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Mars Small Spacecraft

The opportunity of the roaring 20ties

Vlada Stamenkovic, C. D. Edwards, N. J. Barba, R. C. Woolley, L. Giersch, T. A. Komarek, V. Cormarkovic, P. E. Clark, A. Chmielewski, et al.

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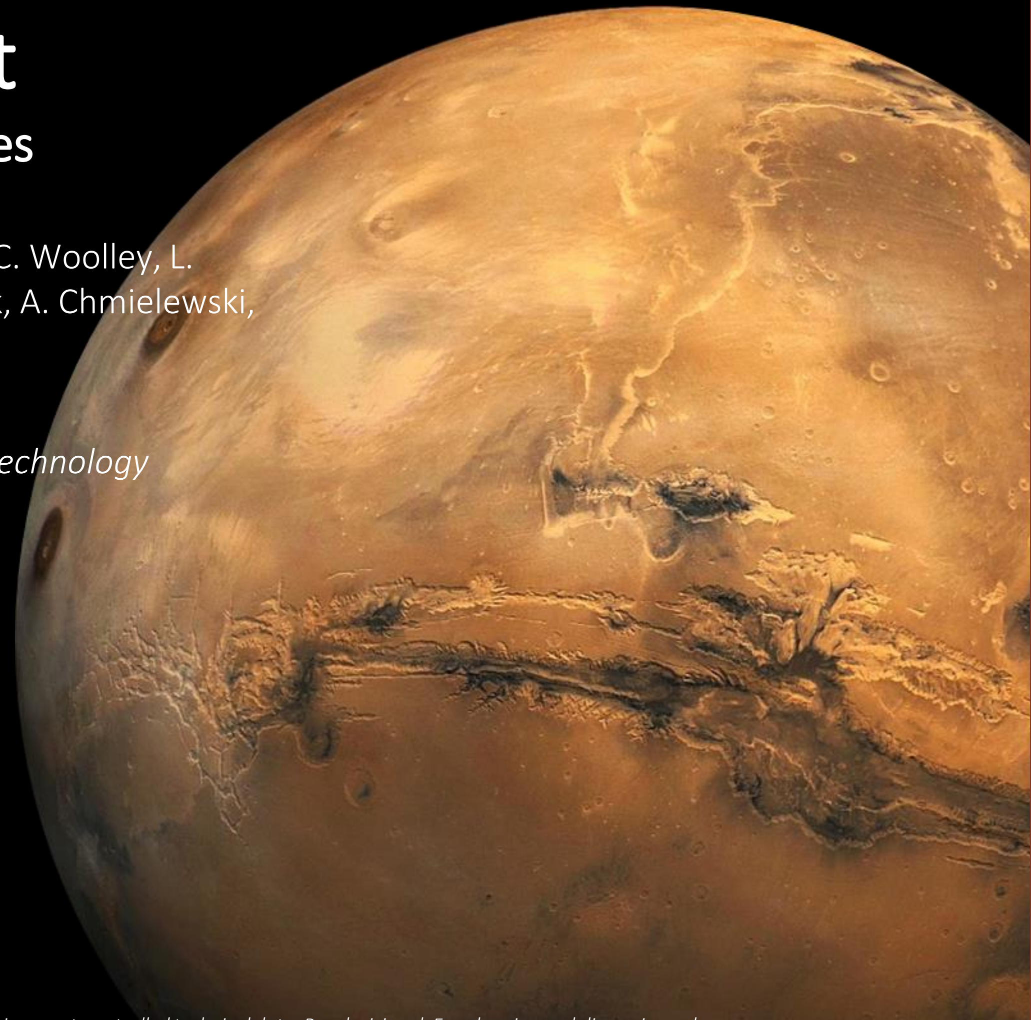
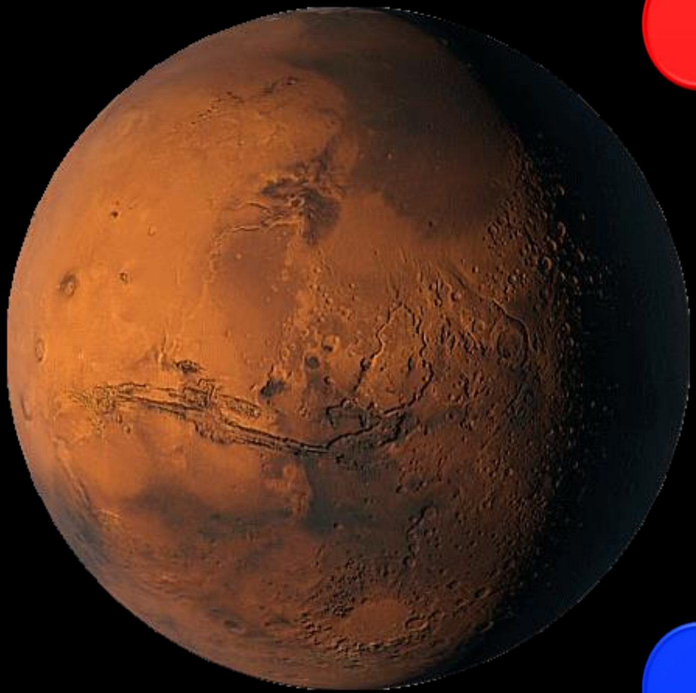
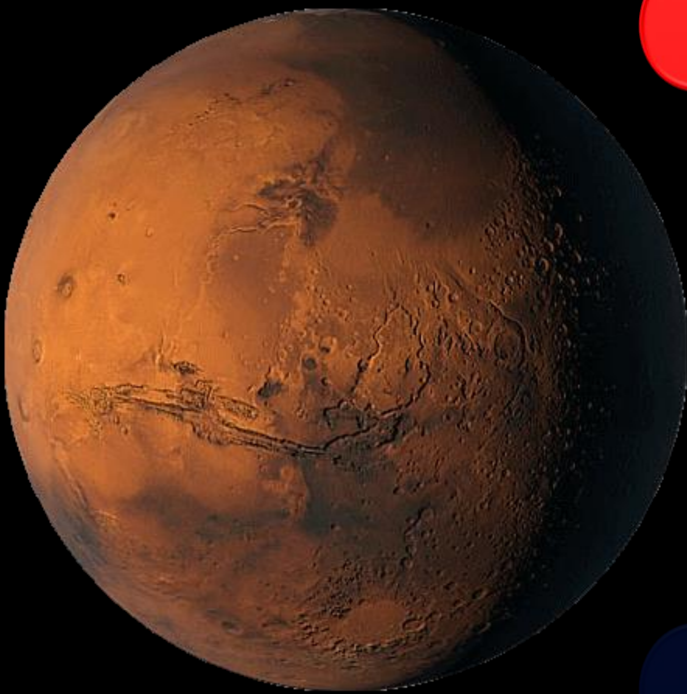




- Why Mars?
- How to do it small?
- What science?
- What mission concepts?
- Last thoughts & summary



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Mars today…been there, done that?

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- P = 6 mbar
- T = 140-300
- f_{O_2} = 0.146 %
- Organics being destroyed on the surface

BUT…whiffs of weird gases…

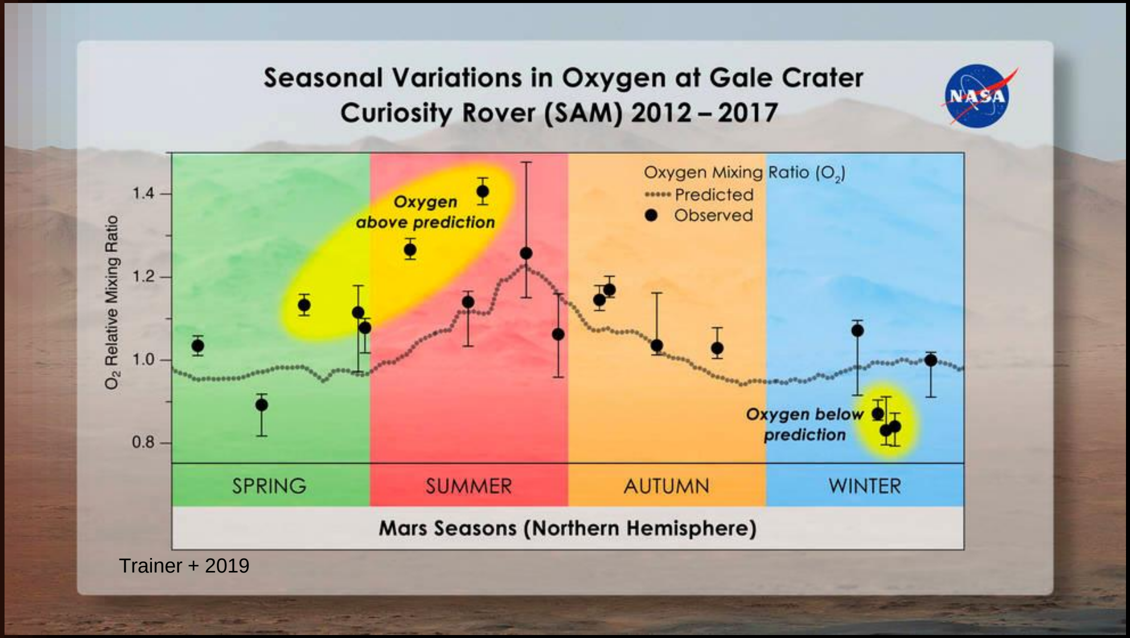
Methane?

The New York Times

"The mysterious appearance and disappearance of methane in the Martian atmosphere remains the most compelling hint of possible life in the subsurface of Mars,"

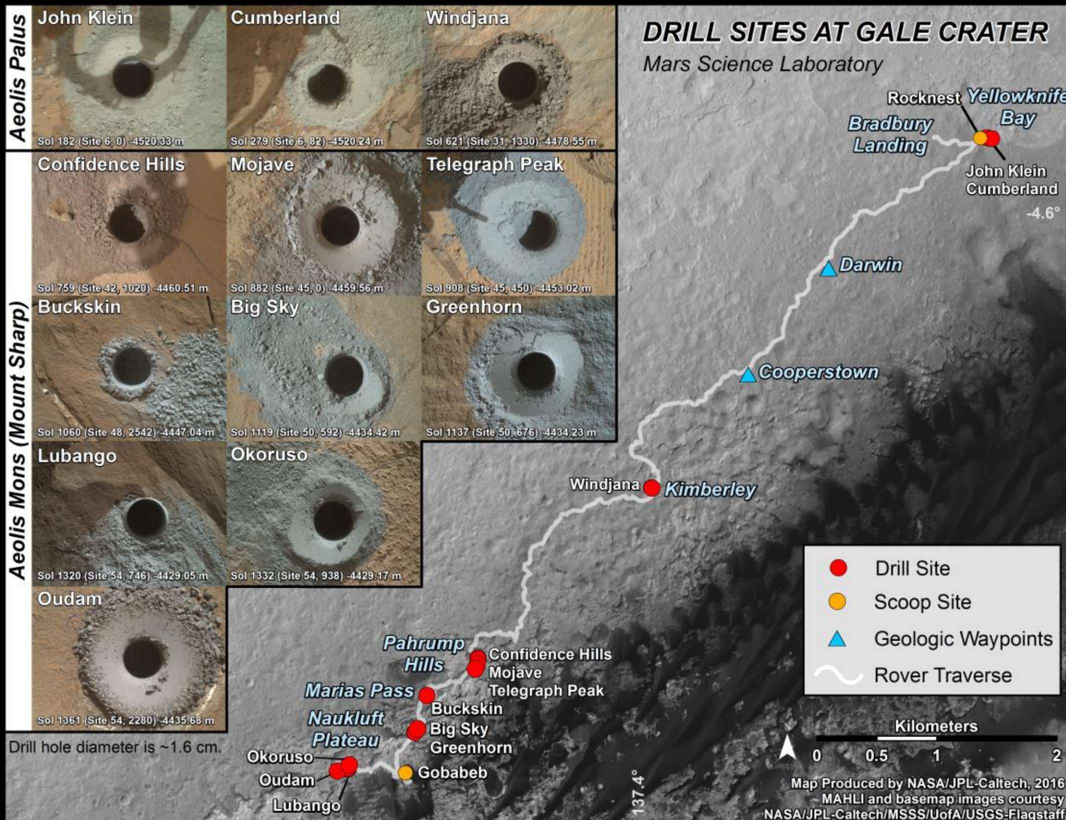
Dr. Pratt (NASA PP).

Oxygen?

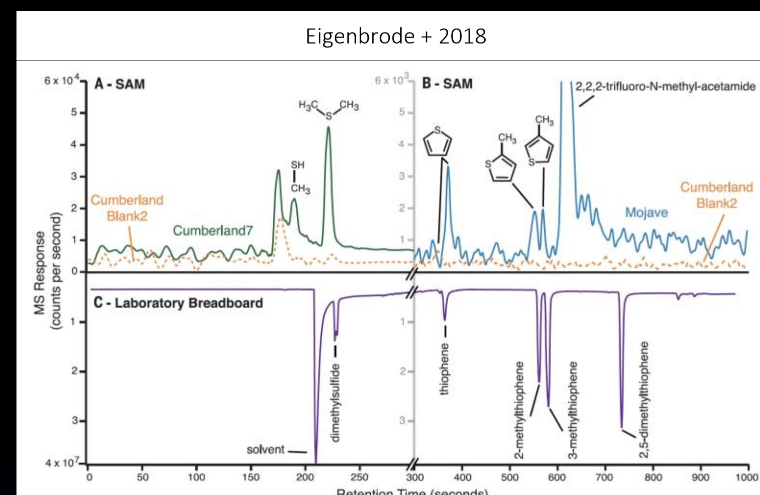


Hidden diversity below…power to fuel life?

Redox gradients with depth?



Where is the organics coming from?



A refresher…young water?

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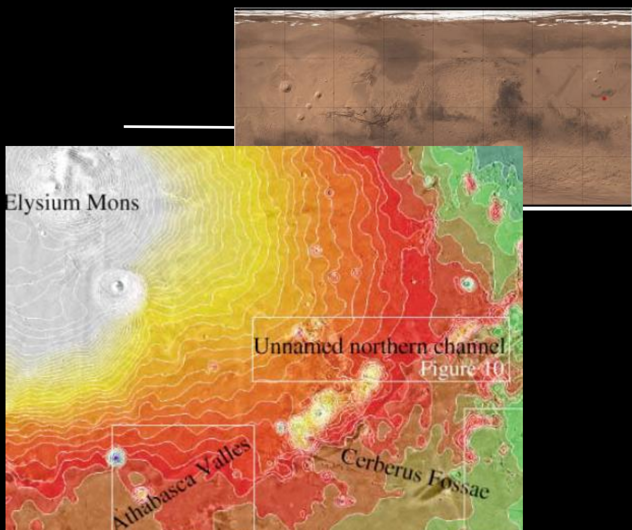
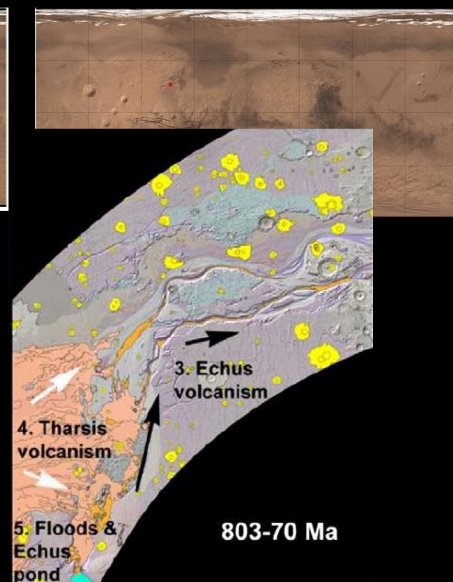
Young Outflow Channels in Athabasca and Kasei

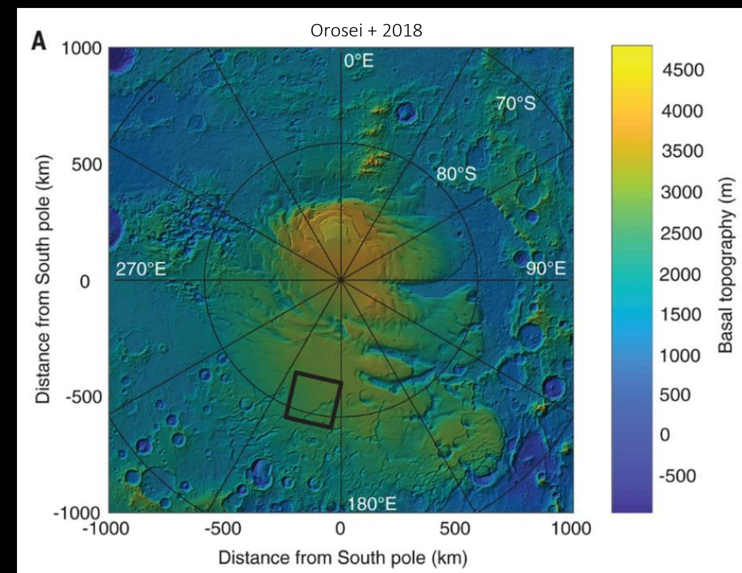
[Burr et al., 2002; Chapman et al., 2010]

- Aquifer or juvenile water?





Liquid (ground)water today?



Mars today…<u>been there, done that</u>?

- P = 6 mbar
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Been there…but haven't done that!

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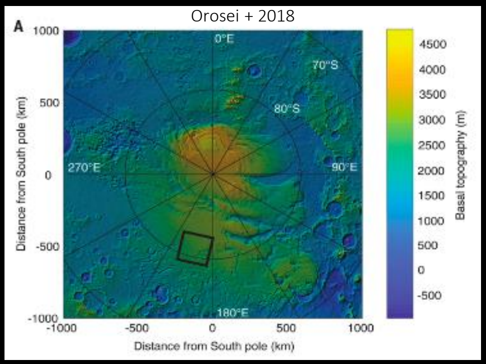
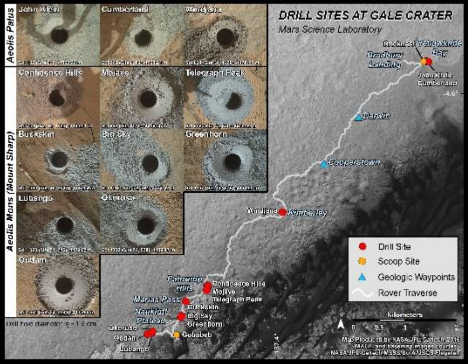
Big, game-changing, Mars questions left unanswered.

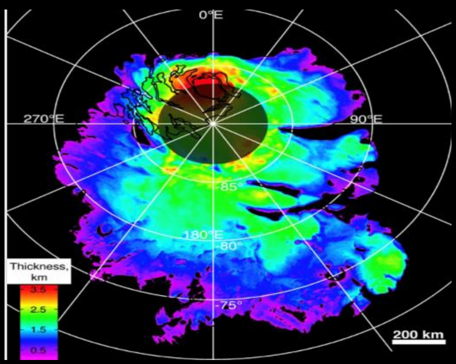
Water?



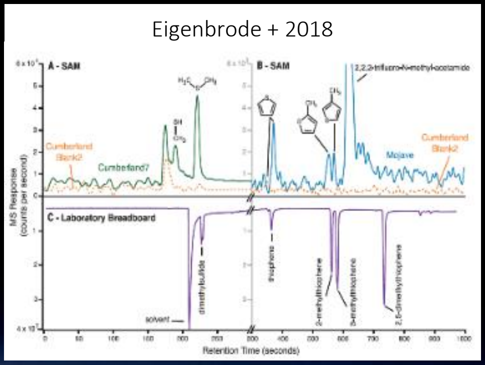
Power to fuel life?



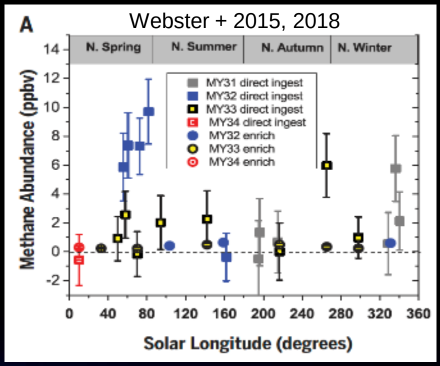
Climate record?



Organics?



Trace Gases?

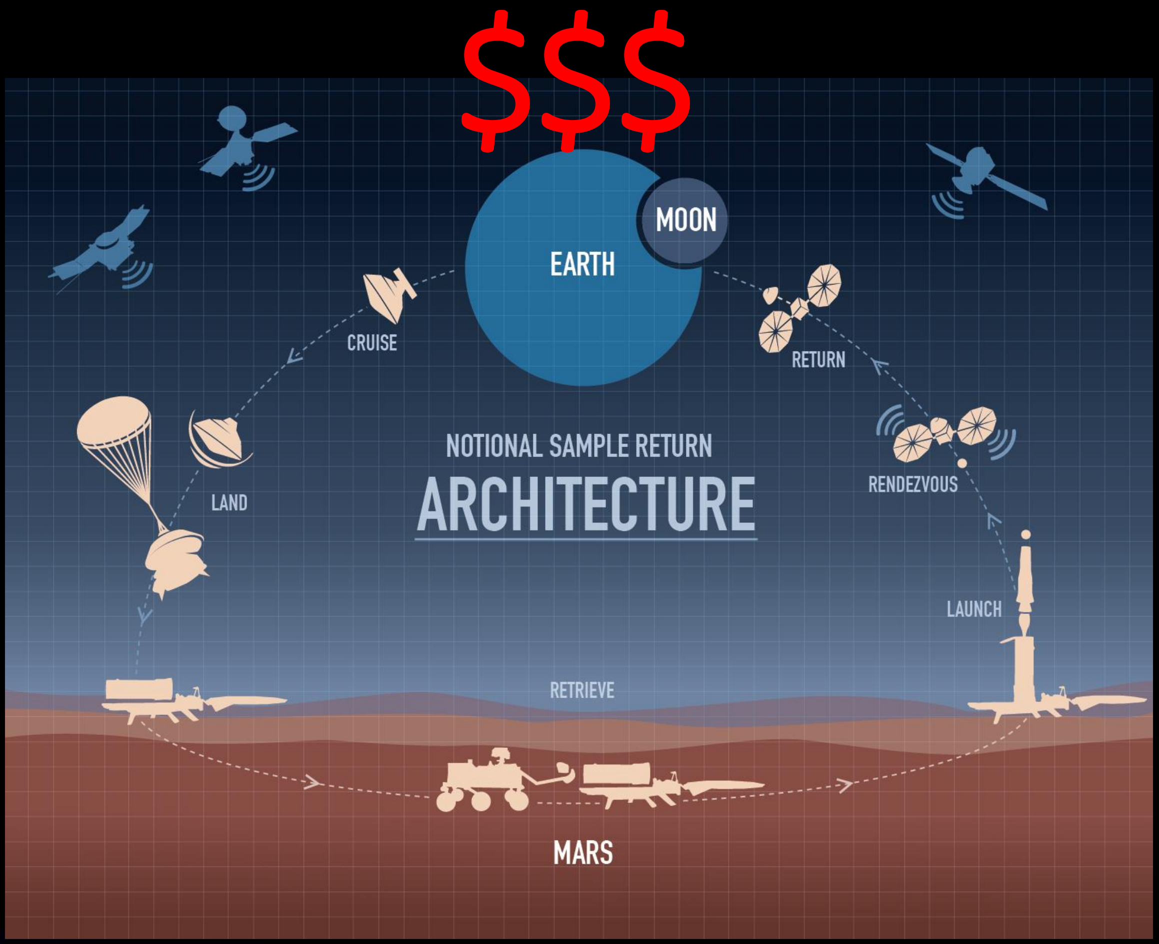


MEPAG changes: subsurface & extant life

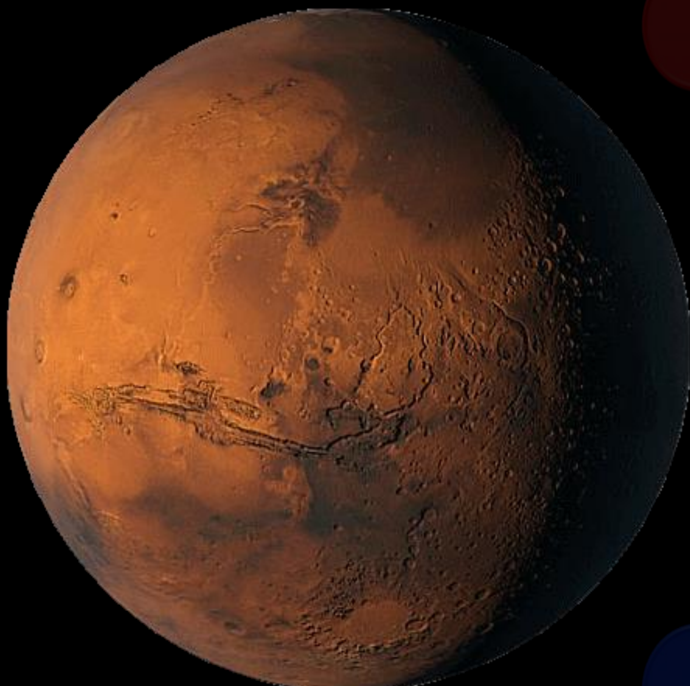
- These questions reflect recent (March 2020) changes in the MEPAG documents, especially to Goal I (Life).
- Back to life, into the deep → tight new bonds to Ocean Worlds & Human Exploration

Objectives	Sub-objectives	Investigations
GOAL I: Determine if Mars ever supported, or still supports, life.		
A. Search for evidence of life in environments that have a high potential for habitability and preservation of biosignatures.	**A1.** Determine if signatures of life are present in environments affected by liquid water activity.	1. Search for chemical signatures of life in surface or subsurface environments that have a high potential for modern/past habitability and preservation of biosignatures.
		2. Search for physical structures or assemblages that might be associated with life in surface or subsurface environments that have a high potential for modern/past habitability and preservation of biosignatures.
		3. Test for evidence of physiological activity in surface or subsurface environments that have a high potential for modern habitability.
	A2. Investigate the nature and duration of habitability near the surface and in the deep subsurface.	1. Constrain the availability of liquid water with respect to duration, extent, and chemical activity.
		2. Identify and constrain the magnitude of possible energy sources, chemical potential and flux, and how they change with depth.
		3. Characterize the physical and chemical environment, particularly with respect to parameters that affect the stability of organic covalent bonds.
		4. Constrain the abundance and characterize potential sources of bioessential elements.
		5. Provide overall geologic context.
	A3. Assess the preservation potential of biosignatures near the surface and with depth.	1. Evaluate conditions and processes that would have aided preservation and/or degradation of complex organic compounds as a function of depth, such as aqueous, thermal, and barometric diagenesischemical and biological oxidationor radiolytic ionization.
		2. Evaluate the conditions and processes that would have aided preservation and/or degradation of physical structures on micron to meter scales and as a function of depth such as physical destruction by mechanical fragmentation, abrasion, and dissolutionand protection by minerals (i.e., inclusions, surface bonding, grain boundaries).
		3. Evaluate the conditions and processes that would have aided preservation and/or degradation of environmental imprints of active metabolism near the surface and as a function of depth, such as chemical alteration or dilution.
B. Assess the extent of abiotic organic chemical evolution.	**B1.** Constrain atmospheric and crustal inventories of carbon (particularly organic molecules) and other biologically important elements over time.	1. Characterize the inventory and abundance of organics on the martian surface and subsurface, including macromolecular organic carbon, as a function of exposure time/age.
		2. Characterize the atmospheric reservoirs of carbon and their variation over time.
		3. Constrain the abiotic cycling (between atmosphere and crustal reservoirs) of bioessential elements on ancient and modern Mars.
		4. Characterize bulk carbon in the martian mantle and crust through investigations of martian meteorites.
	B2. Constrain the surface, atmosphere, and subsurface processes through which organic molecules could have formed and evolved over martian history.	1. Investigate atmospheric processes (e.g. photolysis, impact shock heating) that could potentially create and transform organics.
		2. Investigate the role of ionizing radiation in organic synthesis and destruction and how it changes with depth.
		3. Investigate surface and subsurface processes, such as mineral catalysis, that play a role in organic evolution.
		4. Investigate the role of subsurface processes (e.g. hydrothermalism, serpentinization) in driving organic evolution.

Planned Mars Sample Return Campaign



We need to find affordable options!



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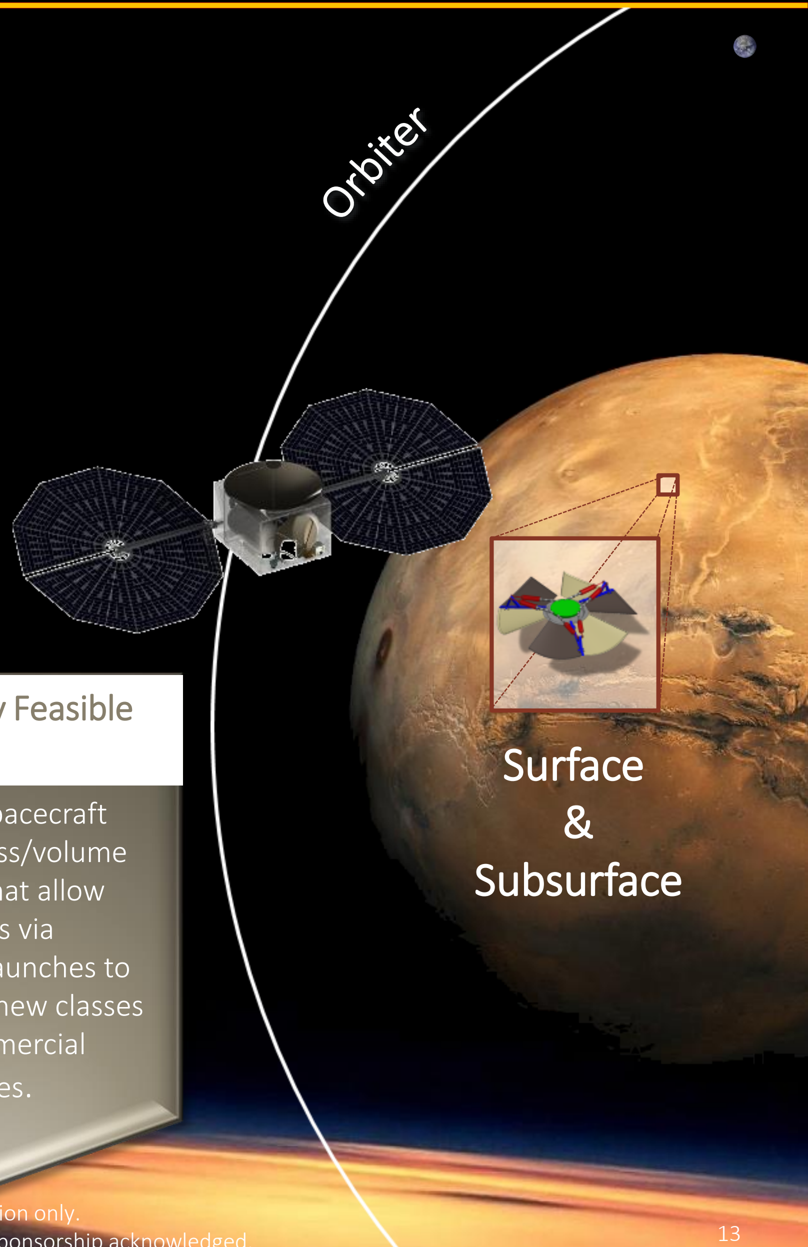
Small Spacecraft is the solution

Solution

- Small spacecraft can provide low cost access to compelling science investigations at Mars.
- From Mars orbit to the Martian <u>surface/subsurface</u> (the latter being key).



Scientifically Compelling

Mars small spacecraft can accomplish decadal class science while being complementary to Flagship missions in type of science investigation.

Low Cost

Mars small spacecraft can get to Mars for costs of ~$100M - 300M including phases A to D and the launch costs.

Technically Feasible

Mars small spacecraft can meet mass/volume constraints that allow reaching Mars via "rideshare" launches to GTO and/or new classes of small commercial launch vehicles.

Three Key Methods to Get Small Spacecraft to Mars

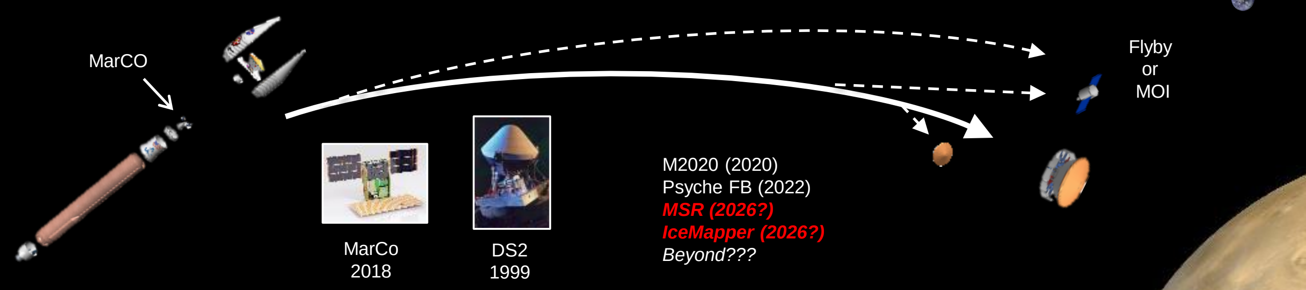
1. Piggyback to Mars

Pro: Cheap, direct delivery

Con: Few reliable options

Mass: varies

Frequency: > 2 years



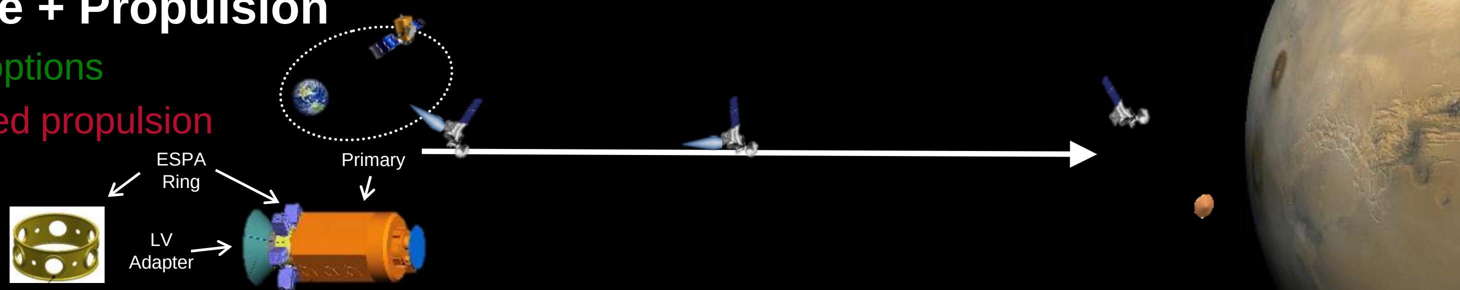
2. Earth Rideshare + Propulsion

Pro: Cheap, lots of options

Con: Secondary, need propulsion

Mass: 100-400 kg

Frequency: > 6 per yr



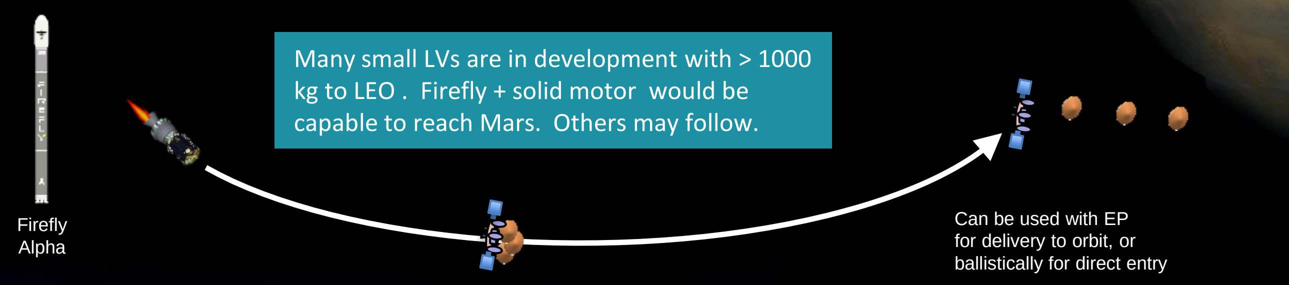
3. Dedicated Launch

Pro: Custom, full control

Con: Kick stage, low TRL

Mass: 100-300 kg

Frequency: 2021+



Promising Small Launch Vehicles for Mars

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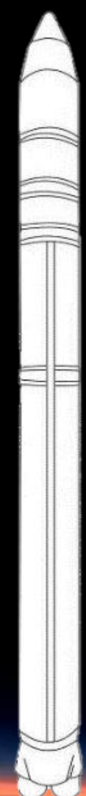
Company	Rocket	Cost	1st Launch	Fairing	LEO	Mars Entry*	LMO* (w/ AB)
FireFly	Alpha	$15M	late 2019	2.0	1000 kg	200kg	130 kg
Relativity Space	Terran 1	$10M	late 2020	1.9	1250 kg	250 kg	160 kg
ABL Space	RS1	$12M	late 2020	1.8	1200 kg	240 kg	150 kg



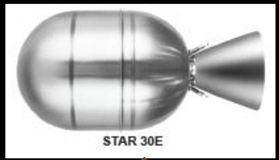
**Additional "kick" stage required for Trans-Mars Injection*

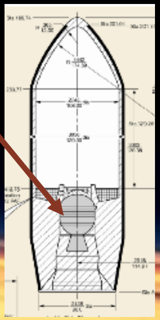
Assumptions

- *Use STAR 30E kick stage*
- *May need to be stretched*
- *20 kg for adapter*
- *300 km LMO uses biprop to 24hr orbit*
- *6 mos. for aerobraking*

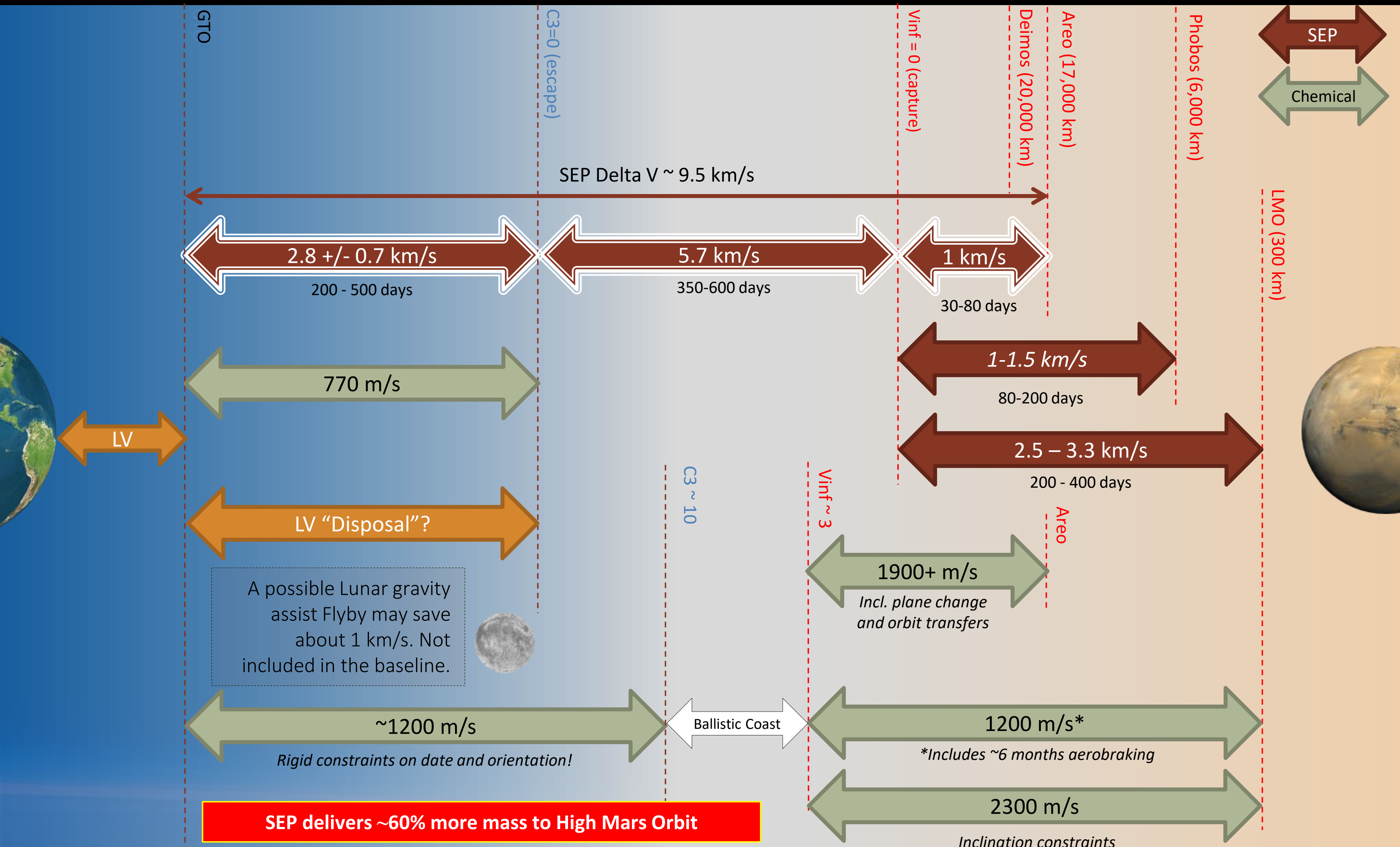
The fully assembled *Lunar Prospector* spacecraft is shown mated atop the Star 37 Trans Lunar Injection module

Lunette Concept (2009)
Star 27, 2 km/s LOI





Path to Mars Orbit Via Rideshare

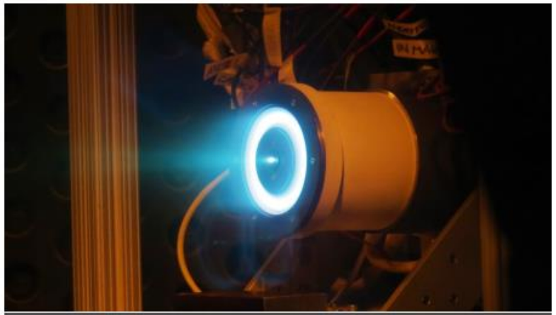


MaSMi (AXE) Interplanetary EP Thruster

- MaSMi thruster ideally suited for small EP missions to Mars
  - Magnetically Shielded Miniature Hall Thruster
  - Developed and tested at JPL
  - Recently licensed to Apollo Fusion for production (labeled Apollo Xenon Engine or AXE)
- Shielding → 10x lifetime vs. conventional Hall

Lifetime: 10,000+ hrs
Production: 2020
Mass: < 5 kg
Xenon: 200+ kg

Max Power	1075 W
Min Power	160 W
Isp	1935 s
Thrust	69 mN
Efficiency	51%



SN NEWS OPINION VIDEO LAUNCH CIVIL CO

Apollo Fusion obtains Hall thruster technology from JPL

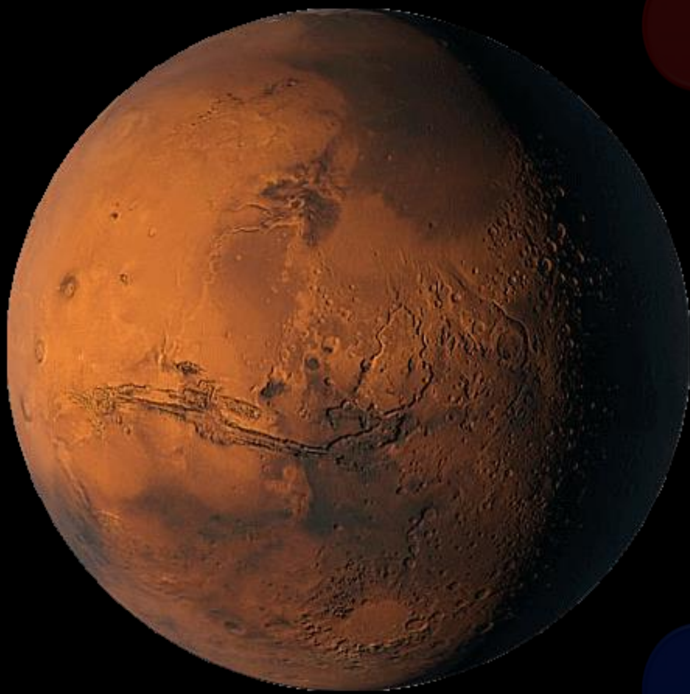
by Jeff Foust — May 7, 2019

Apollo Fusion is licensing technology from JPL to create a new high-power Hall thruster called AXE that offers a longer lifetime than existing systems. Credit: R. Conversano, Jet Propulsion Laboratory, California Institute of Technology

WASHINGTON — Satellite electric propulsion startup Apollo Fusion is expanding its product line through an agreement with NASA's Jet Propulsion Laboratory, giving it access to advanced Hall thruster technology.

The Silicon Valley-based company said May 7 that it signed a deal that gives it an exclusive worldwide commercial license for JPL's Magnetically Shielded Miniature, or MaSMi, Hall thruster technology, as well as a contract to provide JPL with three thrusters that use that technology.

Pre-decisional. For planning and discussion only.



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Compelling Science from Small Spacecraft

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Fundamental & New Single Measurements

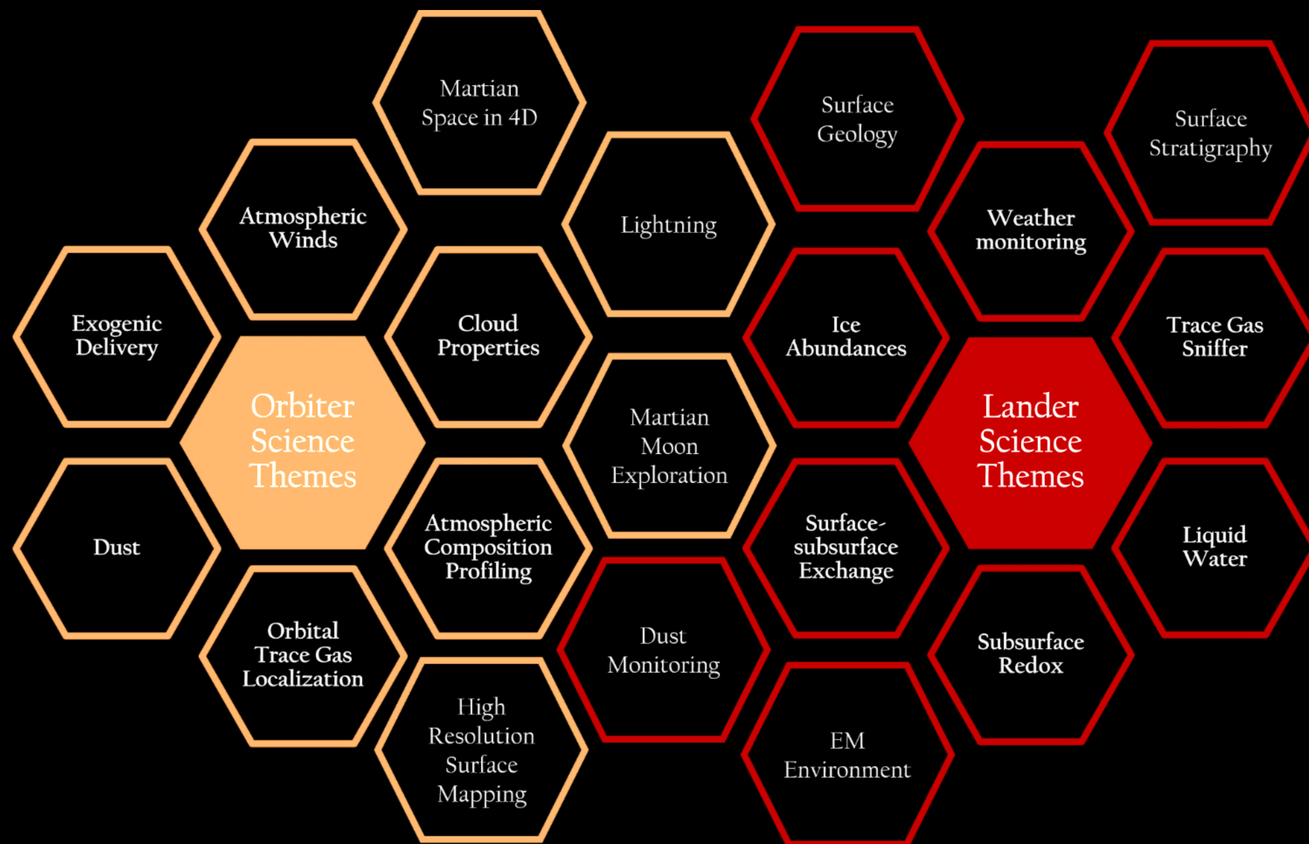
Targeted Science

- One instrument drives all.

Special Landing Zones are Enabled

3D/4D is the Science

- Global Coverage
- Networks
- Causality
- Processes
- Scouts

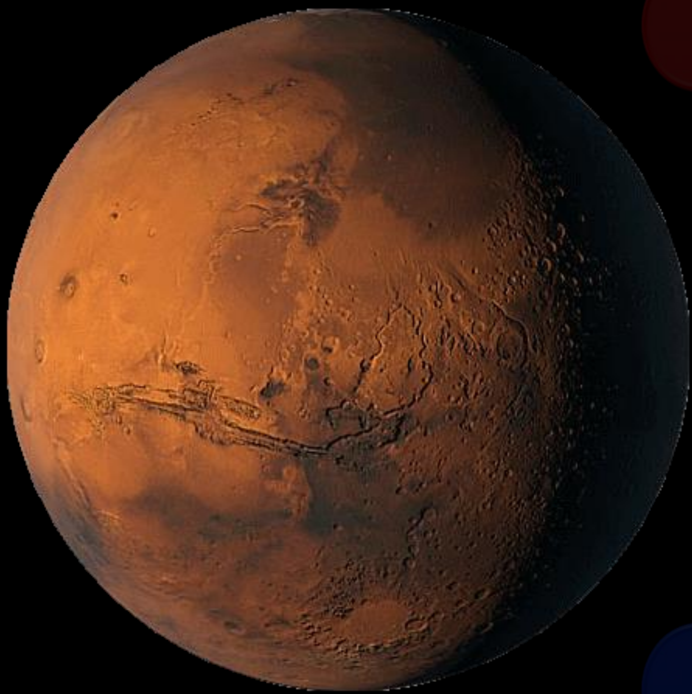


High value science at low cost, complementary to MSR.

Compelling Science from Small Spacecraft

Fundamental & New Single Measurements	Groundwater; EM Fields; H_2O/CO_2 Condensation at Poles; Subsurface Redox Profiles; Exogenic Influx; etc.
Targeted Science • One instrument drives all.	High Resolution Imaging (Visual, IR, Spectroscopic) for landing site selection and reconnaissance; Exogenic Influx & Chemistry; Trace Gas Sinks, Sources, and Transport; Groundwater, etc.
Special Landing Zones are Enabled	Special Locations, such as Poles, Valles Marineris, Southern Highlands, Lowest Altitude, Caves, etc.
3D/4D is the Science • Global Coverage • Networks • Causality • Processes • Scouts	Atmospheric Erosion Drivers; Trace Gas Sinks, Sources, and Transport; Weather Dynamics; Wind Dynamics; Dust & Aeolian Dynamics; Surface-Subsurface Exchange of Vapor Dynamics/Transport. 3D Seismology; 3D Radar; EM Propagation, etc.

High value science at low cost, complementary to MSR.



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Compelling Smallsat Science
From Orbit and On the Surface

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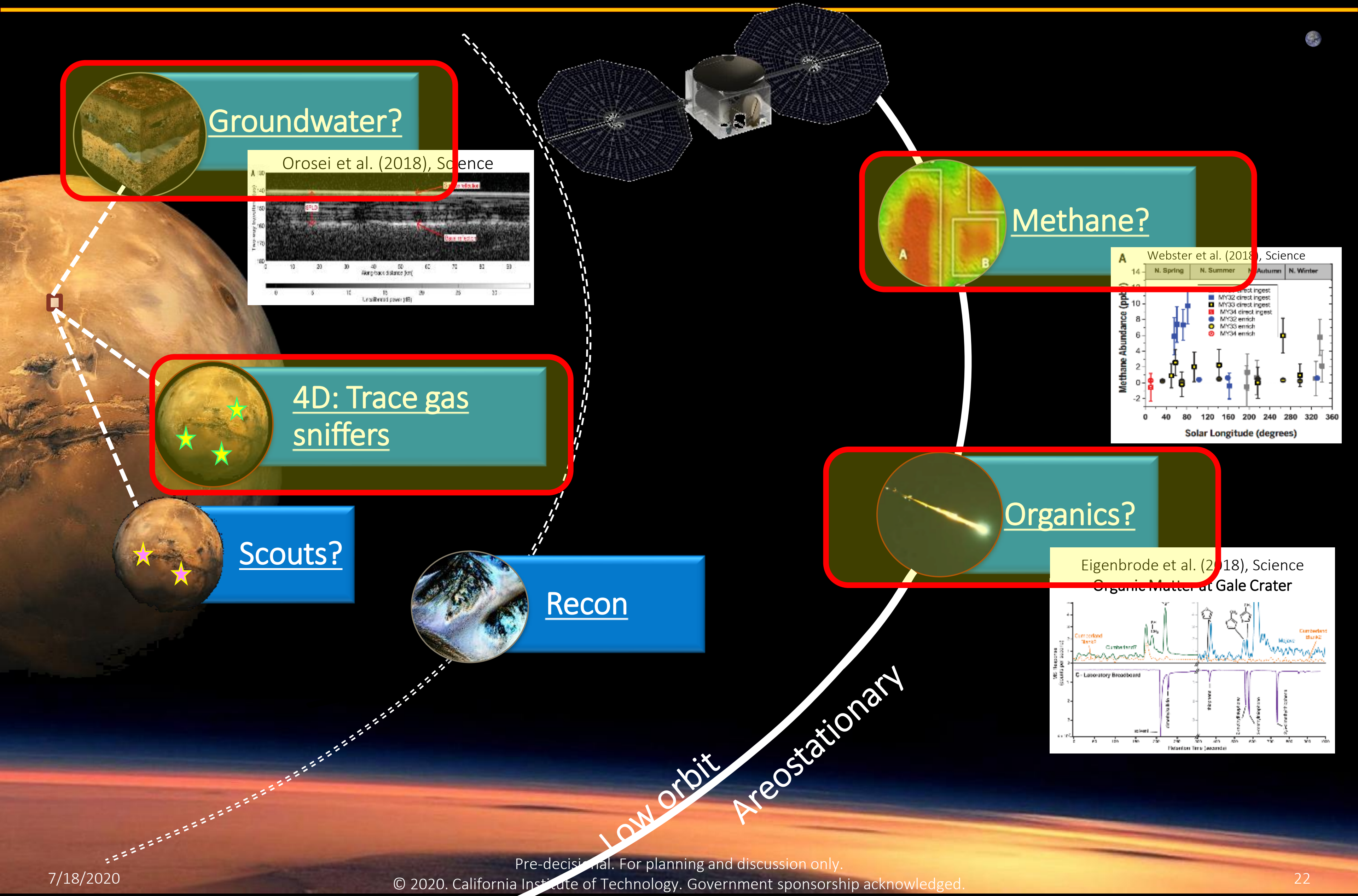

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Find the water with SHIELD & TH_2OR!

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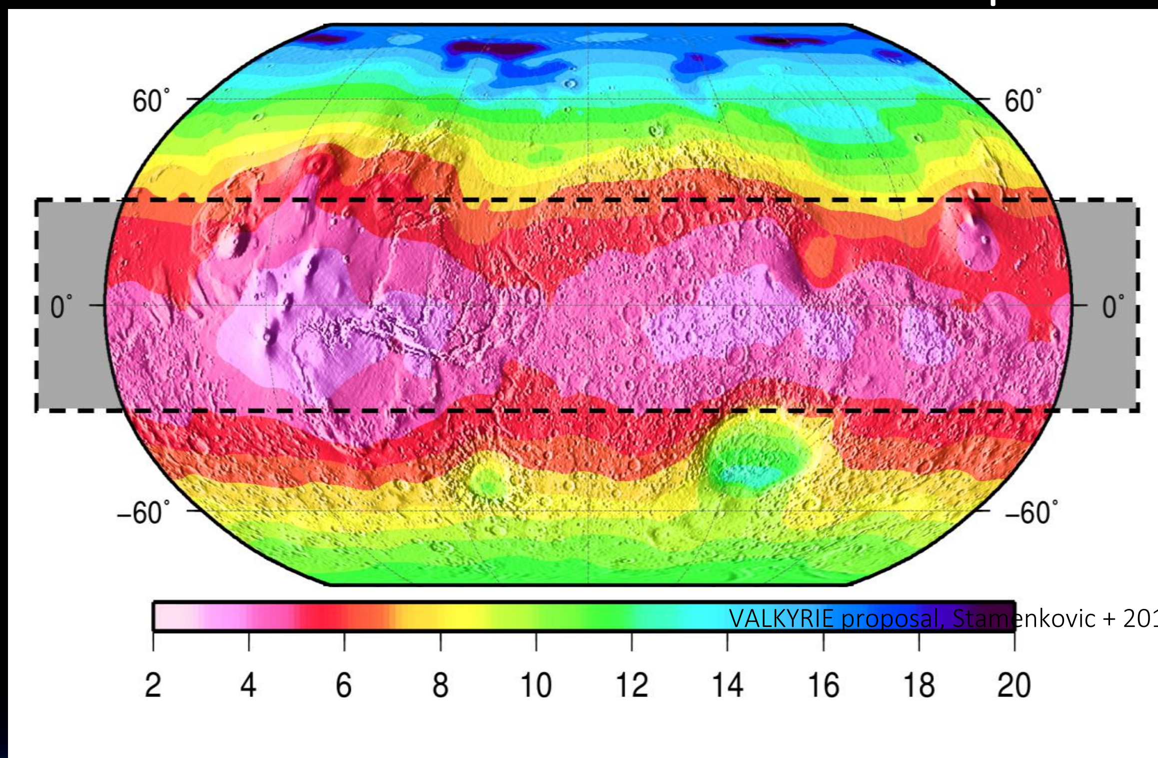
PURE WATER IN THE TROPICS ~2-6 km depth



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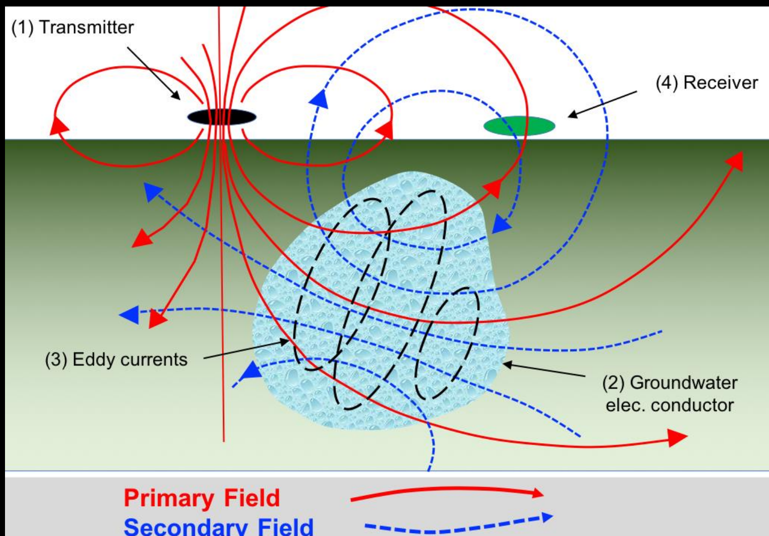
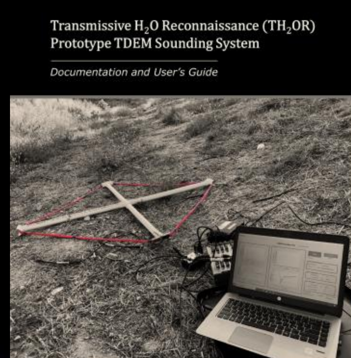


Challenge: Is there liquid water on Mars? What is its composition? Could this be a modern habitat?

Objectives: Demonstrate that we can uniquely sound from the Martian surface for groundwater, expected to be at depths of kilometers, using a low-mass (<5-10 kg) and low-power (<10-100 W average) EM system and to determine its salinity.



Mars is ideal for TEM groundwater search:

	Earth	Mars
Typical crustal conductivity	10^{-2} S/m	10^{-7} S/m
Ocean water	1 S/m	
Contrast	~10^2	~10^7

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Find the water with SHIELD & TH_2OR!

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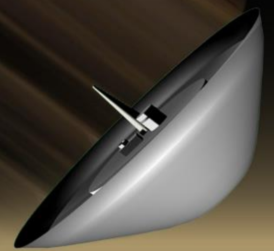
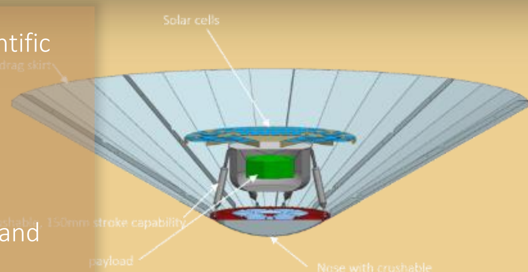


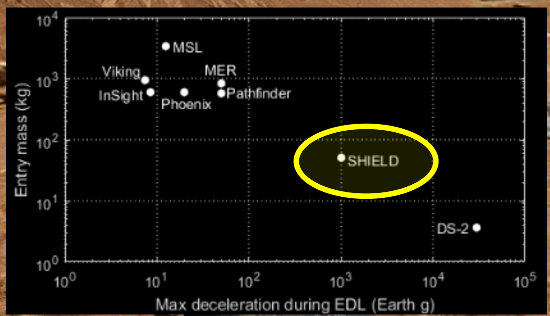
SHIELD enables the transportation of small scientific payloads affordably to the surface.

- Landed Mass: 50kg
- Science Payload Mass: 6kg
- Impact load range 1000 g – 2000 g.
- Static science platform, options for surface and aerial mobility.
- Target mission duration: 90 sols to 1 Martian year (latitude dependent)

<u>Low Cost Approach</u>

- Hosted, secondary, or dedicated P/L configurations.
- No parachute or propulsive deceleration. Low ballistic coefficient to slow down.





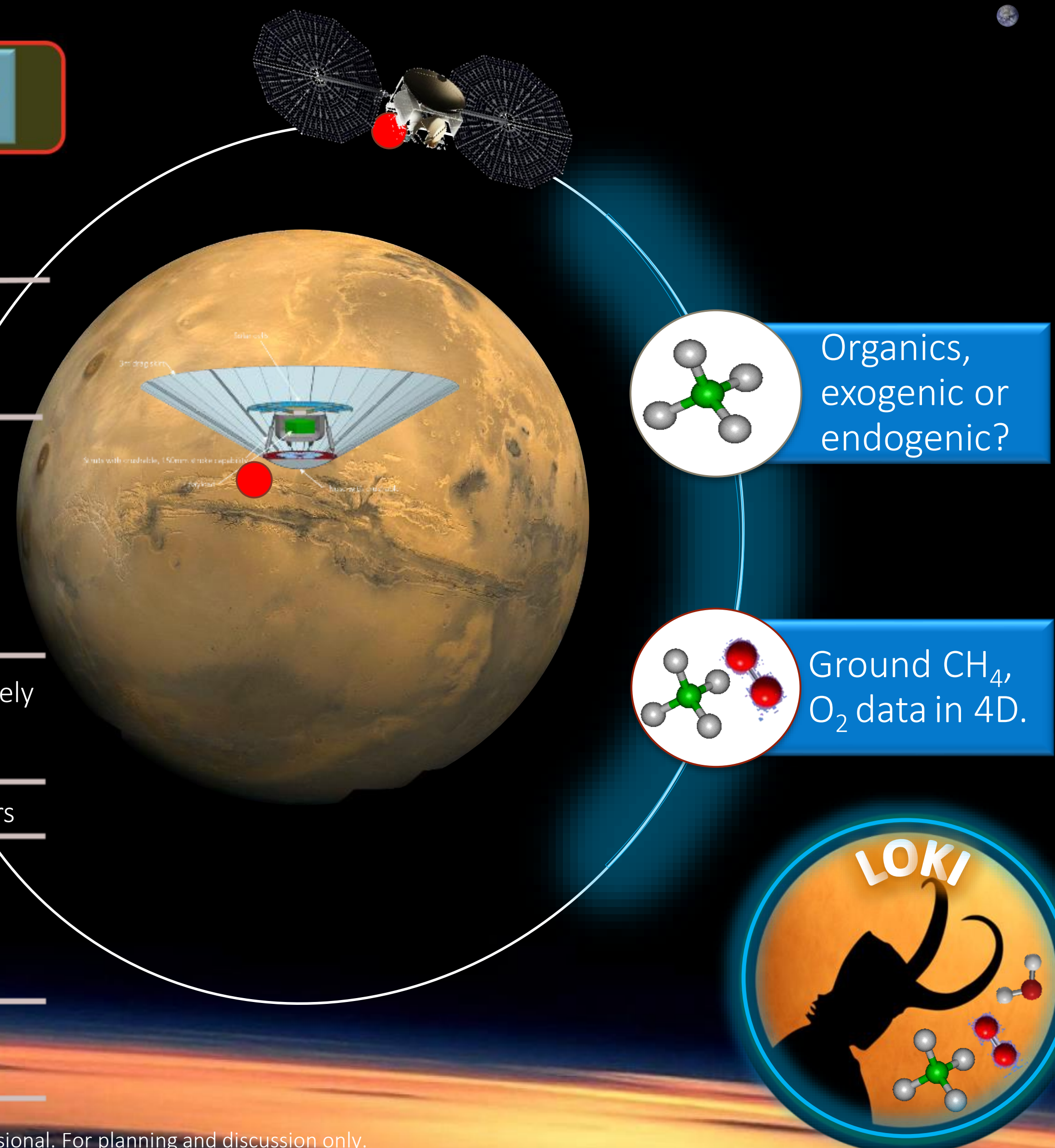
TH_2OR Mission Concept

Science Objective:	Subsurface liquid water detection using transient electromagnetic sounder.
Primary Instrument:	TH_2OR TEM Liquid Sounder; 100 m transmit loop, receive loop, detector electronics.
Secondary Instrument:	Meteorological sensors, trace gas sensors, dust sensors, and/or imager(s). Ruggedized for impact and environment
Mission Duration:	Primary -1 month, Extended -1 Mars year
Configuration:	Multiple SHIELD landers with cruise stage
Mission Design:	Ballistic trajectory, landing at equator +/- 30° latitude

Find the source of organics

LOKI (**L**ocalizing **O**rganic **K**ey **I**ngredients)

Science Goal:	Localize the sources and sinks for methane and organics on Mars.
Science Objectives:	Measure exogenic organic influx. Measure atmospheric $CH_4/O_2/H_2O/H_2O_2$ variability on the surface.
Surface Instruments:	Mini-TLS [2 (CH_4 and H_2O)-4 channels (+O_2, H_2O_2)]
Orbiting Instrument:	Widefield camera with appropriate filter (likely UV).
Mission Duration:	Primary: 1 Mars year, Extended: 2 Mars Years
Configuration:	Ballistic trajectory Landing at equator +/- 30° latitude Orbit areostationary
Mission Design:	One SHIELD lander with cruise stage, cruise stage stays in orbit as mothership



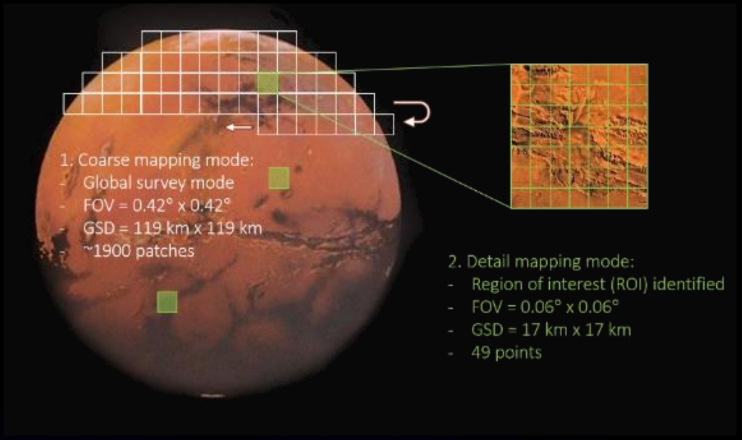
Global Monitoring & 4D science
The Example of Areo-TGL

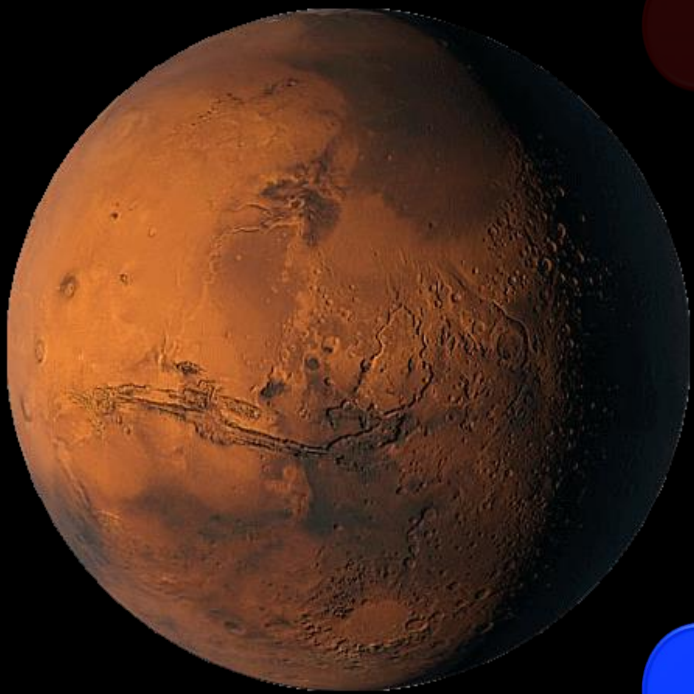
Science Objective

Localization and diurnal concentrations of methane and water and its isotopologues.

Features

Mass: ~190 kg dry mass
Target: Mars – Areostationary Orbit
Instrument: Spacial Heterodyne Spect.
Configuration: Single s/c, constellation
Launch: Secondary P/L on ESPA Grande
Cruise: Solar electric propulsion
Risk Class: D
Lifetime: ~3 years in orbit then replenished
Telecom: Ka-Band, Direct to Earth, MAVEN-class data rates.





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Summary Thoughts & Discussion

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Several emerging trends are creating a unique new opportunity for ***compelling Mars science*** missions at ***radically reduced cost*** relative to Discovery

- Low-cost rideshare and new commercial launch vehicle providers
- Efficient smallsat-scale EP solutions for Mars transfer from GTO
- New small-mass instruments that can achieve decadal-class science.
- Low-complexity hard-lander concepts for Mars surface access
- \$100M - \$300M represents a technological "sweet spot" with high science return above current SIMPLEx \$55M cap.

Opportunities?

- Refine focused Mars science mission concepts suited to smallsat implementation
- Consider smallsat missions for critical Mars infrastructure (e.g., telecom relay, hi-res recon…)
- Seek international partnerships leveraging complementary capabilities to further affordability.
- Going together massively reduces the cost/unit.

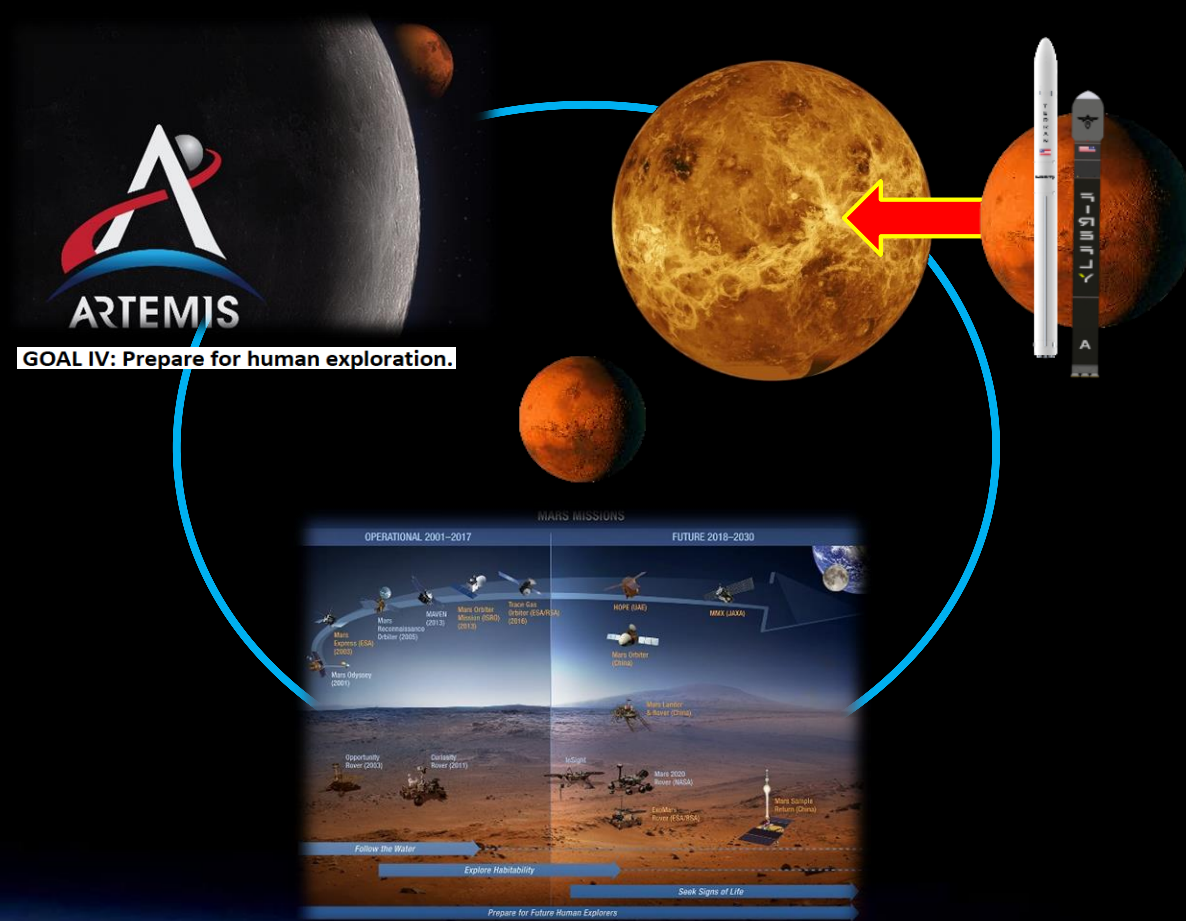
The cost information contained in this document is of a budgetary and planning nature and is intended for informational purposes only. It does not constitute a commitment on the part of JPL and/or Caltech.
Pre-decisional. For planning and discussion only.

Why particularly Mars for SmallSats?

Mars is especially well suited for a SmallSat Opportunity because:

- Close enough to keep costs low enough to enable SmallSats to perform decadal-class science.
- Hotspot for international collaboration (in the early 20ies missions lifting off from China, the Emirates, ESA, JAXA, and India; plans growing in Australia, Canada and Poland as well)
- Commercial capabilities will enable soon to explore Mars: Mars as a testbed and catalyzer for commercial contributions to the exploration of Venus, asteroids and beyond.

- BUT ALSO: Mars Exploration support from the Artemis program and growing HEO support for Mars Program in SMD.



Mars SmallSats in the 2020ties can…

Jet Propulsion Laboratory
California Institute of Technology

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