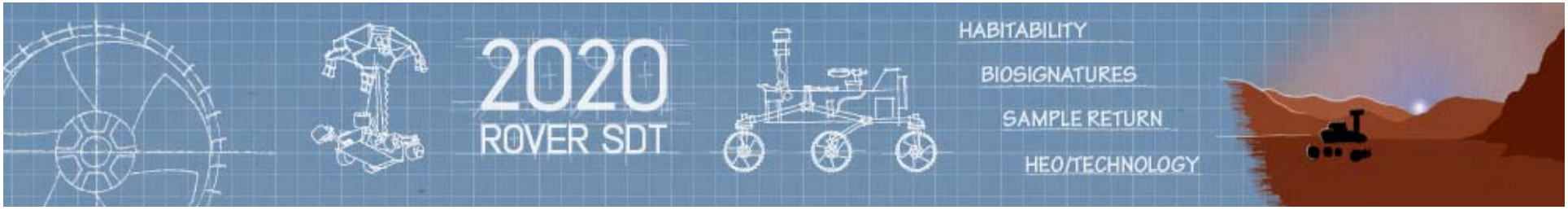


Final Report of the 2020 Mars Rover Science Definition Team (SDT)

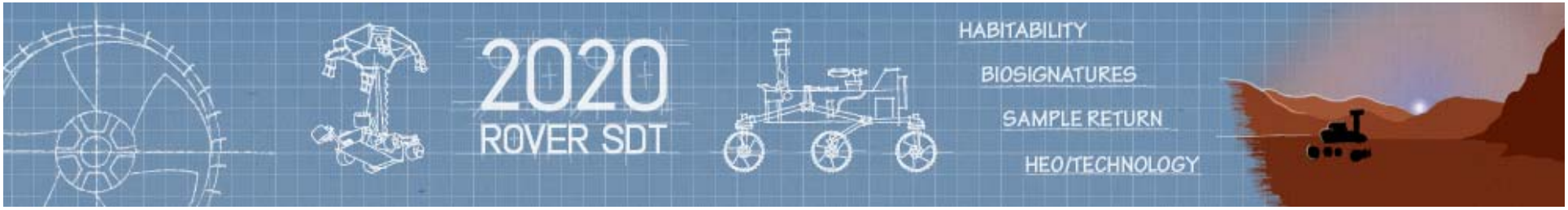
(Jack Mustard, Chair)

Mitch Schulte

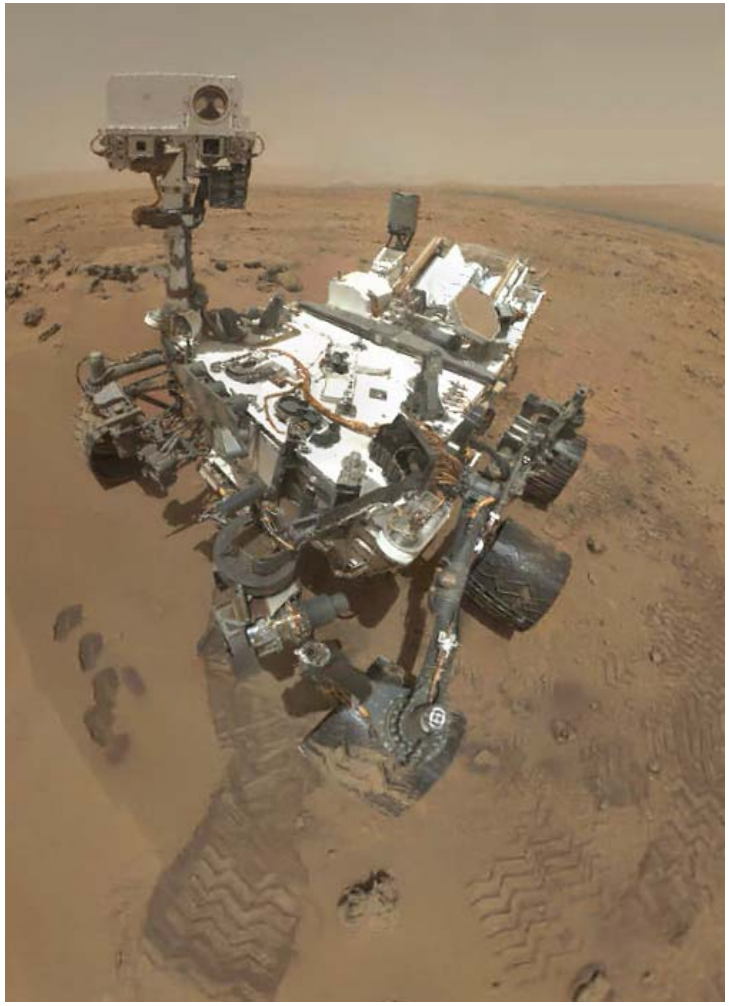
Mars 2020 Program Scientist

NASA HQ

NOTE: *This package is for oral presentation of the SDT's text report (July 1, 2013). In case of discrepancies, the SDT text report should be judged to be superior.*



Mars Rovers



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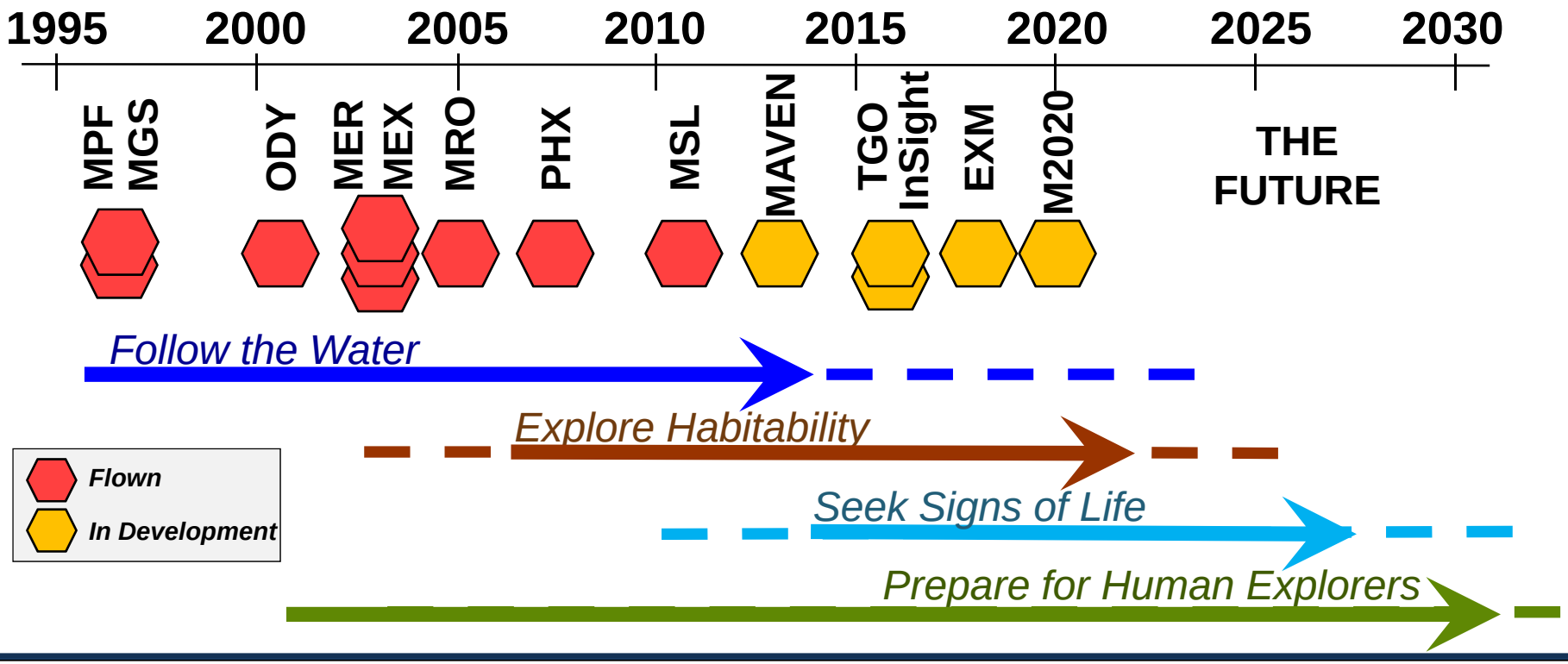
The Exploration of Mars – What's Next?



The proposed Mars 2020 mission would be:

- ***positioned to capitalize on past strategic investments at Mars, and to set the stage for direct testing of life-related hypotheses***
- ***A crucial element in executing NASA's strategic plan***
- ***The most important next strategic mission to Mars***
- ***Aligned with Decadal Survey's priorities for solar system exploration***

Backup

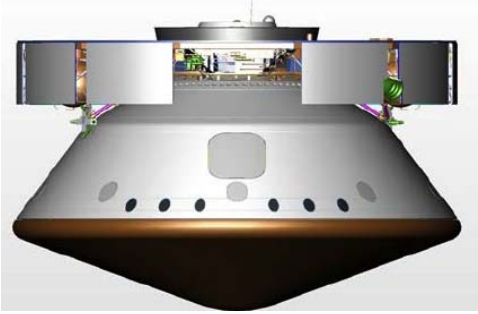
SDT Roster

Chair	Professional Affiliation	Interest/Experience
Mustard, Jack	Brown University	Generalist, geology, Remote Sensing, MRO, MEPAG, DS, MSS-SAG
Science Members (n = 16)		
Allwood, Abby	JPL	Field astrobiology, early life on Earth, E2E-SAG, JSWG, MSR
Bell, Jim	ASU	Remote Sensing, Instruments, MER, MSL, Planetary Society
Brinckerhoff, William	NASA GSFC	Analytical Chemistry, Instruments, AFL-SGG
Carr, Michael	USGS, ret.	Geology, Hydrology, ND-SAG, E2E, P-SAG, Viking, MER, PPS
DesMarais, Dave	NASA ARC	Astrobio, field instruments, DS, ND-SAG, MER, MSL, MEPAG
Edgett, Ken	MSSS	Geology, geomorph, MPF, MER, MRO, MSL, MGS, cameras
Eigenbrode, Jen	NASA GSFC	Organic geochemistry, MSL, ND-SAG
Elkins-Tanton, Lindy	DTM, CIW	Petrology, CAPS, DS
Grant, John	Smithsonian, DC	geophysics, landing site selection, MER, HiRISE, E2E, PSS
Ming, Doug	NASA JSC	Geochemistry, MSL (CHEMIN, SAM), MER, PHX
Murchie, Scott	JHU-APL	IR spectroscopy, MRO (CRISM), MESSENGER, MSS-SAG
Onstott, Tullis	Princeton Univ	Geomicrobiology, biogeochemistry
Ruff, Steve	Ariz. State Univ.	MER, spectral geology, MGS (TES), MER, ND, E2E, JSWG
Sephton, Mark	Imperial College	Organics extraction and analysis, ExoMars, Astrobiology, E2E
Steele, Andrew	Carnegie Inst., Wash	astrobiology, meteorites, samples, ND-, P-SAG, AFL-SSG, PPS
Treiman, Allen	LPI	Meteorites, Samples, Igneous Petrology
HEO/OCT representatives (n = 2)		
Adler, Mark	JPL	Technology development, MER, MSR,
Drake, Bret	NASA JSC	System engineering, long-lead planning for humans to Mars
Moore, Chris	NASA	Advanced Engineering Systems
Ex-officio (n = 6)		
Meyer, Michael	NASA	Mars Lead Scientist
Mitch Schulte	NASA	Mars 2020 Program Scientist
George Tahu	NASA	Mars 2020 Program Executive
David Beaty	JPL	Acting Project Scientist, Mars Program Office, JPL
Deborah Bass	JPL	Acting Deputy Proj. Sci, Mars Program Office, JPL
Jim Garvin	NASA	Mars Program Scientist
Supporting resources (n = 2)		
Wallace, Matt	JPL	Deputy Project Manager M-2020, designated engineering liason
Sarah Milkovich	JPL	SDT documentarian, logistics
Observer (n = 1)		
Vago, Jorge	ESA	Project Scientist, ExoMars

Introduction

Scientific Theme	NASA's Mars Exploration Program Scientific Theme: ***Seeking Signs of Life*** *(Decadal Survey, MEPAG, etc.)*
Highest Priority Science Goal	Following the MSL, MAVEN, ExoMars, and Insight missions, ***to address in detail the questions of habitability &*** ***the potential origin and evolution of life on Mars***. *(Planetary Decadal Survey–Mars Chapter)*
Next Step To Achieve Highest Priority Science Goal	***To explore on the surface an ancient site*** ***relevant to the planet's early habitability with sophisticated*** ***context, contact, and spatially coordinated measurements*** in order to perform detailed exploration of sites on Mars that could reveal past habitability and biosignature preservation potential.
Mars 2020 Science Definition Team Task	With this overarching strategy in mind, to define ***detailed objectives, measurements, payload options and priorities &*** ***an integrated mission concept for a 2020 rover mission to address***: ***A. past habitability,*** ***B. potential biosignature preservation,*** ***C. progress toward sample return, &*** ***D. contributed technology/HEO payloads.***

Mission Overview

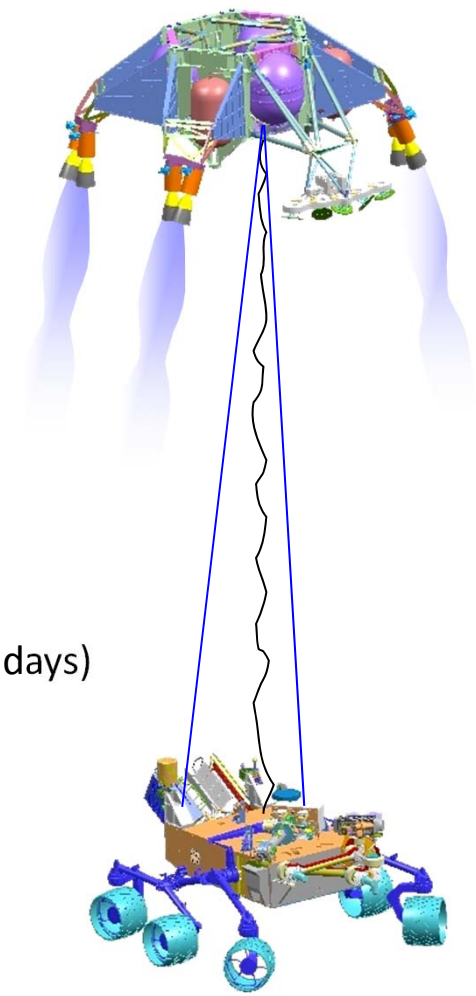


CRUISE/APPROACH

- 8 to 9-month cruise
- Arrive Jan/Mar 2021
- No changes from MSL (equivalent checkout capability, etc.)

ENTRY, DESCENT, LANDING

- MSL EDL system: guided entry and powered descent/Sky Crane
- 25 x 20 km landing ellipse*
- Access to landing sites ±30° latitude, ≤ 0 km elevation*
- ~950 kg rover
- Technology enhancements under consideration



*EDL in work

SURFACE MISSION

- Prime mission is one Mars year (669 days)
- Latitude-independent and long-lived power source
- Ability to drive out of landing ellipse
- Direct (uplink/downlink) and relayed (downlink) communication
- Fast CPU and large data storage

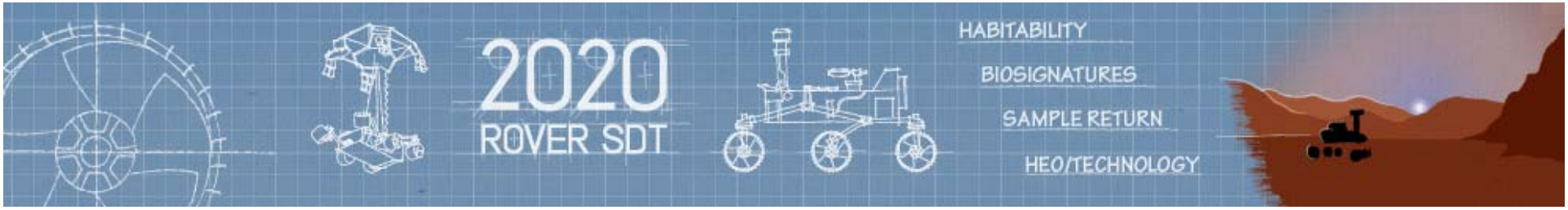
LAUNCH

- Atlas V
- Period: Jul/Aug 2020

Executive Summary

The SDT envisions a 2020 Mars Rover mission that would:

- **Conduct Rigorous *In Situ* Science**
  - **Geologic Context and History** Carry out an integrated set of sophisticated context, contact, and spatially-coordinated measurements to characterize the geology of the landing site
  - ***In Situ* Astrobiology** Using the geologic context as a foundation, find and characterize ancient habitable environments, identify rocks with the highest chance of preserving signs of ancient Martian life if it were present, and within those environments, seek the signs of life
- **Enable the Future**
  - **Sample Return** Place carefully and rigorously-selected samples in a returnable sample cache as the most scientifically, technically, and economically compelling method of demonstrating significant technical progress toward Mars sample return
  - **Human Exploration** Conduct a Mars-surface critical ISRU demonstration to prepare for eventual human exploration of Mars
  - **Technology** Demonstrate technology required for future Mars exploration
- **Respect Current Financial Realities**
  - Utilize MSL-heritage design and a moderate instrument suite to stay within the resource constraints specified by NASA



Options and Priorities to Achieve

Objective A

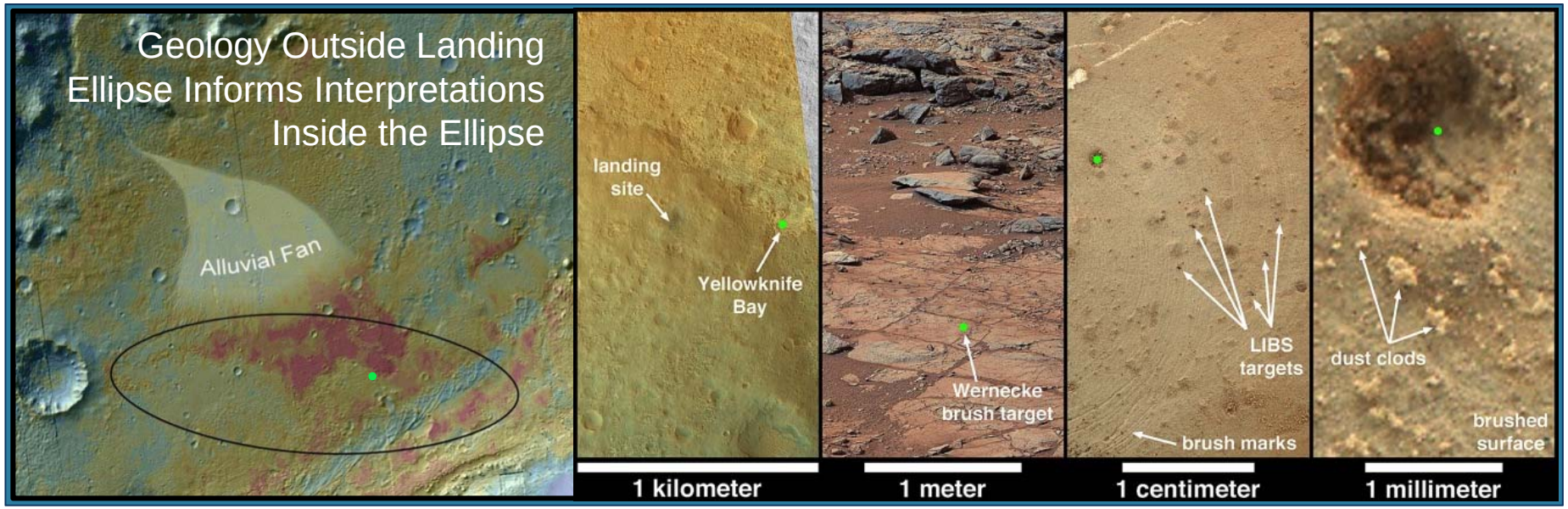
OBJECTIVE A	Explore an astrobiologically relevant ancient* environment on Mars to decipher its geological processes and history, including the assessment of past habitability.

**"Ancient" implies a location where the astrobiologically relevant environment no longer exists, but is preserved in a geologic record.*

Deciphering Geological Processes and History

Integrate Observations Across km to mm Scales

In order to explore and document geologic processes and history of a site, it is essential to integrate observations from orbital (regional) scales to microscopic (sub-millimeter) scales.

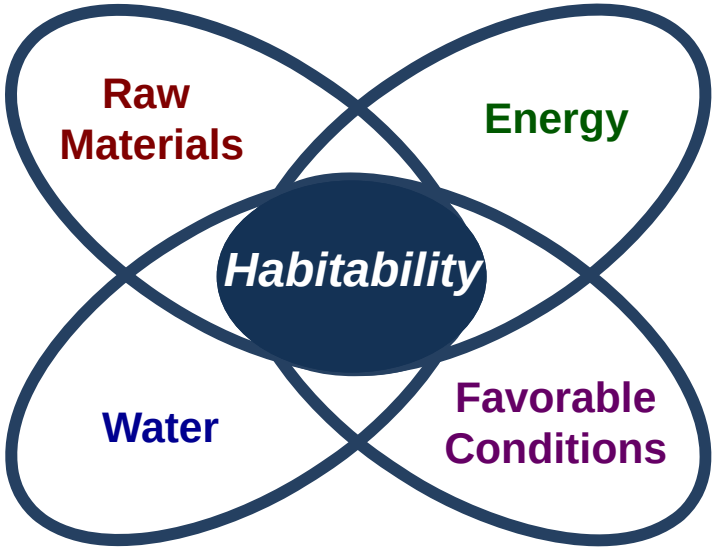


The footprint and spatial resolution of measurements is critical for ensuring observations can be correlated across scales.

The Process of Assessing Habitability

To assess the habitability of a past environment, the rover must be able to examine the geologic record of that environment and evaluate the following characteristics of that environment:

Availability of CHNOPS elements (beyond those species present in the atmosphere) and electron donors



Energy sources and availability (i.e., mineral suites of mixed valence states for redox energy; proximity to paleosurface for photosynthesis; radiogenic elements for radiolysis)

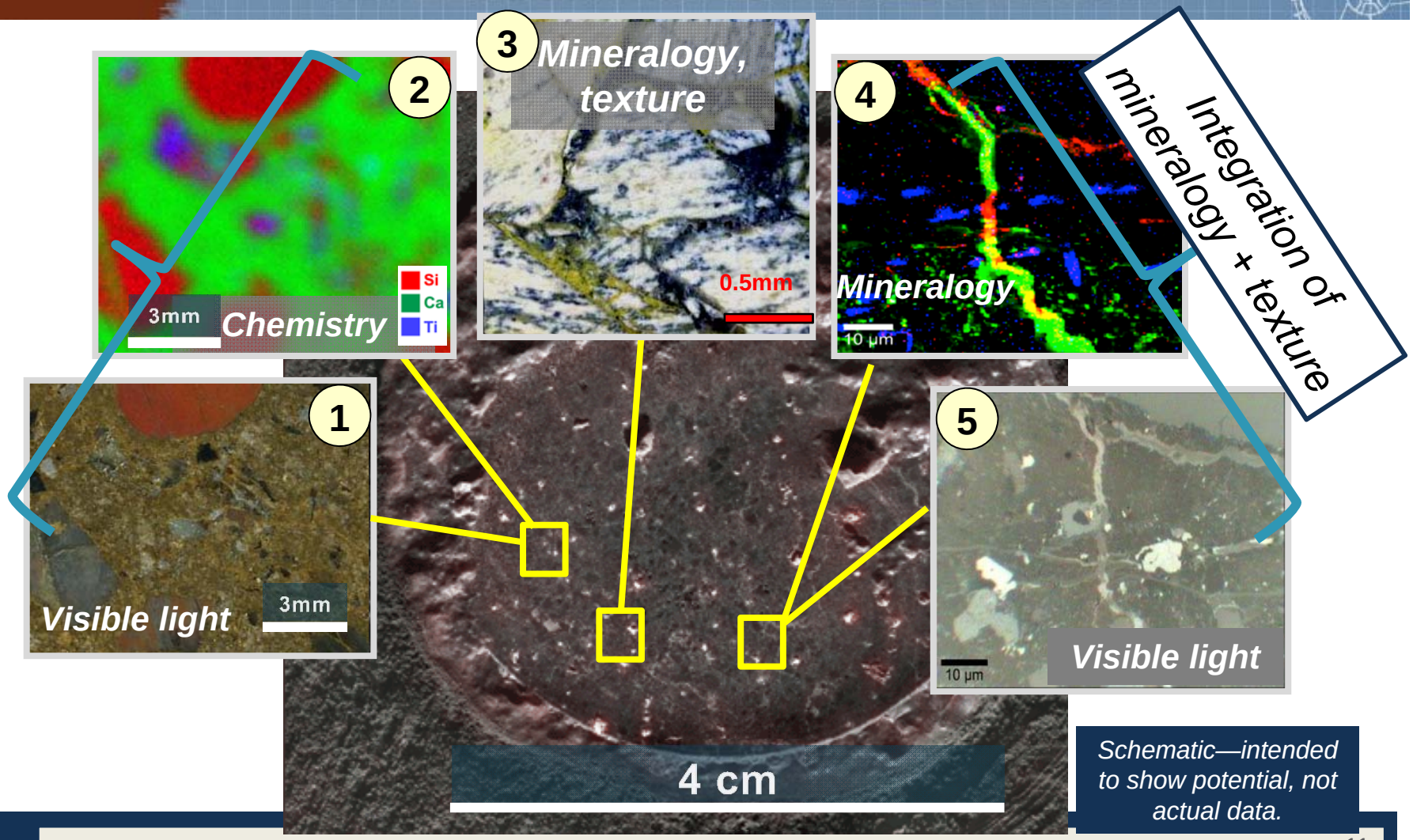
- **Amount of water that was present (e.g. mineral-bound or interstitial fluids in subsurface; small/shallow surface water or large/deep surface water body)**
- **Persistence of the aqueous conditions**

- **Water properties (e.g., salinity, pH, and temperature)**
- **Protection from radiation (e.g. planetary dipole field)**
- **Water energy (quiet vs. high energy - implications for stabilization of microbial communities)**
- **Rate of burial (e.g. lacustrine - implications for establishment of microbial communities)**

Adapted from Tori Hoehler

Deciphering Geological Processes and History

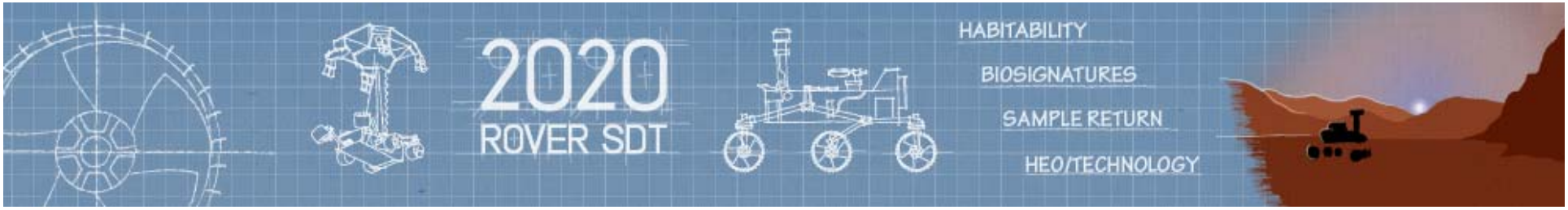
Correlate Composition with Fine Texture & Structure



Schematic—intended to show potential, not actual data.

SDT MAJOR FINDING #2

The ability to spatially correlate variations in rock composition with fine scale structures and textures is critical for geological and astrobiological interpretations.



Options and Priorities to Achieve

Objective B

OBJECTIVE B	Assess the potential for preservation of biosignatures within the selected geological environment and search for potential biosignatures.

Objective B

Scientific Process for Detecting Past Martian Life

PRE-CONDITIONS THAT MUST HAVE BEEN MET

PAST HABITABLE ENVIRONMENT

Past conditions suitable for the existence of life at the site.

POTENTIAL FOR BIOSIGNATURE PRESERVATION

Past conditions suitable for the preservation of past life in the geologic record.

POSSIBLE EVIDENCE OF ANY PAST LIFE

EXISTENCE OF POTENTIAL BIOSIGNATURE

An observable feature that might be evidence of past life.

PAST LIFE DETECTED

RECOGNITION OF DEFINITIVE BIOSIGNATURE

An observable feature that is confirmed to be evidence of past life.

Proposed Mars 2020 Rover

MSR

Labs on Earth

SDT MAJOR FINDING #3

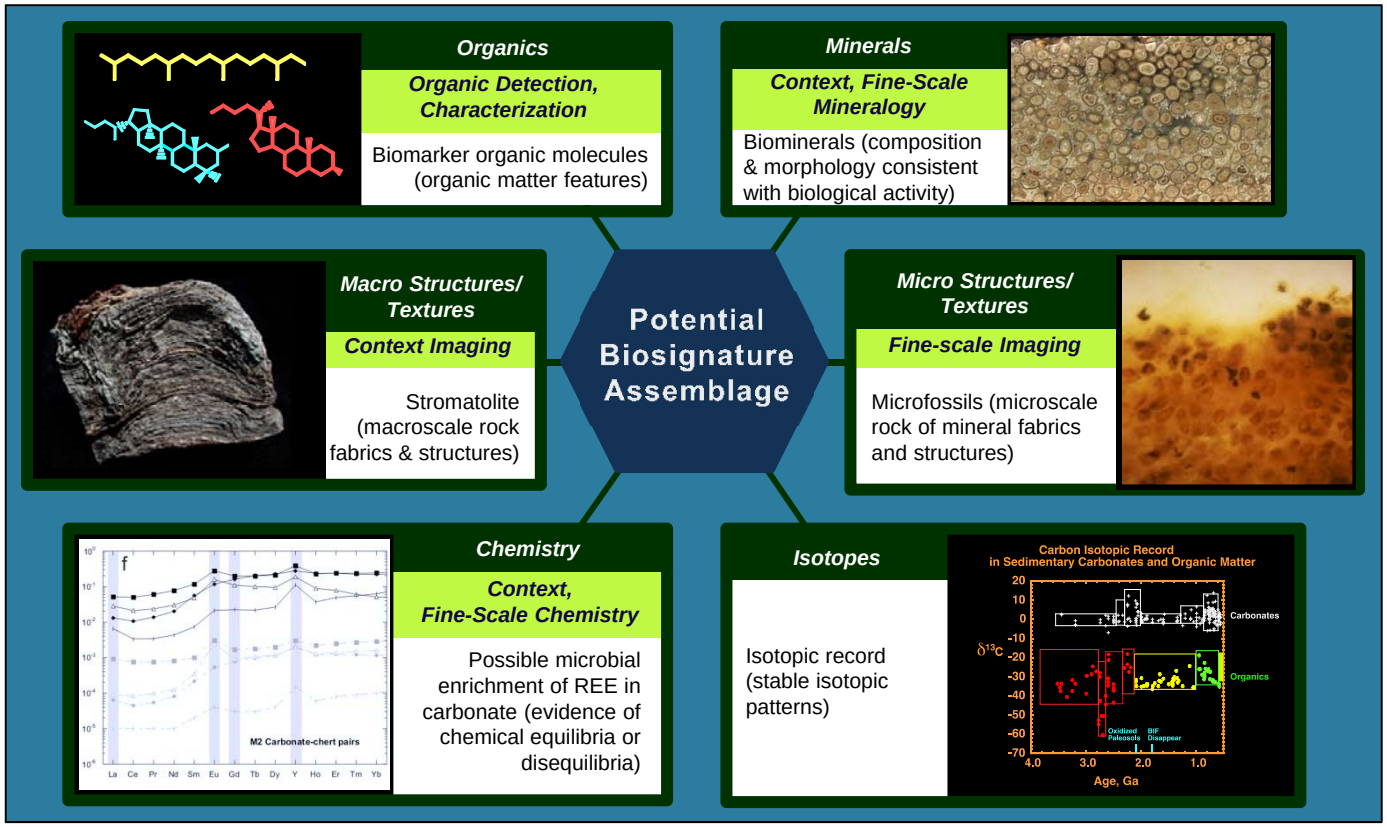
The existence of evidence for past Martian life requires both a habitable environment and suitable conditions for biosignature preservation.
The subsequent recognition of any preserved biosignatures will require the combination of a capable rover and advanced analysis of returned samples on Earth.

Objective B

Categories of Ancient Biosignatures Hypothesized to Exist in Martian Rocks

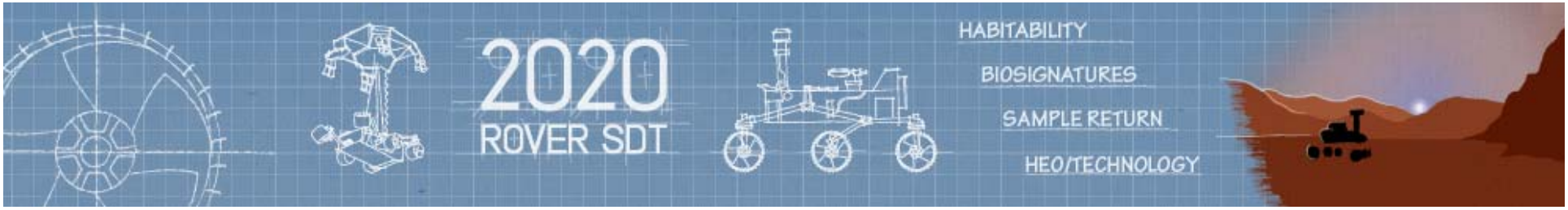
These hypothesized potential Martian biosignatures represent independently observable features.

Legend:
Biosignature Category
Detection method using Proposed M-2020 Rover



The *2020* Mars *Rover must have the capability to detect as many of these signatures as possible* to have a credible chance to find evidence of past life on Mars, because:

1. We cannot anticipate which of these (if any) will be present or well-preserved…
2. …therefore we cannot anticipate which categories will provide the most information.
3. Confidence in confirming biological origin(s) increases as more categories are detected.

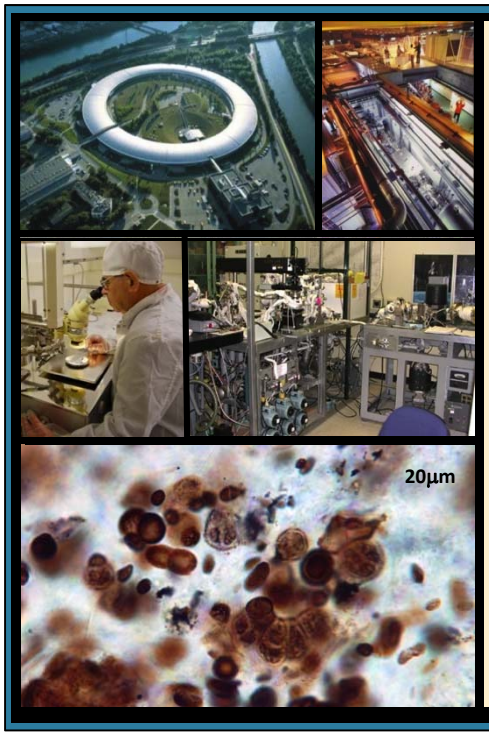


Options and Priorities to Achieve

Objective C

OBJECTIVE C	Demonstrate significant technical progress toward the future return of scientifically selected, well-documented samples to Earth.

The Return of Samples to Earth
The Importance of Mars Sample Return



Reasons for returning samples for analysis on Earth…

- Perform definitive detection of a biosignature. As the range of measurements that can be accommodated on a single rover is extremely limited, neither the detection of a PBS nor the non-detection of one would be considered definitive until performed in a lab.
- Use advanced instrumentation not amenable for flight to Mars
- Employ techniques requiring complex sample preparation
- Use a virtually unlimited array of different instruments, including future instruments not yet even designed
- Gain the ability to run sequential analyses and replicate analyses in different labs.

Adapted from iMARS (2008); NRC Decadal Survey (2011)

From ***Vision and Voyages for Planetary science in the Decade 2013-2022:***

Committee on the Planetary Science Decadal Survey; National Research Council, March 2011

"*The analysis of carefully selected and well documented samples from a well characterized site [on Mars] will provide the highest scientific return on investment for understanding Mars in the context of solar system evolution and addressing the question of whether Mars has ever been an abode of life.*"

SDT MAJOR FINDING #5

The SDT concurs with the detailed technical and scientific arguments made by the Decadal Survey (2011) and MEPAG (most recently summarized in E2E-iSAG, 2011) for the critical role returned samples will play in the scientific exploration of Mars.

Objective C

SDT Interpretation of "Significant Technical Progress"

Spacecraft Launch from Earth/Land on Mars → Rover Select Samples → Acquire/Cache Samples

If we don't advance to here we would need to send <u>another</u> rover in the future, with science and sampling capability, to complete the first step of MSR. →

Samples on Mars

Options for Technical Progress Towards MSR	New Capability?	Consistent with Proposed Mars-2020 Resources?	Resulting contribution to MSR	
			Reduces Science or Engineering Risk	Achieves Major Campaign Milestone
Select Samples (for future collection)		✓		
Select Samples & Assemble Demonstration Cache	✓	✓	✓	
Select Samples & Assemble Returnable Cache	✓	✓	✓	✓

<u>Note</u>: A variety of candidate MSR technology demonstrations were identified and evaluated during the Mars Program Planning Group effort in 2012. Those demonstrations were not addressed again by this SDT.

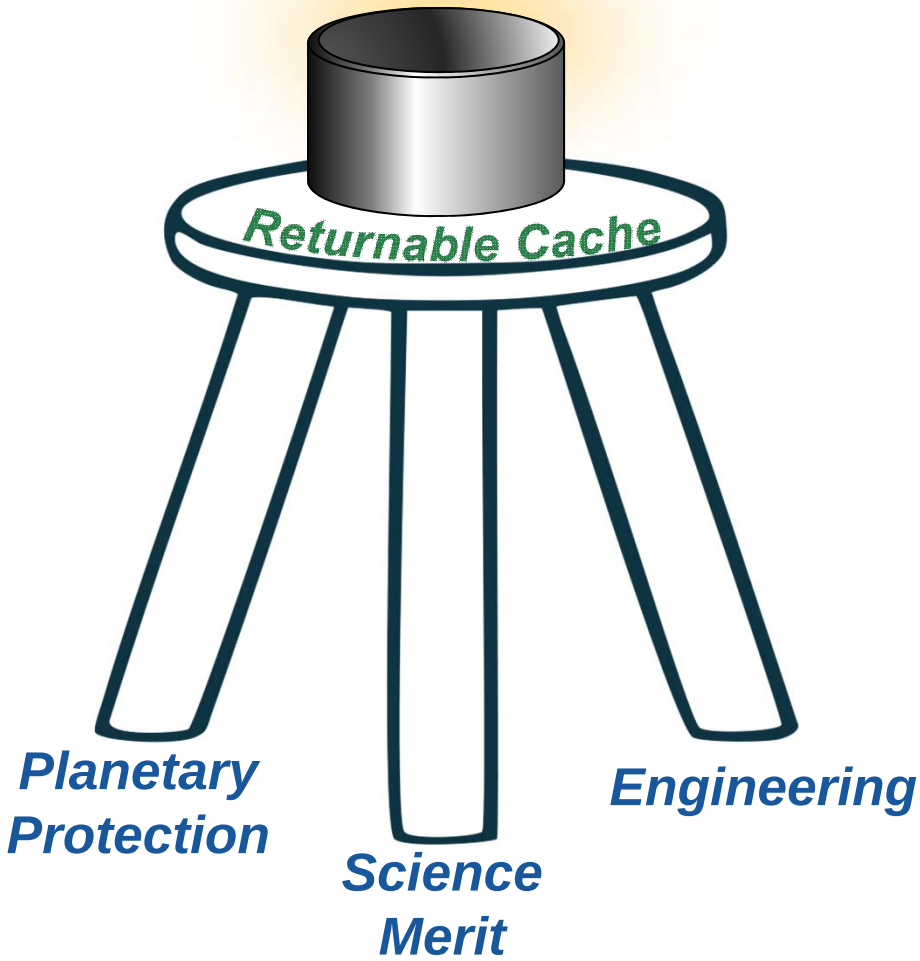
SDT MAJOR FINDING #6

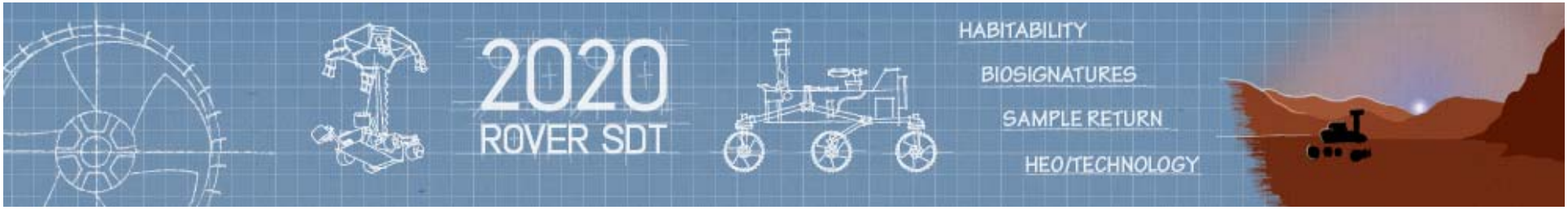
Of the options shown above, only the **assembly of a returnable sample cache** achieves a major milestone of MSR.

What Constitutes a "Returnable Cache"?

The SDT concludes that three attributes are essential to making a cache returnable:

1. The cache has enough scientific value to merit returning.
2. The cache complies with planetary protection requirements.
3. The cache is returnable in an engineering sense.





Options and Priorities to Achieve

Objective D

OBJECTIVE D	Provide an opportunity for contributed HEOMD or Space Technology Program (STP) participation, compatible with the science payload and within the mission's payload capacity.

2020 Mars Rover: Why are these important NOW?

2010 National Space Policy: Humans to Mars by mid-2030s

2020s	2030s

Proof of Concept → Validation → Human Mission

2020 Rover

ISRU O_2 Production

- Demonstration of CO_2 collection in actual Mars environment reduces future risks. O_2 production is critical path of future human missions

MEDLI+

- Obtaining data lower in atmosphere reduces EDL uncertainties and risks

Surface Weather

- Understanding of long-term atmosphere behavior reduces future EDL risks

Biomarker

- Demonstrate detection of microbial contamination for future human missions

Human Sub-Scale Validation Demos

- Land Large Payload
- Advanced Aeroassist
- Supersonic Retro-Propulsion
- ISRU O_2 Production and Use
- Surface power

Future demonstration of sub-scale human relevant systems and technologies necessary to reduce risk and feed forward to human flight systems development

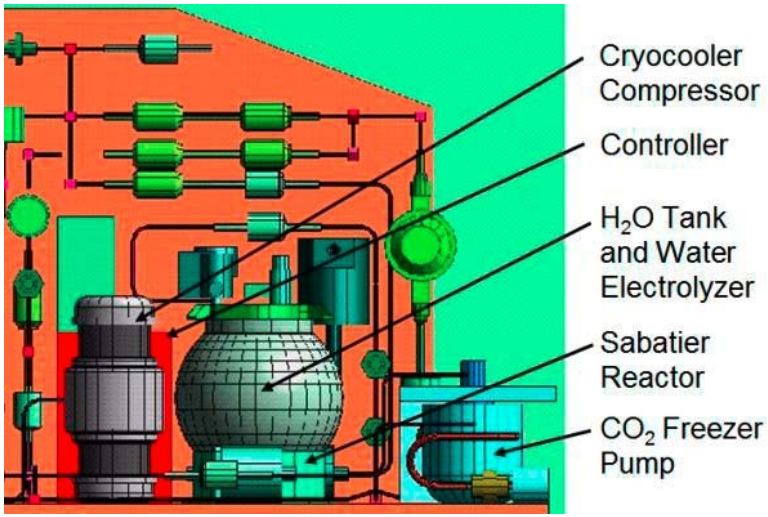
Human Systems Development

2020 Mars Rover: ISRU Is the TOP priority

#1 HEO Priority: ISRU Demo

- Utilizing locally produced consumables (e.g. oxygen for ascent) provides great leverage for human exploration of Mars
- Key technical issue: Data needed to support performance and reliability assessments, before we bet the lives of a crew of astronauts on it
- Much progress can be made in Mars environmental chambers on Earth, but some things require information from a Mars surface mission.
  - Testing in the actual relevant environment (discover unknown unknowns)
  - Most important general area of concern is the dust environment, which varies in unpredictable ways, and could have severe consequences on a future ISRU systems

O2 ISRU Schematic



NOTE:

This kind of demo can be run on a non-interference basis with science ops.

The Importance of Supporting Atmospheric Data

- Need to understand regional dust context to understand WHY and HOW dust is affecting the ISRU demo.
- Needed to interpret data from the demo to apply to other places/times
- Data of value (priority order): Wind, Pressure, Temperature

SDT MAJOR FINDING #10

In-Situ Resource Utilization is the HEOMD top priority demonstration for the 2020 Mars Rover

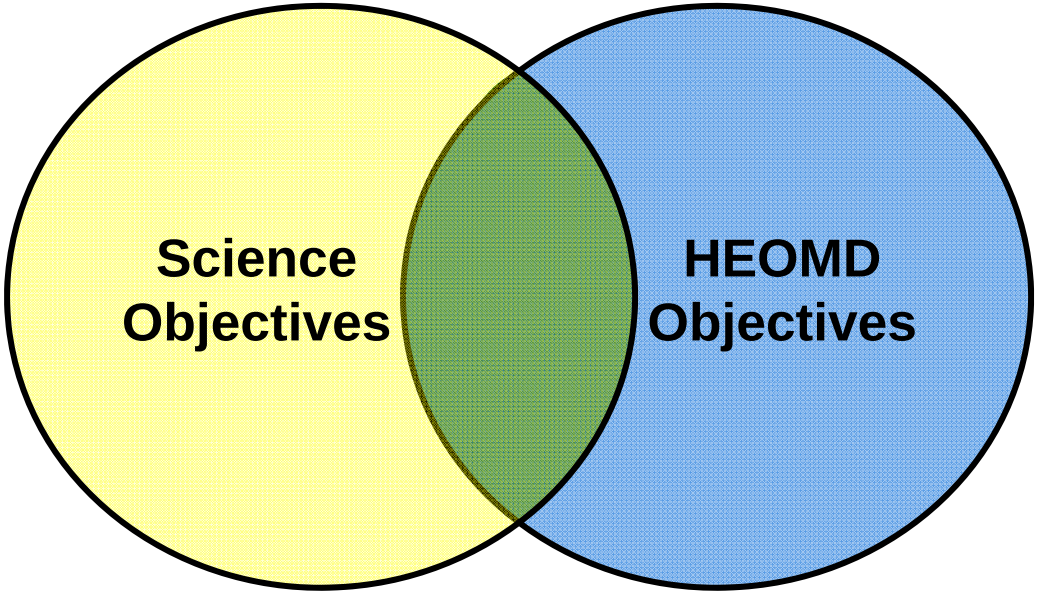
How much synergy between HEOMD & SMD?

In the proposed mission concept, science & human preparation objectives have synergy in three significant ways:

1 The instruments required for the science objectives are relevant to many SKGs.

2 The measurements/demos proposed by HEO satisfy some Mars science objectives.

3 A returnable cache of samples, if properly selected, would be of major interest to both.



SDT MAJOR FINDING #11

The 2020 Mars Rover offers excellent opportunities for synergy between planetary science and preparation for human exploration objectives.

Measurements/Demos by Objective

Objective Af *Geology*	Objective B *Biosignatures*	Objective C *Caching*	Objective D *HEO/Tech*
THRESHOLD Instruments addressing all 6 threshold measurements			OPTIONS
Measurements/Capabilities	**Measurements/Capabilities**	**Measures/Capabilities**	
•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy	•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy •Reduced/Organic C detection	•Context Imaging •Fine-Scale Imaging •Context Mineralogy •Fine-Scale Elem Chem •Fine-scale Mineralogy	• ISRU Demo • EDL Data • EDL Precision & Site Access • Surface Weather Monitoring • Biohazards to Astronauts
BASELINE OPTIONS Enhanced-capability instrument(s) in THRESHOLD category **OR** add one of the following:			
•Subsurface Sensing •Organic C detection	•2nd method of Organic C Detection	•Organic C Detection	
ENHANCED OPTIONS Enhanced-capability instrument(s) in THRESHOLD category **AND** an additional BASELINE or ENHANCED instrument			
	•Molecular Analysis		

SDT MAJOR FINDING #14

The measurements required to meet Objectives A – C are nearly identical. Thus, these three objectives are highly integrated and compatible with a common mission.

SDT MAJOR FINDING #15

Measurements or demonstrations associated with Objective D would enhance the value of the mission to HEO, ST, and SMD.

Proposed "Straw" Instrument Lists

The priority of baseline options depends on budget scaling up or down, and the strength of the proposals submitted in response to the AO.

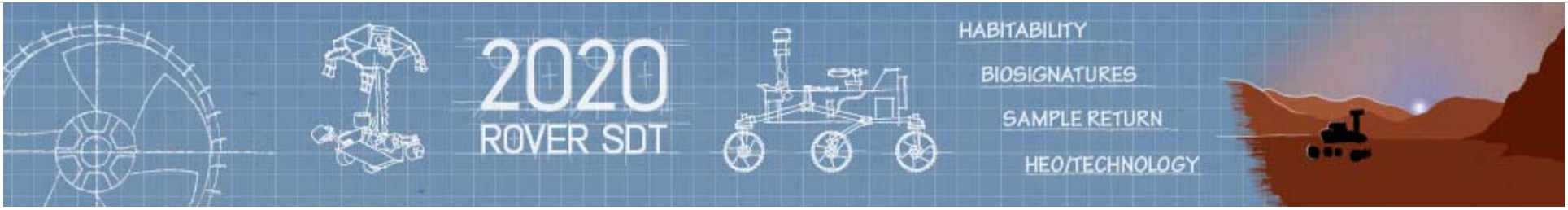
Science Instrument Straw Payloads[1]				
Functionalities Required	Blue Straw Payload	$M	Orange Straw Payload	$M
Context imaging	**Mastcam-like**	M	**Mastcam-like**	M
Context Mineralogy	**UCIS-like**	M	**mTES-like**	M
Elemental Chemistry	**APXS-like**	L	**µXRF-like**	L
Fine-scale imaging	**MAHLI-like**	M	**MMI-like**	M
Fine-scale mineralogy	**Green Raman-like**	H		
Organic Detection			**Deep UV-like**	H
Science support equipment	Includes cache, sampling system, surface prep tool			
Threshold Total (SMD funded)		**~90**		**~90**
Additional Instrument Options	**GPR**	M	**GPR**	M
HEO contributed payload	**ISRU**		**ISRU**	
Technology payload elements	Includes range trigger and TRN			
Baseline Total (SMD funded)		**~105**		**~105**

[1]*Cost totals are instruments only; do not include science support equipment.*

Baseline and Threshold Options

A baseline mission would include one or more of the following (not listed in priority order):

- **Superior capabilities (e.g., resolution, range of minerals detected, accuracy) for instruments in the threshold measurements category: "superiority" to be evaluated in the instrument competition**
- **A second organic detection capability complementary to the first one**
- **An instrument that measures subsurface structure or composition**



Planning Considerations Related to the
Surface Operations Scenario

Strategy: High-level Conclusions

Plausible mission scenarios can be found throughout this triangle –

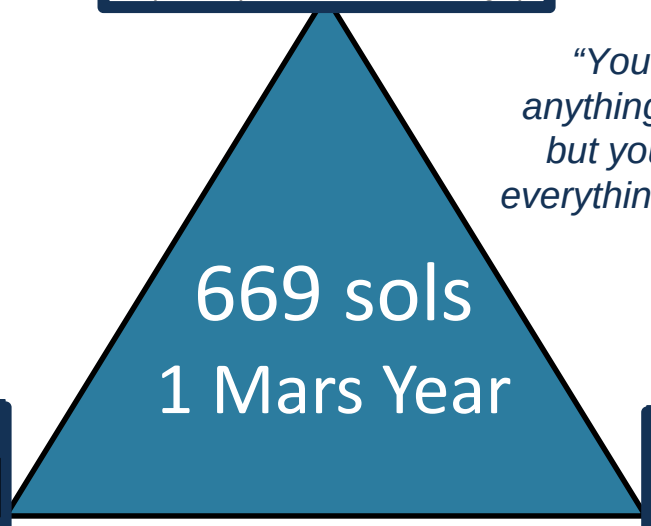
trading drive distance, total number of cached samples, & number of cached samples within a characterized suite

– to suit a variety of possible landing sites.

Quantity of

Field Work

e.g.,
3 km total driving
20 samples
full complement of fieldwork
(1 core per characterized target)



"You can get anything you want, but you can't get everything you want."

Quantity of

Coring/Caching

e.g.,
5 km total driving
34 samples
2 cores per characterized target

Quantity of

Driving

e.g.,
15 km total driving
20 samples
2 cores per characterized target

SDT MAJOR FINDING #18

The charter-specified objectives for Mars 2020 can be achieved with the mission concept proposed at a variety of different landing sites.

SDT MAJOR FINDING #19

Multiple strategies to improve on the modeled, reference scenarios are available as the mission is further developed.

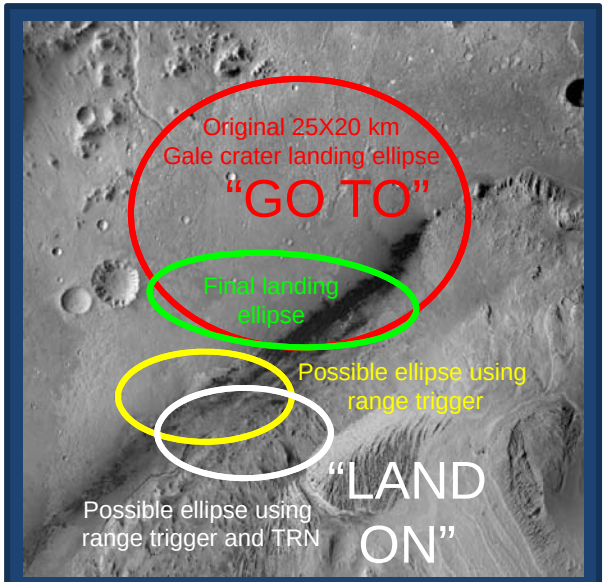
Major Findings

Primary Technical Conclusions

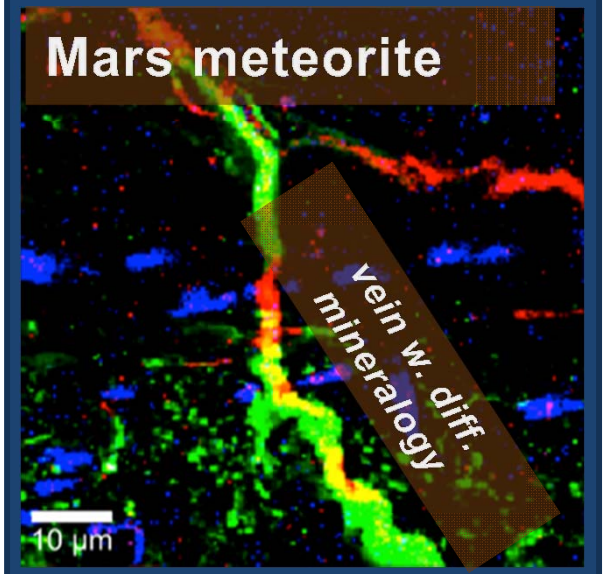
- The **measurements** needed to explore a landing site on Mars to interpret habitability and the potential for preservation of biosignatures and to select samples for potential future return to Earth are identical.
- Significant technical progress towards MSR requires a returnable cache.
- Arm- and mast-mounted instrument data are necessary and sufficient to achieve the required science.
- An instrument set capable of the following measurements would be the foundation of an efficient, lower cost rover.
  - Context Imaging
  - Context mineralogy
  - Fine-scale imaging
  - Fine-scale elemental chemistry
  - Fine-scale mineralogy
  - Organic detection
- The payload needed to achieve the three scientific objectives of the mission fill much, but not all, of an MSL heritage rover. This creates valuable opportunity for HEO to address long-lead strategic knowledge gaps.

Why is the SDT Excited about this Mission?

The 2020 Mars Rover mission offers many important advances relative to MER and MSL:

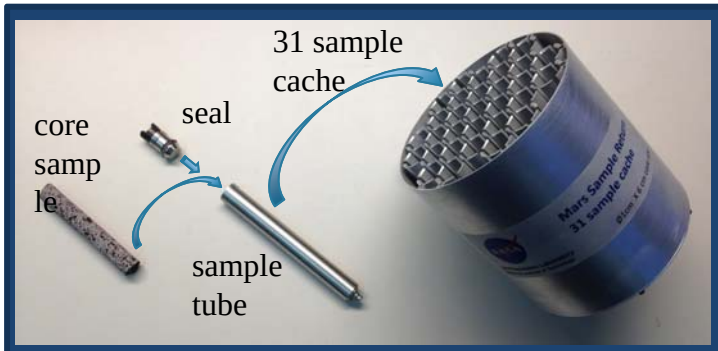


Potential to land on high priority scientific targets previously out of reach, shorten drive distances



Measurements of fine-scale mineralogy, chemistry, and texture in outcrop (petrology)

Payload designed to recognize potential biosignatures in outcrop



The ability to collect compelling samples for potential future return

Prepare for the future human exploration of Mars