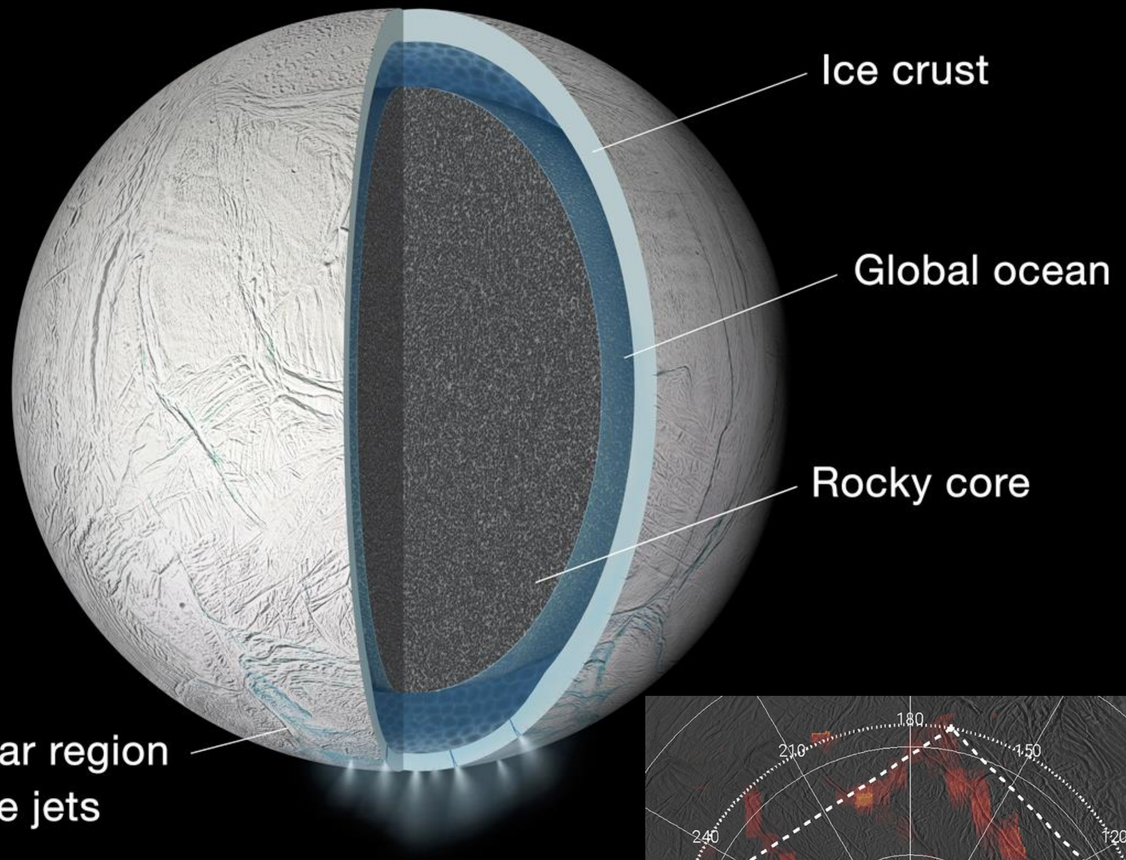


Sotin et al. (2021)

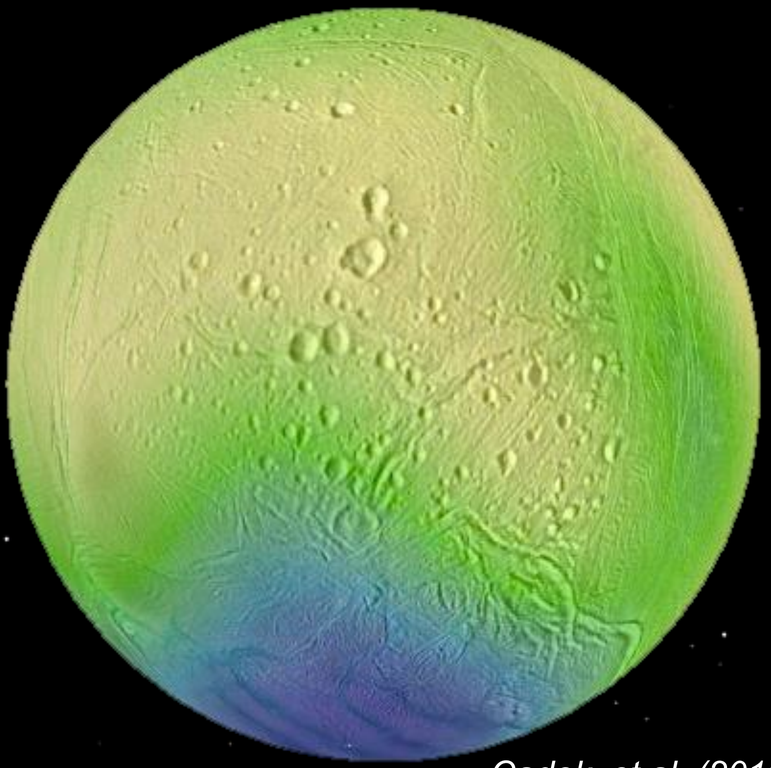
Cassini
2004-2017

ENCELADUS

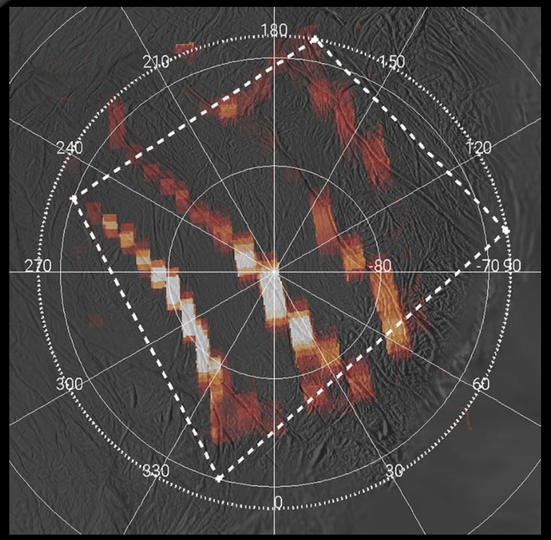
Détection d'un océan océan global à partir de sa rotation



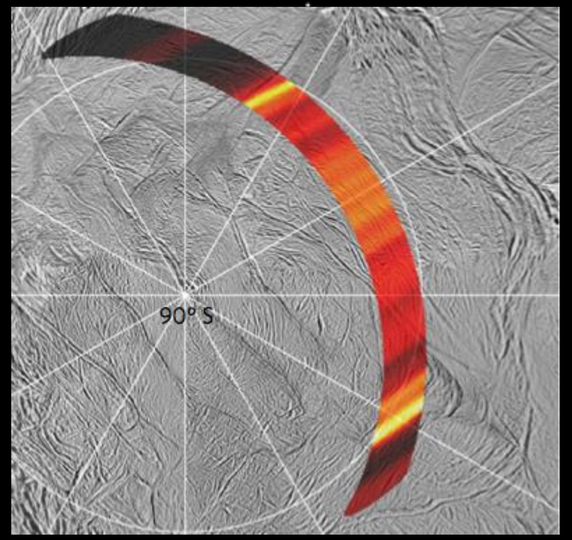
Thomas et al. (2016)



Cadek et al. (2016, 2019)



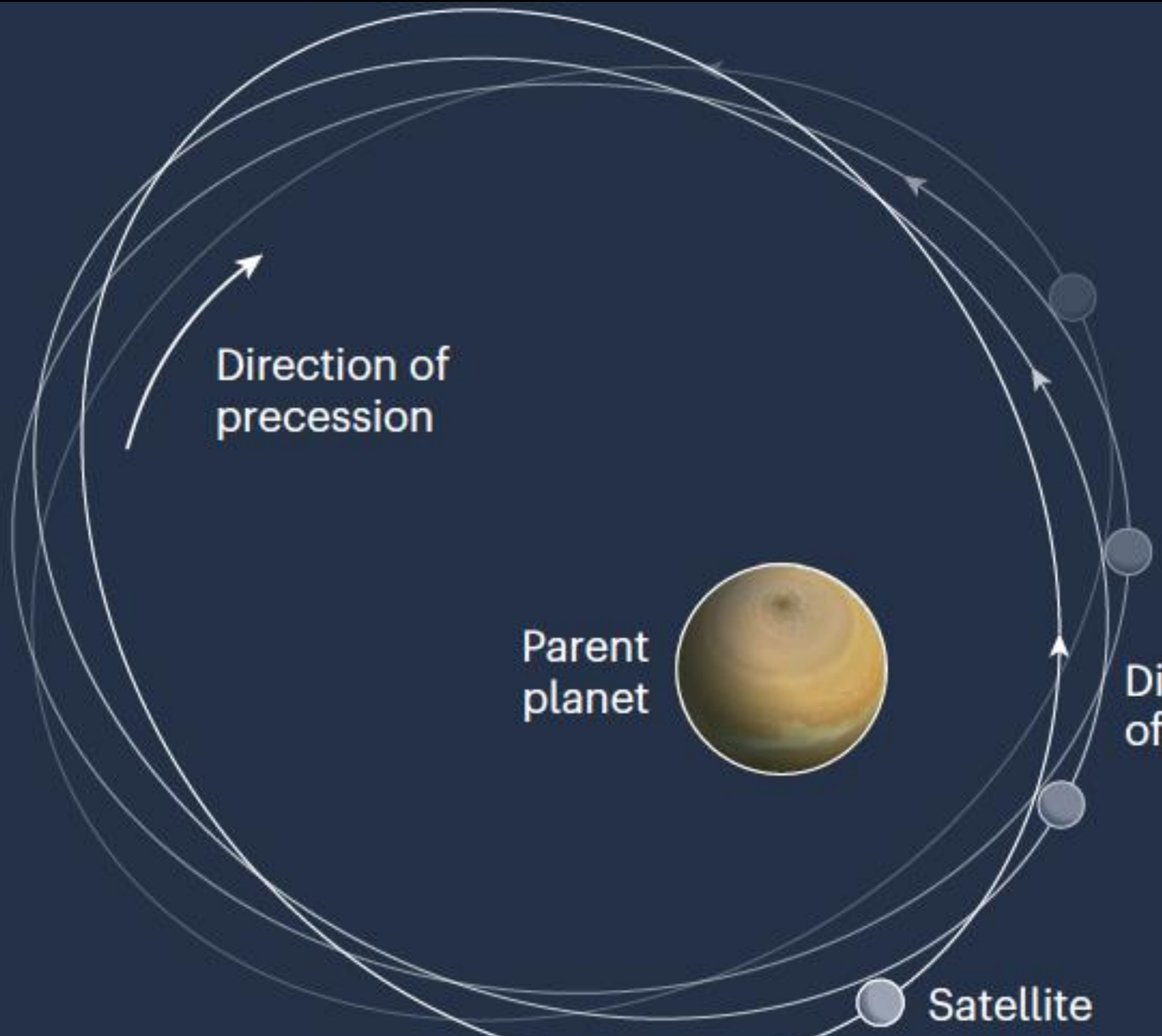
Howett t al. (2015)

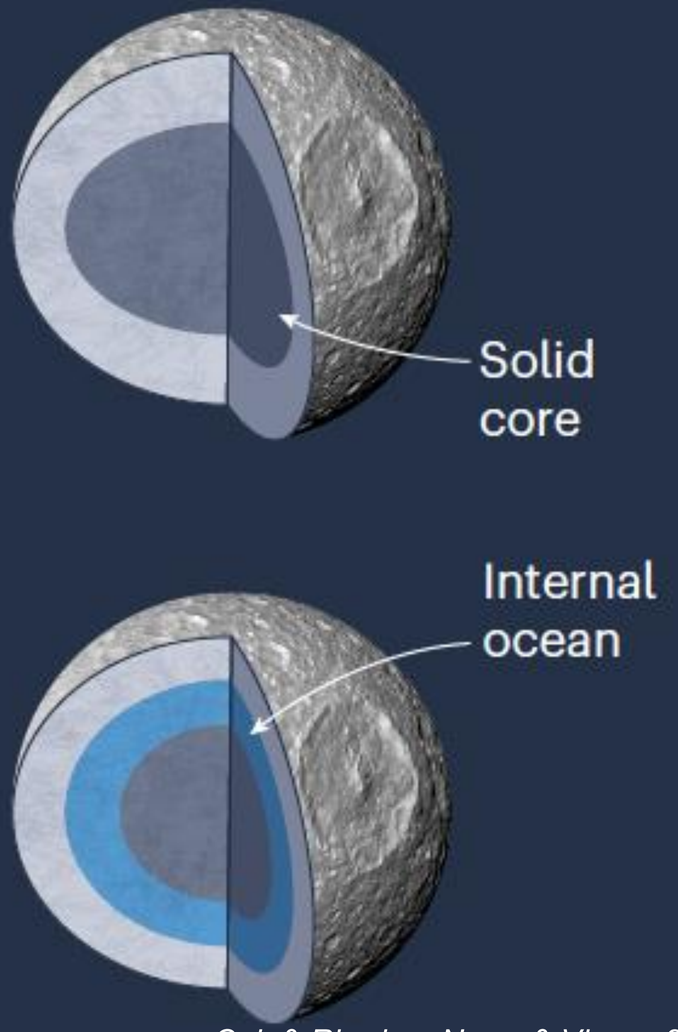


Le Gall et al. (2017)

Fort amincissement de la couche de glace au pôle sud et fort flux de chaleur

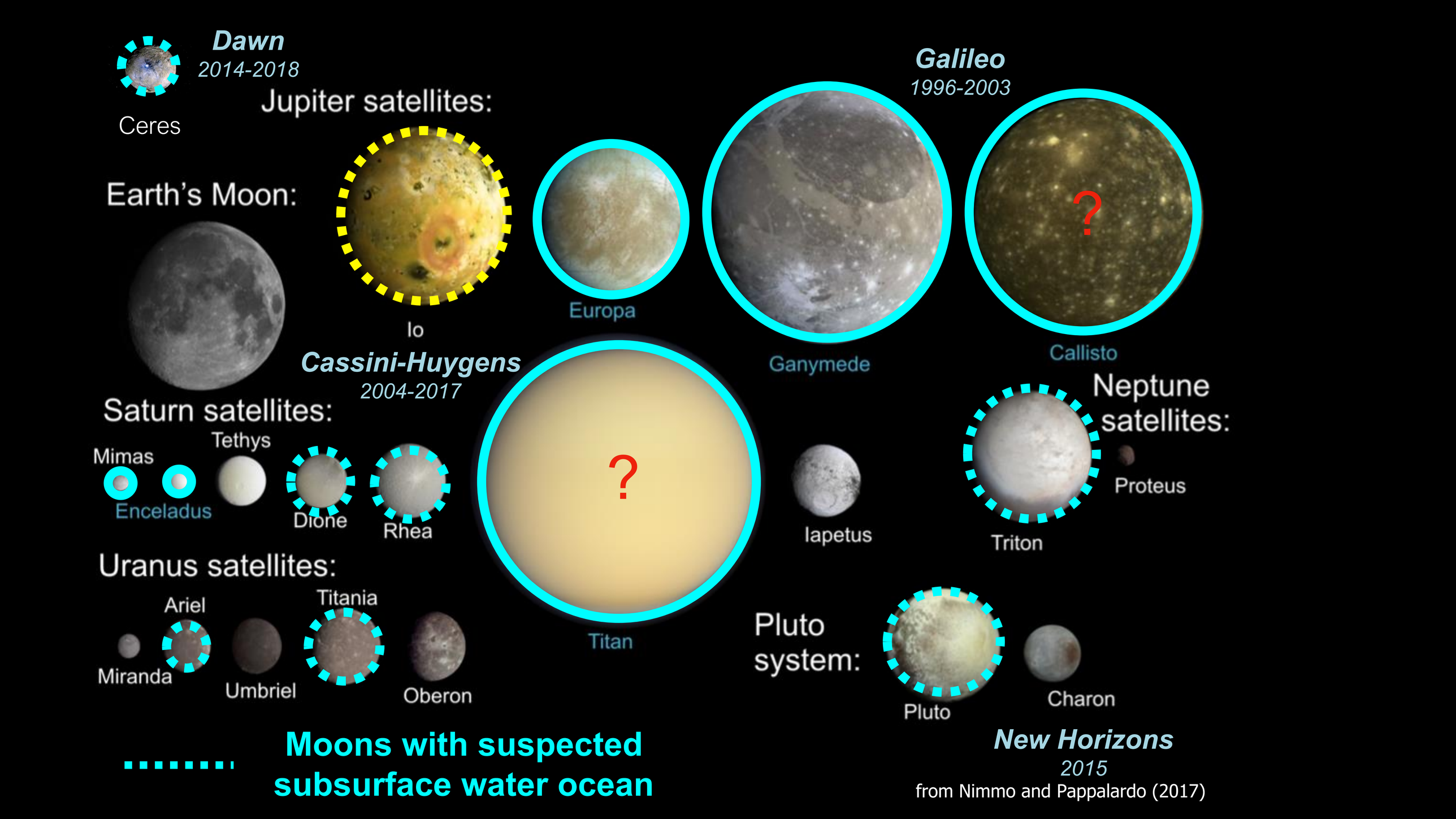
Détection surprise d'un océan océan global dans Mimas





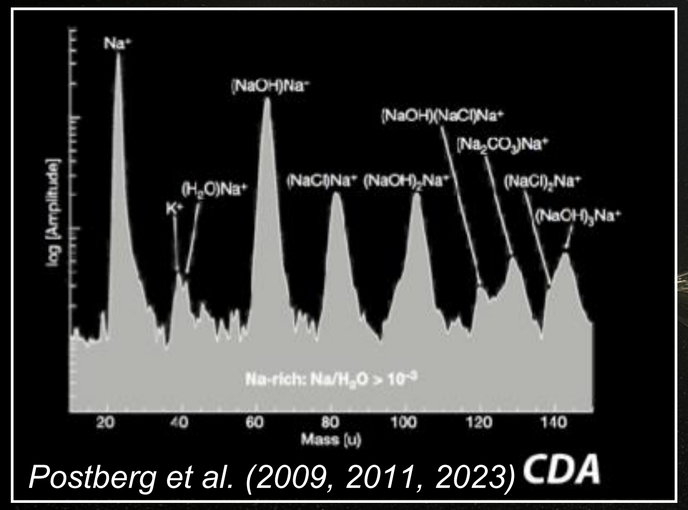
Cuk & Rhoden, News & Views, 2024

Evidence for a recently formed ocean on Mimas Lainey et al. (2024)

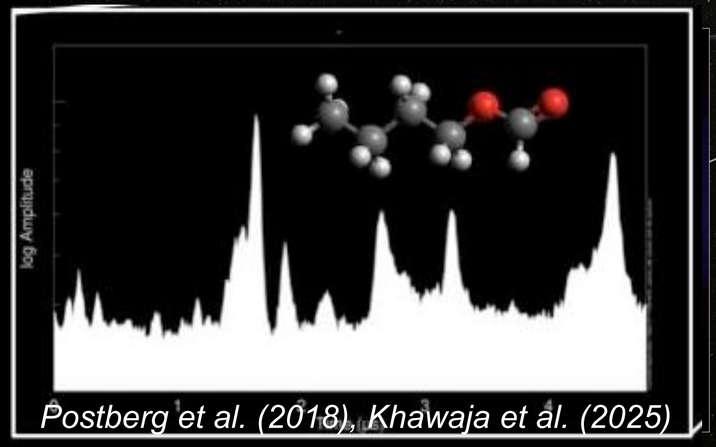

Dawn
2014-2018
Ceres
Jupiter satellites:
Galileo
1996-2003
Earth's Moon:
Io
Europa
Ganymede
?
Callisto
Cassini-Huygens
2004-2017
Saturn satellites:
Mimas
Tethys
Enceladus
Dione
Rhea
?
Titan
Iapetus
Neptune satellites:
Proteus
Triton
Uranus satellites:
Ariel
Titania
Miranda
Umbriel
Oberon
Pluto system:
Pluto
Charon
New Horizons
2015
Moons with suspected subsurface water ocean
from Nimmo and Pappalardo (2017)

Premier échantillonnage d’un océan extraterrestre

Détection de sels dans les grains glacés



Postberg et al. (2009, 2011, 2023) CDA

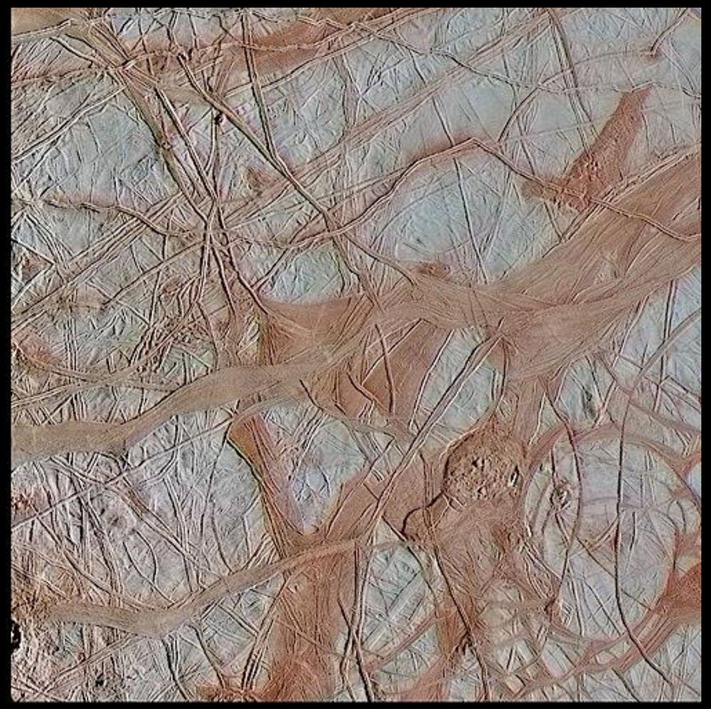


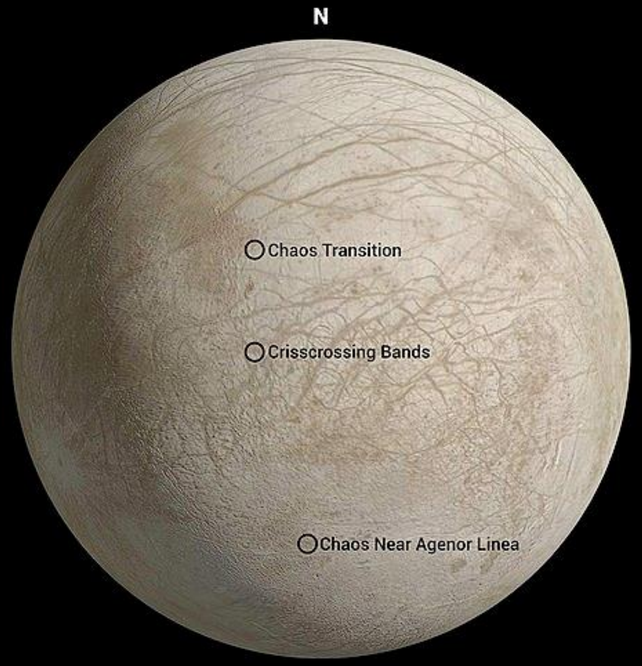
Postberg et al. (2018), Khawaja et al. (2025)

+ Molécules organiques complexes

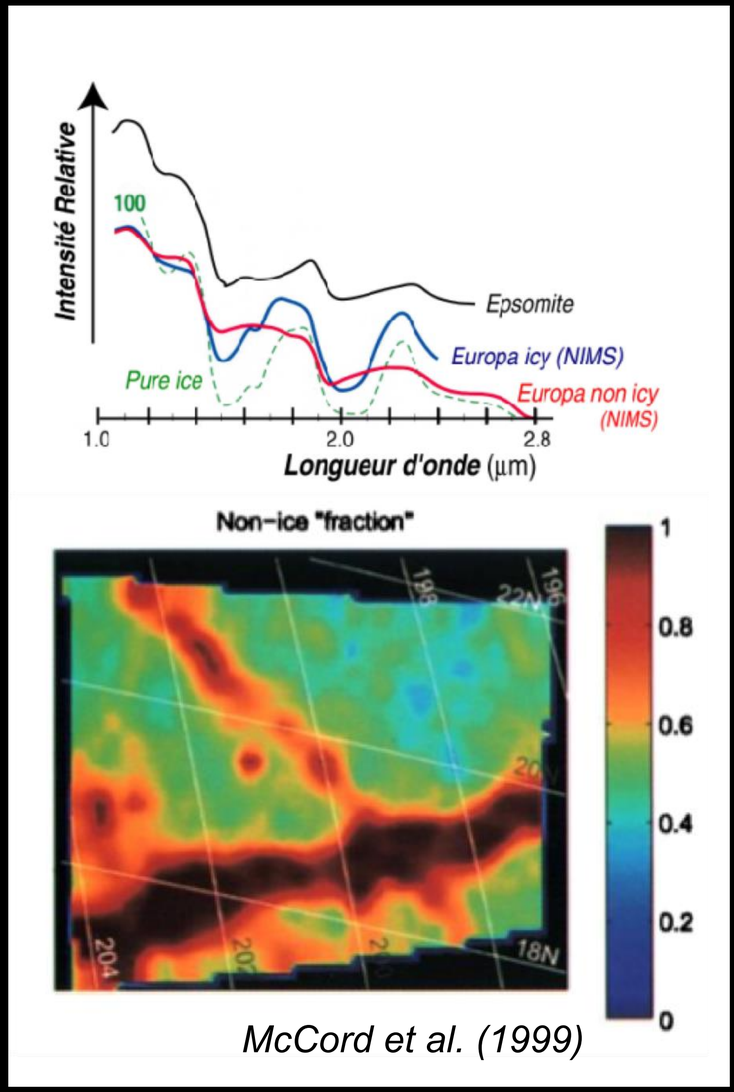
VR2Enceladus

Identification de dépôts de sels à la surface d'Europe



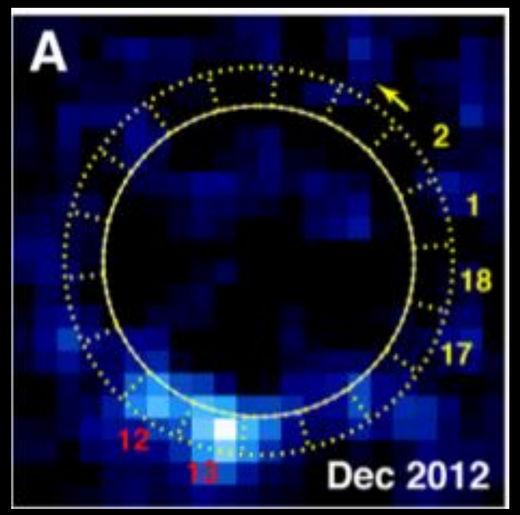


NASA/JPL-Caltech/SETI Institute

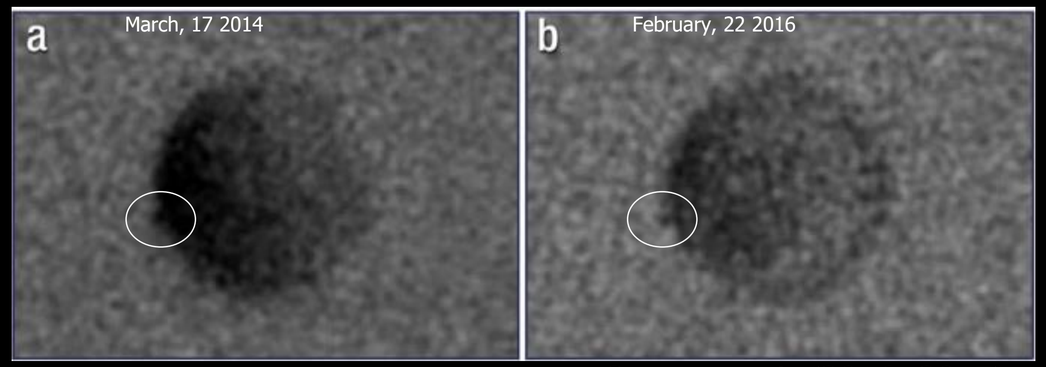


McCord et al. (1999)

Indice d’éruption de vapeur d’eau sur Europe

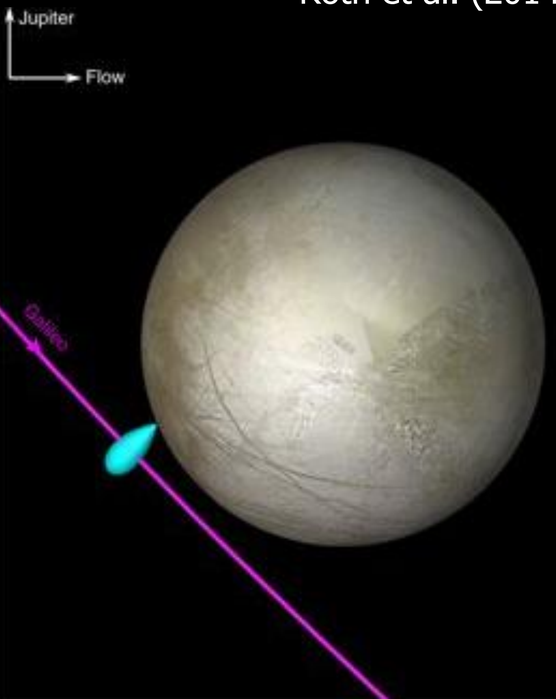


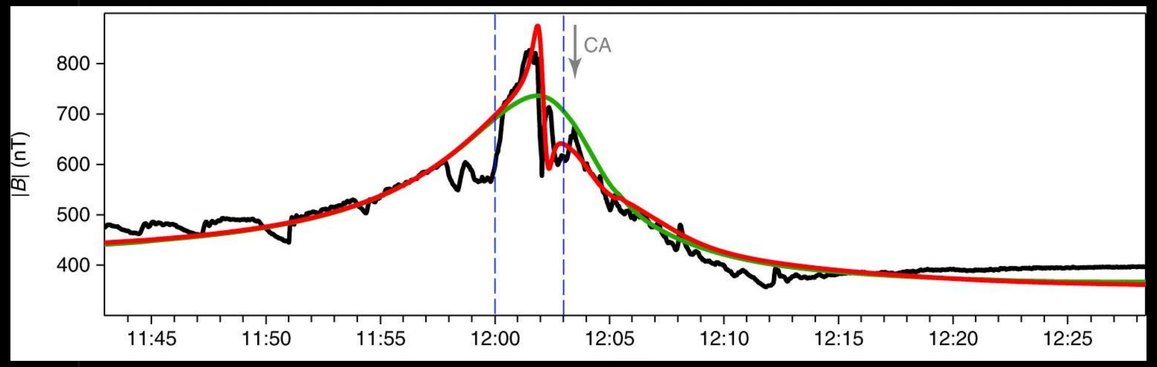
Roth et al. (2014)



Sparks et al. (2016, 2017)

Observation sporadique d’un panache de vapeur d’eau à partir d’observation UV avec Hubble



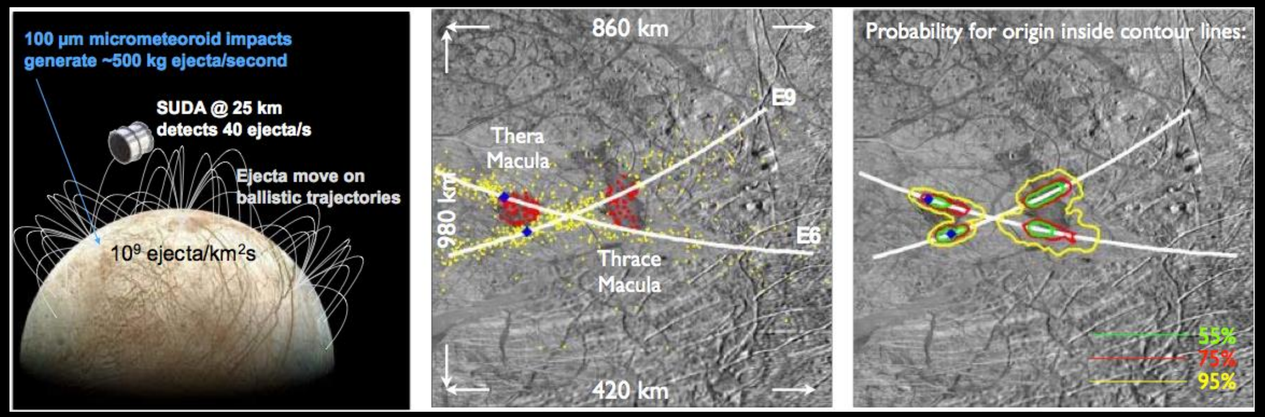


Potentiel détection d’un panache de vapeur d’eau dans les données magéntiques de Galileo

Jia et al. (2018)

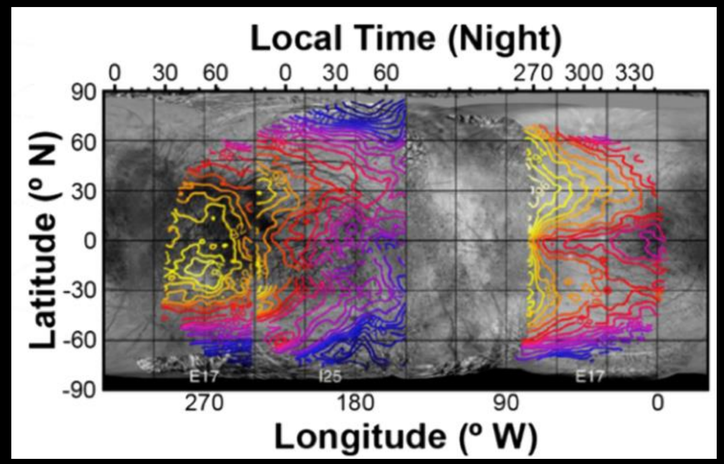
Recherche d’échantillons frais de l’océan d’Europe

MISE



SUDA + MASPEX

E-UVS



E-THEMIS

EUROPA CLIPPER

+ JUICE payload

Un nouveau chapitre de l'exploration commence …


Suite de l’histoire en 2030-31 !