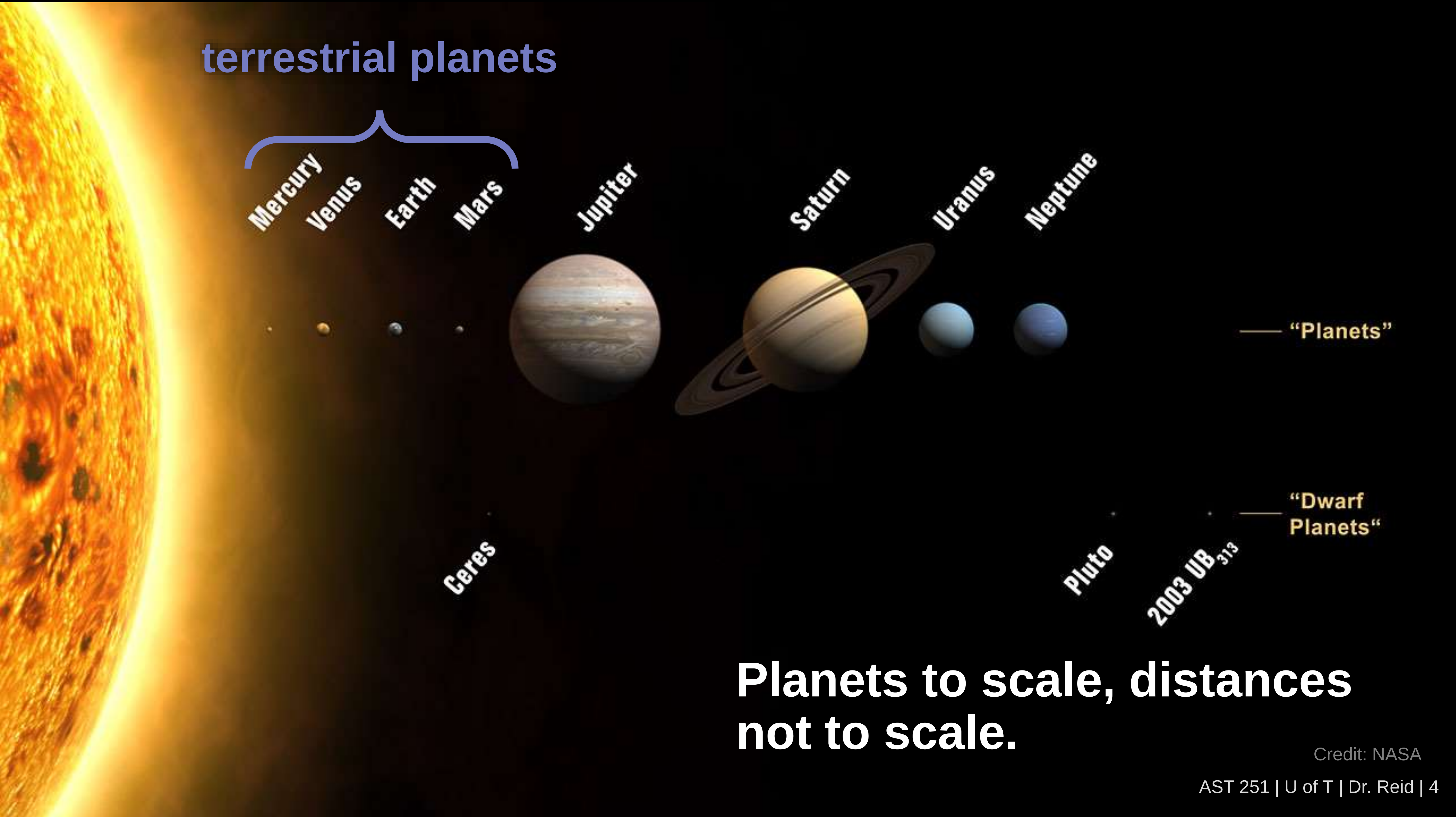
The Search for Life on Mars*, Part 1

*and the other terrestrial planets of our solar system

Why spend so much attention on exoplanets when we have 3 terrestrial planets in our own solar system to check for life?

What are the prospects of finding life in our own solar system?



Planets to scale, distances not to scale.

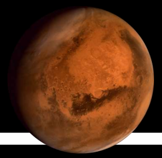
Credit: NASA

Mercury and the Moon are both airless and arid—not likely habitats for life like us.

Credit: MESSENGER & Luc Viatour

Earth, Venus, and Mars all have atmospheres.

Credit: NASA and the ISRO

			
Mass (M_{Earth})	**1**	**0.82**	**0.11**
Radius (R_{Earth})	**1**	**0.95**	**0.53**
Surface gravity (g)	**1**	**0.90**	**0.38**
a (AU)	**1**	**0.72**	**1.52**
Axial tilt	**23.5^{o}**	**177^{o}**	**25.2^{o}**
Day (Earth Days)	**1**	**243**	**1.03**
Year (Earth days)	**365.24**	**225**	**687**
Surface atmospheric pressure (atm)	**1**	**91**	**0.0063**
Mean surface temperature (^{o}C)	**15**	**460**	**-63**

Mass (M_{Earth})	1	0.82	0.11
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Surface gravity (g)	[illegible]	90	0.38
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Mean surface temperature (^{o}C)	15	460	-63

Earth and Mars have remarkably similar axial tilts and day lengths.

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Venus rotates very slowly and backwards.

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Surface gravity (g)	1	0.90	0.38
a (AU)	1		
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Surface atmospheric pressure (atm)	$\boxed{1}$	$\boxed{91}$	$\boxed{0.0063}$
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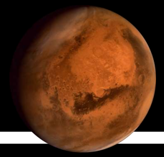
Venus has a crushingly thick atmosphere, while Mars has hardly any.



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Radius (R_{Earth})	1	0.95	0.53
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a (AU)	1	0.72	1.52
Axial tilt	23		
Day (Earth Days)			
Year (Earth days)	36		
Surface atmospheric pressure (atm)	1	91	
Mean surface temperature (^oC)	15	460	-63

Venus' entire surface is boiling hot all the time, while some parts of Mars regularly climb above freezing.

Atmospheres play a major role in determining habitability.

Why do our terrestrial planets have the atmospheres that they do?

0.04% CO_2
78% N_2
1 atm

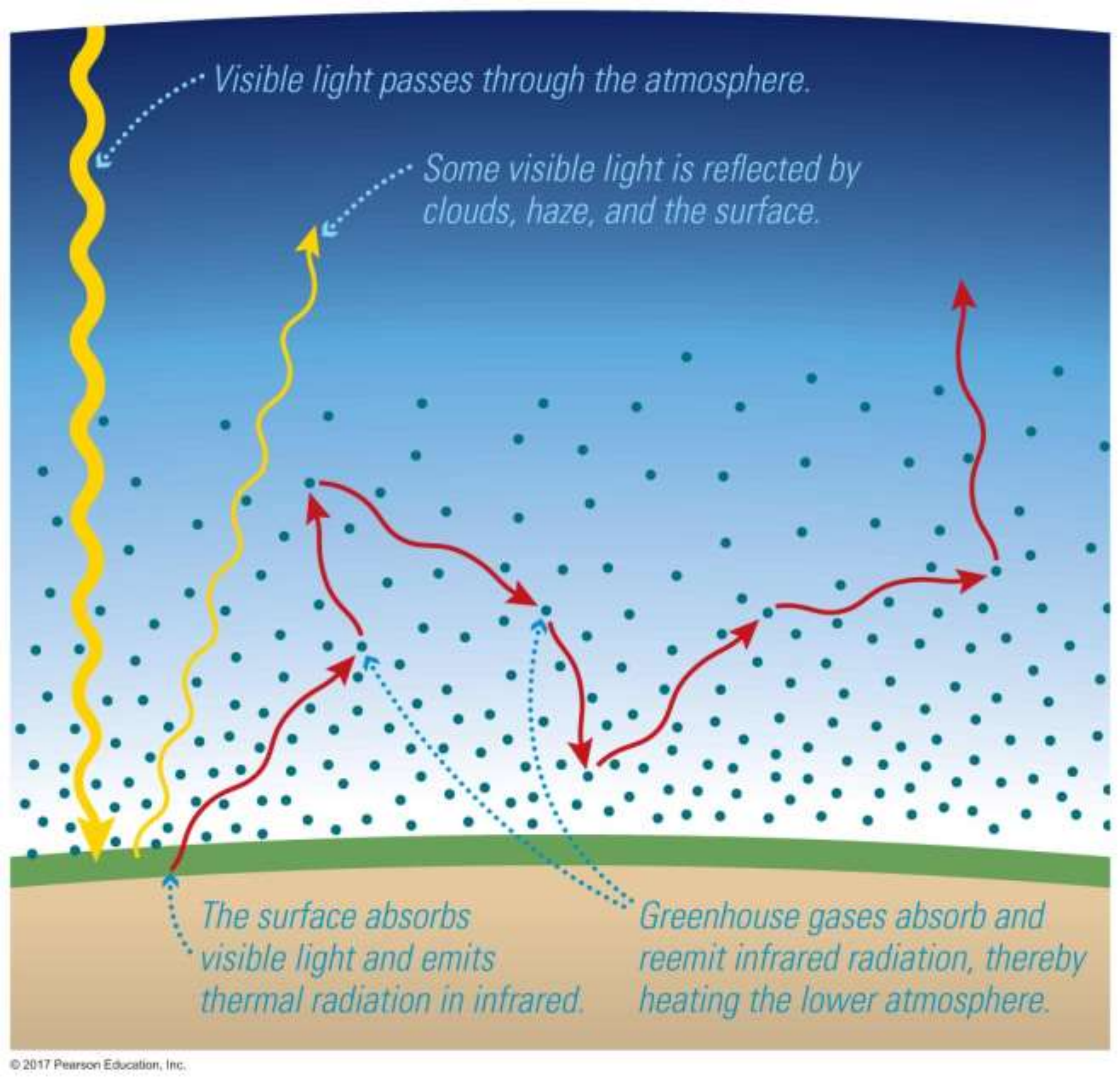
96.5% CO_2
3.5% N_2
91 atm

96% CO_2
2% N_2
0.0063 atm

Credit: NASA and the ISRO

The Greenhouse Effect:

Greenhouse gases such as CO_2, CH_4, and even H_2O trap IR light, keeping planets warmer than they would otherwise be.



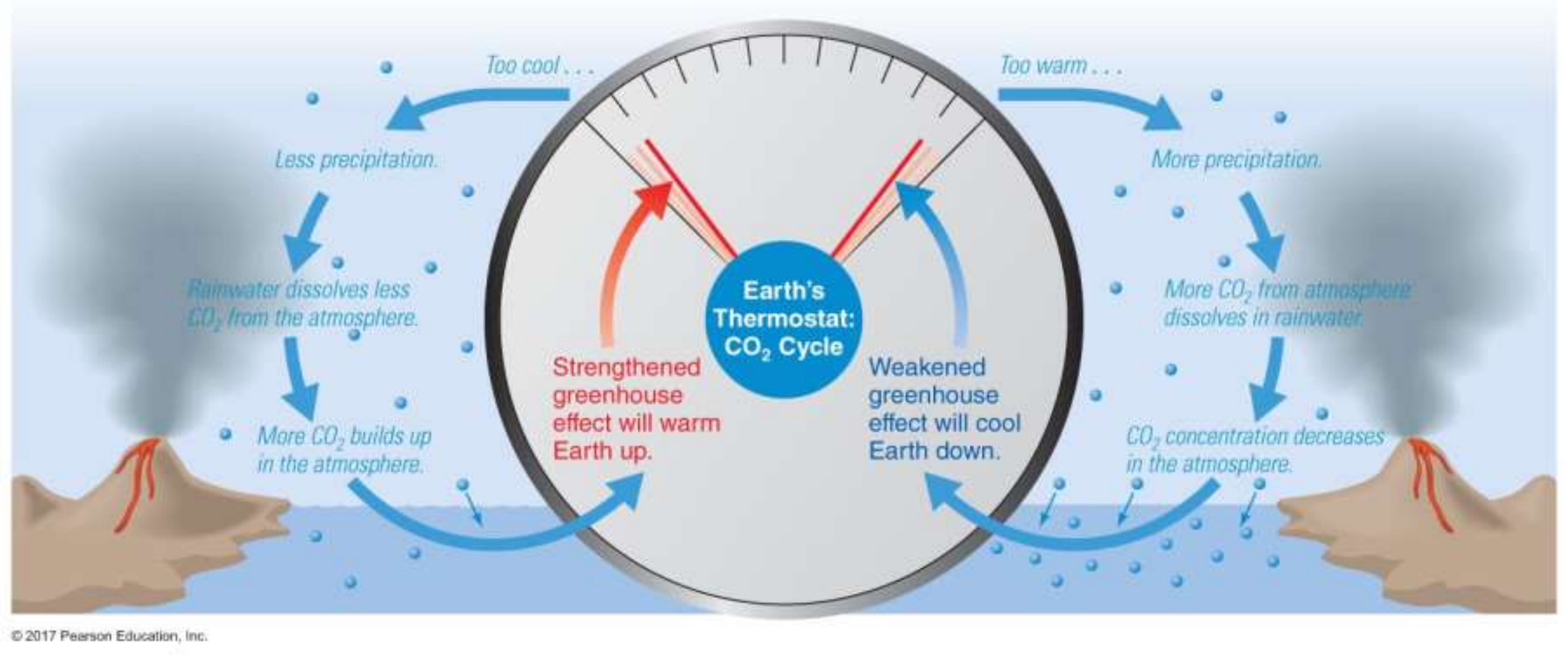
On Earth, the greenhouse effect raises the global average temperature from the equilibrium temperature of around -18°C to an actual global average around 14°C

On Venus, a runaway greenhouse effect has raised the global average temperature from the equilibrium temperature of around -13°C to an actual global average around 470°C

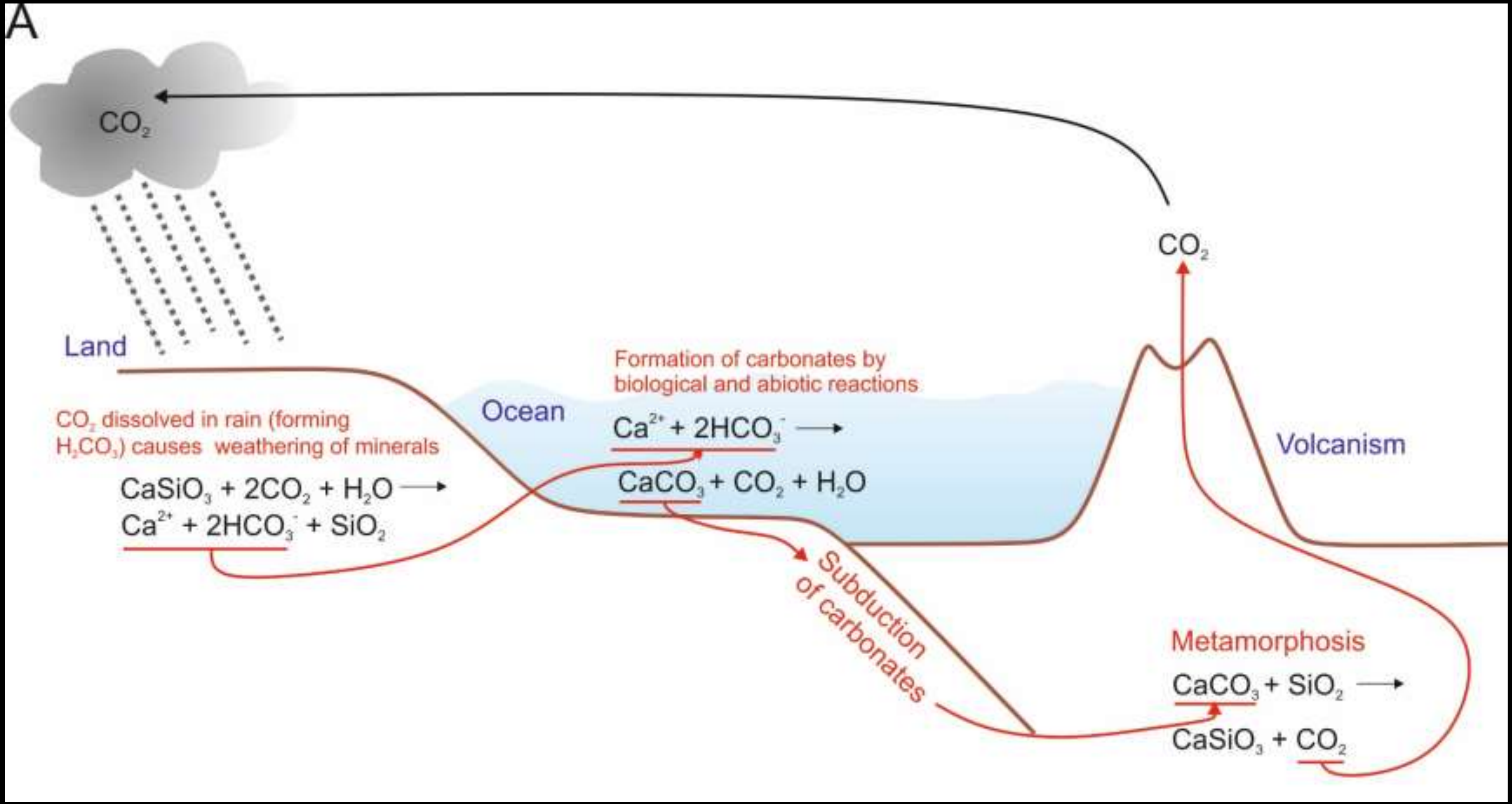
A runaway greenhouse effect occurs when the concentration of greenhouse gases in a planet’s atmosphere reaches the point where added heat can no longer escape.

Instead, the added heat goes into evaporating material from the planet's surface, which can worsen the warming if some of that material itself enhances the greenhouse effect.

In the <u>short-term</u>, Earth's climate is regulated by the greenhouse effect, which reverses small temperature changes.



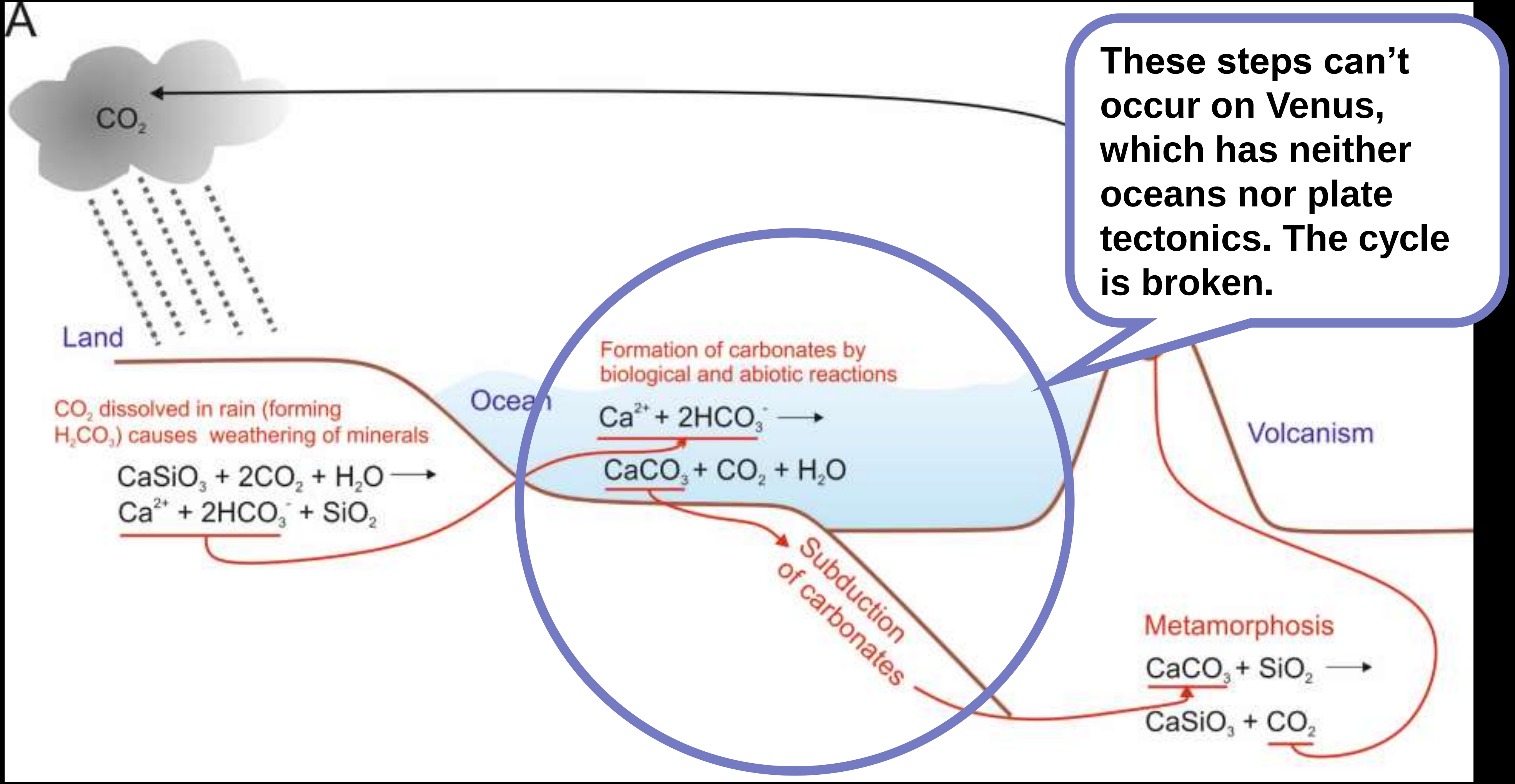
In the long-term, Earth's climate is regulated by the carbon cycle, which regulates the concentration of greenhouse gases in the atmosphere.



Credit: Charles Cockell

When they formed, Earth and Venus probably both had primarily CO_2 atmospheres and H_2O oceans.

What changed?



Credit: Charles Cockell

When Venus was young, it probably received a little too much solar heating, evaporating large quantities of water into its atmosphere, causing the runaway greenhouse effect.

With neither oceans nor active plate tectonics, Venus is missing several pieces of a functioning carbon cycle.

In the case of Venus, the global carbon cycle has been disrupted so that it can no longer regulate the planetary climate.

Because of the runaway greenhouse effect, surface conditions on Venus are totally incompatible with life like us, as seen in these Venera 13 image taken by the USSR in 1982.

Credit: Venera 13

The Search for Life on Mars*, Part 2

*and the other terrestrial planets of our solar system

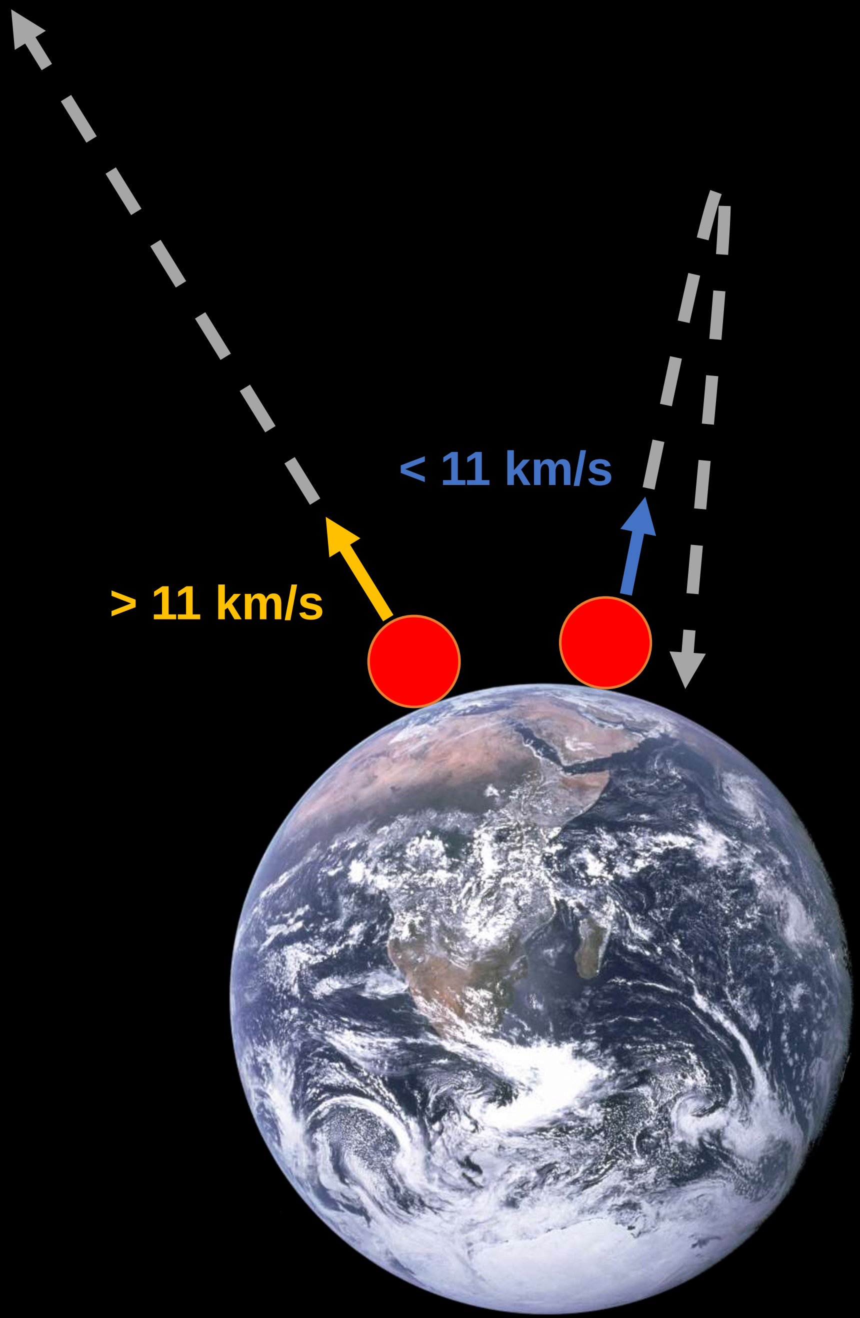
What about Mars?

Credit: ISRA

Why do Earth and Venus have thick atmospheres while Mars and Mercury have nearly none?

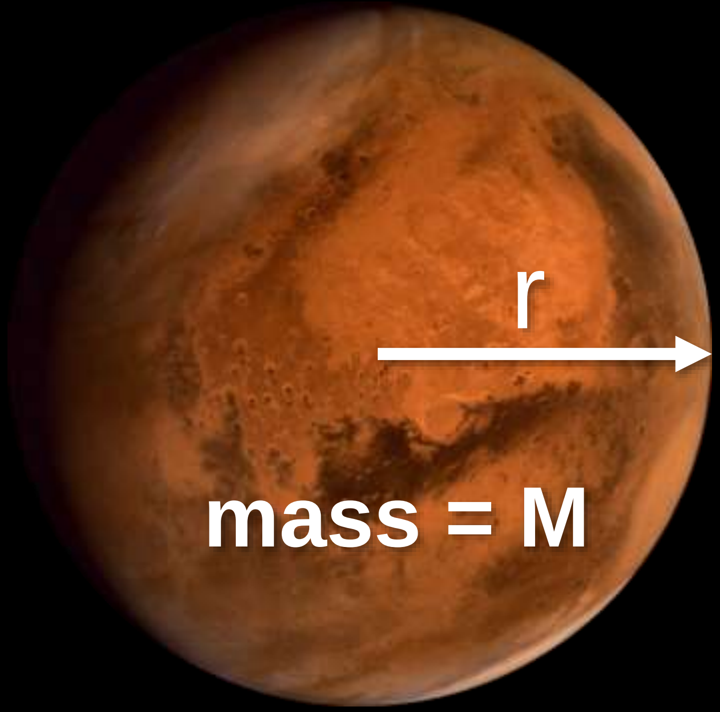
To understand atmosphere loss, we need to understand the concept of escape speed.

The escape speed is the speed an projectile needs to be moving at in order to completely break free from the gravity of another object.



The escape speed from a planet's surface depends only on the planet's radius and mass.

$$v_{escape} = \sqrt{\frac{2GM}{r}}$$



Concept Check

Mars has about one tenth the mass of Earth and is about half the radius of Earth. Which planet should have the higher escape speed?

A. Earth
B. Mars
C. They should be about the same
D. We need more information

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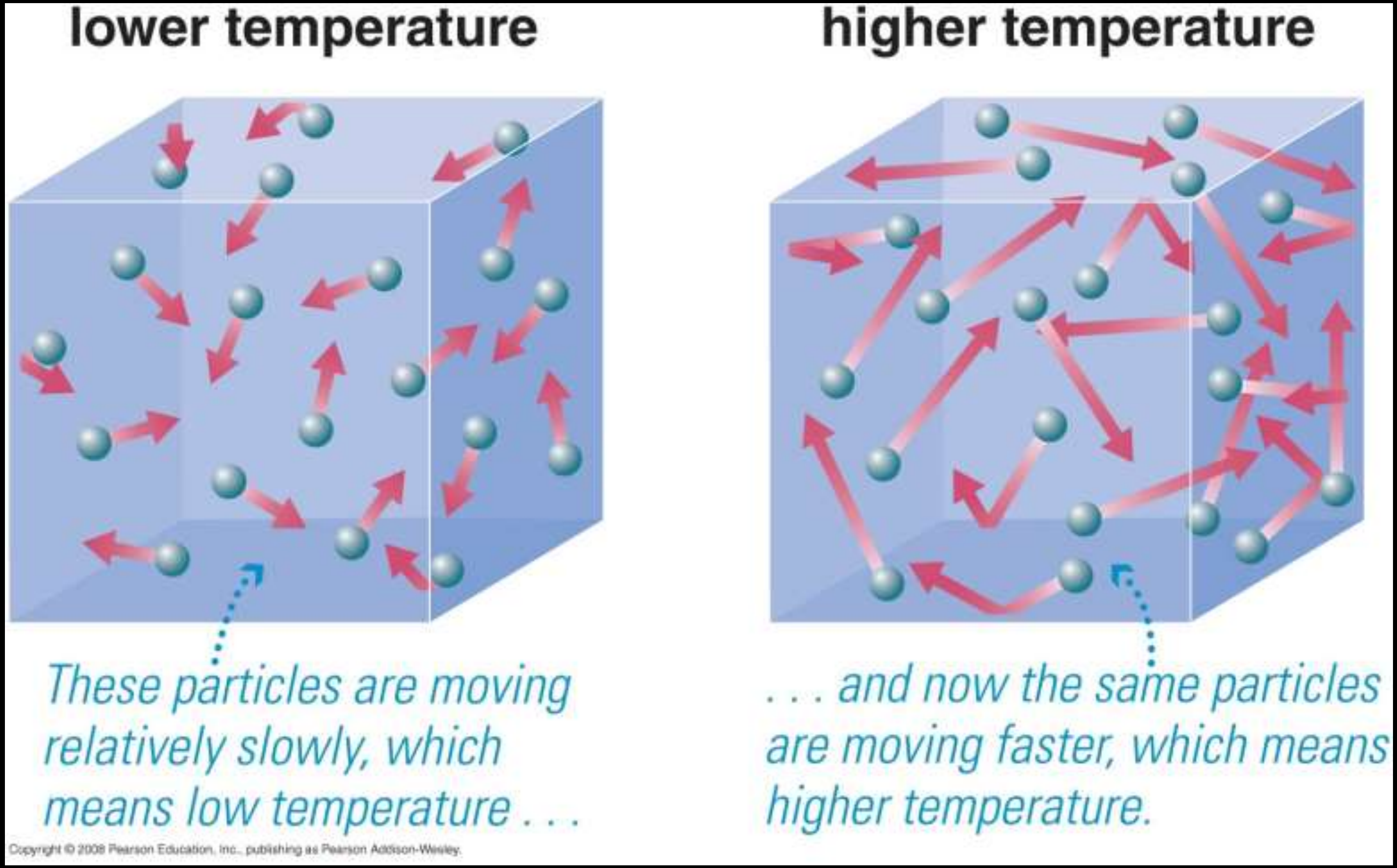
$$\mathbf{v_{escape}} = \sqrt{\frac{\mathbf{2G\ (0.1M_{Earth})}}{\mathbf{0.5r_{Earth}}}}$$

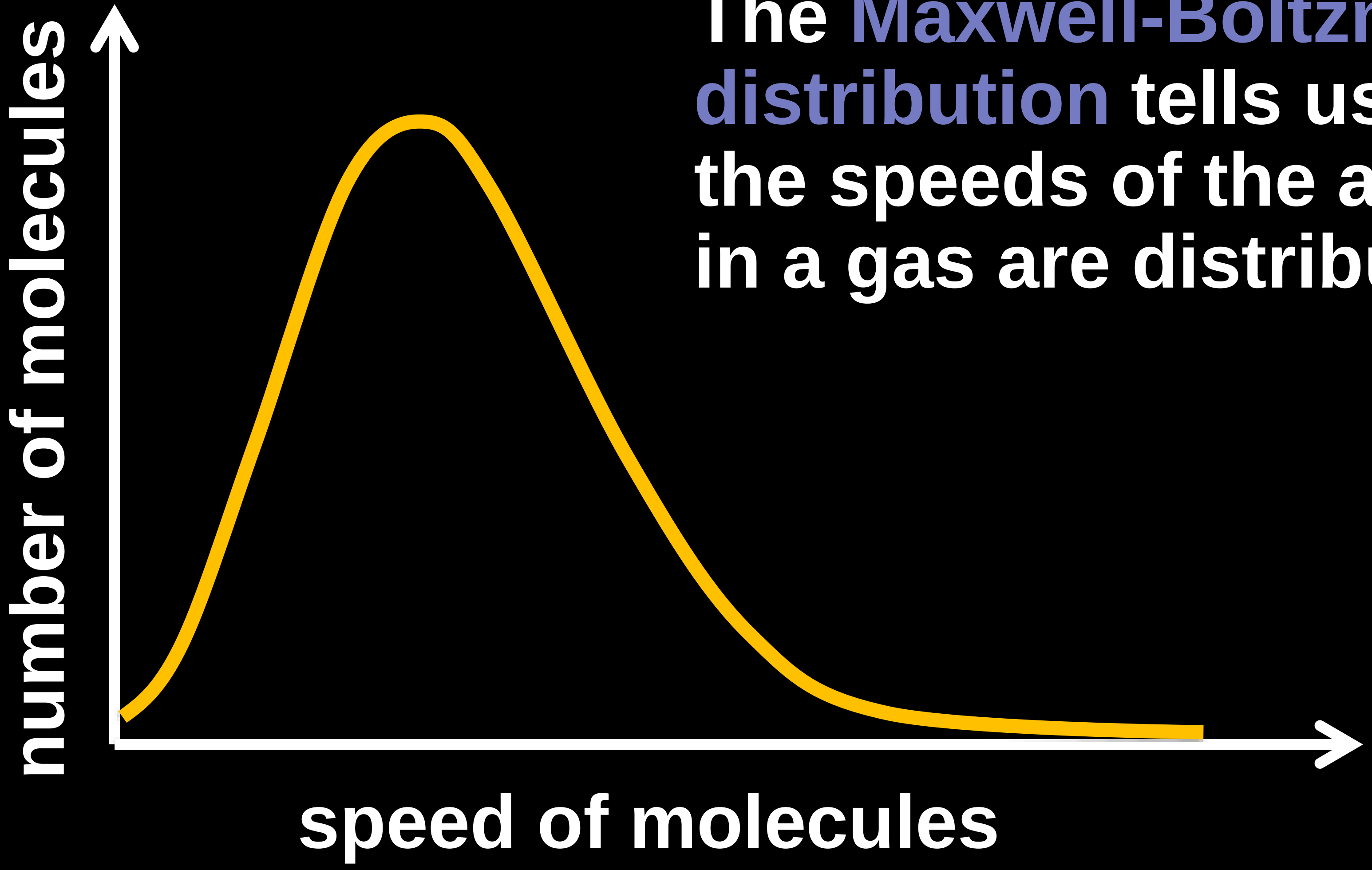
$$\mathbf{v_{escape}} = \sqrt{\frac{\mathbf{2GM}}{\mathbf{r}}}$$

$$\mathbf{v_{escape}} = \sqrt{\frac{\mathbf{2G\ (0.1M_{Earth})}}{\mathbf{0.5r_{Earth}}}}$$

$$\mathbf{v_{escape}} = \mathbf{0.44}\sqrt{\frac{\mathbf{2GM_{Earth}}}{\mathbf{r_{Earth}}}}$$

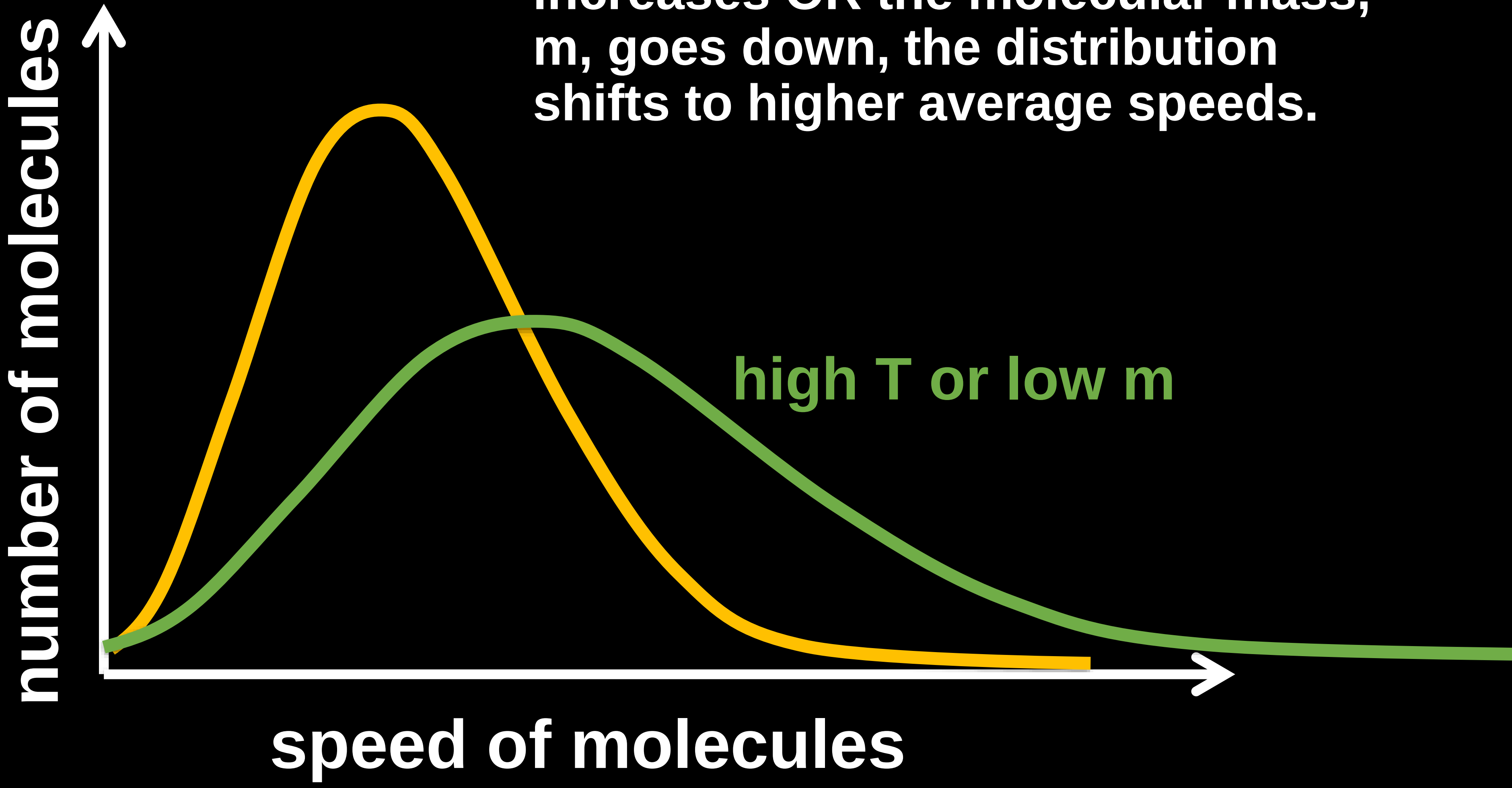
The temperature of a gas is a measure of the average speed of its molecules.

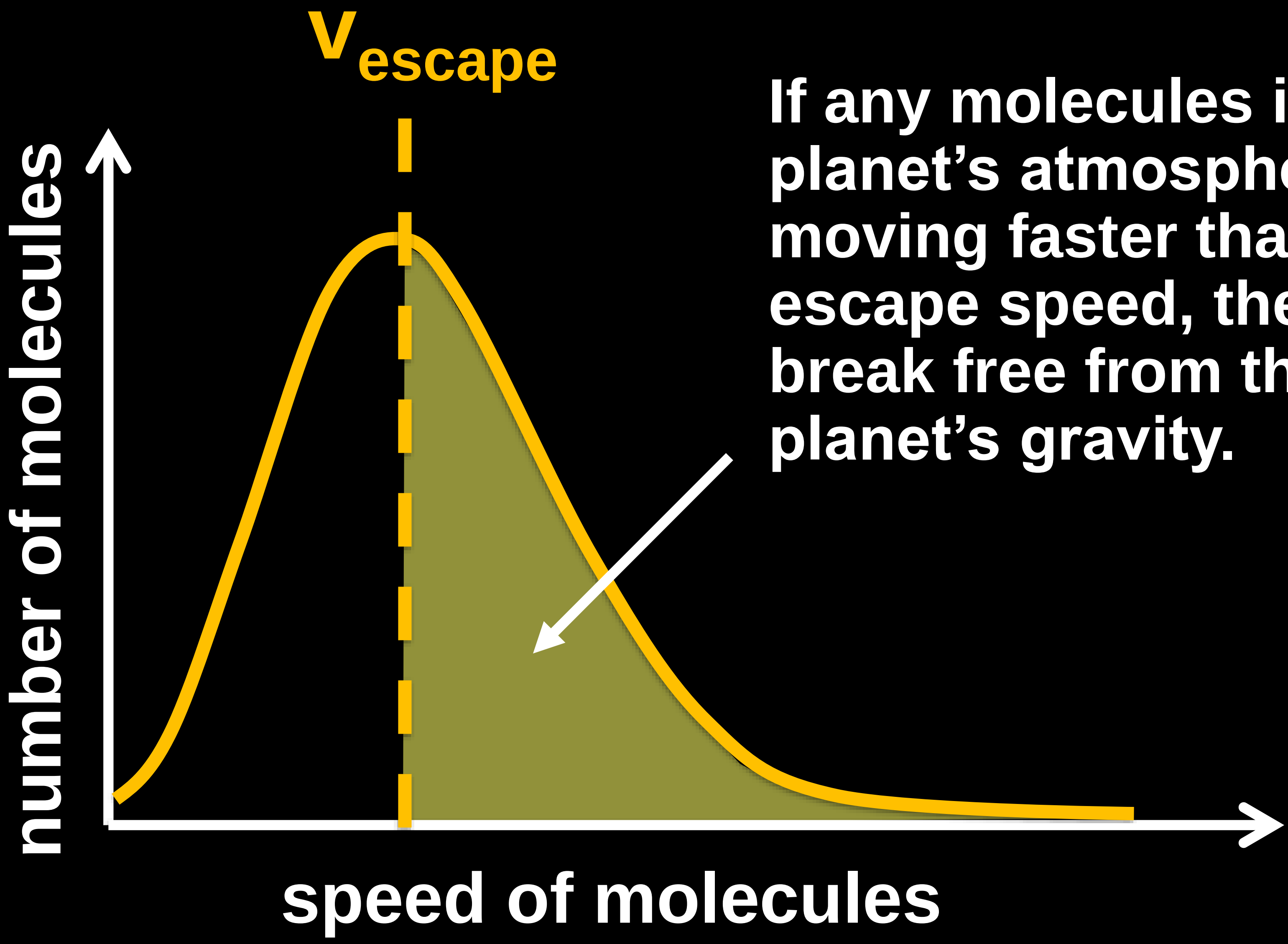




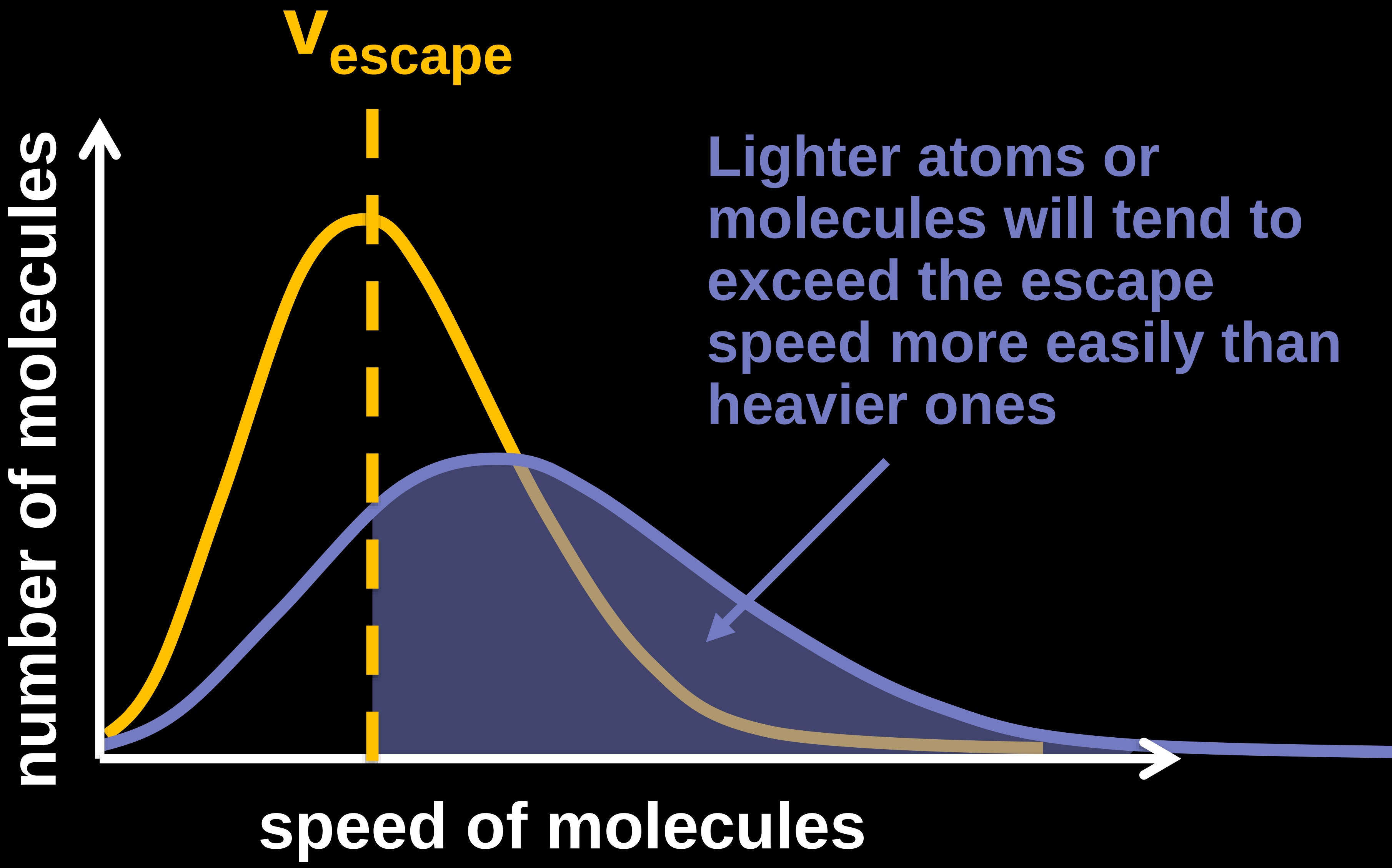
The **Maxwell-Boltzmann distribution** tells us how the speeds of the atoms in a gas are distributed.

As the temperature, T, of the gas increases OR the molecular mass, m, goes down, the distribution shifts to higher average speeds.

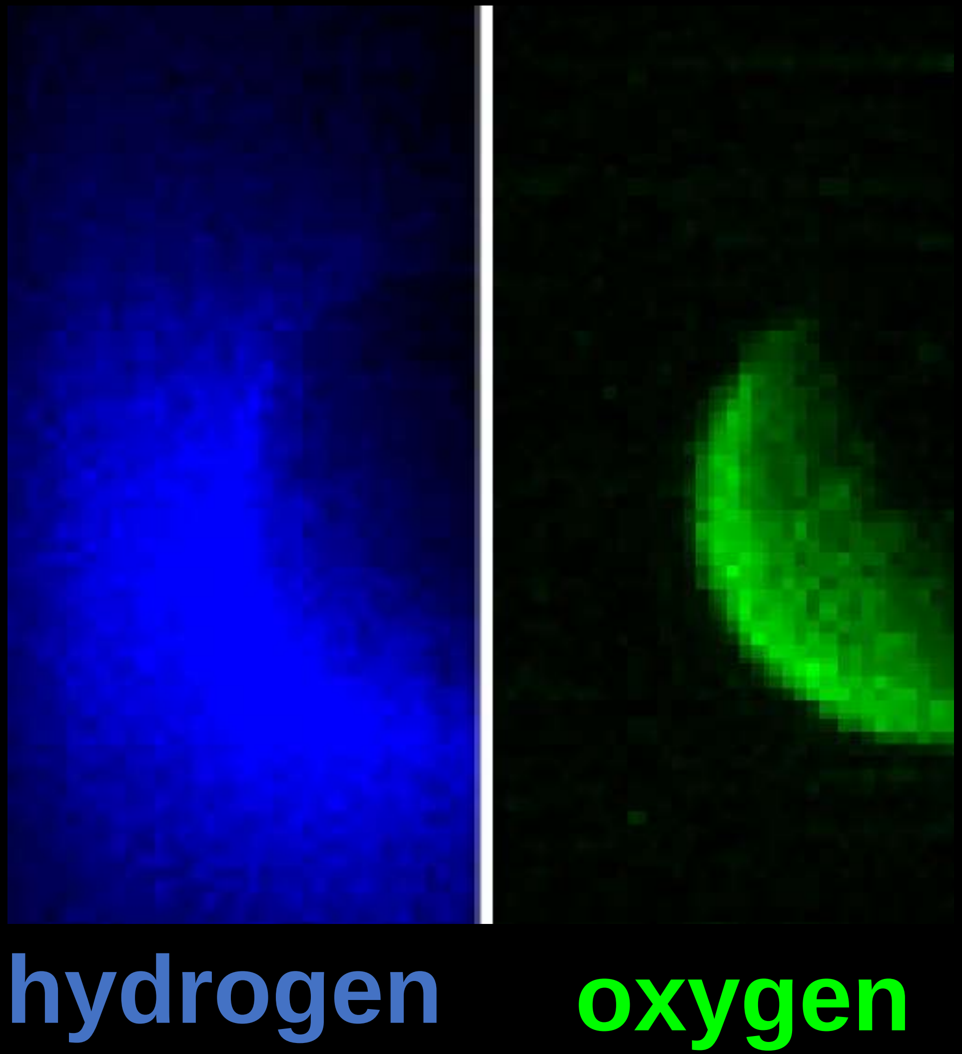




If any molecules in a planet's atmosphere are moving faster than the escape speed, they can break free from the planet's gravity.


vescape
number of molecules
speed of molecules
Lighter atoms or molecules will tend to exceed the escape speed more easily than heavier ones

In these MAVEN images of Mars, we can actually see that the heavier oxygen atoms cling closer to the planet while lighter hydrogen atoms form a diffuse cloud.

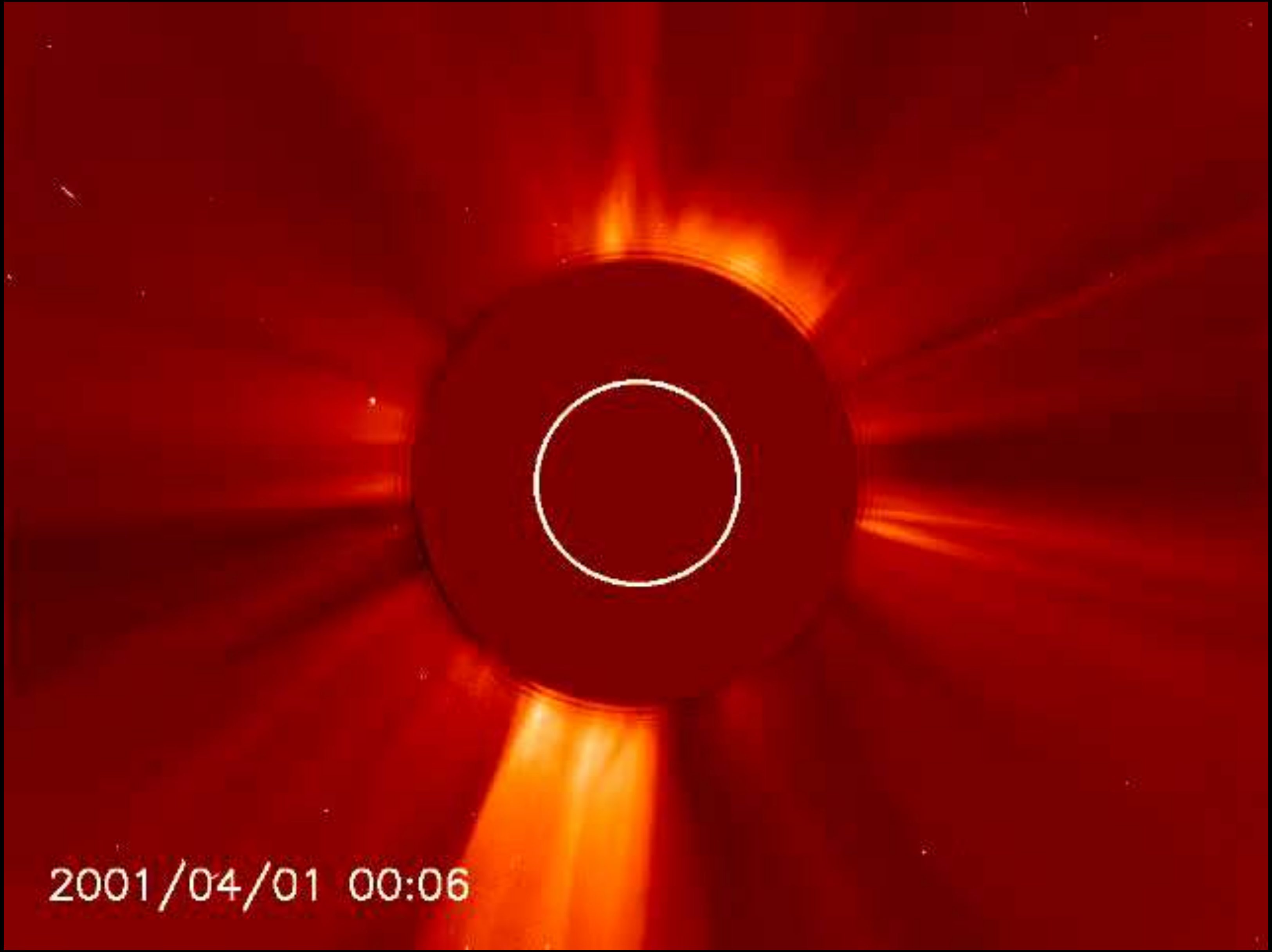


Credit: Laboratory for Atmospheric and Space Physics /University of Colorado; NASA

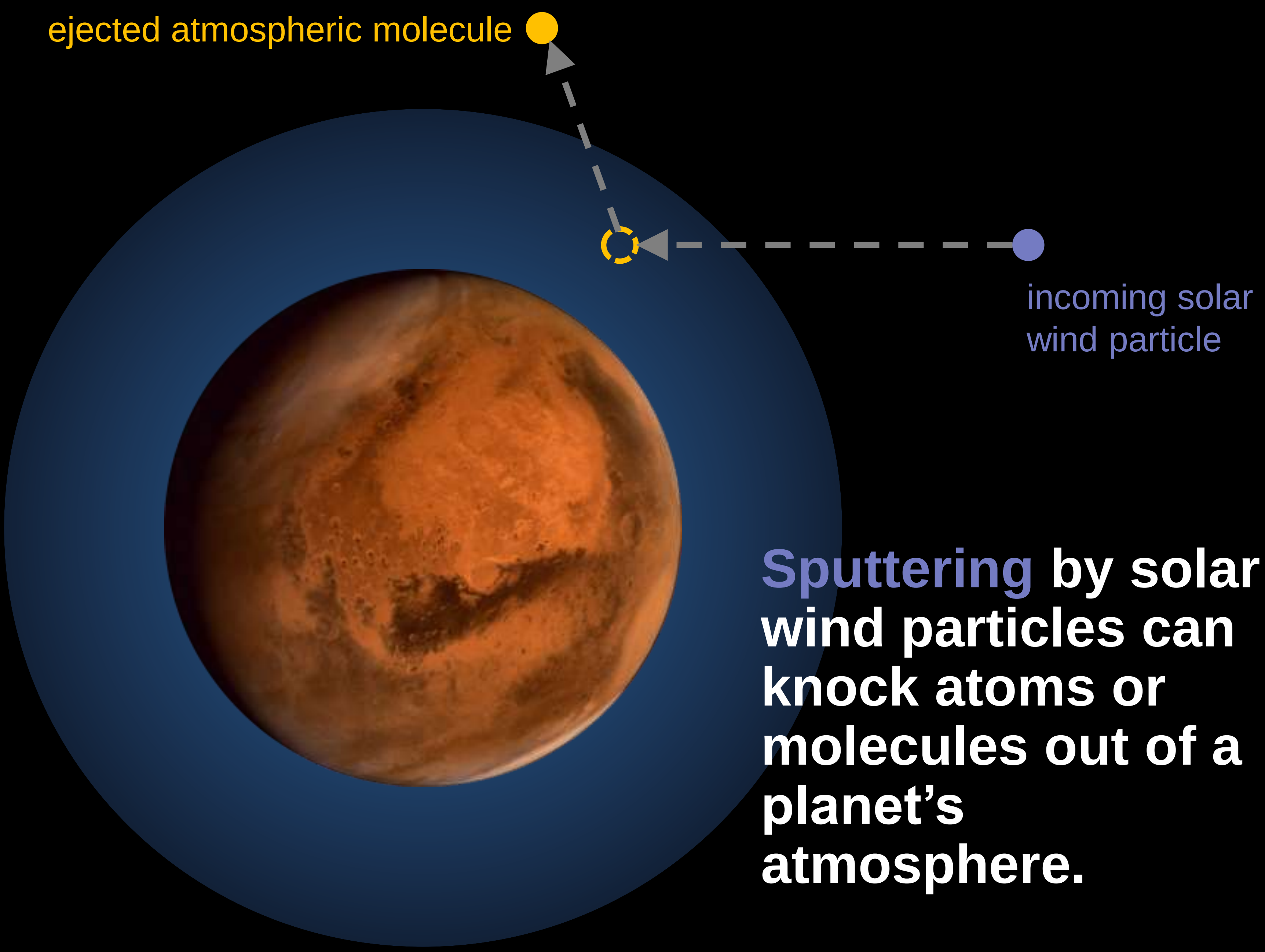
Over time, the portion of a planet's atmosphere that exceeds the escape speed will bleed away into space.

On Mars, this process has been greatly accelerated by **solar wind sputtering**.

The solar wind consists of energetic particles that stream continuously from the Sun.



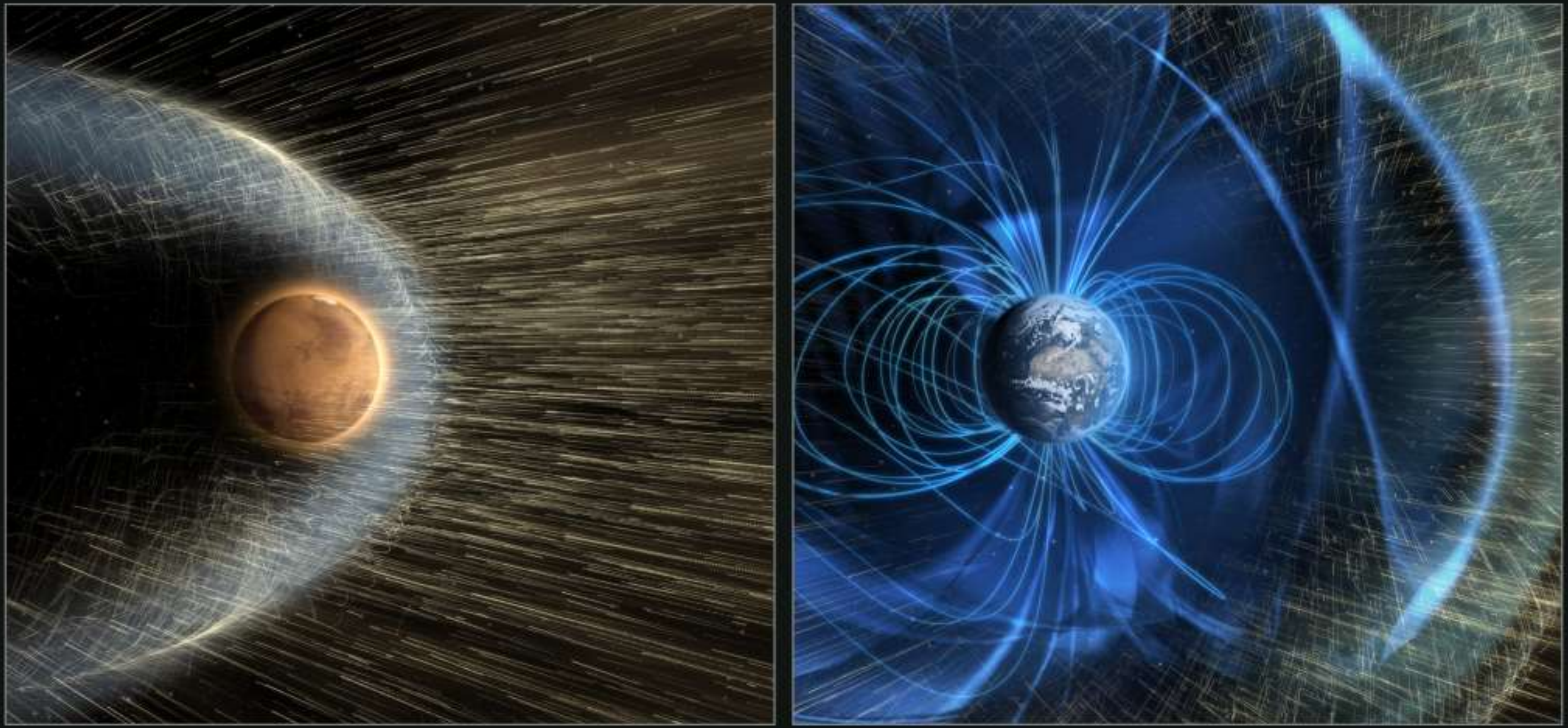
Credit: SOHO



Sputtering by solar wind particles can knock atoms or molecules out of a planet’s atmosphere.

NASA's Scientific Visualization Studio and the MAVEN Science Team

Earth’s atmosphere is less vulnerable to solar wind sputtering because Earth has a strong planetary magnetic field that deflects much of the charged solar wind.



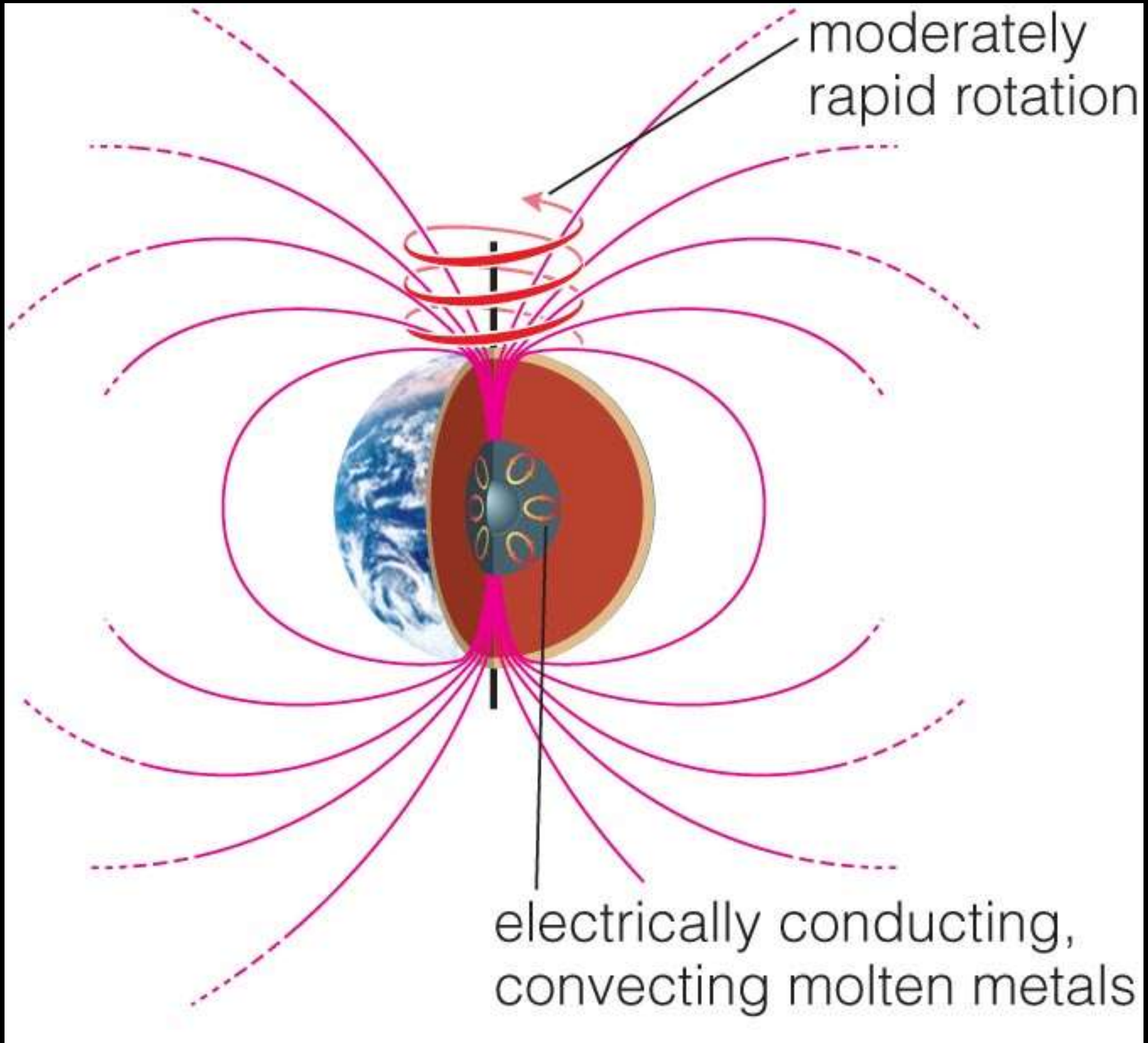
Mars’ atmosphere is blasted by the solar wind.

Earth’s magnetic field protects our atmosphere.

Credit: NASA /GSFC

Why doesn't Mars have a planetary magnetic field?

Earth has a magnetic field because of the motion of charged particles within its molten interior.



Credit: Pearson Education

The rate at which a planet loses heat to space depends on its **surface area to volume ratio**.

$$\frac{\textbf{surface area}}{\textbf{volume}} = \frac{}{}$$

$$\frac{\text{surface area}}{\text{volume}} = \frac{4\pi r^2}{}$$

$$\frac{\textbf{surface area}}{\textbf{volume}} = \frac{\mathbf{4\pi r^2}}{\mathbf{\frac{4}{3}}\pi r^3}$$

$$\frac{\text{surface area}}{\text{volume}} = \frac{4\pi r^2}{\frac{4}{3}\pi r^3}$$

$$\frac{\text{surface area}}{\text{volume}} \propto \frac{1}{r}$$

Because it is so much smaller than Earth, Mars cooled and solidified long ago,so it can no longer generate a protective planetary magnetic field.

As a planet cools, its magnetic dynamo will shut down.

So, very small or very old planets may be less habitable, because they are more vulnerable to atmosphere loss.

Remember also that many types of stars are much more "active" than the Sun, capable of generating intense flares.

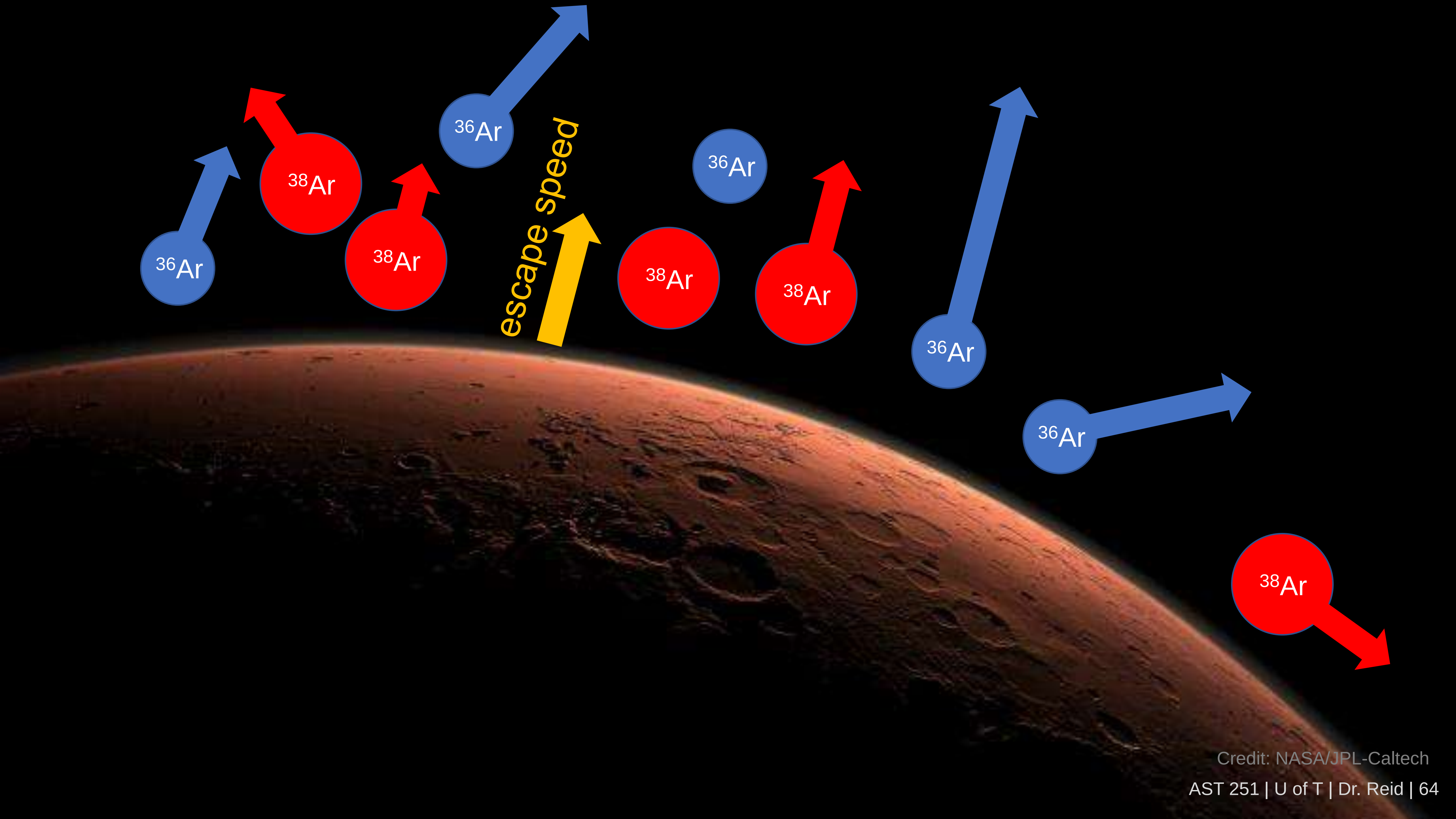
Even a planetary magnetic field might not be enough to protect from the worst of these.

How do we know that Mars had an atmosphere in the first place?

Measurements of Ar isotope ratios in Mars' atmosphere show that it once had a thick atmosphere, perhaps similar to Earth.

Argon is an inert gas, meaning that it does not participate in chemical reactions.

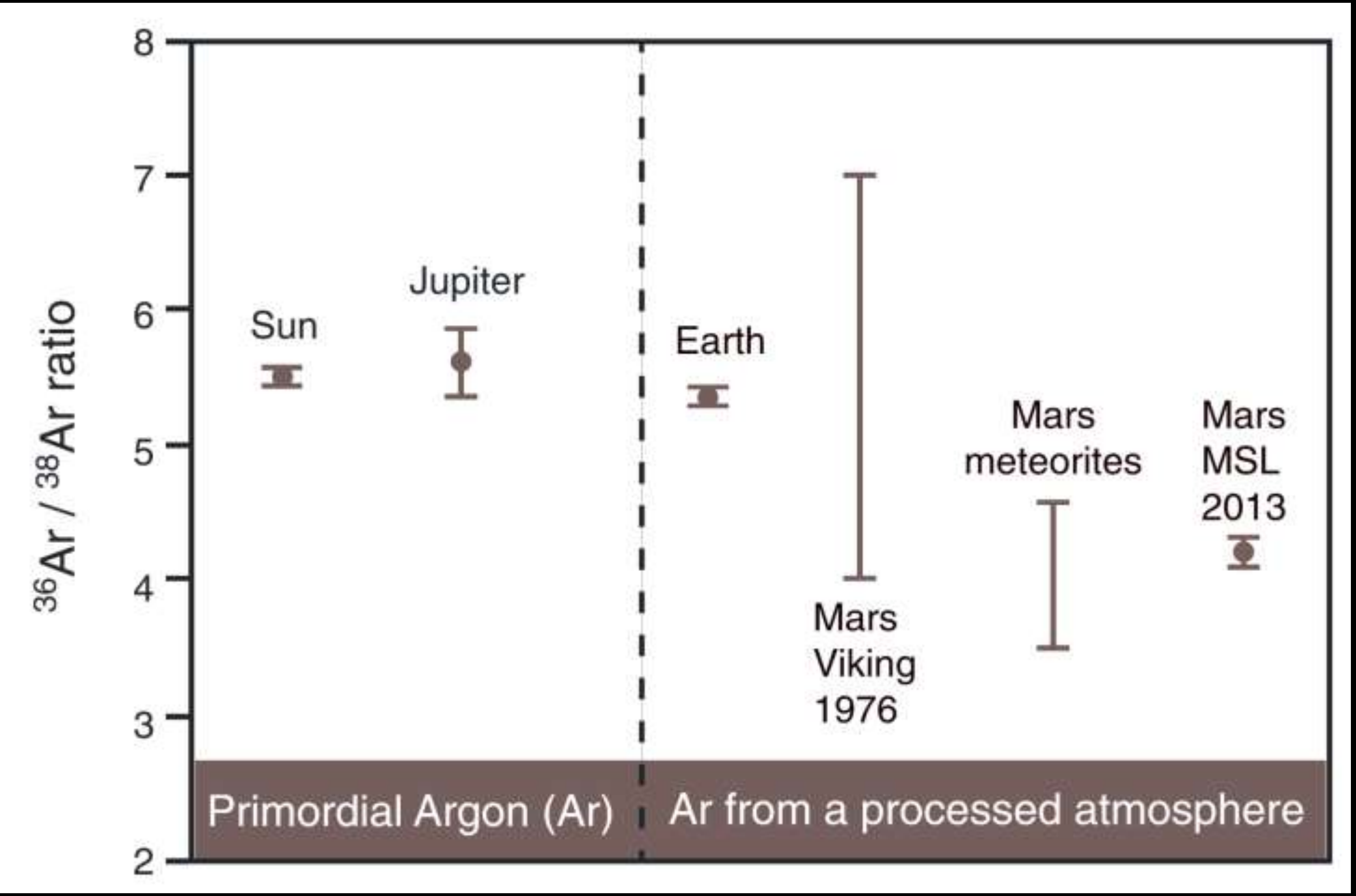
This means that argon in a planet's atmosphere is not removed by chemical processes.



Credit: NASA/JPL-Caltech

Measurements of argon isotope fractionation in the atmospheres of the planets of our solar system suggests that Mars has lost a significant fraction of its atmosphere.

(Atreya et al., GRL, 2013)



If Mars had an atmosphere in the past, might it also have had sustained liquid water?

The Search for Life on Mars*, Part 3

*and the other terrestrial planets of our solar system

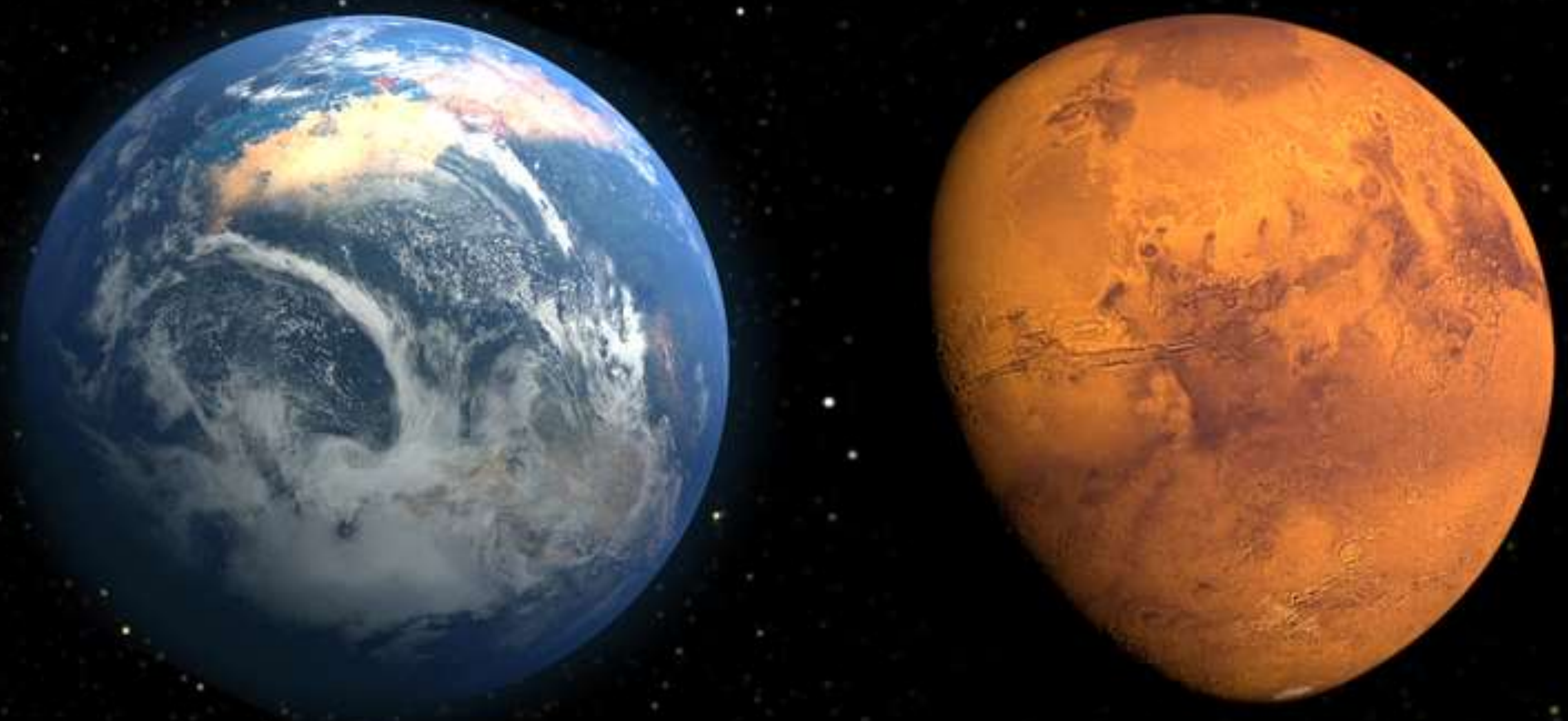
If Mars had an atmosphere in the past, might it also have had sustained liquid water?

There is ample evidence from surface features on Mars that water once flowed freely there.

Credit: ESA/Mars Express

In fact, measurements of D/H fractionation (analogous to argon fractionation) on Mars indicate that it once had much more water than it currently does.

Young Mars **Mars today**



Credit: NASA /GSFC

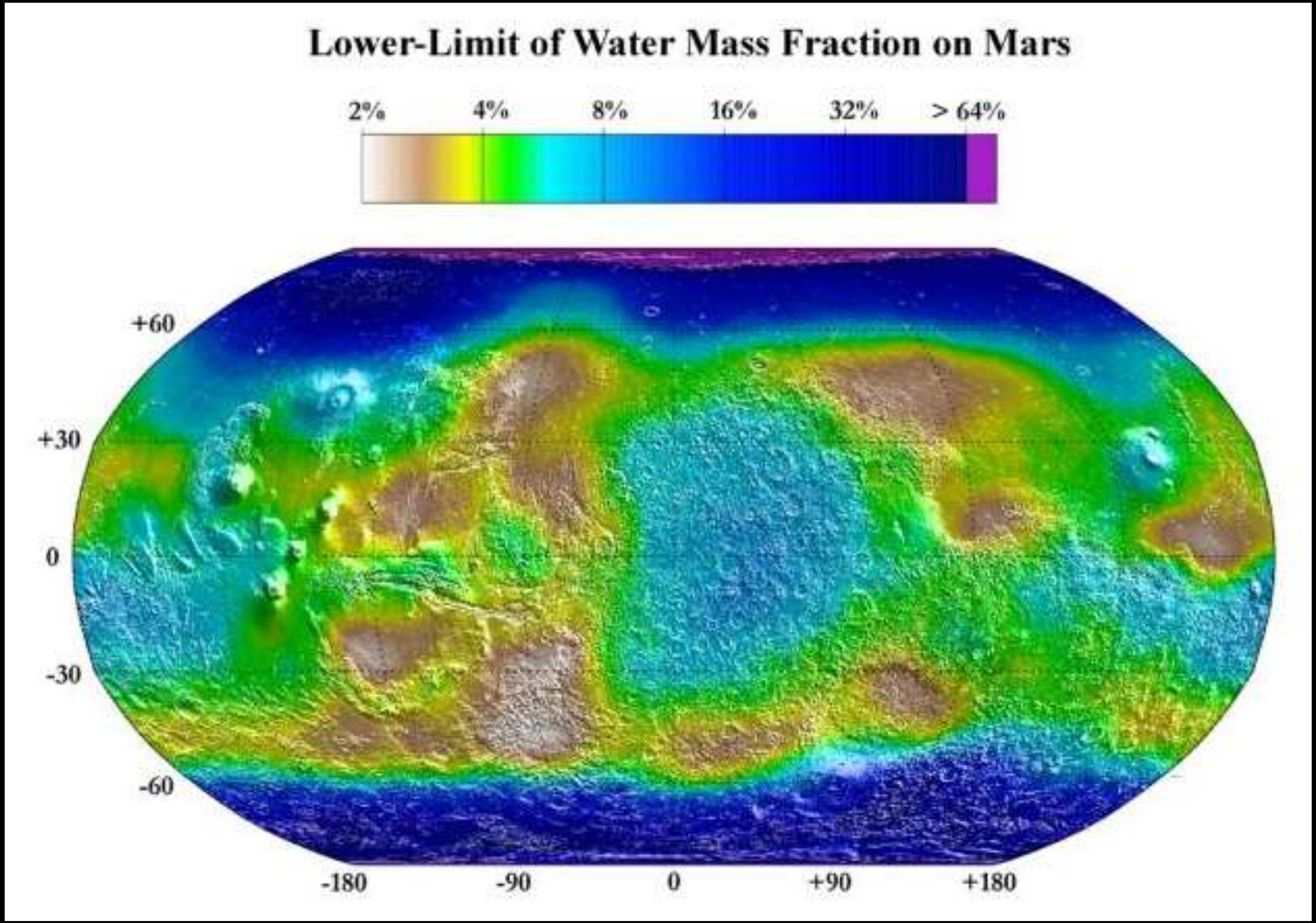
How much of that water remains today?

Mars has prominent polar ice caps, which are a mix of water and carbon dioxide

Credit: NASA, Philip James (University of Toledo), Steven Lee (University of Colorado)

Ice in Korolev crater on Mars

Measurements made by the Mars Odyssey spacecraft show abundant water frozen into the soil on Mars.



Credit: NASA/JPL/LANL

Water-ice frost at the site of the Viking 2 Lander, which landed on Mars in 1976

Credit: NASA/JPL

Does water flow freely on the surface of Mars today?

Recurring slope lineae are features that appear in Martian summer on the slides of slopes.

Credit: NASA/JPL-Caltech/Univ. of Arizona

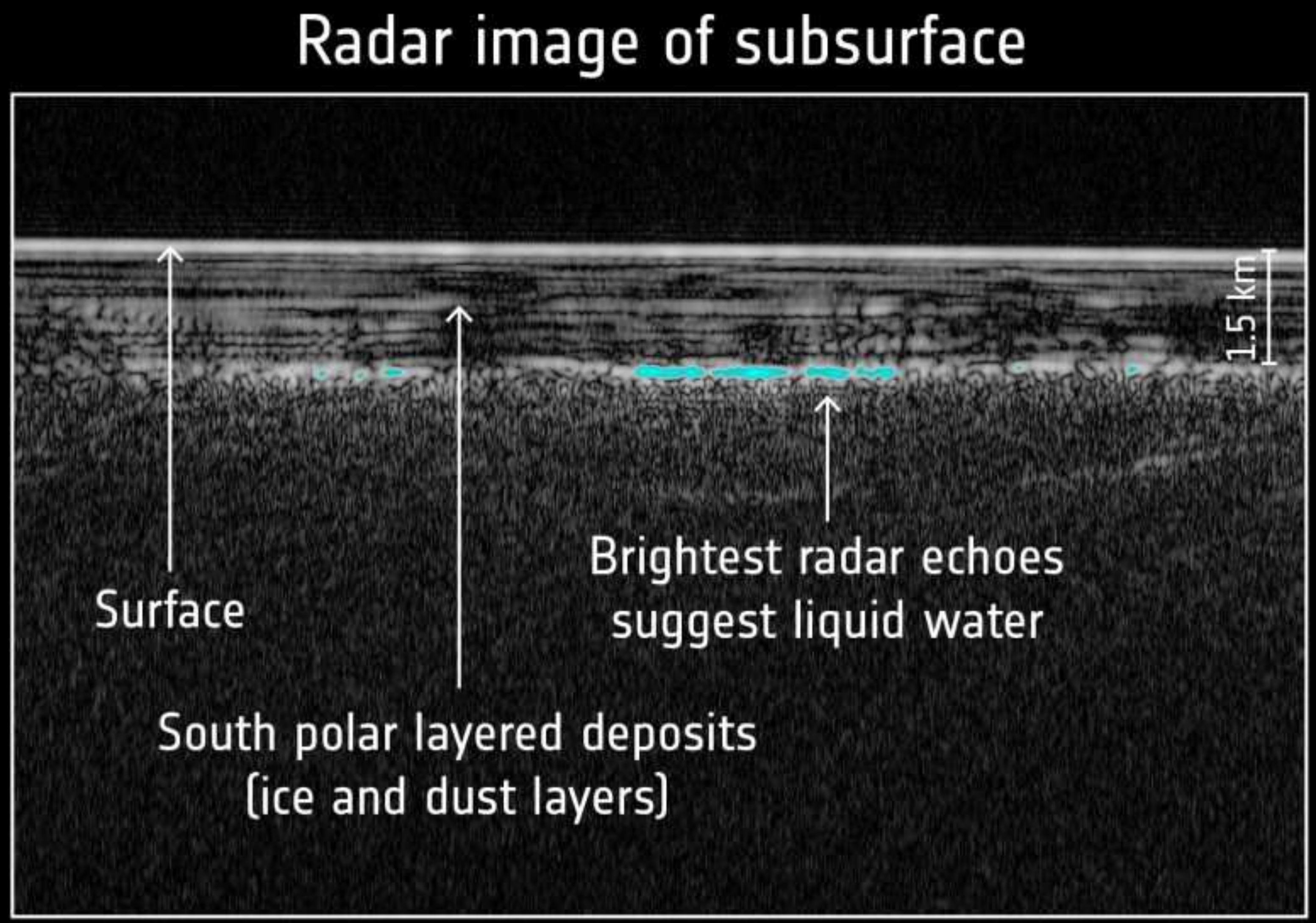
There was a strong claim in 2015 that RSL represented brief seasonal water flows, based on the presence of hydrated salts.

(Ojha et al., Nature, 2015)

A more recent claim is that they are sandy flows.

(Dundas et al., Nature, 2017)

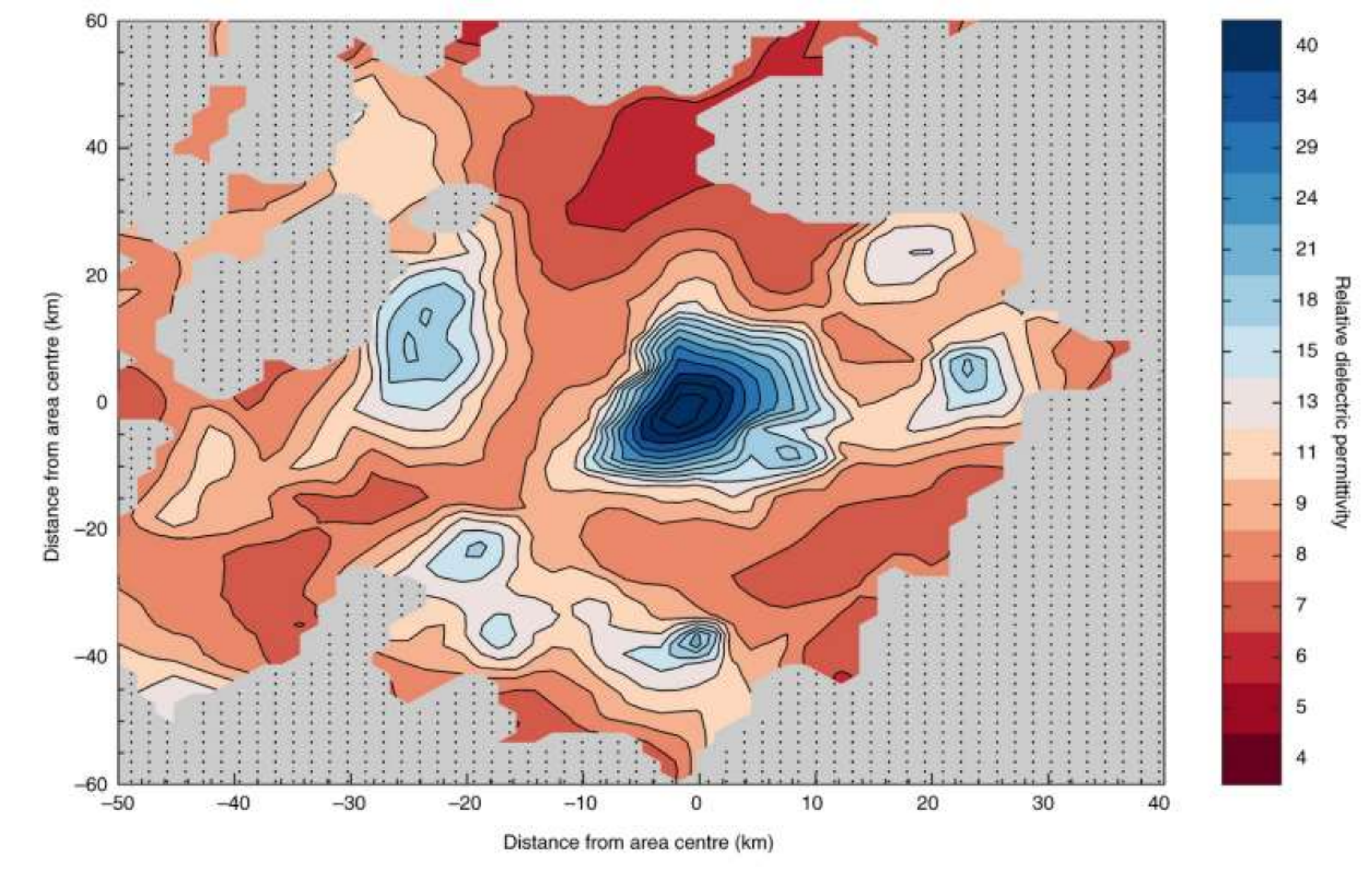
In 2018, radar maps of the South Polar Layered Deposits on Mars revealed a highly reflective subsurface layer that suggested the presence of an underground lake. (Orosei et al., *Science*, 2018)



Credit: ESA/NASA/JPL/ASI/Univ. Rome

In 2020, a second study of the same area found independent evidence for a subsurface lake.

In this map of the dielectric permittivity, values greater than about 15 suggest liquid water.
(Orosei et al., *Science*, 2018)



Even these more recent results are hotly disputed.

If subsurface lakes are present, they would have to be extremely salty to remain liquid under such cold conditions.

Currently, although the evidence is tantalizing, we can’t be sure whether there is liquid water on Mars today.

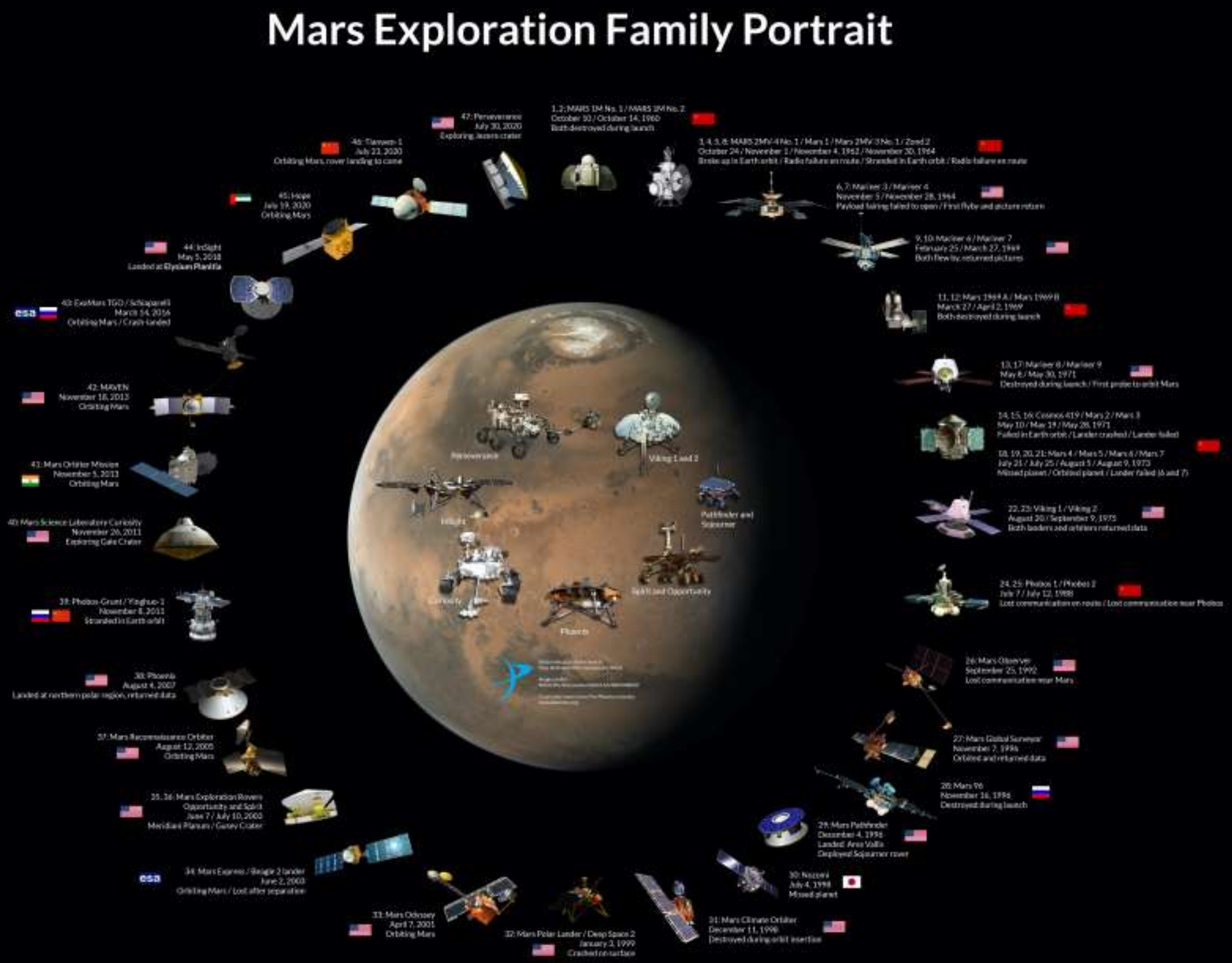
We *can* be sure that there was liquid water in the past.

Mars may have been habitable in the past, but is it habitable today?

This question is extremely hard to answer, particularly because it depends on what kind of life we are talking about.

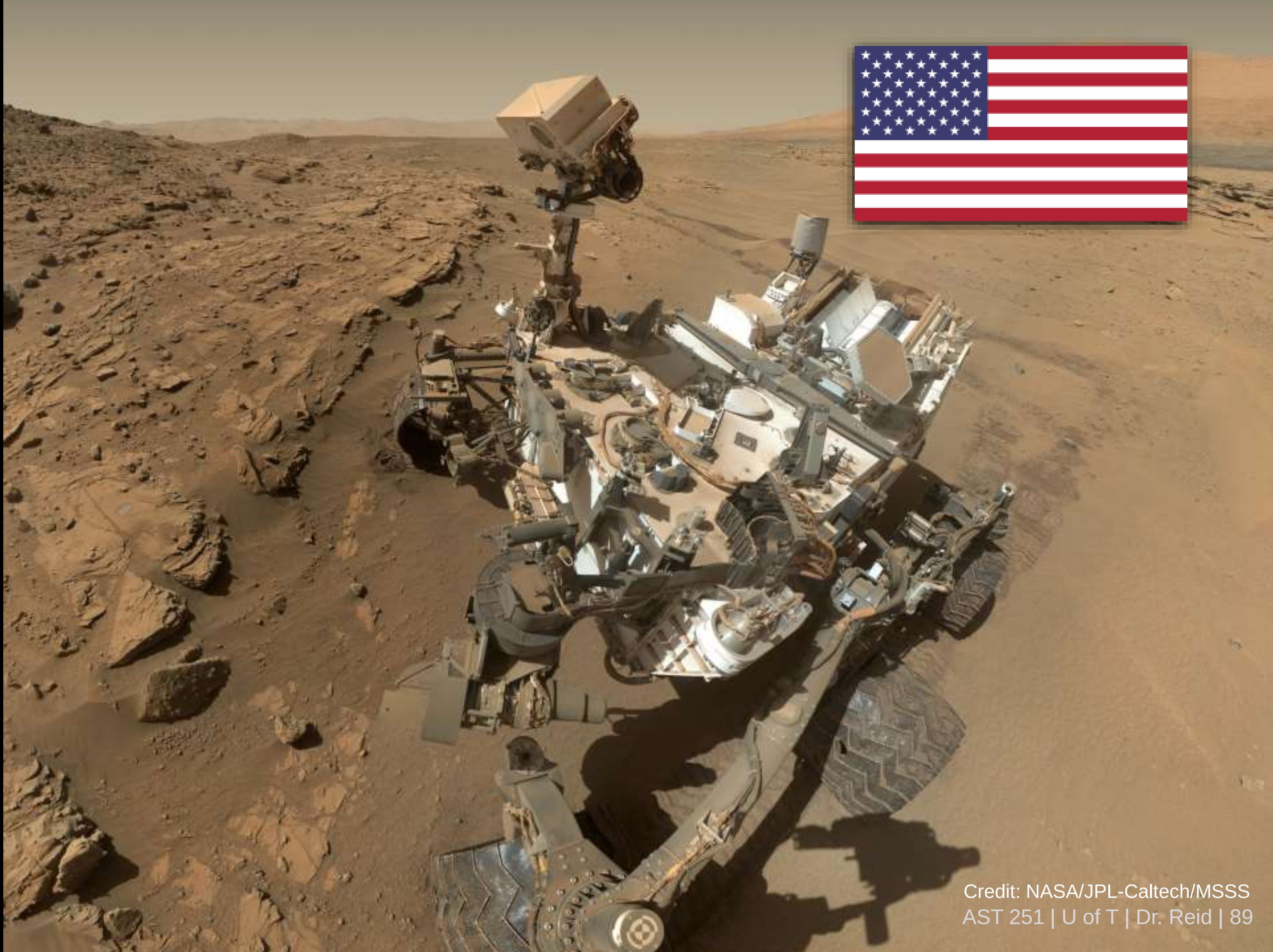
Let’s have a look at the surface and get a sense of what it would actually be like to be there.

While we do it, let's also think about *who* took all these photos, and *why*, and what the future holds.



Credit: NASA/JPL/Roscosmos/JAXA/ESA/ISRO/MBRSC/Jason Davis/The Planetary Society

A “selfie” taken by NASA’s Curiosity rover, which landed on Mars in 2012.



Credit: NASA/JPL-Caltech/MSSS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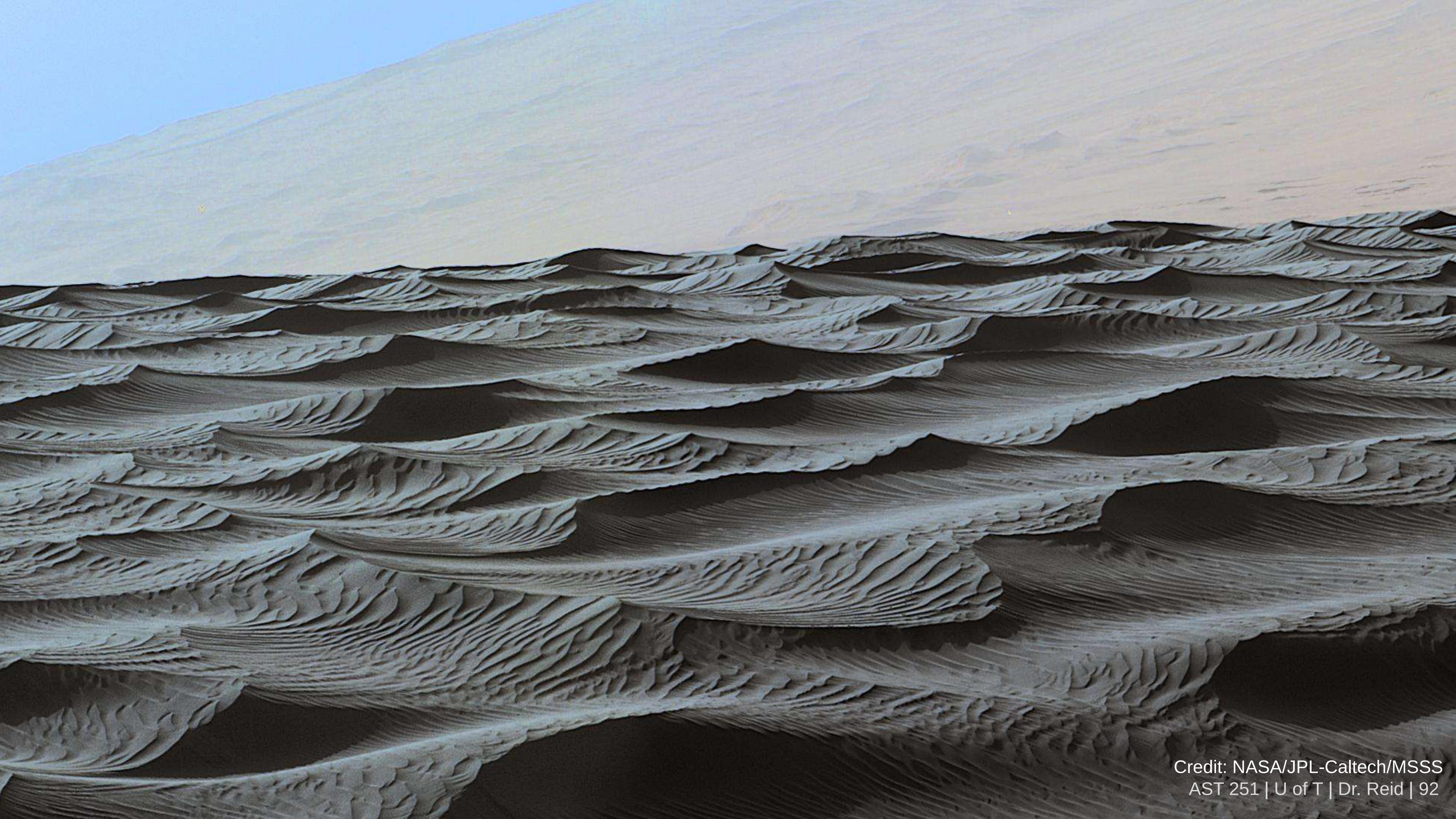

Credit: NASA/JPL-Caltech/MSSS

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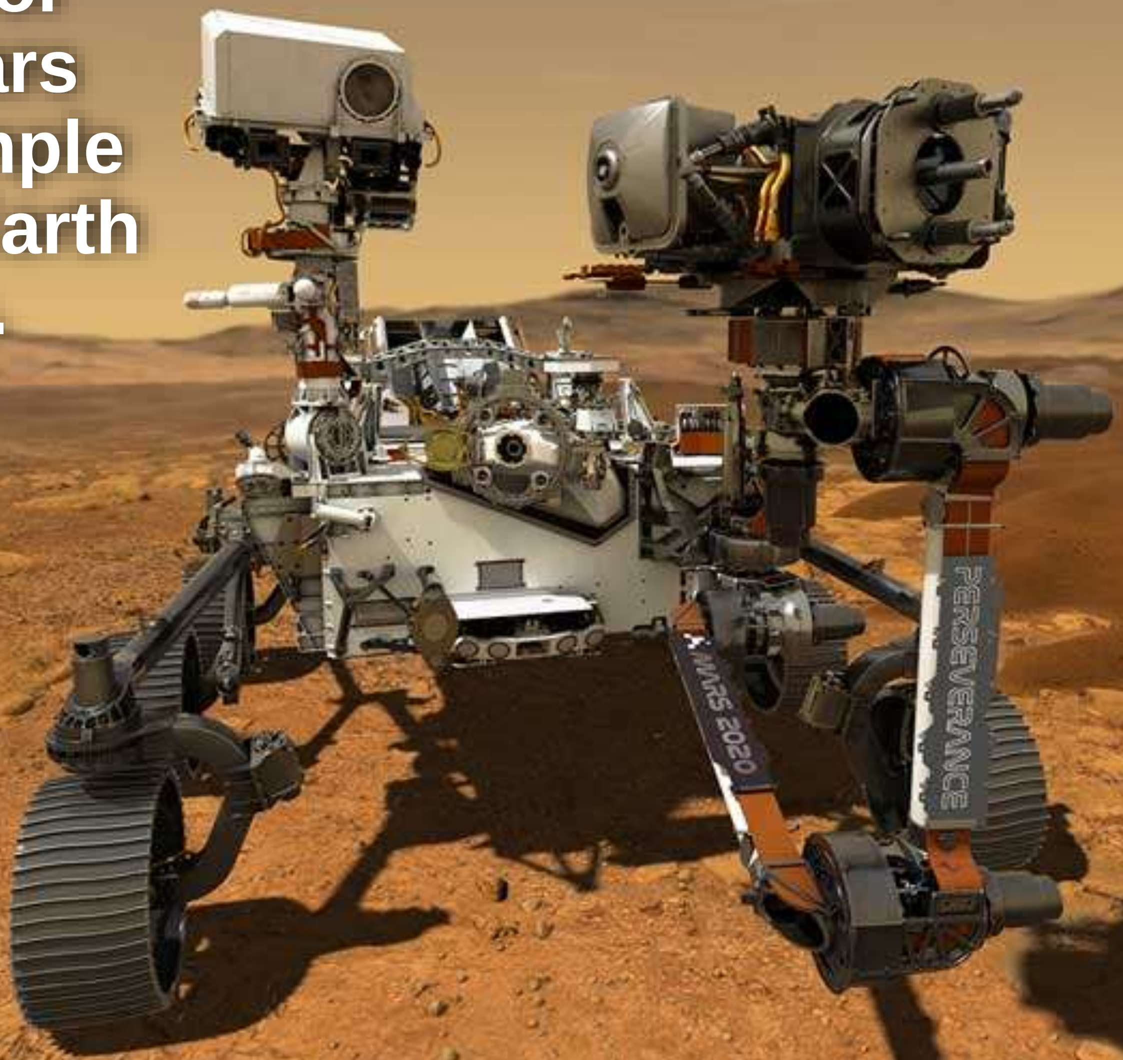
Credit: NASA/JPL-Caltech/MSSS

FLIGHT OVER JEZERO CRATER

based on data of the
High Resolution Stereo Camera (HRSC)
on ESA's Mars Express

presented by
Planetary Sciences and Remote Sensing
Freie Universität Berlin

NASA’s Perseverance rover will search for signs of life on Mars and prepare a sample to be brought to Earth by a later mission.



Credit: NASA/JPL-Caltech

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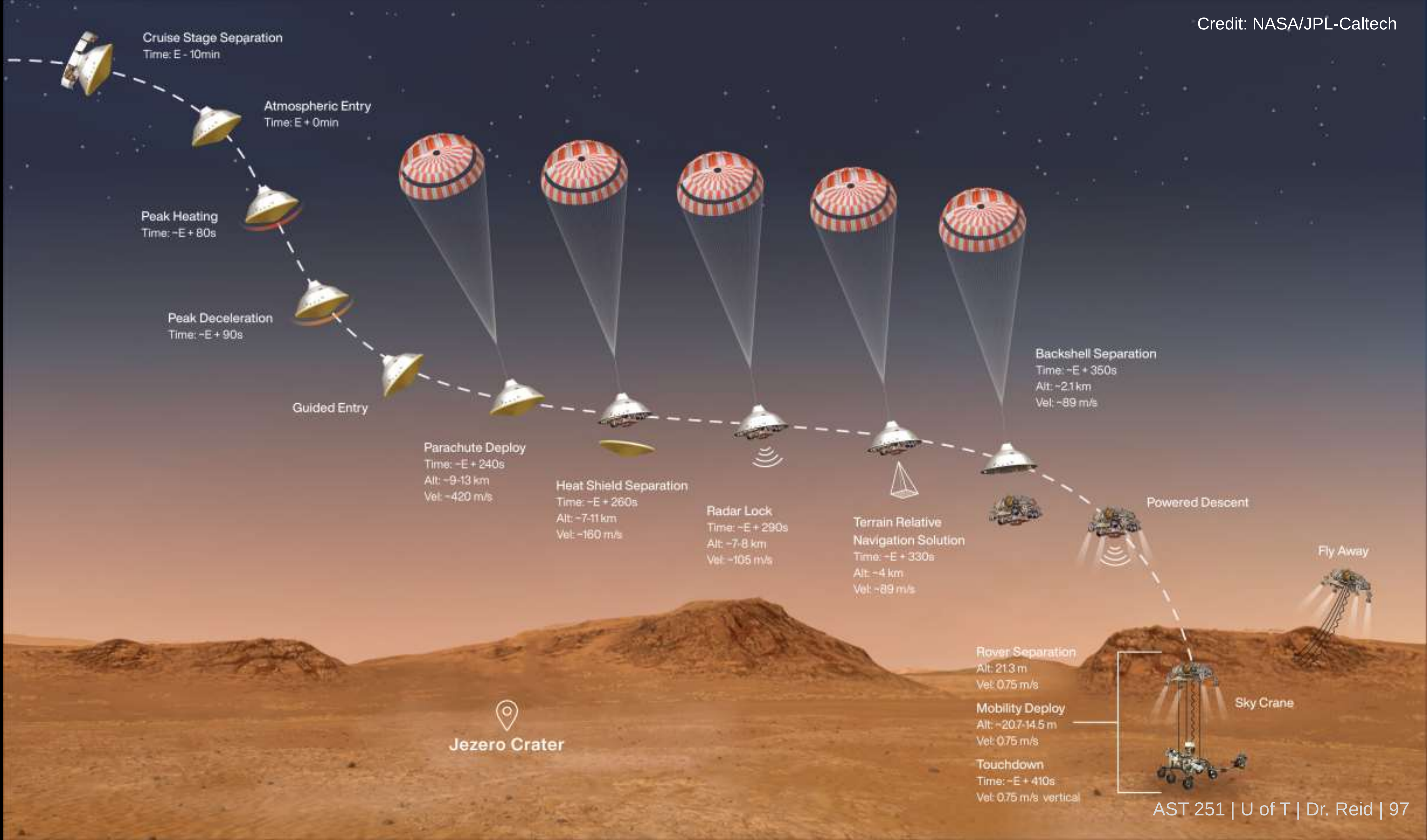
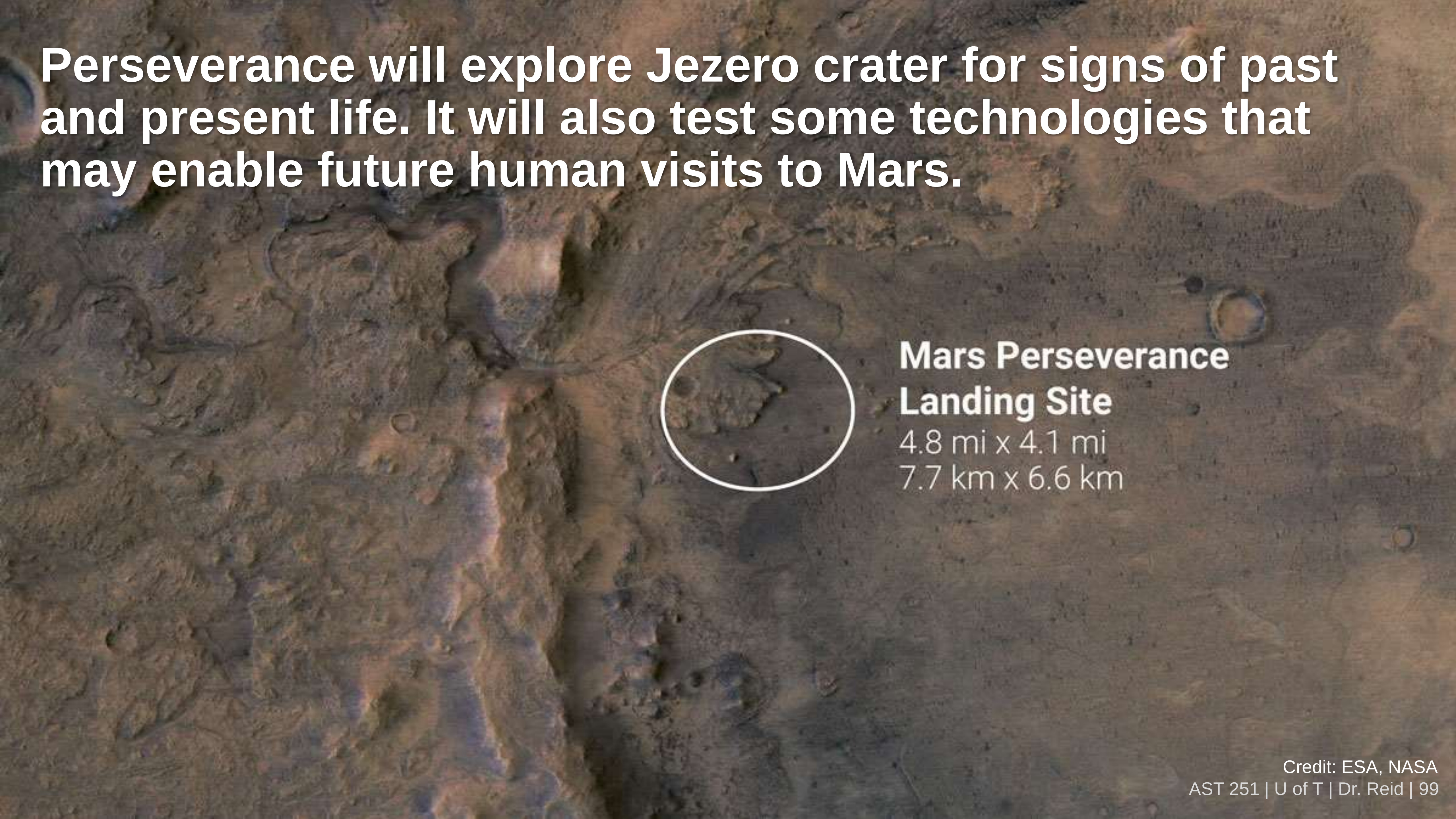



NASA
MARS 2020
JPL
Uplink Lead
Flight Director

Perseverance will explore Jezero crater for signs of past and present life. It will also test some technologies that may enable future human visits to Mars.



Credit: ESA, NASA

The Perseverance landing site has been named Octavia E. Butler Landing after the famous science fiction author.

Credit: ESA, NASA
Joshua Trujillo/seattlepi.com, via Associated Press

Perseverance landed on Mars in February 2021 and has already begun returning a wealth of data.

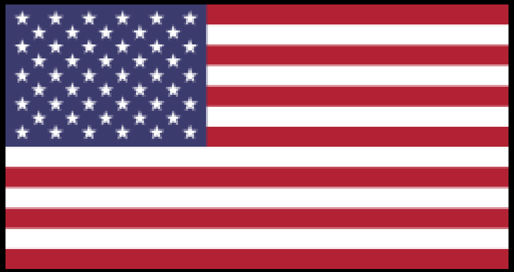
Credit: NASA/JPL-Caltech

Perseverance landed on Mars in February 2021 and has already begun returning a wealth of data.

Credit: NASA/JPL-Caltech

Perseverance also carries a helicopter called Ingenuity, which will be the first airborne (human…) vehicle on Mars.

Credit: NASA/JPL-Caltech



Credit: NASA/JPL-Caltech

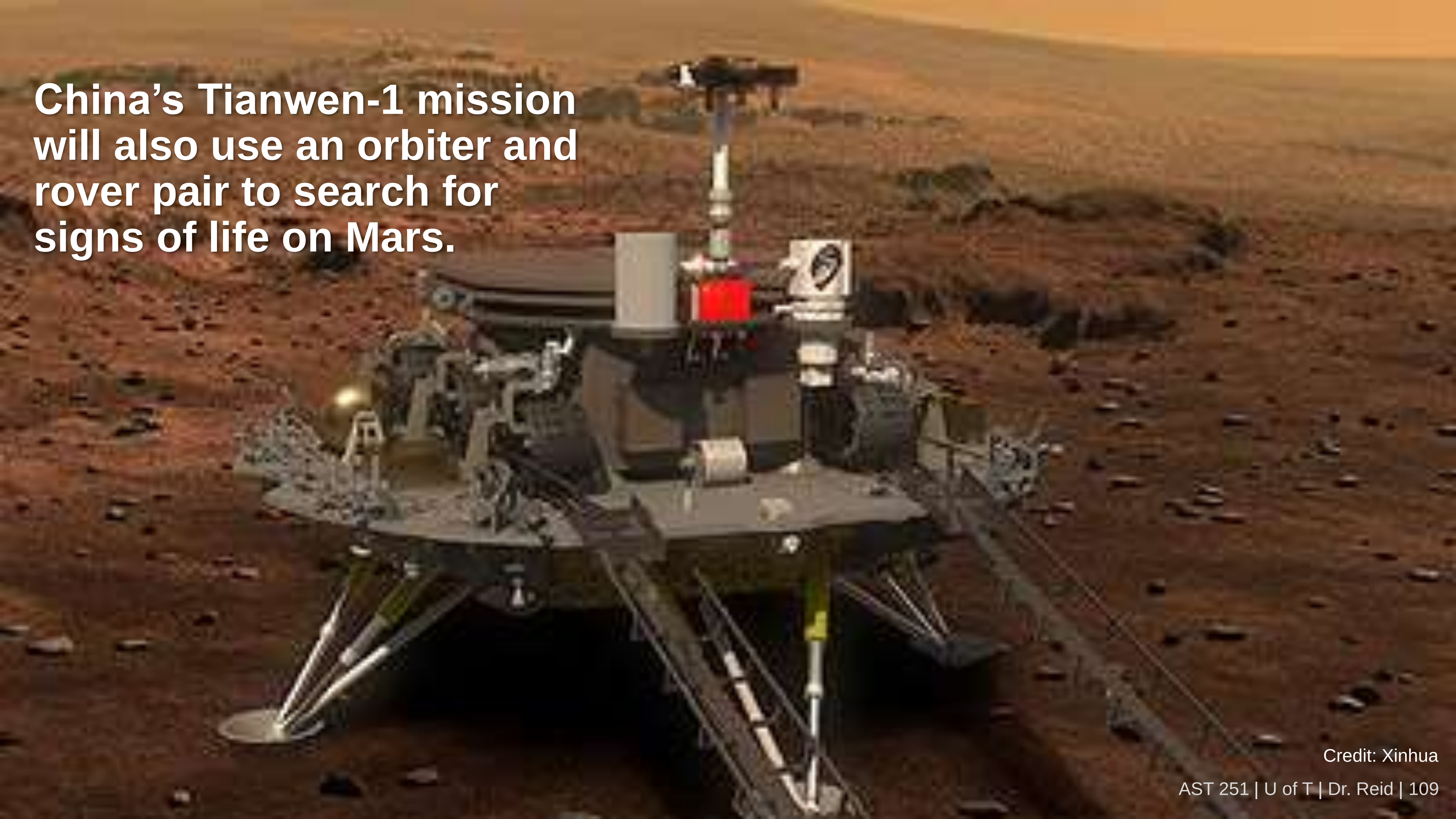
Who else goes to Mars these days?

Water ice clouds photographed on Mars by India’s Mars Orbiter Mission, *Mangalyaan*, which reached Mars in 2014

The UAE’s Hope mission arrived in February 2021 and will study the Martian climate and atmosphere from orbit.

Credit: UAE Space Agency

Credit: UAE Space Agency

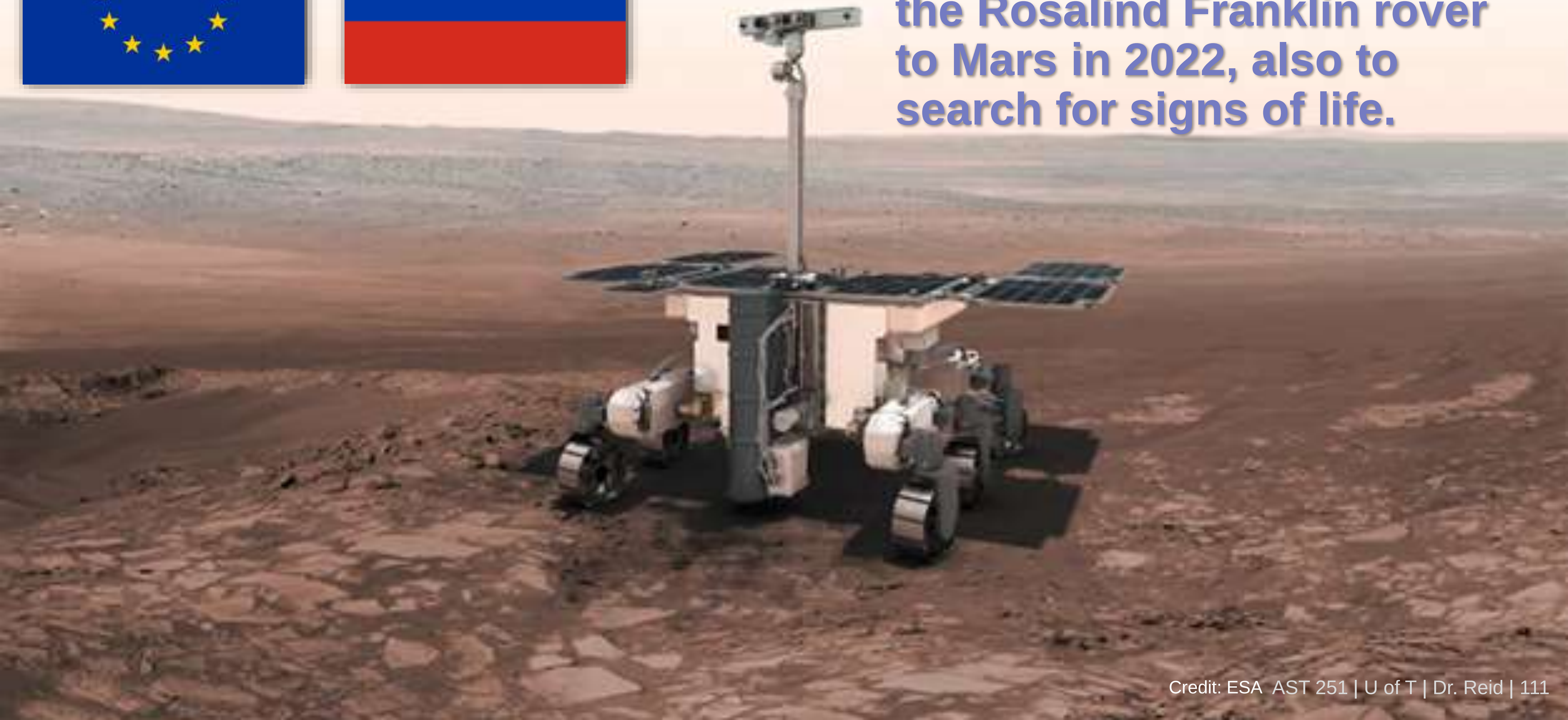


China’s Tianwen-1 mission will also use an orbiter and rover pair to search for signs of life on Mars.

Credit: Xinhua

One of Tianwen-1’s first pictures of Mars, from March 2021

The ESA/Roscosmos ExoMars mission will deliver the Rosalind Franklin rover to Mars in 2022, also to search for signs of life.



Credit: ESA

Although many of these missions list “astrobiology” among their objectives, none of them will directly test for the presence of living organisms on Mars.

However, such tests have been done in the past.

In 1976, the Viking 1 and 2 landers both tested Martian soil for evidence of microbial activity.

Credit: NASA/JPL-Caltech

The Viking landers each did four tests for life.

In each case, one of the four tests--the labeled release test--came back positive and the other three came back negative.

In the labeled release test, nutrients containing radioactive ^{14}C were released into the soil. Both landers detected the production of $^{14}CO_2$, as if the nutrients had been metabolized by life.

The tests failed at high temperatures—also consistent with biology.

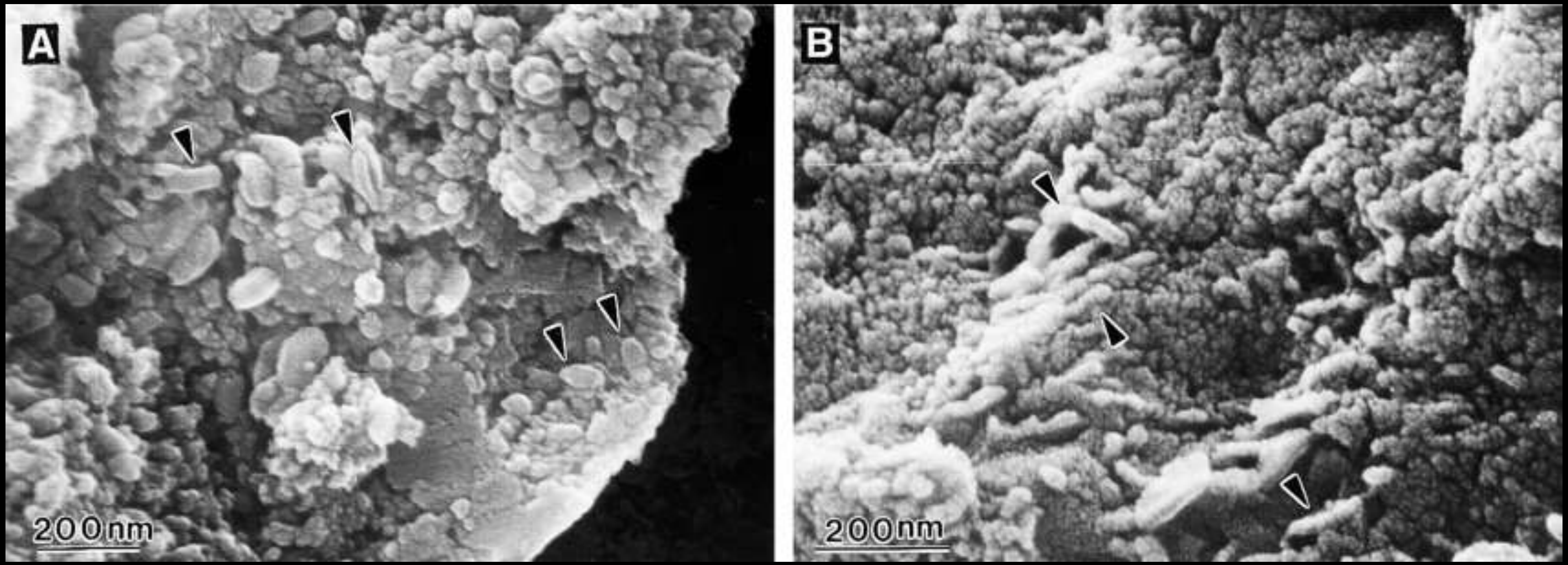
However, the LR tests only worked once—addition of further nutrients didn't lead to the release of more gas.

This suggested the gas may have come from unknown oxidative agents in the soil.

Even today, people still argue hotly in major journals whether the Viking missions detected life on Mars.

In 1996, Martian meteorite ALH84001 was found to contain small structures that looked like fossilized lifeforms.

(McKay et al., Science, 1996)



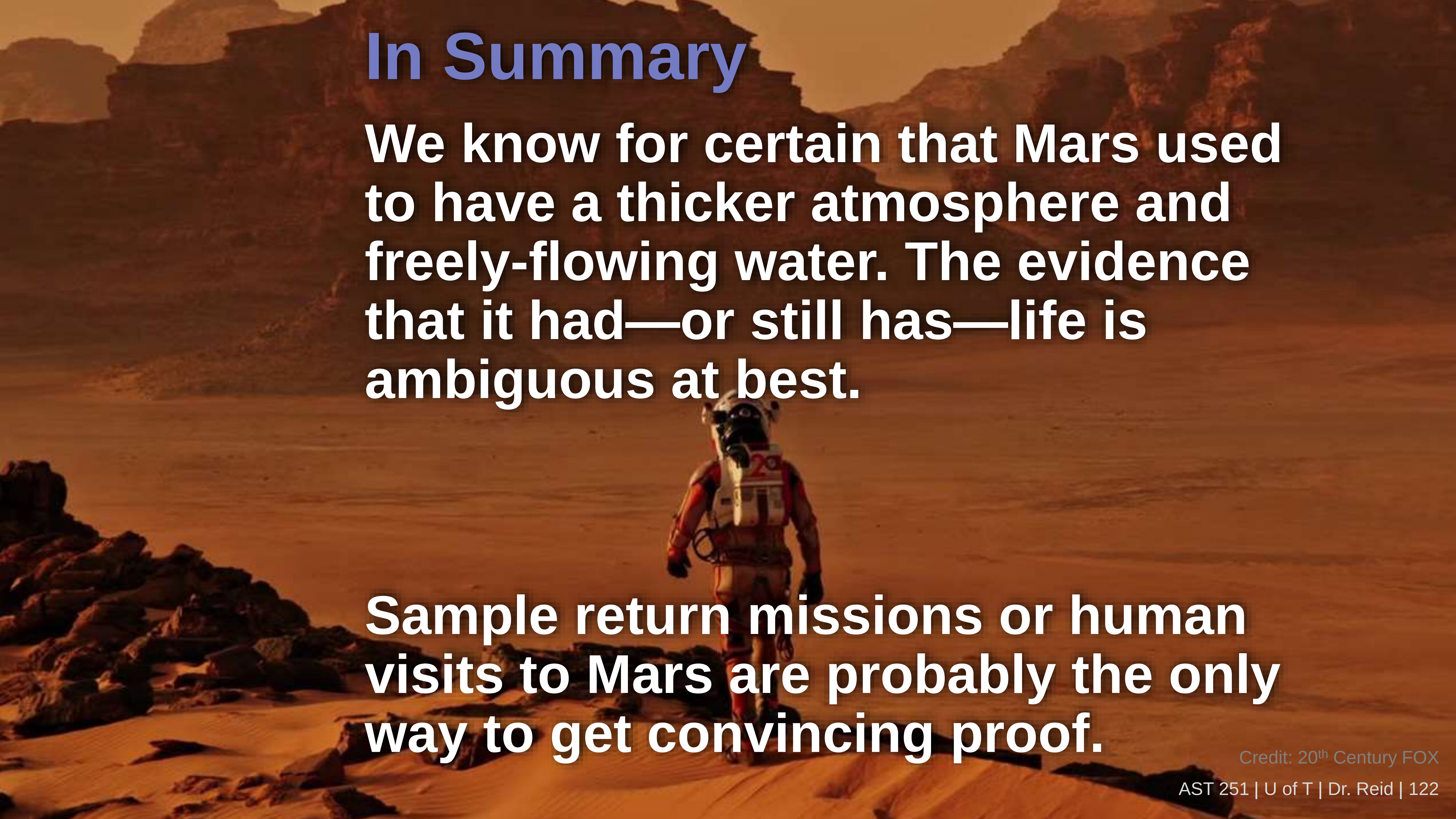
The supposed fossils are smaller than the smallest organisms known on Earth—not much bigger than an empty membrane.

As with the Viking results, the ALH84001 results are still debated, but the current consensus far is that they are not biological in nature.

In Summary

We know for certain that Mars used to have a thicker atmosphere and freely-flowing water. The evidence that it had—or still has—life is ambiguous at best.

Sample return missions or human visits to Mars are probably the only way to get convincing proof.



Credit: 20th Century FOX