Planet Mars : Exploration, environment and ressources

François Forget, CNRS
Institut Pierre Simon Laplace (LMD, Paris)

Mars Express HRSC Image
ESA / DLR / FU Berlin / Justin Cowart

Missions to Mars

Key past missions

←Mariner 9
1971
←Viking
1976

Mars Global Surveyor *(NASA)*
1996-2006

Spirit
(NASA) 2003-2011

Opportunity
(NASA) 2003-2018

Pathfinder
(NASA) 1996

Phoenix
(NASA) 2008

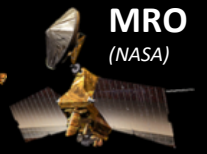
Operating

Mars Express
(ESA)

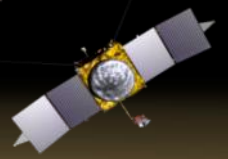
Mangalayan
(India)

Mars Odyssey
(NASA)

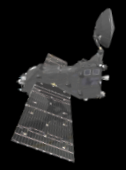
MRO
(NASA)



MAVEN
Areonomy
(NASA)



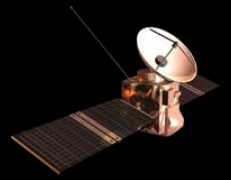
Exomars
Trace Gas
orbiter
(ESA-Russia)



Curiosity
(NASA)

InSight
(NASA-CNES-DLR)

Emirates
Mars Mission
HOPE



Ingenuity

Perseverance
(NASA)

Tianwen-1
(China)
Zhurong
Lander

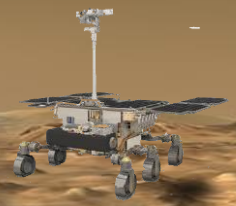
2022 & beyond

MMX
(Mars Moon
eXploration)
(Japan), 2024?

Phobos

"Mangalayan 2"
(Inde)

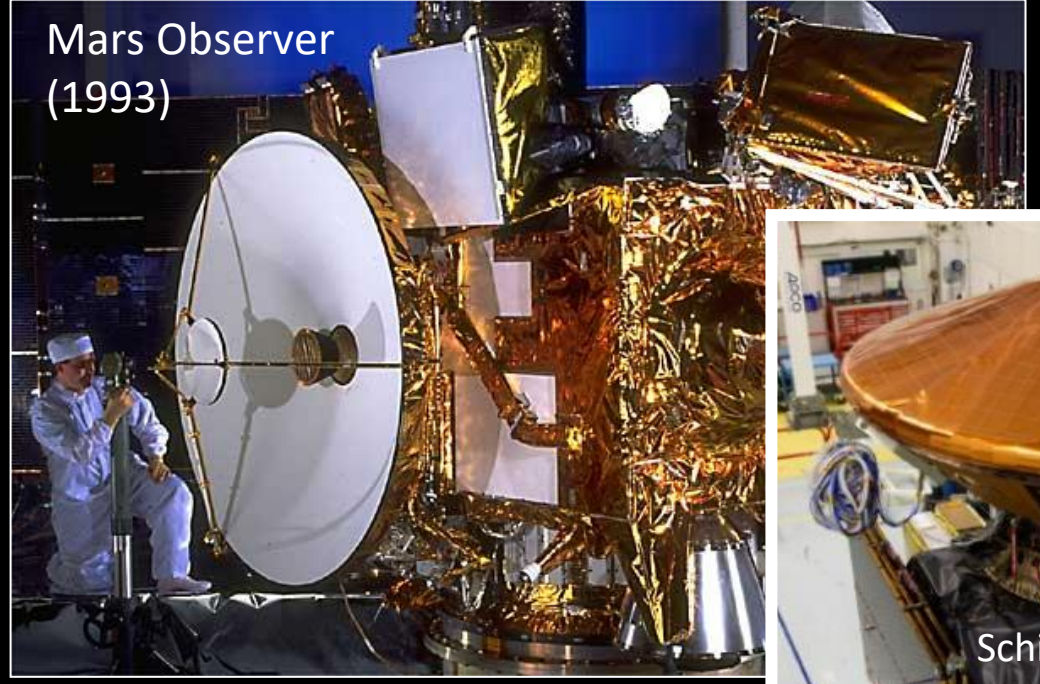
Rosalind
Franklin
(Rover, ESA)
(~~2022~~ =>2028 ?)

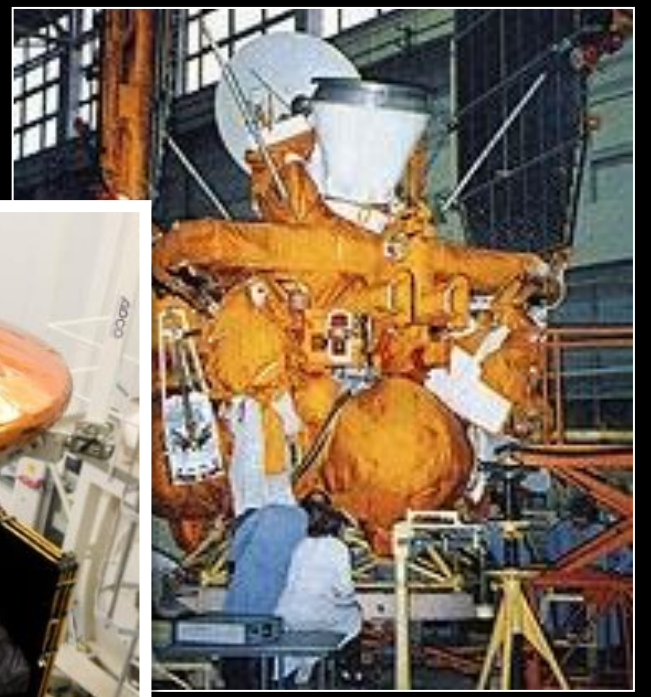


Mars
Sample
Return
(NASA-ESA)
>2028

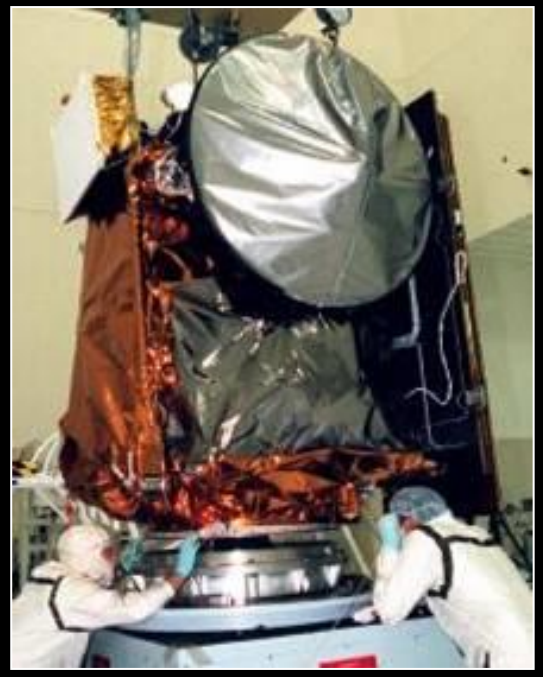
A difficult exploration

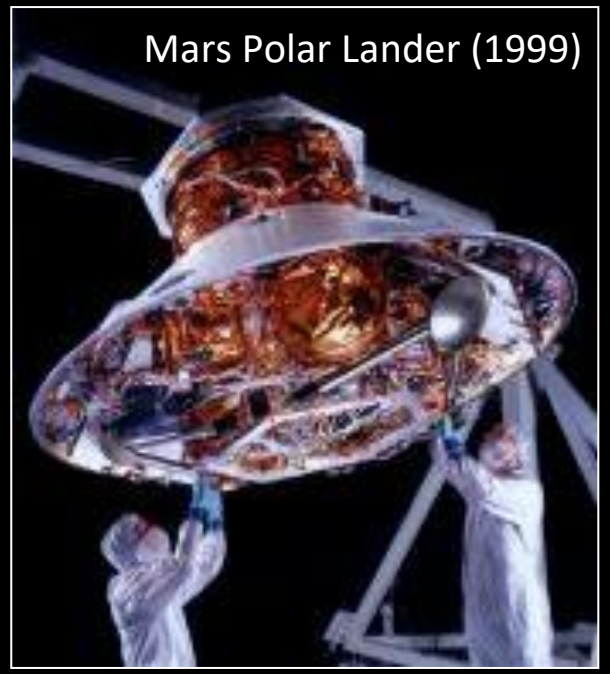
(My experience on Mars)

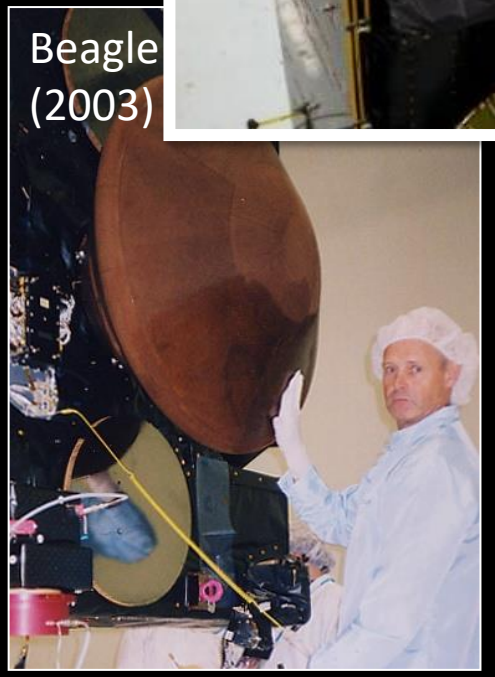


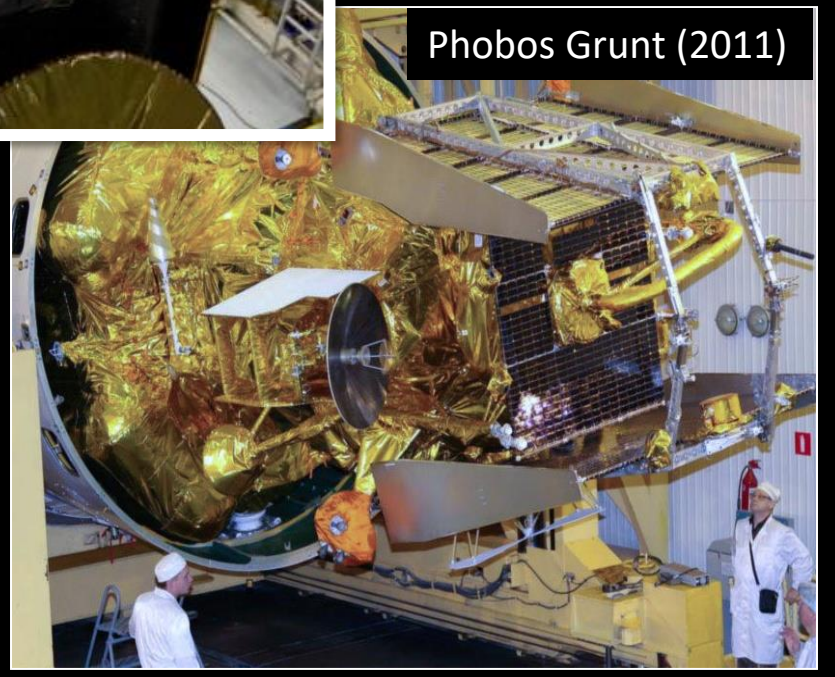


Mars Climate Orbiter (1999)









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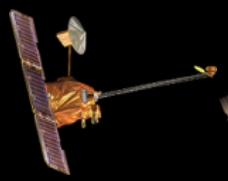
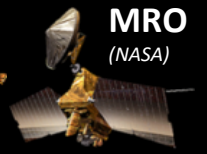


MRO
(NASA)



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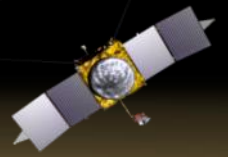

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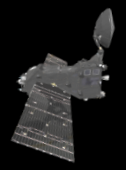

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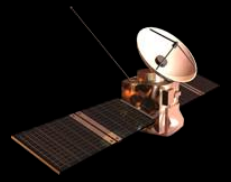

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Lander

Curiosity
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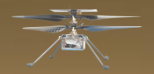


Perseverance
(NASA)

What have we learned ?

Earth

Patm ~ 1000 hPa

(N_2 . O_2)

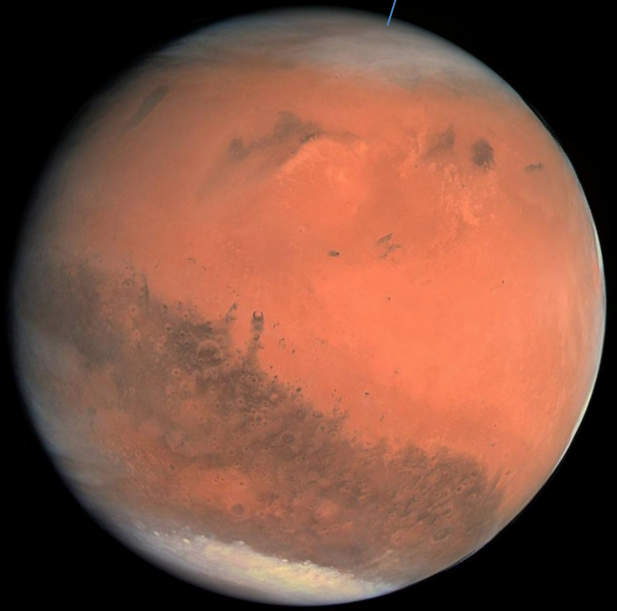
23.5°

1 jour = 24h

Mars :

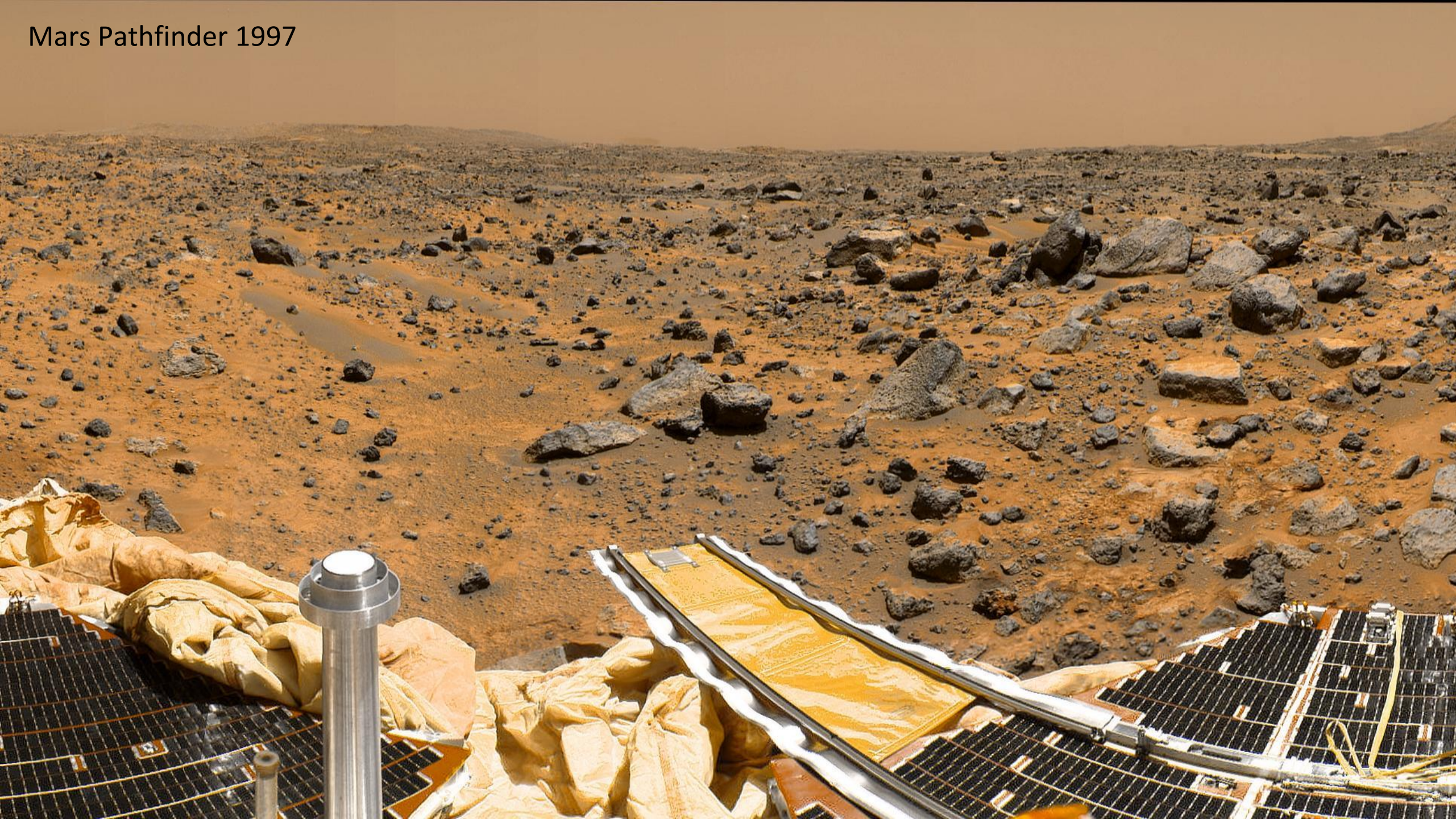
Patm ~ 6 hPa (95% CO_2)

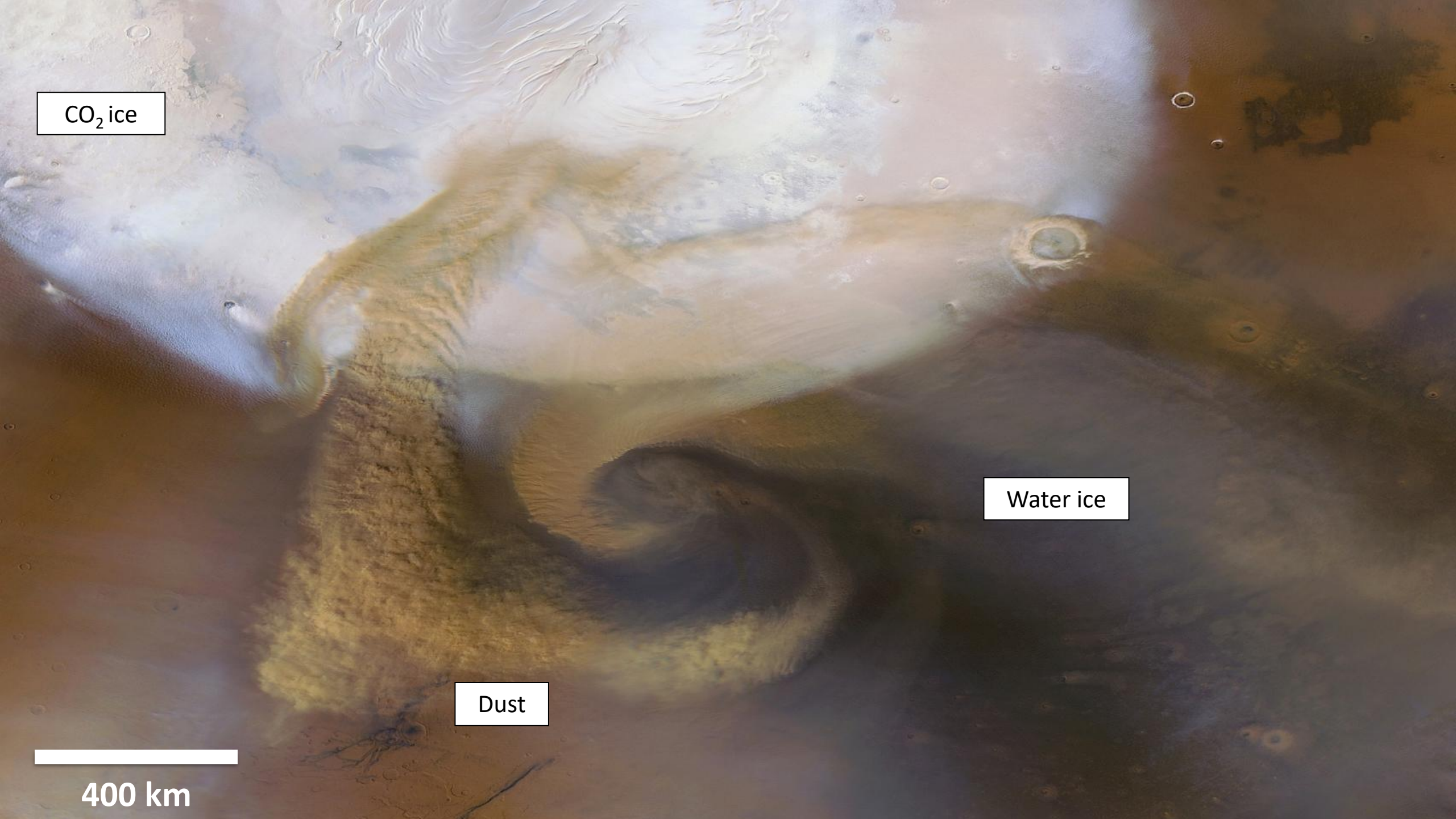
25.2°



1 sol = 24h40’

Mars Pathfinder 1997




CO_2 ice
Water ice
Dust
400 km

Water ice frost (Viking 2 48°N, 1978)

Haberle et al. 2003

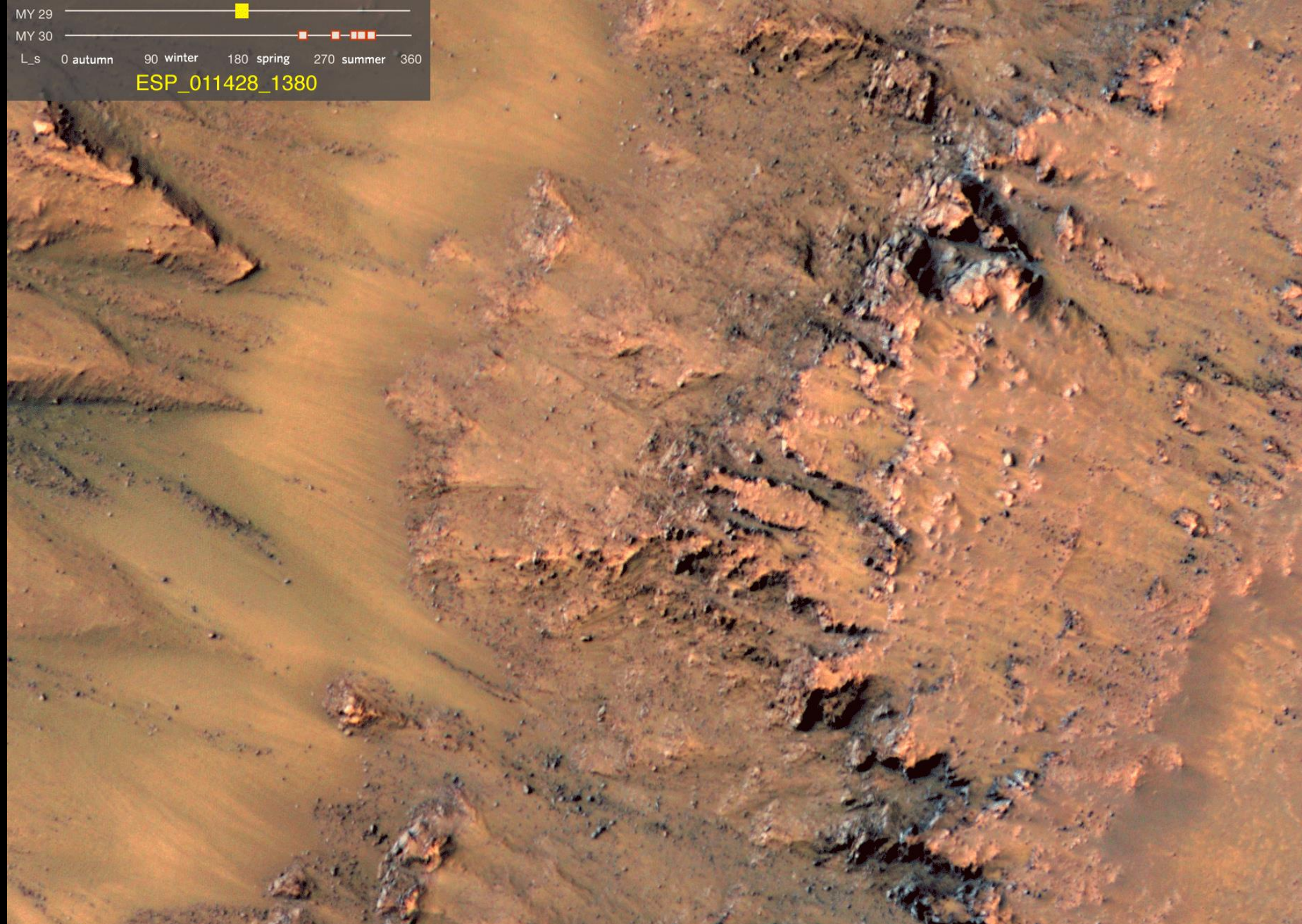
Enigmatic

“Recuring Slope Lineae”

observed to form on warmest slopes during southern spring and summer…

Flowing Brines ???

McEwen, Science August 2011



September 2015

CNN US

SPACE SCIENCE

Liquid water exists on Mars, boosting hopes for life there, NASA says

By Michael Pearson, CNN

Updated 1141 GMT (1941 HKT) September 29, 2015

News & buzz

Bill Cosby accuser Valentino reacts to release from...

'Shaking all the time:' Surfside condo owners complained of...

The steep slopes of Coprates Chasma on Mars are marked by dark streaks called recurring slope lineae, which scientists have discovered are produced by flowing saltwater.

PHOTOGRAPH BY NASA/JPL-CALTECH/UNIV. OF ARIZONA

NATIONAL GEOGRAPHIC

NASA Finds 'Definitive' Liquid Water on Mars

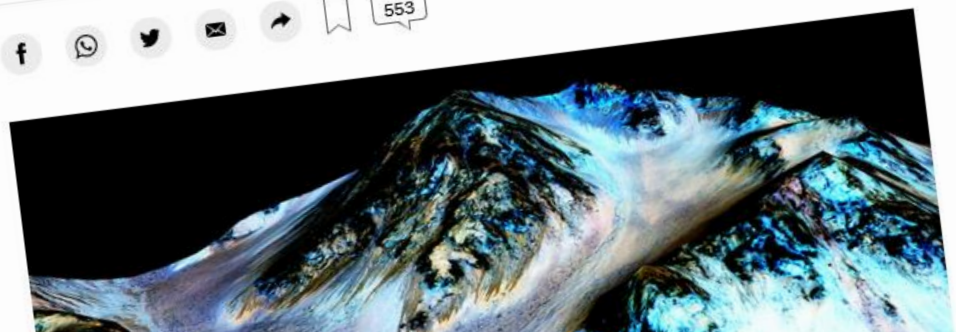
Dark streaks that appear and vanish seasonally are made of salty wat

new observations show.

The New York Times

Mars Shows Signs of Having Flowing Water, Possible Niches for Life, NASA Says

553

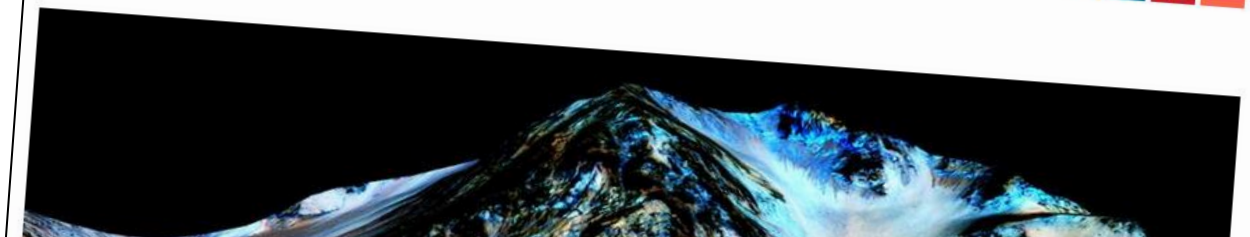


MRO

Sep 28, 2015

RELEASE 15-195

NASA Confirms Evidence That Liquid Water Flows on Today's Mars



nature geoscience

LETTERS

PUBLISHED ONLINE: 28 SEPTEMBER 2015 | DOI: 10.1038/NGEO2546

Spectral evidence for hydrated salts in recurring slope lineae on Mars

Lujendra Ojha[1]*, Mary Beth Wilhelm[1,2], Scott L. Murchie[3], Alfred S. McEwen[4], James J. Wray[1], Jennifer Hanley[5], Marion Massé[6] and Matt Chojnacki[4]

Determining whether liquid water exists on the Martian surface is central to understanding the hydrologic cycle and potential for extant life on Mars. Recurring slope lineae, narrow streaks of low reflectance compared to the surrounding terrain, appear and grow incrementally in the downslope direction during warm seasons when temperatures reach about 250–300 K, a pattern consistent with the transient flow of a volatile species[1–3]. Brine flows (or seeps) have been proposed to explain the formation of recurring slope lineae[1–3], yet no direct evidence for either liquid water or hydrated salts has been found[4]. Here we analyse spectral data from the Compact Reconnaissance Imaging Spectrometer for Mars instrument onboard the Mars Reconnaissance Orbiter from four different locations where recurring slope lineae are present. We find evidence for hydrated salts at all four locations in the seasons when recurring slope lineae are most extensive, which suggests that the source of hydration is recurring slope lineae activity. The hydrated salts most consistent with the spectral absorption features we detect are magnesium perchlorate, magnesium chlorate and sodium perchlorate. Our findings strongly support the hypothesis that recurring slope lineae form as a result of contemporary water activity on Mars.

the surface, or detection of hydrated salts precipitated from that water.

The mineralogic composition of RSL and their surroundings can be investigated using orbital data acquired by the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) on the Mars Reconnaissance Orbiter (MRO), which acquires spectral cubes with 544 spectral channels (~0.4 to 3.92 μm; ref. 14). Within the infrared (IR) detector spectral range of CRISM (1–3.92 μm), both liquid water and hydrated salts have diagnostic absorption bands at ~1.4 μm, ~1.9 μm and a broad absorption feature at ~3.0 μm (ref. 15; Fig. 1). In addition, hydrated salts may exhibit combinations or overtones at other wavelengths from 1.7 to 2.4 μm. Given the coarser spatial sampling of CRISM (~18 m pixel^{-1}) compared to HiRISE, few locations exist in which RSL are wide or dense enough to fill even a single CRISM pixel. In this work, we devised a variety of methods to reduce uncertainties from extraction of CRISM spectra from individual pixels (Supplementary Information), allowing examination of pixels mostly filled by RSL.

At Palikir crater, RSL are observed to be longest and widest towards the end of the southern summer. In the HiRISE image acquired at the end of the southern summer of Mars Year (MY) 30, wide RSL were observed on the slopes of Palikir (Fig. 1

Enigmatic "**Recuring slope Lineae"** observed to form on warmest slopes during southern spring and summer…

Flowing Brines ???

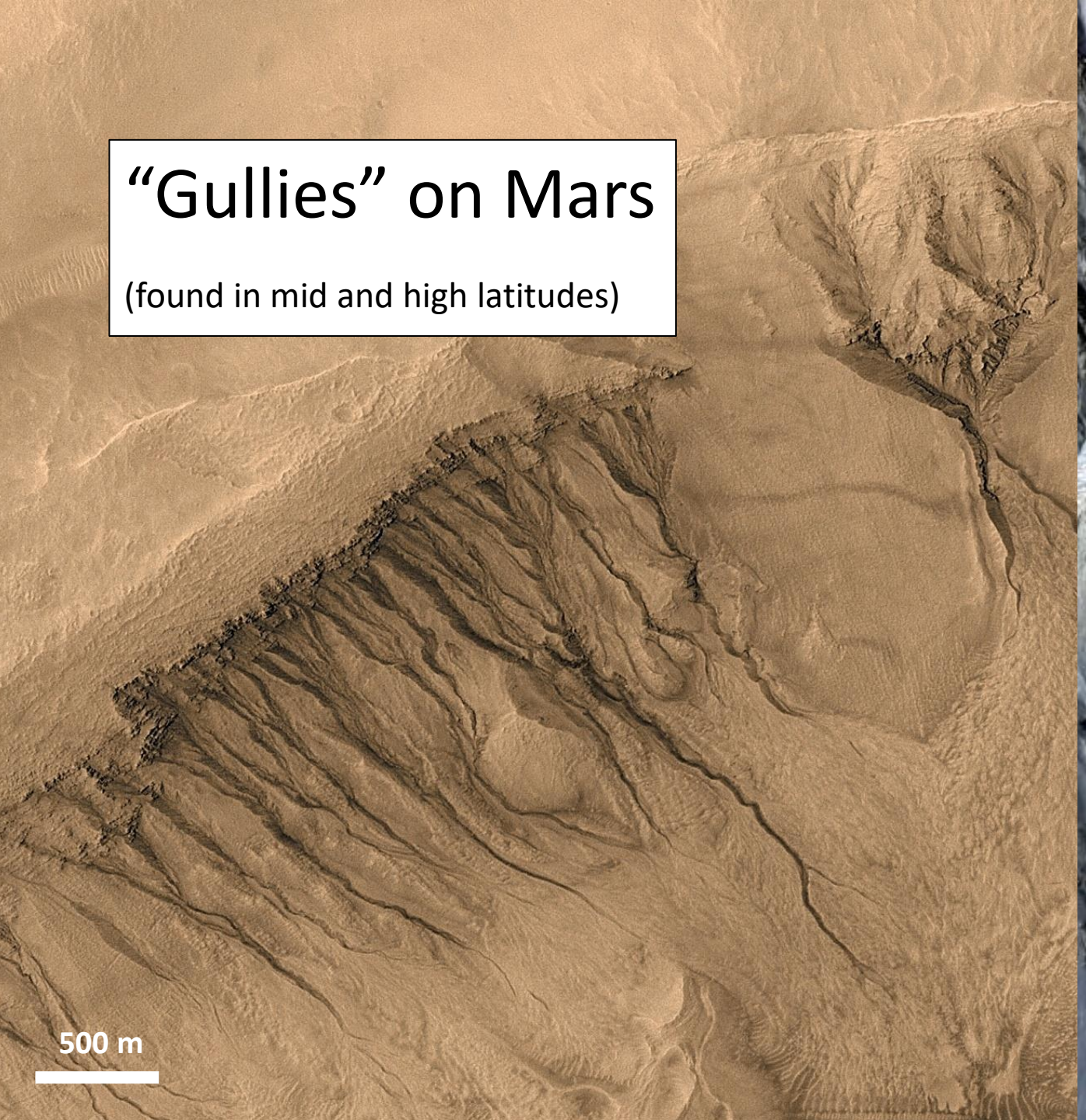
McEwen, Science August 2011

Recurring Slope Linae : most likely dry, eolian processes

Edwards and Piqueux (2016), Schmidt et al. (2017), Dundas (2017, 2020), Vincendon et al. (2019), Schaefer et al. (2019)

“Gullies” on Mars

(found in mid and high latitudes)



Observed Active formation of Gullies on present-day Mars!

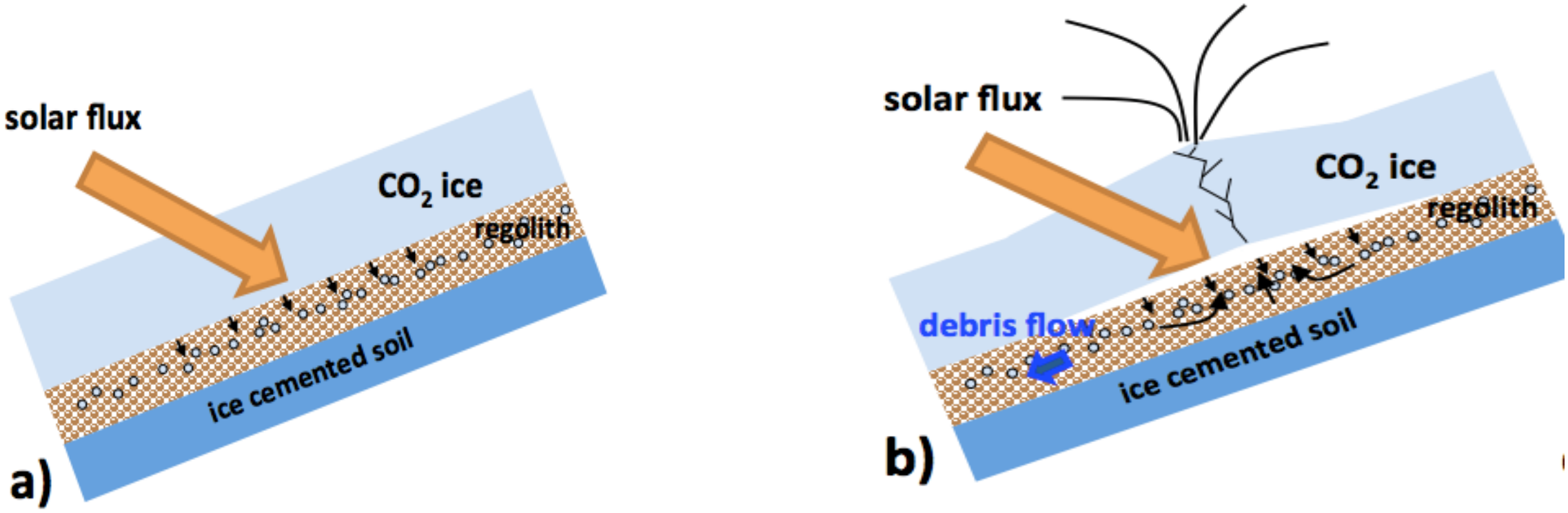
(in relation to CO_2 ice)

Dundas et et al. 2010, 2012, 2014, Reiss et al. 2010, Diniega et al., 2010 Hansen et al. 2011

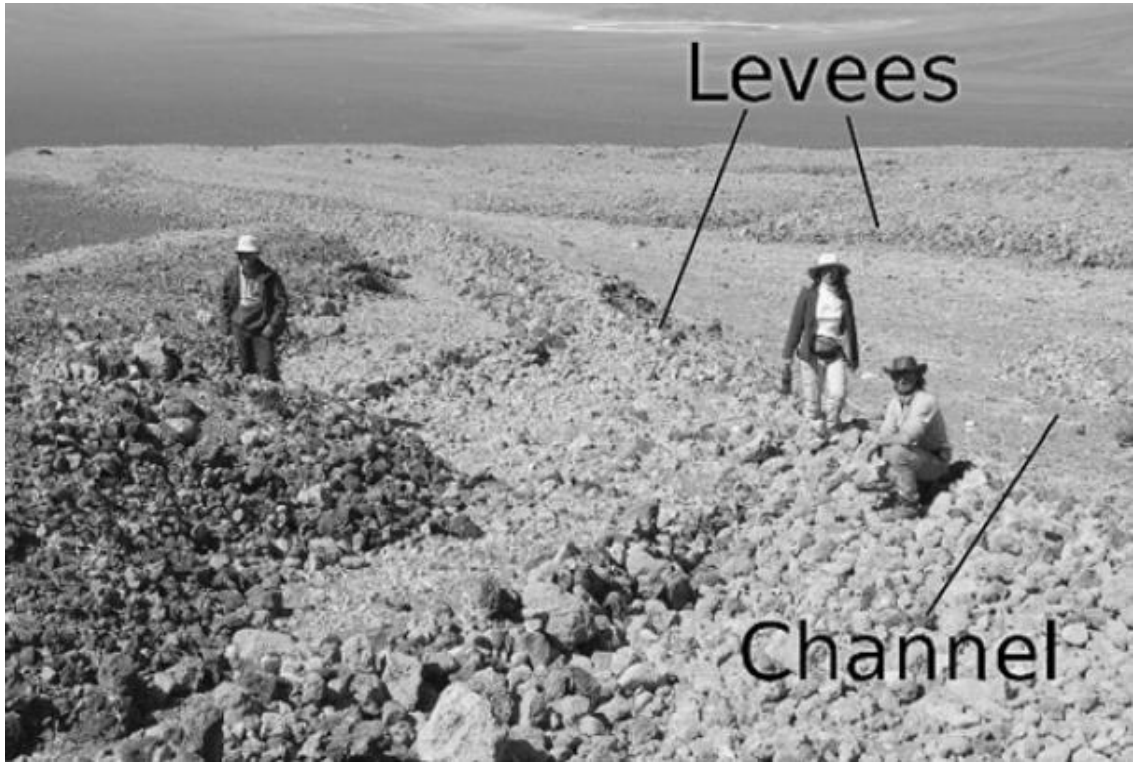
Hirise Nov. 5, 2010, and May 25, 2013.

Gullies are formed by subliming CO_2 ice, not liquid water

Exemple of process : Gas fluidized debris flow (*Pilorget and Forget, Nature Geoscience 2016*)



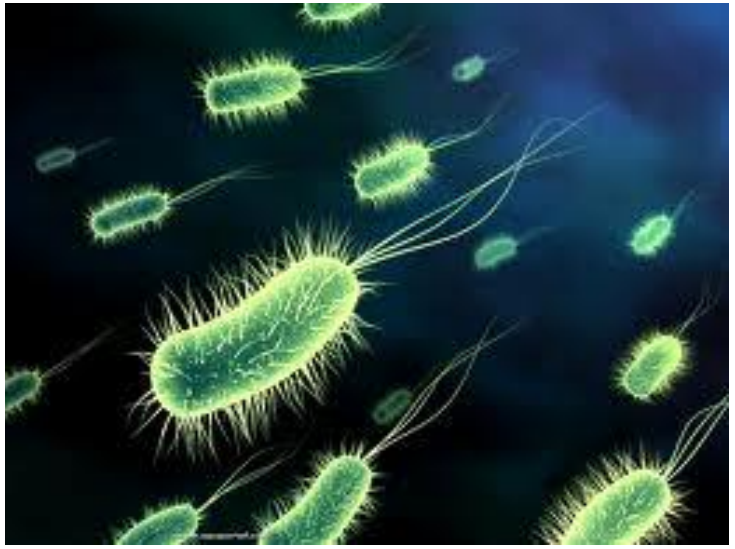
Gas fluidized Dense pyroclastic flows on Earth (gerenated by volcanic eruption)



Felix and Thomas 2004
Jessop et al. 2012

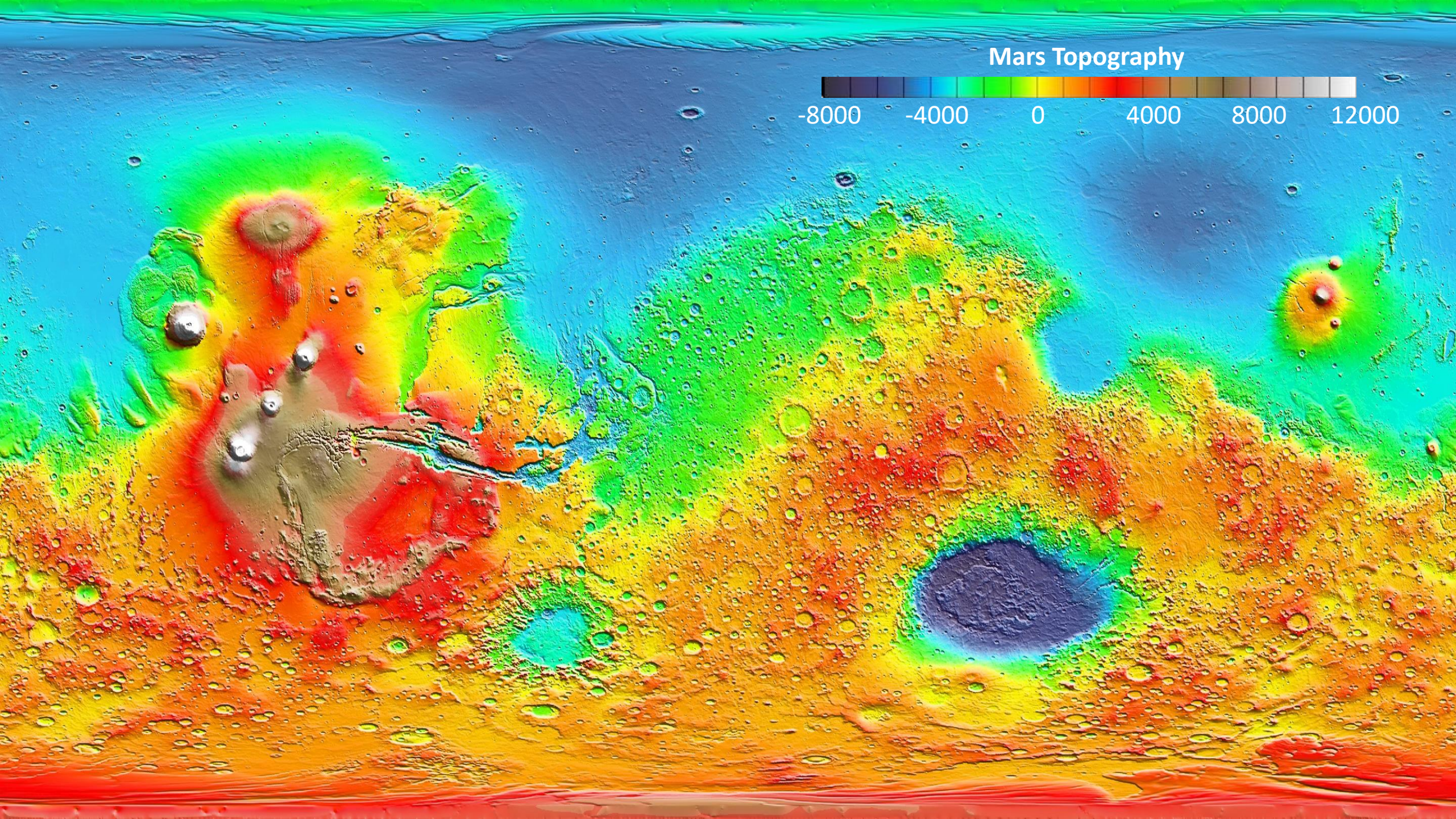
On Mars : Ice, but no liquid water on the surface

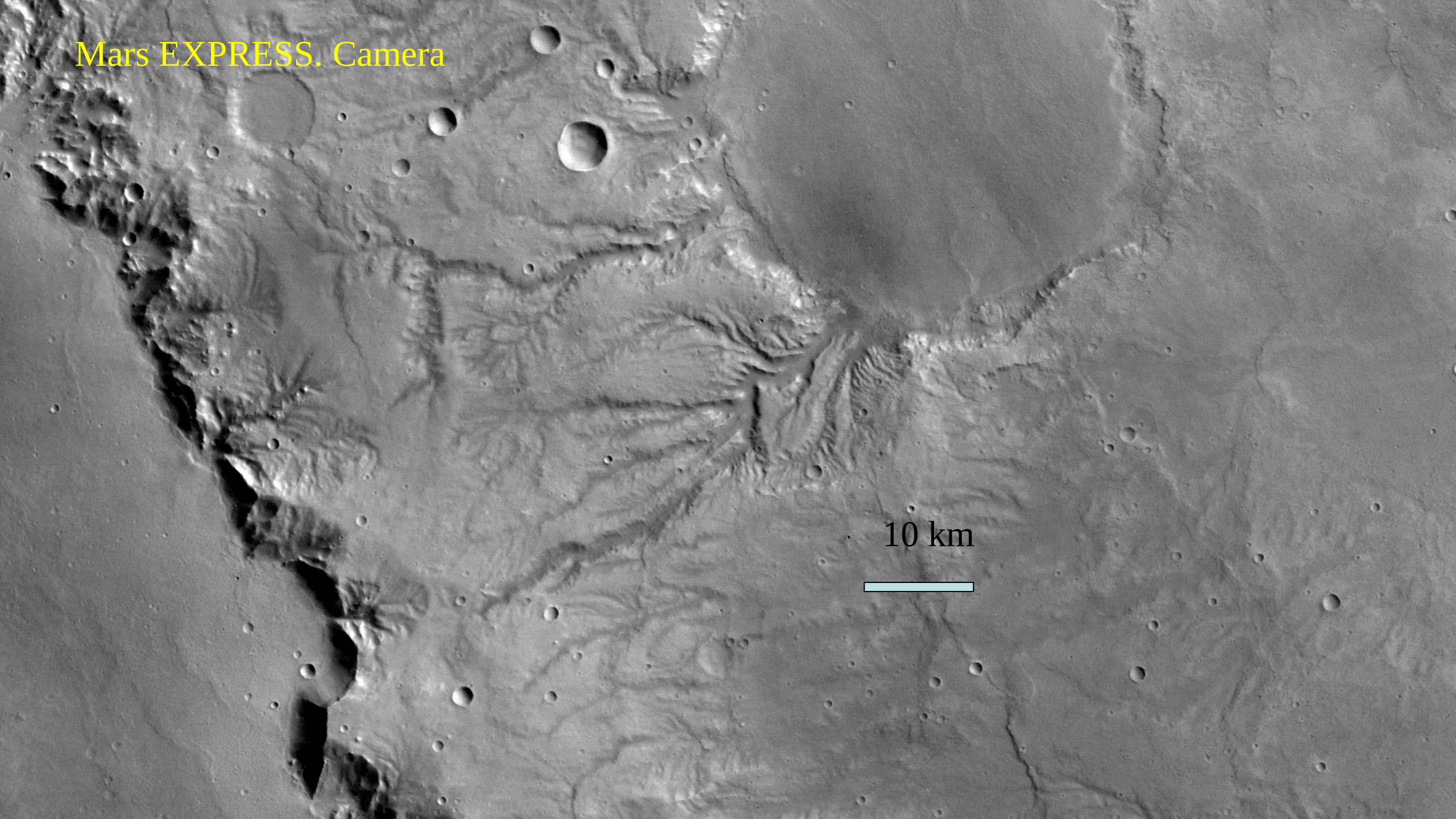
- On the Earth : life = liquid water

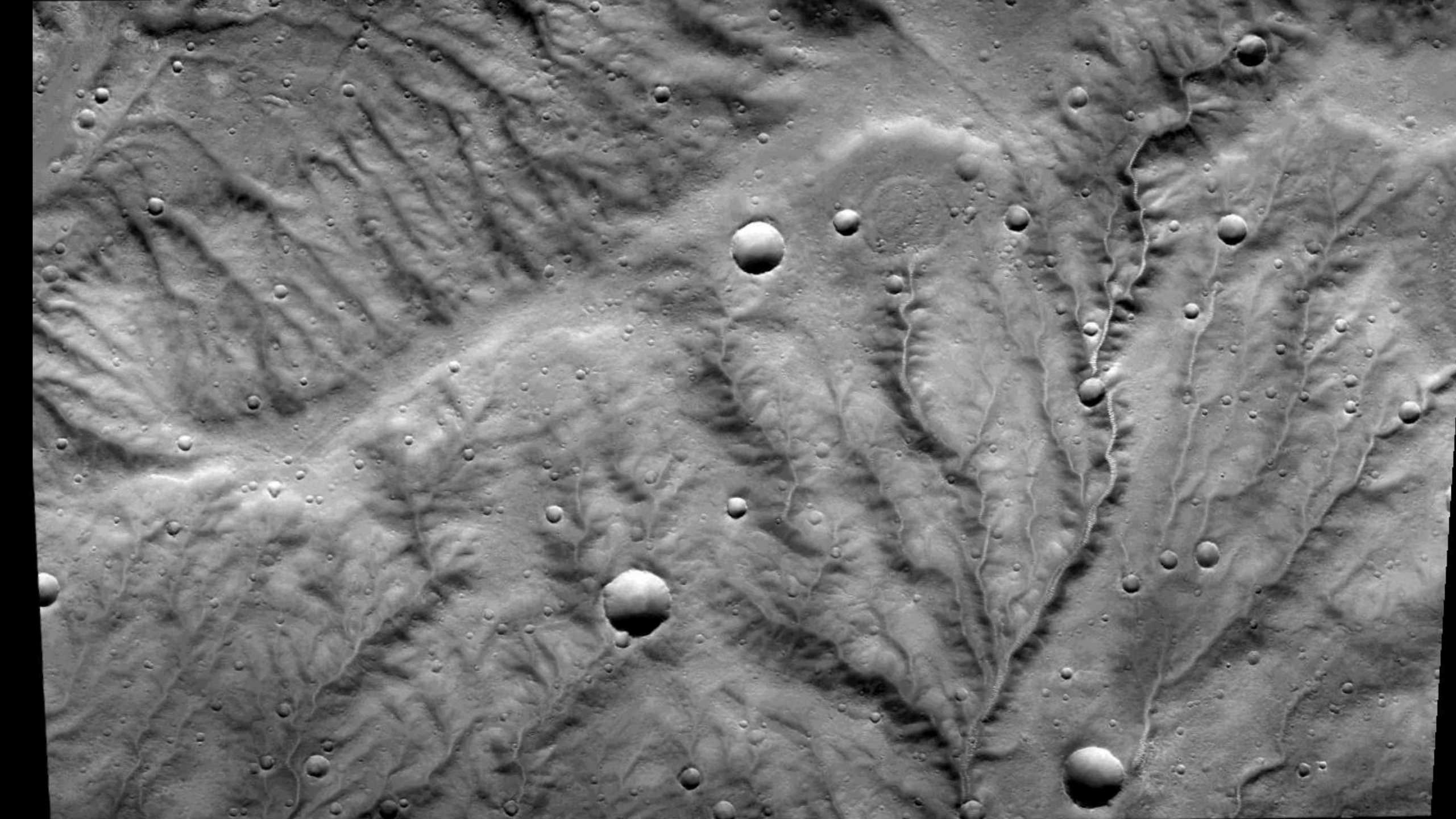


- No liquid water = No life on Mars ?

- AND IN THE PAST ?

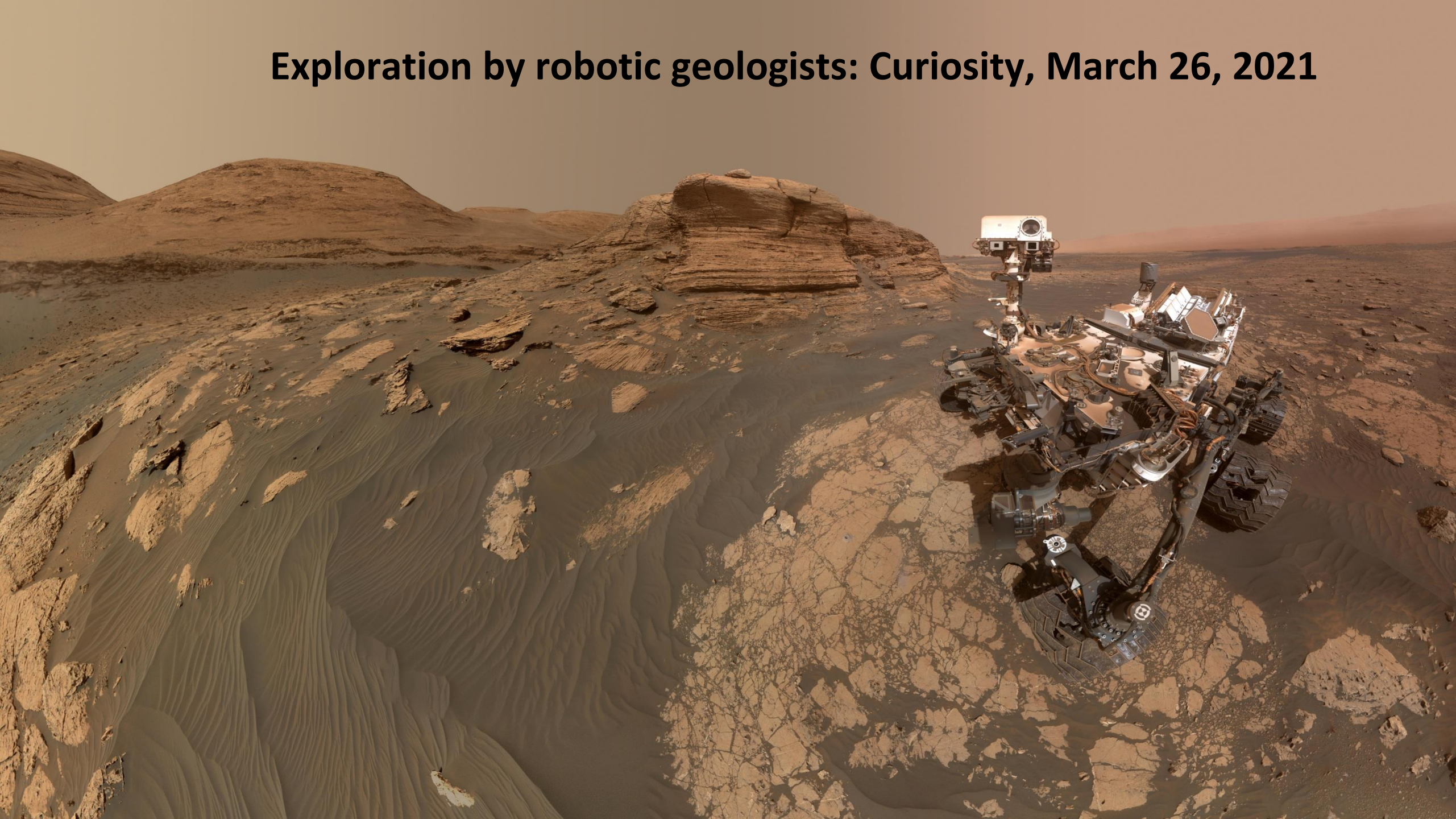

Mars Topography
-8000
-4000
0
4000
8000
12000

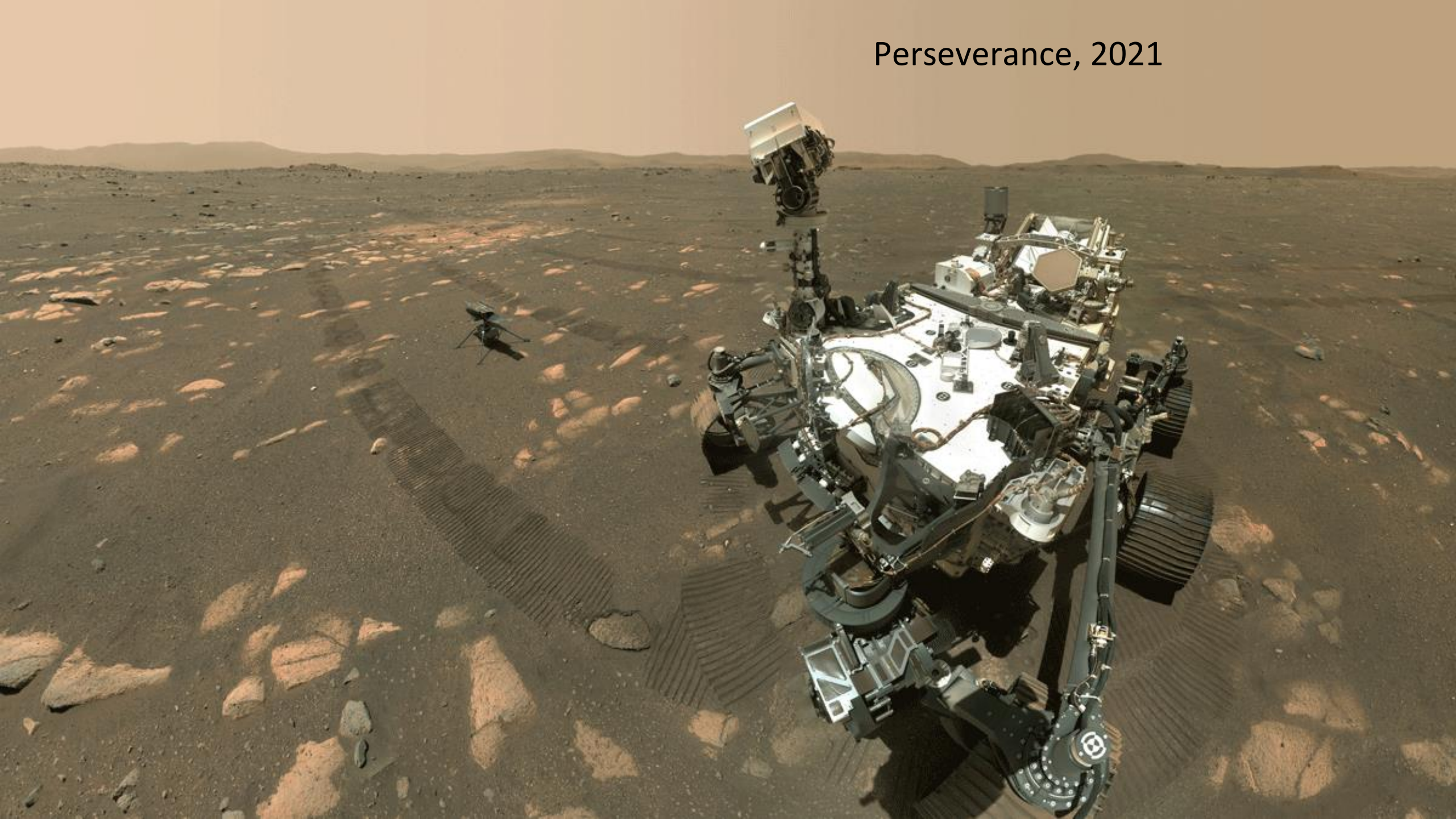

Mars EXPRESS. Camera
10 km

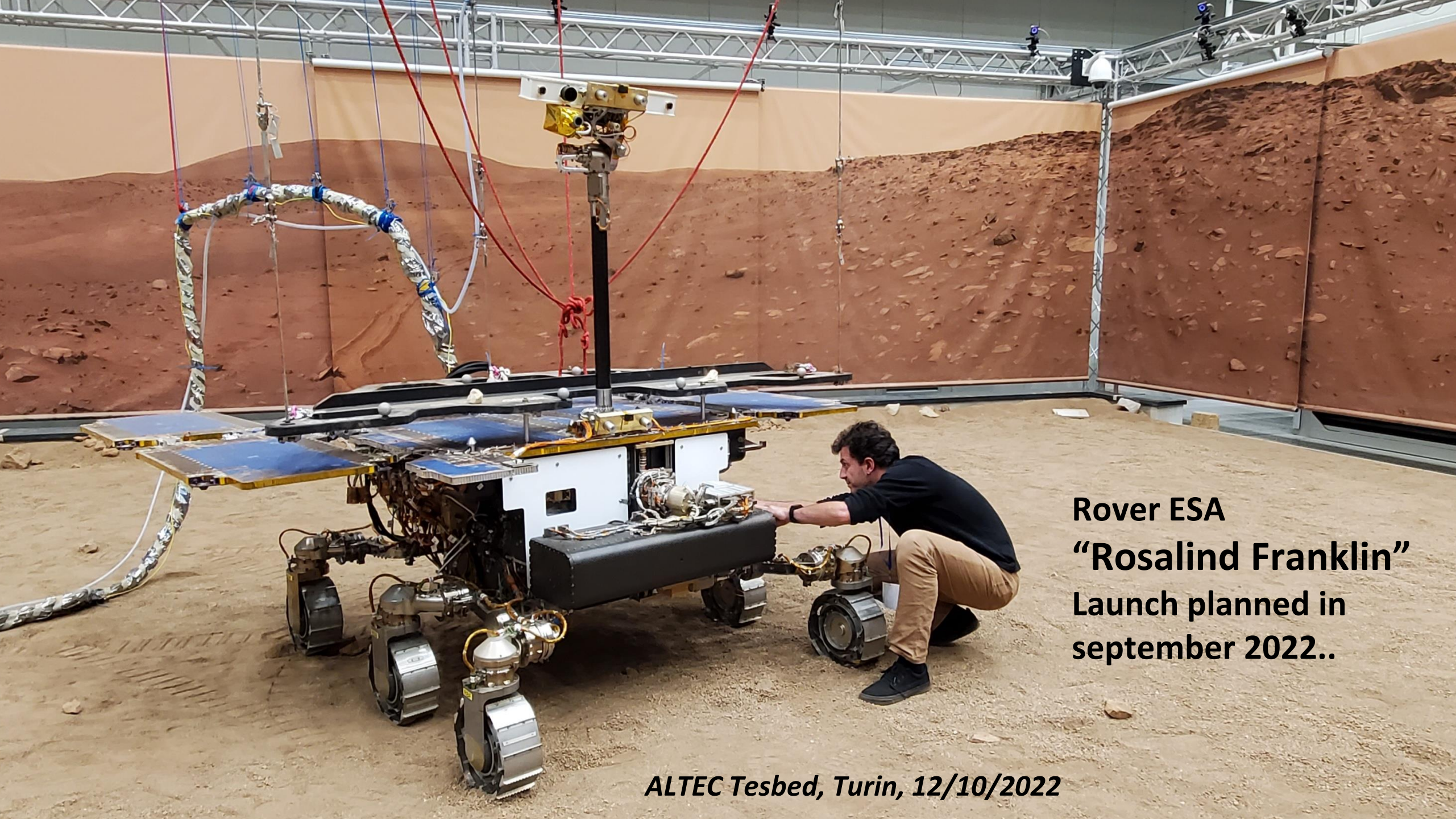


Geomorphology + Mineralogy ⇨ Mars 3-4 Billions years ago ?

Exploration by robotic geologists: Curiosity, March 26, 2021




Perseverance, 2021

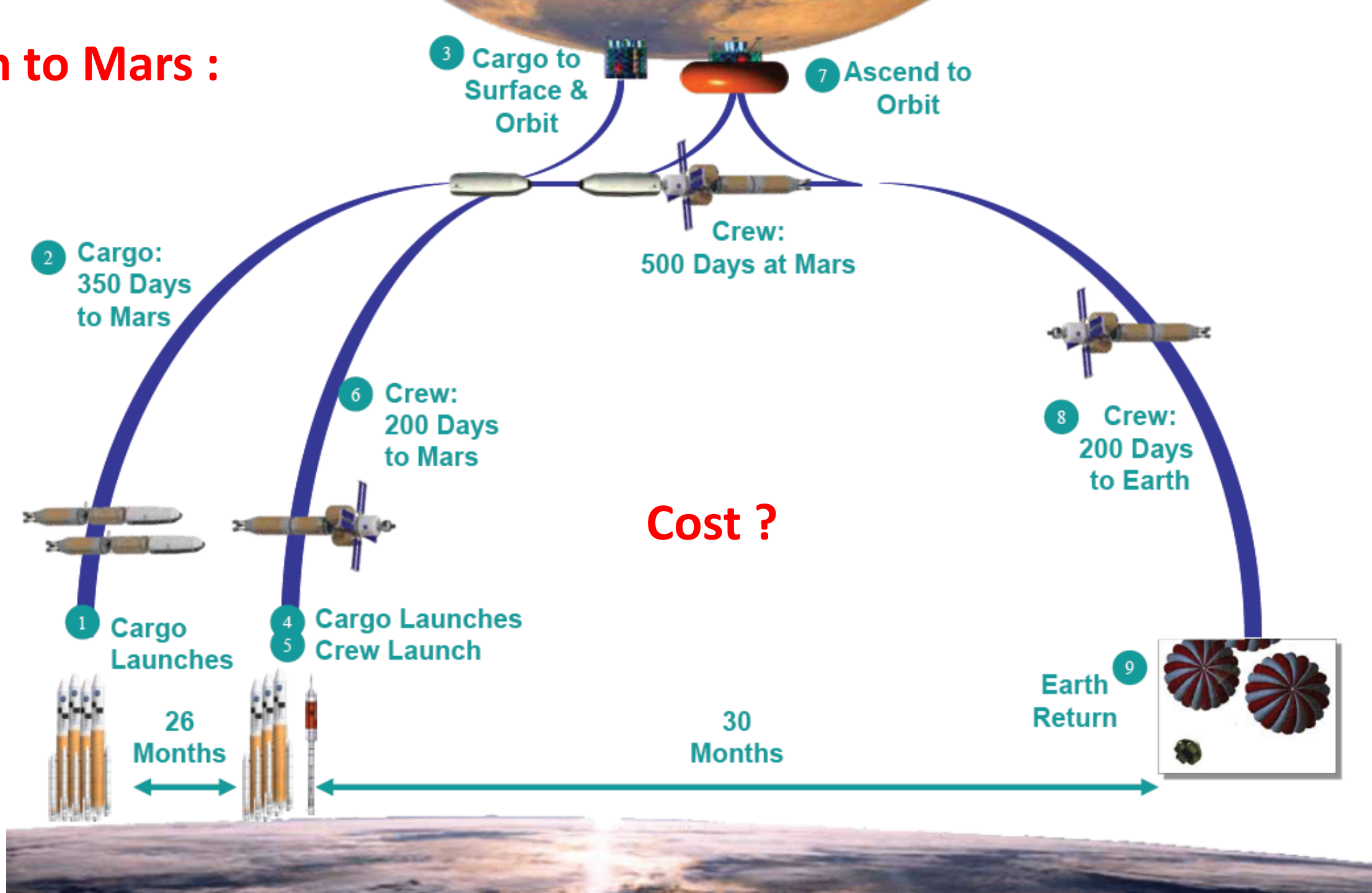


Rover ESA
“Rosalind Franklin”
Launch planned in september 2022..

ALTEC Tesbed, Turin, 12/10/2022

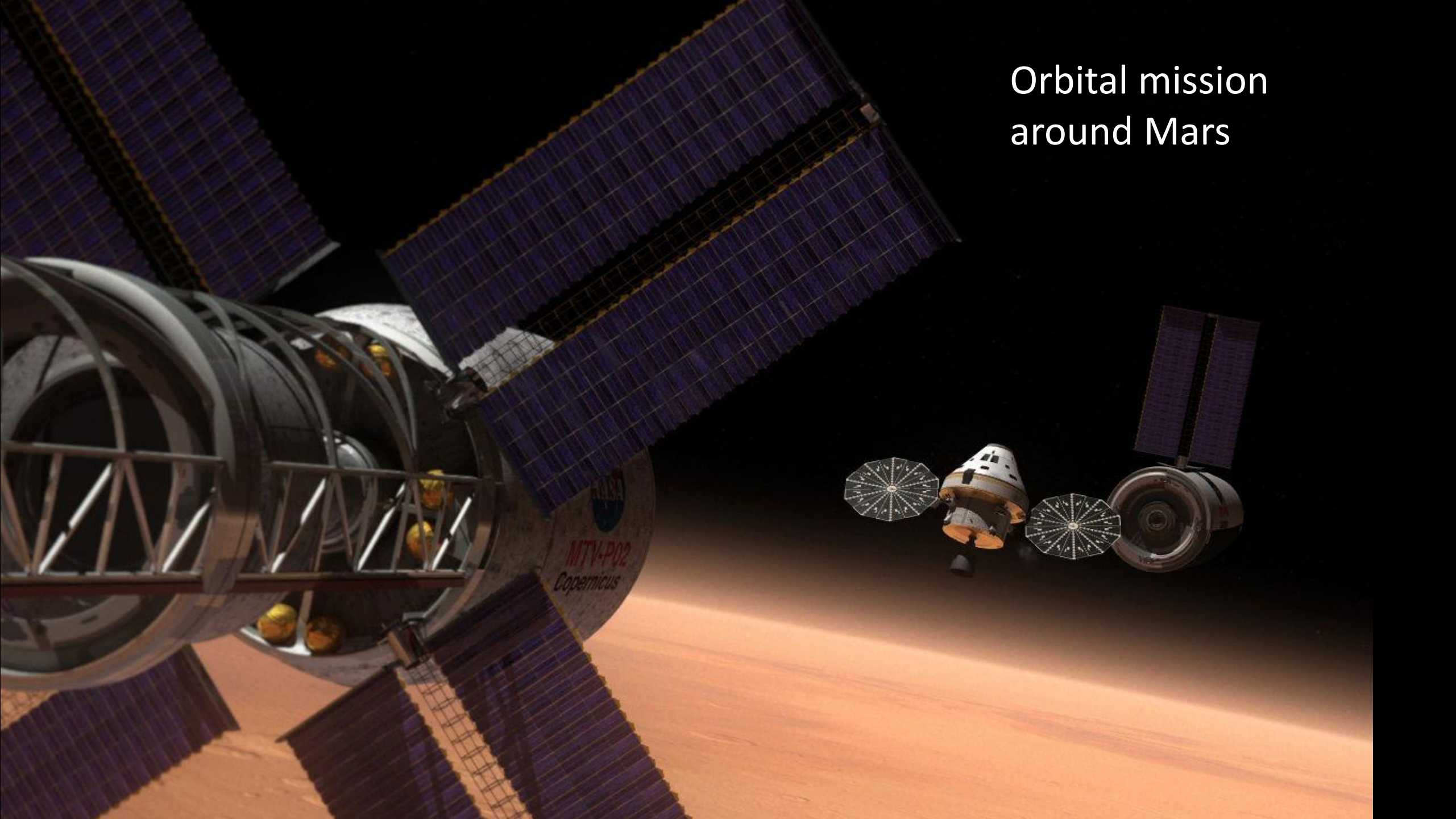
Humans on Mars ?

Mission to Mars :

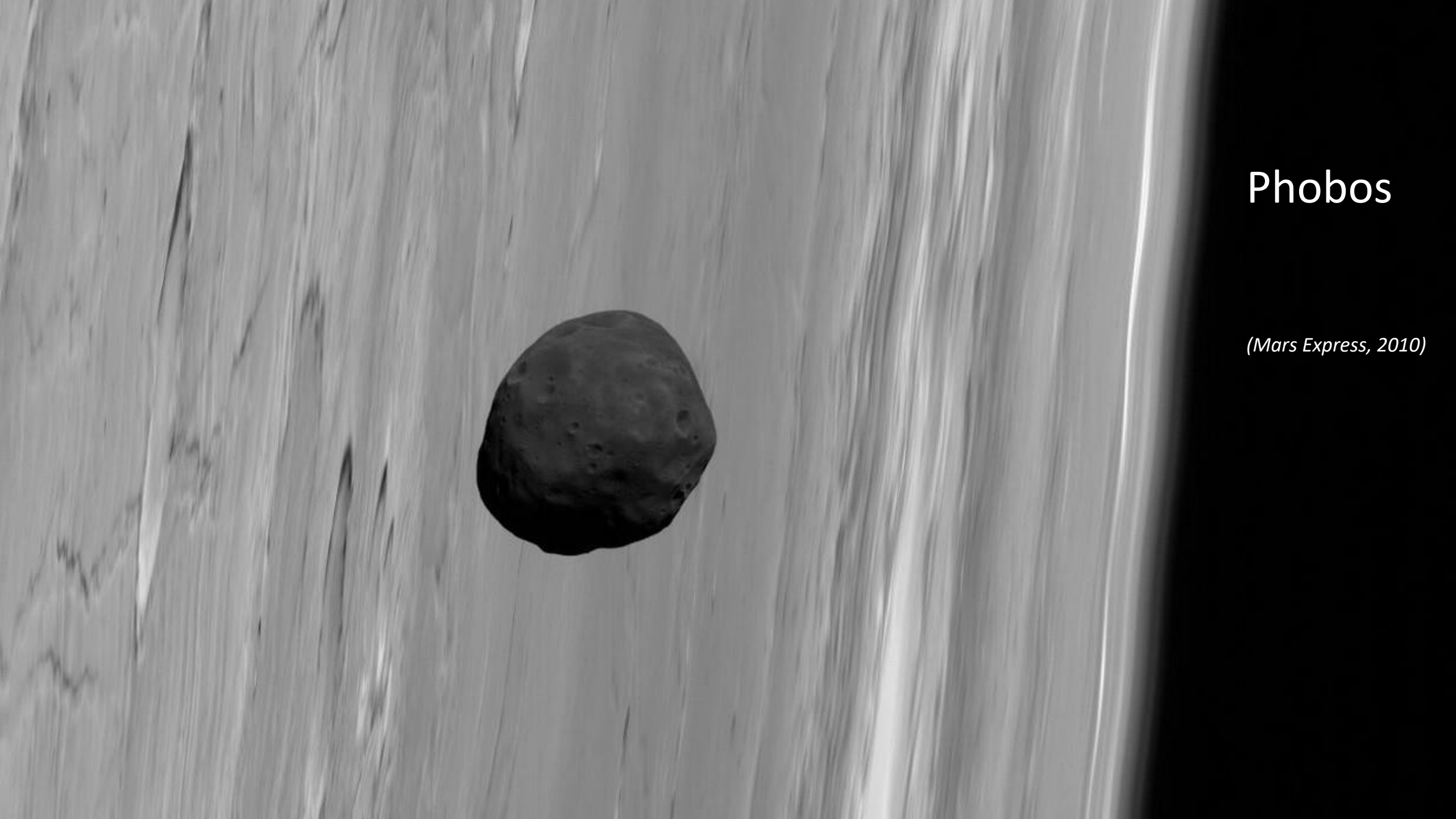


Technical Challenges of a crewed Mars mission

- **Journey to Mars:**
  - A long duration transportation/habitation spaceship
    (roomy enough, perfectly recycling, repairable)
  - Health and psychology (microgravity, radiation, confinement)
- **Landing on Mars**
- **Living on Mars** (habitats, spacesuits, power, ressources, contamination)
- **Getting back from Mars surface**

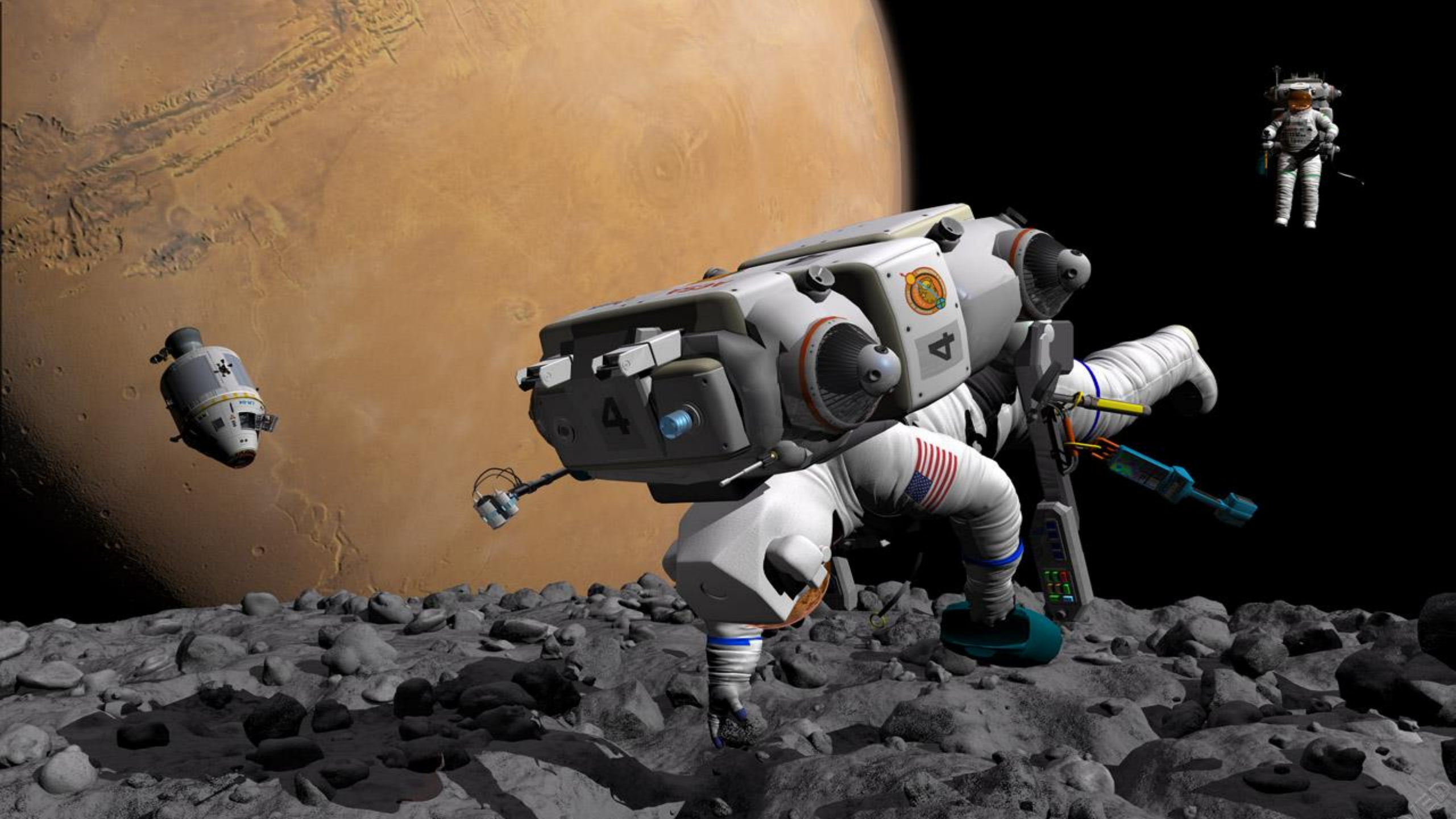


Orbital mission around Mars



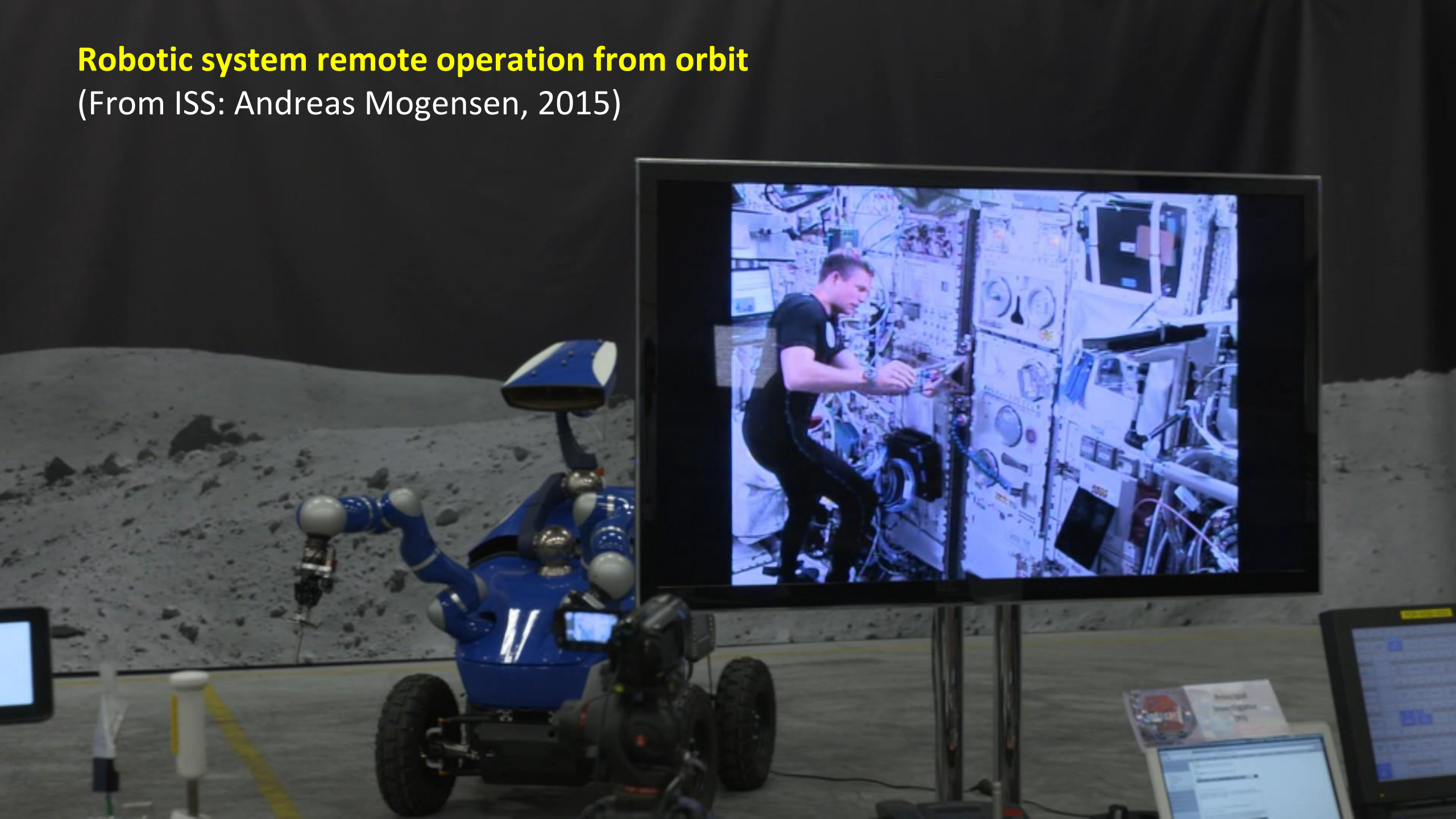
Phobos

(Mars Express, 2010)


4
4

Robotic system remote operation from orbit

(From ISS: Andreas Mogensen, 2015)



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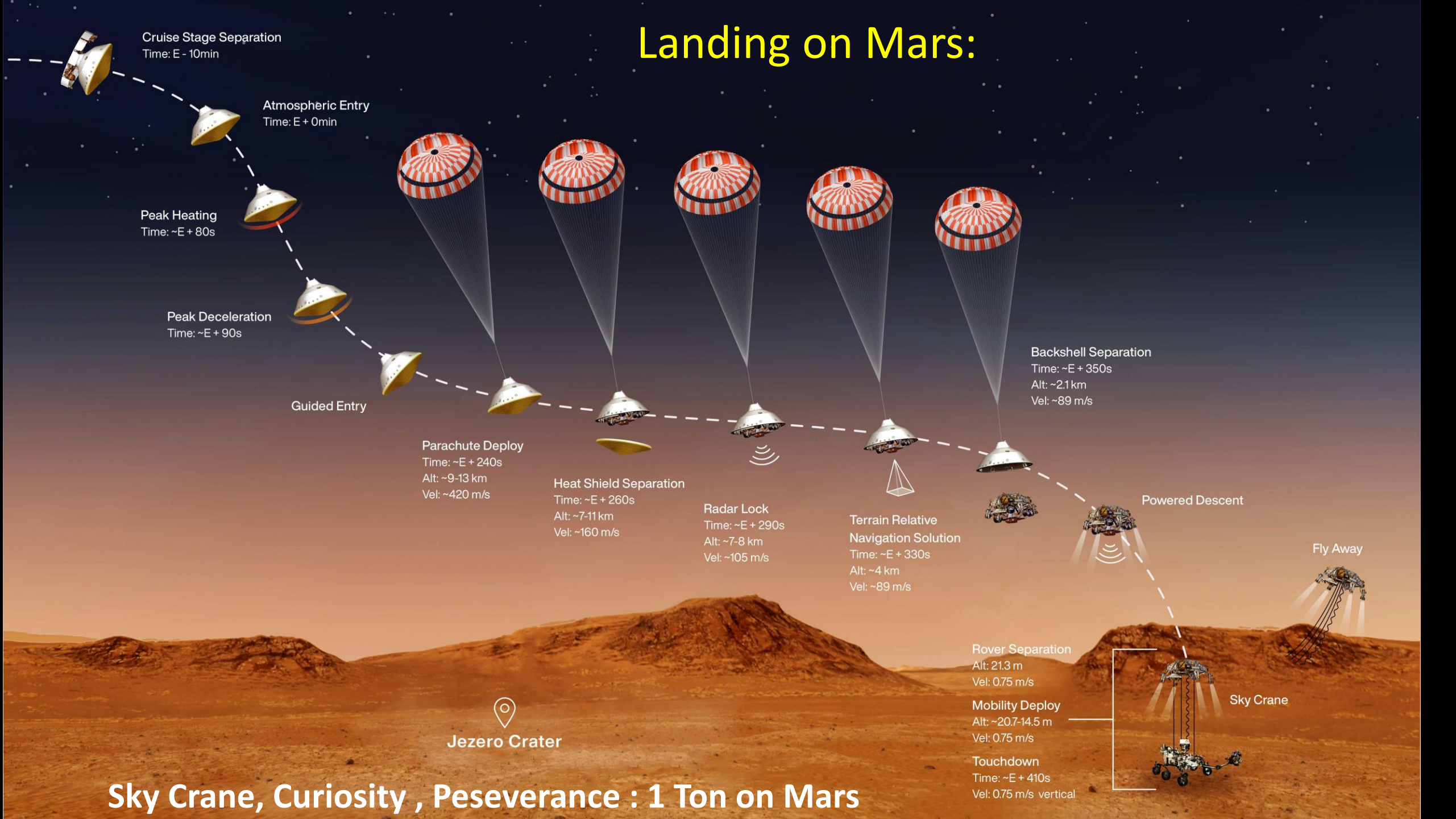
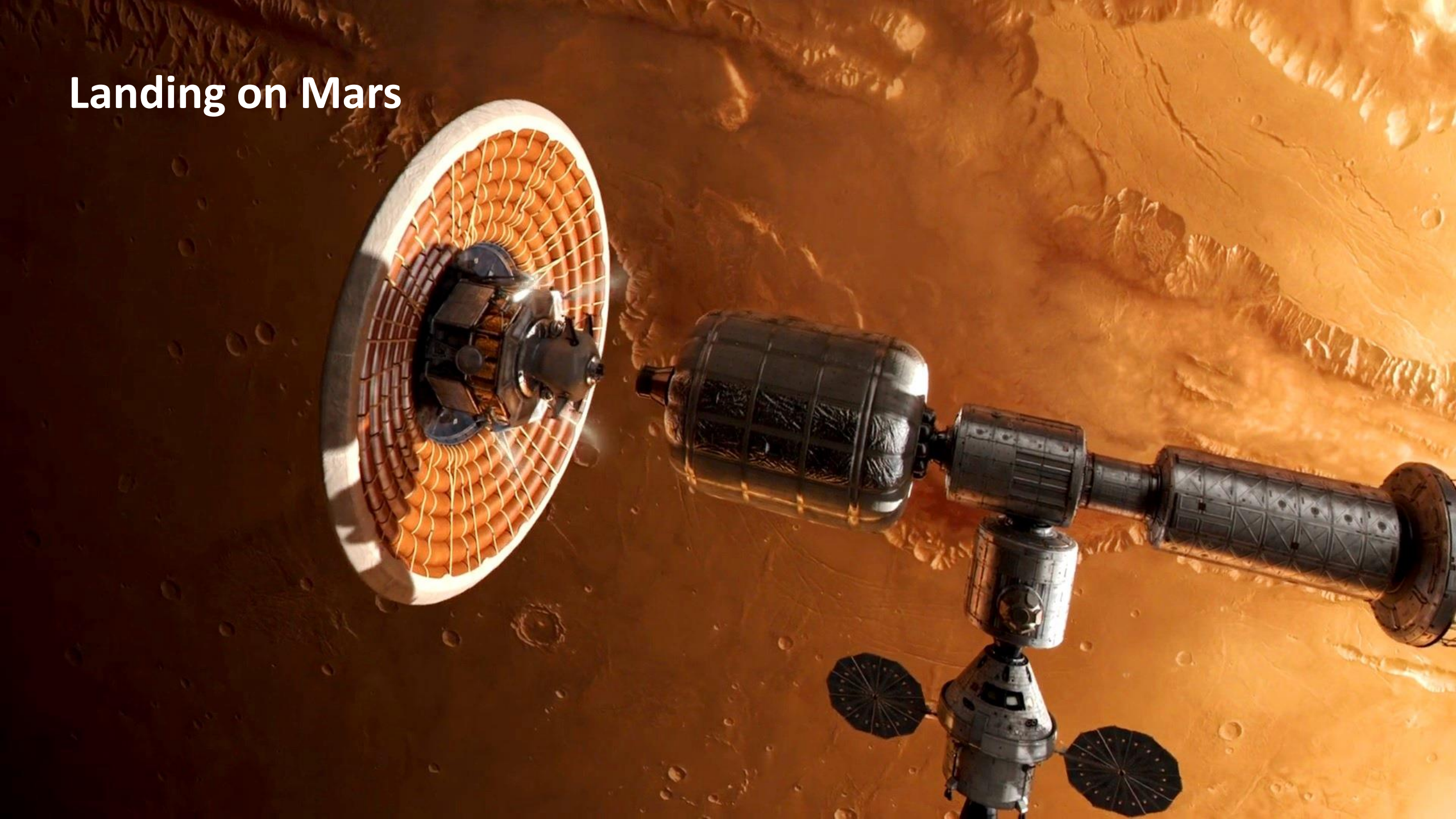
Landing on Mars:

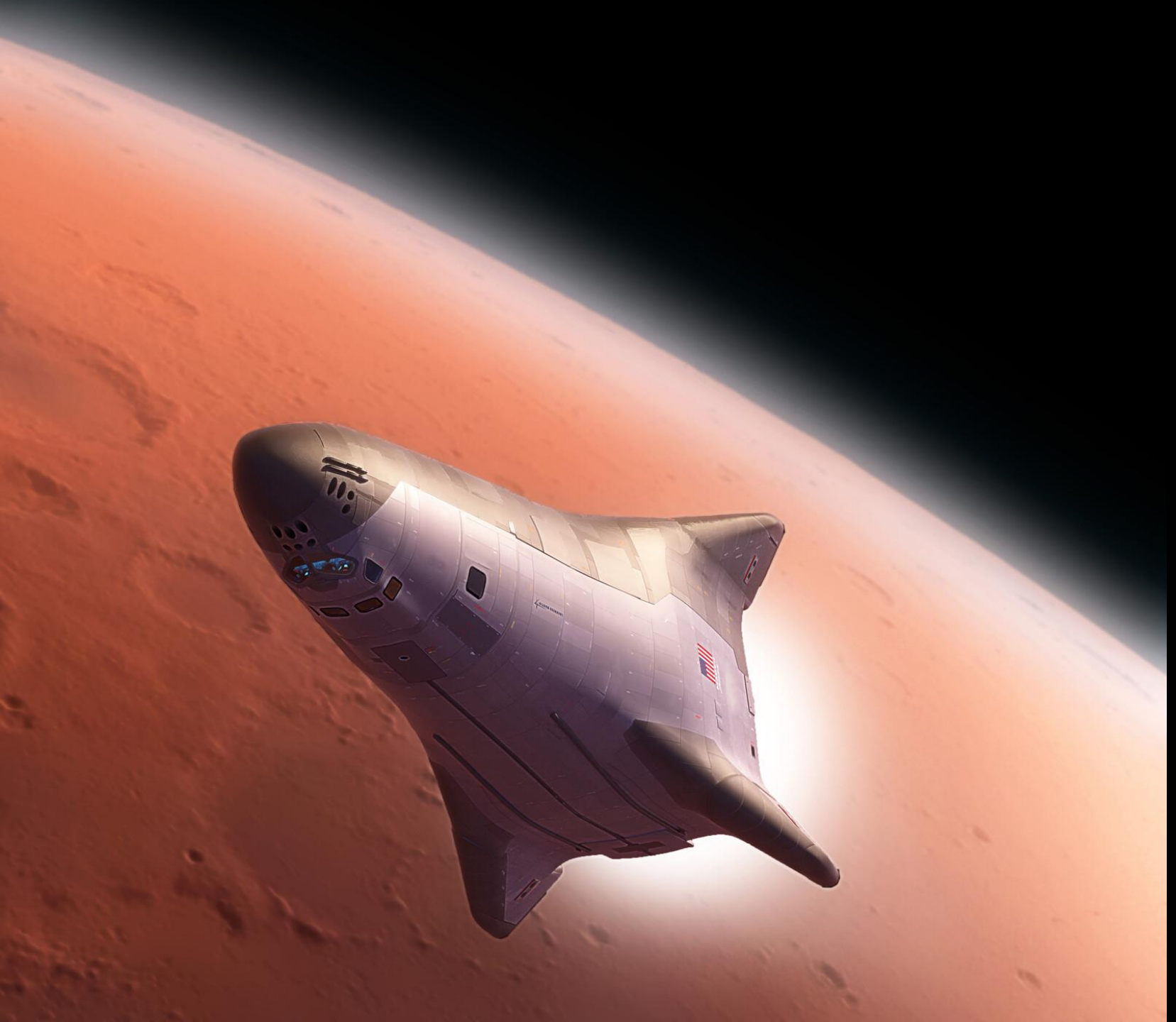


Sky Crane, Curiosity , Peseverance : 1 Ton on Mars

Landing on Mars



The
Hypersonic Inflatable Aerodynamic Decelerator,



With retrorockets…


SPACEX


SPACEX

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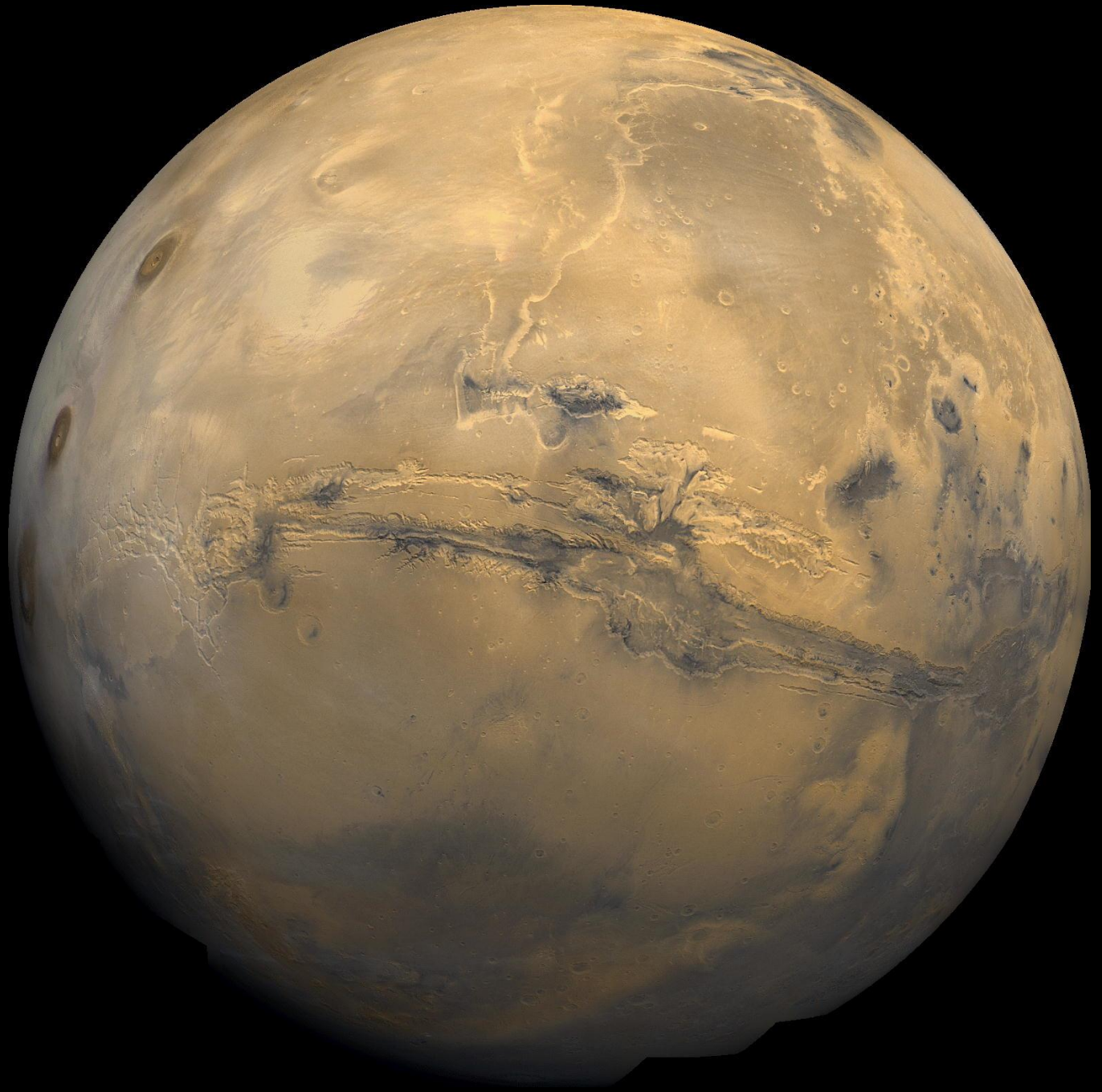
Living on the Martian Surface

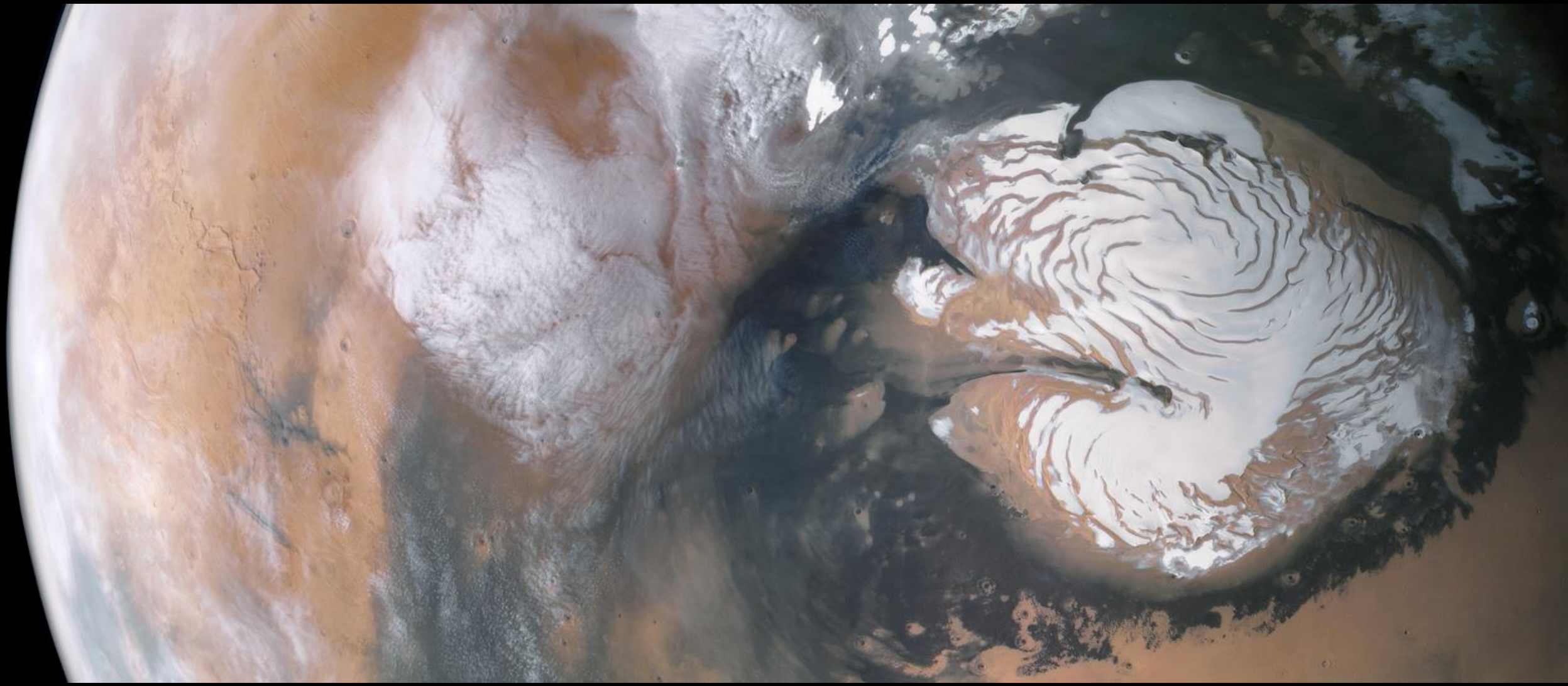
Wojciech Fikus

Water
In-situ ressources on Mars

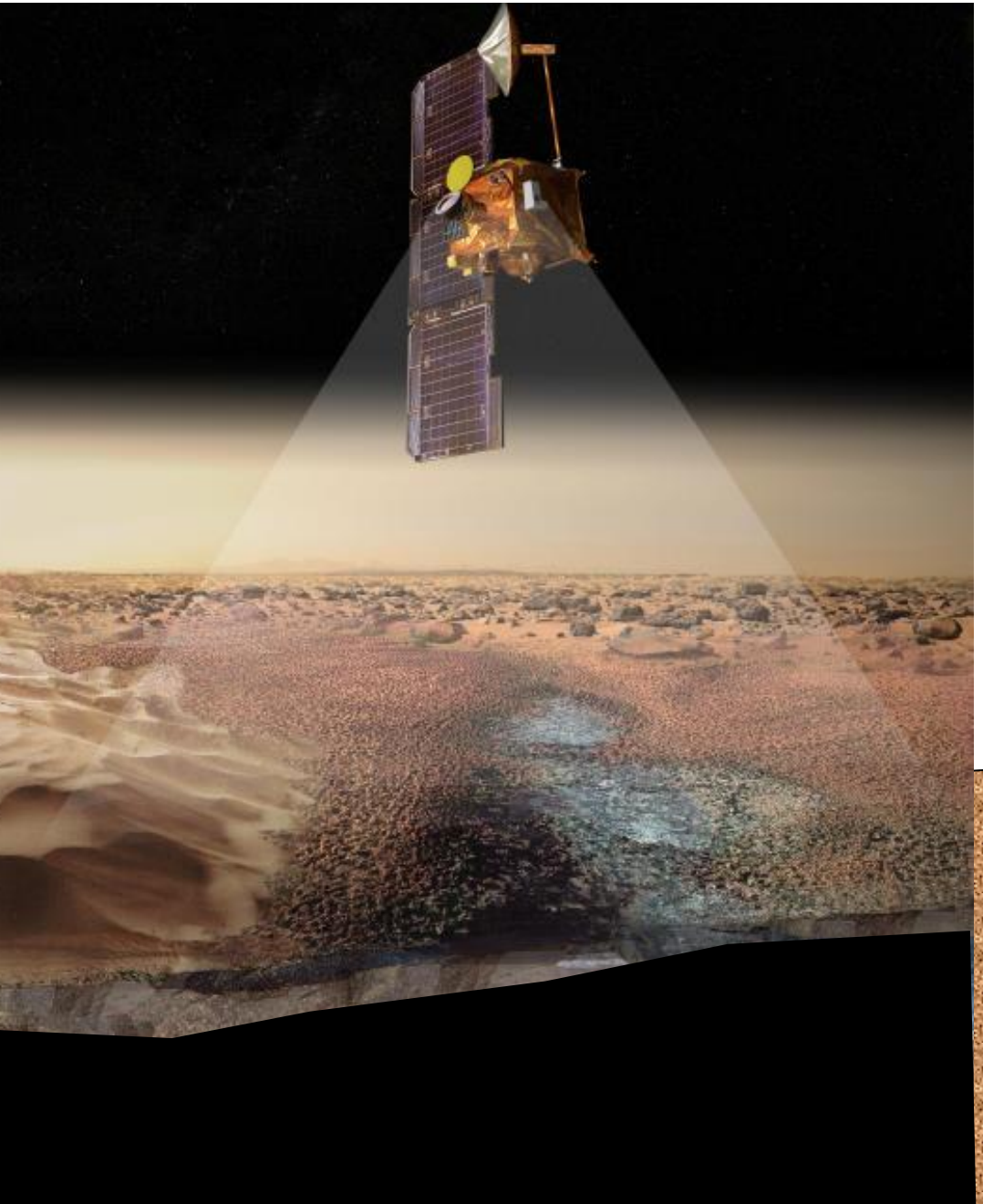
to drink, breathe, manufacture rocket propellant, etc…°

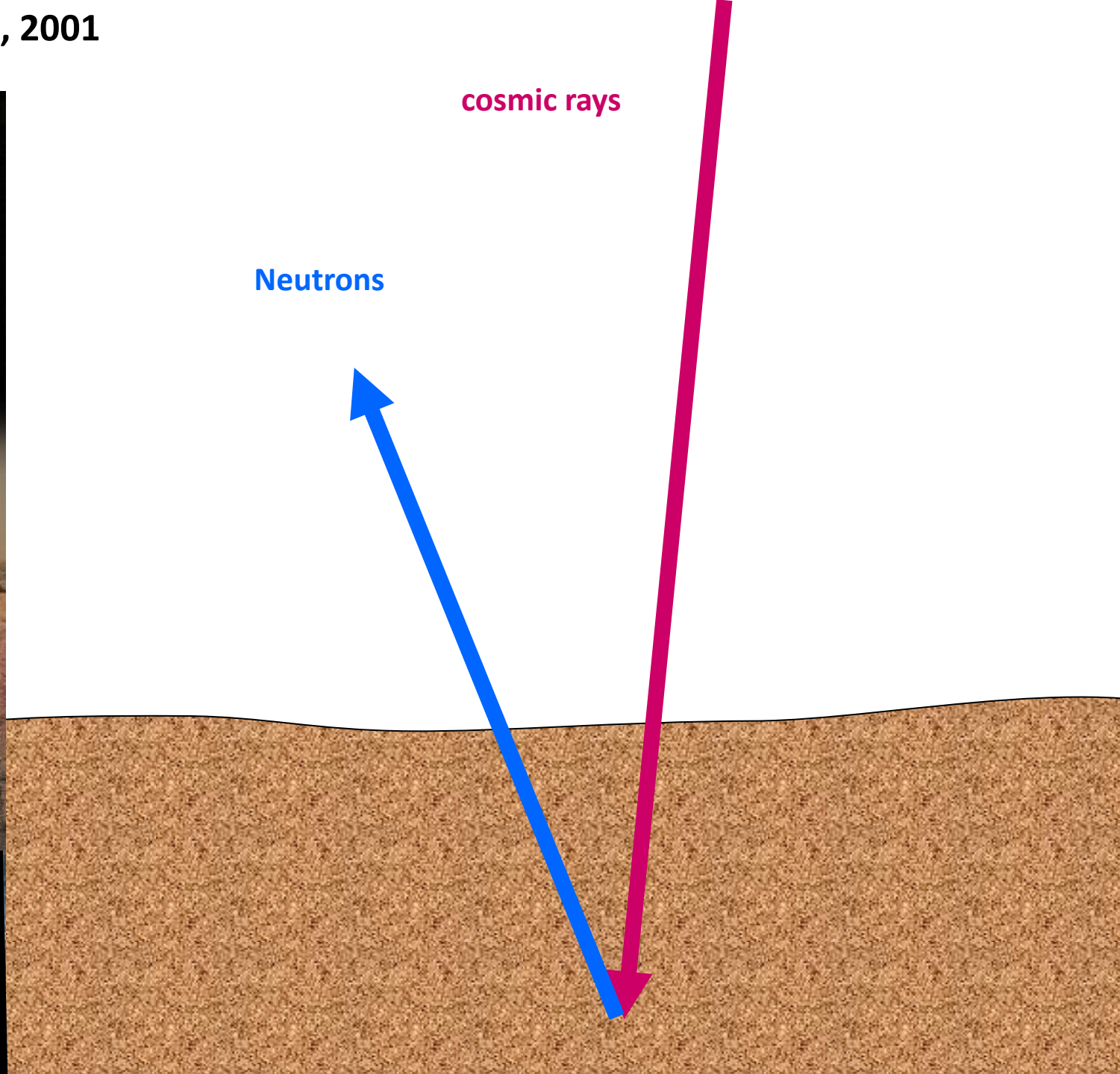


(Mosaic from Viking mission in 1977)

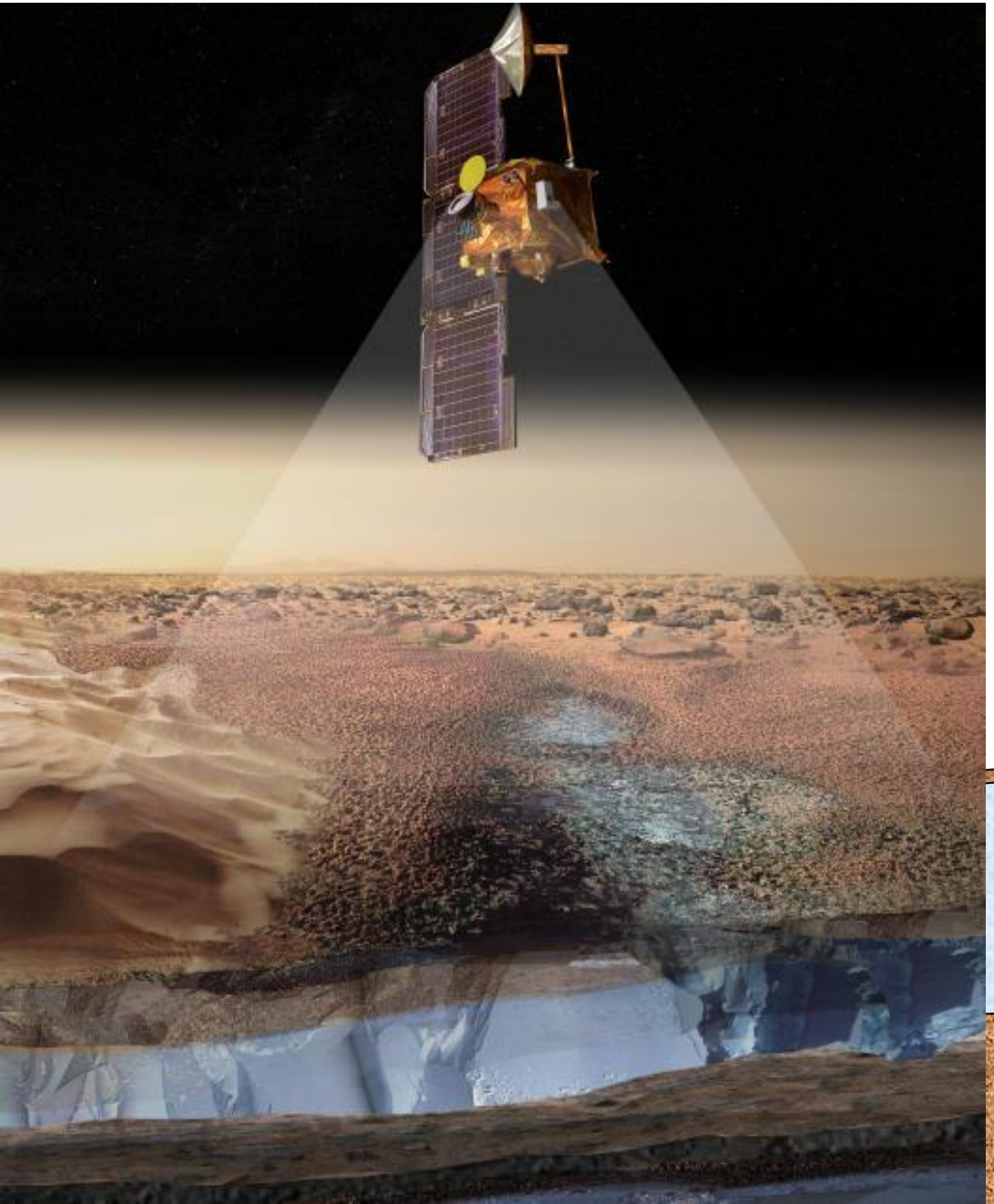

200 km

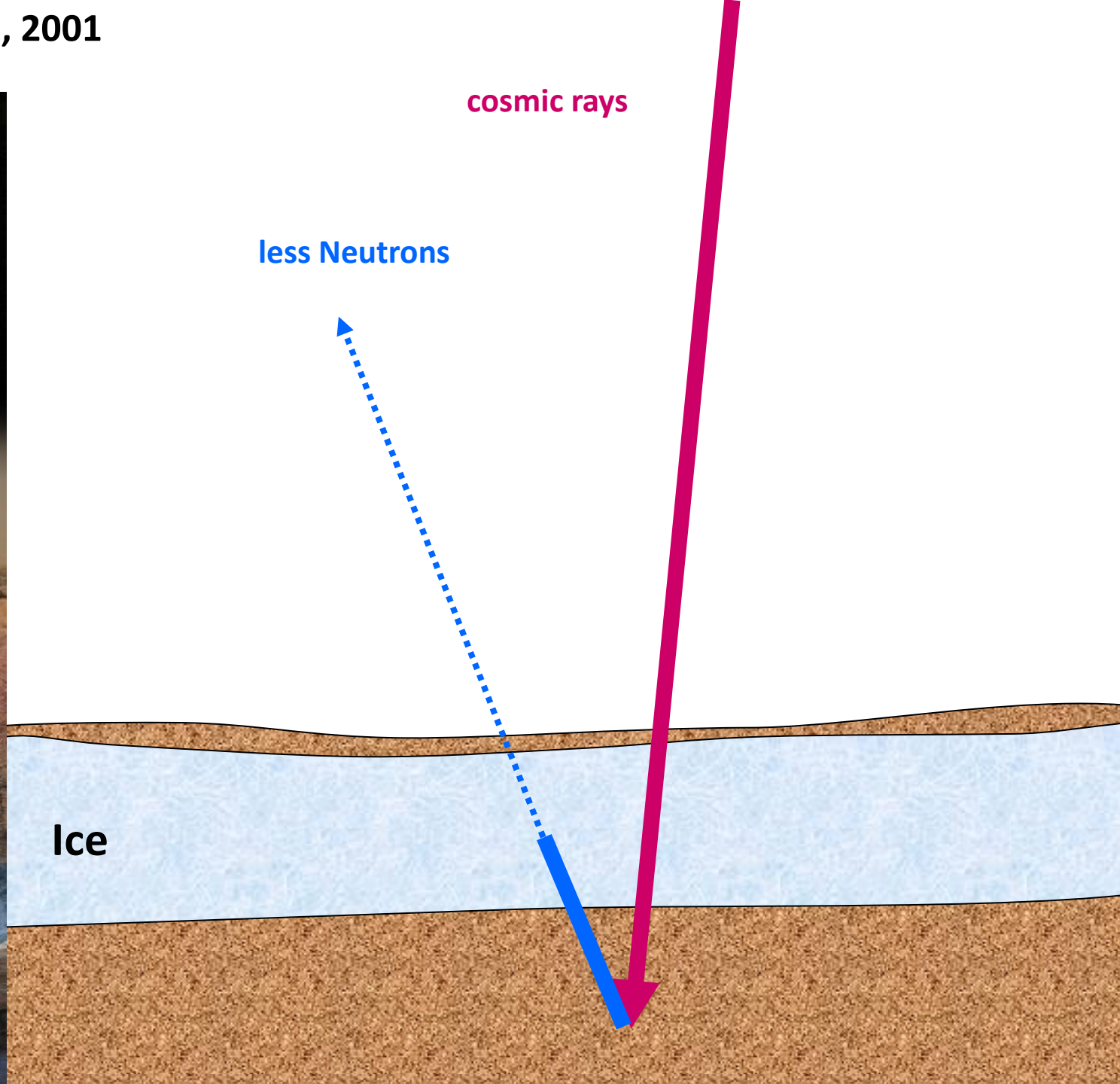
Neutron Spectrometer, NASA Mars Odyssey , 2001





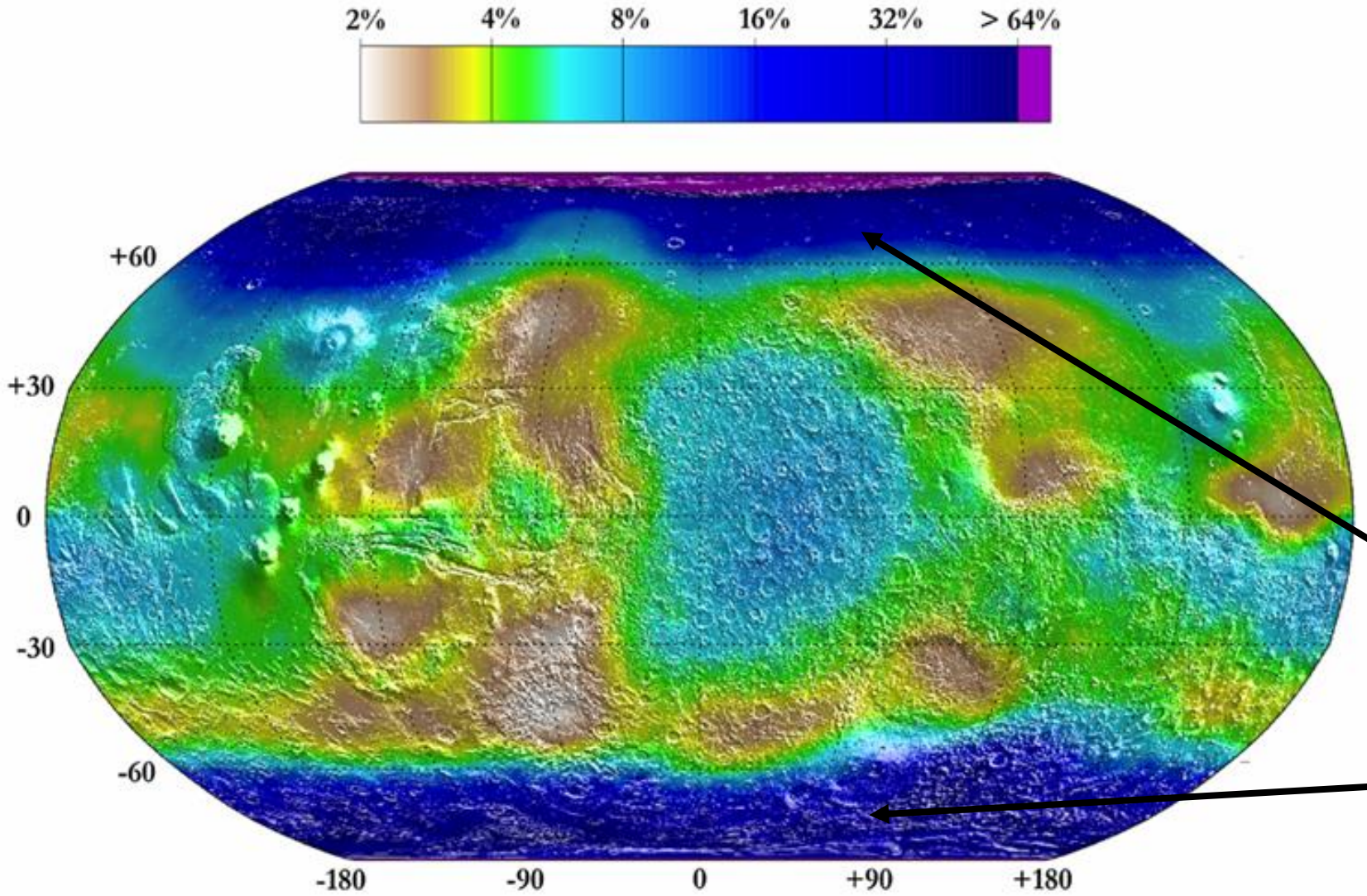
Neutron Spectrometer, NASA Mars Odyssey , 2001

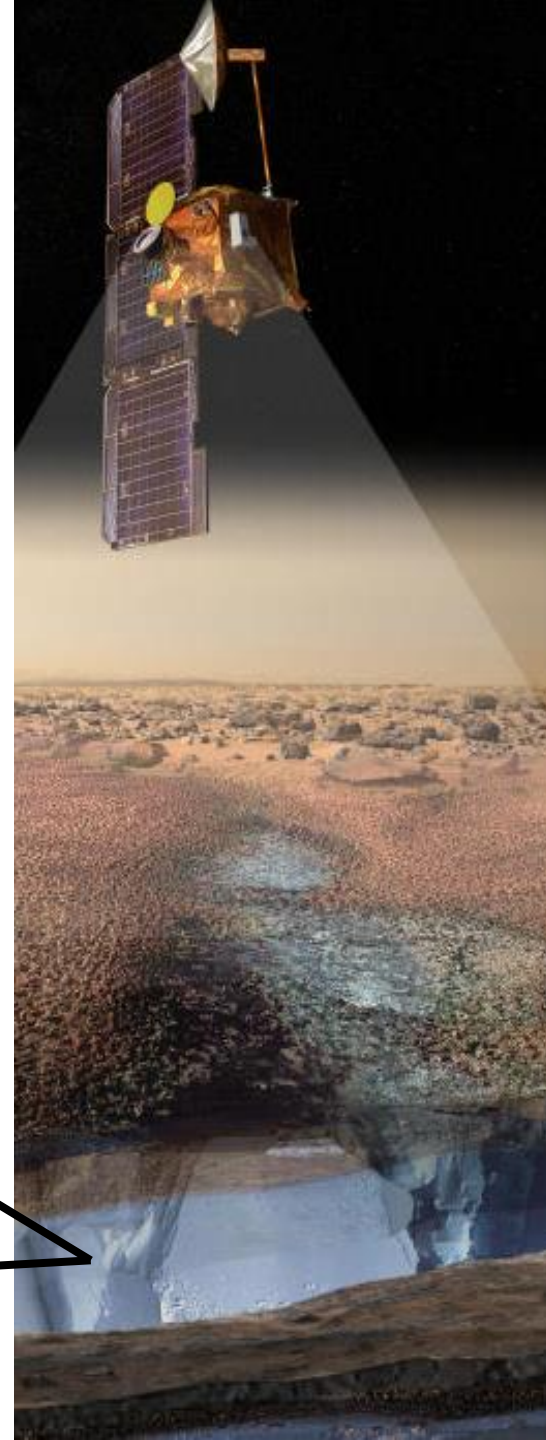




An ice-rich layer discovered by Mars Odyssey below a few cm of dry sediments

Minimum water equivalent hydrogen abundance (weight percent) deduced from Neutron flux
(Boynton et al. 2002 , Feldman et al. 2004)

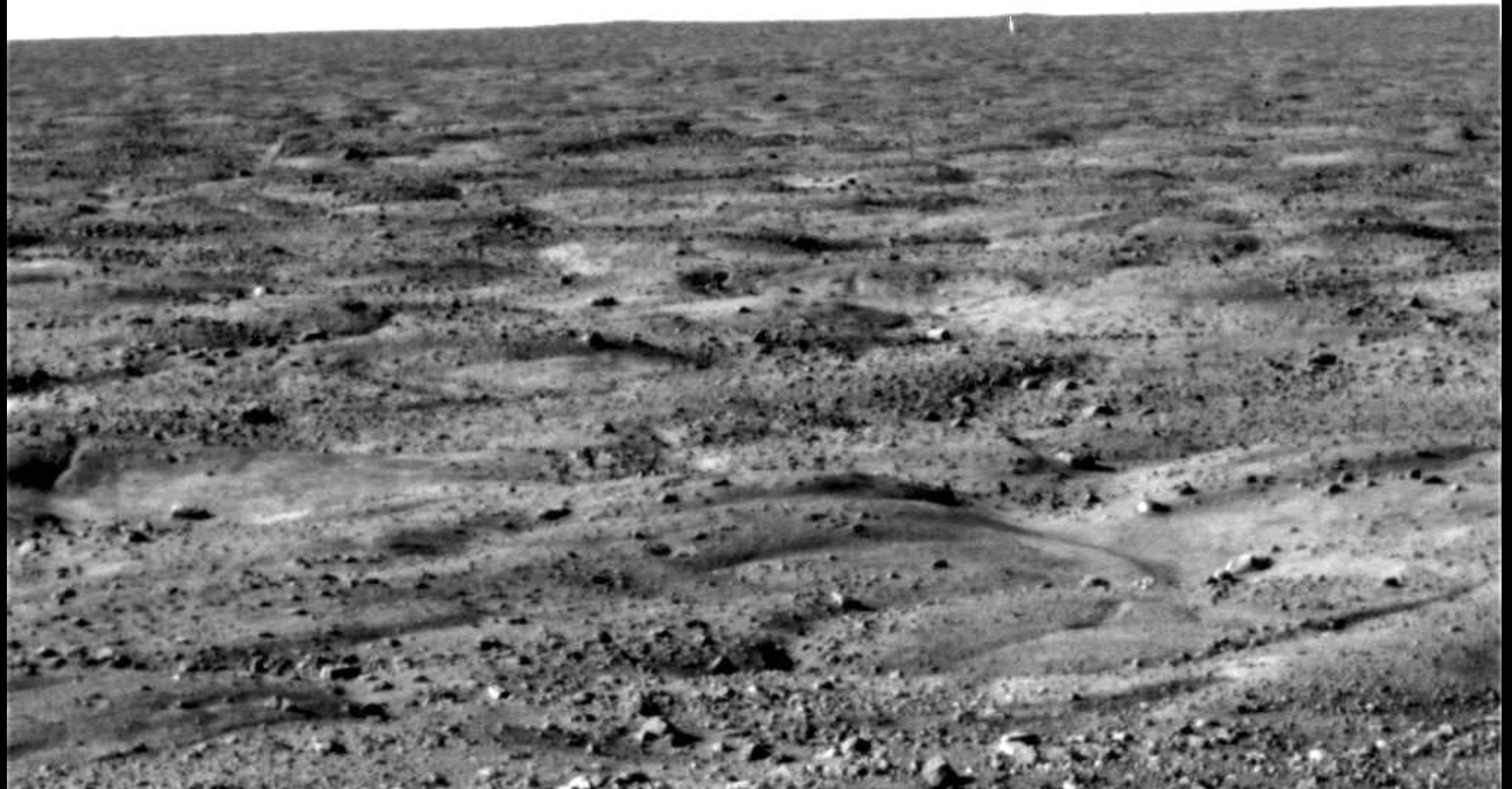


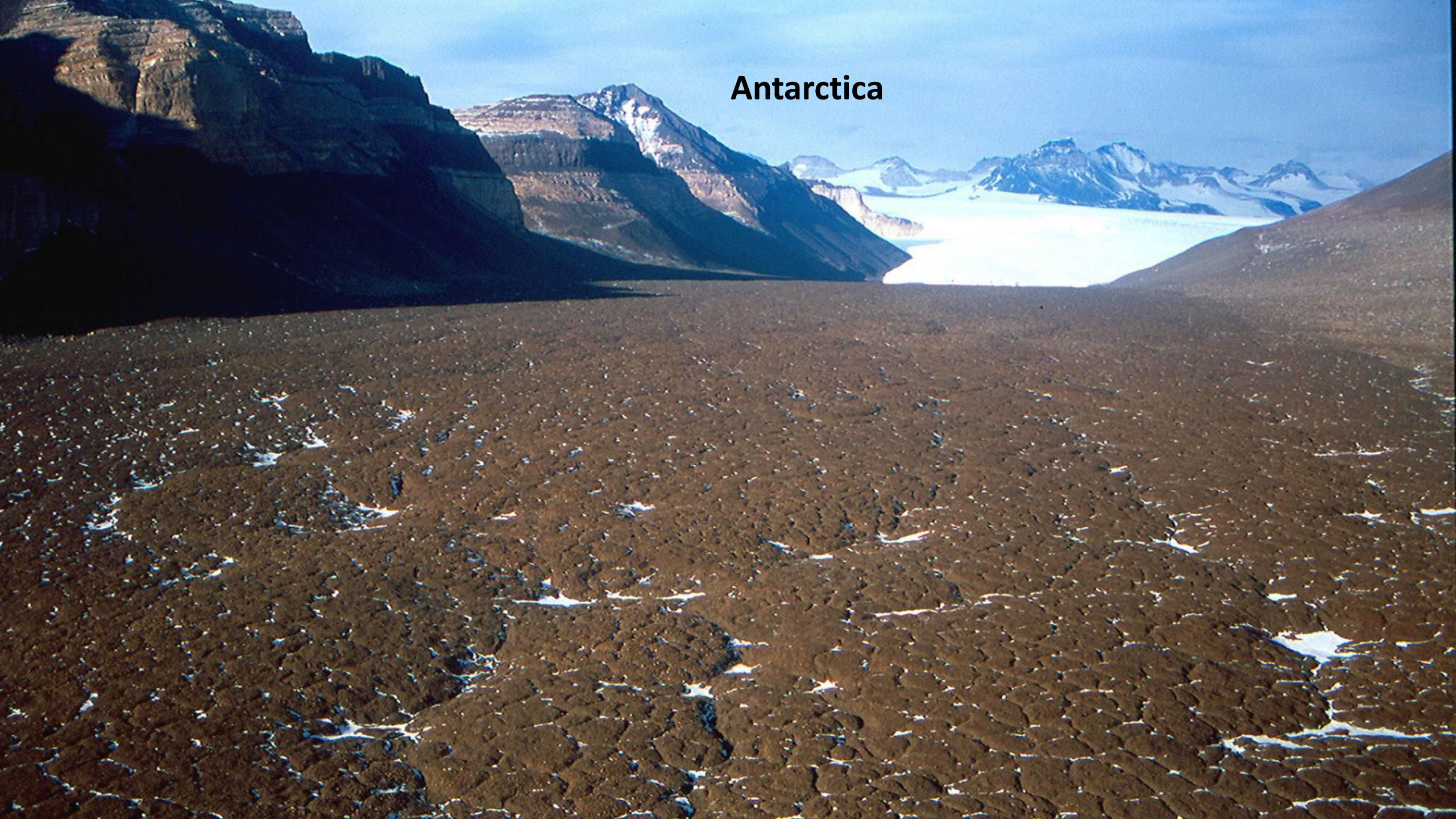


Phoenix: May 25, 2008 68°N

First Ground View of the Mars Polar Region

1st image Phoenix, may 2008

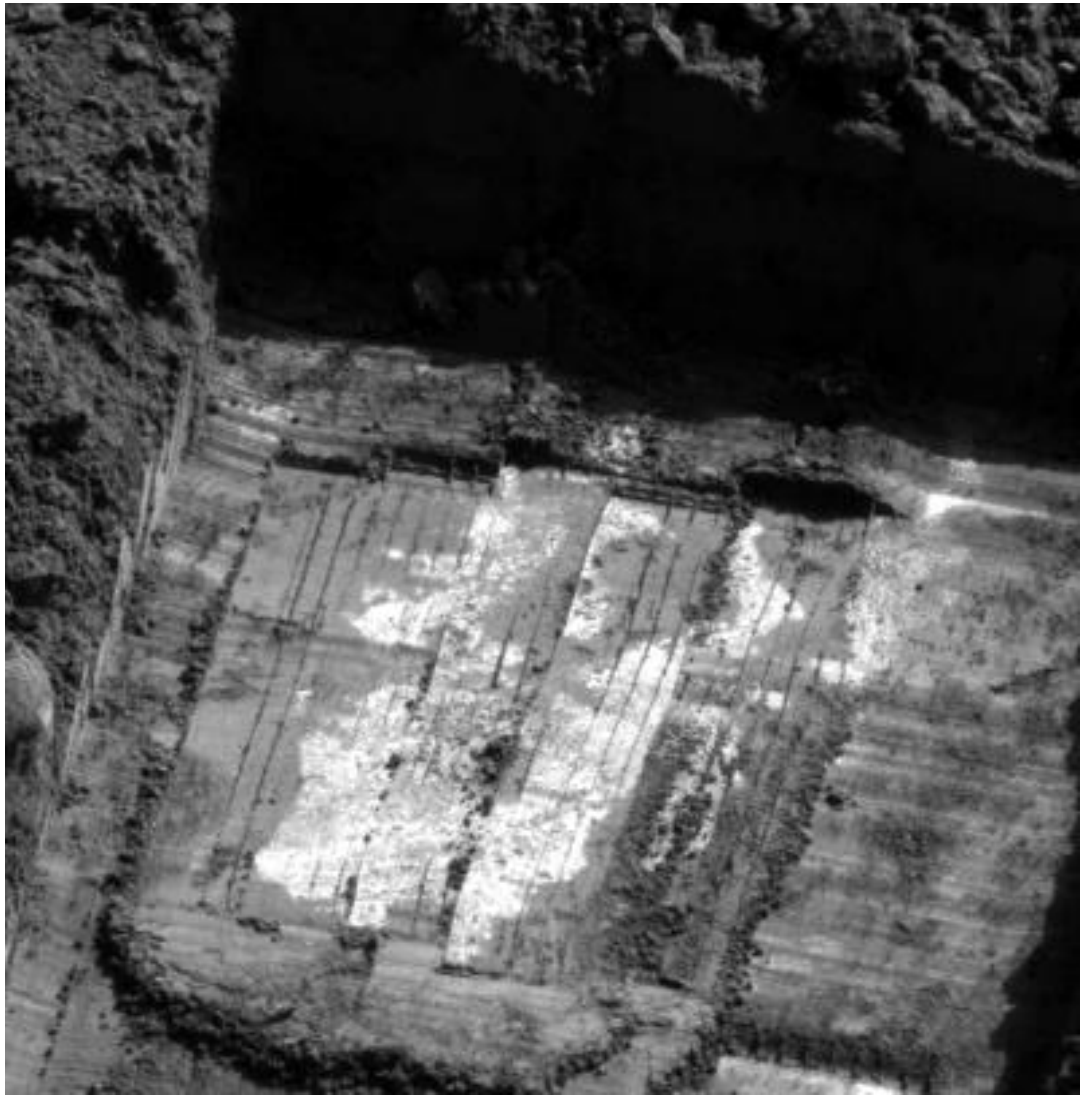



Antarctica

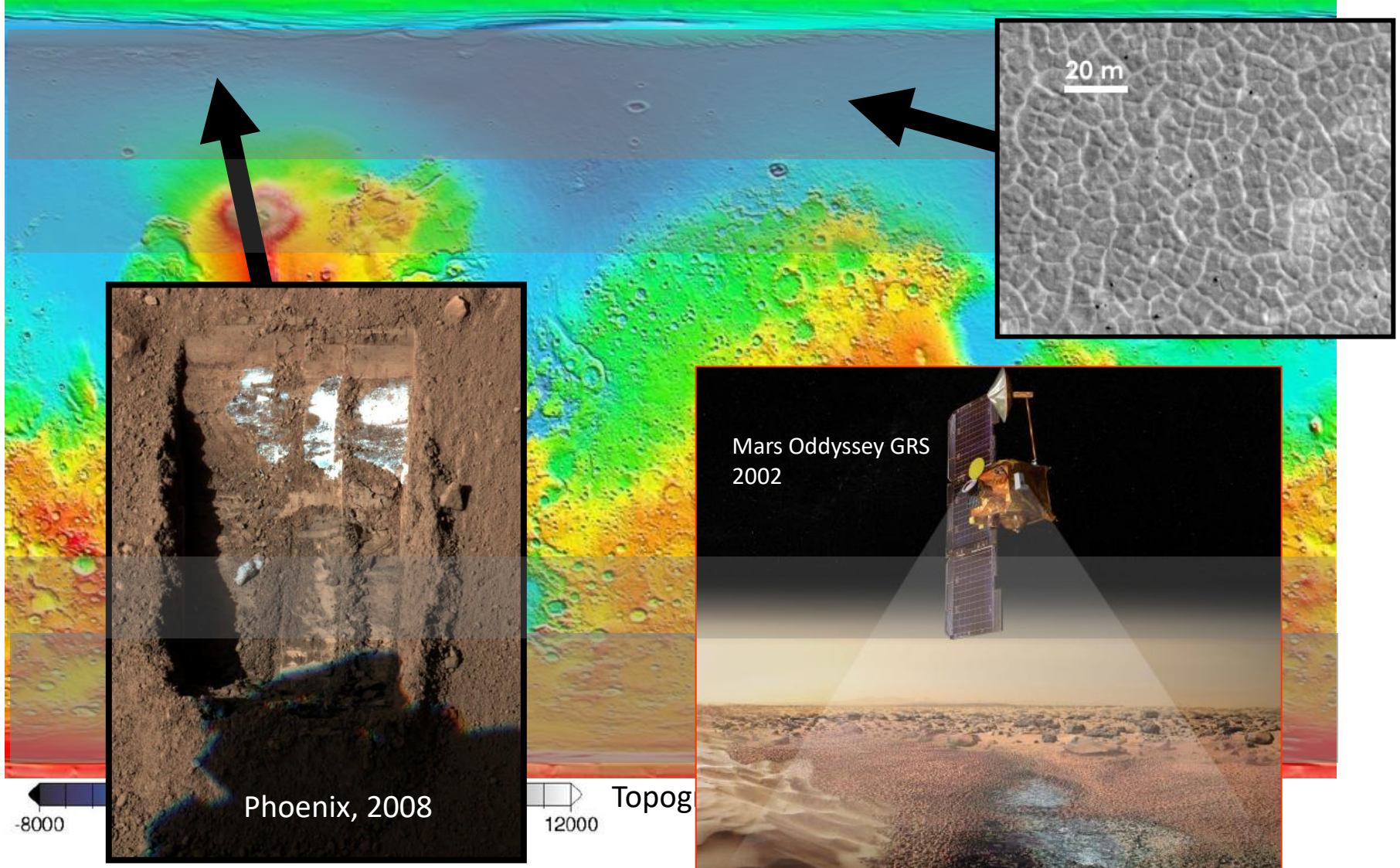
Below Phoenix : ice exposed by landing thrusters

Phoenix Ice-Bottomed Trenches

Dodo-Goldilocks



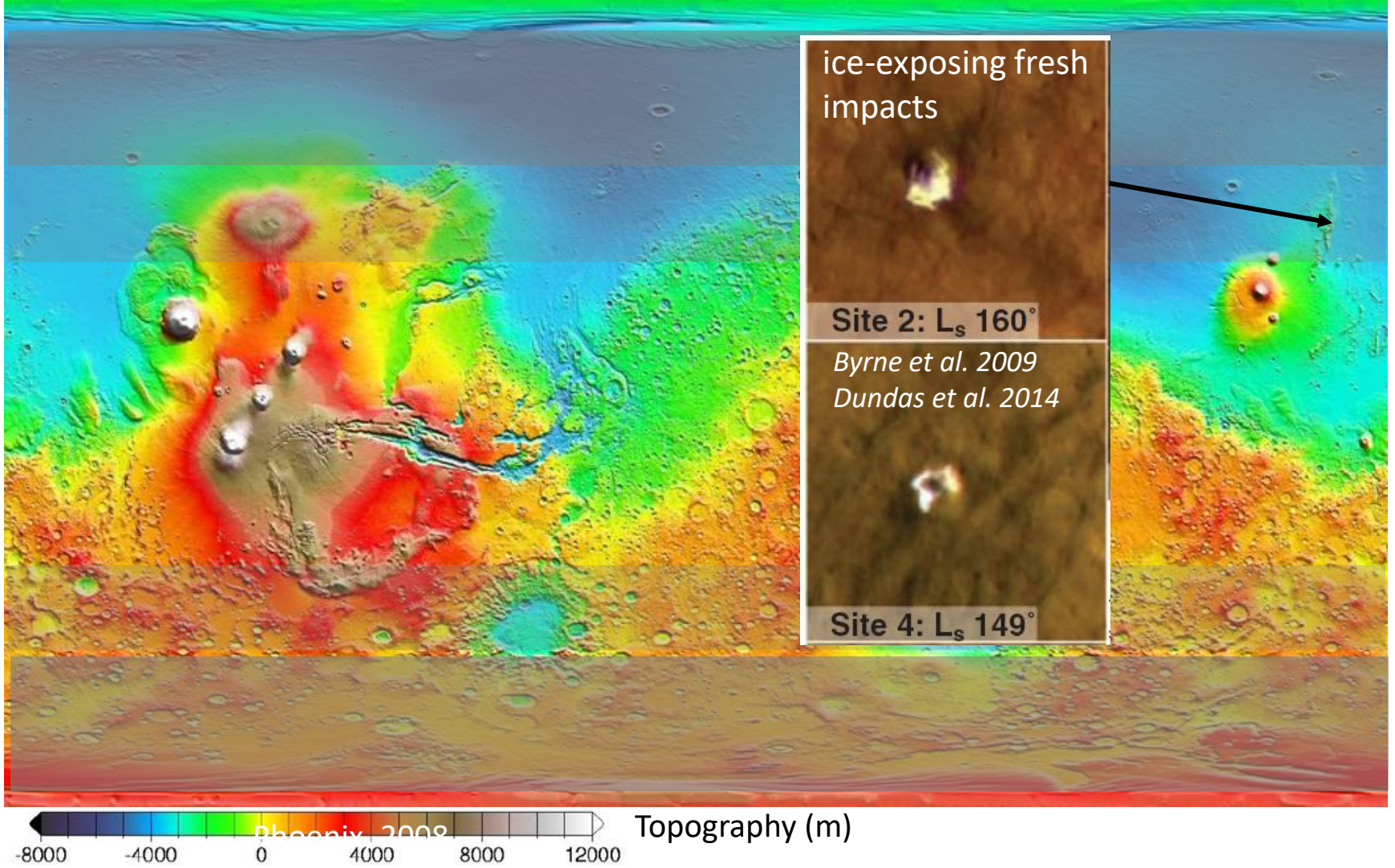
Snow White



“Latitude dependant ice Mantle”

AGE < 2 Myr

Mustard et al., 2001, Boynton et al. 2002 Head et al., 2003, Milliken et al., 2003 Mangold, 2005, Levy et al., 2009,, ETC…

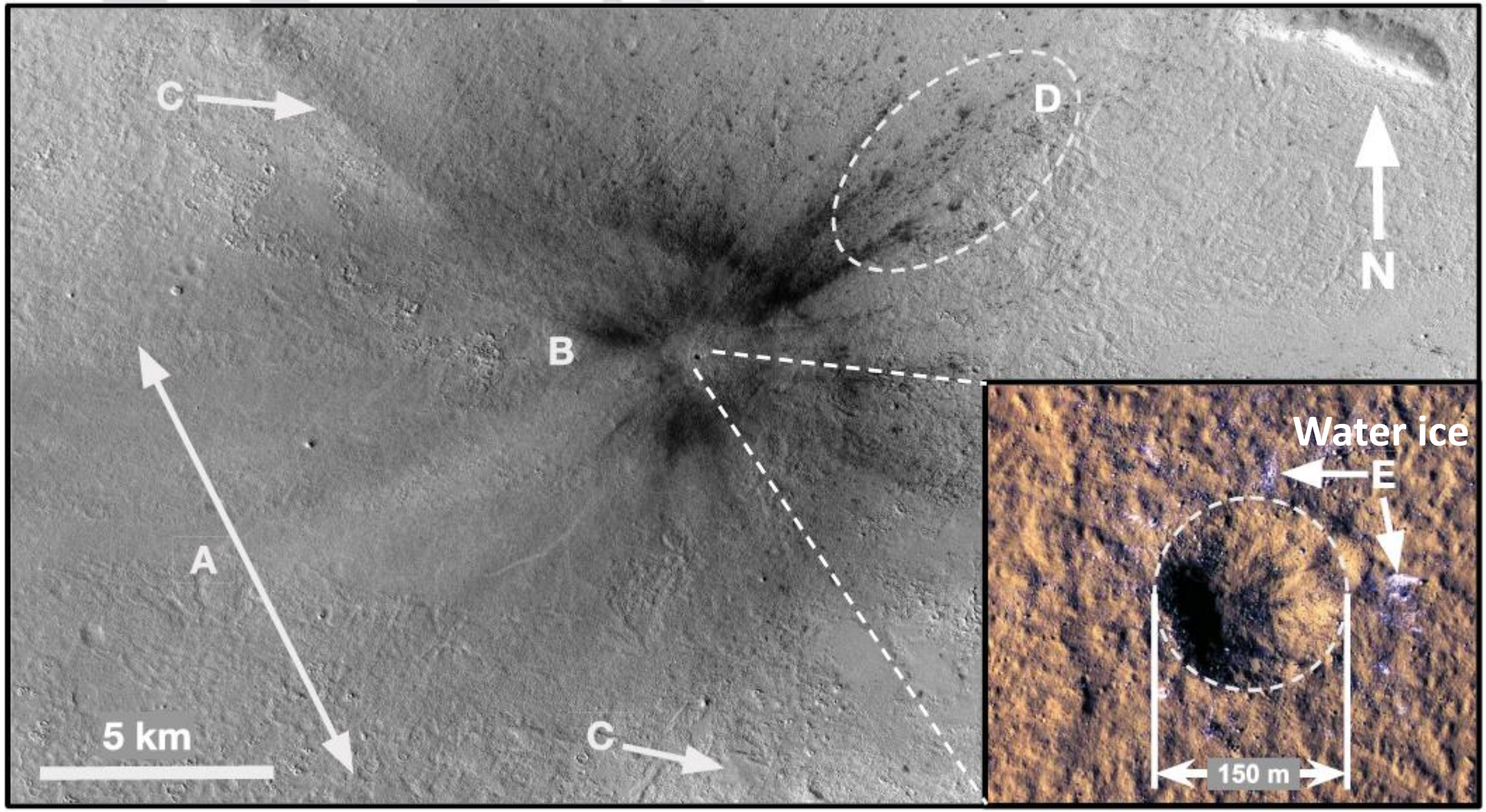


Latitude dependant ice Mantle

AGE < 2 Myr

Mustard et al., 2001, Head et al., 2003, Milliken et al., 2003 Mangold, 2005, Levy et al., 2009, **etc…**

Posiolova et al. (*Science*, October 27, 2022) **: Subsurface Water ice at 35°N**



Water ice in the subsurface down to 25°S on pole-facing slope

GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L01202, doi:10.1029/2009GL041426, 2010

Near-tropical subsurface ice on Mars

Mathieu Vincendon,[1] John Mustard,[1] François Forget,[2] Mikhail Kreslavsky,[3] Aymeric Spiga,[4] Scott Murchie,[5] and Jean-Pierre Bibring[6]

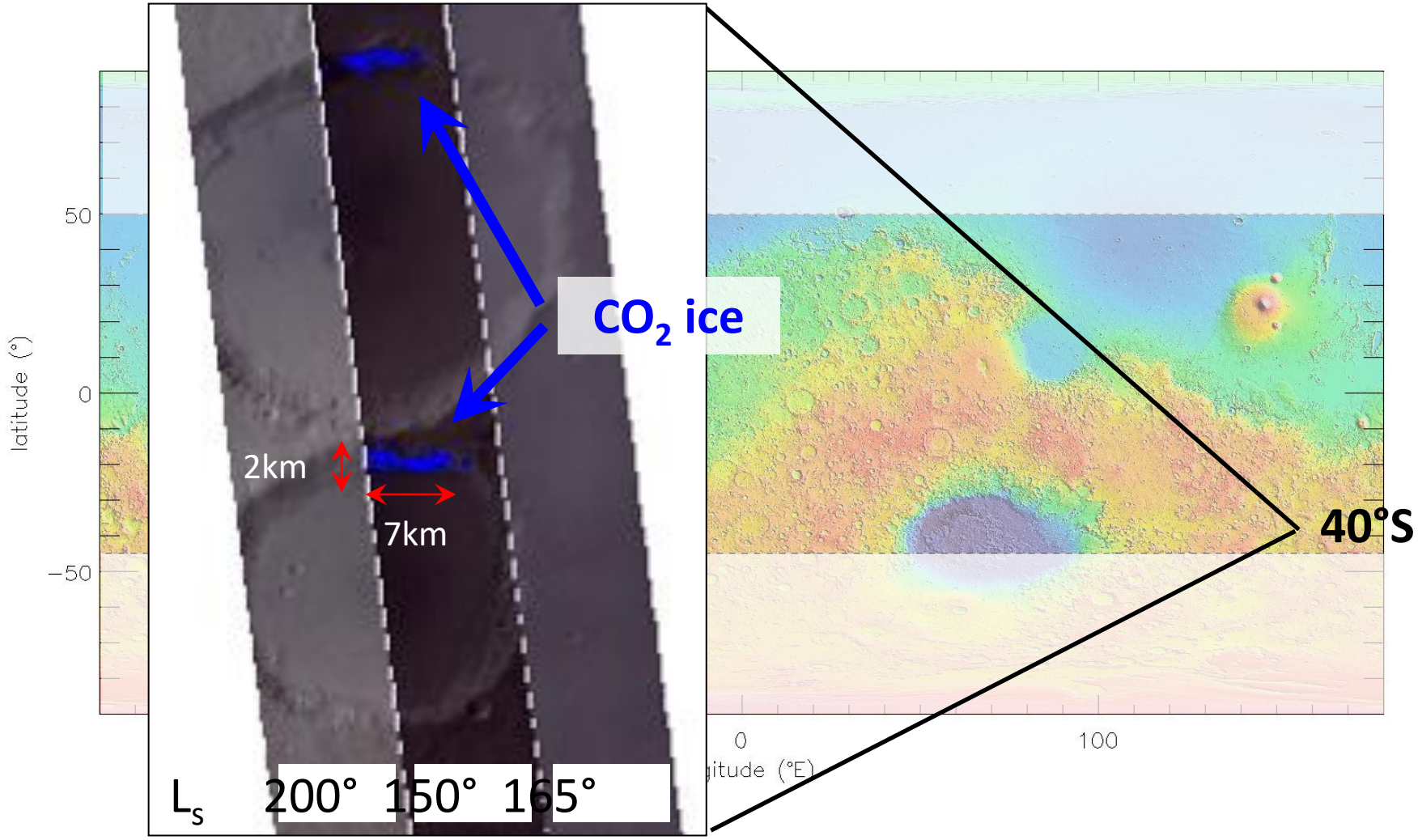
Received 19 October 2009; revised 23 November 2009; accepted 2 December 2009; published 12 January 2010.

[1] Near-surface perennial water ice on Mars has been previously inferred down to latitudes of about 45° and could result from either water vapor diffusion through the regolith under current conditions or previous ice ages precipitations. In this paper we show that at latitudes as low as 25° in the southern hemisphere buried water ice in the shallow (<1 m) subsurface is required to explain the observed surface distribution of seasonal CO_2 frost on pole facing slopes. This result shows that possible remnants of the last ice age, as well as water that will be needed for the future exploration of Mars, are accessible significantly closer to the equator than previously thought, where mild conditions for both robotic and human exploration lie. **Citation:** Vincendon, M., M. Kreslavsky, A. Spiga, S. Murchie, and ice on Mars,

dictions indicate that subsurface water ice could be stable today on pole facing slopes at those latitudes [*Aharonson and Schorghofer*, 2006]. However, there is no observational evidence.

[3] The OMEGA (*Observatoire pour la Minéralogie, l'Eau, les Glaces et l'Activité* onboard Mars Express) and CRISM (*Compact Reconnaissance Imaging Spectrometer for Mars* onboard Mars Reconnaissance Orbiter) near-infrared imaging spectrometers have been observing the surface of Mars since 2004 and 2006 respectively. These instruments measure solar radiation scattered by the surface, mainly in the first upper hundreds of microns. They provide spectral images with a spatial resolution ranging from 20 meters to 5 kilometers and a spectral sampling between 7 nm and 40 nm. While these data have been widely used to assess the composition of both minerals and condensates on they do not provide direct evidence of

On pole facing slopes, CO2 ice is stable closer to the equator

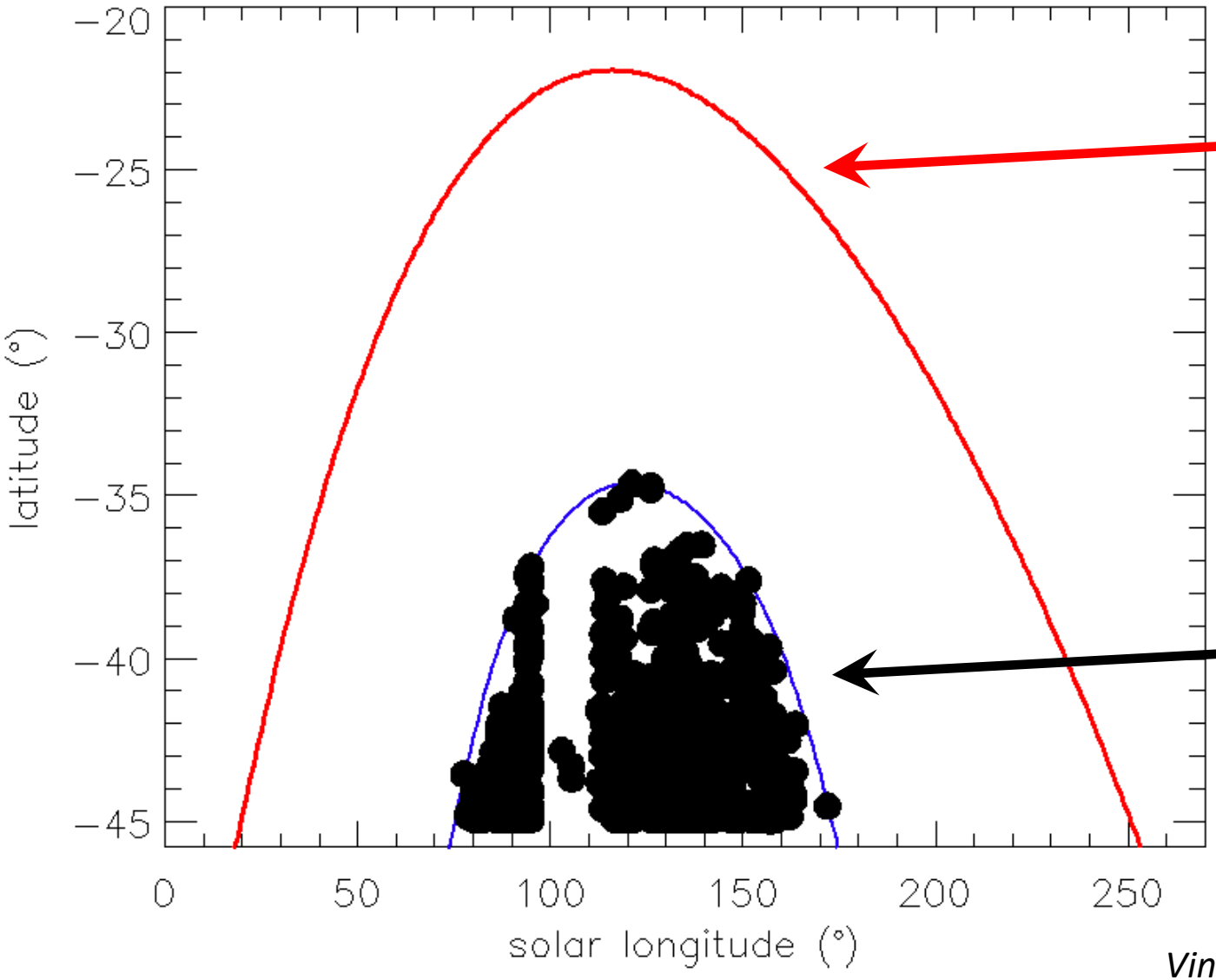


CRISM "MSP" data – 230 m spatial resolution

Vincendon et al. 2009

Climate model prediction: ice stability over-predicted

a source of heat localized on slopes is required

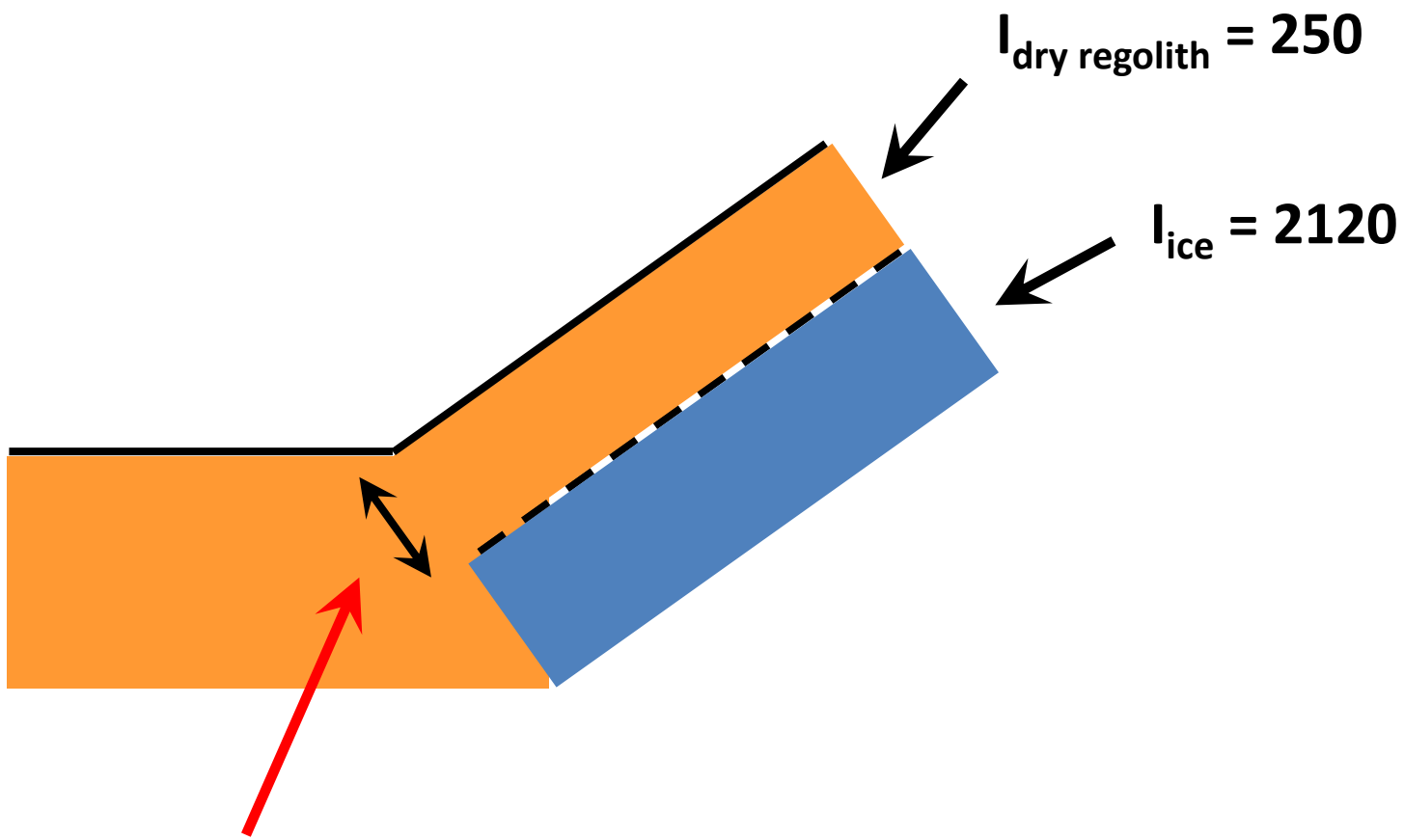


modeled stability limit of CO_2

observed CO_2

Vincendon et al. 2009

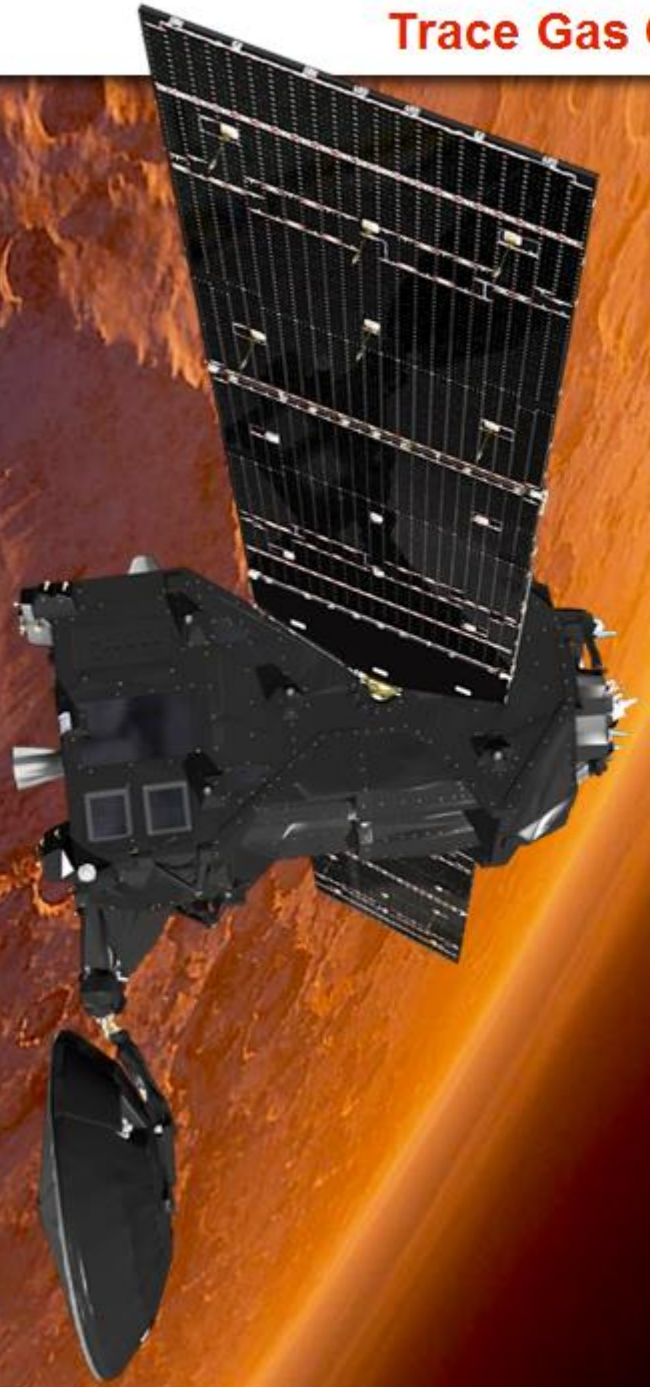
Ground model: dry regolith above H_2O ice rich regolith



Ice table depth: free parameter, latitude dependent

Vincendon et al. 2009

Trace Gas Orbiter



NOMAD
High-resolution occultation and nadir spectrometers

Atmospheric composition (CH_4, O_3, trace species, isotopes) dust, clouds, P&T profiles

UVIS (0.20 – 0.65 µm) λ/Δλ ~250	SO, Limb, Nadir
IR (2.3 – 3.8 µm) λ/Δλ ~10,000	SO, Limb, Nadir
IR (2.3 – 4.3 µm) λ/Δλ ~20,000	SO

CaSSIS
High-resolution, stereo camera

Mapping of sources Landing site selection

ACS
Suite of 3 high-resolution spectrometers

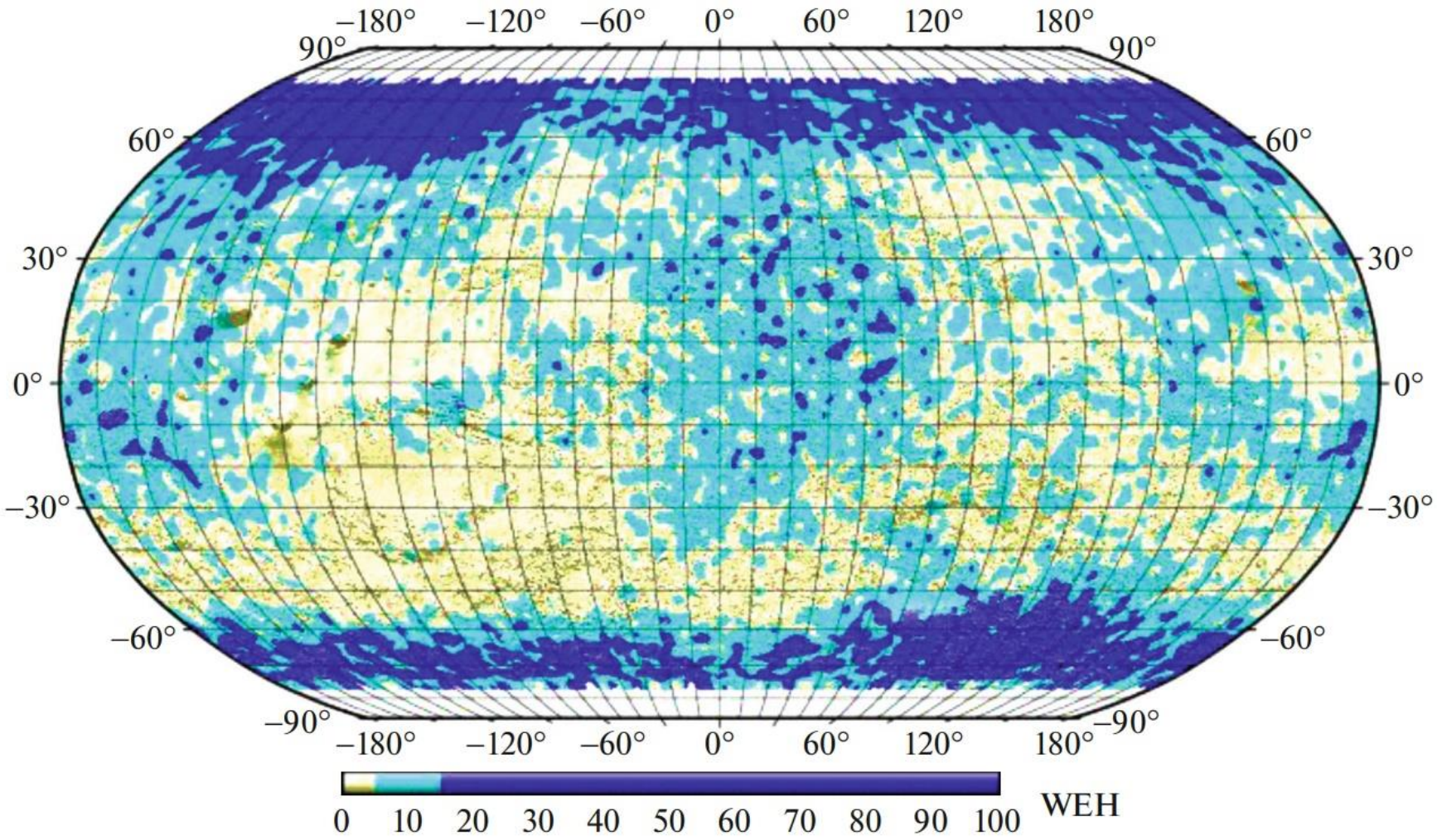
Atmospheric chemistry, aerosols, surface T, structure

Near IR (0.7 – 1.7 µm) λ/Δλ ~20,000	SO, Limb, Nadir
IR (Fourier, 2.5 – 25 µm) λ/Δλ ~4,000 (SO)/500 (N)	SO, Nadir
Mid-IR (2.3 – 4.5 µm) λ/Δλ ~50,000	SO

FREND
Collimated neutron detector

Mapping of subsurface water and hydrated minerals

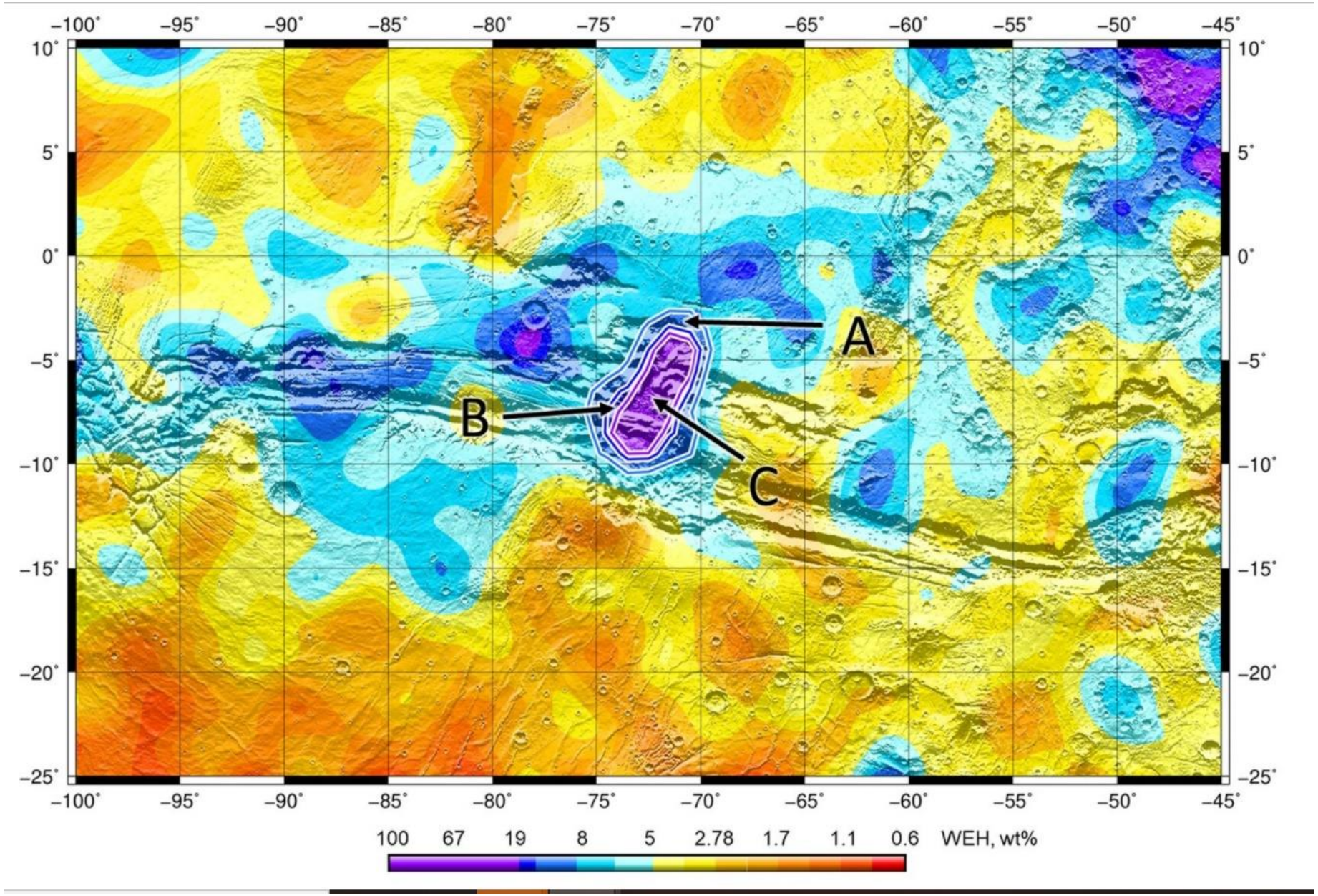
H_2O mapping using TGO/FREND

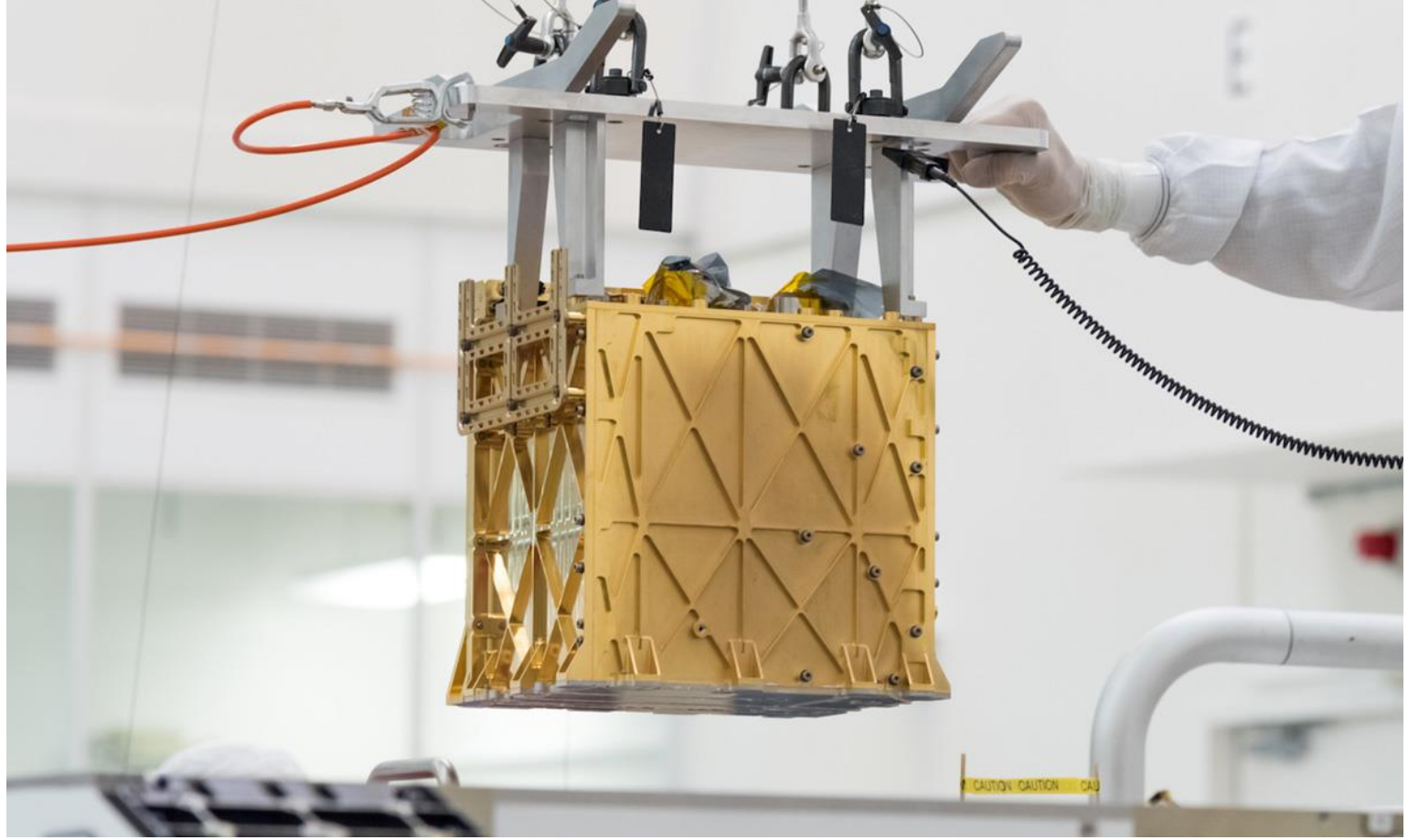


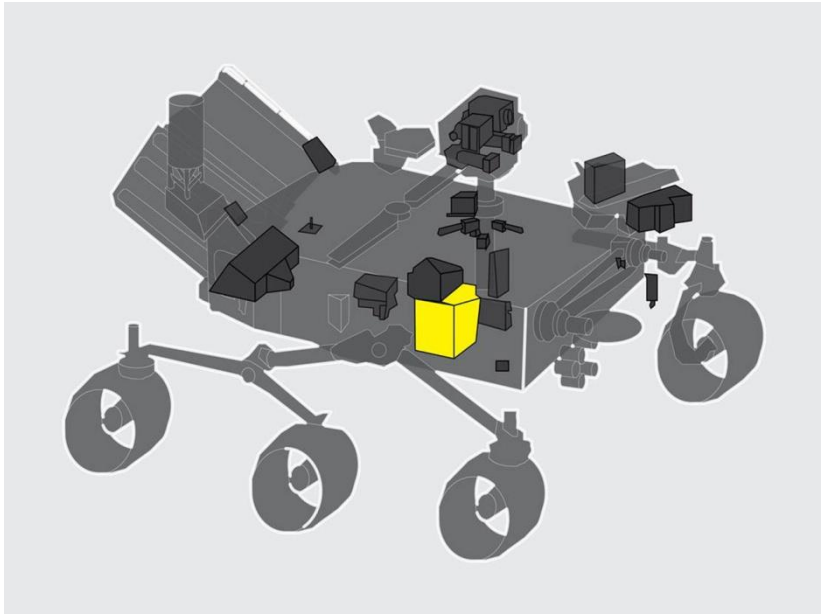
Malakhov et al., Ast. Lett., 2020

Fig. 3. Martian surface hydrological types. The areas with water content of 0–5% WEH (beige), 5–15% WEH (blue), and above 15% WEH (dark blue) are highlighted with color.

H_2O mapping using TGO/FREND







MOXIE Experiments on Perseverance

(*Hoffman et al*. 2022, *Hecht et al.* 2022*)*

solid oxide electrolysis of carbon dioxide in the martian atmosphere

$2CO_2 \rightarrow 2CO + O_2$ (so far 50g of O_2…)

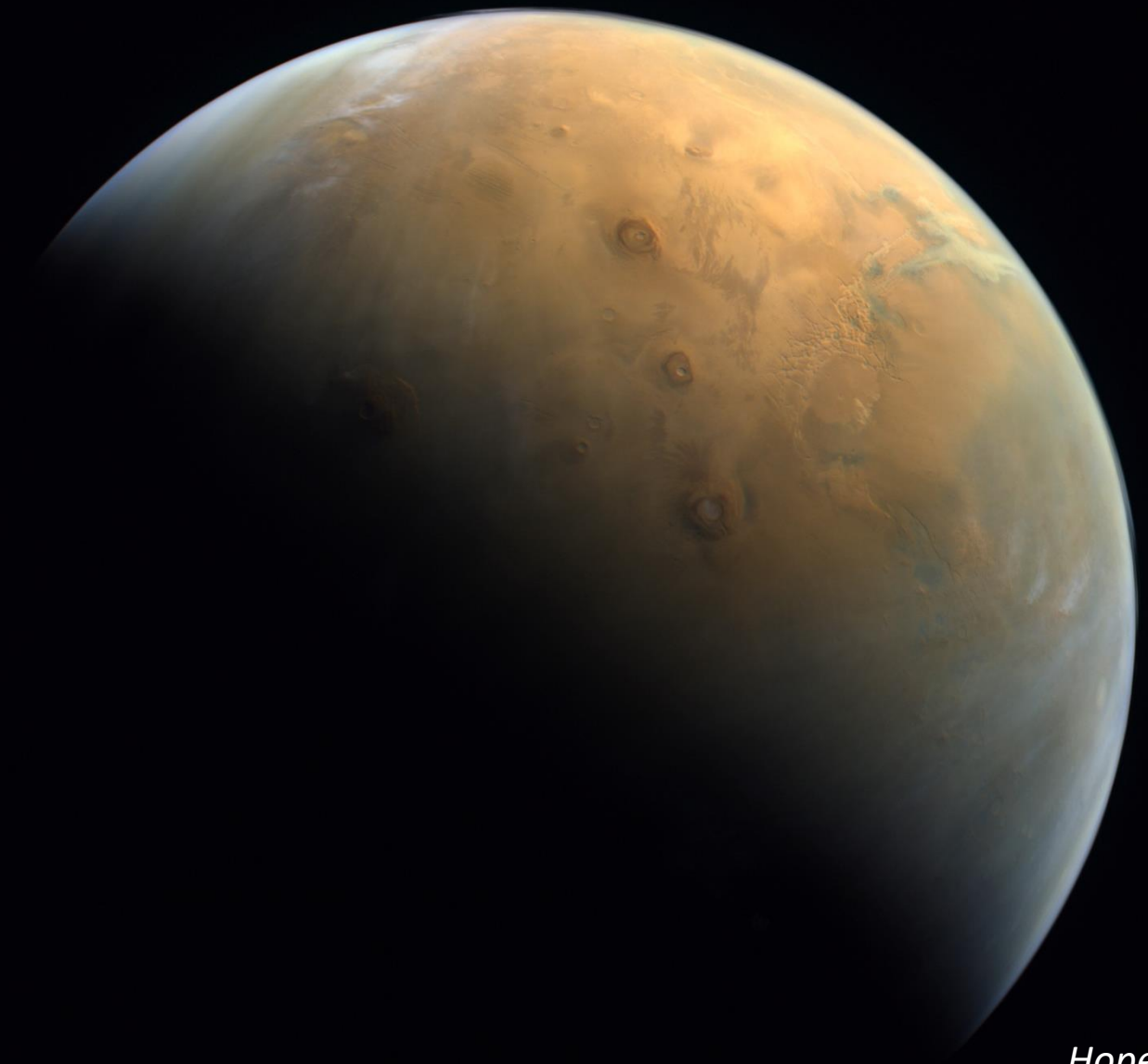
Sabatier reaction:

$CO_2 + 4H_2 \Rightarrow CH_4 + 2H_2O$

$2H_2O \Rightarrow O_2 + 2H_2$

Technical Challenges of a crewed Mars mission

- **Journey to Mars:**
  - A long duration transportation/habitation spaceship
    (roomy eough, perfectly recycling, reparable)
  - Health and psychology (microgravity, radiation, confinement)
- **Landing on Mars**
- **Living on Mars** (habitats, spacesuits, power, ressources, contamination)
- **Getting back from Mars surface**



Thank you

Hope Mars mission first image, February 11, 2021