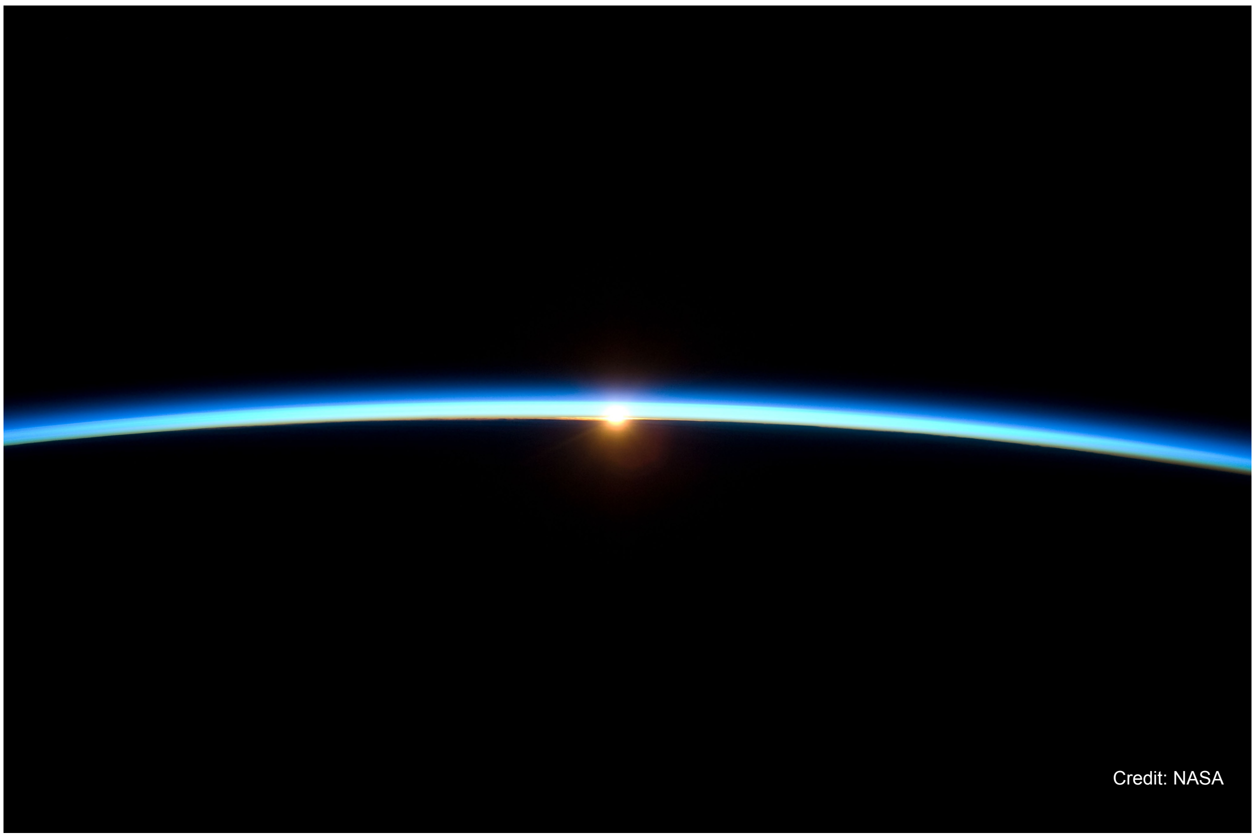
Cold hearted orb that rules the night,
Removes the colors from our sight,
Red is grey and yellow white,
But we decide which is right,
And which is an illusion.

Moody Blues

Classical Gas

Hi Astronomy 111. In this module we'll talk a little bit about atmospheres - classical gasses.



So what is an atmosphere? Well at the zeroth order, an atmosphere is just a layer of gas that surrounds a world. Nothing fancy. The image above shows Earth's atmosphere taken at sunrise from the Space Station. You should notice how thin the blue area really is. It is not the ocean of air you've maybe imagined it was. Delicate. Beautiful. And its the only one we got.

What does an atmosphere do? An atmosphere creates pressure. It can absorb and scatter sunlight. It can interact with the solar wind. It can cause a greenhouse effect that would warm the planet more than if it was just receiving light from the Sun. A greenhouse effect can be good, like on Earth. Sometimes too much of greenhouse effect can be a bad thing, like on Venus.

While each atmospheres of the planets are unique, just like the comparative approach we took with geology of the terrestrial planets, there are basic properties that set the characteristics of all atmospheres. Take a look at this table:

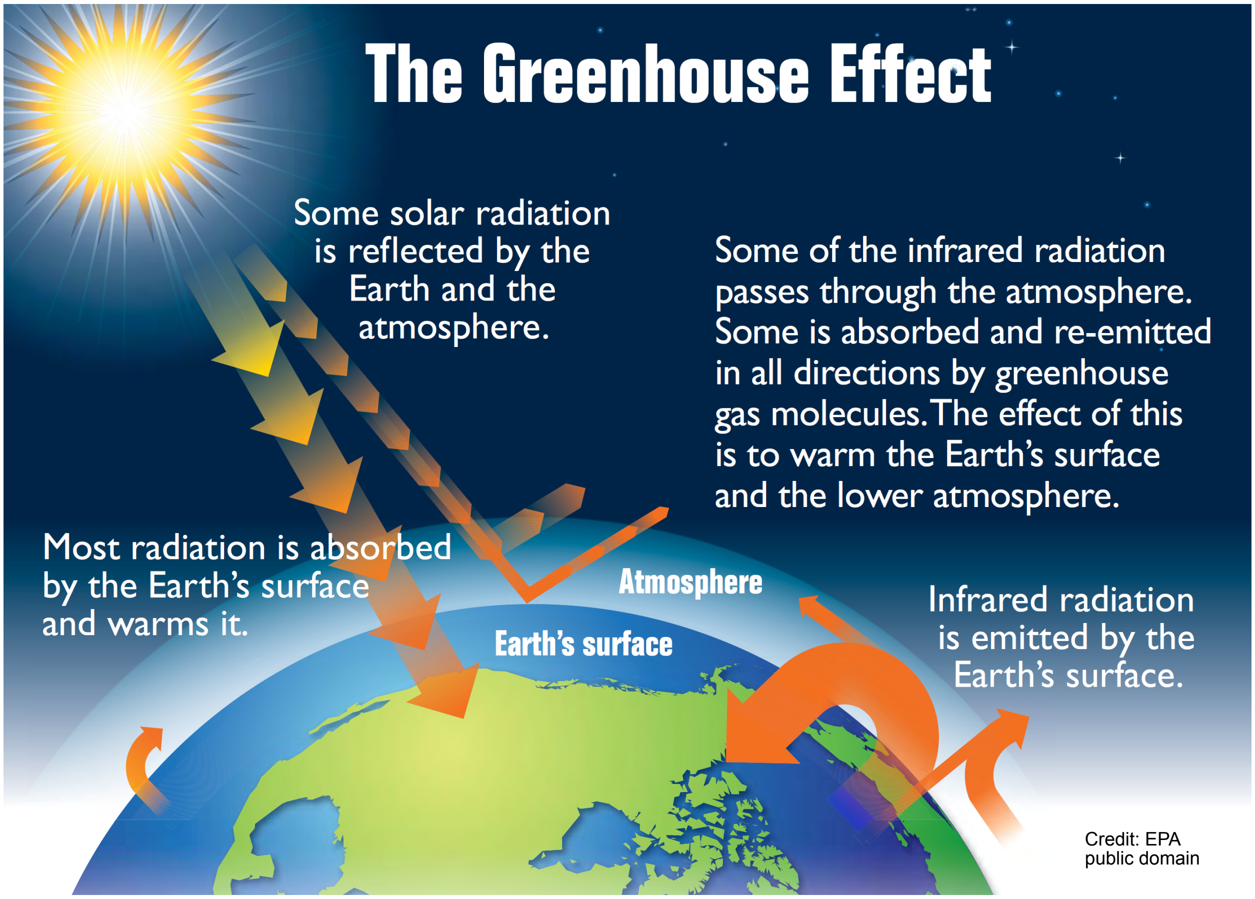
World	Pressure (bar)	Temperature (F)	Composition	Weather	Clouds
Mercury	10^{-14}	day: 800 night: -175	He, Na, O	none	none
Venus	90	900	96% CO_2 3% N_2	slow winds acid rain	H_2SO_4
Earth	1	60	77% N_2 21% O_2 1% Ar	winds rain, snow	H_2O haze
Moon	10^{-14}	day: 125 night: -175	He, Na, Ar	none	none
Mars	0.007	-50	95% CO_2 2.7% N_2 2% Ar	winds dust storms	CO_2 H_2O dust

Mercury and the Moon have almost no atmosphere. Super low pressures. The unit here is a “bar”. By definition the pressure at sea level on Earth is one bar. What tenuous atmosphere they do have - kicked up from the surface by micrometeorites and the solar wind - is mostly helium and sodium. At the other extreme is Venus. A crushing pressure some 90 times the pressure on Earth and mostly made of carbon dioxide with sulfuric acid clouds. Mars is also dominated by carbon dioxide with a James Bond 007 atmospheric pressure at the surface.

Earth's atmosphere is presently mostly nitrogen - that seems to surprise a lot of people. We breathe the second most abundant gas. Note we have hardly any carbon dioxide. We’re not that different from Venus or Mars - so where did all our carbon dioxide go? We'll cover that.

Pay a bit more attention to the surface temperatures. We’re going to bear down on this below. On planets with no atmosphere you've got extreme hots during the day and extreme colds at night. Planets with atmospheres have a more modest and a single characteristic average temperature.

We should say the table above is for the current atmospheres of the terrestrial planets. Their initial compositions at birth could have been - and were - quite different.



Credit: EPA
public domain

How does a greenhouse effect warm a planet? Well, greenhouse gasses are things like carbon dioxide, CO_2, methane, CH_4, and water vapor, H_2O. They are great absorbers of infrared light.

So, sunlight comes down. It hits the planet's surface. The planet absorbs this energy. The planet then re-radiates the energy, mostly in the infrared - just like thermal radiator should. That infrared radiation goes on up into the atmosphere and hits these greenhouse gas molecules. The molecules absorb that infrared radiation. Fine. When these molecules eventually re-emit the infrared energy - this is the key part - they do so in all directions. Up, sideways, any random direction at all, including downwards.

Part of that radiation continues upwards away from the planet is going up. Fine, that's what the the photon was doing before that pesky greenhouse gas got in the way. But a fraction of that radiation is directed back down toward the planet's surface. This is what helps warm the surface of the planet. It is sort of like a warming blanket around the surface of the planet. Because photons are redirected back towards the planet surface.

OK?

How warm would a planet's surface be *without* an atmosphere? That depends on three factors.:

One - how far away you are from the sun. The closer to the Sun you are, the more energy the you receives from sunlight for each square meter of surface.

Two - the reflectivity of the surface. The reflectivity describes the fraction of sunlight reflected by a planet. A reflectivity of 0 means nothing is reflected, its all absorbed. A reflectivity of 1 means everything is reflected, nothing is absorbed.

Three how fast the planet rotates. For slow rotation the days will be long and hot and the nights long and cold. For rapid rotation then the heat can equilibrate across the planet. and you'll end up with more or less the same daytime and nighttime temperatures.

These three factors are rolled into the simple formula

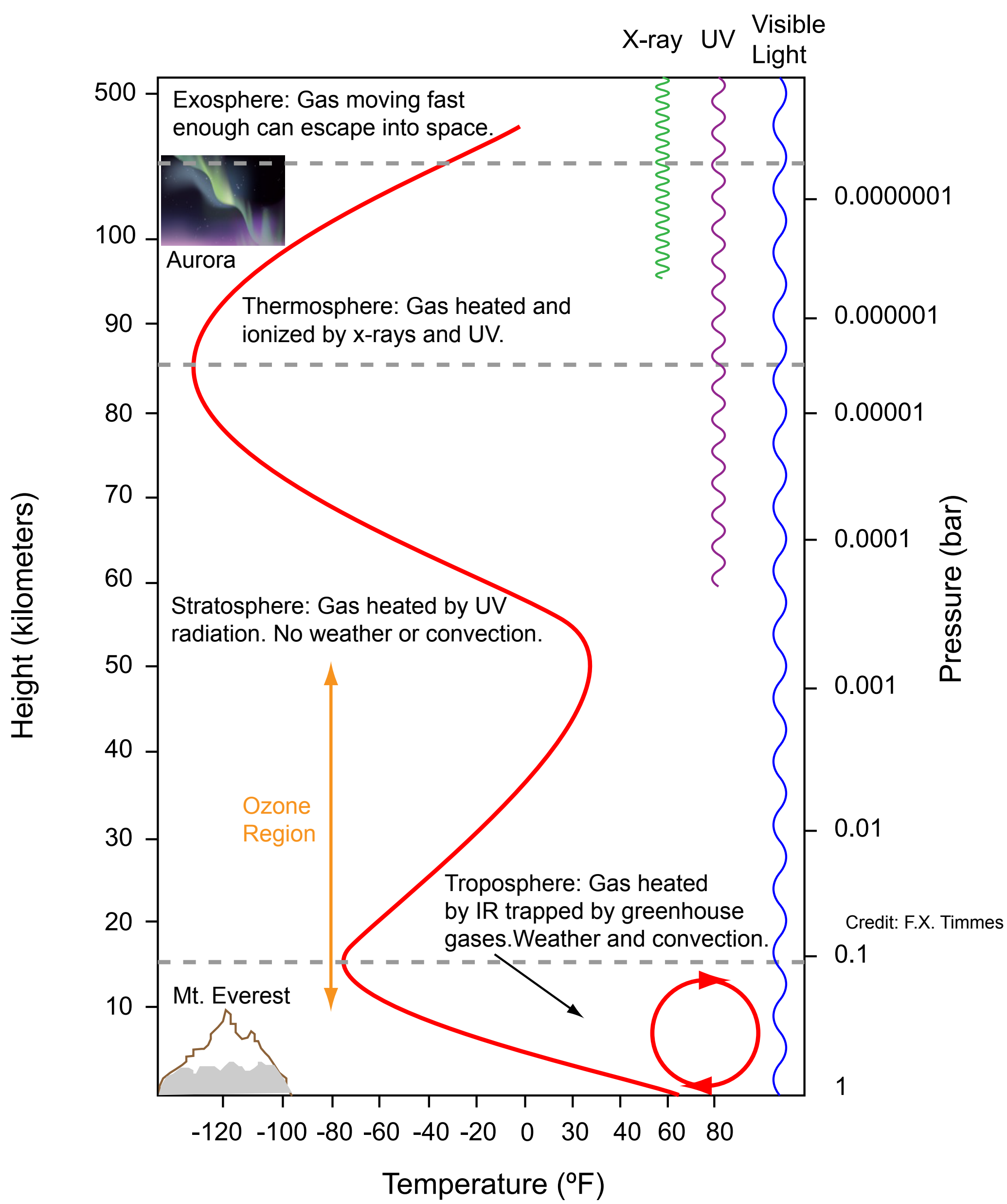
$$\text{Temperature}_{\text{no atmos}} = 280 \left(\frac{1 - \text{reflectivity}}{d^2} \right)^{1/4} \quad K$$

World	Distance (AU)	Reflectivity	"No Atmosphere" Temperature (F)	Actual Temperature (F)	Greenhouse Warming (F)
Mercury	0.4	12%	325	day: 800 night: -175	none
Venus	0.7	75%	-40	900	940
Earth	1	29%	3	60	57
Moon	1	12%	28	day: 125 night: -175	none
Mars	1.5	16%	-67	-50	17

Now let’s look at the terrestial planet’s “no atmosphere” temperature and its actual temperature. This will tell us how important the greenhouse effect is. We’ll convert to Fahrenheit to make it easier to grasp
So the first column gives the planet. The second column gives the distance.Third column gives the reflectivity. Fourth column is the “no atmosphere” temperature, which is calculated just from that formula above. The actual temperature is in the fifth column there. The difference between the no atmosphere” temperature and the actual temperature is in the last column.

Mercury and the Moon have a “no atmosphere” temperature that lies almost in the middle of their day and night temperatures. This is comforting becuase they have no atmosphere. So the “no atmosphere” temperature formula is in some sense giving the average between their extreme hot and their extreme cold temperatures.

Mars is just 17 °F warmer because of its greenhouse gases. Earth, about 57 °F warmer. Venus, a whopping 940 °F warmer. Without the greenhouse effect, Earth's oceans would freeze. So a little bit of a greenhouse is a good thing for us on Earth.



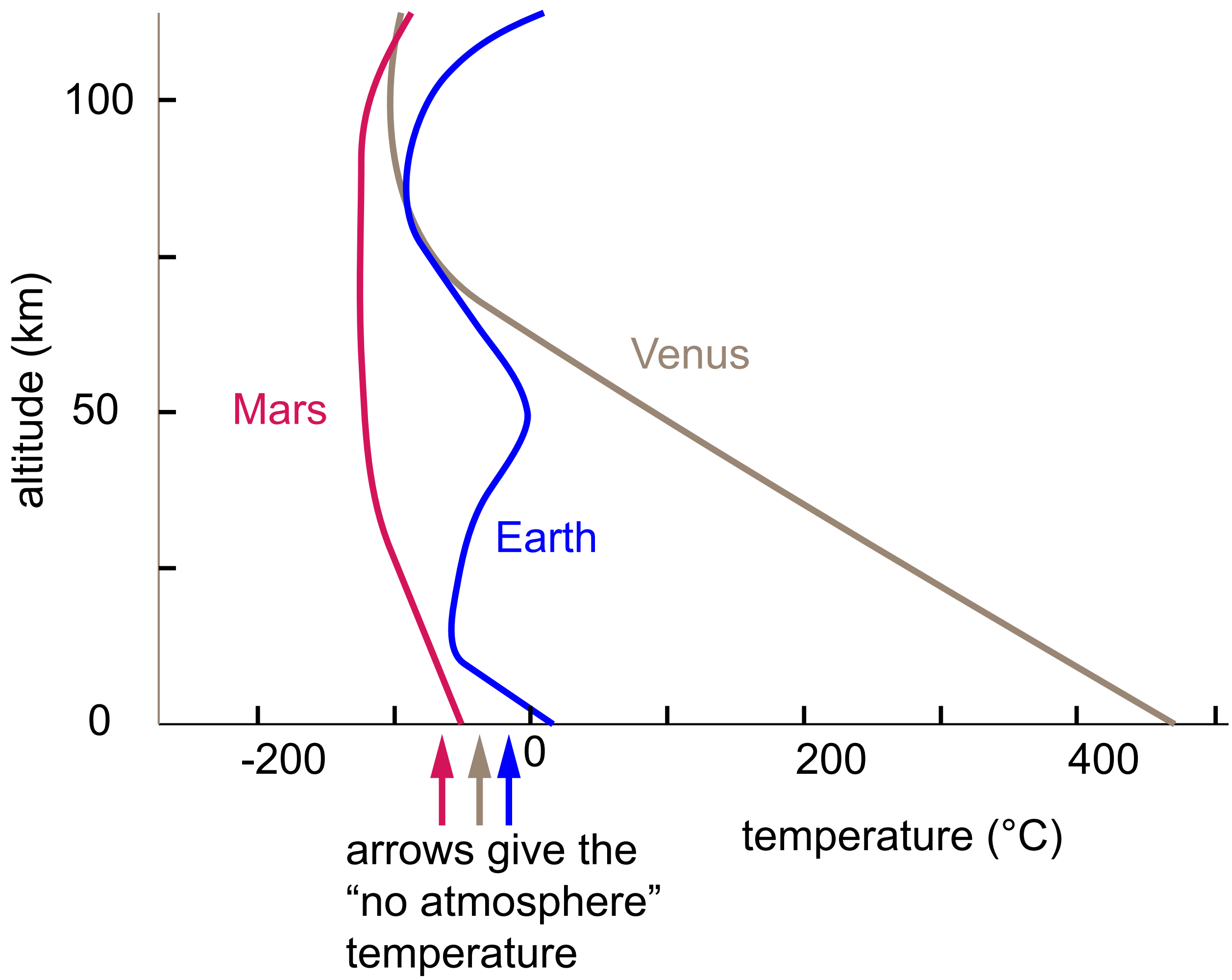
We all know its colder at higher elevations, like on a mountain top, than at lower elevations. So how does an atmosphere vary with altitude? The structure is determined by what types of light interact with the gases.

The illustration above shows the atmospheric structure for Earth. The x-axis gives the temperature and the y-axis gives the height. The lowest layer is called the troposphere. This is where weather occurs. This is where greenhouse warming from infrared light occurs. “Tropo" means turning, as in turning over. And so that's the idea of weather, that you get this turning over if air in the troposphere. In the troposphere it gets colder as you climb higher. This is what we know from everyday experience. The troposphere ends at height of about 15 kilometers - above the tallest mountains.

Above the troposphere is what's called the stratosphere. Airplanes will fly just into the stratosphere where there is no convection, no turbulence, where their is no weather. The lower part of the stratosphere is where ozone absorbs ultraviolet light from the Sun. In this region, the temperature gets hotter as you climb higher! Eventually you get above the ozone and the atmosphere does the usual of getting colder as you climb higher. The stratosphere ends at a hight of about 85 kilometers.

Above the stratosphere is the thermosphere, where X-rays are absorbed. This is where you get auroras. From gas being ionized by the high energy photons and colar wind funnled down the magnetic poles. IN this region, Above the thermosphere is called the exosphere, which is the outermost layer of the atmosphere before it smoothly blends into what we would call outer space.

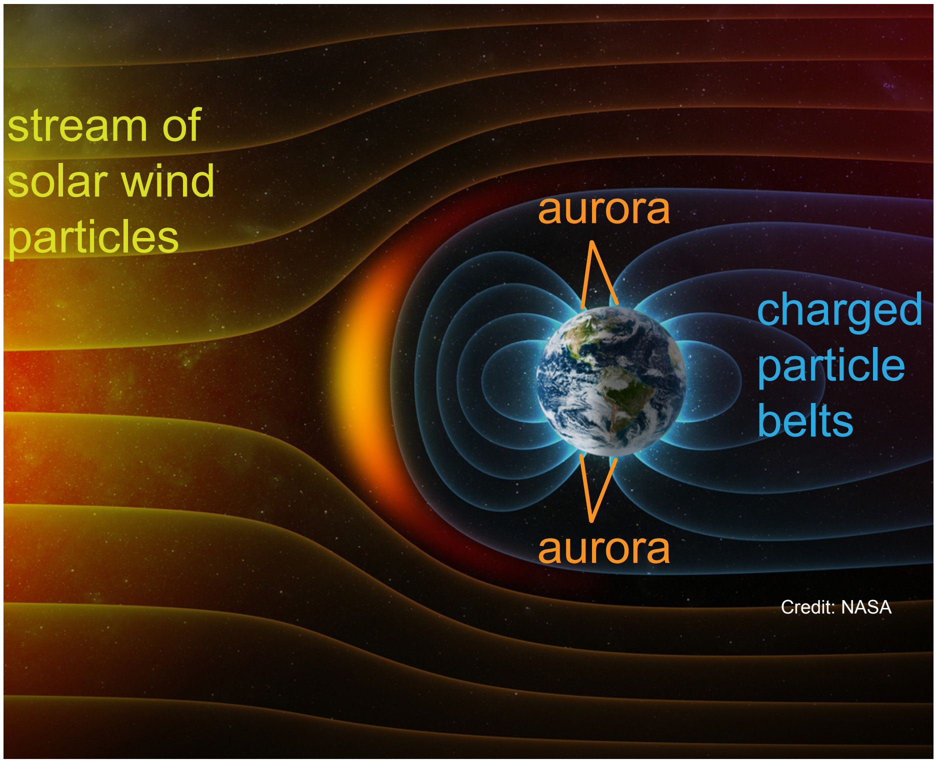
So the basic structure that you get -- troposphere, stratosphere, thermosphere, exosphere -- all from on the type of light they absorb. Visible light and infrared light down low, ultraviolet as you move further up, followed by X-ray until you run out of atmosphere.



Let’s compare the atmospheric structure of the terrestrial planets. The graph above is just like the previous one. Temperature versus Height. First look at Earth. That’s the one we just covered. We have the troposphere, stratosphere with a bump, the thermosphere.

Mars and Venus also have a warm troposphere at the surface due to infrared radiations and the greenhouse effect. They also have a thermosphere at the very top where X-rays are absorbed. The biggest difference is Earth has that extra bump in the stratosphere where the ultraviolet is absorbed by ozone.

The temperature the planets would have if i they didn't have an atmosphere, our “no atmosphere” temperature, is labeled on the x-axis. Those values are from the table we looked at earlier. Here you get a visual representation of the difference between having atmosphere and not having an atmosphere.



Last item. Planets with magnetic fields are able to retain their atmospheres longer because they effectively make a cocoon, a protective cocoon, that protects the atmosphere from being stripped by the solar wind. The image above shows our protective shield. Without a magnetic shield, an atmosphere can get stripped fairly rapidly. Just ask Mars.

So, the solar wind impinges upon a planet with a magnetic field. That magnetic field shuttles the wind around the atmospheres, so the atmosphere's not constantly being bombarded by the very fast moving particles from the solar wind. There are two weak links in the armor. That's at the North and South magnetic poles, where the particles can spiral on down. This is what gives us, the Aurora Borealis, the Northern Lights. Or the Southern Lights, if you're in the Southern hemisphere.

What causes the lights? Well, those particles slide down the chinks in the armor and they hit the atoms in the upper atmosphere. It causes the electrons in the jump into an excited state. When the electrons fall back down to lower energy states, a photon of a specific wavelength, a specific color is emitted. atoms to fluoresce. Green primarily corresponding to nitrogen. It's the most common color because it's the most common gas in the atmosphere! But on occasion, you'll see blue, indicative of oxygen, our atmosphere’s second most abundant gas.

Thanks! Bye Bye.