HABITABILITY
BIOSIGNATURES
SAMPLE RETURN
HEO/TECHNOLOGY

2020
ROVER SDT

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

2020 Mars Rover Science Definition Team

(Jack Mustard, Chair)

NOTE: *This presentation is in support of the SDT's text report (located at http://mepag.jpl.nasa.gov/reports/mep_report.html). In case of discrepancies, the SDT text report should be judged to be superior.*

For oral presentation
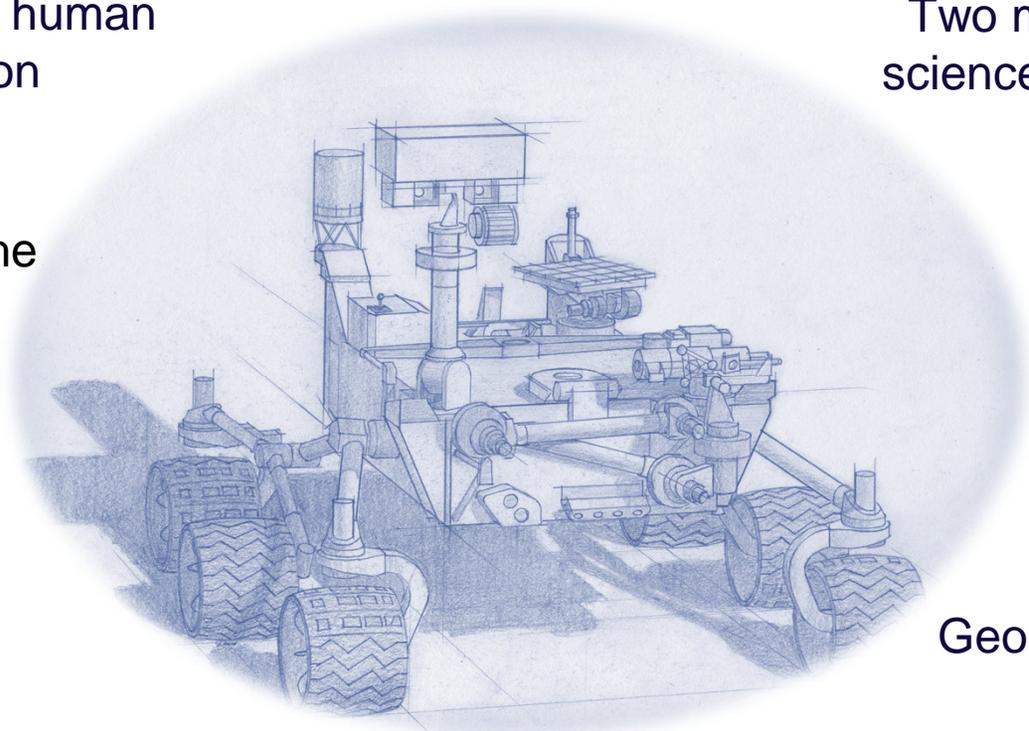
Seeking signs of past life

Prepare for human exploration

Two major *in situ* science objectives

Returnable cache of samples

Coordinated, nested context and fine-scale measurements

Coring system

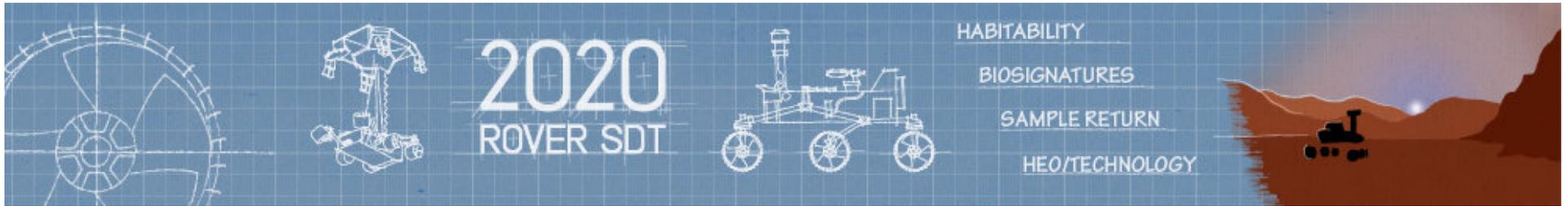Geologically diverse site of ancient habitability

Efficient surface operations, one Mars-year lifetime

MSL heritage rover

Improved EDL for landing site access

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

Recap of SDT Process and Key Concepts

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/human exploration payloads.**

MISSION OBJECTIVES

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

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

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

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

Note: *The phrasing of Objectives A and B above is modified slightly from that given in the SDT charter, and the analysis in this package is organized along the lines of the above objectives statements.*

ASSUMPTIONS & CONSTRAINTS

1 Launch in 2020

2 Instrument cost nominal limit of $100M (including margin/reserves)
  - ~$80M for SMD instruments
  - ~$20M for contributed elements
  - Surface operations costs and science support equipment (e.g., arm) not included in the above limits

3 Utilize MSL Sky Crane EDL flight systems and Curiosity-class roving capabilities
  - Address potential value and cost for improving access to high-value science landing sites

4 Mission lifetime of one Mars year (~690 Earth days)

5 Mission pre-project will provide additional constraints on payload mass, volume, data rate, and configuration

Deciphering geologic processes and history and assessing habitability:
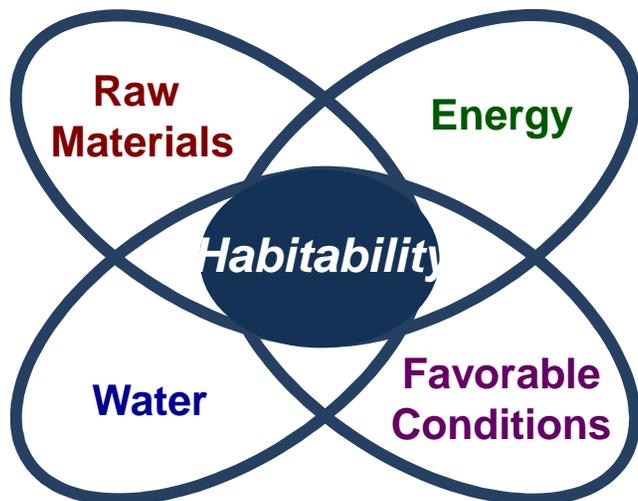
1. Provides science results in its own right

2. Lays the foundation for objective B (Assessing potential for preservation of biosignatures, and seeking potential biosignatures)

3. Lays the foundation for objective C (careful selection of well-documented samples for MSR)
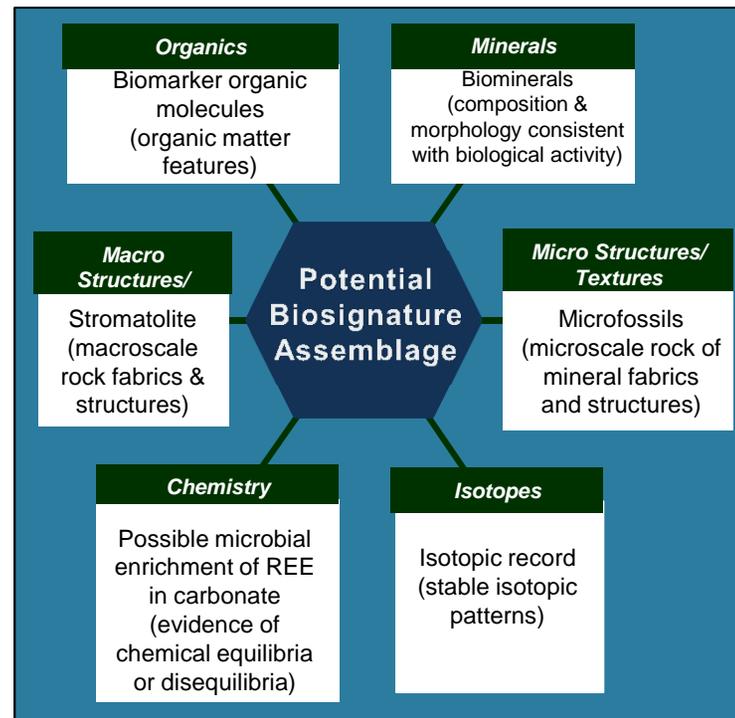
In situ science results

+

Essential scientific foundation for MSR science results

Raw Materials

Energy

Habitability

Water

Favorable Conditions

Adapted from Tori Hoehler

Potential Biosignature Assemblage

Organics
Biomarker organic molecules (organic matter features)

Minerals
Biominerals (composition & morphology consistent with biological activity)

Macro Structures/
Stromatolite (macroscale rock fabrics & structures)

Micro Structures/ Textures
Microfossils (microscale rock of mineral fabrics and structures)

Chemistry
Possible microbial enrichment of REE in carbonate (evidence of chemical equilibria or disequilibria)

Isotopes
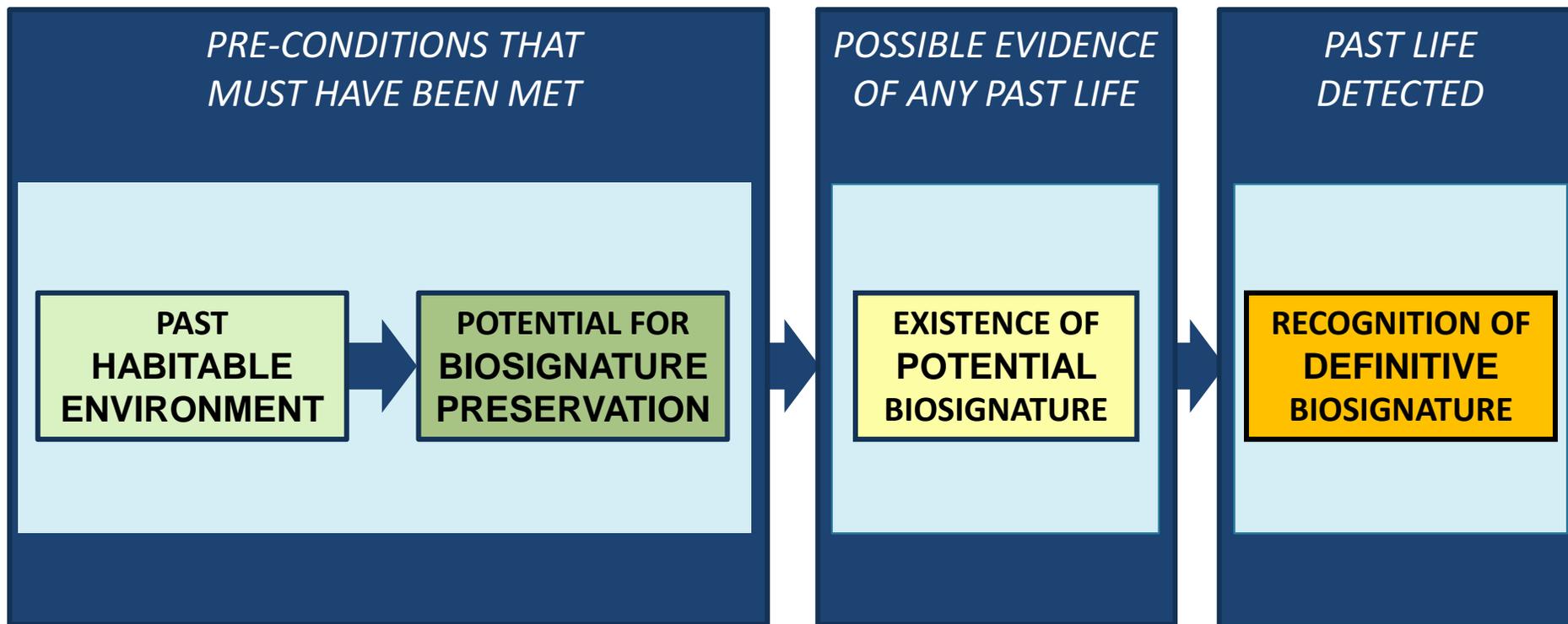Isotopic record (stable isotopic patterns)

Preservation (Two Issues)

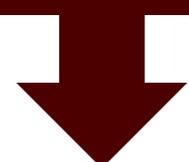**Preservation of the Evidence of a Prior Habitable Environment**
Evidence for the criteria above are preserved as geological or geochemical proxies, or may not be preserved at all

Preservation of Biosignatures
If life existed in the past, biosignatures will exist today ONLY if conditions were favorable for biosignature preservation

PRE-CONDITIONS THAT MUST HAVE BEEN MET

POSSIBLE EVIDENCE OF ANY PAST LIFE

PAST LIFE DETECTED

PAST HABITABLE ENVIRONMENT → **POTENTIAL FOR BIOSIGNATURE PRESERVATION**

EXISTENCE OF POTENTIAL BIOSIGNATURE

RECOGNITION OF DEFINITIVE BIOSIGNATURE
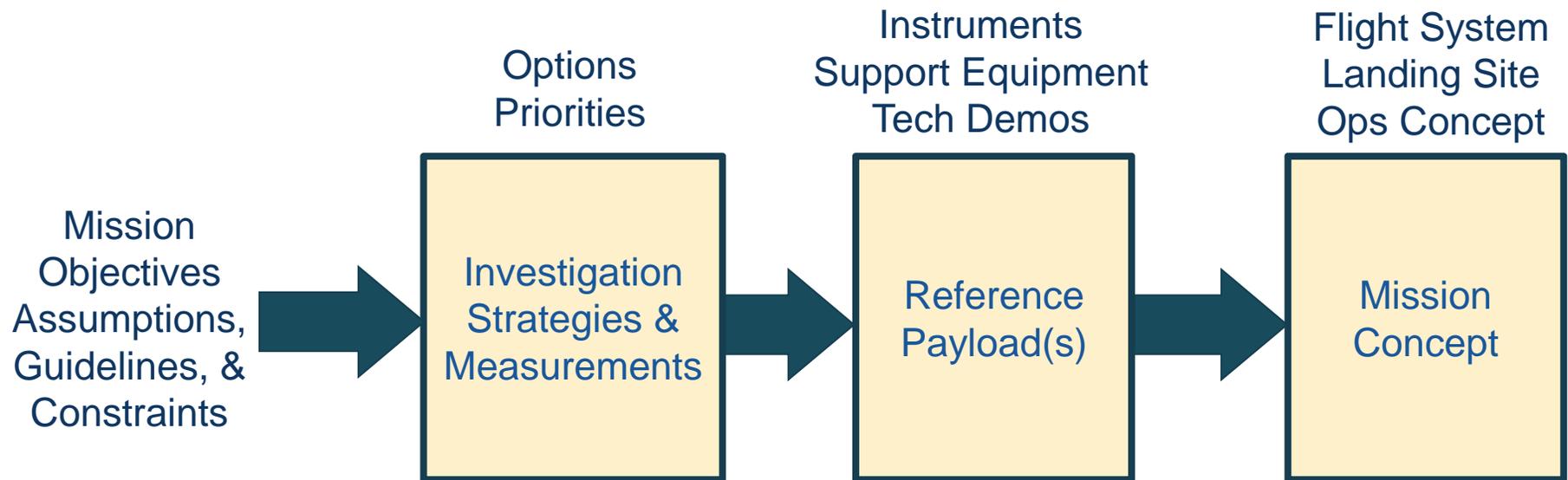
Proposed Mars 2020 Rover

Mars Sample Return

Labs on Earth

Optimize: *Science Return; Progress Toward NASA Goals*

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Mission
Objectives
Assumptions,       Investigation
Guidelines, &  →   Strategies &   →
Constraints        Measurements
```

Options
Priorities

Investigation Strategies & Measurements

Instruments
Support Equipment
Tech Demos

Reference Payload(s)

Flight System
Landing Site
Ops Concept

Mission Concept

Investigation Strategies & Measurements

Mission
Objectives
Assumptions
Guidelines
Constraints

Options
Priorities

Investigation
Strategies &
Measurements

Instruments
Support Equipment
Tech Demos

Reference
Payload(s)

Flight System
Landing Site
Ops Concept

Mission
Concept

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.*

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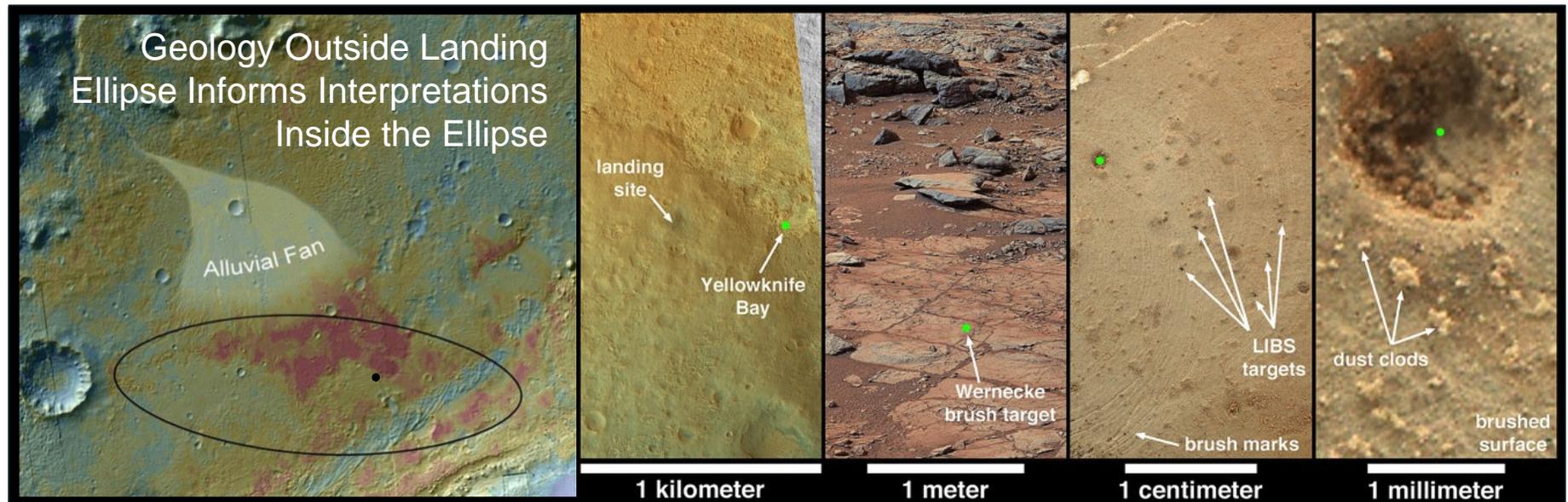
The footprint and spatial resolution of measurements is critical for ensuring observations can be correlated across scales.

What kinds of in situ observations and measurements are required?

Full details of the required observations at a particular site cannot be predicted precisely. However, the *types* of observations that are likely to be critical are well understood, as shown by the following examples among two broad rock classes.

Relevant Features When Interpreting Water-laid or Water-altered Rocks	Relevant Features When Interpreting Unaltered Igneous Rock
• Lateral/vertical changes in a sedimentary deposit or hydrothermal sediments • Physical variations in a mineral phase: texture, crystal habit, or residence in veins/ layers/ cement/ clasts / concretions • Inferred salinity gradient in a saline mineral assemblage • Variations in detectable organic matter: host mineralogy, concentration, spatial arrangement • Sedimentary structures and textures, associated mineralogical variations • Mineral transition across a zone of alteration • Sequence of vein-fill deposits • Proximal-distal trends at a hydrothermal vent	• Petrologic character: ultramafic to granitic, mineralogic, trace element properties • Age • Type and intensity of aqueous alteration [if they are unaltered (see above) this bullet is not relevant] • Type of occurrence: outcrop, "subcrop," or float • Igneous setting: intrusive, extrusive • Grain size, chemical variation in minerals • Degree of weathering • Degree of impact shock metamorphism, including brecciation

After E2E-iSAG

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

Raw Materials — Energy — Habitability — Water — Favorable Conditions

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

Fundamental Principles of Past Environment Assessment in the Field

Capabilities that a Rover Would Need

Evidence of an ancient environment's characteristics lie in the mineralogy, chemistry, texture, and structure of the rocks. The evidence is subject to alteration over time.

- Ability to measure **mineralogy, chemistry, texture and structure** of the rocks.

- Ability to make **sufficient quantity and quality of measurements** to decipher the record of ancient environments and subsequent alteration

Environments typically vary spatially and in time, which manifests as spatial variations in the rock record.

- **Mobility** (e.g., range, ability to navigate rough terrain and slopes, etc.)

- Ability to **perform and integrate measurements across multiple scales**
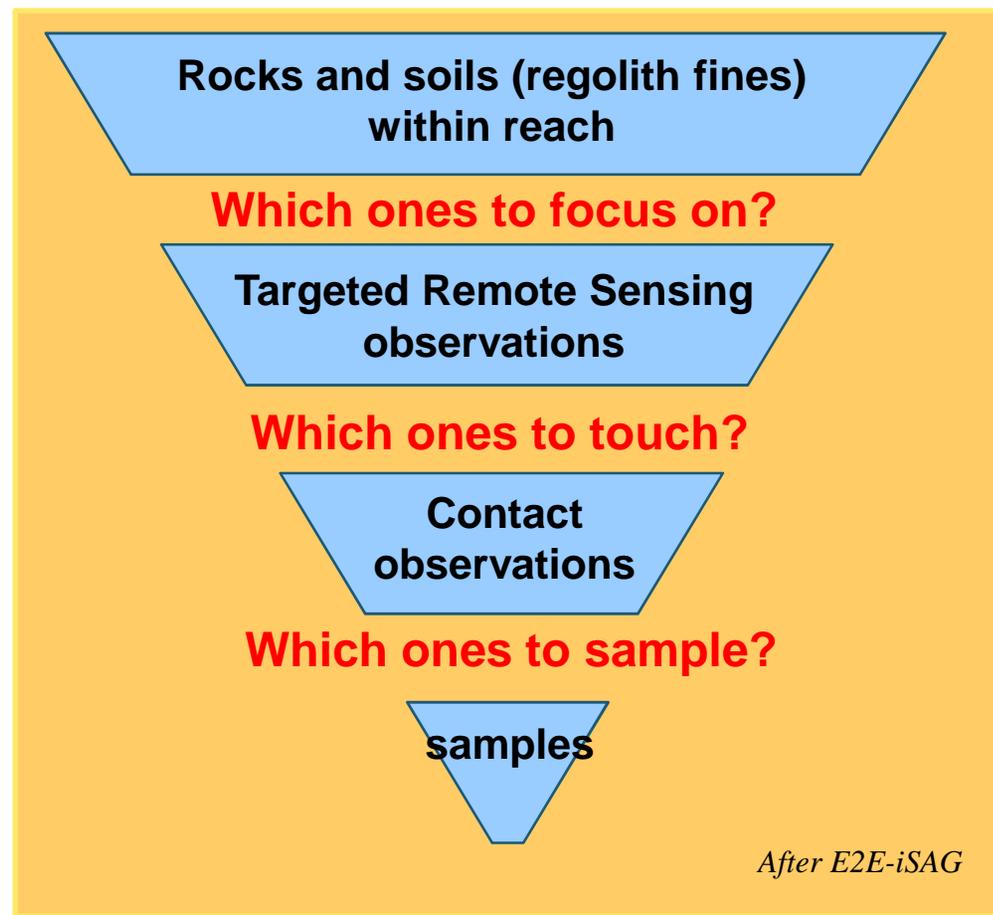
SDT MAJOR FINDING #1

Assessing habitability and preservation potential at a site with a record of an astrobiologically relevant ancient environment requires a rover that can navigate the terrain to conduct lateral and stratigraphic surveys across multiple scales and targets.

"Well documented" means that the appropriate geologic measurements have been carried out across the exploration area to provide maximum constraints on the interpretation of the sample analysis.

SDT FINDING

To ensure that a site, or samples from it, are "well documented" requires using the rover's tools and instruments to make a sufficient quantity, variety and quality of geologic observations to interpret past environmental conditions and understand spatial and temporal relationships in the geologic record.

QUANTITY OF GEOLOGIC OBSERVATIONS

Rocks and soils (regolith fines) within reach

Which ones to focus on?

Targeted Remote Sensing observations

Which ones to touch?

Contact observations

Which ones to sample?

samples

After E2E-iSAG

Seventeen different categories of measurements were identified from two community workshops (see Appendix) and evaluated for responsiveness to the four objectives of the Mars 2020 mission.

- Contact mineralogy
- Context imaging
- Elemental chemistry
- Microscopic imaging
- Context mineralogy
- Atmospheric trace gas detection
- Contact organic detection/characterization
- Stable Isotopic ratios
- Organic characterization in processed samples

- Mineralogy in processed samples
- Redox potential
- Subsurface characterization
- Geochronology
- Remanent Magnetic Properties
- Radiation environment
- Regolith/dust properties
- Meteorology

Objective A — Correlate Composition with Fine Texture & Structure
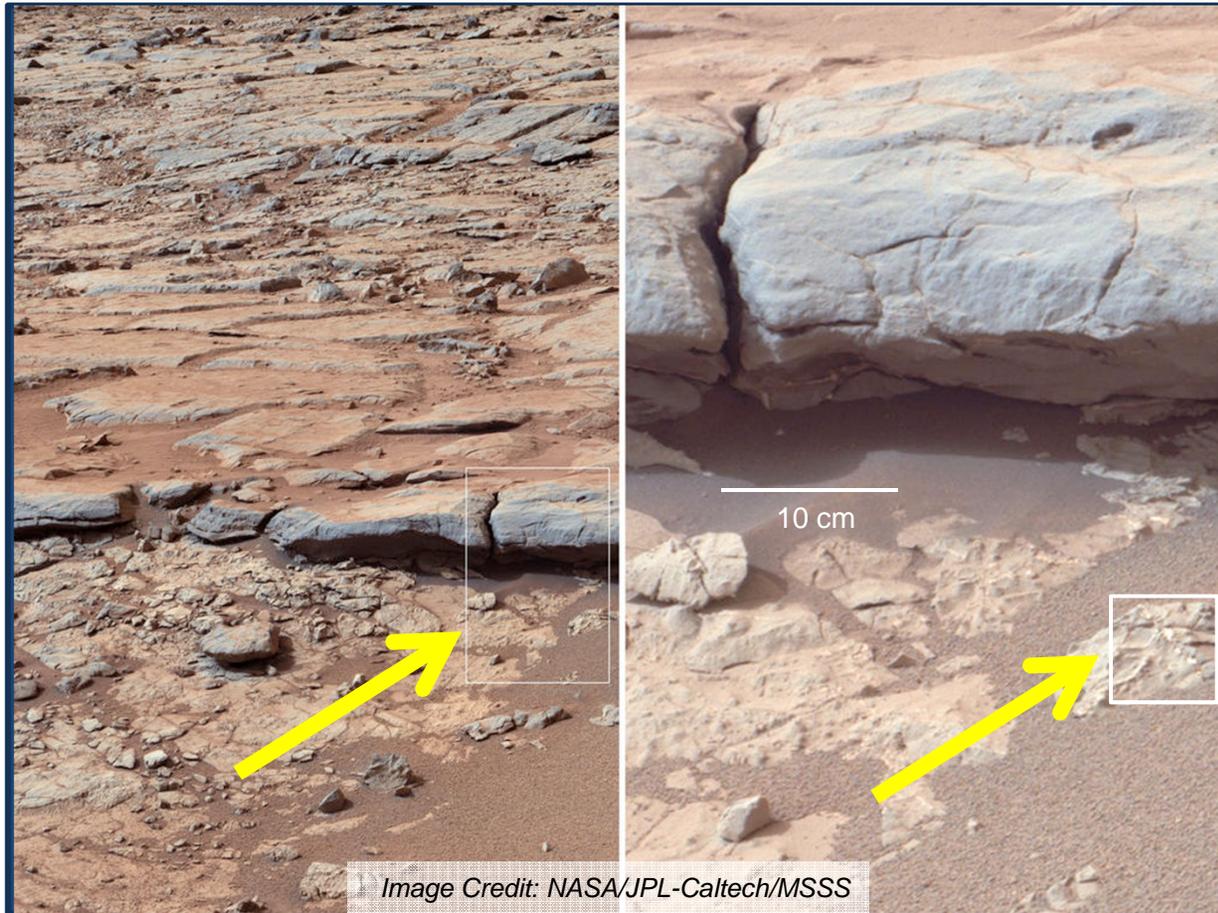
Image Credit: NASA/JPL-Caltech/LANL/CNES/IRAP/LPGNantes/CNRS/LGLyon/Planet-Terre

Veins of hydrated calcium sulfates

Sediments with basaltic composition

Site for core

Site for fine-scale measurements

1 cm

« Sheepbed rock »

10 cm

Image Credit: NASA/JPL-Caltech/MSSS

Mars meteorite

vein w. diff. mineralogy

10 µm
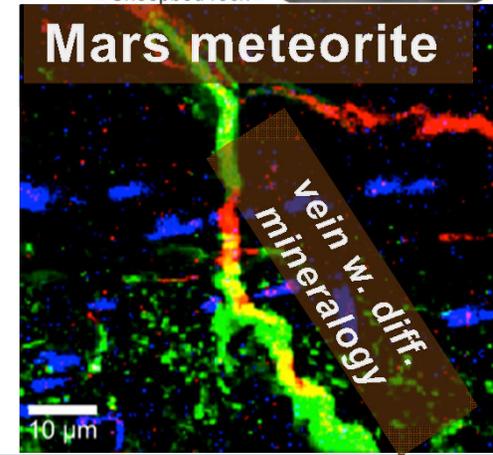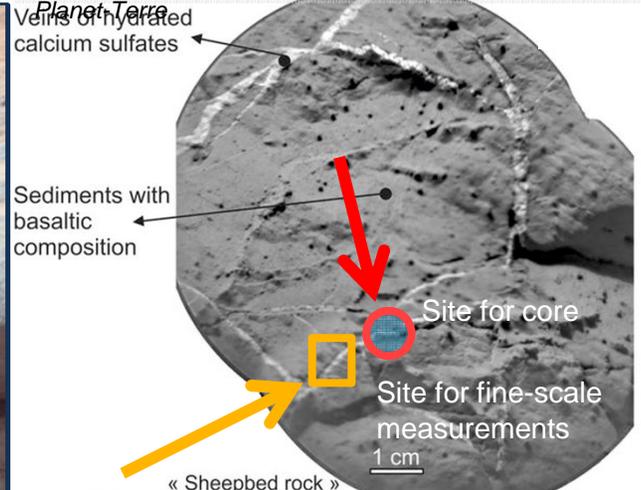
SDT FINDING

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

These are the measurement priorities for effectively and efficiently characterizing the geology of a site, assessing habitability, and supporting the informational/decisional needs of Objectives B and C.

- Required Measurements:
  - Context imaging
  - Context mineralogy
  - Fine-scale imaging of arm work volume
  - Fine-scale elemental chemistry of arm work volume
  - Fine-scale mineralogy of arm work volume

Science Threshold

- Additional "Baseline" Measurements
  - Organic detection
  - Subsurface characterization

Science Baseline

- Additional Desirable Measurements (unranked)
  - Geochronology (absolute age dating)
  - Redox potential in target material
  - Isotopic ratios in target material
  - Surface physical properties (e.g., regolith; dust)
  - Paleomagnetic data
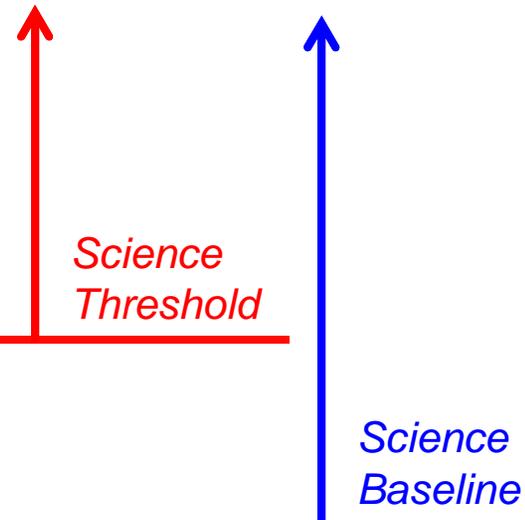
Priorities determined using the traceability matrix

Organic matter detection provides valuable observations for assessing the processes that influence preservation of information about ancient environments

- Detection of organic matter helps to characterize meteoritic inputs, hydrothermal processes, and other potential processes that might form abiotic (pre-biotic?) organic matter

- Acquiring rock samples that contain organic matter is a very high priority for MSR scientific objectives 1, 3-6 and 8 of the E2E-iSAG report

> Knowledge of *structure* and *composition* of subsurface materials could augment identification and refine context of targets for detailed measurement

SUBSURFACE STRUCTURE
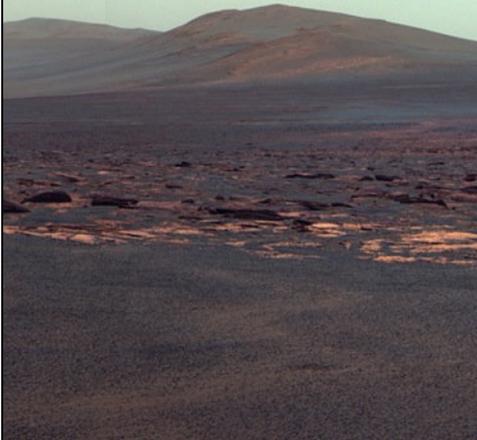
Problem:
- Information on setting is gained from limited outcrops accessible to threshold instruments. MER experience shows that considerable time spent traversing to outcrops could be saved by better knowledge of stratigraphy.

Example:
- Opportunity crossed multiple contacts as it traversed the onlap of sulfate-bearing deposits onto Noachian terrain; unclear relationship of units at Cape York
- 3D structure would inform a continuous cross-section, providing context

Relevant measurements:
- Lateral, depth variation in structure, density, conductivity; depth of discontinuities

Examples: ground-penetrating radar

Problem:
- Lithologies of interest for detailed measurement or sampling can be hidden from threshold instruments by centimeters or more of dust or regolith

Example:
- Spirit discovered high concentrations of silica where a stuck wheel removed a few cm of overburden
- Ability to sense to ~ >5 cm depth **by design** could detect scientifically important lithologies that would otherwise not be investigated

Relevant measurements:
- Detection at depth of key minerals or associated elements – sulfates (S), silica (Si), carbonates (C), highly hydrated minerals (H) – can pinpoint key locations for sampling and/or evaluation of stratigraphy

Examples: gamma-ray spectrometer, neutron spectrometer, trenching tool

SUBSURFACE COMPOSITION
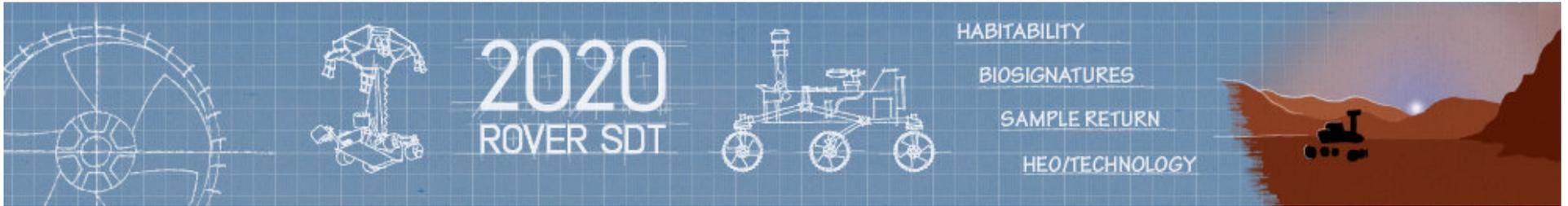
Options and Priorities to Achieve

Objective B

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

Scientific Process for Detecting Past Martian Life

Objective B

PRE-CONDITIONS THAT MUST HAVE BEEN MET	POSSIBLE EVIDENCE OF ANY PAST LIFE	PAST LIFE DETECTED

PAST HABITABLE ENVIRONMENT → **POTENTIAL FOR BIOSIGNATURE PRESERVATION**

EXISTENCE OF POTENTIAL BIOSIGNATURE

RECOGNITION OF DEFINITIVE BIOSIGNATURE

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

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

An observable feature that might be evidence of past life.

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

Proposed Mars 2020 Rover

MSR

Labs on Earth

SDT MAJOR FINDING

To search for potential biosignatures, it is necessary to (a) identify sites that very likely hosted past habitable environments, (b) identify high biosignature preservation potential materials to be analyzed for potential biosignatures, and (c) perform measurements to identify potential biosignatures or materials that might contain them.

These hypothesized potential Martian biosignatures represent independently observable features.

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

Organics
Organic Detection, Characterization
Biomarker organic molecules (organic matter features)

Minerals
Context, Fine-Scale Mineralogy
Biominerals (composition & morphology consistent with biological activity)

Macro Structures/ Textures
Context Imaging
Stromatolite (macroscale rock fabrics & structures)

Potential Biosignature Assemblage

Micro Structures/ Textures
Fine-scale Imaging
Microfossils (microscale rock of mineral fabrics and structures)

Chemistry
Context, Fine-Scale Chemistry
Possible microbial enrichment of REE in carbonate (evidence of chemical equilibria or disequilibria)

Isotopes
Isotopic record (stable isotopic patterns)

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.

Minerals & Rocks that Preserve Terrestrial Biosignatures

Least Stable	Dominant Process Controlling Loss
Ice	**Climatic warming**
Halides, Sulfates	**Dissolution**
Metallic Sulfides	Oxidation
Clay-rich Shales **Water-laid Pyroclastics** **Marine Carbonates** **Metallic Oxides**	**Metamorphism** **Recrystallization** **Dissolution**
Phosphates **Silica**	**Deep Burial** **Recrystallization** **Metamorphism**

Most Stable

After *Farmer & Des Marais (1999)*

Certain minerals and rock types are more effective than others for enhancing the preservation of biosignatures in Earth's geologic record.

An assessment of Biosignature Preservation Potential (BPP) should consider the minerals and rock types that might contain Potential Biosignatures (PBS).

Biosignatures must "run a gauntlet" of processes through geologic time that can either lower or elevate their BPP.

GEOLOGIC TIME

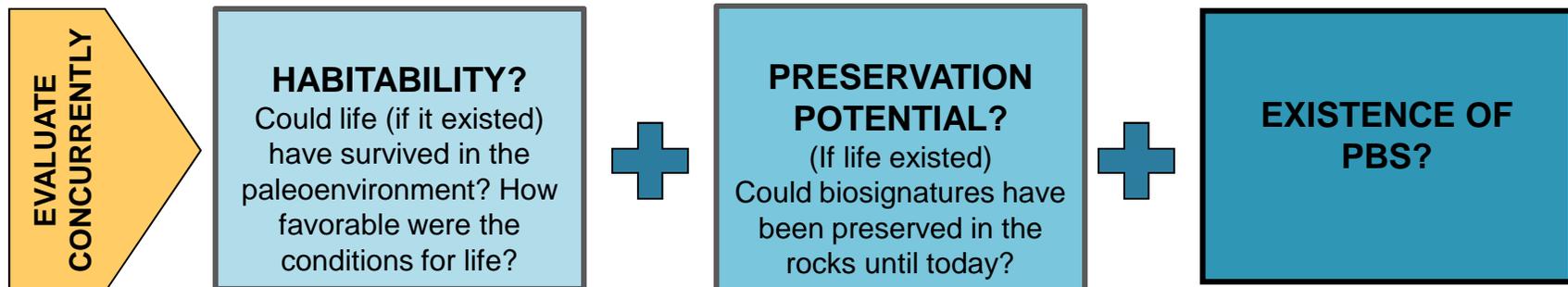| Environment of PBS Formation	Initial Sequestration of PBS in a Geologic Deposit	Long-term sequestration of PBS	Surface exposure to impacts, erosion and/or weathering of the host deposit
e.g., microorganisms degrade or recycle organic and mineral PBS*, OR PBS preservation is enhanced in reducing environments that minimize degradation of organics and/or reduced minerals	e.g., degrade PBS by microorganisms*, reactions with minerals, dissolution, compaction, etc. OR preserve PBS by rapid burial and/or entombment in impermeable matrices	e.g., degrade PBS by microorganisms*, oxidation, radiolysis, dissolution, thermal degradation, impact, deformation, chemical replacement due to migrating fluids, etc. OR preserve PBS by desiccation, sequestration in impervious host rock, low irradiation, and benign temperatures and pressures	...same examples as those indicated for long-term sequestration of PBS

* Thereby at least partially replacing PBS from the initial environment of formation with a new set of PBS

SDT FINDING

Assessing the potential for preservation of any given type of biosignature requires interpretation of past geological environments and processes. This interpretation requires measurements of rock chemistry, mineralogy, oxidation state, and rock texture, morphology and context.
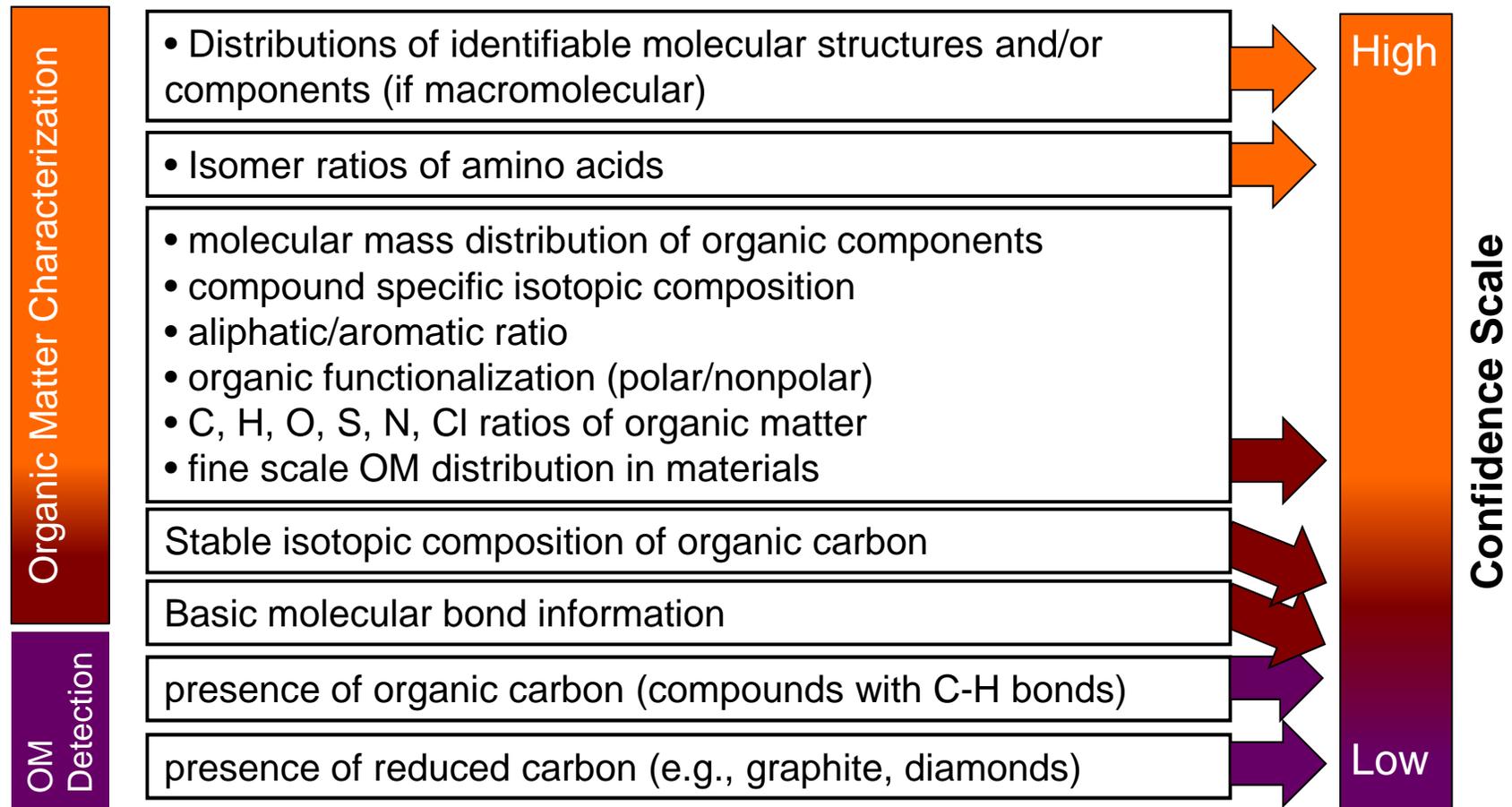
The strategy <u>first</u> to evaluate habitability and BPP in an area, and <u>then</u> to search for PBS, though logical, is typically not practical during rover operations. Because a rover rarely returns to previously visited locations, it must complete all observations before it moves to the next location. Accordingly, evaluations of habitability and BPP and any measurements of PBS must be executed concurrently before leaving a particular location.

EVALUATE CONCURRENTLY →

| **HABITABILITY?** Could life (if it existed) have survived in the paleoenvironment? How favorable were the conditions for life? | **+** | **PRESERVATION POTENTIAL?** (If life existed) Could biosignatures have been preserved in the rocks until today? | **+** | **EXISTENCE OF PBS?** |

SDT FINDING

Although it would be logical to assess habitability and biosignature preservation potential before seeking potential biosignatures, for practical considerations, evidence for all three would be sought concurrently during exploration at a particular rover location.

Different types of organic matter measurements provide different levels of confidence in a biological origin for the organic matter (OM)*

Organic Matter Characterization

- • Distributions of identifiable molecular structures and/or components (if macromolecular)

- • Isomer ratios of amino acids

- • molecular mass distribution of organic components
- • compound specific isotopic composition
- • aliphatic/aromatic ratio
- • organic functionalization (polar/nonpolar)
- • C, H, O, S, N, Cl ratios of organic matter
- • fine scale OM distribution in materials

Stable isotopic composition of organic carbon

Basic molecular bond information

OM Detection

presence of organic carbon (compounds with C-H bonds)

presence of reduced carbon (e.g., graphite, diamonds)

High

Low

Confidence Scale

* The level of confidence provided by a given measurement varies depending on the specific details (e.g. degree of thermal degradation) of the sample being investigated
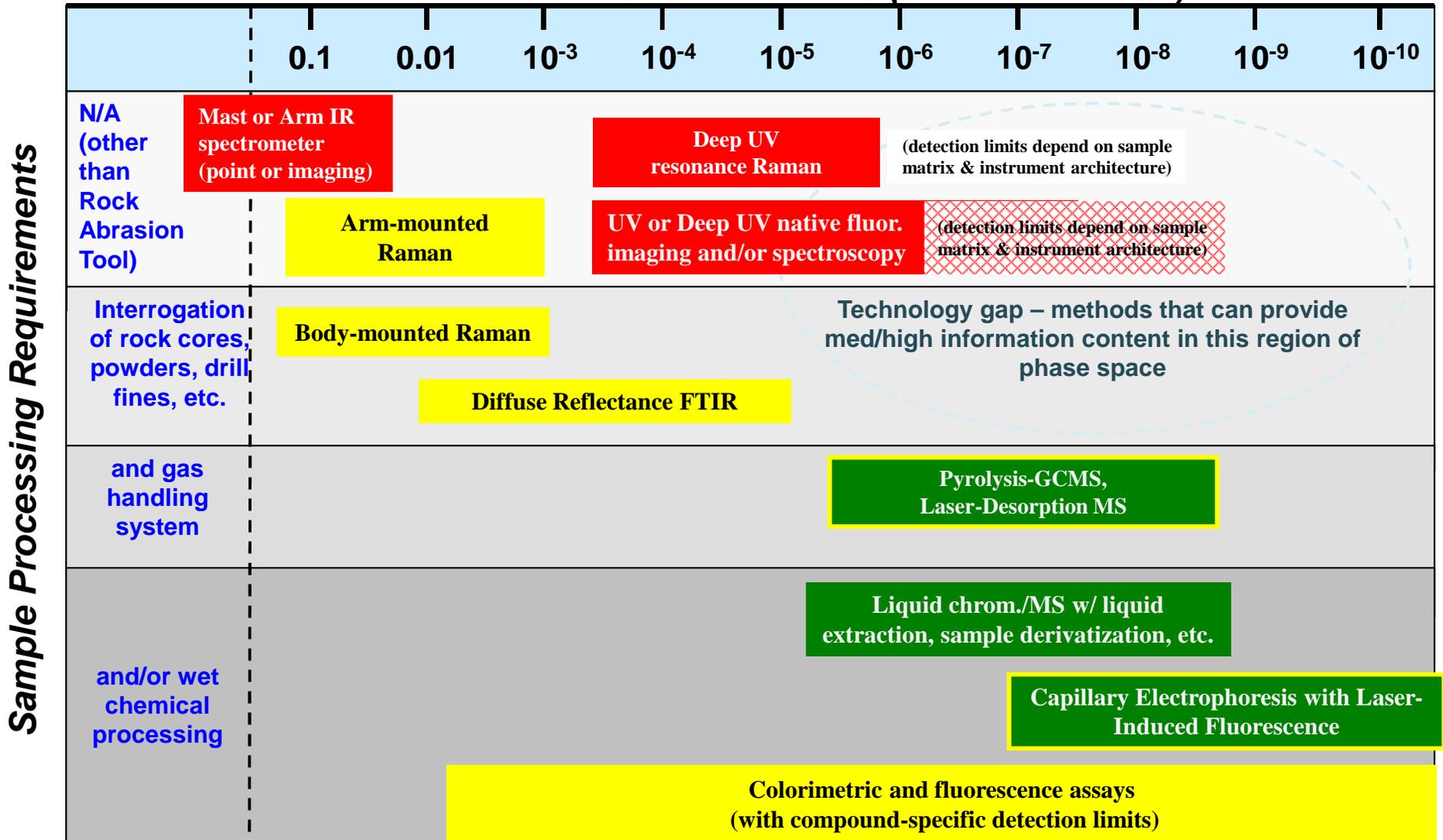
High characterization capability   **Intermediate**   **Specialized/limited information**

Estimated Detection Limits (volume fraction)

	0.1	0.01	10^{-3}	10^{-4}	10^{-5}	10^{-6}	10^{-7}	10^{-8}	10^{-9}	10^{-10}

Sample Processing Requirements

N/A (other than Rock Abrasion Tool)

- Mast or Arm IR spectrometer (point or imaging)
- Arm-mounted Raman
- Deep UV resonance Raman
- UV or Deep UV native fluor. imaging and/or spectroscopy

(detection limits depend on sample matrix & instrument architecture)

(detection limits depend on sample matrix & instrument architecture)

Interrogation of rock cores, powders, drill fines, etc.

- Body-mounted Raman
- Diffuse Reflectance FTIR

Technology gap – methods that can provide med/high information content in this region of phase space

and gas handling system

- Pyrolysis-GCMS, Laser-Desorption MS

and/or wet chemical processing

- Liquid chrom./MS w/ liquid extraction, sample derivatization, etc.
- Capillary Electrophoresis with Laser-Induced Fluorescence
- Colorimetric and fluorescence assays (with compound-specific detection limits)

Value of organic characterization:

- The complexity and diversity of organic compounds can help to characterize processes that are very important for habitability and any life. A more thorough characterization of a sample's organic components will access more of this important information that is stored in a sample's organic components.

- Characterization and molecular analysis of organic matter helps to characterize more precisely any meteoritic inputs, hydrothermal processes, and other abiotic processes that create organic matter.

- The caching and return of samples bearing organic carbon provides critical insight into the origin of organic carbon signatures in Martian meteorites (e.g. ALH84001, Steele et al. 2012a,b, Agee et al., 2013).

- Confidence in interpretation of the other five classes of biosignatures is greatly enhanced if any associated organic matter is analyzed more thoroughly.

- Organic matter characterization of bulk and molecular components would help to constrain the assessment of processes that influence various types of BPP.

SDT FINDING	Additional *in situ* organic detection and characterization of organic matter, such as provided by a second spectroscopic technique, would significantly improve our understanding of biosignature preservation potential and ability to detect potential organic biosignatures.

- Required Measurements

  Note: These five measure-ments are common with Obj. A

  - Context imaging
  - Context mineralogy
  - Fine-scale imaging – co-registered with Mineralogy
  - Elemental chemistry (mapping at fine scale is desired)
  - Fine-scale Mineralogy
  - Reduced C detection
  - Organic detection method #1

  Science Threshold

- Additional "Baseline" Measurements

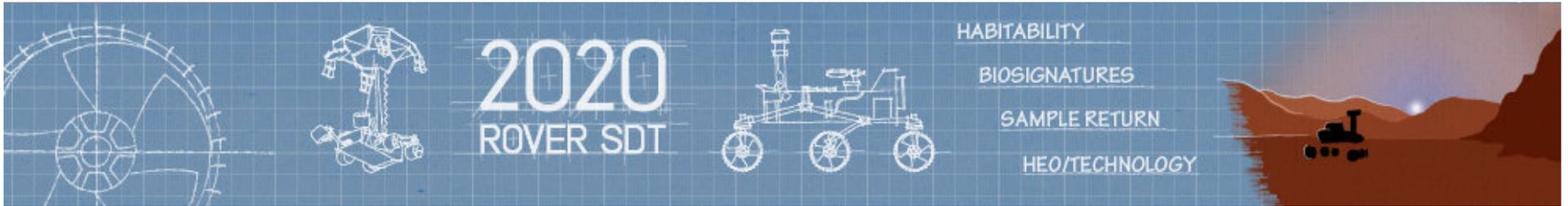 - Organic detection method #2 (enables characterization)

  Science Baseline

- Additional Desirable Measurements

  - Organic molecular analysis (characterization)

- Other Required Capabilities:

  - Ability to remove rock coating and weathering layers

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. |
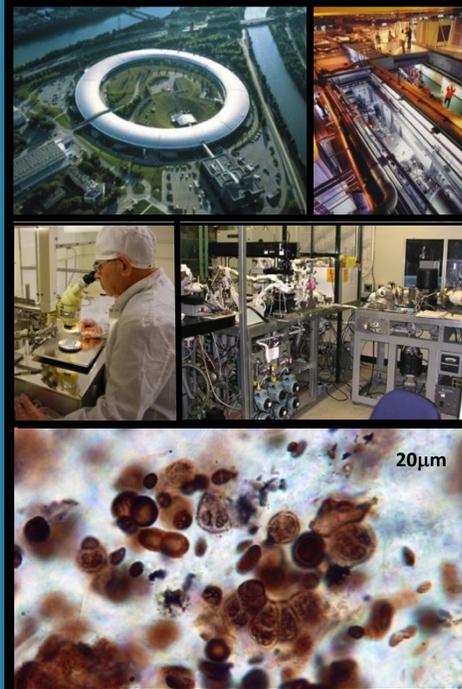
Reasons for returning samples for analysis on Earth...

- 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 FINDING

The SDT concurs with the detailed technical and scientific arguments made by the Decadal Survey (2011) and MEPAG (most recently summarized in E2E-iSAG, 2012) for the critical role returned samples will play in the scientific exploration of Mars.

Have there been any very recent new findings that could alter the logic leading to the conclusions of those reports?

- **Post-Decadal Survey Discovery of Recurring Slope Lineae (RSLs)**
  - Might be signs of present-day surface release of liquid water. However, understanding of RSL is too immature to conclude that exploring them *in situ* is more compelling for astrobiology than sample return. Also, their possible "special region" status could place complex and/or costly Planetary Protection constraints on potential missions to RLSs.

- **Recent MSL and MER mission results**
  - Discovery of sedimentary rocks containing reducing components, water-formed conglomerates, phyllosilicate minerals, water-deposited minerals in veins, etc., reinforces inference of past habitability and of BPP; provides even stronger support for the need for sample return!

- **Recent Mars meteorite results**
  - Findings of abiotic macromolecular carbon (with N, O, H) in martian meteorites, and of abundant water in NWA7034, confirm availability of compounds needed for life, and show that organic PBS can be preserved near the martian surface. Provides support for Mars' BPP; emphasizes need for sophisticated analyses capabilities on Earth.

> None of the discoveries of the last decade have changed the fundamental rationale for Mars Sample Return.

Objective C

The Return of Samples to Earth
What Role Should the Mars 2020 Rover Play?

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

Because of the overall importance of Mars Sample Return to NASA's strategic objectives, the Mars 2020 mission is expected to make significant technical progress towards MSR.

How does the SDT interpret "significant technical progress"?

As shown on the following slides, delivering scientifically selected martian samples to Earth involves a series of functional steps (spanning several missions) that must be completed in order, beginning with the selection and acquisition of samples.

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

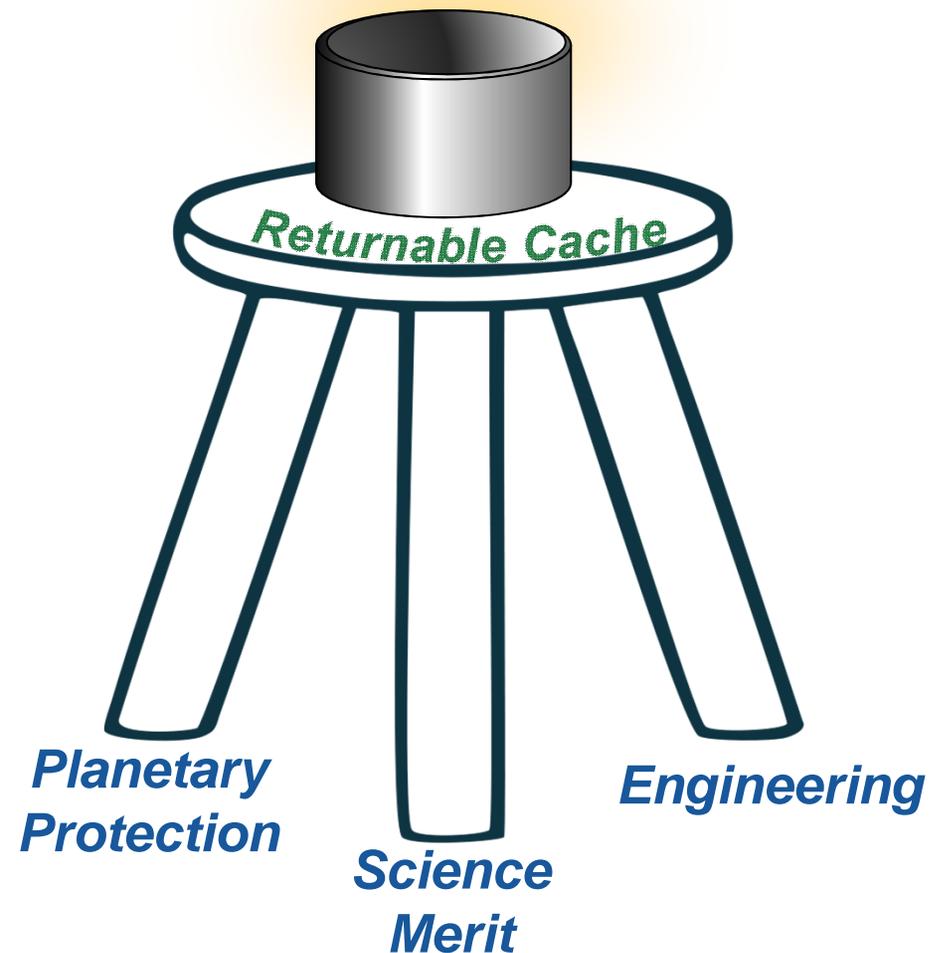| Options for Technical Progress Towards MSR	New Capability?	Consistent with Proposed Mars-2020 Resources?	Resulting contribution to MSR	
			Reduces Science or Engineering Risk	Achieves Major Campaign Milestone
Select Samples (for future collection)		✔		
Select Samples & Assemble Demonstration Cache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

Note: 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

<u>Significant technical progress</u> by Mars 2020 towards the future return of samples to Earth within the mission constraints demands the development and deployment of a sampling and encapsulation system and the assembly of a cache of scientifically selected, well-documented samples packaged in such a way that they could be returned to Earth.

What Constitutes a "Returnable Cache"?

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

1 The cache has enough <u>scientific value</u> to merit returning.

2 The cache complies with <u>planetary protection</u> requirements.

3 The cache is returnable in an <u>engineering</u> sense.

Returnable Cache

Planetary Protection

Science Merit

Engineering

SDT FINDING

A cache that merits returning in a scientific sense is one that has the potential to achieve the scientific objectives of sample return identified by E2E-iSAG (2012).

Scientific Objectives in Priority Order

1	Critically assess any evidence for past life or its chemical precursors, and place detailed constraints on the past habitability and the potential for preservation of the signs of life
2	Quantitatively constrain the age, context and processes of accretion, early differentiation and magmatic and magnetic history of Mars.
3	Reconstruct the history of surface and near-surface processes involving water.
4	Constrain the magnitude, nature, timing, and origin of past planet-wide climate change.
5	Assess potential environmental hazards to future human exploration.
6	Assess the history and significance of surface modifying processes, including, but not limited to: impact, photochemical, volcanic, and aeolian.
7	Constrain the origin and evolution of the martian atmosphere, accounting for its elemental and isotopic composition with all inert species.
8	Evaluate potential critical resources for future human explorers.

Mandatory: Determine if the surface and near-surface materials contain evidence of extant life

Sample Types in Priority Order

1A. Subaqueous or hydrothermal sediments (EQUAL PRIORITY)
1B. Hydrothermally altered rocks or Low-T fluid-altered rocks

2. Unaltered Igneous rocks

3. Regolith

4. Atmosphere, rocks with trapped atmosphere

Key engineering factors for M2020 cache design

Interfaces to downstream elements
- Transfer equipment (arm, etc.)
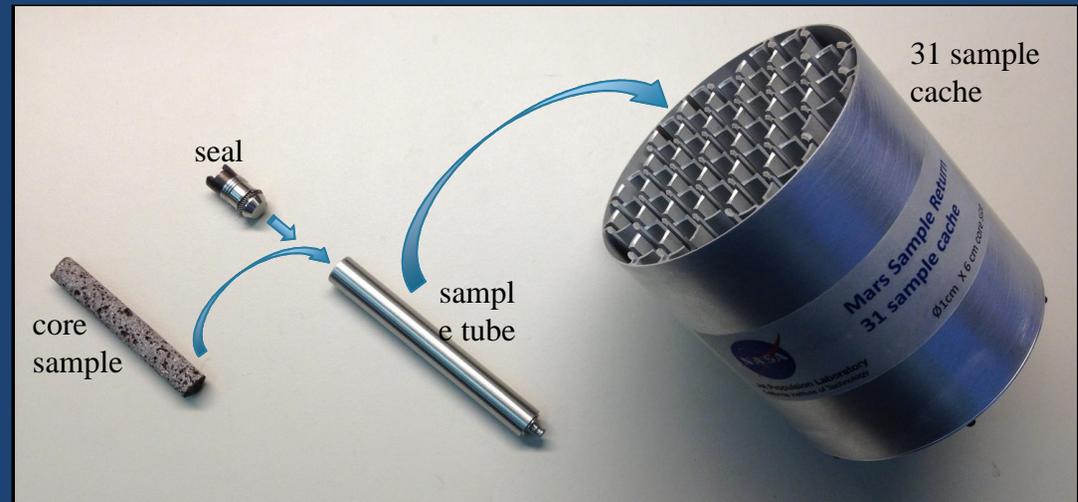- Mars Ascent Vehicle/Orbiting Sample

Long-term storage in Mars surface environment
- External or internal to rover
- Nominal or anomalous retrieval by later mission

Thermal design and history of cache environment over time
- Characterize exchange of volatiles into or out of the samples
- Analyze/predict thermal history of the cache

The Cache Enables Future Science

seal

core sample

sample tube

31 sample cache

Mars Sample Return
31 sample cache

The ability to collect compelling samples for potential future return

Information Source: Whetsel/Parrish

SDT FINDING

For a cache to be returnable, it must comply with NASA Planetary Protection requirements in order for future planners to request permission to return it, should they choose to do so.

Direct excerpts from the current NASA Procedural Requirement document for PP related to the returning a sample cache

5.3.3 PP Category V. The Earth return portion of a Mars Sample Return mission is classified as "Restricted Earth return," with all outbound portions required to meet associated requirements.

5.3.3.2   Unless specifically exempted, the outbound leg of the mission **shall meet PP Category IVb** requirements. This provision is intended to avoid "false positive" indications in a life-detection and hazard-determination protocol, or in the search for life in the sample after it is returned.

　　a.   A "false positive" could prevent distribution of the sample from containment and could lead to unnecessary increased rigor in the requirements for all later Mars missions.

5.3.2.2 PP Category IVb. Lander systems designed to investigate extant Martian life shall comply with all of the requirements of PP Category IVa and also with one of the following requirements:

EITHER

　　a. The entire landed system is restricted to a surface biological burden level of

≤ 30 spores (see 5.3.2.4) or to levels of biological burden reduction driven by the nature and sensitivity of the particular life-detection experiments, whichever are more stringent, and protected from recontamination.

　　OR

　　b. The subsystems which are involved in the acquisition, delivery, and analysis of samples used for life detection are sterilized to these levels. Methods for preventing recontamination of the sterilized subsystems and preventing contamination of the material to be analyzed is provided.

Information Source: K. Buxbaum

Measurements required by the 2020 Mars Rover **to achieve Objective C** are almost identical to those required for Objectives A and B.

- Required Measurements
  - Context imaging
  - Context mineralogy
  - Fine-scale imaging of arm work volume
  - Elemental chemistry of arm work volume
  - Fine-scale mineralogy of arm work volume

Science Threshold

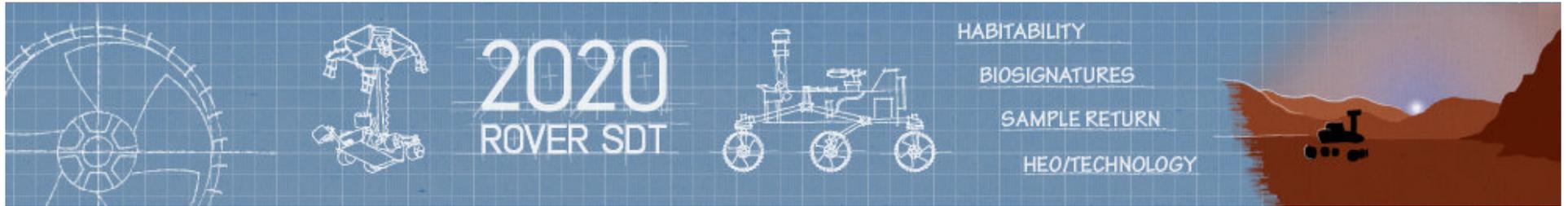- Additional "Baseline" Measurements
  - Organic detection

Science Baseline
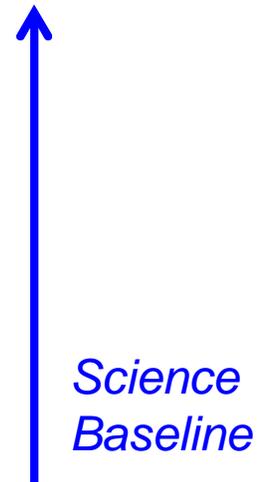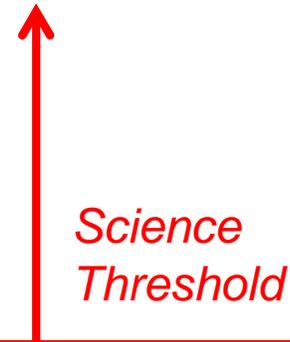
UNRANKED Additional Possible Measurements Below the Baseline

Observations of the Collected Sample	Magnetometer	Age Dating

Options and Priorities to Achieve
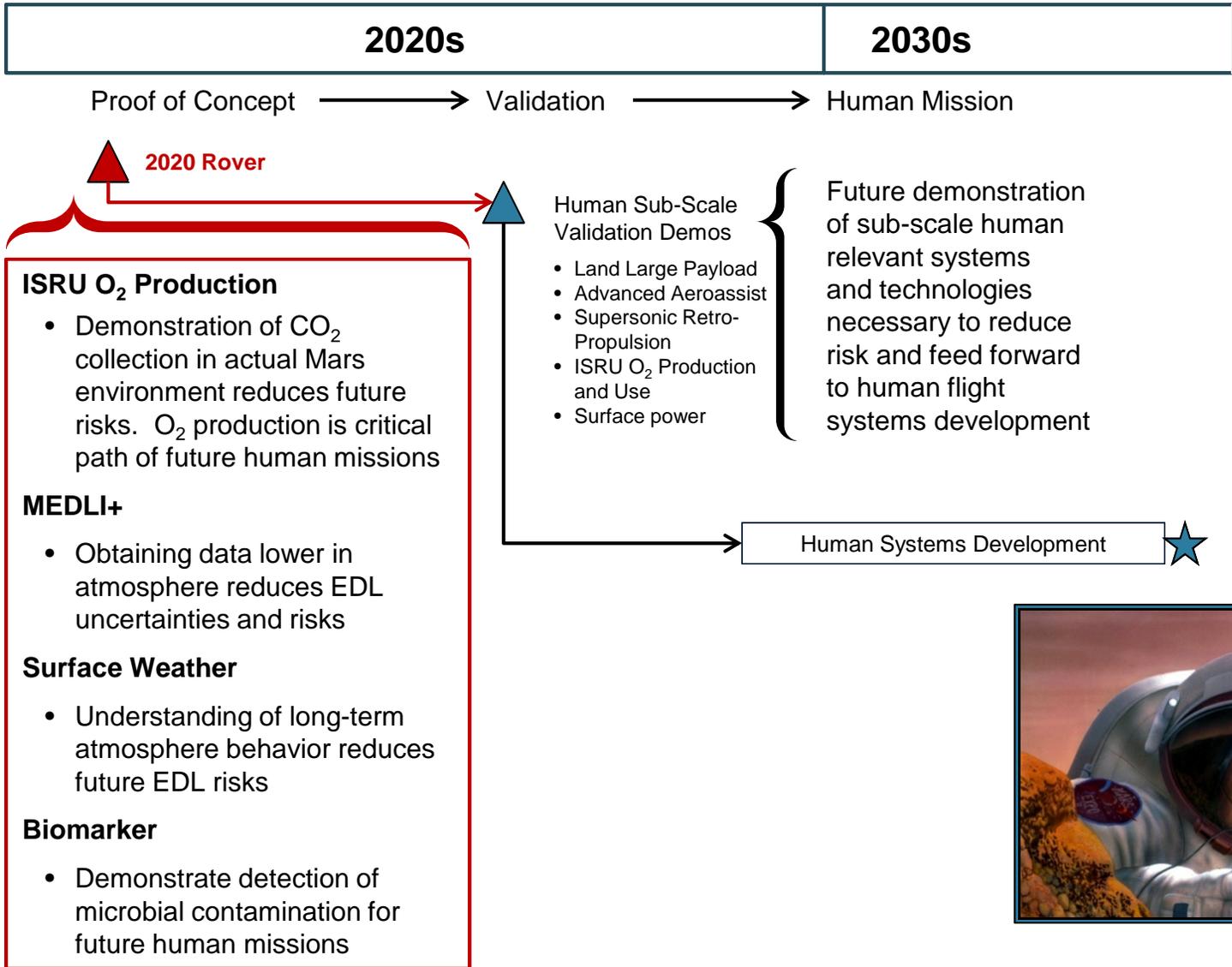
Objective D

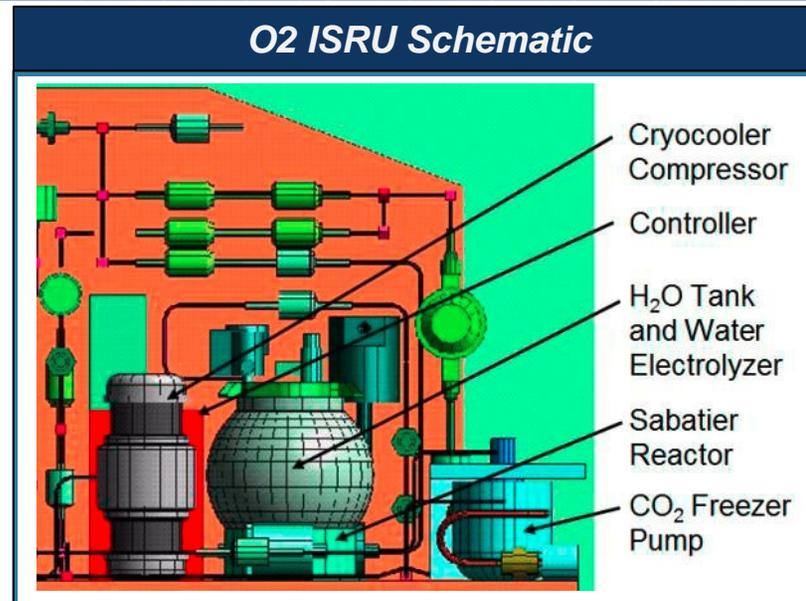| OBJECTIVE D	Provide an opportunity for contributed HEOMD or Space Technology Program (STP) participation, compatible with the science payload and within the mission's payload capacity.

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

#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

- Cryocooler Compressor
- Controller
- H_2O Tank and Water Electrolyzer
- Sabatier Reactor
- CO_2 Freezer Pump

NOTE:

This kind of demo can be run on a non-interference basis with science ops.
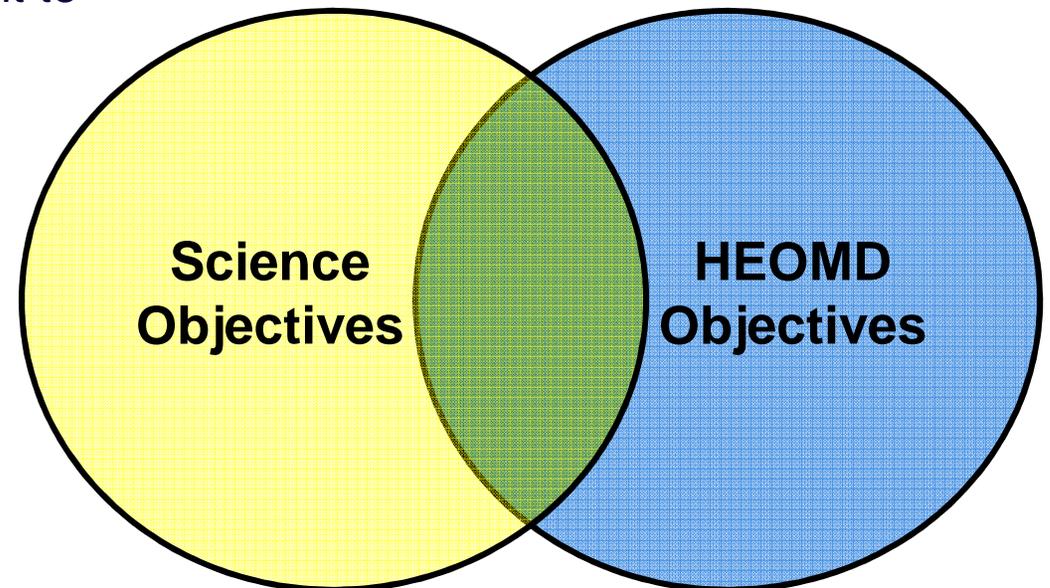
The Importance of Supporting Atmospheric Data

- 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

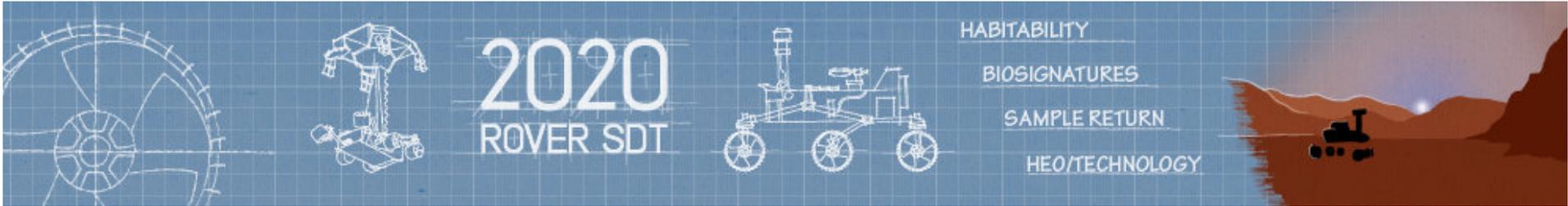**In-Situ Resource Utilization is the HEOMD top priority demonstration for the 2020 Mars Rover**

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.
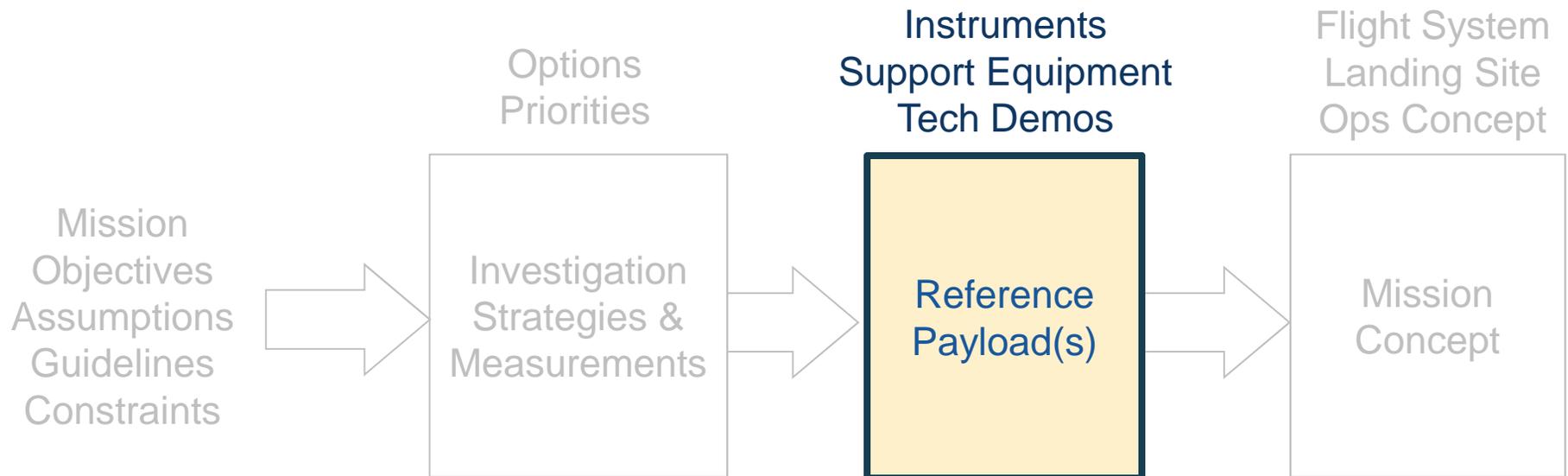
Science Objectives

HEOMD Objectives

SDT MAJOR FINDING — The top-priority measurements that address HEOMD strategic knowledge gaps also benefit Mars science.

High Priority Candidate STMD Payloads

Instrument/Demo	Description	Forward Benefits	STP Priority	Funding
Range Trigger	Software for parachute deployment based on range to target	Precision landing, site access	**H**	SMD
Terrain-relative Navigation (TRN) [1]	Divert to avoid a priori hazards and/or get closer to science targets	Precision landing, site access, pinpoint landing	**H** [2]	STMD HEO
MEDLI	EDL instruments as flown on MSL	Inform future applications and developments	**H**	STMD HEO
MEDLI +Up [3]	Parachute deployment, operation and drag observations	Inform future applications and developments	**H**	STMD

1. Recommended instantiation for 2020 would be location determination only — enhancements could include altimetry, velocimetry, and/or real-time hazard avoidance

2. To be considered by the Landing Site subteam in Phase II.

3. Development risk depends on existence and complexity of up-look camera and its interface.

SDT FINDING

The high-priority technology payloads, based on benefit and risk are: Range Trigger, Terrain-Relative navigation, and MEDLI/MEDLI+Up

Reference Payloads

Mission
Objectives
Assumptions
Guidelines
Constraints

→

Options
Priorities

Investigation
Strategies &
Measurements

→

Instruments
Support Equipment
Tech Demos

Reference
Payload(s)

→

Flight System
Landing Site
Ops Concept

Mission
Concept

Objective A *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

The measurements that would be required to meet the geology and habitability, biosignatures, and caching objectives are similar.
Thus, these three objectives are compatible and well-suited to be assigned to the same mission.

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

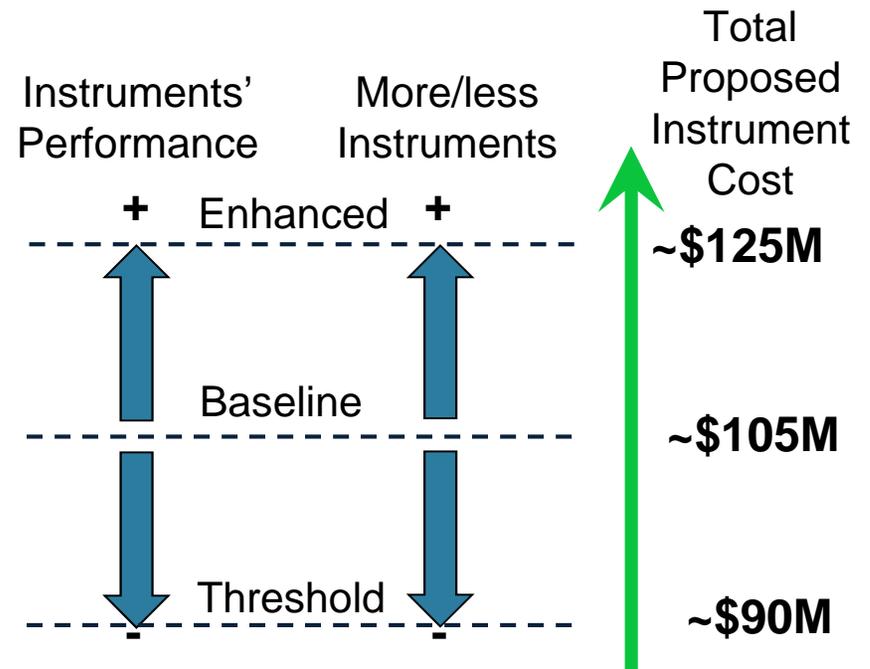| Science Instrument Straw Payloads[1]				
Functionalities Required	Blue Straw Payload	$ High, Med, Low	Orange Straw Payload	$ High, Med, Low
Context imaging	Mastcam-like	M	Mastcam-like	M
Context Mineralogy	UCIS-like	M	mTES-like	M
Elemental Chemistry	APXS-like	L	µXRF-like	L
Fine-scale imaging	MAHLI-like	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			
Technology payload elements	Includes range trigger			
Threshold Total (SMD funded)		~90		~90
Additional Instrument Options	GPR	M	GPR	M
HEO contributed payload	ISRU		ISRU	
Technology payload elements	Includes TRN			
Baseline Total (SMD funded)		~105		~105

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

Baseline and Threshold Options

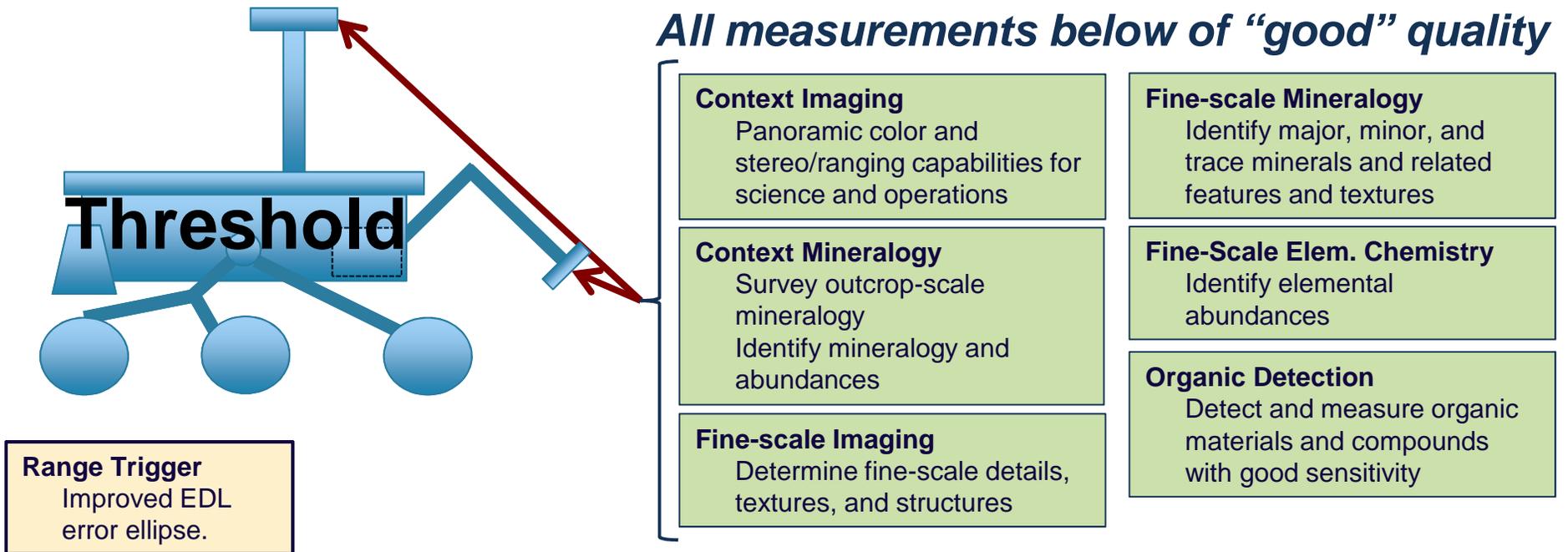**A baseline mission would include one or more of the following (not listed in priority order):**

- **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**

- The SDT has been asked to "*describe priorities for scaling the mission concept either up or down (in cost and capability).*"

- Many of the threshold measurements can be implemented by a range of instruments that vary in cost and performance.

- Thus, to first order, scaling either up or down can be accomplished within the SDT's vision of the mission by NASA selecting either higher or lower cost/performance instruments in each measurement category, and/or by selection of an instrument from the "baseline" and "enhancement" set.

Instruments' Performance	More/less Instruments	Total Proposed Instrument Cost
+ Enhanced +		~$125M
Baseline		~$105M
Threshold		~$90M

This trade and cost scaling needs to be done as part of evaluating the response to the AO, not by this SDT.

Threshold

Range Trigger
Improved EDL error ellipse.

All measurements below of "good" quality

Context Imaging
Panoramic color and stereo/ranging capabilities for science and operations

Context Mineralogy
Survey outcrop-scale mineralogy
Identify mineralogy and abundances

Fine-scale Imaging
Determine fine-scale details, textures, and structures

Fine-scale Mineralogy
Identify major, minor, and trace minerals and related features and textures

Fine-Scale Elem. Chemistry
Identify elemental abundances

Organic Detection
Detect and measure organic materials and compounds with good sensitivity

It is assumed that ~2-3 instruments would be located on the mast, with the remainder located on the arm, but some of these measurements can be performed from either position.

Science Support Functions

Sample Cache

Sample Encapsulation/Caching
• Encapsulation dust-tight

Surface Preparation Tool
Brushing and grinding capabilities
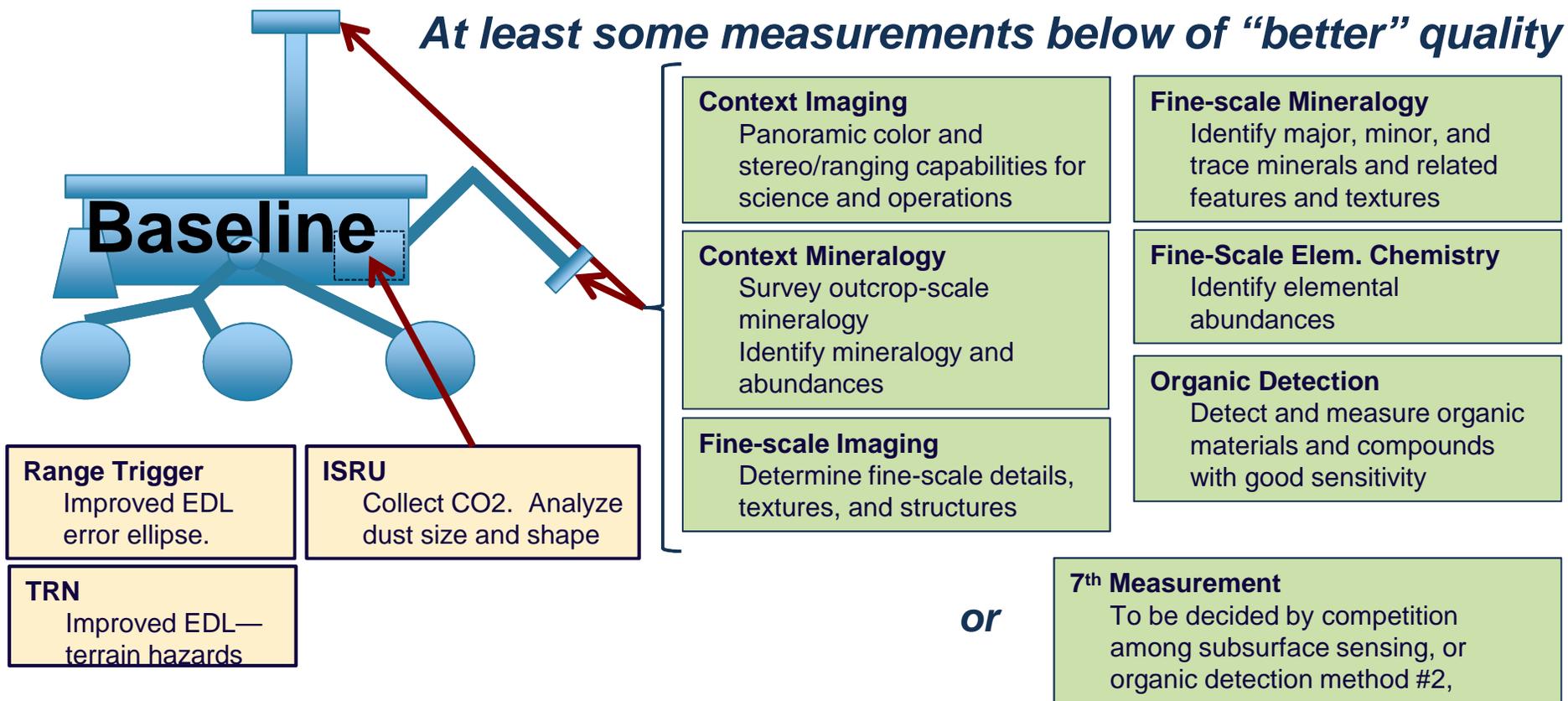
Rock/Regolith Coring Tool
For sample acquisition

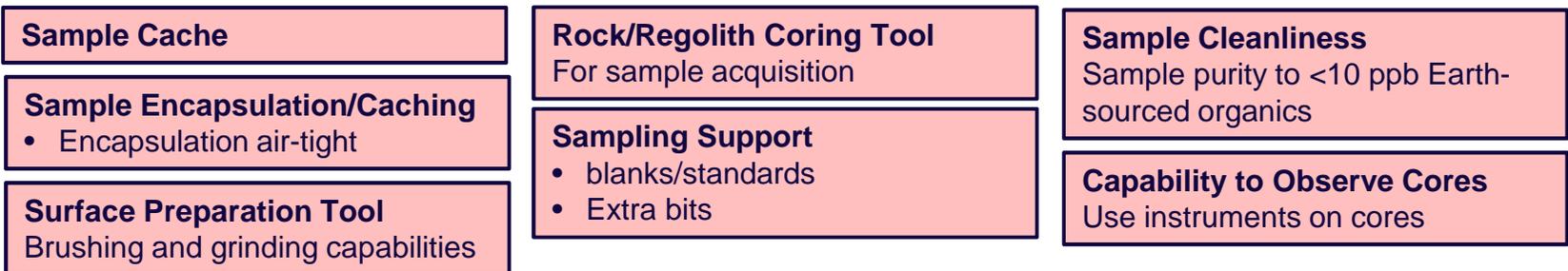**Sampling Support**
• blanks/standards
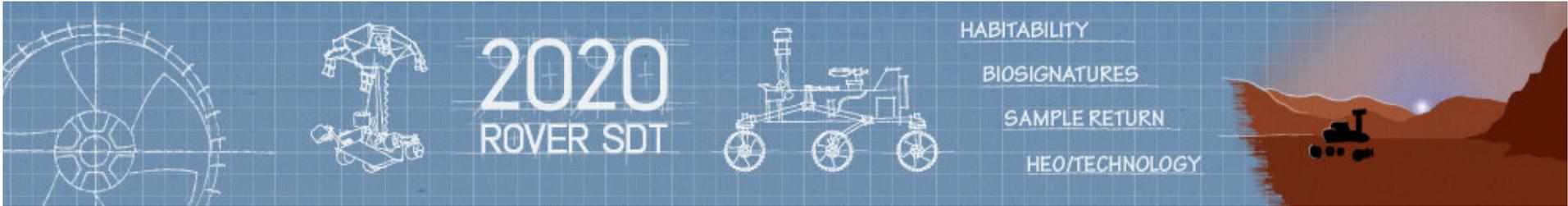• Extra bits

Sample Cleanliness
Sample purity to <40 ppb Earth-sourced organics
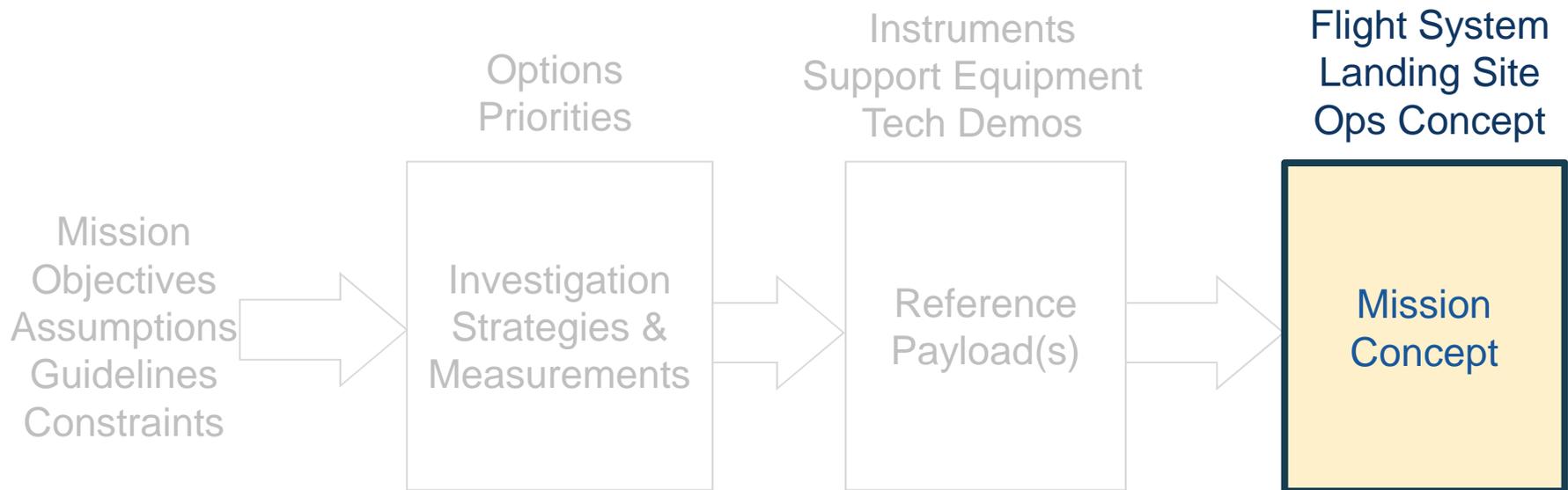
At least some measurements below of "better" quality

Baseline

Range Trigger
Improved EDL error ellipse.

TRN
Improved EDL—terrain hazards

ISRU
Collect CO_2. Analyze dust size and shape

Context Imaging
Panoramic color and stereo/ranging capabilities for science and operations

Context Mineralogy
Survey outcrop-scale mineralogy
Identify mineralogy and abundances

Fine-scale Imaging
Determine fine-scale details, textures, and structures

Fine-scale Mineralogy
Identify major, minor, and trace minerals and related features and textures

Fine-Scale Elem. Chemistry
Identify elemental abundances

Organic Detection
Detect and measure organic materials and compounds with good sensitivity

or

7th Measurement
To be decided by competition among subsurface sensing, or organic detection method #2,

Science Support Functions

Sample Cache

Sample Encapsulation/Caching
• Encapsulation air-tight

Surface Preparation Tool
Brushing and grinding capabilities

Rock/Regolith Coring Tool
For sample acquisition

Sampling Support
• blanks/standards
• Extra bits

Sample Cleanliness
Sample purity to <10 ppb Earth-sourced organics

Capability to Observe Cores
Use instruments on cores

Mission Concept

Mission
Objectives
Assumptions
Guidelines
Constraints

→

Options
Priorities

**Investigation
Strategies &
Measurements**

→

Instruments
Support Equipment
Tech Demos

**Reference
Payload(s)**

→

Flight System
Landing Site
Ops Concept

**Mission
Concept**

Planning Considerations Related to the
Surface Operations Scenario

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."

669 sols
1 Mars Year

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 FINDING — With the proposed mission concept, the charter-specified objectives for Mars 2020 can be achieved at a variety of different landing sites.

SDT MAJOR FINDING — Multiple strategies to improve on the modeled, reference operations scenarios

Will be available as the proposed mission is further developed.
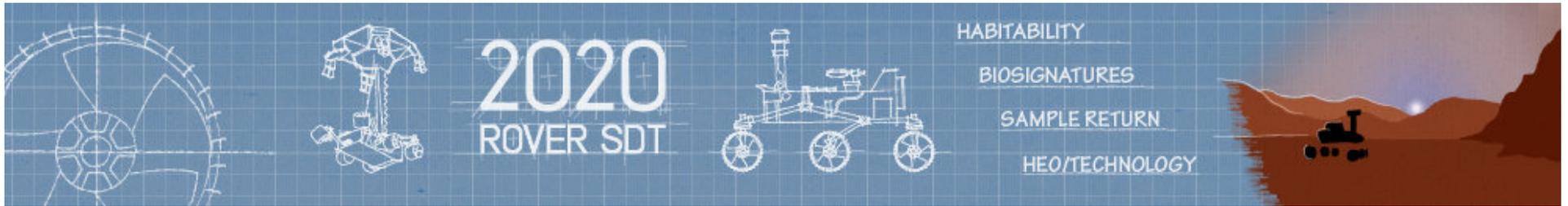
Planning Considerations
Related to the Landing Site

- Pressure cycle very favorable for 2020
  - Mars orbit eccentricity transfers CO_2 from polar caps to atmosphere
  - Atmosphere significantly more dense than for MSL landing

- More density = capability to land safely at higher elevation

- 2020 atmosphere provides *significant "no cost" improvements* to landing elevation for same mass

- Expect 2020 unmargined capability up to 0.5 km elevation, -0.5 km margined
  - Some variability depending on landing site specific characteristics
  - Generic atmosphere assumptions believed to be conservative
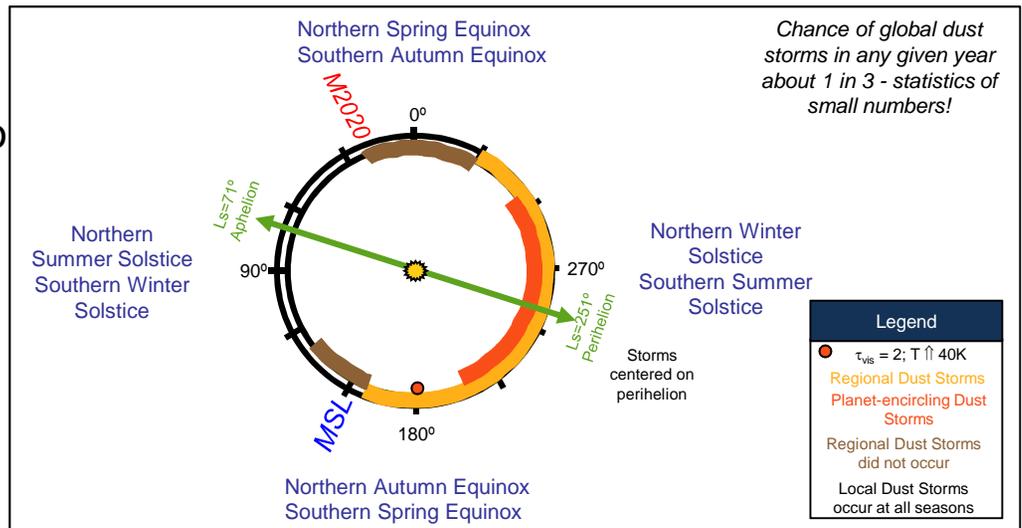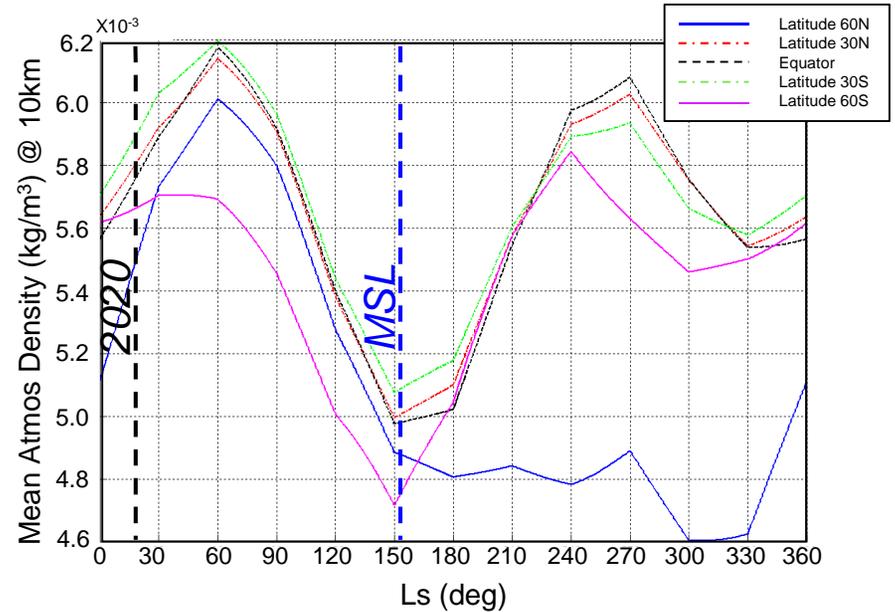
- Previous landing sites (e.g. Gale, Gusev, Meridiani) merit consideration as landing sites for Mars-2020, science Objectives B and C are different from those of prior missions and discoveries to date do not warrant pre-selection of any prior landing sites as the Mars-2020 landing site.

- There is also a growing inventory of diverse data available for evaluating the relative merits of varied existing and new candidate landing sites that will shed new light on their potential when evaluated by the broad expertise of the science community.

- If the 2020 mission carries Range Trigger, Terrain Relative Navigation (TRN), and/or Terminal Hazard Avoidance (THA) capabilities (discussed later), it will be able to access landing sites that could not have been considered or suggested previously.

- The SDT recommends that a landing site selection process be conducted, which would gather community input on candidate field sites and on critical decisions that will influence mission design and final site selection.

SDT FINDING	Mars 2020 would be the first mission to cache samples for possible return to Earth and may require a landing site selection process differing from those previous and tailored to a diverse set of scientific goals. It is therefore crucial to involve the broad expertise of the science community in proposing and evaluating candidate sites for the 2020 rover, thereby leading to science community consensus on the optimal site for meeting the mission goals

- E2E-iSAG observed that to maximize returned sample science, the MSR sample collection would need to include **unaltered igneous rocks collected from outcrop**.

- E2E-iSAG evaluated the ~65 landing sites proposed for MSL, and found ~10 where **outcrops** of both igneous rocks and sedimentary/ hydrothermal rocks appear to be present at the same landing site. However, most of these sites would not be accessible to the MSL system as applied (see Slides 105-106).

- If unaltered igneous rocks in outcrop is a threshold-level landing site requirement (final decision on this to be reached by later groups/activities), then there may not be a sufficient population of sites to choose from given MSL as-flown EDL capabilities.

Reconciling the Issue: one or both of the following steps needs to be taken:

1. Relax the E2E-iSAG-proposed landing site criterion to **unaltered igneous rocks collected from either outcrop or float**. The latter would have adverse science consequences for the sample caching objective of Mars 2020.

   Sample community take note

2. Improve the MSL as-flown EDL system to increase the number of sites that can be accessed.

SDT FINDING

Access to unaltered igneous rocks as float is considered a threshold-level field site requirement, but requiring that they be collected from known stratigraphic context would add significant science risk to the mission—it may be impossible to access a suitable field site using 'as applied' MSL capabilities.

| Reference Landing Site	Stressing Parameter	TRN[†] Required	THA[†] Required	Notes
Holden Crater	Latitude (-26° S)	Maybe – land closer to layers	No	Pushes southerly lat limits; TRN might enable "land on"
Jezero Crater	Rock Abundance	No	Yes	>1% failure without THA
Nili Fossae	Elevation (-0.6 km)	Yes	Yes (No if smaller ellipse)	Landing ellipse ranges up to 0 km elevation, 6% area scarps
E Margaritifer	Inescapable Hazards	Yes	Probably Not	>3% of landing ellipse is inescapable, 99% success with 300 m divert
NE Syrtis	Scarps	Yes	Maybe	>4% ellipse scarps, 99% success with 300 m divert
Melas Chasma	Landing Ellipse Size Wind	Yes	Probably	V. Marineris - Wind and Relief Issues? (ellipse size)

SDT FINDING

Six potential landing/field sites are identified as "stressors" on landing capabilities and encompass a sufficiently large population of candidate sites (>60, see table in Appendix 6) as to ensure high priority candidates remain as constraints evolve. These form an envelope which includes accommodation of the prior MER and MSL landing sites and many of the > 60 other sites between 30˚N and 30˚S that have been proposed by the science community for MSL and future missions.

* The threshold engineering requirements defined by these reference sites enable access to prior landing sites in Gale, Gusev, and Meridiani
[†] TRN = Terrain-Relative Navigation; THA = Terminal Hazard Avoidance.

Landing Site

Example Benefits of Using Range Trigger & Terrain-Relative Navigation:
Eliminating the Drive to Mt. Sharp in Gale Crater
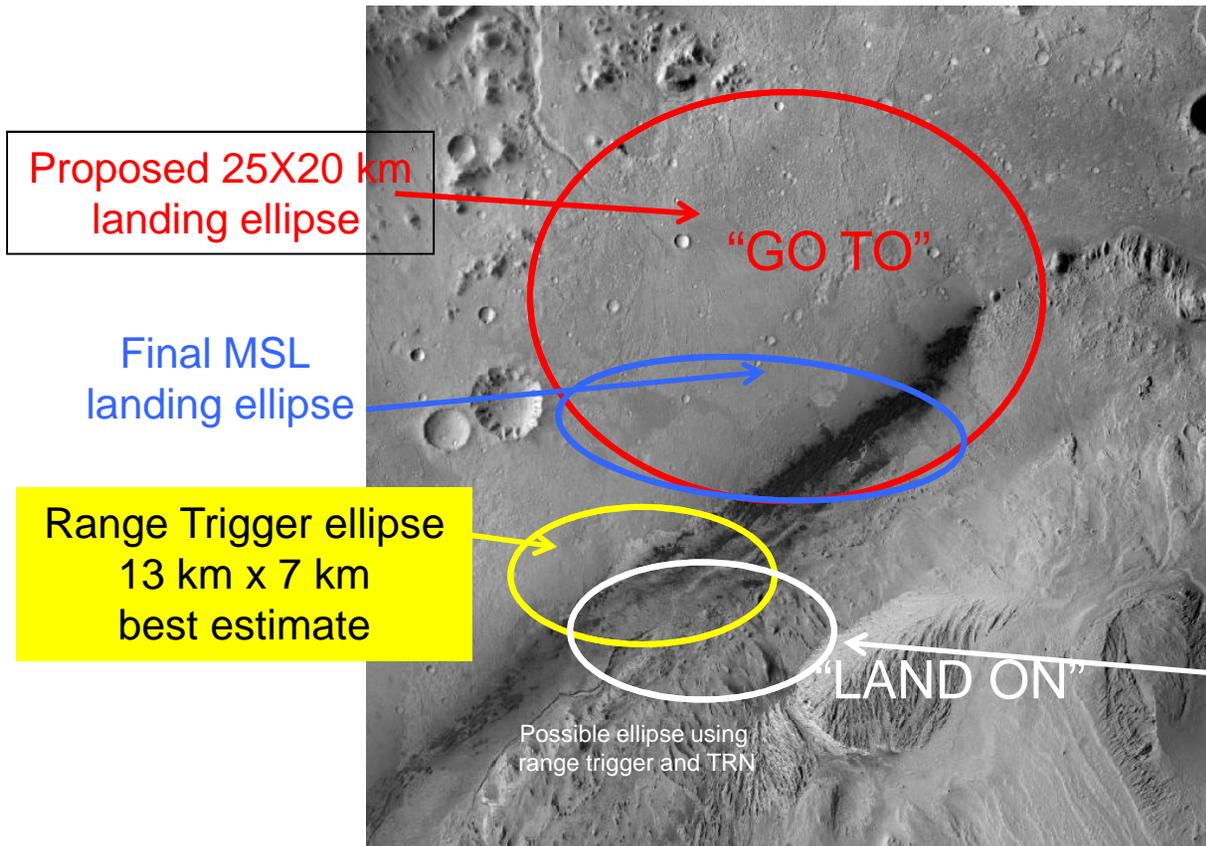
The combination of range trigger and TRN effectively makes Gale crater "land on" the lower slopes of Mt. Sharp.

Proposed 25X20 km landing ellipse

Final MSL landing ellipse

Range Trigger ellipse 13 km x 7 km best estimate

"GO TO"

"LAND ON"

Possible ellipse using range trigger and TRN

Possible Ellipse in Gale crater using range trigger (best estimate) and TRN

From Matt Golombek

SDT MAJOR FINDING #24

The SDT concludes that Range Trigger should be a threshold capability and strongly recommends inclusion of TRN as highest priority baseline to help ensure access to a sufficient number of high priority sites and to reduce science risk related to site selection. Terminal Hazard Avoidance (THA) has less impact on access to unique classes of sites and is considered "enhanced."

EDL Capabilities Needed for 2020 Reference Sites

| Reference Landing Site	Stressing Parameter	MSL As Flown	MSL+ Range Trigger	MSL+ Range Trigger+ TRN	MSL + HA	Notes
Holden Crater	Latitude (-26 ˚S)	🟢	🟢	🟢	🟢	Pushes southerly lat limits, TRN might enable "land on"
Jezero Crater	Rock Abundance	🔴	🔴	🔴	🟢	>1% failure without HA
Nili Fossae	Elevation (-0.6 km)	🟡	🟢	🟢	🟡	Landing ellipse ranges up to 0 km elevation, 6% area scarps
E Margaritifer	Inescapable Hazards	🔴	🟡	🟢	🔴	>3% ellipse inescapable, 99% success with 300 m divert
NE Syrtis	Scarps	🔴	🟡	🟢	🔴	>4% ellipse scarps, 99% success with 300 m divert
Melas Chasma	Landing Ellipse Size, Wind	🔴	Not Assessed	Not Assessed	Not Assessed	Constrains ellipse size in V. Marineris - likely wind and relief issues?

SDT FINDING

The SDT concludes that Range Trigger should be a threshold capability and strongly proposes inclusion of TRN as highest priority baseline so as to help ensure access to a sufficiently high number of of high priority sites and reduce science risk related to site selection. Access to an equivalent number of aqueous sedimentary and hydrothermal landing targets likely requires both Range Trigger and TRN to be implemented. Terminal Hazard Avoidance has less impact on access to unique classes of sites and is considered "enhanced."
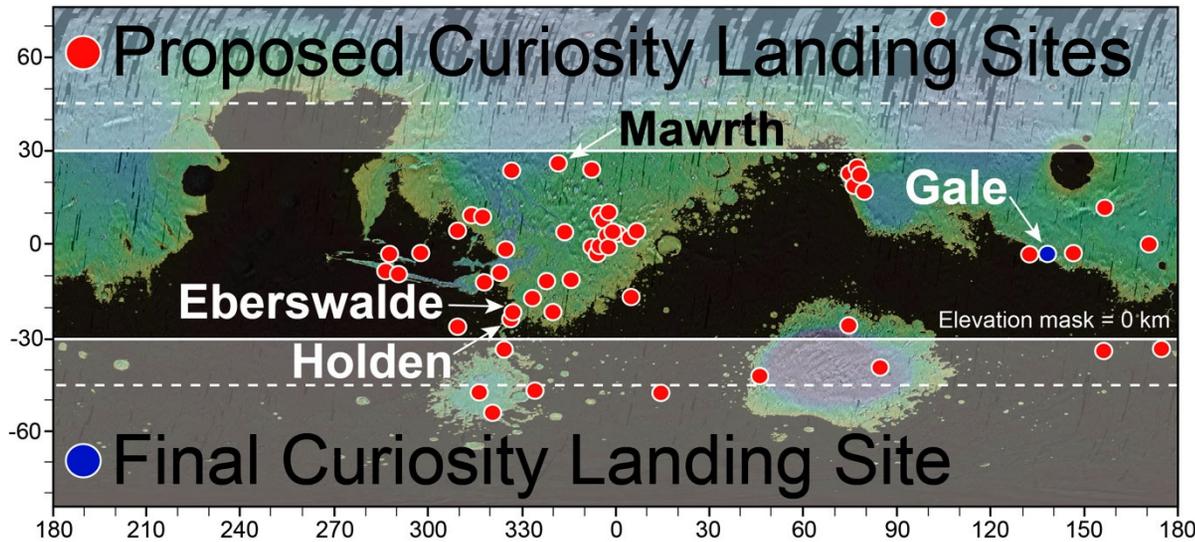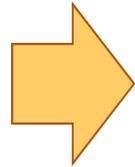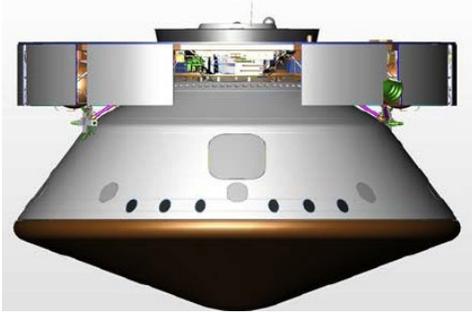
- Site selection for the Mars 2020 mission must satisfy the aspirations of *in situ* science and creating a returnable cache.

- A process to perform careful and full evaluation of diverse new and existing candidate landing sites is warranted.

SDT FINDING

The expertise of the science community can assist in making critical decisions about landing sites early enough in the mission design phase to limit costs for capabilities that are not adopted (e.g., if community consensus finds that sites that need TRN can be eliminated from consideration for a Mars 2020 landing site, then TRN can be descoped before incurrent significant costs).
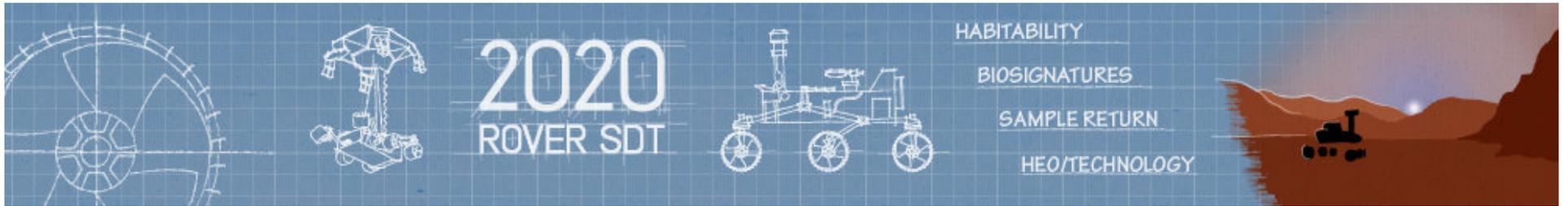
Strawman Spacecraft Accommodation

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

CRUISE/APPROACH

- 8 to 9-month cruise

- Arrive Jan/Mar 2021

- No changes from MSL (equivalent checkout capability, etc.)

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
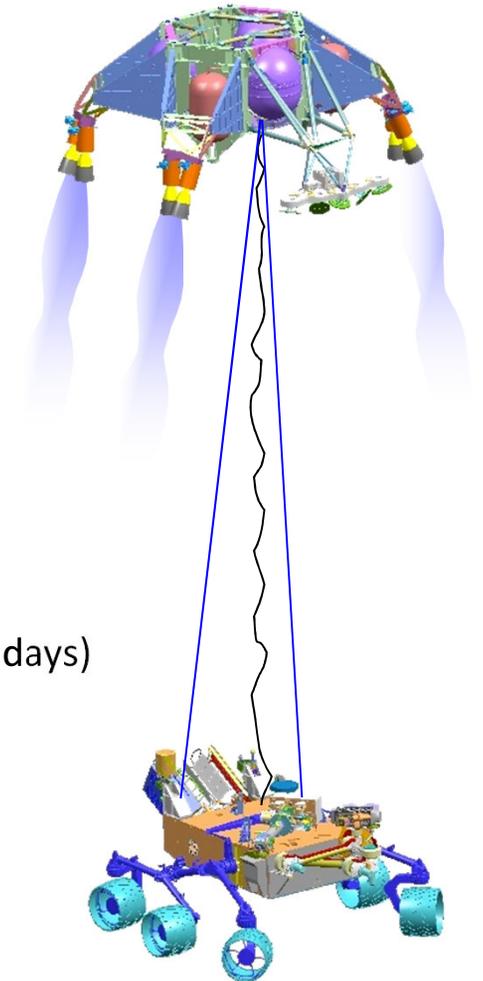
LAUNCH

- Atlas V Class

- Period: Jul/Aug 2020

*EDL in work
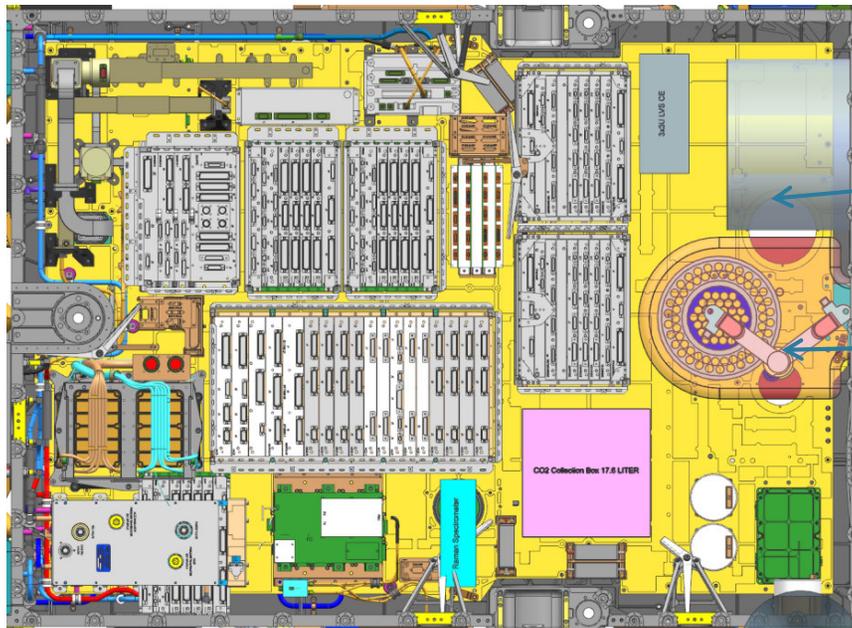
Bit Boxes

Sample Caching System
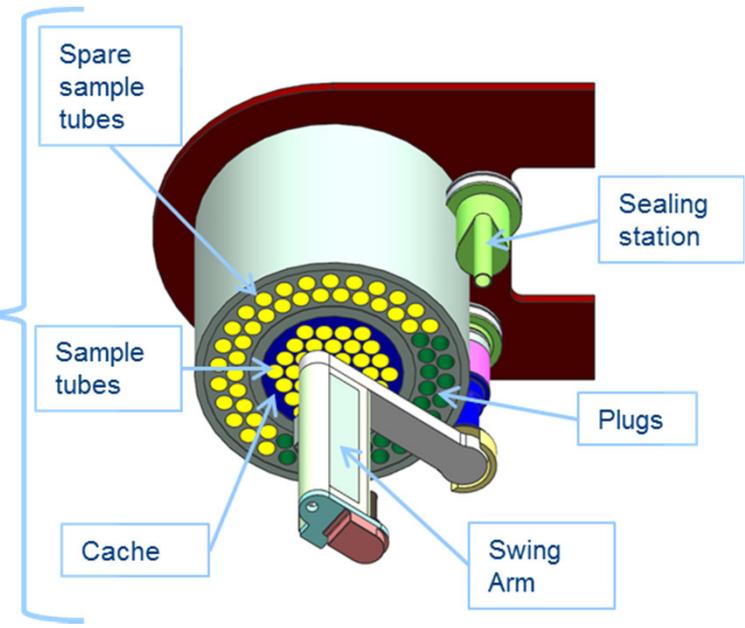
Spare sample tubes

Sealing station

Sample tubes

Plugs

Cache

Swing Arm

Concept shown is one of many possible design solutions

SDT MAJOR FINDING — This mission concept preserves maximum MSL heritage. The payload and a few specific elements are unique to the Mars 2020 rover concept.
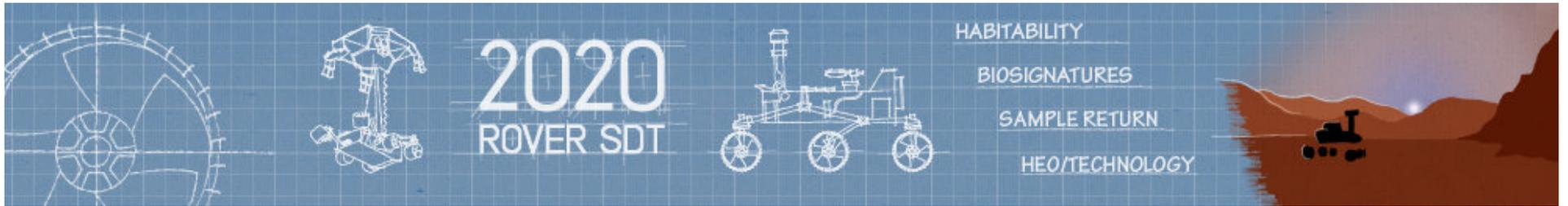
Conclusions

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   ➢ Fine-scale elemental chemistry

➢ Context mineralogy   ➢ Fine-scale mineralogy

➢ Fine-scale imaging   ➢ 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.
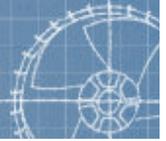
Seeking signs of past life

Prepare for human exploration

Two major *in situ* science objectives

Returnable cache of samples

Coordinated, nested context and fine-scale measurements

Coring system
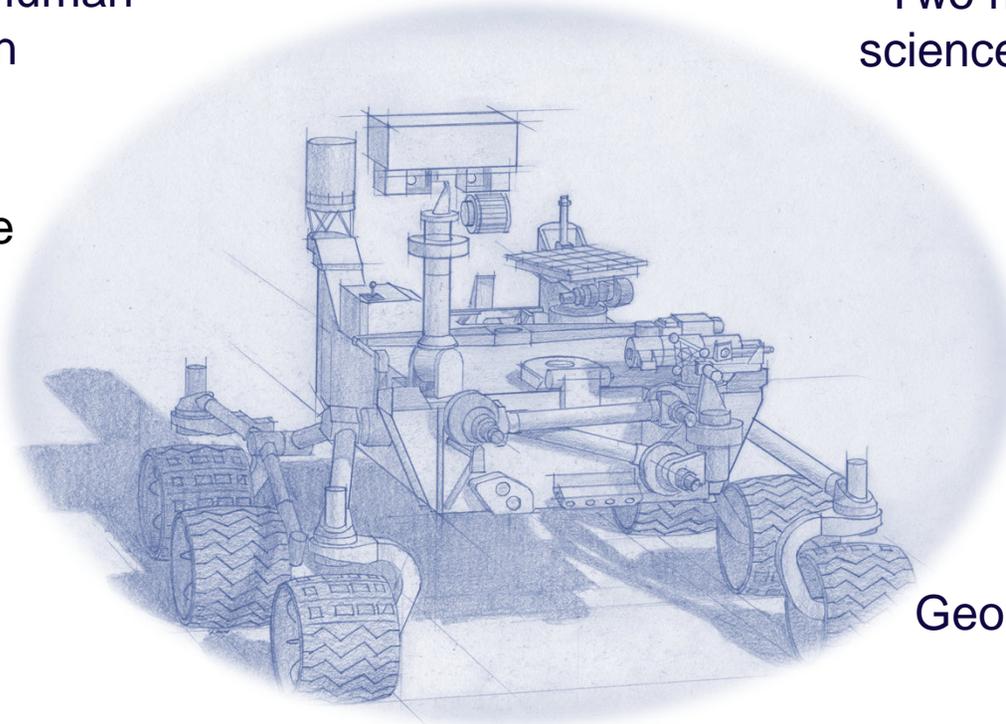
Geologically diverse site of ancient habitability

Efficient surface operations, one Mars-year lifetime

MSL heritage rover

Improved EDL for landing site access

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

Original 25X20 km Gale crater landing ellipse
"GO TO"

Final landing ellipse

Possible ellipse using range trigger

"LAND ON"

Possible ellipse using range trigger and TRN

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

Mars meteorite

vein w. diff. mineralogy

10 µm

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

Payload designed to recognize potential biosignatures in outcrop

seal

core sample

sample tube

31 sample cache

The ability to collect compelling samples for potential future return

Prepare for the future human exploration of Mars

The Exploration of Mars – What's Next?

1995   2000   2005   2010   2015   2020   2025   2030

MPF MGS   ODY   MER MEX   MRO   PHX   MSL   MAVEN   TGO InSight   EXM   M2020   THE FUTURE

Flown
In Development

Follow the Water

Explore Habitability

Seek Signs of Life

Prepare for Human Explorers
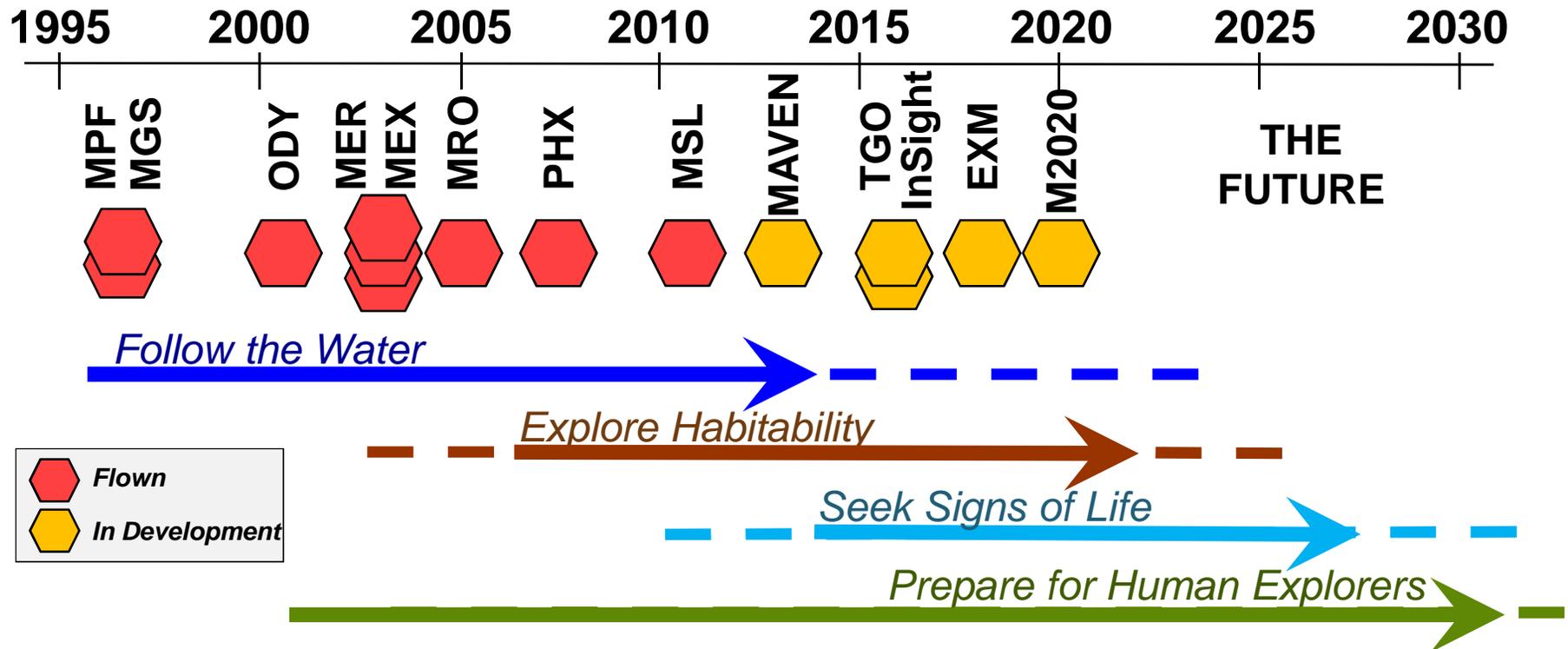
The proposed Mars 2020 mission would be:

- **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 Material

5. Consider downstream investigations before selecting s/c materials containing organics.

→

6. Create a materials archive of s/c materials

→

Characterize potential contamination

7. Analyze types of organics and their degradation products

→

Discriminate Mars-sourced from Earth-sourced organics, interpret martian biological potential/reality.

Spacecraft

1-2. Clean the s/c surfaces that will have direct contact with samples to a best practical level

protect against recontamination.

→

Characterize remaining contamination

3. Characterize contaminants remaining on s/c surfaces

4 and 9. Use witness plates and blanks to sample contamination at different places/times

8. Genomic and lipid bioinventory (terrestrial "passenger list")

→

Analyze returned samples

Minimize analytic contamination.

Analyze types of organics in/on returned samples and blanks.

Determine spatial relationships of organics in/on returned samples and blanks.

Compare to terrestrial bioinventory.

→

2020 Mars Rover Science Definition Team

All topics below are requested by the charter and are included in the July 1 Report.

INPUTS

Preliminary Objectives

A: Habitability
B: Biosignatures
C: Sample Return
D1: HEOMD
D2: STMD

Assumptions & Guidelines

- Launch date
- Mission duration
- EDL/rover type

Constraints

- Resources
- Risk posture

OBJECTIVE-LEVEL OPTIONS & PRIORITIES

- Cost
- Up/downscale options
- Payload priority trades

Objective A
Objective B
Objective C
Objective D1

CANDIDATE PAYLOAD ELEMENTS

- Measurement/ Performance specs
- Resource allocations

Instrument A
Instrument B
Support Equip A

TECHNOLOGY DEVELOPMENT

- Options & Priorities (Obj. D2)

Level 0 Science Traceability Matrix

Payload Options & Priorities (Objectives A, B, C, D1)

INTEGRATED PAYLOAD CONCEPT: INSTRUMENTS

INTEGRATED PAYLOAD CONCEPT: SUPPORT EQUIP.

INTEGRATED PAYLOAD CONCEPT: HEO

- Threshold/baseline Upscale/downscale options
- Cost vs. performance

FLIGHT SYSTEM CONCEPT

- Payload resources and constraints
- Mission parameters
- Required mission capabilities (duration, power/volume/mass budgets)

- **BASELINE & THRESHOLD PAYLOADS**

MISSION CONCEPT

- Refined objectives
- Functional measurements (baseline, threshold)
- Operations concept

LANDING SITE

- Where to send it?
- Range needed

OPS STRATEGY

- How to use it?

Supporting material for competitive Announcement of Opportunity

Name	Professional Affiliation	Interest/Experience
Chair		
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-SSG, MSL(SAM), EXM, P-SAG
Carr, Michael	USGS, ret.	Geology, Hydrology, ND-SAG, E2E, P-SAG, Viking, MER, PPS
Des Marais, Dave	NASA ARC	Astrobio, field instruments, DS, ND-SAG, MER, MSL, MEPAG
Edgett, Ken	MSSS	Geology, geomorph, MRO, MSL, MGS, cameras, E/PO
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 (T.C.)	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 = 3)		
Adler, Mark	JPL	Technology development, MER, MSR,
Drake, Bret	NASA JSC	System engineering, long-lead planning for humans to Mars
Moore, Chris	NASA HQ	technology development, planning for humans to Mars
Ex-officio (n = 7)		
Meyer, Michael	NASA HQ	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	Science Mission Directorate
Mike Wargo	NASA	HEO Mission Directorate
Observer (n = 1)		
Jorge Vago	ESA	Observer
Supporting resources (n = 2)		
Wallace, Matt	JPL	Deputy Project Manager, 2020 Surface Mission, designated engineering liaison
Milkovich, Sarah	JPL	SDT documentarian, logistics
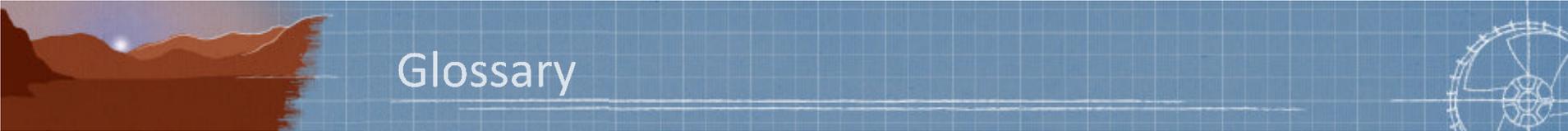
AO Announcement of Opportunity

APXS Alpha-Particle X-ray Spectrometer

CCBU ChemCam Body Unit

CE Compute Element

CheMin Chemistry & Mineralogy X-Ray Diffraction/X-Ray Fluorescence Instrument

CHNOPS carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur

CPU Central Processing Unit

EDL Entry, Descent, and Landing

EPC Electronic Power Conditioner

EXM ExoMars

HA Terminal Hazard Avoidance

HEO or HEOMD Human Exploration and Operations Mission Directorate

IMU Inertial Mass Unit

ISRU In Situ Resource Utilization

LVS Lander Vision System

MAHLI Mars Hand Lens Imager

Mastcam Mast Camera, an MSL instrument

MAVEN Mars Atmosphere and Volatile EvolutioN

MEDLI MSL Entry Descent and Landing Instrument

MEDLI+ next generation of MEDLI

MEPAG Mars Exploration Program Analysis Group

MER Mars Exploration Rovers

MEX Mars Express

MGS Mars Global Surveyor

µXRF Micro X-Ray Fluorescence

MMI Mars Micro Imager

MPF Mars Pathfinder

MRO Mars Reconnaissance Orbiter

MSL Mars Science Laboratory

MSR Mars Sample Return

mTES or mini-TES Miniature Thermal Emission Spectrometer

IR Infrared

OCM Organic Check Material

ODY Mars Odyssey

OM Organic matter

PHX Mars Phoenix Lander

RAD Radiation Assessment Detector

RAT Rock Abrasion Tool

RCE Rover Compute Element

REE Rare Earth Elements

REMS Rover Environmental Monitoring Station

RGB red, green, blue

SAM Sample Analysis at Mars instrument suite

SCS Sample Caching System

SDST Small Deep Space Transponder

SDT Science Definition Team

SKG Strategic Knowledge Gaps

SMD Science Mission Directorate

SSPA Solid State Power Amplifier

STP Space Technology Program

TGO Trace Gas Orbiter

THA Terminal Hazard Avoidance

TRN Terrain-Relative Navigation

TWTA Travelling Wave Tube Amplifier

UCIS Ultra Compact Imaging Spectrometer

UV Ultraviolet

XRF X-Ray Fluorescence

Backup

Mission Objectives:
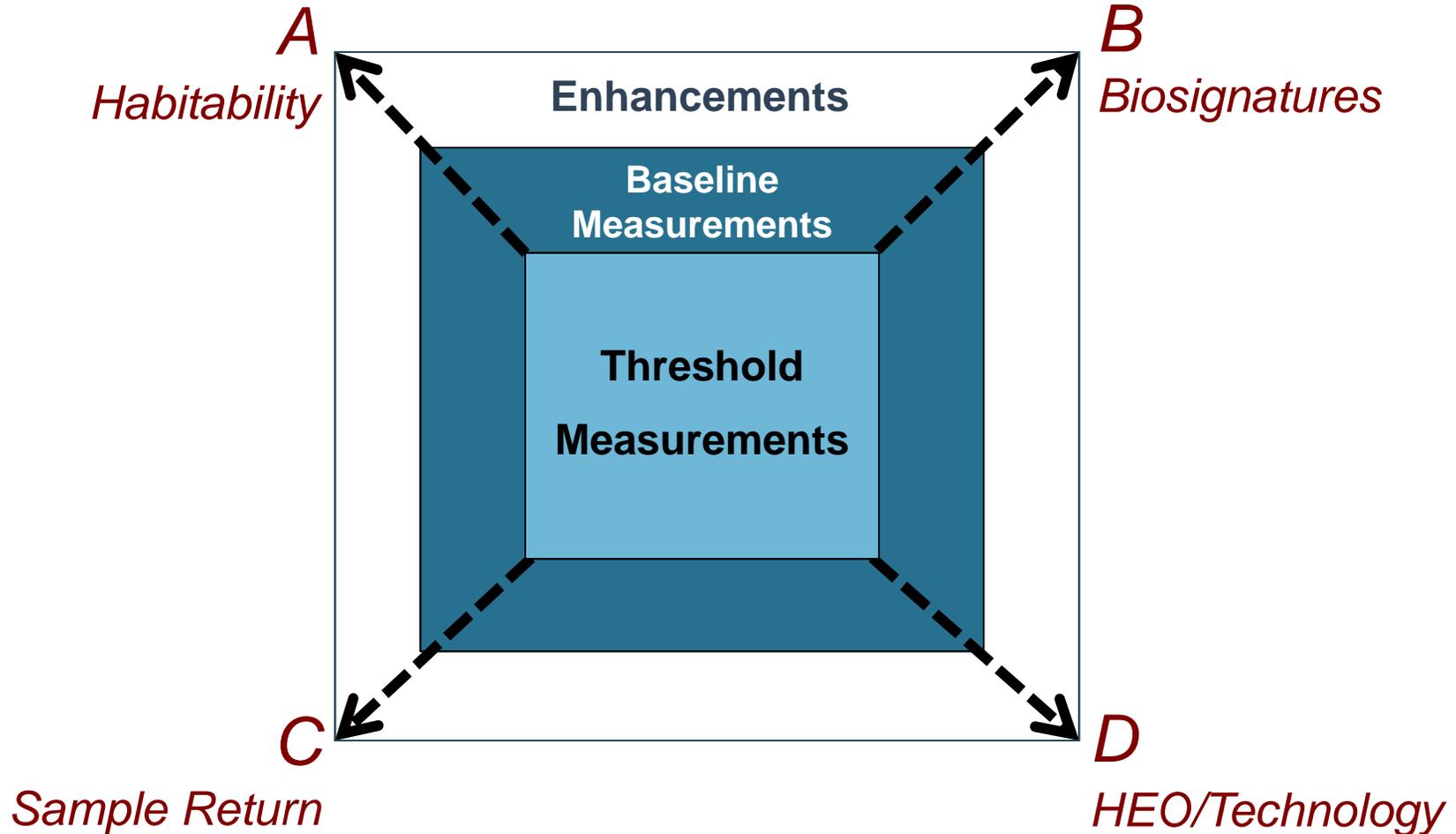SDT Charter Wording vs. SDT Adopted Wording

REORGANIZED OBJECTIVES*	OBJECTIVES FROM SDT CHARTER
A Explore an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability.	Explore an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of past habitability ~~and potential preservation of possible biosignatures~~.
B Assess the biosignature preservation potential within the selected geological environment and search for potential biosignatures.	~~*In situ science*: Search for potential biosignatures within that geological environment and preserved record.~~
C Demonstrate significant technical progress towards the future return of scientifically selected, well-documented samples to Earth.	
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.	

Note: *The phrasing of Objectives A and B above is modified slightly from that given in the SDT charter, and the analysis in this package is organized along the lines of the above objective statements.*

Measurements → Payload Trade Space

A — *Habitability*

B — *Biosignatures*

C — *Sample Return*

D — *HEO/Technology*

Enhancements

Baseline Measurements

Threshold Measurements

All four Objectives require flight system resources (mass, power, volume, operations), and must be balanced against each other in terms of accommodation within the vehicle.