

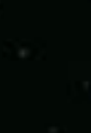
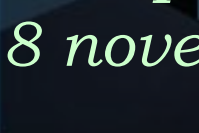
L'esplorazione delle lune ghiacciate del Sistema Solare: Implicazioni astrobiologiche

Federico Tosi

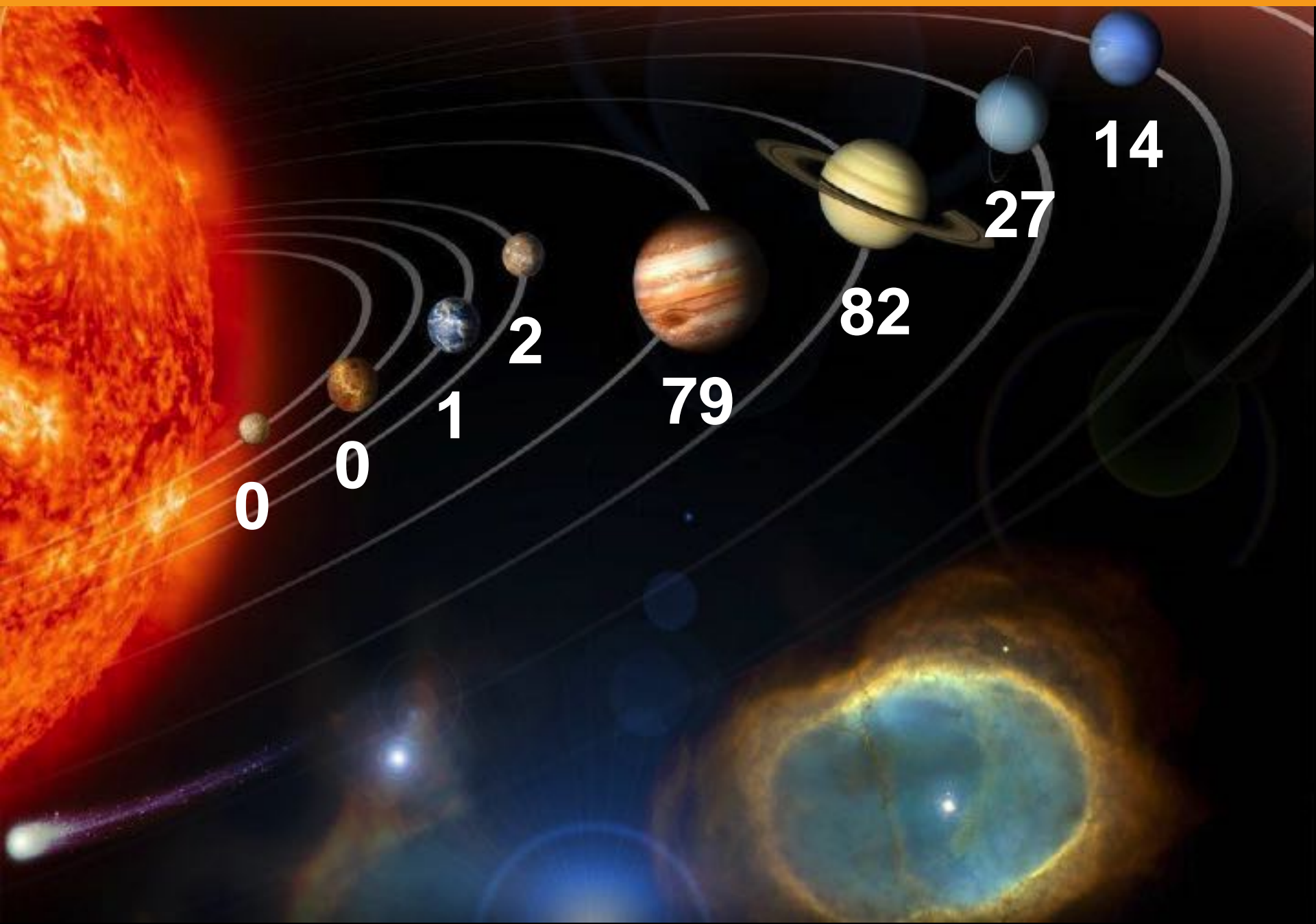
INAF-IAPS

Istituto Nazionale di Astrofisica, Roma

*Annibale de Gasparis Workshop,
Napoli, 8 novembre 2019*



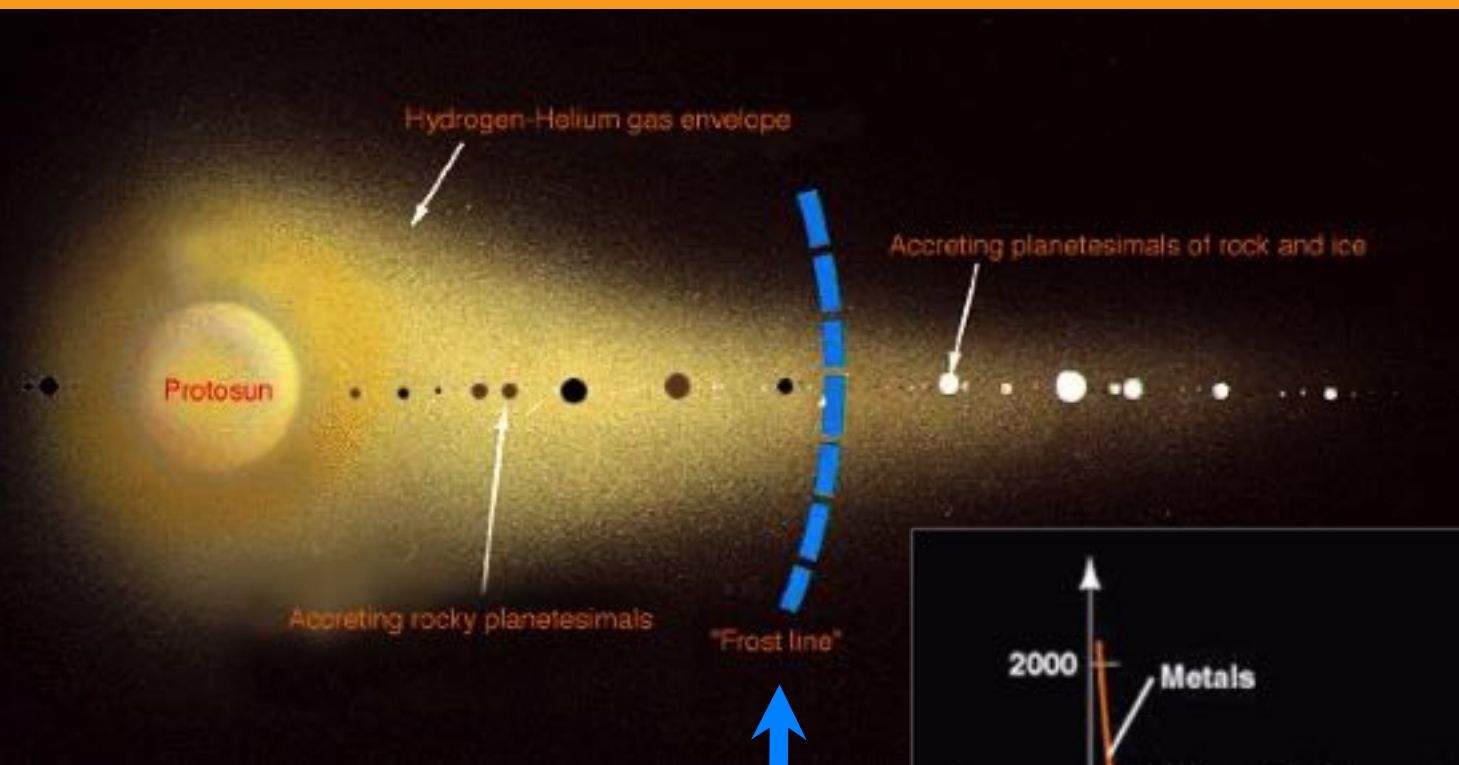
Satelliti naturali nel Sistema Solare



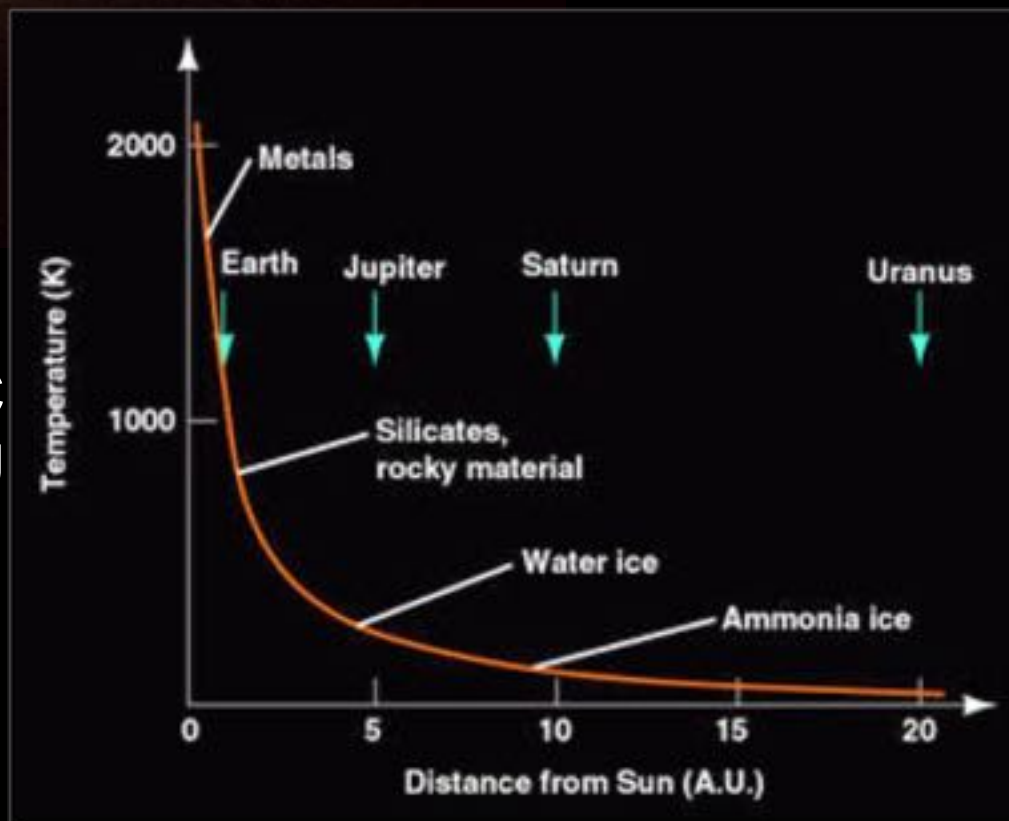
Dimensioni relative dei pianeti "terrestri" e dei principali satelliti naturali



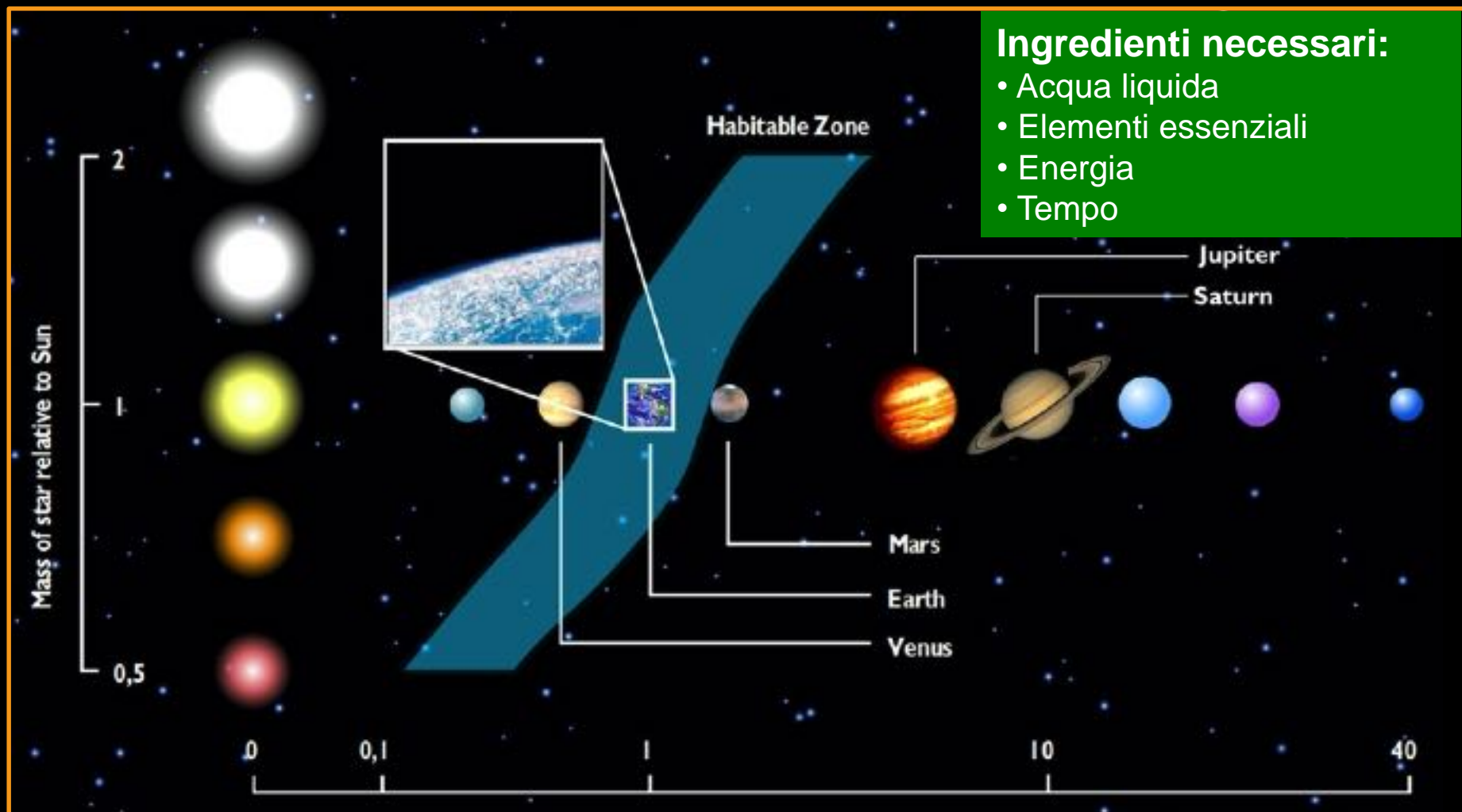
La "snow line" o "frost line"



$$T = 150 \text{ K} = -123^\circ \text{ C}$$
$$d = 2.7 \text{ AU}$$



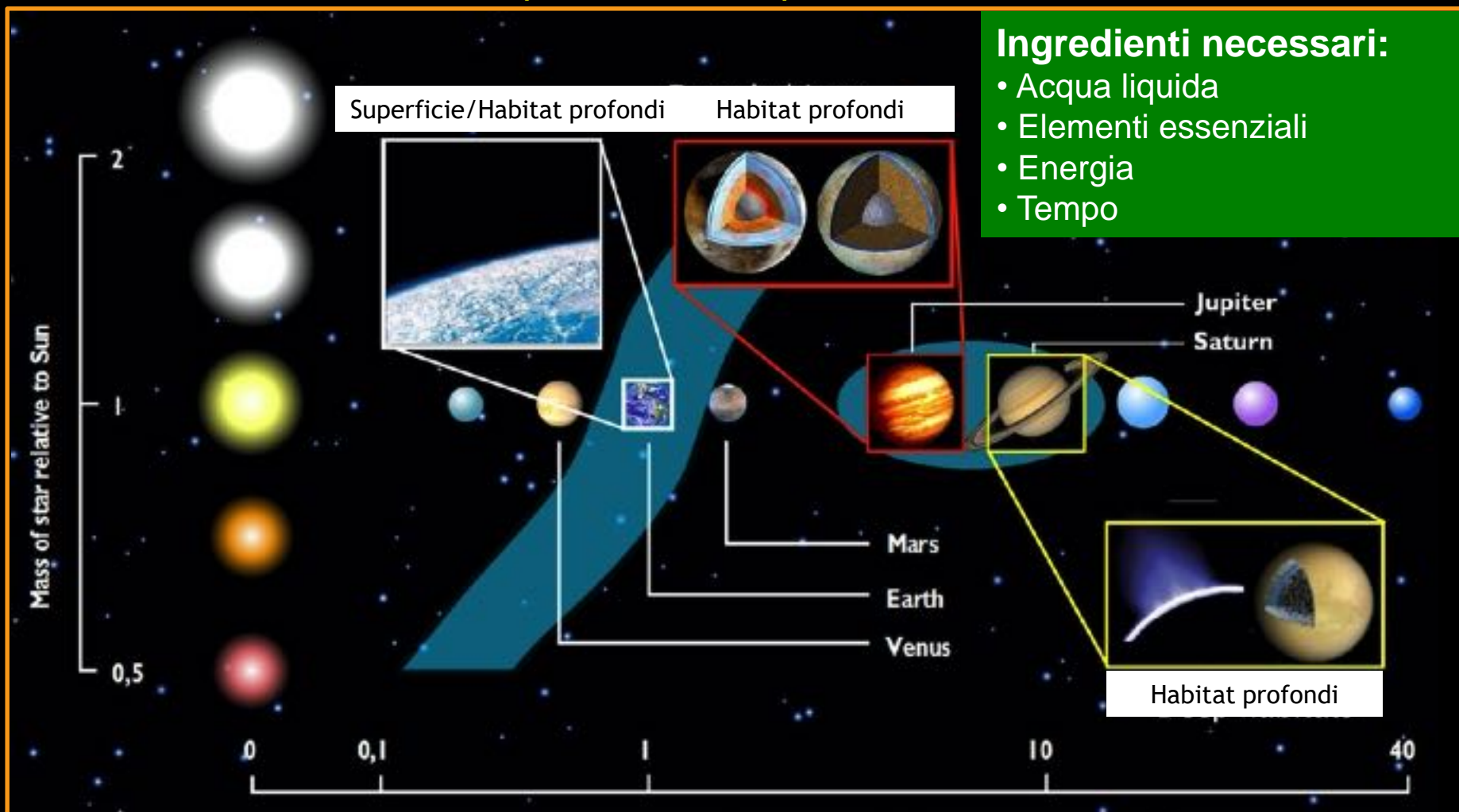
Introduzione : Abitabilità delle lune ghiacciate



La caccia alla prova dell'esistenza di forme di vita nel nostro Sistema Solare inizia dalla comprensione di cosa rende un pianeta 'abitabile'

Introduzione : Abitabilità delle lune ghiacciate

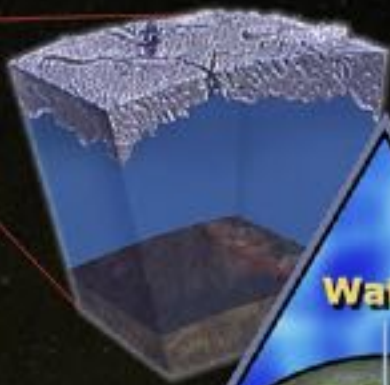
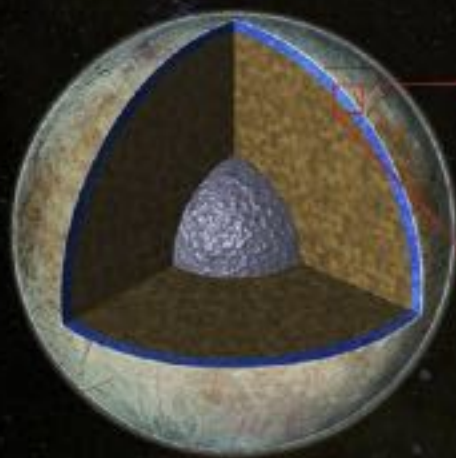
Ganimede ed Europa sono mondi potenzialmente 'abitabili' ?



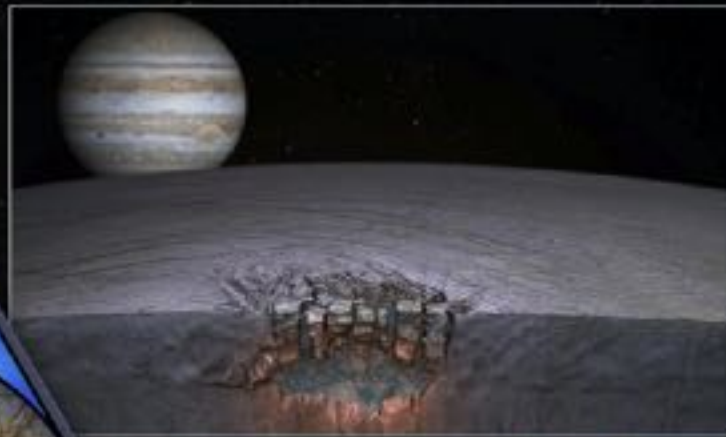
Forme di vita elementari potrebbero avere popolato ambienti 'acquosi' esterni alla Terra

Ganimede ed Europa sono gli archetipi di due classi di mondi abitabili

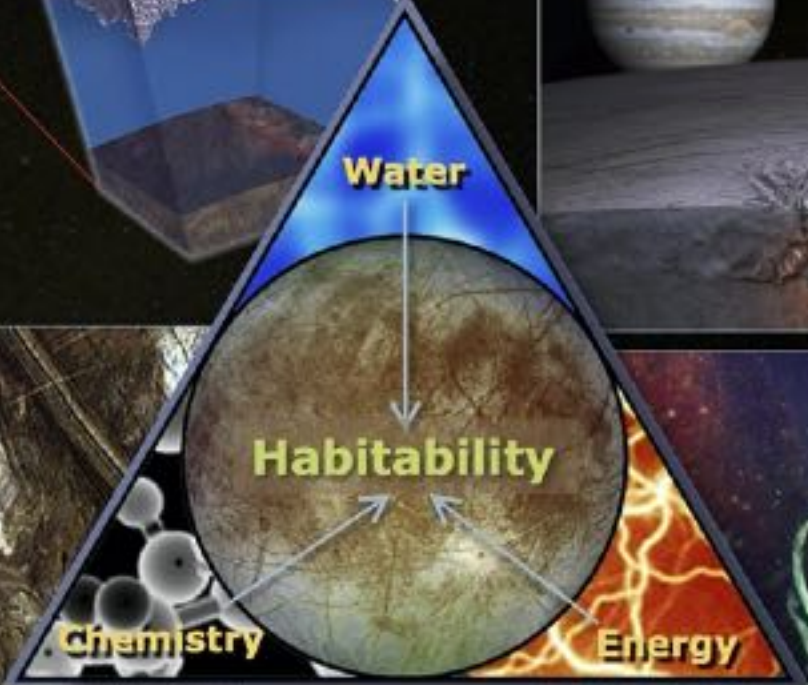
Ingredients for Life



Water: Are a global ocean and lakes of water hidden below the ice?

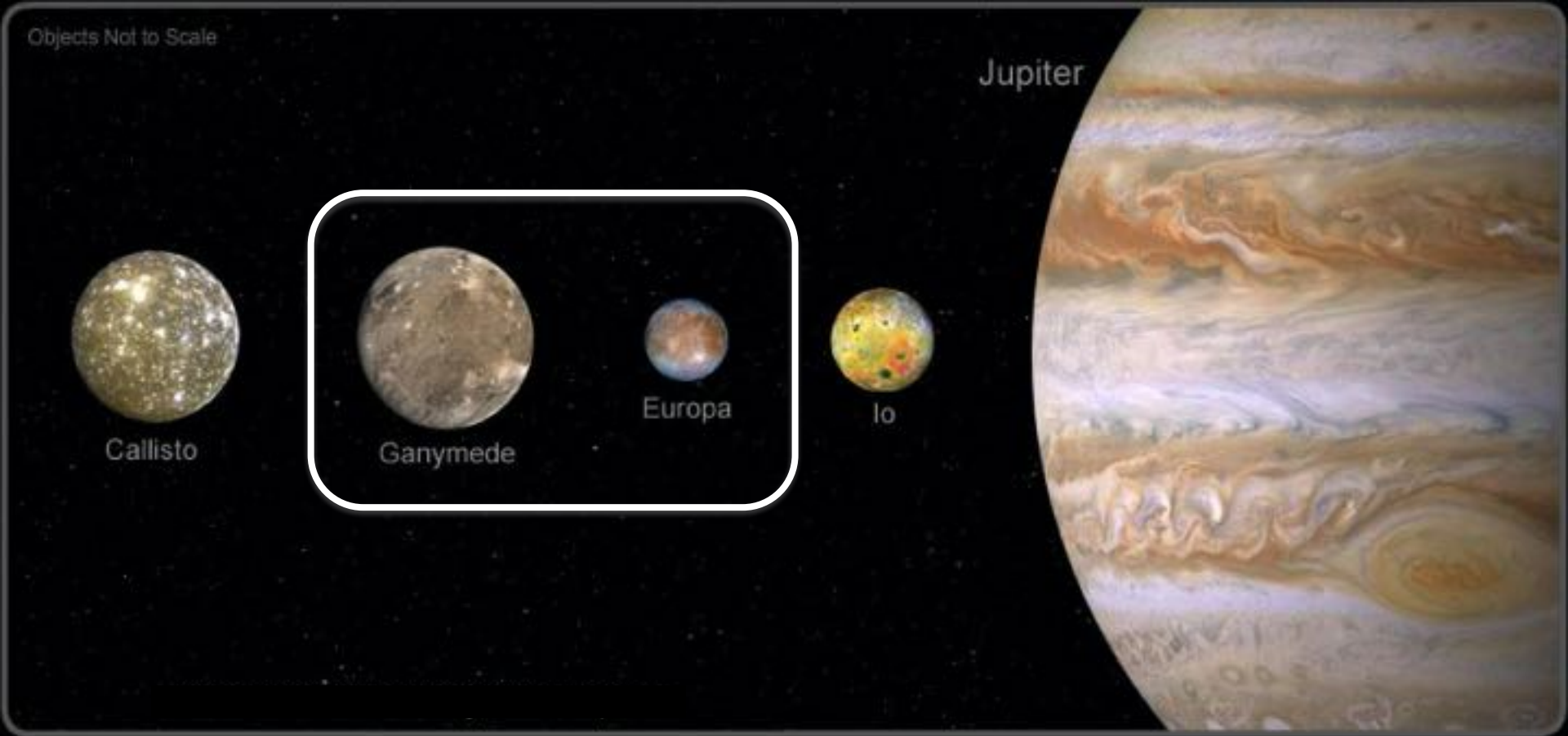


Chemistry: Do red surface deposits tell of habitability below?

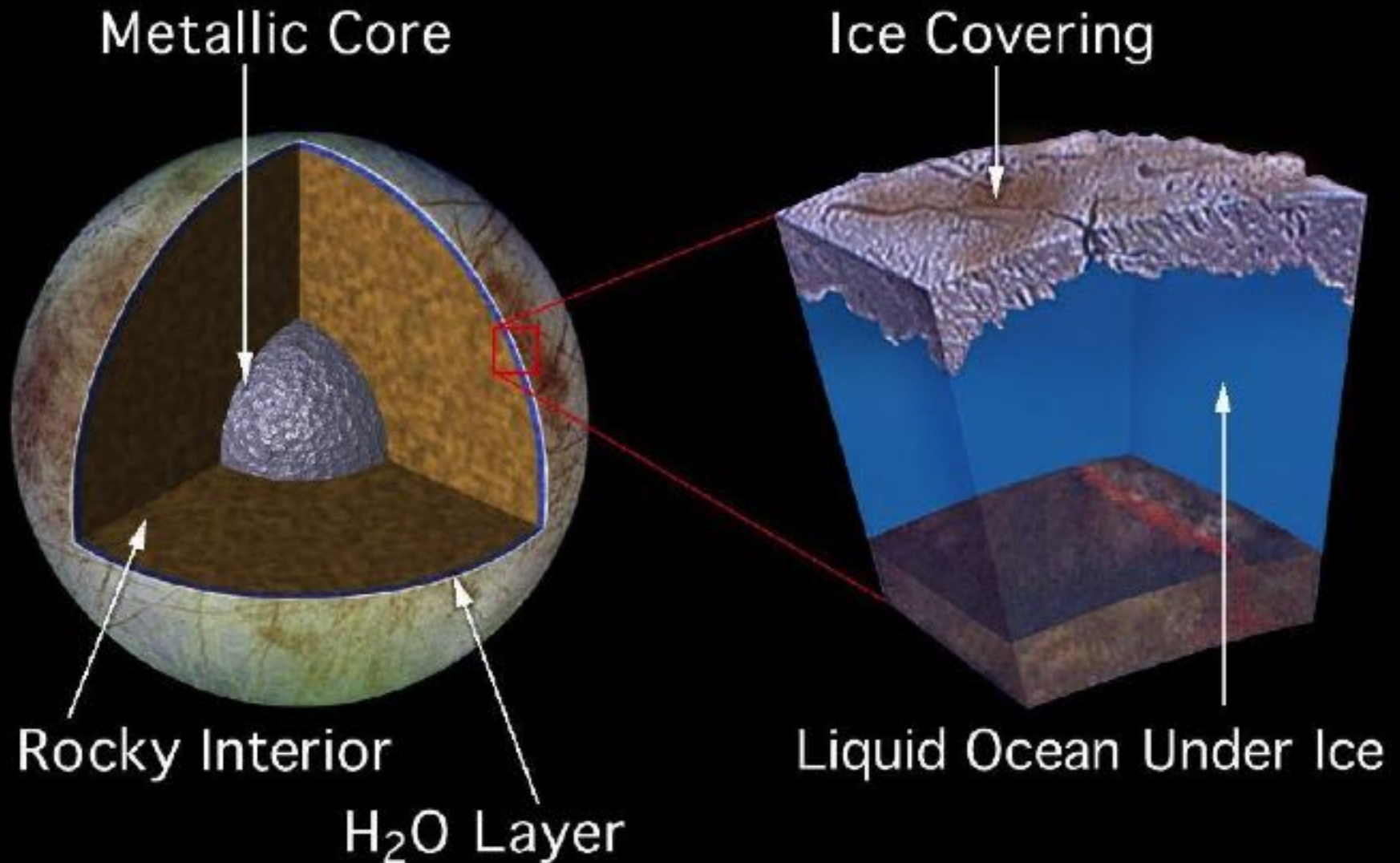


Energy: Can chemical disequilibrium provide energy for life?

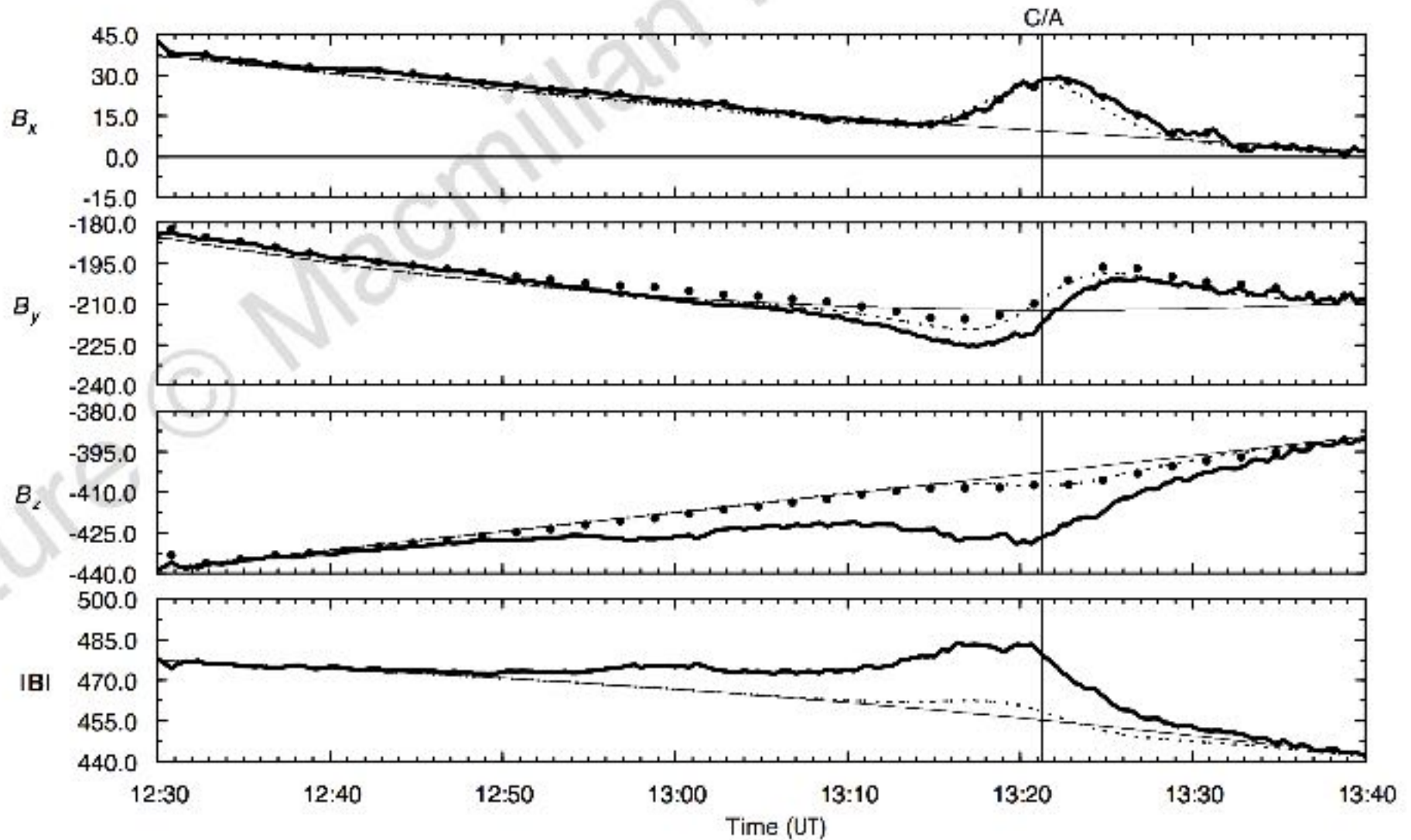
Le lune galileiane di Giove: Un “Sistema Solare in miniatura”



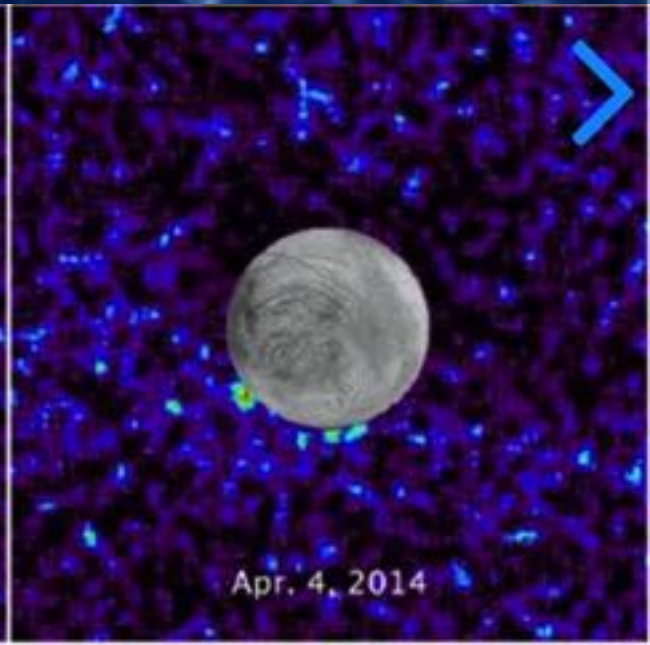
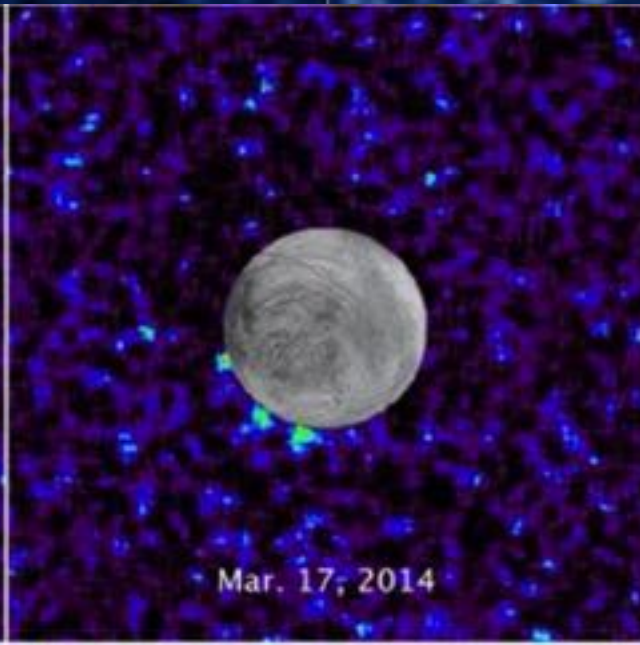
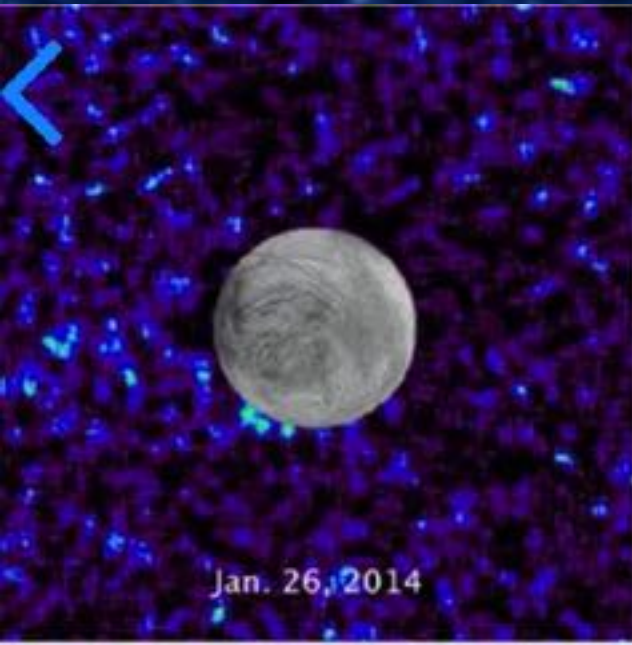
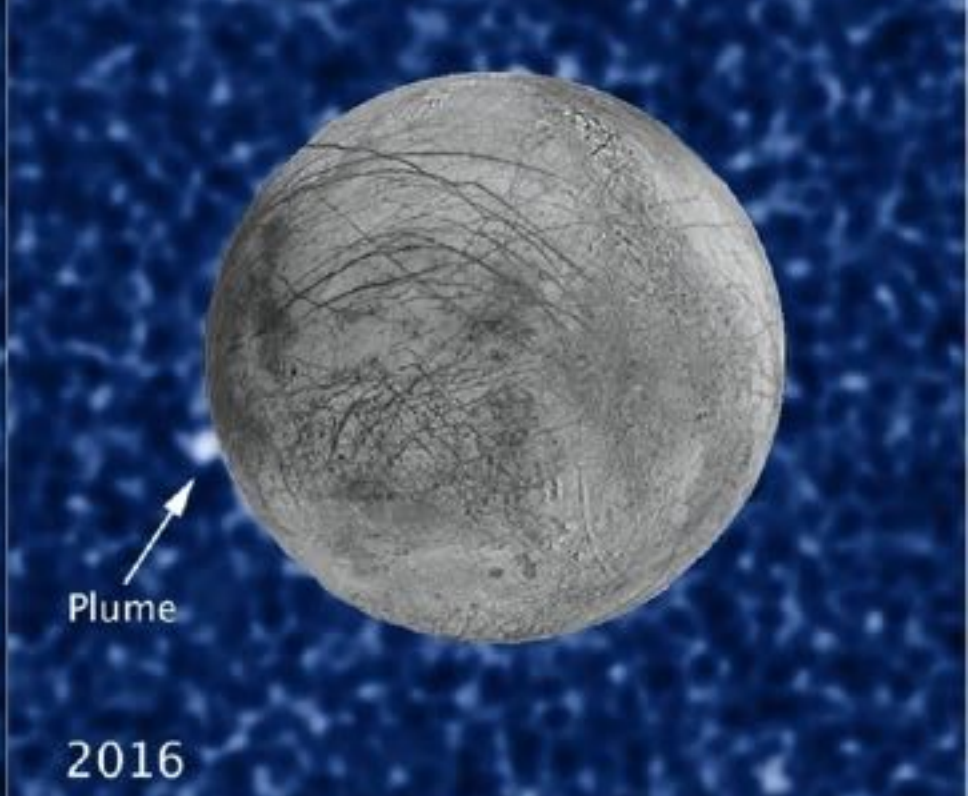
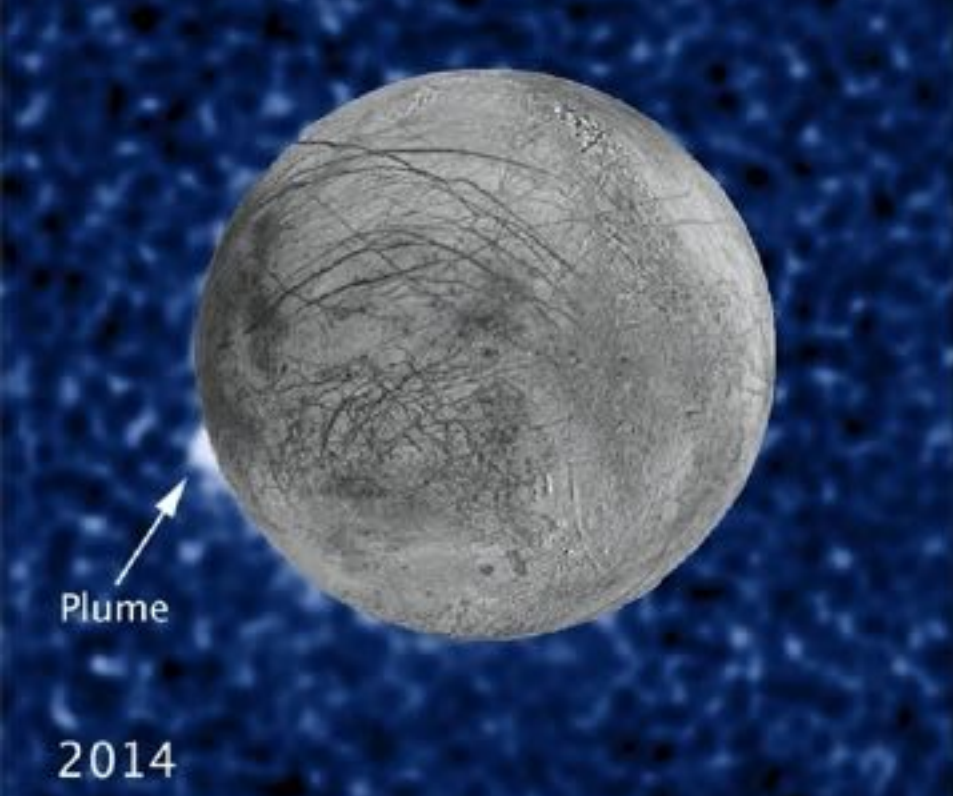
Struttura interna di Europa



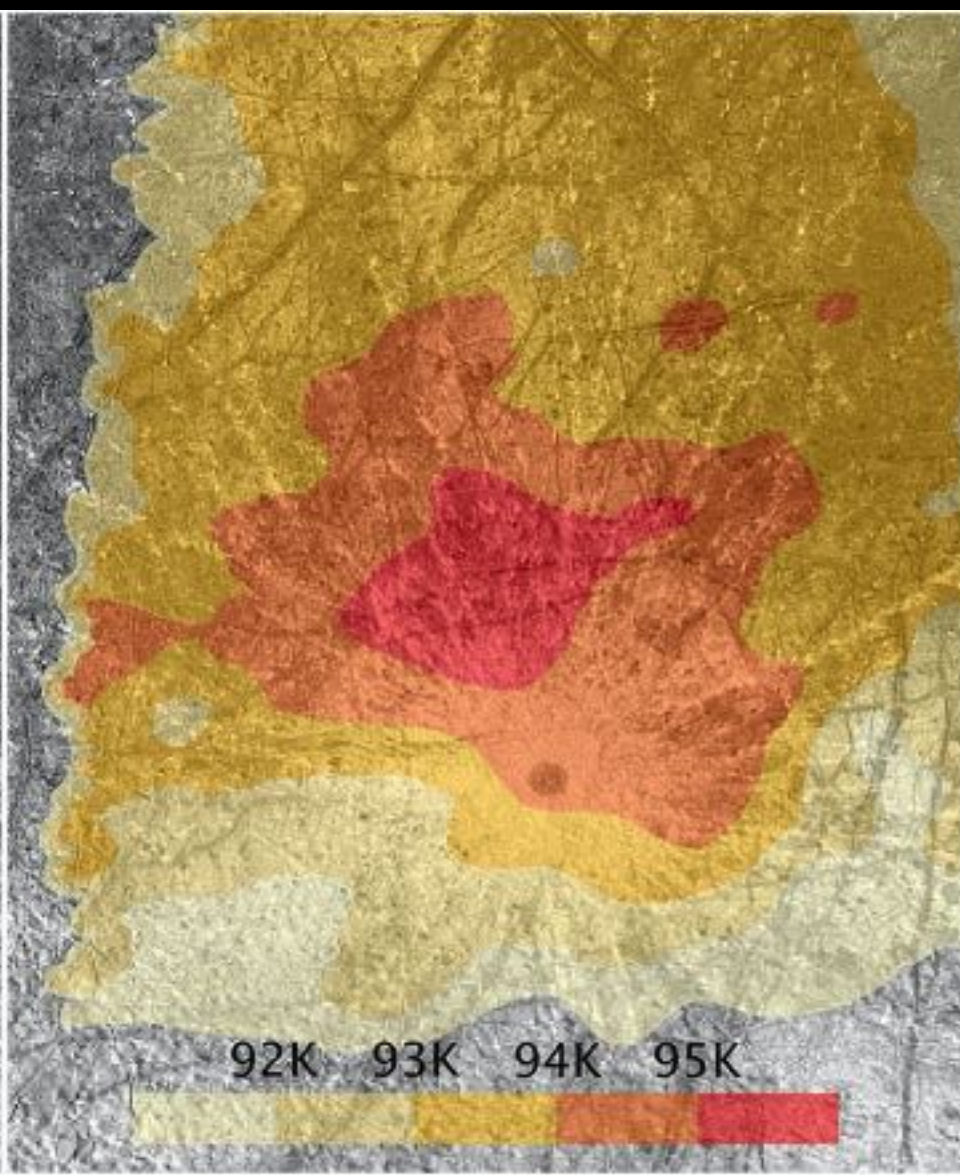
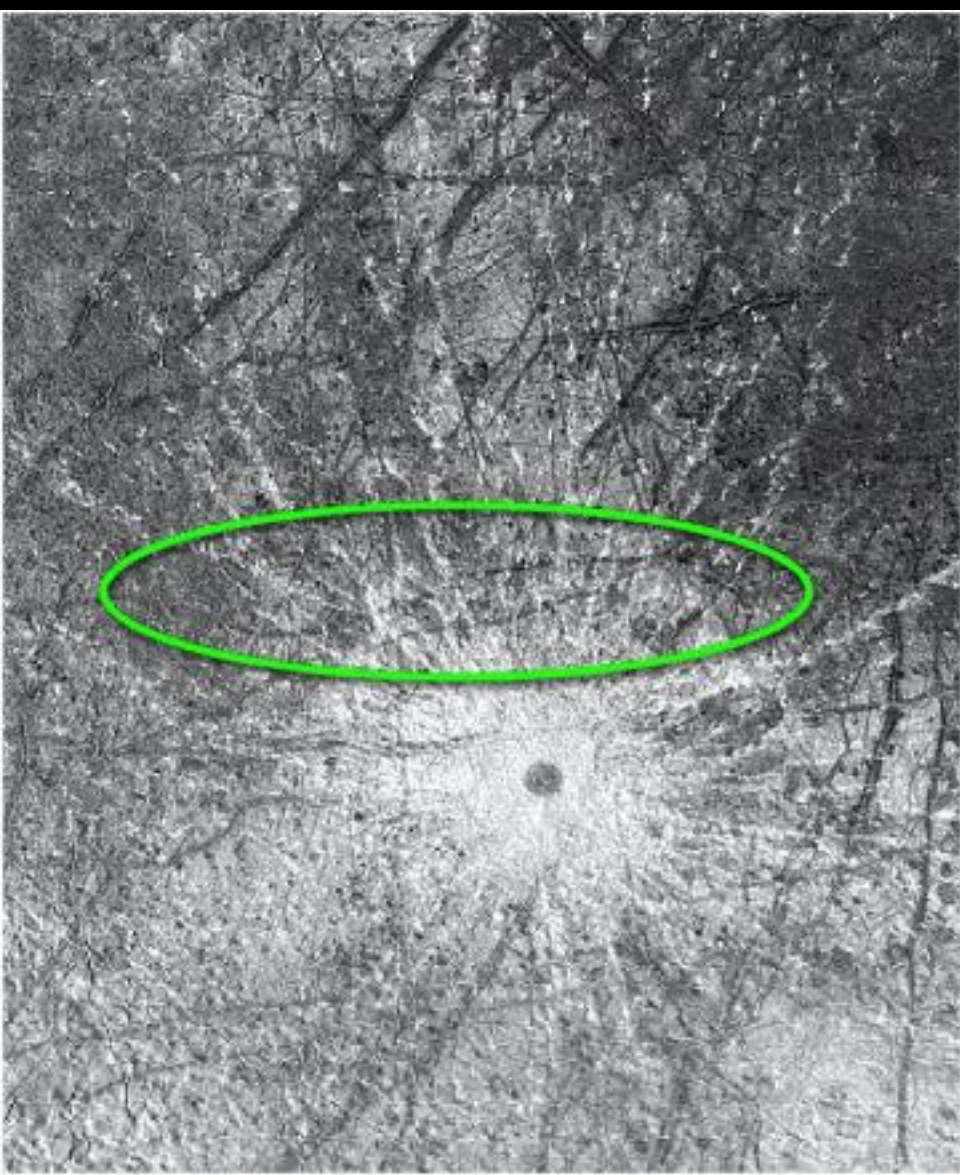
Struttura interna di Europa: Il campo magnetico indotto



Khurana et al., 1998



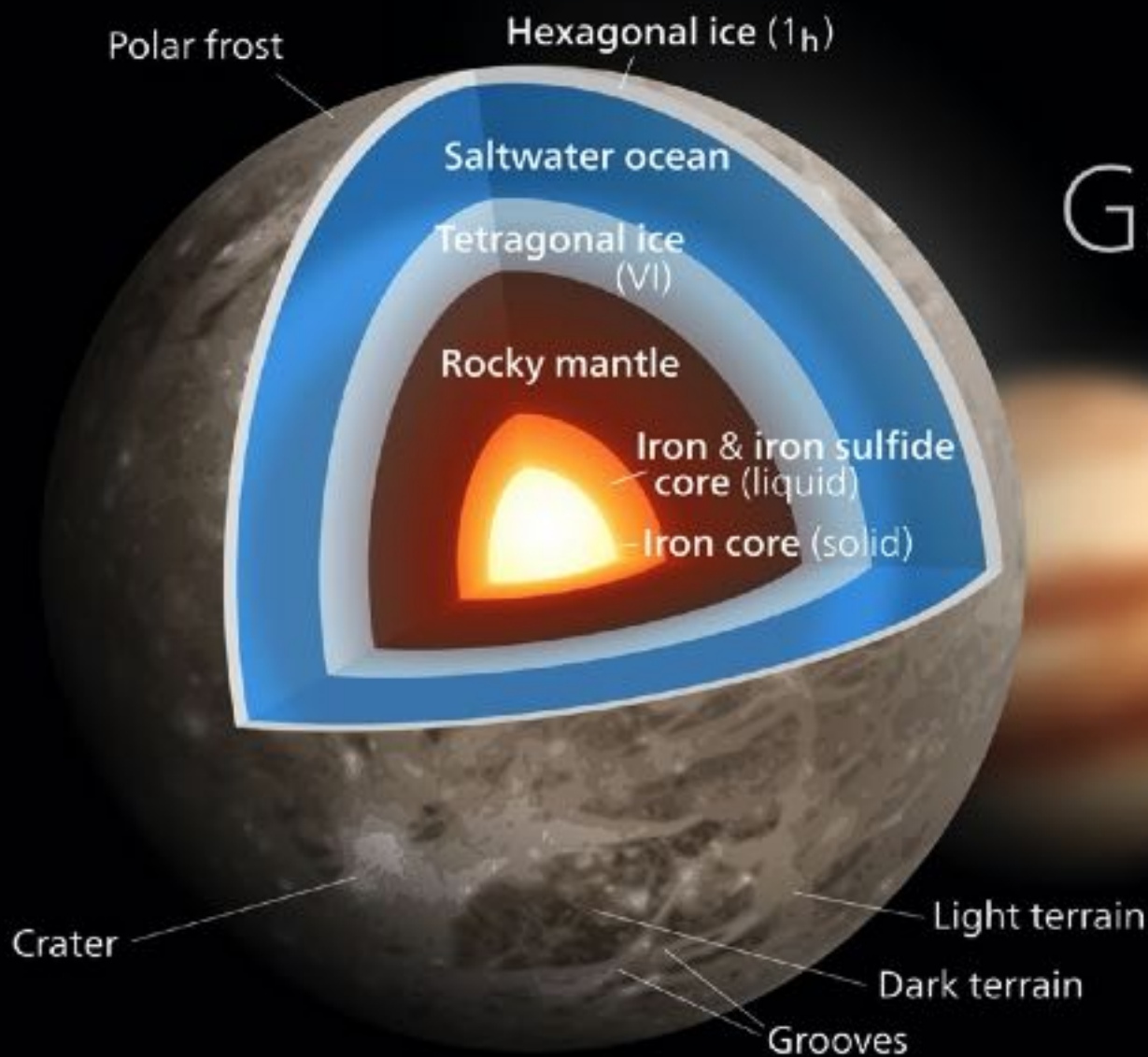
Plumes di Europa: Uno dei presunti siti (cratere Pwyll)



Plumes di Europa (visione artistica)



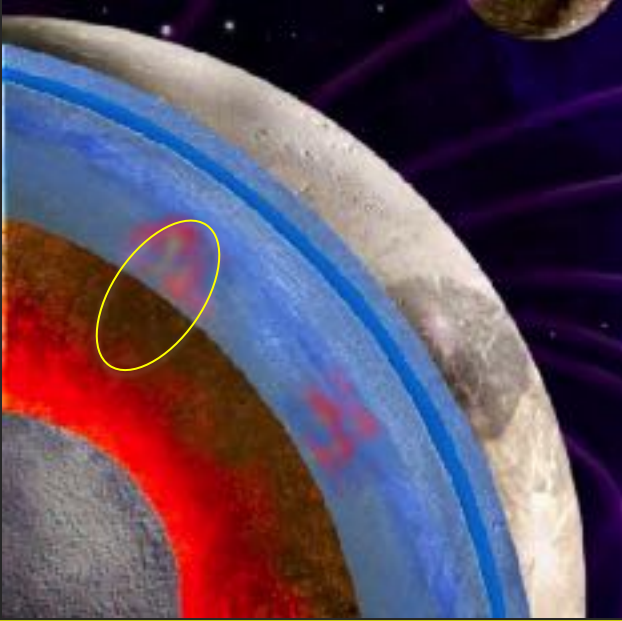
Struttura interna di Ganimede



Ganymede
layers drawn to scale

Due archetipi di mondi “acquosi”

Tipo ‘Ganimede’ o ‘Titano’: Se abitabile, gli strati liquidi sono compresi tra due strati di ghiaccio



Ricorrenza:

Lune maggiori, hot ice giants, ocean-planets...
E' l'habitat più comune nell'universo ?

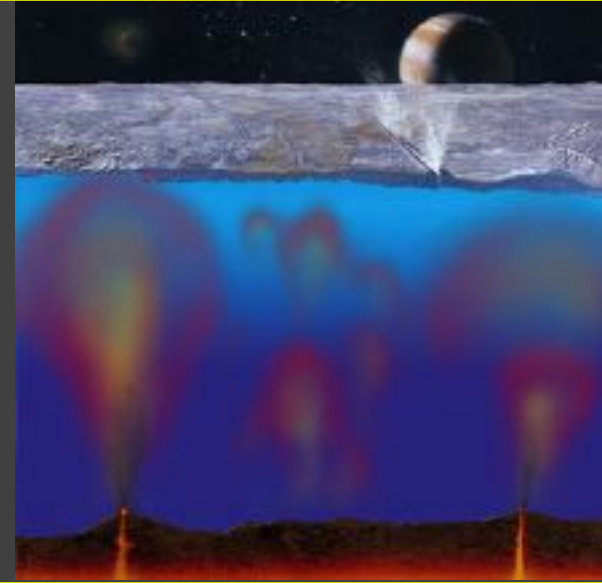
Domanda chiave:

Questi mondi acquosi sono abitabili ?

Cosa farà JUICE:

Tramite la caratterizzazione di Ganimede,
vincolerà la probabilità di abitabilità nell'universo

Tipo ‘Europa’ o ‘Encelado’: Se abitabile, gli strati liquidi possono essere a diretto contatto con i silicati come sulla Terra



Ricorrenza:

Europa, Encelado
Possibile solamente per mondi piccoli

Domanda chiave:

Come si legano le aree superficiali attive ai
potenziali habitat profondi ?

Cosa farà JUICE:

Preparerà la strada per futuri elementi di
superficie (lander) per Europa
Migliore comprensione della probabilità di
habitat profondi

→ JUPITER ICY MOONS EXPLORER

Exploring the emergence of habitable worlds around gas giants



Tre grandi lune ghiacciate da esplorare

Ganimede

- Maggiore satellite del Sistema Solare
- Un oceano profondo
- Dinamo interna e campo magnetico indotto (unicità)
- Ricchezza di morfologie geologiche
- Archetipo dei waterworlds
- Migliore esempio di ambiente liquido intrappolato tra due strati di ghiaccio

Callisto

- Miglior luogo per studiare la storia degli impattori
- Differenziazione – ancora un enigma
- Unico esempio noto di mondo non attivo ma con uno strato interno liquido
- Un testimone di epoche remote

Europa

- Un oceano profondo
- Un mondo attivo?
- Migliore esempio di ambiente liquido in contatto con i silicati

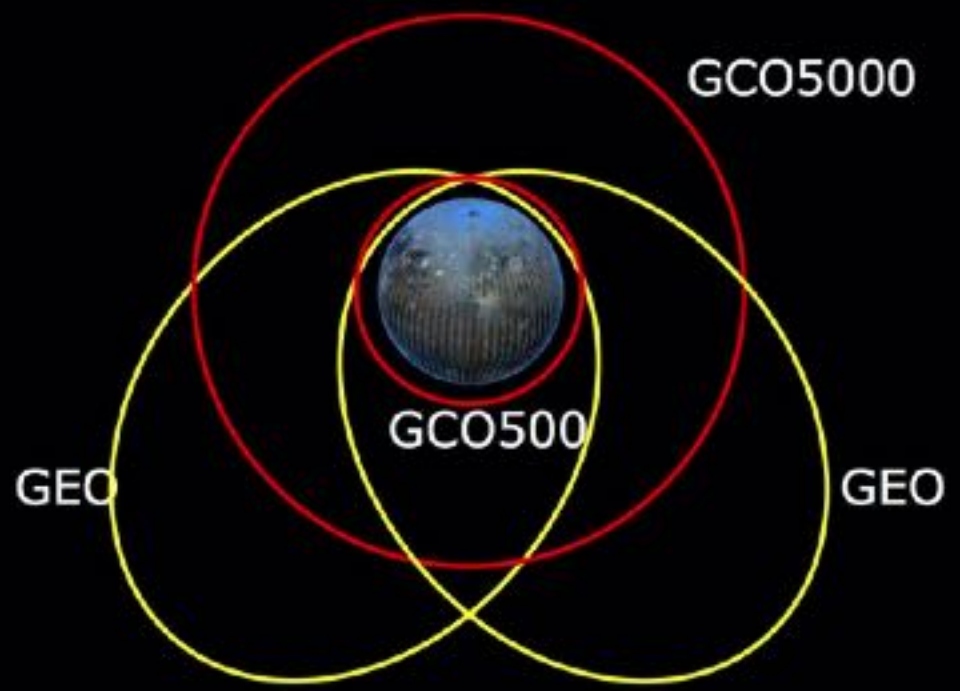
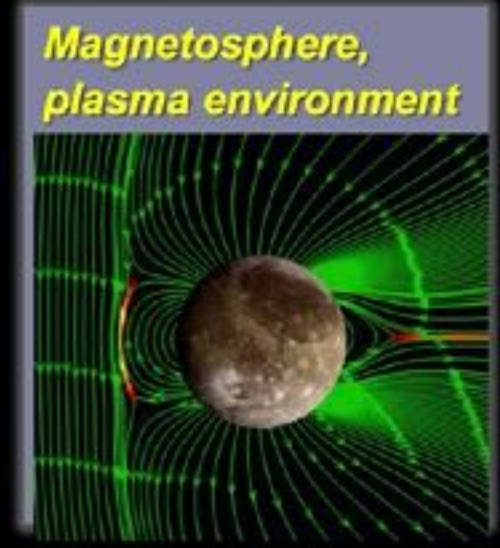
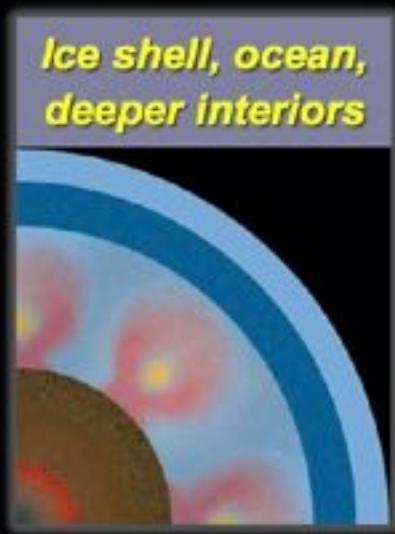
Domande chiave:

- Il sistema di Giove ospita mondi 'abitabili'?
- Quali sono i processi che operano nel sistema di Giove?



La sonda JUICE che esplora il sistema di Giove
(artista: M. Carroll)

Ganimede: Un oggetto planetario e un potenziale habitat JUICE



3-axis stabilised

Mass:

- Dry mass: **2420 kg**
- Instruments: **280 kg**
- Propellant tank capability: **3650 kg**

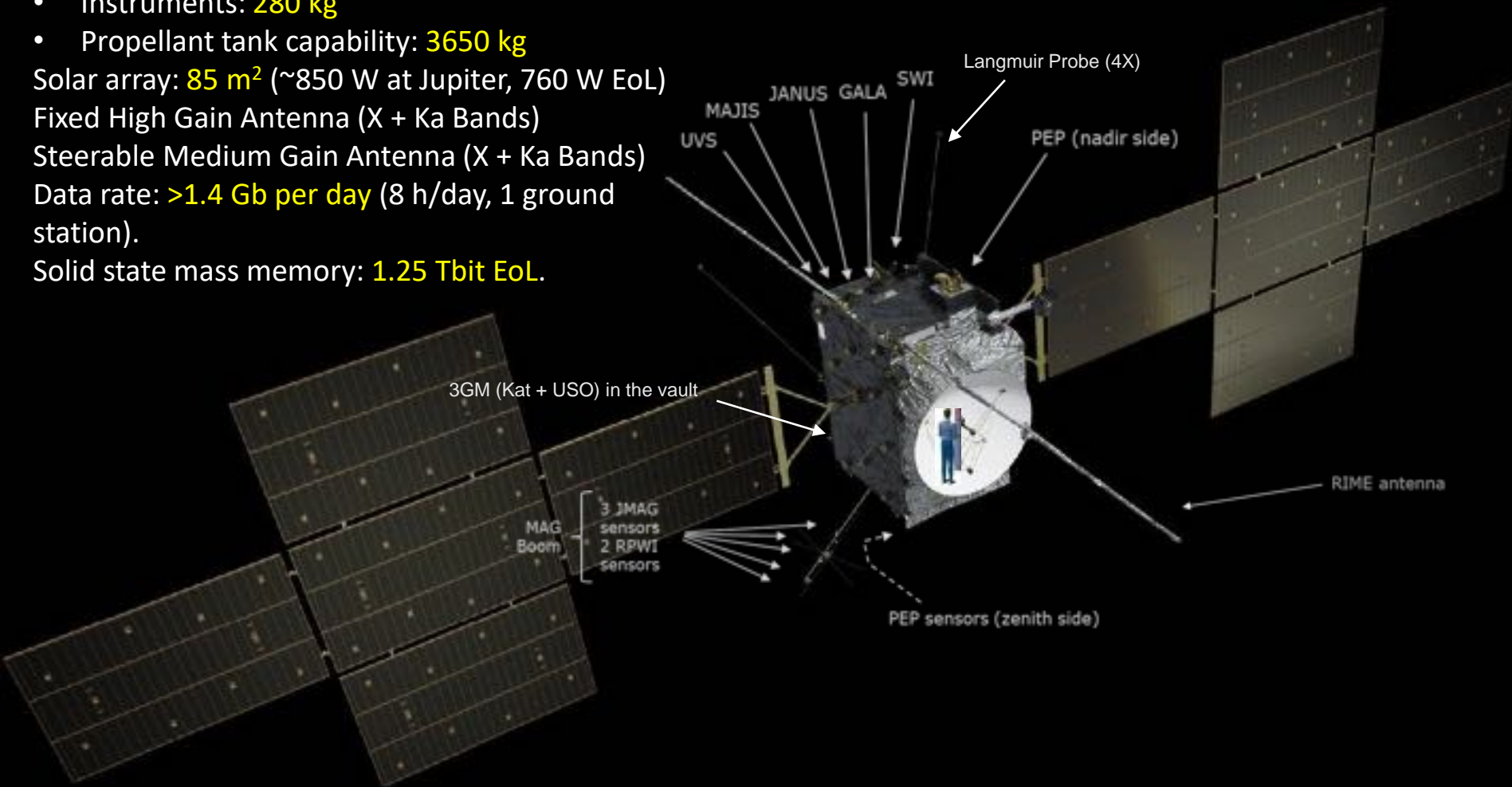
Solar array: **85 m²** (~850 W at Jupiter, 760 W EoL)

Fixed High Gain Antenna (X + Ka Bands)

Steerable Medium Gain Antenna (X + Ka Bands)

Data rate: **>1.4 Gb per day** (8 h/day, 1 ground station).

Solid state mass memory: **1.25 Tbit EoL**.

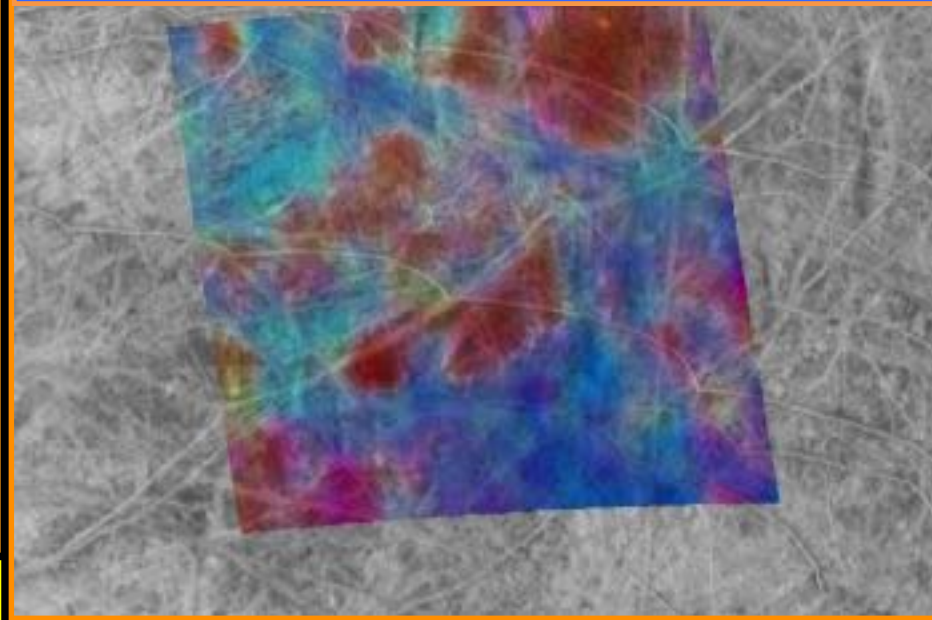


Prove di un'eccezionale complessità superficiale

Possibile criovulcanismo su Europa



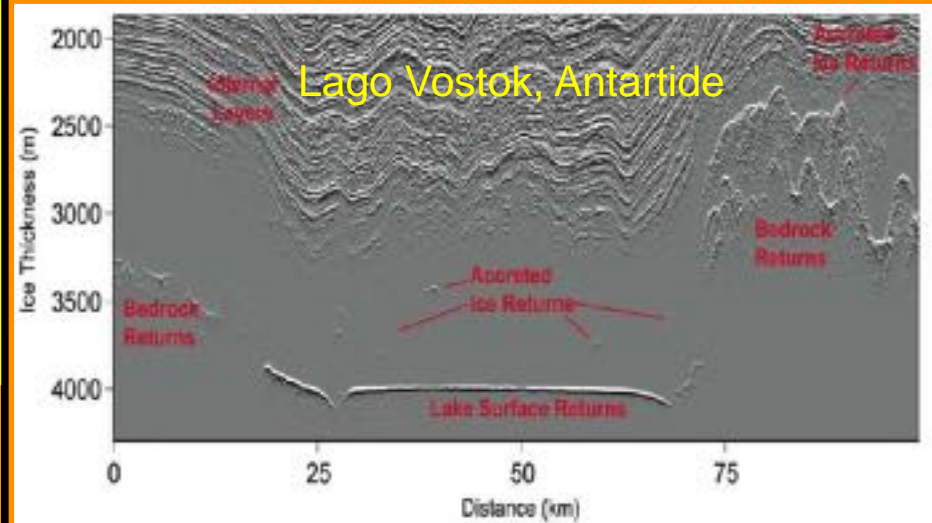
Mappatura spettroscopica della superficie



Obiettivi scientifici

- ✧ Capire l'origine delle formazioni superficiali e loro relazione con la sotto-superficie, l'oceano e l'interno profondo
- ✧ Ricerca di serbatoi di acqua liquida nella crosta di ghiaccio
- ✧ Natura dei composti non-ghiaccio (inc. organici)
- ✧ Processi di scambio superficie / sotto-superficie
- ✧ Contributi endogeni / esogeni

Strumenti chiave: Camere ottiche
Spettrometri
Plasmi e particelle in situ

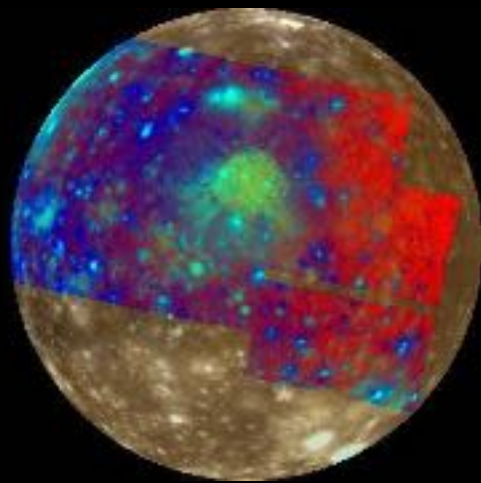


Callisto: un testimone di epoche remote

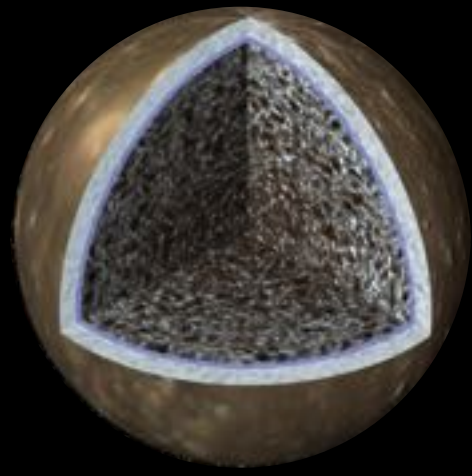
La superficie più antica



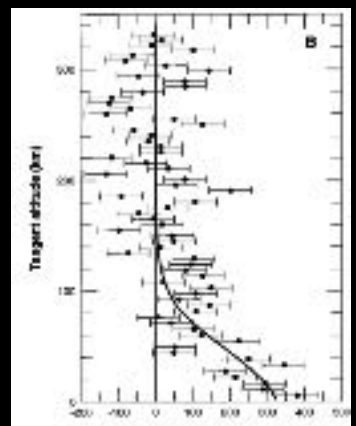
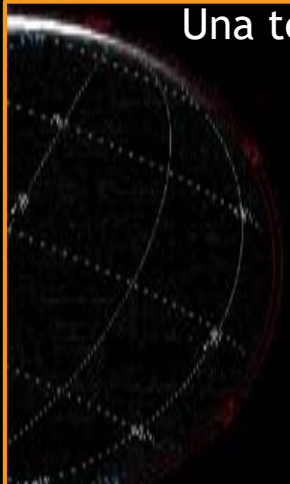
Chimica complessa



Non del tutto differenziato



Una tenue atmosfera



Obiettivi scientifici

- ✦ Esistenza ed estensione di un oceano sotto-superficiale
- ✦ Grado di differenziazione (→ fly-by ad elevata latitudine)
- ✦ Conteggio dei crateri e storia geologica recente
- ✦ Composizione superficiale, inclusi composti organici e CO2
- ✦ Composizione e struttura dell'esosfera

Strumenti chiave:

Camere ottiche, Spettrometri,
Radar sounder e Radio scienza
Plasmi e particelle in-situ



Year	2030	2031	2032	2033
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Europa Clipper Science Goals

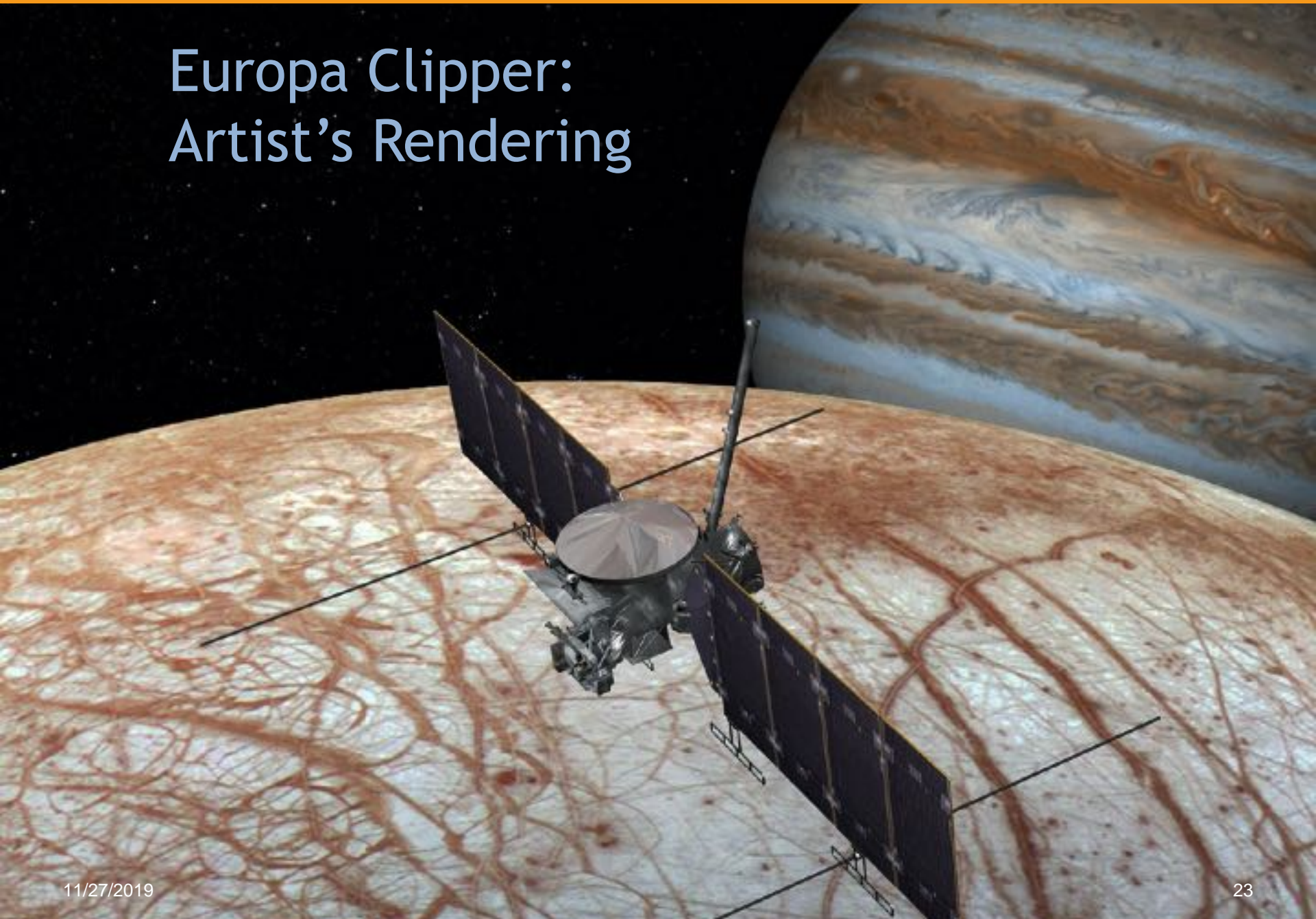
Goal: Explore Europa to investigate its habitability

Objectives:

- **Ice Shell & Ocean:** Existence and nature of water within or beneath the ice, and processes of surface-ice-ocean exchange
- **Composition:** Distribution and chemistry of key compounds and the links to ocean composition
- **Geology:** Characteristics and formation of surface features, including sites of recent or current activity

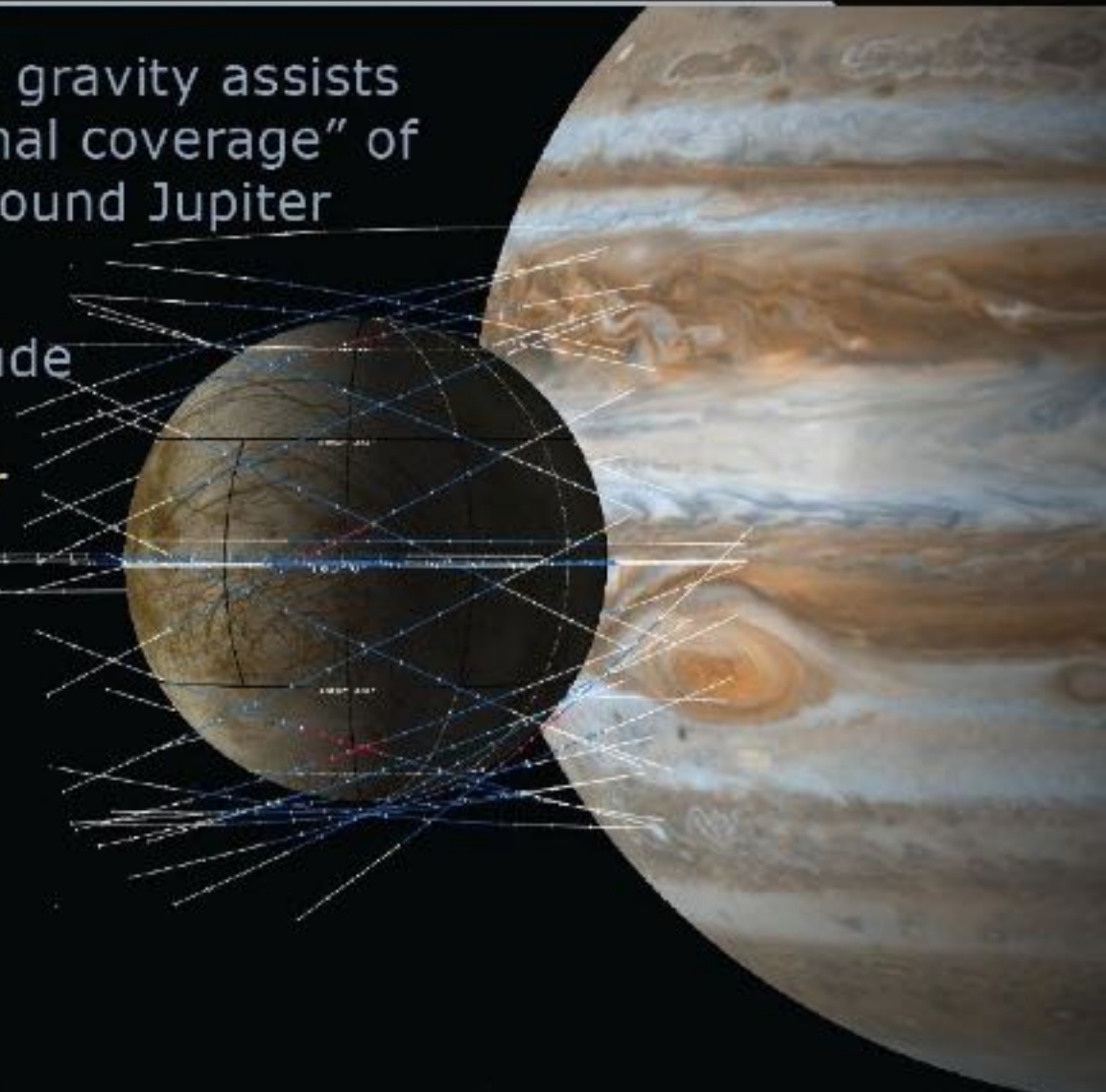


Europa Clipper: Artist's Rendering



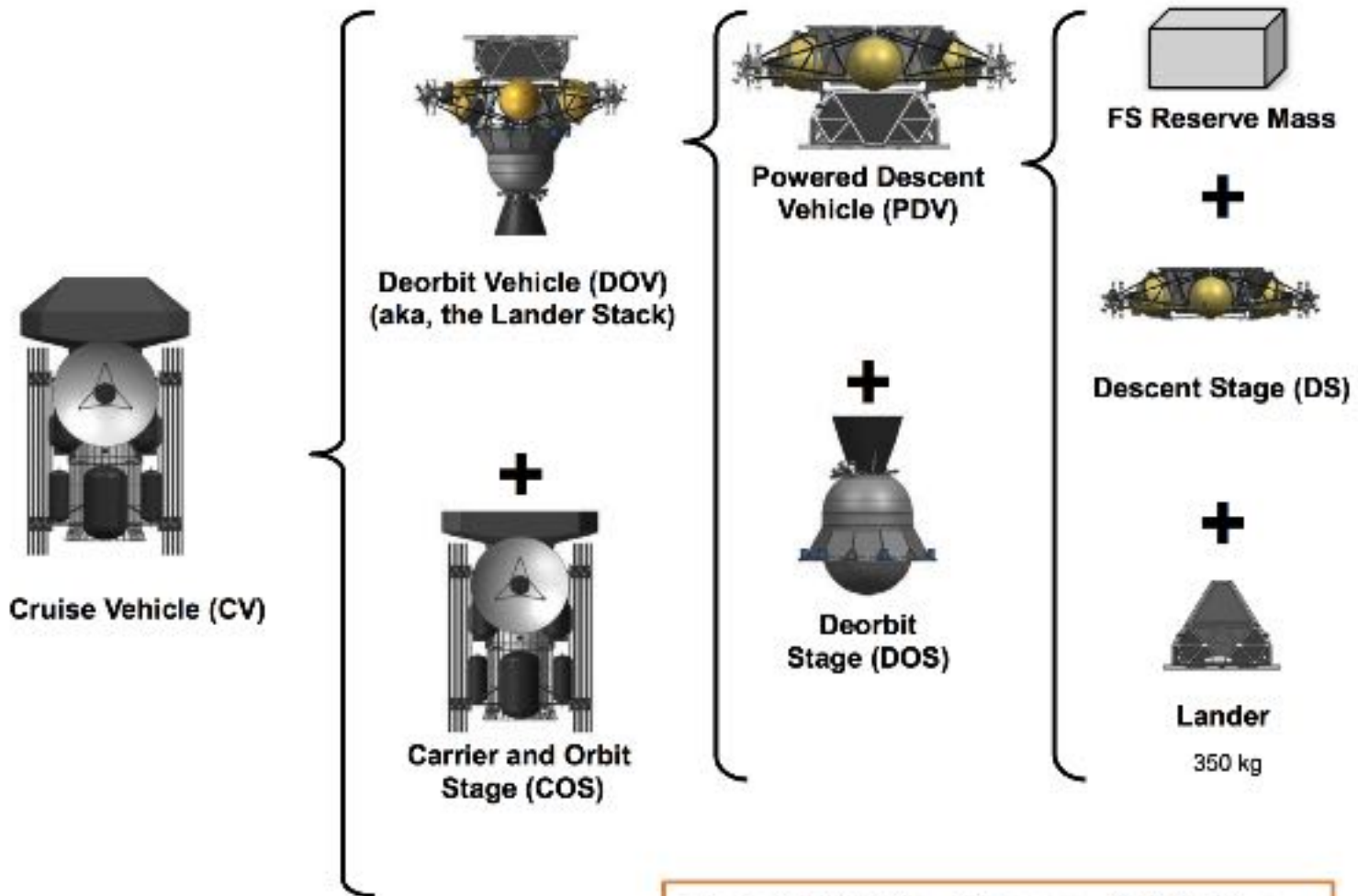
Europa Clipper Mission Profile

- Utilize multiple satellite gravity assists to enable “global-regional coverage” of Europa while in orbit around Jupiter
- Current mission design consists of **45** low-altitude flybys of Europa from Jupiter orbit over **3.5 yr**
- Minimizes time in high radiation environment (2.1 Mrad TID*)
- Simple repetitive operations



*Si behind 100 mil Al, spherical shell

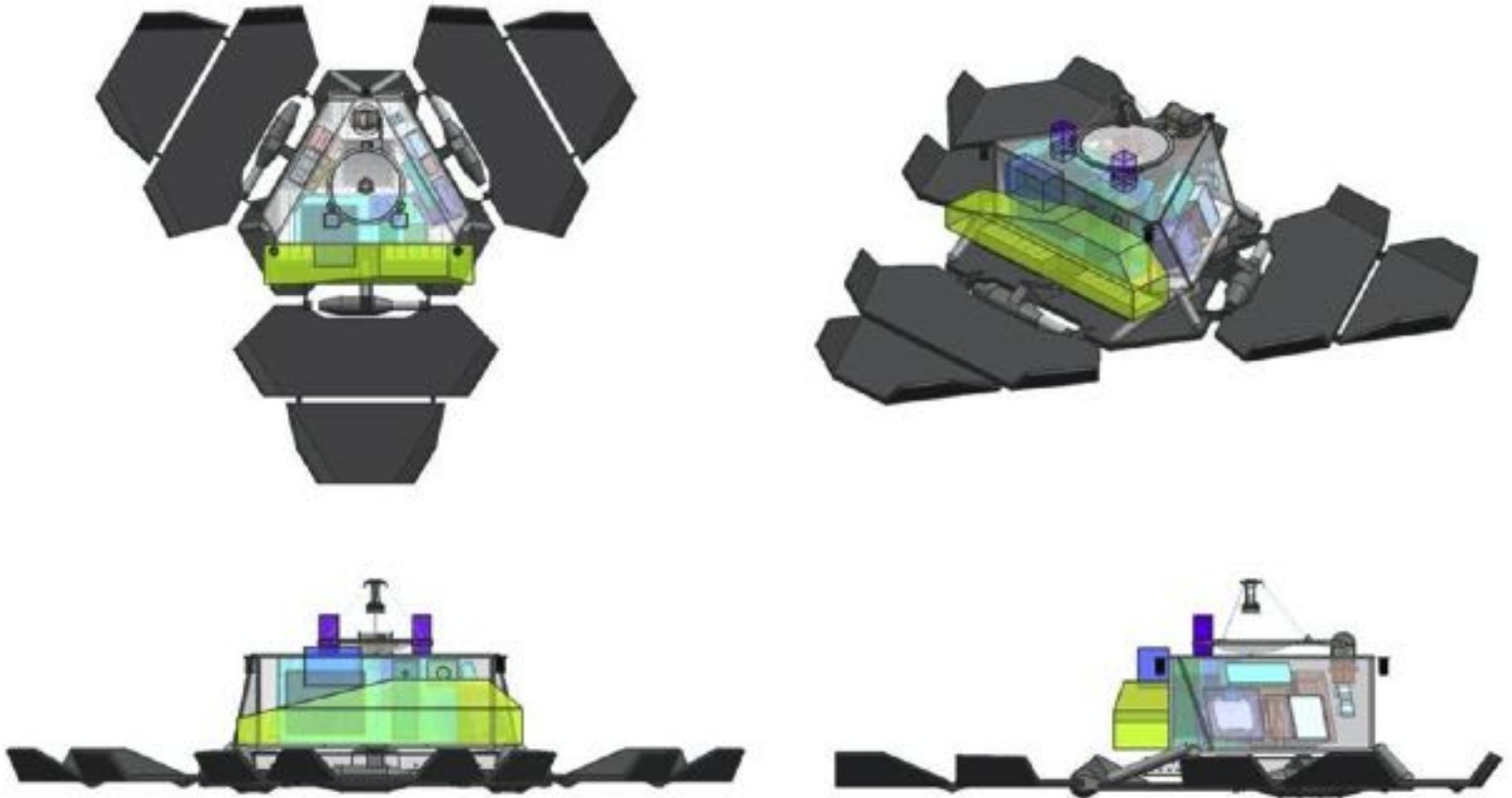
Spacecraft MPV Mass Stackup



Total FS Dry Mass: 4400 kg
Total FS Prop Mass: 8200 kg



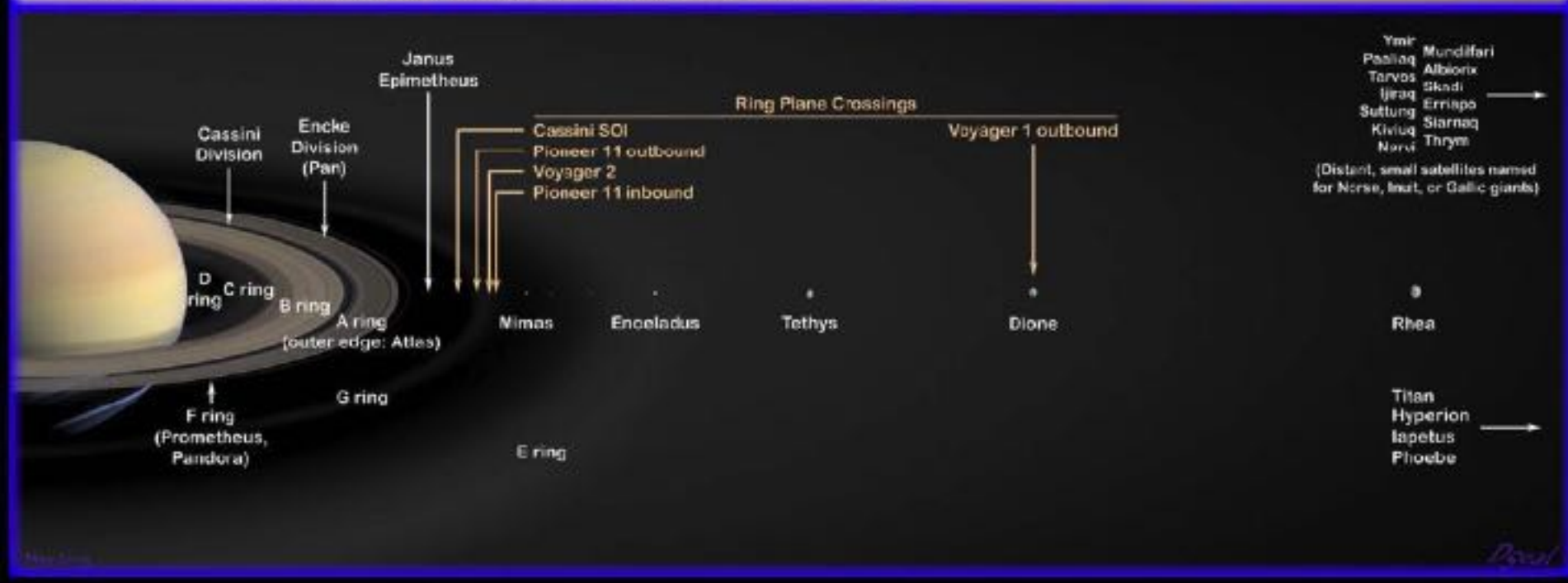
Payload Envelopes



Il futuro remoto: Cryobot nell'oceano di Europa (?)

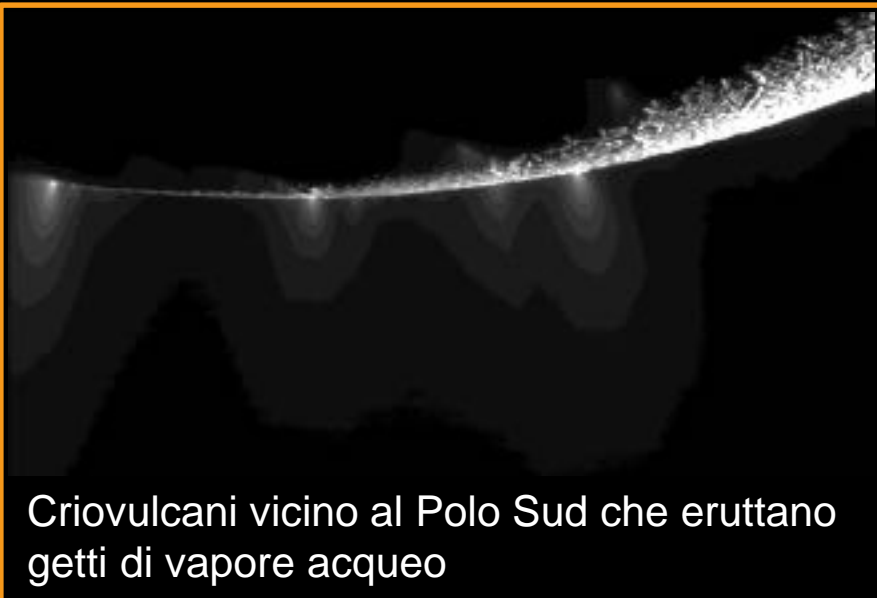


Ritratto del Sistema di Saturno



Encelado: Un piccolo mondo ricco d'acqua

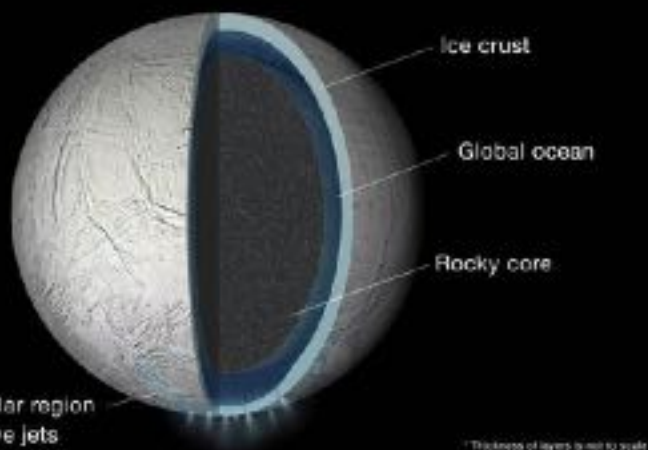
Encelado: un potenziale habitat per microbi extraterrestri



“Graffi di tigre” nella regione polare meridionale

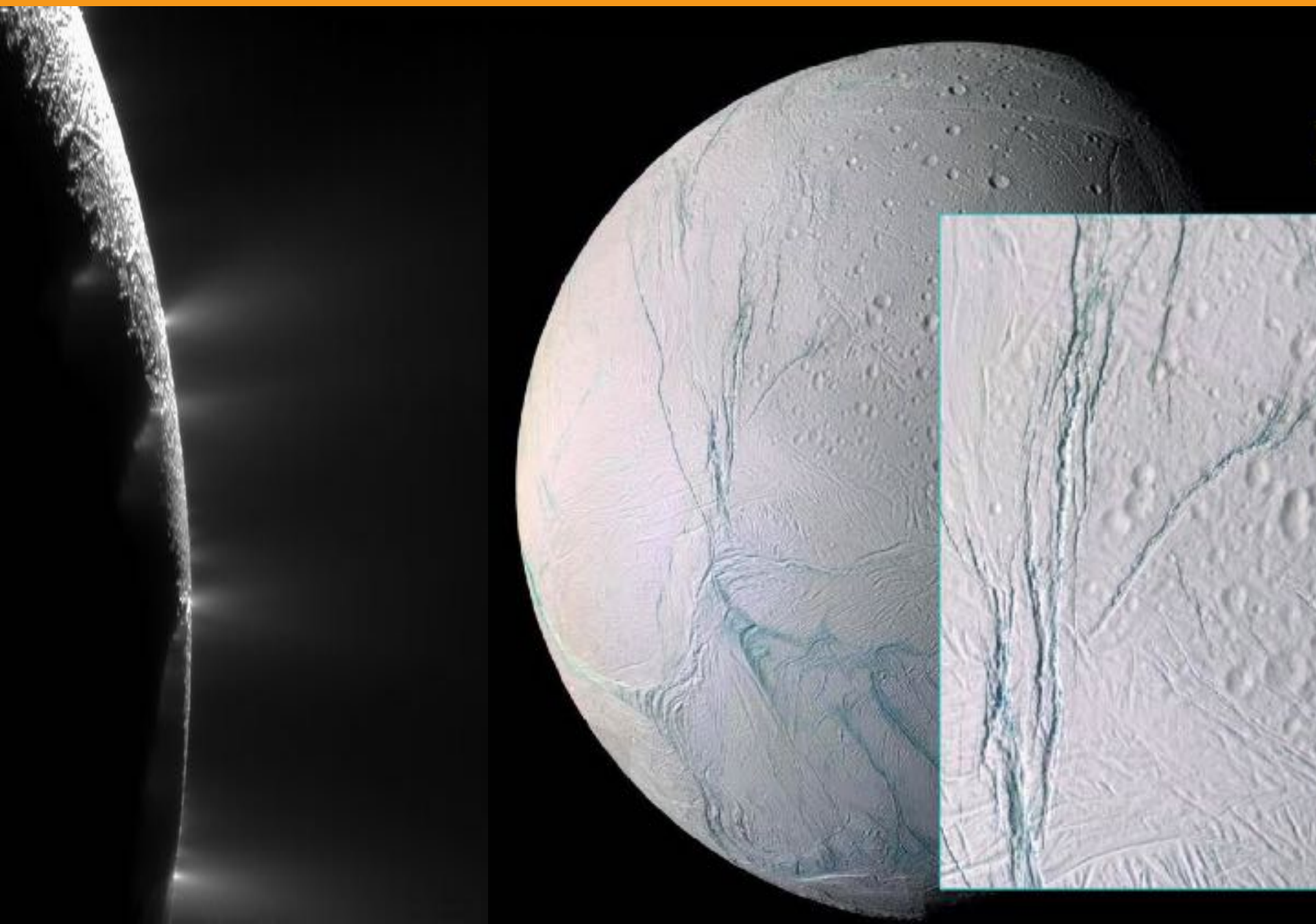


Global Ocean on Saturn's Moon ENCELADUS



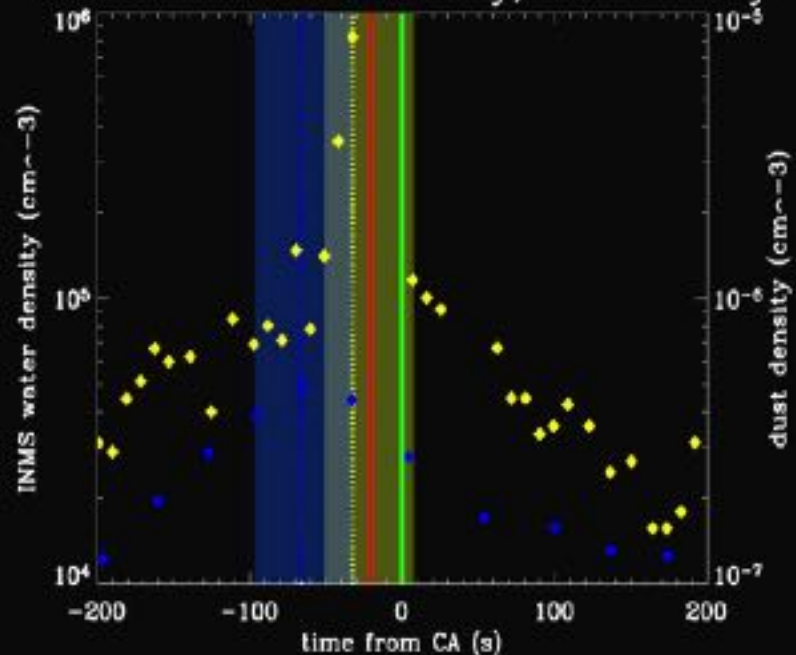
Un mare sotterraneo sotto il Polo Sud

Encelado: Tiger stripes e geyser

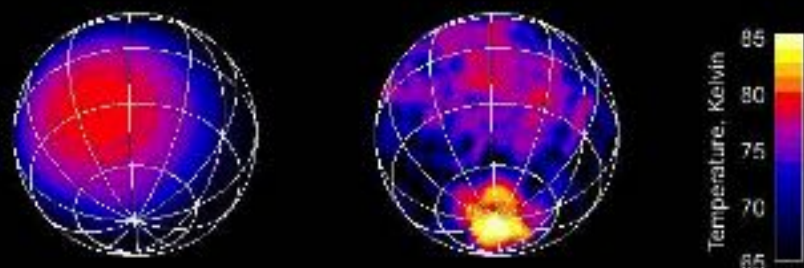


Encelado: Composizione dei plumes

Enceladus - Water Density, Dust density



Enceladus Temperature Map



Predicted
Temperatures

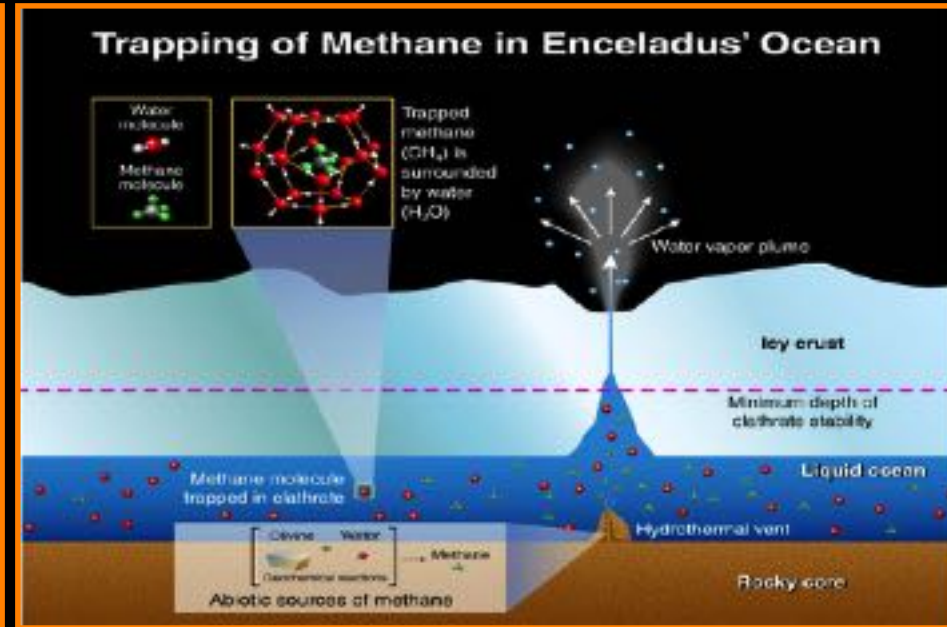
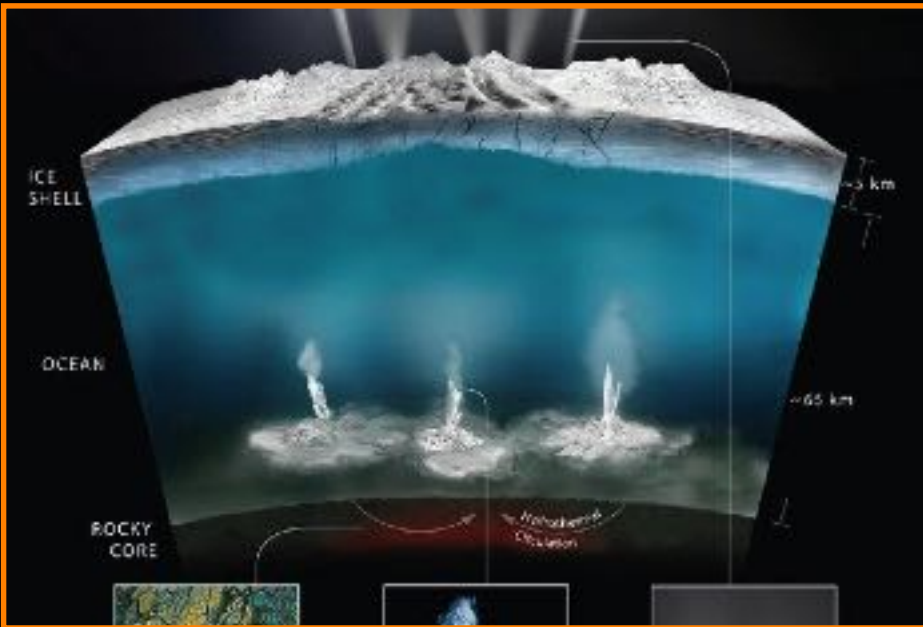
Observed
Temperatures

Table 1 | INMS determination of plume composition on 9 October 2008

Species	Volume mixing ratio
H ₂ O	0.90 ± 0.01
CO ₂	0.053 ± 0.001
CO	[0.044]
H ₂	[0.39]
H ₂ CO	(3.1 ± 1) × 10 ⁻³
CH ₃ OH	(1.5 ± 0.6) × 10 ⁻⁴
C ₂ H ₄ O	<7.0 × 10 ⁻⁴
C ₂ H ₆ O	<3.0 × 10 ⁻⁴
H ₂ S	(2.1 ± 1) × 10 ⁻⁵
⁴⁰ Ar	(3.1 ± 0.3) × 10 ⁻⁴
NH ₃	(8.2 ± 0.2) × 10 ⁻³
N ₂	<0.011
HCN [†]	<7.4 × 10 ⁻³
CH ₄	(9.1 ± 0.5) × 10 ⁻³
C ₂ H ₂	(3.3 ± 2) × 10 ⁻⁵
C ₂ H ₄	<0.012
C ₂ H ₆	<1.7 × 10 ⁻³
C ₃ H ₄	<1.1 × 10 ⁻⁴
C ₃ H ₆	(1.4 ± 0.3) × 10 ⁻³
C ₃ H ₈	<1.4 × 10 ⁻³
C ₄ H ₂	(3.7 ± 0.8) × 10 ⁻⁵
C ₄ H ₄	(1.5 ± 0.6) × 10 ⁻⁵
C ₄ H ₆	(5.7 ± 3) × 10 ⁻⁵
C ₄ H ₈	(2.3 ± 0.3) × 10 ⁻⁴
C ₄ H ₁₀	<7.2 × 10 ⁻⁴
C ₅ H ₆	<2.7 × 10 ⁻⁶
C ₅ H ₁₂	<6.2 × 10 ⁻⁵
C ₆ H ₆	(8.1 ± 1) × 10 ⁻⁵

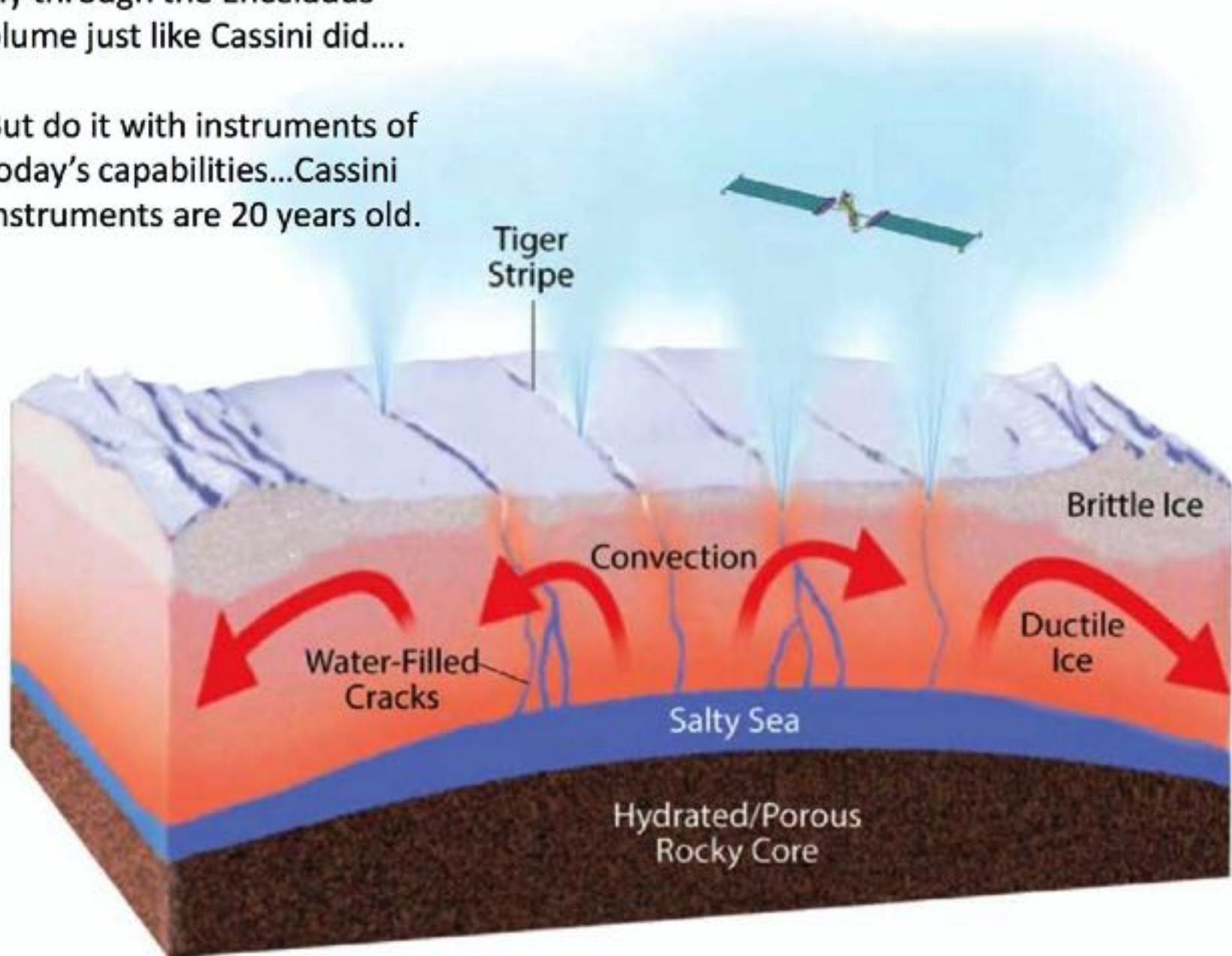
The mixing ratios shown here for CO and H₂ (values in square brackets) are included in the mixing ratios for CO₂ and H₂O given in the first two rows. Analysis of the data from all five encounters shows that the ratios of mass 44 (CO₂) to mass 28 and of mass 18 (H₂O) to mass 2 (H₂) decrease with increasing spacecraft velocity, suggesting that H₂ and CO are produced by the dissociation of H₂O and CO₂ through hypervelocity impact on, and reaction with, the walls of

Enceladus: Un potenziale habitat per microbi extraterrestri

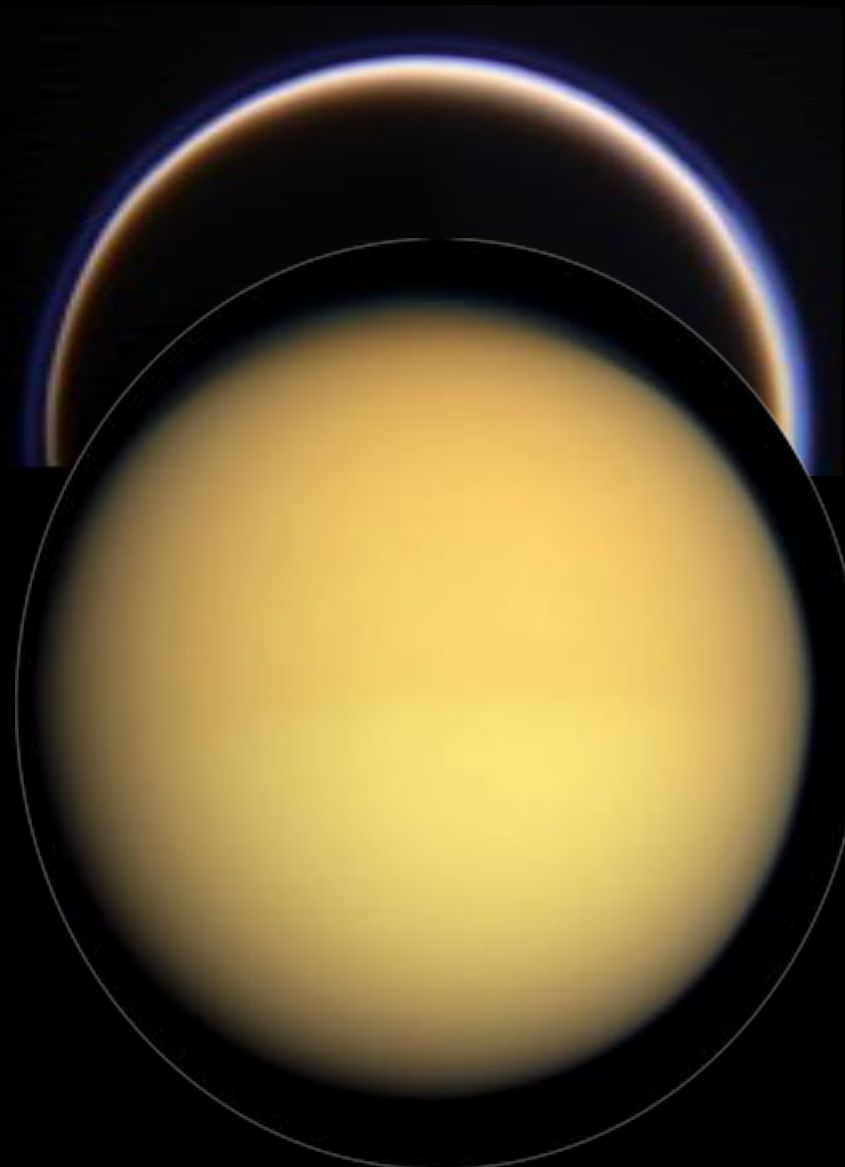


Encelado: Futuri concetti di missione

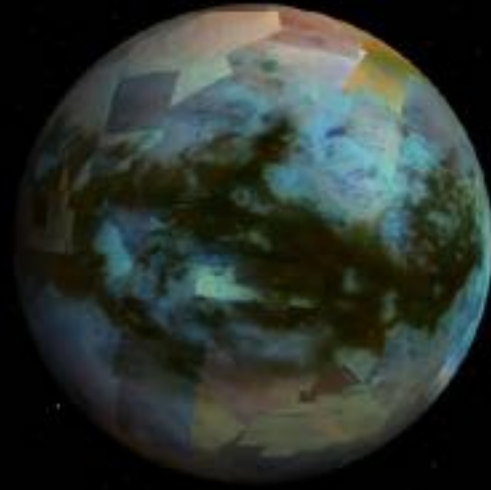
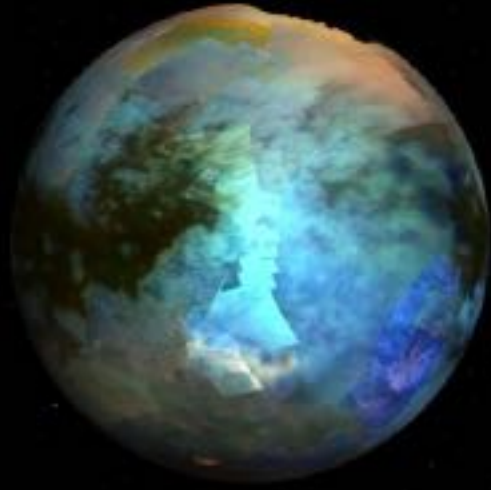
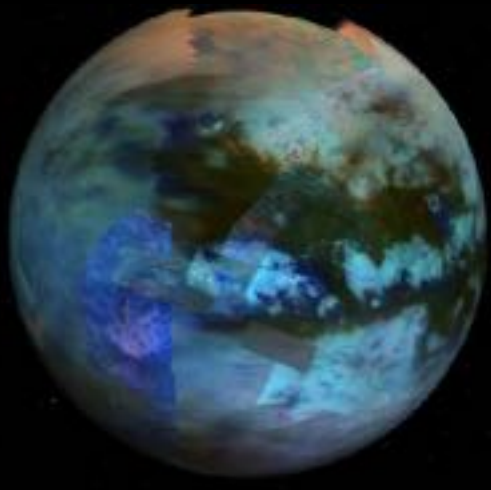
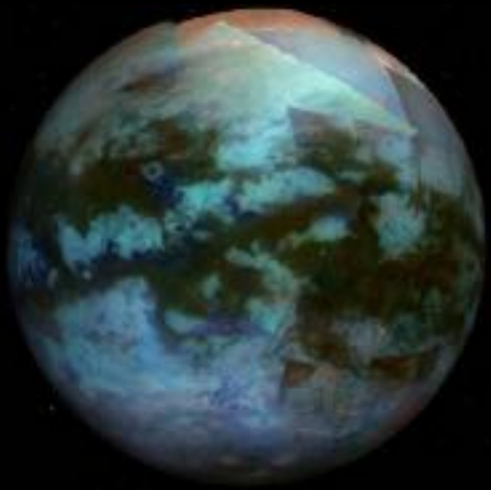
- Fly through the Enceladus plume just like Cassini did....
- But do it with instruments of today's capabilities...Cassini instruments are 20 years old.



Titano con e senza veli

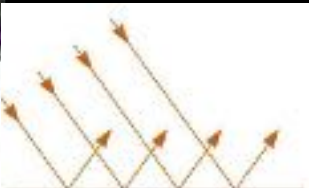
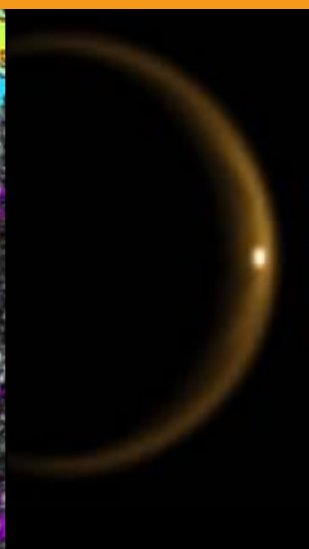
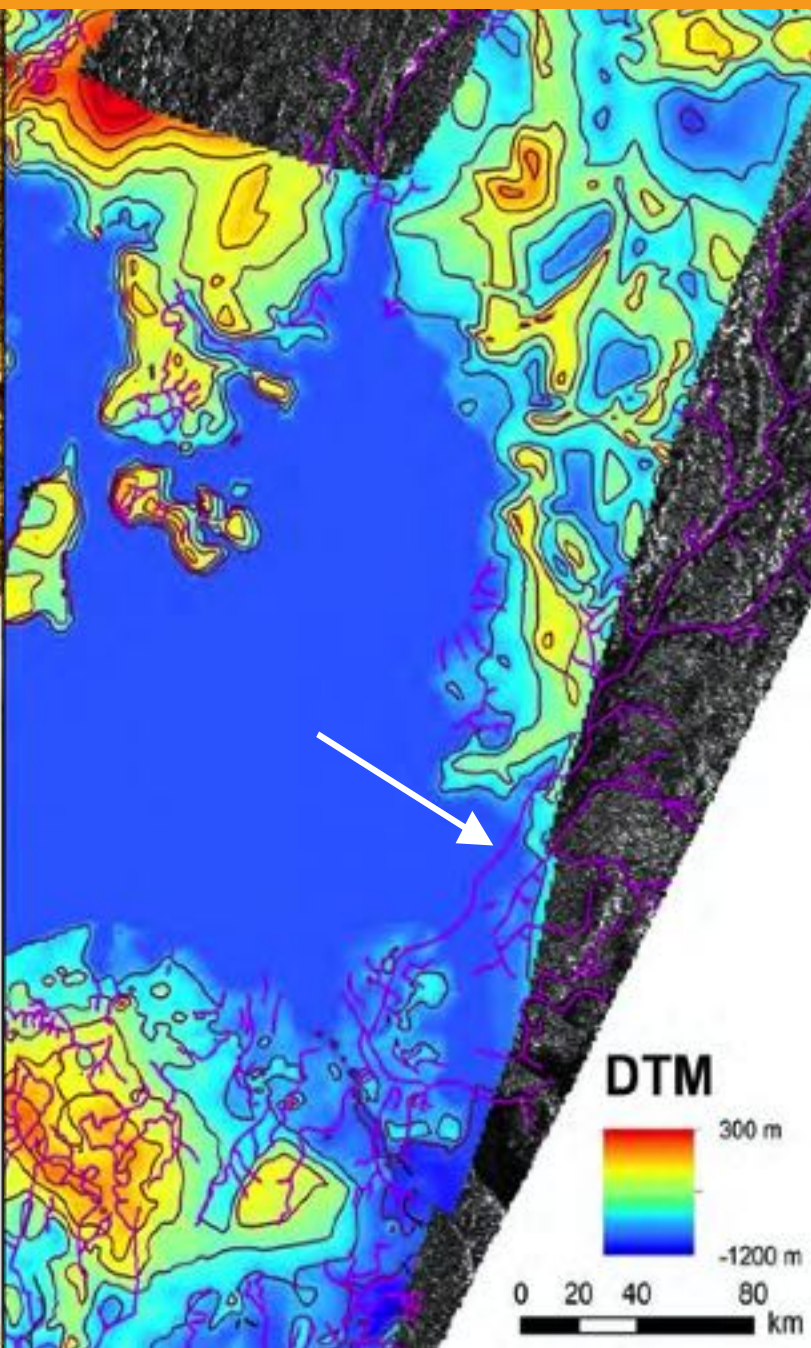
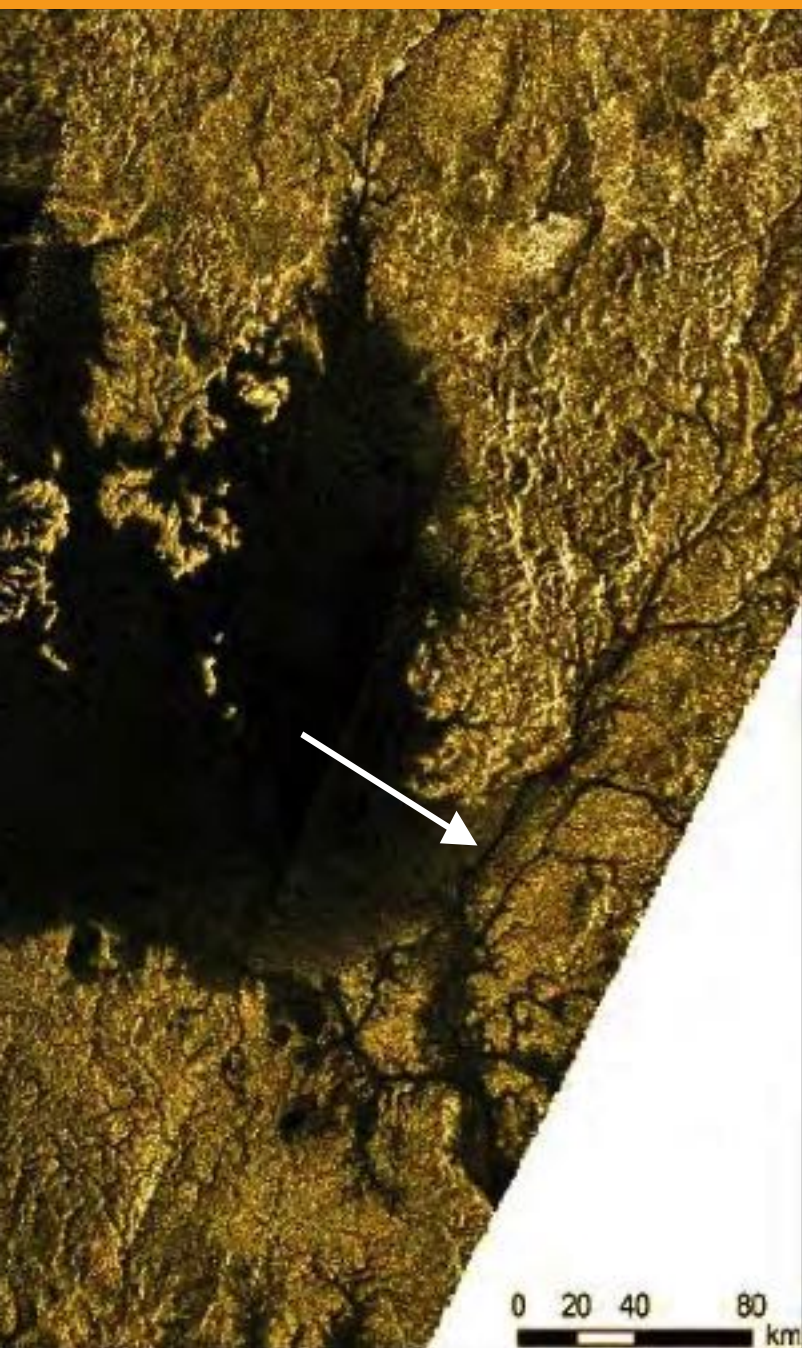


Visibile

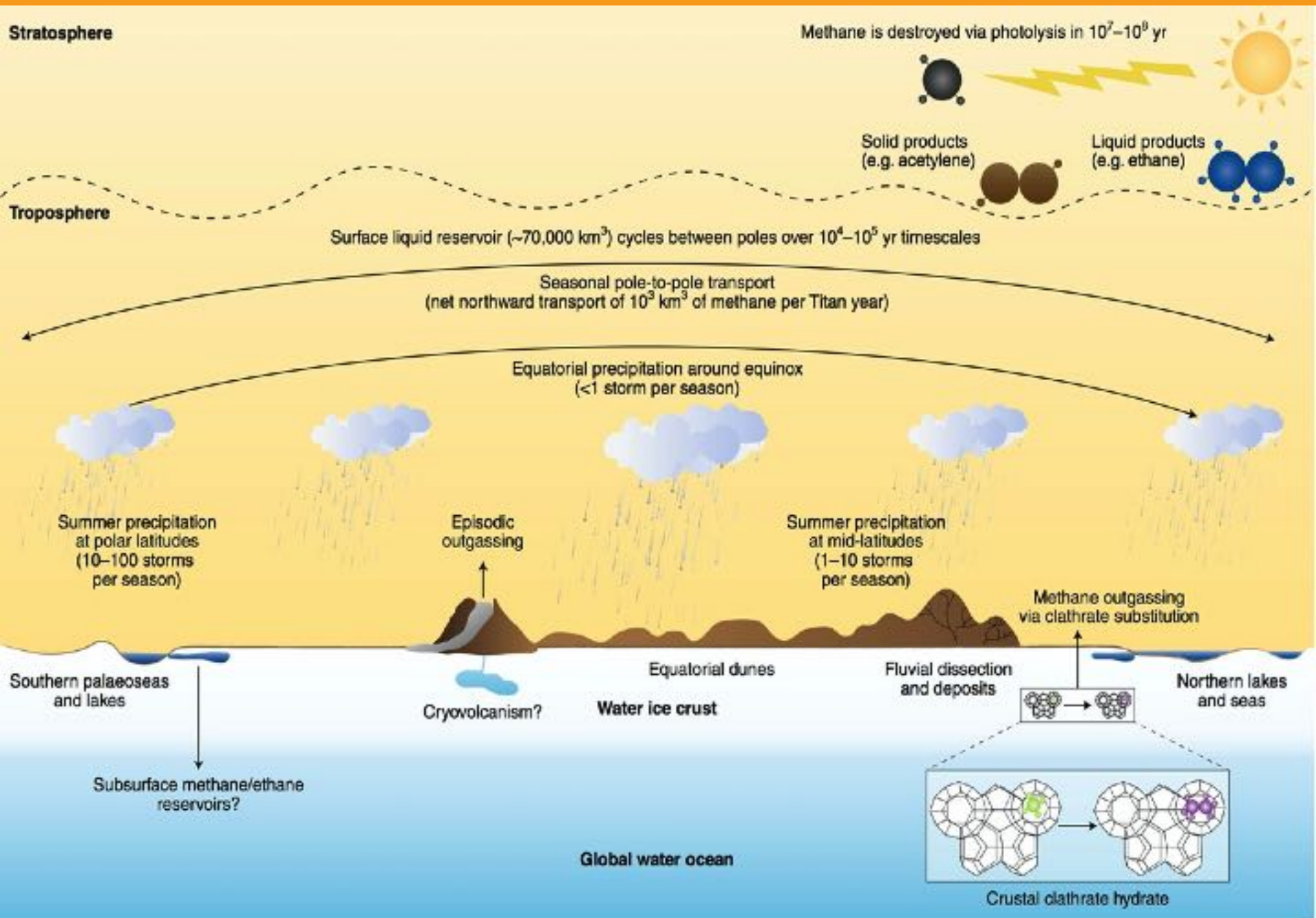


Infrarosso

Laghi e mari di idrocarburi

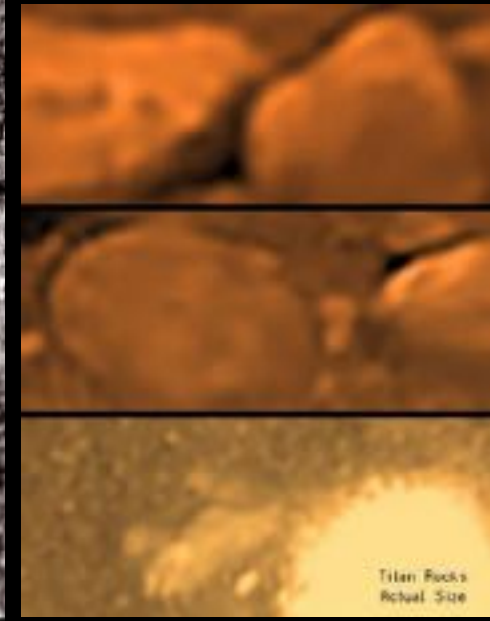
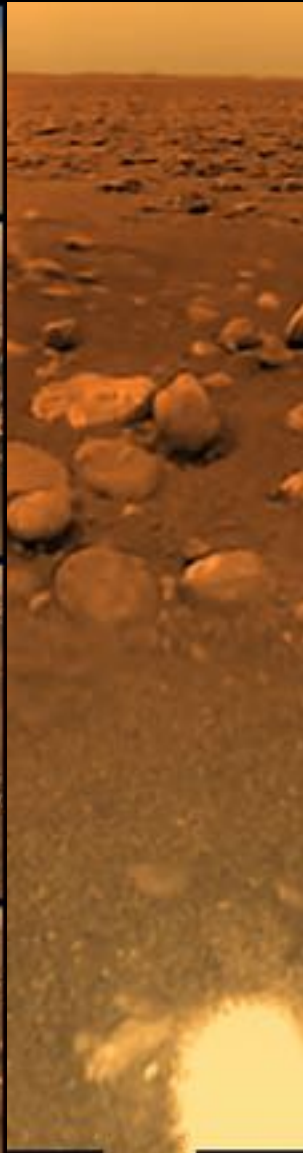
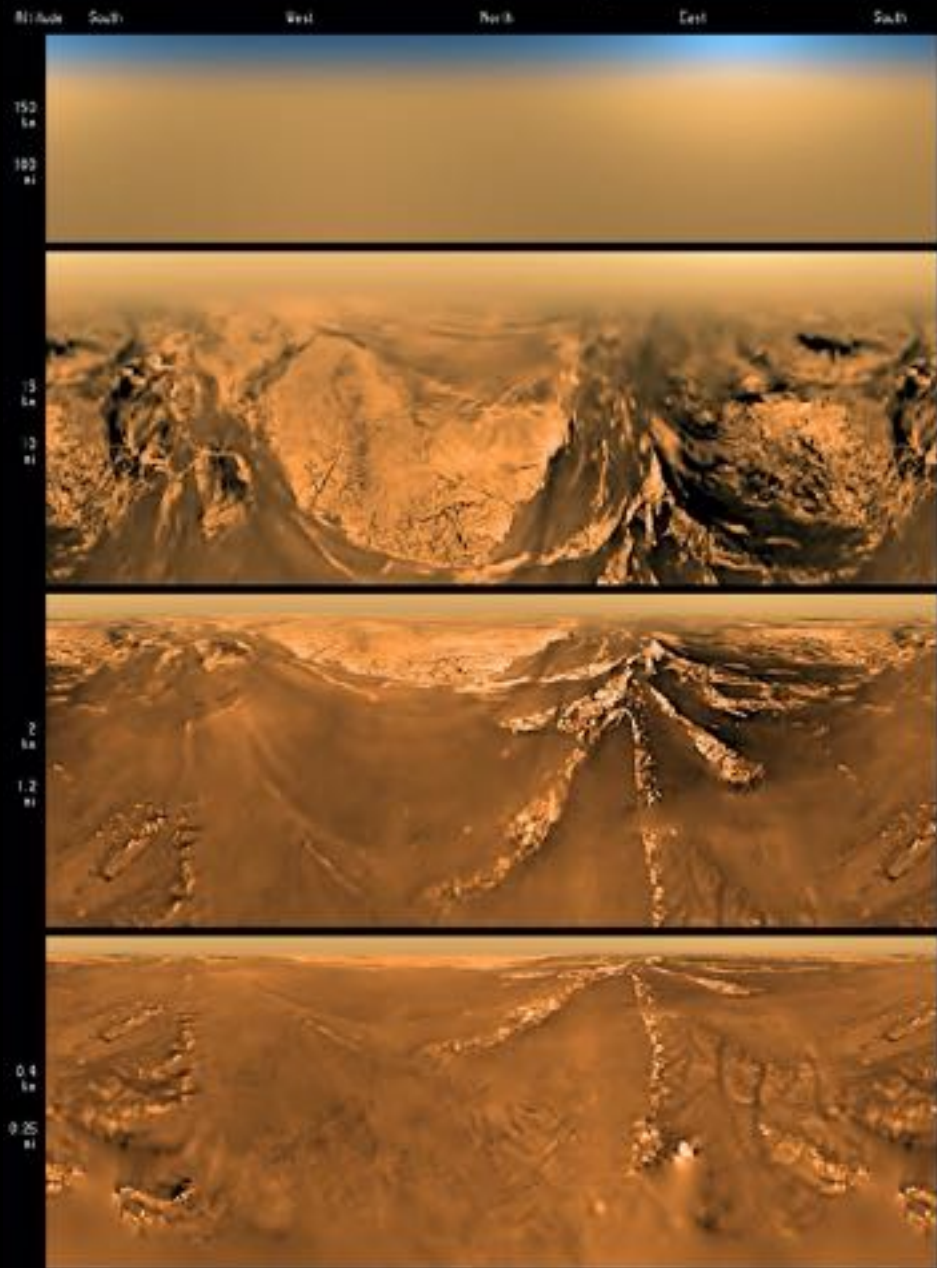


Il ciclo del metano



La superficie di Titano (VIS-NIR)

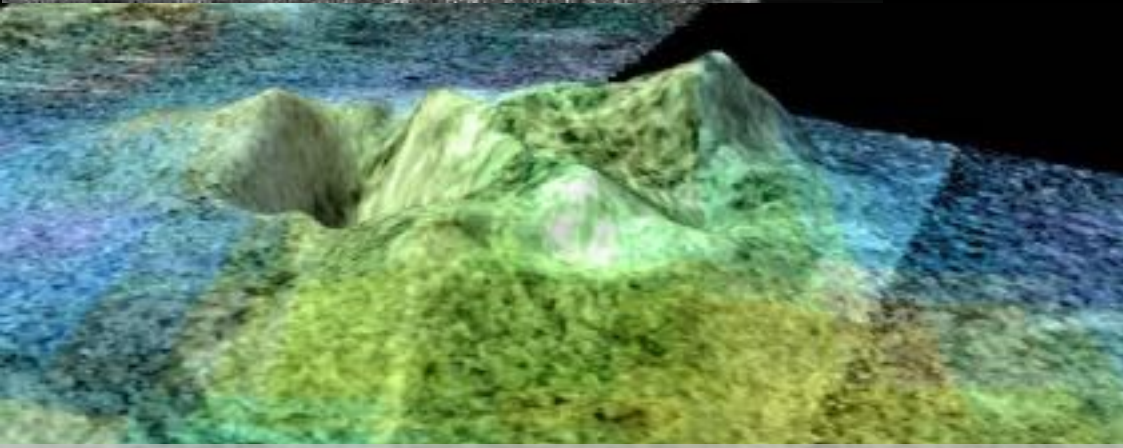
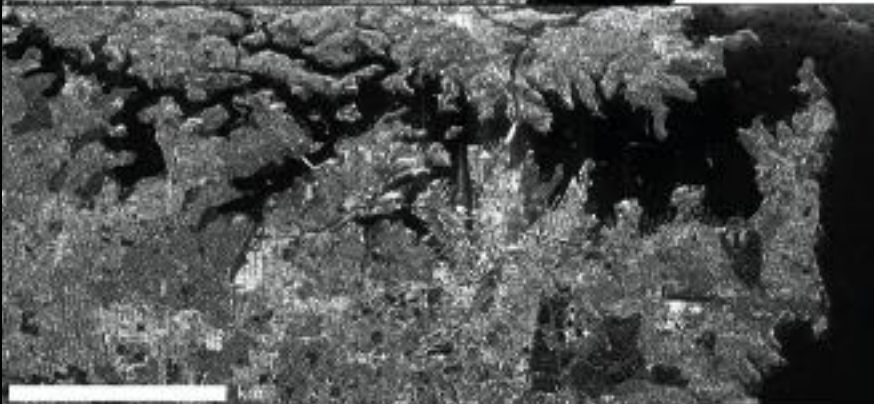
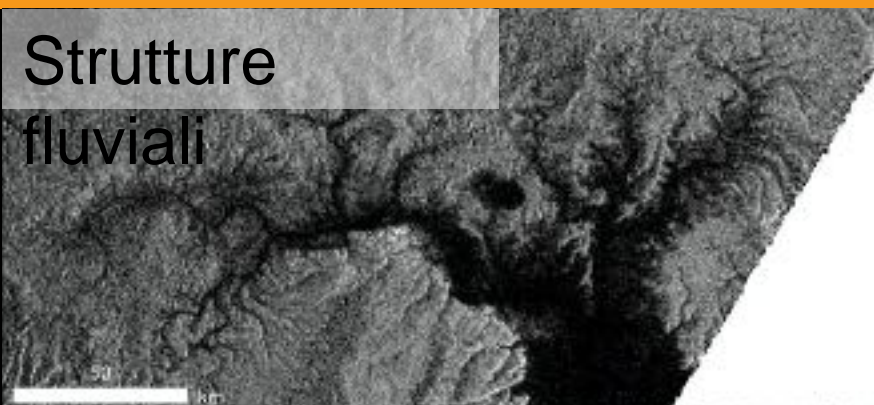
Aerial Views of Titan Around the Huygens Landing Site

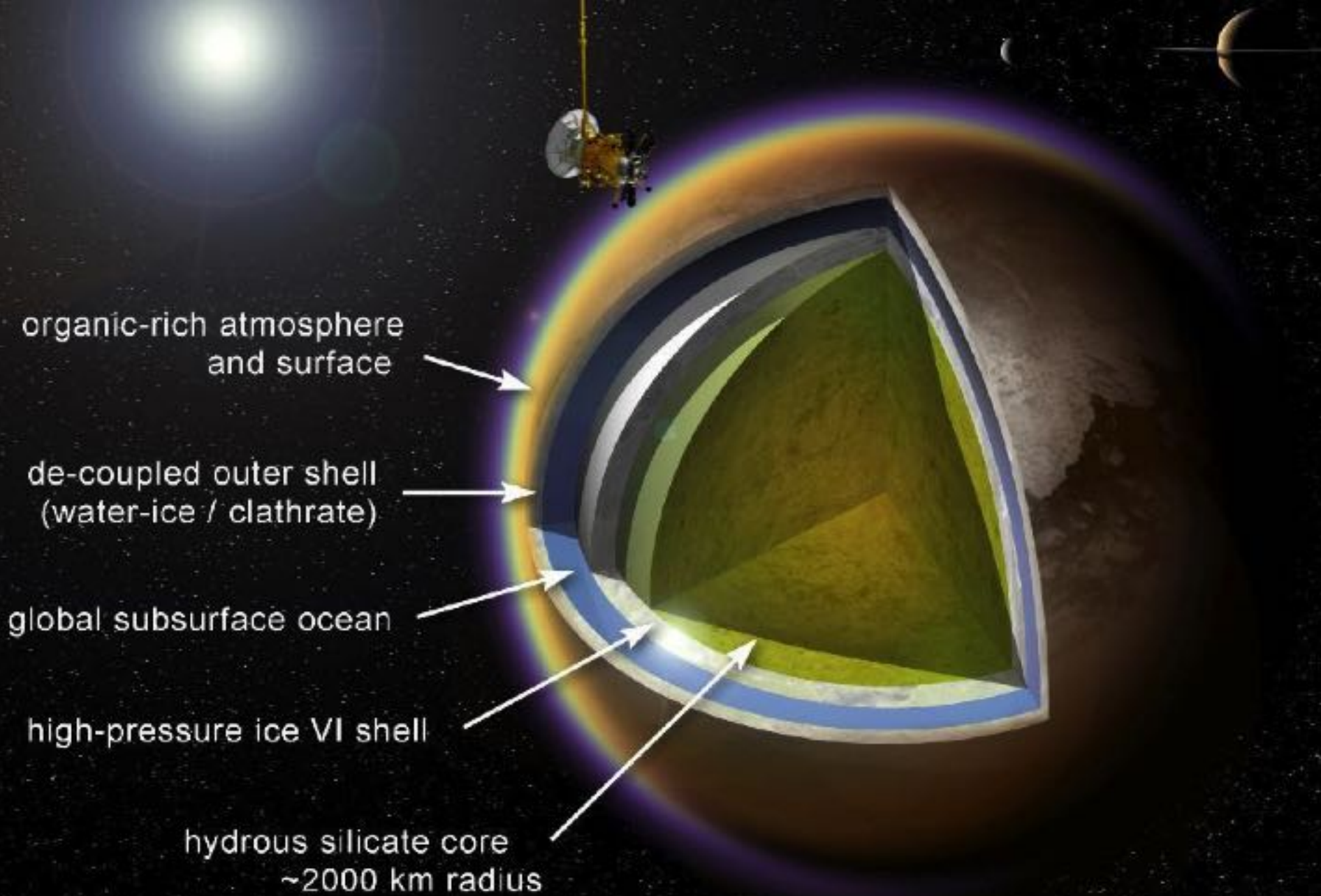


Titan

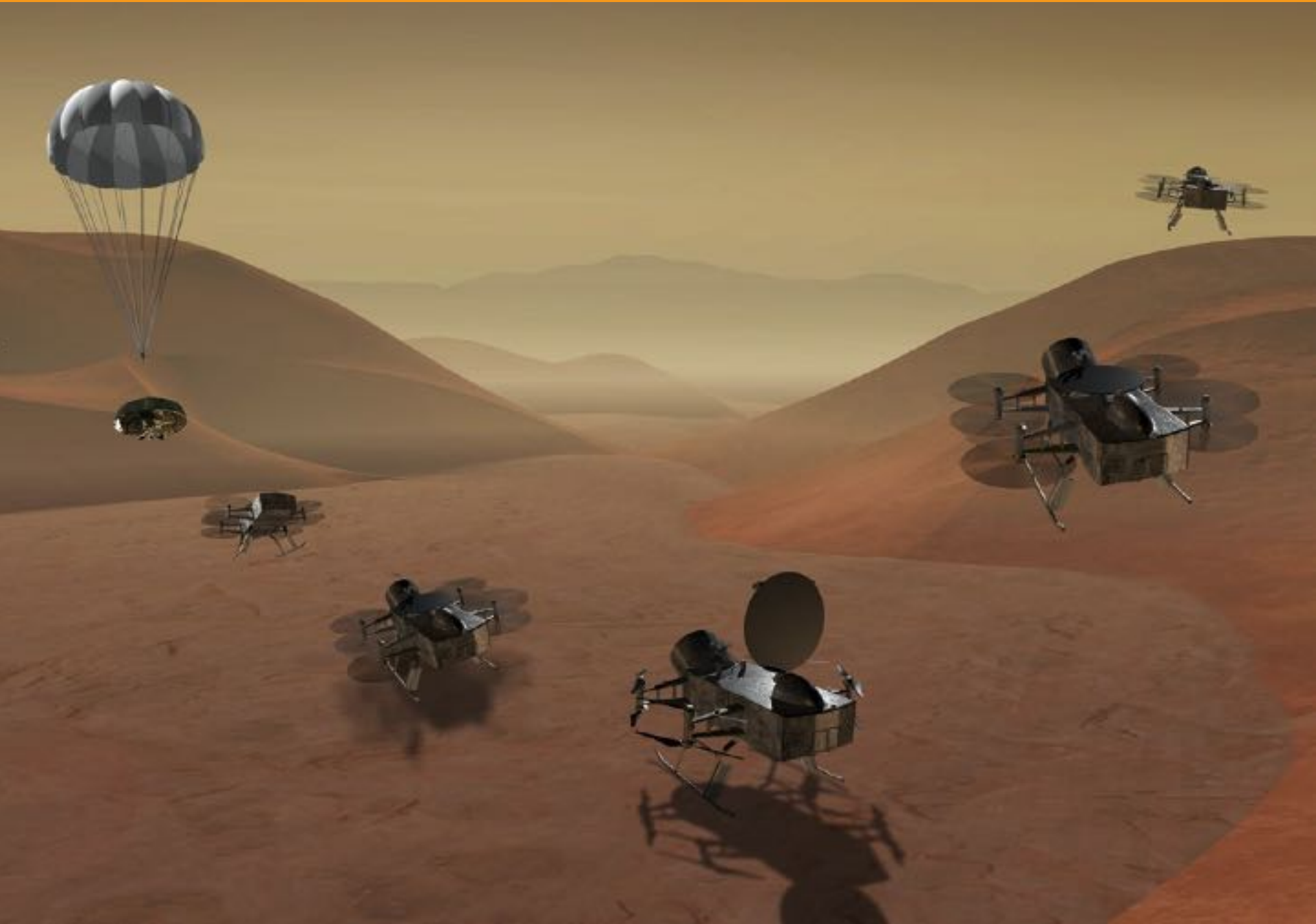
Moon at Similar Scale

La superficie di Titano (RADAR)

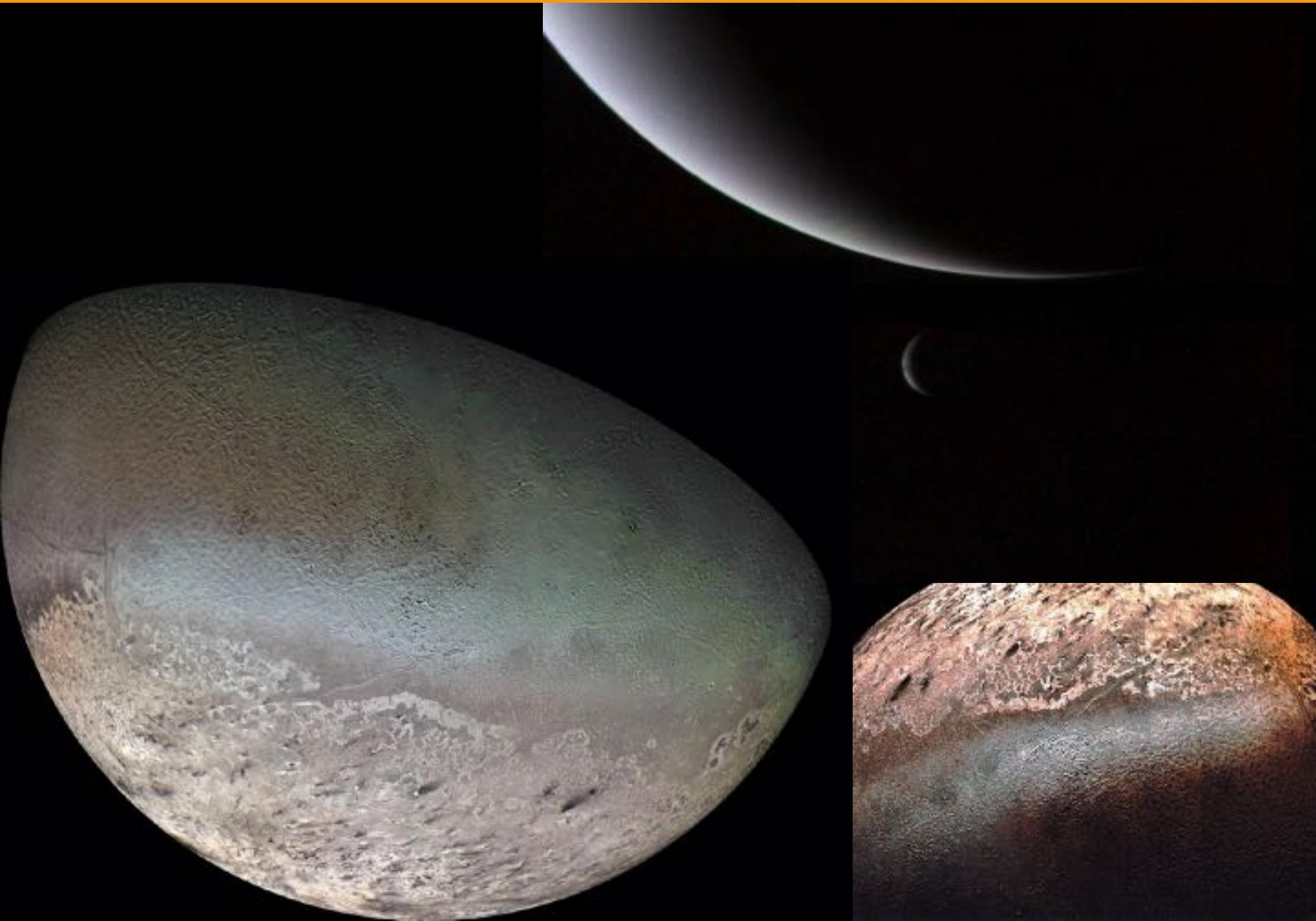




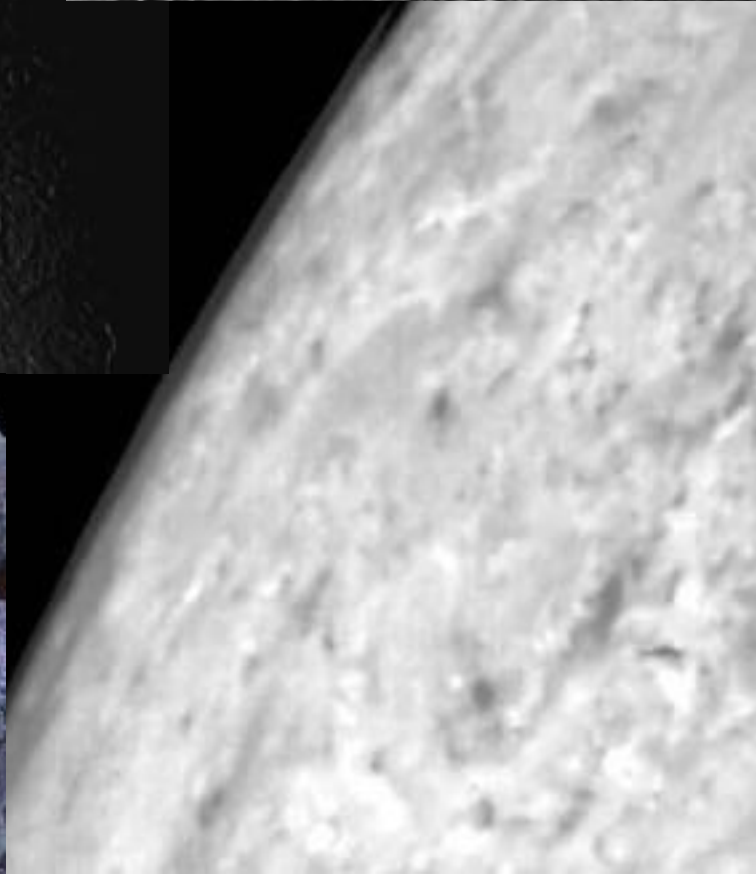
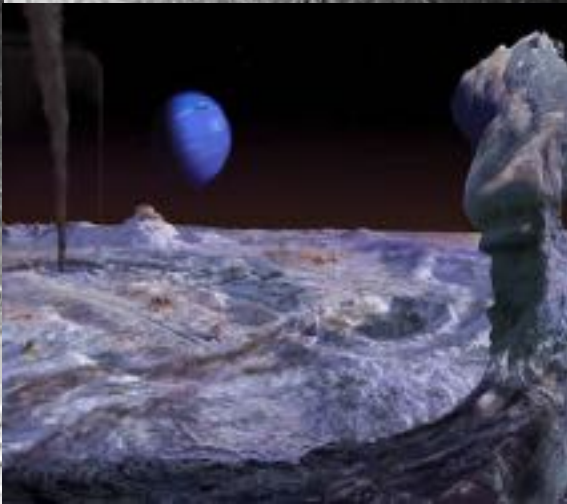
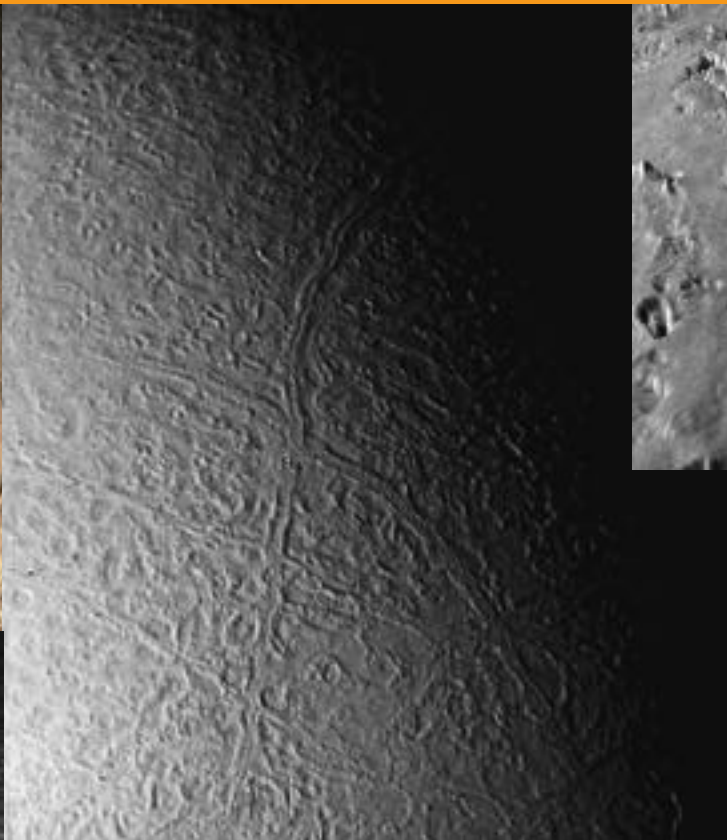
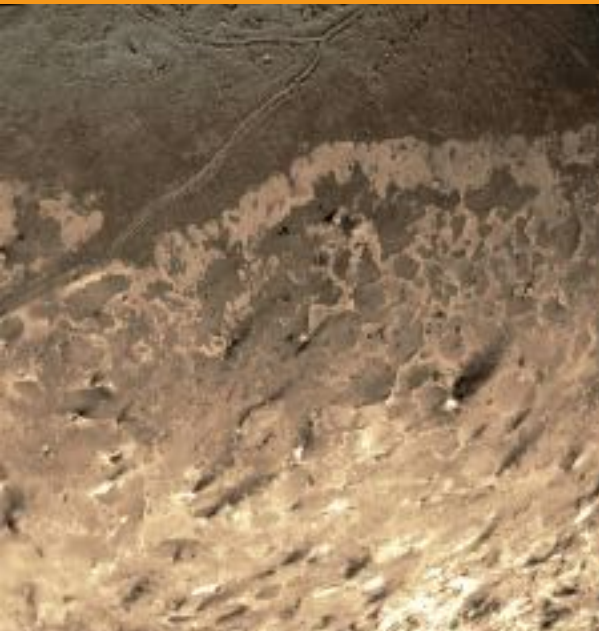
Future missioni a Titano: Dragonfly



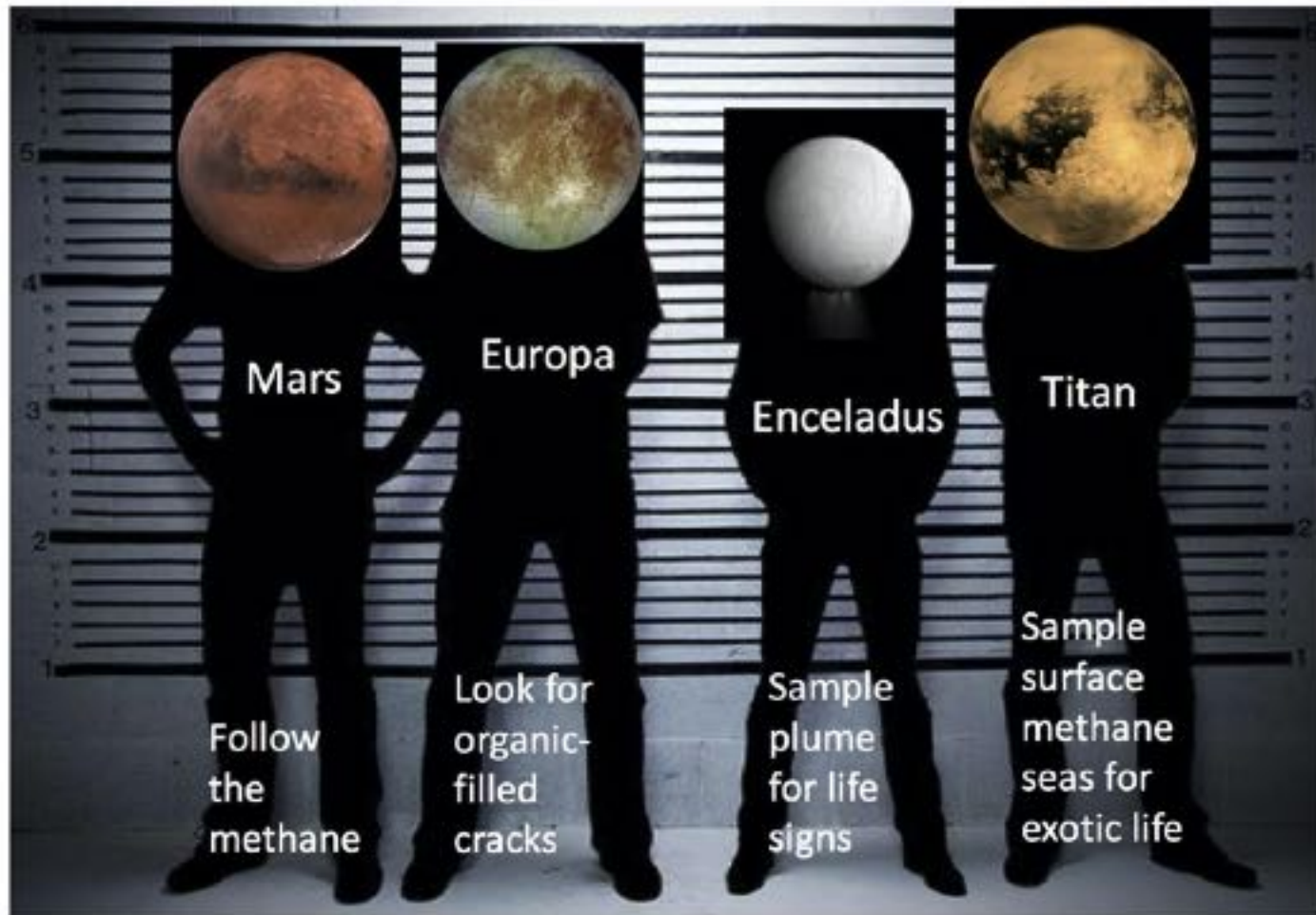
Tritone: La prima prova di criovulcanismo nel Sistema Solare



Tritone: La prima prova di criovulcanismo nel Sistema Solare



The lineup of solar system suspects in the search for life



Conclusioni

È tempo di progredire dall'esplorazione alla caratterizzazione dei mondi abitabili !

Grazie!

