

# Mars: Once A Habitable World?

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*Artist's conception  
by Mike Carroll*

Nick Schneider

Dept. of Astrophysical & Planetary Sciences (APS)

Laboratory for Atmospheric & Space Physics (LASP)

Instrument Lead for MAVEN's Imaging UV Spectrograph

# Mars: Once a Habitable Planet?

- What makes planets habitable?
- What's the evidence for Mars' past habitability?
- What made Mars habitable? What changed, and how?

# Discussion: What are the requirements for a Habitable Planet?

- Energy source
- Chemicals (nutrients)
- Liquid water

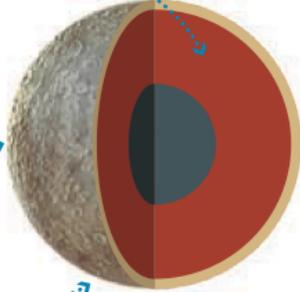
# The Role of Planetary Size

## Small Terrestrial Planets

*Interior cools rapidly...*

*...so that tectonic and volcanic activity cease after a billion years or so. Many ancient craters therefore remain.*

*Lack of volcanism means little outgassing, and low gravity allows gas to escape more easily; no atmosphere means no erosion.*



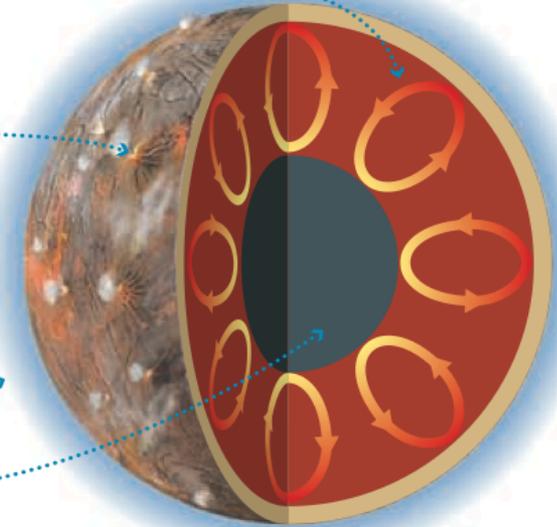
## Large Terrestrial Planets

*Warm interior causes mantle convection...*

*...leading to ongoing tectonic and volcanic activity; most ancient craters have been erased.*

*Outgassing produces an atmosphere and strong gravity holds it, so that erosion is possible.*

*Core may be molten, producing a magnetic field if rotation is fast enough.*

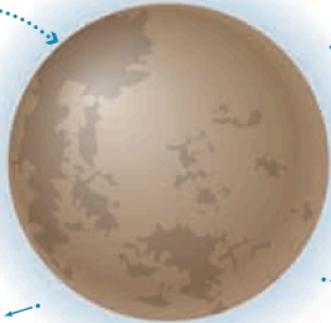


- Smaller worlds cool off faster and “harden” earlier
- Larger worlds stay warmer inside, leading to more volcanism and tectonics
- Larger worlds CAN have more erosion because they can create and hold an atmosphere

## The Role of Distance from the Sun

### Planets Close to the Sun

*Surface is too hot for rain, snow, or ice, so little erosion occurs.*



*High atmospheric temperature allows gas to escape more easily.*

### Planets at Intermediate Distances from the Sun

*Moderate surface temperatures can allow for oceans, rain, snow, and ice, leading to substantial erosion.*



*Gravity can more easily hold atmospheric gases.*

### Planets Far from the Sun

*Low surface temperatures can allow for ice and snow, but not rain or oceans, limiting erosion.*



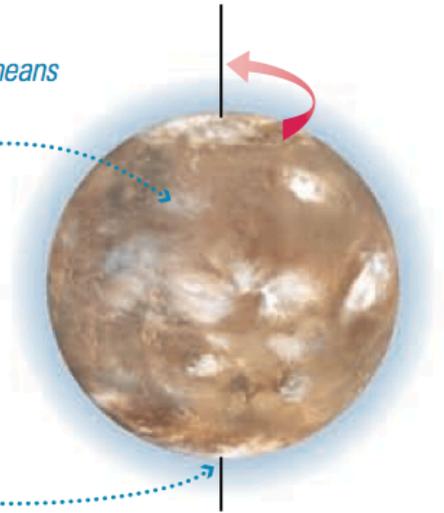
*Atmosphere may exist, but gases can more easily condense to make surface ice.*

- Planets closer to the Sun are too hot for rain, snow or ice, so have little erosion
- Close planets are hotter, so they don't retain their atmospheres as well
- Planets far from the sun are too cold for rain, limiting erosion
- Planets with liquid water have the most erosion

## The Role of Planetary Rotation

Slow Rotation

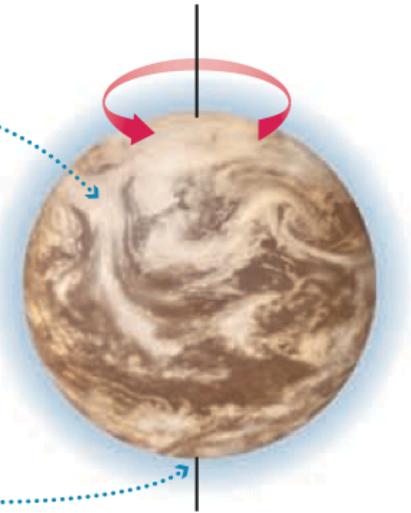
*Less wind and weather means less erosion, even with a substantial atmosphere.*



*Slow rotation means weak magnetic field, even with a molten core.*

Rapid Rotation

*More wind and weather means more erosion.*

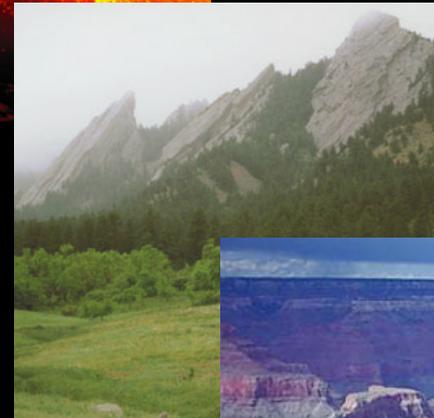


*Rapid rotation is necessary for a global magnetic field.*

- Planets with slow rotation have less weather and less erosion, and (we think) weaker magnetic fields
- Planets with fast rotation CAN have more weather and more erosion, and stronger magnetic fields

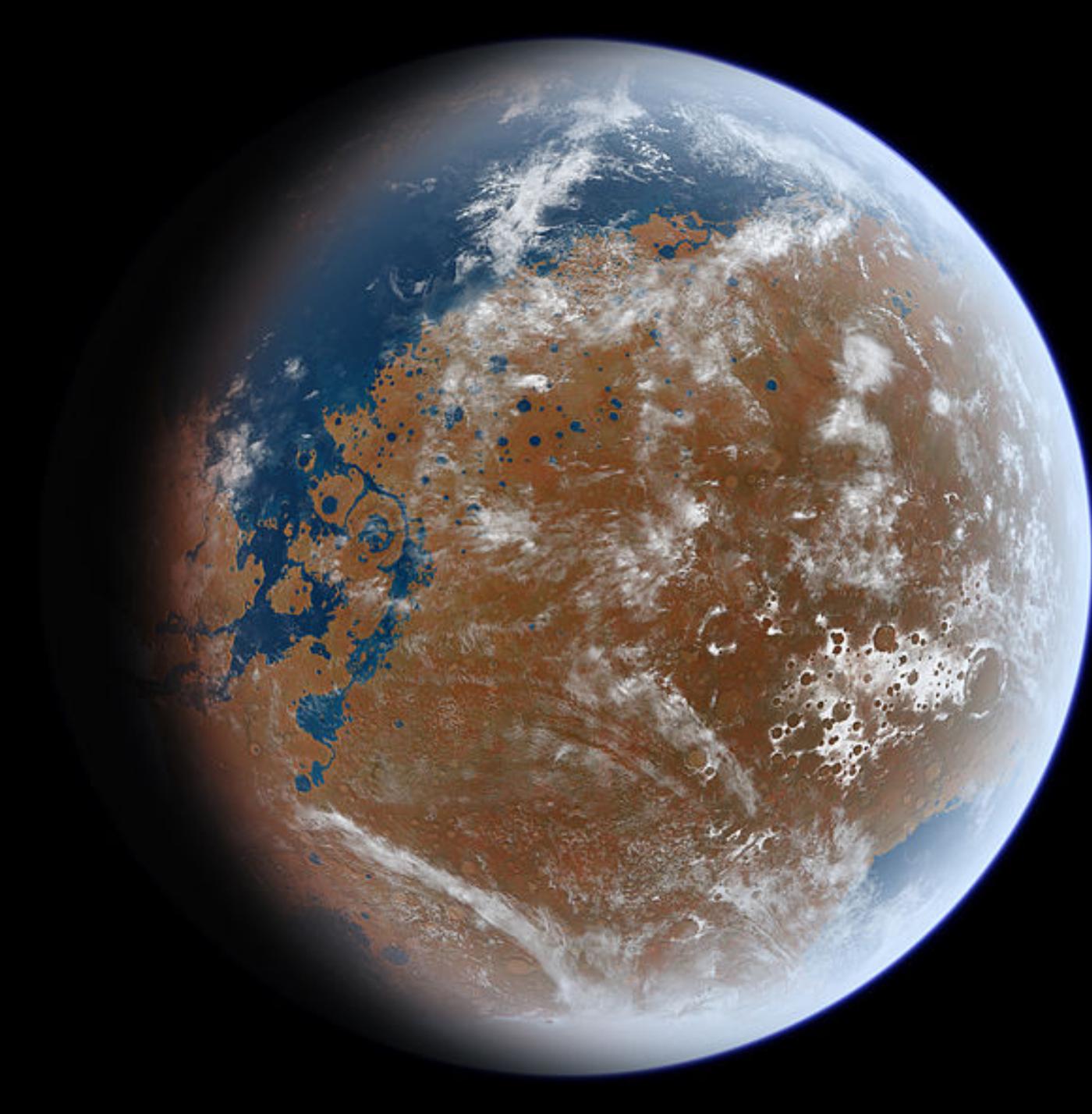
# Decoding Planetary Images: The Four Basic Geological Processes

- Impact cratering
- Volcanism
- Tectonics
- Erosion



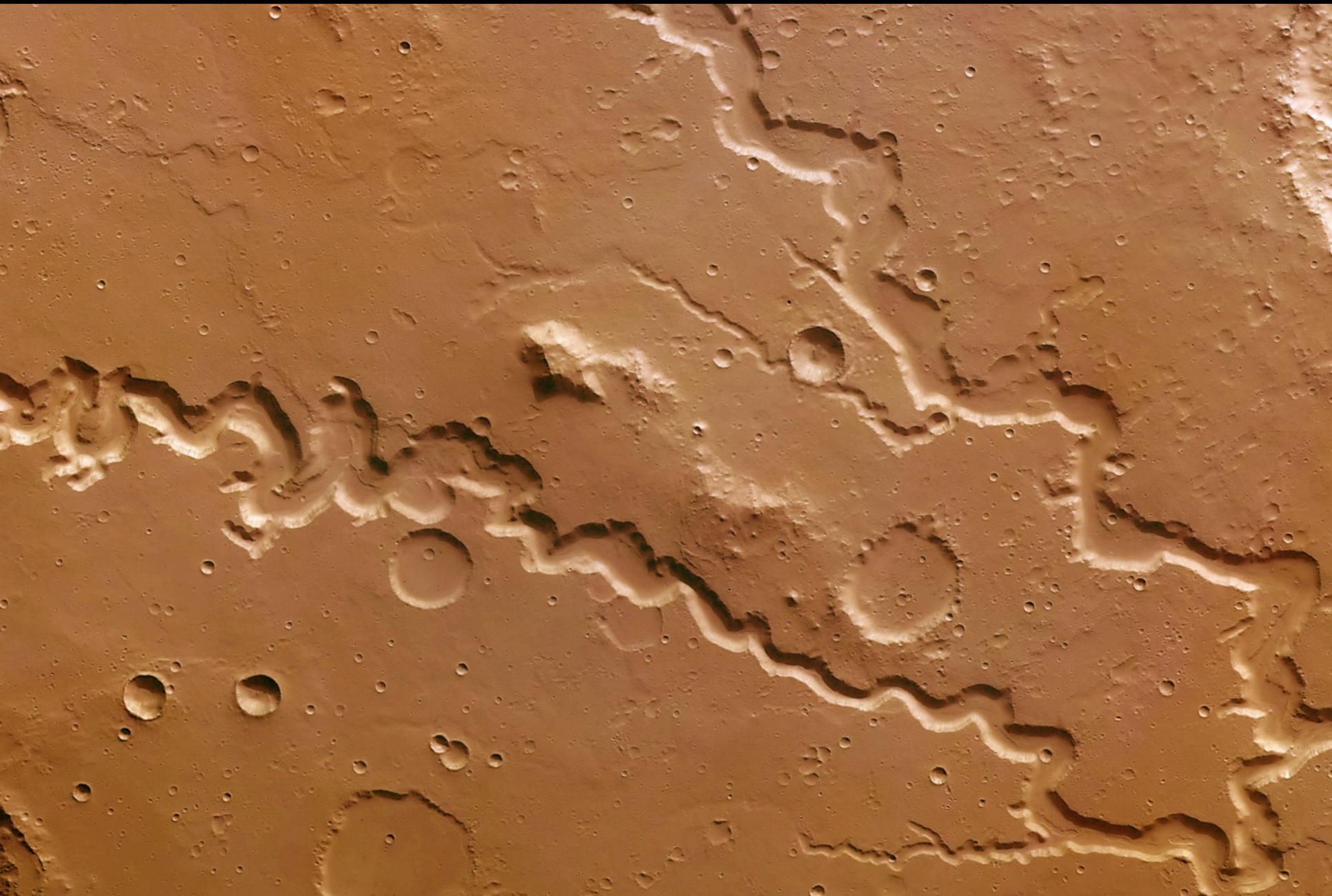
# Mars Today

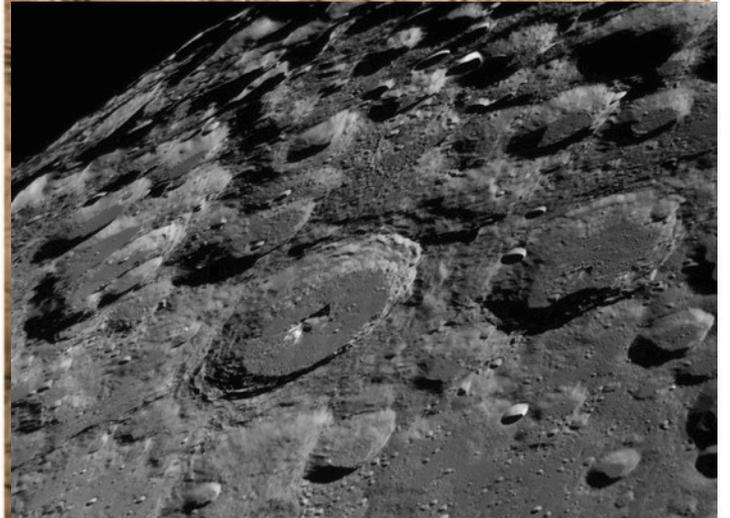
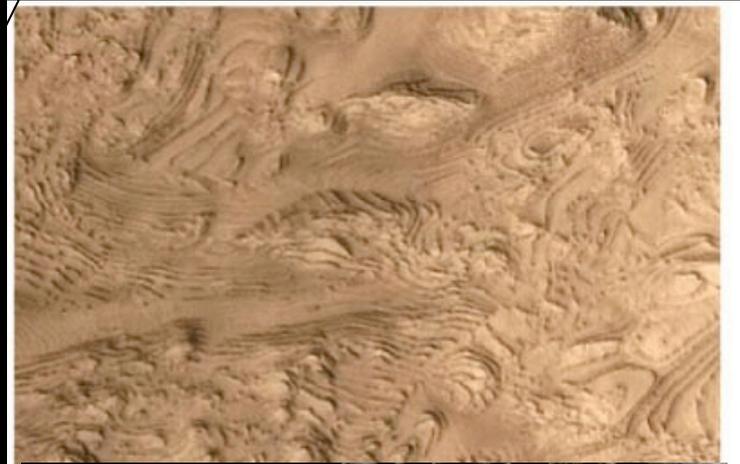
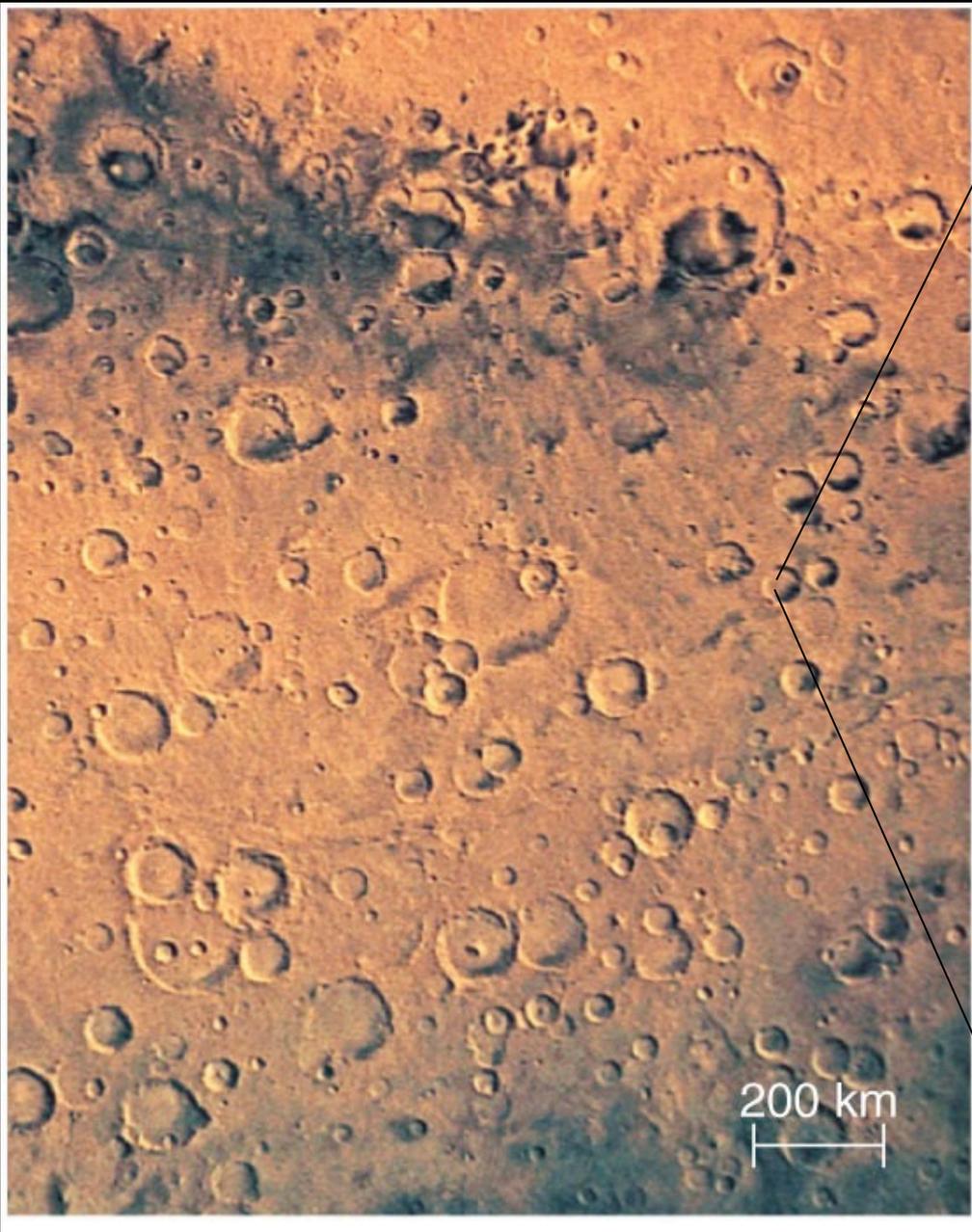




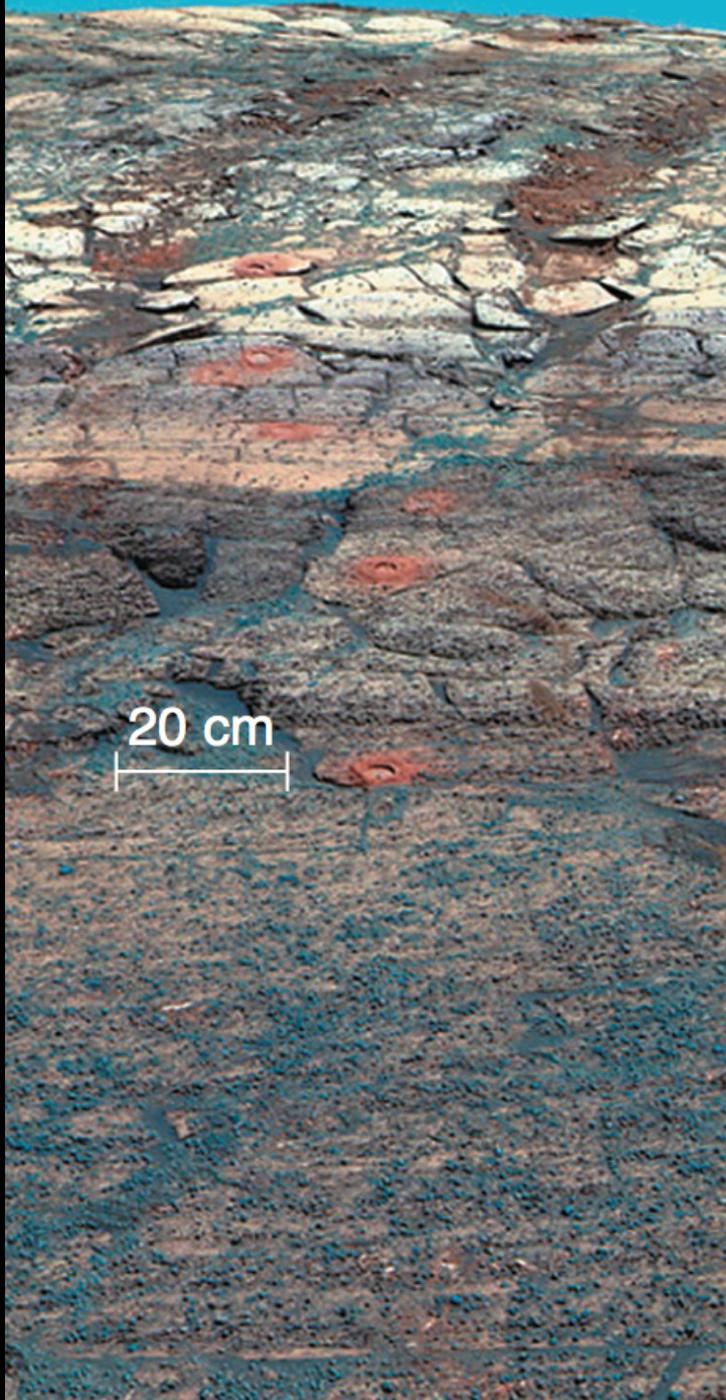
# A Different Mars











What do rocks tell us about habitability?

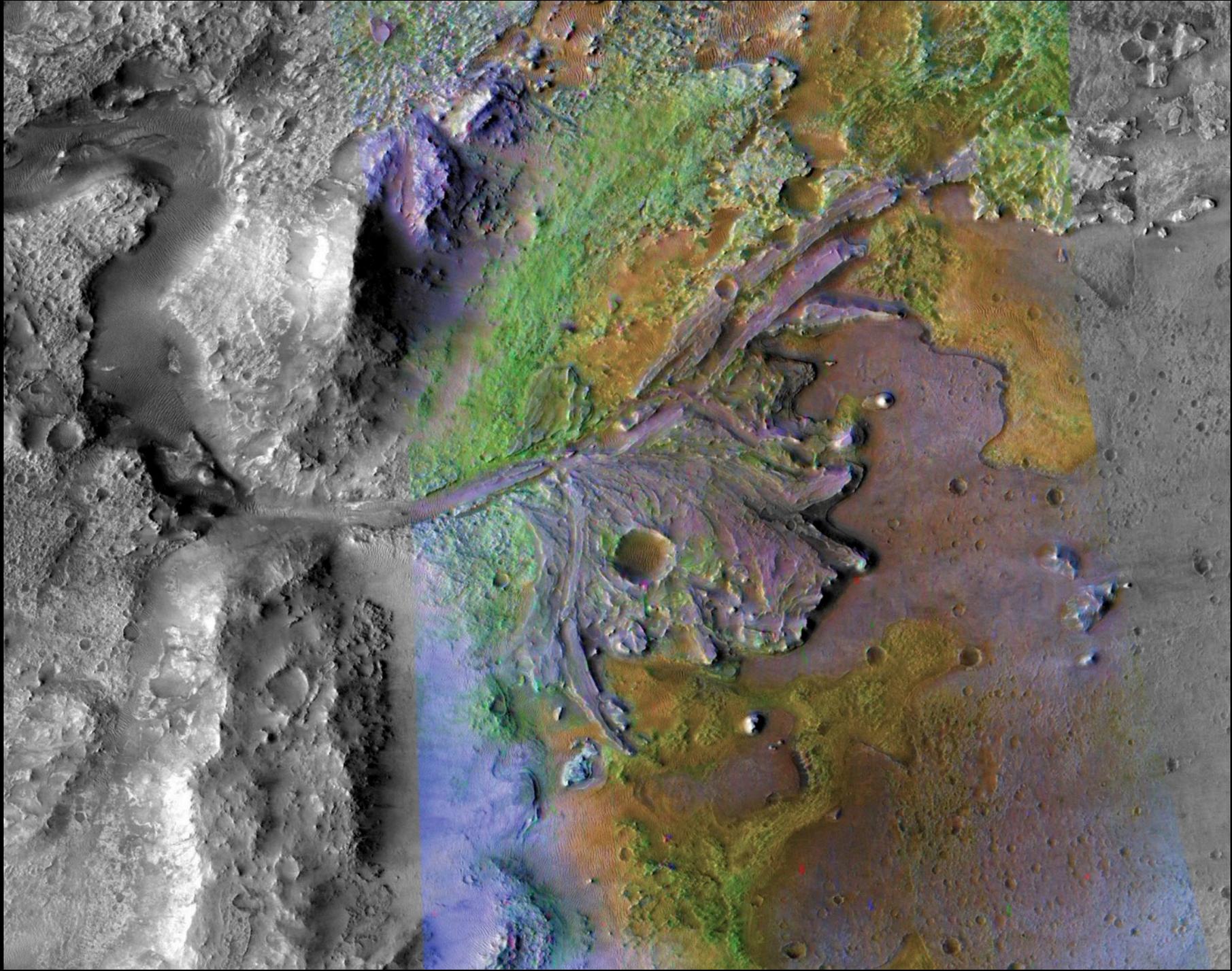


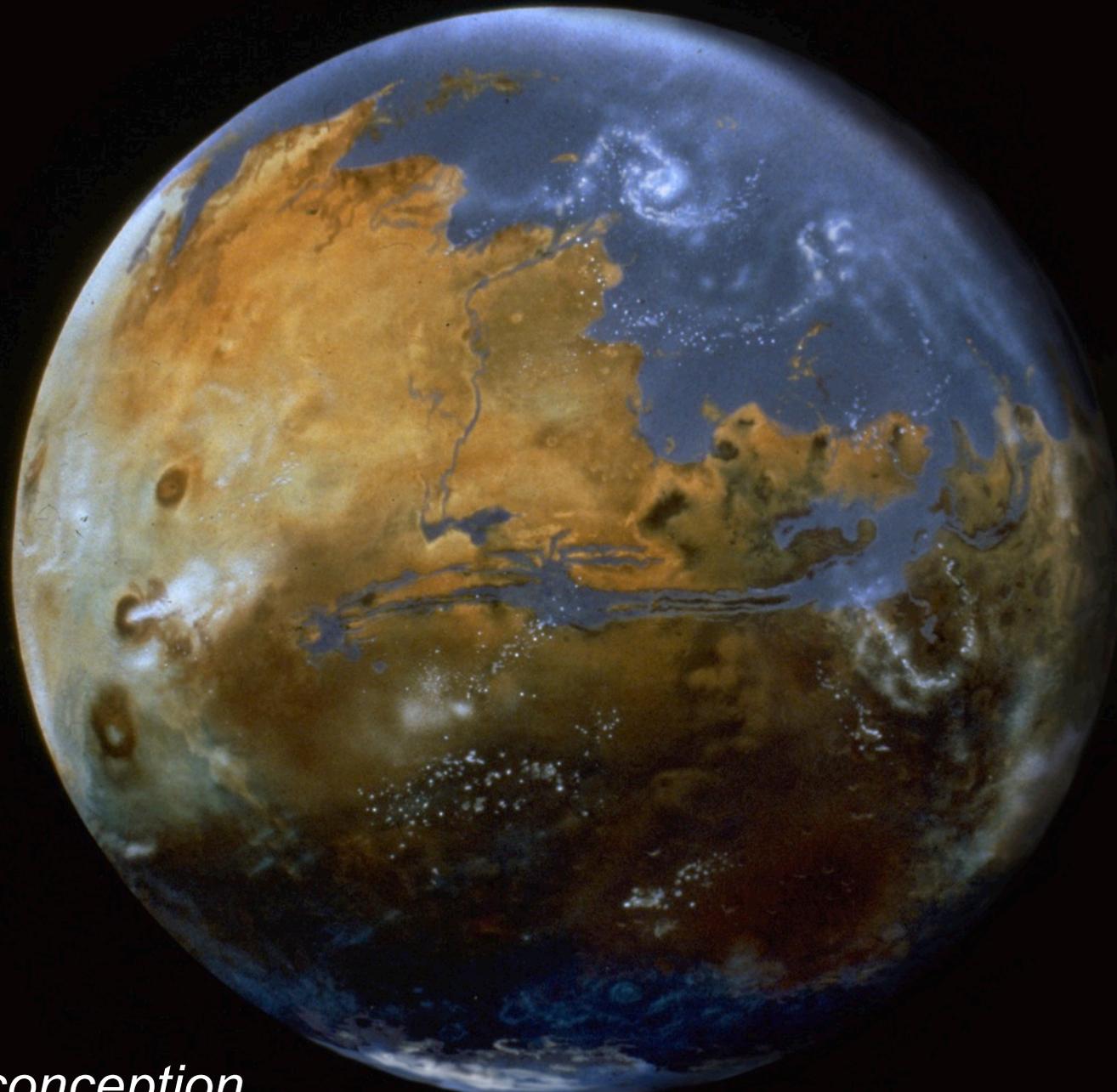






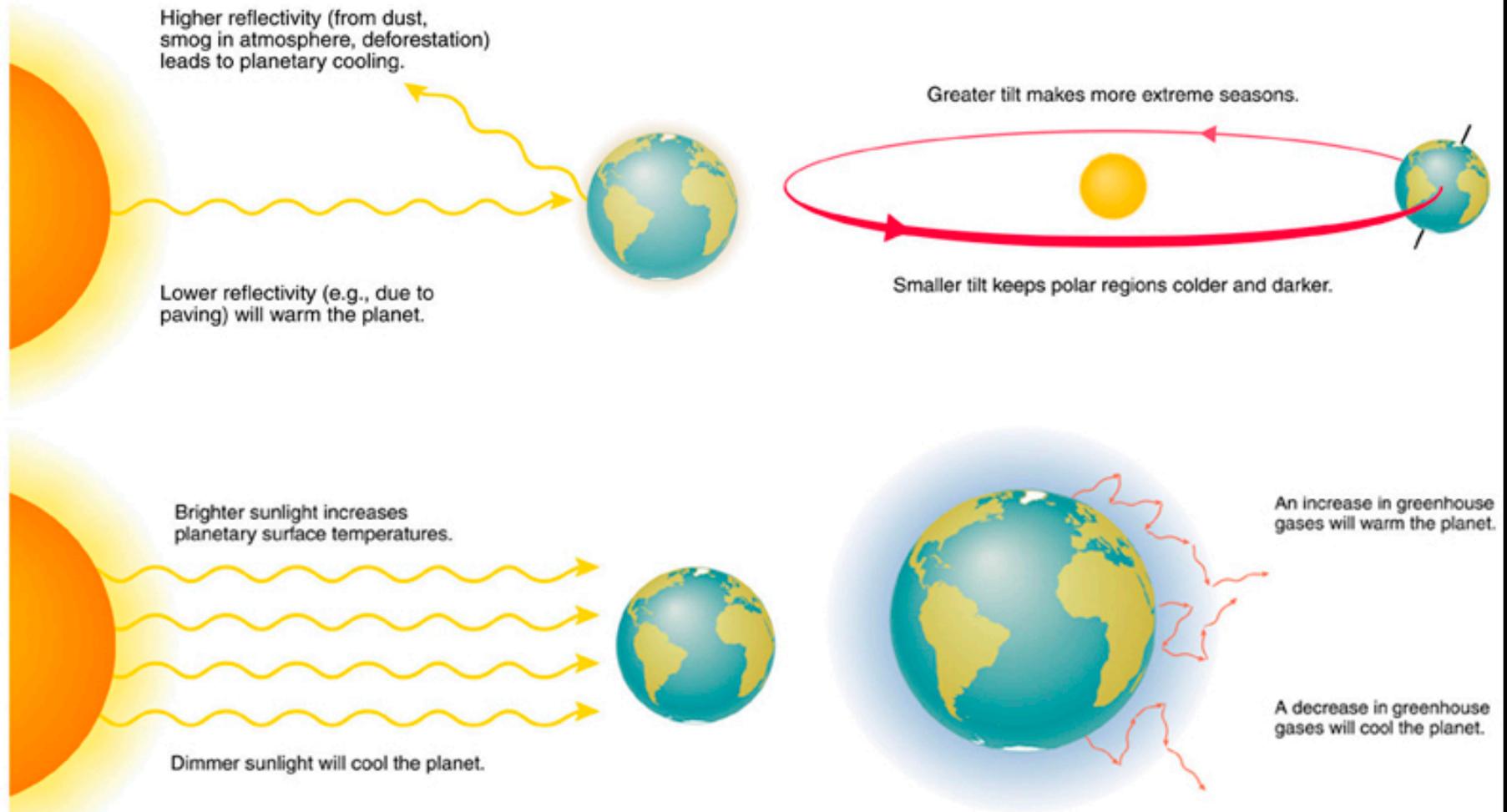






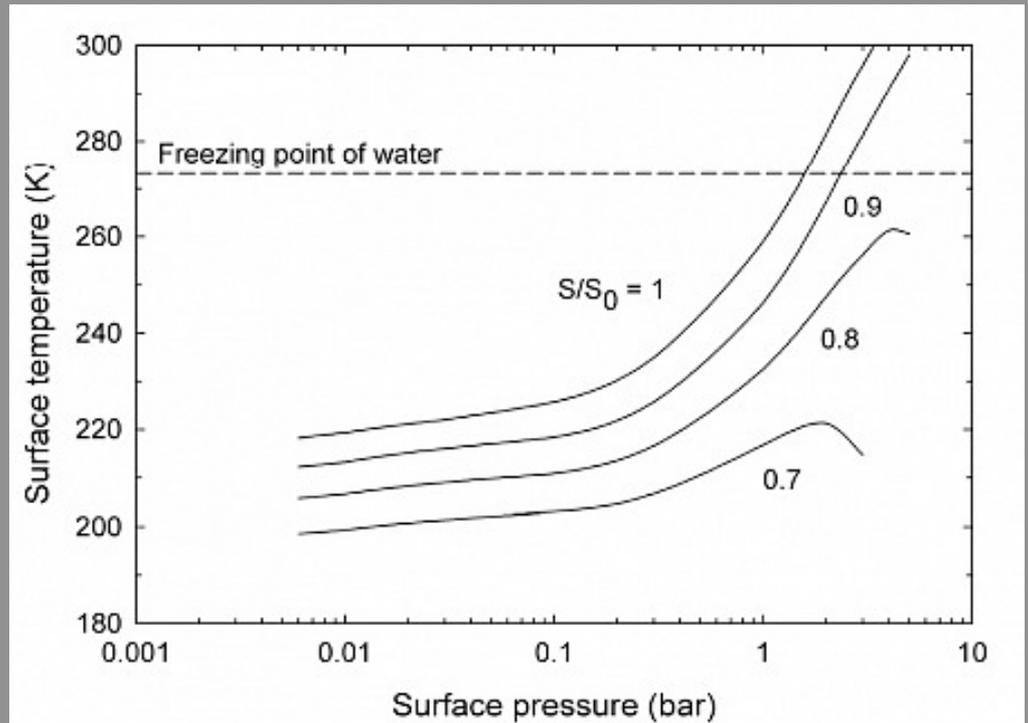
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# Four Major Factors which affect Long-term Climate Change



# What could have sustained an early wetter environment?

- Greenhouse warming required to raise temperature from current ambient surface temperature average of  $\sim 220\text{K}$ .
  - Degree of greenhouse warming required unclear, since ambient temperature during warmer epoch is uncertain.
- Problem exacerbated by faint young Sun problem
  - Sun  $\sim 30\%$  dimmer in total output 4 b.y. ago.
- Possible greenhouse agents
  - $\text{CO}_2$  and  $\text{H}_2\text{O}$ ?
  - $\text{CH}_4$ ,  $\text{NH}_3$ ?
  - Organic haze protectant?



If Mars had a thick atmosphere, where is it now?  
If Mars had an ocean, where is all the water now?



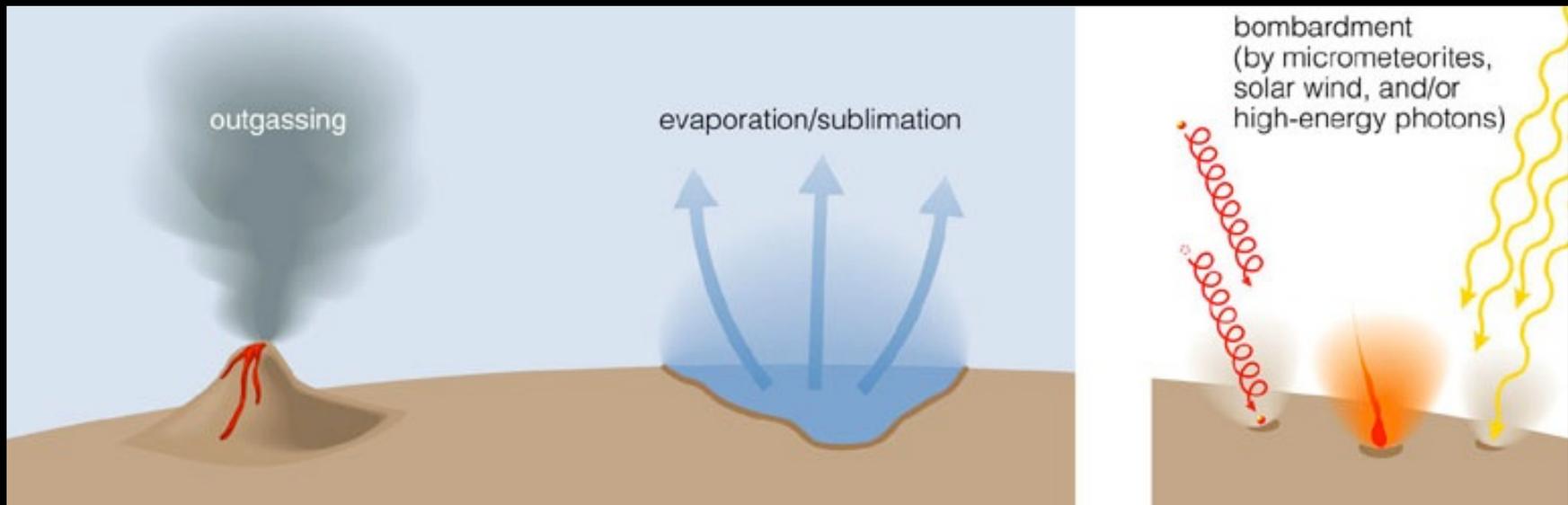
- Frozen at the poles?
  - Not enough!
- Locked underground?
  - Not *nearly* enough!

What other possibilities  
are left?

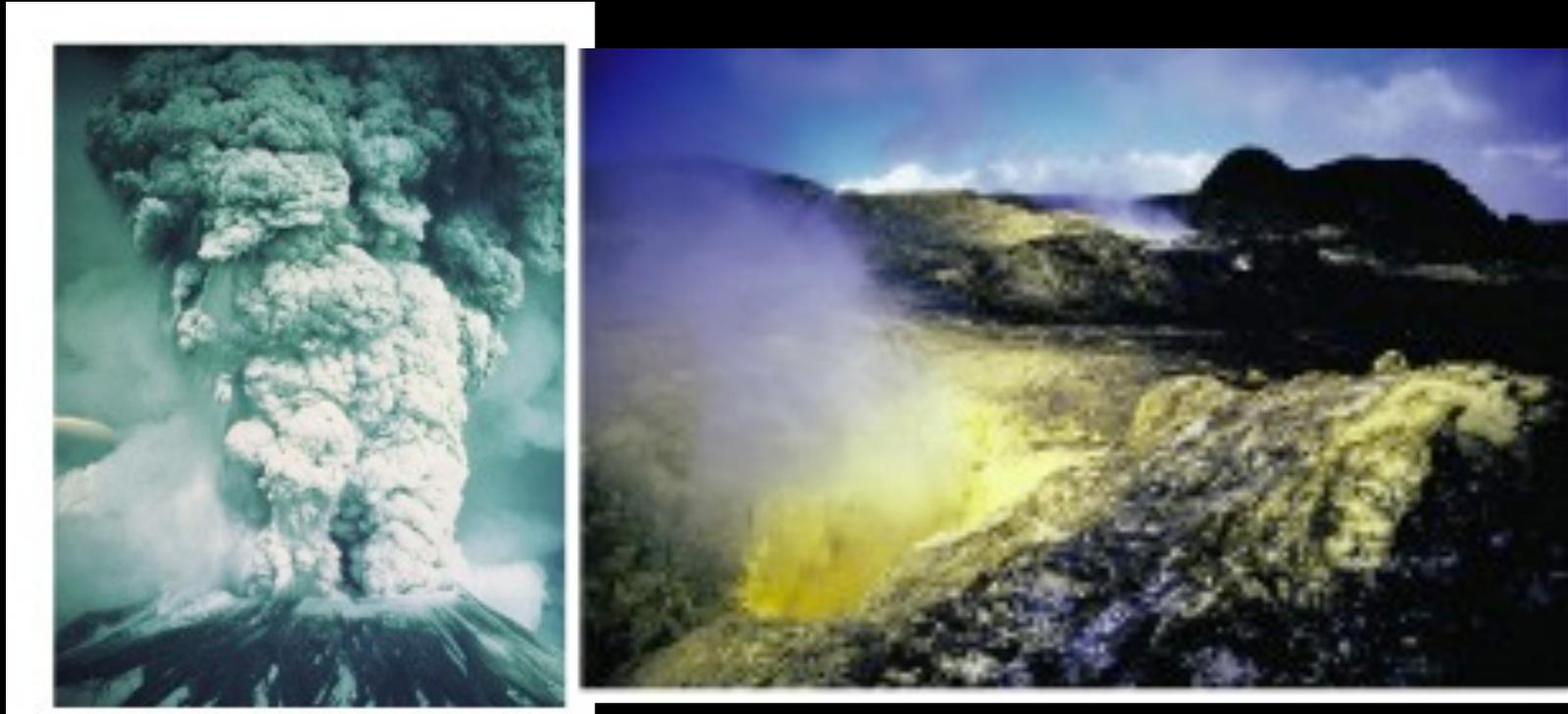
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### 3 Sources of Atmospheric Gas

- TP' s too small to capture much gas from the Solar nebula.
- Sources of atmospheric gas:
  - **outgassing** – release of gas trapped in interior rock by volcanism
  - **evaporation/sublimation** –liquids or ices turn to gas when heated
  - **bombardment** or “surface ejection” – micrometeorites, Solar wind, or high-energy photons blast atoms/molecules out of surface rock
    - occurs only if the planet has no substantial atmosphere already



# Volcanism: More than making mountains....



- Volcanism also releases gases from Earth's interior into atmosphere
- Outgassing: *The origin of TP atmospheres!*

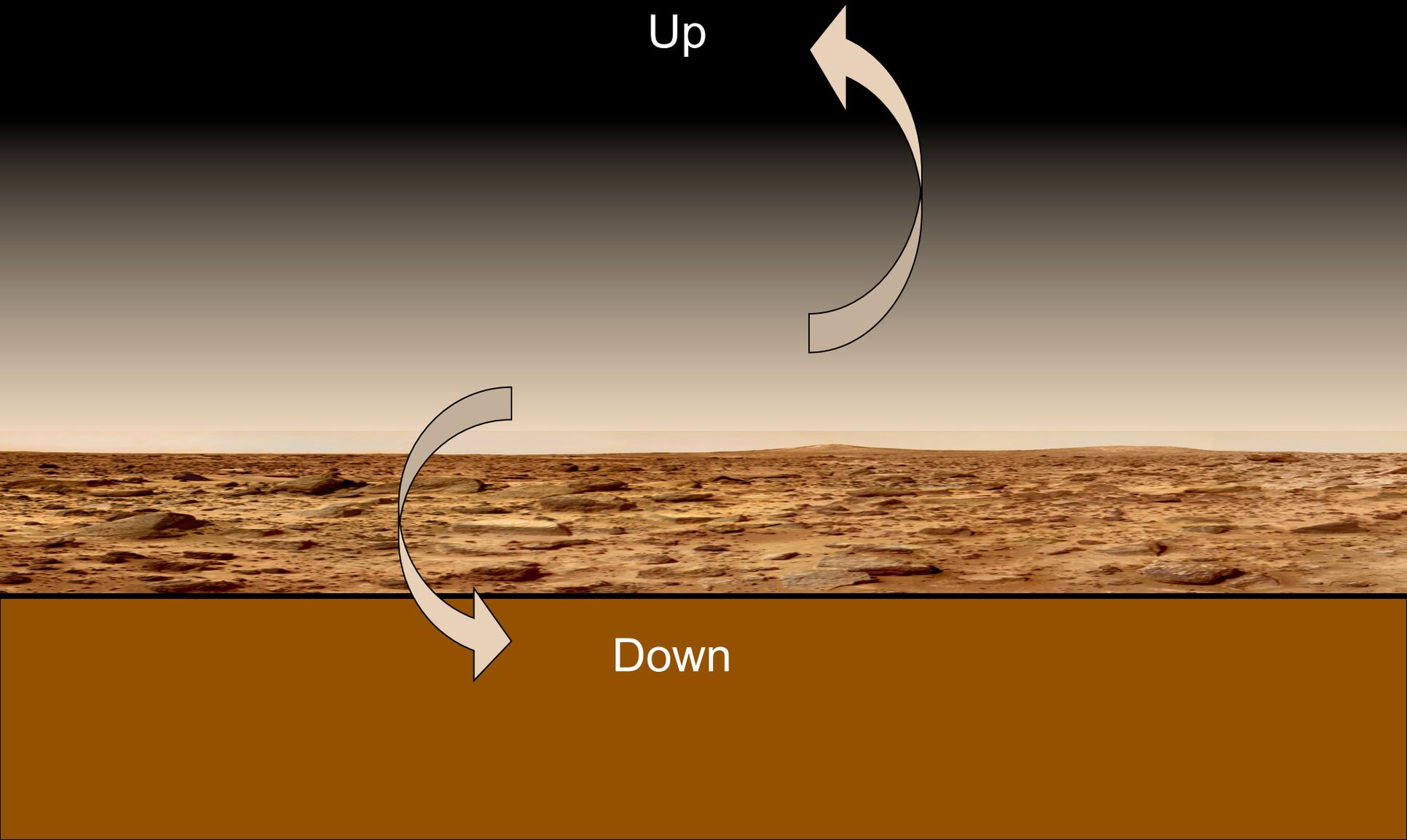
# Outgassing

Important for large terrestrial planets' s (warm interior --> volcanoes)

Outgassing releases:

1. Lots of  $H_2O$ ,
2. Some  $CO_2$ ,
3. A little  $N_2$ ,
4. A hint of sulfur-bearing gases

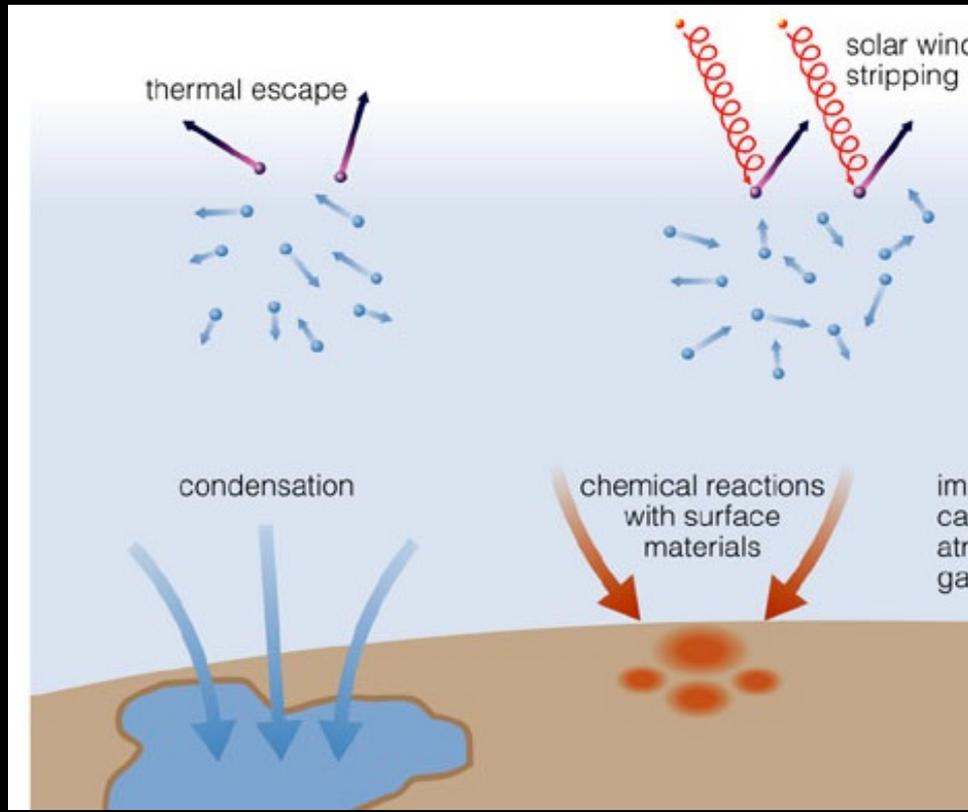
# Where Did the Atmosphere Go?

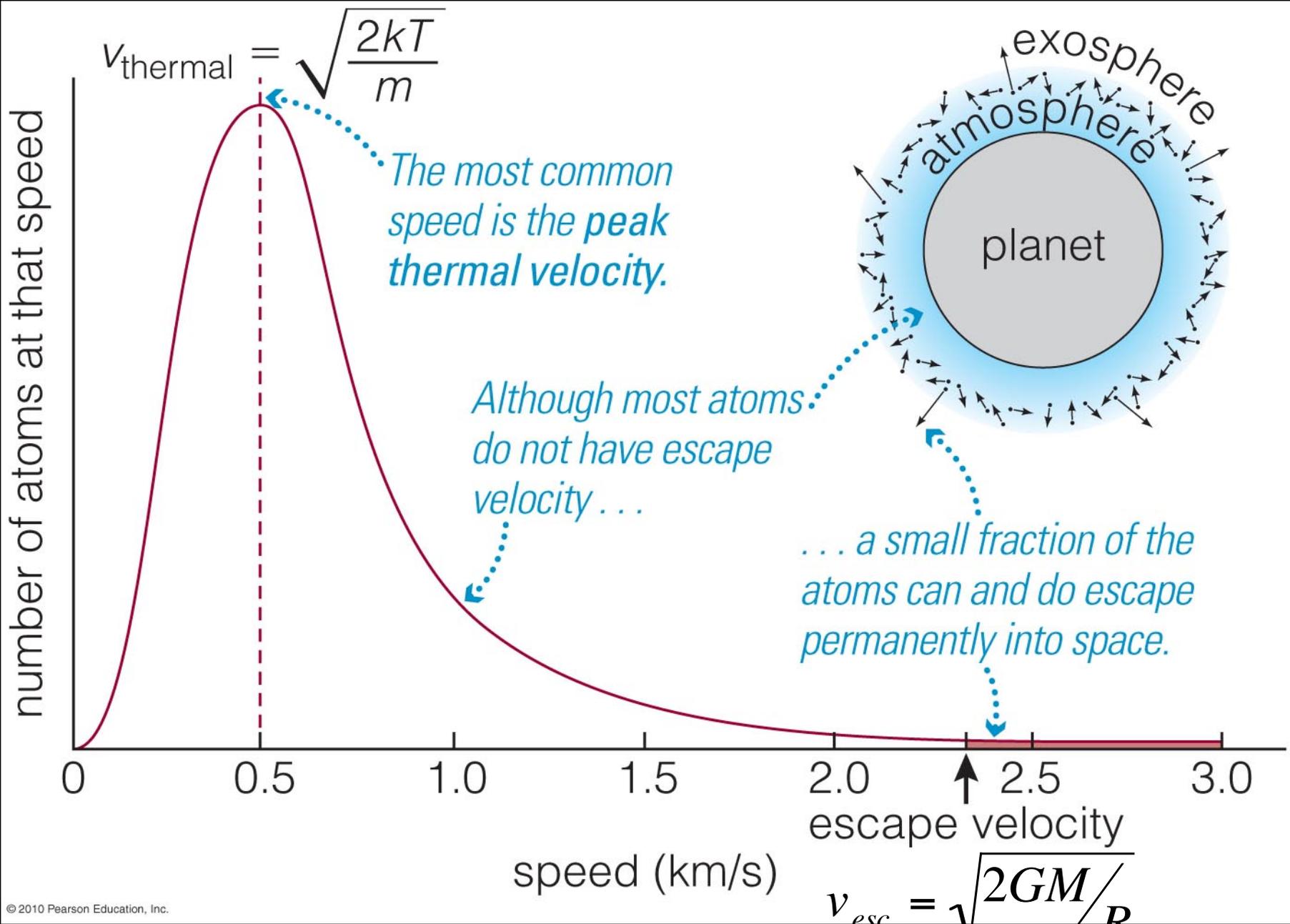


# Loss Processes of Atmospheric Gas

## 4 Ways to lose atmospheric gas:

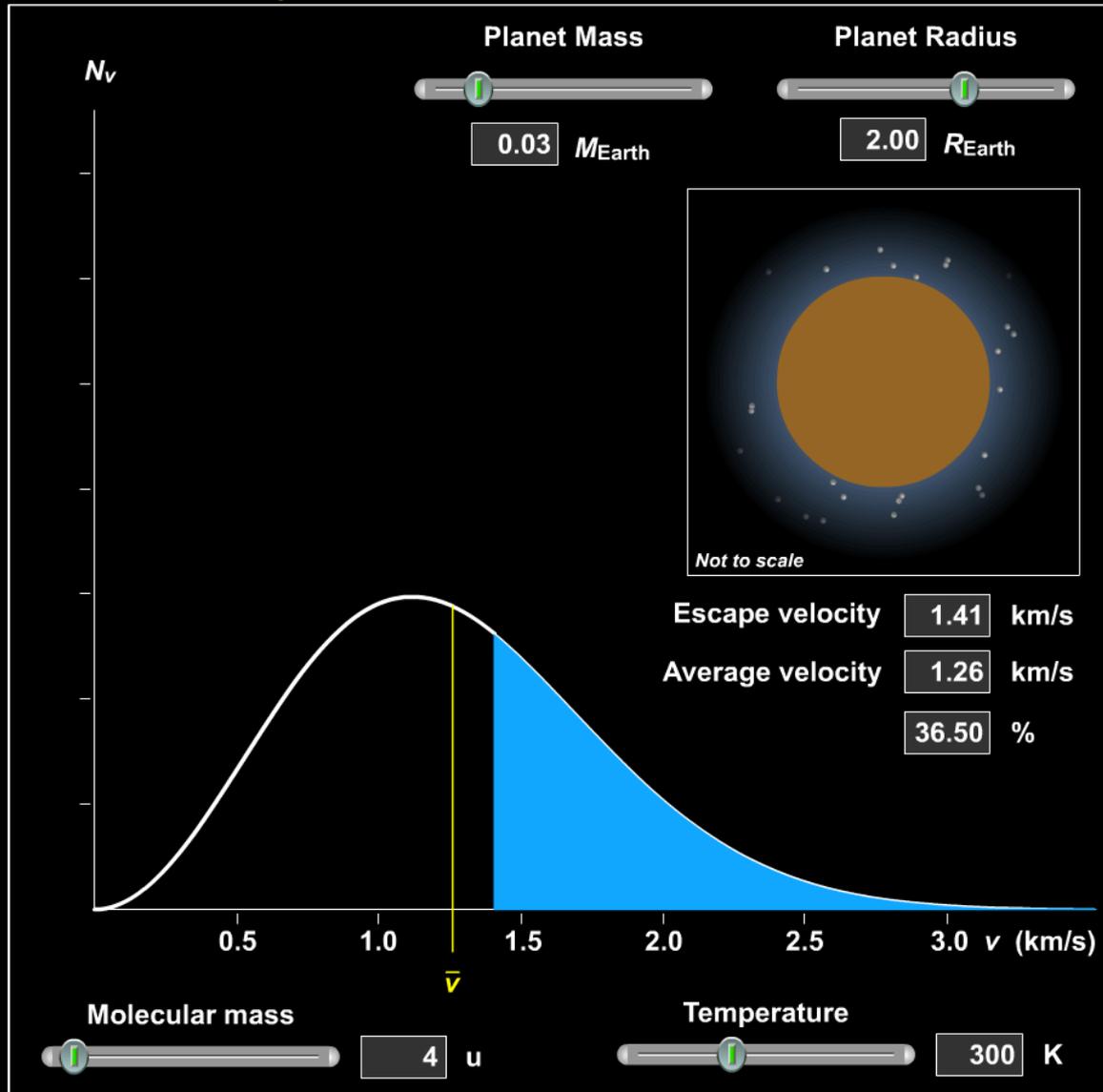
- **condensation** – gas turns into liquids/ices on the surface when cooled
- **chemical reactions** – gas is bound into surface rocks or liquids
- **SW stripping** – gas knocked out of the exosphere by Solar wind
- **thermal escape** – lightweight atoms lost to space when they achieve escape velocity





# Thermal Escape Applet – Building Intuition

## Retention of Atmosphere about a Planet

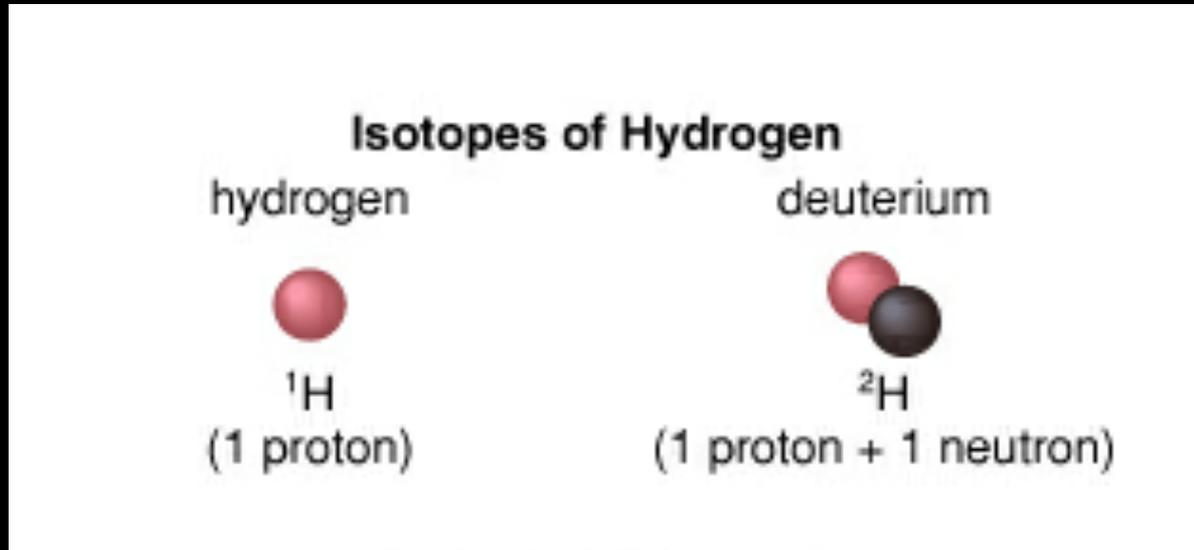


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# Thermal Escape

Easiest for:

- Small worlds
- Hot worlds
- Light gases



## Early Mars

Warmer core generated stronger magnetic field.

Warmer interior caused extensive volcanism and outgassing.

Stronger magnetosphere protected atmosphere from solar wind.

Thicker atmosphere created warmer and possibly wetter climate.

## Mars Today

Lack of core convection means no global magnetic field.

Cooler interior no longer drives extensive volcanism or outgassing.

Some remaining gases condense or react with surface.

Weaker magnetosphere has allowed solar wind to strip away much of the atmosphere.

Thinner atmosphere reduces greenhouse warming.

# The End of the World – for Martians?

*Earth*



*Mars*

