CHEM 302: Atmospheric Environmental Chemistry

Case Study 2: The Goldilocks Effect
The Atmospheres of Venus, Earth and Mars

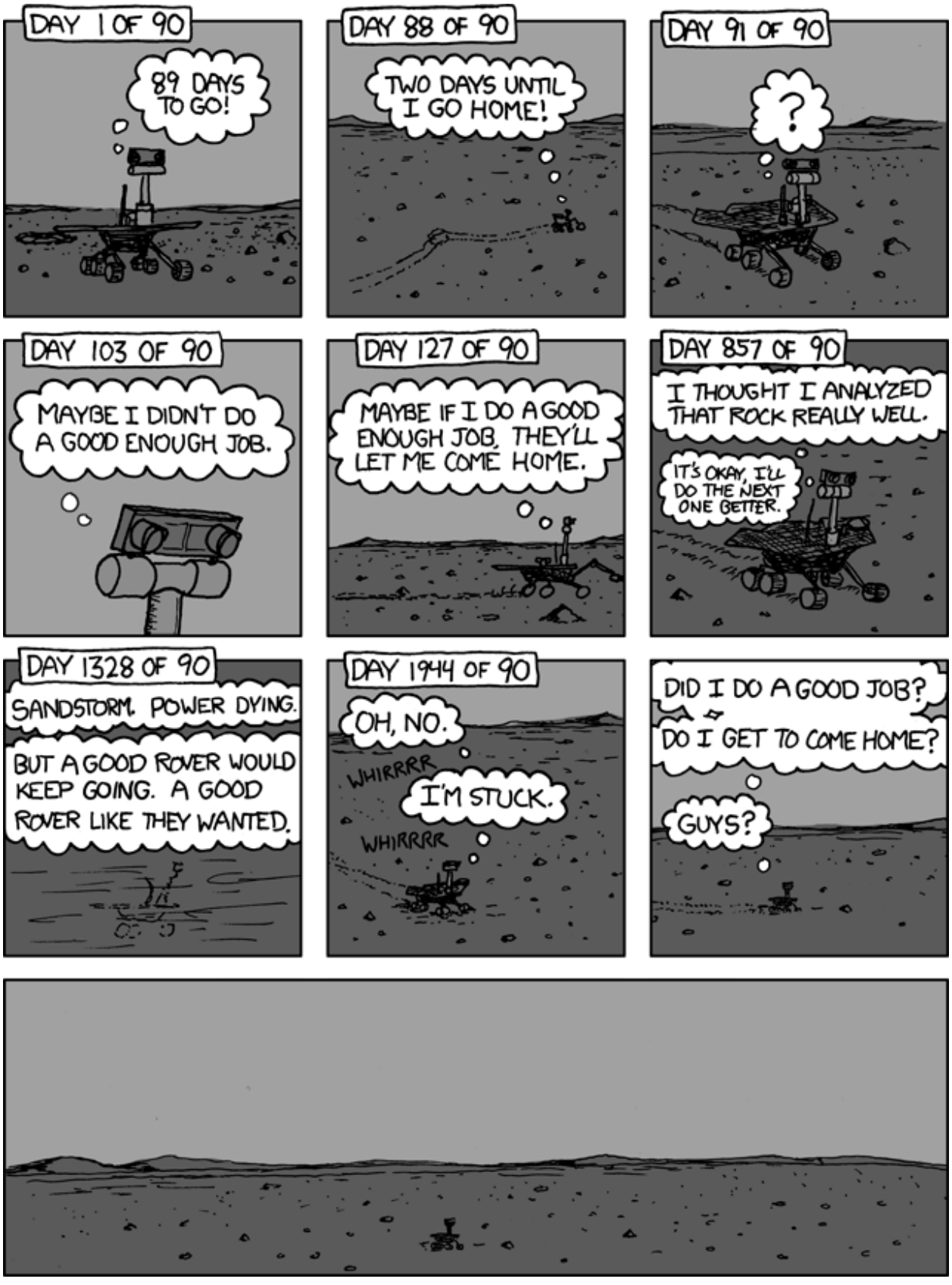
Presented by Kimberly Quant and Larissa Richards on September 23, 2011

Attached Readings:

1. Spirit, *xkcd*, Retrieved September 21, 20011 from http://xkcd.com/695/
2. Climate and Evolution, *European Space Agency,* Retrieved September 21, 2011 from http://www.esa.int/esaMI/Venus_Express/SEMGK373R8F_0.html
3. Mars Methane Media Mess, *Bad Astronomy for Discover Magazine,* Retrieved September 21, 2011 from http://blogs.discovermagazine.com/badastronomy/2009/01/19/mars-methane-media-mess/
4. Vladimir A. Krasnopolsky, Atmospheric chemistry on Venus, Earth, and Mars: Main features and comparison, Planetary and Space Science, Volume 59, Issue 10, August 2011, Pages 952-964
5. Lodderes, K. & Fegley, B. Jr., The Planetary Scientist's Companion. Oxford University Press; New York. 1998
6. Bagenal, F. (2005). *Class 14- Earth, Venus, Mars* [Lecture Notes] Retrieved on September 21, 2011 from http://lasp.colorado.edu/~bagenal/3720/CLASS14/14EVM-5.html

Additional Readings and Weblinks:

1. Venus Express, European Space Agency, http://sci.esa.int/venusexpress
2. Methane Debate Splits Mars Community, Mars Daily, http://www.marsdaily.com/reports/Methane_Debate_Splits_Mars_Community_999.html
3. Evolution Of Venus: First Too Fast, Then Too Slow. *ScienceDaily*. http://www.sciencedaily.com/releases/2008/04/080402202055.htm#
4. Mars Methane Mystery: What's Making the Gas? *Discovery Magazine,* http://news.discovery.com/space/mars-methane-mystery.html
5. The Goldilocks Effect: How Other Earths Form Just Right, *Science Daily,* http://www.spacedaily.com/news/early-earth-01e.html


DAY 1 OF 90
89 DAYS TO GO!
DAY 88 OF 90
TWO DAYS UNTIL I GO HOME!
DAY 91 OF 90
?
DAY 103 OF 90
MAYBE I DIDN'T DO A GOOD ENOUGH JOB.
DAY 127 OF 90
MAYBE IF I DO A GOOD ENOUGH JOB, THEY'LL LET ME COME HOME.
DAY 857 OF 90
I THOUGHT I ANALYZED THAT ROCK REALLY WELL.
IT'S OKAY, I'LL DO THE NEXT ONE BETTER.
DAY 1328 OF 90
SANDSTORM. POWER DYING.
BUT A GOOD ROVER WOULD KEEP GOING. A GOOD ROVER LIKE THEY WANTED.
DAY 1944 OF 90
OH, NO.
WHIRRRR
I'M STUCK.
WHIRRRR
DID I DO A GOOD JOB?
DO I GET TO COME HOME?
GUYS?

Climate and Evolution

28 November 2007
Today, Venus is a hellish place of high temperatures and crushing air pressure. Venus Express is showing that this was not always the case. Instead, some time in the past, Venus was probably much more Earth-like and contained large quantities of water.

Planetary scientists have long wondered just how Earth-like Venus is or might have been. Until the 1960s, astronomers speculated that Venus might be a tropical forest planet. This view changed when microwave observations began to suggest an extremely hot surface. The Russian and American spacecraft of the 1960s and 70s confirmed that Venus possesses surface temperatures of over 400°C and surface pressure a hundred times that of Earth.

The winds in Venus's atmosphere are severe, blowing at speeds of up to, and over, a 100 m/s. Yet, as fierce as they are, not even the winds from the giant south polar vortex extend all the way down to the planet's surface.

Venus Express can see down to about 45-50 km above the surface in the south polar region. Feeding this data into computer models suggests that the vortex cannot penetrate into the lower atmosphere because of the great density of gas there. "It is difficult to move around such a heavy mass of atmosphere. We do not expect big winds at the surface of Venus," says Giuseppe Piccioni, IASF-Istituto Nazionale di Astrofisica, Italy.

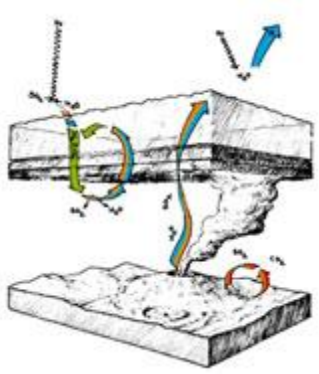
How did Venus turn out like this?
Geologists say that the present is a clue to the past and the same is true for atmospheric physics. Venus Express has revealed an atmospheric process that points to a catastrophic event in Venus's history.

"Venus has suffered a radical climate disaster but we don't yet know how, why and when," says David Grinspoon, a Venus Express interdisciplinary scientist from the Denver Museum of Nature and Science, Colorado, USA.

The disaster was the loss of Venus's water. If you could condense all of the water vapour in Venus's atmosphere, it would create a thin covering of water just 3-cm thick. For comparison, if Earth were a smooth ball, all of the water in the oceans and atmosphere would create a covering 3-km deep.

Venus may once have had this much water as well but it has been gradually stripped off into space by the collision of energetic particles from the Sun. Today, Venus Express has shown that the last remnants of the process are still taking place with the escape of hydrogen and oxygen from the top of the atmosphere.

“We now know that Venus was once more Earth-like,” says Grinspoon, “We cannot tell the full story yet, but the data we are getting shows that Venus Express will reveal the history of water on Venus.

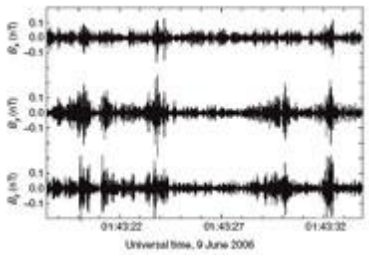


Climate evolution on Venus

Venus has no seasons because its rotation axis is already perpendicular to its orbit. It rotates just once in 243 Earth days and has a very massive atmosphere. This is chiefly composed of carbon dioxide with clouds primarily of sulphuric acid droplets.

It sounds nothing like Earth, and yet, thanks to Venus Express, planetary scientists now know that it can be explained in the same framework, but with Venus being driven in a different direction.

“The three most important parameters that determine a planet’s ‘behaviour’ are its distance from the Sun, its surface pressure and its rotation rate,” says Fred Taylor, a Venus Express interdisciplinary scientist from the University of Oxford, UK. So, although Venus is similar in size to Earth, it is drastically different in the three parameters that drive its behaviour.



Wave events showing lightning at Venus

There is another large unknown in the evolution of the atmosphere: the amount of lightning on the planet. Lightning drives the chemistry of an atmosphere by breaking molecules into fragments that can then join other fragments in unexpected ways. Nitric oxide formed in this manner is present in sufficient quantities to be detected from Earth.

“There may be as much lightning on Venus as there is on Earth,” says Chris Russell at the University of California at Los Angeles, who was part of the magnetometer team that searched for, and found, lightning on Venus.

Throughout its extended mission, Venus Express will continue collecting vital data to better understand the evolution of this fascinating planet.

Mars methane media mess

By now you've probably heard the news about Mars: methane gas is being generated on the Red Planet, and the amount varies with season and location. There are really only two ways to make methane that we know of: geologically (volcanoes, chemical changes under the surface, and so on) and biologically (little critters basically belching).

Mars is an interesting place, and anytime we find something new and interesting about it, it's not surprising to see the media covering it. It's also not surprising to see the scientists involved excited about it. But when that news deals with biology, well, things tend to get a little out of control.

Or as in this case, a lot out of control.

First, what do we *know?*

1) A few years back (in 2004 specifically), methane was detected on Mars. However, those observations were not sensitive enough to do much more than measure the amount (10 parts per billion in the atmosphere, more or less).

2) New maps made of the Martian methane found it changes from place to place, and time to time. Methane is not stable in Mars' atmosphere: it goes away rapidly. So there must be a source of it that is making methane *now*, actively.

3) The easiest way to get methane is from volcanoes, but they spew out other gases, and these were not detected.

4) Another, related way is for chemical processes under the surface to create methane. However, we don't understand what is happening chemically on Mars terribly well, or beneath the surface.

5) Methane is a natural byproduct of life on Earth. Maybe that's happening on Mars as well.

That's it. That's what we *know*. It might be geological, it might be chemical, it might be biological. **We don't know which**.

That didn't stop some of the media from totally exaggerating the article to the point of irresponsible journalism.

Take the UK newspaper The Sun. The headline they ran? "Nasa reveals life on Mars". Incredible. The lead line was "ALIEN bugs are responsible for strong plumes of methane gas detected on Mars, it was claimed tonight."

That's simply *wrong*. Completely and utterly! All the scientists said they didn't know for sure. Some implied microbes were a good candidate, but none came out and said "It was alien bugs."

Sure, The Sun is a rag, best used to line bird cages (even the online version, if you can scrape enough electrons together), but it's widely read. And lest you think it was just them, then check out The Mirror, with its headline "Mars: Nasa experts to confirm there is life on Mars", or The Money Times, which had "Methane plumes indicate 'life on Mars'". Lots of blogs ran with this idea, too.

To be fair, NASA is not blameless in this. Their press release for this was titled "DISCOVERY OF METHANE REVEALS MARS IS NOT A DEAD PLANET". Now, they are playing with the word "dead", since you can interpret that to be about geological activity, as opposed to biological. But still, that's fanning the flames they must have known would erupt. I would've hoped they had learned their lesson from the last time they pulled a PR stunt like this.

OK, so NASA goaded tabloid media into false headlines, and some ran with it (when they didn't need provocation). What's the real deal?

I'll be frank: *we don't know*. Methane is a very simple molecule (CH_4, just four hydrogen atoms bonded to a carbon atom), and is pretty easy to produce in a number of ways. As noted above, volcanoes are probably ruled out due to the lack of any detection of other gases they usually produce.

Chemistry? Maybe. Mars is different than Earth. The laws of chemistry are the same there as here, but the chemistry *going on* is different. The air is thin, and mostly CO_2. We know the surface chemistry of the planet is pretty different than here; the water that once flowed on its surface was probably acidic and *very* salty, and when it dried up left weird things like jarosite. Not only that, there appears to be perchlorate in the soil found by Phoenix, and that tends to dissolve terrestrial life. However, it's possible that CO_2 could combine with water under the surface (if there's a heat source like magma) to make methane.

And what of biology? It can't be ruled out, but it cannot be ruled in either. The amount of methane detected was pretty substantial, implying a large amount of biological activity, but there has been no evidence of any life on Mars at all up to now. It's all circumstantial: ice under the surface was found by Phoenix, but near the north pole. Water used to be abundant, but no conclusive proof of *extant* liquid water on the surface has been found… not even temporarily (like recent flooding events). All the evidence for liquid water (like gullies in craters) could be from other sources, like clathrates.

The bottom line here is that if we want to figure out what's causing this gassy Martian eructation, we need better instrumentation at the site. I hope that NASA will equip their next landers with something that can taste the air and perhaps nail down the source of the methane.

Finally, a thought: where you get your news is just as if not *more* important than *what* that news is. When it comes to science, there are very few newspapers you can trust. When it comes to astronomy and space news, your best bet is to go to the people who know what they're talking about, and go to multiple sources to cross-check them.

And who would that be? Who got this methane story right?

Universe Today, unsurprisingly, nailed it with "Large Quantities of Methane Being Replenished on Mars". Also unsurprisingly, Emily at The Planetary Society blog has an excellent article as well. My fellow Hive Overmind blogger Carl Zimmer live blogged the press conference and produced an excellent report.

Other bloggers noticed the media nonsense too, including my friends and colleagues Dave Mosher and Carolyn Collins Petersen.

I suppose that after all this, there's one thing we know for absolute sure: methane, both chemically and journalistically, is a volatile substance.

Table 1: Past and Present Abundances of Main Volatiles on the Terrestrial Planets

Compound	Venus		Earth		Mars	
	Past	**Present**	**Past**	**Present**	**Past**	**Present**
CO_2 (atm)	*88.8*	88.8	111	$4.9x10^{-4}$	15.8	0.0059
N_2 (atm)	*1.97*	1.97	2.47	0.79	0.345	$9.7x10^{-5}$
H_2O (m)	3600	0.013	*4000*	4000	1500	15

Values adopted for scaling are shown in italics
Reference 4

Table 2: Chemical Composition of the Most Abundant Gases in the Atmosphere of Venus

Gas	Abundance	Gas Source(s)	Gas Sink(s)
CO_2	96.5±0.8%	Outgassing	Carbonate formation
N_2	3.5±0.8%	Outgassing	---
SO_2*	150±30ppm (22-42km) 25- 150ppm (12-22km)	Outgassing and reduction of OCS, H_2S	H_2SO_4 formation & $CaSO_4$ formation
H_2O*	30±15ppm (0-45km) 30-70 (0-5km)	Outgassing	H escape & Fe^{2+} oxidation

*Abundances of these species are altitude dependant
Reference 5

Table 3: Chemical Composition of the Most Abundant Gases in the Atmosphere of Mars

Gas	Abundance	Gas Source(s)	Gas Sink(s)
CO_2	95.32%	Outgassing & evaporation	Condensation
N_2	2.7%	Outgassing	Escape as N
O_2	0.13	CO_2 photolysis	Photoreduction
CO	0.08%	CO_2 photolysis	Photooxidation
H_2O*	0.03%	Evaporation and desorption	Condensation and Adsorption
O_3*	~ 0.04-0.2 ppm	Photochemistry (CO_2)	Photochemistry

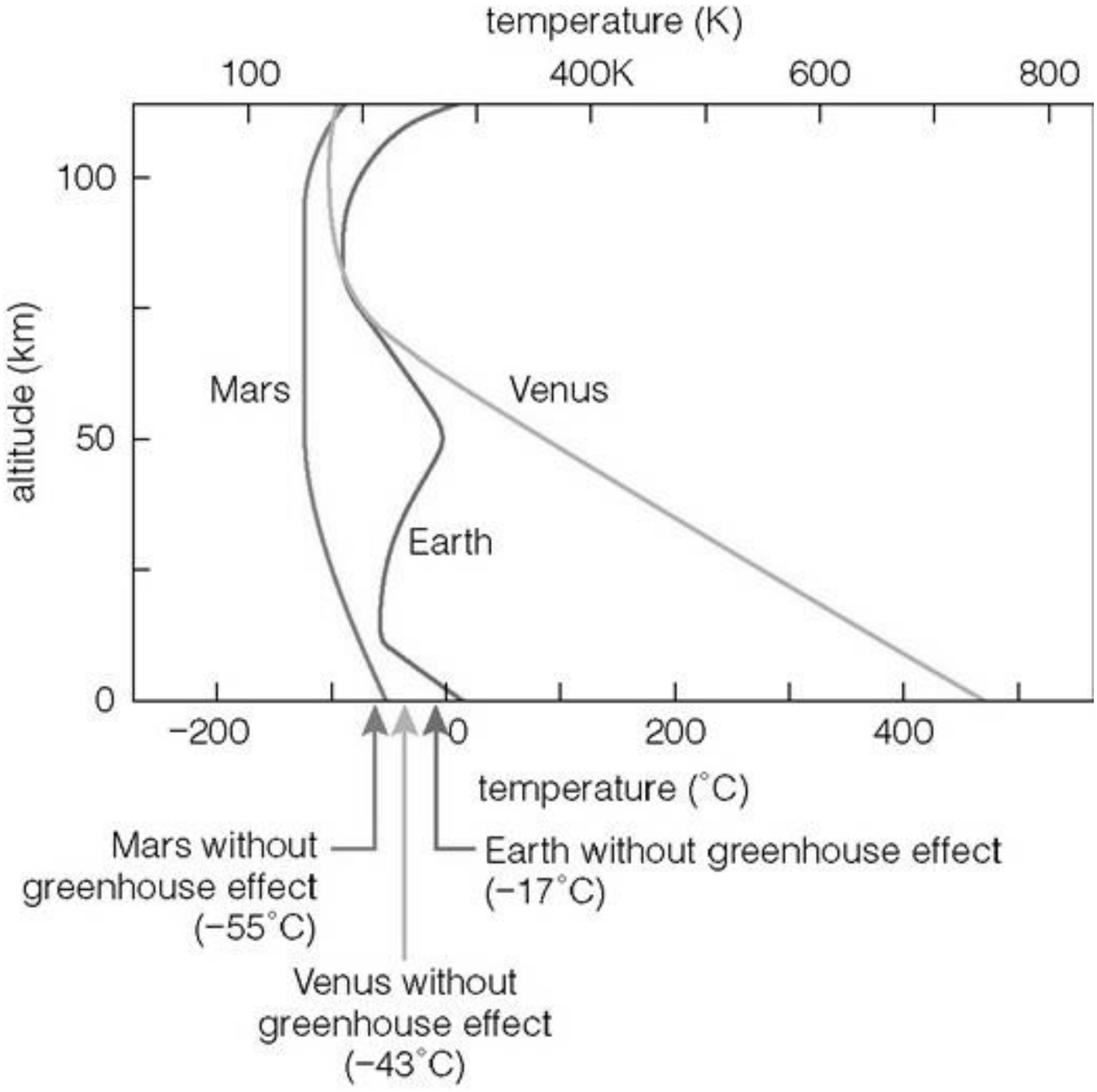
*Spatially and temporally variable
Reference 5

Table 4: Chemical Composition of the Most Abundant Gases in the Atmosphere of Earth

Gas	Abundance	Gas Source(s)	Gas Sink(s)
N_2	78.084%	Denitrifying bacteria	Nitrogen fixing bacteria
O_2	20.946%	Photosynthesis	Respiration and decay
H_2O	<4%	Evaporation	Condensation
CO_2	390ppm	Combustion, biology	Biology
O_3	~ 10-100ppb	Photochemistry	Photochemistry

Reference 5

Figure 1: Comparing Temperature Versus Altitude for Venus, Earth and Mars



Reference 6