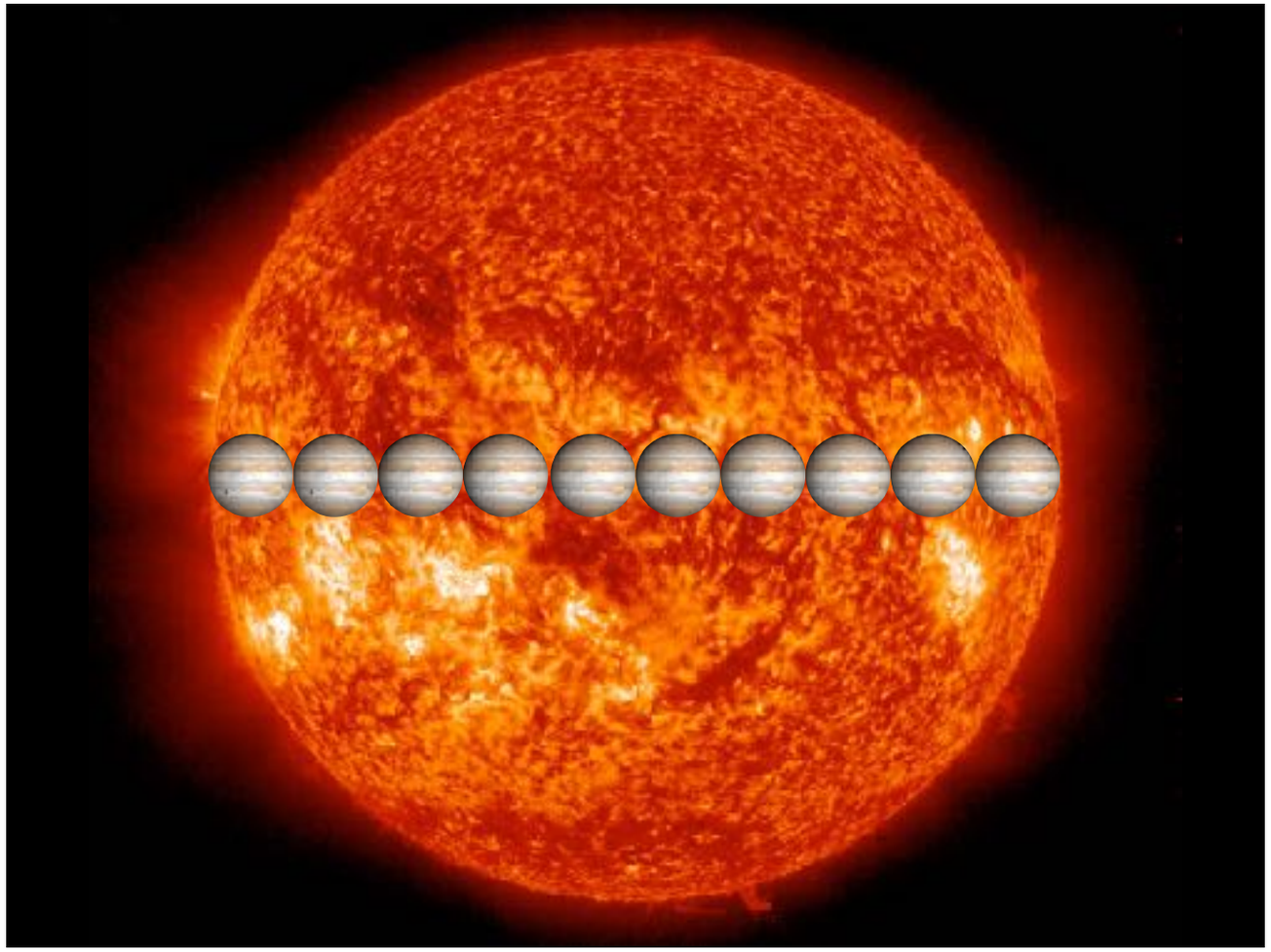
WELCOME TO THE NEIGHBORHOOD

SCENE II: EARTH & THE SOLAR SYSTEM

The Solar System — everything held sway by the Sun's gravity

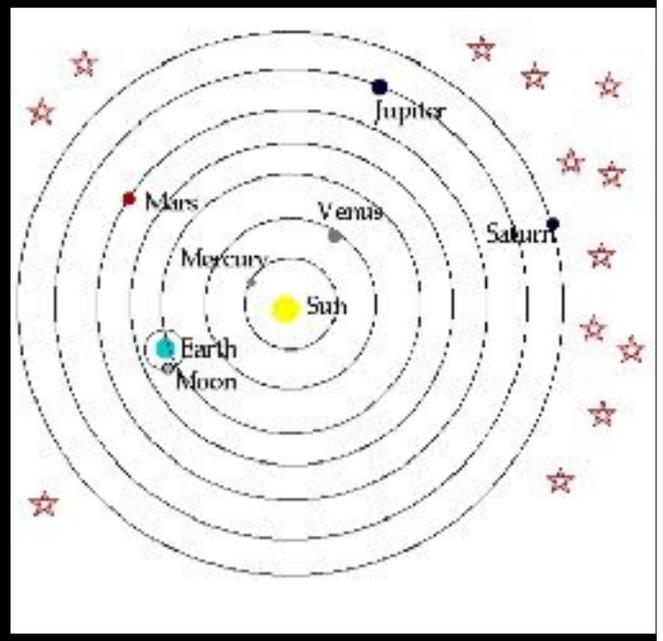
i.e. The Sun itself, planets, moons, asteroids, comets, dust, and very thin gas



If you take a step back, like *way* back, you might define the solar system as the Sun. That's because the Sun comprises more than 98% of the mass of the entire Solar System. The next most massive object, Jupiter, is only a tenth the diameter and less 1% the mass of the Sun

RECAP

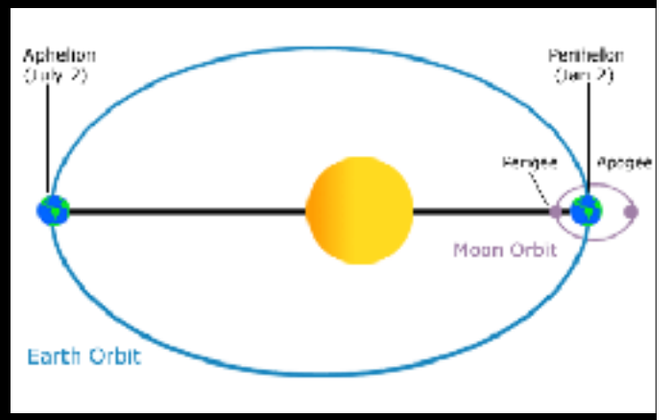
- Copernicus proposes the Earth and other **planets orbit around the Sun**



Fun fact: Aristarchus of Samos proposed Sun-centered orbits a full 2000 years before Copernicus, but it didn’t get much attention

RECAP

- Copernicus proposes the Earth and other **planets orbit around the Sun**
- Kepler realizes the **planets orbit in ellipses**, not circles, fixing the Heliocentric model



RECAP

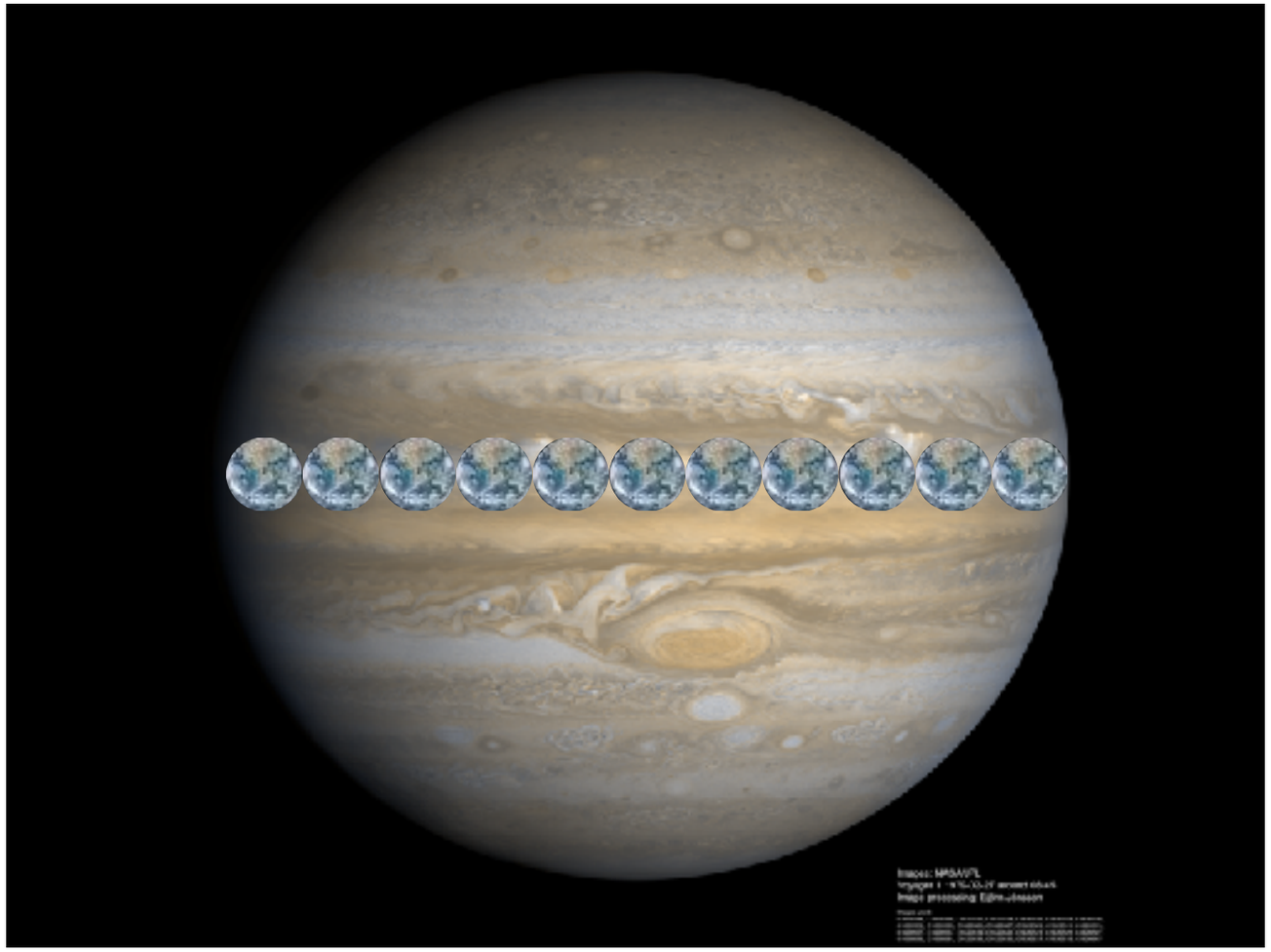
- Copernicus proposes the Earth and other **planets orbit around the Sun**
- Kepler realizes the **planets orbit in ellipses**, not circles, fixing the Heliocentric model
- This paves the way for Newton to apply physics to determine how **gravity** works

$$F_g = \frac{GMm}{r^2}$$

Gravity is the cornerstone of our modern understanding of how the Solar System truly operates. The Sun, being the most massive thing in our solar system by far, has the strongest gravity and basically runs the Solar System

SOLAR

Sol is Latin for “sun”



The planets are tiny compared to the Sun but still huge compared to us humans. On the big end is Jupiter — 11 times the diameter of Earth and 1000 times its volume

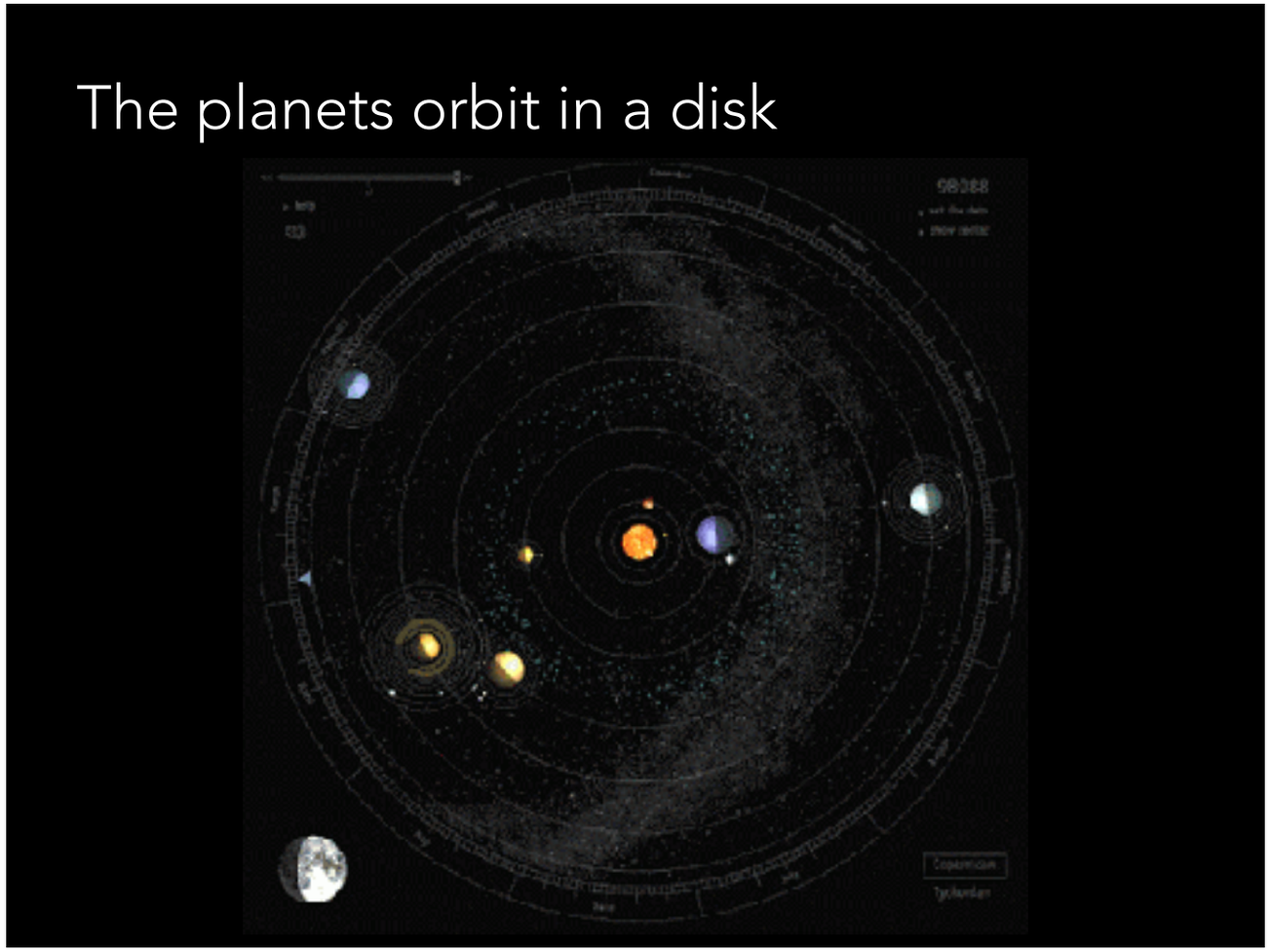
IS PLUTO A PLANET?

The definition of “planet” is pretty ambiguous

PROPOSED DEFINITIONS FOR "PLANET"

- Big enough to be round
  - But a lot of moons are round and so are some asteroids
- Has its own moon
  - But Mercury and Venus don't have moons, and many asteroids do
- Bigger than (pick a size)
  - But Jupiter's moon Ganymede is bigger than Mercury

No matter what definition you come up with, you'll find there are lots of exceptions. That's a good indication that trying to rigidly define "planet" is a mistake

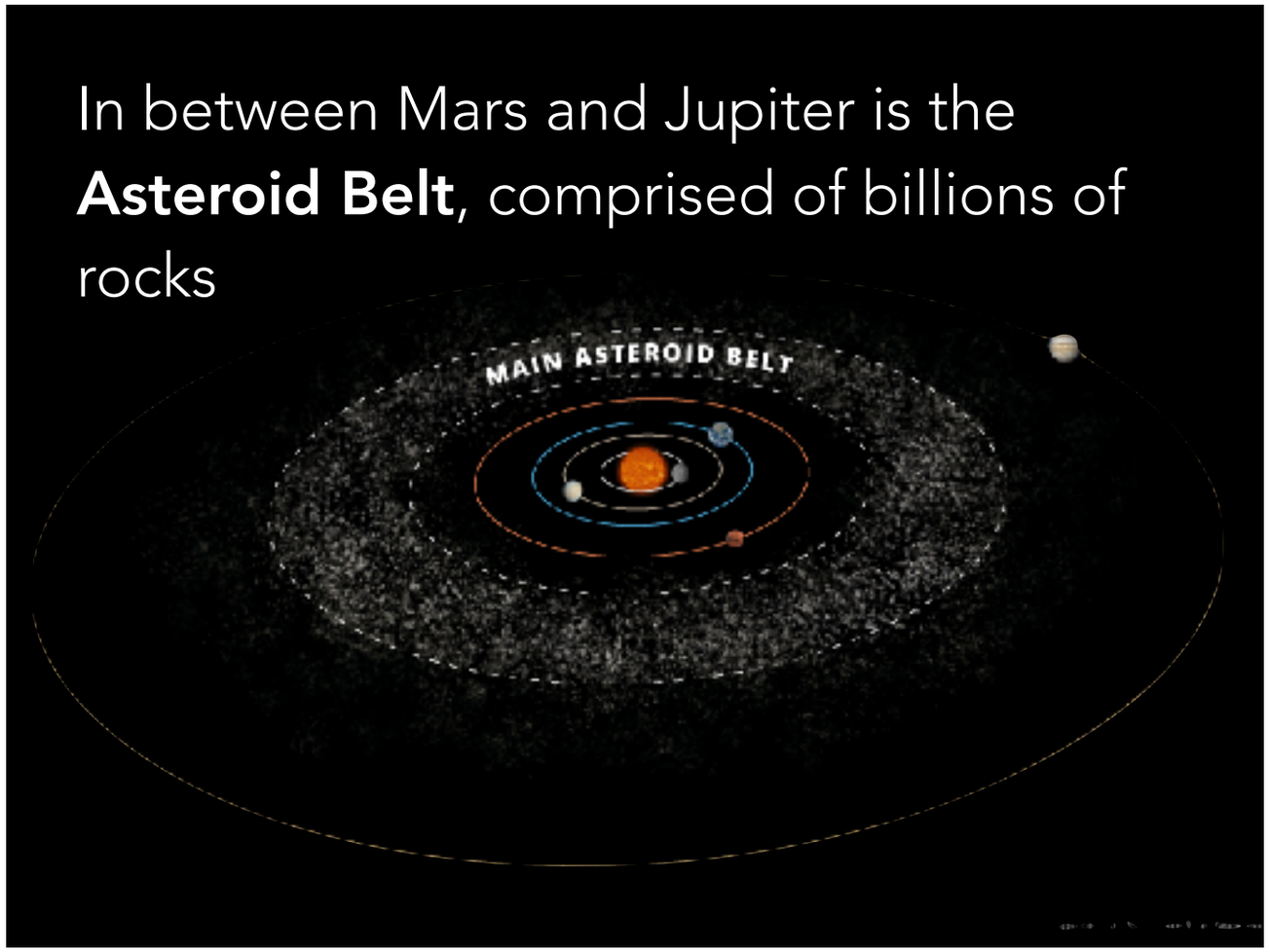


Pay attention to trends — nature’s trying to tell you something

The **inner planets** are all relatively small and rocky

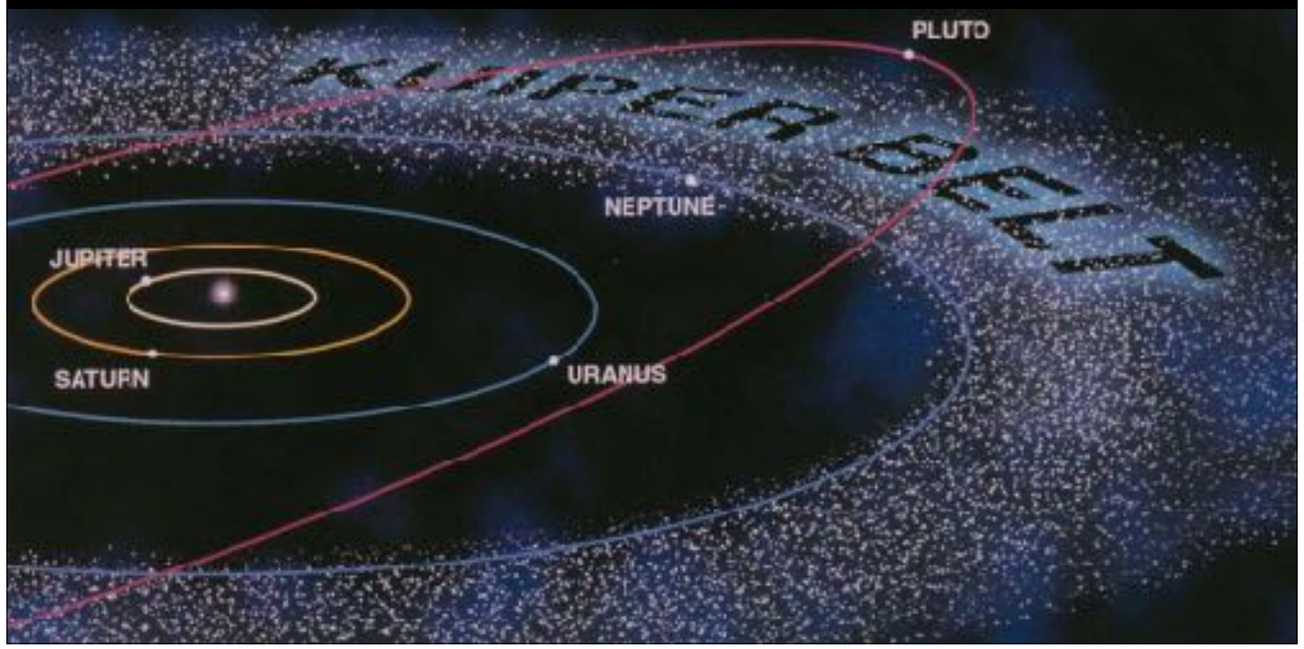
The **outer planets** are much larger and have tremendously thick atmospheres

In between Mars and Jupiter is the **Asteroid Belt**, comprised of billions of rocks



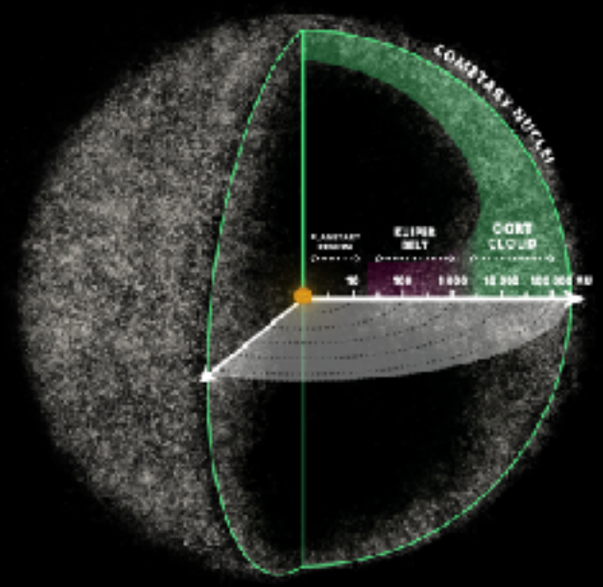
There are lots more asteroids scattered around the Solar System, but most of them are in the main belt

Out beyond the orbit of Neptune, there's a collection of rocky ice balls called **Kuiper Belt** objects



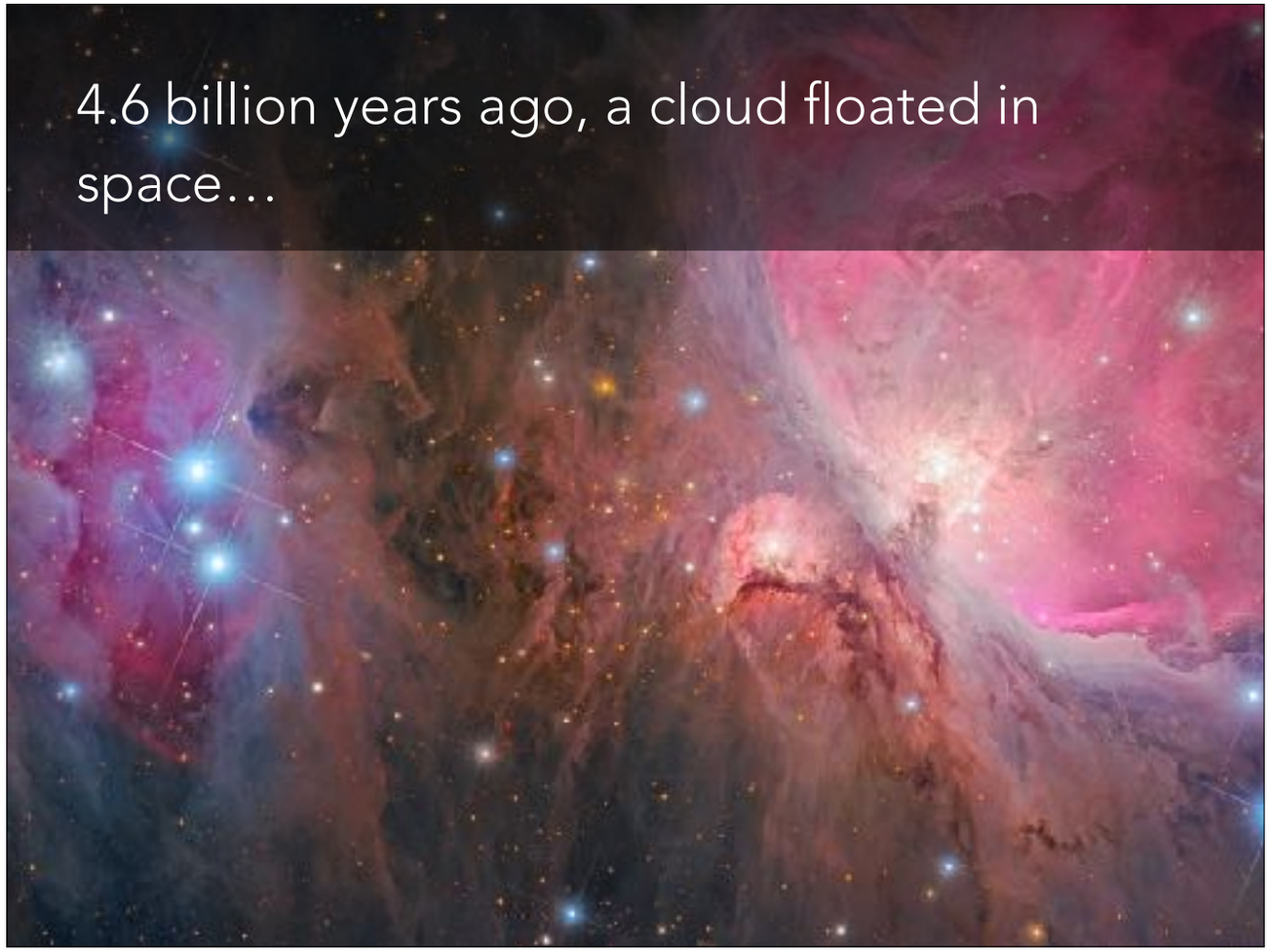
The biggest Kuiper Belt objects are over 1,000 miles across, but most are much smaller. They tend to follow the plane of the planets, too

Further out, starting tens of billions of kilometers from the Sun, that disk of Kuiper Belt objects merges into a vast *spherical* cloud of these ice balls called the **Oort Cloud**



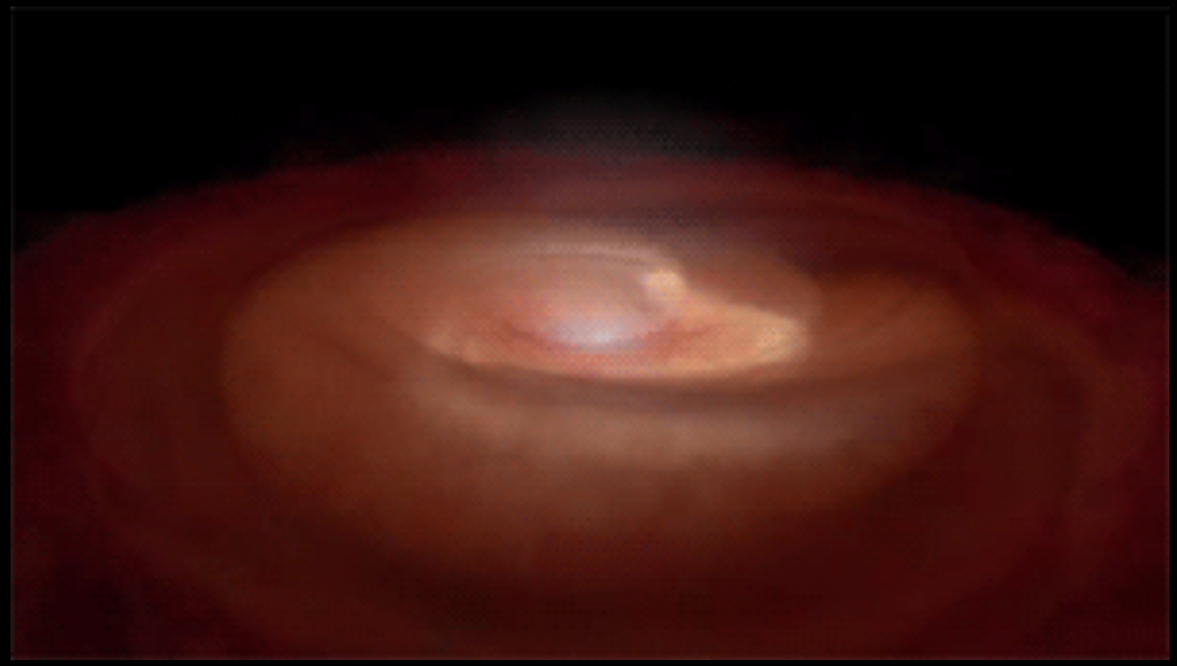
Objects in the Oort Cloud don’t follow the plane of the Solar System but orbit every which way

All these trends give us hints about how the Solar System formed



This cloud was in balance. The gravity trying to pull it together was counteracted by the heat trying to push it apart. But then something happened. Maybe the shockwave from an exploding star slammed into it, maybe it collided with another nebula, either way, the cloud got compressed, upsetting the balance

Gravity took over and angular momentum became important



- **Regular momentum**: *an object in motion stays in motion*
- **Angular momentum**: *an object that spins continues to spin*
  - depends on the object's size and how rapidly its rotating
  - decrease the size and rotation rate goes up

That's what happened in the cloud. Any small amount of spin it had got ramped up as it collapsed. The faster it spun, the more it flattened out

As the cloud collapse, material fell to the center, getting very dense and hot

Further out, where it was cooler, material started to clump together

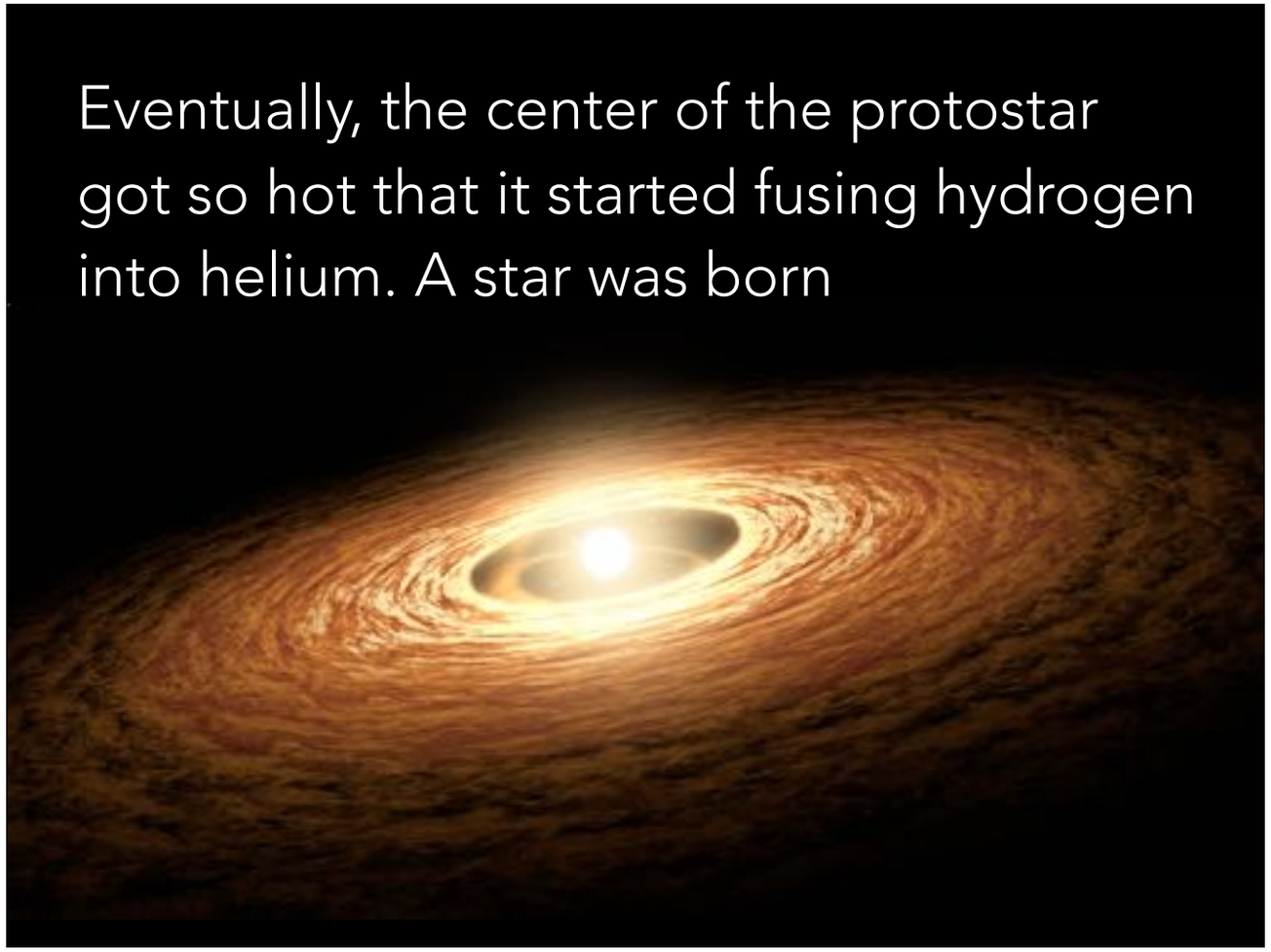
As these clumps grew, their gravity increased and started drawing more material in

Little bits dust randomly bump into other little bits and stick together to make a bigger clumps

PLANETESIMALS

Wee baby planets

As they grew, so did the center of the disk. The object forming there was a protostar (or, spoiler alert, proto-*Sun*)



This produces a LOT of energy. The new Sun blasted out fierce light and heat that, over millions of years, blew away the rest of the disk material that hadn’t yet assimilated into planets. The Solar System was born

Near the Sun it's warmer. Hydrogen and helium are very light gases, and the warm baby planets there couldn't hang onto them

The inner planets contain large percentages of heavy elements, such as iron or nickel. These planets lost they less dense gases because at the temperature of the gases, gravity was not strong enough to hold them. Other lighter elements may have been blown or boiled away by radiation from the Sun

Further out, there was more material in the disk, and the planets were bigger. Since it was cooler, too, they could hang onto those lighter gases. They became **gas giants**

The outer planets' atmospheres grew tremendously, eventually out-massing the solid material in their cores

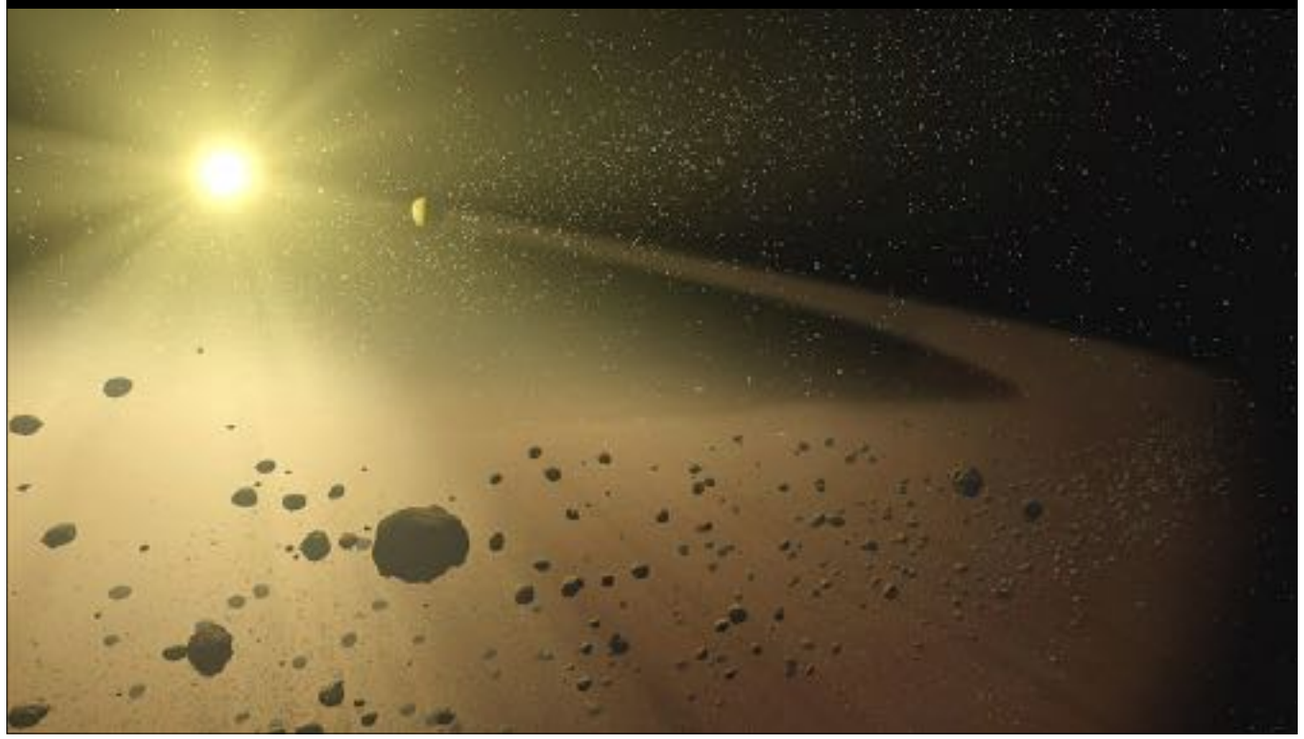
Lots of water far from the Sun, in the form of ice

Chunks of ice beyond Neptune clumped together but never got too big

Billions of these clumps got too close to the big planets and were flung all over the place

This accounts for the Kuiper Belt and Oort Cloud

Closer in, material between Mars and Jupiter also failed to form a planet



Jupiter’s gravity kept agitating it, and collisions between two bodies tended to break them up, not aggregate them together

THE SOLAR SYSTEM

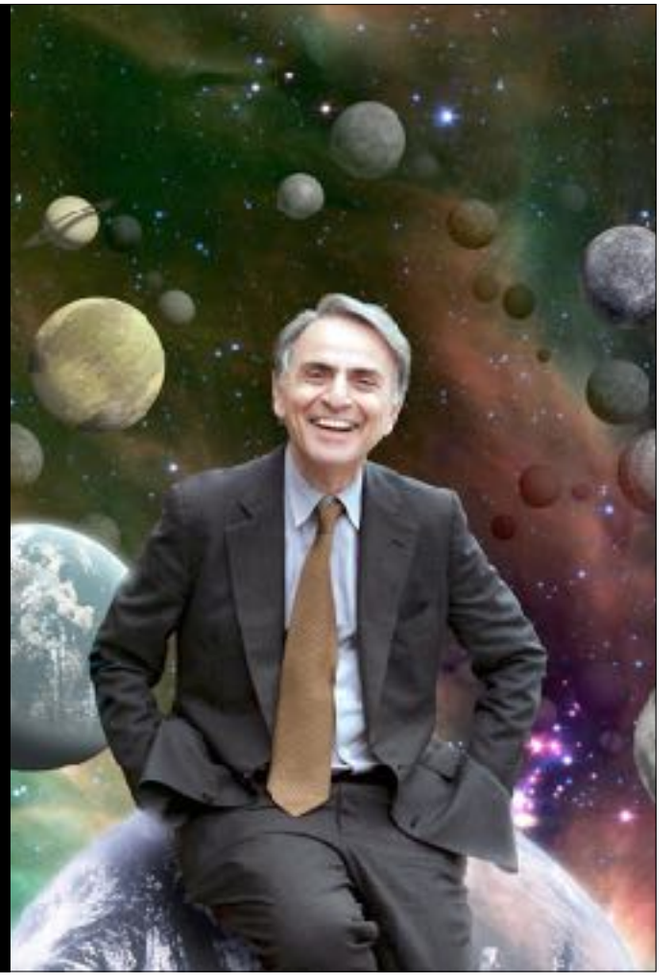
Formed from a disk. Sculpted by gravity

Echos of that disk live on today, seen in the flatness of the Solar System

This isn’t guess work. The math and physics bear it out. Not only that, but we see it happening now, today, as new solar systems are born in distant gas clouds all around the galaxy

"The nitrogen in our DNA, the calcium in our teeth, the iron in our blood, the carbon in our apple pies were made in the interiors of collapsing stars. **We are made of starstuff**"

— CARL SAGAN



THE EARTH IS A PLANET

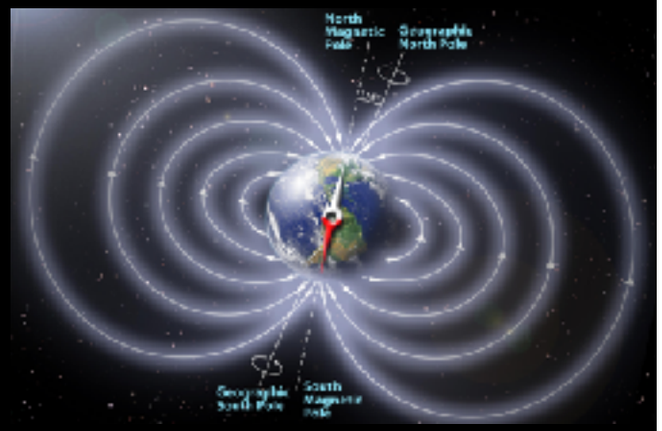
For thousands of years, planets were just bright lights in the sky, one-dimensional points that wandered among the fixed stars. With the invention of the telescope, those dots became worlds, and with spacecraft, they became places. The Earth went from being our unique home in the Universe to being one of many such planets

- The Earth is the largest of the terrestrial planets
- It's about 13,000 km across
- It has a single large moon
- Earth has water

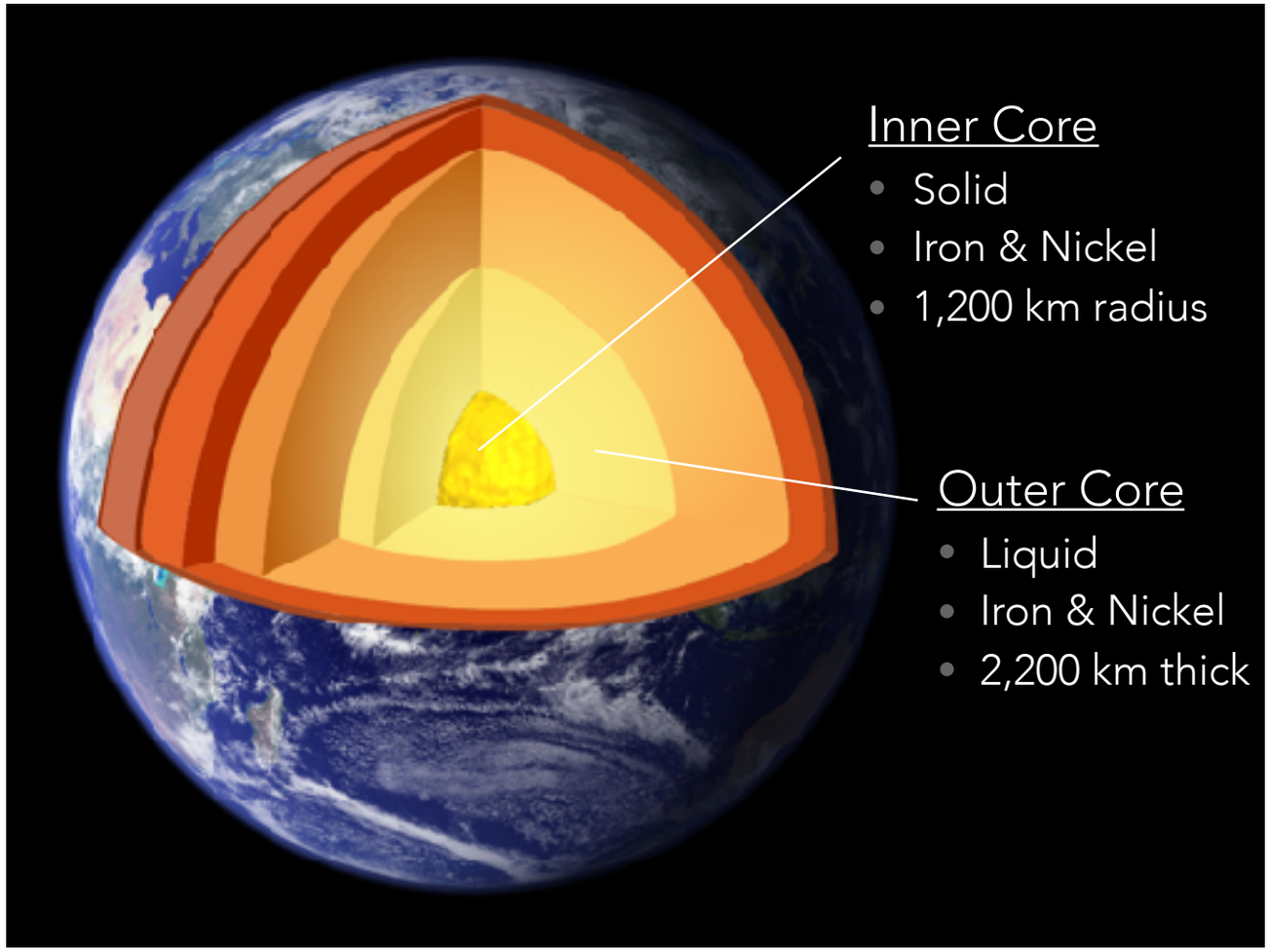
- The terrestrial planets are the four, small, rocky planets orbiting nearest the Sun
- Specifically, and unlike the other planets, Earth has *liquid* water on its *surface* where it can flow around, evaporate, become clouds, rain down, and mix up chemicals to get them to do interesting and complex things, like support life

EARTH'S ABILITY TO SUPPORT LIFE...

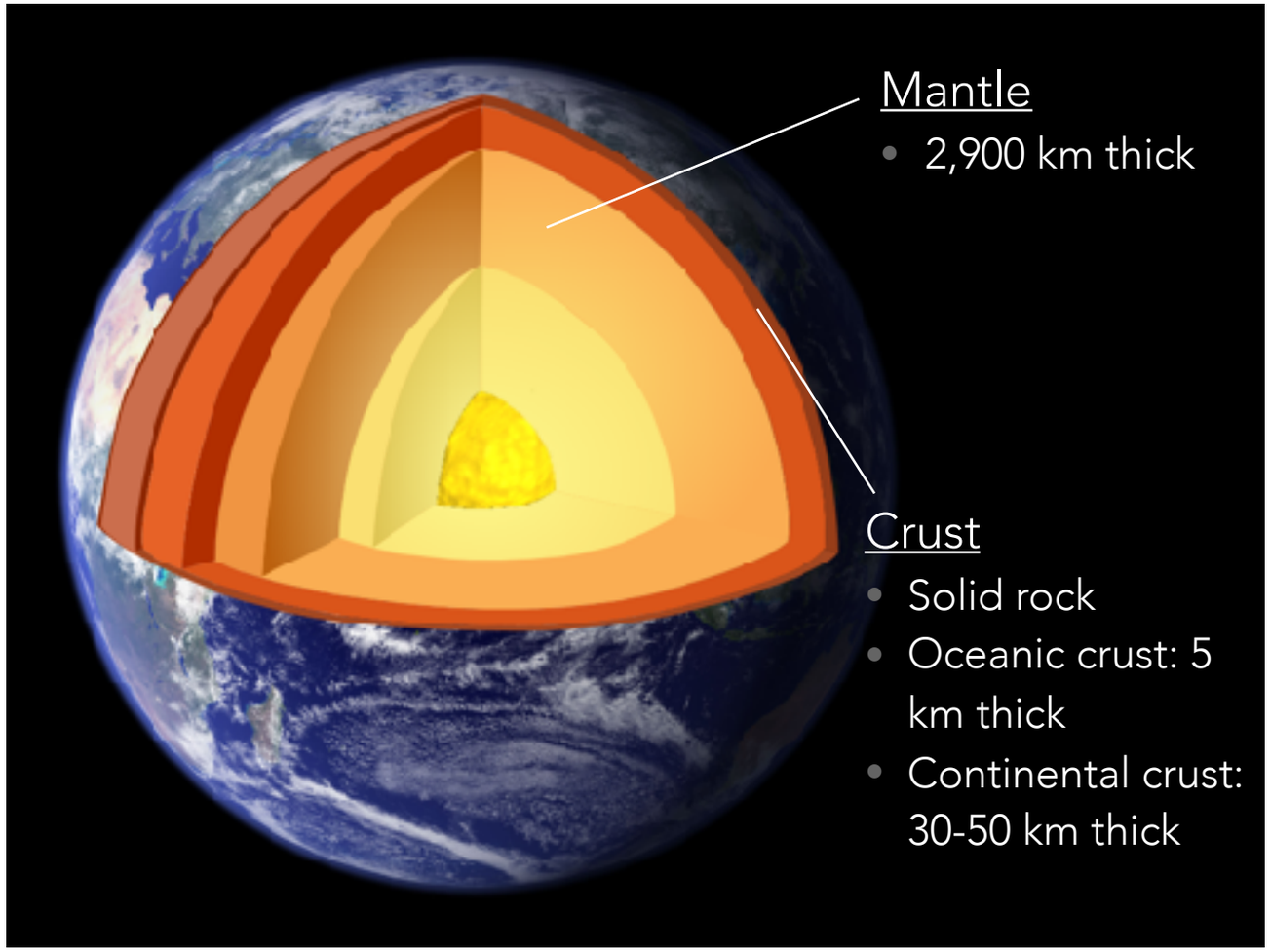
- depends on water
- and Earth's atmosphere
  - both of which depend on Earth's magnetic field to exist



The magnetic field, in turn, depends on what's going on deep inside our planet

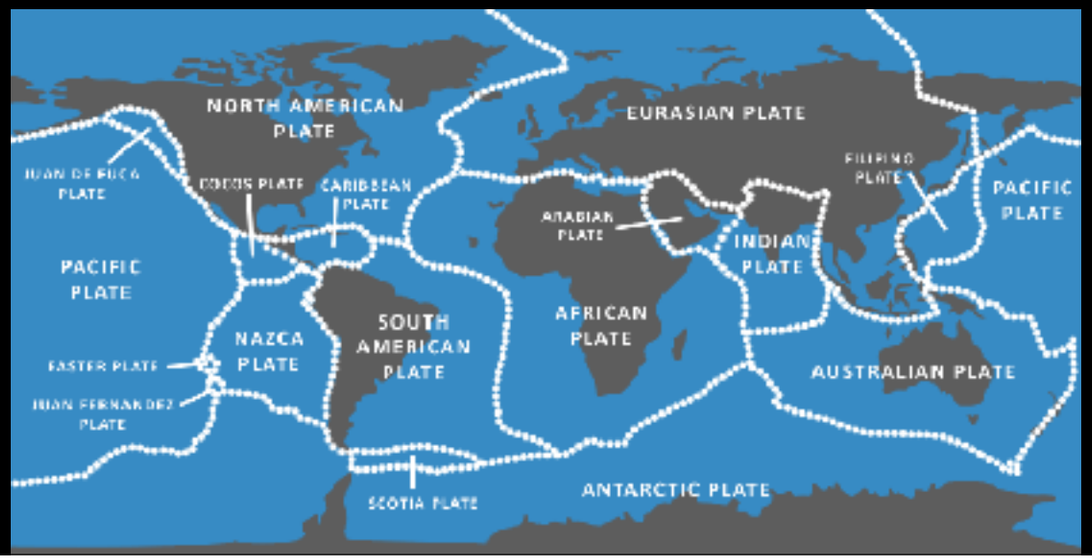


- Heavy elements sank to the center of Earth while it was forming, leaving the lighter elements, like oxygen, silicon, and nitrogen, to rise to the surface
- The temperature in the core reaches 5,500ºC. The pressure is also tremendous. You might think at such high temperatures iron would melt into a liquid, but iron can stay solid if the pressure is high enough (like in the inner core)



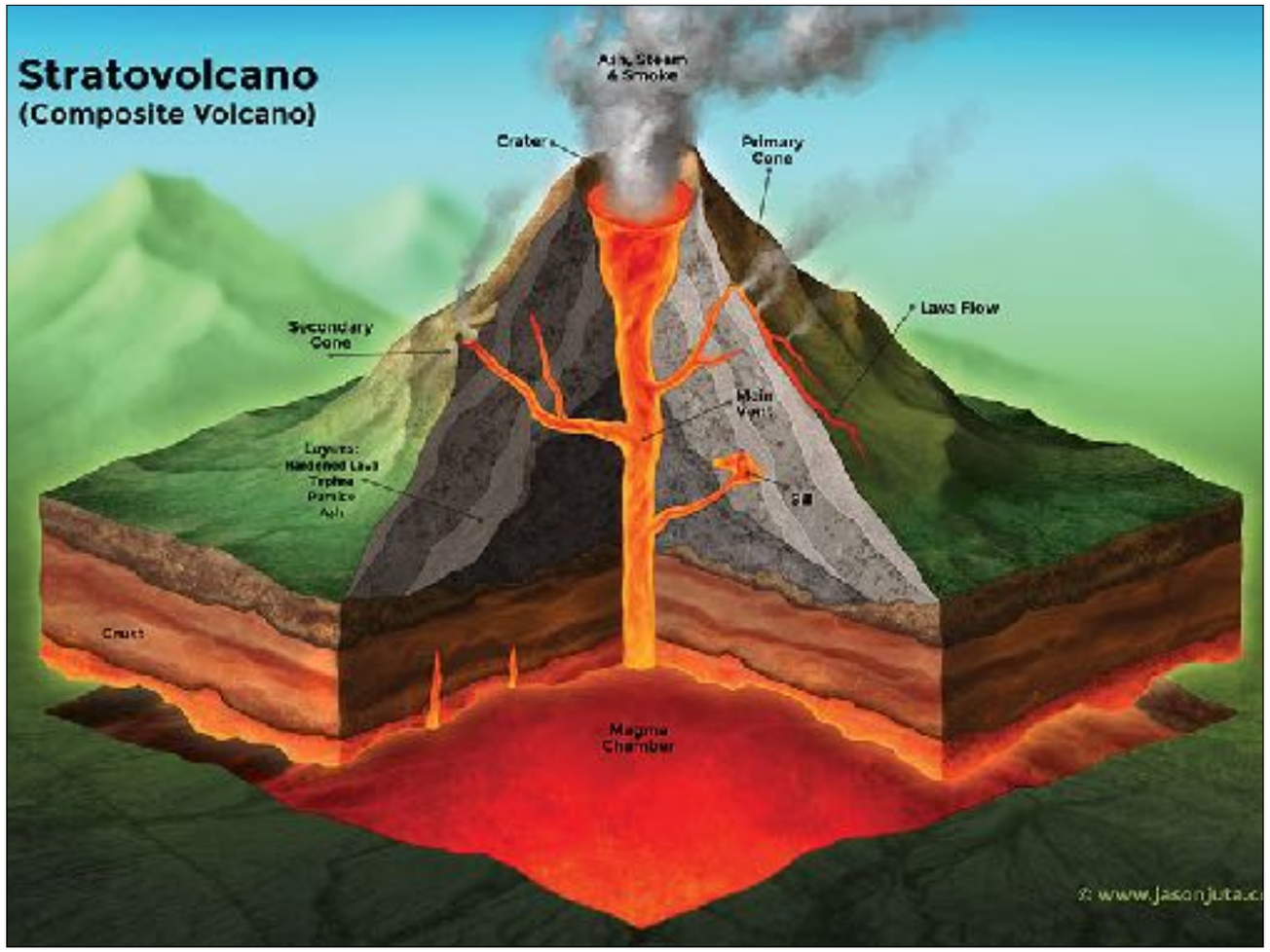
- The consistency of the mantle is weird, like very thick, hot plastic. It behaves more or less like a solid, but over huge, geologic periods of time, it can flow
- The density of the crust is less than the mantle, so in a sense it floats on the mantle

- The crust is broken up into huge plates
- The plates can move, driven by the flow of the rock in the mantle
  - That flow is powered by heat



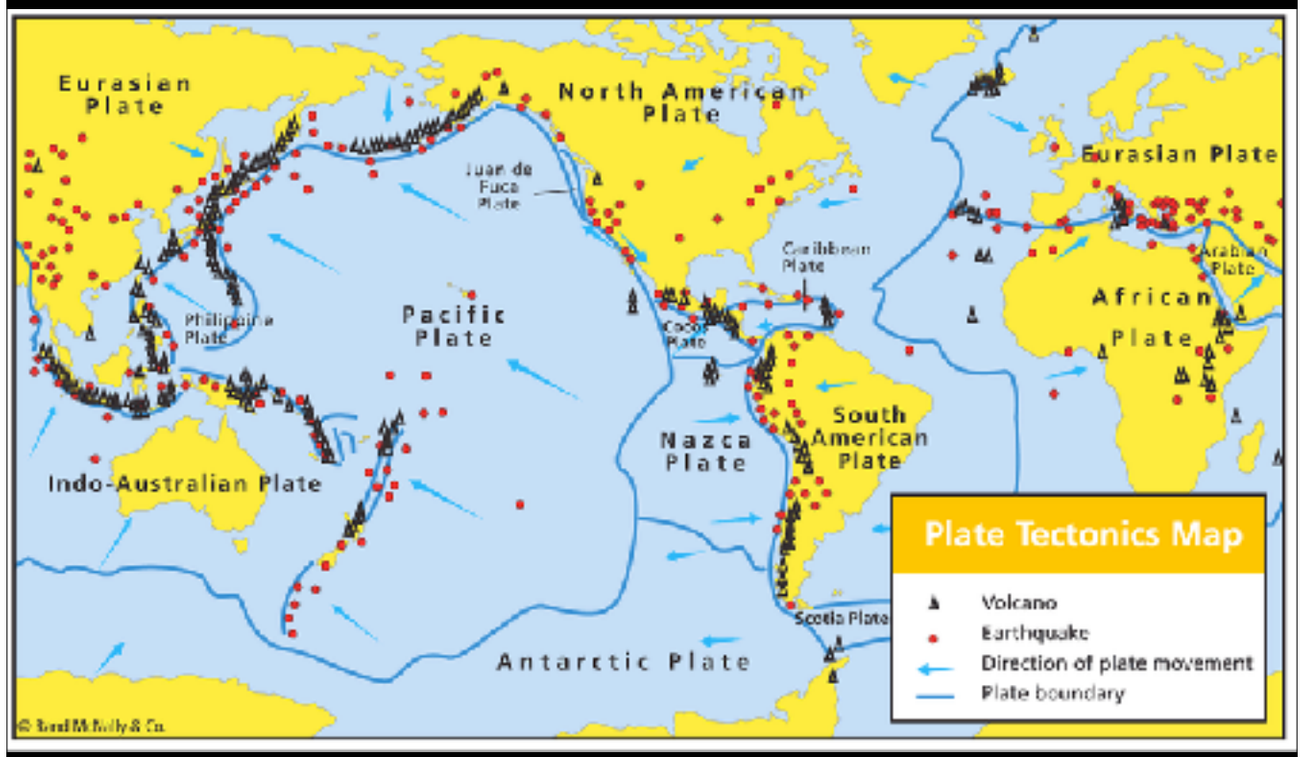
The core of the Earth heats the bottom of the mantle, this causes convection — the warmer material rises. It only moves at a rate of a few centimeters per year, so it can take 50,000 to 60,000 years for a single blob to move 1 km. The rising hot material hits the bottom of the crust, pushing on it, causing the plates to slide around *very slowly*

Your fingernails grow at about the same rate the continents move. Over millions of years, though, this adds up, changing the surface geography of Earth



In some place, generally where the plate come together, the crust is weaker. Magma can push its way through, erupting onto the surface, forming volcanos

Other volcanos, like Hawaii or the Canary Islands, are thought to be from a plume of hotter material that punched its way right through the middle of a continental plate



As the plate moves, the hot spot forms a linear chain of volcanos over millions of years

- Volcanos create new land as material wells out
- They also pump gas out of the Earth
  - A large part of Earth's atmosphere was supplied from volcanos

WHY IS THE EARTH'S CORE HOT?

The interior of the Earth is hot. In the core, it's about as hot as the surface of the Sun!

Most of that heat is left over from the Earth’s formation more than 4.5 billion years ago. As rock and other junk accumulated to form the proto-earth, their collisions heated them up. As the Earth grew, that heat built up, and it’s still hot inside even today

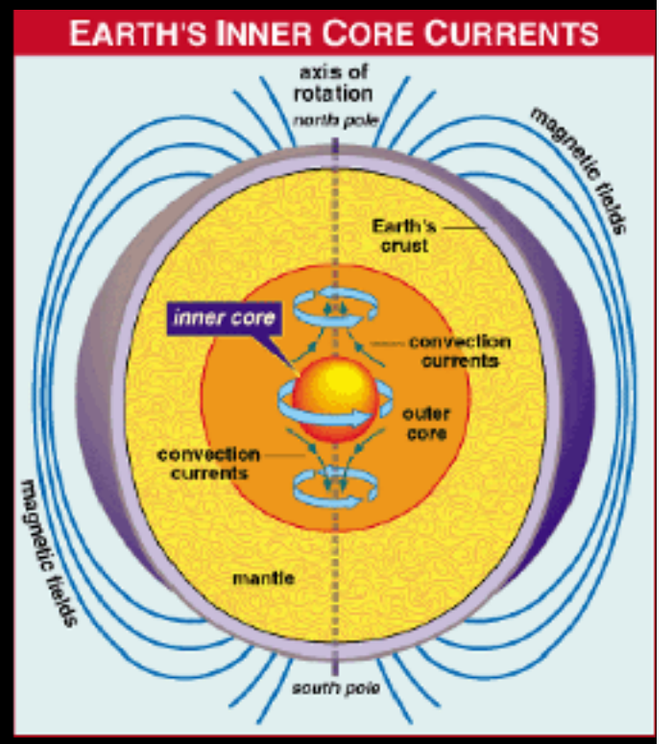
Also, as the Earth formed, it gained mass and began to contract under its own gravity. This squeezing added heat to the material. Another source of heat is elements like uranium deep inside the Earth, which add heat as the atoms radioactivity decay. A fourth source of heat is from dense materials like iron and nickel sinking to the center of the Earth, which warms things up due to friction

WHY IS THE EARTH'S CORE SO HOT?

- Leftover heat from formation
- Gravity's squeeze
- Decaying uranium
- Friction

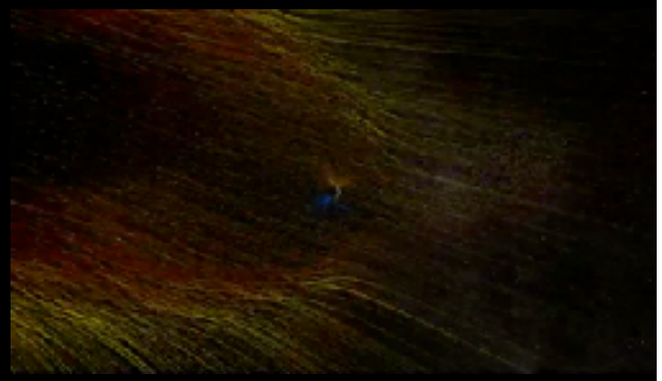
All of these add up to a lot of heat, which is why, even after billions of years, the Earth still has a fiery heart

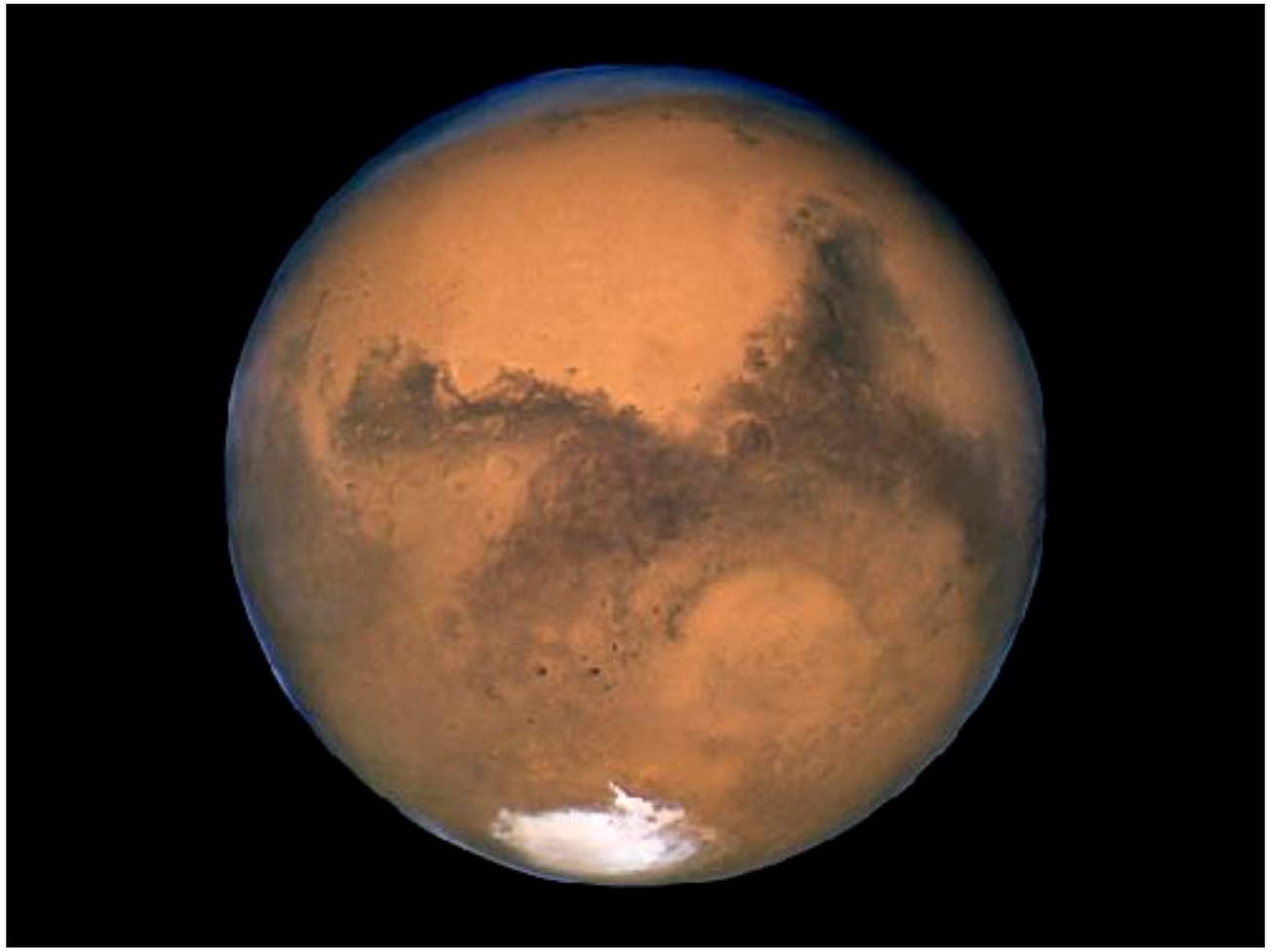
- The outer core is liquid metal which conducts electricity
- The liquid convects, and this motion generates magnetic fields
- The Earth's rotation organizes this motion



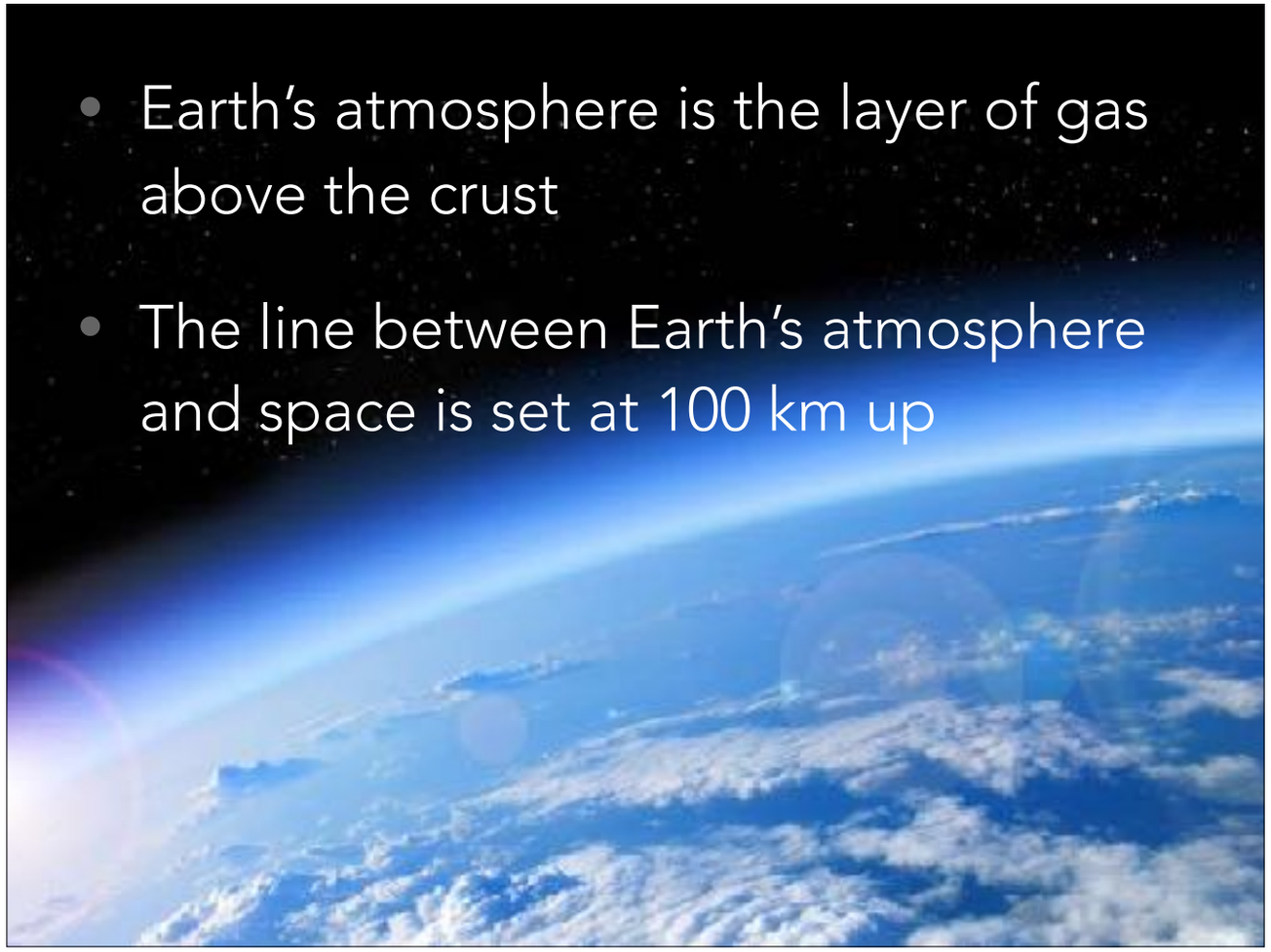
The overall effect generates a magnetic field similar to a bar magnet, with a north and south pole near the geographic poles

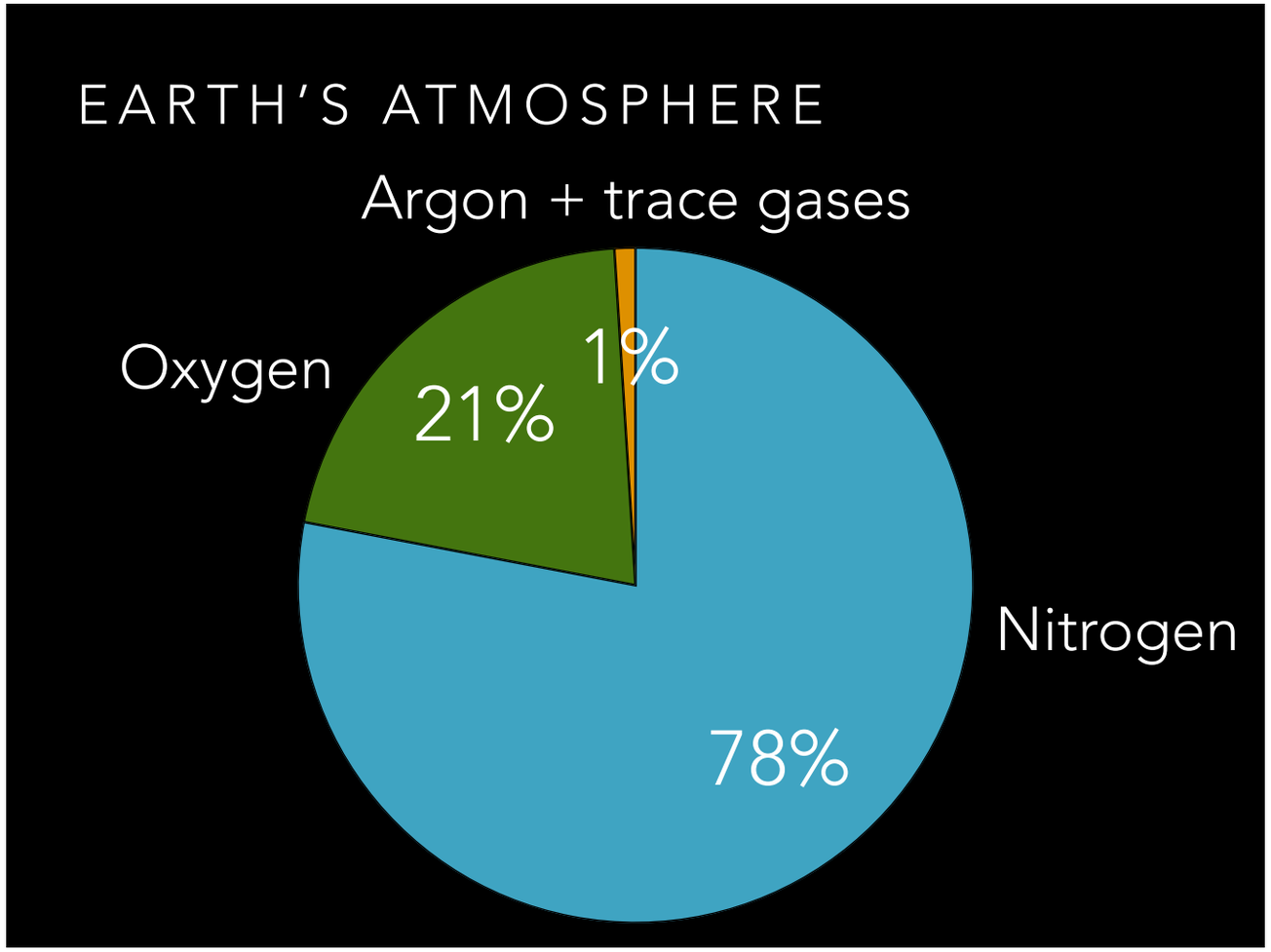
- The Earth's magnetic field deflects most of the charged particles from the solar wind (and trap some, too)
- Without the magnetic field, the solar wind would, over billions of years, strip Earth's atmosphere away



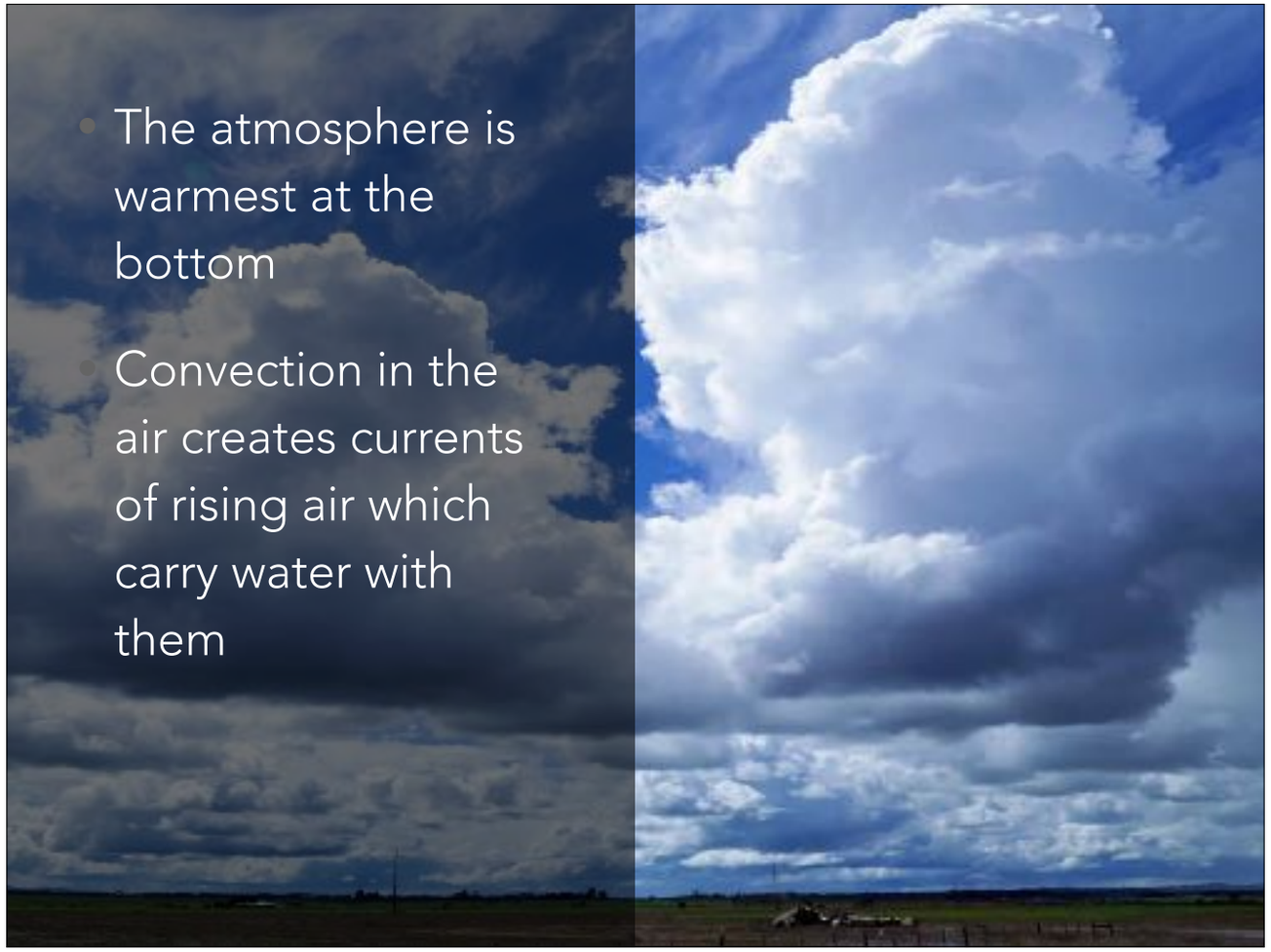


Mars doesn’t have a strong magnetic field, and we think that’s why most of its atmosphere is gone today

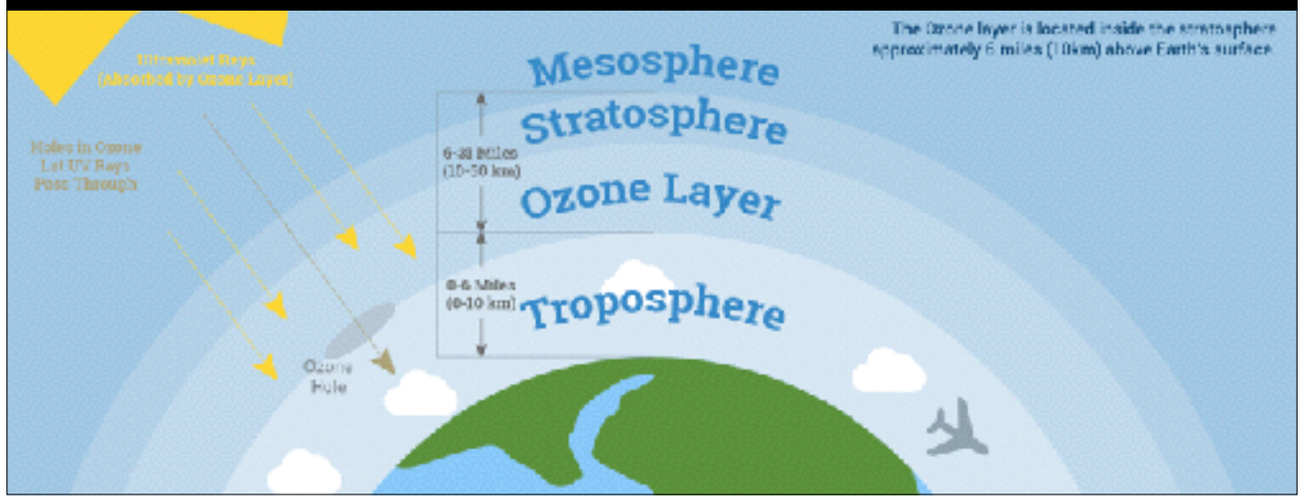

• Earth's atmosphere is the layer of gas above the crust
• The line between Earth's atmosphere and space is set at 100 km up



There's water vapor, too, almost all of it below a height of 8-15 km


The atmosphere is warmest at the bottom
Convection in the air creates currents of rising air which carry water with them

- At a height of about 25 km is a layer of ozone
- Ozone is a molecule of oxygen that's good at absorbing solar UV light



UV radiation can break apart biological molecules, so the ozone layer is critical for our protection

- The Earth's magnetic field channels some solar wind particles down into the atmosphere where they slam into air molecules 150 km up
- This energizes the molecules which respond by emitting light
  - Nitrogen glows red and blue
  - Oxygen glows red and green
  - This glow is called the **aurora**

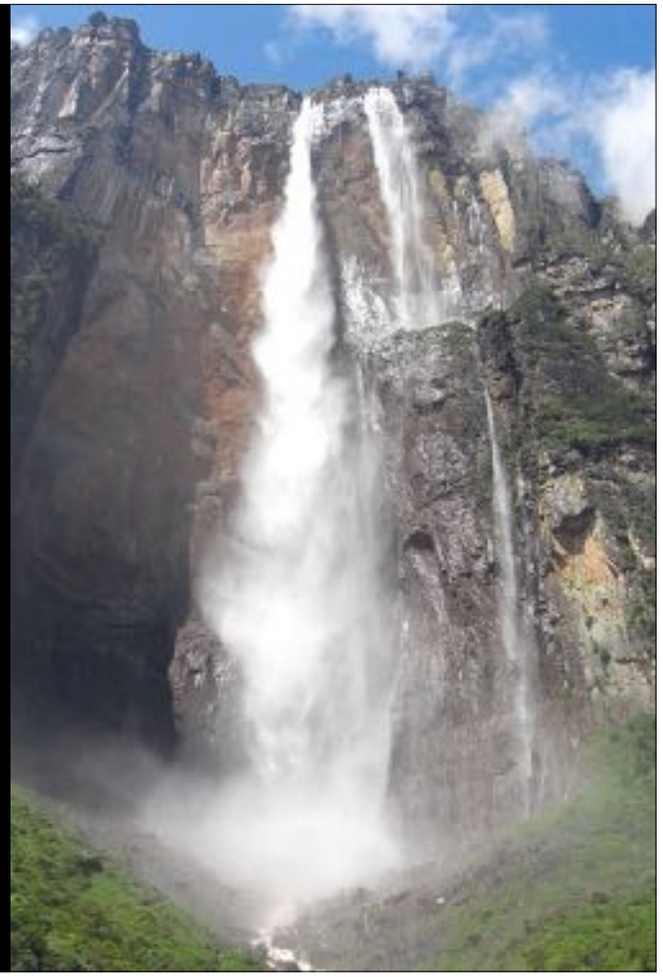
Auroras only happen near Earth's poles, and there shapes depend on the shape of the magnetic field


© Kory Funk 2015

Earth's atmosphere exerts a pressure on the surface of about 1 kg/cm^2, or nearly ten tons per square meter

There's roughly a ton of air pushing down on you right now. You don't feel it because it's push in all directions and our body has an internal pressure that balances that out

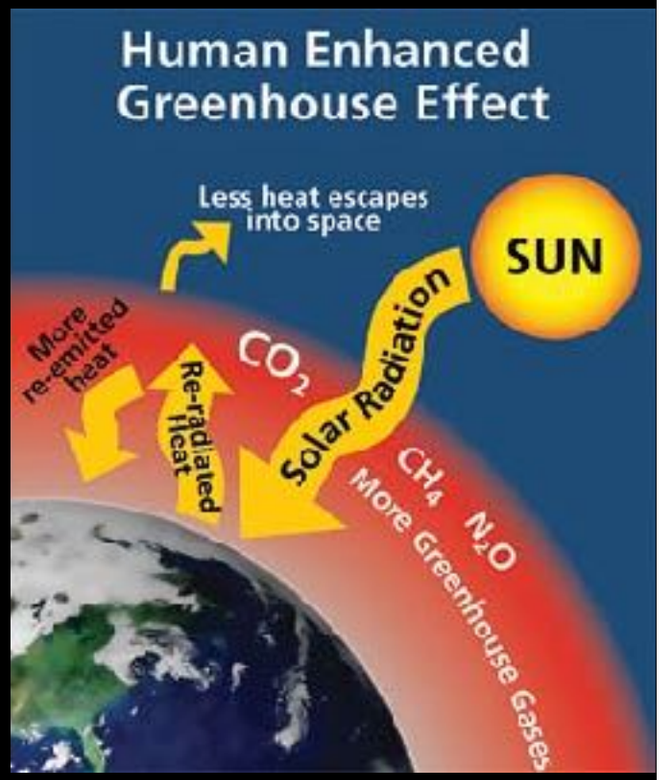
- Earth is the only planet in the Solar System with liquid water on its surface
- 70% of Earth's surface is covered with water
- Some of this water formed when Earth itself formed
- Some probably came from comet and asteroid impacts billions of years ago



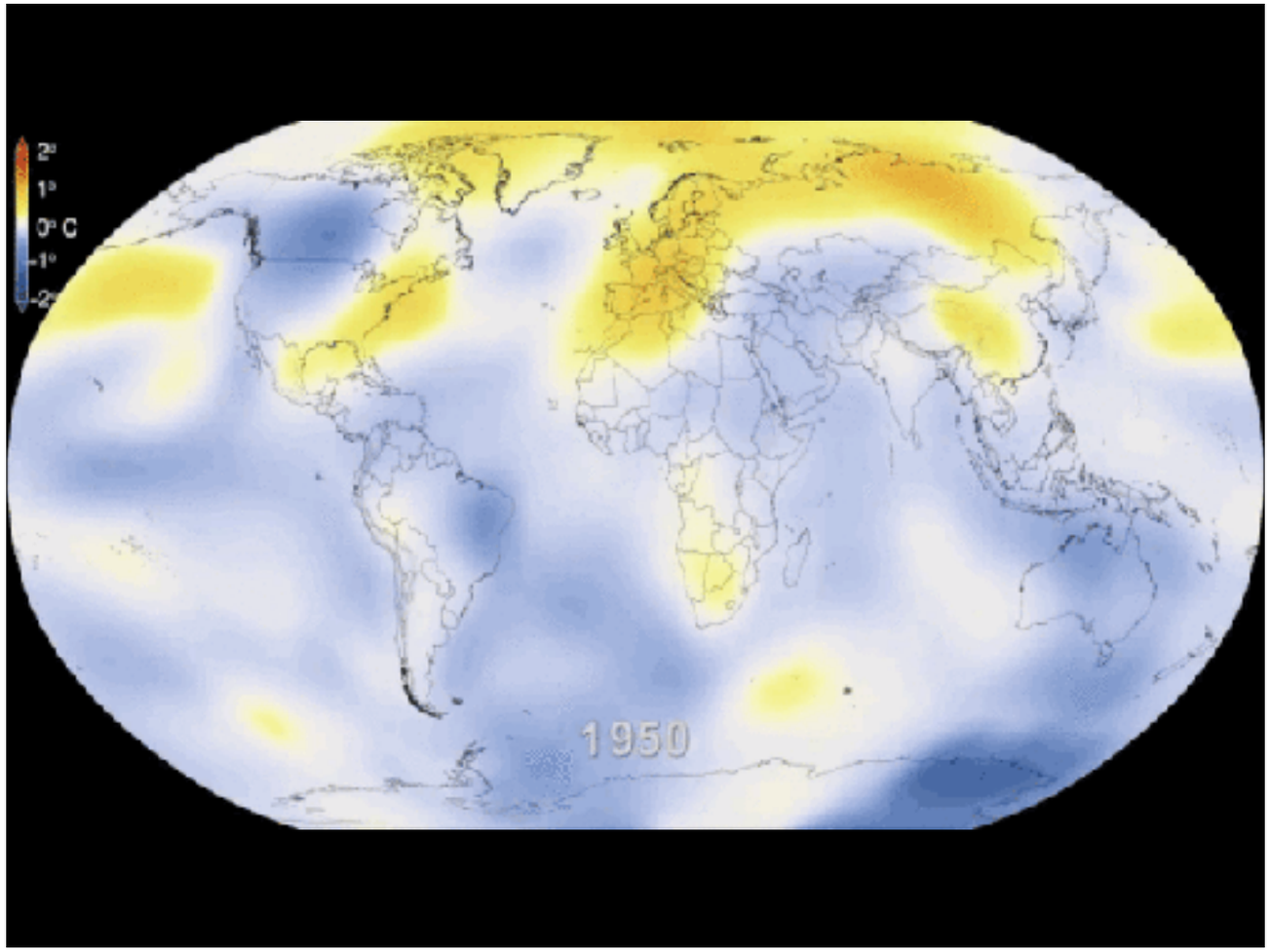
The proportions of locally sourced vs. extraterrestrial water is still a topic of argument among scientists

One of the aforementioned “trace gases” is carbon dioxide, which only constitutes 0.04% of the atmosphere, but it’s critical

- As Earth's surface heats up, it emits infrared light
- CO_2 traps that kind of light, preventing it from escaping into space
- This "greenhouse effect" warms the Earth. Without it, the average temperature on Earth would be below freezing



So a little CO2 is a good thing, but too much can be dangerous



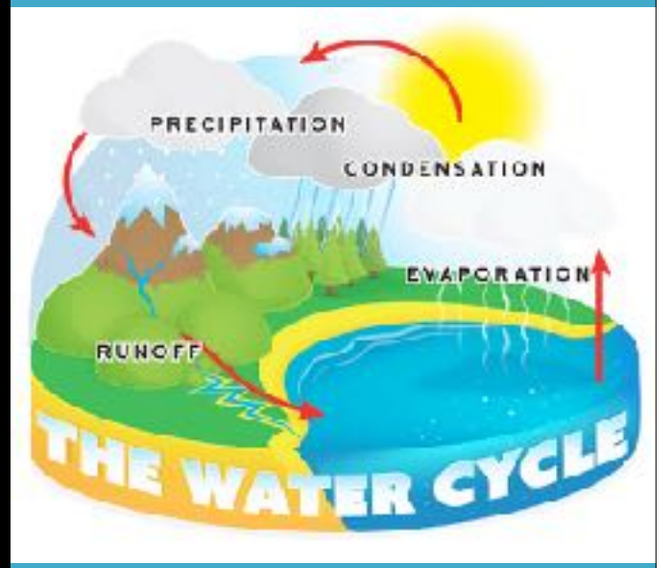
Since the Industrial Revolution, we've added a lot of the gas to our atmosphere, trapping more heat. By every measure available, the heat content of the Earth is increasing.

- it's melting glaciers in Antarctica and Greenland, as well as sea ice at the North Pole
- sea levels are going up
- some of the extra CO2 is absorbed by the oceans, acidifying them

Science fiction talks about terraforming — engineering an uninhabitable alien planet to make it more Earth-like. Whatever the opposite of that is, we’re doing it to Earth

EARTH SYSTEMS

WATER & CARBON CYCLES



Hydrologic Cycle — how water moves on, above, and below the surface of the Earth, driven by energy supplied by the sun and wind

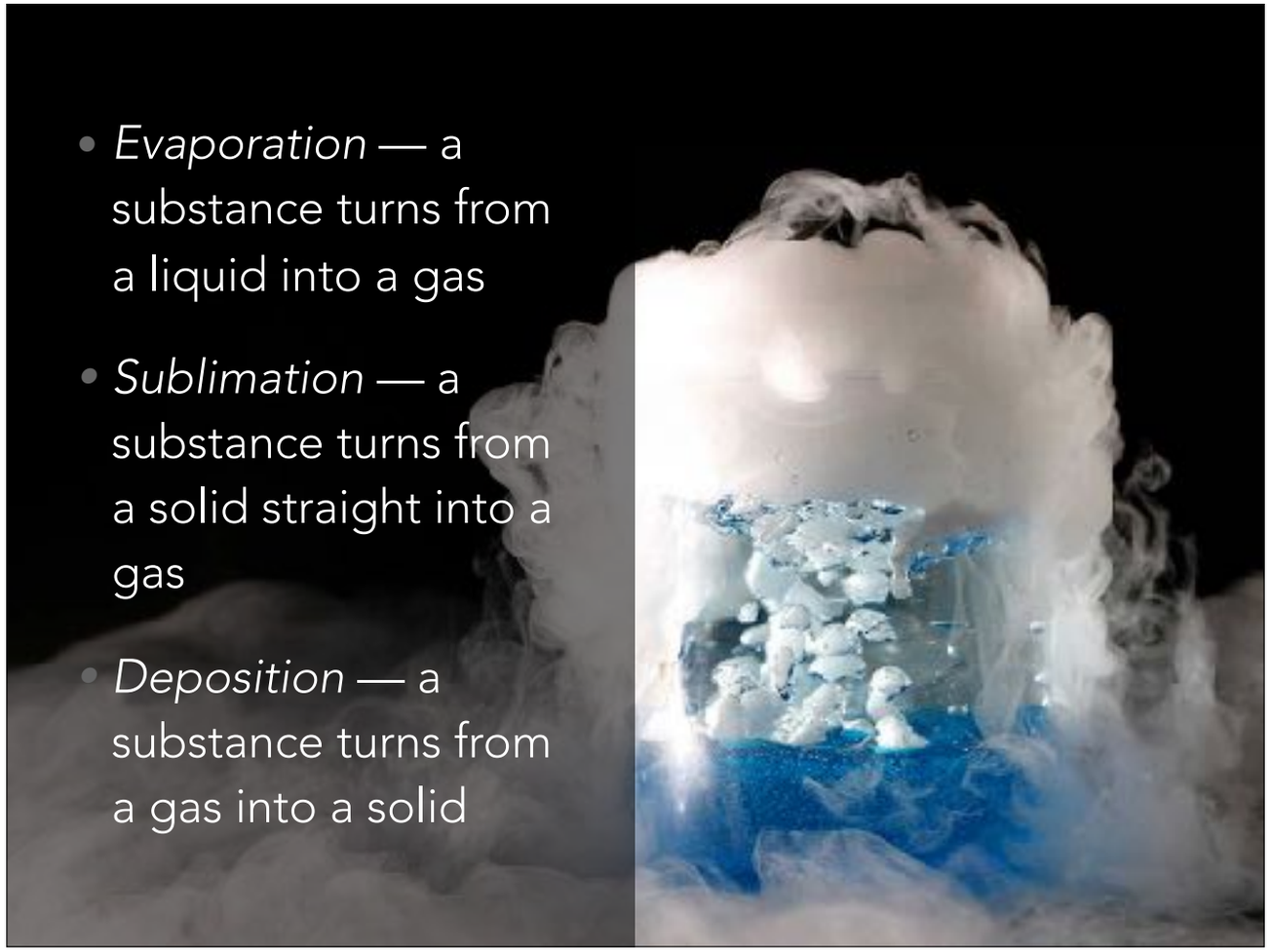
When talking about the hydrologic cycle, it’s useful to think about all the water on Earth as being stored in a series of reservoirs. The oceans, for instance, or the atmosphere in the form of clouds, or in polar icecaps

Not only does water cycle through different places, it also takes different forms at different places in the cycle: liquid, solid, or gas

Since it’s a cycle, there is no beginning and no end, so where we start our discussion is arbitrary

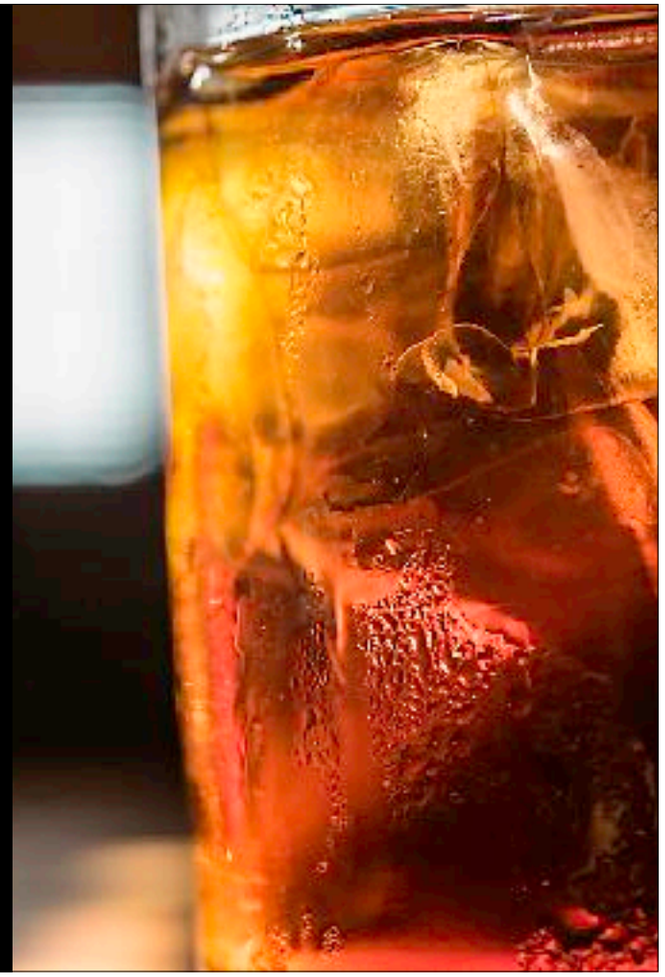
- *Precipitation* — when water in the atmosphere condenses and falls to the ground
- *Condensation* — when a substance turns from a gas into a liquid

Water turns from a gas into a liquid (and occasionally freezes into a solid) right up in the air



But let’s go back to condensation…

- Clouds form when air containing water vapor rises and cools or is compressed to the point where it can no longer be a gas
- The water vapor forms droplets
- Clouds drift over the landscape and move water around the globe



In a sense, a cloud is just a big pile of condensed water droplets — it's gigantic floating reservoir. Thanks to clouds, water evaporated from the ocean can be deposited somewhere else

- As water keeps condensing, the clouds get heavier and heavier
- Eventually, gravity takes over and pulls the condensed droplets to the ground

- Gravity always wants to pull water to the lowest point available
  - either across the landscape as **runoff**
  - or underground
- Some gets stored temporarily in lakes and ponds and wetlands
- Most gets pulled lower and lower until it reaches the ocean

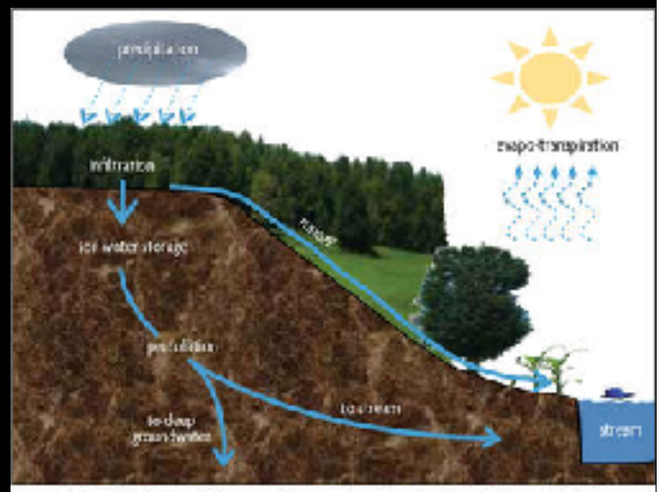


Figure 5.3. The fate of precipitation at the land surface determines whether water infiltrates or runs off the surface.

In really cold places, water freezes and hangs around as ice, sometimes for thousands of years at a time, like at the Poles or in glaciers or at the tops of very tall mountains, but when it melts, it, too, runs off into the oceans

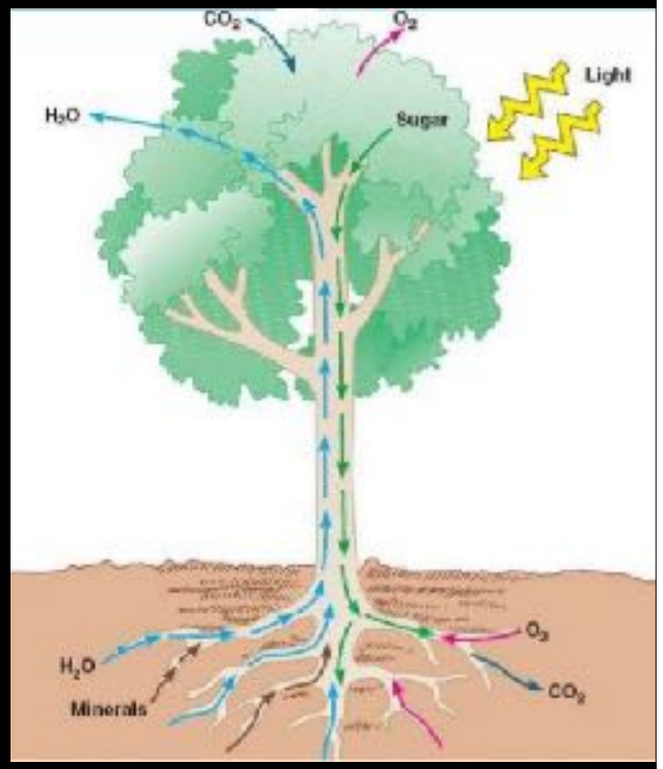
Oceans are a big deal. They’re the only reason we have the hydrologic cycle (or weather or life)

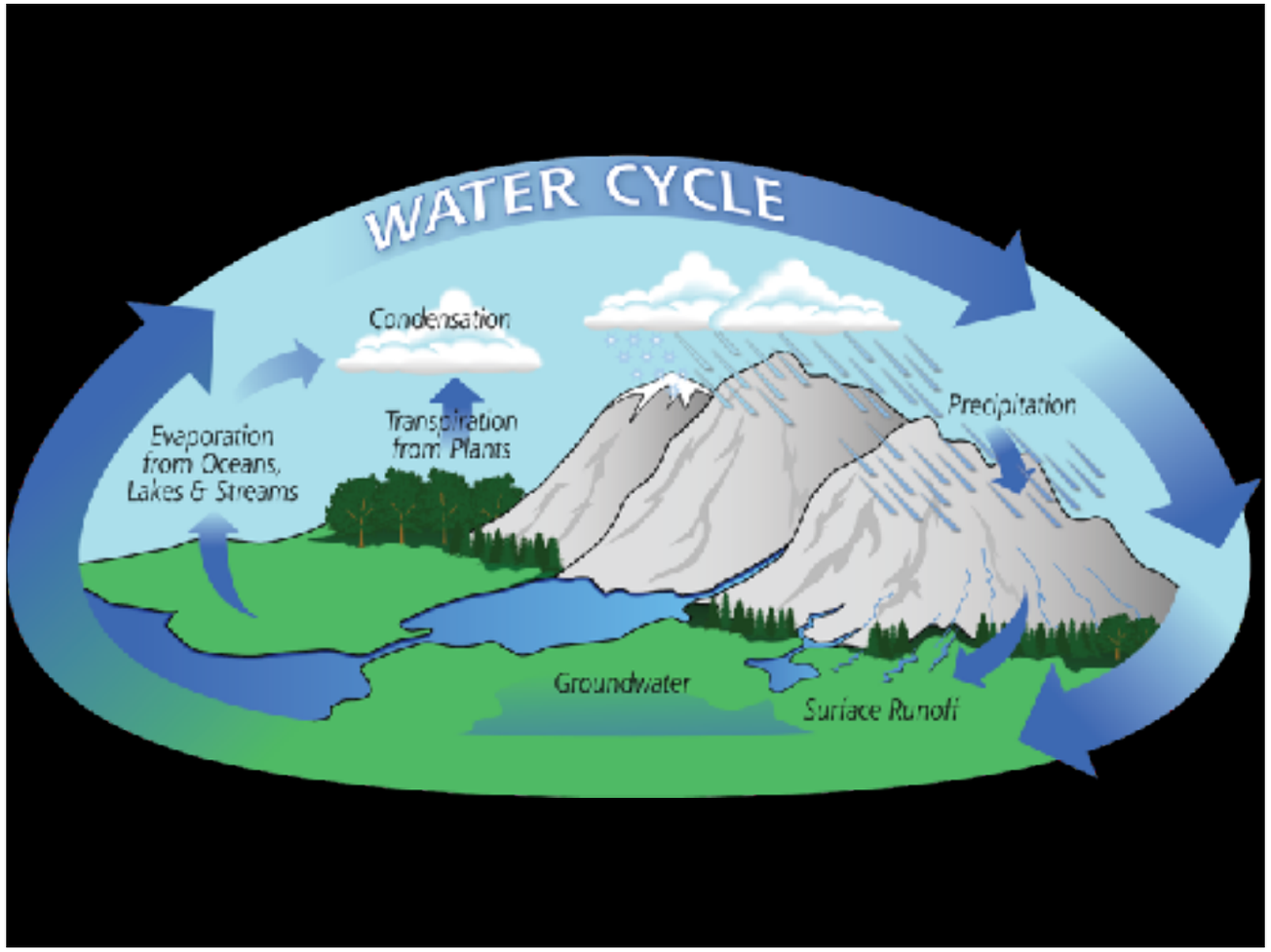
OCEANS ARE SALTY

- As water runs to the ocean, it erodes minerals like salt from the soil and carries it to the ocean
- When the water evaporates, the salty does NOT evaporate with it

The water in rivers might not taste salty, but it’s there. Salt gets left behind when the pure water evaporates, and new runoff returns to the ocean with a little bit more salt. Keep that up for a few billion year and there’s your recipe for a billion cubic kilometers of brine

- Life also plays a role in the hydrologic cycle
- Plant and animal life requires liquid water to perform its biologic functions
- That water later returns to the Earth through evaporation from our skin, the water vapor we exhale, and urination





And the whole thing repeats on itself

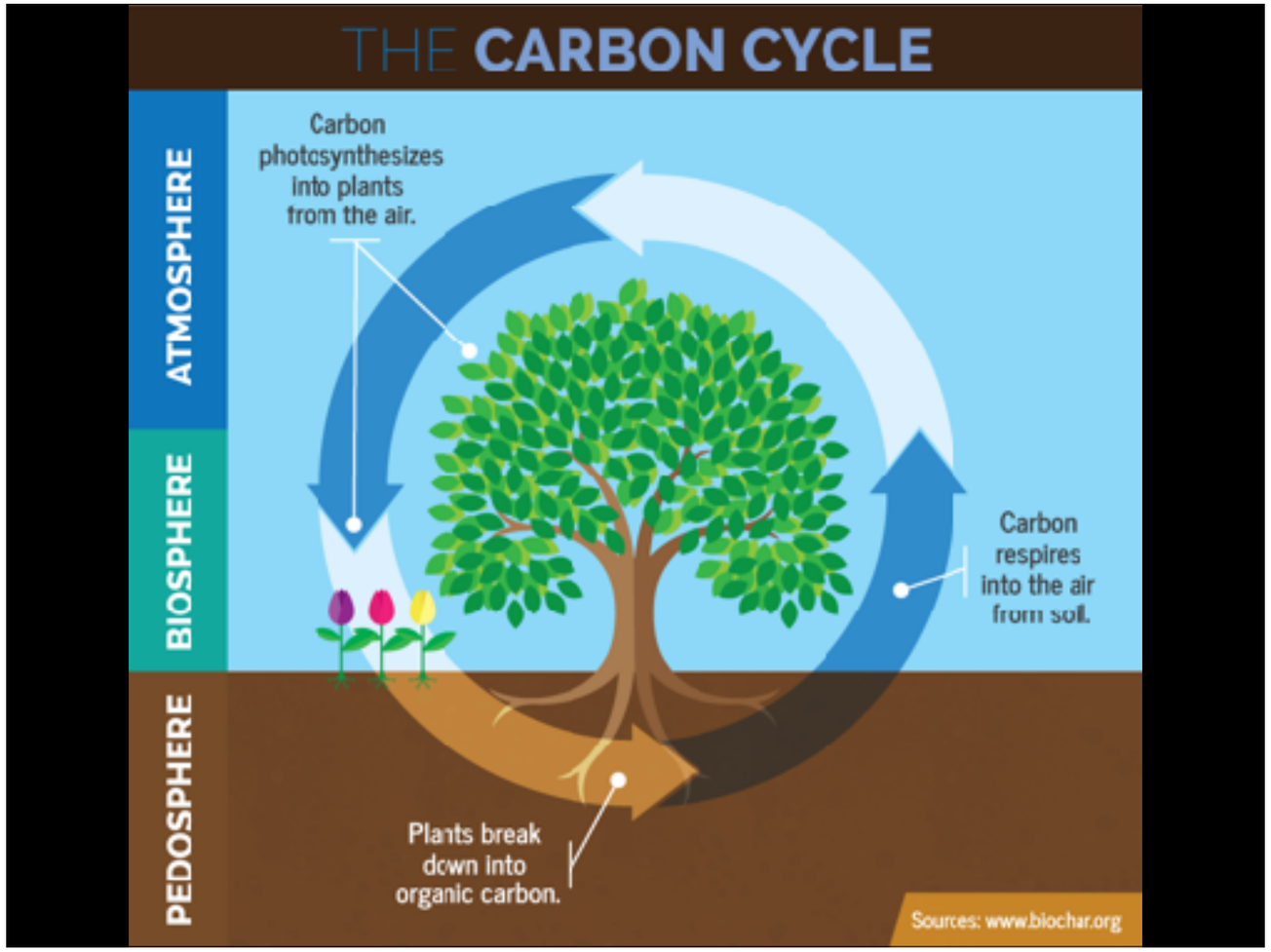
Carbon Cycle — like the hydrologic cycle, but for carbon

Carbon is always on the move, just like water, jumping from one reservoir to the next

- All living things require carbon for their structure and to fuel their bodies
- It's a part of non-living things as well: rocks, the ocean, trapped in ice, and in the atmosphere (where it regulates the temperature)

Without carbon dioxide, the Earth would be a frozen wasteland. But lucky for us there's a lot of it out there (it's the fourth most abundant element in the Universe)

Focussing on living things, if you took out all the water in your body, carbon would account for about half of what remained in the pile of dust that used to be you

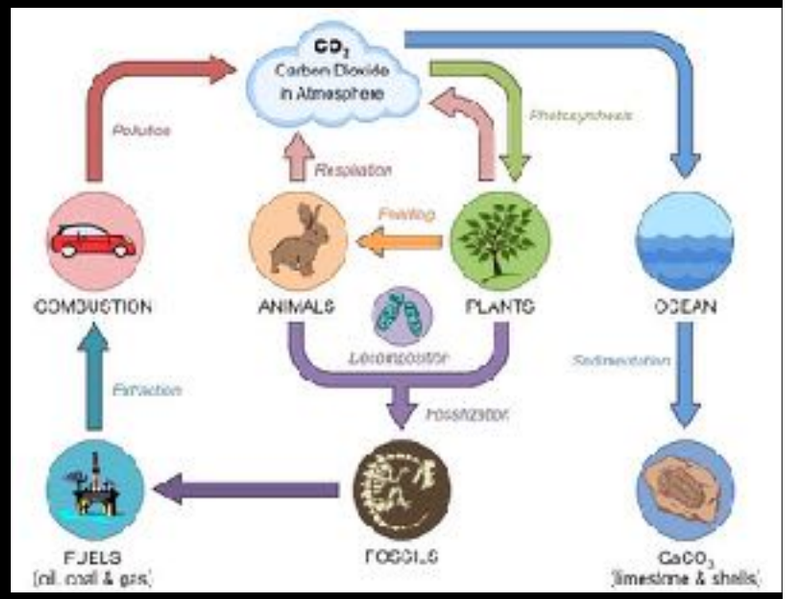


The first biological carbon reservoir is plants. They absorb and lot of carbon dioxide out of the atmosphere in order to photosynthesize

Plants don’t use all the carbon dioxide they take in, the carbon they do keep is put toward becoming the body of the plant

CARBON ABSORBED BY PLANTS CAN...

- be respired back into the atmosphere
- get eaten by an animal
- hang out till the plant dies



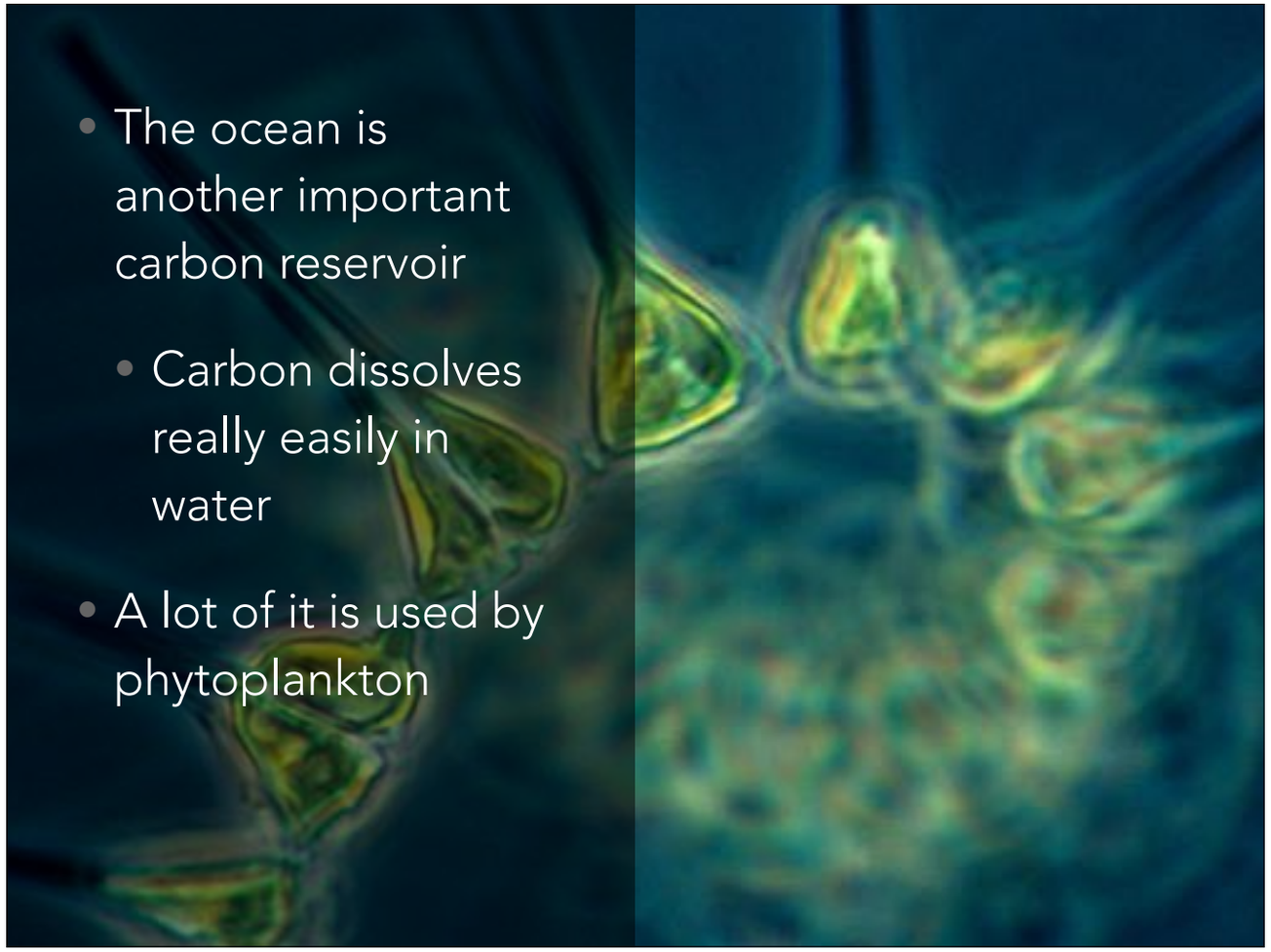
A tree falls in the forest…

- it's the right kind of forest
- other plants fall on top of it and die
- they all get squished together into rocks

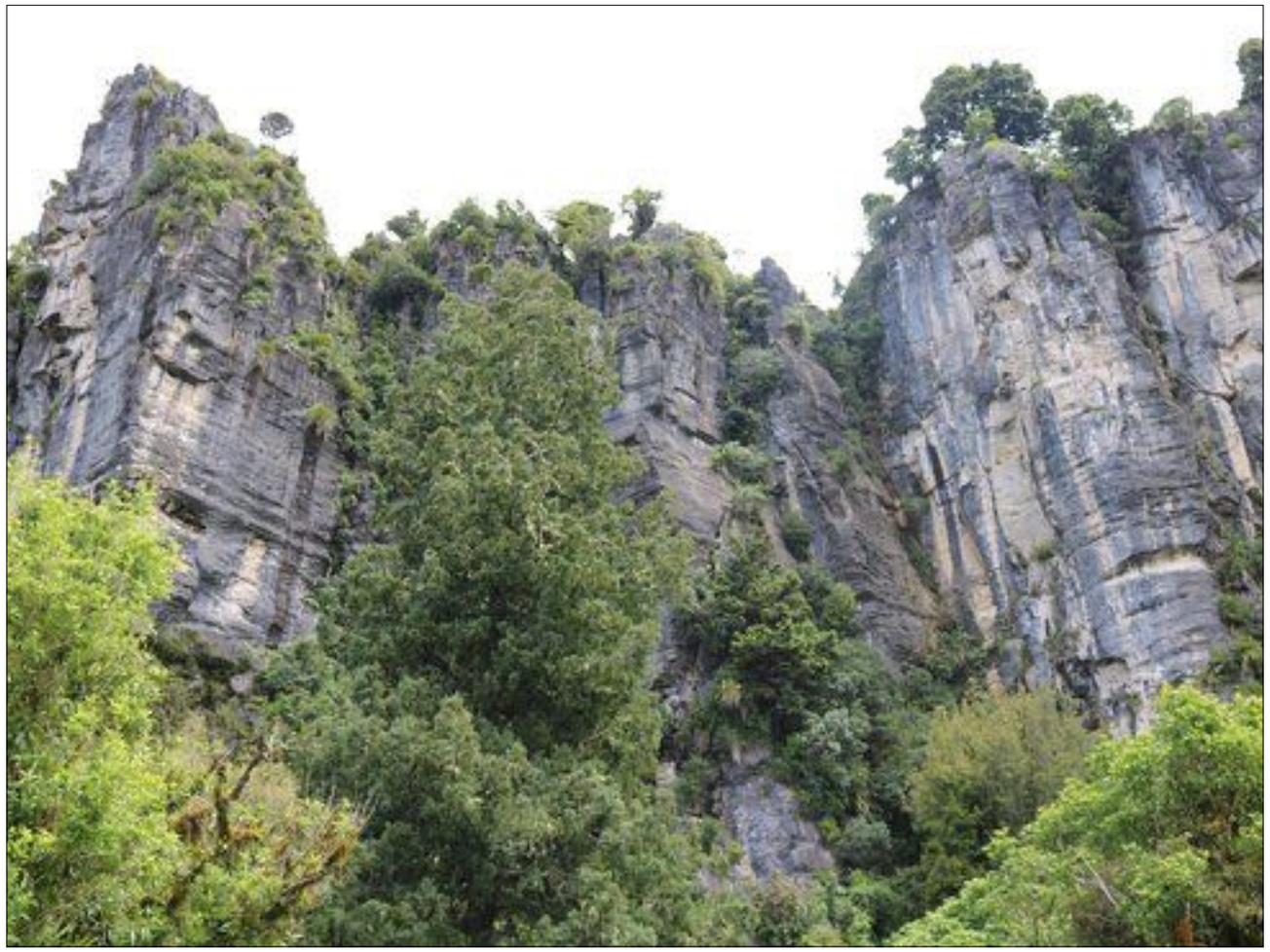
- We call these carbon-rich geological deposits **fossil fuels**

Coal is a great example of this

Lately, a favorite pastime of us humans has been digging up all this old carbon in the form of coal, oil, and natural gas and burning it to fuel our everything



Phytoplankton are tiny plant-like organisms that form the base of the marine food chain. They use it to photosynthesize and form their calcium-carbonate shells



When phytoplankton die, their shells fall to the bottom of the ocean, pile up, become compressed, and, over time, make rocks like limestone. Limestone doesn’t burn well, so it’s not considered a fossil fuel. As limestone is eroded by water, it breaks down eventually forming, among other things, carbon dioxide and carbonic acid

We use limestone to make cement, and we burn fossil fuels to use as an energy source, all of which release carbon dioxide into the atmosphere. This is carbon that had been stored for hundreds of millions of years underground in rocks, and this process has caused carbon dioxide levels in the atmosphere to rise like crazy in the past couple hundred years

- Carbon is often trapped in ice
- In cold places that have plants contain huge carbon reserves that are trapped in **permafrost**
- If the permafrost melts, the plants buried there can decompose, and, in doing so, release carbon dioxide and methane into the atmosphere, creating a positive feedback loop

Unfortunately, even cutting ourselves off from digging up additional carbon wouldn’t solve the problem. Places like Siberia, Alaska, or northern Canada have areas that are frozen all year round