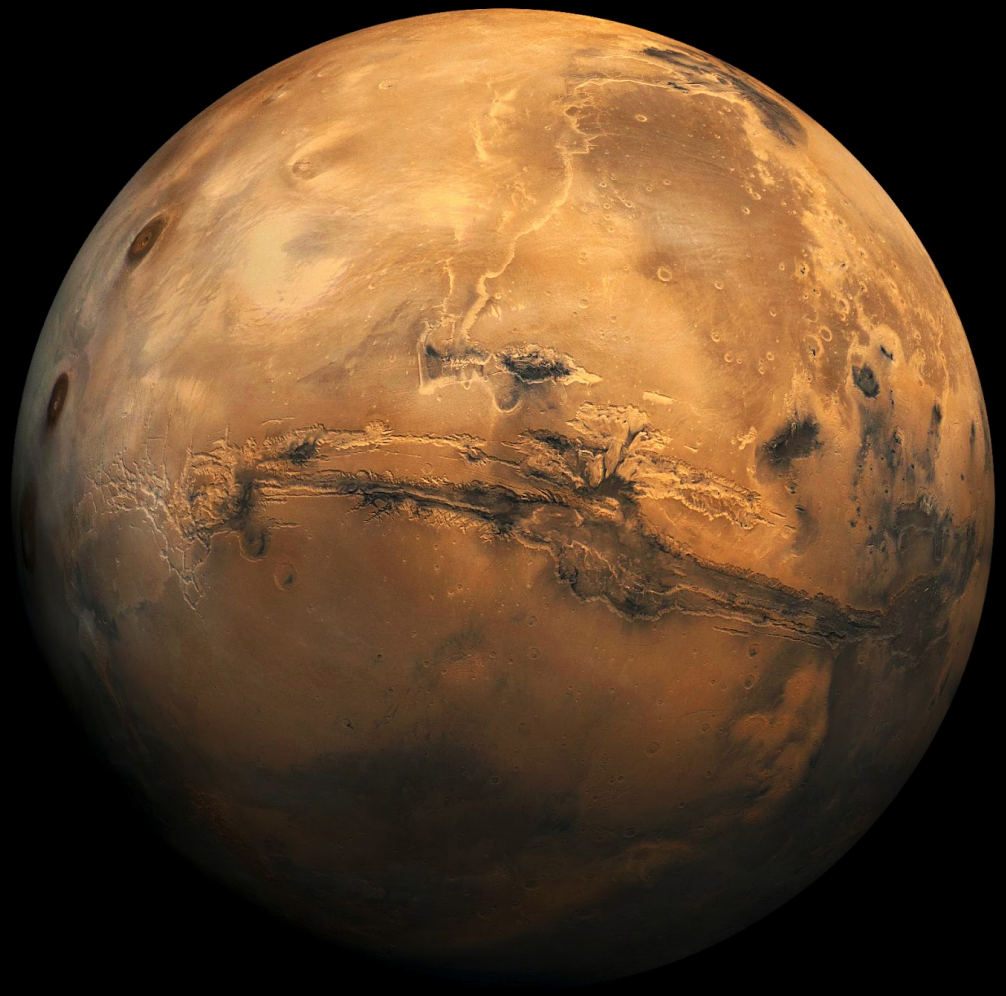

Mars Exploration Ideas Beyond 2020

Vlada Stamenković

Jet Propulsion Laboratory (JPL)

California Institute of Technology

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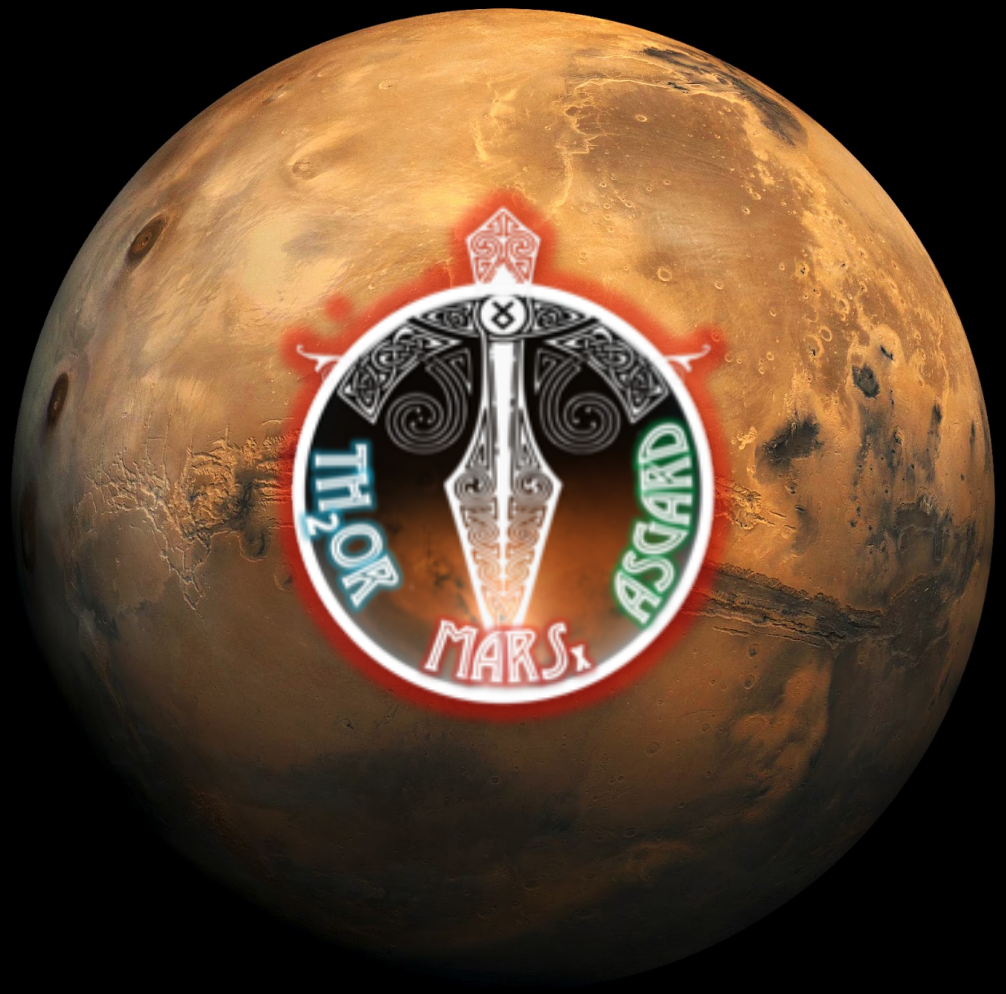

Mars Exploration Ideas Beyond 2020

A "New Mars Underground" Perspective

Vlada Stamenković

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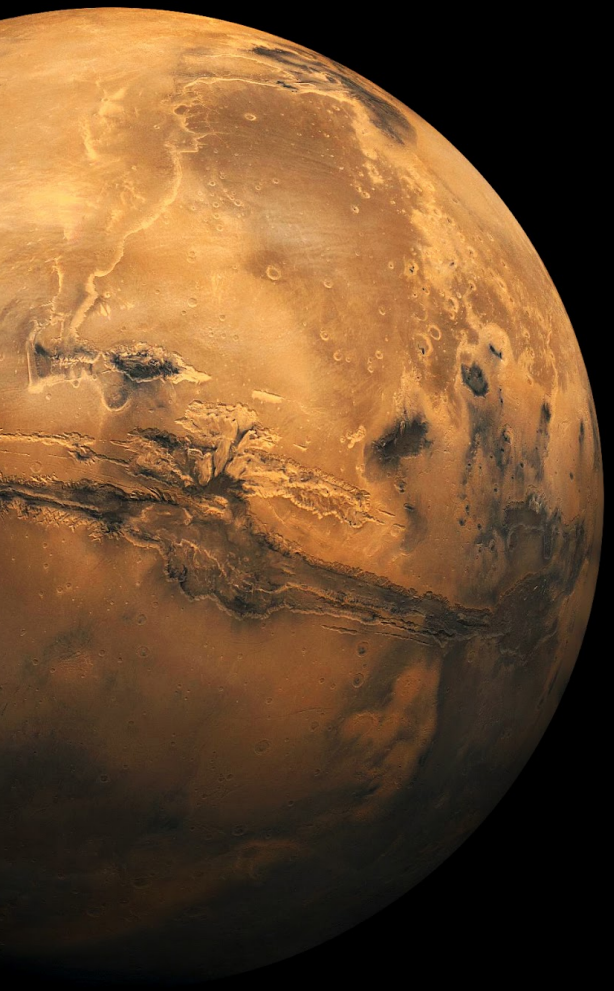

Mars Exploration Beyond 2020

The Plans So Far…

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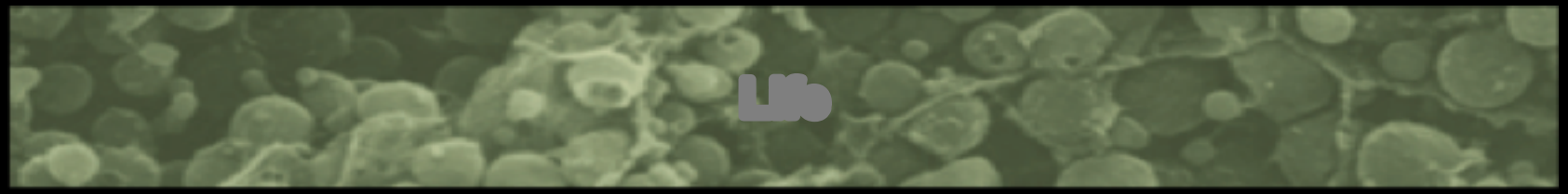
Mars Exploration Program Science Goals (MEPAG)



Prepare for Human Exploration

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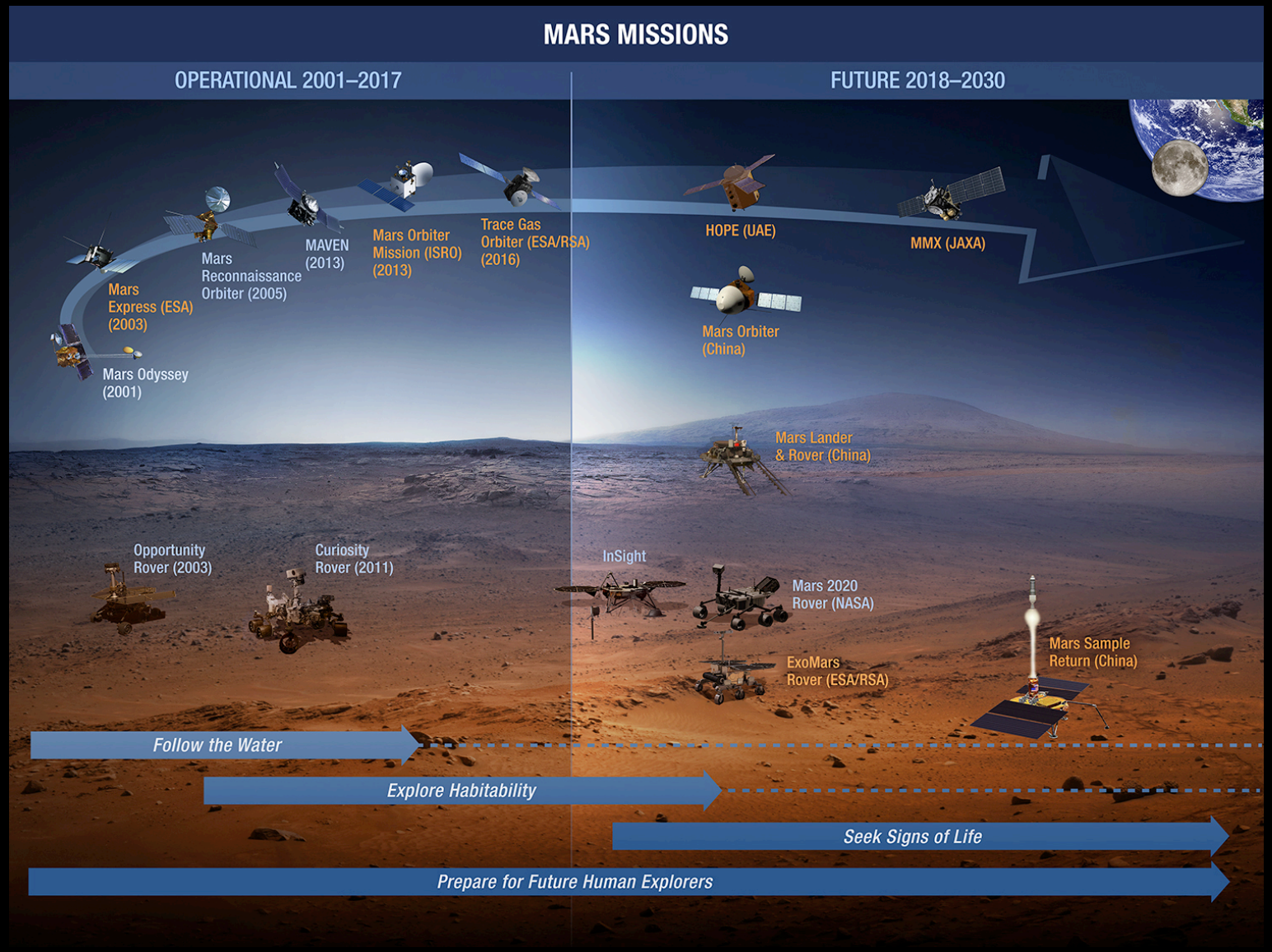
Mars Missions



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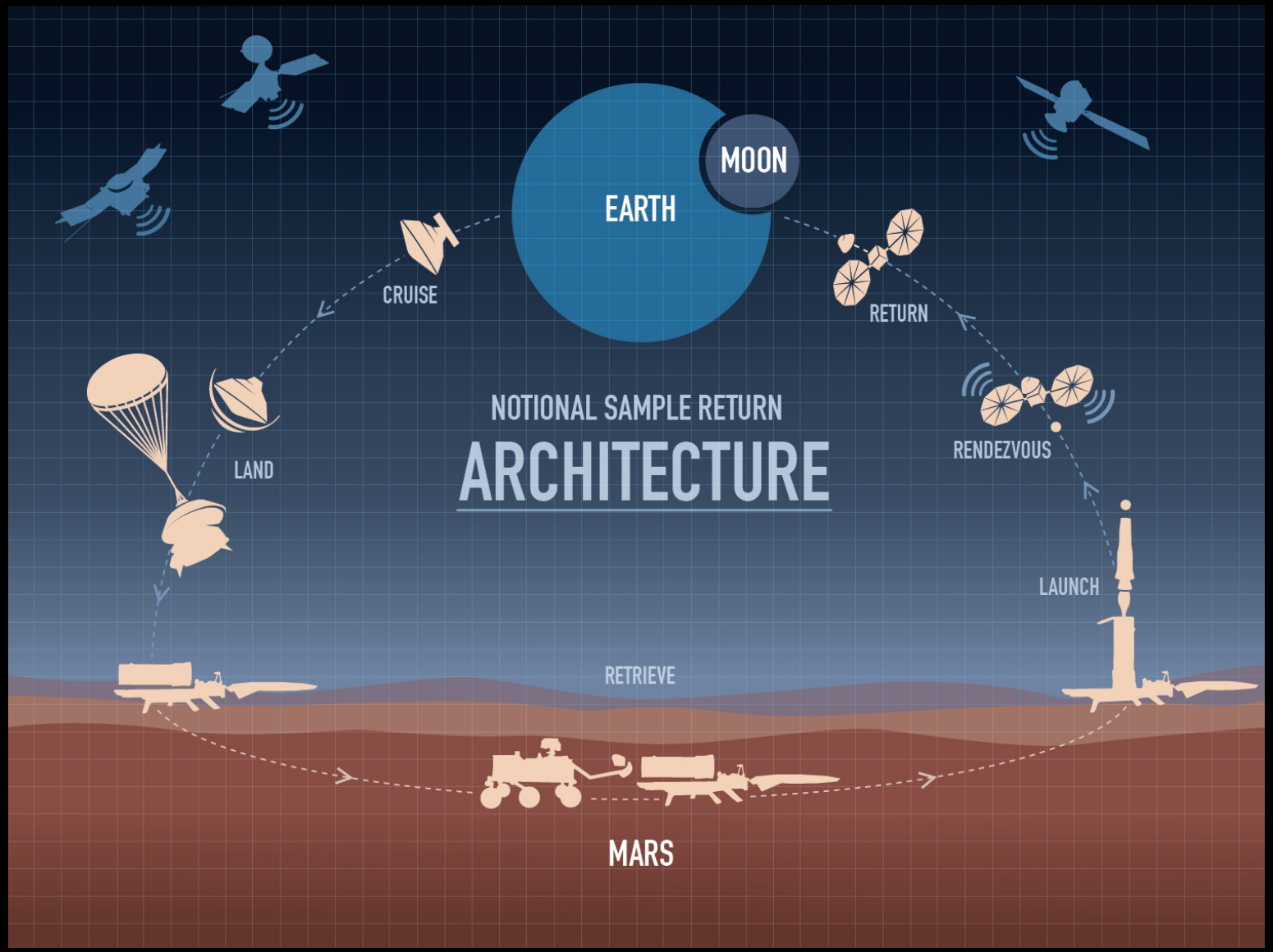
Mars Sample Return



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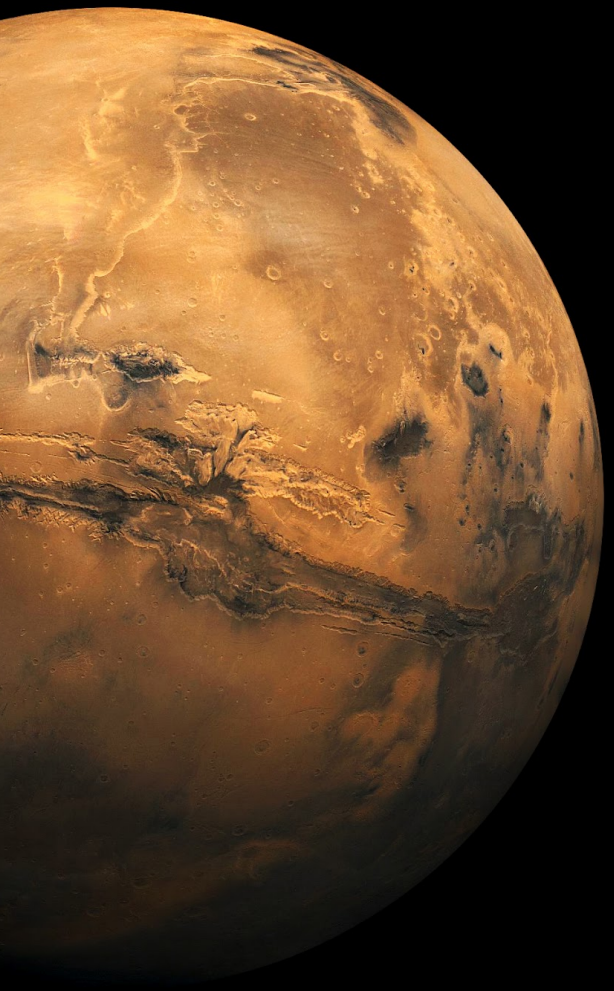

Mars Exploration Beyond 2020

The New Mars Underground

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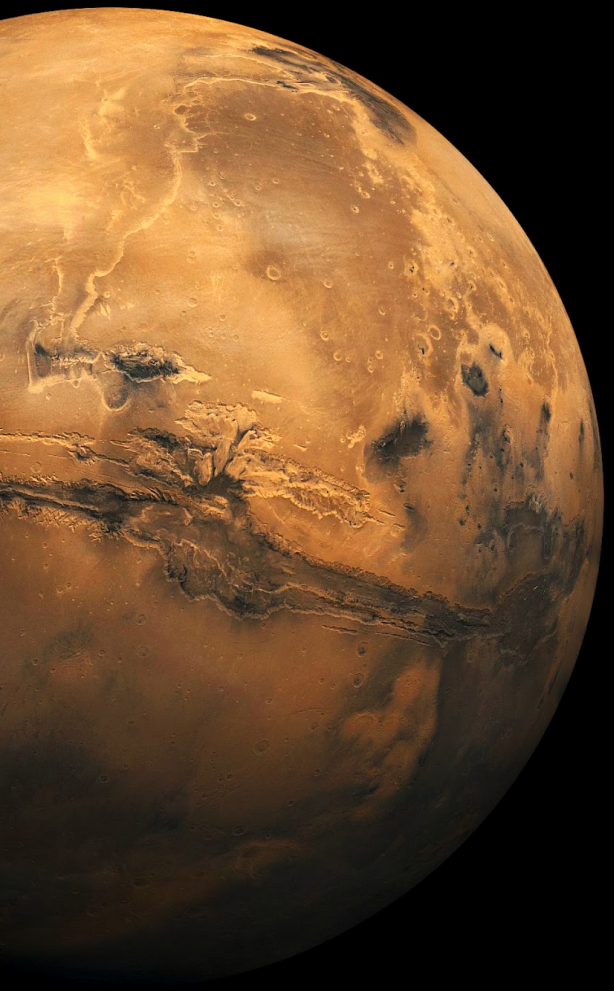

Why Mars Subsurface?

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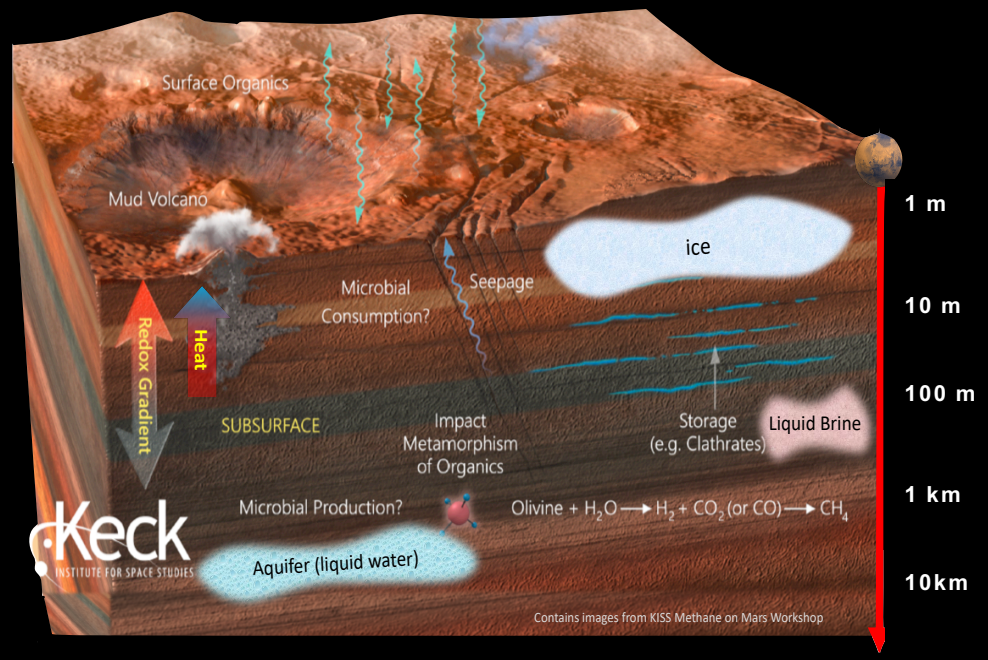
A New Dimension of Science



The Martian Subsurface

- **Next frontier of Mars exploration.**
- The subsurface is very poorly constrained.
- Next planetary decadal survey inputs are being developed now.
- Three investigations that we expect to be proposed to the next planetary decadal survey in some manner:
  - Search for subsurface life and water.
  - Identification of ISRU resources.
  - Better understanding of the Martian history.

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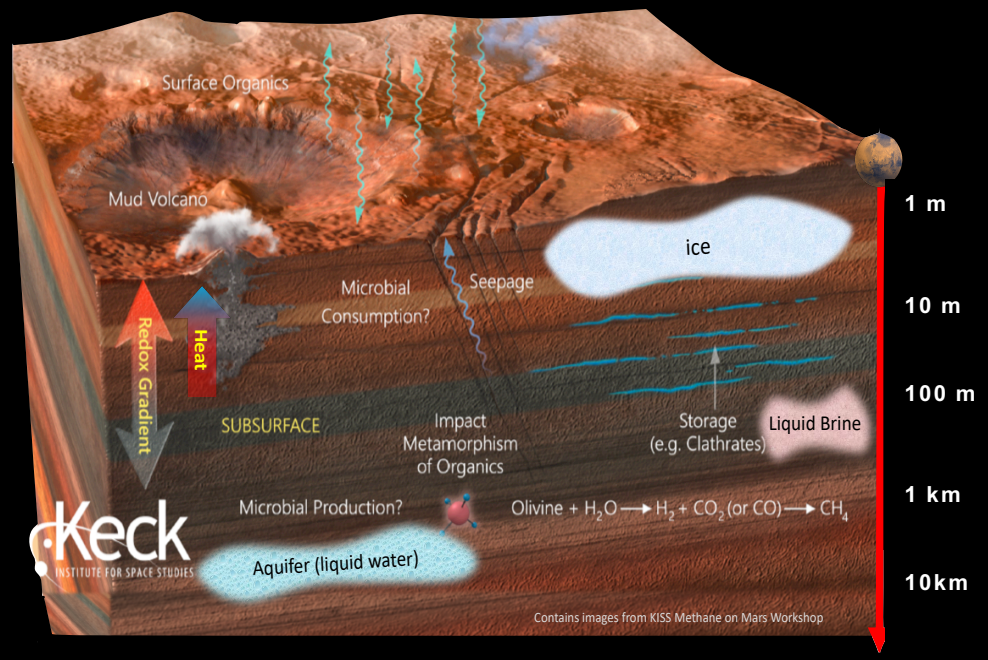
A New Dimension of Science



Searching for Life & Water

- **Life requires water.**
- If life started on Mars, it may have followed the water into the underground as the atmosphere thinned and cooled.
- Stable liquid water only possible in the subsurface (>1-10 km for pure groundwater, shallower for brines).
- Best preservation of ancient bio-molecules at depths.
- Climate & planet evolution can be understood more completely with drill cores.

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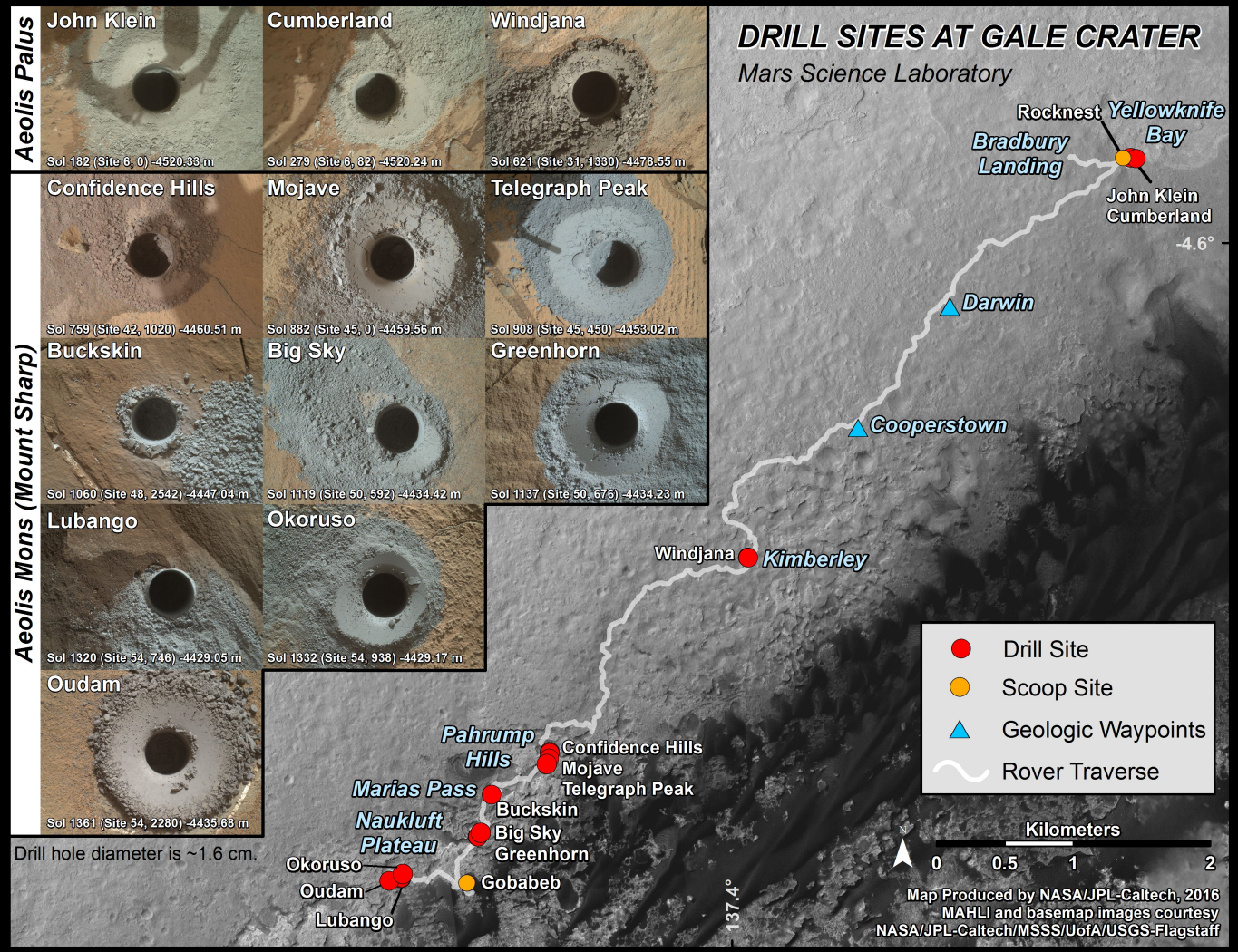
Subsurface Diversity



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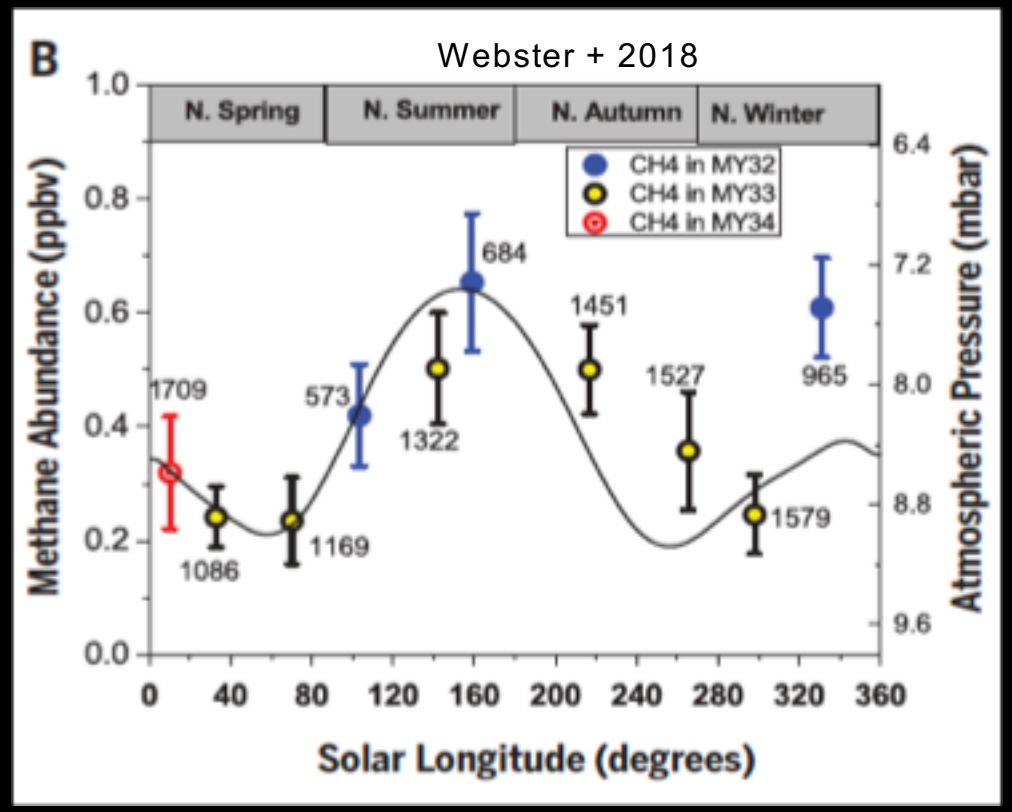
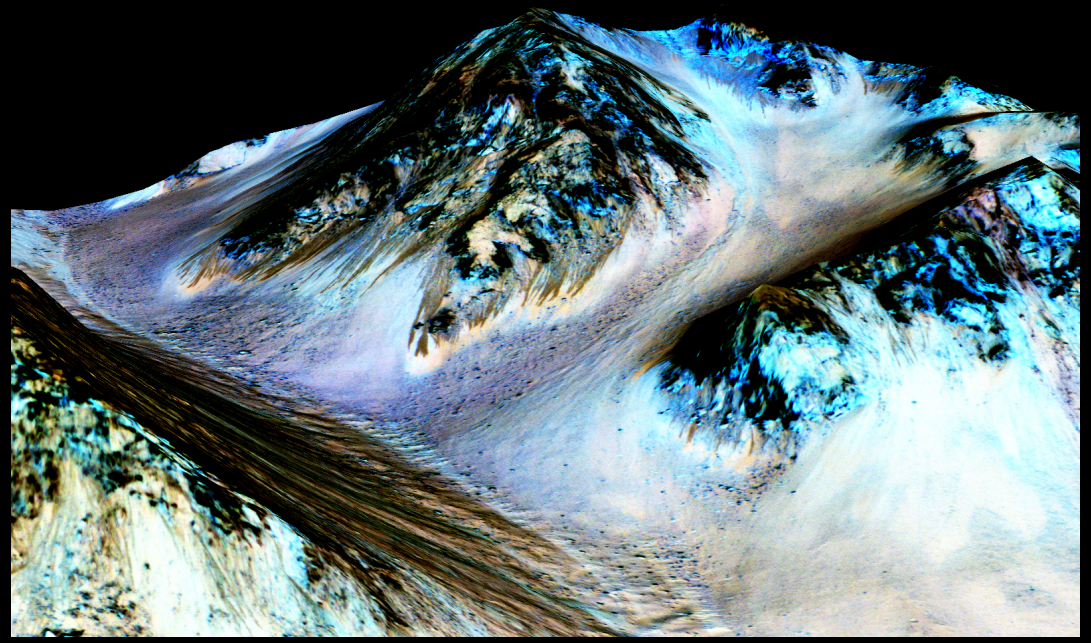
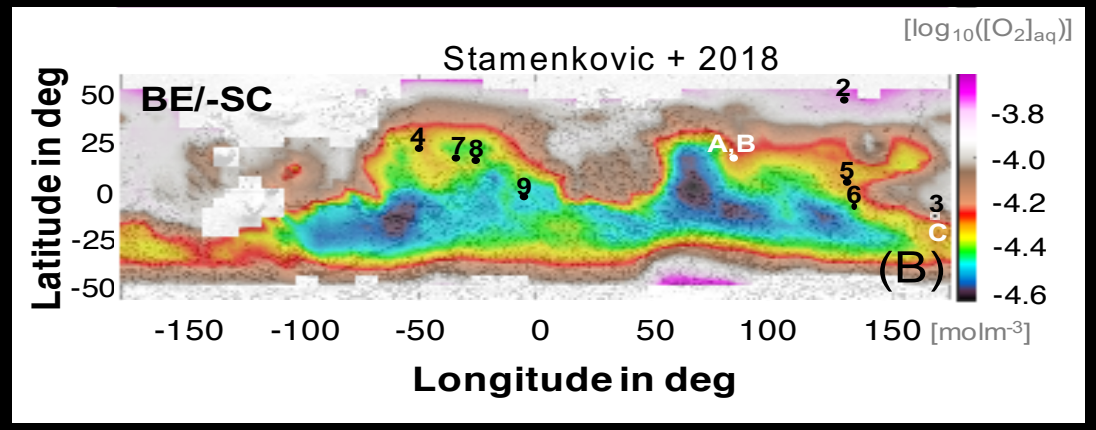
Evidence of Modern Groundwater







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A New Dimension of Opportunity

Resources for Humans (& before Humans!)

- Human spaceflight plans call for exploring subsurface chemistry and groundwater resources.
- Commercial collaboration opportunities through, e.g., SpaceX could help get there cheaper and sooner.
- Subsurface chemistry and water are necessary for ISRU, and to better understand planetary evolution and habitability.
- **We should search for life before humans get there!**

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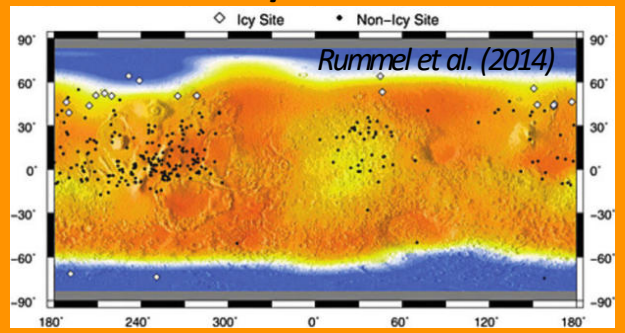
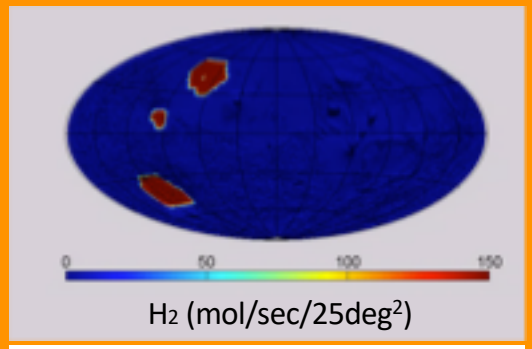
New 3D Science

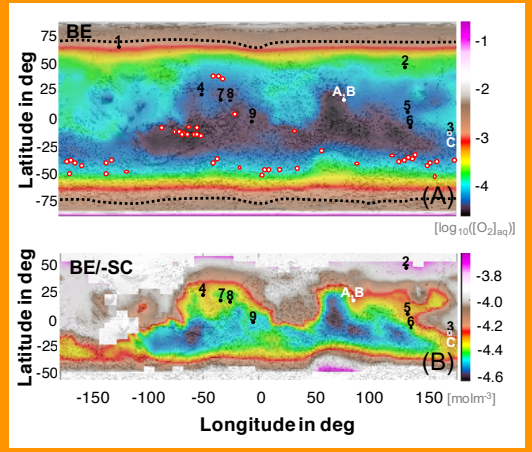
RSL

ICE/WATER

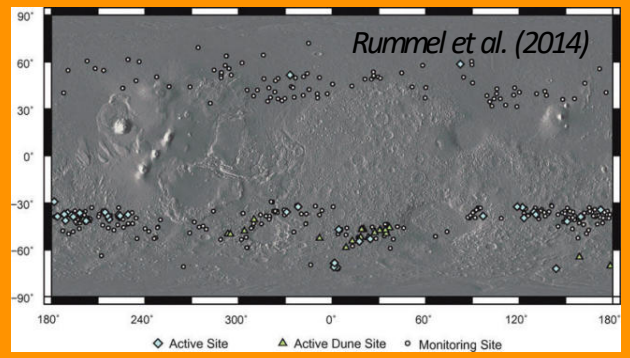


REDOX GRADIENTS

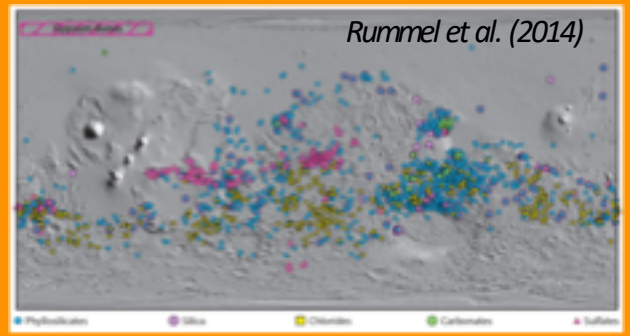




ACTIVE GULLIES



MINERALOGY



Stamenkovic et al. (2018), in review

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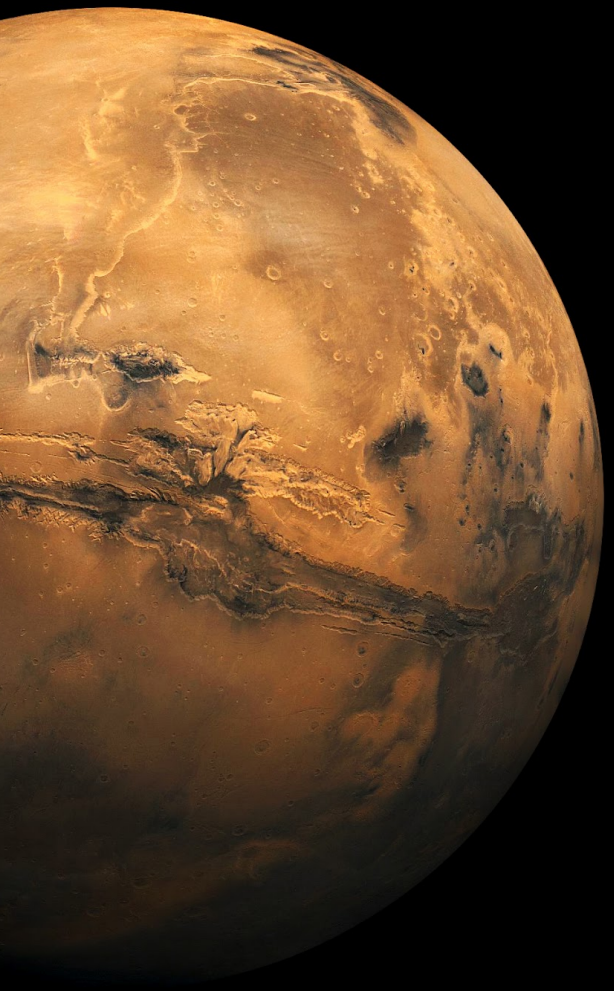

Missions With Depth So Far

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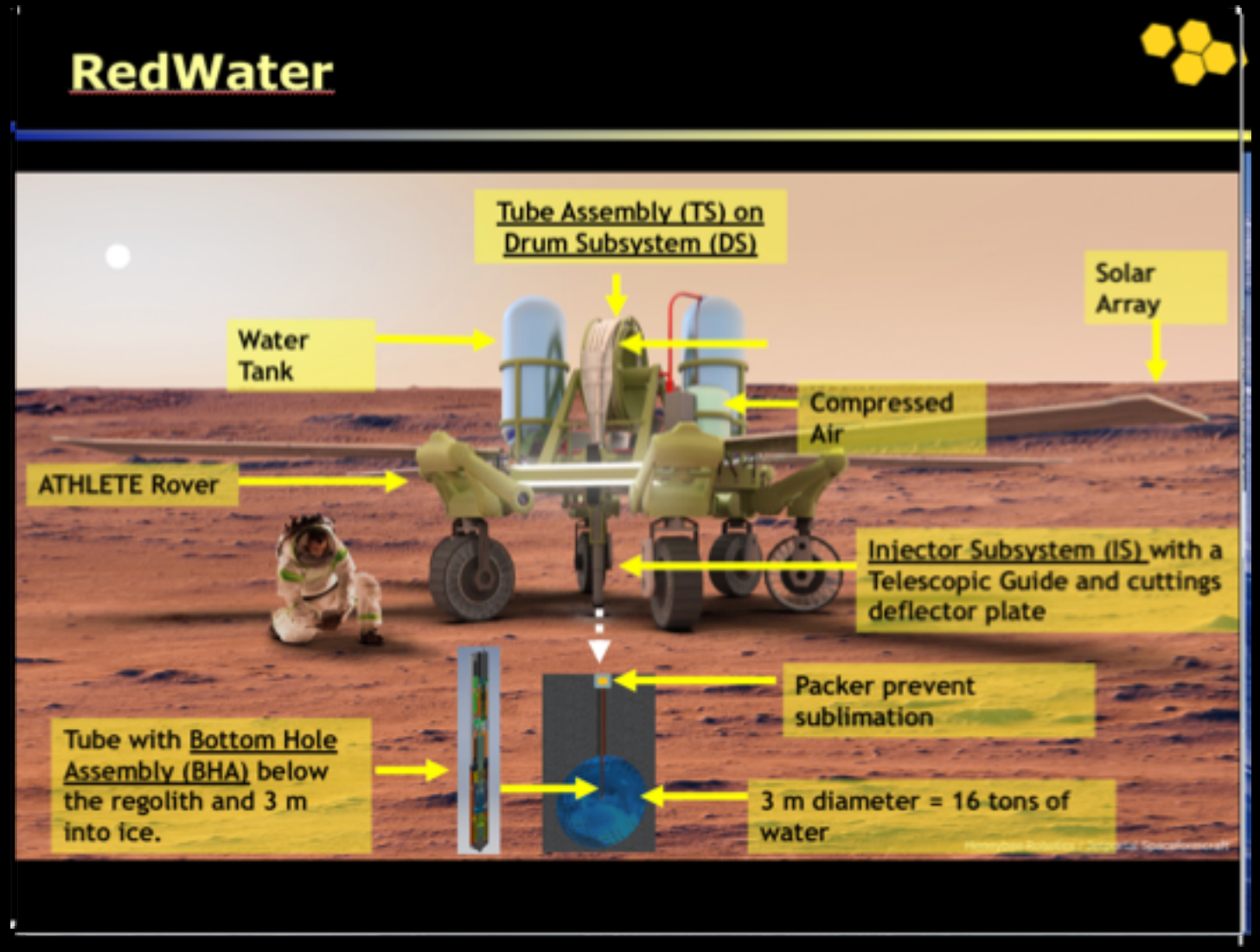
Drilling From mm to cm Until Today & Proposal Concepts For Beyond…



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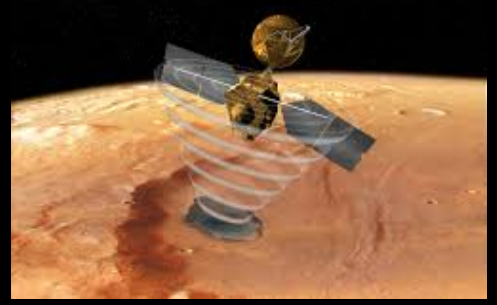
Sounding for Liquid Water & Ices: So Far



Challenge for liquid water

- We need to detect groundwater to depths of 1-10 km.
- Be ready for small amounts and gradients in water availability.
- And we need to also infer the salinity of groundwater (for astrobiology).

MARSIS (Mars Express) & SHARAD (MRO)

- **(Opinion 1)** No evidence of frequent large contrast aquifers (> 10s of km) down to a depth of ~1km.
- **(Opinion 2)** MARSIS & SHARAD cannot generally see below ~200 m due to too much EM absorption and clutter response (not useful echoes).
- **(Opinion 3)** Outside of polar regions almost no penetration beyond 200 m other than through ice or volcanic ash overburdens.
- **Independent of scientific view:** MARSIS & SHARAD were not capable of sounding for groundwater at depths greater than 1 km, where it most likely resides.

InSight & seismic techniques

- InSight is not optimized to detect (or localize) groundwater.
- Seismic has weaker water detection sensitivity than other methods.
- Little seismicity and possibly little amounts of groundwater expected on Mars (problems associated with passive seismic sounding).
- Large footprint needed for active seismic sounding.

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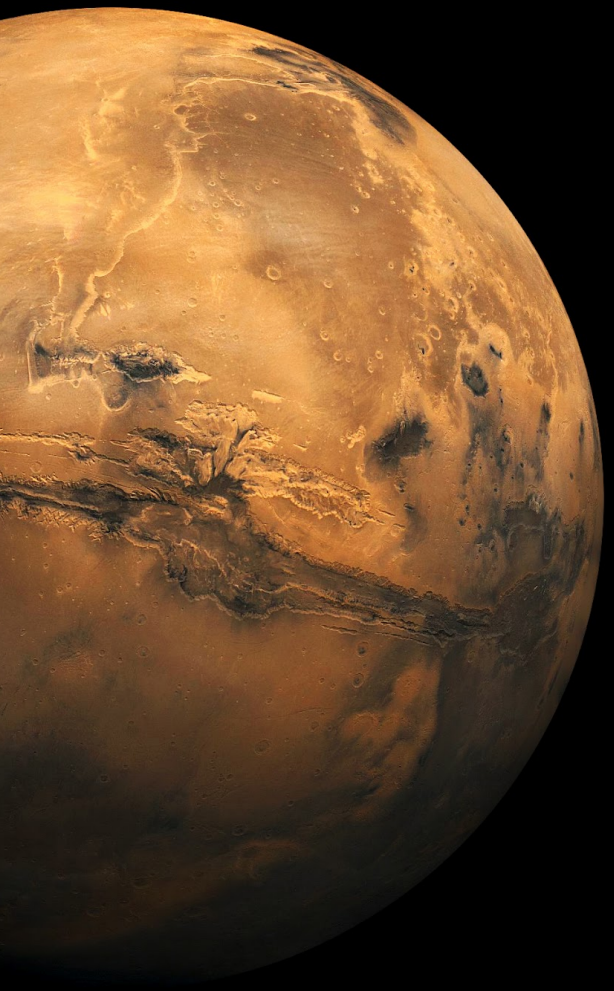

MARSx

Mars Subsurface Exploration

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MARSx Development

KISS Workshop—Methane on Mars

- 30 people from across JPL, Caltech, and academia.

KISS Workshop—MARSx

- 25 people from JPL, Caltech, ESA, 5 NASA centers, academia, and industry (SpaceX & Schlumberger).

Jet Propulsion Laboratory
California Institute of Technology
Caltech
NASA Astrobiology Institute
NASA Johnson Space Center
esa
HONEYBEE ROBOTICS
Schlumberger
SPACEX

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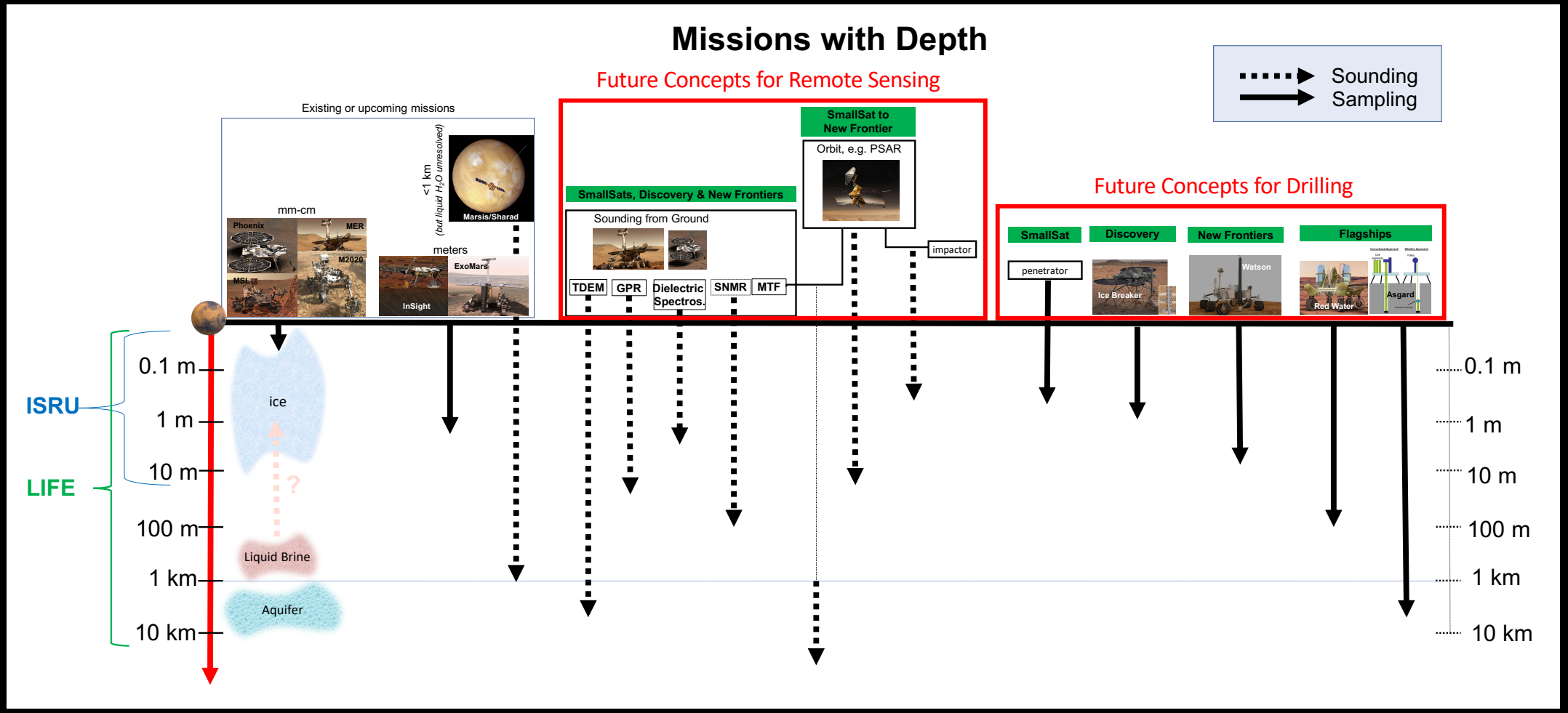
Options for Subsurface-Driven Mars Missions



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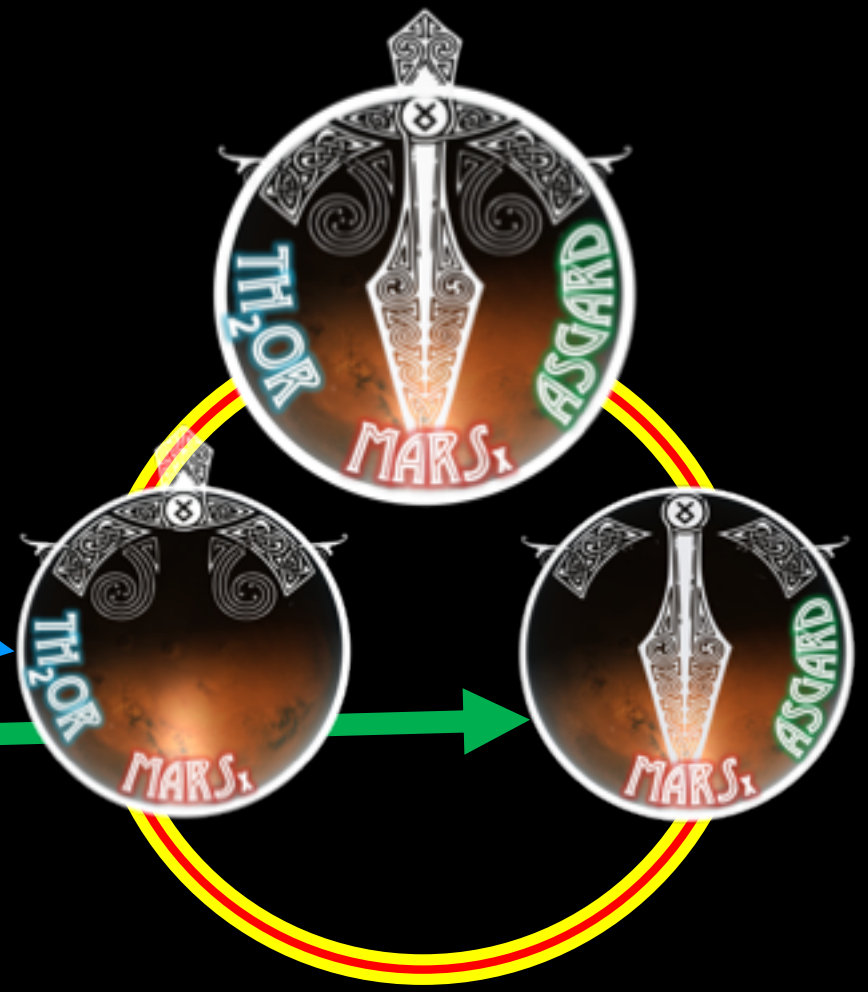
MARS$_X$ — Visions for a New World

KISS Studies Led to Conclusion

The Mars Subsurface is an "unexplored planet" and is an ideal near future opportunity to find the "holy grail of planet exploration"—evidence of extinct or extant life.

Recommendation (Yung + 2018, in press)

- Chemical characterization of the Martian subsurface (**down to the theoretical groundwater-stability depth, which can be as deep as a few km**) is pivotal ….
- We need a) deeper subsurface sounding (e.g. radar **and preferably low-frequency electromagnetic sounding** [illegible]) to obtain a more global and refined understanding of the [illegible]rface volatile, liquid water, brine, ice, & clathrate inventory [illegible] **drilling operations to characterize the chemical composition & redox state of the subsurface** [illegible].



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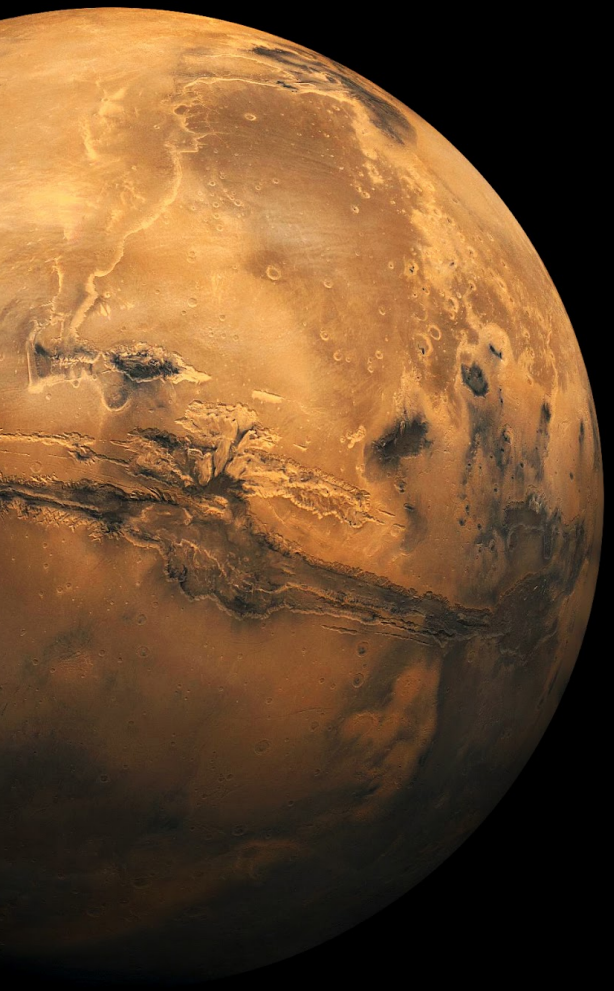

TH_2OR Concept

Transmissive H_2O Reconnaissance

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Objectives

This effort seeks to demonstrate that it is feasible to sound from the Martian surface for liquid (subsurface) groundwater, expected to be at depths as large as 1-10 km, using a low-mass (<5 kg) and low-power (<10 W average) ElectroMagnetic (EM) system…and to determine the salinity of such groundwater—which might be the only habitat for extant life on Mars if it still exists today.

- ***Do high-impact science with a payload that could fit on a small spacecraft.***
- ***Show this as a viable approach for considerations in the upcoming planetary decadal survey.***

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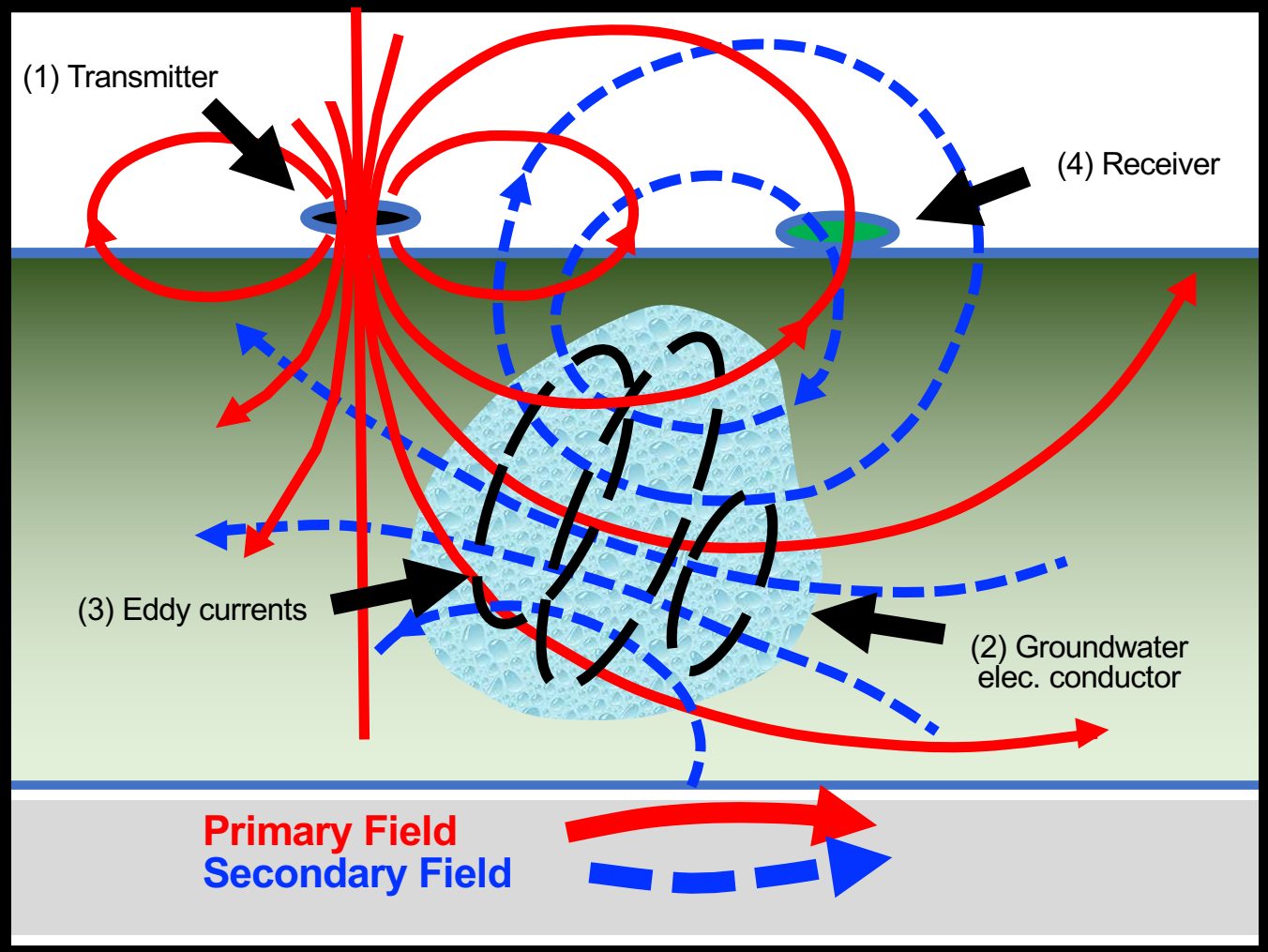
Approach EM Sounding



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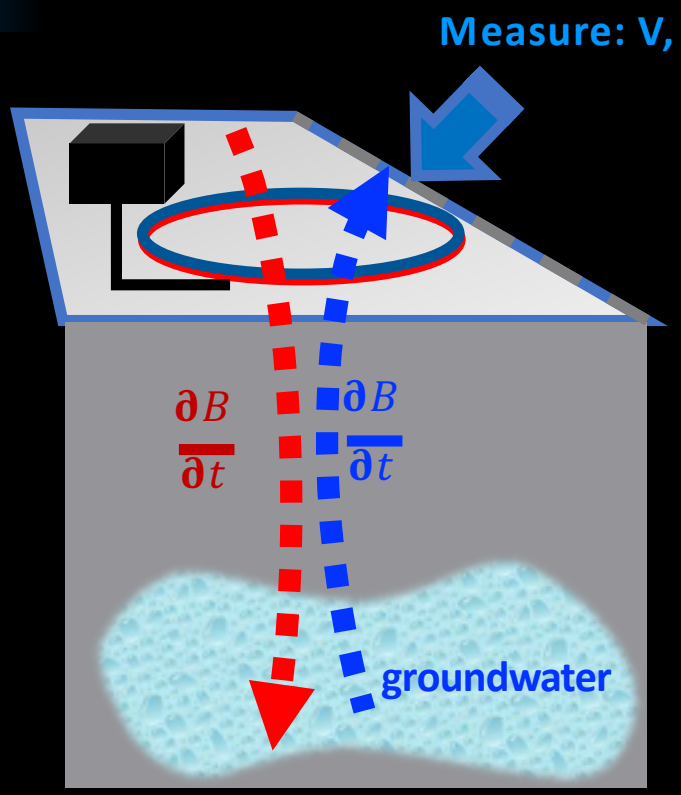
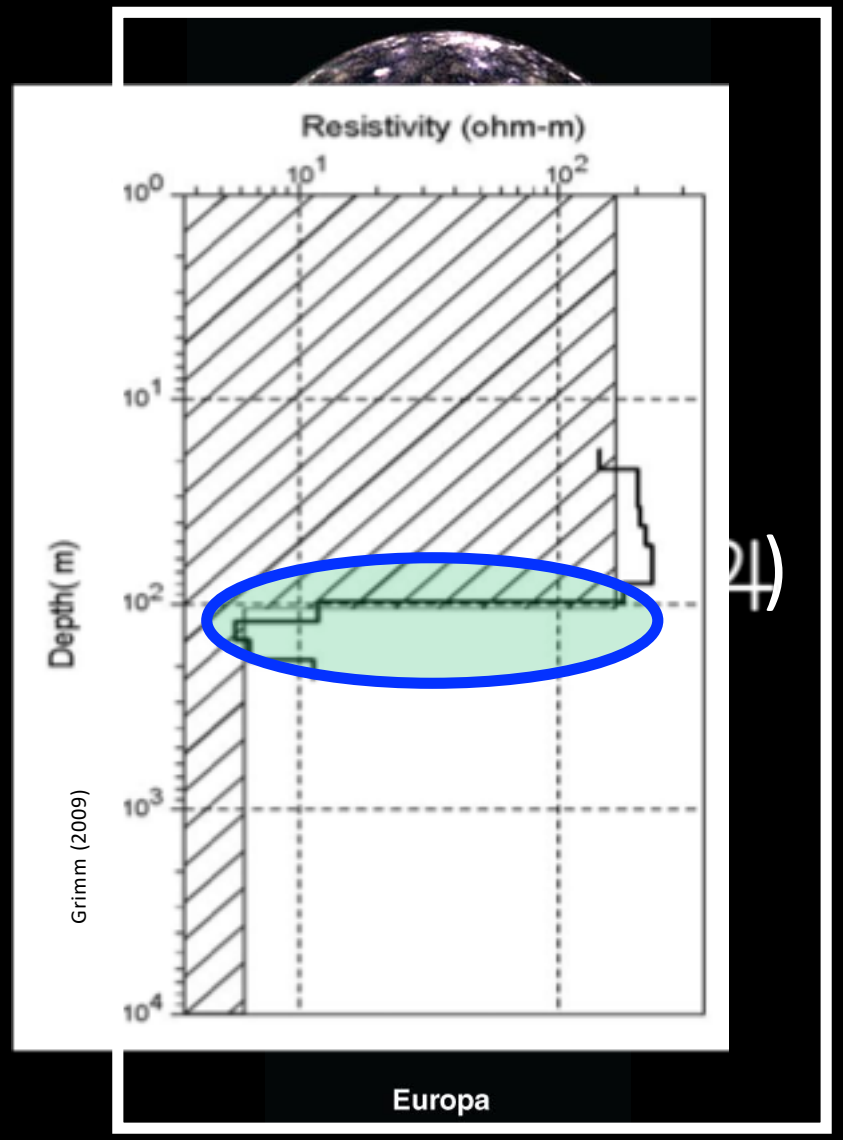
Approach EM Sounding



Receive
Resistivity Profile



Electric Conductivity is Inferred

Dry crust:	~10^{-6} S/m
Wet crust:	10^{-2} S/m
Ocean water:	5 S/m

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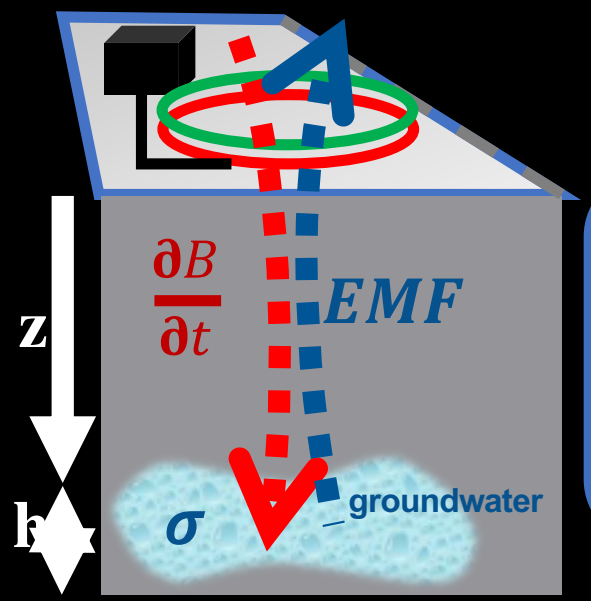
Approach in Equations



$$B_Z \propto \frac{M_T}{(bt+z)^3} \propto \frac{Id^2n}{(bt+z)^3} \propto \frac{Id^2n}{(t/(\sigma h)+z)^3}$$

$$V = EMF = -An\frac{\partial Bz}{\partial t} \propto \frac{bd^2nM_T}{(bt+z)^4} \propto \frac{Id^4n^2}{(\sigma h)(t/(\sigma h)+z)^4}$$

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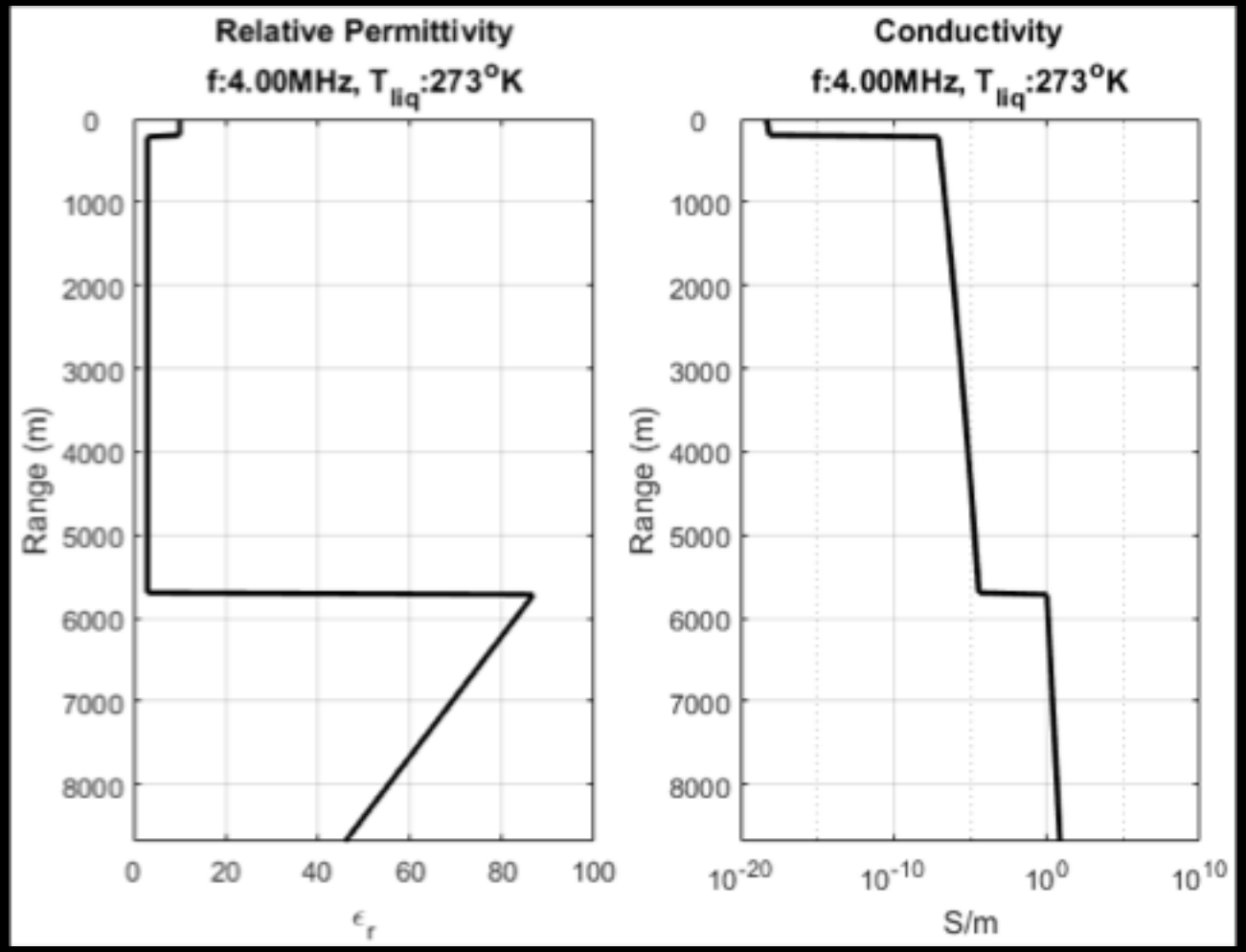
Why This Rocks So Much

Example

- Dry Rock:
  - 0 - 0.2km
  - Peridotite
- Water Ice:
  - 0.2km to 5.7km
- Saline Water:
  - >5.7km.



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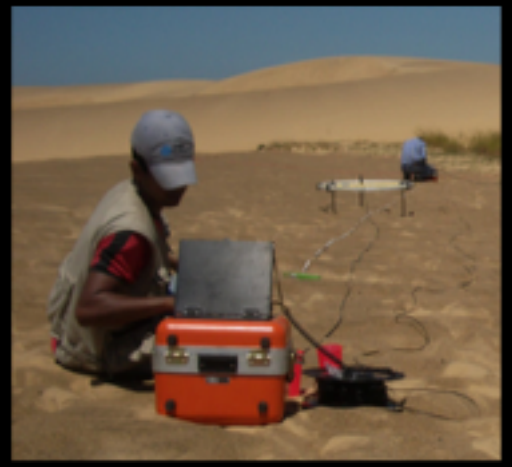
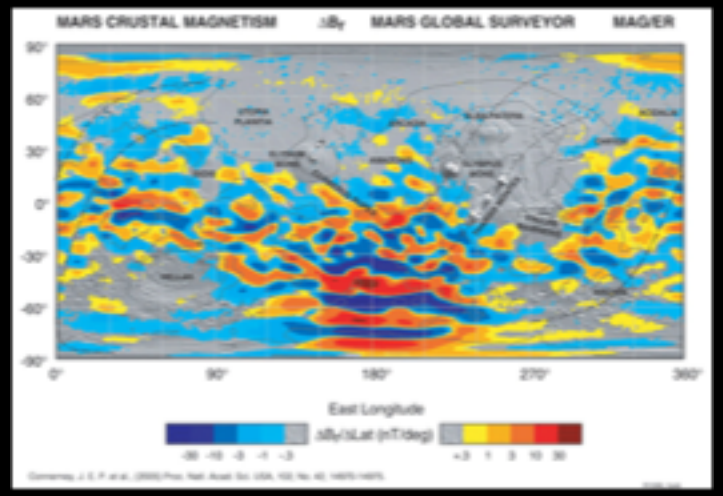
Potential Challenges

Large mass, volume & power footprint

Human tended





False-positives

Only on Earth so far

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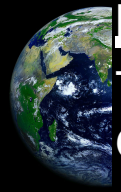
Innovations



Earth

Typical Earth crust: 10^{-2} S/m
Ocean water: 5 S/m

Mars

Dry Mars crust: ~10^{-6} S/m
Ice: 10^{-13}-10^{-6} S/m

USE THE MARS ENVIRONMENT IN OUR FAVOR

- Low overburden conductance of Mars crust and cryosphere.
- Surface is cold (*20℃ vs -60℃*) and no EM noise.
- Larger integration time possible.
- Greater sensitivity, smaller error, and greater sensing depth for same power.

CLASSIC APPROACH BUT MINIATURIZATION

- Leveraging well-proven technique and package it into a planetary scale mission.
- Preliminary calculations and a basic testing unit from Co-I Grimm show it is feasible to reach our established mass, volume, and power targets.

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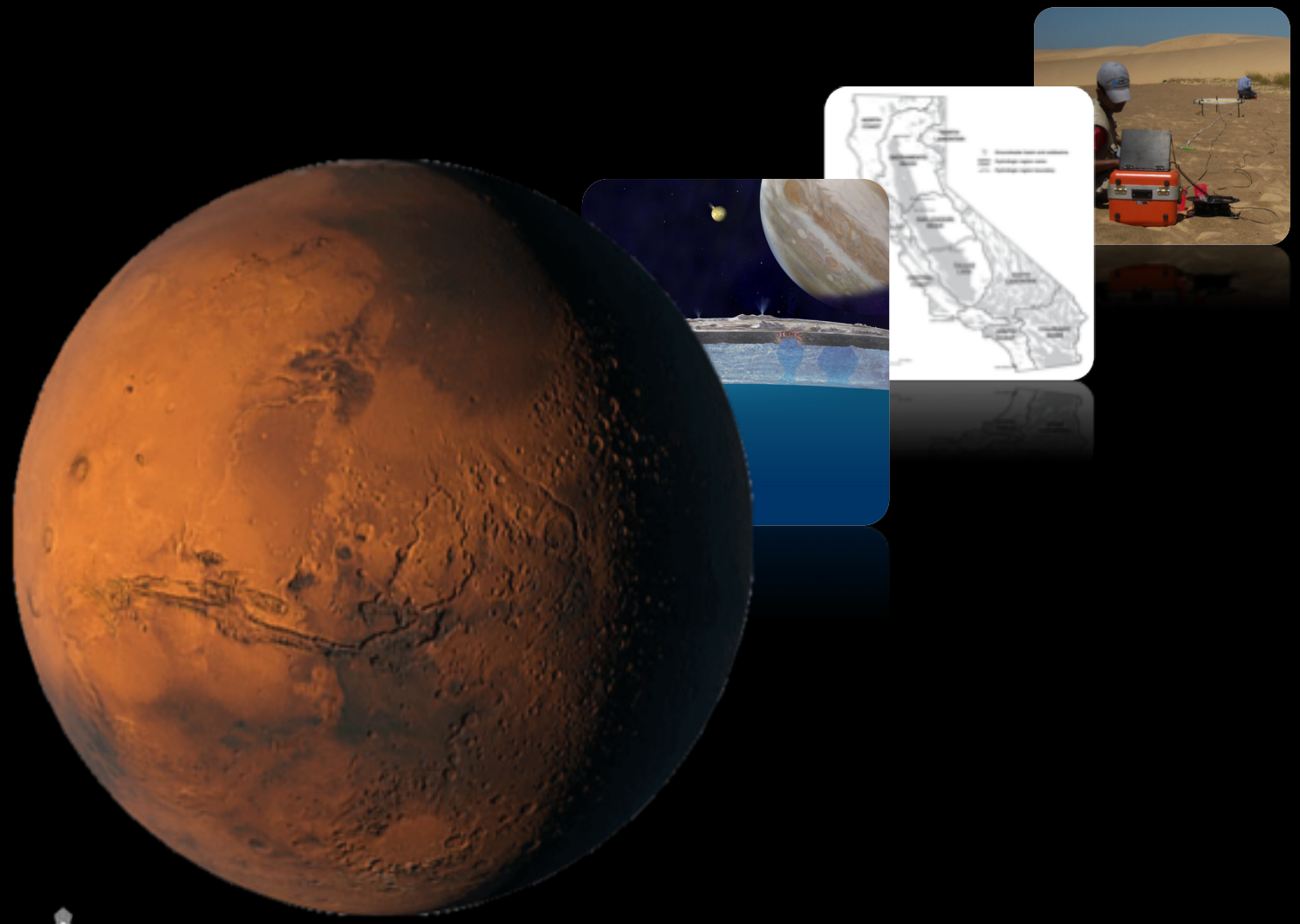
Opportunities



Low-cost Mars Opportunities

- Small spacecraft usability
- Discovery class usability
- Ride along with Flagship (e.g., ASGARD, MSR)
- Payload on Fetch rover.

Forging a New Expertise Beyond Mars

- Europa
- Moon
- Earth

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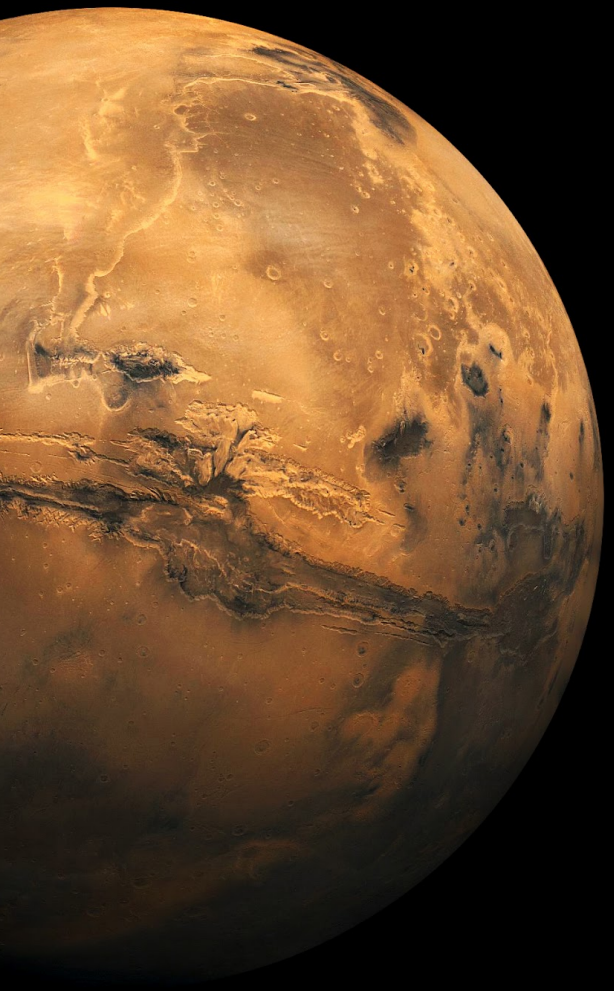

ASGARD Concept

Ares Subsurface Great Access & Research Drill

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Objectives

This effort seeks to demonstrate that it is possible to drill in reasonable time (2 Earth years) deep (up to 10 km or more) into competent rock (from an outcrop) using a low-mass (<100 kg) and low-power (<100 W average) system, whose downhole elements can be sterilized consistent with planetary protection protocols currently or likely to be established for Mars Special Regions.

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Proposed Technical Approach Highlights

- Create a small-diameter downhole assembly that drills the rock and flushes the cuttings into a bailing bucket on the back of the downhole assembly.
- Downhole assembly is all-mechanical, powered by compressed liquid CO_2 driven down hole through a sub-mm fused silica capillary tube that is also used as a wireline to raise and lower the downhole assembly in and out of the hole once or more per Mars day.
- Downhole assembly has a rotary-percussive mechanism powered by progressive depressurization of the liquid CO_2, culminating in the liquid flashing to vapor where it is used to flush the cuttings away from the drill bit and up the annulus between the mechanism and the hole where they settle into a bailing bucket in approximately the reverse stratigraphic order that they were drilled (e.g., first-drilled is at the bottom).
- Once or more per sol, the fused silica wireline spool is used to lift the downhole assembly out of the hole where the cuttings are removed from the bailing bucket and presented to triage instruments in stratigraphic order for decision on further analysis or disposal.

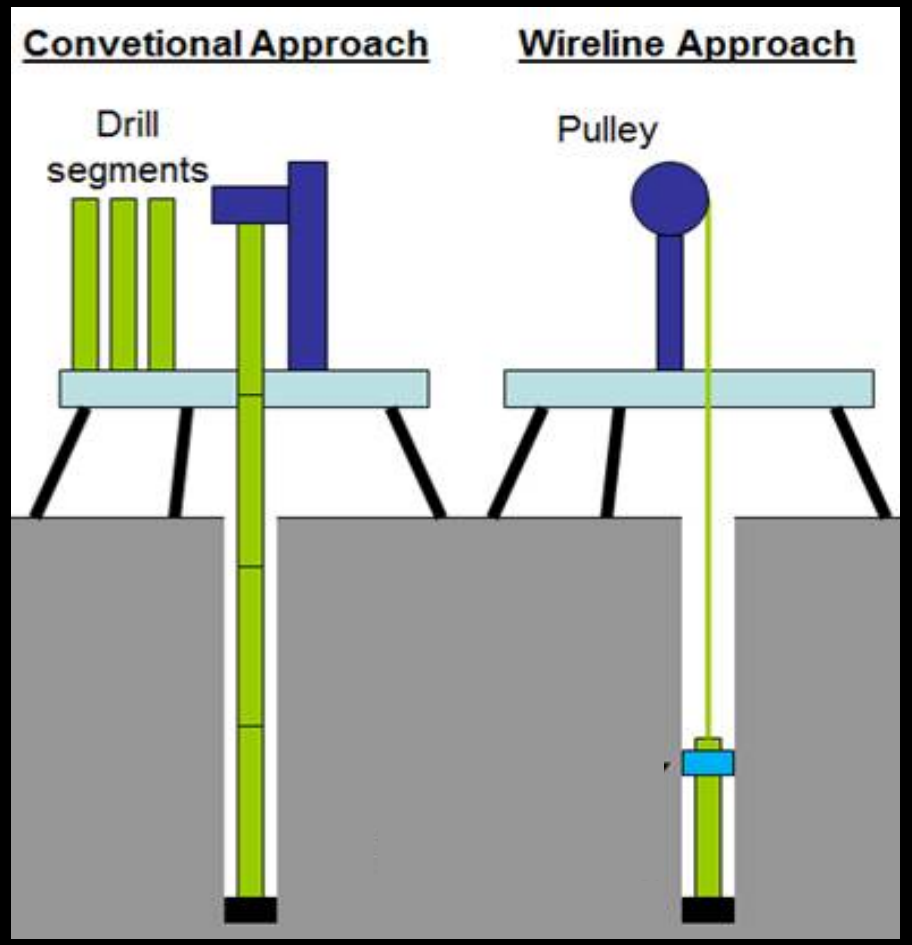

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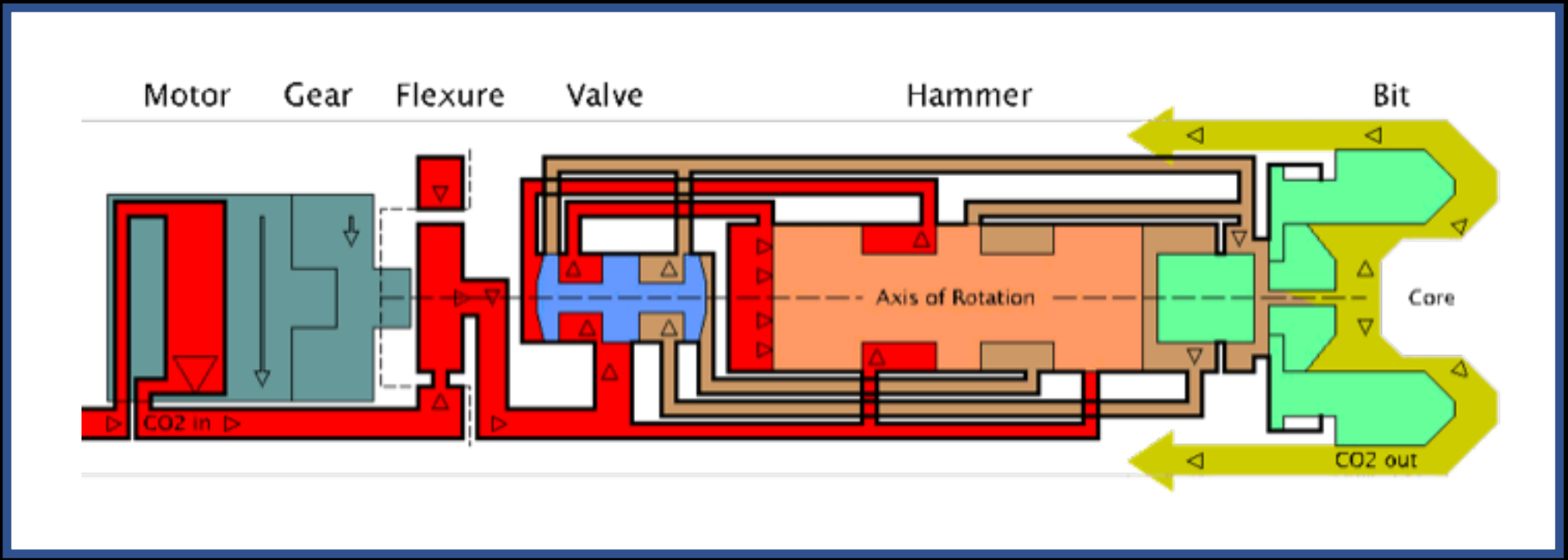
Illustration of a Pneumatic Jackhammer Concept



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Possible Innovations

- Uses CO_2 ingested from the Mars atmosphere (like MOXIE) as both the means for conveying power to the downhole assembly and also as the means to flush the cuttings away from the drill face. CO_2 has remarkably low viscosity and so is suitable for transmitting hydraulic power long distances through fine capillary tubes.
- The capillary and all other downhole components are rated for temperatures of 300°C or higher so that virtually any sterilization protocol can be implemented.
- The rotary-percussive downhole mechanism requires no electronic controls or electrical sensing to drill a wide variety of rock types and is gravity-stabilized to drill straight down. Spring-loaded spiked roller wheels stabilize the back of the assembly in the center of the hole and resist the rotary torque of the mechanism.
- By starting the drill on an outcrop of competent rock (as every Mars rover since Sojourner has explored), the walls of the hole are unlikely to collapse behind the drill, eliminating the tremendous mass required to line the hole. Therefore, the only incremental mass needed per unit additional hole depth is the mass of a fine fused-silica capillary, commercially available in km-scale lengths.
- Our initial prototype downhole assembly is planned to be 35 mm in diameter, but we expect to reduce this to 25 mm or smaller by the end of the third year of the task by making a smaller hydraulic motor than those currently available. At an average of 500 J of mechanical energy per cubic centimeter of rock excavated (an industry rule-of-thumb), the average power required at the rock face to drill 10 km in two Earth years will drop from ~75 W to ~40 W with this change.

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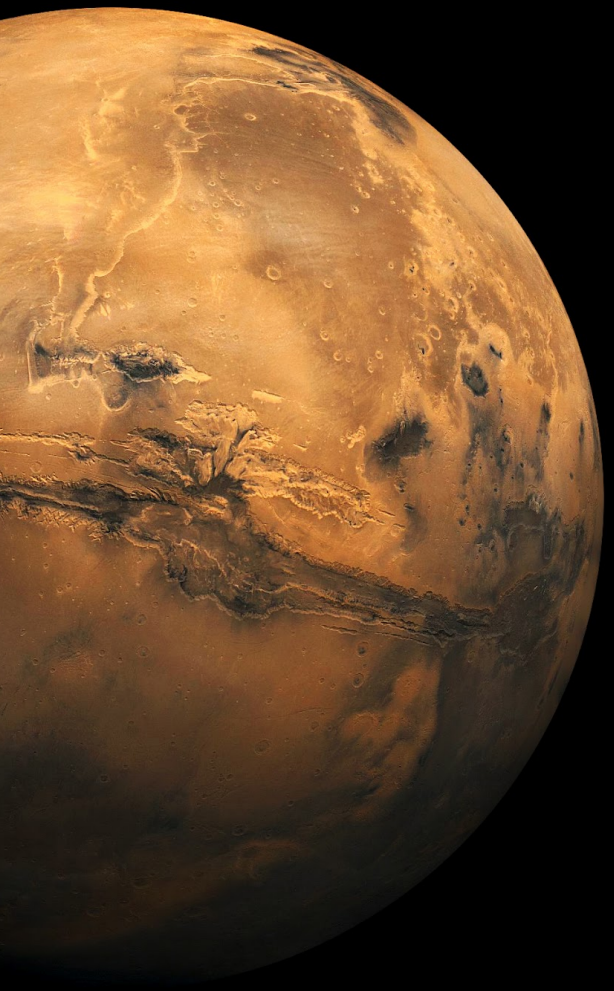

Summary & Conclusions

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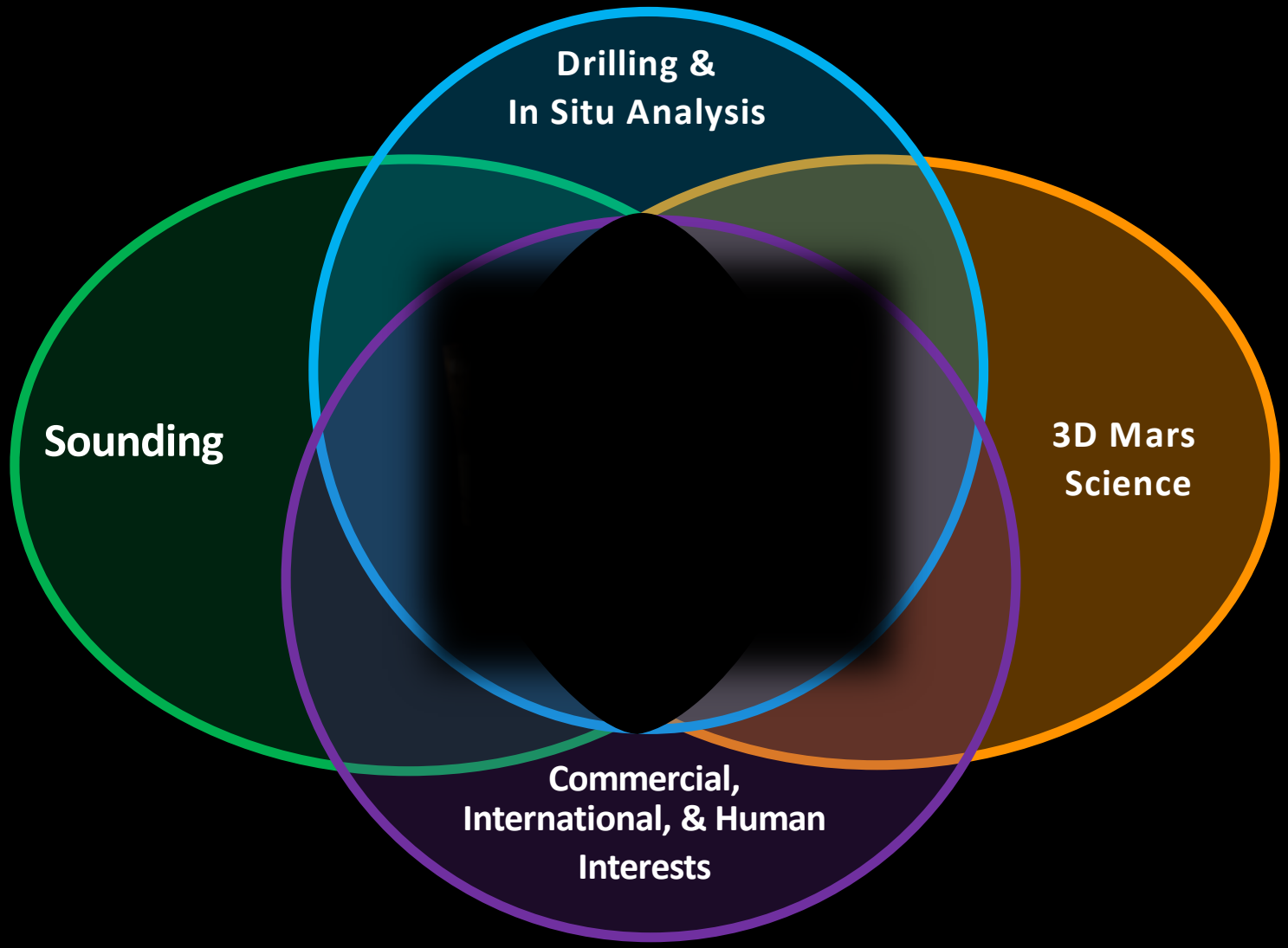
Summary

- ***The quest for life (extinct and extant), water, & resources leads inevitably into Mars' underground.***
- We have not yet explored this alien dimension.
- 3D Mars science has evolved enough to start informing us about subsurface diversity.
- Drilling & sounding technologies are mature enough and should be explored in parallel as they are complementary.
- Human exploration and commercial worlds can help achieve these goals.
- **We have the tech that could change the Mars game. So why not use it?**



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More Info/Meetings

- Astrobiology Decadal White Paper is out.
- KISS marsX workshop paper in Nature Astronomy and report out soon.
- AGU Session "*New Mars Underground*".
- *Vlada.Stamenkovic@jpl.nasa.gov*"

AGU 100 **FALL MEETING**
Washington, D.C. | 10-14 Dec 2018

Session ID: 51671
Session Title: P046. "The New Mars Underground": Science and Exploration of a New Deep Frontier
Section/Focus Group: Planetary Sciences
View Session Details: https://agu.confex.com/agu/fm18/gateway.cgi

Mars Subsurface Access: From Sounding to Drilling

A White Paper Submitted to The National Academies of Sciences, Engineering and Medicine's Astrobiology Science Strategy for the Search for Life in the Universe Meeting January 2018

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Organizations

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