life on Mars
what to know before we go

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Early Mars?
Ancient Outflow Channel
Mars Global Surveyor (1997-2006):
Outflow channels appear near eastern edge of the Hellas Basin.
Ancient floodwaters flowed downhill (toward bottom, into Hellas Basin).
Hellas Planitia: a large impact crater (largest in solar system)
Diameter: 1400 miles    Depth: 23,465 feet
(a) Dao Vallis
--- wide braided channel
--- flow to SW

(b) Mangala Vallis
  – release of subsurface volatiles
  – flow to N

(c) Ravi Vallis
  – release under pressure of fluid from subsurface aquifer
Athabasca Outflow Channel --- formed from ground fissures that formed from stresses associated with growth of giant volcanoes
Lake Missoula: 12,000 years ago, glacial dam (2,500 feet tall) collapsed. Outflow rate: 60 times greater than Amazon River, flow rate 50 miles/hr
Giant Current Ripples - Camas Prairie, MT
### Table 3


<table>
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<tr>
<th>Outflow channel</th>
<th>Range of ages</th>
<th>Minimum estimated water volume (km³)</th>
<th>Minimum estimated GEL range (m)</th>
<th>References</th>
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<tbody>
<tr>
<td>Ma’adim</td>
<td>1–3.5 Gy</td>
<td>$3.5 \times 10^4 – 5.6 \times 10^5$</td>
<td>0.2–3.8</td>
<td>1, 2, 12</td>
</tr>
<tr>
<td>Ravi</td>
<td>3.5 Gy</td>
<td>$1.1 \times 10^4 – 6.5 \times 10^4$</td>
<td>0.1–0.5</td>
<td>3</td>
</tr>
<tr>
<td>Kasei</td>
<td>1.5–3 Gy</td>
<td>$5.5 \times 10^5$</td>
<td>3.8</td>
<td>4, 12</td>
</tr>
<tr>
<td>Ares</td>
<td>2.5–3.6 Gy</td>
<td>$3 \times 10^4 – 2.2 \times 10^5$</td>
<td>0.2–1.5</td>
<td>5, 6</td>
</tr>
<tr>
<td>Total for Circum-Chryse formation</td>
<td>2.5–3.6 Gy</td>
<td>$1.5 \times 10^6 – 5 \times 10^6$</td>
<td>10.4–34.6</td>
<td>4, 7, 8</td>
</tr>
<tr>
<td>Mangala</td>
<td>0.5–3 Gy</td>
<td>$2 \times 10^4 – 4 \times 10^4$</td>
<td>0.1–0.3</td>
<td>9, 10, 12</td>
</tr>
<tr>
<td>Athabasca</td>
<td>2 My–30 My</td>
<td>$2 \times 10^2 – 1.4 \times 10^4$</td>
<td>$1.4 \times 10^{-3} – 0.1$</td>
<td>10, 11</td>
</tr>
<tr>
<td>Global estimates</td>
<td>2 My–3.6 Gy</td>
<td>$7 \times 10^7 – 1.4 \times 10^8$</td>
<td>$5 \times 10^2 – 10^3$</td>
<td>7, 8</td>
</tr>
</tbody>
</table>

**Total original water:** 1,500 – 3,000 feet (500-1000 meters) **Global Equivalent Layer (GEL)** -- most recent: Athabasca
Far side of Earth’s moon: heavily cratered terrain (old)
Near side of Earth’s moon
Mare Humorum
Ancient Valley Network

200 km
Nanedi Vallis, one of the Martian valley systems in Xanthe Terra region

Left: Viking image (1977)
Right: Mars Global Surveyor image (1998)
Xanthe Terra
Quantitative Assessments of the Martian Hydrosphere

Table 5 MARSIS and SHARAD specifications. Vertical resolution and penetration depth depend on the radar wavelength and permittivity of the sounded material, while horizontal resolution is linked to the radar’s antenna design, speed of the spacecraft, pulse repetition frequency, and surface roughness. From Jordan et al. (2009) and Seu et al. (2007)

<table>
<thead>
<tr>
<th></th>
<th>Frequencies</th>
<th>PRF</th>
<th>Resolution (along × across-track)</th>
<th>Maximum penetration depth in H₂O ice</th>
<th>Resolution (vertical)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MARSIS</td>
<td>1.8, 3, 4, 5 ± 0.5 MHz</td>
<td>127 Hz</td>
<td>5–10 × 15–30 km</td>
<td>&lt;5 km</td>
<td>75–150 m</td>
</tr>
<tr>
<td>SHARAD</td>
<td>20 ± 5 MHz</td>
<td>700 Hz</td>
<td>0.3–1 × 3–6 km</td>
<td>&lt;1.5 km</td>
<td>10–24 m</td>
</tr>
</tbody>
</table>
Mars Orbiter Laser Altimeter (MGS) map north of 75 degrees latitude (North Polar Region):

Contour interval = 100 meters

The cap volume of 300,000 to 400,000 cubic miles is about half that of the Greenland ice cap.

If melted: global layer of water 30 feet deep
Mars Express radar measurements (color) of depth of water ice at southern polar cap (image from MGS)

Total ice volume: 400,000 cubic miles

If melted: global layer of water 36 feet deep
Table 4  Total planetary water content estimated from geomorphological evidence (see text for details and references)

<table>
<thead>
<tr>
<th>Geological feature</th>
<th>Formation age</th>
<th>Estimated inventory of H₂O (m GEL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern Ocean and Hellas Basin sea</td>
<td>Episodically from ~200 My–4.5 Gy (with maximum areal extent during the Noachian)</td>
<td>~160–1000</td>
</tr>
<tr>
<td>Valley networks</td>
<td>Mid-Noachian to Early Hesperian</td>
<td>~300–1000</td>
</tr>
<tr>
<td>Outflow channels</td>
<td>2 My–3.6 Gy (mostly Hesperian)</td>
<td>~500–1000</td>
</tr>
<tr>
<td>South Polar Layered Deposit (SPLD)</td>
<td>10 My–100 My</td>
<td>11–16</td>
</tr>
<tr>
<td>North Polar Layered Deposit (NPLD)</td>
<td>4 My–1 Gy</td>
<td>8–12</td>
</tr>
<tr>
<td>Lobate Debris Aprons</td>
<td>Late Amazonian</td>
<td>~1</td>
</tr>
<tr>
<td>Softened terrains permafrost</td>
<td>Late Amazonian</td>
<td>50–200</td>
</tr>
<tr>
<td>Ice-sublimation mantle</td>
<td>&lt;1 My</td>
<td>few meters</td>
</tr>
<tr>
<td>Total amount of water necessary for SPDL, NPD and young, cold climate surface features</td>
<td>–</td>
<td>80–240</td>
</tr>
</tbody>
</table>
H₂O, HDO and D₂O

1 in 6,400 H atoms is a D atom
1 in 3,200 water molecules is HDO
1 in 41 million water molecules is D₂O

D/H ratio on Mars 8 times D/H on Earth:
-- implies escape of H atoms
-- assumes D/H same on Mars and Earth when planets first formed

Loss of D implies evaporation of water, then UV-triggered destruction of water, then escape of D atoms to space

Estimate: Mars has lost 13/15 (85%) of original water.

Original ocean: 450 feet GEL
MAVEN (2017): "We've determined that most of the gas ever present in the Mars atmosphere has been lost to space," said Bruce Jakosky, principal investigator for the Mars Atmosphere and Volatile Evolution Mission (MAVEN), University of Colorado in Boulder. The team made this determination from the latest results, which reveal that about 65 percent of the argon that was ever in the atmosphere has been lost to space.

--- Mars is losing about ½ pound of its atmosphere to space every second
Water detected with orbiting radar: 30 m GEL detected (so far)

Historical Mars: GEL of several 100 to 1000 meters
MGS: crater wall in Terra Sienum

Left: Dec 22, 2001
Right: Aug 26, 2005
Evidence of active erosion? Of water flow on surface?
Giovanni Schiaparelli (1835-1910)
Credit: Images by Jim Scotti, University of Arizona

1866: showed Perseid meteor shower (August) is debris shed by Swift-Tuttle
1868: won Lalande Prize from French Academie des Sciences
8.6-inch Merz refractor at Brera Observatory

First Mars observations: 1877

Decided to make most accurate maps of Mars yet made
Differences in color due to differences in “depth, transparency, and chemical composition”

“the difference in salinity between terrestrial seas causes the differences between the colours of these seas. The saltier the water, the darker it appears. ... It is the same on Mars.”
Questi disegni sono proiezioni ortografiche col centro nella longitudine areografica di 0°, 90°, 180° e 270° e nella latitudine areografica australe di 25°.
• “the complicated reseau of dark lines, which links the patches we regard as seas ... owe their colour to the same cause as with the seas, and can only be canals or communicating straits.”
• “on the planet crossing the continents there are a large number of dark lines to which I have given the name canals”
• “I have recognized a considerable number --- at least sixty.”
Major discoveries: 1879 – 1882

• Canal system growing
• Shortest 75 miles in length
• Longest 3,000 miles in length
• Width: typically 75 miles
• Every canal “terminated, to either end, in a sea or in another canal”

• “This is not all. At certain seasons these canals are doubled, or more accurately, double themselves.”
• That is, one canal almost overnight doubled into two parallel canals
• Called this ‘gemination’
• First observed in 1879 for “the Nile”
• In 1882, gemination seen for four more canals, “and the majority of the other canals, showed up as clear and uncontestable doubles”
• “these doublings are not an optical effect”

• “It is not necessary to suppose them the work of intelligent beings.”

• Reaction: skepticism
MARS 1883-84.
MARS 1890.
Confirmation:

First, by Irishman C. E. Burton (1882) --- canals yes, gemination not confirmed

Second: by Frenchmen Henri Perrotin and Louis Thollon, confirmed gemination --- “By the end of that night [April 5, 1886], under good conditions, we had been able to recognize successively, several canals presenting, in nearly all respects, almost the character attributed to them by the Director of the Milan Observatory.” We “ have noted the two shaded parallel lines which make up the double canal TU.”
Confirmation:

Third: Frenchman Francois Terby (1888) --- “We find that in 1888 we have verified at Louvain the existence of the following canals.” [He names thirty!] Also, he was able to “get a glimpse of the doubling of one of them.”

Terby Crater on the northern edge of Hellas Planitia, Mars
Confirmation:

Fourth: American William Henry Pickering (1890) --- He “had no difficulty in also seeing Styx, Fretum Anian, and Hyblaeus. Several other canals in this same region have been recognized. He opined that he “had the highest admiration for the eyesight of the astronomer who could discover them in the first place with an 8-inch telescope.”
Clark Telescope Dome, Lowell Observatory (1894 --- first light, 1896)
• 1894 campaign with a borrowed 12-inch telescope --- identified 183 canals, including 100 not seen by Schiaparelli; saw 8 instances of gemination

Early support for Lowell:
• 1896: Leo Brenner (actually, Serbian ‘quack’ Spiridon Gopcevic) reported seeing “70 of Schiaparelli, 12 of Lowell, and 20 new [canals]” --- no training in astronomy, but had money to build himself an observatory [like Lowell!] --- also measured [absurd] rotation period of Venus as 23h 57m 36.27728s
1894: six-article series in *Popular Astronomy*

1895: four-article series in *Atlantic Monthly*

1895: series of public lectures on Mars

1895: *Mars*
1906: *Mars and Its Canals*

- Life evolves naturally and inevitably from chemical processes
- Existence of life on Mars is inevitable
- If plant life exists, higher forms of life are likely
- Since it has all the ingredients for life, the evolution of living things must have occurred

- A “wave of darkening” sweeps from poles to the equator at 51 miles per day
- Speed corresponds to the speed at which water is pumped through canals, thereby allowing vegetation to grow, spread and bloom
“It is a direct sequitur from this that the planet is at present the abode of intelligent, constructive life. .... I may say in this connection that the theory of life upon Mars was in no way an *a priori* hypothesis on my part, but the deduced outcome of observation, and that my observations since have fully confirmed it. No other supposition is consonant with all the facts observed here.”

MARTIANS BUILD TWO IMMENSE CANALS IN TWO YEARS


By Mary Proctor.

Three New Diagrams by Prof. Lowell and Prof. H. G. Heye Show the New Canals and Marsians.

MARTIANS FINISH CANAL ON PLANET

MARS' IRRIGATION SCHEME SEEN TO WORK WONDERS.

Professor Percival Lowell, of Flagstaff, A. T., says he's photographed Redeemed Desert.

CHICAGO, Feb. 14.—(Special)—An announcement of final proof that the planet Mars is inhabited was made by Professor Percival Lowell, the famous
WATTERTSON'S PAPER BURNED.
Fire Early This Morning In the Courier-Journal Building.
LOUISVILLE, Ky., Friday, Aug. 30.—Fire started early this morning in the building of the Louisville Courier-Journal, of which Henry Watterson is editor. At 1 o'clock it seemed that the building was doomed. All the employees escaped.

SHUT OFF LA FOLLETTE.
Teachers Wouldn't Let Him Speak on Partisan Politics.
Special to The New York Times.
PITTSBURG, Aug. 29.—United States Senator Robert A. La Follette of Wisconsin, was prevented from discussing partisan politics at the teachers' institute here this afternoon by Superintendent of Schools, Samuel Hamilton. Senator La Follette was scheduled to speak on "Representative Government."
Earlier in the day he had been requested to keep off of partisan politics, and in opening his speech he said:
"I have been warned not to be partisan in my speech here this afternoon, but I want to say to the superintendent and the officials of the institute just what I think."

MARS INHABITED, SAYS PROF. LOWELL
Declares the Planet to Be the Abode of Intelligent, Constructive Life.

THE RECENT OBSERVATIONS
Changes in Canals Confirm Former Theory—Splendid Photographs Were Obtained.

Special Cable to THE NEW YORK TIMES.
LONDON, Aug. 29.—In answer to a request from the editor of Nature for an authoritative statement of the observations of Mars made during the 1907 opposition, Prof. Percival Lowell communicates to that publication what he describes as "two or three of the most important results obtained."
He declares that the planet is at present covered with a "network" of canals which he calls "the most wonderful thing in the night sky."

REBUKE BY KING EDWARD.
He Walks Out of a Café Owing to the Nature of the Performance.
MARIENBAD, Aug. 29.—King Edward has administered a rebuke to the singing of indecent songs in places of public amusement, and his action, which was taken publicly, has created intense excitement in Marienbad.
His Majesty entered a café chantant tonight, and, after listening to one or two items on the programme, he walked out as a protest against the scandalous nature of the performance. A Viennese company was playing. His Majesty was followed by the Duke of Teck and the other members of his suite, and all the Americans and Englishmen present.
"This is horrible, appalling," said the King to a member of his entourage, and the accuracy of his description of the performance is admitted on every side.

YELLOW FEVER NEAR HAVANA.
It Appears at Campo, Across the Bay from the City.
“Certainly it has not been the financial panic which is occupying our minds to the exclusion of most other thoughts.” No, “The most extraordinary development has been the proof afforded by astronomical observations of the year that conscious, intelligent human life exists upon the planet Mars.” This proves “the existence of intelligent life upon that globe.” “There could be no more wonderful achievement than this, to establish the fact of life upon another planet.”
Canals were used by Martians to transport water from the water-rich polar caps to equatorial (agricultural) regions.
temperature on Mars:
• Lowell (1907): At surface, +47 F
• Reality: -243 F to +68 F (at equator, midsummer). Average = -80 F

Surface pressure on Mars:
• Lowell (1907): 1/12 surface pressure of Earth
• Reality: 6/1000 surface pressure of Earth

Retention of atmosphere:
• Lowell (1907): Mars’ gravity strong enough to hold onto all gases except H
• Reality: loss of H, N, Ar all measured (and so loss of water)

Composition of atmosphere:
• Lowell (1907): like Earth (oxygen, water vapor)
• Reality: 96% carbon dioxide, almost no water vapor
Sixth Interim Report for 1909, dealing with some further Notes on the so-called Canals (for the British Astronomical Association):

- “It is high time that evidence of this kind should be pronounced worthless; and but for such uncertain data, usually obtained with inferior telescopes, there would never have been a question of canals on Mars.”
- “We have, of course, no more right to speak of the true canals on Mars than of their dykes of Mars or the roads of Mars. Whether such things exist or not on the planet we cannot know; and any consideration regarding them must be treated as unwarranted speculation. The term ‘canal’ has no more relevancy on Mars than ‘sea’ on the Moon.”
- 1913: “The canal fallacy, after retarding progress for a third of a century, is doomed to be relegated into myths of the past.”