The Martian climate: terrible!

- Average temperature around -80°F
- Average pressure 6 mbar (= Earth at ~35 km altitude!)
- Very little O₂ (~0.1% of atmosphere)
- Very little H₂O (<0.1 precipitable mm)
- No ozone layer to protect from UV
- No magnetic field to protect from charged particles
- Planetwide dust storms every few years

*But all of this may have been different in the past...*
So why do we like Mars?

- At least it has a surface and atmosphere!
  - Also true for Venus, but 870°F at 92 bars is not pleasant...
- It “feels” familiar
  - dark vs. bright terrains [Huygens, 1659]
  - polar ice caps [Cassini, 1666]
  - 24.7-hour day
  - water ice clouds
  - Earth-like seasons [Herschel, 1774]
  - moons [Hall, 1877]

Humans will go there

Martian mythology

- Schiaparelli [1877, etc.] mapped Martian “canali” (channels)
- Lowell [1894, etc.] attributed “canals” to innovative Martians transporting water from poles to equatorial deserts
- fictionalized by Edgar Rice Burroughs [1912–1948] and others
Martian mythology

The spacecraft era
1964: Mariner 4

- Revealed cratered, "Moon-like" surface
- First accurately measured low atmospheric density: ~6 mb CO₂

1971: Mariner 9 (1st planetary orbiter!)

- Also discovered huge volcanoes, canyons (Valles Marineris)

Low atmospheric pressure → liquid unstable

- Lowest elevations today are above triple point, but liquid would still evaporate
- Average Mars today at the triple point: did ancient lakes draw down CO₂ until the lakes themselves evaporated? (Kahn 1985)
Map of valley networks & outflow channels

Do valley networks trace an ancient precipitation belt? Some outflows start near volcanoes; others seemingly random.

Deltas suggest persistent flow

Note meander with cutoff, cross-cutting channels.

1976: Viking orbiters

Dry (river?) valley networks \(\rightarrow\) precipitation?
1976: Viking orbiters

- Chaos
- Degraded craters
Viking Biology Experiment
(offer food, see what happens)

- All three experiments got positive results!
- But GEx and PR also got these results for sterilized soils…

Viking GC / Mass Spectrometer

- Detected no organics*, not even from meteorites that hit Mars

After Viking…

20 years went by; people got to know the Viking data really well…
And then, manna from Heaven!

ALH84001—McKay et al. (1996) noted:

• Tiny “elongate” or “tubular-shaped bodies”
• Organics (PAHs) exceeding Antarctic backgrounds
• Complex textures / chemistries of Fe-rimmed carbonate globules

Most scientists now favor abiogenic explanations. Nevertheless…

Movie
The Modern Era

Why even consider water?

- Fundamental chemical (H and O) affects mineralogy, volcanism, tectonics
- Geomorphic role: erosion and deposition
- Climate
- Life!

Low atmospheric pressure → liquid unstable "phase diagram"

- Lowest elevations today are above triple point, but liquid would still evaporate
- Average Mars today near the triple point: did ancient lakes draw down CO$_2$ until the lakes themselves evaporated? (Kahn 1985)
Expectations of water on Mars have evolved greatly!
– Before “modern” investigations, scattering of ideas, from Lowellian canals to forests to dry rock.
– Mariner 4 (1965) lunar-like appearance, low atmospheric pressure.
– Mariner 9 (1971-2) global mapping: valley networks and “outflow channels.”
– Subsequent mapping of ground ice, possible recent liquid flow.

1976: Viking orbiters: Valley Networks

Dry (river?) valley networks ➔ precipitation?

Dendritic Drainage on Earth
Outflow Channels

Flood Discharge Comparison (m$^3$/s)

Low atmospheric pressure: Viking’s MAWD:

Measured water vapor: <100 precipitable microns: Very dry.

So, now = dry, very little atmosphere
Then = at least some periods with at least locally lots of water

Where has it gone? Or, where is it hiding?
How much was there?
How long was it around?
Do valley networks trace an ancient precipitation belt?
Some outflows start near volcanoes; others seemingly random

How “mature” are valley network systems?
Early maps ➔ low drainage density; sapping?
Newer data ➔ Earth-like densities; rain/snow?
Stream orders of 6 or more

Deltas suggest persistent flow
In far past
Note meander with cutoff, cross-cutting channels

Malin & Edgett (2003)
Martian lakes

- Most topographic basins are impact craters
- Valleys flowing into—and out of—basins imply ponding
- Volumes comparable to Great Lakes!

A Brief History of Earth

- Heavy impact bombardment.
- Valley networks.
- “Warm/Wet” early Mars?
- Volcanism.
- Outflow channels.
- Oceans?
- South circumpolar deposits.
- Low impact rates.
- Tharsis volcanism continues.
- Outflow channels continue.
- Late-stage polar caps.
- “Cold/Dry” late Mars.
Past: Evidence for Surface Water

- major classes of “Channels”
  - Outflow Channels
    - Very Old
    - Large Amounts of Water Released
  - Valley Networks
    - Very Old
    - Minimal Water Released
    - Rainfall? Did not fully transform landscape the way common in humid terrestrial settings.

What’s the current water inventory on Mars?
Mars Polar Layered Deposits
3 km of water ice-rich materials

Southern polar layered deposits also store significant CO₂ ice, but is mostly H₂O

Near-surface Ice revealed by impacts

Observed to fade over time

Byrne et al. (2009)
Direct samples and remote sensing of water ice (and hydrated minerals)
Data from Mars Odyssey Neutron Spectrometer [Feldman et al. 2004]
Upper cm of regolith

Lower-Limit of Water Mass Fraction on Mars

Current orbital surveys, such as:
Mars Reconnaissance Orbiter

More data than all other interplanetary missions combined
(DSN-supported)

MRO’s high-resolution surface imaging

CTX (Context Imager)
- ~30 cm/pixel, 3 colors (BG, RED, IR)
- <2% of Mars (to date) ∆ needs updating

HiRISE (High Resolution Imaging Science Experiment)
- ~30 cm/pixel, 3 colors (BG, RED, IR)
- <2% of Mars (to date)

CRISM (compact reconnaissance imaging spectral mapper)
- visible/NIR (362 – 3920 nm) hyperspectral imaging:
  - <18 or 36 m/pixel targeted images at 6.55 nm/channel
  - ~200 m/pixel mapping in 72/544 channels (<2% of Mars to date)
Modern water? Gullies look like water-carved features…
...but the evidence doesn’t all add up (they are most active in cold seasons!)

Schon et al. (2009)
Dundas et al. (2012)

Recurring slope lineae

McEwen et al. (2011)

Evidence for present day brines on Mars?

• RSL appear and grow incrementally on Sun-facing slopes, consistent with salty water (brine) flows
• More animations at: http://www.uahirise.org/sim/
Activity confined to warm seasons

Gough et al. (2011)

CRISM does not detect H₂O in RSL; wrong time of day?

Gough et al. (2011)
Minor aqueous alteration

Coatings & veins in basaltic rocks, apparently enriched in S and Cl

Ancient conditions

Recapping the highlights

• Did it ever rain on Mars?
  • Almost certainly, but no in the recent geologic past?
  • Evidence from distant past remains confusing.

• Geologic Timeline
  • Early-Mid Noachian: warm wet surface or subsurface
  • Late Noachian: extensive fluvial activity
  • Hesperian: catastrophic floods, outflow channels, oceans?
  • Early Amazonian: outflow channels continue
  • Mid Amazonian-Present: rare flows, subsurface brines?

Curiosity rover landed on an alluvial fan!
Curiosity's Science Payload

- **ChemCam** (Chemistry)
- **Mastcam** (Imaging)
- **REMS** (Weather)
- **DAN** (Surface Hydrogen)
- **SAM** (Chemistry and Isotopes)
- **CheMin** (Mineralogy)
- **MARDI** (Imaging)
- **APXS** (Chemistry)
- **MAHLI** (Imaging)
- **RAD** (Radiation)
- **Drill Scoop Brush Sieves**

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Mars 2020 Rover

- **MISI** (Electronics and Pressure Sensor)
- **MEDA Radiation & Dust Sensor**
- **SuperCam Mast Arm**
- **MEDA Mast Sensor**
- **SHERLOC Sensor**
- **MEDA Calibration Target**
- **MEDA-G***
- **MEDA Calibration Target**
- **MEDA Sensor**
- **MEDA-C***
- **MEDA Calibration Target**
- **MEDA Air Temperature Sensors**
- **SuperCam**
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