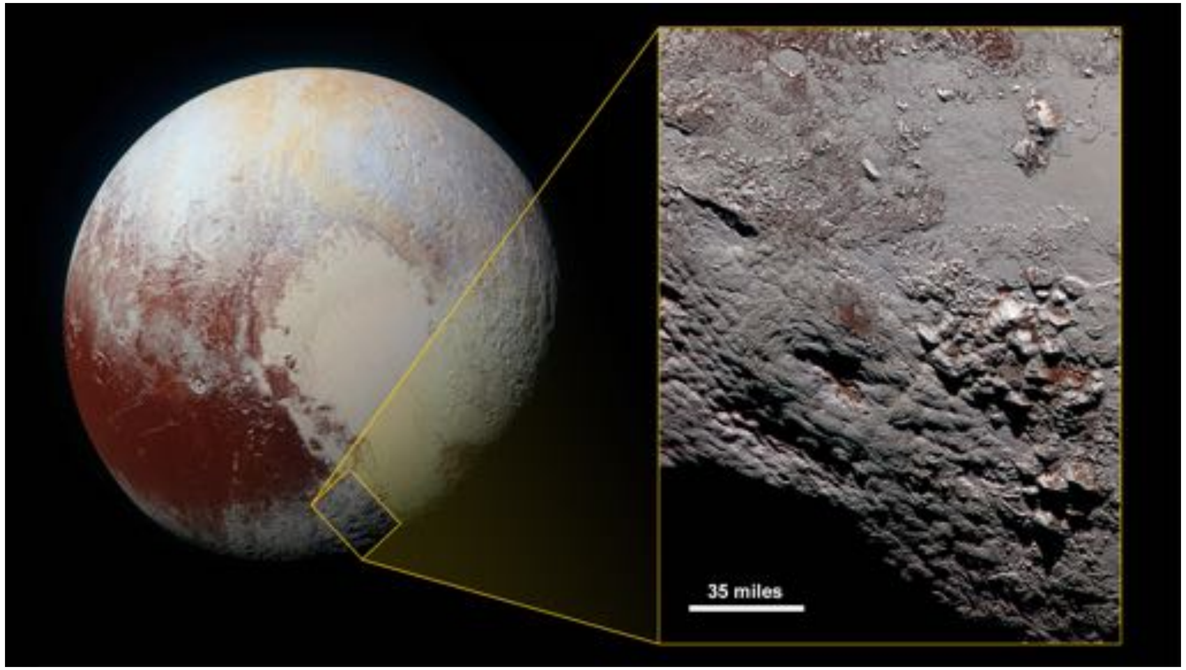

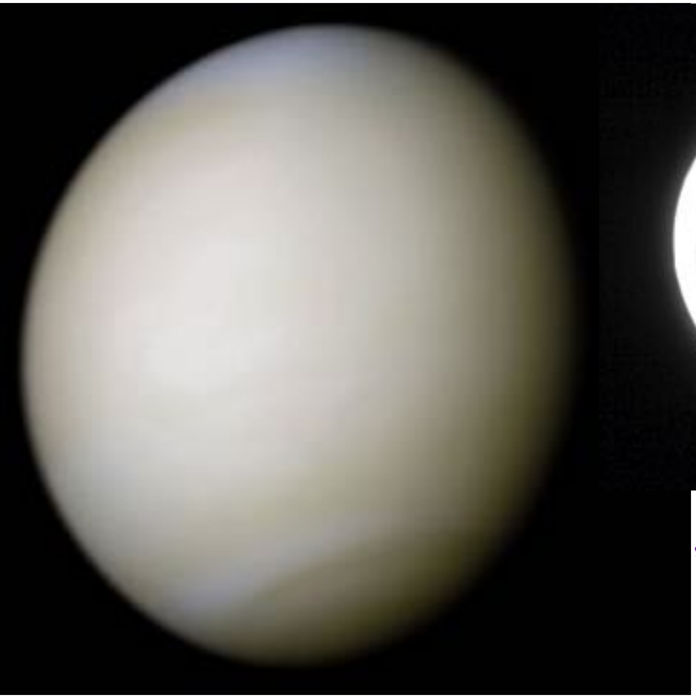

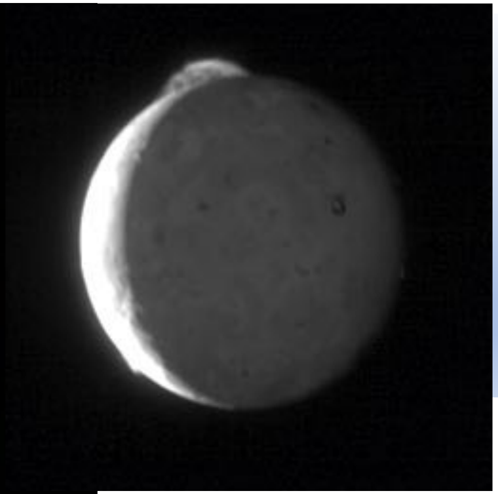

Planetary Science
Our Solar System

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Outline

- Our solar system members
- Formation of our solar system: temperature dependence vs. chemical composition
- Origin of the terrestrial planet and its layering
- What do we study for planetary science?
- Planetary surface and interior, Atmosphere, Space weather, Small bodies, Astrobiology……

International Astronomical Union (IAU)

The definition of the astronomical objects:

- Star: nuclear fusion is sufficient for thermal pressure to balance gravity
- Stellar remnant: dead star – no more fusion
- Brown dwarf: Deuterium fusion
- Planet: negligible fusion + orbits one and more stars

In the Solar system

Planet:

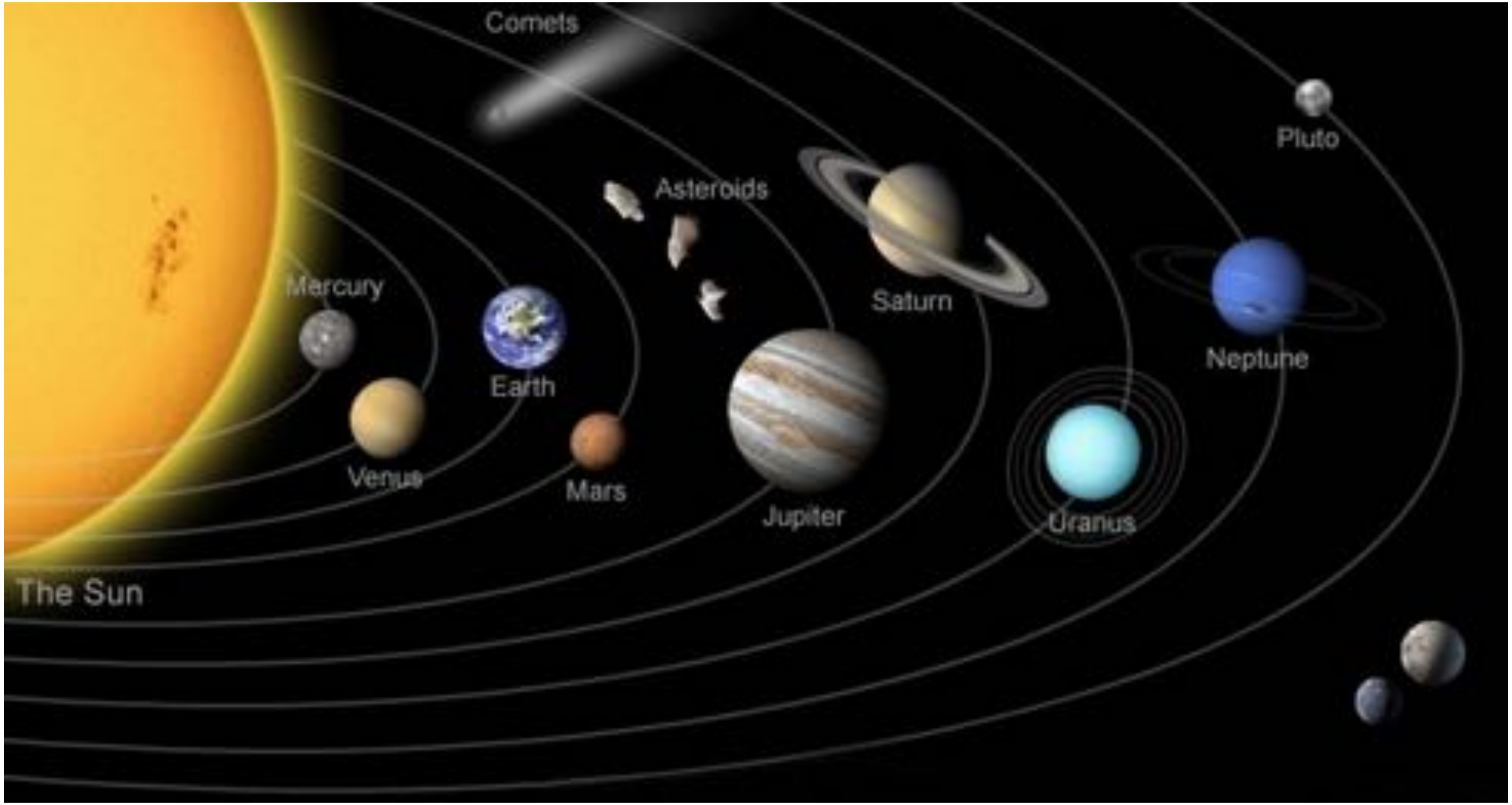
1) orbit around the Sun
2) sufficient mass for its self gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium shape (nearly round)
3) cleared the neighborhood around its orbit

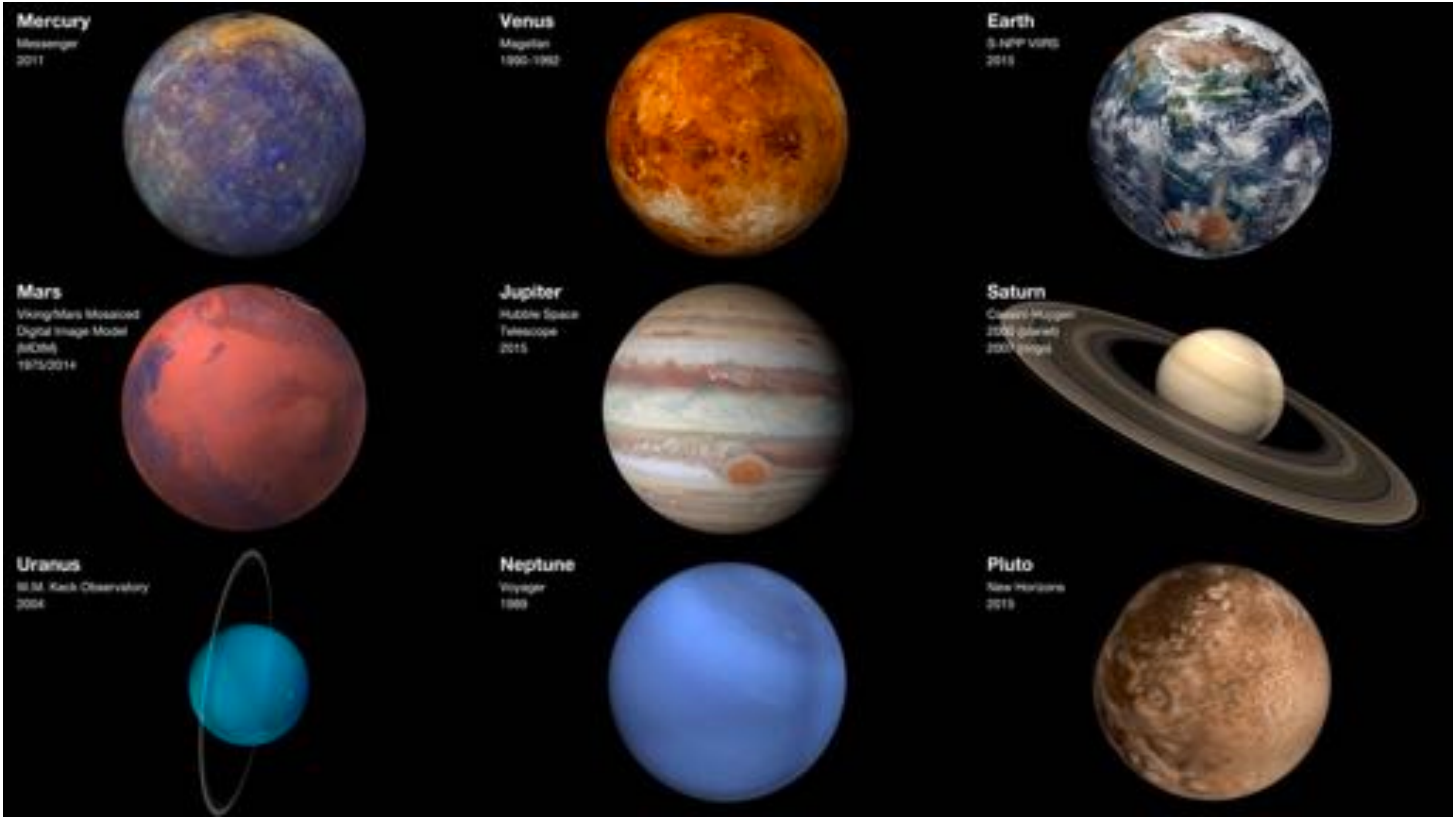
Dwarf planet: 1 & 2 shown above and -

3) not cleared the neighborhood around its orbit
4) is not a satellite

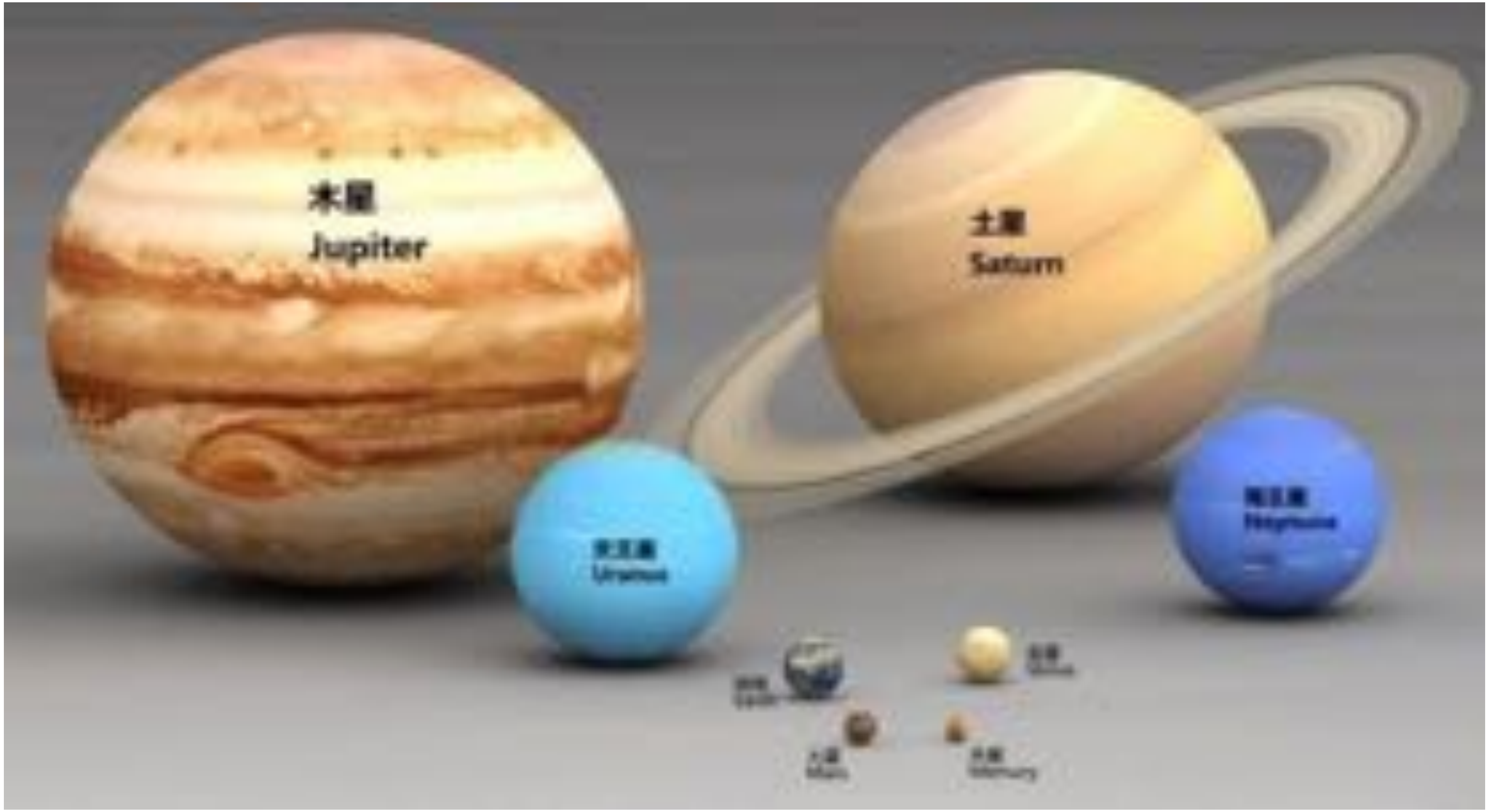
Planets: The terrestrial planets dominate the inner Solar system, while the gas/ice giant planets dominate the outer Solar system

Small bodies: dwarf planets, moons, asteroids, comets, KBOs…



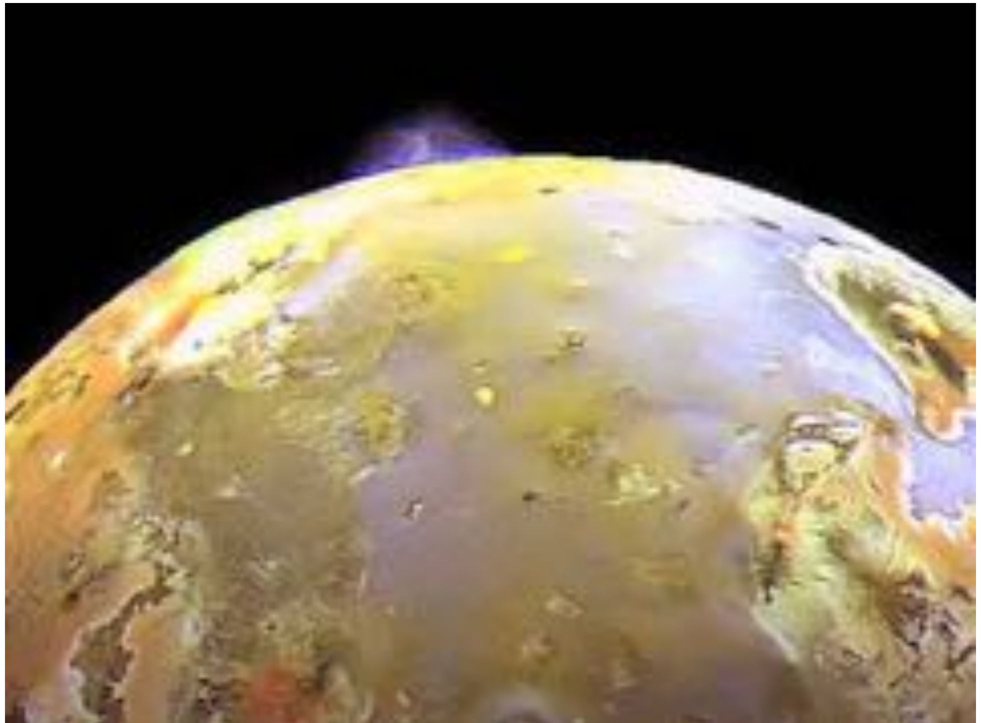

Mercury
Messenger
2011
Venus
Magellan
1990-1992
Earth
S-NPP VIIRS
2015
Mars
Jupiter
Hubble Space
Telescope
2015
Saturn
Uranus
W.M. Keck Observatory
2004
Neptune
Voyager
1989
Pluto
New Horizons
2015

Terrestrial Planets vs. Gas/Ice Giants - the masses and volumes



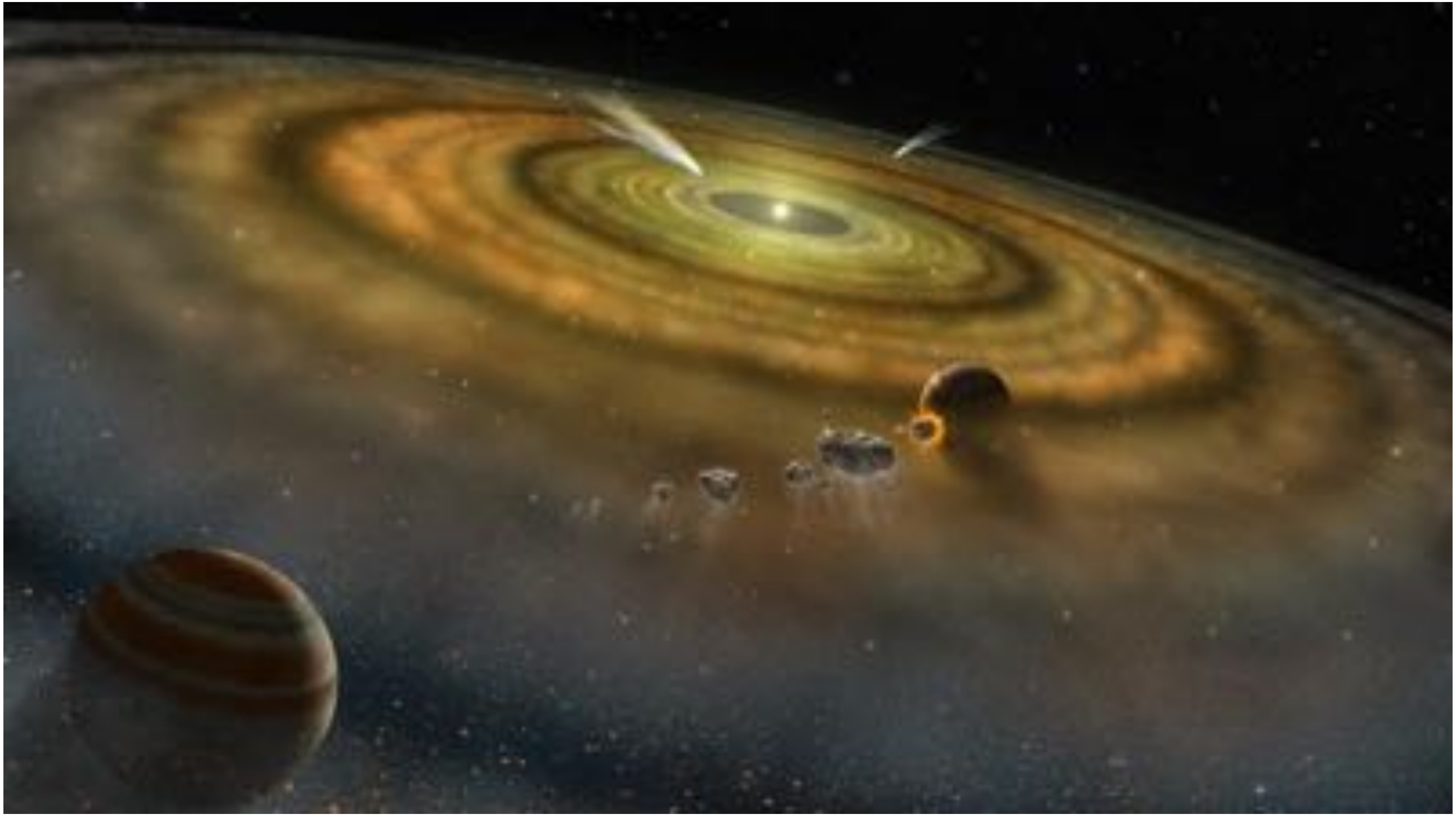
The Galilean Moons

https://stellarium-labs.com/blog/3dgalileanmoons/

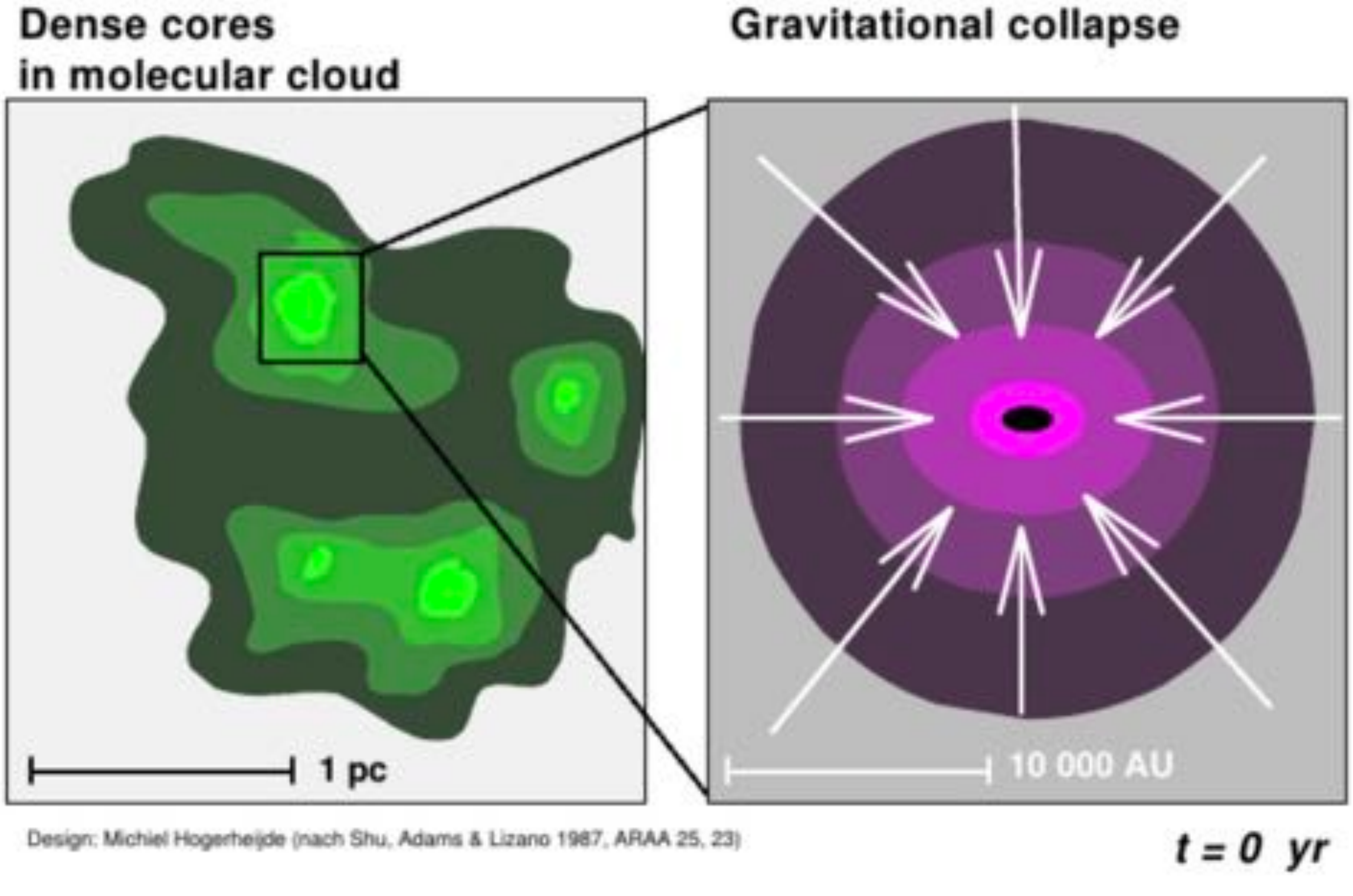


Asteroids - important building blocks of our solar system

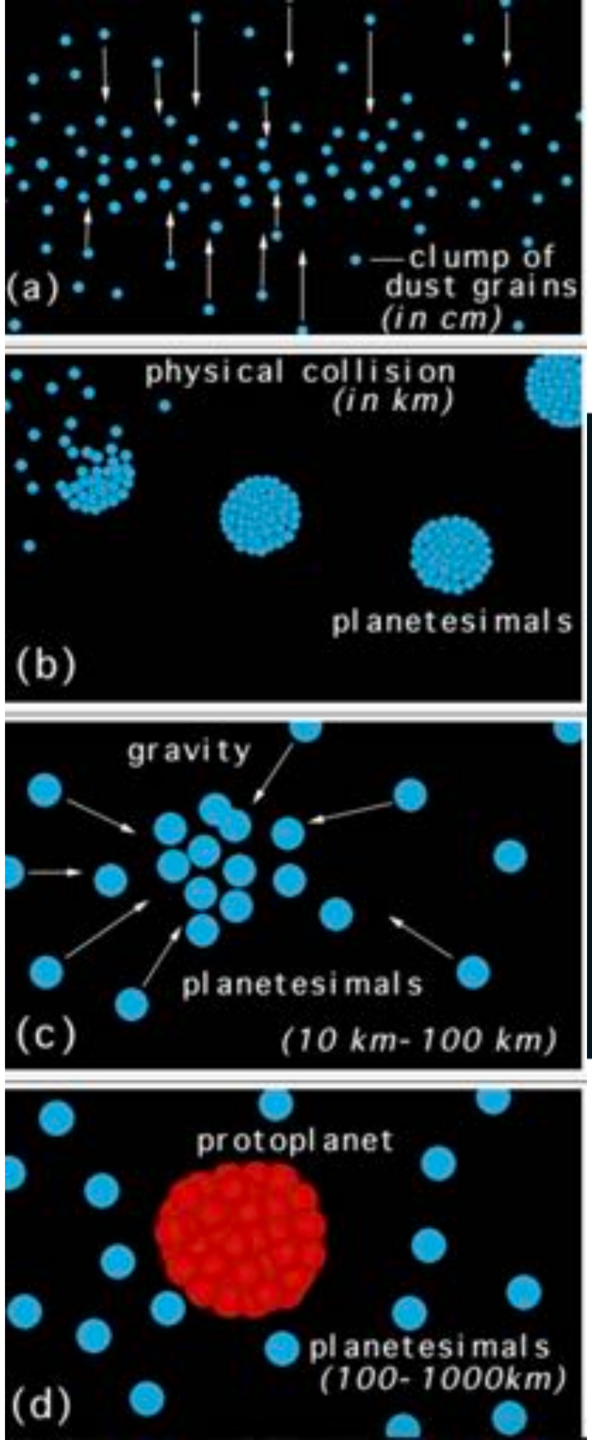
Formation of our Solar System

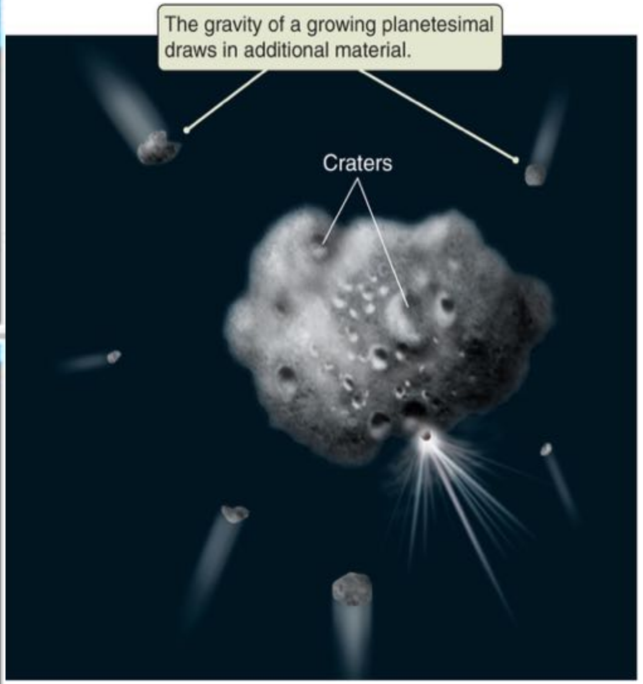


Star Formation: nebulae collapse



http://spaceplace.nasa.gov/solar-system-formation/en/





- **Planet formation**
- Within the disk, small particles will collide and stick lead to larger particles called **planetesimals**.
- Will pull more particles onto them by gravity, i.e., impact & accretion leading to **planets**.
- Today's remaining planetesimals: **asteroids** & **comets**.

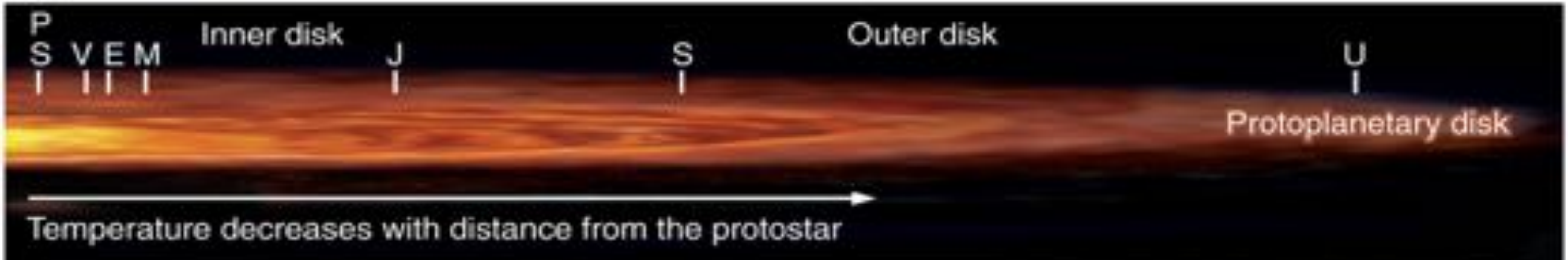
http://homework.uoregon.edu/pub/class/121/formation.html

Evolution of our Solar system: chemical composition

- **Terrestrial Planets:**
  - Cores → Small & rocky (refractory elements, silicates & iron)
  - Atmospheres: Thin, no H/He, some ices or volatiles (C, N, O, Ne)
- **Jovian Planets:**
  - Cores → large rocks/metals/ices
  - Atmospheres → H or H-compounds (e.g. CH_4)
- **KBOs: planetesimals and icy bodies:**
  - Small ice & rock mixtures with frozen volatiles.

Do you see any pattern?

Why rocky/metal material in the inner region and gas/ice in the outer region?

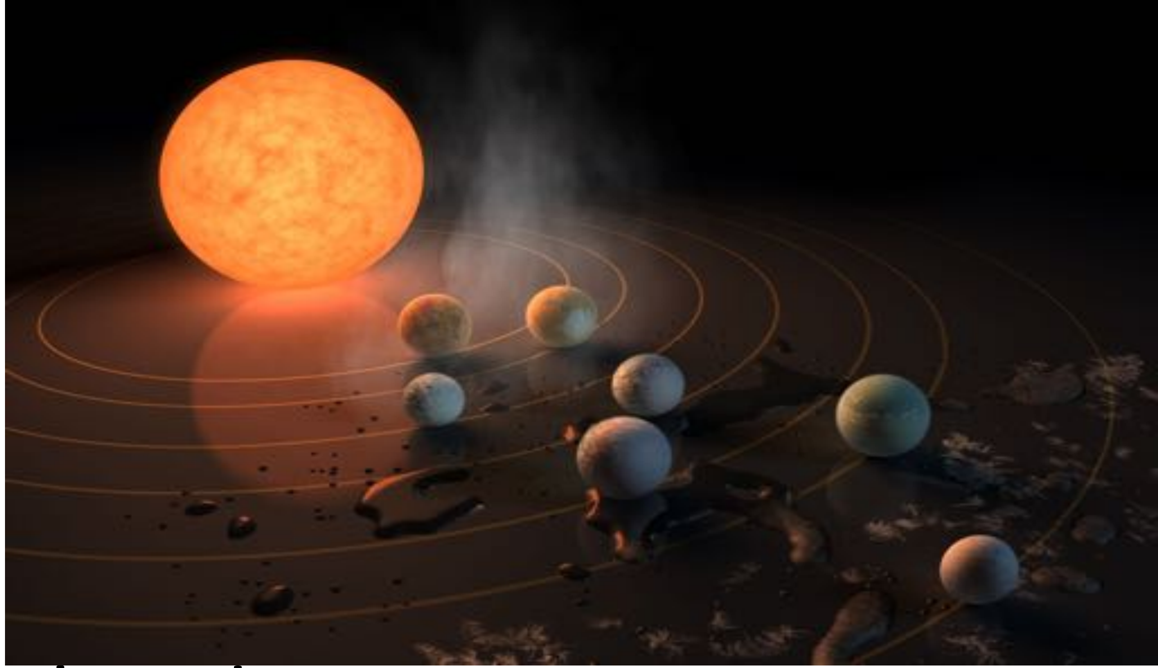


Temperature controls

Temperature decreases

The temperature difference between the inner and outer disks causes a difference in composition.

Chemical composition: Volatility



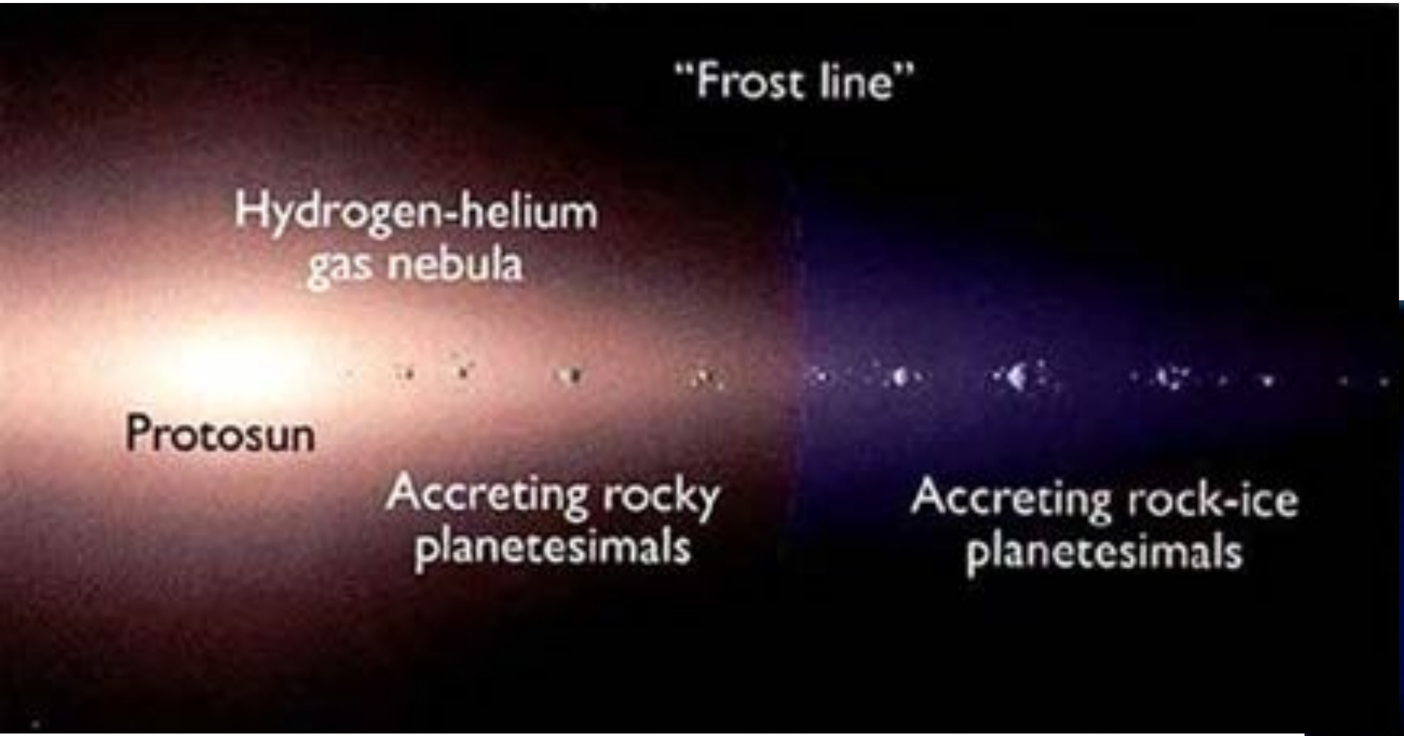
Inner disk (high T): Only materials that do not melt/evaporate at high temperatures can form or remain.

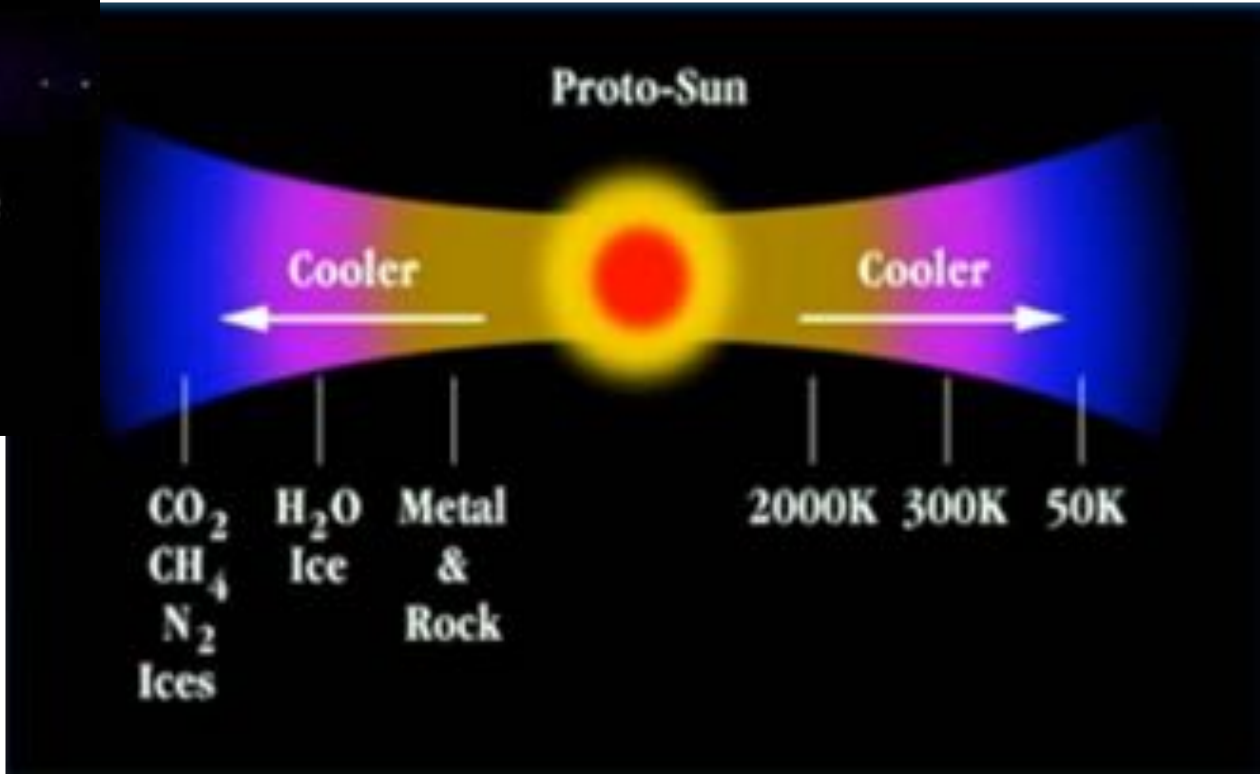
Refractory material: Rocks + Metals

Outer disk (low T): Materials can melt or evaporate at low temperatures.

Volatiles: Water, CO, NH_3 gases + ices etc

Everything about Location, Location, Location… Thermodynamics in the Protoplanetary Disk

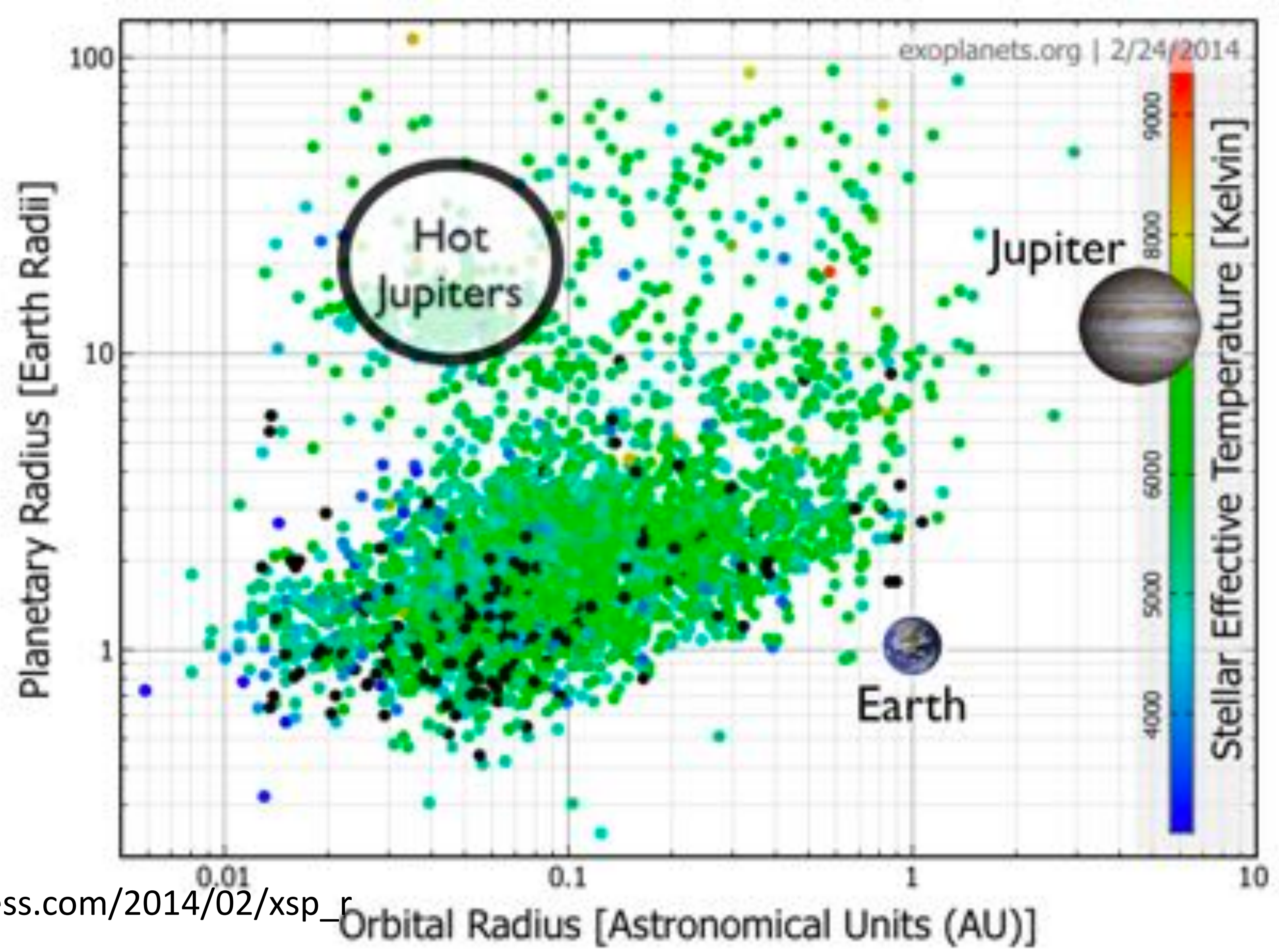




https://www.astronoo.com/en/articles/frost-line.html

However, the exoplanets tell us a different story……

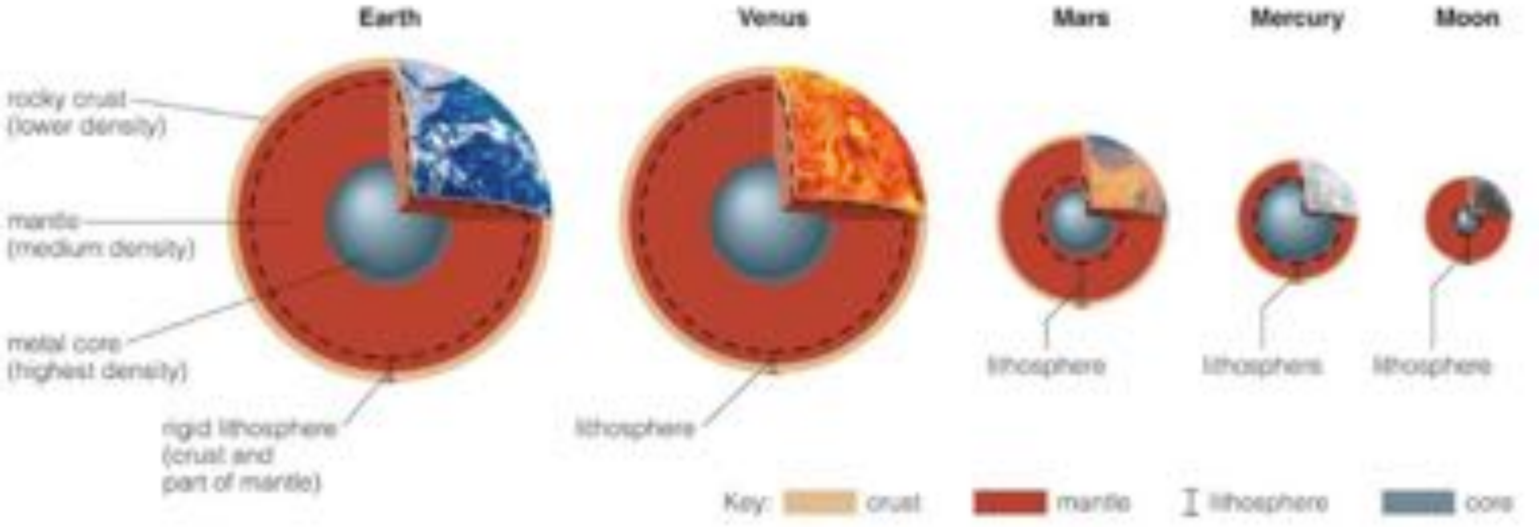
Something about migration!



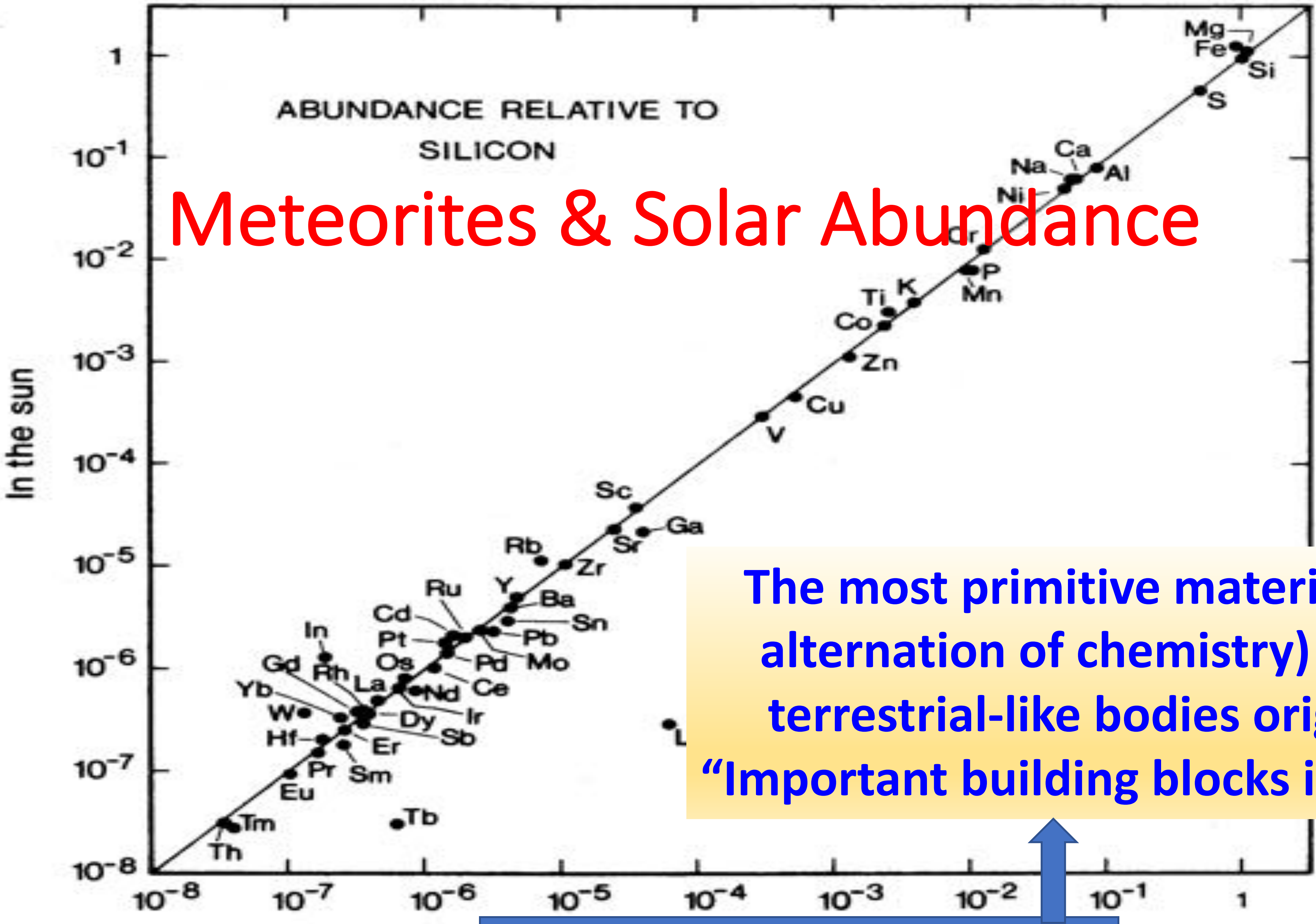
https://planetplanetdotnet.files.wordpress.com/2014/02/xsp_r_a_teff-010.jpg

Origin of the terrestrial planet and its layering

- In the protoplanetary disk: condensation - refractory vs. volatile (temperature/distance dependence)
- Accretion: planetesimals; gravitationally attracted
- Collisions
- Assembly, melting, differentiation
- Core formation (rain-out model: Fe/Ni & Si are immiscible => sink under gravity)



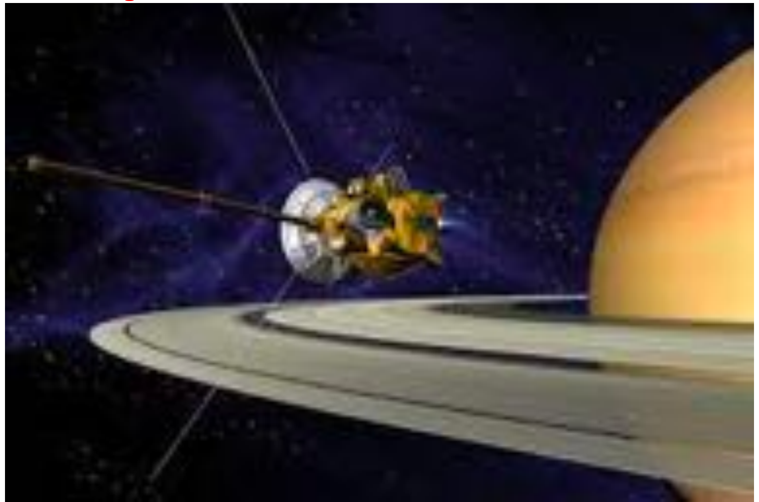
Meteorites & Solar Abundance



The most primitive material (no secondary alternation of chemistry) => formation of terrestrial-like bodies originally accreted "Important building blocks in the solar system"

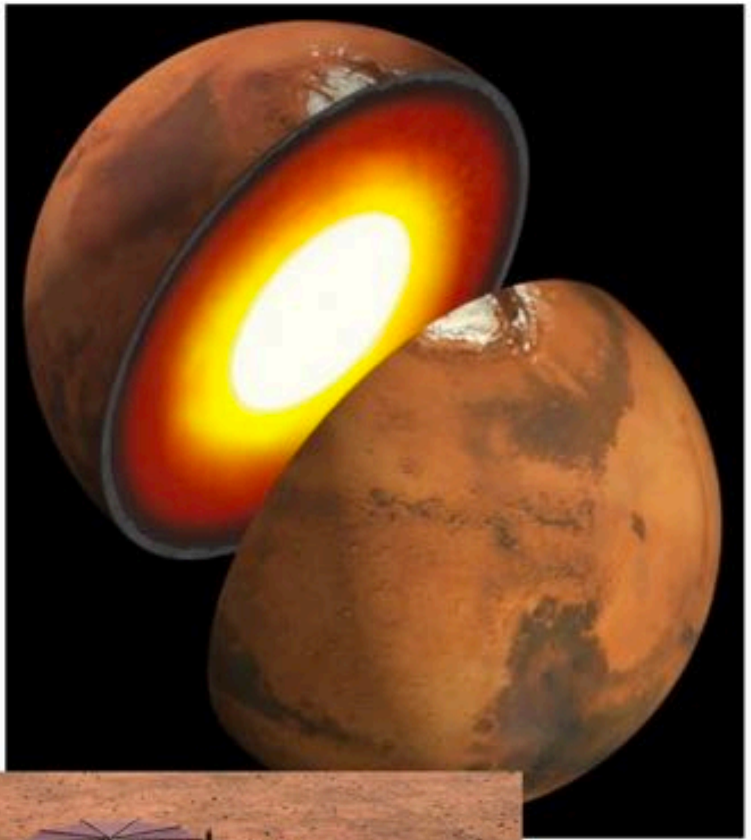
How do we study for planetary sciences?

- In addition to the ground-based & space telescope observations, computer simulations and lab experiments
- We have a unique tool conducting **spacecraft missions** to explore and study various celestial bodies within the solar system, such as planets, moons, asteroids, and comets.
- **Including: multi-wavelength remote sensing, and in-situ measurements to gather data of fields, particles and waves, i.e., magnetometer, plasma spectrometer, neutral mass spectrometer, dust analyzer**……

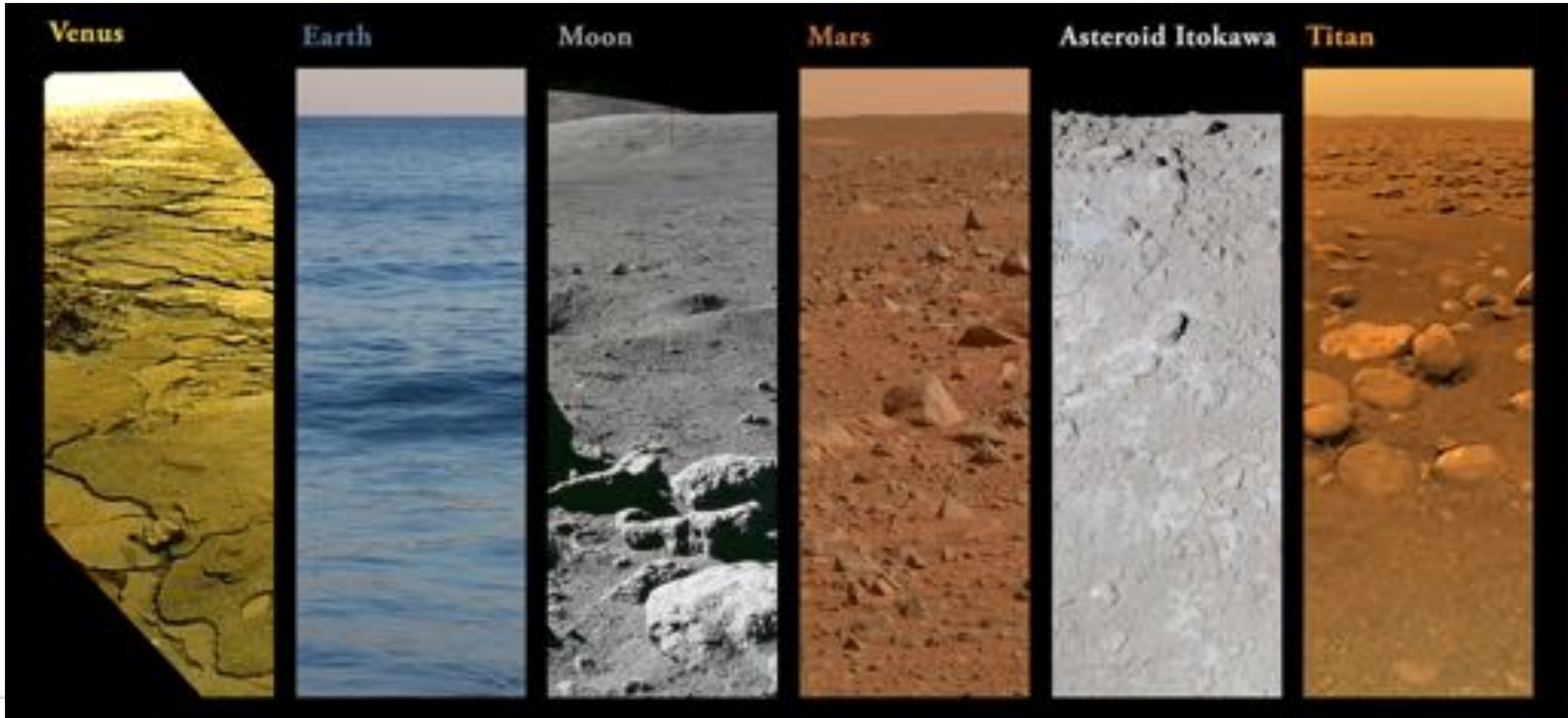


What do we study for planetary sciences? – (1)

- Investigating the formation, evolution, and physical properties of planets, including their atmospheres, surfaces, and interiors.
- This field includes studying the geology, composition, and dynamics of planets, as well as planetary atmospheres and climate.

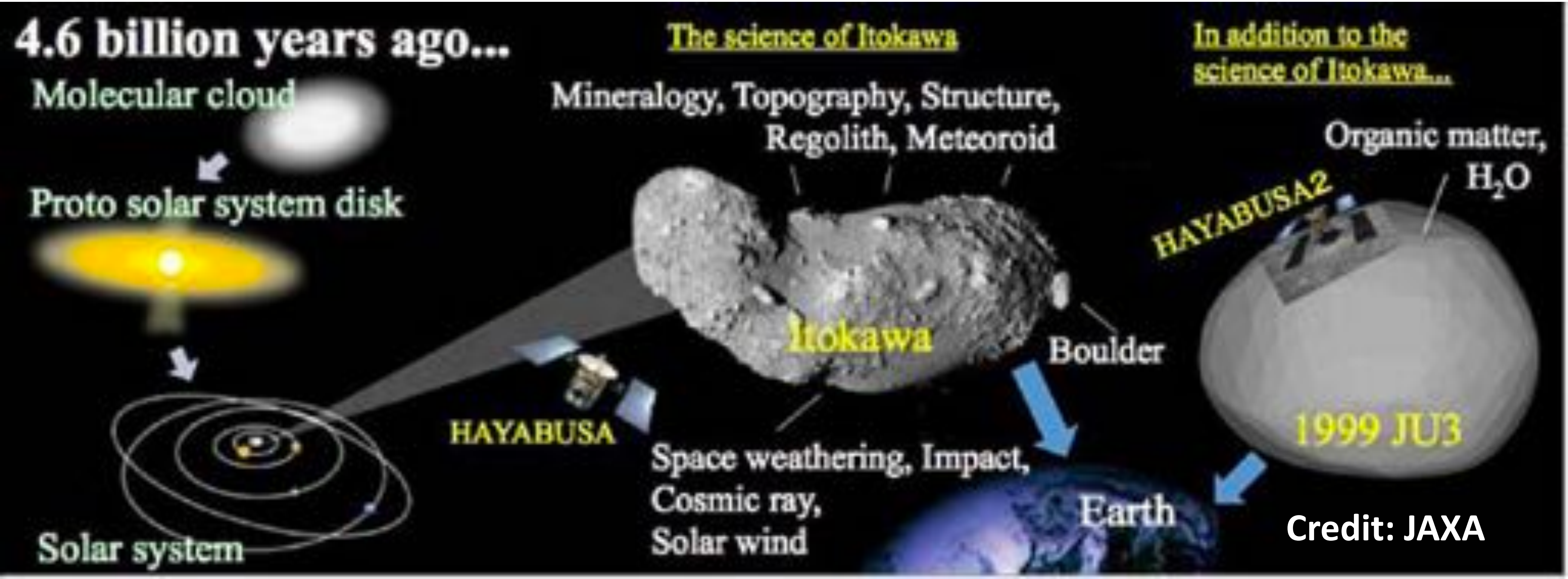


Credit: NASA



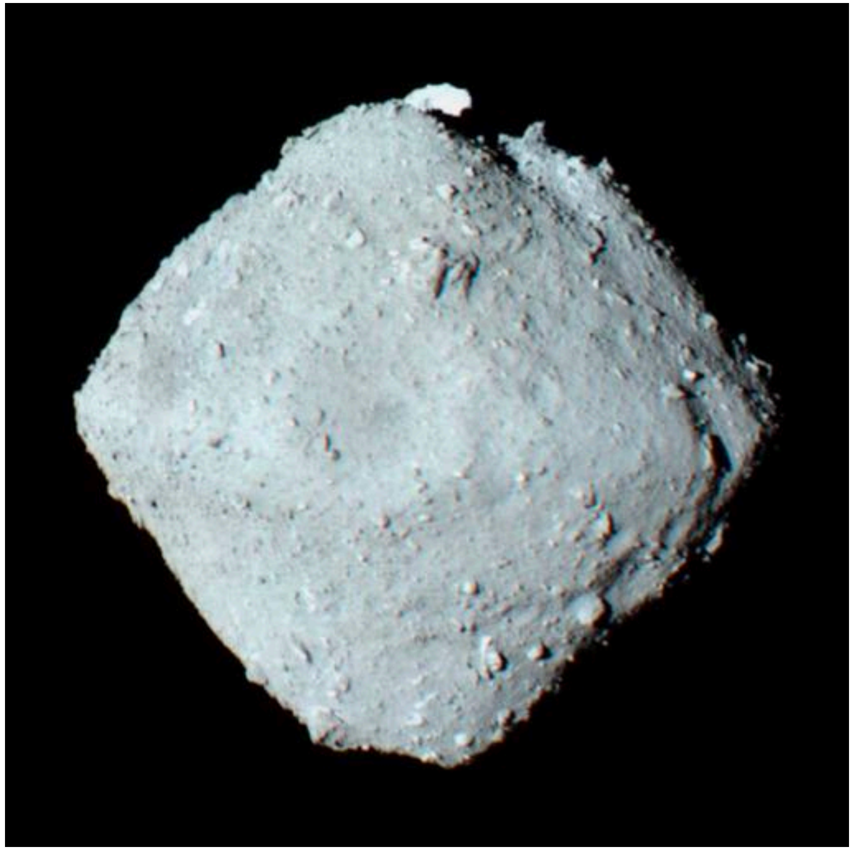
(2) Small Solar System Bodies

- Investigating **important building blocks such as asteroids and comets** to understand their composition, origins, and potential impact hazards.



Hayabusa 2: returning asteroid sample could help uncover the origins of life and the solar system

- https://theconversation.com/hayabusa-2-returning-asteroid-sample-could-help-uncover-the-origins-of-life-and-the-solar-system-151415



Ryugu seen by Hayabusa 2.

Comets as seen from Earth's surface
- Spectacular Coma & Tails

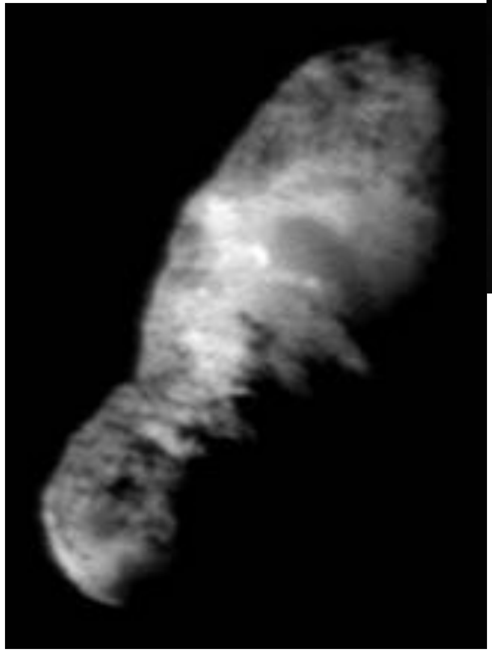
Comet McNaught over the Pacific Ocean. Image taken from Paranal Observatory in January 2007.
Credits: ESO/Sebastian Deiries

Comets:

Nucleus + Coma + Tails/Jets

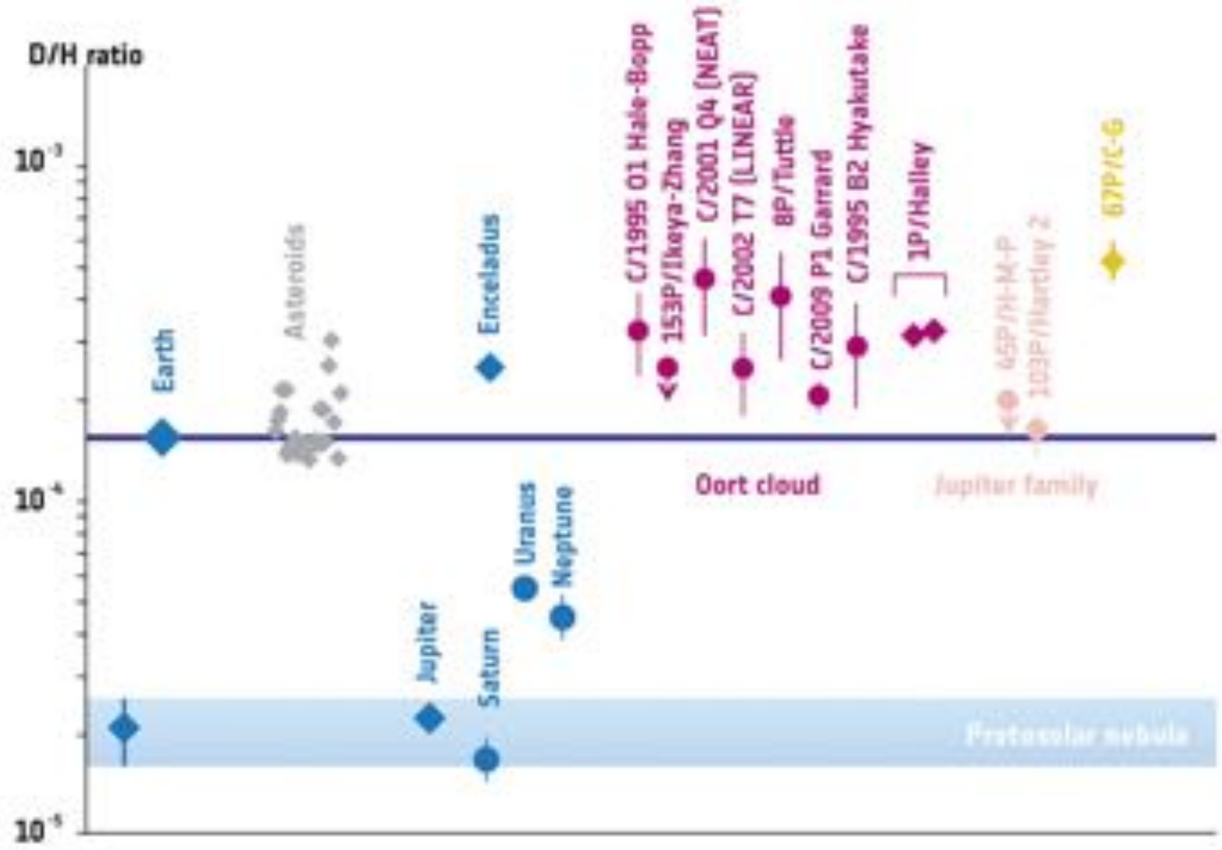
Nucleus: small size (~several to tens kms) = dirty snow ball (dust + icy material) => only seen from the spacecraft flybys

Nucleus:
1. Rich in volatiles => not much thermal evolution (if they come from outer solar system) => the primordial & pristine objects in the solar system
2. Dark surface: influenced by energetic particle bombardment and cosmic rays
3. Complex organics: life-seed?



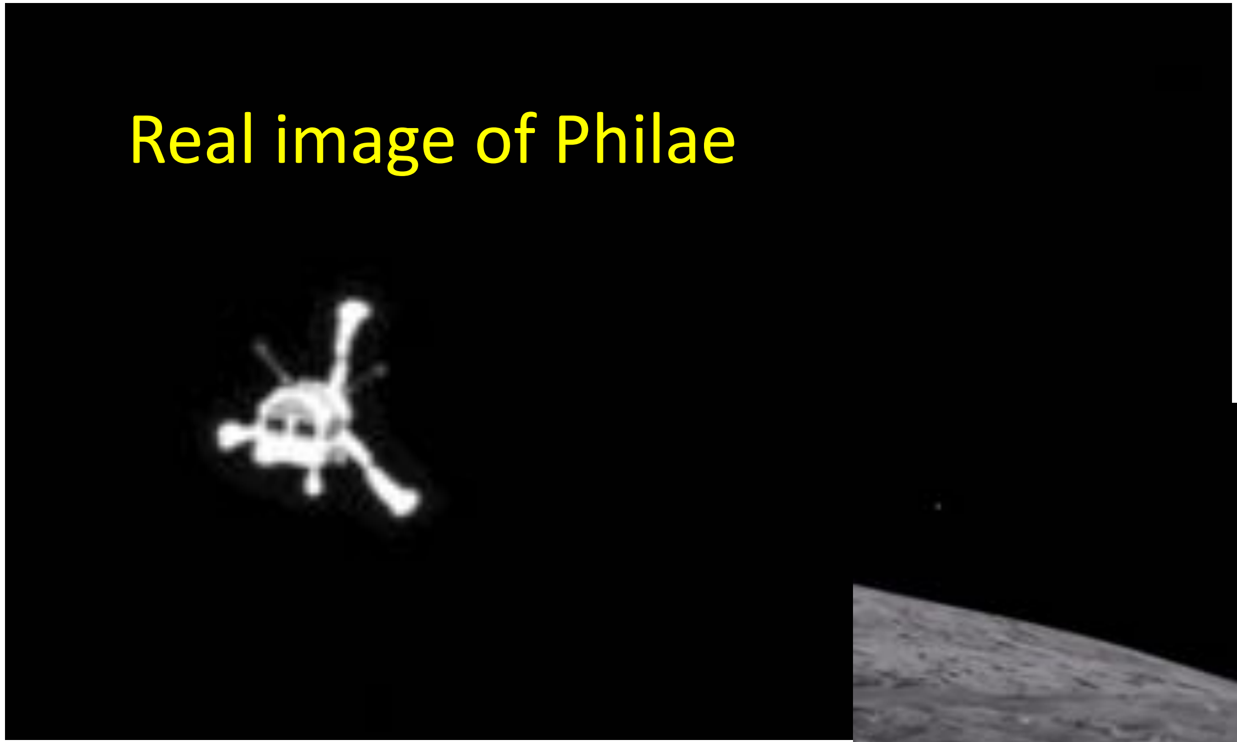
The origin of the ocean water on Earth

- D/H ratio (D: H with an additional neutron)
- the ratio changes based on when and where an asteroid or comet formed

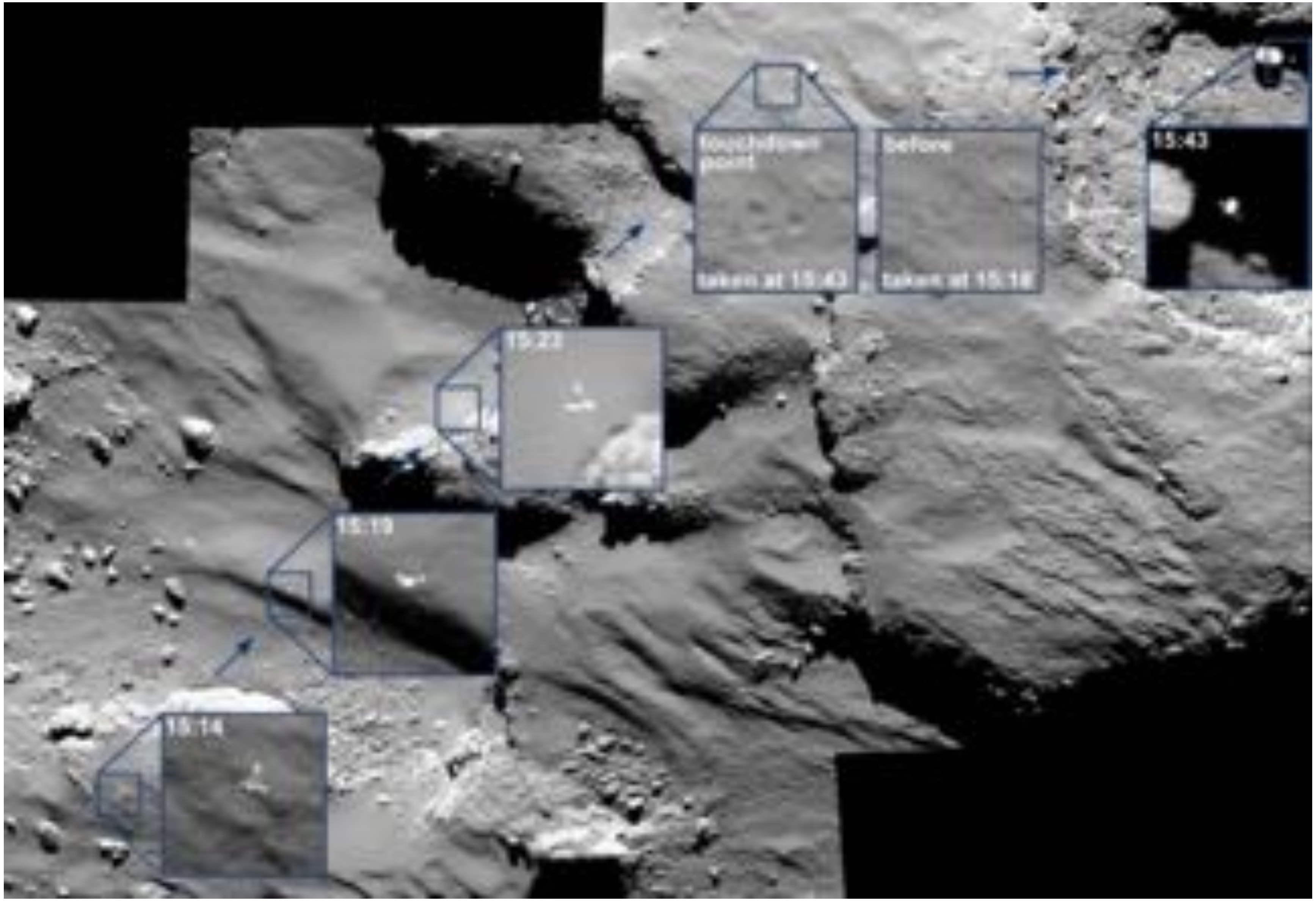


[Rosetta Movies: http://christianready.com/2014/10/25/ambition/](http://christianready.com/2014/10/25/ambition/)

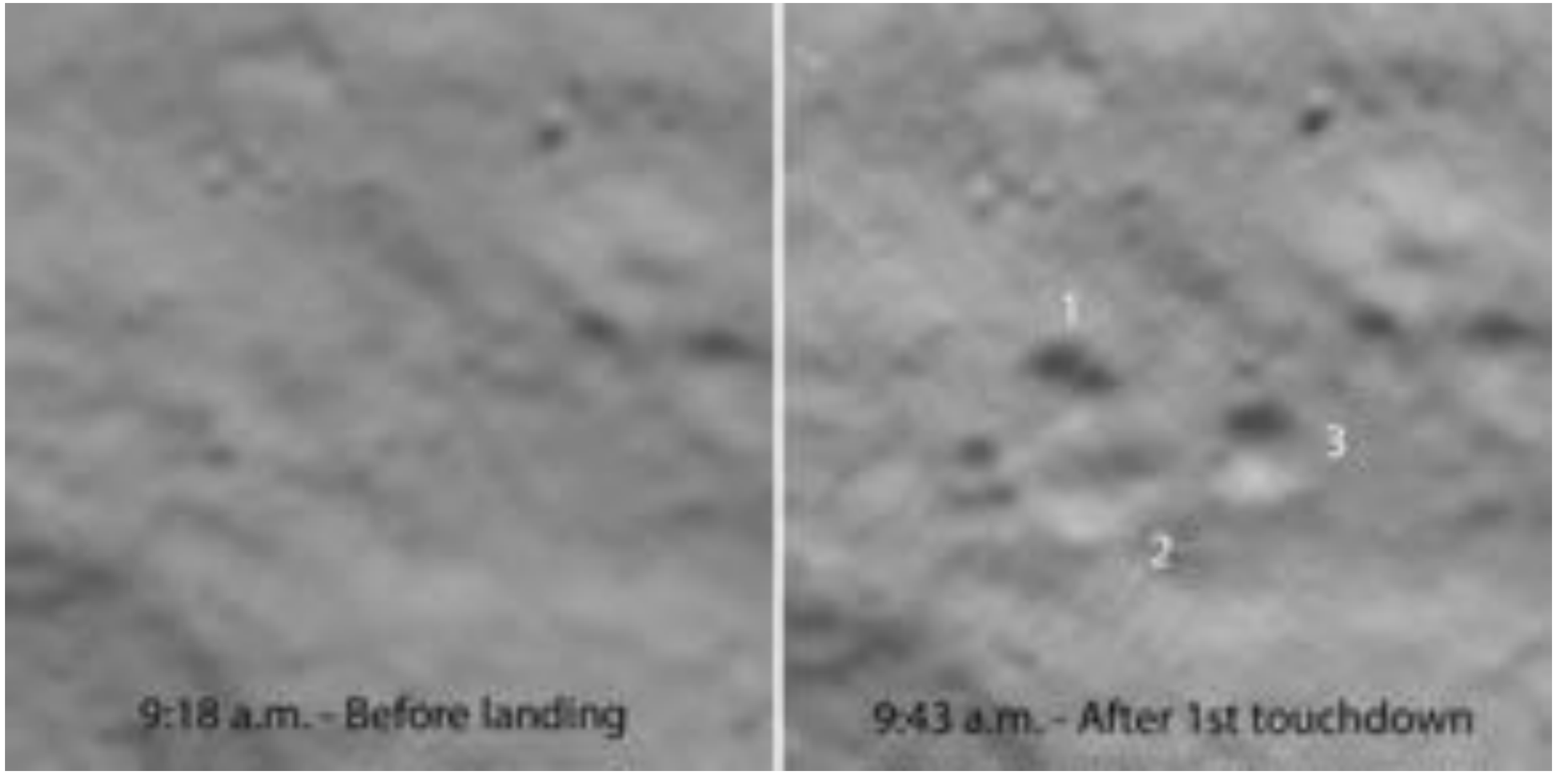
Rosetta Mission – Philae: the comet lander



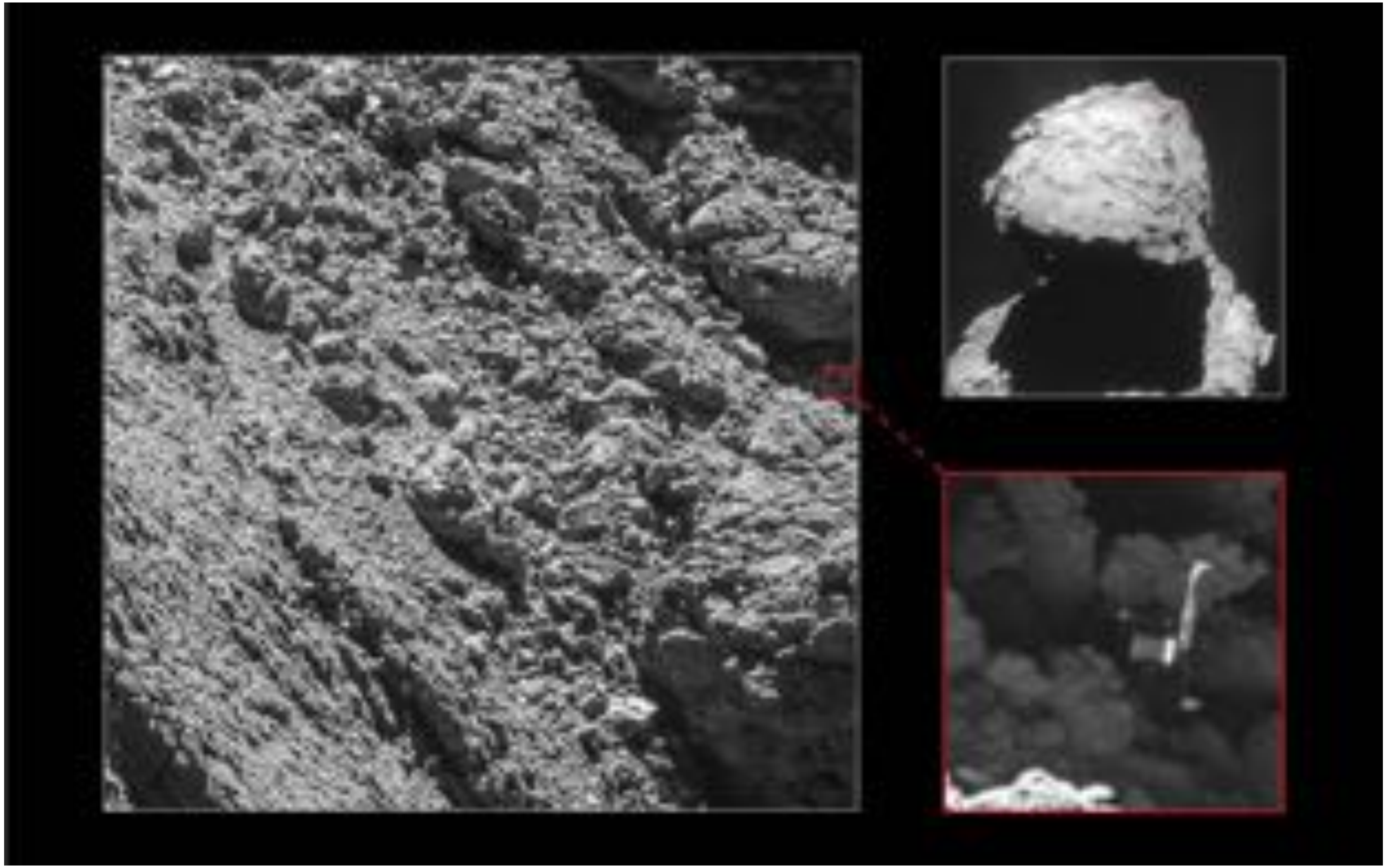
Where is Philae?



Footprints of Philae on comet 67P

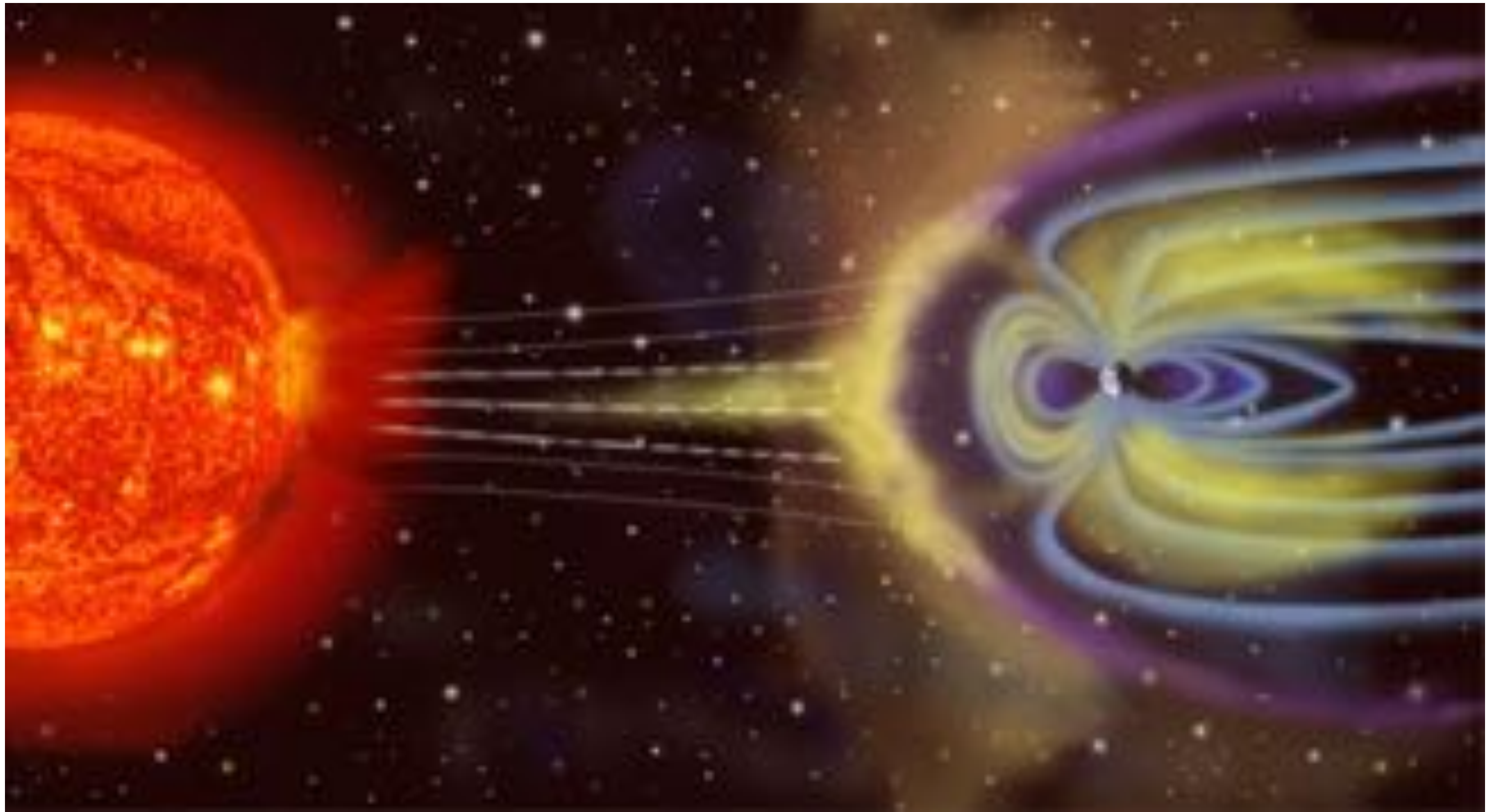


Where is Philae?



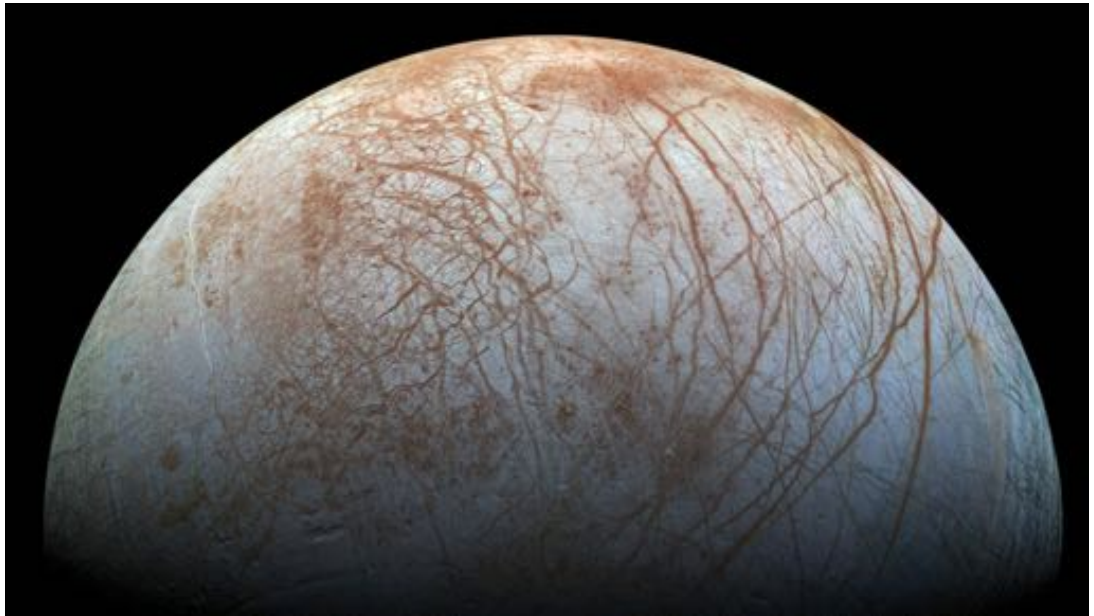
(3) Space Weather and Space Physics

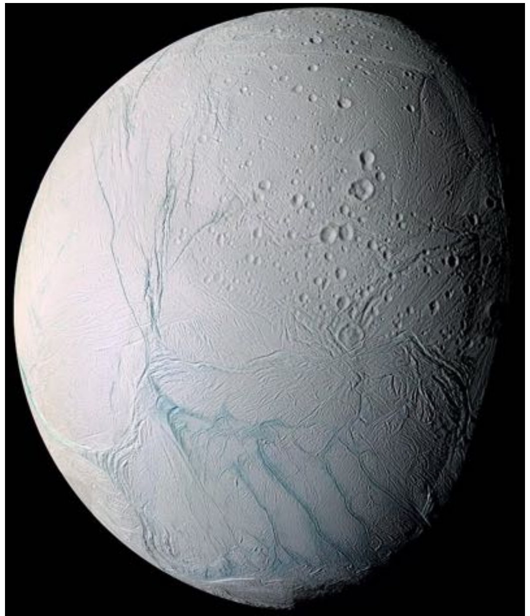
- Examining the interactions between the Sun and the solar system, including the study of solar activity, solar wind, magnetospheres, and their effects on planetary environments and space weather. Understanding these phenomena is essential for spacecraft operations, human space exploration, and protection of technological infrastructure on Earth.



(3) Astrobiology

- Focusing on the study of the origin, evolution, and distribution of life in the universe, including the search for habitable environments and the potential for life beyond Earth.
- Mars
- Icy satellites with subsurface oceans: Europa, **Enceladus, Titan** ……

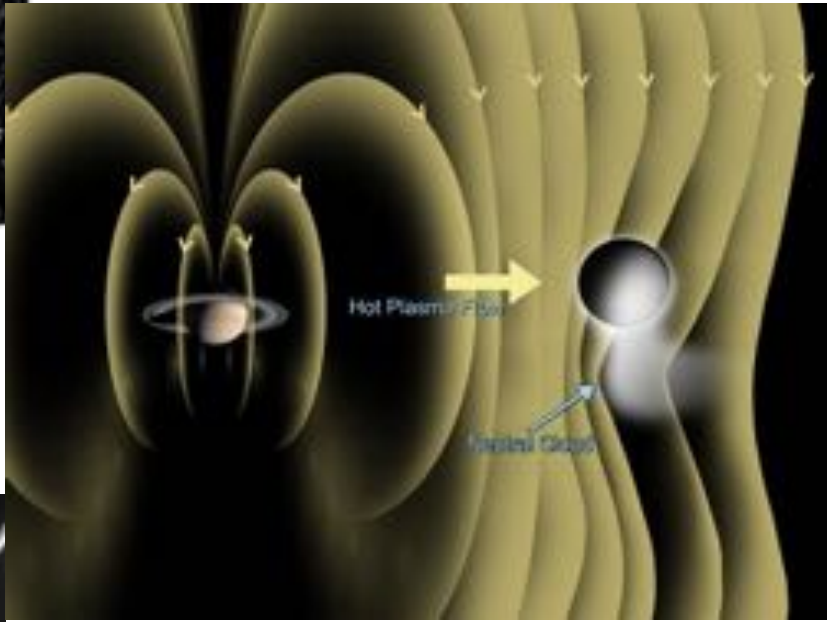




Enceladus' plume activities discovered by Cassini

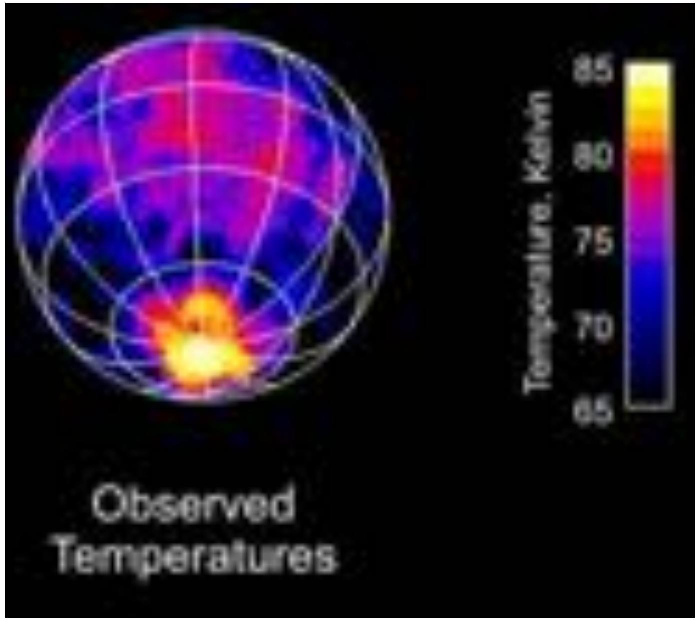
Credit: Cassini ISS

Jet Sources:
South polar region/Tiger Stripes



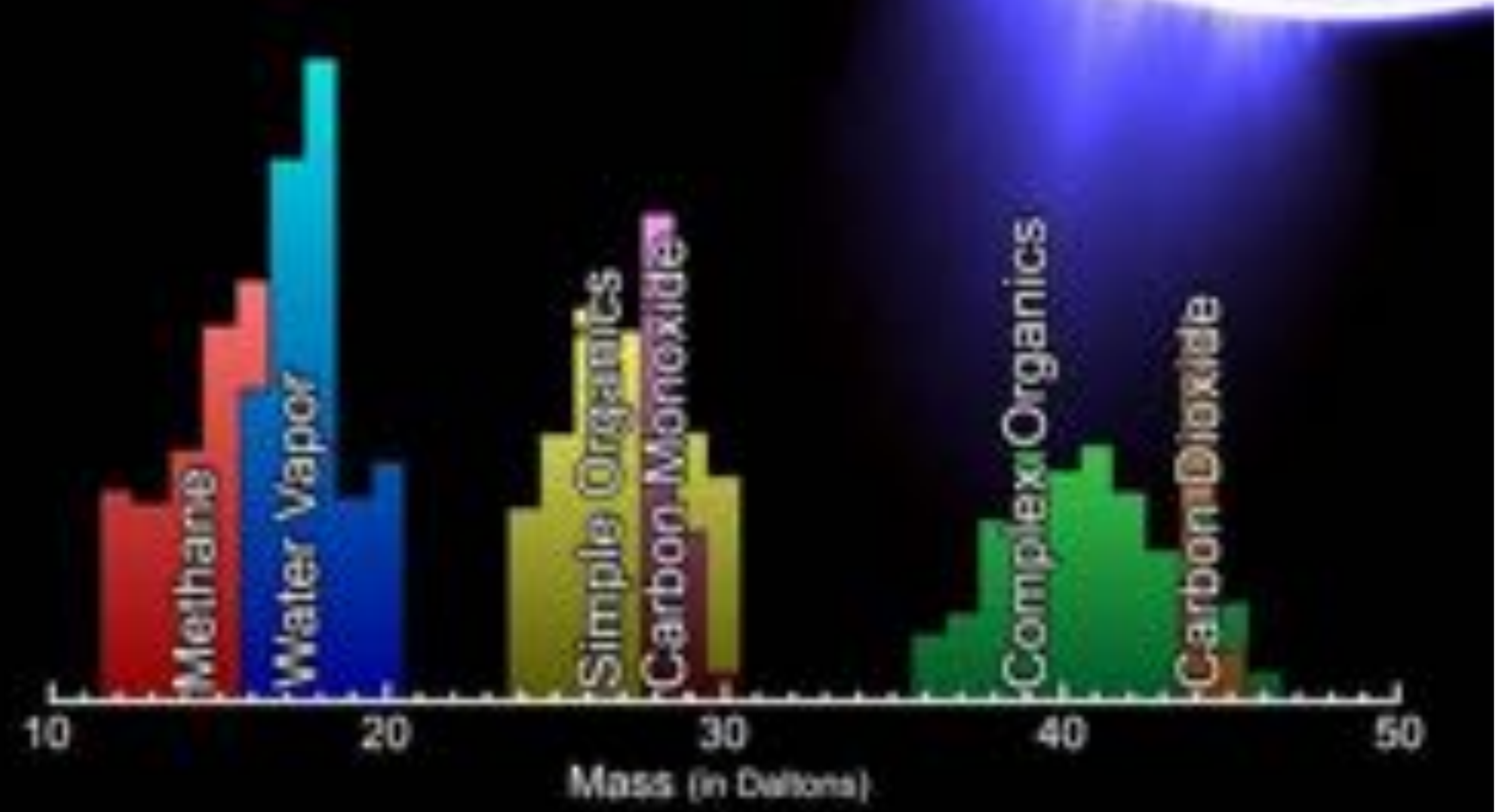
a dynamic atmosphere on Enceladus

Credit: Cassini MAG



Credit: Cassini CIRS

Enceladus Plume (gas) Composition



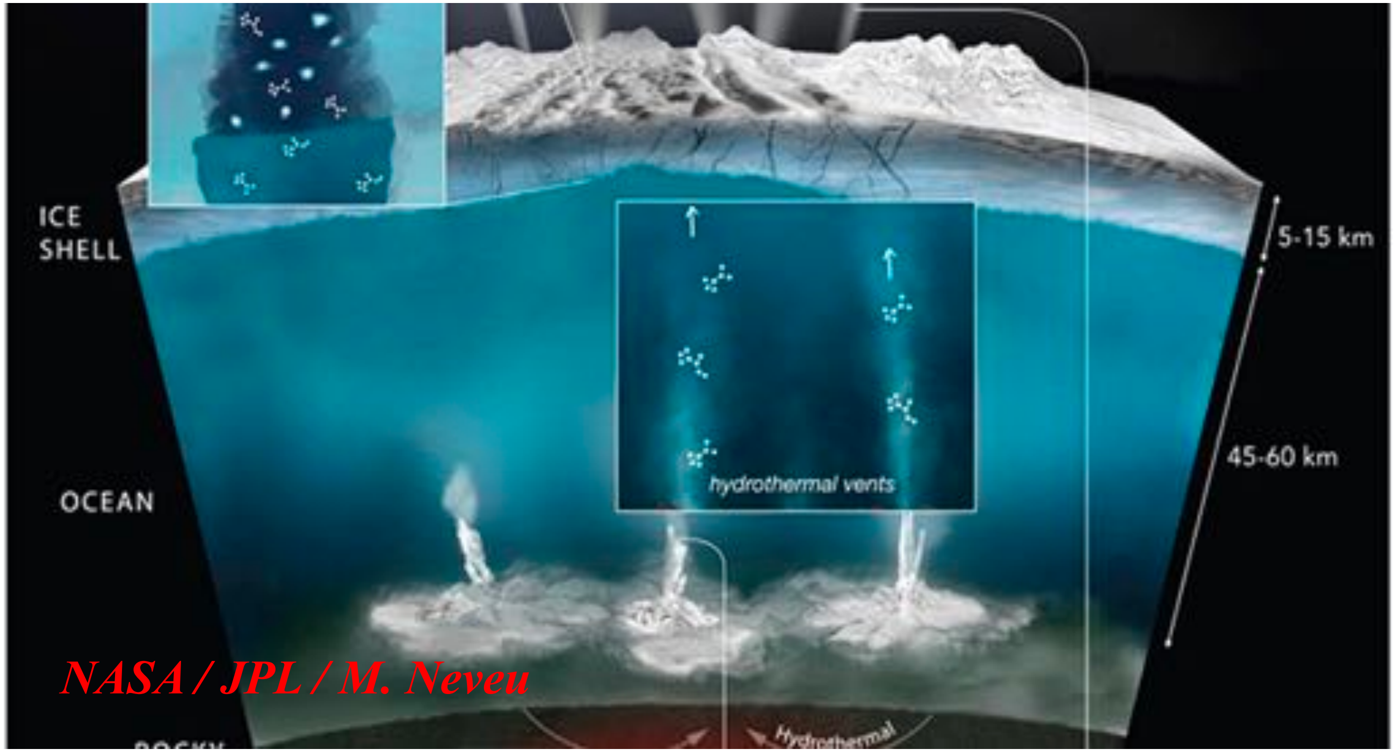
Cassini INMS: mainly water (Waite et al., 2006)

Enceladus: one of the most promising habitable zones in the solar system

heat (tidal) + liquid water + complex organics

the ocean environment in Enceladus?

- Salinity
- pH
- Redox state
- Chemical (free) energy
- Temperature



Evidences for hydrothermal processes

1. Hydrothermal circulation facilitates H_2 production by enabling more extensive water-rock interaction

(Cassini INMS; Waite et al., 2017)

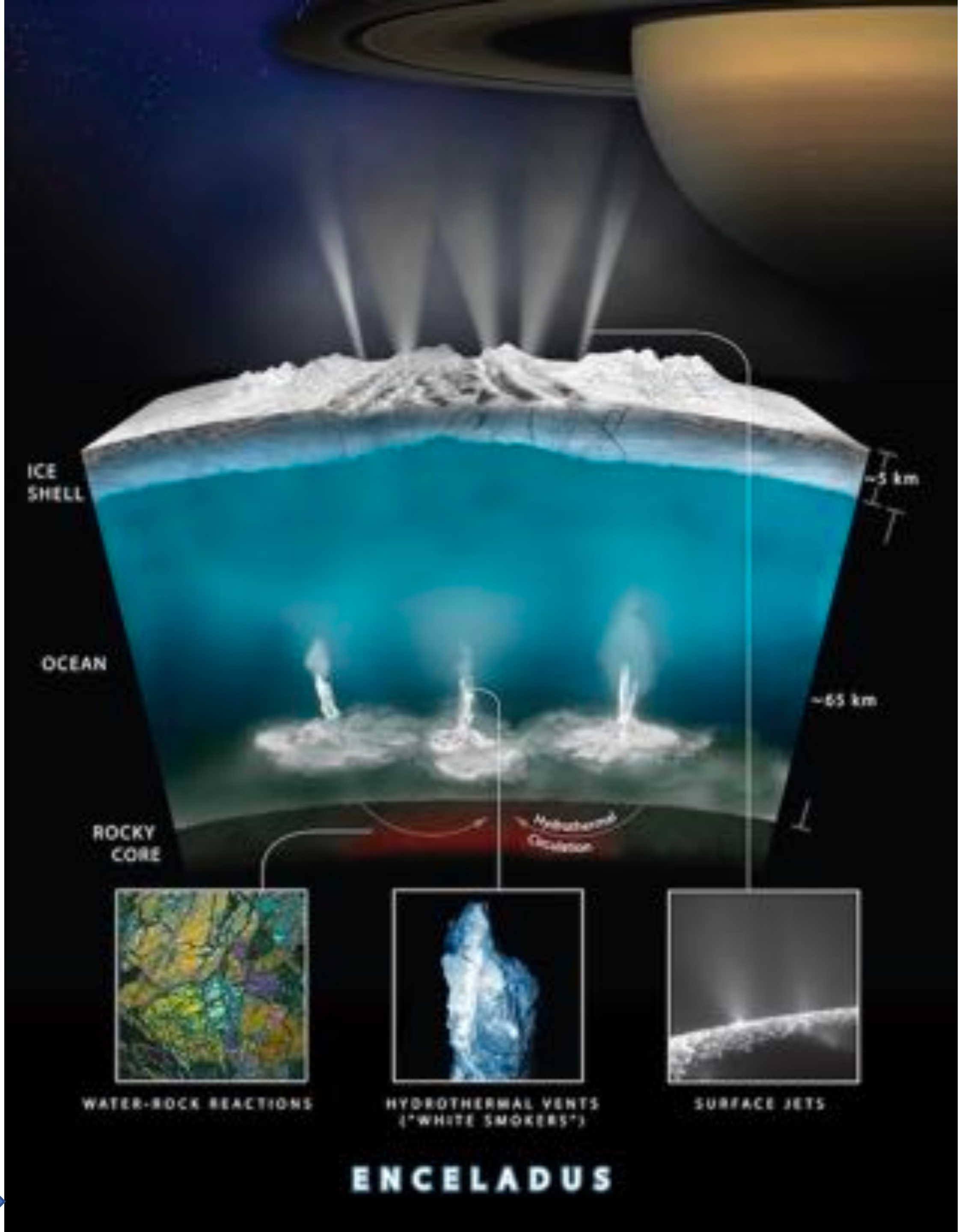
Constituent	Mixing ratio (%)
H_2O	96 to 99
CO_2	0.3 to 0.8
CH_4	0.1 to 0.3
NH_3	0.4 to 1.3
H_2	0.4 to 1.4

2. Homogeneous nucleation of nanometer-sized SiO_2 (Cassini CDA; Hsu et al., 2015)

More information about plume composition and outgassing mechanism can advance understanding of its subsurface ocean properties.

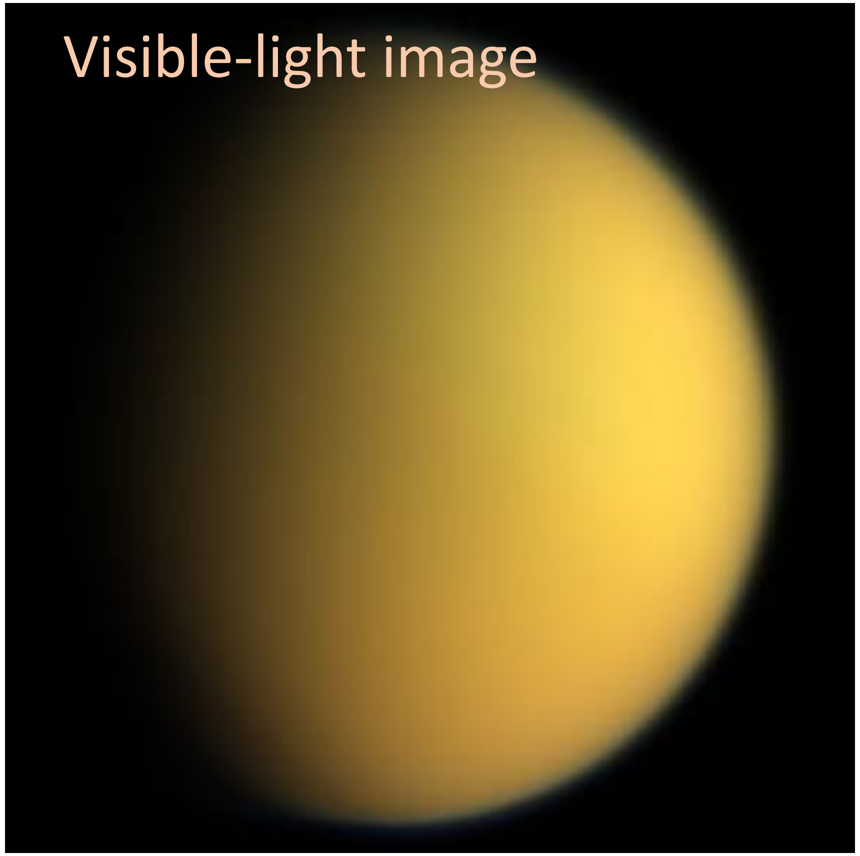
Is Enceladus unique in the solar system? Definitely NOT

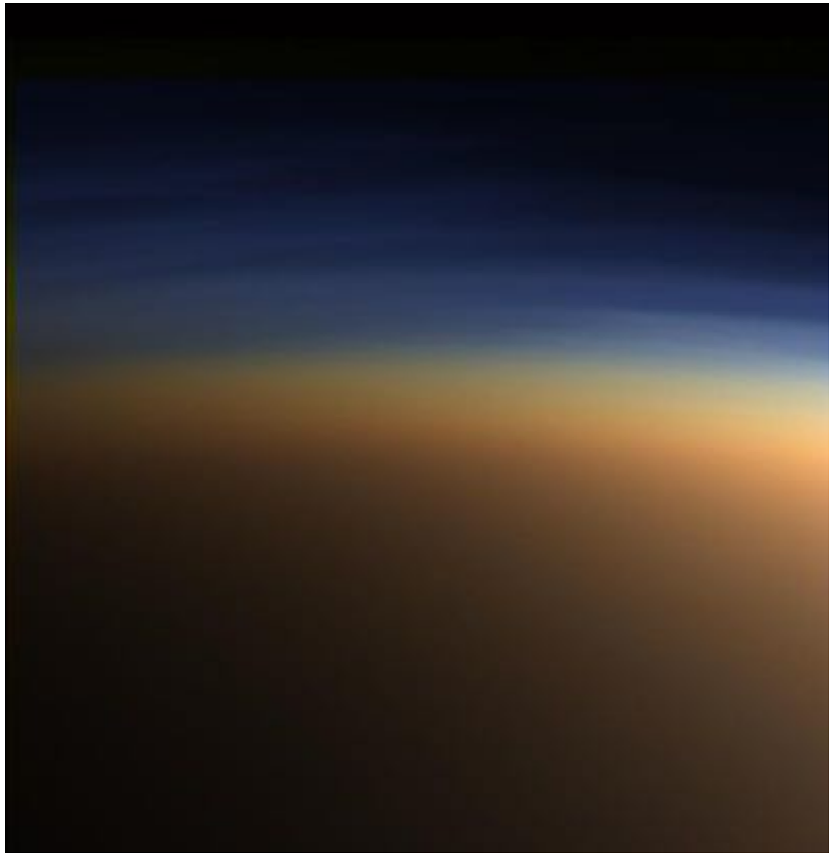
Credit: NASA-GSFC/SVS/NASA/JPL-Caltech /Southwest Research Institute



Why is **Titan** so intriguing?

Titan's atmosphere & Haze





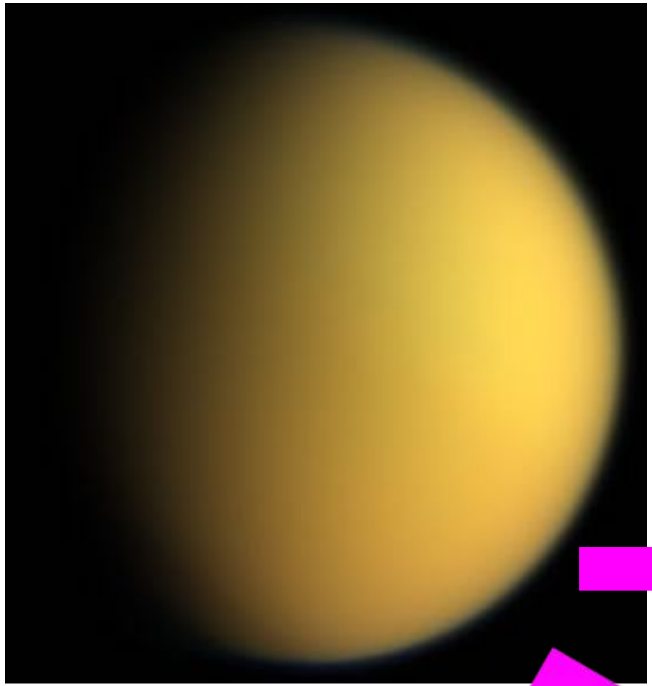
Radius: ~2,575km

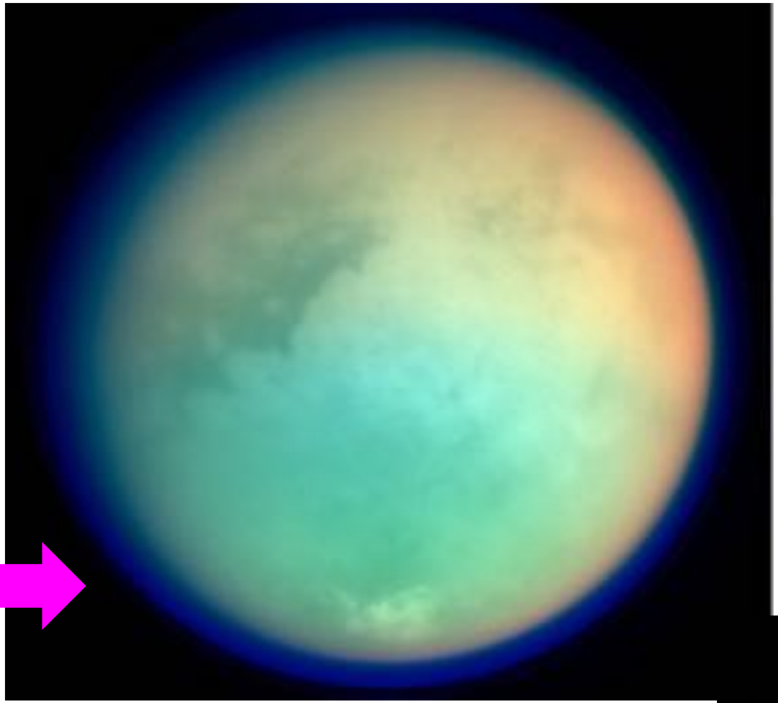
Surface Temperature: 100 K

Atmospheric pressure: ~1.5 atm at surface

Composition: N_2 (~95%), CH_4 (~4%), H_2 .... & many other organic molecules – an early Earth-like environment

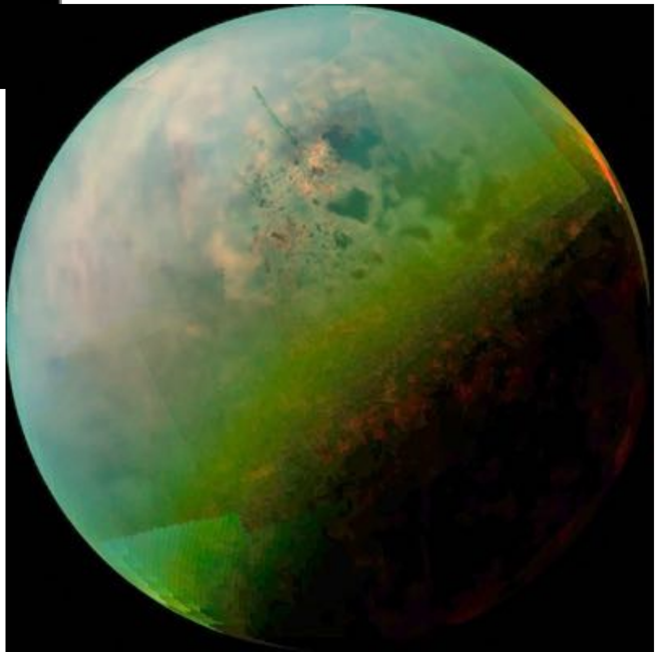
Thanks to Cassini & Huygens!



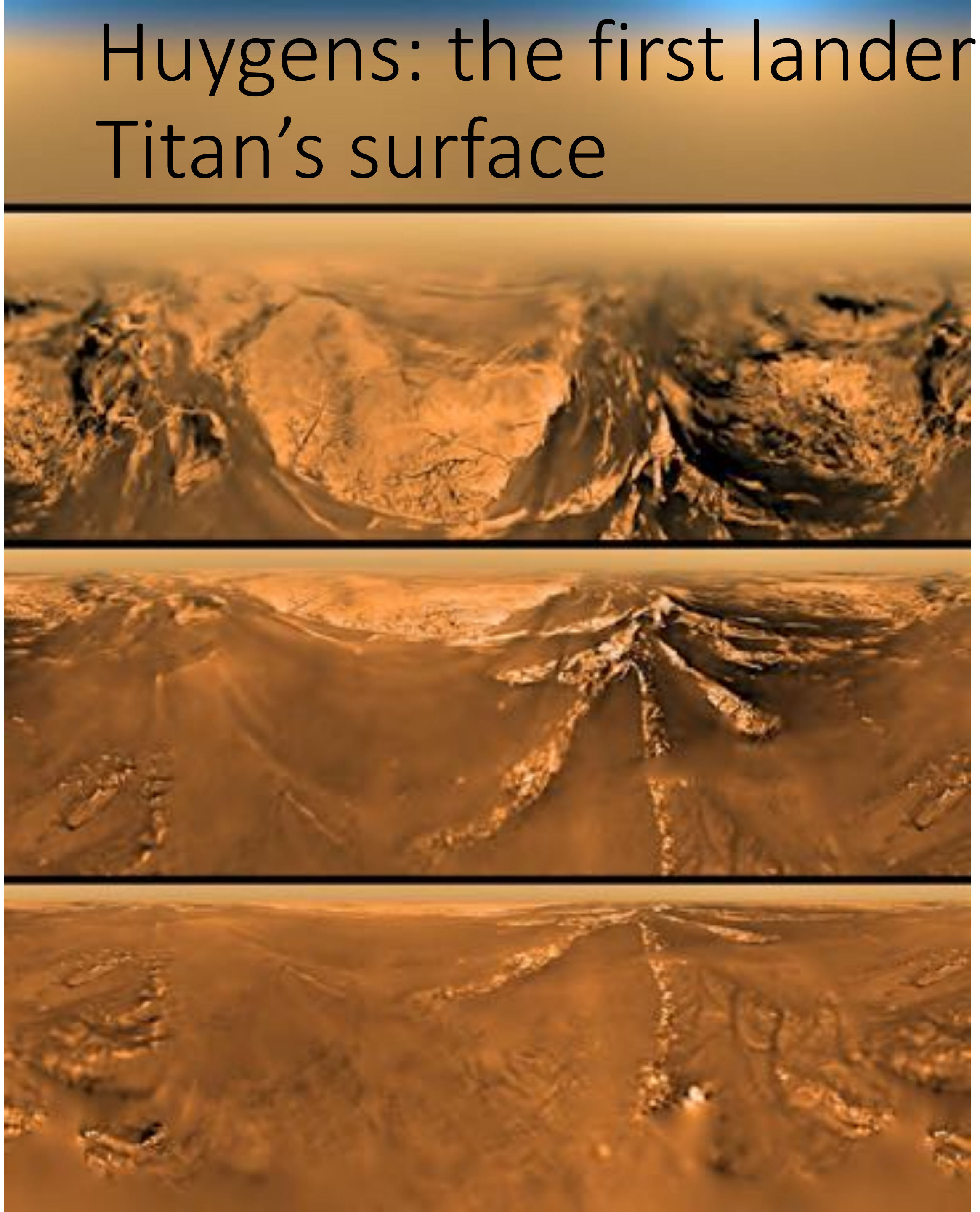


False color from CIRS/UVIS images

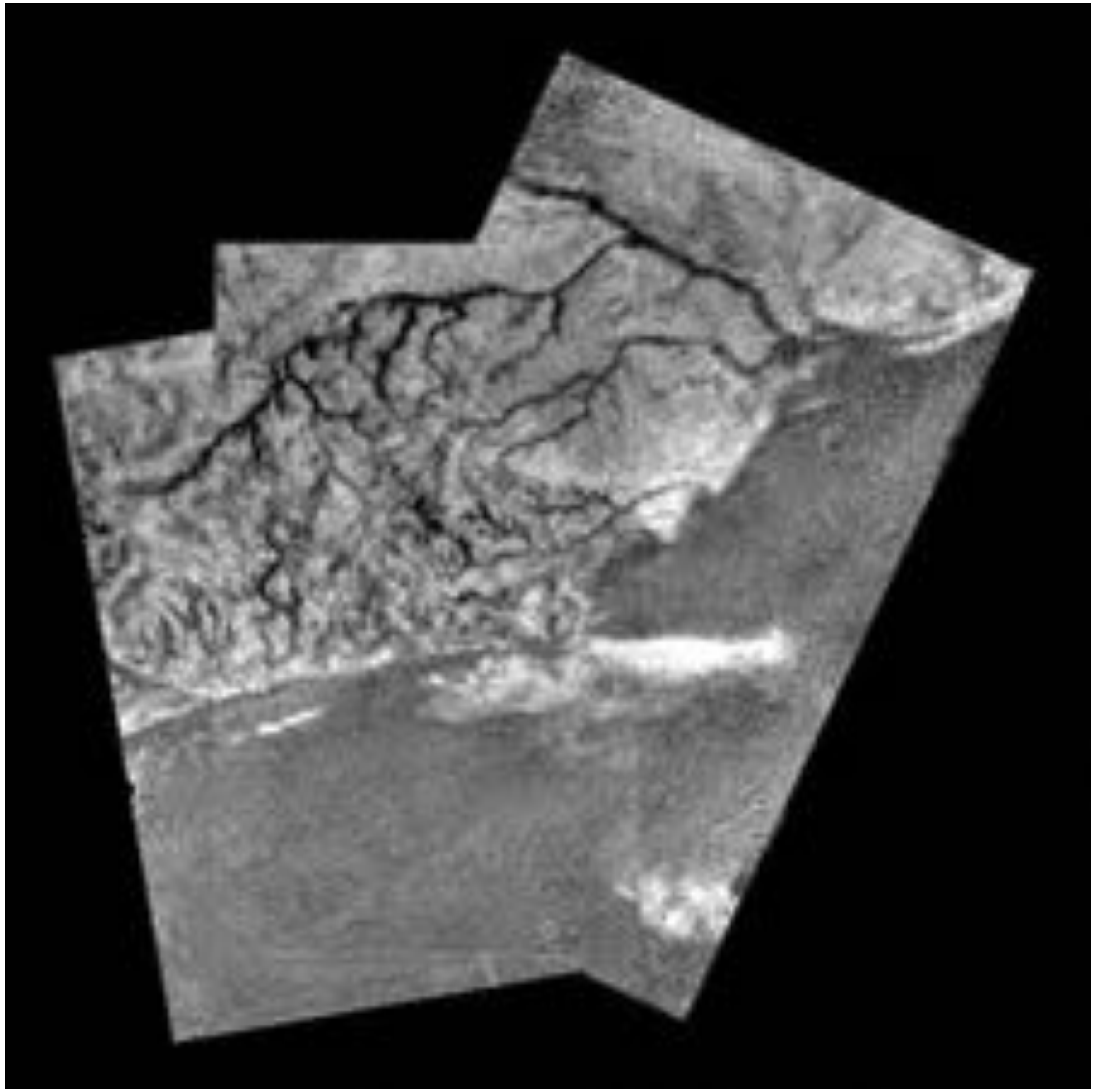
Radar image



Huygens: the first lander probing Titan’s surface

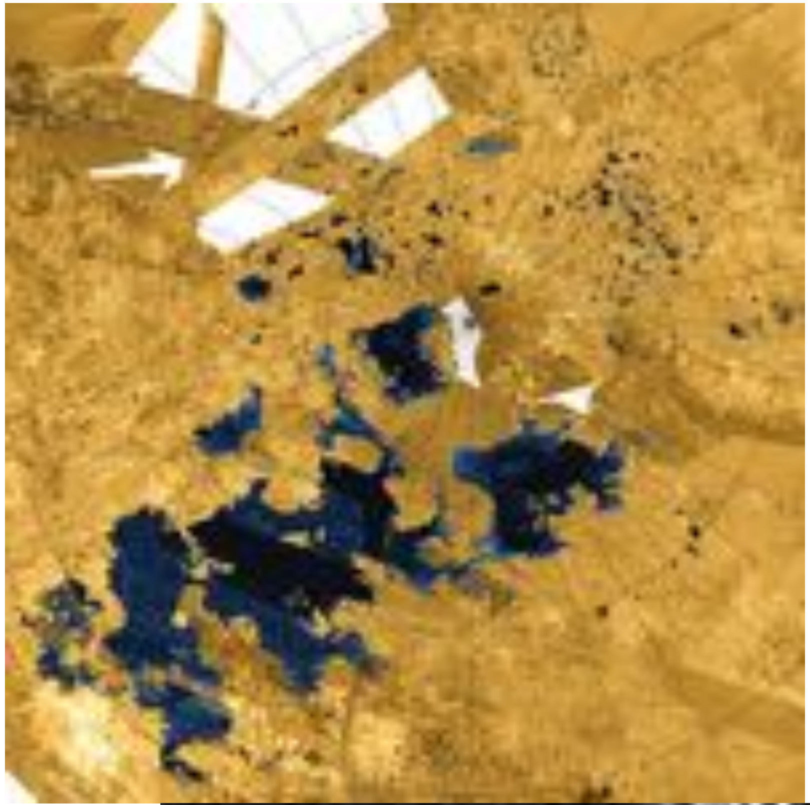


Radar images - River Channels




Dunes on Earth


Dunes on Titan



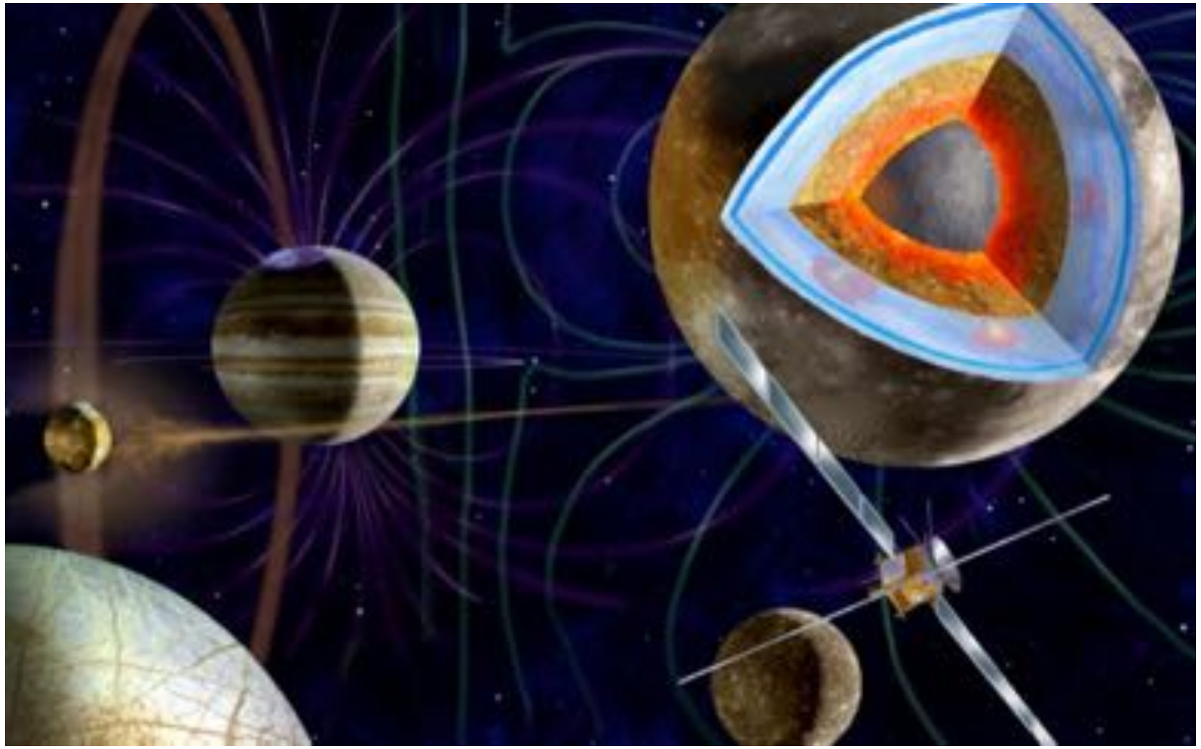
Hydrocarbon Seas on Titan

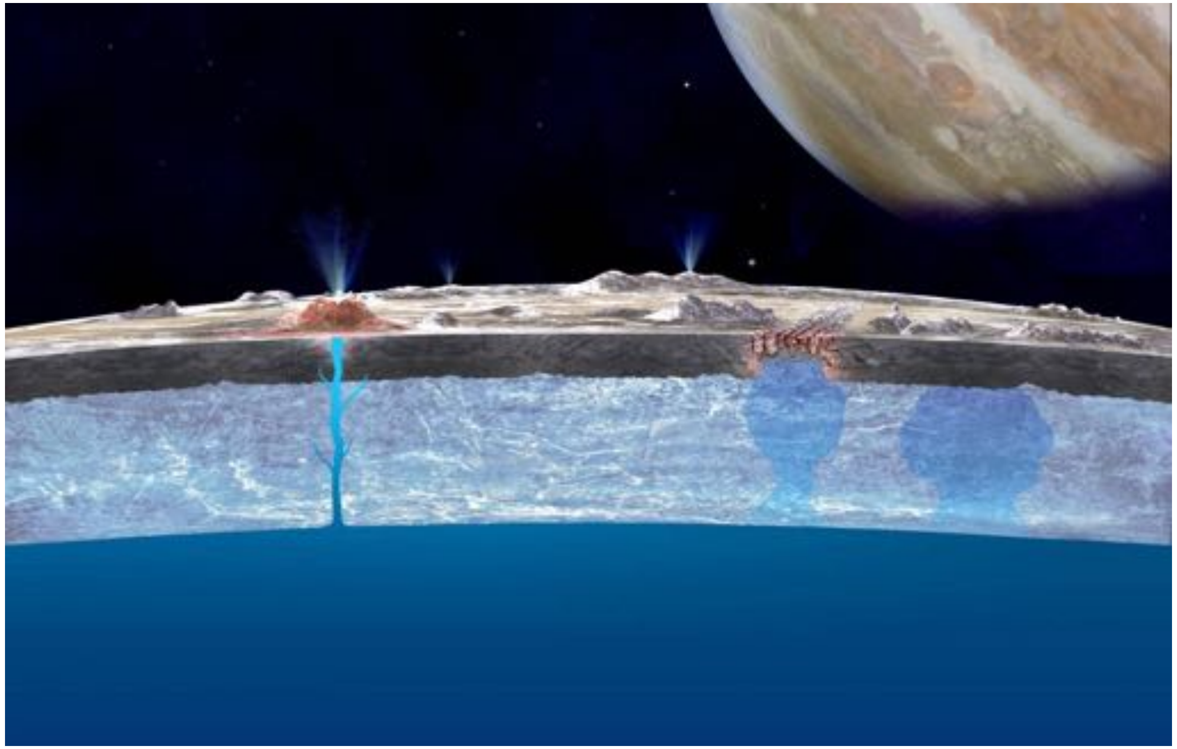
False-color *Cassini* radar image

Dark color: very low radar reflectivity caused by liquid ethane & methane

Seasonal Changes!!

Preparation for Upcoming Space Missions such as ESA JUiCE and NASA Europa Clipper





Thank you for your attention!

Contact: wltseng@ntnu.edu.tw