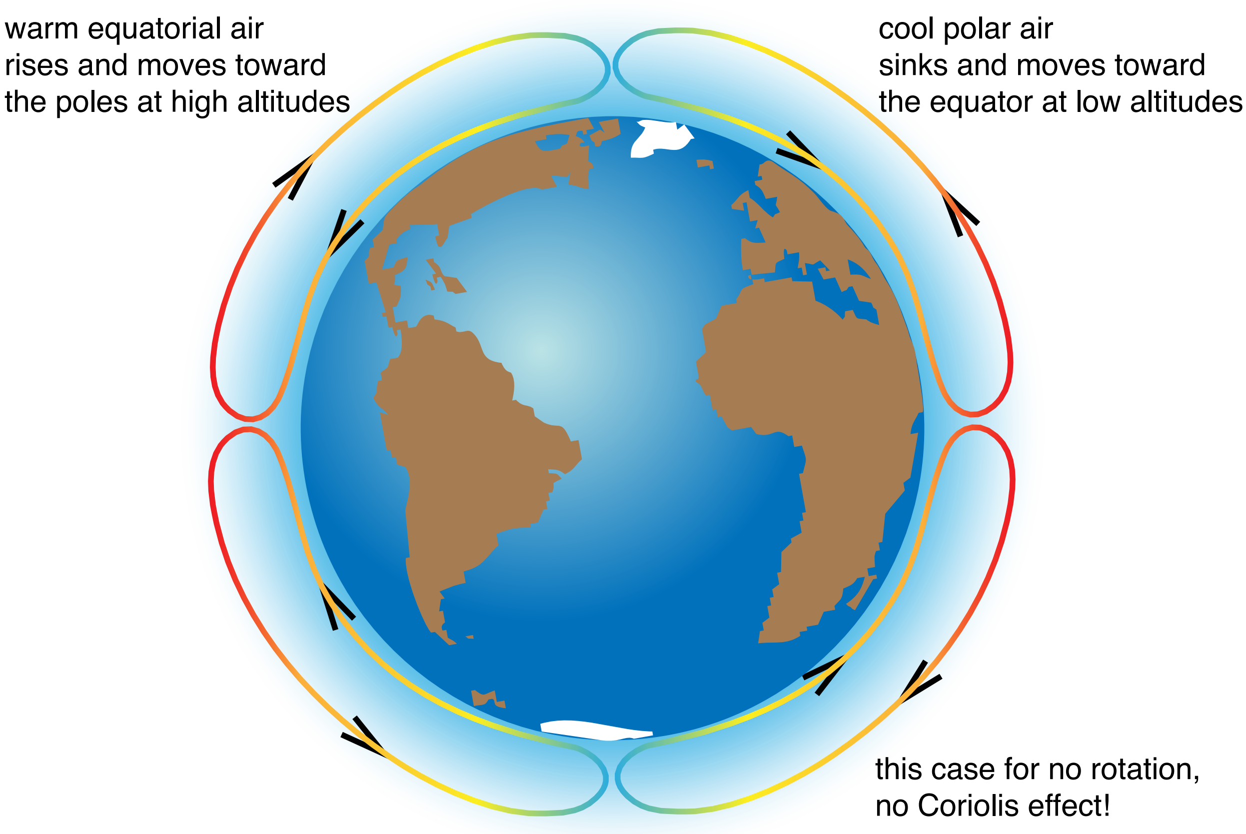
The objects which astronomy discloses afford subjects of sublime contemplation, and tend to elevate the soul above vicious passions and groveling pursuits.

Thomas Dick
Geography of the Heavens

Coriolis - Right

Hi everyone! In this module we'll explore aspects of the forces that cause global winds, how a planet gains an atmosphere, and how planet loses an atmosphere.

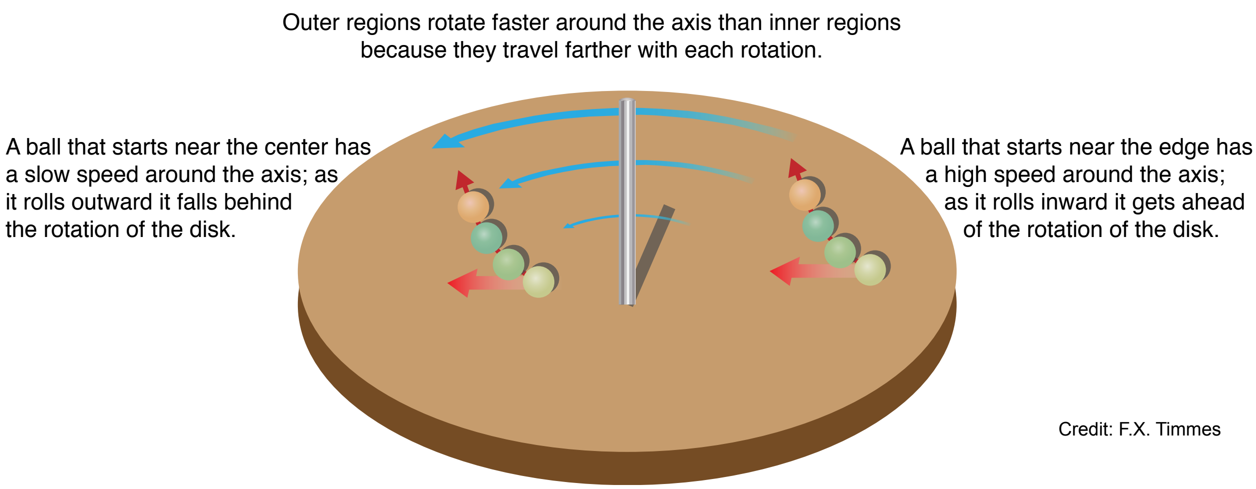


Credit: F.X. Timmes

Global wind patterns are shaped by atmospheric heating and a planet's rotation. Its convection in the troposphere that can lead to clouds, rain, hail, snow, and what that we call weather.

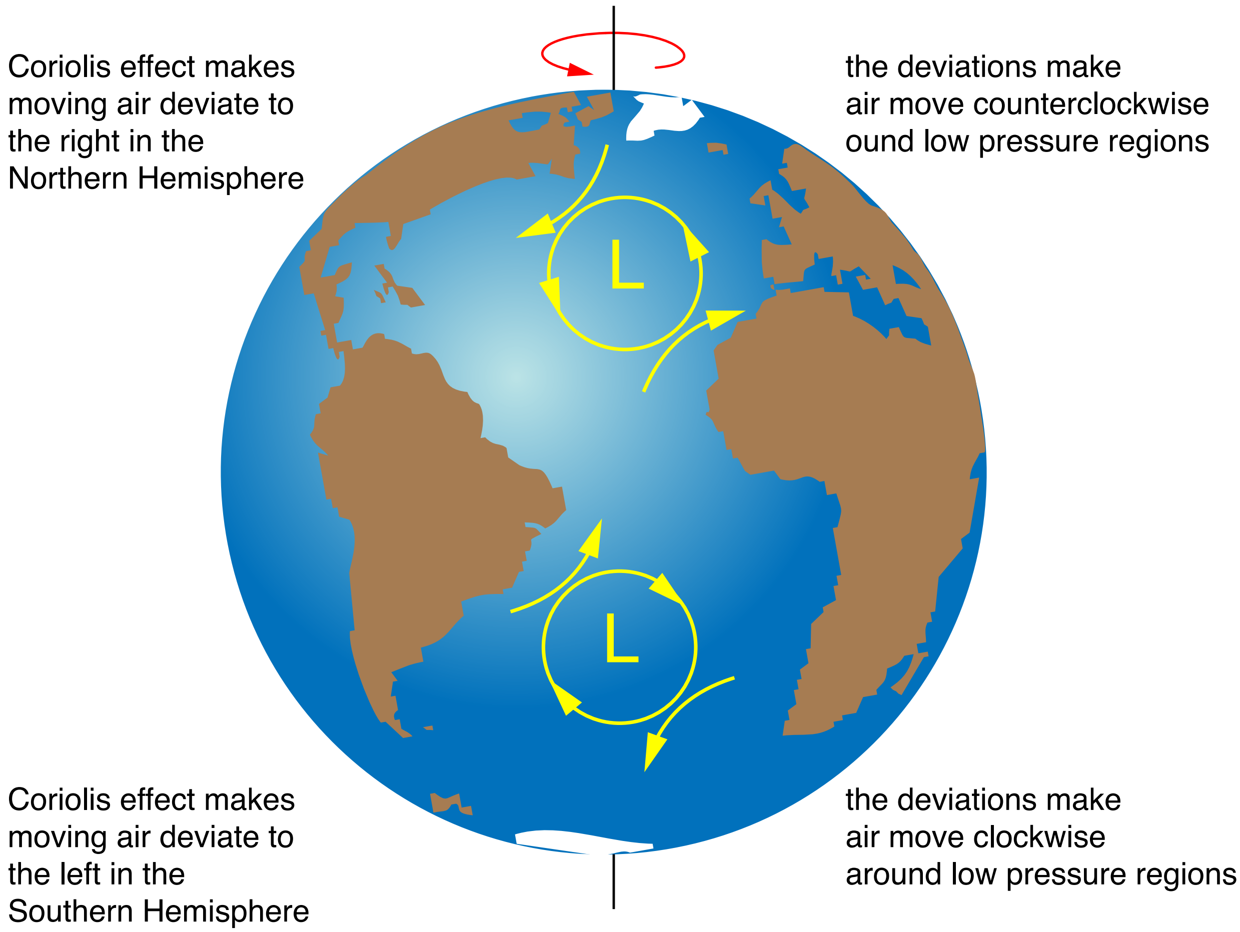
If a planet did not rotate, like in the image above, most of the heating would take place in the equatorial regions. Hot air rises. Convection thens cause that hot wind to flow toward the cooler air near the polar regions. Cold air sinks. Convection causes this cool wind to flow toward the hotter air near the equatorial region. So basically you would get one large convection cell per hemisphere. So two circulation cells total. If the Earth didn't spin, we would have these nasty 200 mph winds from the tropics to the poles and back again. Ugg.

Now let the planet rotate. In a nutshell, this is going to cause the one convection cell per hemisphere to break up into more than one per hemisphere. Because of the Coriolis effect. But one step at a time.



Remember a merry-go-round? Ever roll a ball on one? Maybe that's something only geeky budding scientists do. Anyway, if you roll the ball, what does the want to do? It wants to go in a straight line, per Newton's first law. But the ball does not go in a straight line. Instead, if the merry-go-round is rotating counterclockwise like in the image above, the ball deviates from a straight line by curving to the right. The force causing the ball to deviate from a straight line is due to the rotation. This deviation from a straight line path on a rotating object is called is the Coriolis effect.

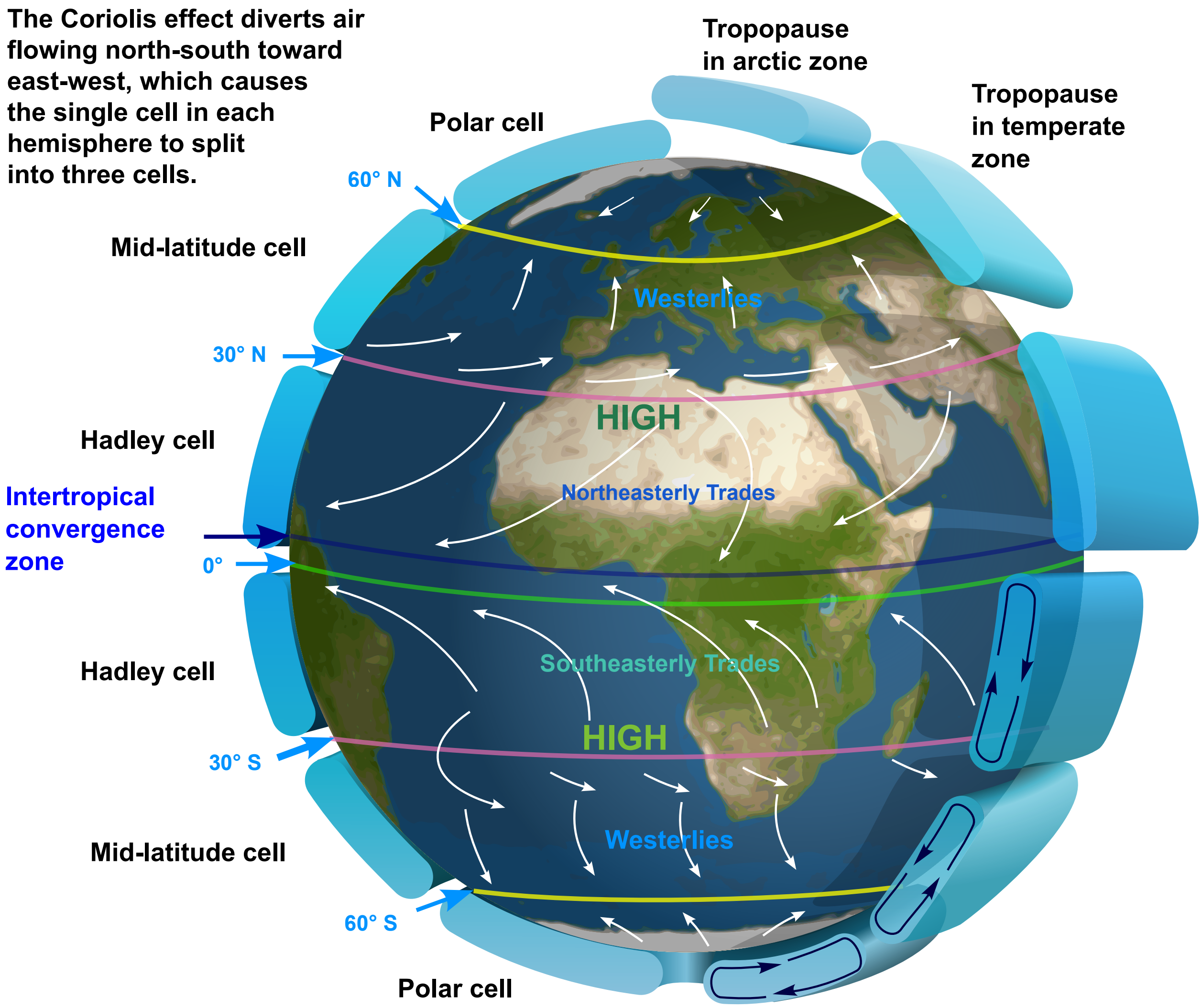
When people were first learning how to fire ordnance in the northern hemisphere, they would launch it and expect it to land somewhere. Lo and behold, it was landing someplace far to the right of where they thought it would land. They had to learn how to adjust for the Coriolis effect, the deviation caused by being on a rotating planet.



The Coriolis effect causes objects on a rotating planet to deviate from straight-line trajectories. In the Northern Hemisphere on Earth where the rotation is counterclockwise that deviation is to the right. Coriolis - Right.

The image above shows the Coriolis effect makes moving air deviate to the right in the Northern Hemisphere. This makes air move counterclockwise around low pressure regions. Ever wonder why a hurricane rotate counterclockwise in the Northern Hemisphere? Now you know.
Coriolis - Right.

So let’s pull this altogether.



Rotation, through the Coriolis effect, causes the single convection cell per hemisphere case we had in a non-rotating Earth to split into three convection cells per hemisphere. This is why, as the prevailing wind illustration above shows, winds generally blow from east to west at the equatorial regions, and then west to east around latitudes that include mainland US, and then shift again from east to west in the polar regions. Three changes in wind direction, one for each convection cell, or Hadley cell as they are called. Note that each Hadley cell, just like in the non-rotating Earth case, transports air from hotter regions to cooler regions.

Mythbusters! Sometimes you'll hear that toilets or other draining water will rotate one way in the Northern Hemisphere and another way in the Southern Hemisphere because of Earth's rotation. This is nonsense because the dimensions of a toilet are far too small to be impacted by the Coriolis effect. If you get any difference at all, it has more to do with the initial conditions that you set up for the draining water.

Now we change gears.

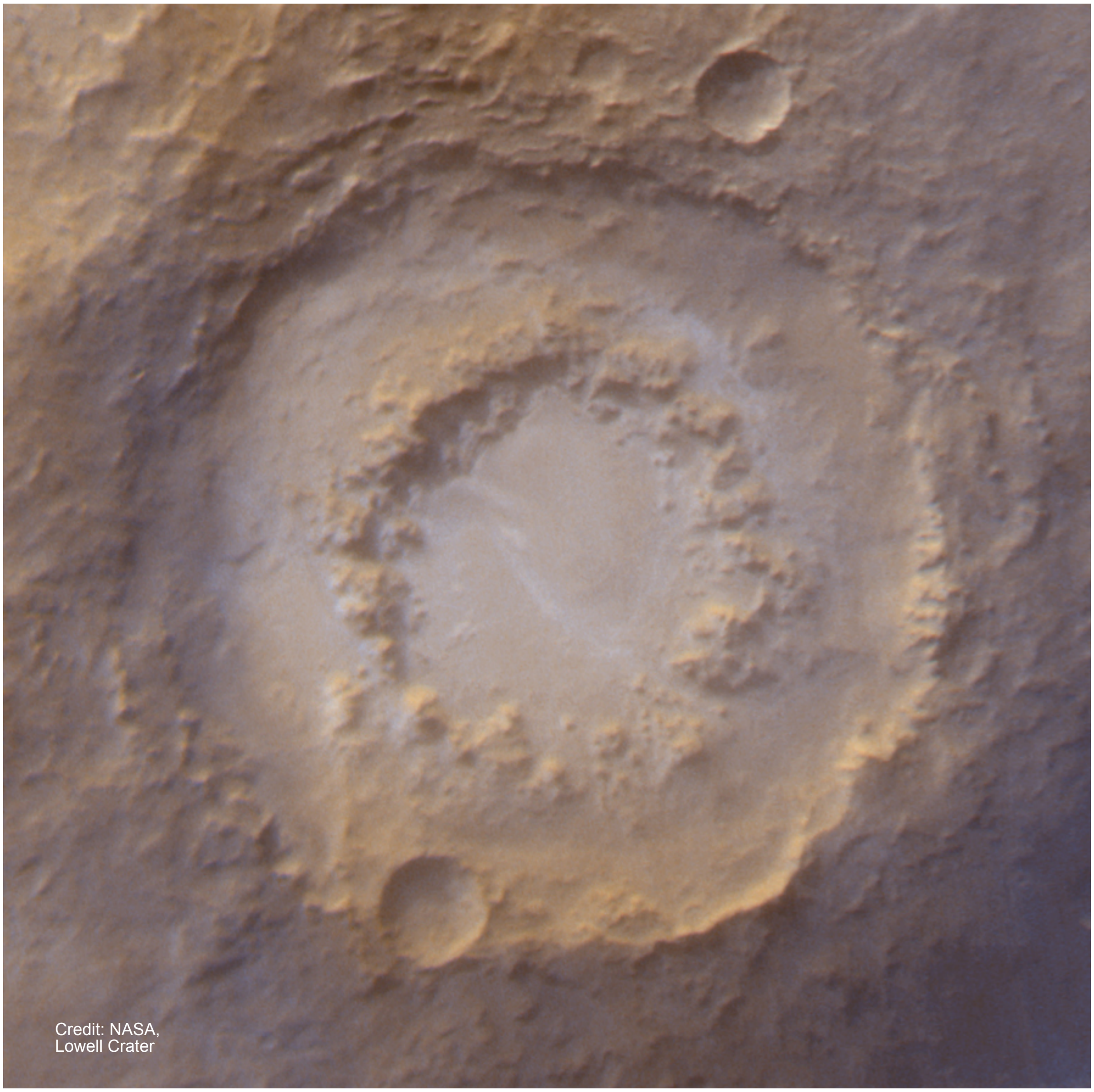
The terrestrial planets were too small to capture significant amounts of gas from the solar nebula before the end of planet formation. Their atmospheres formed after the worlds themselves were formed. So where did the atmospheres come from? There are three sources: outgassing, evaporation, and surface ejection by particles and photons.

So how do planets get their atmosphere in the first place? Well, the terrestrial planets are far too small to have captured significant amounts of gas from the solar nebula before the end of planet formation. They got their deposits of gases and liquids during the era of heavy bombardment. Comets and asteroids brought the gases, in a frozen form, to the planets which then got incorporated into the body of the planet. These gasses are released by three sources: outgassing, evaporation, and surface ejection by particles and photons.


Credit:Wikipedia creative commons

The most important source is outgassing is from volcanoes. The most common gases expelled are water, carbon dioxide, molecular nitrogen, sulphur dioxide. Exactly what the volatile rich comets and astroids would deliver to all the terrestrial planets. Note the first two are especially effective greenhouse gases. So, Its outgassing that supplied most of the gas that became the initial atmospheres of Venus, Earth and Mars. That's not necessarily the atmosphere they have now. Earth’s in particular has evolved dramatically since it was first formed. But it still happens. The image above shows a modern outgassing event: Chaitén in southern Chile erupting in 2008.

Evaporation (liquid to gas) and sublimation (solid to gas) is the second most important process in supplying gases to an atmosphere. This is a big important component for Mars' current atmosphere. Sublimation occurs as the Martian atmosphere warms up the summer session, especially the Southern Hemisphere summer because there's a lot more frozen carbon dioxide at the southern ice cap. So when that warms up, we see lots of carbon dioxide, which is a greenhouse gas, which then helps further warm Mars.



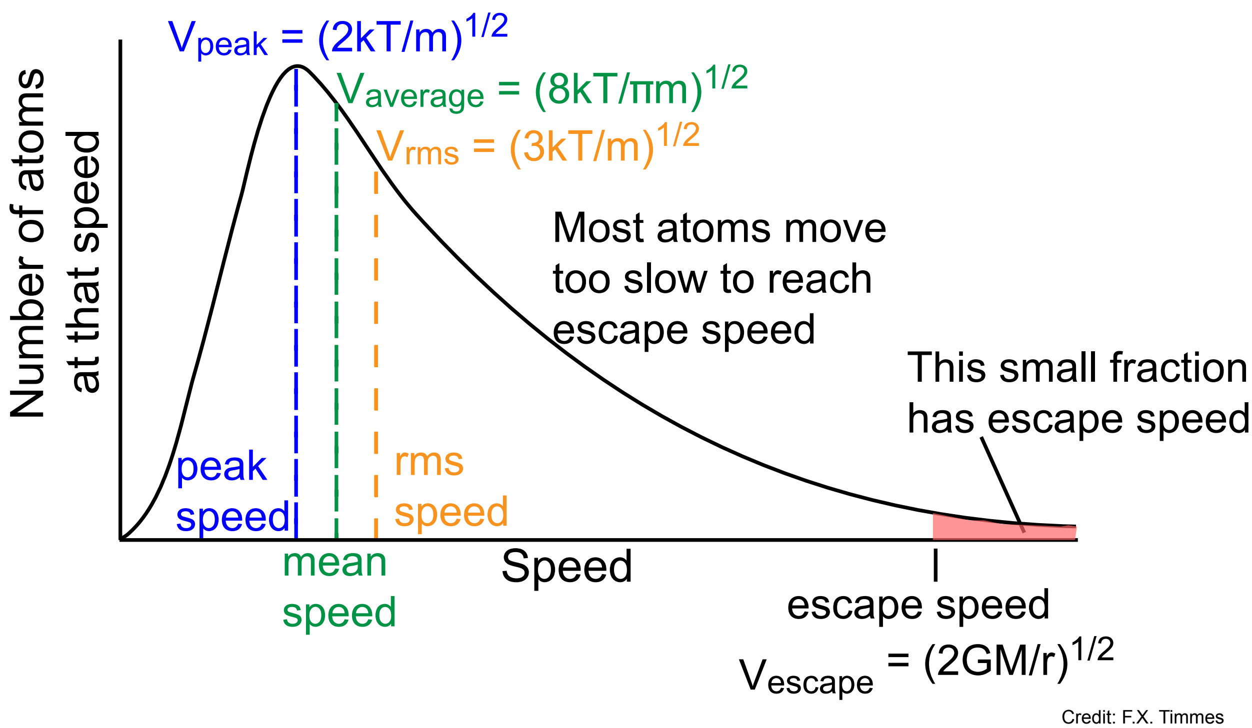
And oppositely, during the winter in the Southern Hemisphere the carbon dioxide condenses. The image above shows carbon dioxide frost in Lowell Crater. The loss of carbon dioxide reduces the greenhouse effect, further cooling Mars even more.

How do planets lose their atmospheres? There are four basic ways: thermal escape, stripping by the solar wind, condensation and chemical reactions with surface materials.

The most important, by far, is thermal escape. And thermal escape is just a particle getting a large enough velocity such that it reaches escape velocity - thus leaving the gravitational field of a planet and being lost to outer space. If you like, atmosphere are leaky. They leak their gasses to space.

Three factors that determine if a gas molecule can escape a planet. One is the temperature -- the higher the temperature, the faster the speed, the higher the average speed. Two is the mass -- lighter gases such as hydrogen and helium move much faster than heavier ones, such as oxygen or carbon dioxide. Three is the planet's escape velocity, so in another words, how big the planet is.

So the particle has to have enough speed to escape gravity. It has to be traveling in the right direction. It cannot not collide with anything else.



The plot above shows the distribution of speeds at a given temperature. Some particles move slowly. Most particles move with speeds near the peak. The vast majority move too slow to reach escape speed. Only the small fraction of particles on the tail of the curve have speeds larger than the escape speed.

This is the primary mechanism by which planets lose their atmosphere. There's nothing you can do about it. It's just the distribution of speeds at a given temperature. This is why Earth has no hydrogen, helium in its atmosphere. All those light gases have escaped. Only the heavier gases, which are moving slower, remain in Earth's atmosphere. Mercury and Moon can't hold an atmosphere at all, because they are too small. Their gravity is too weak to even hold onto the heavier gases.

The other atmosphere loss process that is important for Earth is the atmosphere being locked up through chemical reactions. Earth's volcanoes outgassed huge amounts of carbon dioxide, just like those on Venus and in Mars. They both are carbon dioxide dominated. Where's all our carbon dioxide? Well, almost all of our carbon dioxide is locked up in rocks, particularly limestone, at the bottom of the ocean. It got there because of our vigorous water cycle, as we will in another module.

Thanks! Bye bye.