Resurrecting the Martian atmosphere

Can we do it? If so, when?

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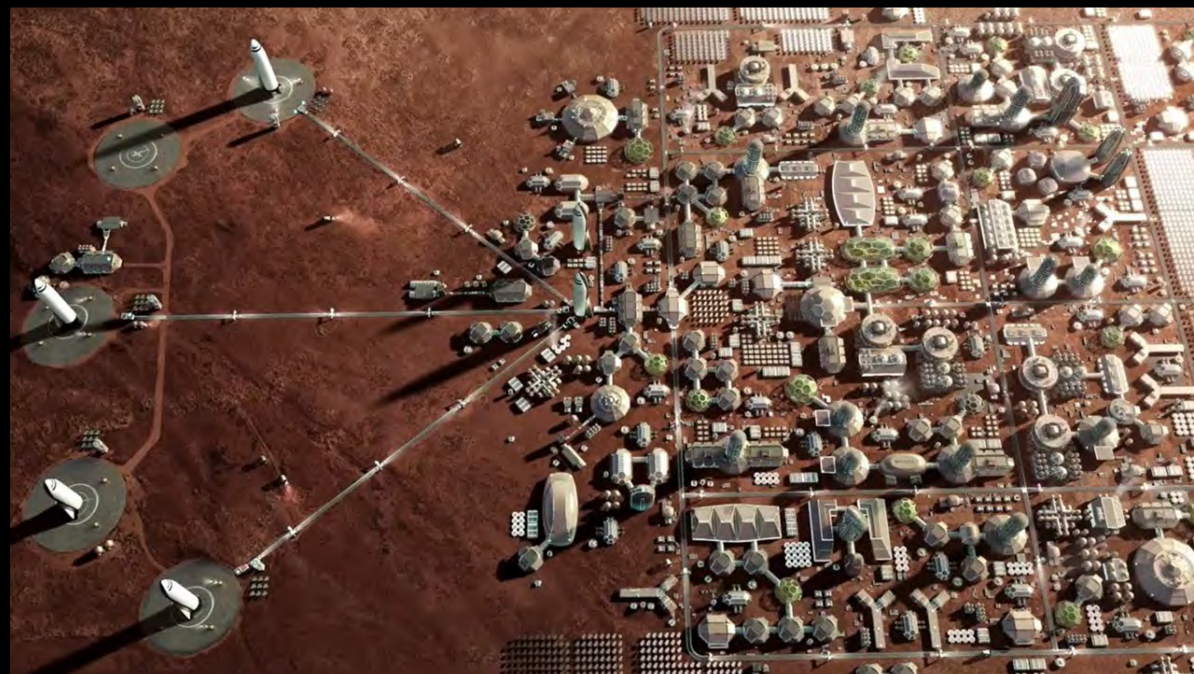
Help from: Bruce Jakosky, Chris Edwards

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?



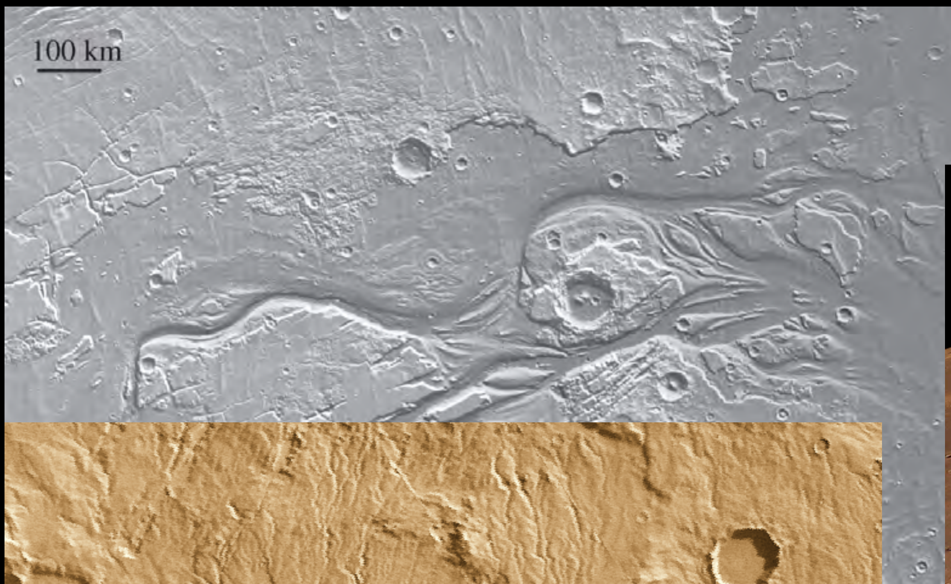
But this might be someday

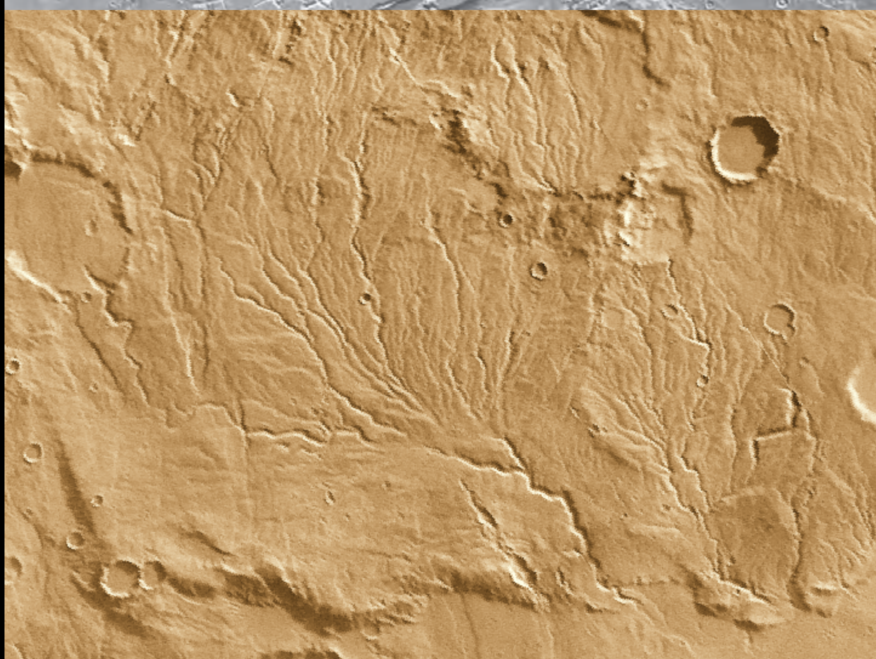
Mars' Present atmosphere & climate

- Composition: 95% CO_2 , 3% N_2 , 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
- TL;DR: thin, cold, dry and poisonous.
- Too thin to stop cosmic rays from giving you cancer

Was it always like this?

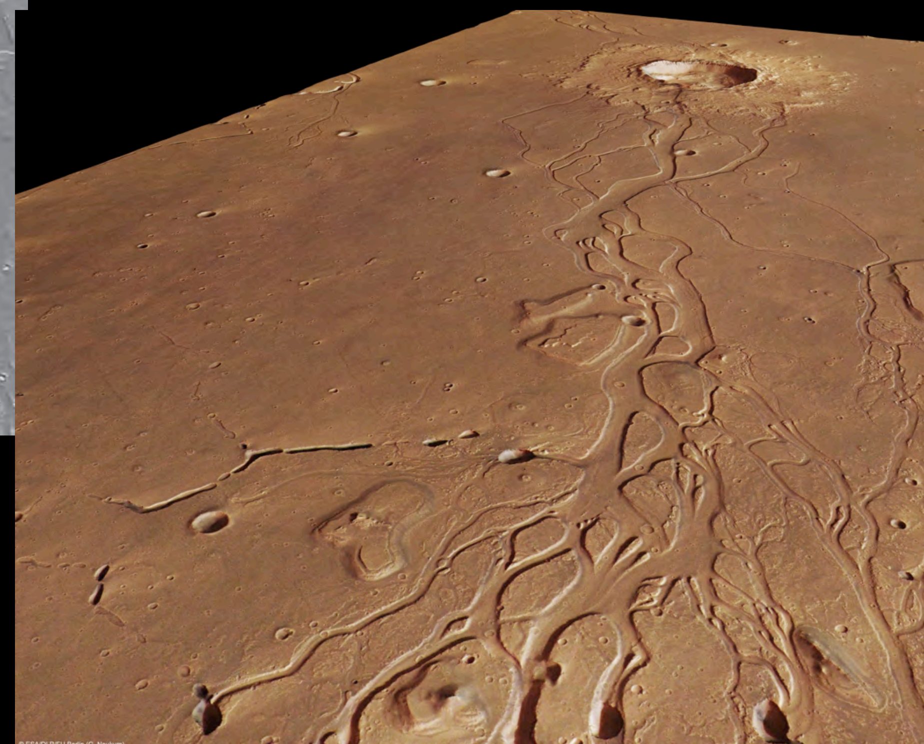
Flood-carved channels





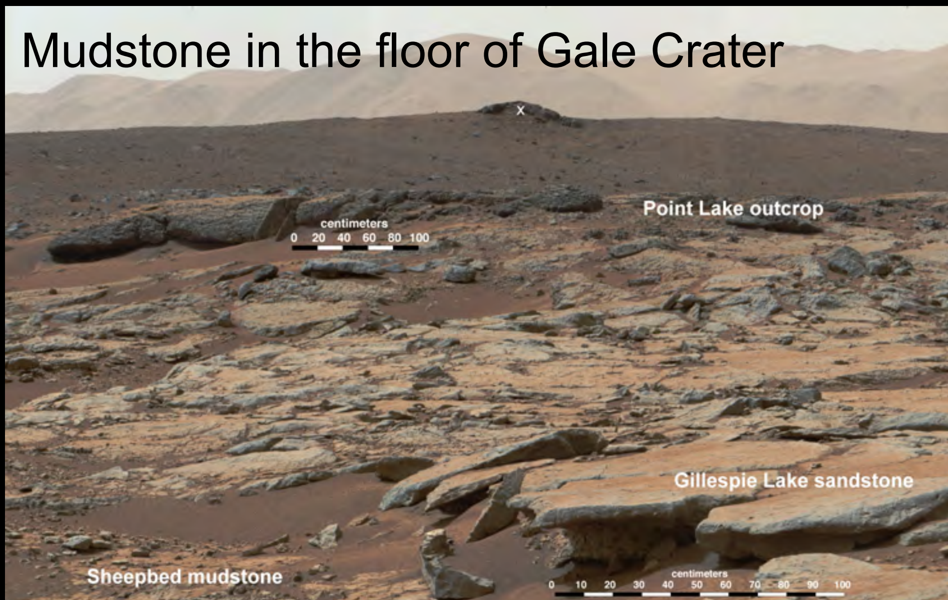
Rain-carved valley networks

Crater lake dams burst



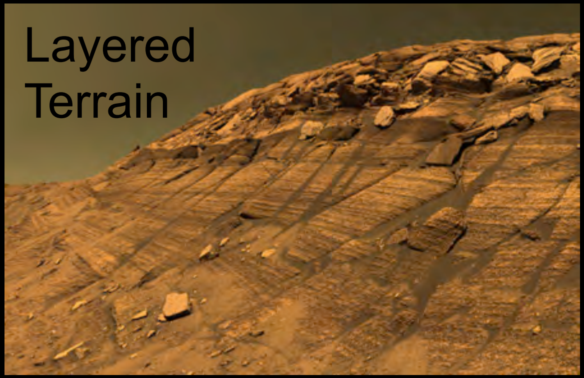
Nope

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

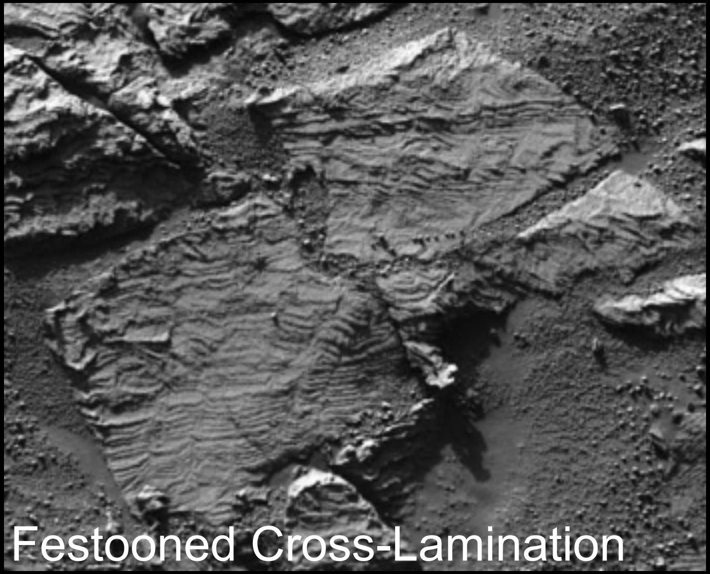


Mudstone in the floor of Gale Crater

"Blueberries"


Layered Terrain

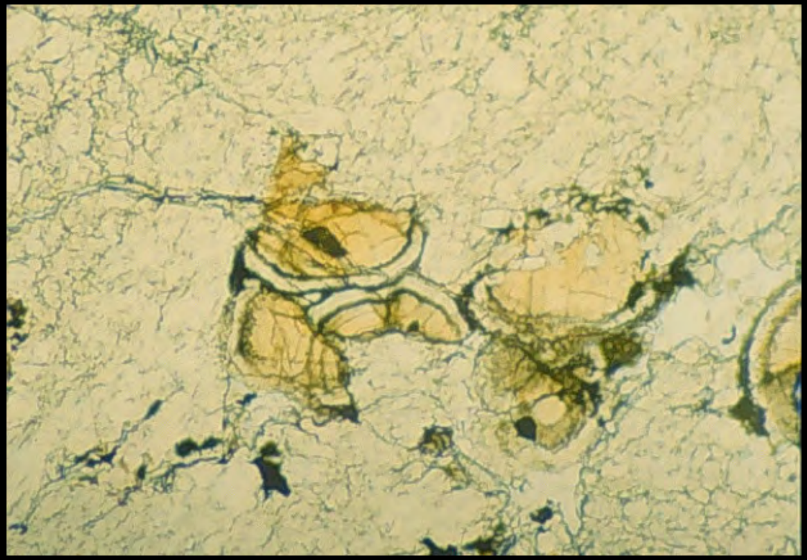

Hydrated silica


Festooned Cross-Lamination (former underwater sand dunes)

Where Did the Water Go? Where Did the CO_2 Go?

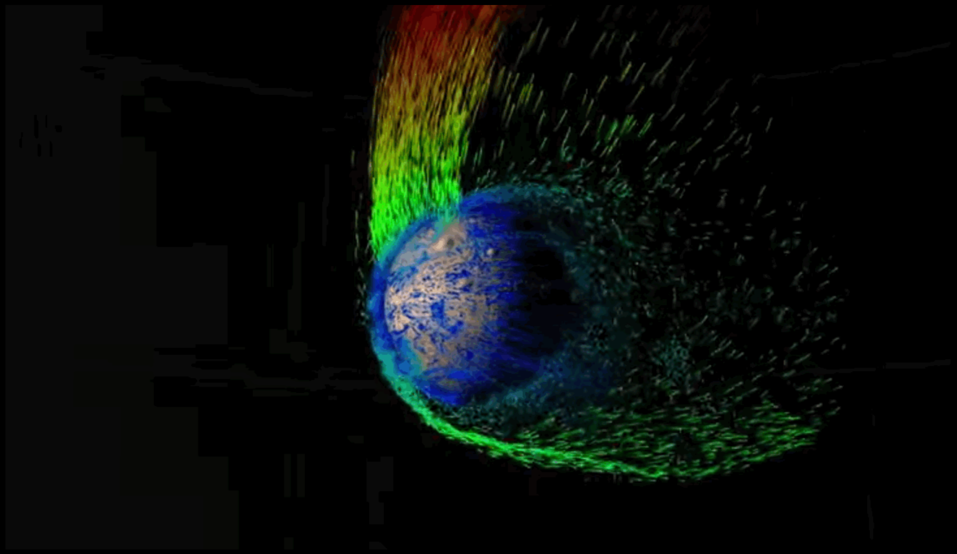
- Even at higher pressures, it's too cold for water to remain liquid in enough places for long enough to explain features
- Must've been a thicker, warmer atmosphere (how much?)
- There's only two places it could've gone:

Volatiles can go into the crust



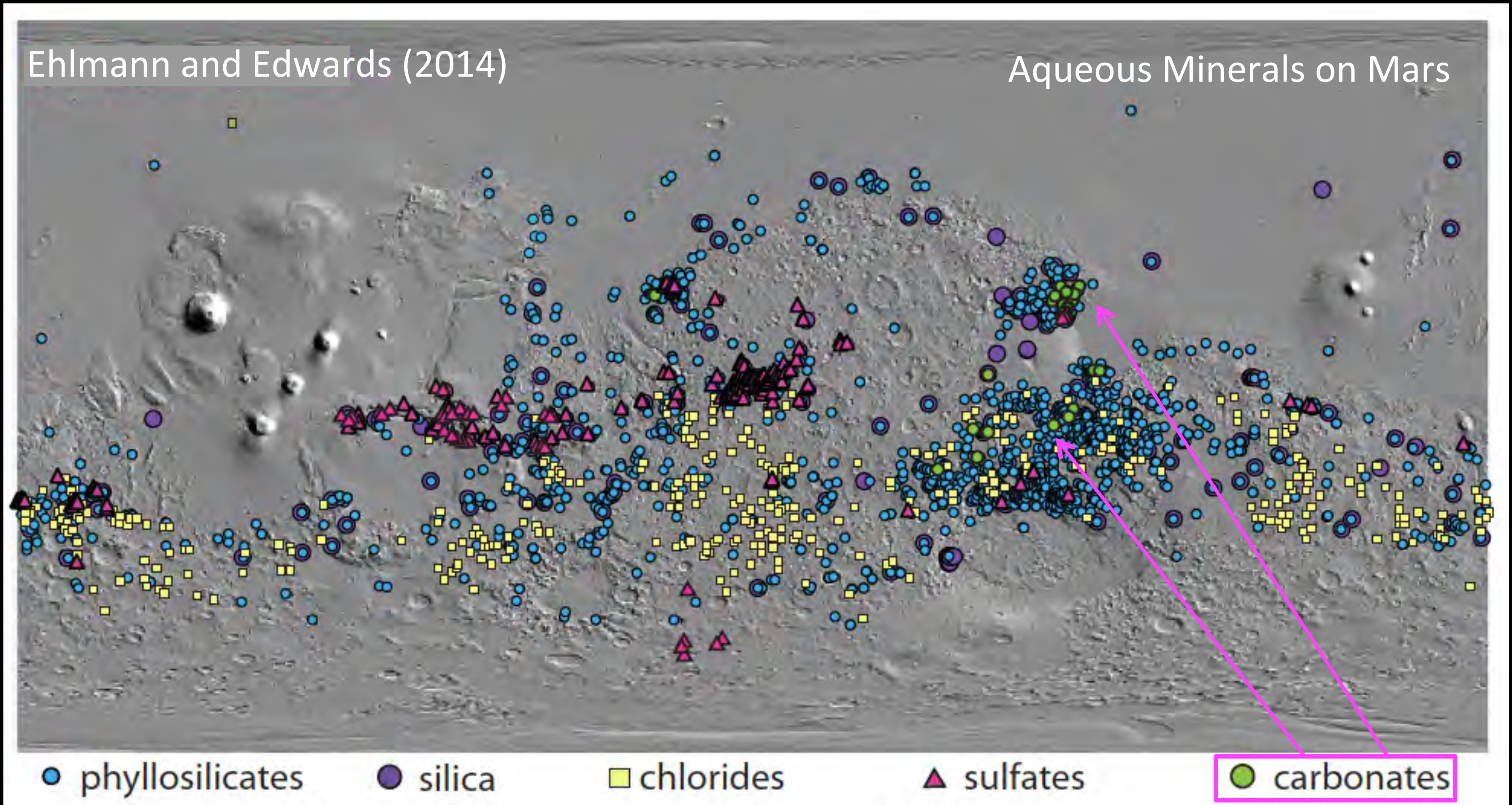
Carbonate deposits in Martian meteorites

Volatiles can be lost to space



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

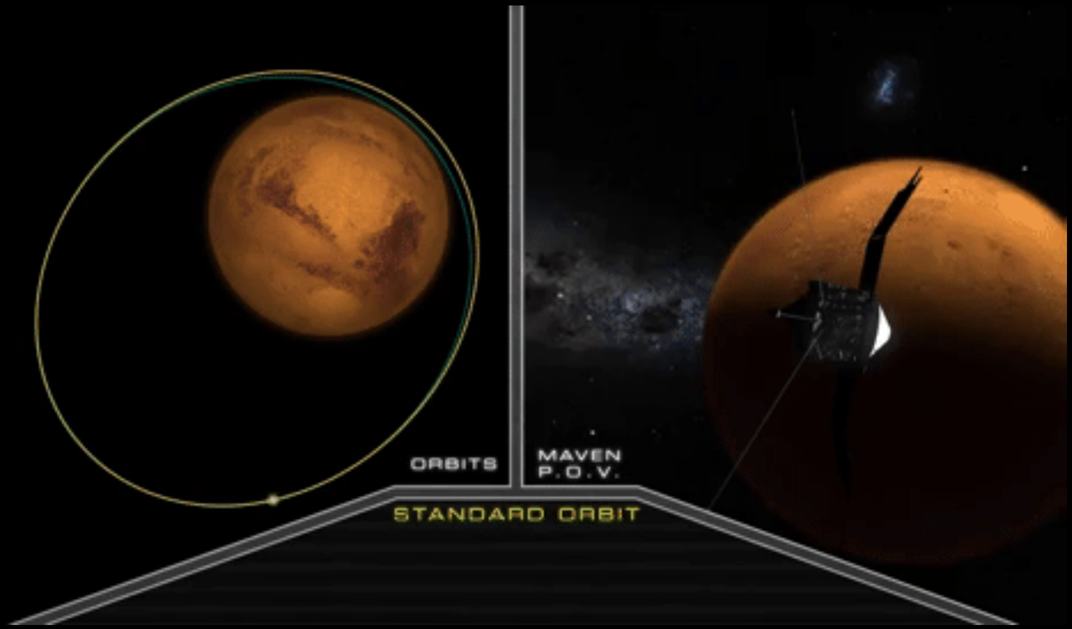
Some atmospheric volatiles (e.g. CO2, water) went down



Lots of aqueous (water-produced) minerals.
Carbonates (which store CO2) are comparatively rare.
Optimistically, might store 20-50 mbar of CO_2

Leaking away for billions of years

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

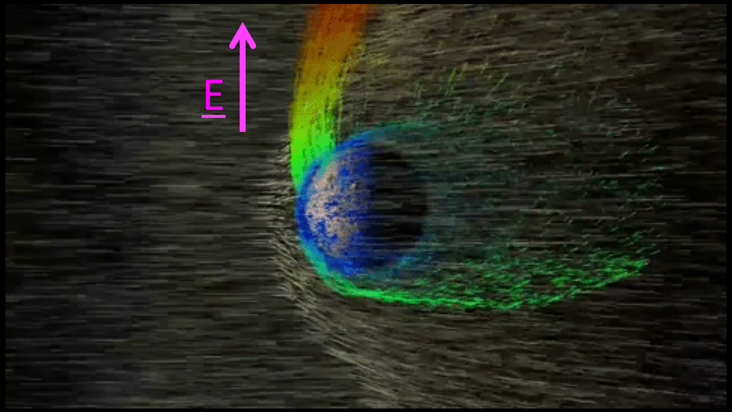


MAVEN's orbit takes it:

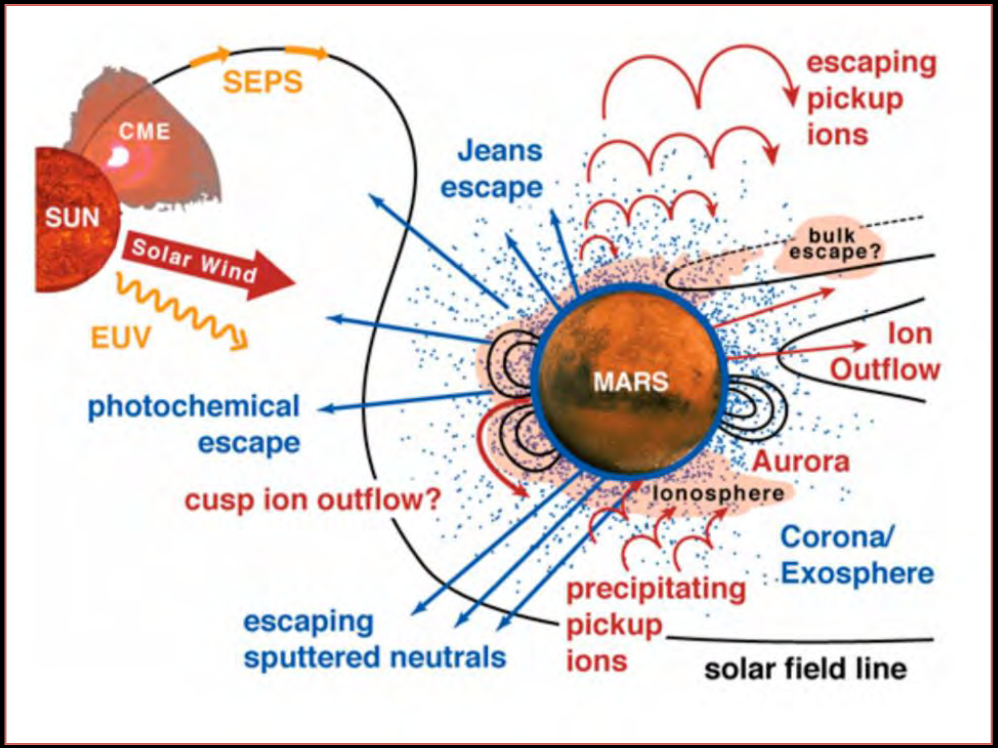
- Close enough to measure physical processes in the atmosphere
- Far enough away to get a global view of atmospheric escape

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

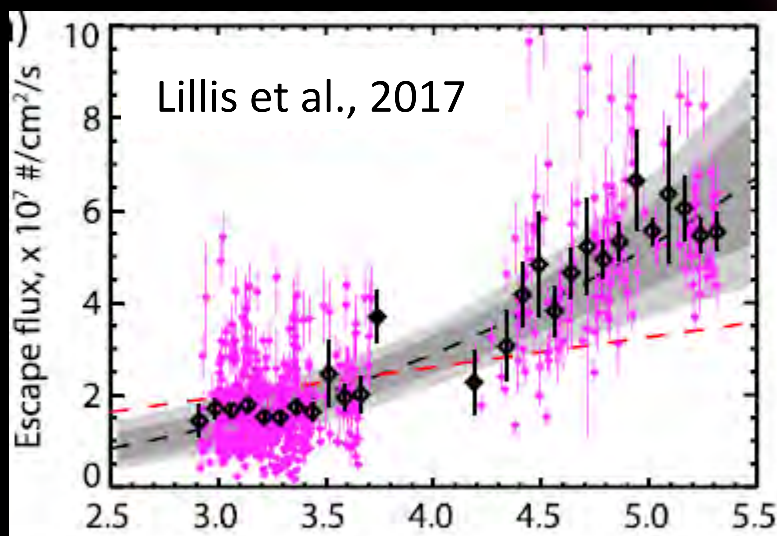


TLDR: full picture is complicated, still working it out!

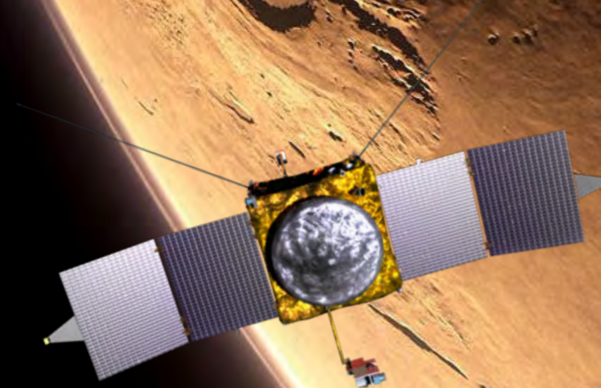
Leaking away for billions of years

- 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.

Oxygen Escape Rate



Solar Extreme Ultraviolet Flux at Mars



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- NASA's MAVEN orbiter has been measuring atmospheric escape from Mars since 2014.
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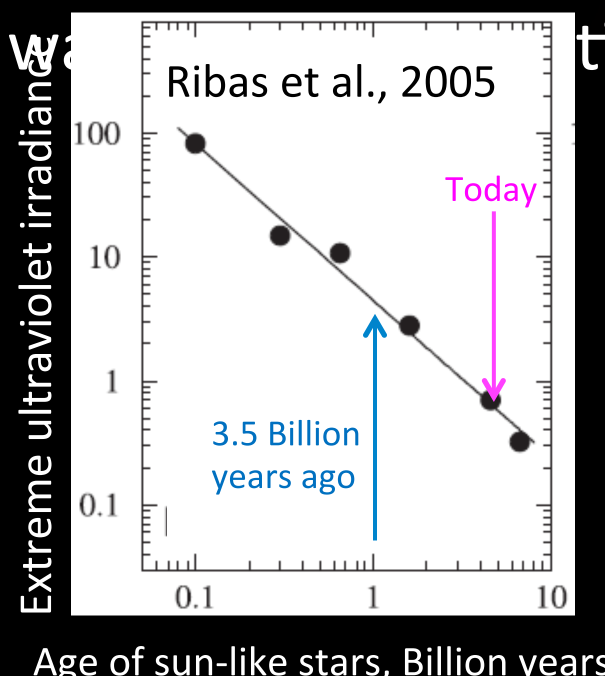
- The early sun wa… …tive than today.



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 CO_2 in the visible surface rocks. What can we do?

Let’s get started

Checklist:

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

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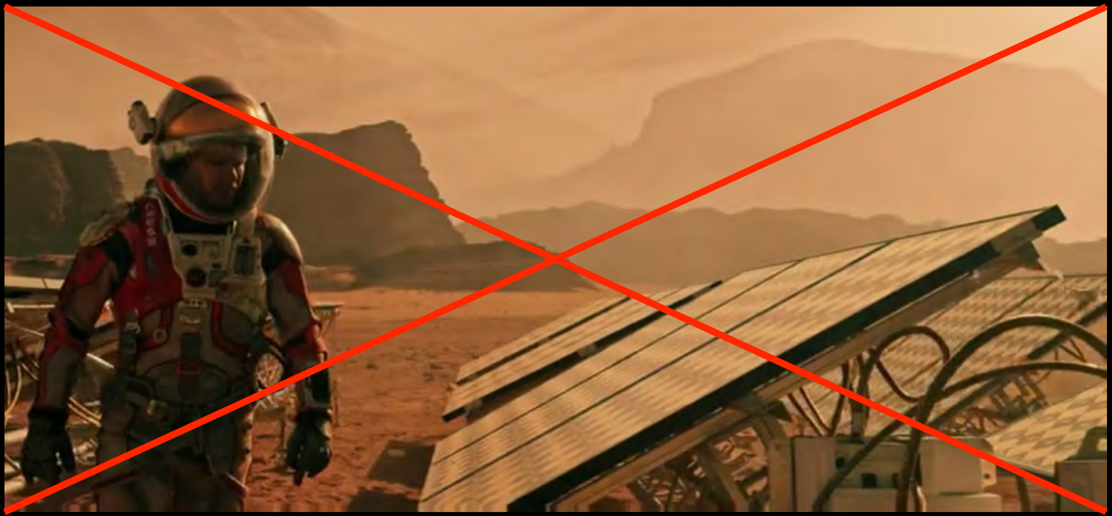

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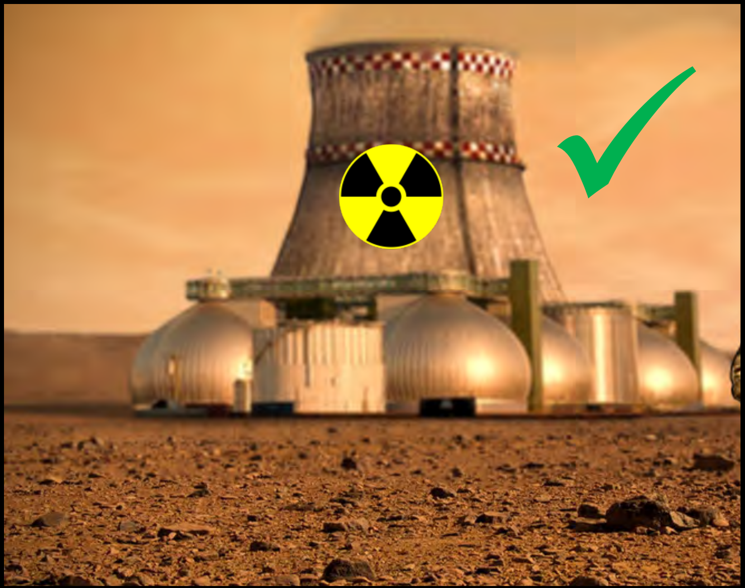

x10000, at least

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

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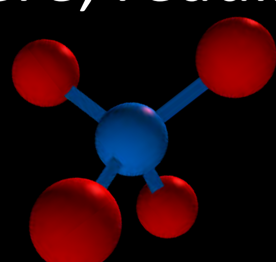
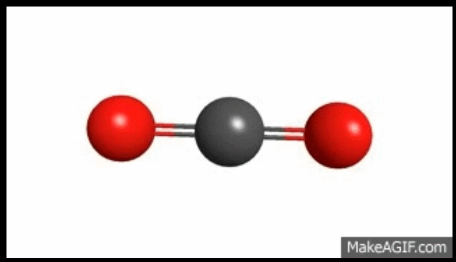
4) Patience. Like, your-great-grandkids-might-just-see-the-start-of-this.
5) A large quantity of the right elements to make an atmosphere, readily available on Mars.

CH_4: methane



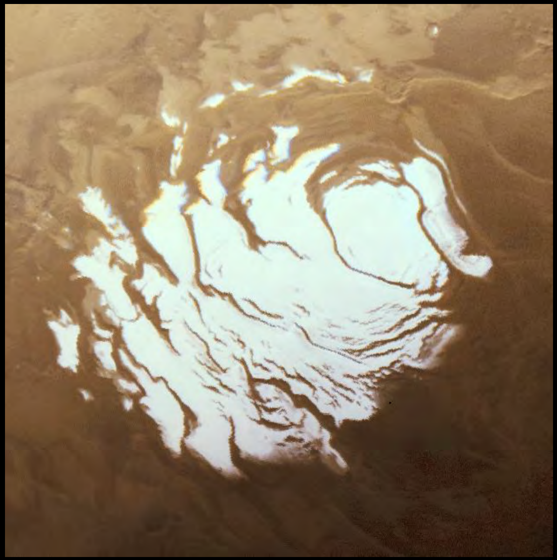
Greenhouse gases



CO_2

Step 1: melt the dry ice

- South Polar CO_2 ice will sublimate into the atmosphere if heated by few 10s of degrees
- **Sublimation** → higher CO_2 pressure → increased greenhouse effect → higher temperature → **sublimation**
- In this way, ~12-14 mbars of CO_2 could be released, tripling the atmospheric pressure.



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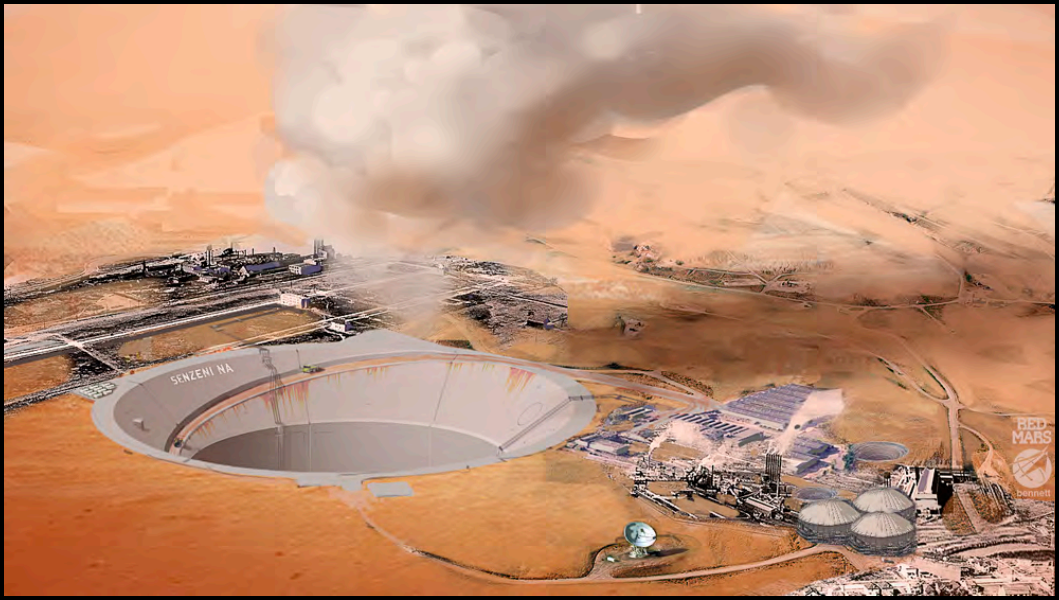
- South Polar CO_2 ice will sublimate into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
  - H-bomb the south pole. Colonists might not like that..

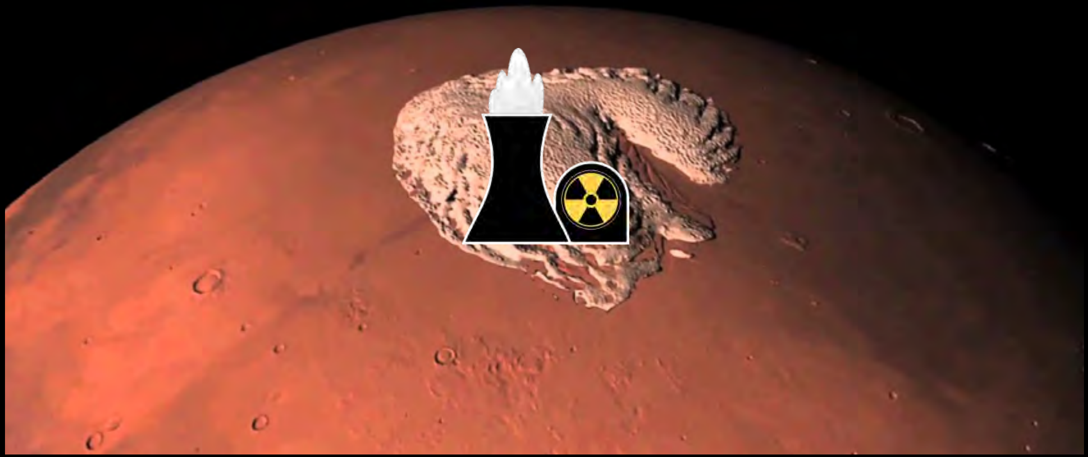
Step 1: melt the dry ice

- South Polar CO_2 ice will sublimate into the atmosphere if heated by few 10s of degrees
- But where would we get the heat?
  - Dig 'moholes'. Reinforced holes 1 km wide x 7 km deep: 300° C at the bottom, release hot air continuously.



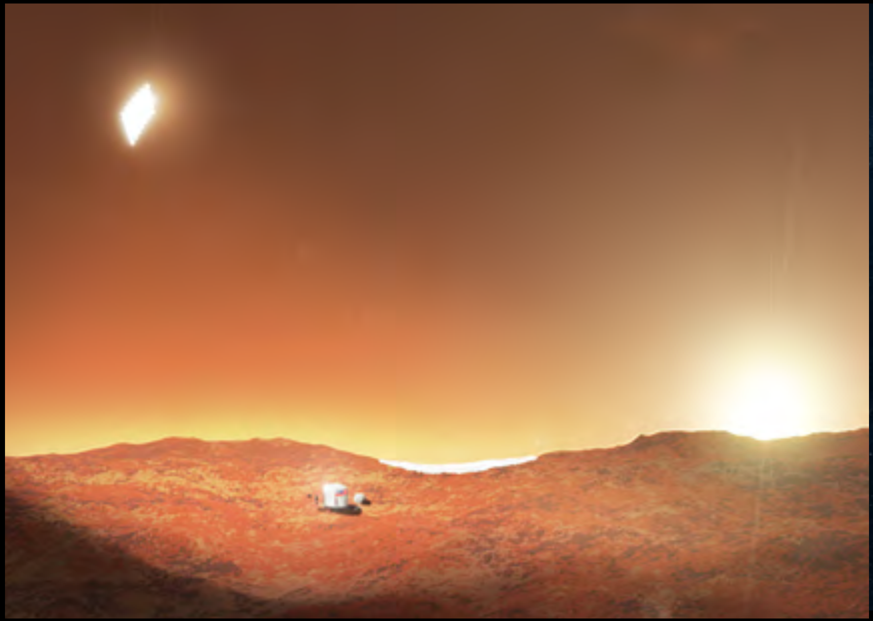
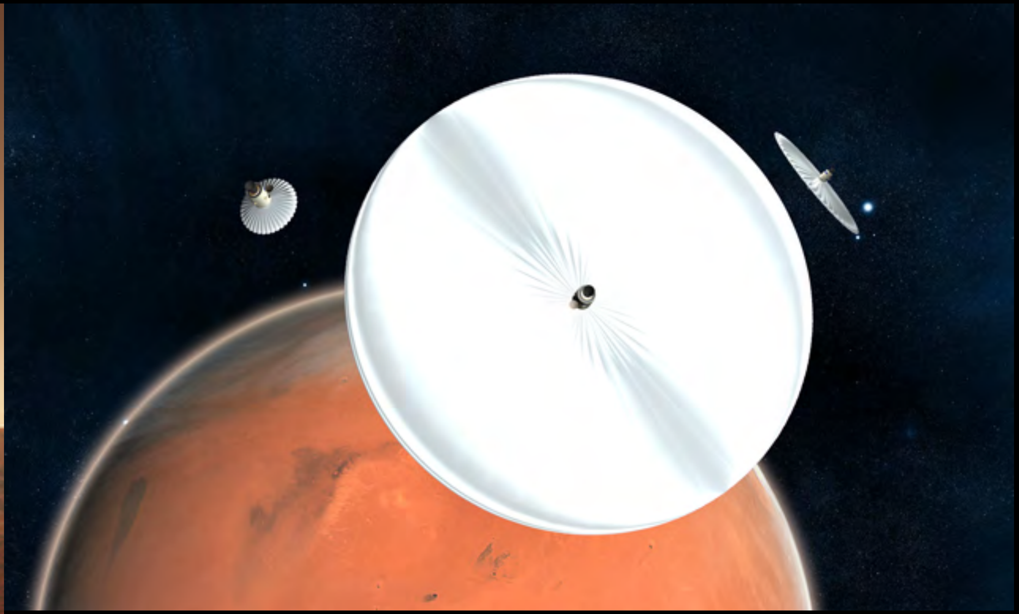
Step 1: melt the dry ice

- South Polar CO_2 ice will sublimate 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 CO_2 ice.



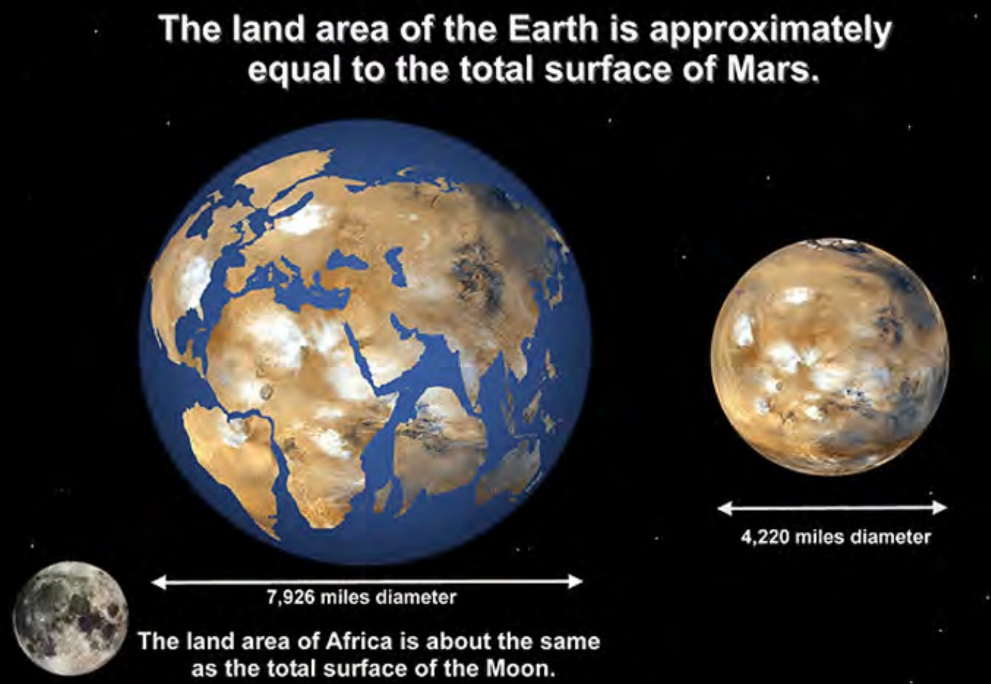
Step 1: melt the dry ice

- South Polar CO_2 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.

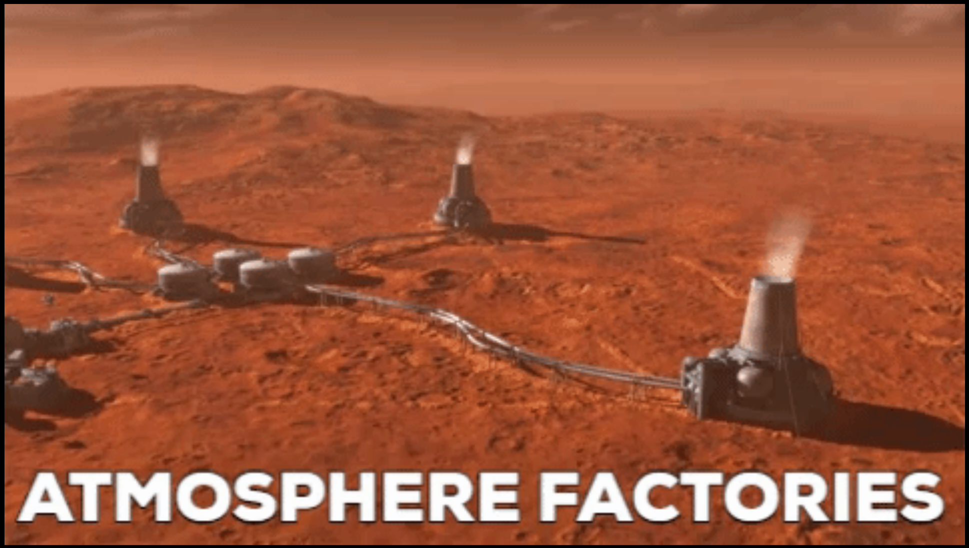


Step 2: Dig Baby Dig

- 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 (10^{18} kg) is a *LOT* of rock to dig up.

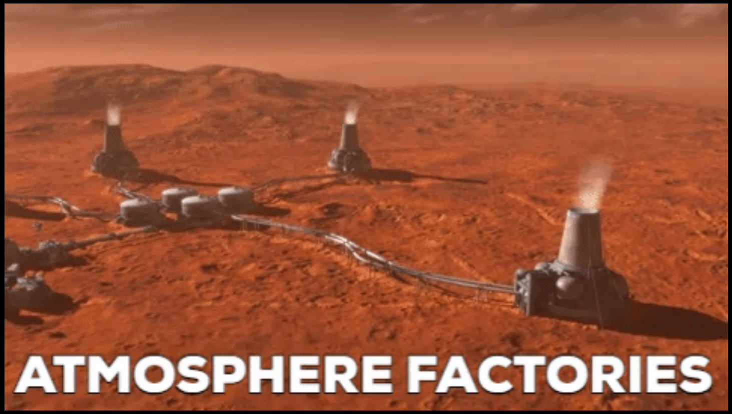
Step 3: make the atmosphere

- CO_2 from the poles (1.5% of what we need) is a start.
  - additional 4% is adsorbed in the regolith, but would need to dig to *100 m planet-wide* to release it. Nah.
- More realistic: liberate O, H, C, N by vaporizing the rocks we dug up and releasing it?



Step 3: make the atmosphere

- ***Vape it***. Vaporizing 1 million billion tons of rock is no big deal, right? Right? Errmm…
- ***Nuke it***: 1 ton of rock takes ~3 gigajoules of energy to vaporize so one big nuclear reactor (1 GW) could vaporize a ton every 3 s or 10 million tons/year.
- ***NBD***: Just need 10,000 nuclear reactors (~equal to Earth's entire electricity output) running for 10,000 years.



Step 3*: but what about comets?

- ***Driving a comet***: turn ice to steam and blast it through a funnel, as a ‘rocket’ to steer them towards Mars.
- ***Great balls of ice***. Comets weigh 1 - 100 billion tons, so we need to crash 10,000-1 million of ‘em into Mars.
- ***Robots to the rescue***: too many for humans. Need autonomous in-space assembly and navigation to drive comets.

Note: most comets are in very long, far, slow orbits, so this is gonna take centuries

Step 3: make the atmosphere

Main Gas:

- CO_2 : effective greenhouse gas to get things going, but prob no more than ~50 mbar available.
  - Its greenhouse advantages diminish 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.

Step 4: it's getting hot in here

Mars is farther from the sun:

- Need a 70°C greenhouse effect.
- CO_2 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%
- 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)
   - Steering comets (yeah this’ll be easy)
   - automated industrial production and mining
   - geo-engineering

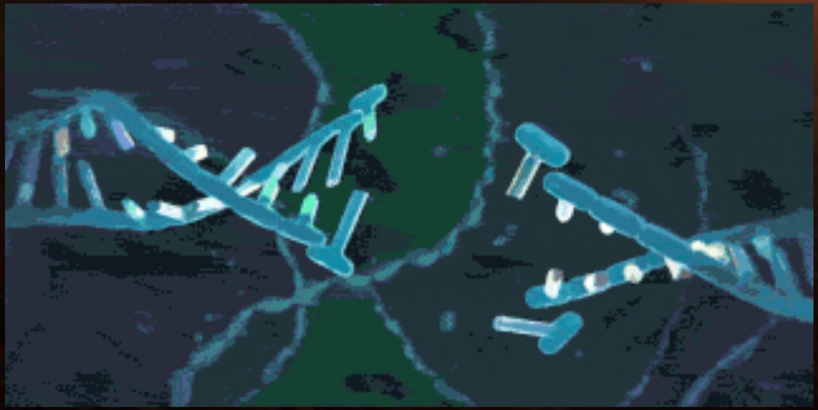
What’s a thousand years between friends?

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

Credit: SpaceX

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

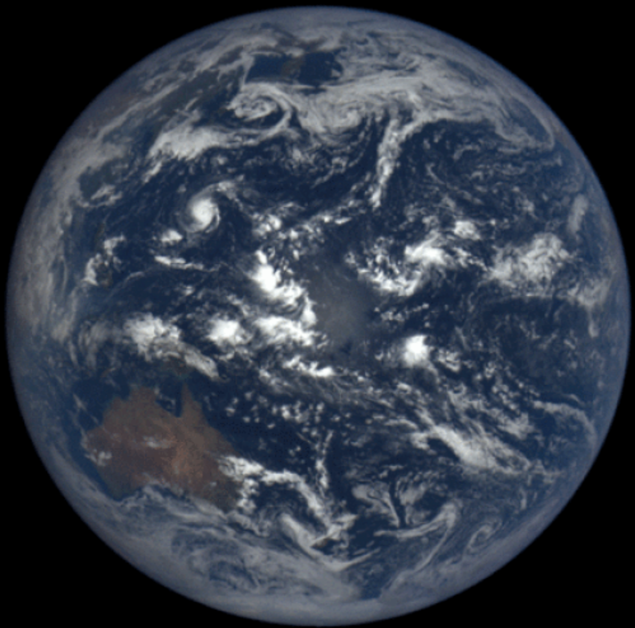
- With colossal amounts of cumulative will, money, time and technology advancement, I believe we can make Mars habitable for humans.
- The unknowns (known and unknown) make the timeline somewhere from “many hundreds of years” to “maybe never”.
- Watch this space. Have your children, grandchildren, distant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


THANK YOU

Why Mars?

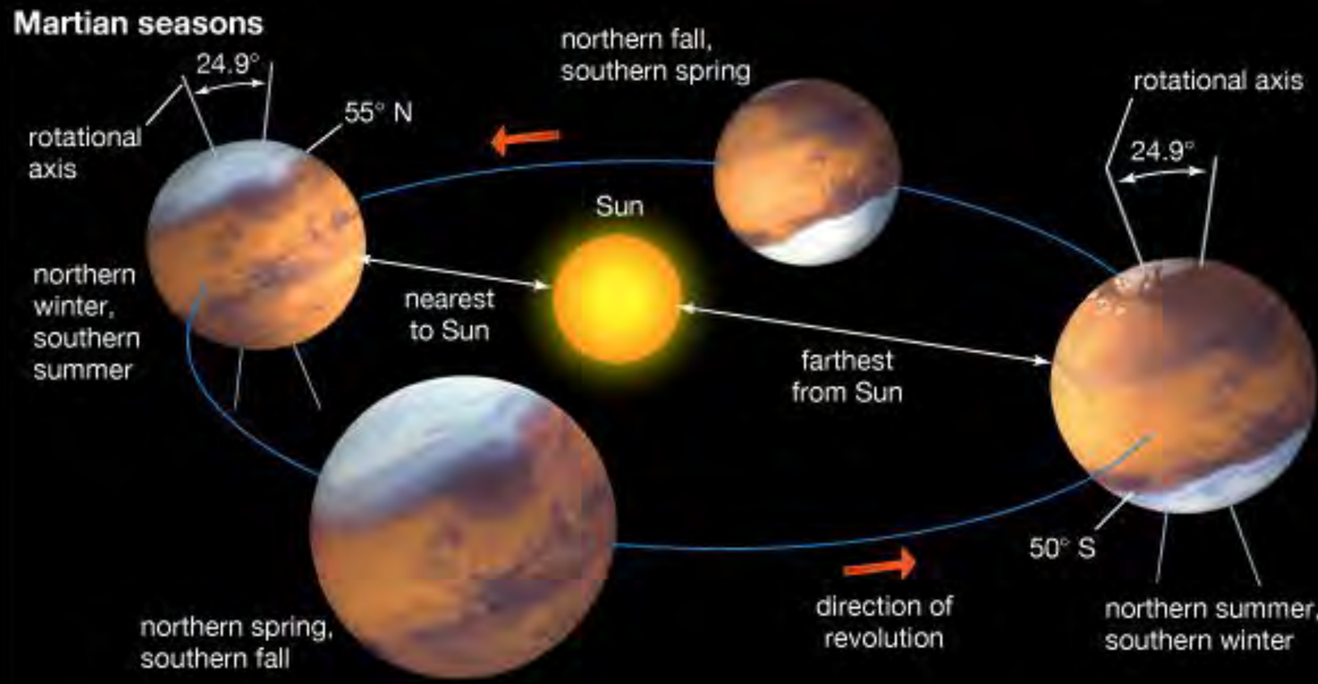
- Length of day: 24.6 hours (won't drive you crazy)
- Seasons! 25° orbital tilt.
- Lots of water (subsurface and polar caps)
- Comfortable gravity, 38% of Earth.

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.