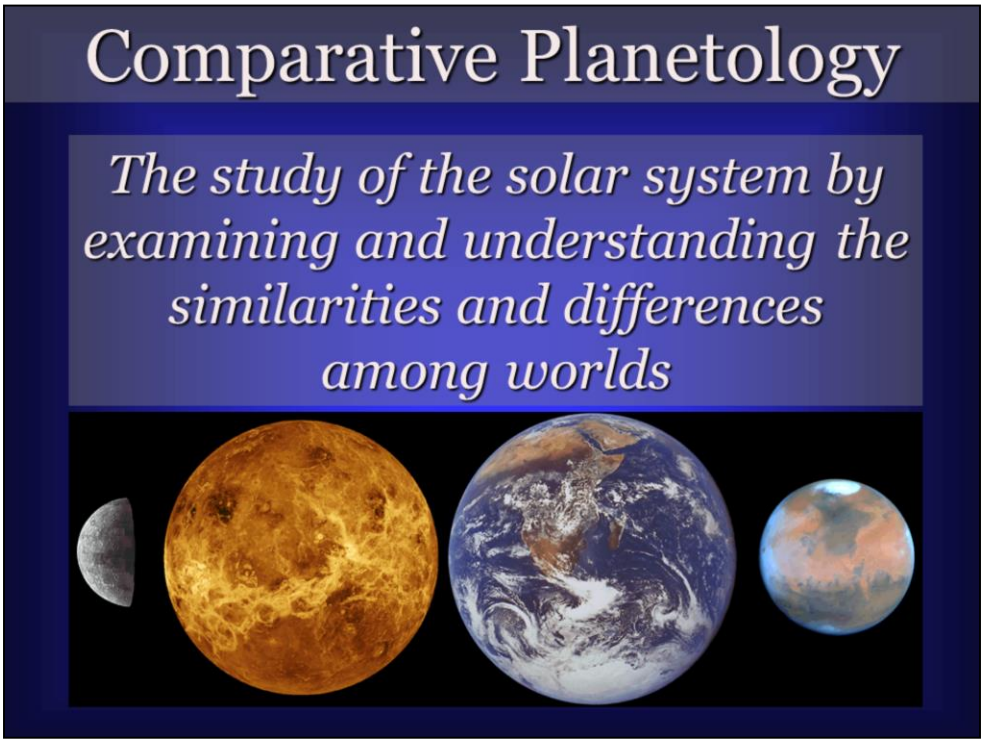
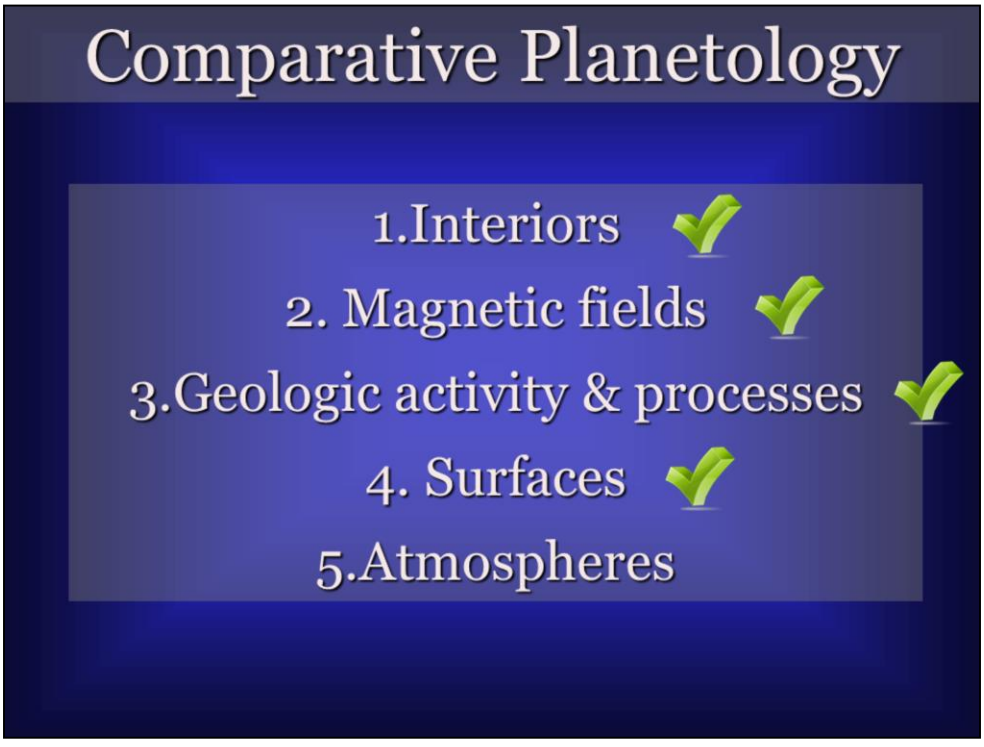
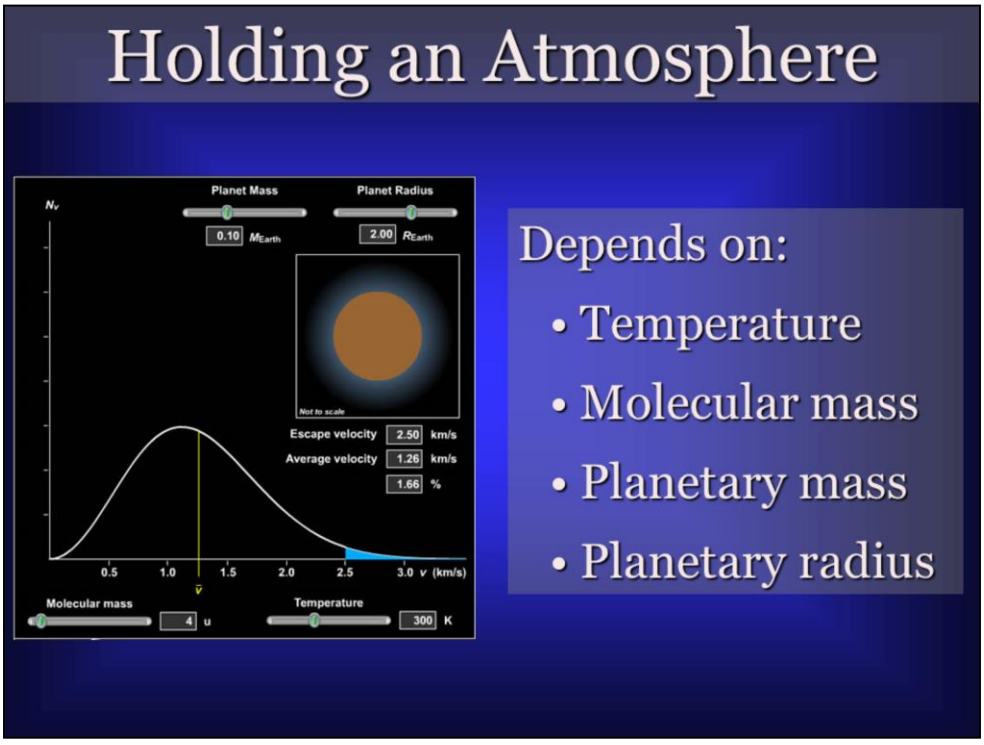


We'll start with the terrestrial planets



These are the things we need to look at to understand how (terrestrial) planets form. We'll start with the Earth, and compare from there.

A picture of the moon through Earth’s atmosphere (from the shuttle)

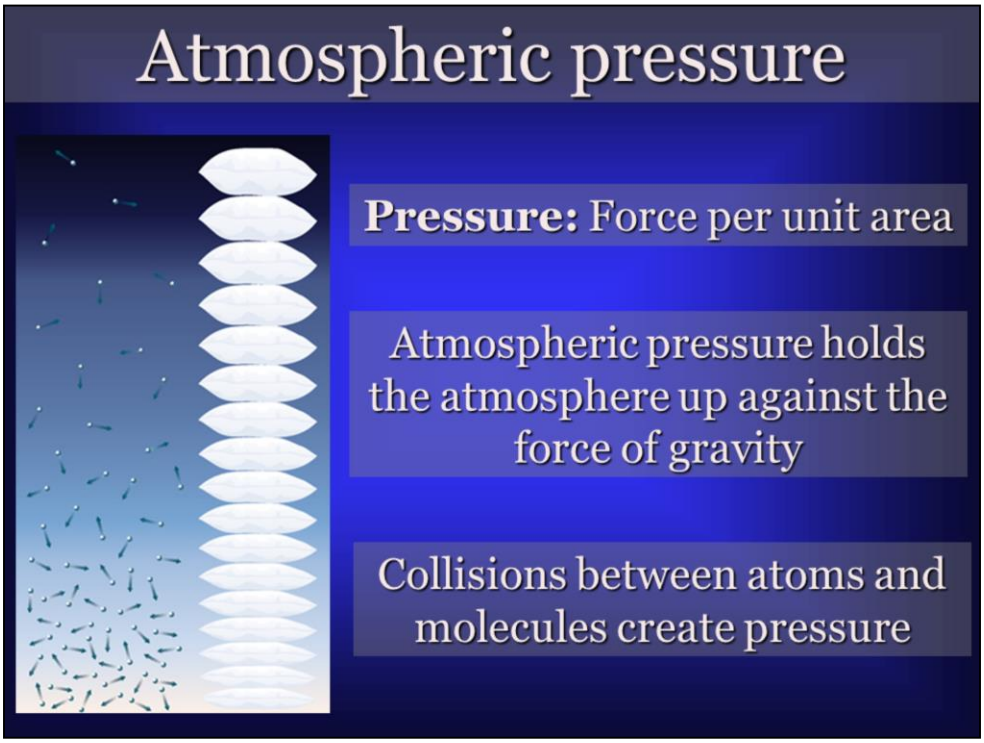


Mercury is small and hot. It can't hold an atmosphere

Venus has a LOT of carbon dioxide.

Earth has a nitrogen/oxygen atmosphere

Mars has a very thin carbon dioxide atmosphere



Air has mass.

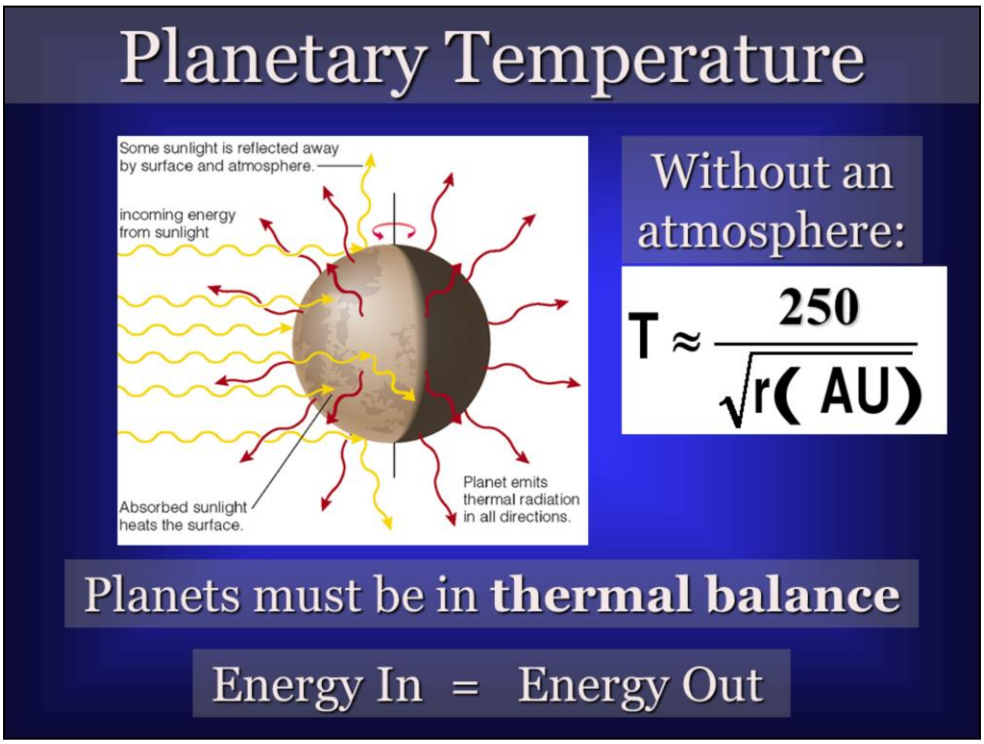
Massive things in a gravitational field have weight, so the air presses down on us with some amount of force.

Something must be holding it up, or it would all collapse. That something is Pressure.

Pressure comes from the molecules in the air knocking into each other.

If I cool a balloon down, the internal pressure decreases and the balloon deflates.

The atmospheric pressure decreases with increasing altitude.



Incident solar radiation is absorbed (some is reflected)

The planet gets warm.

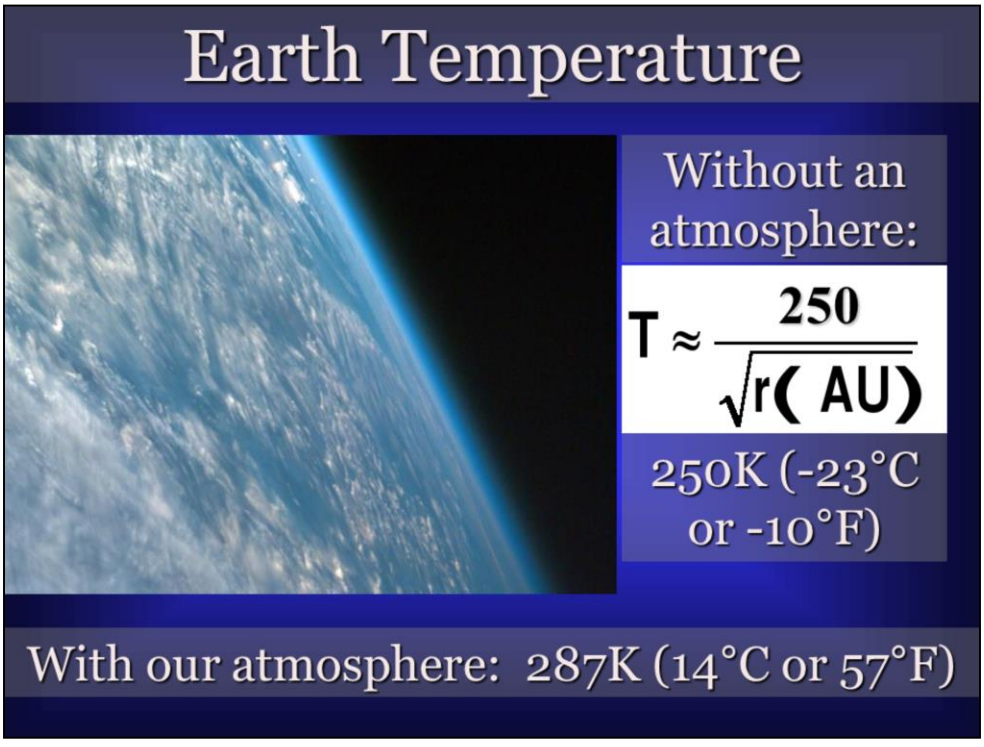
Hot Dense Objects emit radiation. They emit radiation like a … Say it!

Total incoming radiation must equal total outgoing radiation. Hotter objects emit more than cold objects.

The blackbody curve of terrestrial planets peaks in the infrared.

Earth should be about -1 degree Fahrenheit

But it's not because…



This is the temperature at the surface! In general it gets cooler as you go to higher altitudes.

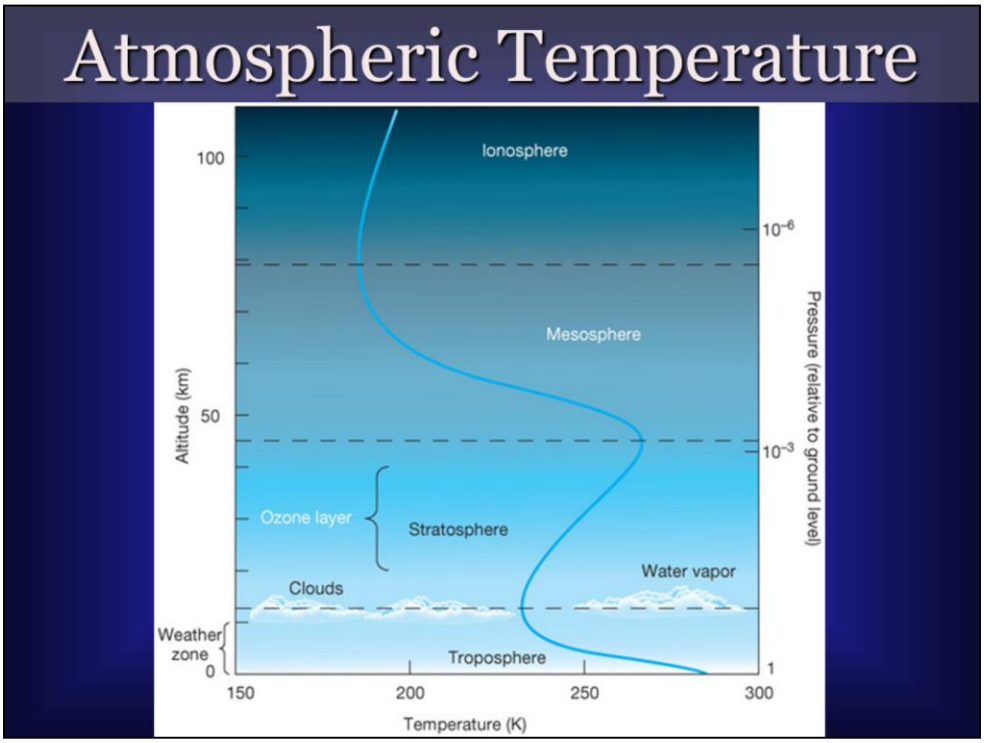
Earth Atmosphere

78% N_2

20% O_2

1% H_2O

(and some other stuff)

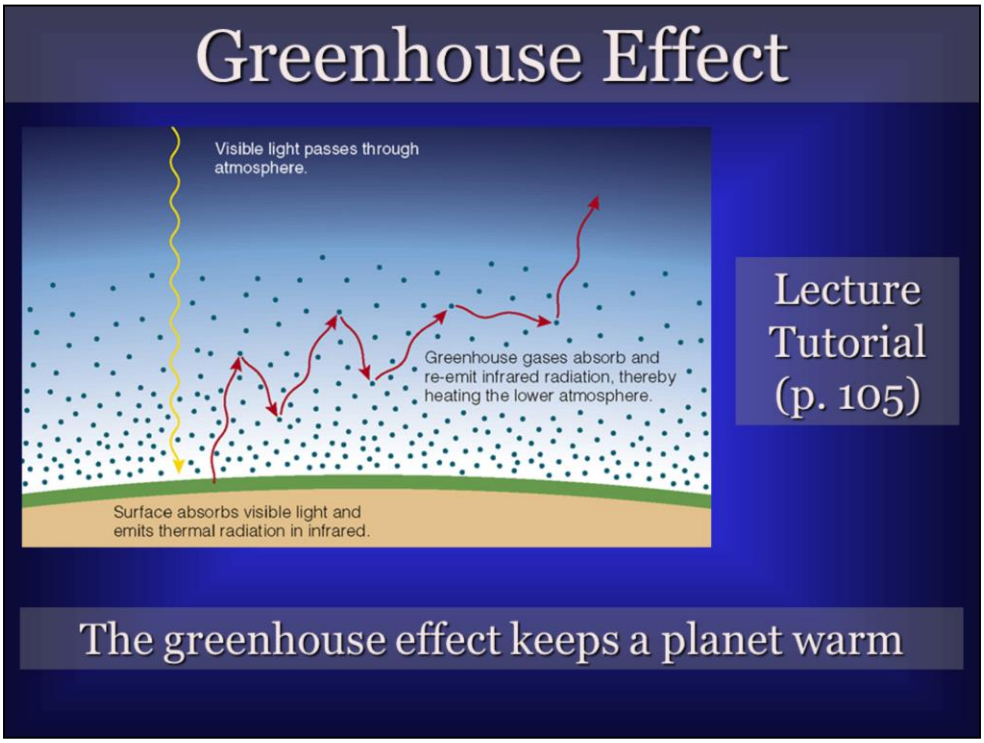


Troposphere: convection occurs here. Ground is heated and in turn heats the atmosphere right above it. Temperature cools as you go upwards.

Stratosphere: ozone layer lies here; in this layer we're absorbing high energy radiation, and more of it is absorbed at the top than the bottom so that at the top it's hotter than at the bottom.

Mesosphere: Here again we have cooling, but the air is too thin for convection to be important

Ionosphere: This is where the air is very thin. Again the temperature rises (slightly) as you go higher in altitude, in part just because things aren't held all that well by gravity, and in part because of the high energy radiation hitting the molecules.



Visible light passes through the atmosphere warming the planet.

The planet emits primarily in the infrared.

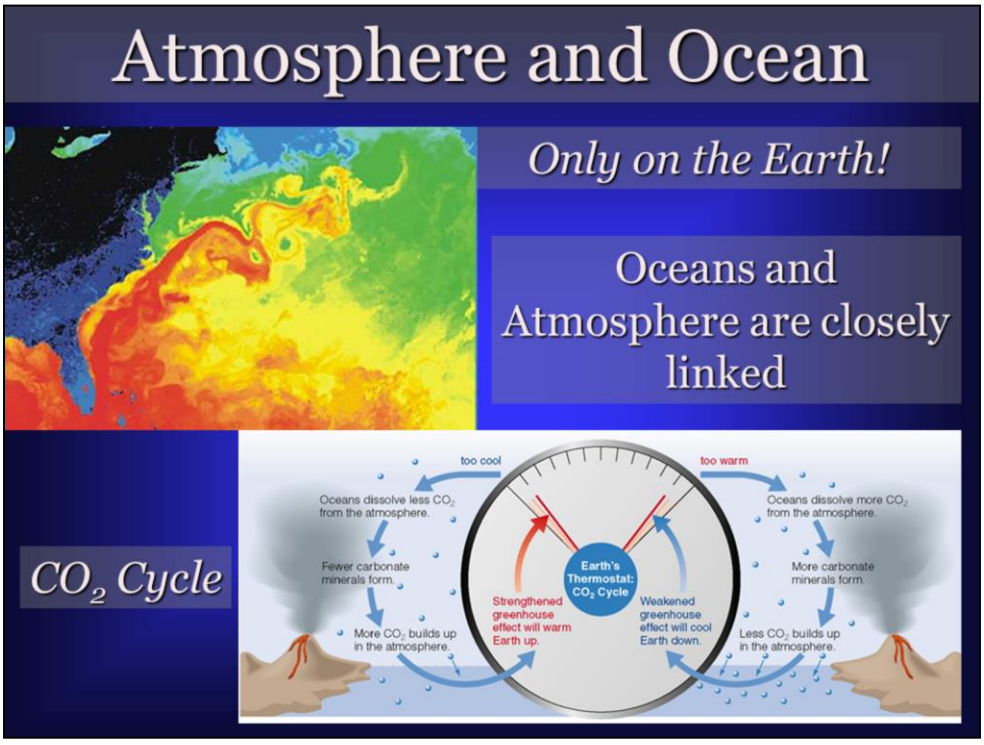
Greenhouse gasses absorb infrared radiation which contributes to their kinetic energy, and therefore the temperature.

Since the atmosphere causes the planet to radiate less efficiently, the planet has to get hotter to stay in thermal balance.

The Greenhouse effect on Venus is whacky out of control. The surface temperature is nearly 900 degrees fahrenheit.

LECTURE TUTORIAL p. 105

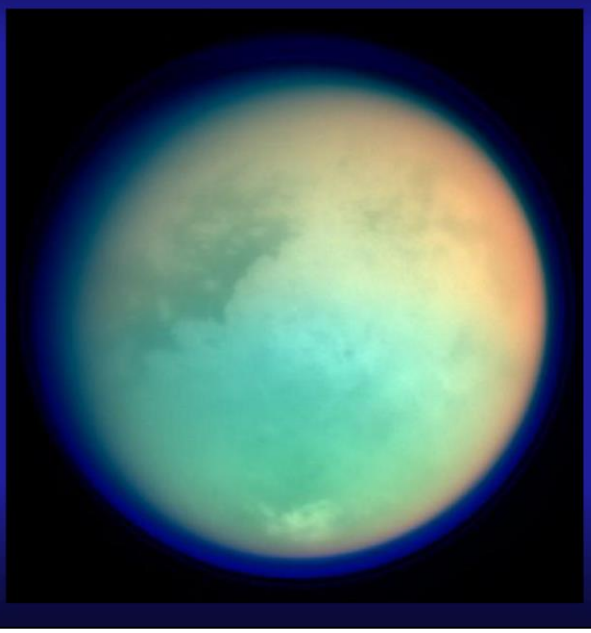
We will talk more in depth about this later.

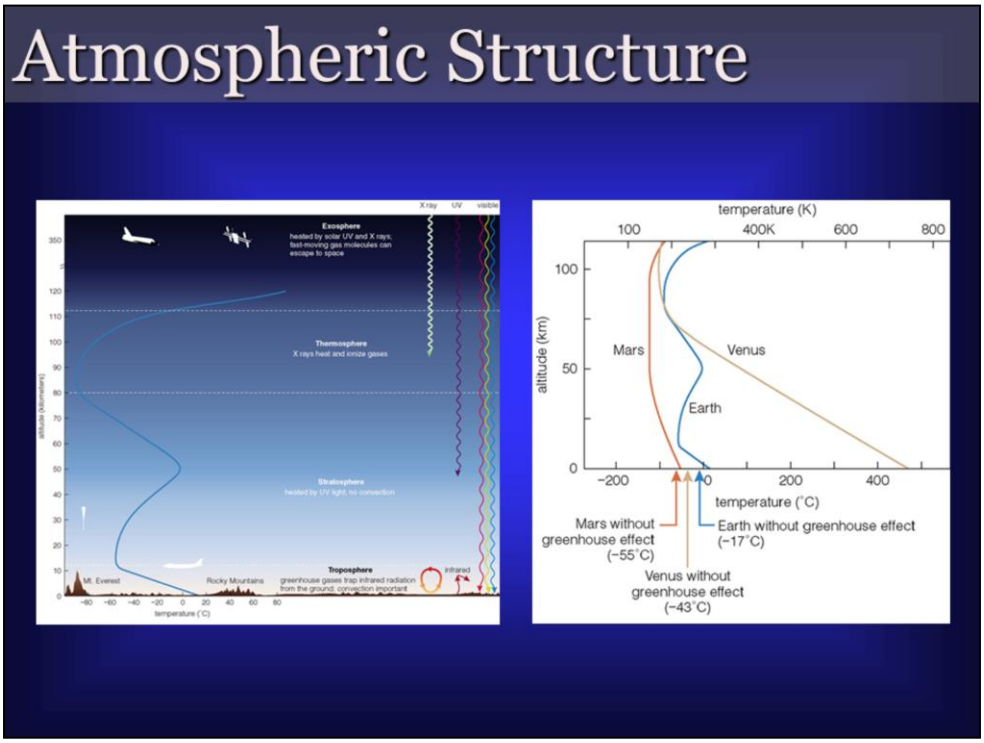


We will come back to this on Friday.

Even without organic matter or life: CO2 -> dissolved in ocean. Silicates also in ocean. CO2 + silicates -> carbonates (e.g. limestone). These are then subducted taking CO2 out of the way. Temp – if hot more CO2 gets dissolved and taken out. If cold, it builds up in the atmosphere, therefore self-regulating.

Other Atmospheres





On the left is the diagram we saw earlier of Earth's atmospheric structure. Notice how much it wiggles back and forth (decreasing temperature, then increasing, then decreasing then increasing again.)

On the right is a comparison with the other two terrestrial planets that have atmospheres. Notice all are warmer at the surface than what their temperatures would be without the greenhouse effect. ****How come Venus is cooler than Earth (without greenhouse effect)?****

Venus

Completely cloud shrouded

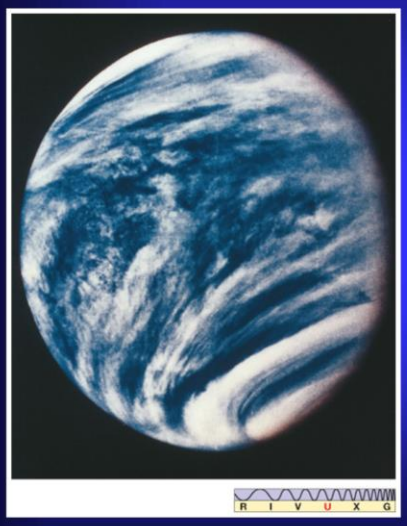
Surface atmospheric pressure 100 times Earth's

Surface temp: 735K (462°C)

Radius: .95 R_{earth}

T~300K without an atmosphere but with it's atmosphere it's much hotter!

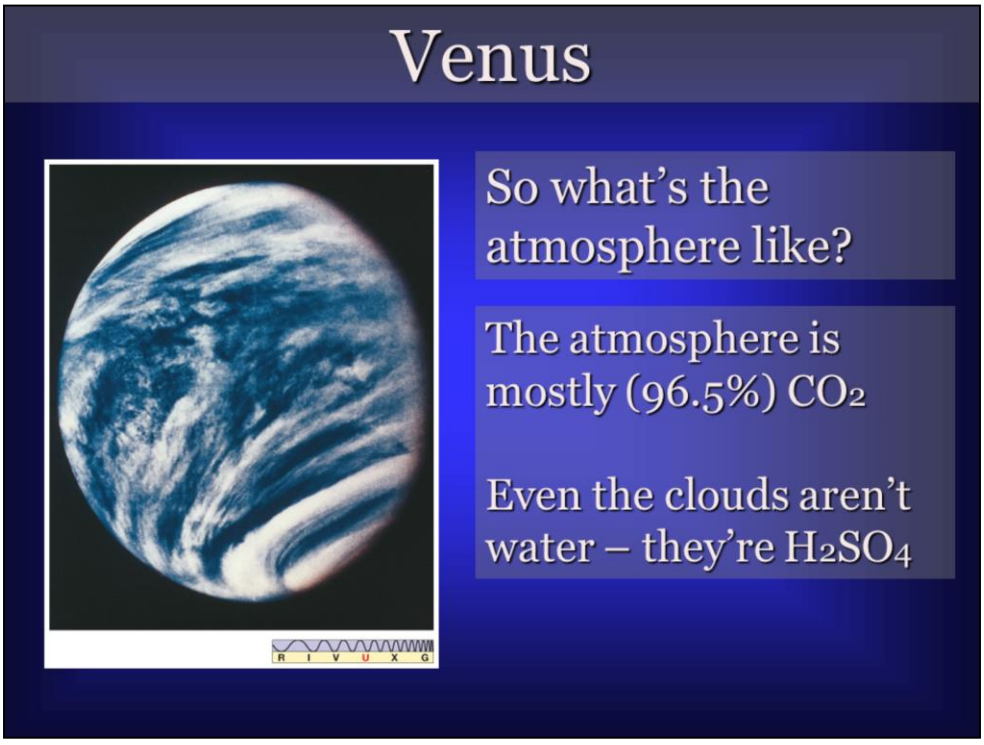
Venus



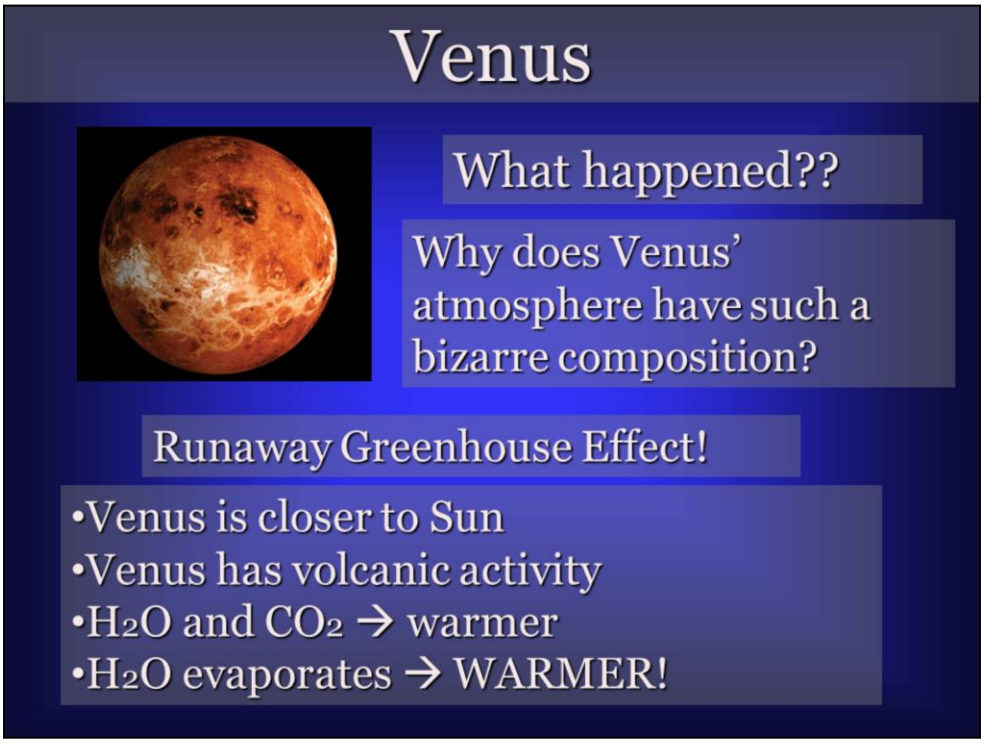
So what's the atmosphere like?

- High winds at high altitudes (~400km/h)
- Hazy below that
- Clear and calm near the surface

This photo is in Ultraviolet light which shows the contrasts better.



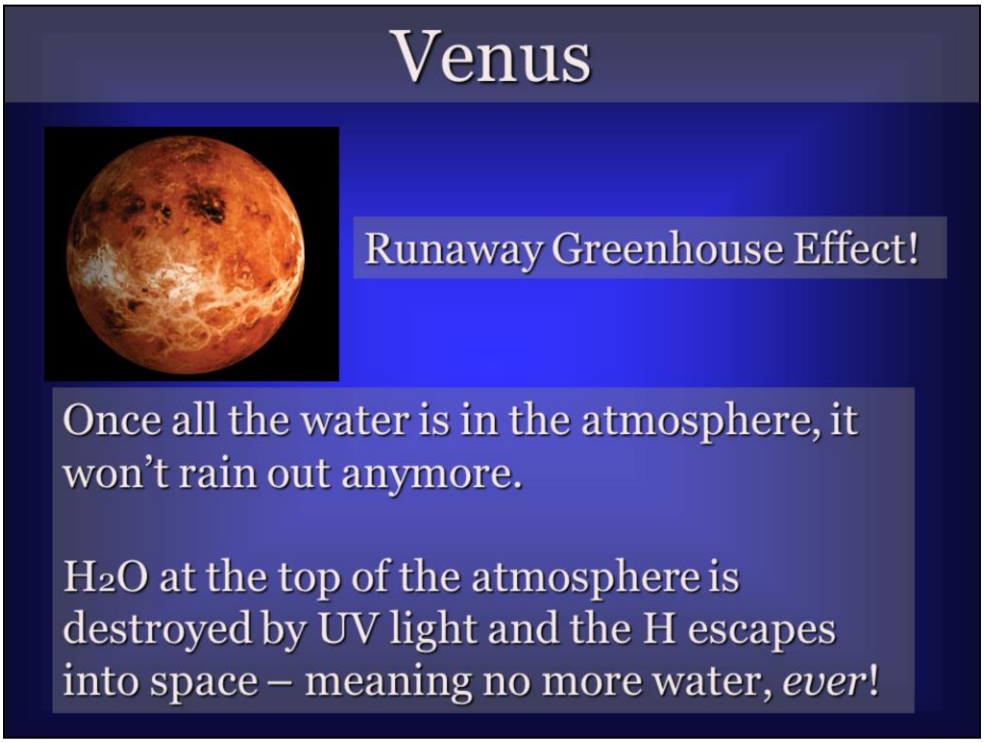
This photo is in Ultraviolet light which shows the contrasts better. H_2SO_4 is sulfuric acid.



This photo is radar imaging of the surface of Venus.

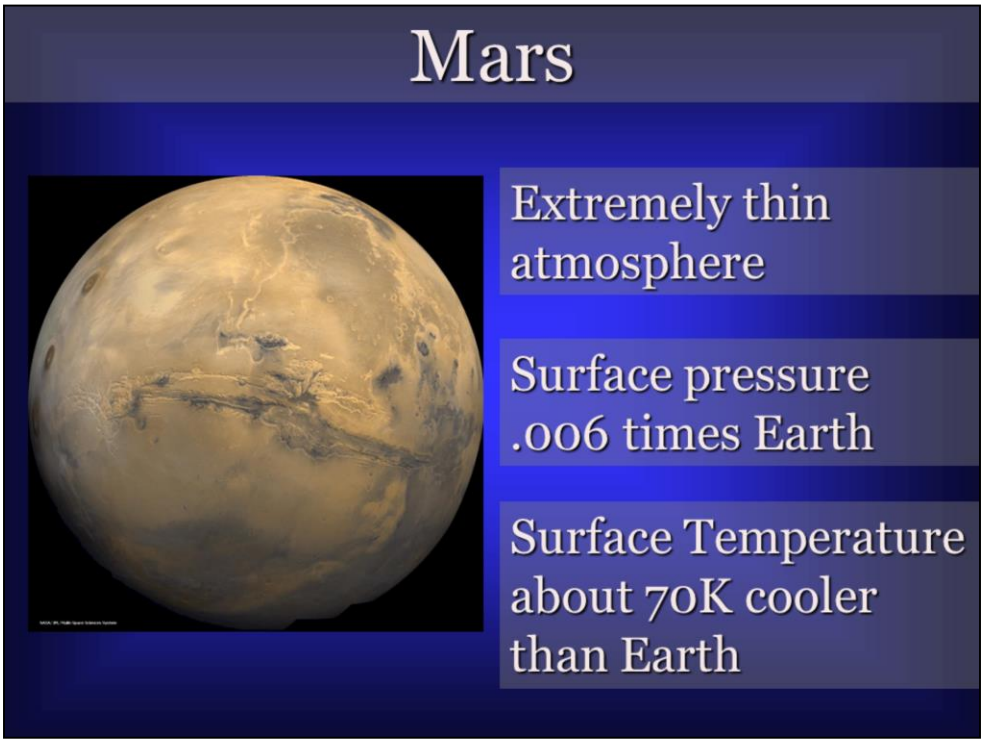
****What's different about Venus, compared to Earth, at the beginning of the solar system?****

Remember which gas is the most effective greenhouse gas! Water! Without any atmosphere, Venus is at about 294K… so a lot more water stays in the atmosphere.



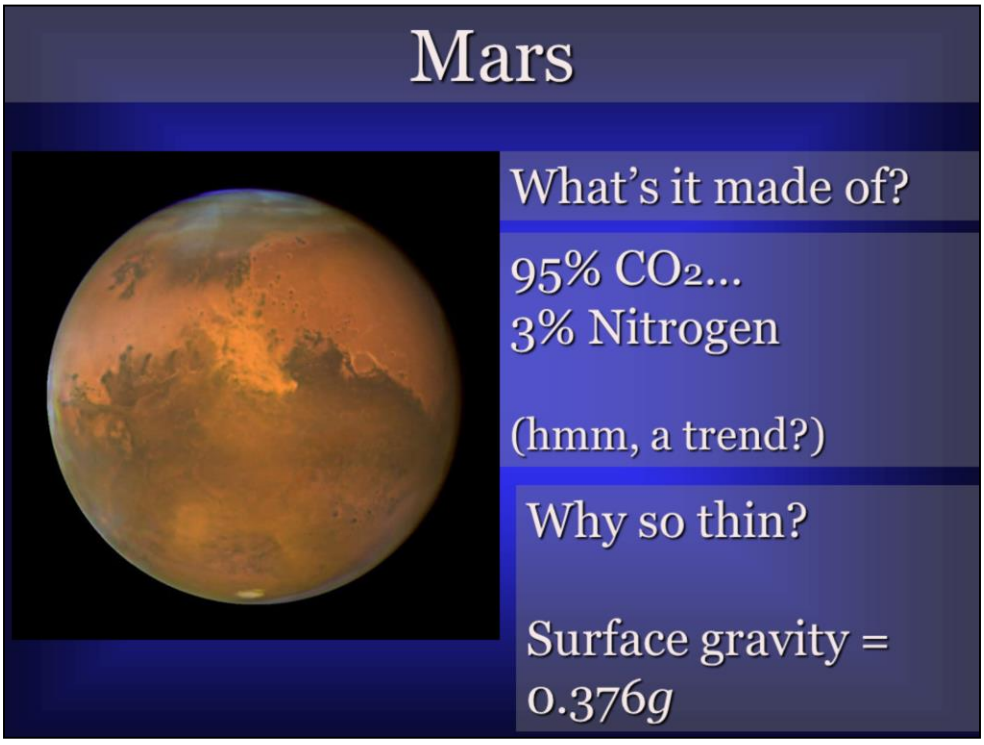
This photo is radar imaging of the surface of Venus.

Once you don't have the any possibility for a CO_2 cycle (need oceans), any volcanic activity is just going to make more and more CO_2 in the atmosphere, and it'll never come out again.



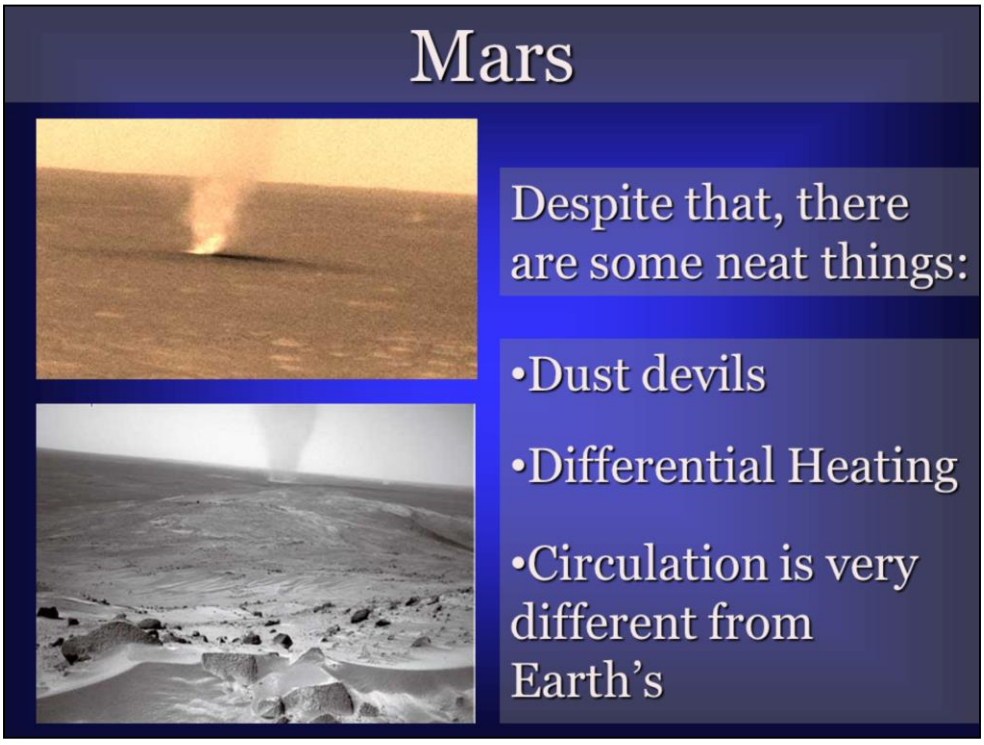
Mars' climate varies a lot, depending on the season and the orbit. Unlike most planets, Mars' orbit has enough eccentricity to matter a little.

Temperature should be about 203K (-70C)

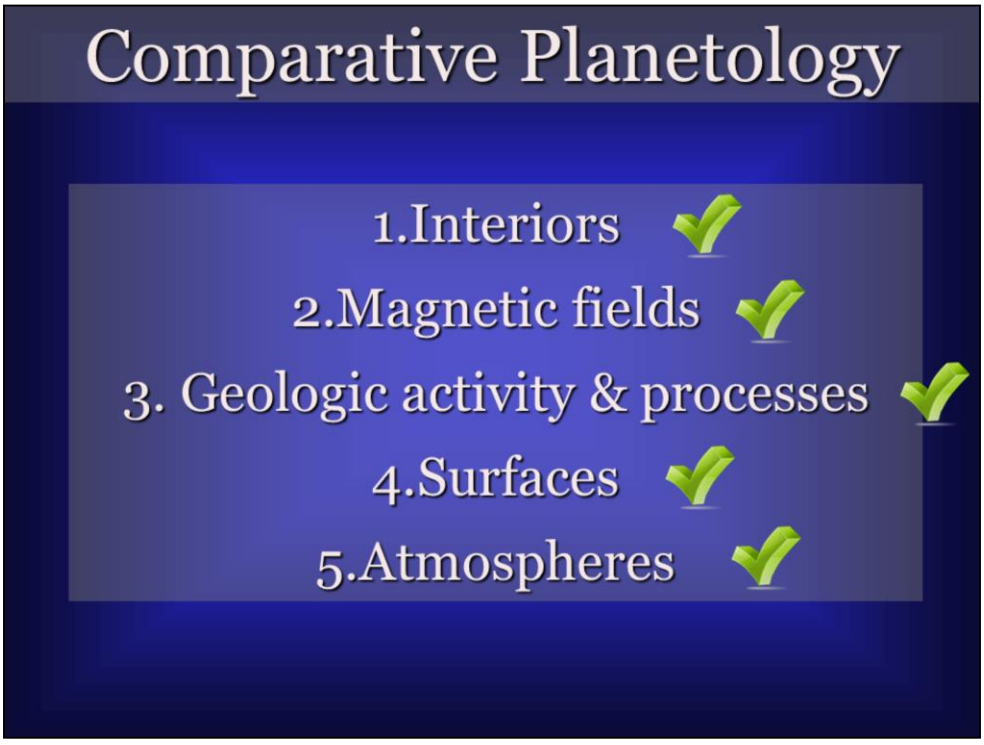


Even though Mars is somewhat colder than the Earth (due to being farther away), it is not cold enough to make a difference for holding onto that atmosphere. Mars' gravity is small enough that it has a hard time holding onto its atmosphere.

Where's the water? Did it escape through dissociation (like Venus)? The UV radiation would be less out this far, but the lack of magnetic field means the atmosphere is bombarded more by particles… a lot of the oxygen is locked up in rusting the surface rocks. On the other hand… we do see evidence of water, just not in the atmosphere.



(Board work for the circulation and heating)



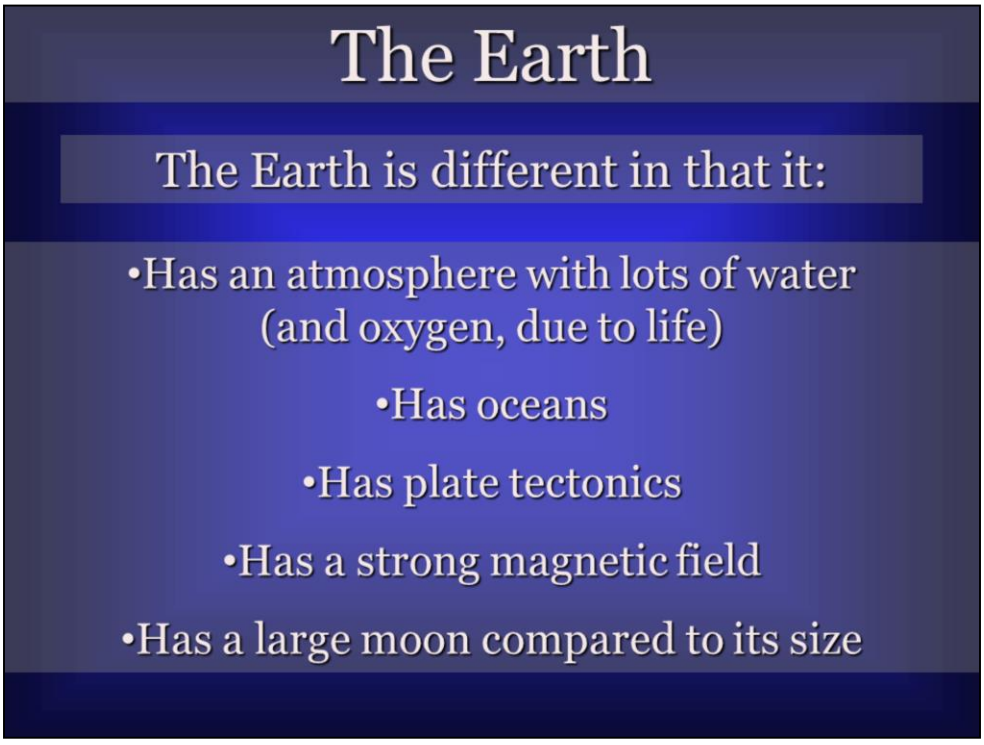
These are the things we need to look at to understand how (terrestrial) planets form. We'll start with the Earth, and compare from there.

Comparison

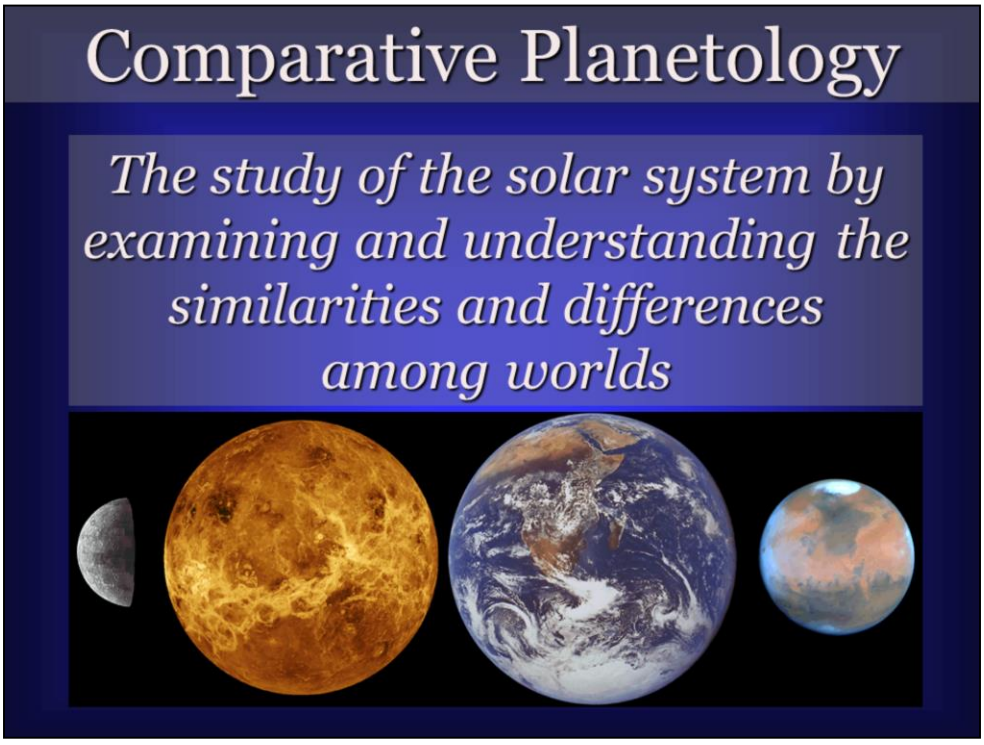
Property	Mercury	Venus	Earth	Mars
Atmosphere	Minimal temporary H & He	Dense 96% CO_2 Hot **H_2SO_4**	Medium density N (77%) **O (23%)**	Thin 95% CO_2 Some water ice clouds
Interior	Large dense core	Molten core	Molten core	(Mostly) solid core
Geologic activity	None currently (some in the past)	Volcanic No Erosion No plate tectonics	Volcanoes earthquakes Plate tectonics	Volcanic in the past Huge tectonic stresses Erosion
Surfaces	Lots of craters	Few craters	Few craters	Some cratered, some newer
Magnetic field	**Surprisingly strong!**	None	Strong	Remnant

Remember: Our oxygen is only because we have life on this planet!! Plant life, specifically.

Similarly there wouldn't be Sulfuric Acid on Venus if there weren't current volcanic activity.



These are the ways that the Earth is *different* from the other terrestrial planets. We will see next week how the Earth is *similar*, and what some of the differences between the other terrestrial planets are. Note that there are more differences with the Earth's atmosphere as well, such as atmospheric structure and composition – but we'll get to that next week.



We could just talk about planets (and one moon with an atmosphere), but there are other objects in the solar system which also undergo some of these processes as well. How do they compare?

Moons of Jovian Planets

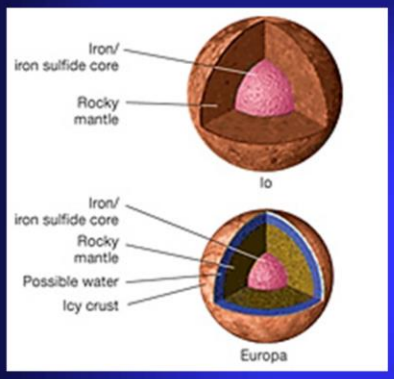
Larger moons likely formed like terrestrial planets

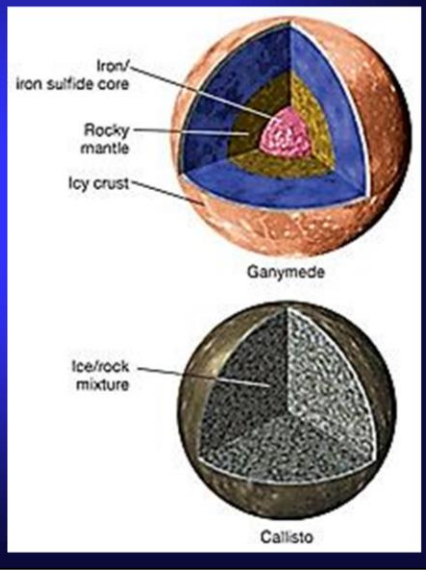
Smaller moons could be captured asteroids or comets

Moons of Jovian Planets

Given what you know about solar system & planetary formation, what would you ***expect*** the Galilean moons, and Titan to be like?

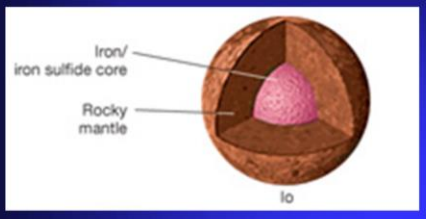
Galilean Moons (Jupiter)





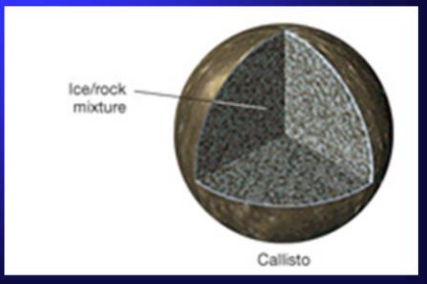
Interiors:
Iron/iron sulfide core
Rocky mantle
Water/icy crusts (2)

Galilean Moons (Jupiter)



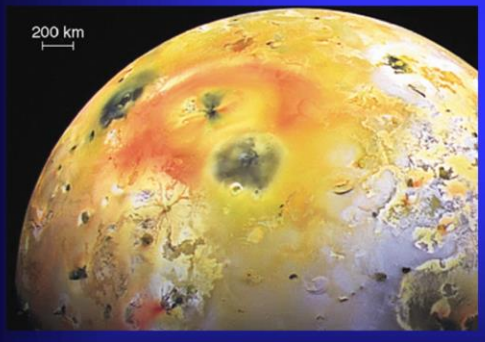
Exceptions:
Io: No water, possibly almost completely molten

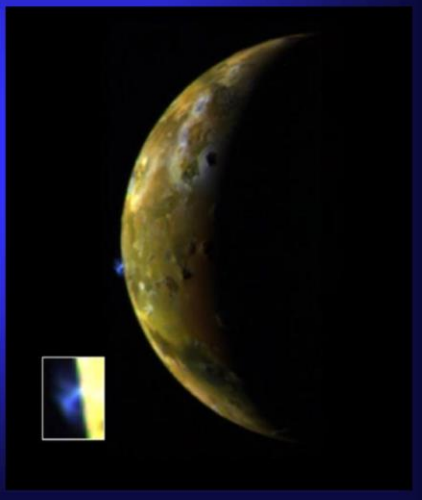
Callisto: "uniform" ice/rock mixture



Io (Jupiter)

Volcanically active!!

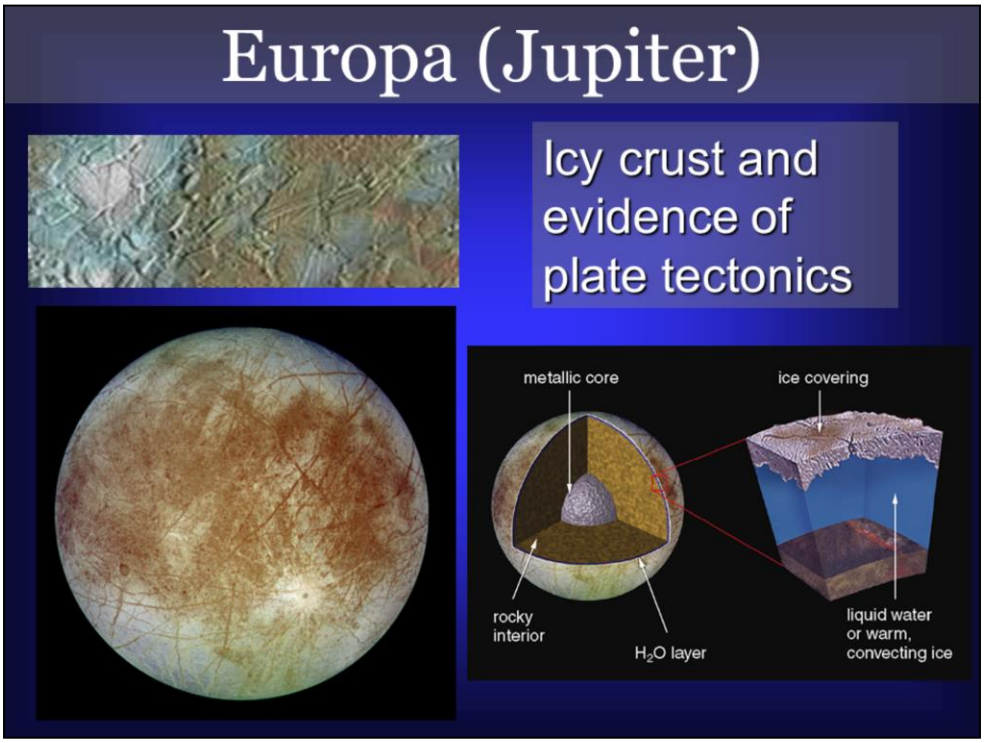




Io (Jupiter)

Volcanically active: why?

- Tidal forces with Jupiter
- Resonances with the other moons, especially Europa tugs it back and forth
- This tugging causes Io to have *lots* of heating due to tides



Metallic core, rocky mantle, and a crust made of H_2O ice

Its fractured surface indicates **plate tectonics**

- few impact craters seen
- double-ridged cracks
- jumbled icebergs

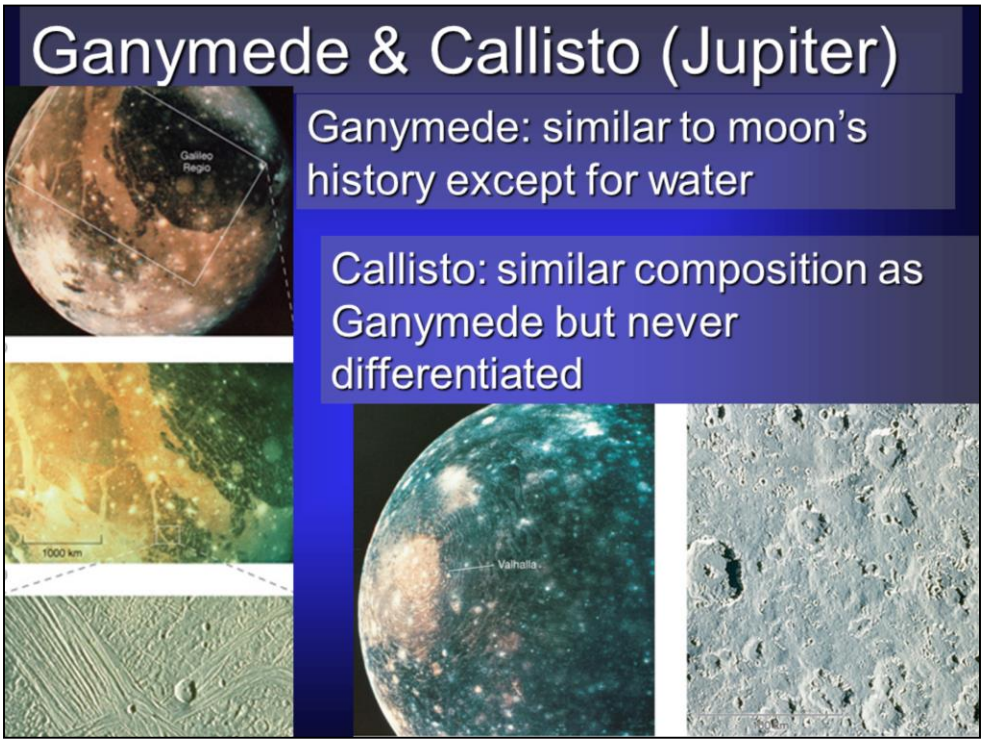
These provide photographic evidence of a subsurface ocean

Europa has a magnetic field

- Implies liquid salt water beneath the icy crust

Where liquid water exists, there could be life!

Again, tidal heating!



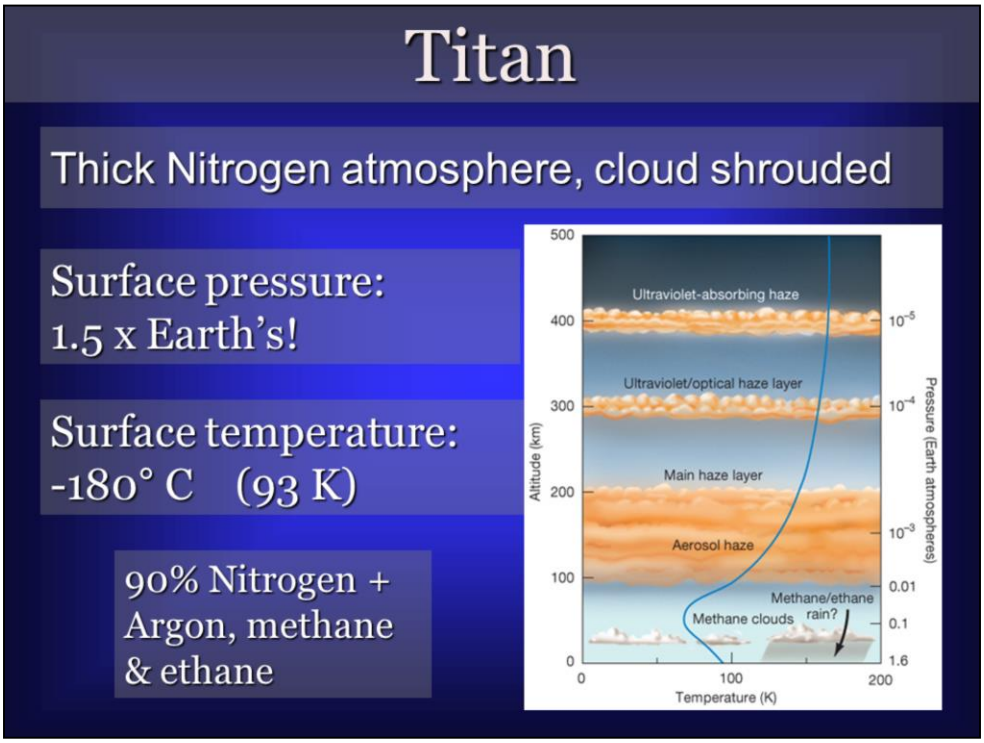
Ganymede: Dark areas are similar to moon's highlands, heavily cratered and old. Light areas are similar to the moon's maria, fewer craters and so younger; likely upwelling (more with water though than lava) after impacts similar to how the maria formed on the moon. May have slushy water ice beneath the surface, because it has a very weak magnetic field.

Callisto: More heavily cratered than Ganymede. Froze before any tectonics could start. Large ringed area was probably a very large impact. Why Callisto didn't differentiate like Ganymede is a mystery.

Titan is Saturn's biggest mooon.

Titan has an atmosphere! (Hubble is visible light – what you would see with your eyes; Cassini is infrared, seeing through the smog) Titan's atmosphere is at the triple point of methane – liquid, gas, and solid methane can exist on Titan… and there's more methane in its atmosphere than there should be, so *something* has to be replenishing it.

Titan's surface temperature without an atmosphere would be 80K (-192C) – so it's gained ~12 degrees from its atmosphere. Its radius is about 2500km (0.4 Earth's radius; compare to Mars which is about 0.5 Earth Radii). Its surface gravity is 0.14g (compare to Mars at about .3g). Yet it has a much thicker atmosphere than Mars. Why? Because it's just so much colder out by Saturn; molecules move much more slowly and therefore it's harder for them to escape.



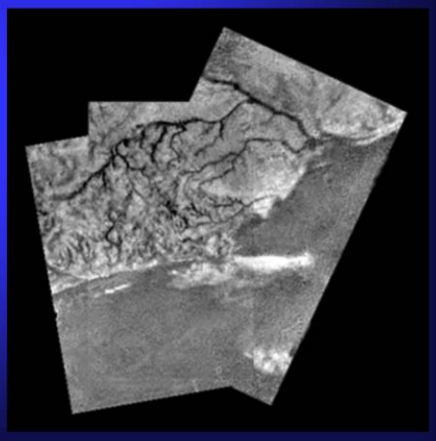
Titan is Saturn's biggest mooon.

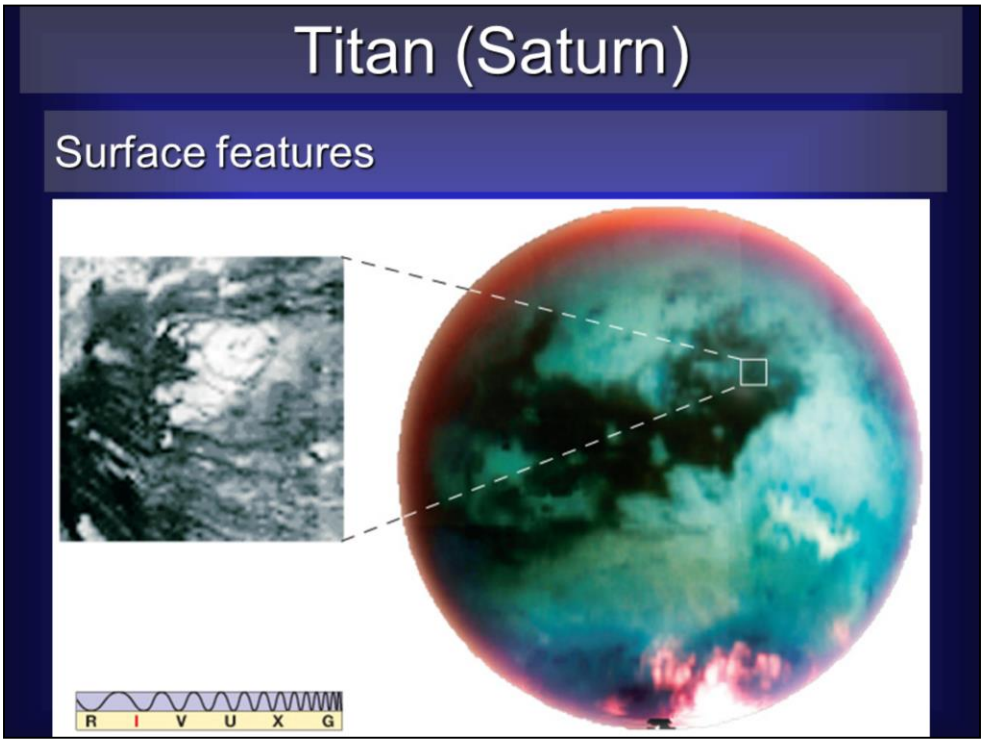
Titan has an atmosphere! (Hubble is visible light – what you would see with your eyes; Cassini is infrared, seeing through the smog) Titan's atmosphere is at the triple point of methane – liquid, gas, and solid methane can exist on Titan… and there's more methane in its atmosphere than there should be, so *something* has to be replenishing it.

Titan's surface temperature without an atmosphere would be 80K (-192C) – so it's gained ~12 degrees from its atmosphere. Its radius is about 2500km (0.4 Earth's radius; compare to Mars which is about 0.5 Earth Radii). Its surface gravity is 0.14g (compare to Mars at about .3g). Yet it has a much thicker atmosphere than Mars. Why? Because it's just so much colder out by Saturn; molecules move much more slowly and therefore it's harder for them to escape.

Titan (Saturn)

Thick Nitrogen atmosphere, cloud shrouded with smoggy haze

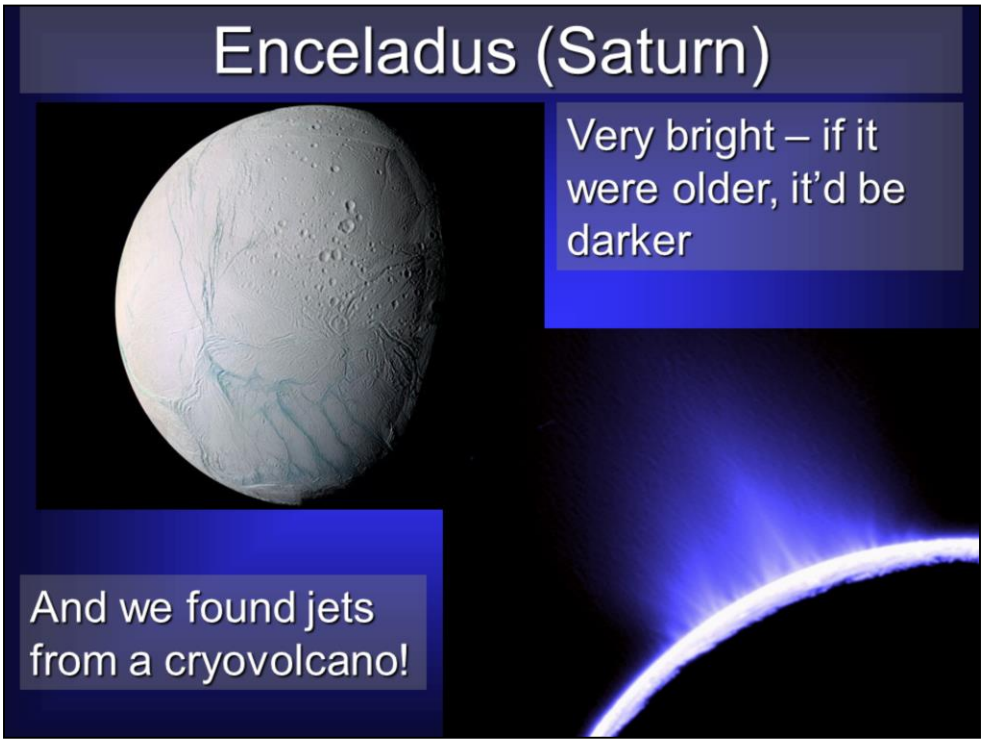




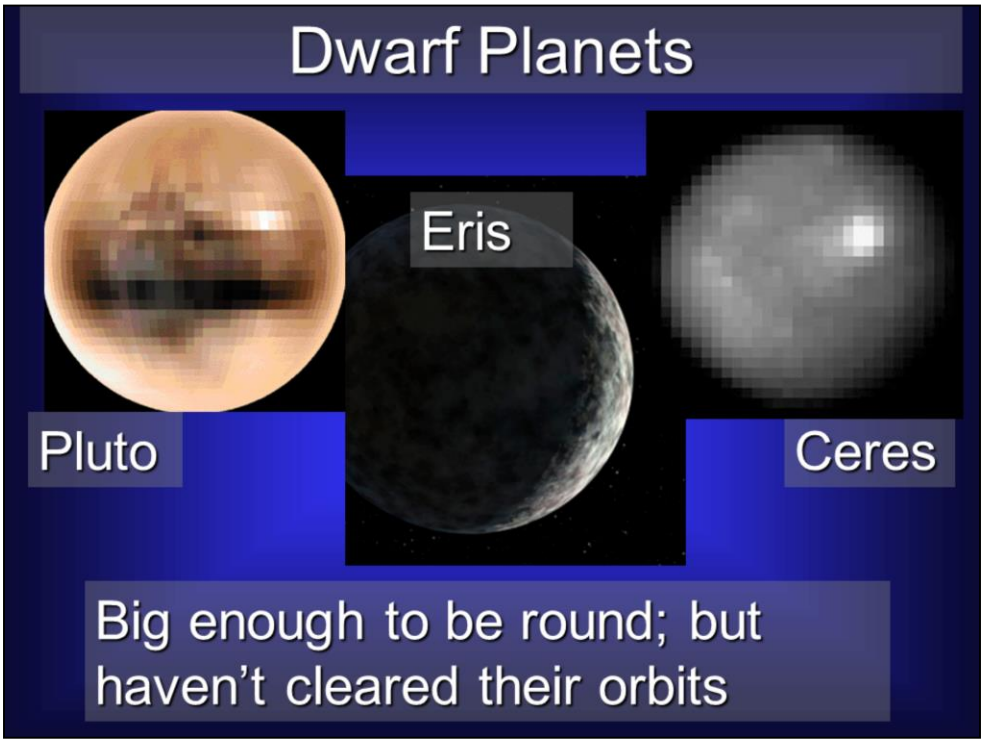
Remember: Using radar, smooth things are dark and rough things (like mountains) are bright.

The image on the left shows an active cryovolcano on Titan.

Are there ethane oceans on Titan? Yes! And methane/ethane rain!



Enceladus is very bright. Reflects almost 100% of the light that falls on it. We see jets, even!! It is tectonically active. We also see places where – similar to the moon's maria – plains have been flooded and frozen with ice. Very few craters!



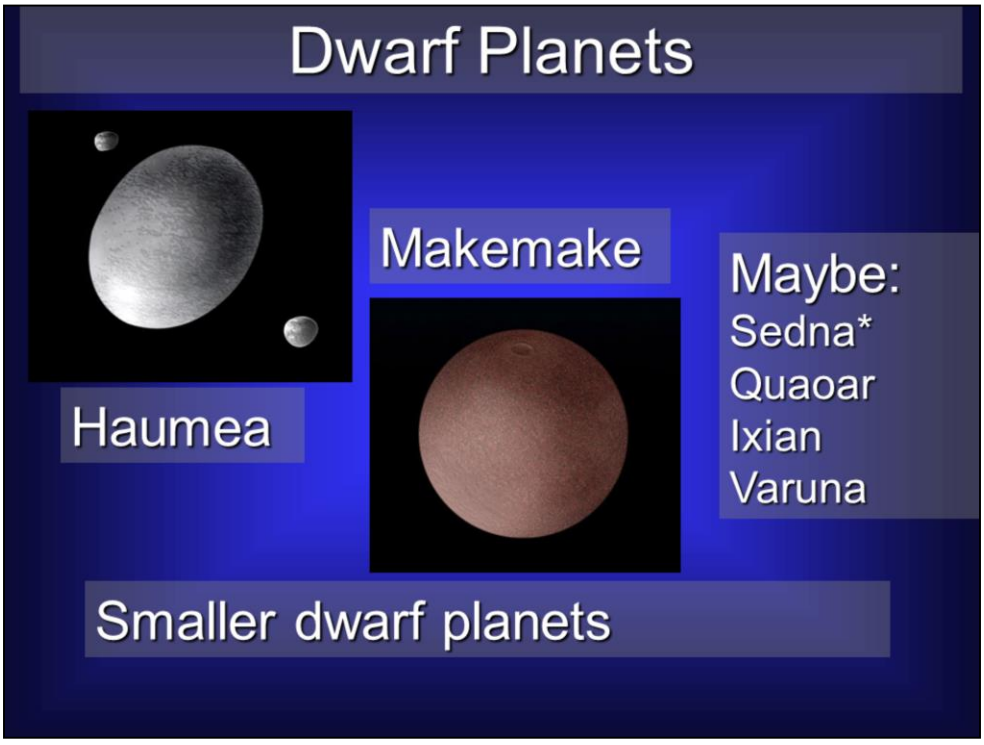
Pluto has many properties in common with Kuiper belt comets.

- Its orbit is very similar to Kuiper belt comets
- Its composition of ice and rock is very similar

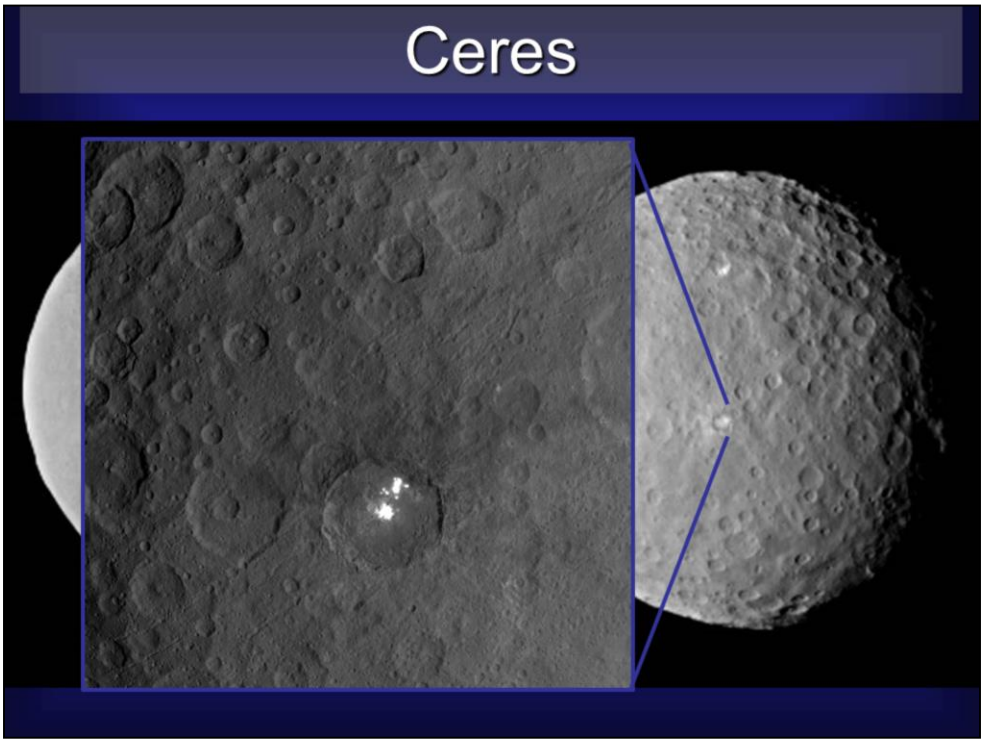
Pluto has some properties which differ from Kuiper belt comets.

- Its surface is much brighter; Nitrogen atmosphere refreezes on the surface rather than escaping
- It is much larger than most Kuiper belt comets
- Charon moon is believed to have formed in the same way as our Moon

Eris is the largest dwarf planet so far.

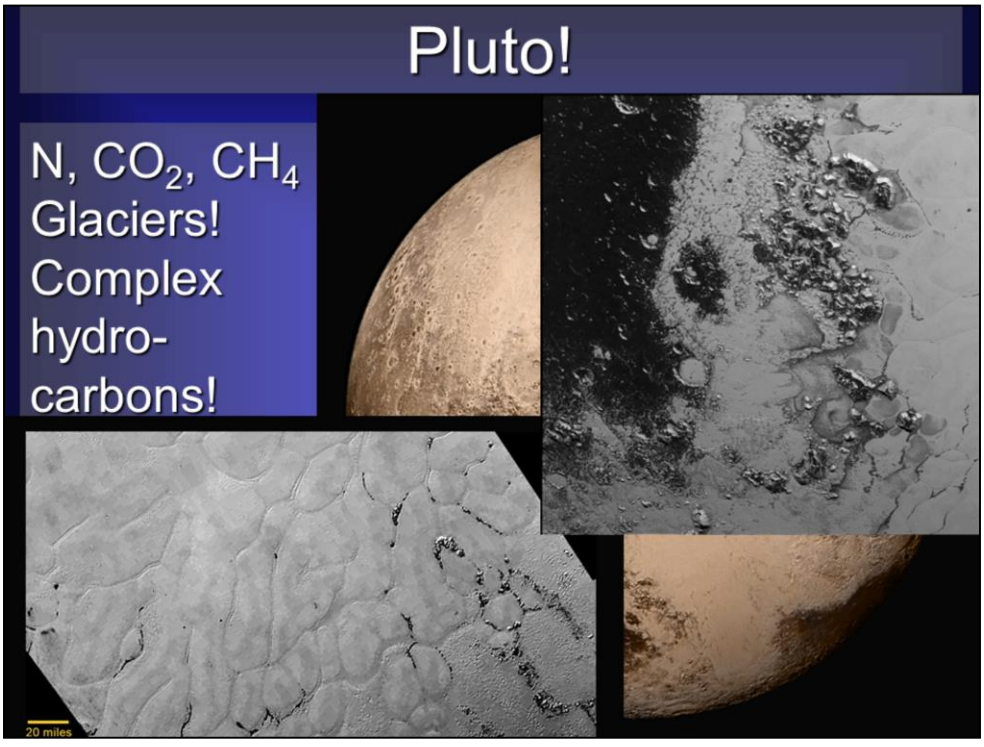


Sedna is a possible Oort cloud object

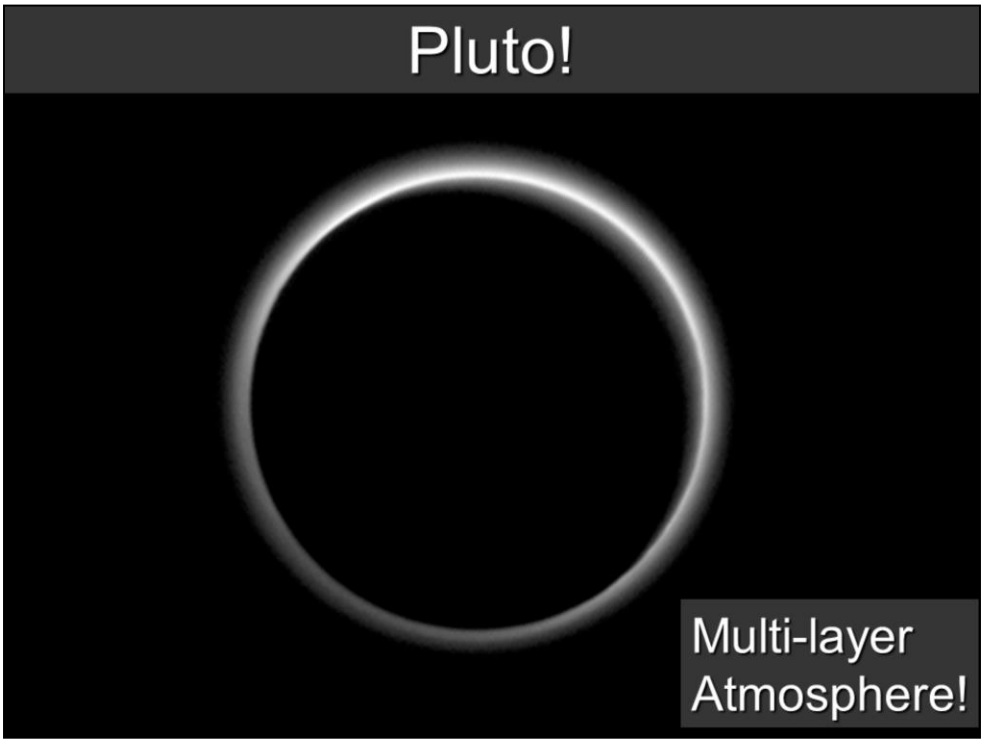


What are the weird bright spots?

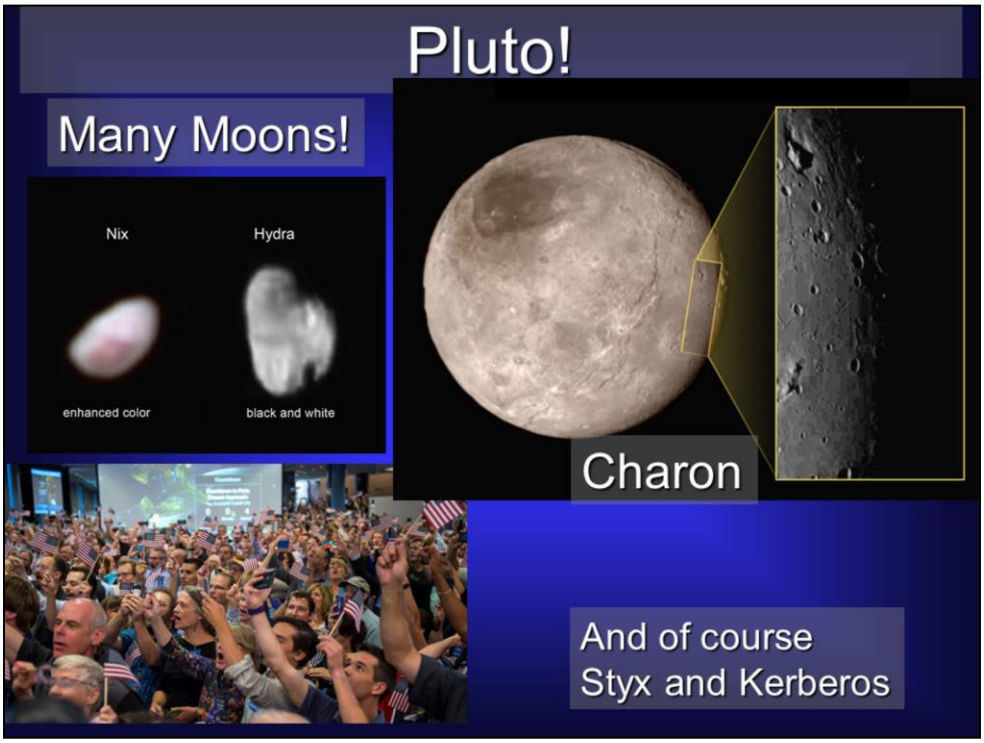
Lots of craters!



Glaciers, ice flows, weird smooth planes with shallow troughs and dark hills, dark complex hydrocarbons, weird looking features… where are the craters???



At least two levels of haze! Mostly nitrogen



Charon, what's up with that big crack eh? Is it an extension crack due to cooling? Or something else?

Well…. After talking about our atmosphere/global warming ☺