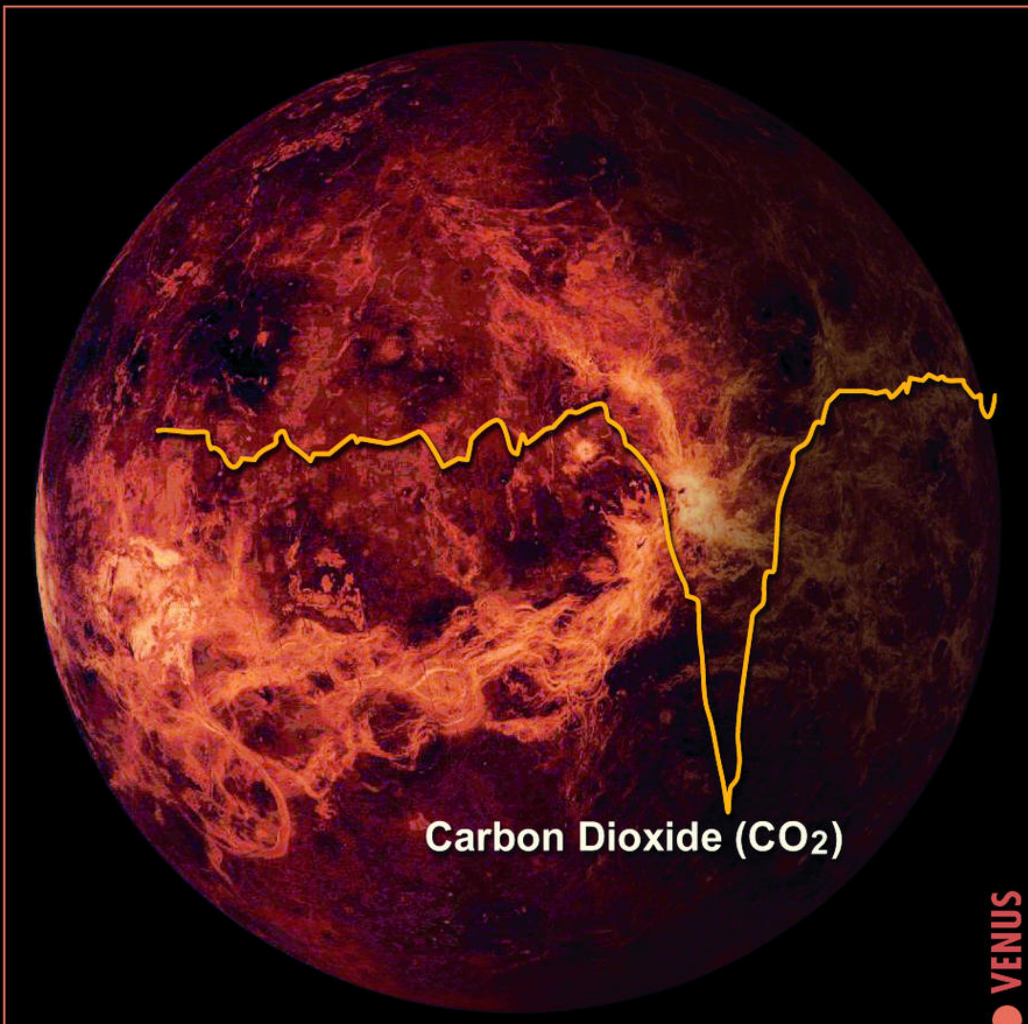
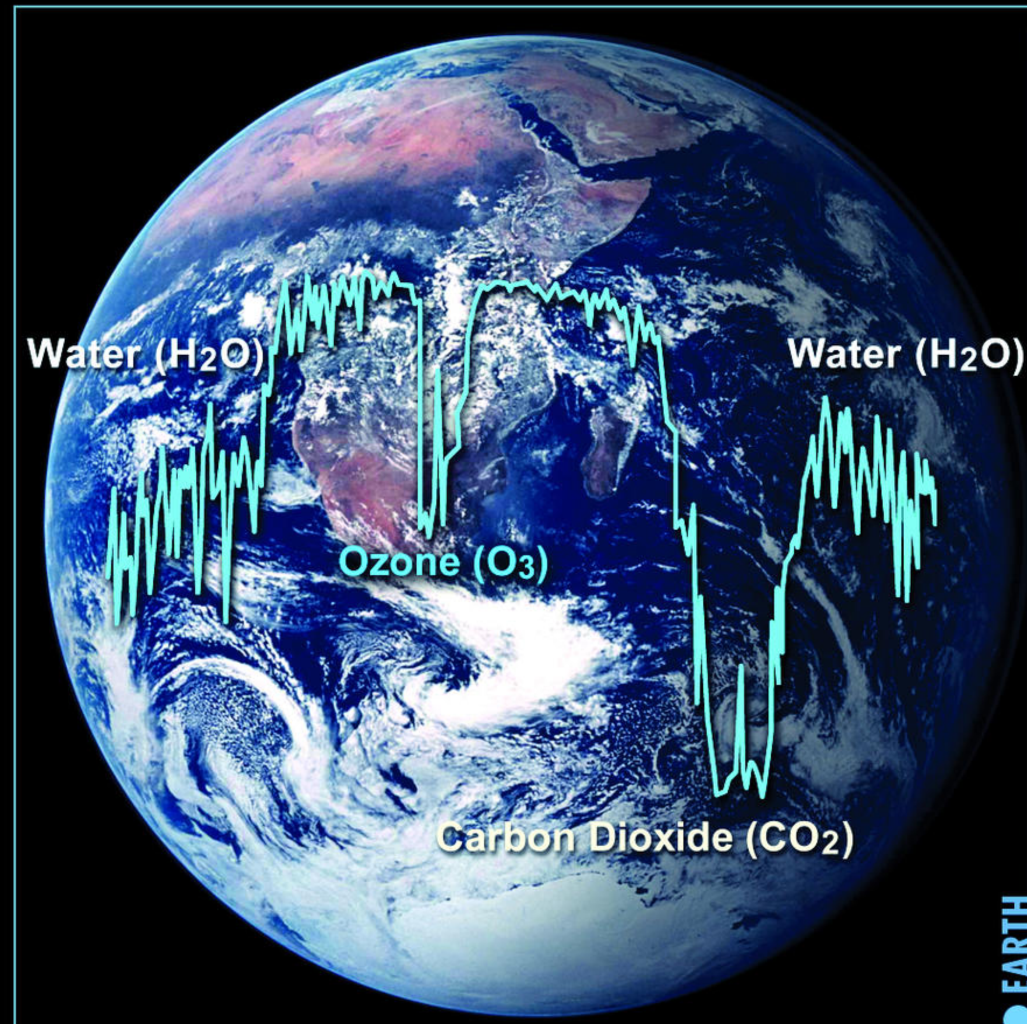
Planetary Habitability





Stephen Kane

UNIVERSITY OF CALIFORNIA
UC RIVERSIDE

Topics

- Lecture 1 – Introduction
- Lecture 2 – Habitability Factors
- Lecture 3 - Stars
- Lecture 4 – Planetary Atmospheres
- Lecture 5 – Planetary Interiors
- Lecture 6 – Planetary Energy Balance
- Lecture 7 – Habitable Zone I
- Lecture 8 – Habitable Zone II
- Lecture 9 – Earth as a Living Planet
- Lecture 10 – Mars
- Lecture 11 – Icy Moons
- Lecture 12 – Venus
- Lecture 13 – Mercury & the Moon
- Lecture 14 – The Role of Giant Planets
- Lecture 15 – Stellar Influences
- Lecture 16 – Magnetic Fields
- Lecture 17 – Milankovitch Cycles
- Lecture 18 – Geological Cycles
- Lecture 19 – The Next Steps
- Lecture 20 – Summary/Discussion

Icy Moon Habitability

- Energy budgets of moons.
- Interiors of icy moons.
- Planned missions.
- Cryovolcanism.
- Sub-surface ocean detectability.

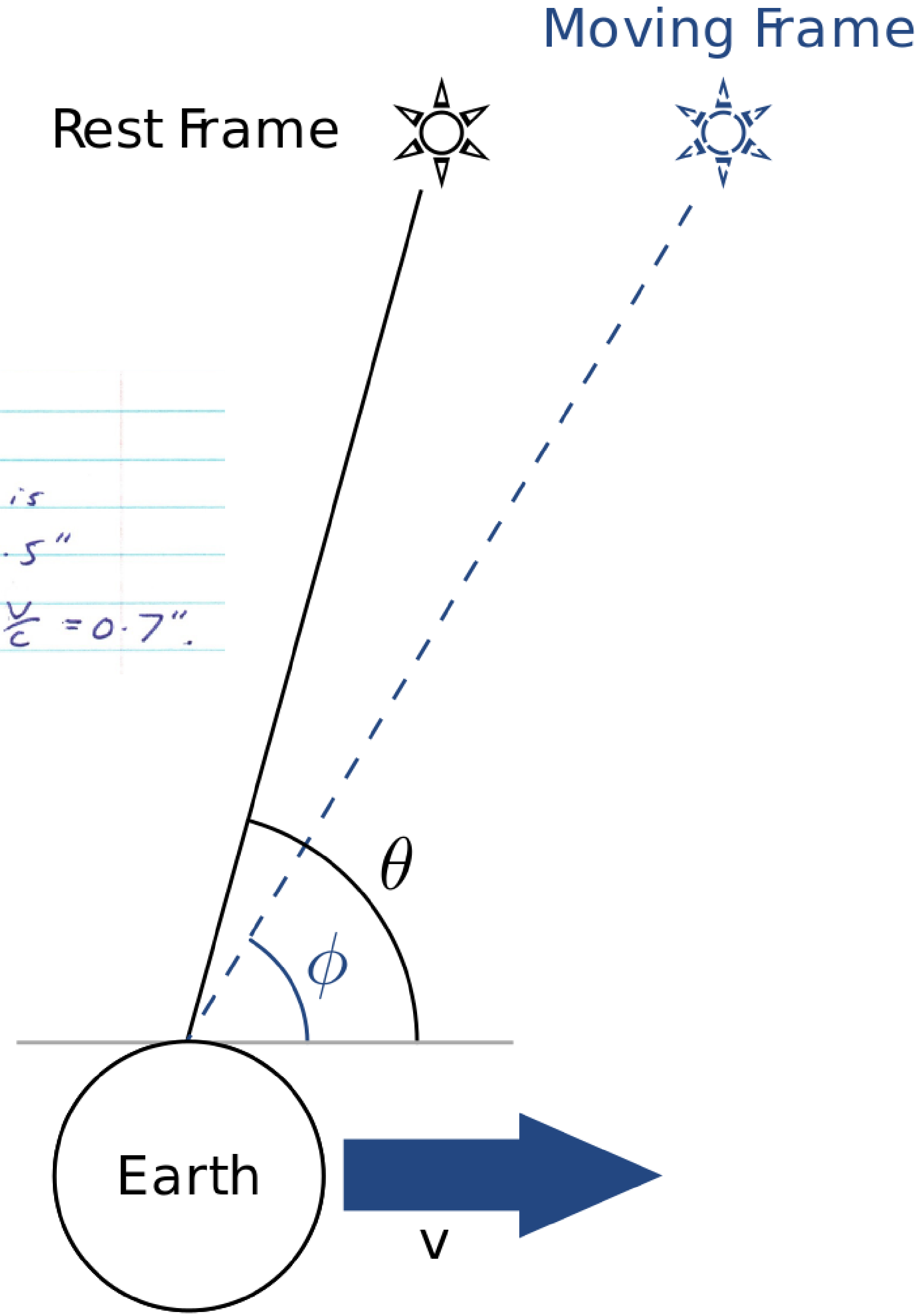
Aberration

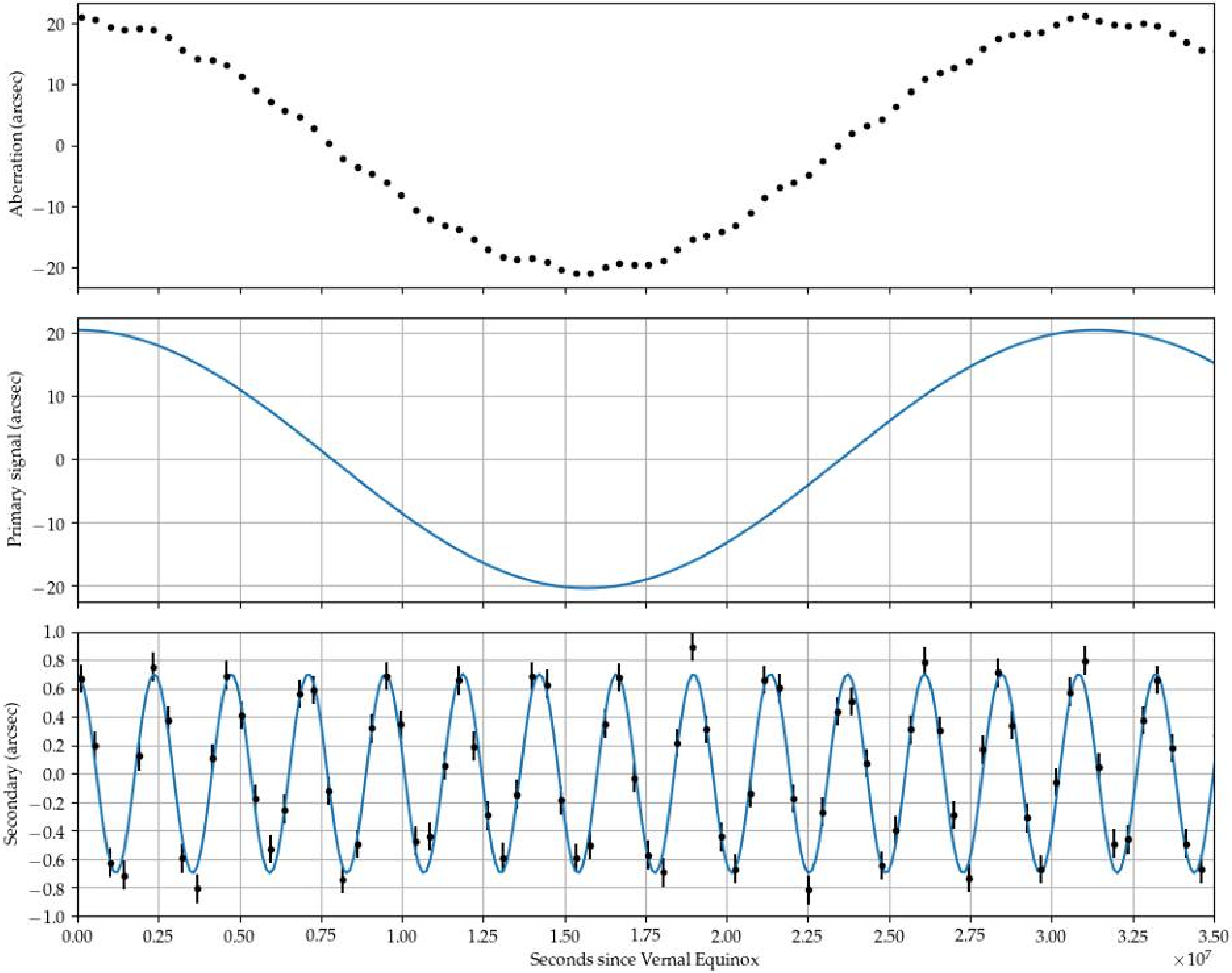
$$v_e = \frac{2\pi(1\,AU)}{365.25\,days}$$

Therefore, stellar aberration amplitude is

$$\frac{v_e}{c} = 0.00009935 \text{ radians} = 20.5''$$

The effect of the moon is $1\,km/s \Rightarrow \frac{v}{c} = 0.7''$.





Aberration (arcsec)
Primary signal (arcsec)
Secondary (arcsec)
Seconds since Vernal Equinox
×10^7

Energy budget of moons

Energy budget

The energy budget of moons may be expressed as:

$$F_m = f_* + f_{ref} + f_{ir} + h_t \qquad \text{(Heller \& Barnes 2013)}$$

Flux from star:

$$f_* = \frac{L_*}{4\pi a^2}$$

Reflected light from planet:

$$f_{ref} = A_g(\lambda)\, g(\alpha,\lambda) \frac{R_p^2}{a^2} \times f_*$$

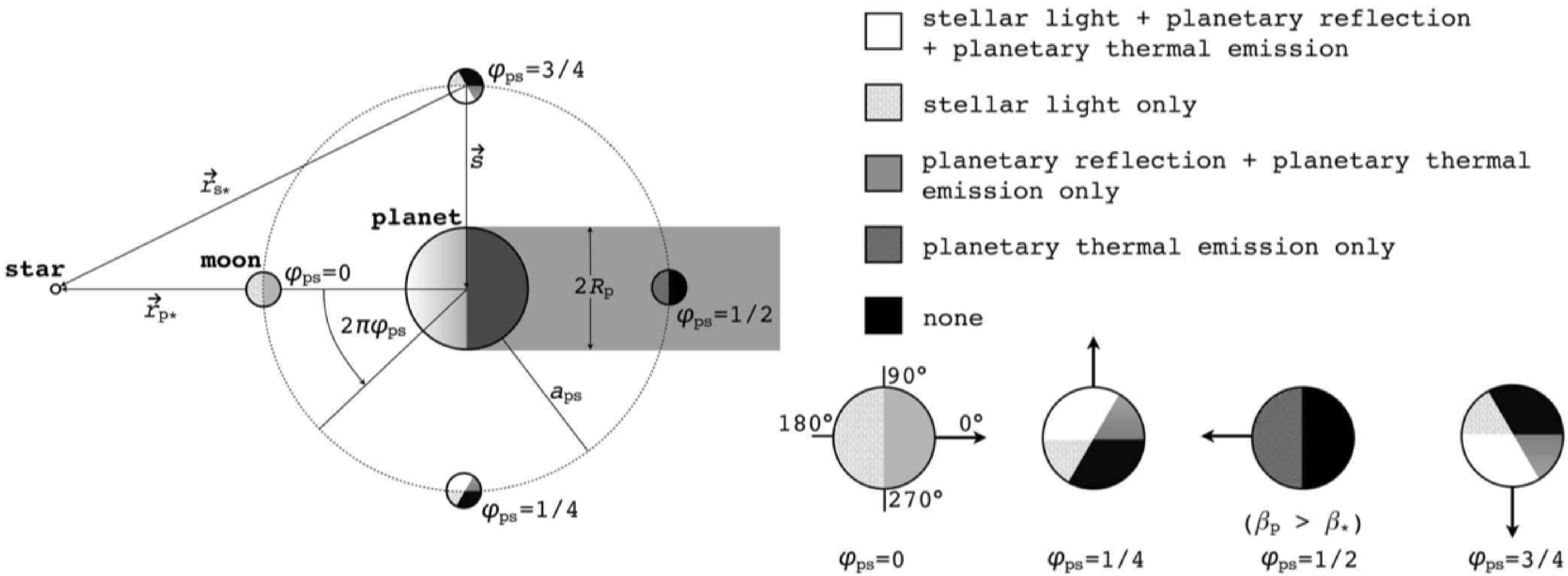
Thermal emission from planet:

$$f_{ir} = \frac{L_p}{4\pi a_m^2} \qquad L_p = 4\pi R_p^2 \sigma T_{eq}^4$$

Tidal forces

$$F_t = \frac{dF}{da_m} \doteq \frac{2GM_pM_m}{a_m^3}$$

Energy budget of moons



$$F_{RG} > \bar{F}_s^{glob} = \bar{f}_* + \bar{f}_r + \bar{f}_t + h_s$$

$$= \frac{L_*(1-\alpha_s)}{16\pi a_{*p}^2 \sqrt{1-e_{*p}^2}} \left(1 + \frac{\pi R_p^2 \alpha_p}{2a_{ps}^2}\right) + \frac{R_p^2 \sigma_{SB} (T_p^{eq})^4}{a_{ps}^2} \frac{(1-\alpha_s)}{4} + h_s,$$

Energy budget of moons

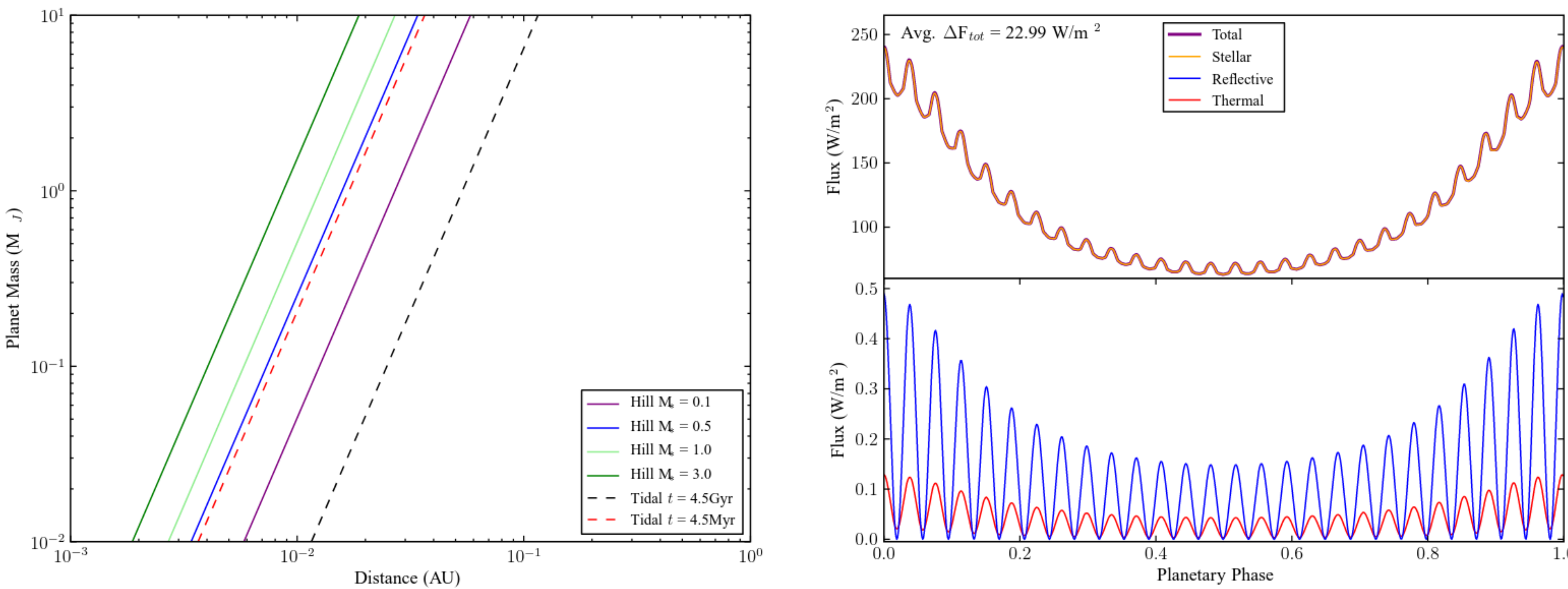
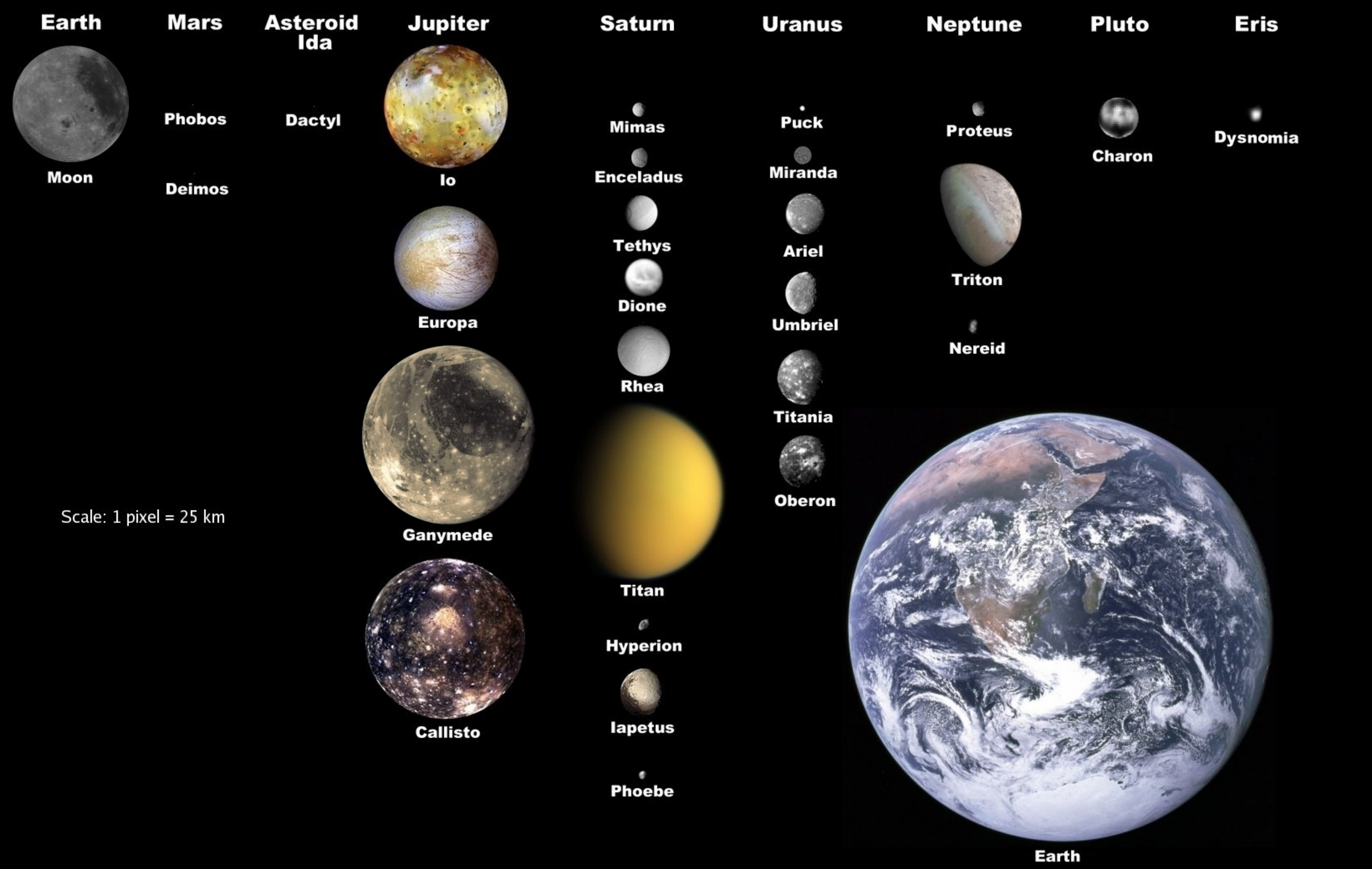


Figure 7. Similar to Figure 5 but for BD +14 1559 b, which spends ~68.5% of its orbital phase in the habitable zone (Kane & Gelino 2012), with the hypothetical moon near the Hill radius at $a = 0.01$ AU.

$$F_{\rm RG} > \bar{F}_{\rm s}^{\rm glob} = \bar{f}_* + \bar{f}_{\rm r} + \bar{f}_{\rm t} + h_{\rm s}$$

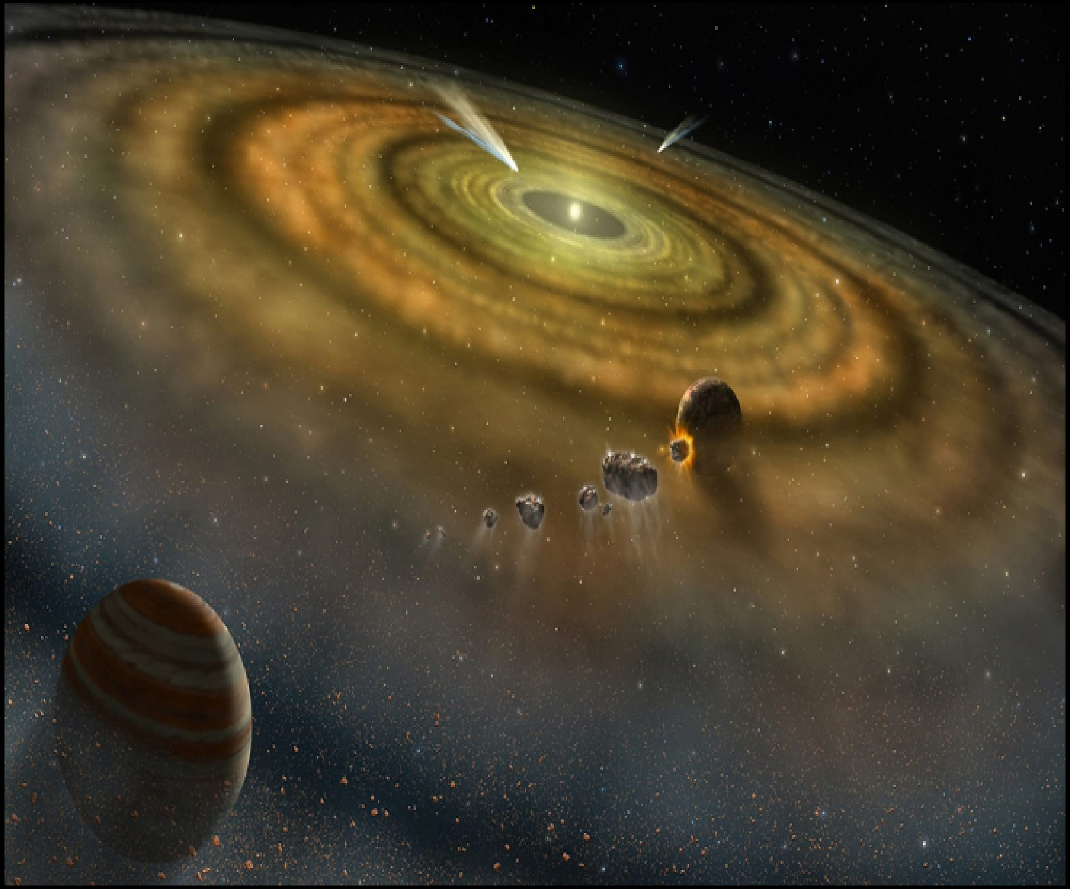
$$= \frac{L_*(1-\alpha_{\rm s})}{16\pi a_{*\rm p}^2\sqrt{1-e_{*\rm p}^2}}\left(1 + \frac{\pi R_{\rm p}^2 \alpha_{\rm p}}{2a_{\rm ps}^2}\right) + \frac{R_{\rm p}^2 \sigma_{\rm SB}(T_{\rm p}^{\rm eq})^4}{a_{\rm ps}^2}\frac{(1-\alpha_{\rm s})}{4} + h_{\rm s},$$

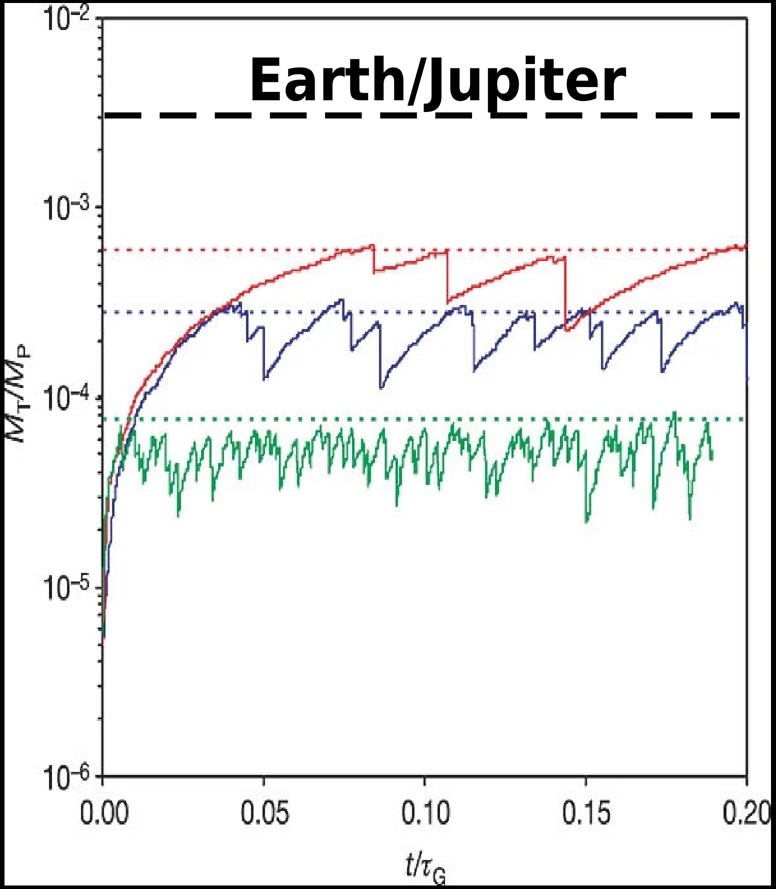
Selected Moons of the Solar System, with Earth for Scale



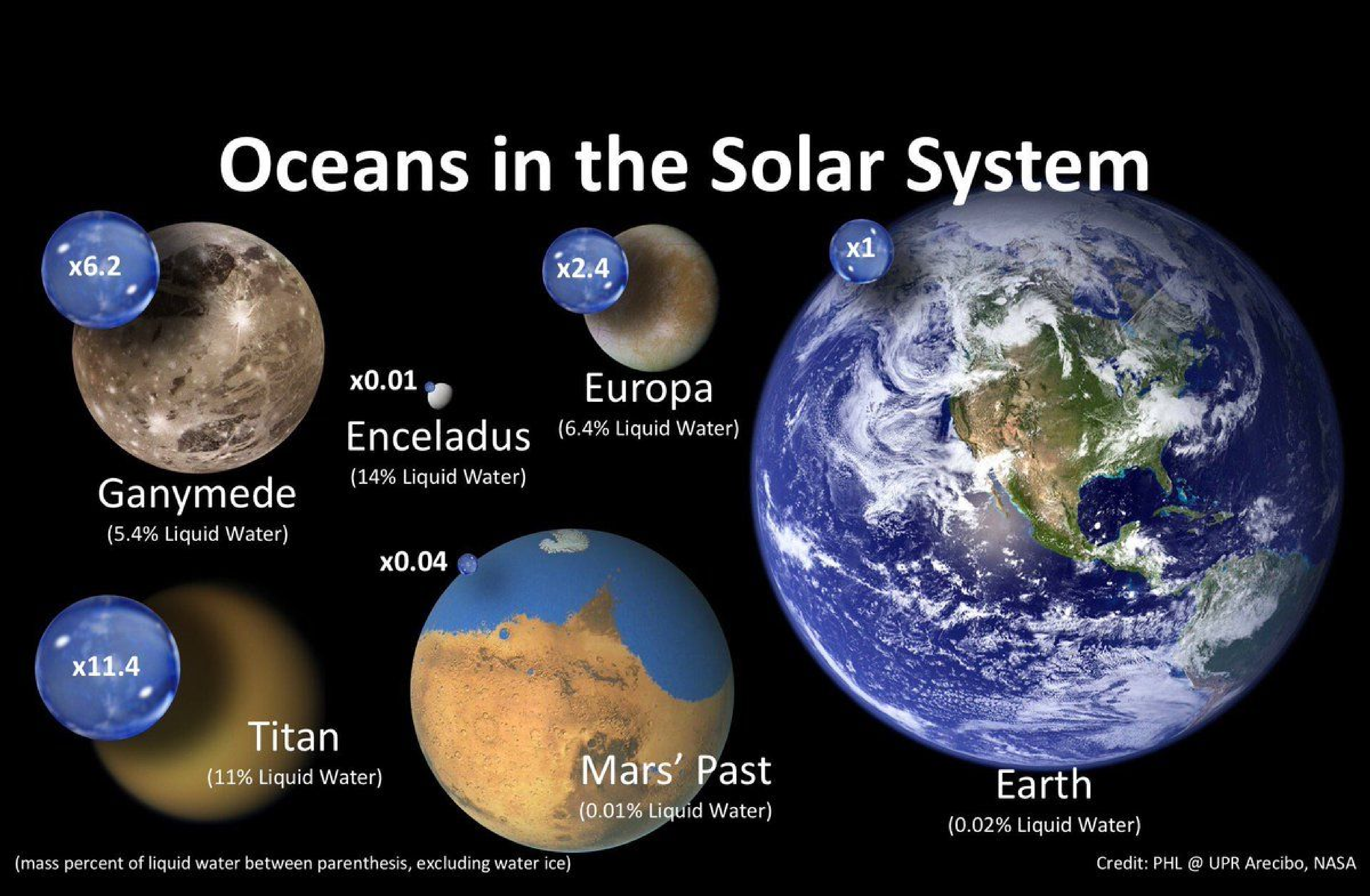
Is an Earth-size moon possible?

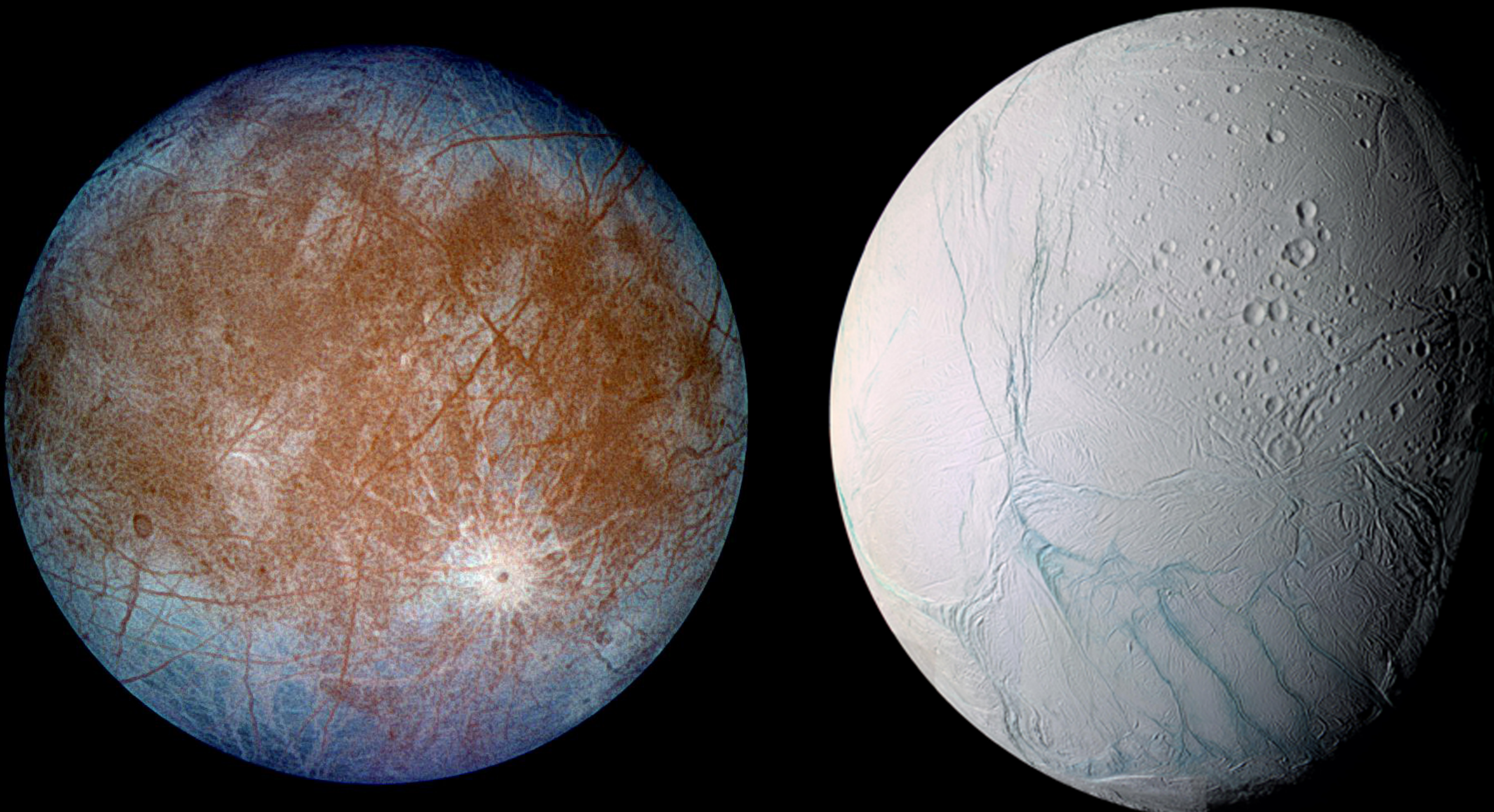
- The most massive moon present in the solar system is Ganymede, a moon of Jupiter, with a mass of 2.5% of Earth's mass.



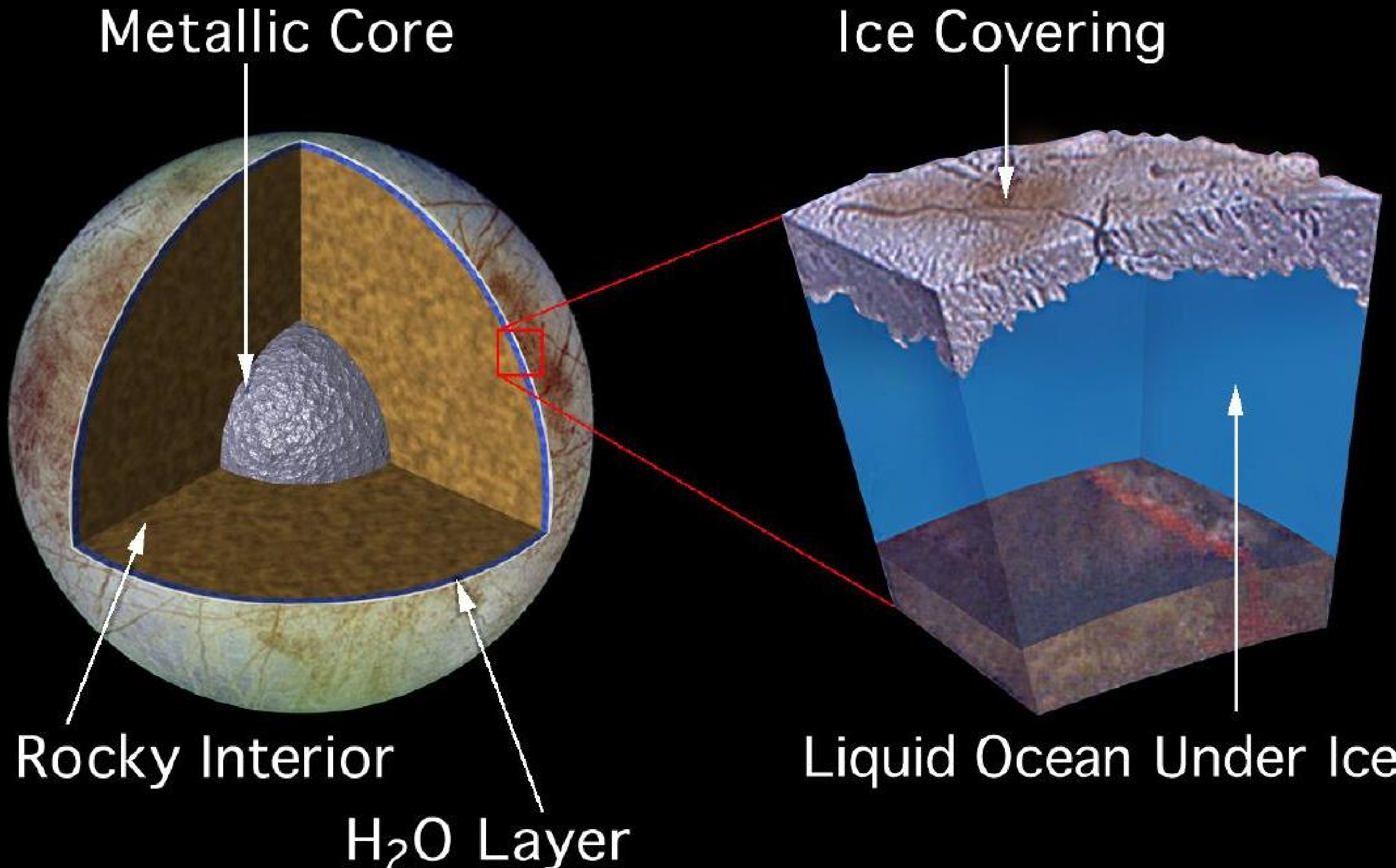


- Are more massive planets possible? Yes! We know of exoplanets that are 20-25 times the mass of Jupiter.


Oceans in the Solar System
x6.2
Ganymede
(5.4% Liquid Water)
x0.01
Enceladus
(14% Liquid Water)
x2.4
Europa
(6.4% Liquid Water)
x1
Earth
(0.02% Liquid Water)
x11.4
Titan
(11% Liquid Water)
x0.04
Mars' Past
(0.01% Liquid Water)
(mass percent of liquid water between parenthesis, excluding water ice)
Credit: PHL @ UPR Arecibo, NASA

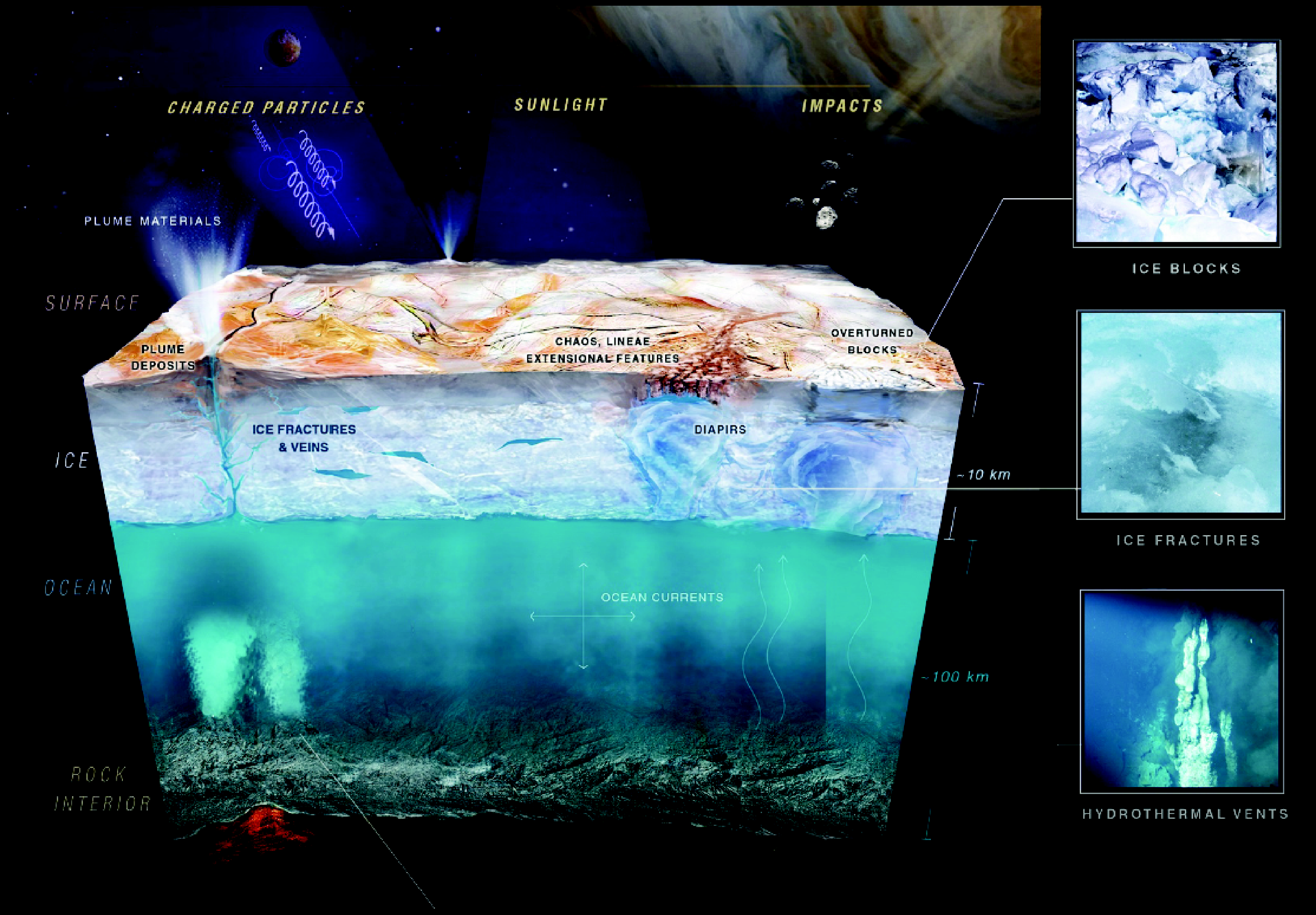


Europa : The Water World?



The center is the metallic core. The top shows the thin wafer like a layer of water ice and beneath that, up to a thickness of about 150 km, there could be liquid water. The radius of Europa is about 3000 km.

EUROPA

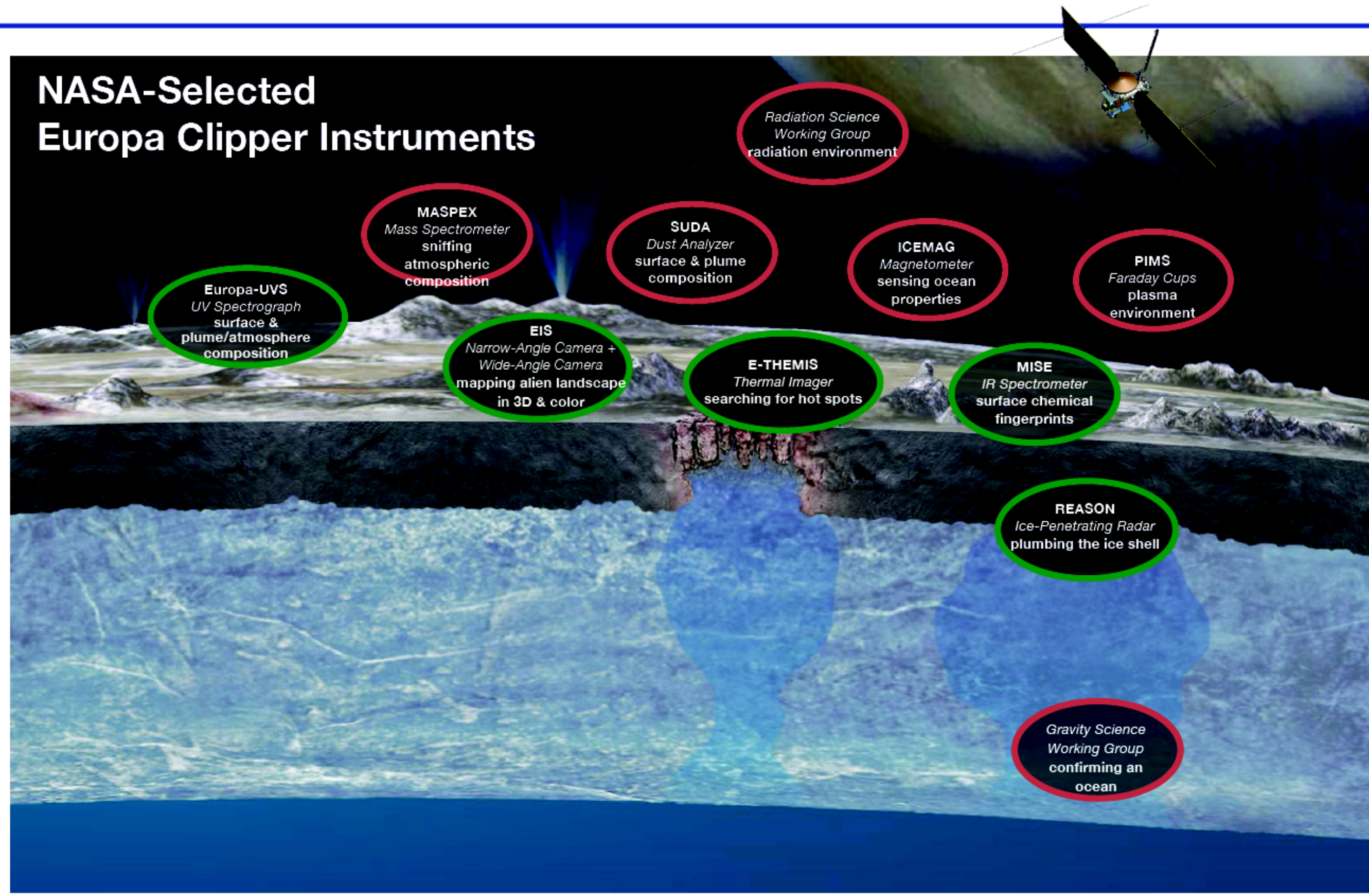


CHARGED PARTICLES
SUNLIGHT
IMPACTS
PLUME MATERIALS
SURFACE
PLUME DEPOSITS
CHAOS, LINEAE
EXTENSIONAL FEATURES
OVERTURNED BLOCKS
ICE
ICE FRACTURES & VEINS
DIAPIRS
~10 km
OCEAN
OCEAN CURRENTS
~100 km
ROCK INTERIOR
ICE BLOCKS
ICE FRACTURES
HYDROTHERMAL VENTS

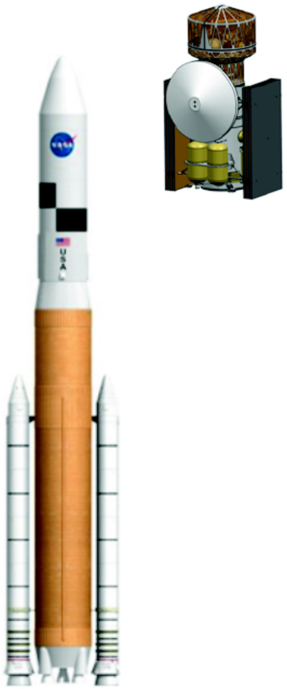
Europa Clipper Mission Science Overview

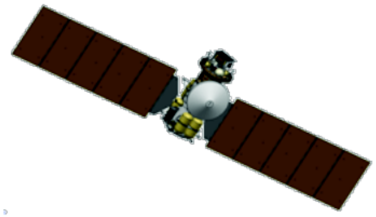
Mission Goal:

Explore Europa to investigate its habitability

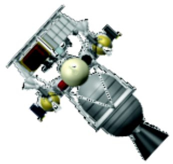


Europa Lander Mission Concept

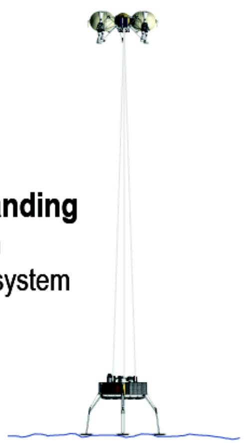


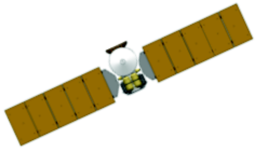


Cruise/Jovian Tour
- Jupiter orbit insertion Apr 2030
- Earliest landing on Europa: Dec 2031

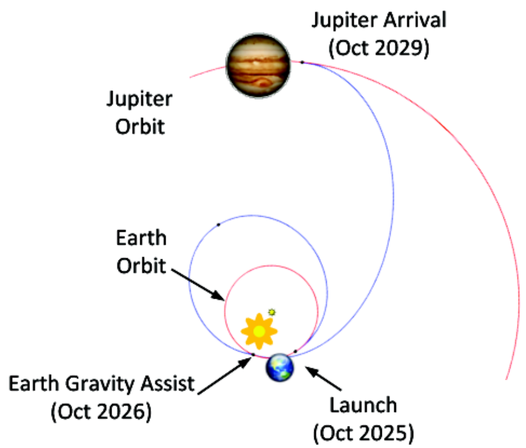


Deorbit, Decent, Landing
- Guided deorbit burn
- Sky Crane landing system
- 100-m accuracy

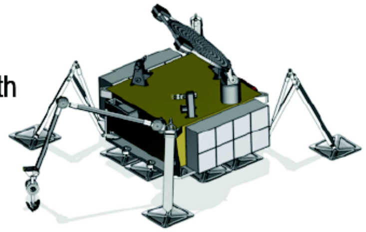




Carrier Relay Orbit
- 24 hour period
- >10 hours continuous coverage per orbit
- 2.0 Mrad radiation exposure



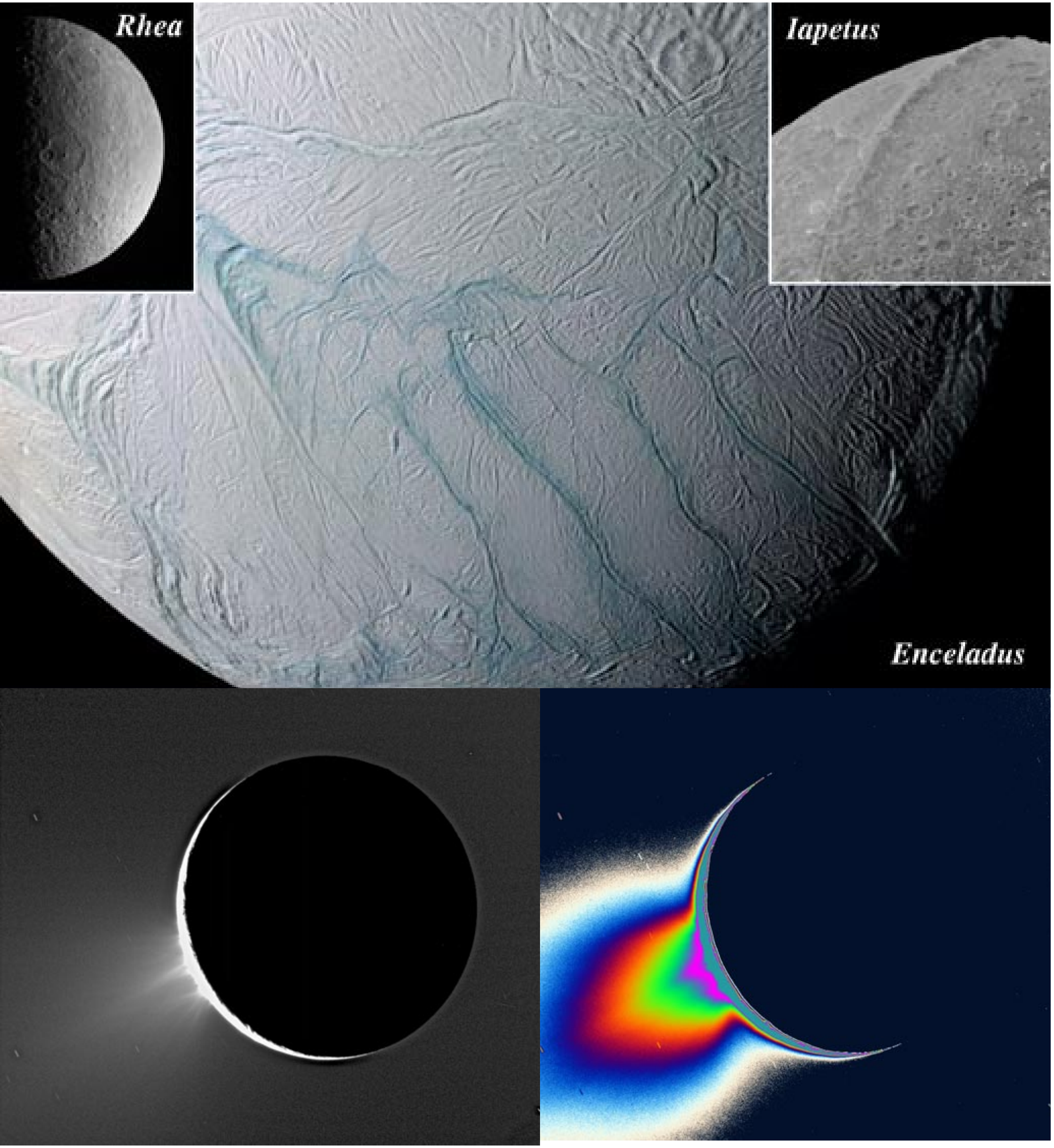
Surface Mission
- 20+ days
- 42.5 kg payload allocation
- 5 samples, 7 cc each, >=10 cm depth
- Relay comm through Carrier or Clipper (backup)
- 3–4 Gbit data return
- 45 kWh battery
- 1.5 Mrad radiation exposure



Launch
- SLS Block 1B
- Oct. 2025 earliest

Enceladus vs Titan

Characteristic	Titan	Enceladus
Distance from Saturn	$20.25R_{Sat}$	$3.95R_{Sat}$
Period (days)	15.95	1.37
Orbit inclination (°)	0.28	0.009
Excentricity of orbit	0.029	0.0047
Mass (10^{22} kg)	13.5	0.011
Radius (km)	2,575	252
Density (kg/m^3)	1,880	1,606
Gravity acceleration (m/s^2)	1.35	0.12
Escape velocity (km/s)	2.64	0.235
Geometric albedo	0.2	1.0
Temperature at surface (K)	94	114–157
Pressure at surface (bar)	1.5	$10^{-10} - 10^{-13}$
Main atmospheric components	N_2, CH_4	H_2O, N_2/CO, CH_4, CO_2



Moons of Saturn from Cassini

(NOTE: No impact craters on Enceladus)

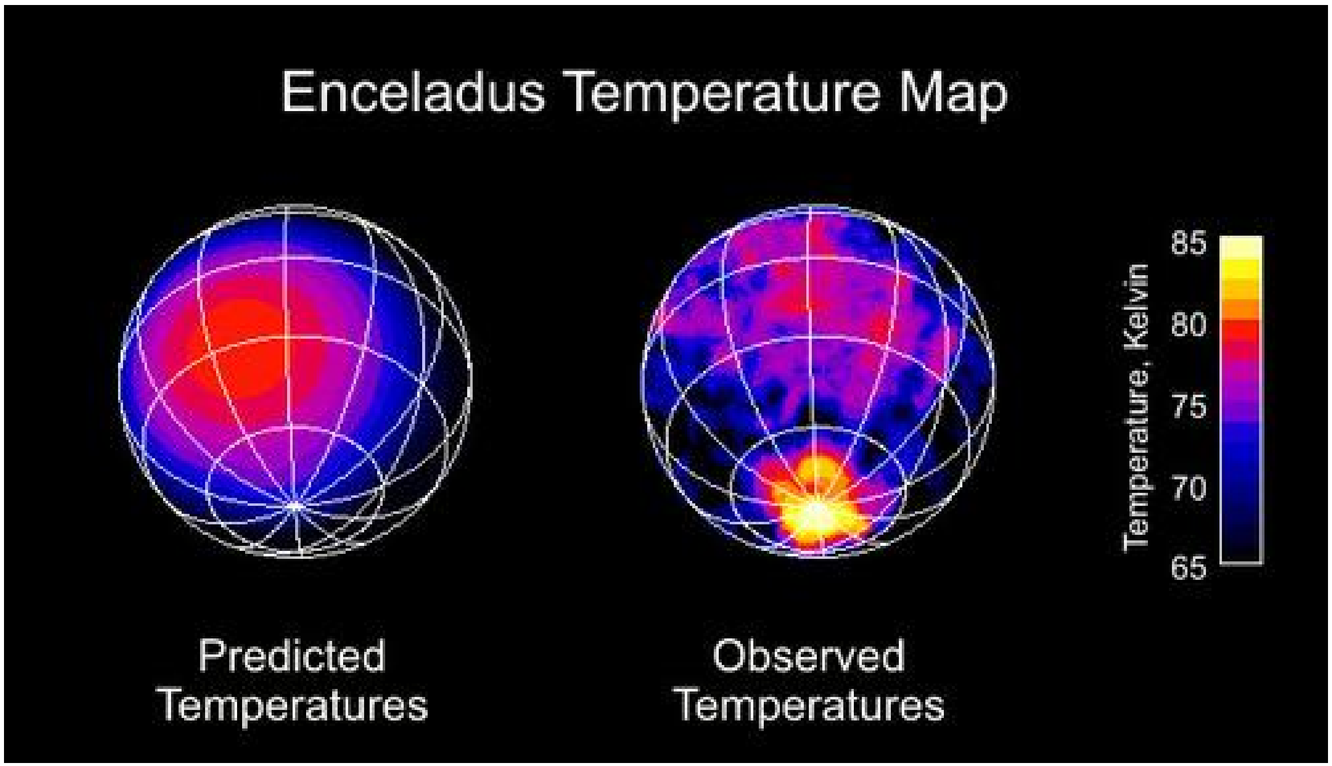
The Cassini spacecraft discovered the long, cracked features dubbed **"tiger stripes"** on Saturn's icy moon Enceladus are very young. **They are between 10 and 1,000 years old.**

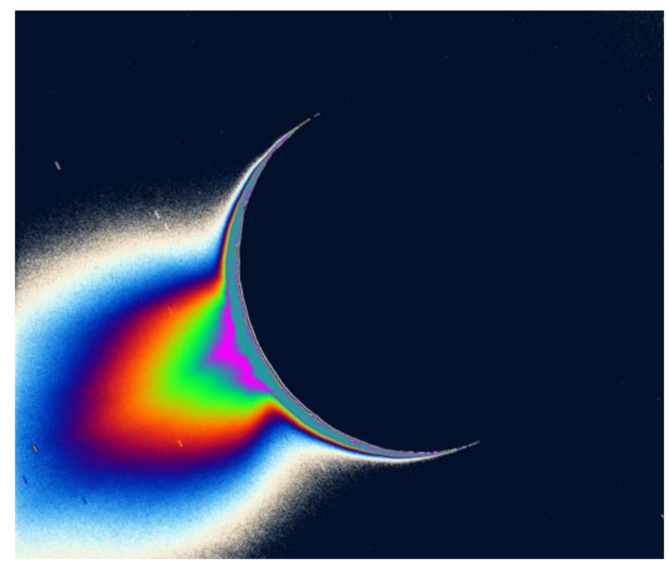
These findings support previous results showing the moon's southern pole is active. The pole had episodes of **geologic activity as recently as 10 years ago.**

These cracked features are approximately 80 miles long, spaced about 25 miles apart and run roughly parallel to each another.

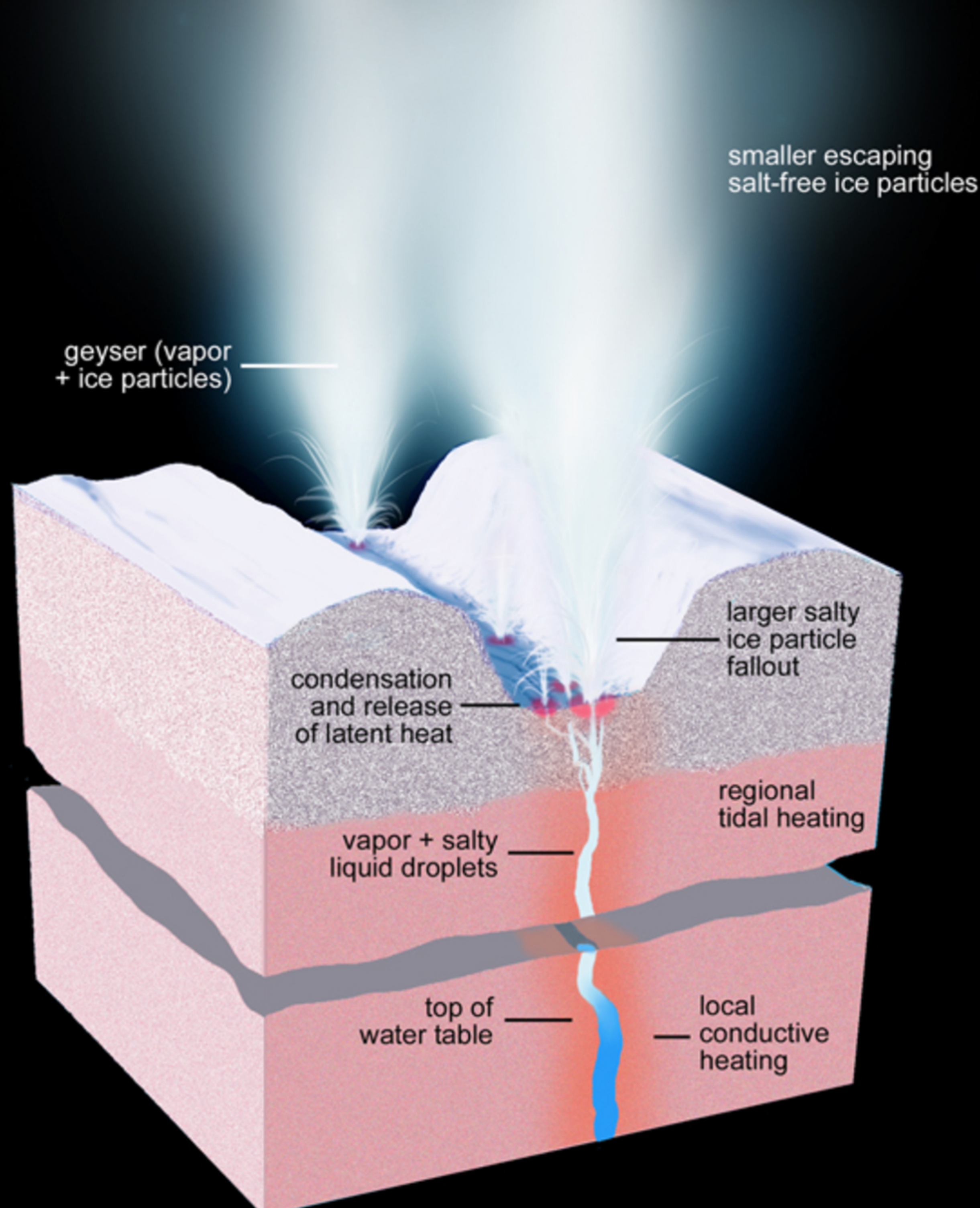
The cracks act like vents. They spew vapor and fine ice water particles that have become ice crystals.

Enceladus, which ought to be cold and dead, instead displays evidence for active ice volcanism.

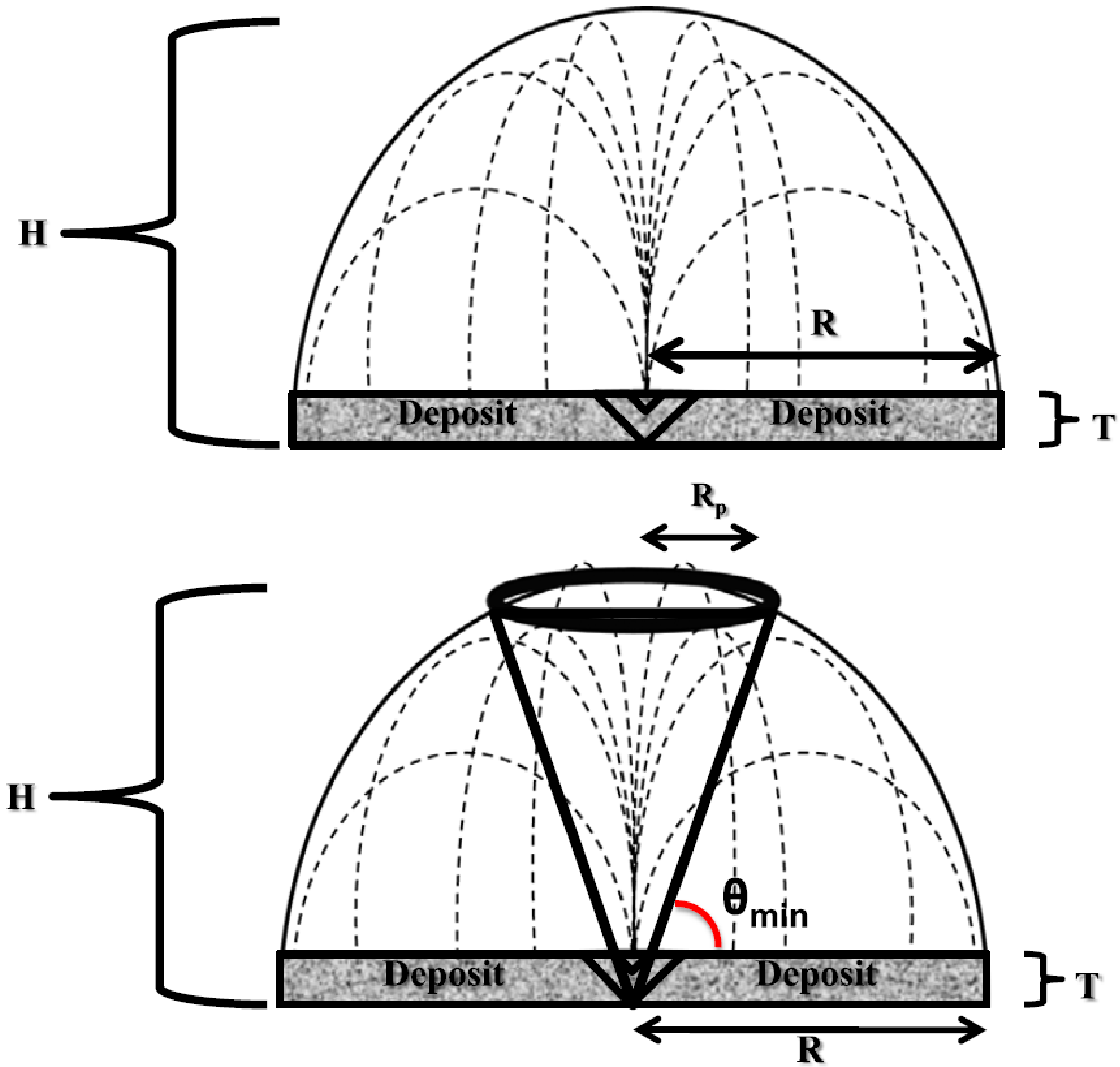




A huge cloud of water vapor over the moon's south pole, and warm fractures where evaporating ice probably supplies the vapor cloud.


smaller escaping
salt-free ice particles
geyser (vapor
+ ice particles)
larger salty
ice particle
fallout
condensation
and release
of latent heat
regional
tidal heating
vapor + salty
liquid droplets
top of
water table
local
conductive
heating

Morgan Cable: Are icy moons in the Habitable Zone?



Conditions for cryovolcanism (Quick et al. 2013).

$v = \left(\frac{gR}{\sin 2\theta}\right)^{1/2}$, $v = \sqrt{\frac{2nR_gT_k}{m(k-1)}}$ n = weight percent of gas, R_g = universal gas constant, $T = 273K$, k & m = specific heats.

Plume height $H = v^2/2g$. Requires: energy source, sustained eruptions.