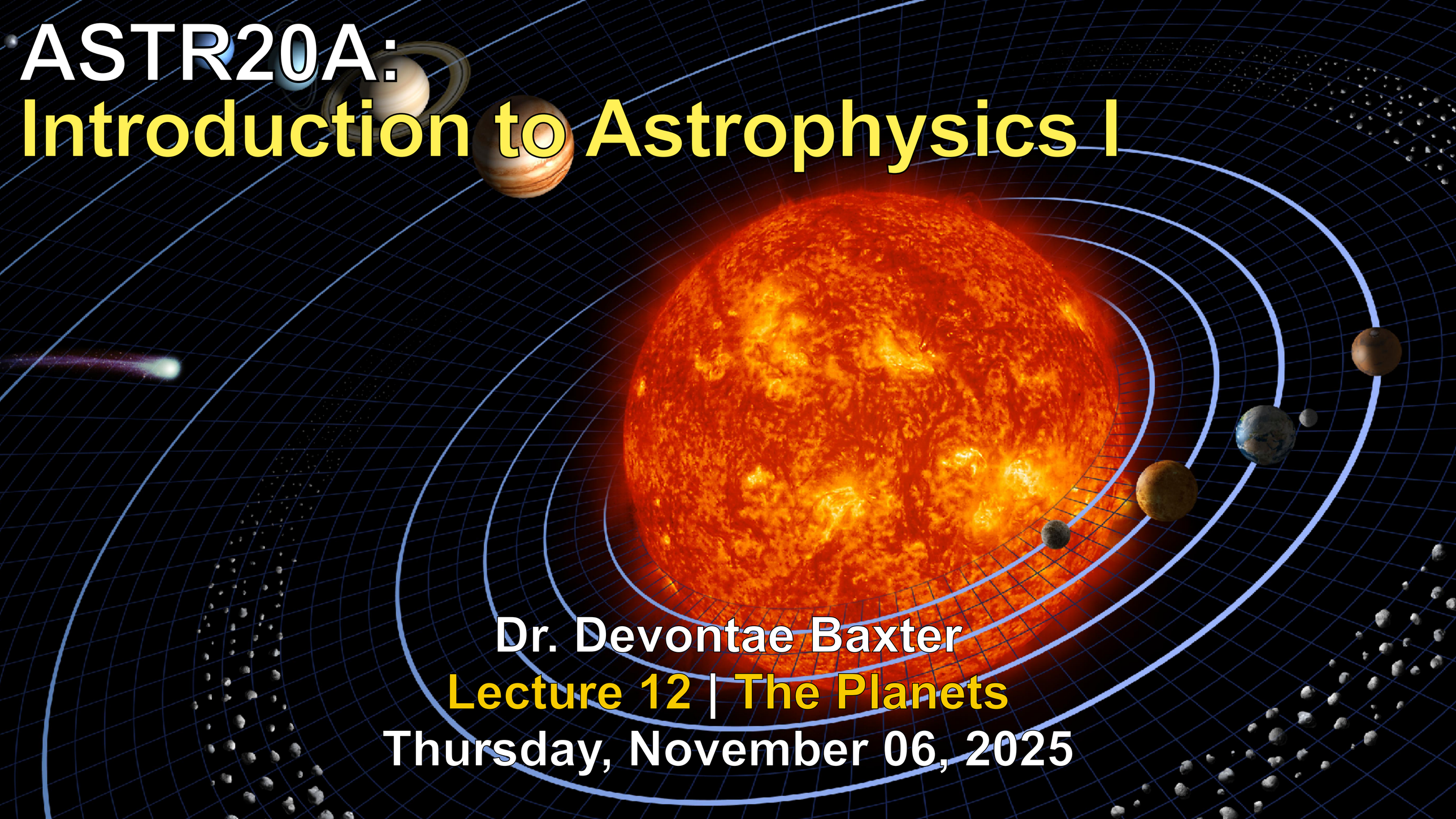
ASTR20A:
Introduction to Astrophysics I



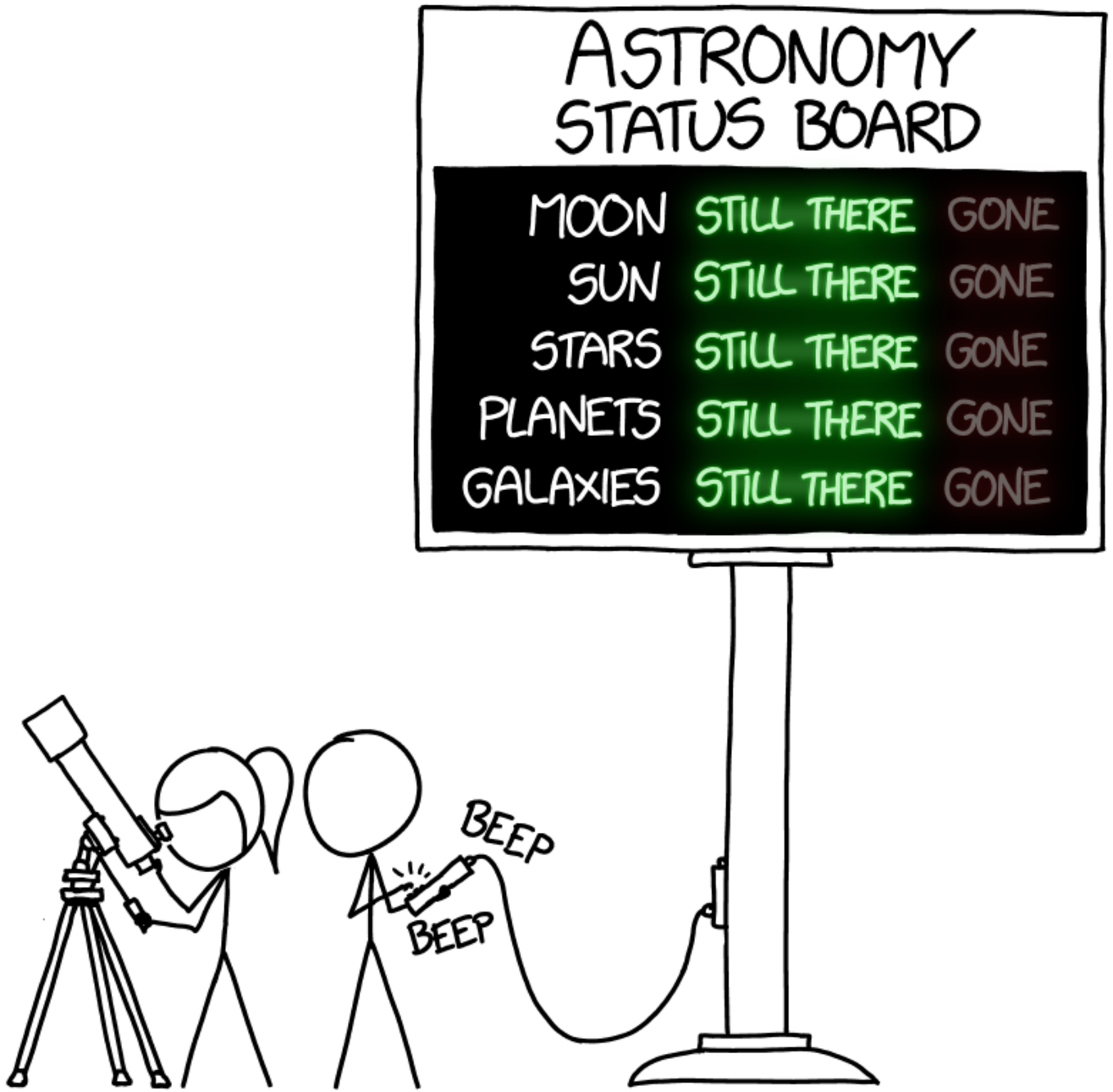
Dr. Devontae Baxter

Lecture 12 | The Planets

Thursday, November 06, 2025

Announcements

- **The last day to drop the course with a "W" is Friday, November 7th.**
- **Groups for the Coding Project have been assigned!**
  - **Visit "People" tab on Canvas to find your group.**
- Midterm Exam II will take place on **Thursday, 11/13 from 2:00-3:10pm**
  - **Study guide will be uploaded to Canvas by Friday.**
- **Coding assignment #4 due Sunday, 11/16 by 11:59 pm via Gradescope.**
- **No HW next week!**
  - **HW #6 will be due Tuesday, 11/18 by 11:59 pm.**




Questions?

Learning Objectives

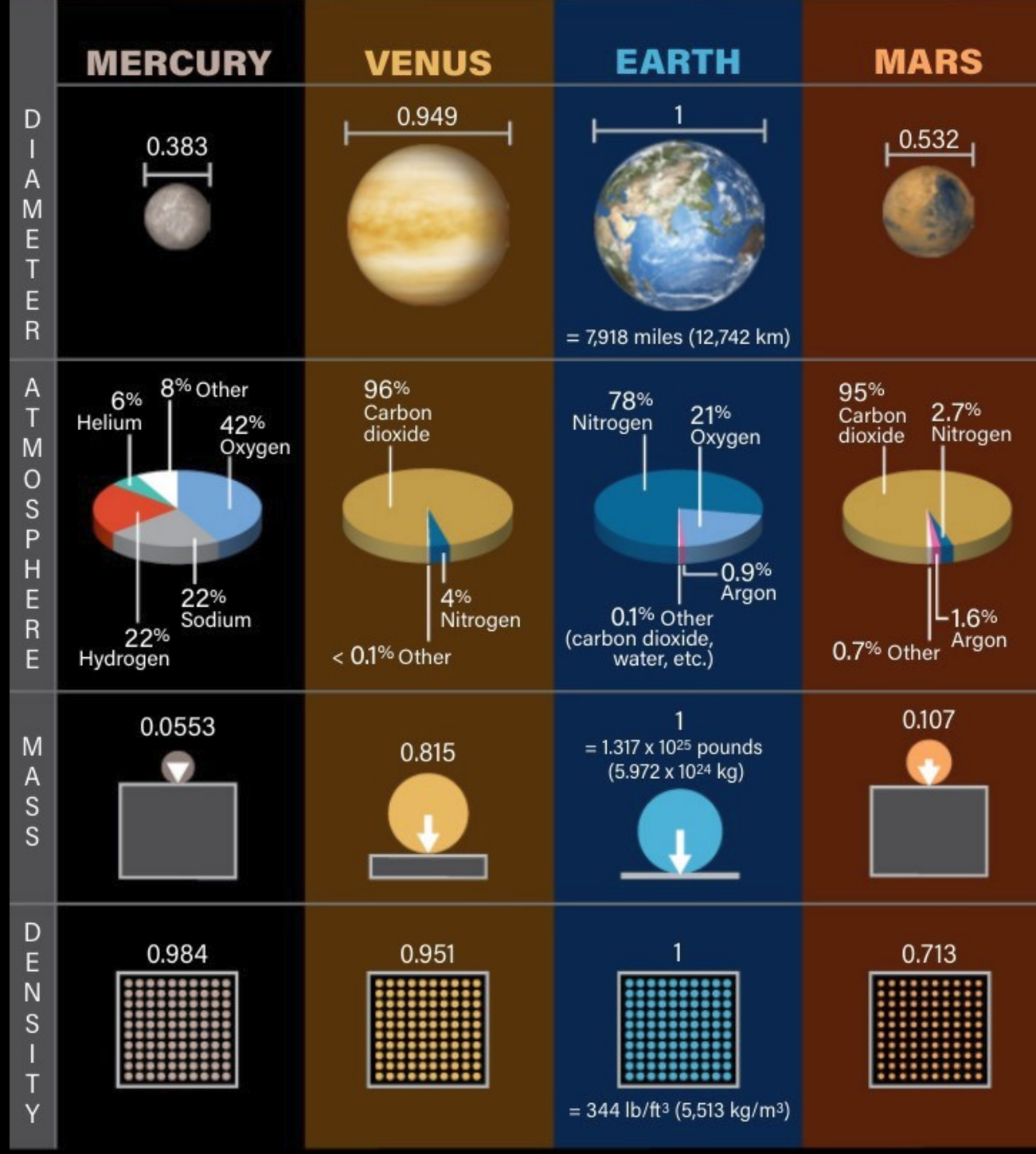
By the end of today's lecture you will be able to:

- Describe the properties **of terrestrial planets.**
- Explain the similarities and differences between the terrestrial planets.
- Describe the properties of the **jovian planets**.
- Understand the similarities and differences among the jovian planets.

What are some fun facts that you already know about the planets in our Solar System?

Terrestrial Planets

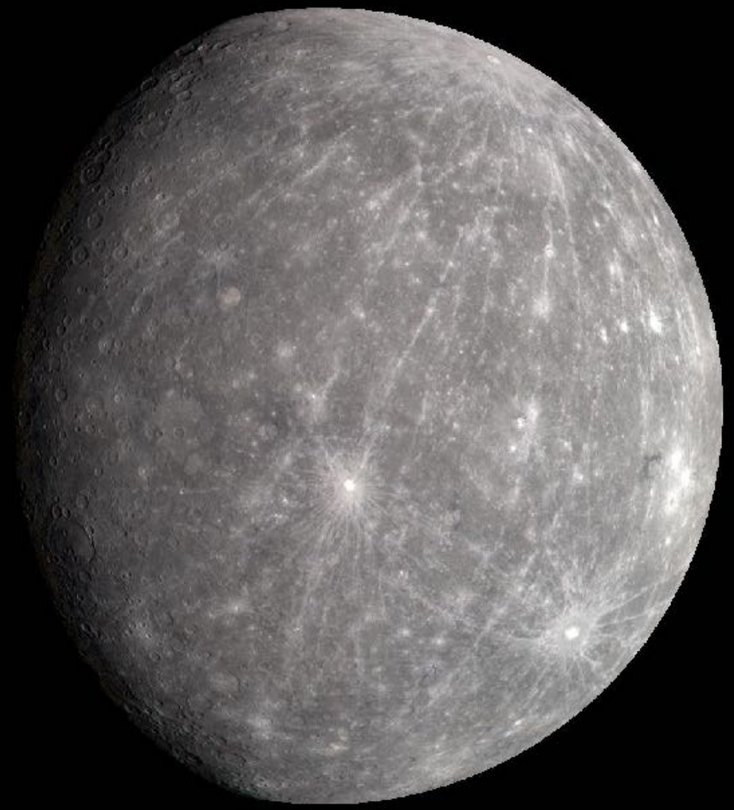
- Four innermost planets to the Sun.
- Relatively high densities.
- Orbit out to ~ 1.5 AU (the snow line for the young Sun was at ~3AU)



Mercury

The Smallest and Most Eccentric World in the Solar System

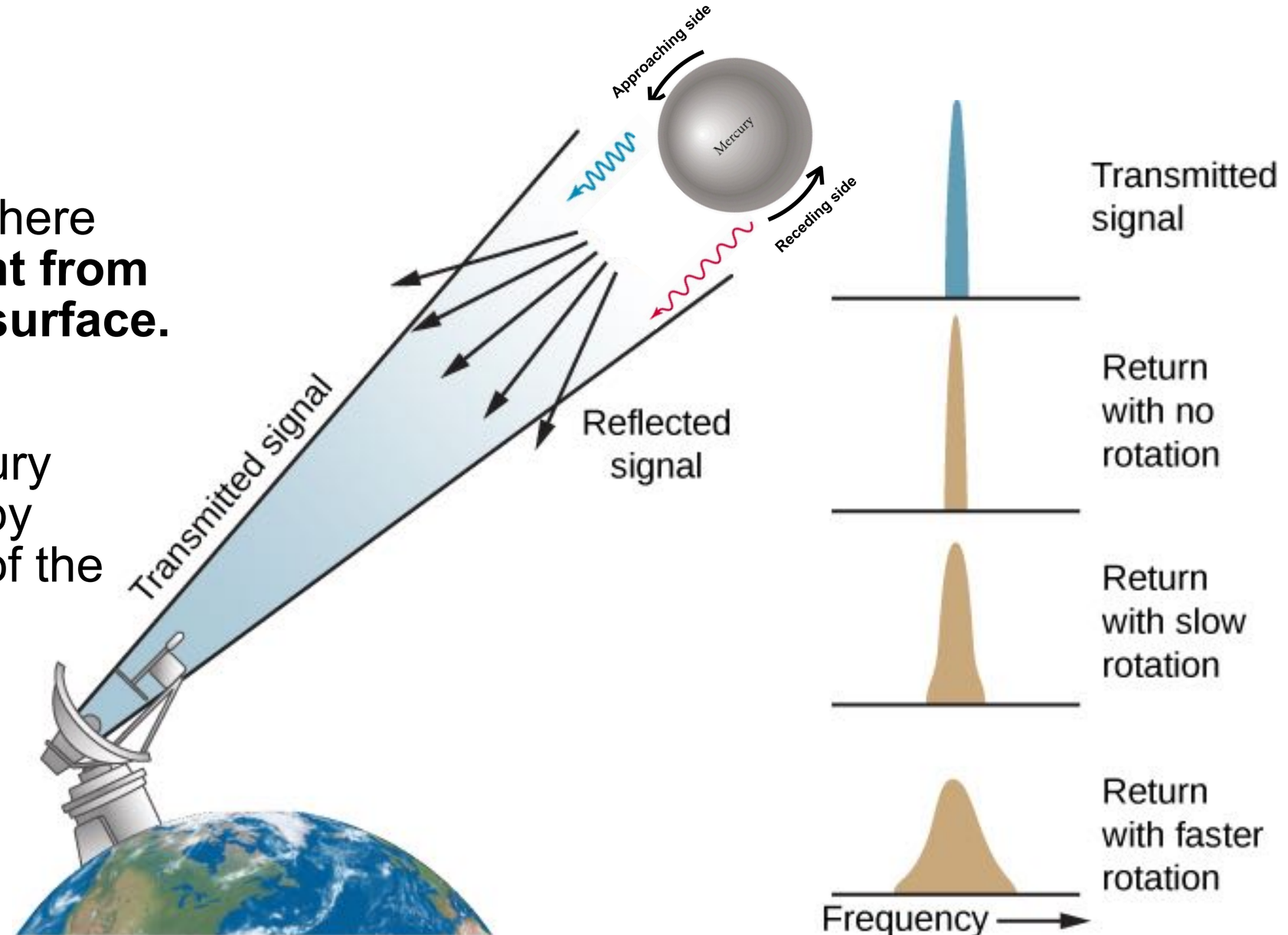
- Mercury has no permanent atmosphere.
- It has a weak magnetic field (1% of the Earth's).
- Due to its proximity to the Sun ($\theta_{\max} \leq 30^{\circ}$), it is difficult to directly observe from Earth except during dawn or twilight.
- Locked to the Sun in a *3:2 spin-orbit resonance* — i.e., rotates three times every two Mercurian years.
  - As such, it **takes 176 Earth days to complete a solar day!**



Mercury’s Rotational Period

- Mercury’s lack of an atmosphere **allows for radio waves sent from Earth to bounce off of its surface.**

- The rotation speed of Mercury was deduced in the 1960s by measuring the broadening of the reflected signal due to the rotation of the planet.



Mercury's Orbit & Rotation

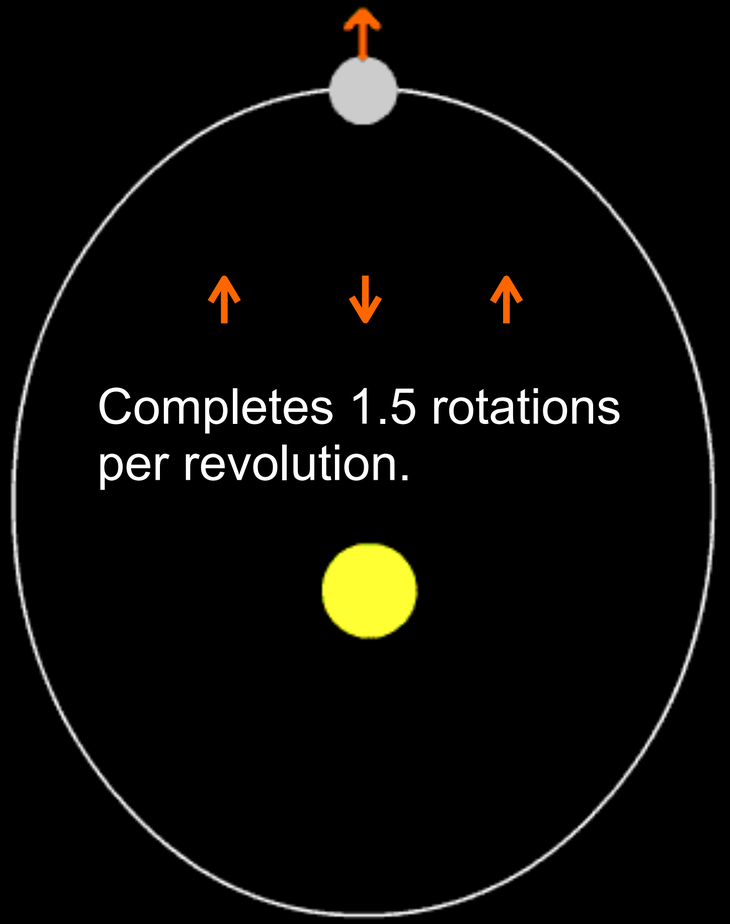
Using this technique, we found the rotational period of Mercury to be $P_{\text{rot}} = 58.65 \text{ days}$.

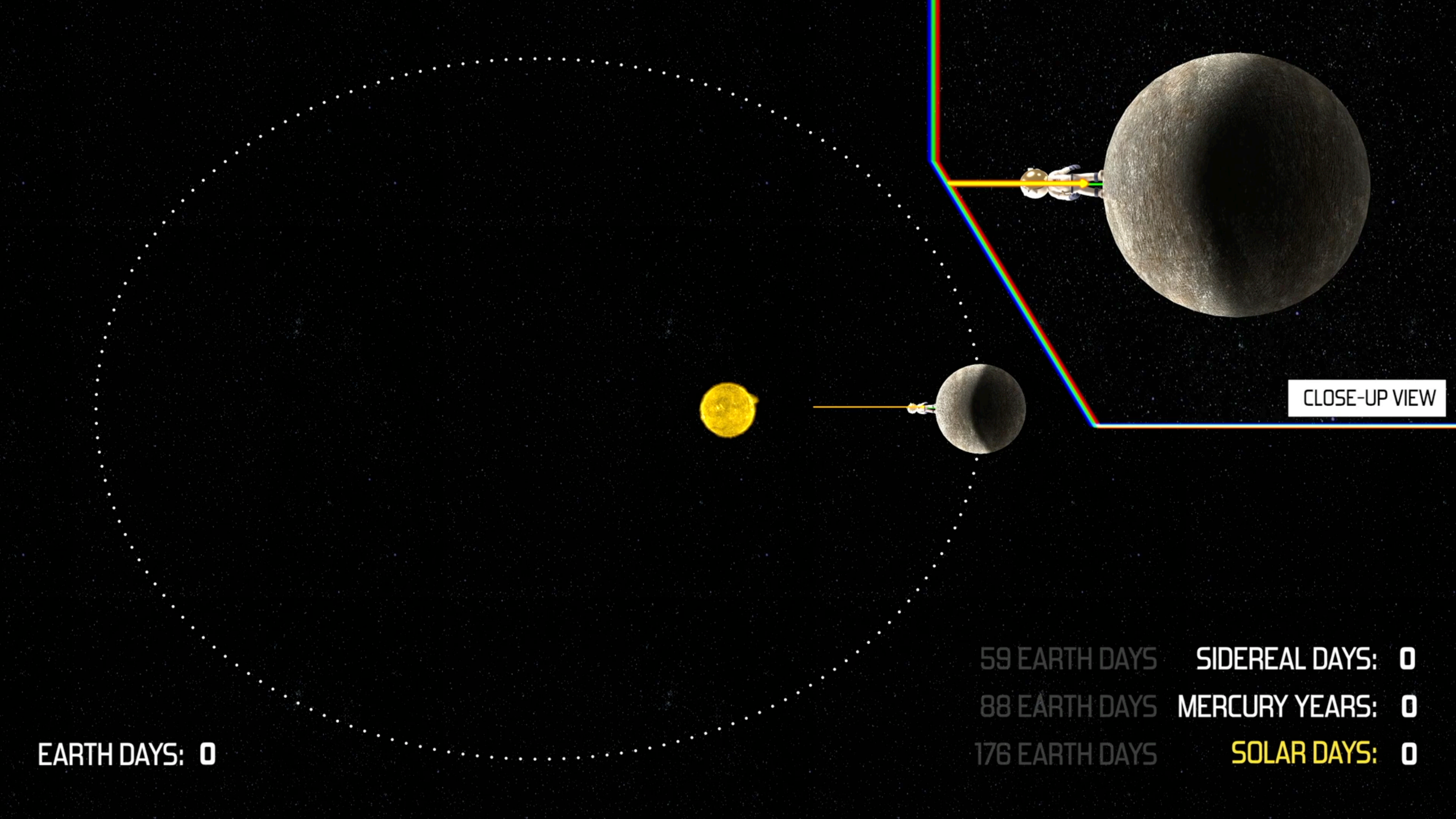
Using Kepler's 3rd Law, we find that the orbital period is $P_{\text{orb}} = 87.97 \text{ days}$.

The ratio of these periods is therefore,

$$\frac{P_{\text{orb}}}{P_{\text{rot}}} = \frac{87.97}{58.65} = \frac{3}{2}$$

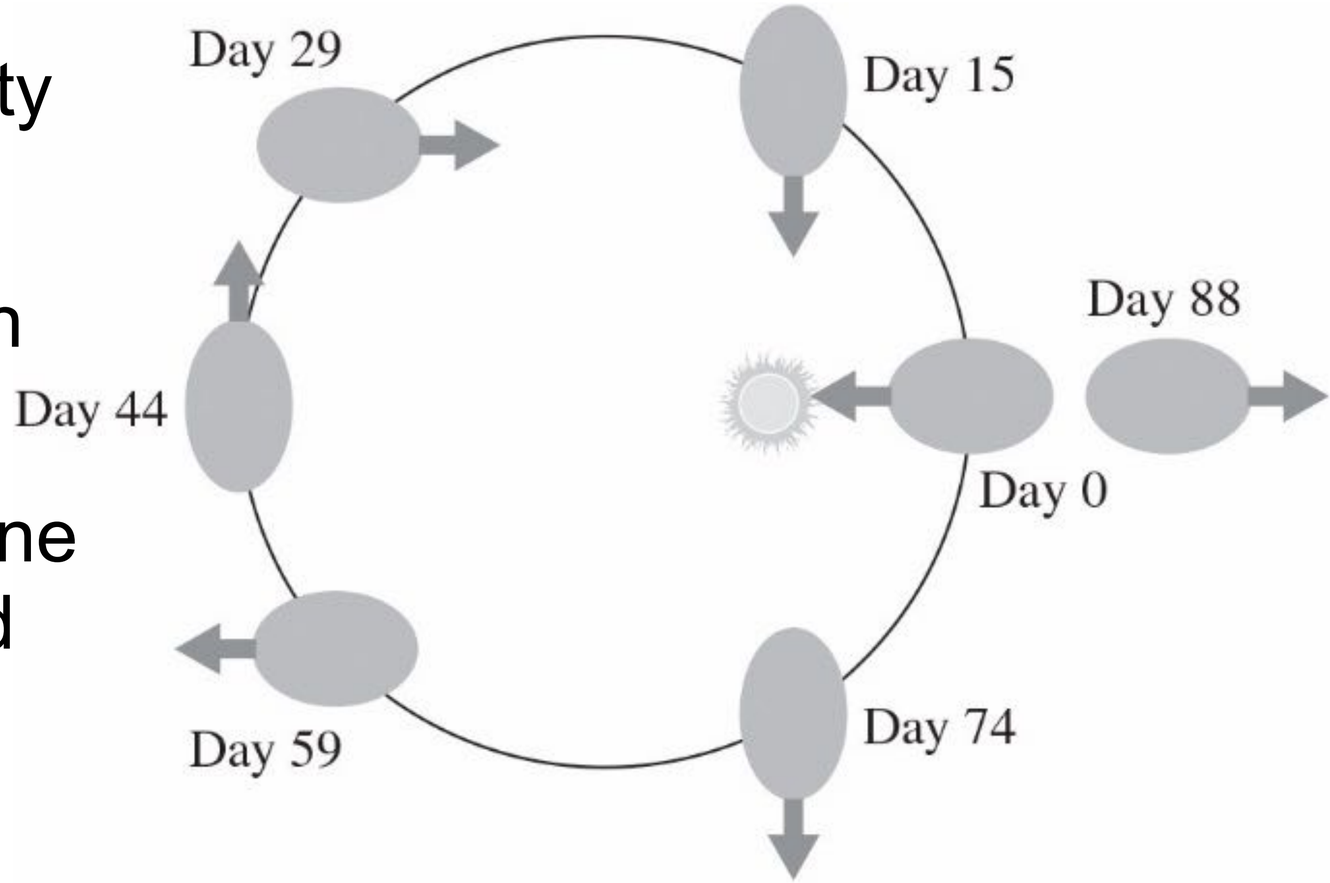
We call this a **commensurate period**, where the ratio of is close to the ratio of two small integers.




CLOSE-UP VIEW
EARTH DAYS: 0
59 EARTH DAYS
88 EARTH DAYS
176 EARTH DAYS
SIDEREAL DAYS: 0
MERCURY YEARS: 0
SOLAR DAYS: 0

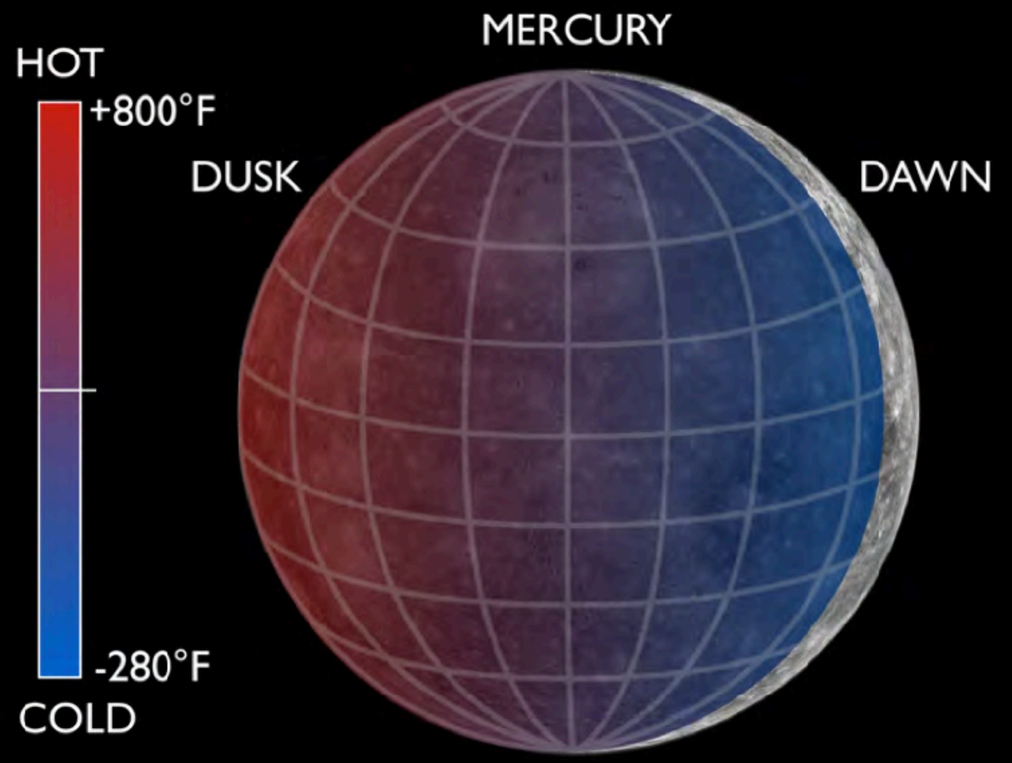
Mercury's Orbit & Rotation

- Mercury has the highest eccentricity of any planet, $e = 0.21$
- It also has two tidal bulges on each side (not spherical).
- At closest approach (perihelion), one of the two bulges is always pointed towards the Sun — hence the 3:2 ratio



Mercury's Day & Night Temperature

- **Mercury has no permanent atmosphere!**
- This results in an extreme temperature difference between the night and day side.
- Temperature range from 100 K (-280 °F) to 700 K (800 °F).
  - This is colder than "Snowball Earth"* and hotter than the melting point of lead*!



*Snowball Earth was 220 K.

*The melting point of lead is 600.3 K

Mercury's Surface

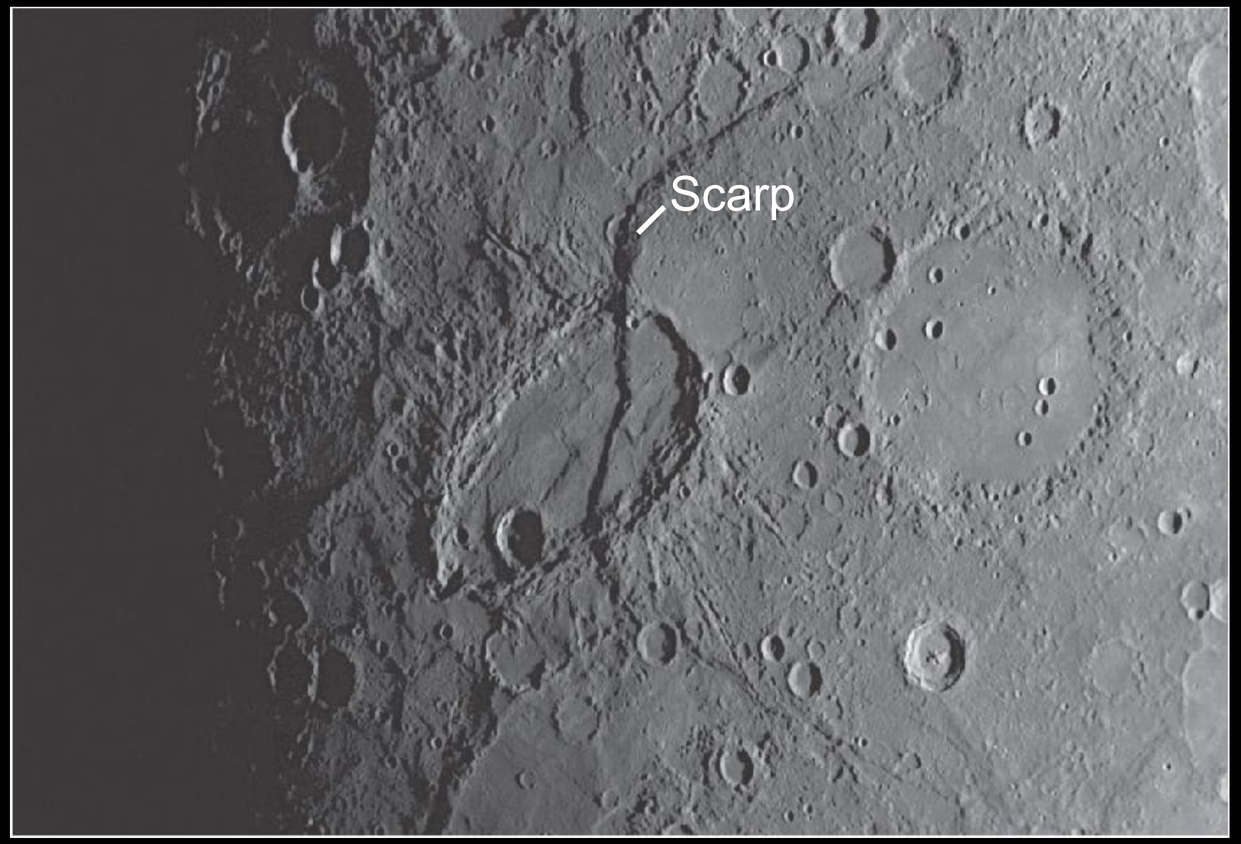
- The relatively low level of cratering indicate the solid surface didn't form until the end of the heavy bombardment era (~3.5 Gyr ago)

- Mercury has linear features called **scarps** that are long linear features.

- These are actually cliffs that range in height from 2-100 km!

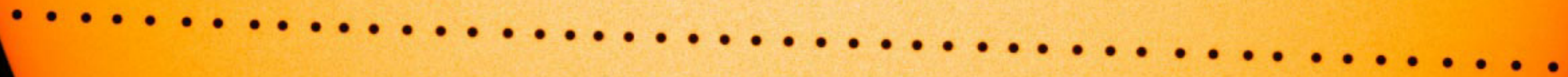
  - For reference, Mt. Everest is only 9 km above sea level.

- They are a result of the planet shrinking as its core cools.



Transit of Mercury

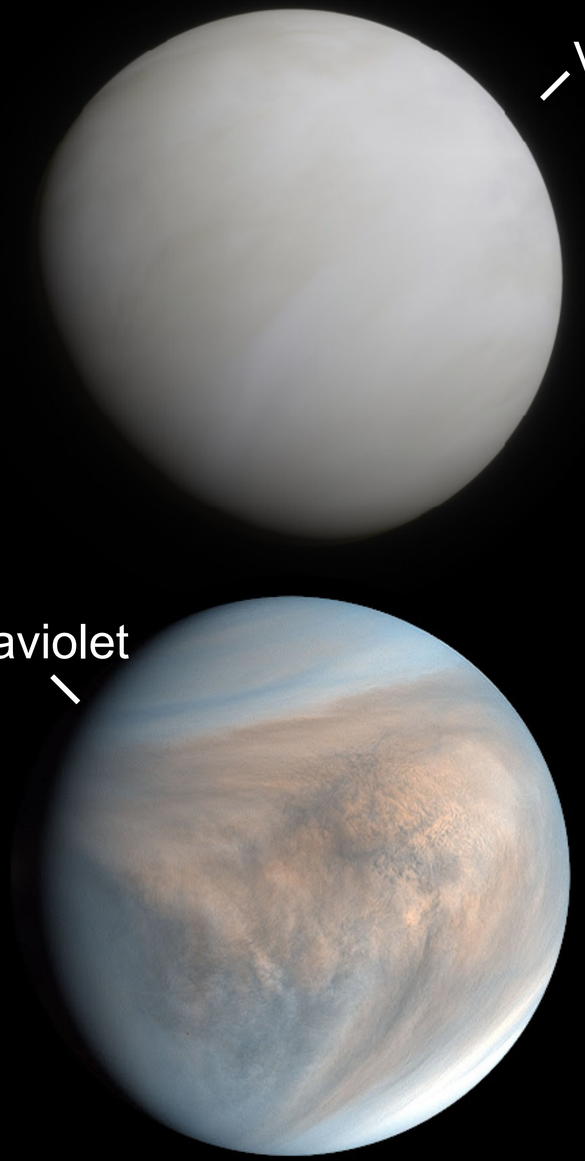
Mercury **transits the Sun more frequently than any other planet**, occurring about 13 times per century.



Next transit will take place in **seven years on November 13, 2032.**

Venus

- Slowest rotating planet ($P_{\mathrm{rot}} = 243$ days).
  - Also measure using radio waves.
- It's also rotates backwards (retrograde)!
- In the optical we can only see the thick cloud deck (top), made of sulfuric acid!
- No detectable magnetic field (maybe linked to slow rotation)
- High surface temperature (740 K), primarily due to the runaway greenhouse caused by CO_2



Why isn't Earth so hot?

Water is an incredible heat sink. CO_2 dissolves in water and create byproducts, namely bicarbonate ions

$$CO_2 + H_2O \rightleftharpoons H^+ + HCO_3^-. \qquad (10.11)$$

The bicarbonate ions combine readily with any calcium ions dissolved in the water:

$$Ca^{2+} + 2\,HCO_3^- \rightleftharpoons CO_2 + H_2O + CaCO_3. \qquad (10.12)$$

Calcium bicarbonate ($CaCO_3$) *precipitates* out to the ocean floor and **creates limestone.**

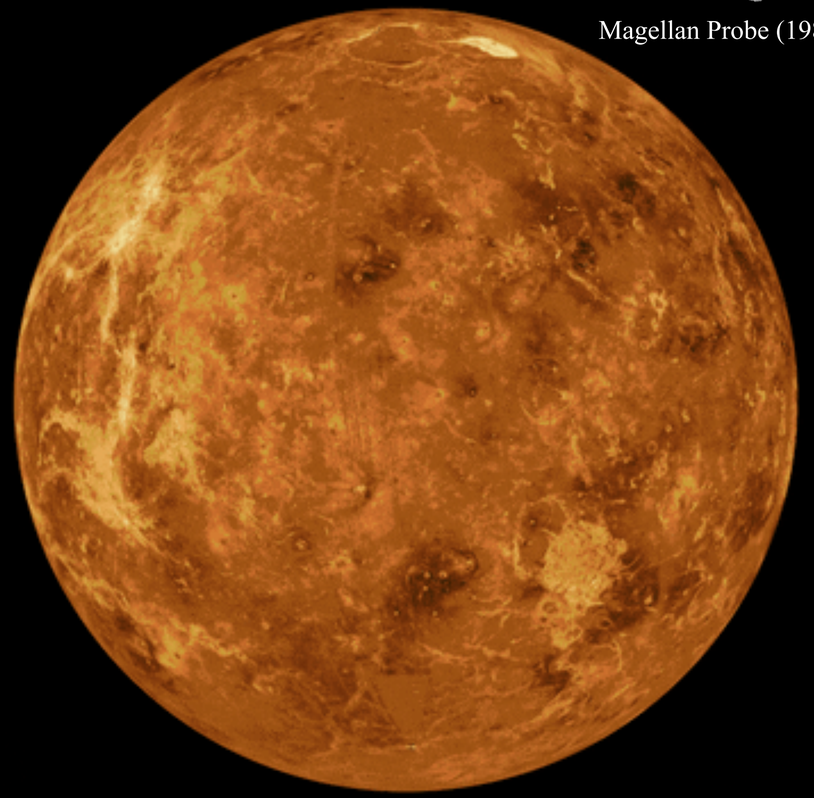
Venus doesn't have liquid water, **so it can't lock up CO_2 in rocks like Earth.**

Below the clouds

Magellan Probe (1989-1994)

We can probe below the clouds using radio waves (radar).

- We find volcanoes, highland regions, and low, rolling plains.
- The volcanoes constantly change the surface, resulting in few impact craters observed.



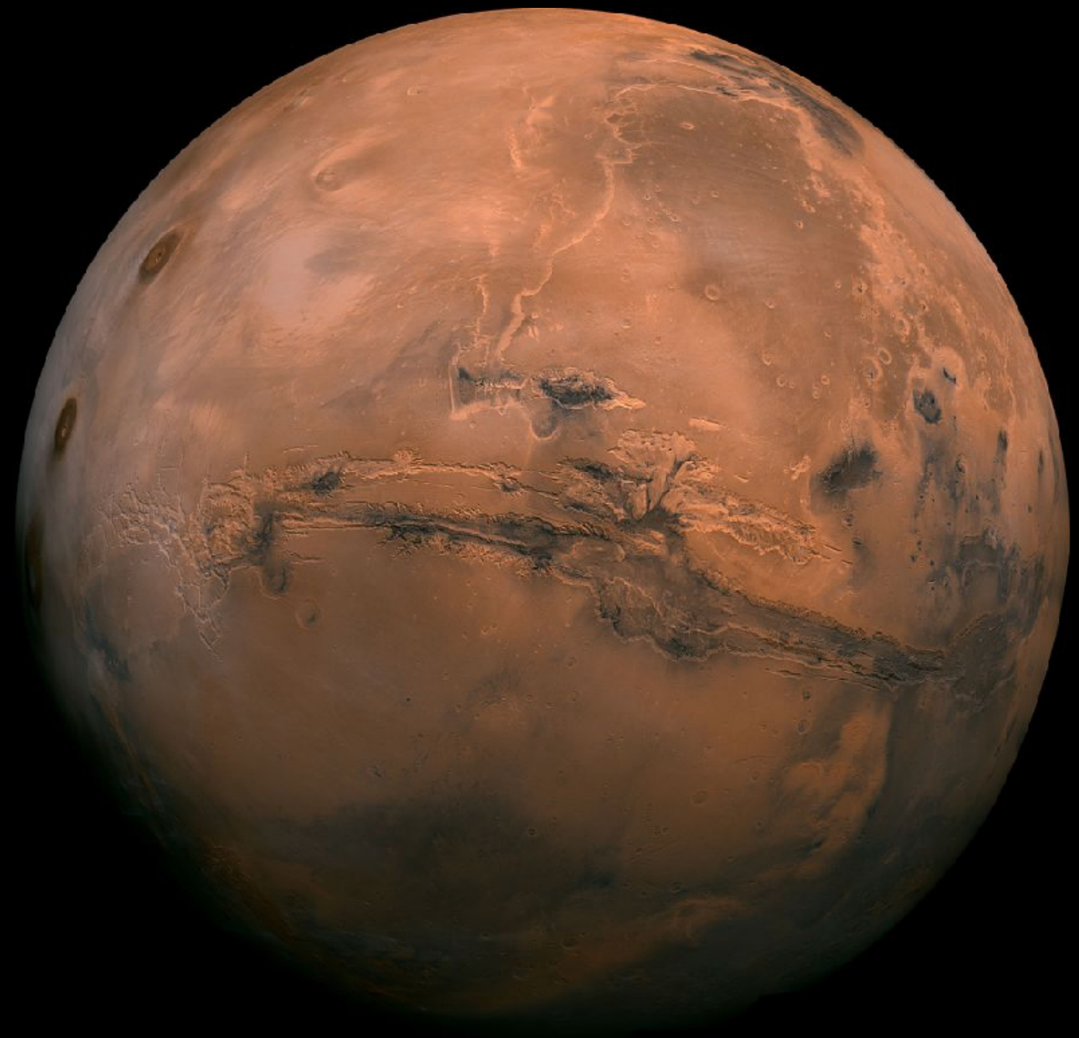
There are no observed plate tectonics, causing the *lithosphere* to be stationary relative to the interior of the planet


Questions?

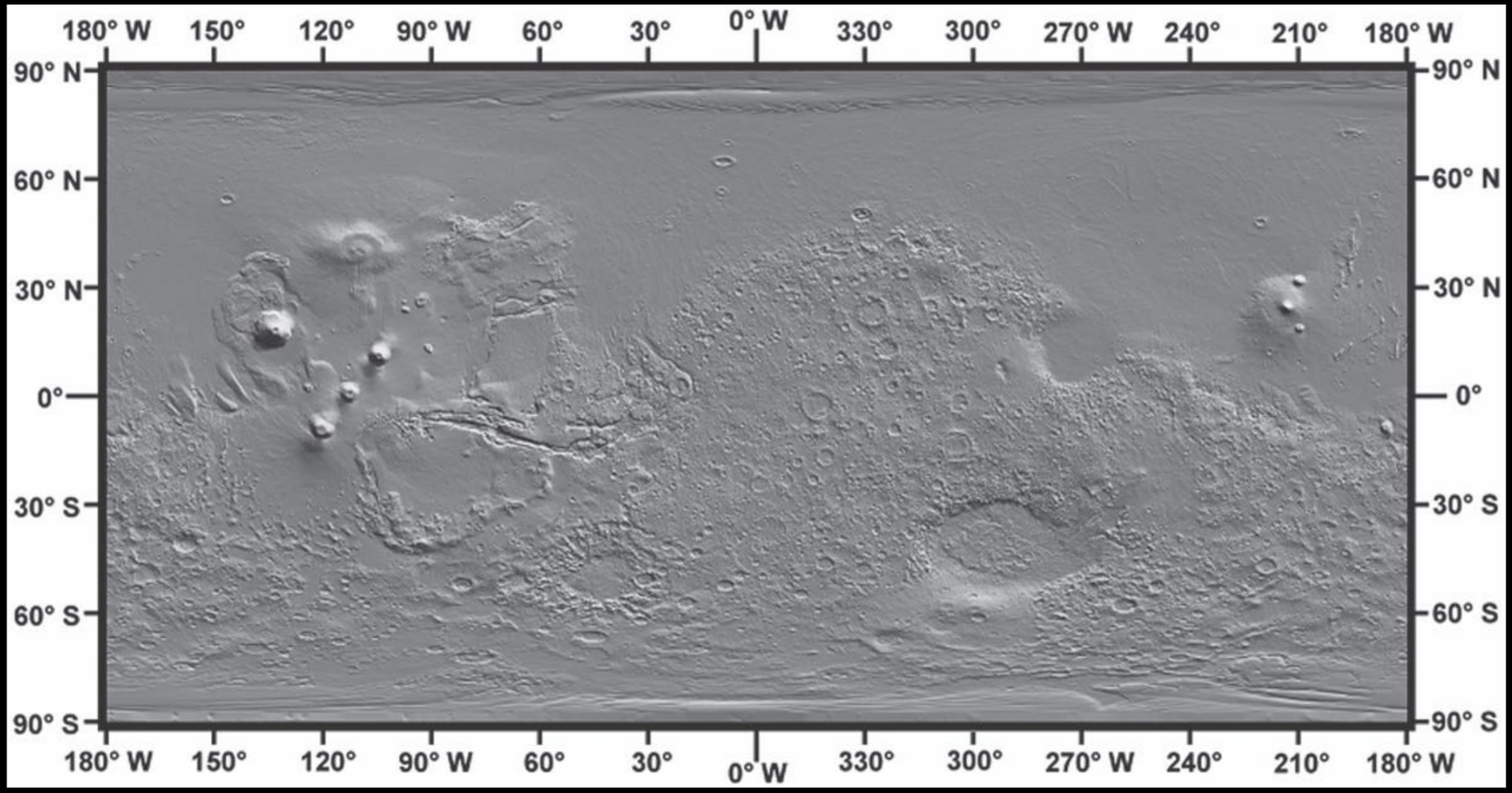
Mars

The Rustiest World in the Solar System

- The farthest terrestrial planet from the Sun (coldest)
- Equator is tilted 25 degrees w.r.t. its orbital plane
- Atmosphere is 95% CO_2
- No ozone, so all the surface water was dissociated by UV light
- Thin clouds made up of CO_2 and H_2O ice crystals.



Mars – North vs. South

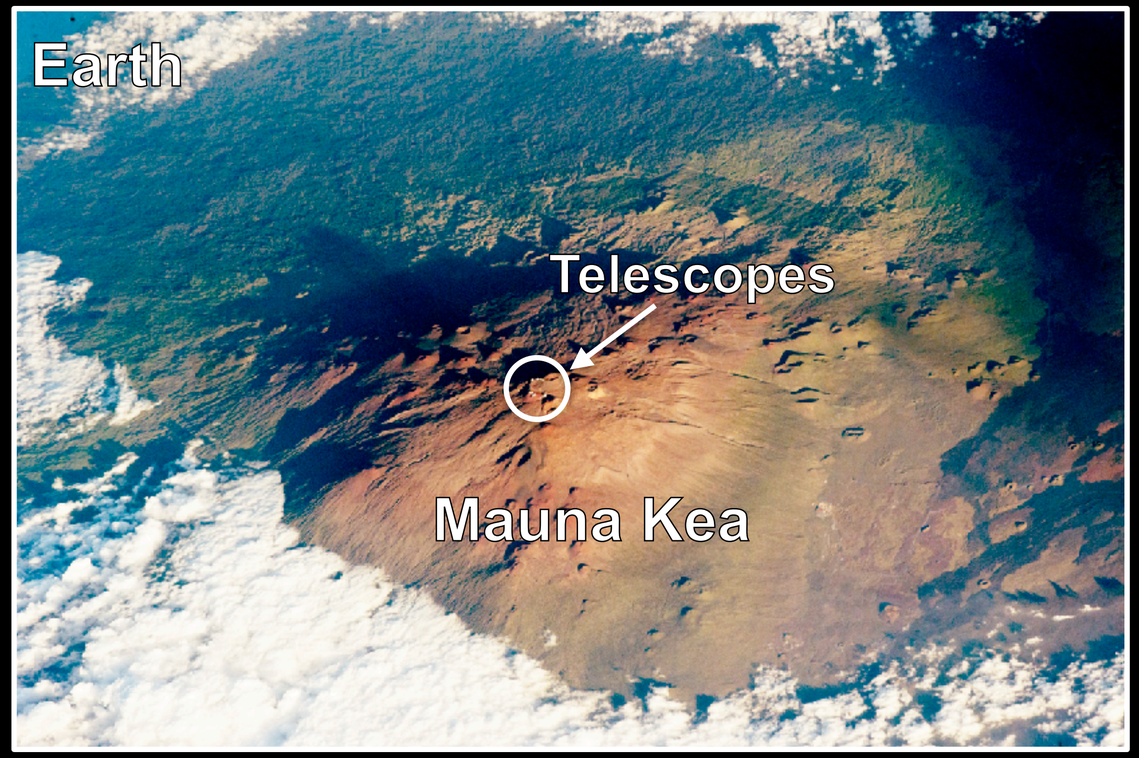


North: Few craters, signs of recent volcanic activity

South: High elevations and a lot of craters, geographically dead

Mars – Highest Highs

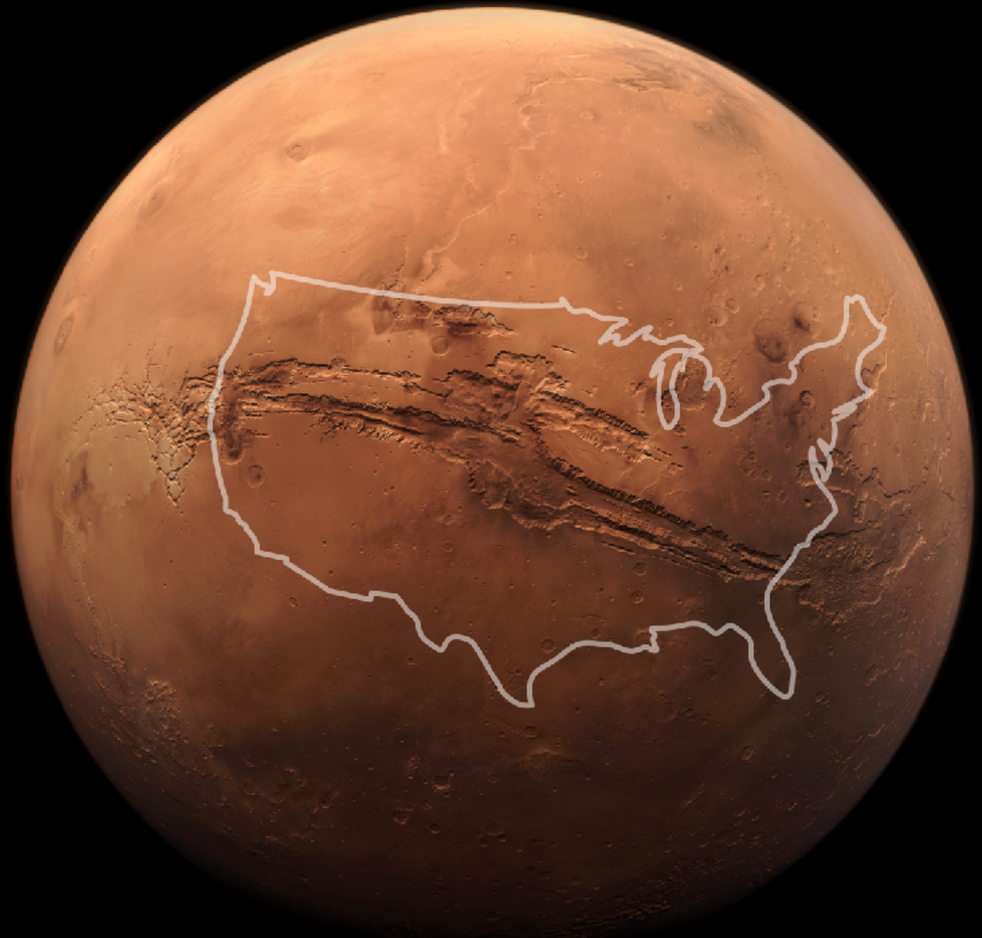
Olympus Mons: Highest mountain in the Solar System



Olympus Mons is a dormant shield volcano, similar to **Mauna Kea** in Hawaii — i.e., the location of the telescopes used by astronomers at UC.

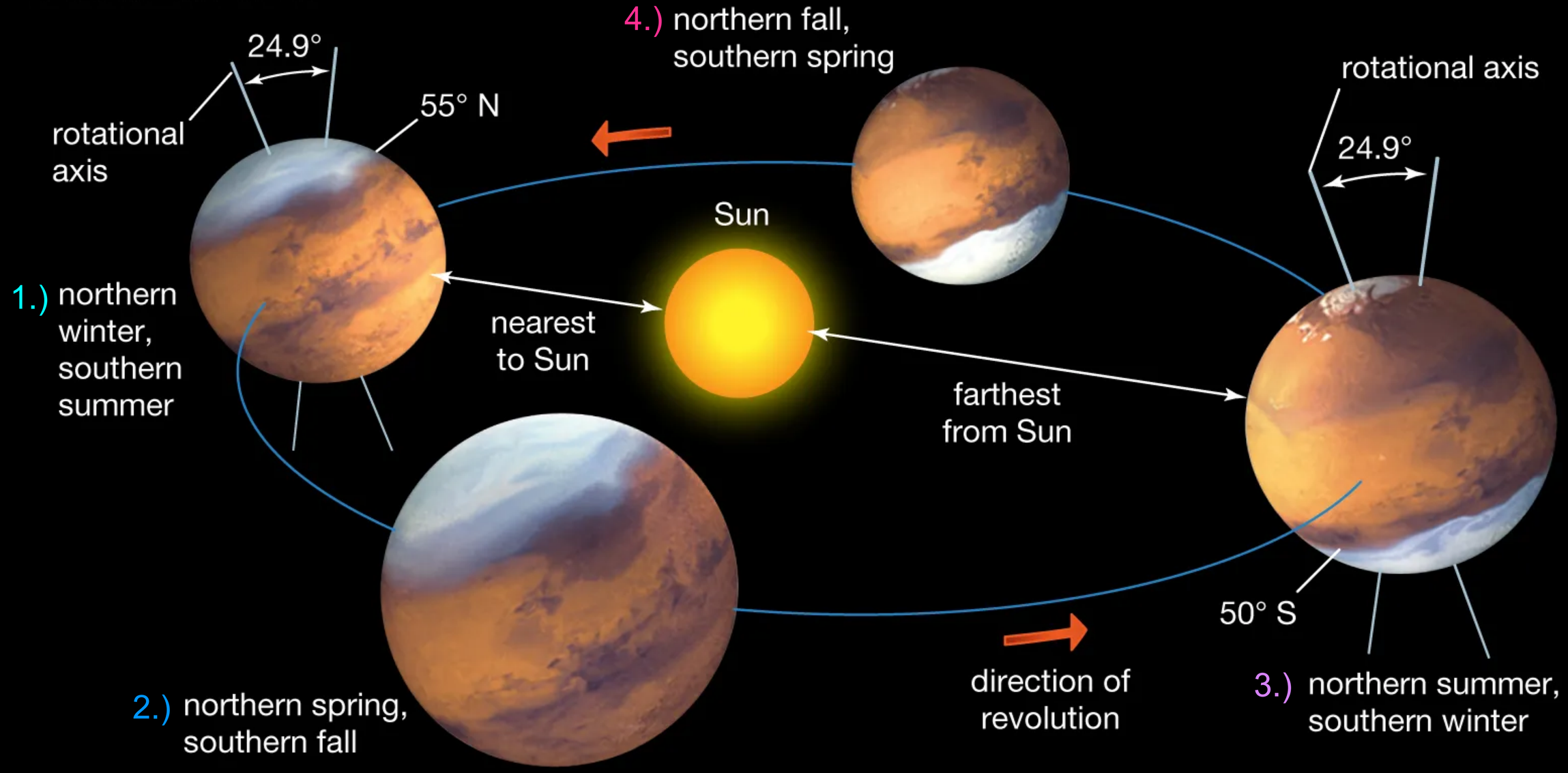
Mars – Lowest Lows

Valles Marineris: Deepest canyon in the Solar System



Valles Marineris is roughly the size of the distance from **Boston to LA!**

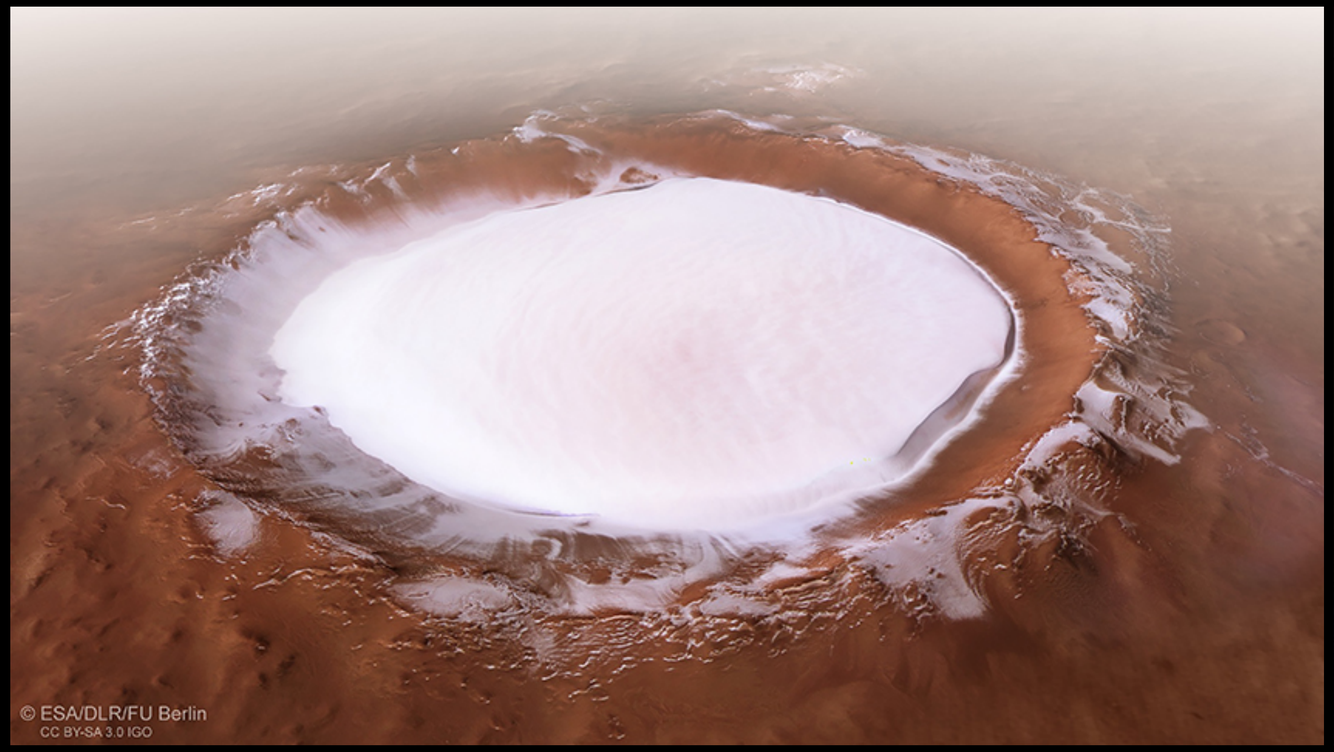
Mars – Seasonal Variations

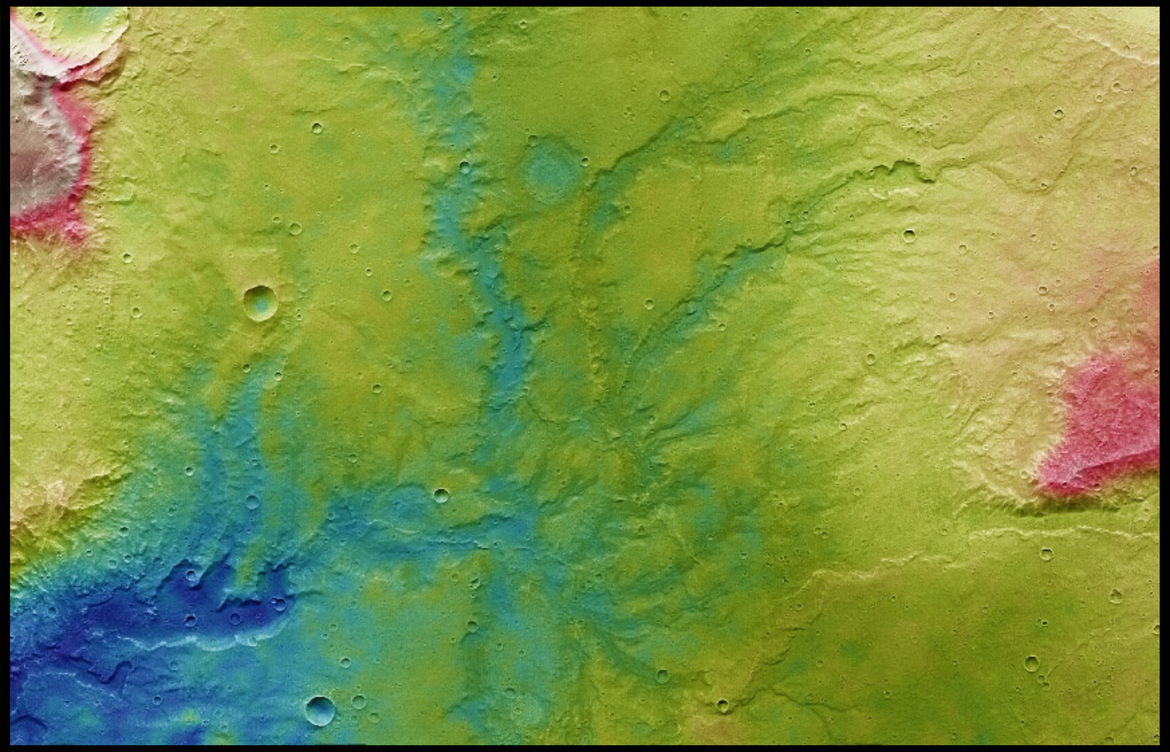


With an eccentricity **5 times larger than Earth's**, the seasonal temperature swings are much larger!

Mars – Surface Water

Frozen water exists as *permafrost* on the top and below the surface of Mars.



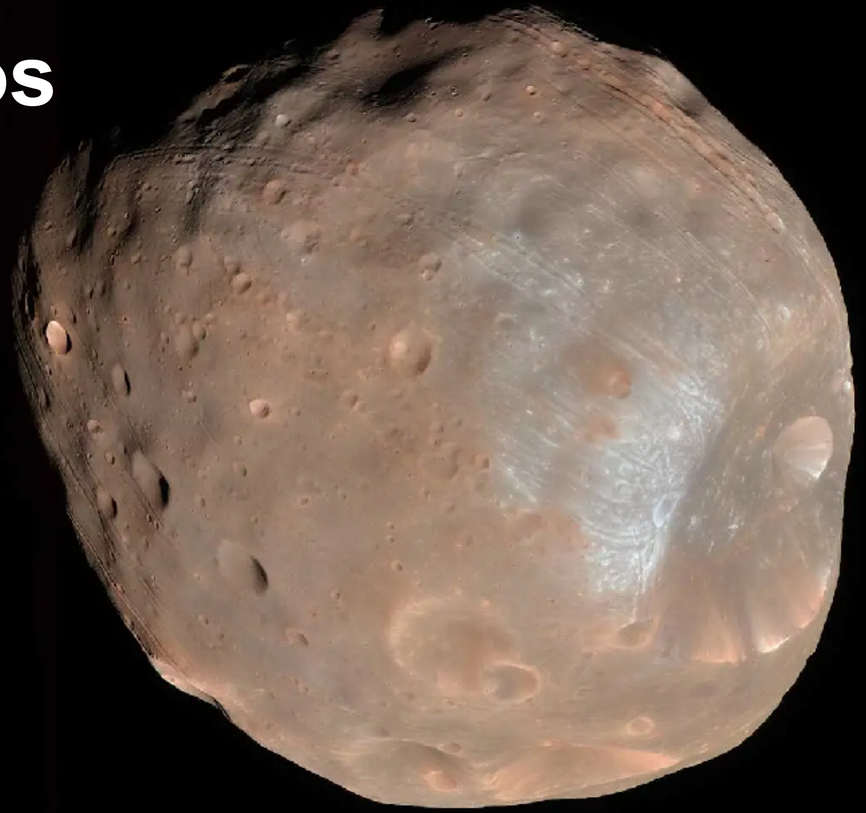


Topology indicates there was a lot more water in the past.

Mars – Moons

Mars has two irregular-shaped satellites.

Phobos



Deimos

They are tidally locked, undifferentiated, have debated origins

Assessment of Learning Objectives

Q1: Which planets have surface temperatures that can exceed the melting point of lead?

Mercury = 1️⃣

Earth = 2️⃣

Mars = 3️⃣

Venus = 4️⃣

Recall that the melting point of lead is 600.3 K

Assessment of Learning Objectives

Q2: All terrestrial planets have satellites.

False = ✊

True = ☝️

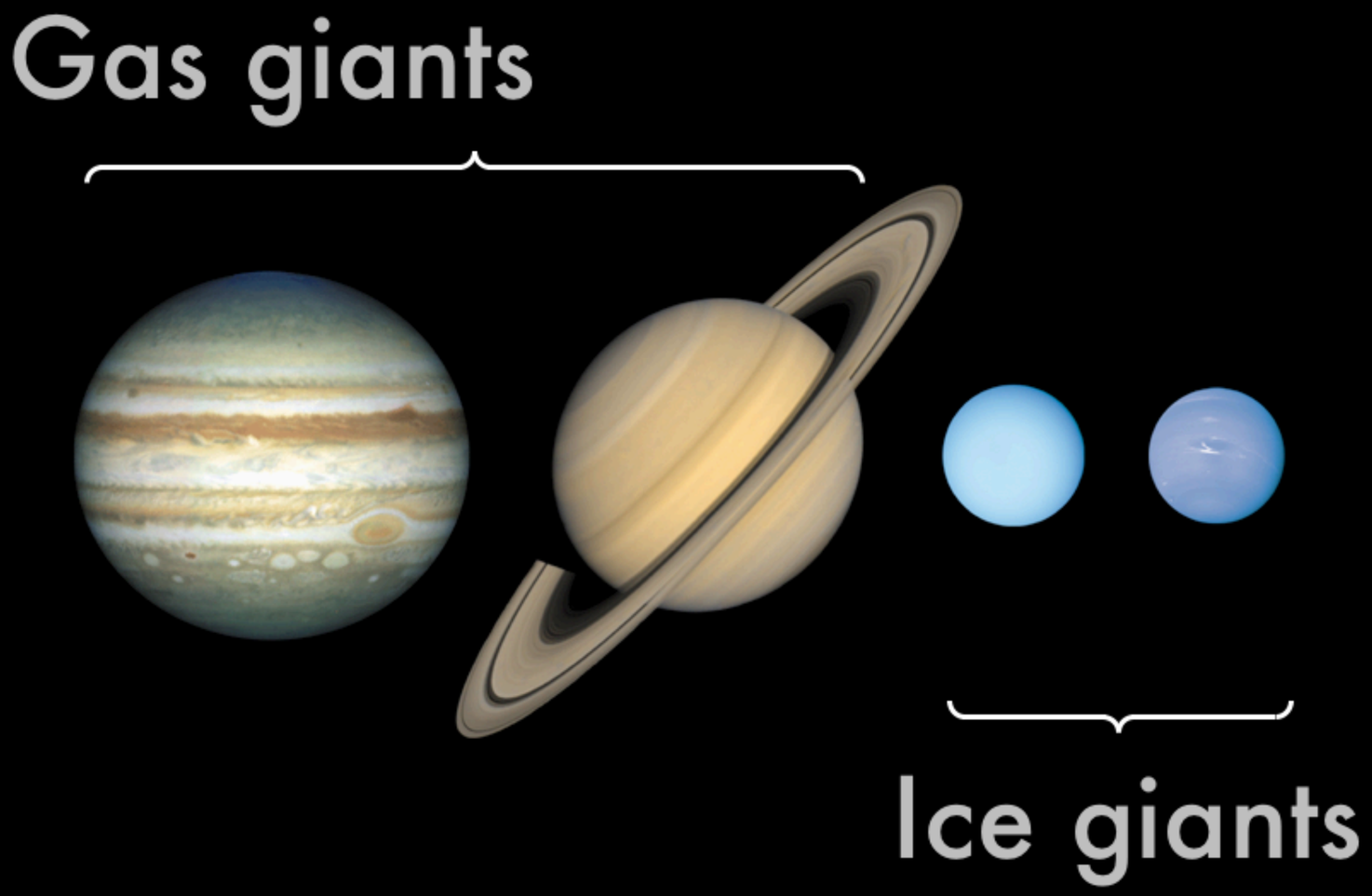
Brain Break – Think-pair-share

We are one major cataclysmic event away from extinction. In light of this, some folks are advocating that we become an interplanetary species by "colonizing" Mars.

However, we have seen that Mars has **no breathable atmosphere** and **lacks liquid water**. With this in mind, answer in the following questions:

1. What do you think are the biggest challenges humanity needs to address before going to Mars?
2. What technologies do you think can help in the future?
3. What are some other possible alternatives than going to Mars?
4. Do you think this humans will step foot on another planet in your lifetime?
5. If so, would you sign up to go?

Jovian Planets



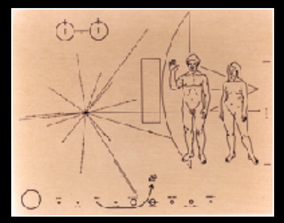
"Gas Planet Sizes"
(Source: Lunar and Planetary Institute)
http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=180

- Four outermost planets to the Sun
- All beyond the snow/ice line
- All have strong magnetic fields (rapid rotators)
- All have ring systems

Missions to the Outer Planets

Pioneer 10 & 11 (1972)

First to fly past Jupiter and Saturn



Pioneer plaque

Galileo (1989)

First to directly measure Jupiter's atmosphere.

Voyager 1 & 2 (1977)

First to visit all Jovian planets and enter interstellar space!

First to orbit Saturn and visit an outer moon (Titan)

Cassini (1997)

First to fly by Pluto and the Kuiper Belt.

New Horizons (2006)

First to peer below Jupiter's dense upper atmosphere

Juno (2011)

Will probe the Europa's subsurface ocean looking for signs of habitability!

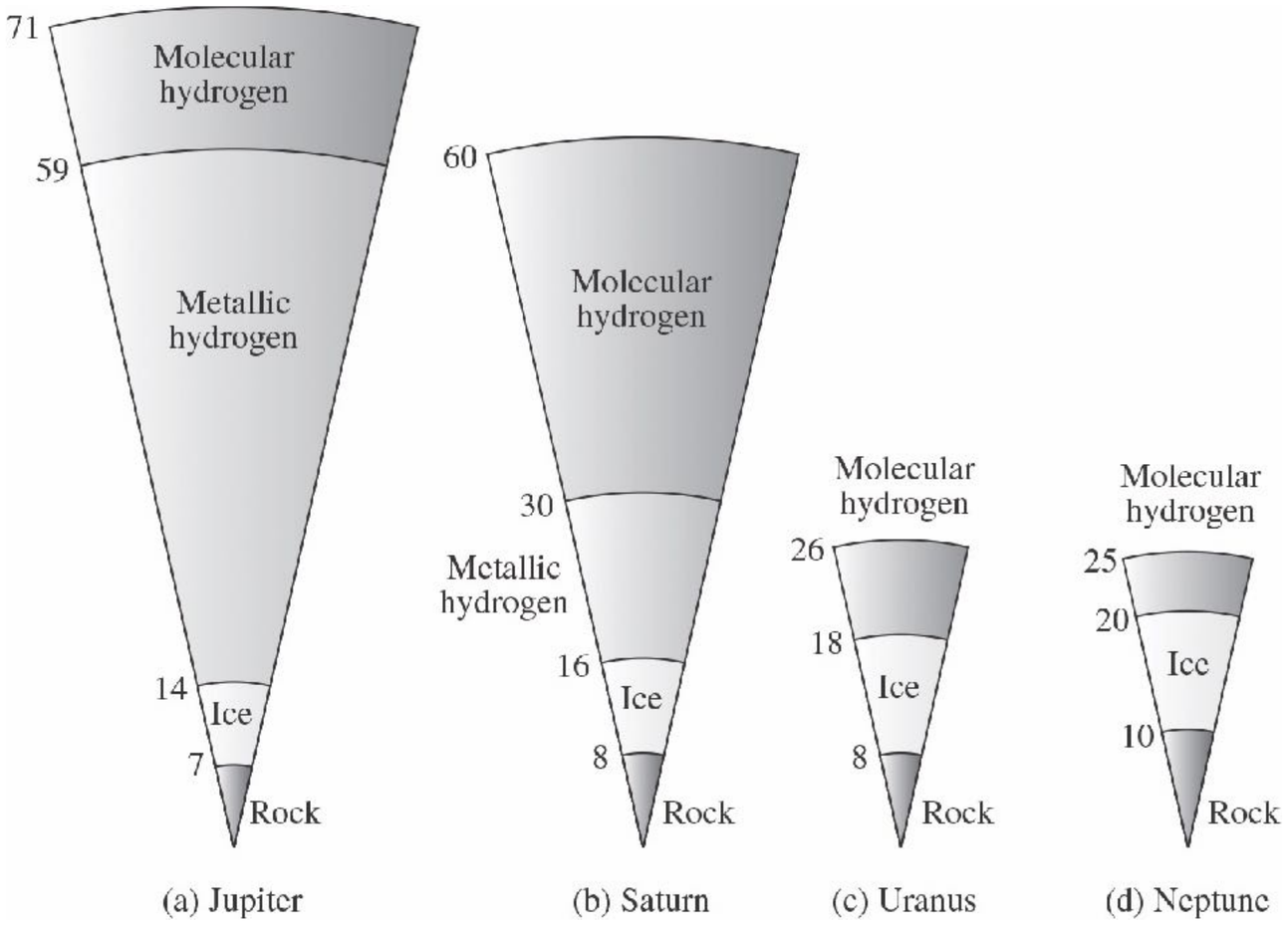
Prof. Samantha Trumbo's research group at UCSD will analyze data from Europa Clipper!

Europa Clipper (2024)

Jovian Planets - Structure

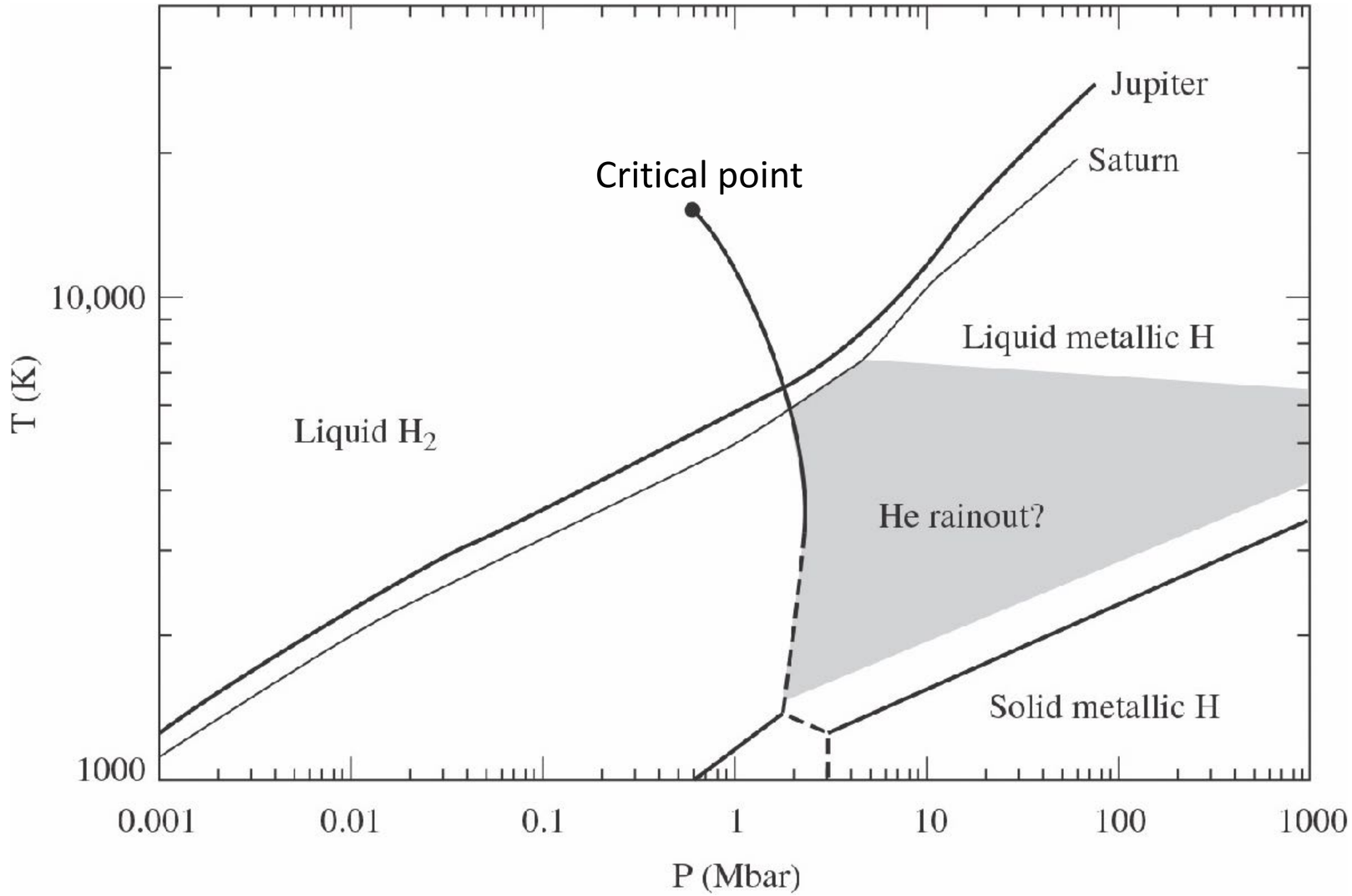
- All have rocky cores followed by a layer of ices (water, ammonia, and methane)

- A **metallic** substance is a regular, lattice-like structure of positive ions surrounded by a cloud of delocalized electrons.



Jovian Planets - Structure

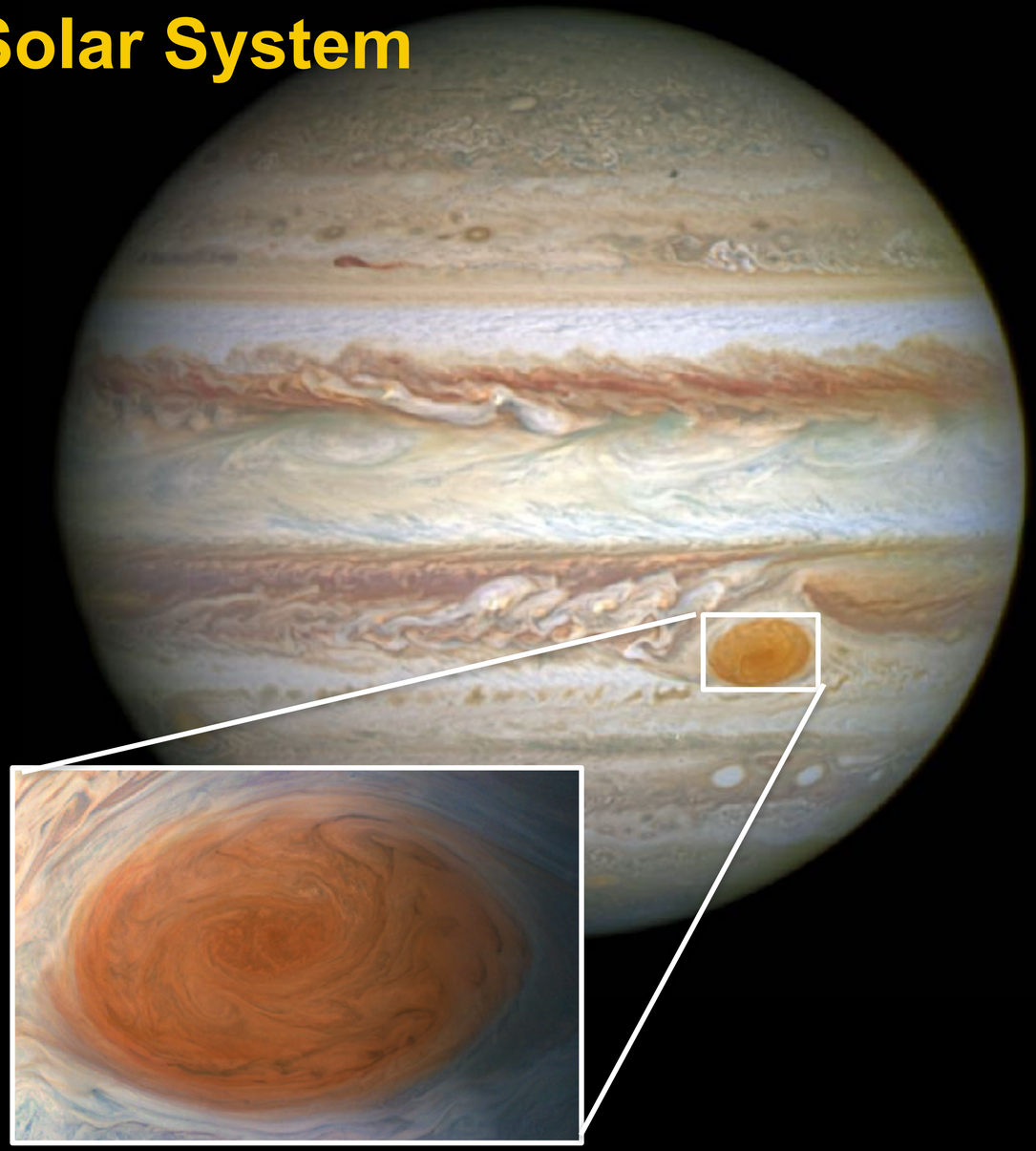
Phase Diagram of Hydrogen



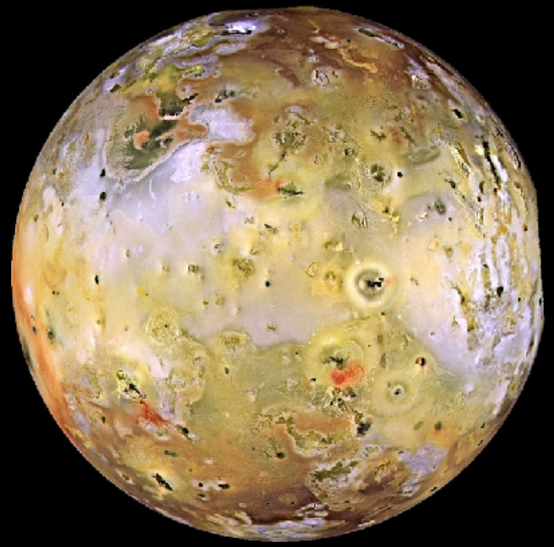
Jupiter

Largest World in the Solar System

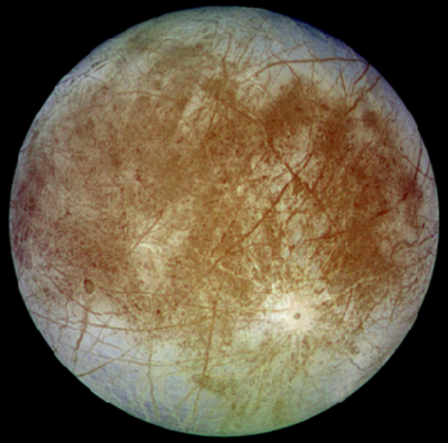
- Radius is 1/10 that of the Sun
- Mass is 1/1000 that of the Sun
- Rapid rotation stretch the clouds into long bands
- The “Great Red Spot” is a storm that has existed since at least 1831!
- 95 moons (and counting)



Galilean Satellites



Io



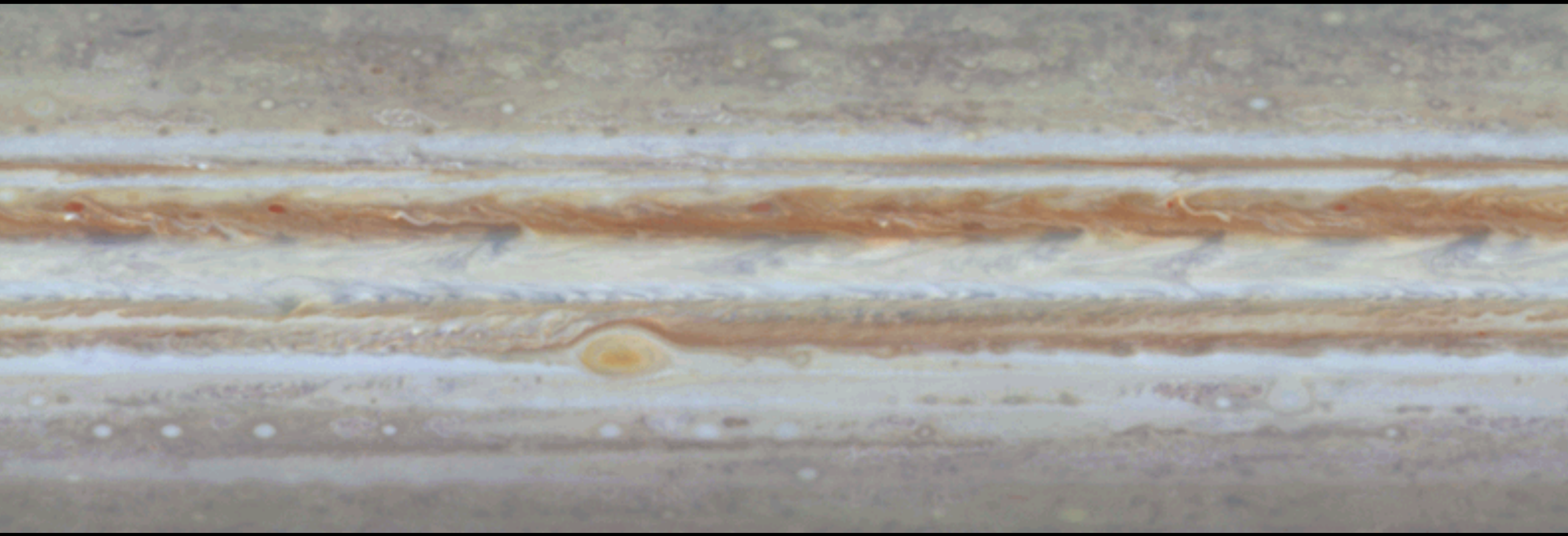
Europa

Ganymede

Callisto

Jupiter - Clouds

Divided into darker bands (**belts**) and lighter bands (**zones**)

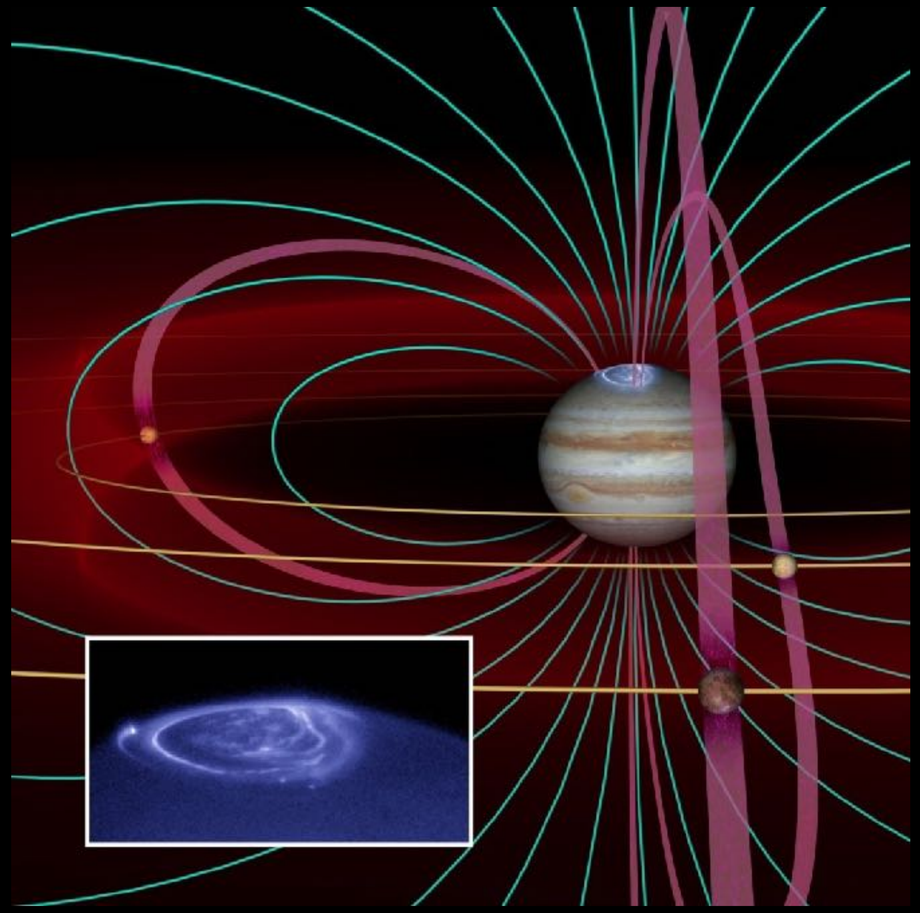


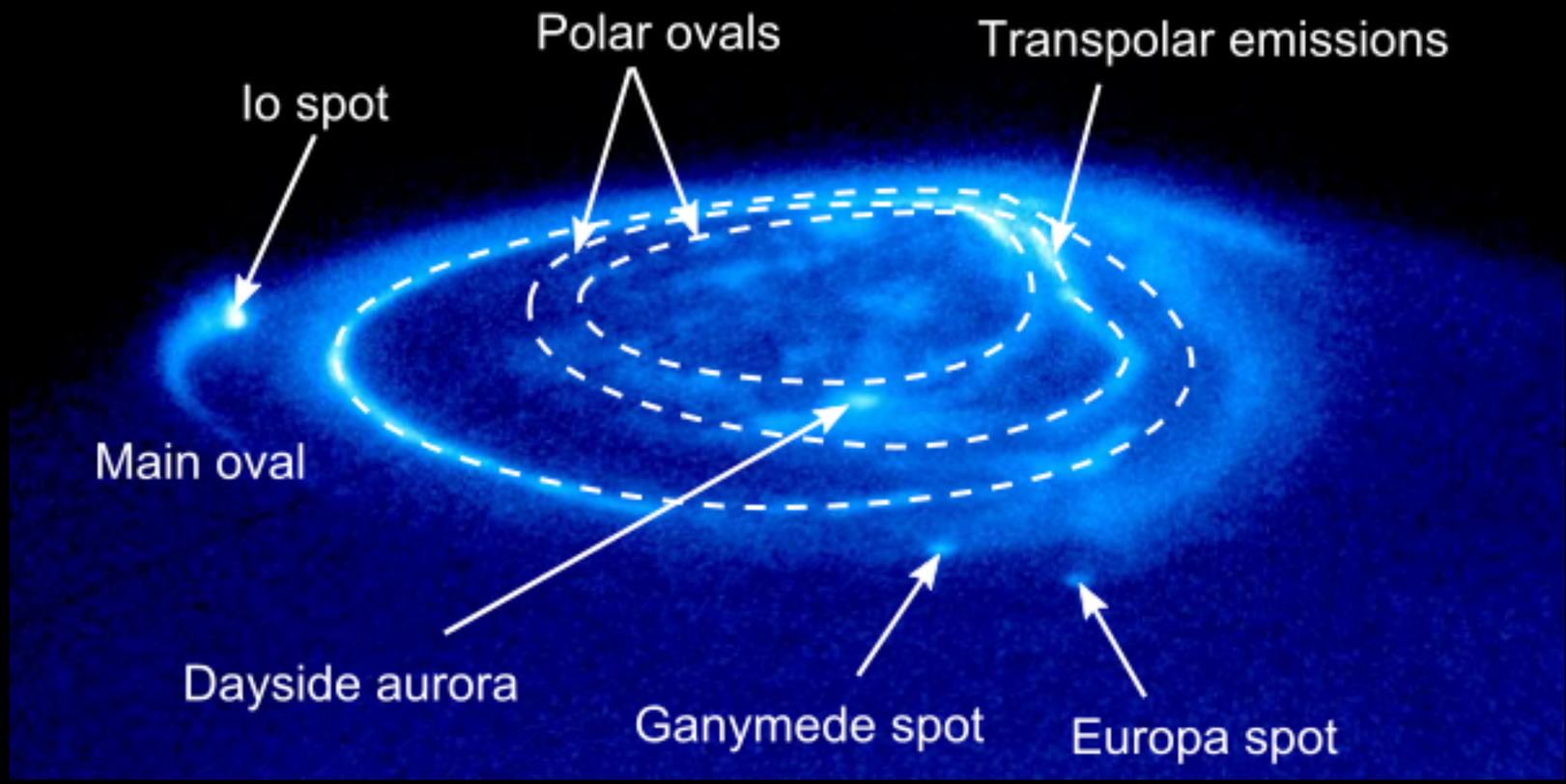
Belts are higher in temperature and lower in altitude

Zones are lower in temperature and higher in altitude

Jupiter – Magnetic Fields

Very strong magnetic field, 10 times that of Earth.



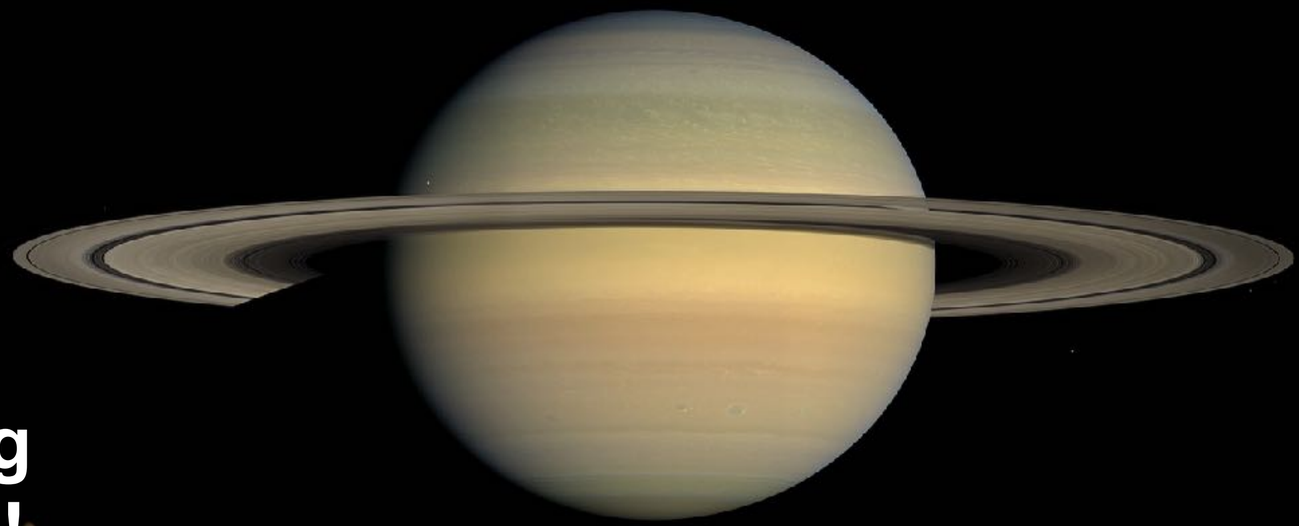


Imprints into its moons which funnel particles into Jupiter’s upper atmosphere.

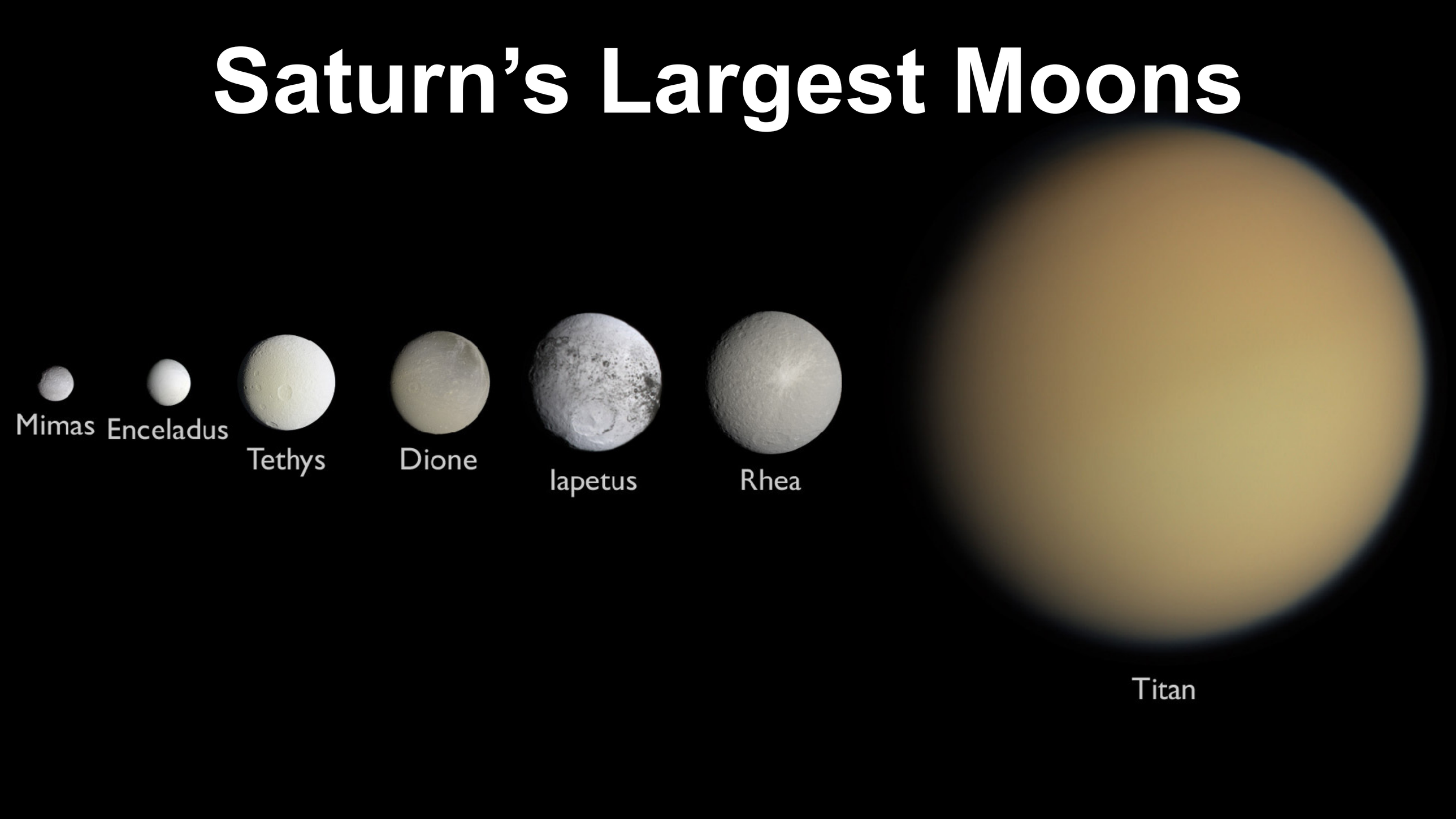
Saturn

Least Dense World in the Solar System

- Radius is 80% that of the Jupiter.
- Rings are prominent
- Mass is 1/3 that of Jupiter
- Average distance between ring particles is 12 meters (40 feet)!
- 274 moons (and counting)



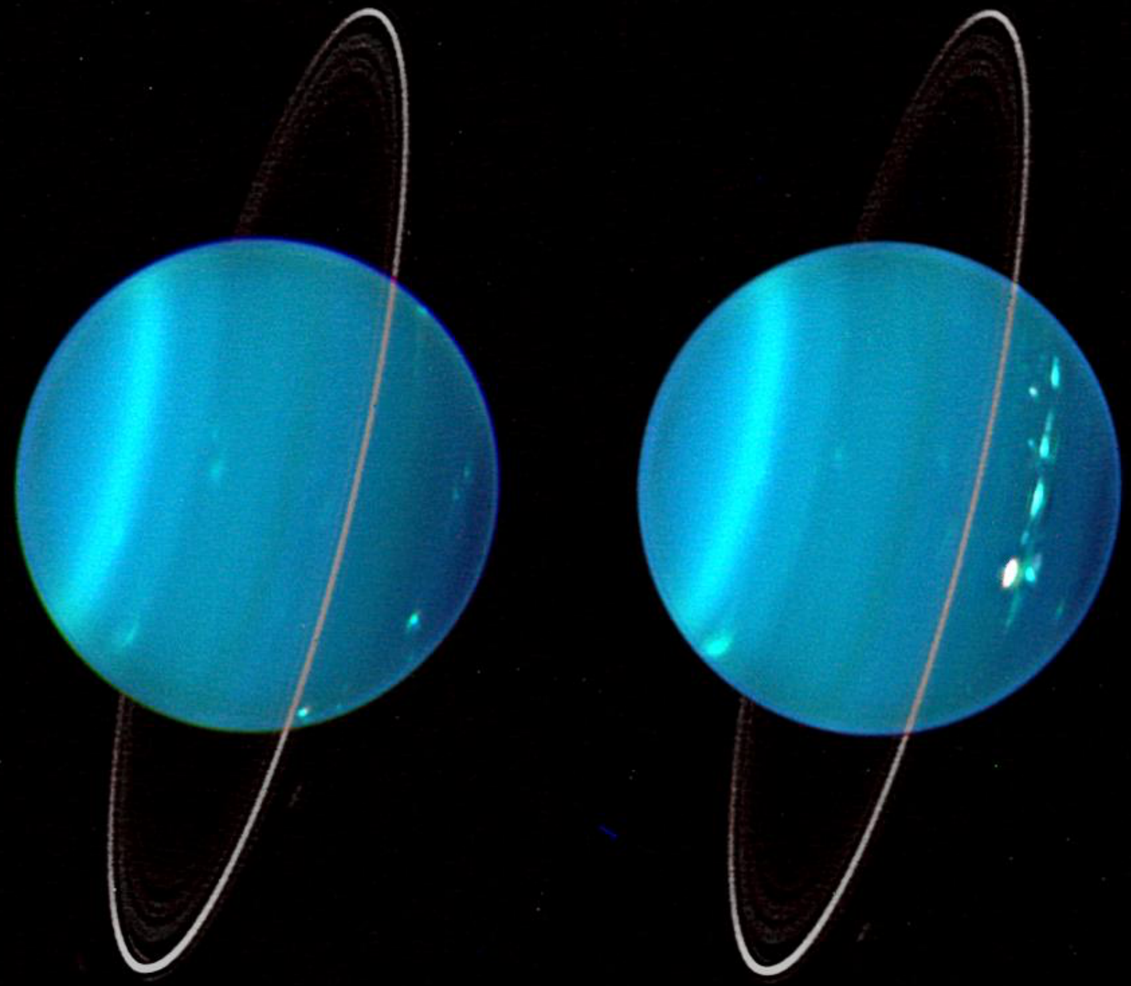
Saturn’s Largest Moons



Uranus

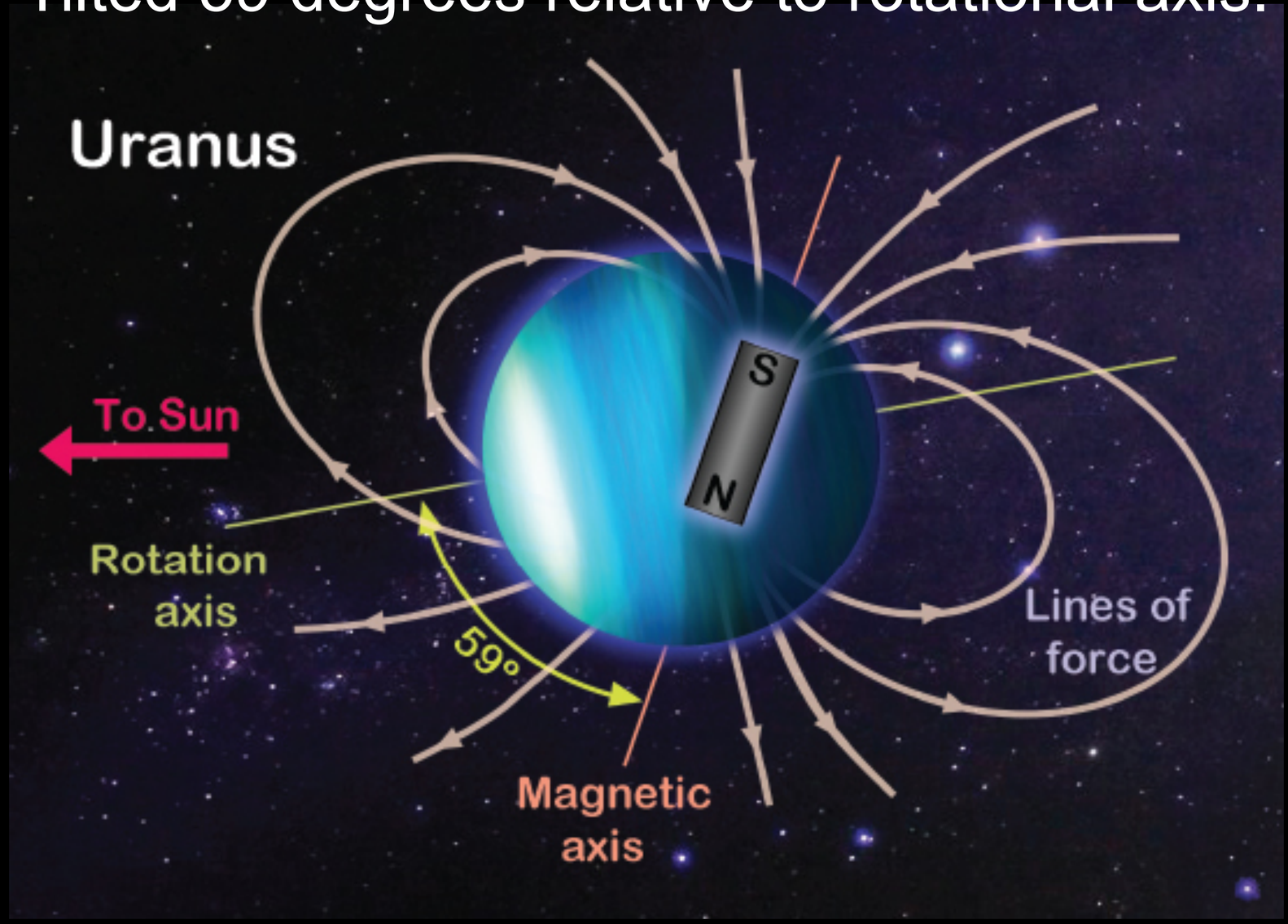
The Coldest World in the Solar System

- **4 times larger than Earth!**
- **15 times more massive than Earth**
- **Axis is tilted 98 degrees relative to orbital plane!**
  - Possibly caused by a collision during formation.



Uranus – Strange B-field

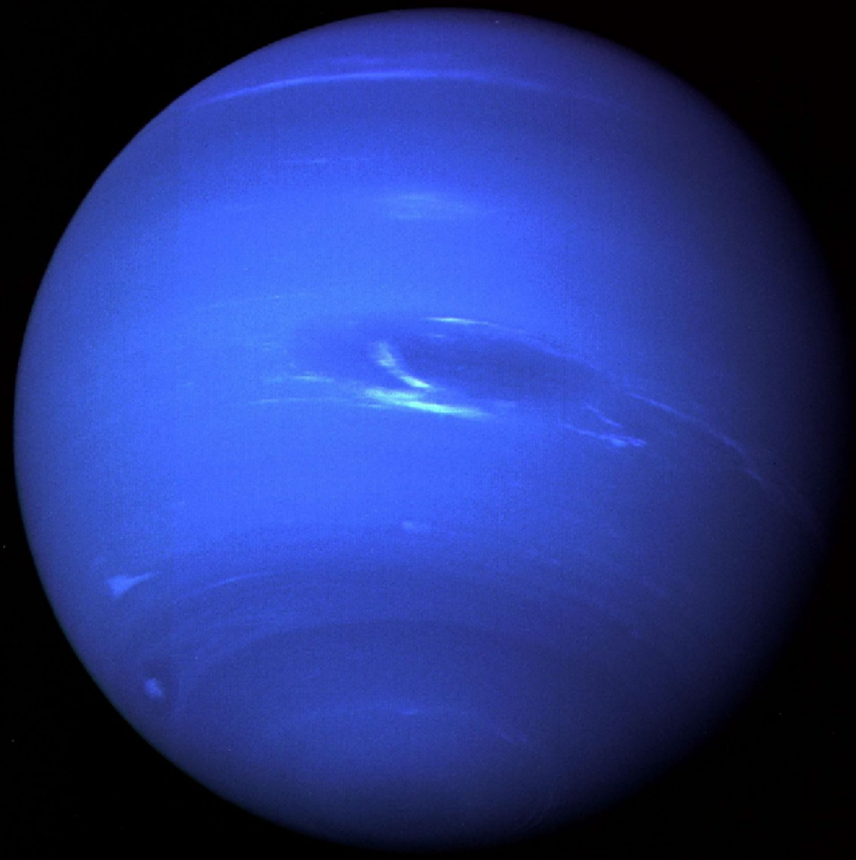
Tilted 59 degrees relative to rotational axis.



Neptune

The Windiest World in the Solar System

- Radius is similar to Uranus
- Mass is similar to Uranus
- Rapid rotation stretch the clouds into long bands
- The “Great Dark Spot” was an Earth-sized storm that was imaged in 1989 (gone in 199
- Only giant planet with a satellite in a retrograde orbit (Triton)
  - i.e., it orbits Neptune in the opposite direction of the planet’s rotation.
- Appears to have an internal heat source (radiates a lot of energy)



Retaining an atmosphere

Recall that to keep an atmosphere you need the speed of the particles to be well below the escape speed

$$v_{\mathrm{rms}}^2 \leq \frac{1}{36} v_{\mathrm{esc}}^2 \quad \text{(See lecture 10)}$$

Which can be rewritten in terms of constants

$$\frac{3kT_{\mathrm{ex}}}{m} \leq \frac{GM}{18R_{\mathrm{ex}}} \quad \text{(See lecture 10)}$$

We can rewrite this in terms of the molecular mass for a given species (μ), and find the condition for retaining a gas is

$$\mu \geq 7.1 \left(\frac{T_{\mathrm{ex}}}{1000K} \right) \left(\frac{M}{M_\oplus} \right)^{-1} \left(\frac{R_{\mathrm{ex}}}{R_\oplus} \right) \qquad \left(\begin{array}{c} \text{Condition for the retention of a} \\ \text{constitutent of molecular weight } \mu \end{array} \right)$$

Retaining an atmosphere — Titan Example

Saturn's moon Titan has a mass $M = 1.3 \times 10^{23}$ kg and a radius $R = 2580$ km. The temperature at the surface of Titan is $T = 94$ K.

a.) Would Titan be able to retain H_2 ($\mu = 2$) in its atmosphere?

b.) Would Titan be able to retain CO_2 ($\mu = 44$) in its atmosphere?

$$\mu \geq 7.1 \left(\frac{T_{ex}}{1000K} \right) \left(\frac{M}{M_\oplus} \right)^{-1} \left(\frac{R_{ex}}{R_\oplus} \right)$$

Assume, $R_\oplus = 6378$ km and $M_\oplus = 5.98 \times 10^{24}$ kg


Questions?

Reminders

- Coding assignment #4 is due Sunday, 11/16 by 11:59 pm.
- Midterm Exam II will take place on **Thursday, 11/13 from 2:00-3:10pm**
- Log into canvas and submit your answer to the discussion question by the end of the day to receive participation credit.