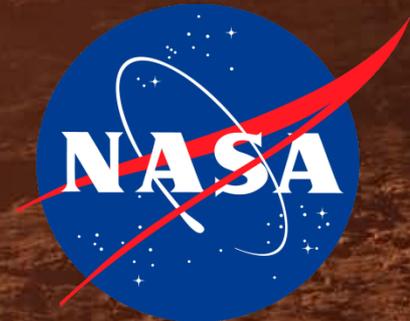


Resurrecting the Martian atmosphere

Can we do it? If so, when?

Rob Lillis

UC Berkeley Space Sciences
Laboratory



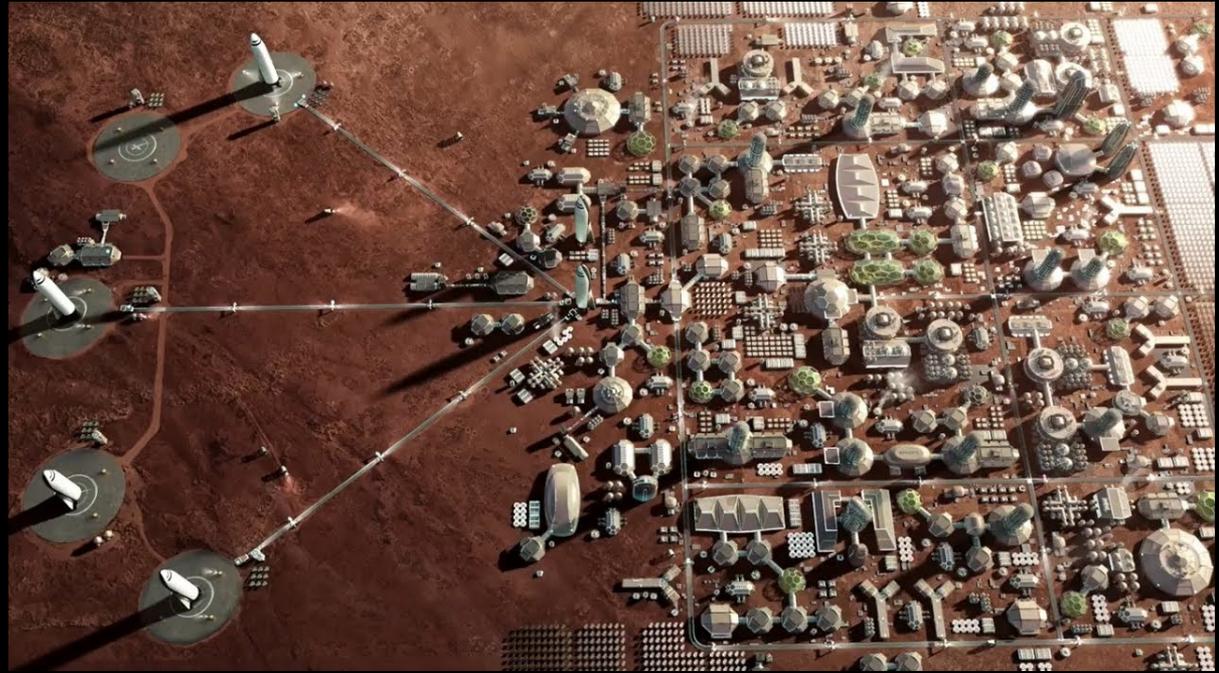
Why might we need to resurrect the Martian atmosphere?



Credit: 20th Century Fox

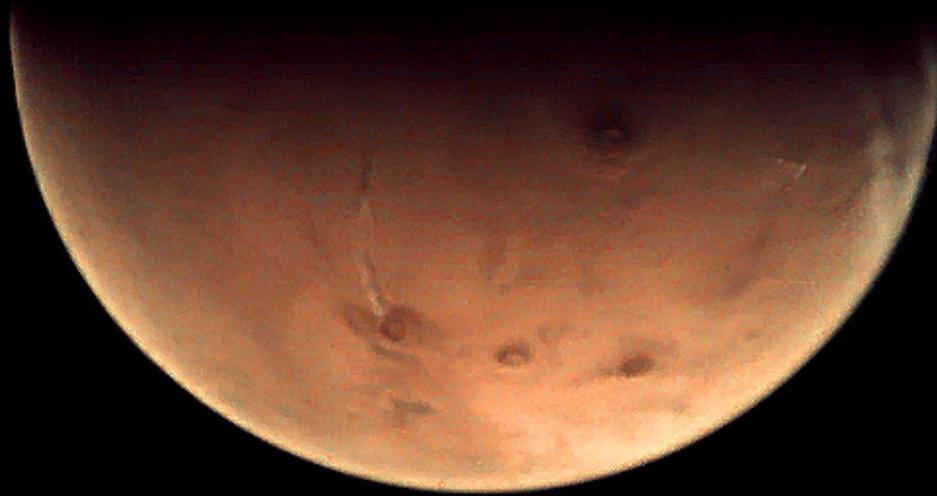
Because *this isn't real*

Why might we need to resurrect the Martian atmosphere?



But this might be someday

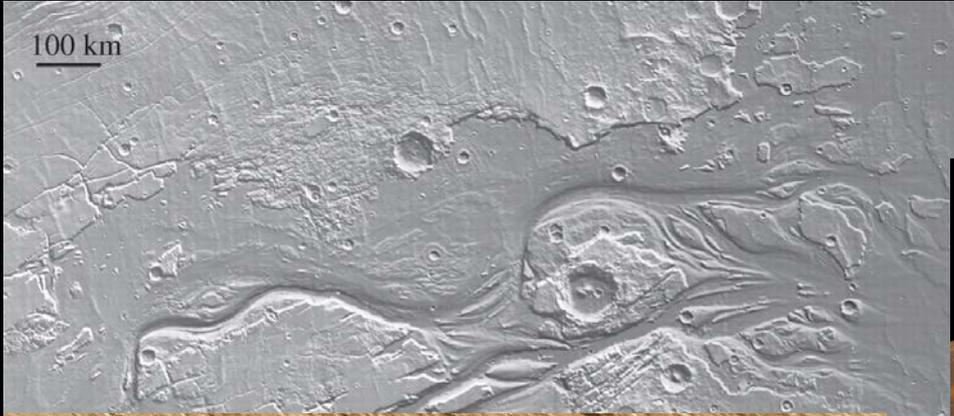
Mars' Present atmosphere & climate



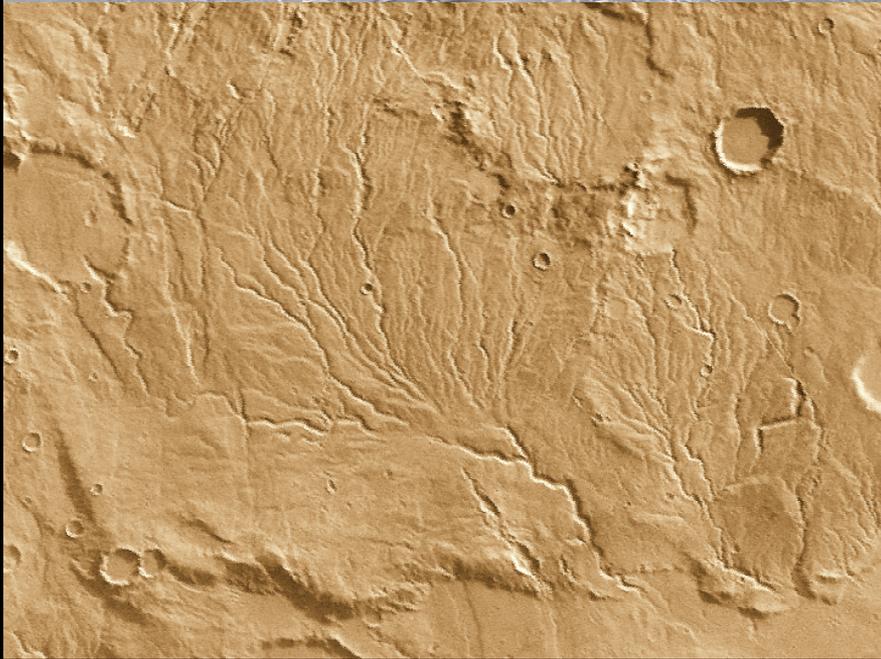
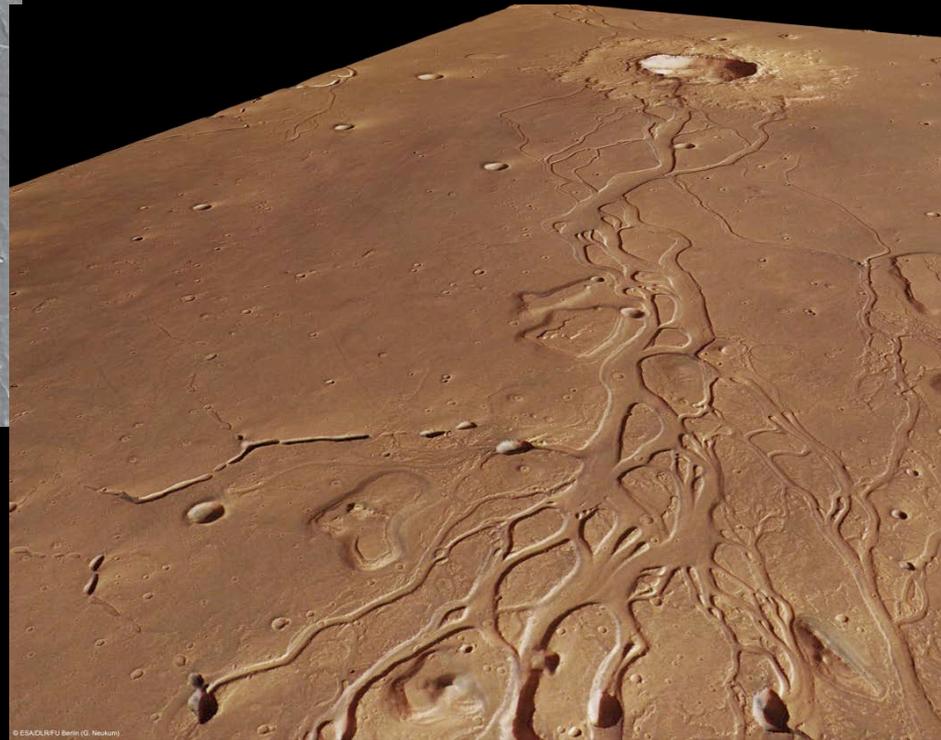
- Composition: 95% CO₂ , 3% N₂ , 1.6% Ar
- Surface Pressure: 0.006 bar, < 1% of Earth's atmosphere
- Receives 50-65% less solar radiation than Earth, so:
 - Average temperature at equator: -60°C (-76°F)
 - Typical temperature at poles: -120°C (-184°F)
- Liquid water is not stable: pressure is too low
- **In other words: thin, cold, dry and poisonous.**
- **Too thin to stop cosmic rays from giving you cancer**

Was it always like this?

Flood-carved channels



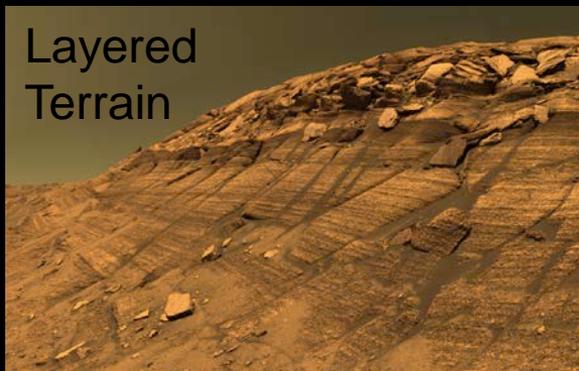
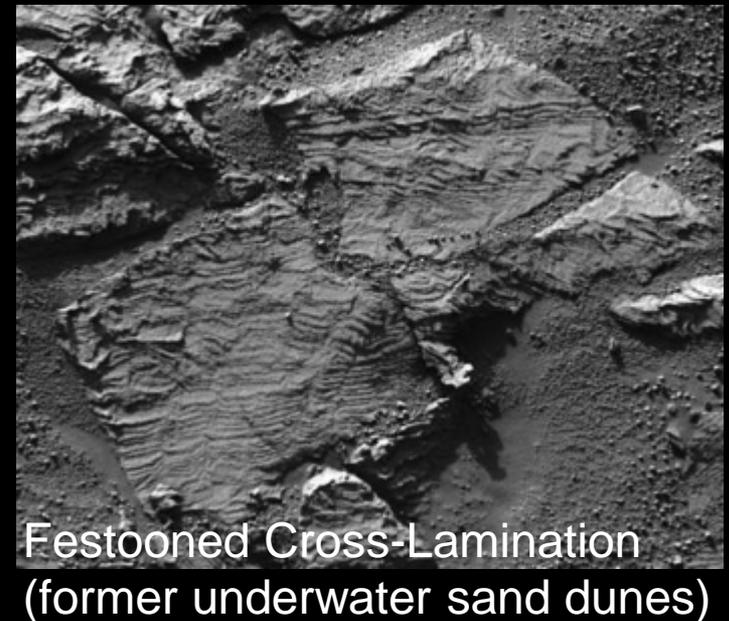
Crater lake dams burst



Rain-carved valley networks

Nope

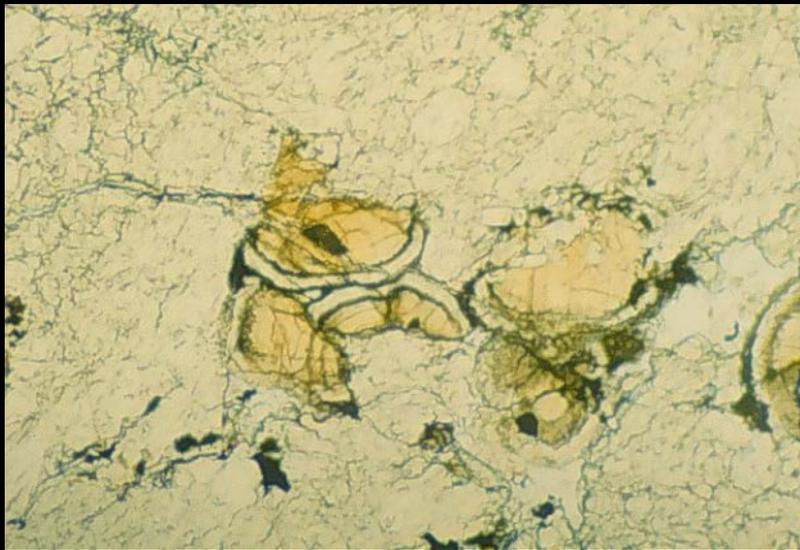
Rovers Have Found Abundance Evidence for Ancient Liquid Water: > 3.5 billion years ago



Where Did the Water Go? Where Did the CO₂ Go?

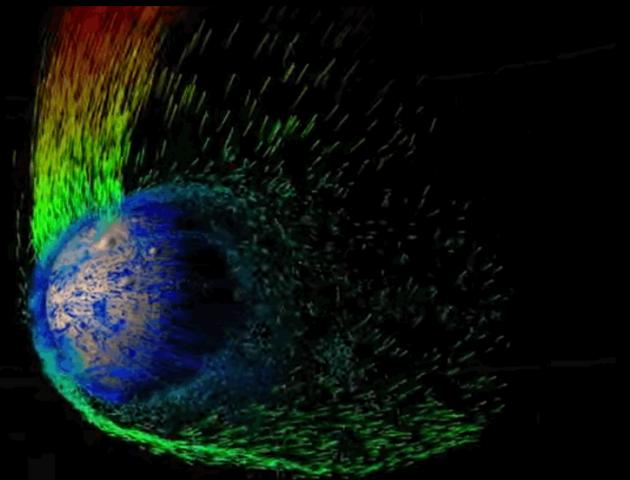
- Surface water isn't stable at Mars' current pressure.
- Even at higher pressures, it's too cold for water to remain liquid in enough places for long enough to explain features
- Must've been a thicker, warmer atmosphere (how much?)
- There's only two places it could've gone:

Volatiles can go into the crust



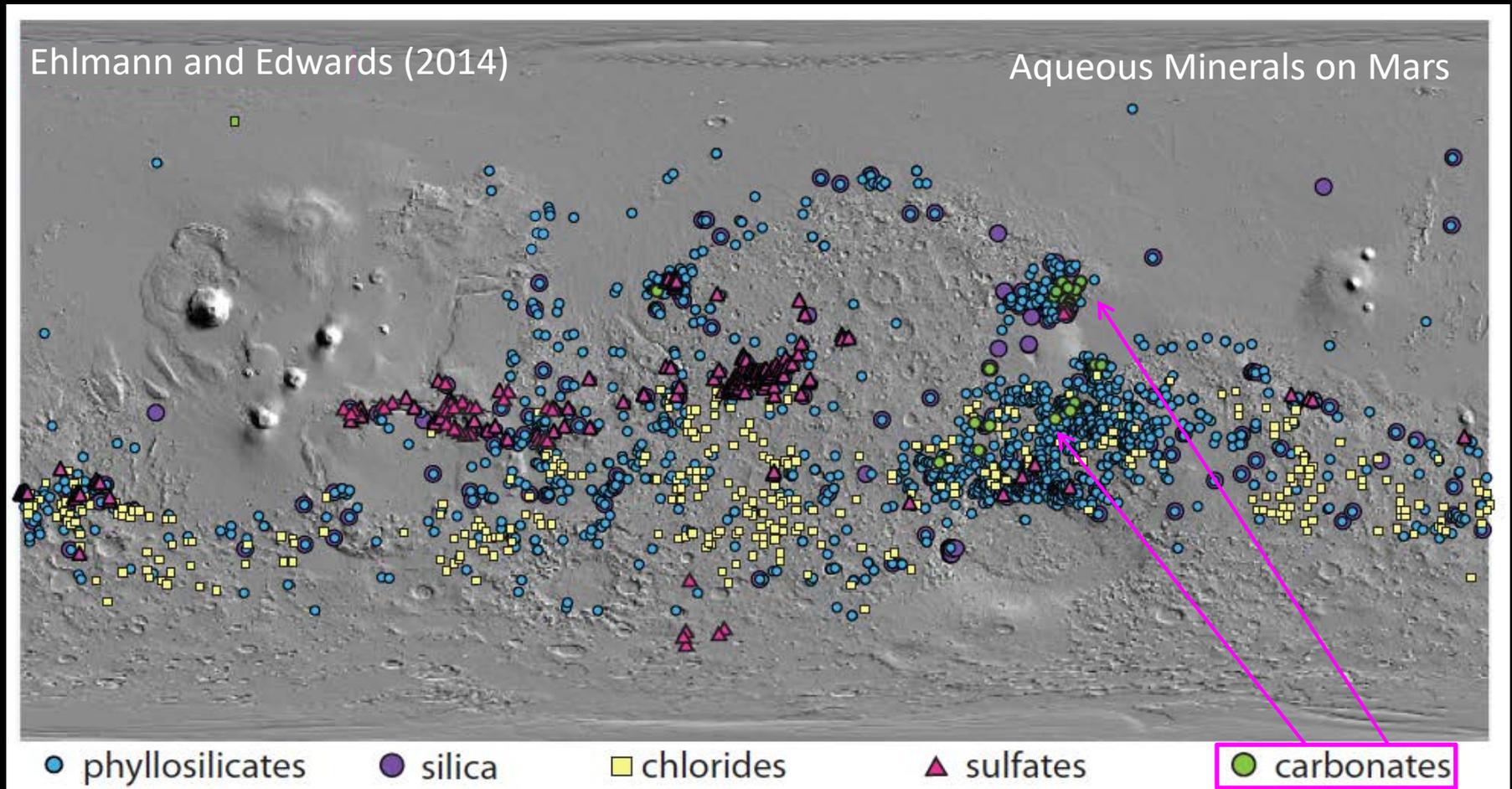
Carbonate deposits in Martian meteorites

Volatiles can be lost to space



Mars atmospheric loss simulation
(Credit: X. Fang/MAVEN/NASA)

Some atmospheric volatiles (e.g. CO₂, water) went down



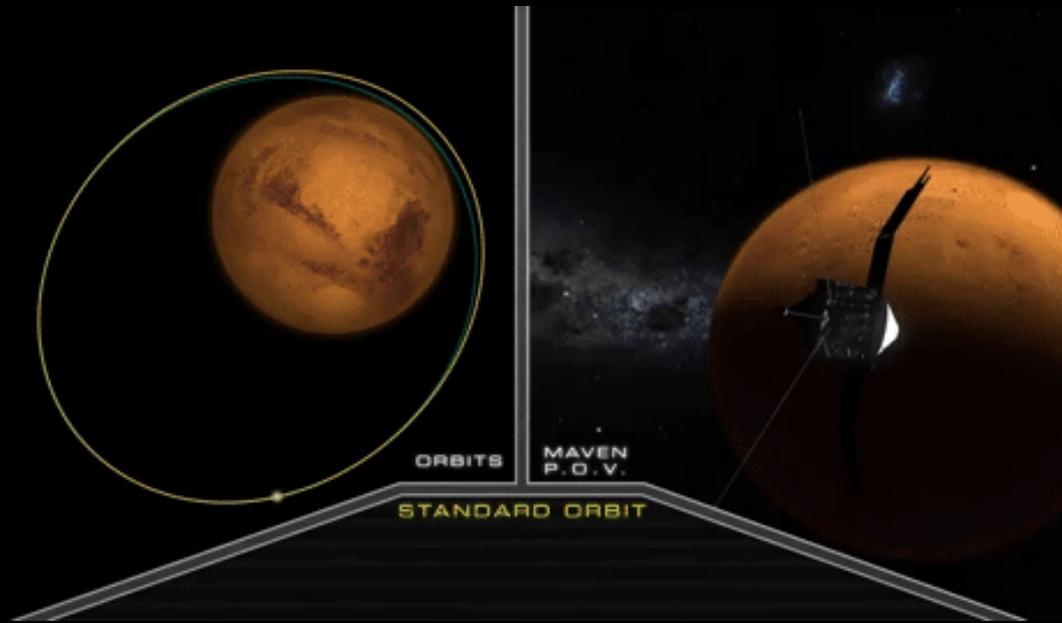
Lots of evidence of aqueous (water-produced) minerals.

Carbonates (which store CO₂) are comparatively rare.

Very optimistically, carbonate outcrops might store ~20-50 mbar of CO₂

Leaking away for billions of years

- NASA's MAVEN orbiter has been measuring atmospheric escape from Mars since 2014.

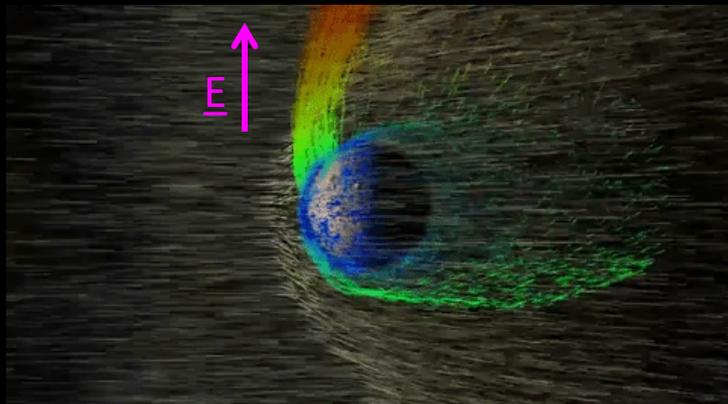


MAVEN's orbit takes it:

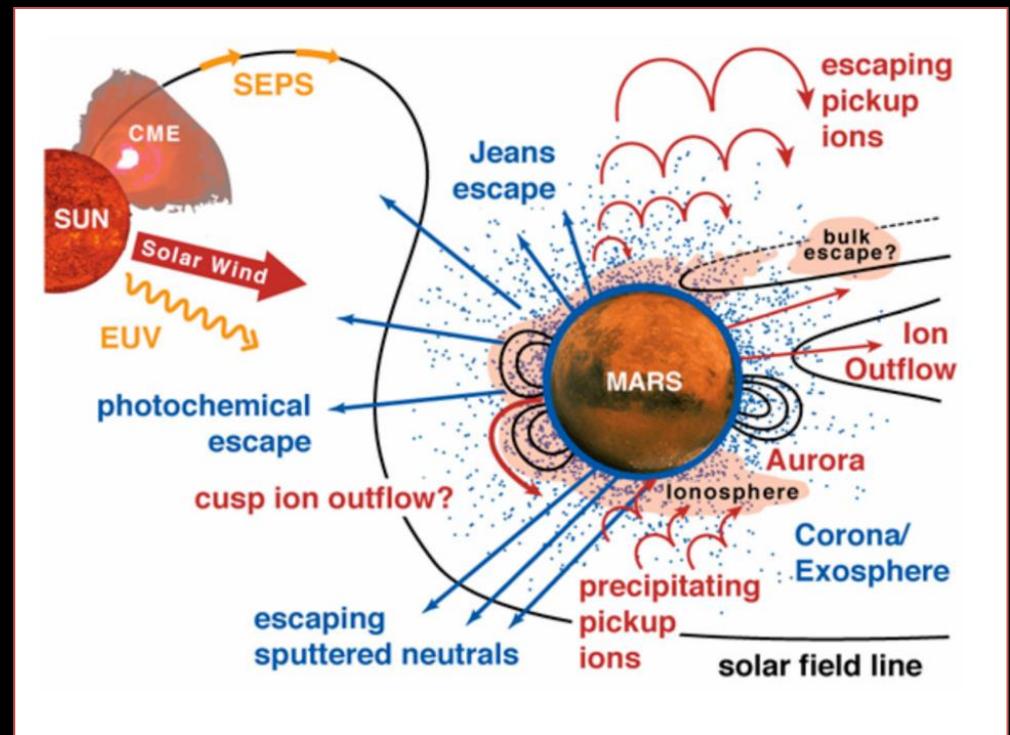
- Close enough to measure physical processes in the atmosphere
- Far enough away to get a global view of atmospheric escape

Leaking away for billions of years

- NASA's MAVEN orbiter has been measuring atmospheric escape from Mars since 2014.
- Multiple physical processes cause atmospheric loss.



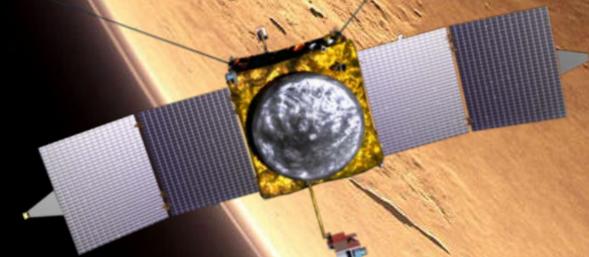
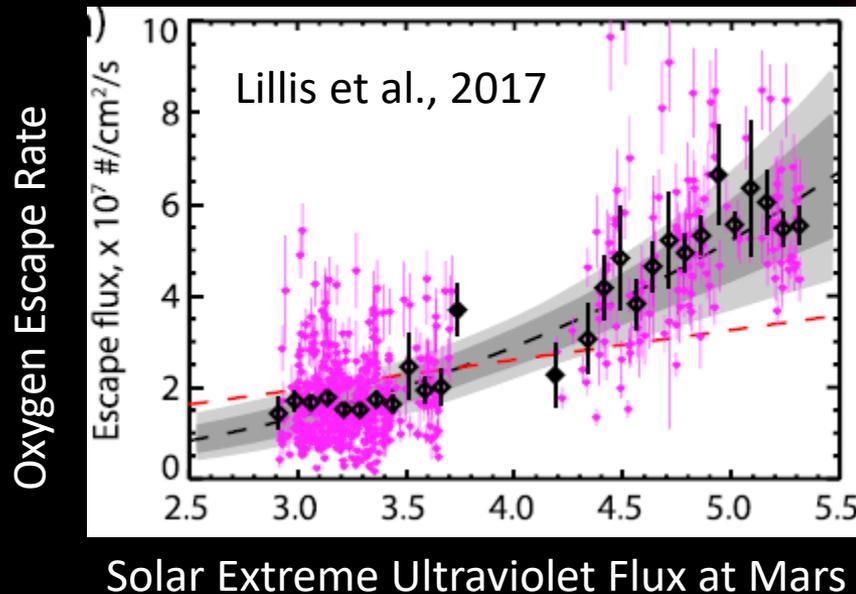
Solar wind stripping ions away
From Mars' atmosphere



TLDR: full picture is complicated, still working it out!

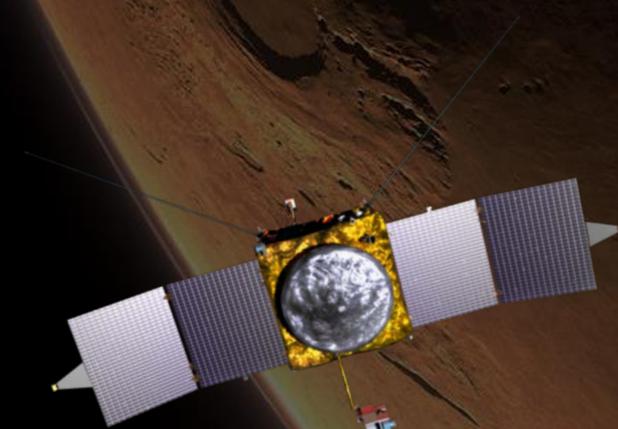
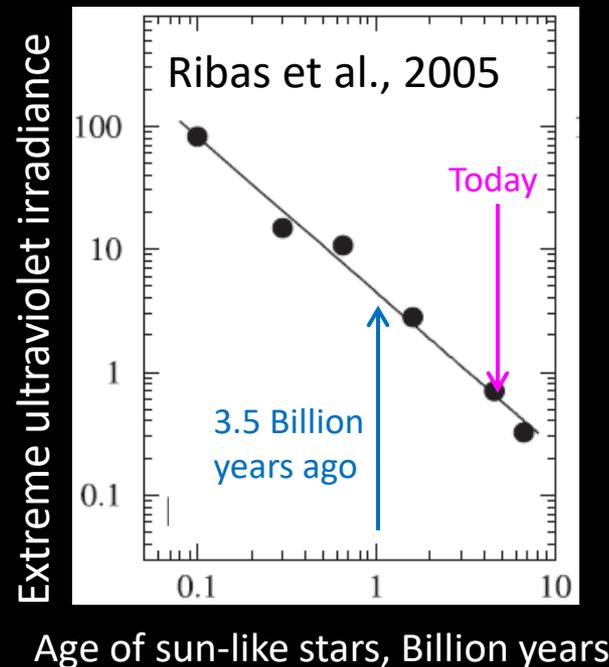
Leaking away for billions of years

- NASA's MAVEN orbiter has been measuring atmospheric escape from Mars since 2014.
- Multiple physical processes cause atmospheric loss.
- Escape rates increase with solar UV and storm activity.



Leaking away for billions of years

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- Escape rates increase with solar UV and storm activity.
- The early sun was much more active than today.



Leaking away for billions of years

- NASA's MAVEN orbiter has been measuring atmospheric escape from Mars since 2014.
- Multiple physical processes cause atmospheric loss.
- Escape rates increase with solar UV and storm activity.
- The early sun was much more active than today.
- By extrapolating MAVEN's escape rates back to these early times, we estimate **several hundred millibars** of atmosphere have escaped over Mars' history.
- Okay, so we've lost a lot of atmosphere. And there's not a lot of obvious CO₂ in the visible surface rocks. What can we do?

Let's get started

Checklist:

- 1) Fanatical will to succeed (folks already living there).



Let's get started

Checklist:

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- 2) \$



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Let's get started

Checklist:

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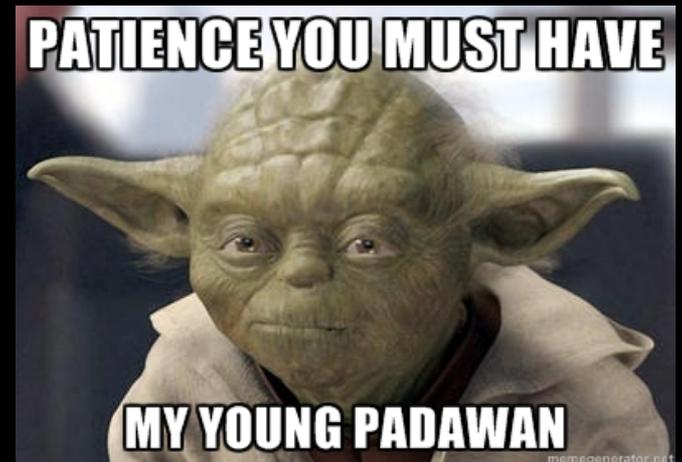


x1000

Let's get started

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- 4) Patience. Like, your-grandkids-might-just-see-the-start-of-this level of patience.

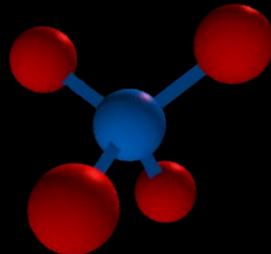


Let's get started

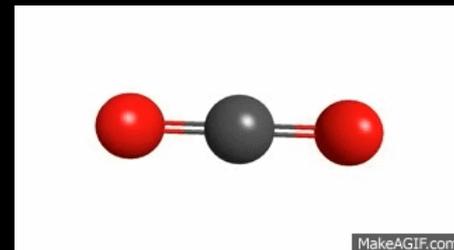
Checklist:

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- 3) Energy. So much Energy. Nuclear Energy. 1000's of (fusion?) nuclear power plants. Built on Mars.
- 4) Patience. Like, your-grandkids-might-just-see-the-start-of-this level of patience.
- 5) A large quantity of the right elements to make an atmosphere, readily available on Mars.

CH₄: methane



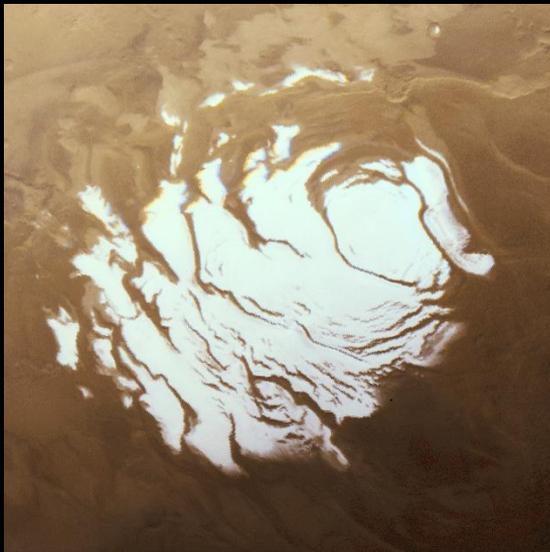
Greenhouse gases



CO₂

Step 1: melt the dry ice

- South Polar CO₂ ice will sublimate into the atmosphere if heated by few 10s of degrees
- **Sublimation** → higher CO₂ pressure → increased greenhouse effect → higher temperature → **sublimation**
- In this way, ~12-14 mbars of CO₂ could be released, tripling the atmospheric pressure.



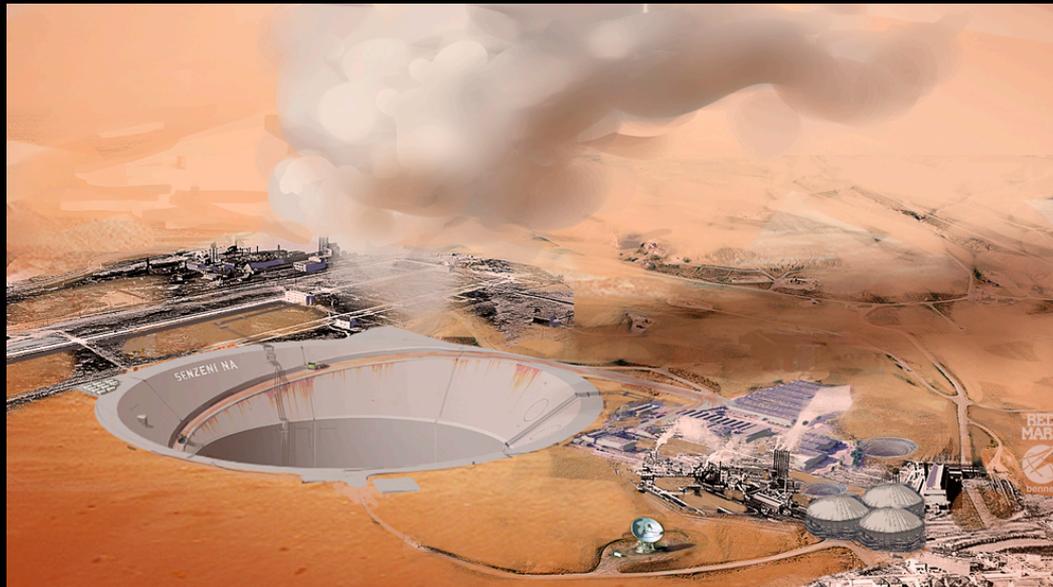
Step 1: melt the dry ice

- South Polar CO₂ ice will sublime into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
 - H-bomb the south pole. Colonists might not like that..



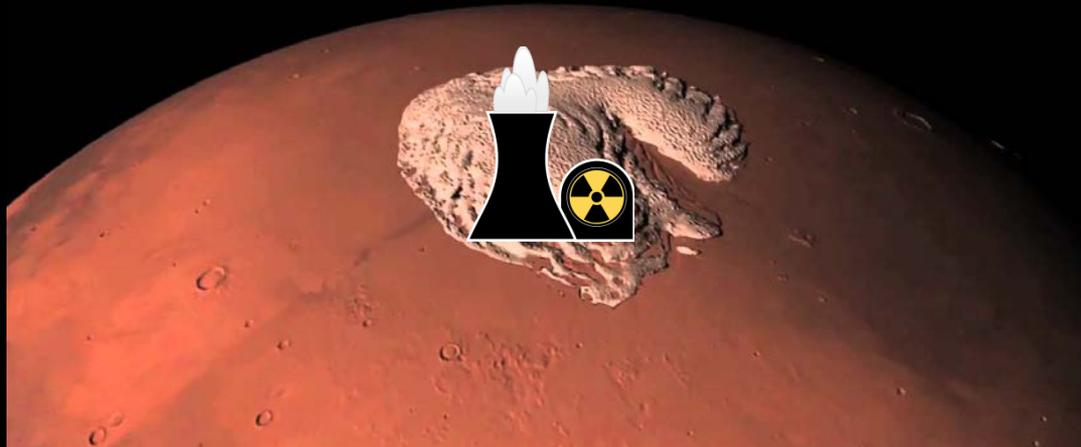
Step 1: melt the dry ice

- South Polar CO₂ ice will sublimate into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
 - Dig ~30 'moholes'. Reinforced holes 1 km wide x 7 km deep: 300° C at the bottom, release hot air continuously.



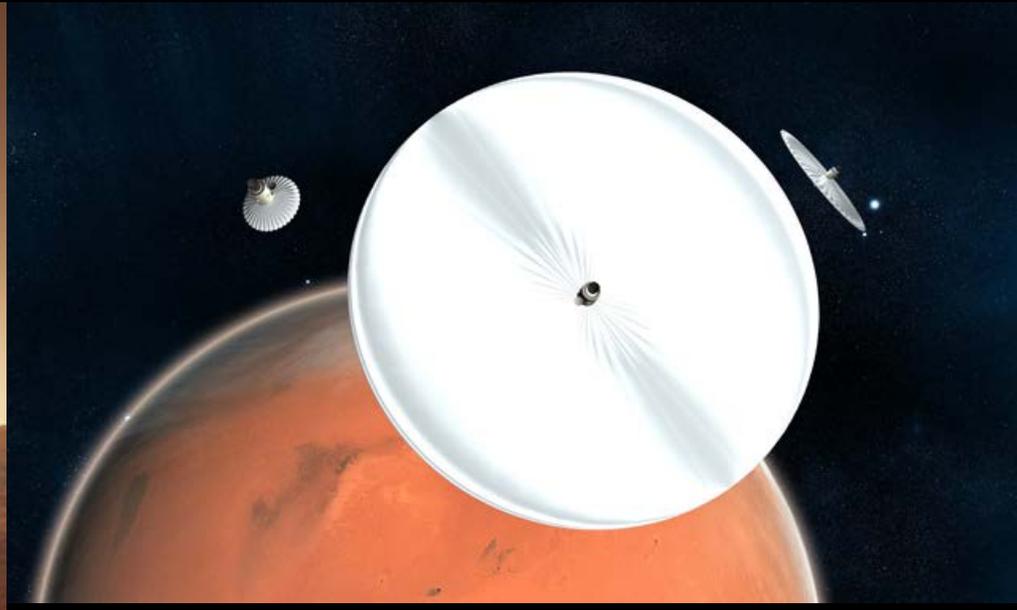
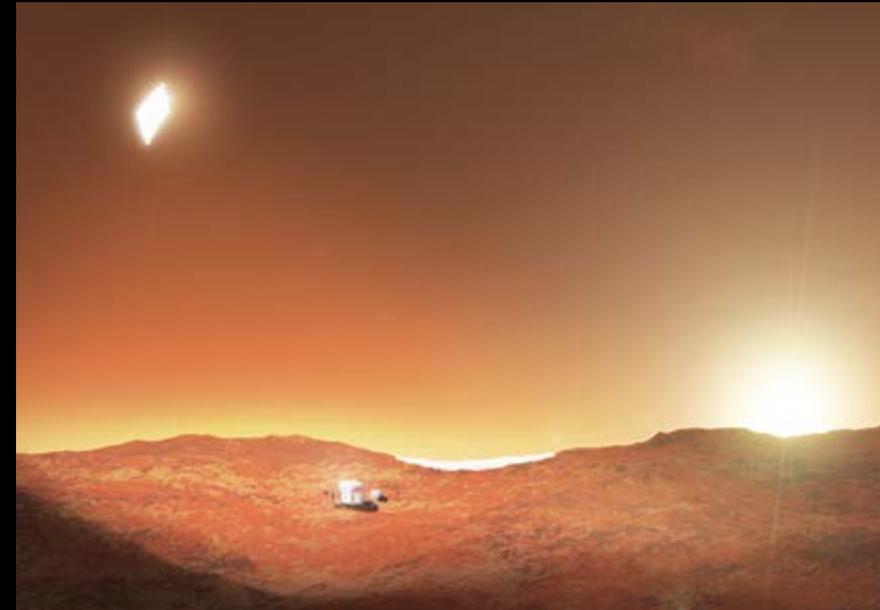
Step 1: melt the dry ice

- South Polar CO₂ ice will sublime into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
 - Fusion power plants at the poles slowly melt the CO₂ ice.



Step 1: melt the dry ice

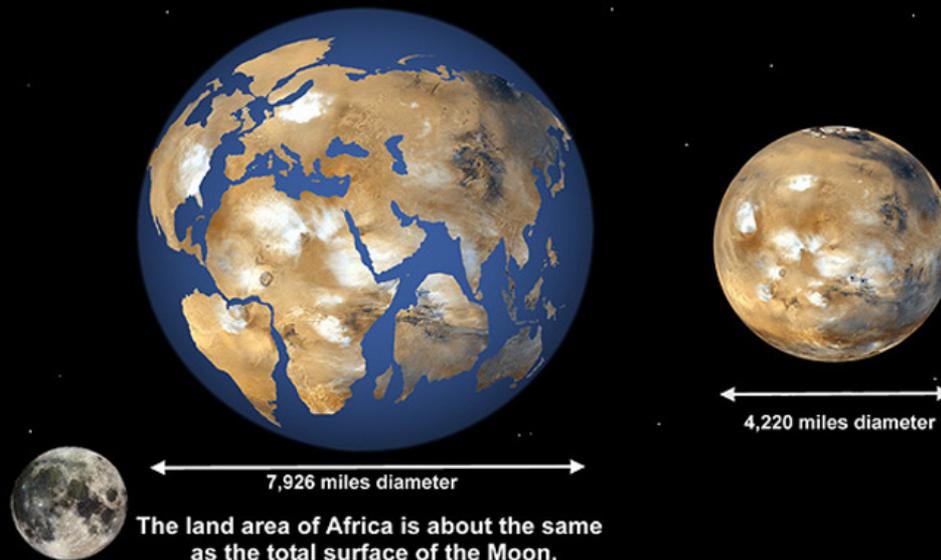
- South Polar CO₂ ice will sublimate into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
 - Orbital Mirrors could reflect sunlight down onto Mars.



Step 2: Dig Baby Dig

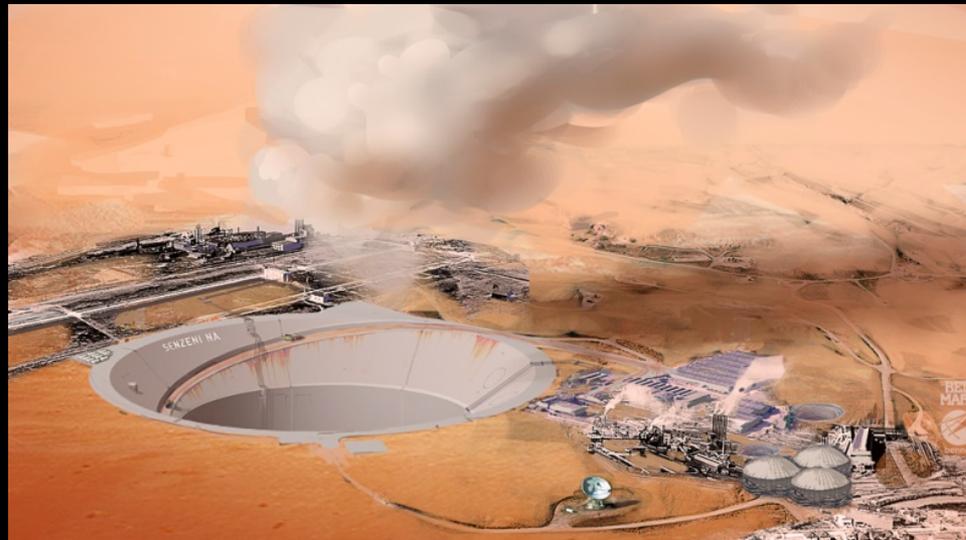
- Every sq. meter of Earth's atmosphere weighs 10 tons.
 - Mars has as much area as all of Earth's continents.
 - → we need to dig up *at least* 10 tons of rock for each of the *144 trillion* square meters on Mars.

The land area of the Earth is approximately equal to the total surface of Mars.



Step 2: Dig Baby Dig

- Every sq. meter of Earth's atmosphere weighs 10 tons.
 - Crustal rocks average 3 tons per cubic meter.
 - → need to dig to an average of 3m over the whole planet.
 - Likely dig to much greater depth in a small area.
 - Could use tailings from Mohole excavation?
 - Still, a million billion tons is a *LOT* of rock.



Phase 3: make the atmosphere

- CO₂ from the poles (15 mbars) is a start.
 - additional ~40 mbars of CO₂ adsorbed in the regolith
 - would need to dig to *100 m planet-wide* to release it.
- More realistic is to liberate O, H, C, N by heating the rocks we dig up: need 10,000s of nuclear-powered atmosphere factories running for 100s of years.



Phase 3: make the atmosphere

Bulk Gas:

- CO_2 : effective greenhouse gas to get things going, but prob no more than ~50 mbar we can get (few carbonates)
 - Its greenhouse advantages diminish with pressure above ~100 mbar anyway
 - Oh yeah: poisonous to humans.
- Oxygen: plenty in rocks, but too much is bad (fire).
- Nitrogen: would be great, but very little on surface (more might be deeper), but doesn't look good.

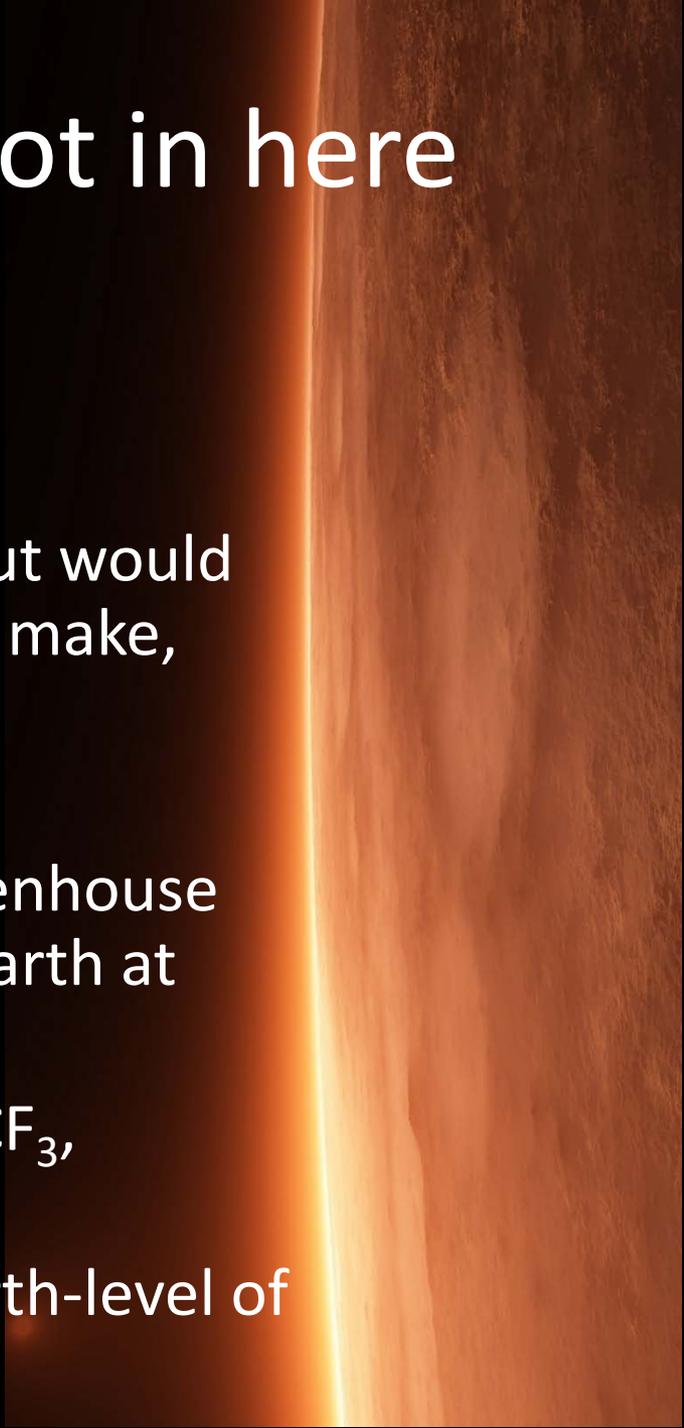
Phase 4: it's getting hot in here

Mars is farther from the sun:

- Need a 70°C greenhouse effect.
- CO₂ not great, as mentioned.
- Methane is 84 times more efficient but would still need too much of it to practically make, plus it's poisonous too.

Potential Solution:

- Cocktail of fluorine-based “super greenhouse gases” could keep Mars as warm as earth at levels of ~200 ppb = 0.00002%
- e.g. CF₃SCF₃, CF₃OCF₂OCF₃, CF₃SCF₂SCF₃, CF₃OCF₂NFCF₃) [Gerstell et al., 2000].
- Could be maintained with current earth-level of mining activity.



Let's not get ahead of ourselves

Prerequisites to even starting:

1. Send humans to Mars & bring them back safely.
2. Send more to Mars to live. Don't let them die there. Then more might go.
3. Establish Martian society large and robust enough with folks who actually care enough to start this.
4. Wait for huge technological advancements in
 - space travel (to bring materials cheaply from Earth)
 - automated industrial production and mining
 - geo-engineering



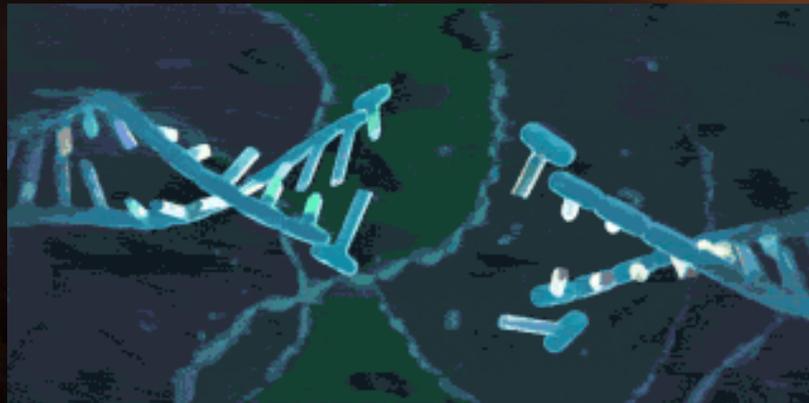
What's a thousand years between friends?

- When will space travel and supporting the Mars colony really get cheap enough? The price tag has to be right.



What's a thousand years between friends?

- When will we be able to fix medical problems inherent to living on Mars, like DNA radiation damage?



What's a thousand years between friends?

- Will Martian society be stable/robust enough to grow to the kind of size needed to start rebuilding the atmosphere?
 - Capitalism vs. collectivism? Do people pay for air?
 - Independence from Earth? Conflict? Anti-immigrant sentiment?



What's a thousand years between friends?

- The right atmospheric raw materials:
 - Do they exist in sufficient quantities?
 - Can they practically be extracted?
 - Can we ship them from Earth or elsewhere (e.g. nitrogen from Titan). How long until that can be done?



The Big Picture

- With colossal amounts of cumulative will, money, time and technology advancement, I believe we can make Mars habitable for humans.
- The unknowns (known and unknown) make the timeline somewhere from “hundreds of years” to “maybe never”.
- Watch this space. Have your children, grandchildren, distant descendants watch it too. It’s gonna be a while.

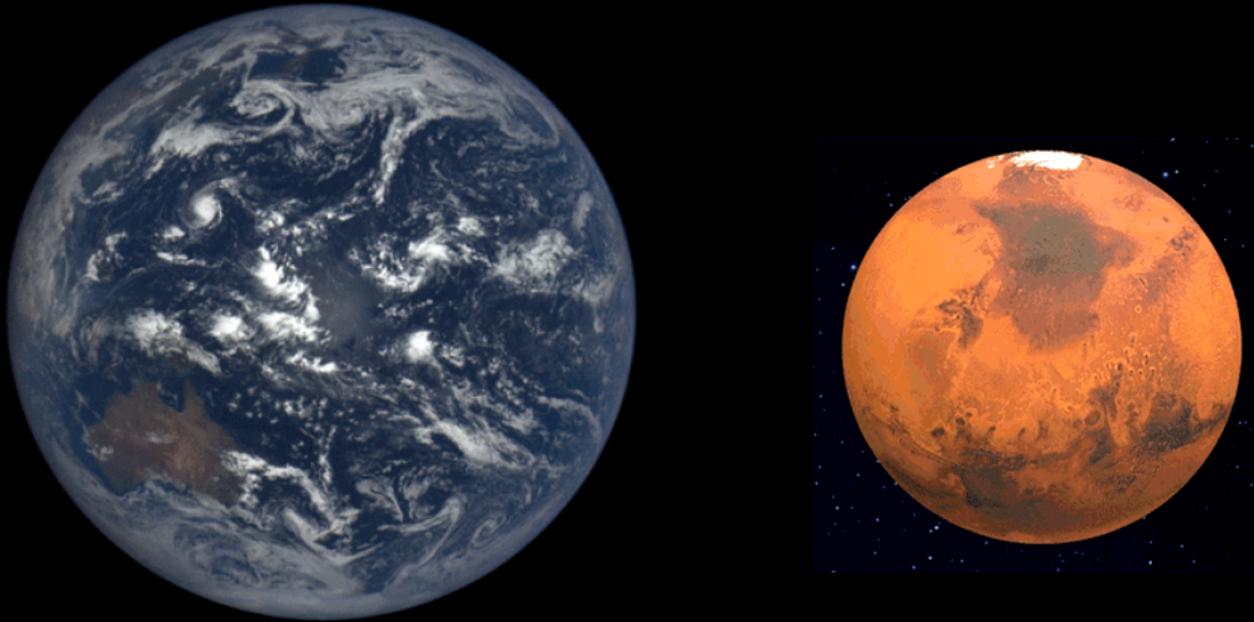


THANK YOU

Why Mars?

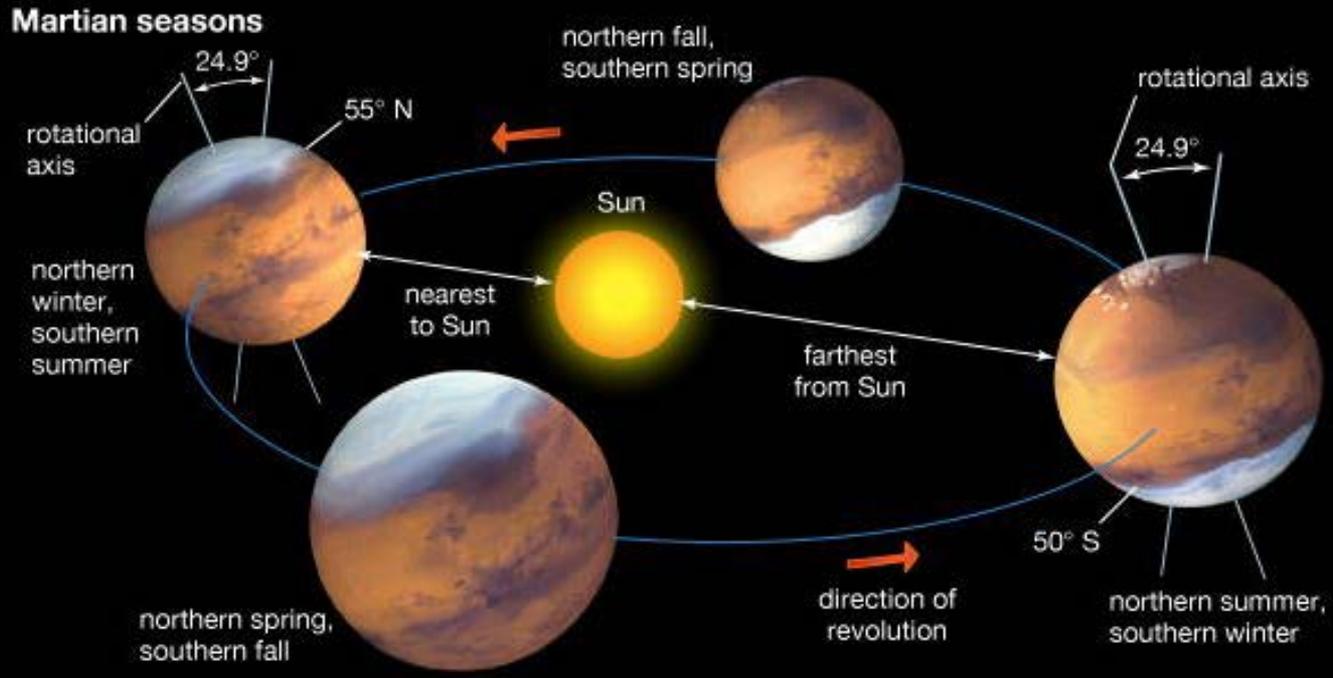
- Length of day: 24.6 hours (won't drive you crazy)
- Seasons! 25° orbital tilt.
- Lots of water (subsurface and polar caps)
- Comfortable gravity, 38% of Earth.

Does size matter?



- **Diameter:** 53%, **Mass:** 10% of Earth. So Mars cooled faster and (mostly) ran out of volcanic activity ~3 billion years ago.
- **Gravity:** 38% of Earth. Lower escape velocity: 2 km/s vs. 7 km/s.
→ Gas can escape more easily from Mars.
- **No magnetic field** to shield the atmosphere. Mars lost its magnetic field ~4 billion years ago. Size wasn't the only culprit but didn't help.

Mars Fast Facts



Compared to Earth:

- **Mass:** 10%
- **Diameter:** 53%
- **Surface Gravity:** 38%

Asymmetric Seasons:

- Southern summer is shorter & hotter than northern summer.