Report to MEPAG by the Mid-Range Rover Science Analysis Group (MRR-SAG)

MEPAG Meeting at Brown University, Providence, RI

July 29, 2009

Note: This document is a draft that is being made available for comment by the Mars exploration community. Comments should be sent by Aug. 7, 2009 via e-mail to Lisa Pratt[1], Dave Beaty[2], or Joy Crisp[2] (prattl@indiana.edu, David.Beaty@jpl.nasa.gov, Joy.A.Crisp@jpl.nasa.gov).

[1]Indiana University, [2]Jet Propulsion Laboratory, California Institute of Technology

Agenda

TOPIC	*WHO*	*time*
Introduction	Beaty	5
Analyze the kinds of high-priority in situ science that could be accomplished with a next-generation rover	Des Marais	15
Determine the most important ways in which this mission could contribute to a potential future sample return	Allen	20
Evaluate the ways in which a next-generation rover could respond to discoveries from MSL	Allwood	10
Presentation of a mission vision encompassing the above considerations	Pratt	20
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PANEL DISCUSSION	ALL	30
		120

Charter-Specified Assumptions

- The mission would include a single rover. Attributes:
  - solar-powered,
  - targeting accuracy of 3 km* semi-major landing ellipse,
  - rover range at least 5 km to allow possible exploration outside of the landing ellipse,
  - lifetime > 1 Earth year,
  - no requirement to visit a Planetary Protection Special Region
- This is to be a dual-purpose mission:
  1. conduct high priority *in situ* science,
  2. prepare for the possible return of samples to Earth.
- The preliminary cost cap for the mission might be ~ $1.3B (to be confirmed).
- Consider for launch in 2018 or 2020

- Adjustments to Charter Assumptions from review June 9, 2009:
  - For 2020 scenarios, a higher cost cap could be possible.
  - *Entry, Descent & Landing assumptions above are too optimistic

Abstract

In this presentation, the MRR-SAG will be presenting the vision of a scientific mission to the martian surface that would:

1. Have an *in situ* scientific exploration capability necessary to respond to discoveries by either MSL or by our orbital mapping missions.
2. Collect, document, and cache samples for potential return to Earth by a future mission.
3. Between its *in situ* functionality and its potential sample return-related functionality, be a key stepping stone to seeking the signs of life on Mars.
4. Have a rover size intermediate between those of MSL and MER.

MRR-SAG Team

(27 Mars experts, including 6 international scientists)

Lisa Pratt	astrobiology
Abby Allwood	field astrobiology
Alfred McEwen	imaging, Mars geology
Ariel Anbar	isotopes, MC-ICP-MS spectroscopy
Barbara Sherwood-Lollar	astrobiology, isotopic signatures, signatures of biogenic hydrocarbons
Carl Allen	Sampling, MSR, sample curation
Daniel Glavin	astrobio, organic chemistry
Dave DesMarais	astrobio
Doug Ming	geochemistry, mineralogy, soils
Frances Westall	astrobio
Francois Poulet	Surface Science, Mineralogy
Gian Gabrielle Ori	sedimentology/stratigraphy, field geology
John Grant	rover field geology, impact craters

John Parnell	field geology, organic geochem.
Ken Herkenhoff	imaging, photometry, geol mapping
Mike Carr	water on Mars
Ralph Milliken	mineralogy, surface geology, sedimentology
Scott McLennan	sedimentology
Sushil Atreya	atmospheric chemistry
Tom McCollom	astrobiology
Vicky Hamilton	TIR spectroscopy, petrology
Vicky Hipkin	atmospheric science
ex officio	
Joy Crisp	Mars Program Office--science
Dave Beaty	Mars Program Office--science
Chris Salvo	Mars Program Office--engineering
Charles Whetsel	Mars Program Office--engineering
Mike Wilson	Mars Program Office--engineering

Additional experts consulted:

Fernando Abilleira, F. Scott Anderson, Paul Backes, Don Banfield, Luther Beegle, Rohit Bhartia, Jordana Blacksberg, Shane Byrne, John Eiler, Sabrina Feldman, Lori Fenton, Kathryn Fishbaugh, Mark Fries, Bob Haberle, Michael Hecht, Arthur (Lonne) Lane, Richard Mattingly, Tim Michaels, Denis Moura, Zacos Mouroulis, Mike Mumma, Scot Rafkin, Carol Raymond, Christophe Sotin, Rob Sullivan, Tim Swindle, Ken Tanaka, Peter Thomas, Ben Weiss, and Rich Zurek.

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Initial MRR-SAG Brainstorming

"What is the most important question about Mars that you could answer with a rover mission?"

- About 30 ideas generated
  - Lots of intellectual diversity
- Ideas were organized into 8 general theme-driven mission concepts
- MRR-SAG self-selected into sub-teams to refine and present mission concepts in the best possible light.
- After refinement, team prioritization of the concepts.
- In addition, two major candidate secondary objectives were recognized.
  - Could go on any of the mission concepts
  - Traceable to MEPAG high-priority surface science

8 Mission Concepts Considered

Early Noachian Astrobiology
Noachian-Hesperian Stratigraphy
Astrobiology - New Terrain

These top 3 (science priority) concepts are described in the following charts

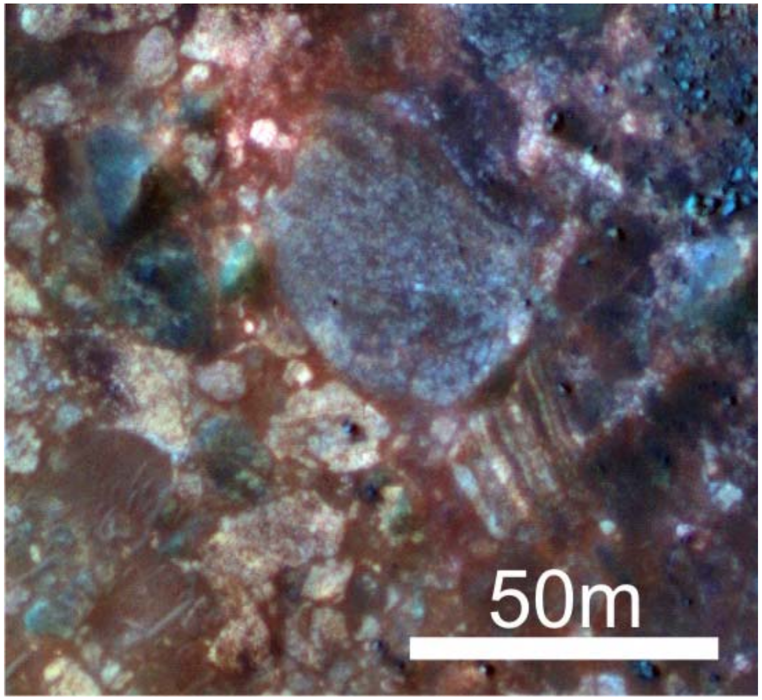
Methane Emission from Subsurface
Radiometric Dating
Deep Drilling *(Discussed in more detail on Slide 12)*
Polar Layered Deposits
Mid-Latitude Shallow Ice

Concept #4

Early Noachian Astrobiology (Priority #1)

Early Noachian (> 4 Ga) terrains may tell us about:

- Whether life arose on Mars and how it lived
- The transition from a prebiotic world to primitive cells
- The early prebiotic environmental context in which life potentially arose
- The fate of life as conditions on Mars changed relative to the history of the magnetic field, atmospheric loss, and the impact cratering rate

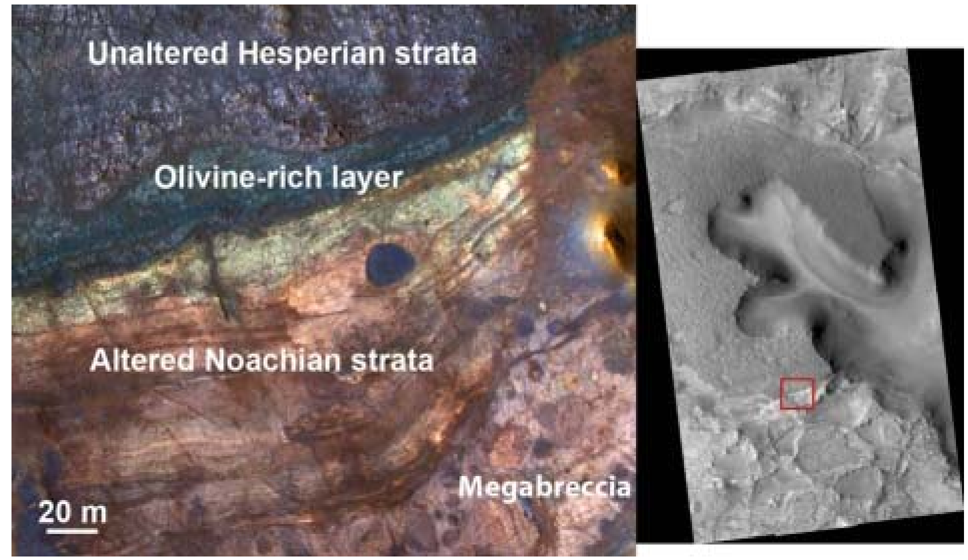


Megabreccia with diverse lithologies in the watershed of Jezero Crater. Portion of HiRISE color image PSP_006923_1995. Credit: NASA/JPL/University of Arizona.

Concept #2

Noachian-Hesperian Stratigraphy (Priority #2)

- What were the surface conditions before and after the transition to a decline in erosion, aqueous weathering, and fluvial activity?
- Were the Noachian and/or Hesperian conditions hospitable for life?
- Did life take hold, and if so how did the change in conditions affect it?



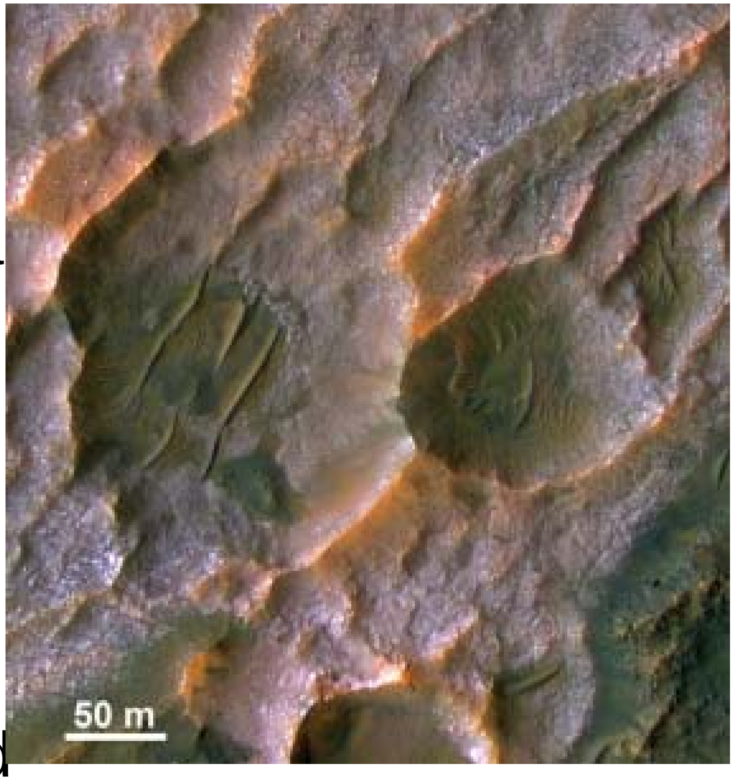
Stratigraphy of phyllosilicate-bearing strata in the Nili Fossae region, showing where CRISM detected phyllosilicates in the Noachian strata and megabreccia. HiRISE image PSP_002176_2025. Credit: NASA/JPL/University of Arizona.

- Was the Noachian aqueous activity episodic or sustained?
- What is the age of the Noachian-Hesperian boundary?

Concept #5

Astrobiology – New Terrain (Priority #3)

- Explore an astrobiology-relevant site distinct from others previously studied
- Test life-related hypotheses related to a specific kind of geologic terrain or geomorphic feature. Many examples have been proposed by the community.
- Is evidence of life preserved in the geologic record or the atmosphere?
- Can samples that could have preserved evidence of prebiotic chemistry or life be recognized and collected?
- Did habitable environments once exist in the subsurface or surface for a sustained period of time?

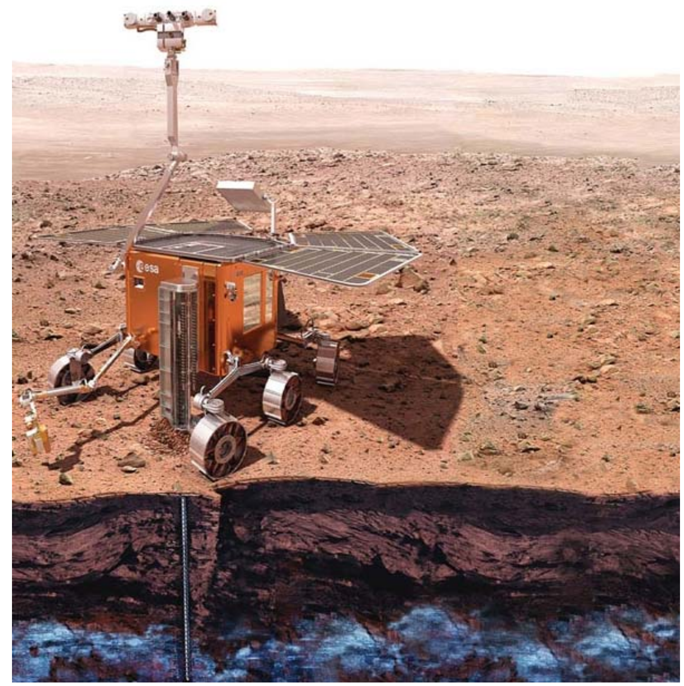


Potential chloride-bearing materials in Terra Sirenum. HiRISE image PSP_003160_1410, 320 m across. Credit: NASA/JPL/University of Arizona.

Complementarity with ExoMars (EXM)

One concept considered related to “deep” (1-2 m) drilling.

- The team assigned this a low relative priority NOT because it has low intrinsic scientific merit, but because it is presumed that this would be accomplished by EXM.
- Until EXM carries out its test, we would not know whether it would be worth doing twice!



Artist's depiction of ExoMars. Credit: ESA/AOES Medialab.

FINDING #1. We have the need to make EXM and the proposed MRR mission complementary, and we have found a way to do so.

MRR *In Situ* Mission Concepts: Science Priorities

		PRIORITY			
Ref. #	**Mission Concept**	**Science value**	**Science Risk**	**Breakthrough Potential**	**OVERALL**
4	Astrobiology Mission to Early Noachian Mars	**2.7**	**2.3**	**2.6**	**2.5**
2	Stratigraphic Sequence near Noachian-Hesperian Boundary	**2.6**	**2.2**	**2.5**	**2.4**
5	Astrobiology: New Terrain	**2.5**	**2.1**	**2.4**	**2.3**
7	Detection of Methane Emission from the Mars Subsurface	**2.3**	**1.2**	**2.5**	**2.1**
3	Radiometric Dating	**2.3**	**1.5**	**2.1**	**1.9**
6	'Deep' Drilling	**1.9**	**1.6**	**1.9**	**1.8**
8	Polar Layered Deposits Traverse	**1.8**	**1.7**	**1.7**	**1.7**
1	Mid-Latitude Shallow Ice	**1.7**	**1.9**	**1.7**	**1.5**

N = 23; For all categories, ratings range is 1-3, with 3 being good.

Top concept priorities, by discipline

Priority	**Geologists**	**Astrobiologists**	**Atm., Geophys.**
1	**4**	**4**	**2**
2	**2**	**2**	**4**
3	**3**	**5**	**5**
4	**5**	**7**	**1**

Secondary Scientific Objectives

FINDING #2. If there is an opportunity to include secondary scientific objectives on a future MRR mission, it would be very valuable to MEPAG.

Candidates -- are there other viable possibilities?

Landed Atmospheric Science

OBJ: Determine the relationships governing surface/atmosphere interaction through exchange of volatiles (including trace gases), sediment transport, and small-scale atmospheric flows.

Discussion

1. Characterize the exchange of momentum, heat, volatiles, and sediment between the surface and atmosphere.
2. Monitoring atmospheric pressure would be particularly high priority.

Mass ~2-6 kg

Paleomagnetics

OBJ: Determine the history of the early Martian magnetic field and its possible connection to climate change, global tectonics, and planetary thermal history.

Discussion

1. Determining when the Martian dynamo was active and disappeared could be possible with rocks of Noachian and /or Hesperian age
2. Test whether Mars had a reversing dynamo and experienced plate tectonics and true polar wander.

Mass ~1-2 kg

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Findings Related to the Potential Return of Samples (1 of 2)

#3. In order for a future surface sample return to deliver value commensurate with its high cost and risk, a precursor caching mission must focus on the life question **AND** have at least one other major scientific objective defined by ND-SAG.

#4. If samples are returned, our ability to address the life question using those samples would be heavily dependent on the properties of the landing site (and our ability to understand its geological relationships) and on the kinds of samples that could be acquired.

#5. In order for a future mission *carrying the Mars Ascent Vehicle (MAV)* to have acceptable risk (both science and engineering), it should be sent to a site previously explored by a rover or lander.

#6. There are many candidate sites of high potential interest for a future sample return beyond those previously visited or to be visited by MSL or EXM.

Discussed in more detail in this package

Findings Related to the Potential Return of Samples (2 of 2)

#7. If the potential future mission that delivers a MAV needs to follow a previous rover or lander, any of these NEW high potential sites (other than those visited and characterized by MSL & EXM or other prior landers) could only be considered if the site is first explored by the proposed MRR mission. Moreover, the *first* opportunity to carry out an open site selection competition with sample return selection criteria, which is very highly recommended, would be via a site competition for the proposed MRR mission.

#8. Given existing results from the two MER sites, future results from MSL and EXM, and an open MSR-relevant landing site competition leading to an MRR mission, it would become possible to select a final site from among these options from which to propose returning samples.

#9. The proposed MRR mission has the potential to establish critical preparation for a future return of samples in at least four areas—thereby significantly reducing the "number of miracles" that would be needed.

FINDING #5. In order for a future mission *carrying the Mars Ascent Vehicle (MAV)* to have acceptable risk (both science and engineering), it should be sent to a site previously explored by a rover or lander.

*Arguments **pro***

- Reduce engineering risk: Knowledge of site-specific EDL requirements, less risky and faster traverse and sampling operations, knowledge of environmental characteristics relevant to Planetary Protection. Potential for pre-collected, verified cache.
- Reduce scientific risk: (From ND-SAG) Knowledge of key site-specific science – would know why we want samples from the site, would know that those samples are present (and collectable), tailor collection hardware and sample preservation procedures to those samples. Having full geological context previously defined would maximize sample diversity.
- Reduce cost: Would allow for very specific operations planning. Would reduce time needed on surface to collect samples because geological context already established. (From ND-SAG) Would allow for smaller instrument suite to characterize samples.
- Improve value: Combining a well-characterized martian site and Earth-based analysis of samples from the same site would be very powerful.

****Note: Because of planetary protection considerations, it might be necessary for a mission that would collect samples for possible Earth return to avoid the exact areas contacted by a prior mission.***

FINDING #5. In order for a future mission *carrying the Mars Ascent Vehicle (MAV)* to have acceptable risk (both science and engineering), it should be sent to a site previously explored by a rover or lander.

*Arguments **con***

- Would reduce the range of geological environments that could be visited, and types of sample suites that could be acquired (and accordingly, the range of scientific objectives that could potentially be achieved by a future sample return).
- Would preclude the return of samples from a compelling new site that might be identified from orbit post-MRR.

*MRR-SAG's **CONCLUSION***

- Arguments for reducing risk and increasing value of the proposed MSR enterprise dominate other arguments and support the return to a previously characterized site.

FINDING #6. There are many candidate sites of high potential interest for a future sample return beyond those previously visited or to be visited by MSL or EXM.

- **Potential Sites for upcoming missions**
  - **MSL**: MSL will explore one of four final candidate landing sites, all of which are of interest for potential sample return. Sample science objectives go beyond habitability (e.g., geochronology); therefore, these sites might not be optimal for a sample return.
  - **EXM.** If approved, would test a specific and very important hypothesis—that the samples we would need are in the shallow subsurface. The specific site is TBD, but would be one that has a relatively large landing ellipse.

- **Recently recognized sites of high potential priority for a future sample return mission**
  - **NRC: Astrobiology Strategy for Mars**: Several additional kinds of sites of high interest to astrobiology for a future return of samples were noted by the NRC (2007).
  - **Community-generated.** Recent Mars-related conferences (LPSC, EPSC, AGU, EGU, AbSciCon, GSA, etc.) the global Mars science community has developed multiple additional site-related astrobiology hypotheses.

FINDING #7. If the potential future mission that delivers the MAV needs to follow a previous rover or lander, any of these NEW high potential sites (other than those visited and characterized by MSL & EXM or other prior landers) could only be considered if the site is first explored by the proposed MRR mission. Moreover, the *first* opportunity to carry out an open site selection competition with sample return selection criteria, which is very highly recommended, would be via a site competition for the proposed MRR mission.

- The best way to evaluate the multiple possible landing sites from which to consider the return of samples would be through an open competitive landing site selection process.
- Developing consensus conclusions regarding potential sample return landing sites would generate a broad base of support, which would be valuable politically.
- A site competition for the proposed MRR mission would be a key step towards finalizing the "short list" of candidate sample return sites.

FINDING #9. The proposed MRR mission has the potential to establish critical preparation for a future return of samples in at least four areas—thereby significantly reducing the "number of miracles" that would be needed.

caching

1. Develop and demonstrate the capability of **sample acquisition and manipulation** (especially coring).
2. **Sample encapsulation and canister loading**, by means of assembly of a sample cache. This would either have direct value (if the cache is returned) or technology heritage value (if not).
3. Develop the procedures needed to do #1 and #2 above consistent with **planetary protection and contamination control** requirements for potential sample return missions.
4. Proposed **Entry-Descent-Landing (EDL)** System
   a) Demonstrate precision landing
   b) Develop and demonstrate use of landed platform under MSL-based skycrane landing system

Initiate & exercise ***international cooperation***
which would be necessary for a full sample return enterprise

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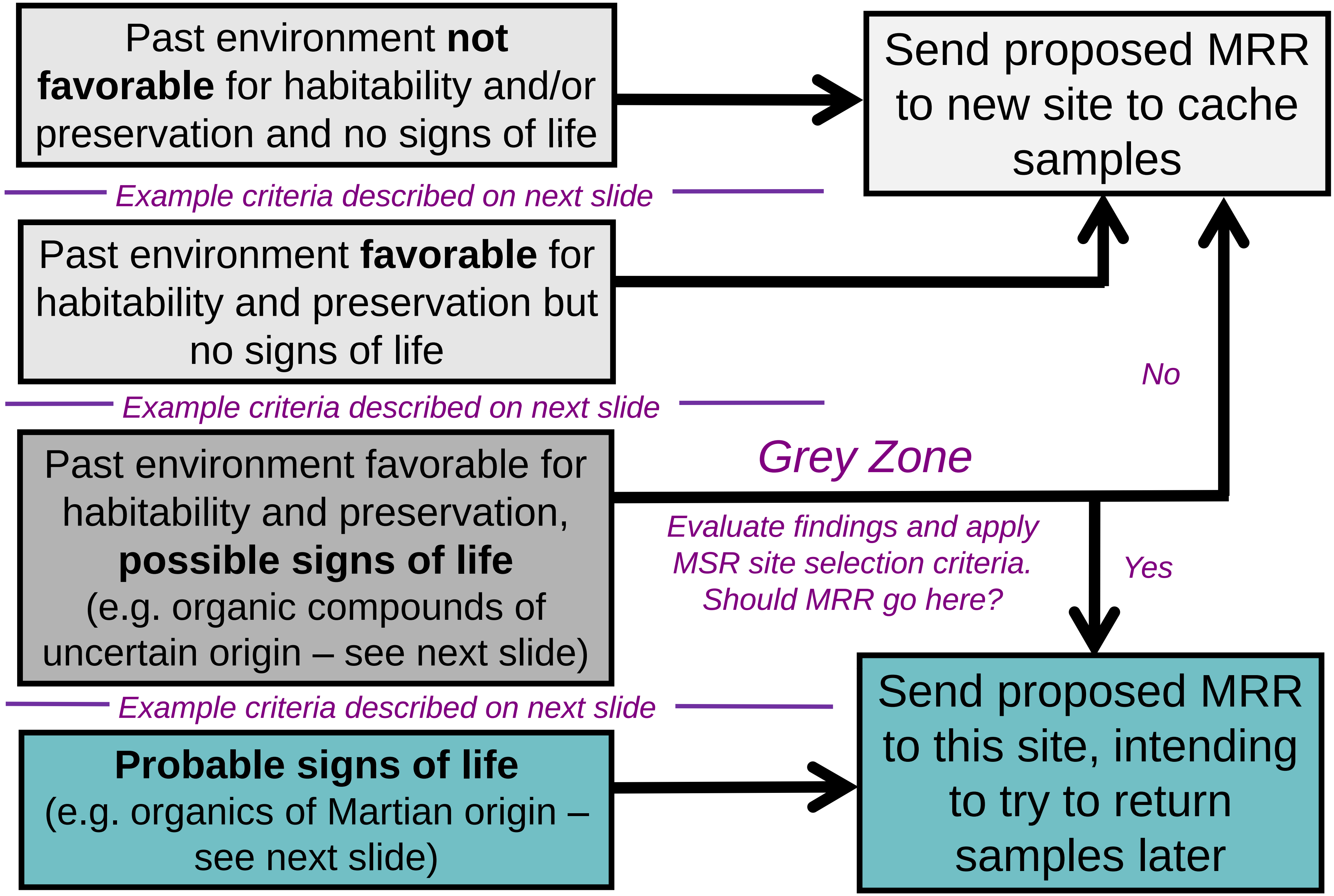
Proposed Discovery Response to MSL



Discovery Response: Threshold Observations

Example observations suggesting site is not favorable for habitability and/or preservation, but lacks evidence of life	(1) No observations of potential evidence of life such as those listed below are made (2) Lack of any phyllosilicates, salts or other mineral deposits that may indicate liquid water (3) No signs of conditions favoring biosignature preservation: no signs of early mineralization (4) Minerals detected indicate oxidizing conditions – No reduced minerals present
Example observations suggesting site is favorable for habitability and/or preservation, but lacks evidence of life	(1) Evidence from orbit suggesting potentially habitable conditions is confirmed *in situ* to have been a favorable environment (2) No observations of potential evidence of life such as those listed below are made (3) Minerals that may indicate liquid water (4) Signs of conditions favoring biosignature preservation: signs of early mineralization (5) Minerals detected indicate reducing conditions
Example observations of possible evidence of life or prebiotic chemistry	(1) Organic materials with molecular composition that could be meteoritic or indigenous with an abiological or biological origin. (2) Isotopically light sulfur or carbon etc. in minerals (3) Textures suggestive of microbial activity e.g. stromatolitic (4) Laminated sediments with crinkled or fenestral texture
Example observations of probable evidence of life or prebiotic chemistry	(1) Organic materials with composition distinct from meteoritic organics (2) "Complex" organic material with overall composition similar to microbial organics on Earth (3) Ancient organic deposits with microbial mat-like characteristics (e.g. cohesive, discrete layers) (4) Isotopic fractionation patterns with petrographic/petrologic observations suggesting primary, possibly biological origin (e.g. organic carbon isotopically light relative to other carbon reservoirs) (5) Clearly distinctive stromatolitic or microbialite-like structures

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N = 23; For all categories, ratings range is 1-3, with 3 being good.

Three convergent concepts with high relevance for a potential future sample return.

Determine specific focus through landing site selection.

Proposed Primary Objective of a Potential MRR Mission

At a site that is likely to have preserved evidence of habitability:

- evaluate paleo-environmental conditions
- characterize the potential for the preservation of biosignatures
- access multiple exposures of layered sedimentary units in search of evidence of ancient life and/or pre-biotic chemistry

Samples containing the essential evidence would be collected, documented, and packaged in a manner suitable for return to Earth by a future mission.

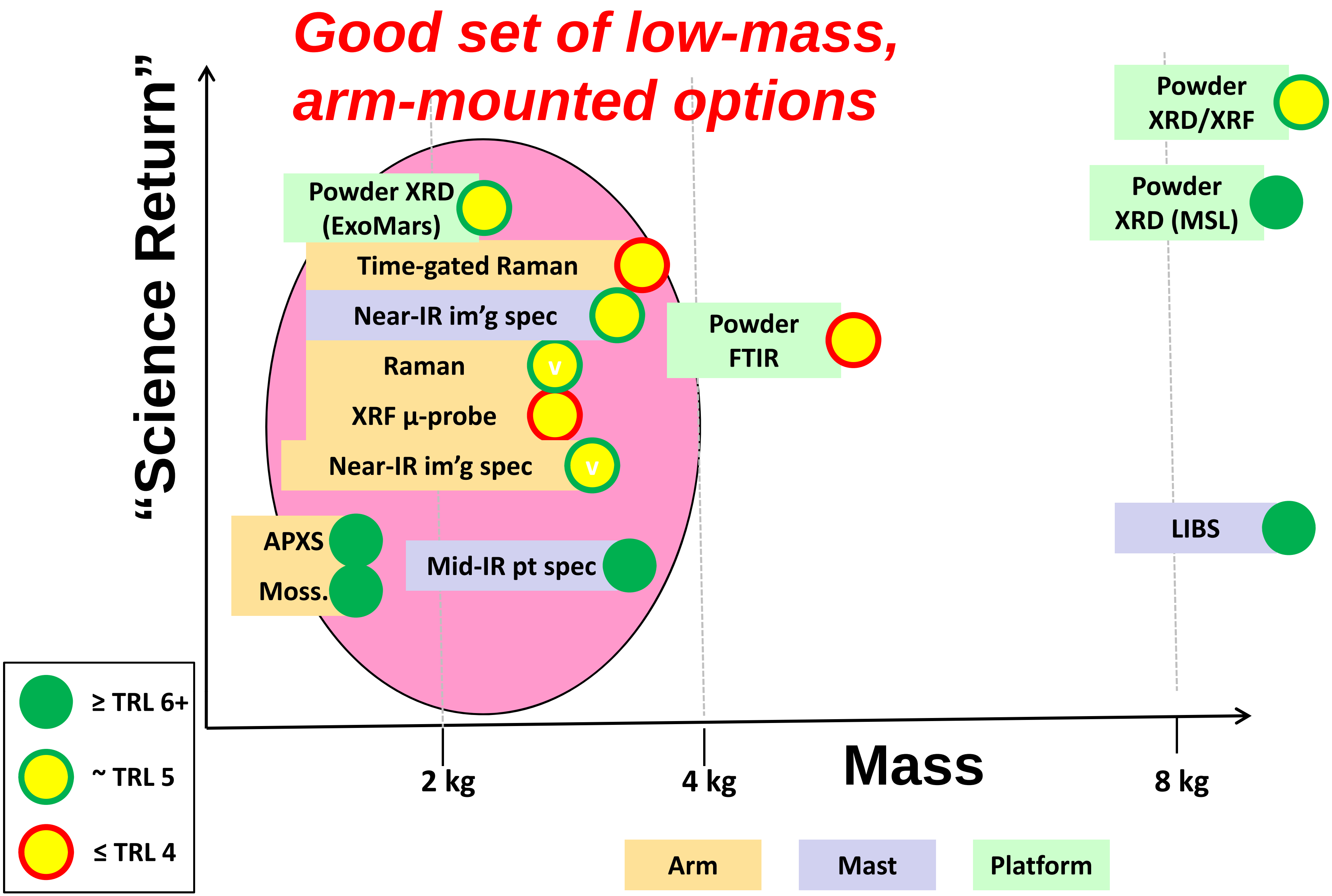
Achieving the Objective

Functionalities needed to achieve the science objectives:

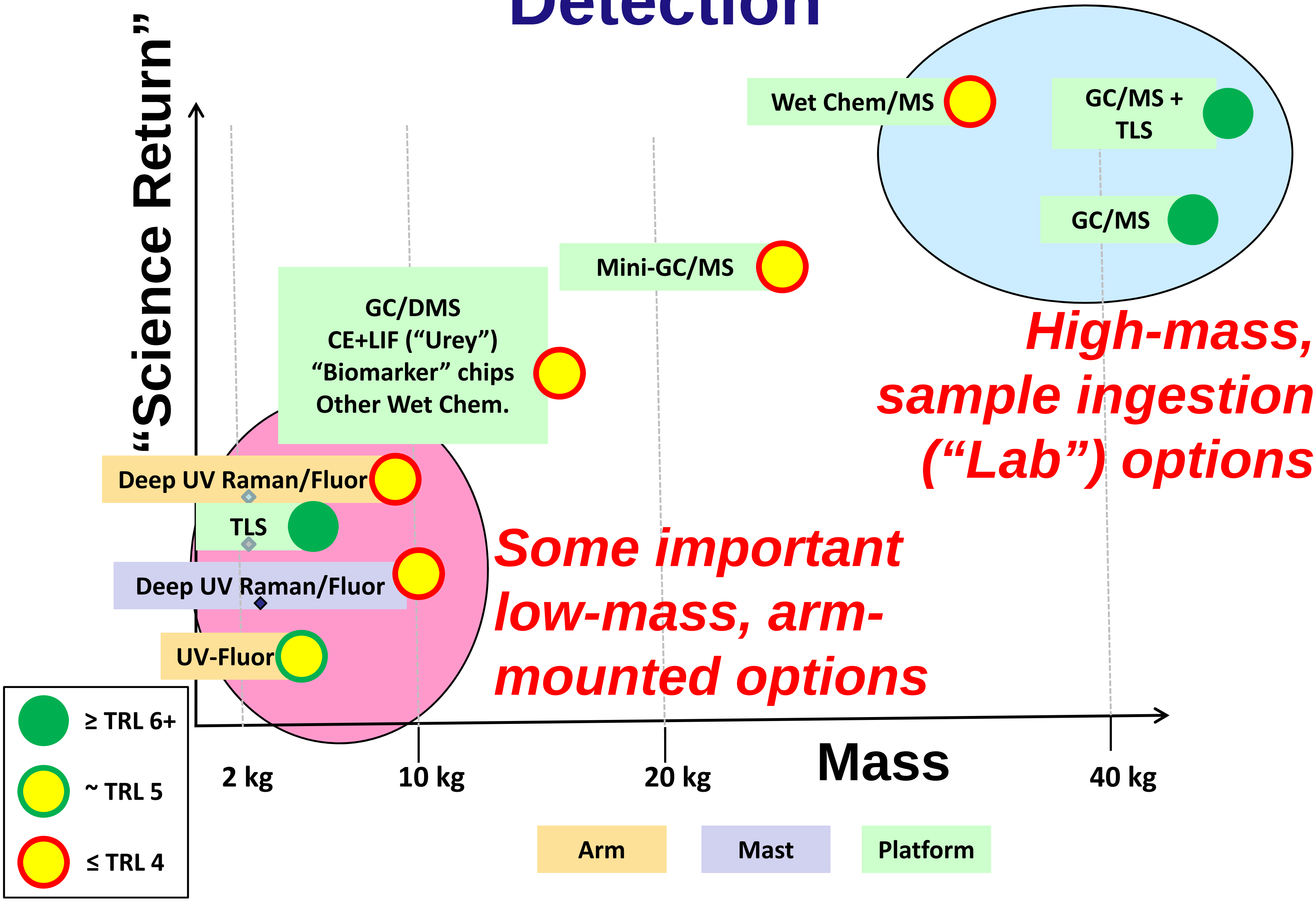
- Access to outcrops
- Target selection capability
- Rock/soil interrogation
  - Chemistry
  - Mineralogy
  - Organics
  - Texture
- Documentation of sample context (micro-, meso-, and macro-scale)

Note: There are multiple ways to characterize mineral phases and organic materials with significantly different implications for payload mass, complexity, and rover operations.

Candidate Instruments for Mineralogy



Candidate Instruments for Organic Detection



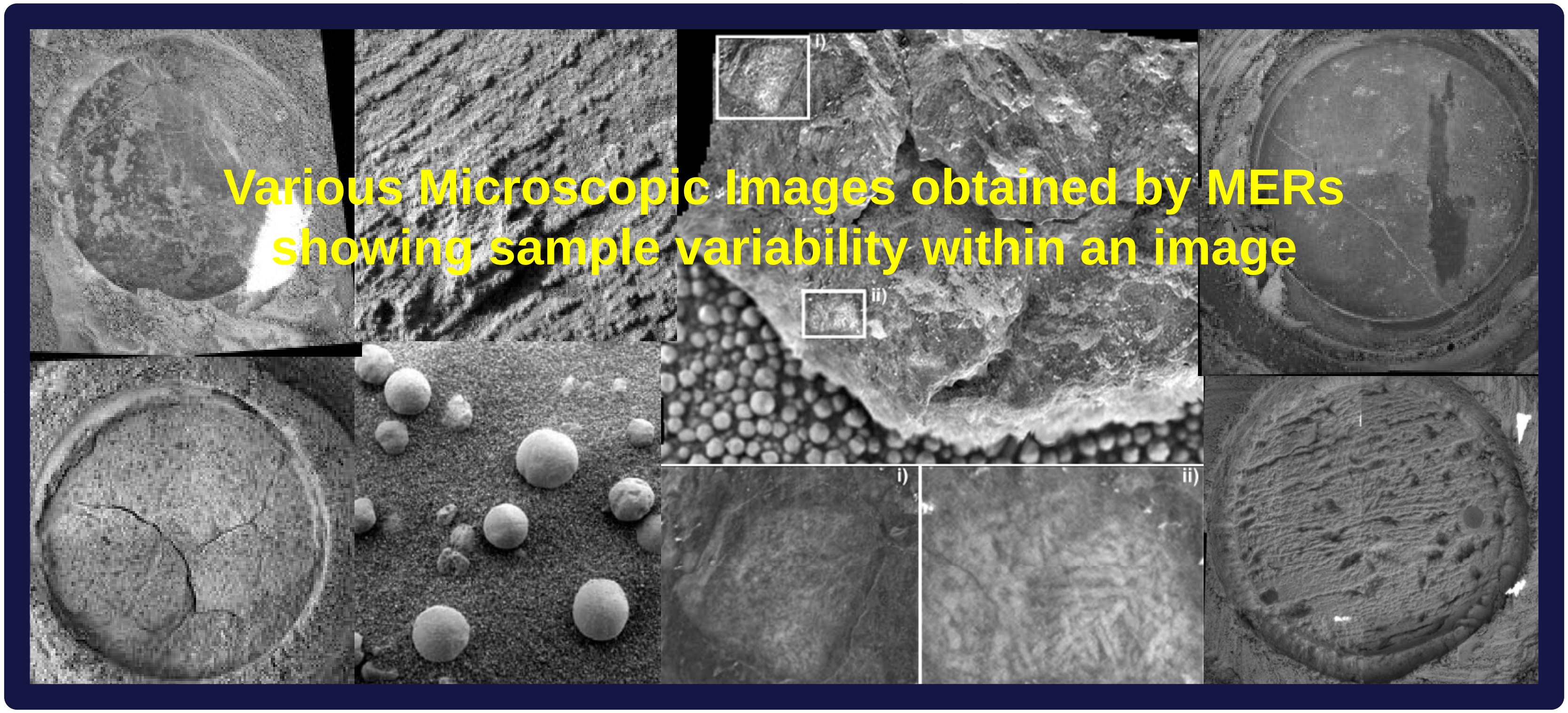
Request for Help

The previous two slides summarize an initial tentative instrument compilation for mineralogy and organic detection measurements.

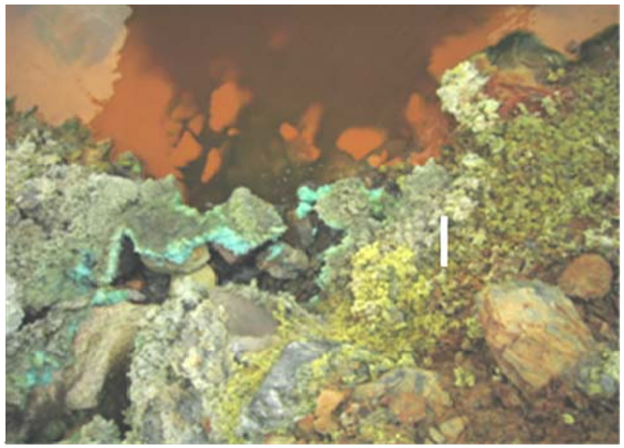
Please help us improve the completeness.

Micro-Mapping: Potential for Application at Mars

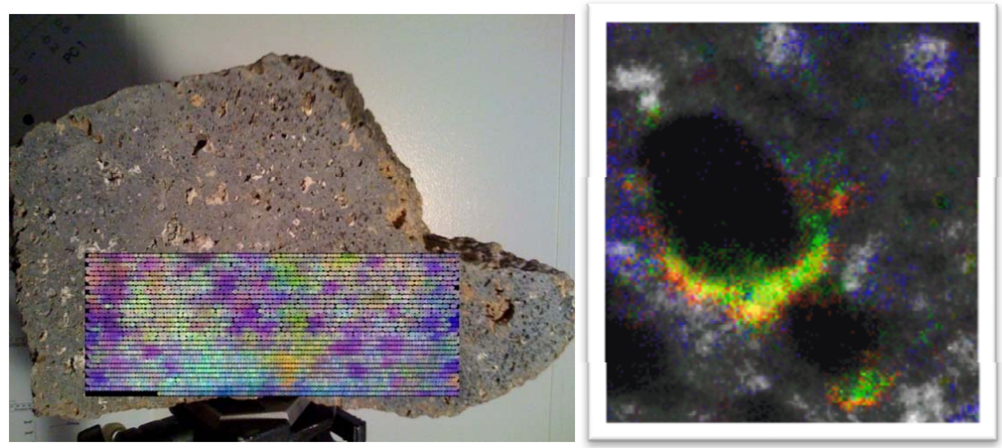
- Images from Mars (MER Microscopic Imager) show presence of fractures, inclusions, layering, blueberries, etc. in Martian rocks
- Mapping could be used to study origins of minerals, depositional / formation sequences, presence and duration of liquid water, presence and nature of organic deposits and biominerals (if present), etc.



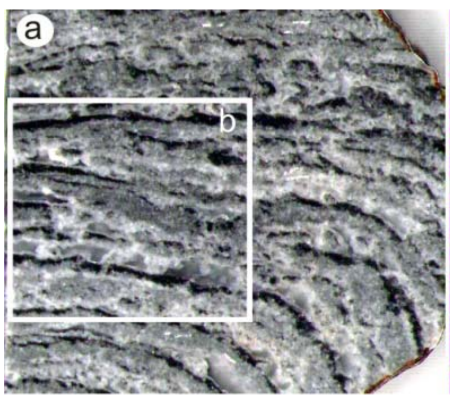
Potential Synergy from 2-D Micro-Mapping



Near-IR mapping – mineralogy



Deep UV Fluorescence and Raman mapping – sub-ppb organics, sub-ppm CHNOPS and H_2O



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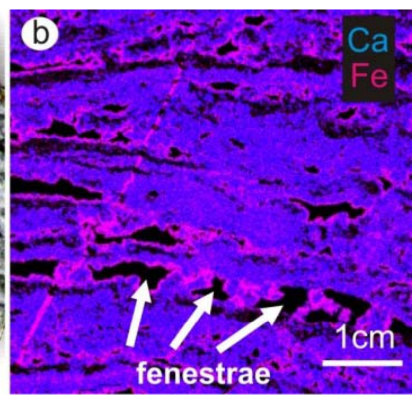
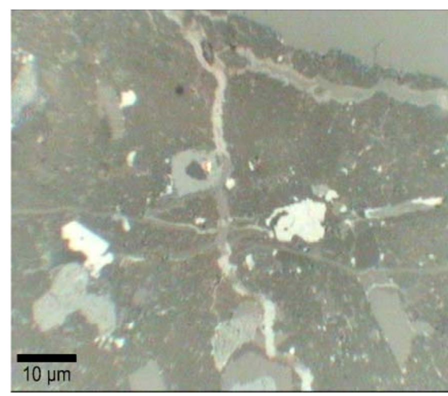


XRF mapping – elemental composition



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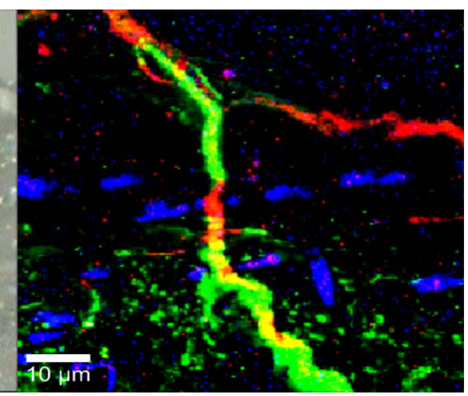


Raman mapping – mineralogy

Mapping instruments could be used to relate mineralogy / chemistry / elemental composition / organics to textures, fabrics, and small scale structures

Implementation: Arm-Mounted Tools

FINDING #10. Using arm-mounted tools to generate multiple, coregistered, micro-scale data sets could offer several key advantages:

- No sample delivery to instruments would reduce mechanical complexity, mass, and cost
- Would greatly improve the scale of focus—critical for recognizing candidate biosignatures on Earth
- Multiple data from same features would enable powerful interpretation capability.

Some implications:

1. Need a smooth, flat, abraded surface
2. Significantly higher data volumes and potentially higher numbers of samples than analytical instruments
3. Context documentation is critical for correct interpretations
4. Capability to map sample surfaces at the micro scale would be valuable in follow-up to any major MSL discoveries
5. Little/no overlap with ExoMars; these missions would be complementary
6. Spatial relationships are lost when materials are powdered for analyses

Implementation: Target Selection, Context

FINDING #11. The proposed MRR mission must have the capability to define geologic setting and remotely measure mineralogy to identify targets from a population of candidates and place them in stratigraphic context for interrogation by the arm-mounted tools.

Implications/Discussion

- MRR traverse capability would affect requirements for remote sensing (resolution, downlink volume)
- All measurements should be prioritized
- Orbital data would be very useful for strategic traverse planning, but not sufficient for tactical planning
- Defining geologic setting and placing observations in stratigraphic context might be greatly aided by subsurface sensing, such as ground-penetrating radar or seismic profiling (latter unlikely to be feasible).

The Dual Purpose: Fitting It All In

1. Conducting compelling *in situ* science, given current science priorities, would likely consume most/all of a modest (e.g. 30-40-kg) payload.
2. The hardware that would be needed to do sample collection, encapsulation, and caching is expected to require similar payload mass.
   – However, doing caching without the instruments needed to do sample characterization and selection makes no sense.

FINDING #12.

- For a rover constrained to a payload of about 30-40-kg, sample caching would be impossible.
- Achieving both caching and strong *in situ* science would require a payload of about twice this size.

Special Priority Note: A mission that could do both these things in 2020 would be far preferable to a mission that does half in 2018.

Payload Concept: Proposed MRR

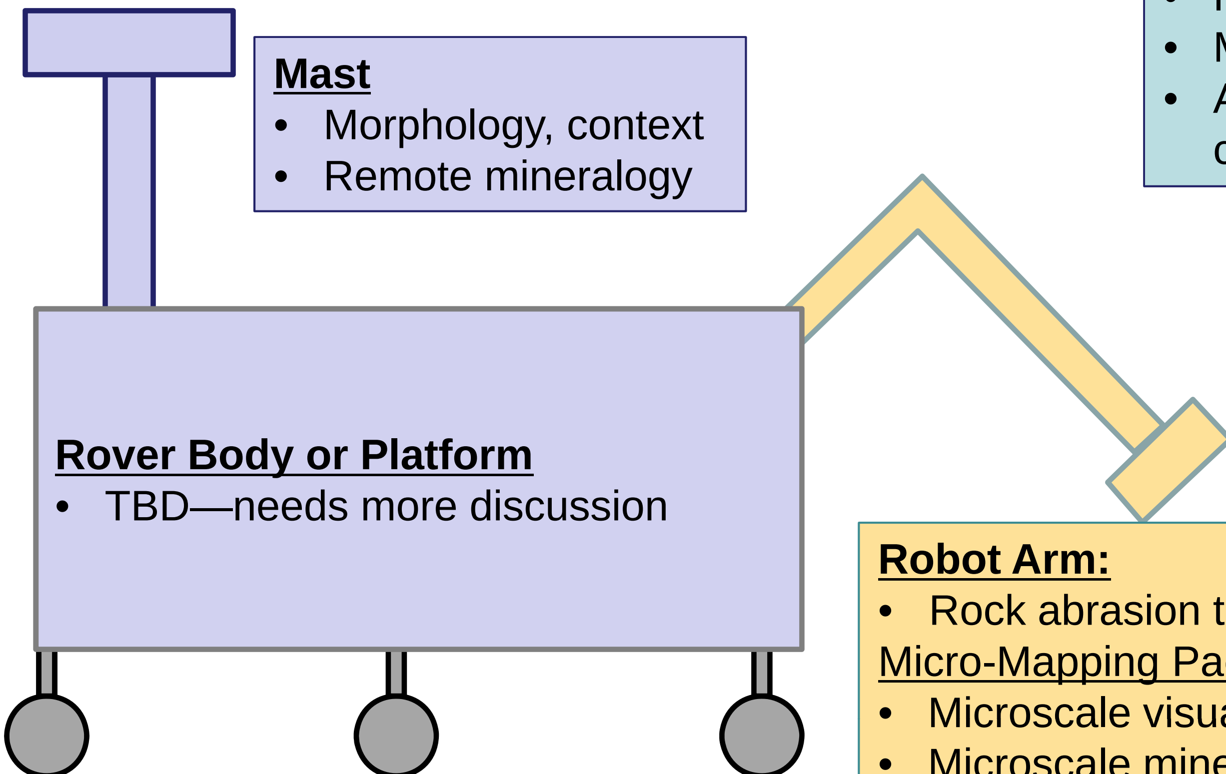
Select targets and establish context

Other candidates:
- Subsurface sounding for stratigraphic imaging
- Remote geochemistry

Mast
- Morphology, context
- Remote mineralogy

Payload measurements related to Candidate Secondary Objectives

TBD, but could be:
- Remanent magnetism
- Meteorology
- Atmospheric composition/isotopes



Rock and Soil Interrogation

Robot Arm:
- Rock abrasion tool

Micro-Mapping Package
- Microscale visual imaging
- Microscale mineralogy imaging
- Microscale organic imaging
- Microscale elemental chemistry imaging

Bulk Rock (if not achievable by above)
- Bulk elemental chemistry

Sample Caching

Sample collection, encapsulation, and caching System (Location TBD)

Need to Access Outcrop

FINDING #13. Outcrop access would be fundamental to the MRR mission concept, and areas of extensive outcrop are typically associated with significant topography.

Two different outcrop access strategies would be possible, depending on EDL capability.

A. "Go-to" Capability

- **Significant topography would not be allowed within the landing ellipse.**
- **Rover traverse capability must exceed the size of the landing ellipse.**

B. "Hazard Avoidance" Landing Capability

- **Significant topographic features (with outcrops) would be allowed in the landing ellipse.**
- **Rover science would be done internal to the landing ellipse.**

Implications:

- Scenario B could have significant advantages by both minimizing the mobility requirements for the proposed MRR mission and by reducing the risk of a future MSR surface rendezvous. If Scenario B is not possible, Scenario A would be the default.

Return to MSL Site vs. New Site

FINDING #14. The proposed rover mission needed to explore a previously unvisited site would be the same as that needed to return to the MSL site in response to a compelling discovery.

Required vs. Desired Instrumentation.

- The ND-SAG team pointed out that a sampling rover that revisits a previously explored route at a well-characterized site could carry reduced instrumentation.
- However, such a mission would have limited ability to select or document samples—this is a potentially crucial science vulnerability. MRR-SAG finds the consequences too severe to accept this risk.
- Moreover, the proposed MRR mission would collect information different from that of MSL, enhancing both sample selection and context definition—thus increasing the value of the samples.

Updated!

	ND-SAG		MRR-SAG	
Measurement	New site	Prev. site	New site	Prev. site
Color stereo imagery	YES	YES	YES	YES
Microscopic imagery	YES	YES	YES	YES
Mineralogy	YES	NO	YES	YES
Bulk Elemental abundance	YES	NO	YES	YES
Organic carbon detection	YES	NO	YES	YES
Abrasion tool	YES	NO	YES	YES

Agenda

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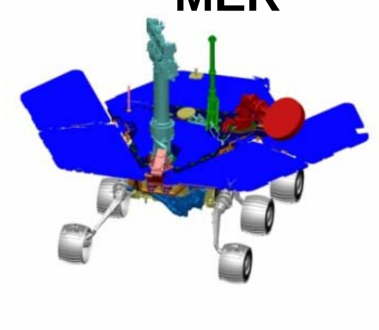
		120

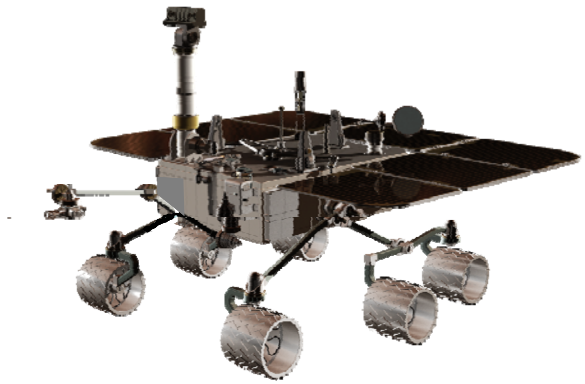
Possible MRR Mission: Summary

There is excellent potential that a rover mission with compelling *in situ* science objectives, that could respond to the discoveries of MSL and EXM, provide critical feed-forward to MSR, and fit program resource constraints, could be realized.

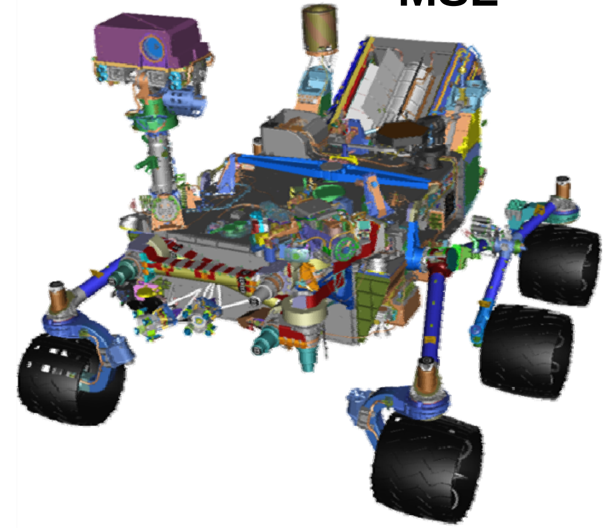
MER



MRR



MSL



Payload+Science Support Equipment Mass		
5+16 kg	~15+50 kg	82+155 kg

Status of Implementation Studies

- Engineering team has begun conceptual studies to scope this mission concept.
- The system architecture and hardware from Mars Science Laboratory (MSL) form the basis for the studies:
  - Cruise and EDL portions of MRR could be a direct clone of MSL (sky-crane landing system).
  - Rover design likely to be based largely on MSL components, but would entail a new system design tailored down to the specific payload.
  - In the process of assessing strawman instrument suites and supporting hardware that could address the proposed science objectives.

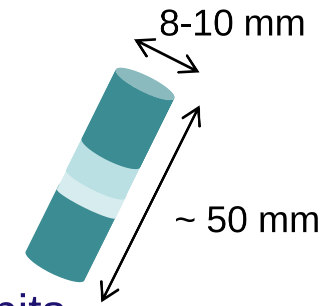
Global/Macro Scale Site Access

- This refers to the ability to apply the payload to the desired location on Mars.
- Power/Thermal design for solar powered vehicle would limit mission to between 25N and 15S latitude.
- EDL performance would limit access to sites below ~0 km or ~1 km altitude (trades against landed mass).
- Combination of EDL ellipse size and roving capability (range and traverse rate) would dictate ability to go to a specific location outside landing ellipse.
  - Ellipse size of ~7 km radius.
  - Traverse distance of 10 km design capability.
    - Would allow 3 km traverse outside the ellipse.
    - Adequate to reach diversity of regions to sample and to leave cache at edge of ellipse for MSR access.
  - Traverse rate with full safety/navigation of ~200 m/sol.
  - Trading improved EDL capability to allow harsher terrain elements (often the science target) to be inside the landing ellipse (would reduce traverse requirements).

Local Scale Site / Feature Access

- This refers to the ability to apply the payload to particular features (outcrops, layers, etc.)
- Dependent upon rover capabilities to traverse slopes, sandy terrain, and rock fields (ground pressure, static stability, wheel size, and belly clearance).
  - Ground pressure as good as or better than MER/MSL rovers. Would allow traverse up loose/sandy slopes of 10-12 degrees.
  - Static stability of ~45 degrees. Would allow traverse on well consolidated or rock-plated terrain up to ~30 degrees.
  - Wheel diameter and belly clearance would be greater than MER but less than MSL.
- Also dependent upon arm preload required for tool usage. Minimal preload approaches planned should allow tool usage on maximum traversable slopes.

Coring

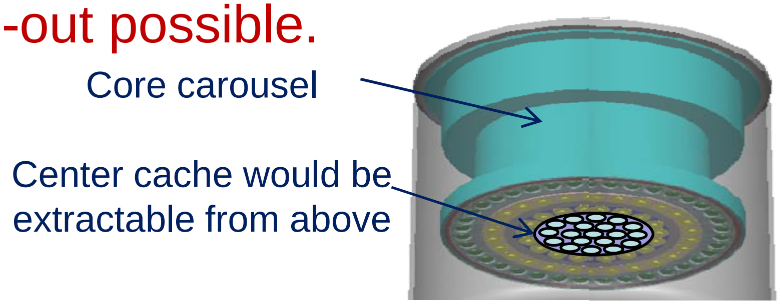


- Rotary percussive coring drill mechanism.
  - Cores would be 8-10 mm diameter and 50 mm long.
  - Bit change-out would allow for broken, stuck, worn-out bits.
  - Cores would be acquired directly into sleeves for caching with minimal additional handling (good for PP/CC*).
  - Extract core in 2-3 hrs, depending upon the type of rock; Sampling temperature rise should be minimal.
  - Core sides would be somewhat rough from percussive fracture dynamics (not a polished cutting action).
- Release of core onto observation tray likely a minimal increase to coring drill requirements.
  - Push-rod augmentation to coring drill to push cores out of sleeves
  - Body-mounted tray with mechanism for dumping old cores/debris.
  - Once cores are released they cannot be placed back in sleeves for caching.

*PP/CC = Planetary Protection/Contamination Control

Core Handling and Caching

- Cylindrical cache assembly would hold 19 cores in close-packed hexagonal configuration of about 70 mm diameter.
  - Cores would be encapsulated in sleeves with pressed-in caps.
- Handling system could handle/store some additional cores that are not part of the packed cache. Swap-out possible.



- Coring bit change-out would be integrated in the same assembly.
  - The coring bit (with sleeved core inside) would be released into the handling system as part of the transfer mechanism for each core.
  - Bit change-out essentially would occur during transfer of every cached core, making it advantageous to combine the more general spare bit change-out function in the same system.
- Entire core handling and caching assembly would be enclosed and sealed with the only entry point being a small port where bit (with sleeved core inside) would be inserted for transfer (good for PP/CC).
  - Bit port would be covered and oriented down so nothing could fall into it.

Surface Abrading

- Surface abrasion could be accomplished through use of a special abrading bit on the coring drill, or by addition of a specific abrasion tool (e.g. MER RAT derivative).
- Abrading bits on coring drill likely more cost and resource effective.
  - Would augment coring bit change-out capability to add abrading bits, or add separate bit change-out station to minimize cross-contamination.
  - Would use arm translation to “scan” or “mosaic” relatively small (~1 cm diameter) individual abrasion points.

Rock Powder and Cuttings

- Both a coring drill and an abrading tool would produce cuttings.
  - Might be potential sources of material for science evaluation, especially remotely sensed as opposed to ingested.
  - Significant challenge associated with gathering and further handling/processing cuttings for ingestion.
- Possible to produce powder with powdering drill bit on coring drill.
  - Would augment coring bit change-out capability to add powdering bits, and potentially modify drill to perform both functions.
  - Additional hardware for handling/processing would be required before ingestion into analytical instruments.
- Powder or cuttings processing/handling would be a difficult task (based on prior experience).
  - MSL design is complex (drives mass/cost/risk), and still needs to be verified.
  - Minimum risk is to avoid handling cuttings/powder.

Payload Mass Estimates

- Two straw-man payload sets have been studied.
  Both include *in situ* astrobiology payloads and coring/caching.
  - Option A: Would have sample-ingesting analytical lab capabilities, as well as a substantial secondary payload suite.
    - Instrument mass = 42 kg
    - Additional 78 kg of supporting payload (33 kg arm; 17 kg mast; and 28 kg of coring/ abrading/ powdering, caching, bit change-out, and powder/cuttings handling hardware).
    - Total Payload = 120 kg
  - Option B: Emphasizes arm mounted mineral and organic microscale mappers, and minimizes secondary suite.
    - Instrument mass = 15 kg
    - Additional 50 kg of supporting payload (25 kg arm; 9 kg mast; and 16 kg of coring/ abrading, caching, bit change-out hardware).
    - Total Payload = 65 kg

Targeting payloads in this mass range and lower in continuing studies

Need for Instrument Development

FINDING #15. There are a number of potentially interesting instruments with Technology Readiness Level (TRL) on order of 3-4, and ongoing development of these instruments lies at the heart of MRR-SAG's mission concept. For these instruments to be mature enough to be selectable for flight (i.e., TRL of 5-6), a commitment must be made now and sustained for the next several years to mature the most promising candidate instruments.

Implications:

- We recommend a MIDDP competition in FY10 that includes specific MRR mission concept needs.
- Strawman payload, needed immediately for engineering trade studies, would necessarily be immature.
- Results of engineering trade studies should be fed back into instrument development.

Development Risk and Cost

- Cruise and EDL inheritance would minimize cost/risk:
  - Clone of MSL cruise stage, entry body, and sky-crane landing system.
  - Huge inheritance expected from MSL in both flight design and test hardware.

- Rover system would be medium risk and medium cost:
  - New intermediate scale of rover would be a new mechanical and thermal development, based on MSL and MER.
  - High engineering component heritage from MSL.
  - Some key new instruments (discussed on previous slide).
  - Technical challenges: Coring/caching system, fast rover navigation algorithms/hardware, hybrid distributed motor control.

- Planetary Protection and Contamination Control would drive an increment of cost and risk (medium).
  - Technical challenges: Bio-cleaning, cataloguing, and transport modeling.

- Total project cost estimated in the >$1B class.

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MRR-SAG Conclusions

Highest priorities for a potential rover mission in 2018-2020:

1. Respond to life-related discoveries/hypotheses by MSL, prior landed missions, orbiters, and telescopes.
2. Commence the transition from the major programmatic strategy of “Explore Habitability” to “Seek Signs of Life.”
3. For a future sample return enterprise, reduce the risk as well as enhance the quality and value of the enabling engineering and the science

The proposed MRR mission could extend our surface and shallow-subsurface exploration of Mars, substantively advance the development of a sample return enterprise, and potentially even become the first component of that enterprise.

Candidate Mission Name

<u>MRR-SAG short list:</u>

1. **ALFIE** Ancient Life Field Explorer
2. **AFE** Astrobiology Field Explorer
   - Variants include: MAFE, AFX, ALE, ALEX
3. **MAX** Mars Astrobiology Explorer
   - Variants include: MAXI, MAESTRO
4. **ASC** Astrobiology Sample Collector
   - Variants include: MSC (best connectivity to a potential future sample return)

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BACKUP SLIDES

MRR-SAG Charter Tasks

1. Evaluate the possible and probable discoveries from MSL and ExoMars that would feed forward to this mission.
2. Based on Task #1, the most recent version of the MEPAG Goals Document, and recent reports from the NRC, analyze the kinds of high-priority science that could be accomplished with this mission concept. Propose draft statements of scientific objective. Evaluate the kinds of instruments, kinds of landing sites, and the nature of the surface operations needed to achieve candidate scientific objectives.
3. Determine the most important ways (scientific and/or technical) in which this mission could contribute to a future MSR.
4. Analyze the trade-offs associated with simultaneously optimizing Task #2 and Task #3.
5. Analyze the incremental value, to science or potential MSR feed-forward, or both, that could be achieved with a modest increase in budget over the baseline assumptions specified above.

MSR Options: Variations on a Theme

The relationship of possible MSR concepts to astrobiology*

	Ground-Breaking MSR Concept	**Astrobiology-Relevant MSR Concept**	**Signs of Life MSR Concept**
SCIM-MSR	**GB-MSR**	**AR-MSR**	**SL-MSR**

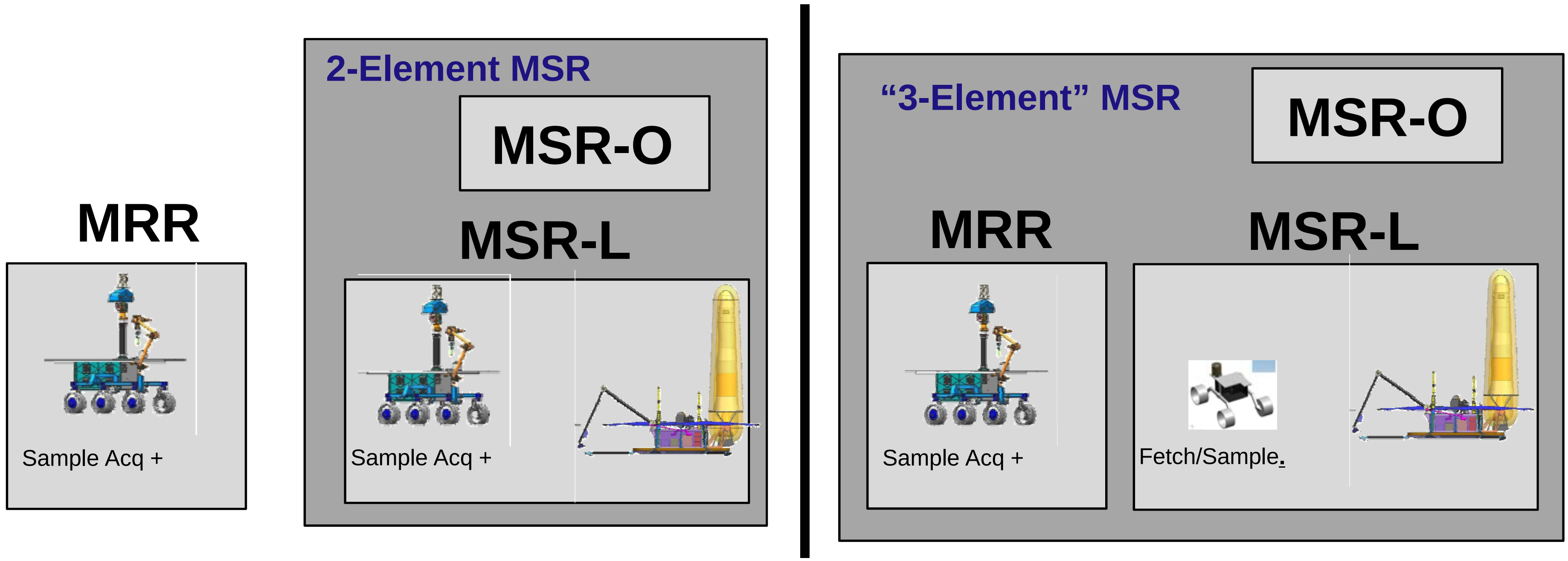
Increasing information invested in sample selection, significance of scientific objectives

Atmosphere, dust	Atm., regolith	Atm., selected rocks & regolith	Atm., selected rocks & regolith
No landing	New site selectable from orbit	Would land a MAV at new site selectable from orbit	Would land a MAV at site previously explored
Atmosphere-borne samples only	sample selection from materials within arm's reach	Samples selected during the course of site exploration	Samples of interest known from prior mission.
Scoping	General context for life	Evaluate habitability potential	poss, biosignatures in high-pot. environ.

*Note that astrobiology would not be not the only scientific purpose of MSR.

2-Element vs. “3-Element” MSR Concepts

Would MRR *enable* MSR engineering?

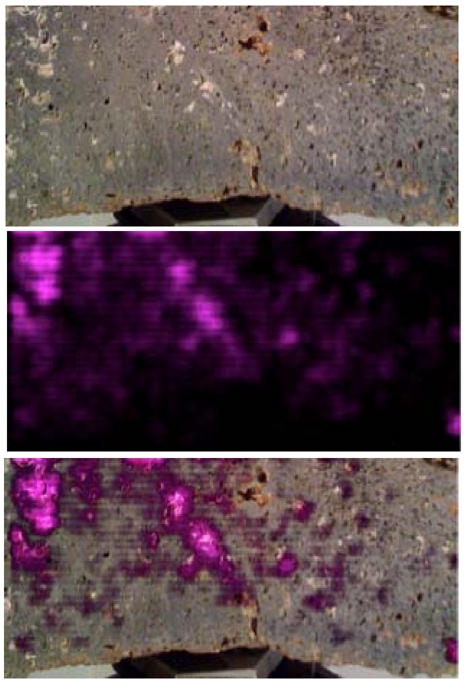


- The development risk of a potential MSR landing system capable of delivering enough mass for both a MAV and a highly capable rover (instrumented per “ND-SAG Case A – New Site” scenario) might be high enough to justify the MRR mission as a necessary first element of the MSR “campaign”
  - Site characterization (and potential caching) would remove this responsibility from the rover sent with the MAV and enable a lighter, simpler system
- The judgment that the proposed MRR mission is needed for scientific reasons is independent of this.

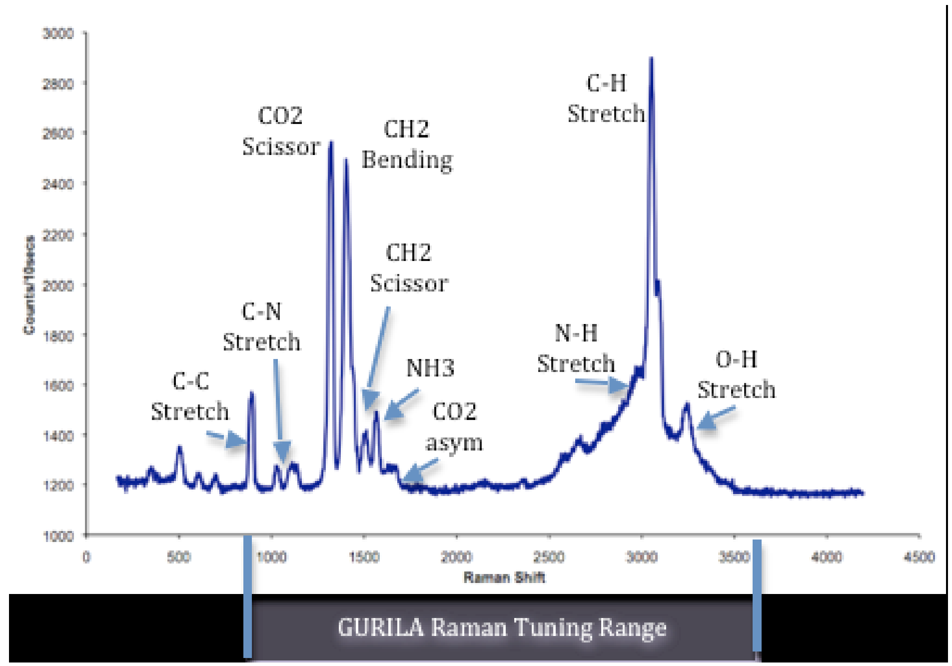
NEEDS MORE ANALYSIS/DISCUSSION!

More information on Deep UV Raman / Fluorescence

***Deep UV Fluorescence can provide sub-parts-per-billion** sensitivity to organic compounds present in planetary materials, without any sample acquisition or processing (although surface weathering rinds may need to be ratted.* Deep UV Fluorescence provides valuable scientific information in its own right by detecting aromatic ring structures of varying ring numbers and conformational arrangements (Bhartia 2008). When combined with the **deep UV Raman, it becomes possible to detect hydrated minerals, water (bound vs. unbound), and many chemical bonds** relevant to astrobiology and general planetary science including C-H, C-O, C-C, C-N, N-H, N-O, S-O, and P-O with sub-parts-per-million detection limits. This combined instrument can thus provide information on the presence and distribution of aromatic ring structures and the key six elements required for life, CHNOPS.



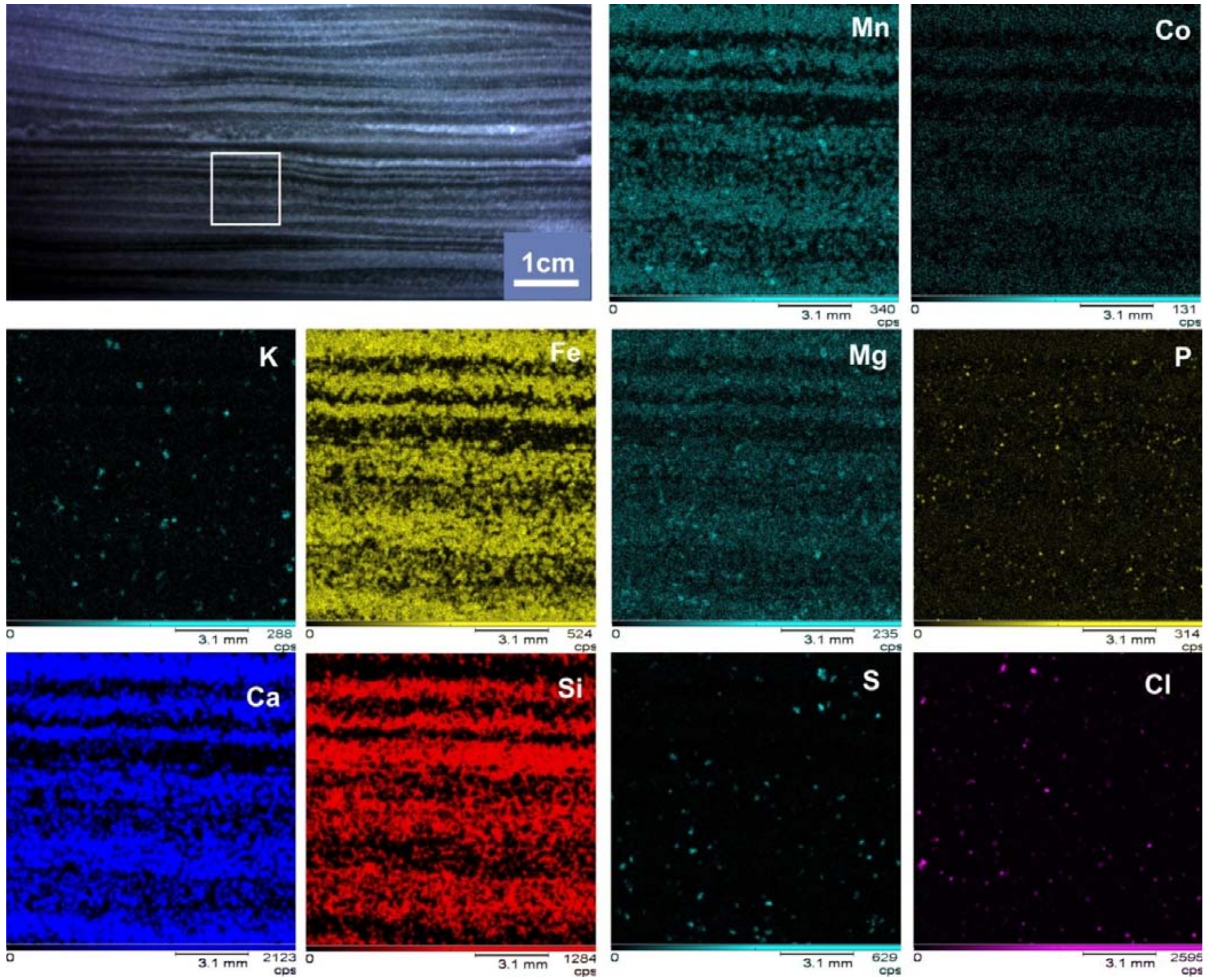
248nm excitation Water Raman map of an fluid altered basalt (8x3”). *Top*: Visible reflectance color image. *Middle*: False color map of the OH stretch Raman band showing where water bearing minerals are located. *Bottom*: Overlay of the reflectance image and the water map. Indicates that carbonate regions (Top: white) are mixed with hydrous mineral phases. (Courtesy of Rohit Bhartia, JPL.)



Deep UV Raman spectrum of glycine, showing no fluorescence background and resonance-enhanced molecular bonds. (Courtesy of Rohit Bhartia, JPL.)

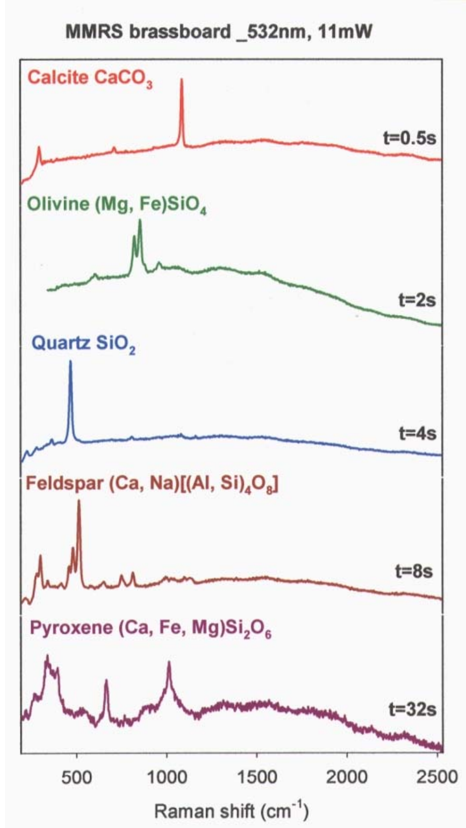
More information on X-ray Elemental Mapping

- APXS is current state-of-the-art for elemental analysis on Mars rovers – averaging over ~1.8 cm diameter region.
- X-ray elemental mapping technique could potentially provide 1-D or 2-D element maps from robot arm on proposed MRR mission w/ sufficiently bright X-ray source. Achievable spot sizes, integration times TBD.
- Maps can be overlaid.
- Images from laboratory state-of-the-art instrument courtesy of Abby Allwood, JPL.

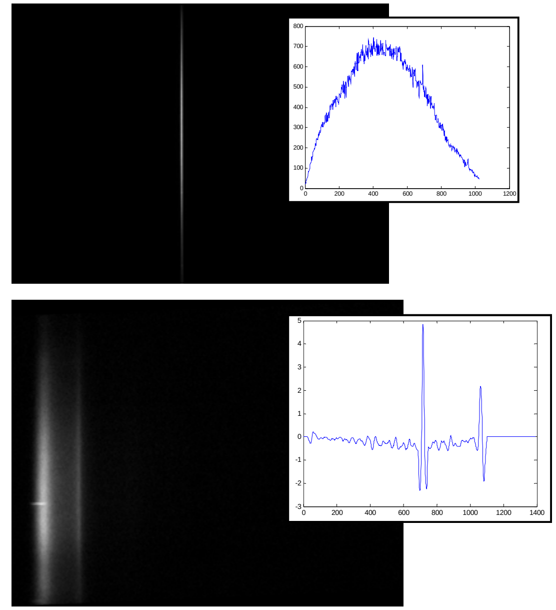


More information on Raman and Time-Gated Raman

- Raman Spectroscopy is a powerful tool for mineralogical analysis, particularly when 1-D or 2-D mapping can be performed.
- Certain mineral types are challenging:
  - Fine-grained materials
  - Clays, phyllosilicates (modes don't add up to sharp peaks)
  - Other materials lacking high degree of symmetry
  - Shocked materials, rare earth elements, and phosphorus-containing materials can exhibit fluorescence
- No sample preparation required
- No *in situ* Raman instrument has flown.
- Current state-of-the-art for Raman analysis on Mars is the Mars Microbeam Raman Spectrometer (MMRS), descoped from Mars '03. MMRS did not provide time-gating capability.
- Developments in time-gated laser & detector technology may allow **time-gated Raman** by Mars 2018 / 2020. Time-gated Raman is a technique for separating Raman signal from background fluorescence.



Sample Spectra Acquired with the MMRS. (Courtesy of Lonne Lane, JPL.)



Top: Normal Raman data of Calcite (not time resolved) showing Raman on top of a fluorescence background – peaks obscured by fluorescence. Bottom: Time-gated Raman data of Calcite showing fluorescence vs. time. (Images courtesy of Jordana Blacksberg, JPL.)

Preliminary Measurement Priorities

High priority:

Mineralogical remote sensing at 1 mrad/pixel (TBD) or better, SNR > 100
Geomorphological context (optical) imaging at 0.3 mrad/pixel or better } *Might be achieved by single instrument*
Ambient trace gas composition (which gases? accuracy/precision?)
Abrasion of 3 cm (TBD) diameter areas on rocks } *Might be achieved by single device*
Rock coring and sample caching
In situ optical texture with 0.1 (TBD) mm resolution, SNR > 100
In situ mineralogical mapping with 0.3 (TBD) mm resolution, SNR > 100
In situ organic detector with 0.1 (TBD) mm spatial sampling (accuracy/precision?)
Elemental composition with 3 cm (TBD) spatial sampling

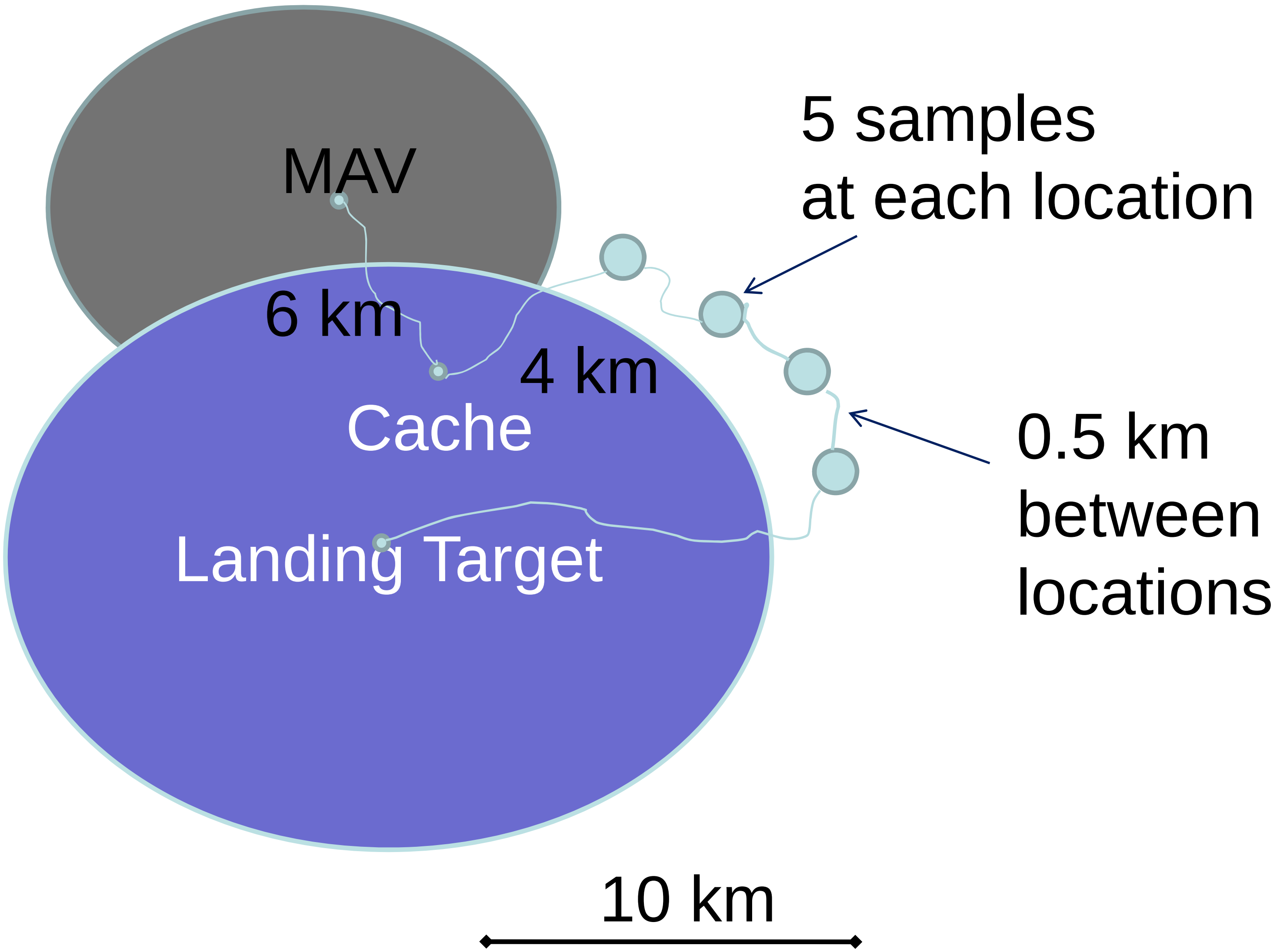
Medium priority:

Subsurface sounding with 10 cm (TBD) depth resolution
Magnetic field
In situ elemental chemistry with 0.1 mm (TBD) spatial sampling
In situ light stable isotopic analysis

Low priority:

Atmospheric temperature, humidity, wind and pressure sensors } *Might have higher programmatic priority*
Magnetic properties
Physical properties (rock hardness, soil cohesion, etc.)
Chirality

Planning for a Possible MRR-MAV Surface Rendezvous (1 of 2)



Planning for a Possible MRR-MAV Surface Rendezvous (2 of 2)

Some attributes that would improve the probability of achieving a surface rendezvous between a possible MRR and MAV:

Proposed MRR:

- Increase the rover traverse speed to at least 105 m/sol
- Implement precision landing technology (to reduce risk arising from traversing 16.5 km)
- Add an upward looking LIDAR to MRR to develop a wind model for the specific MRR landing site. This would help in the precision landing of the MSL-Lander

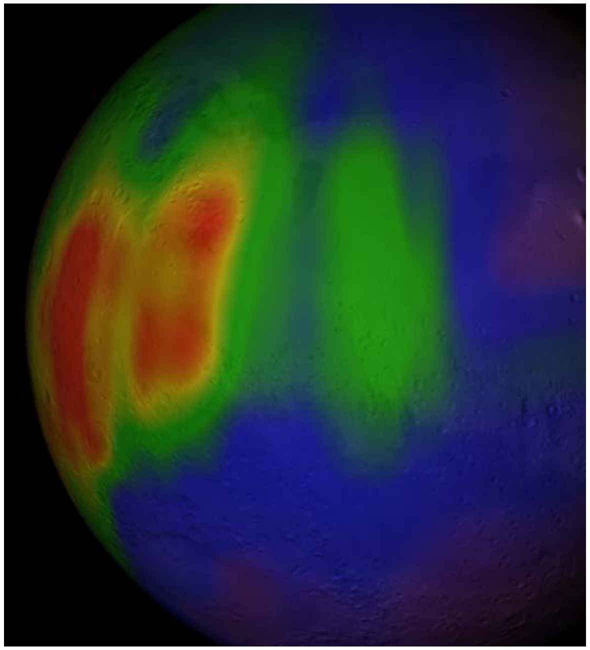
Proposed MSR-MAV:

- Precision landing (using improved wind models from the proposed MRR LIDAR)
- Increase the fetch rover speed to 80 m/sol

Concept #7

Methane Emission from Subsurface (Priority #4)

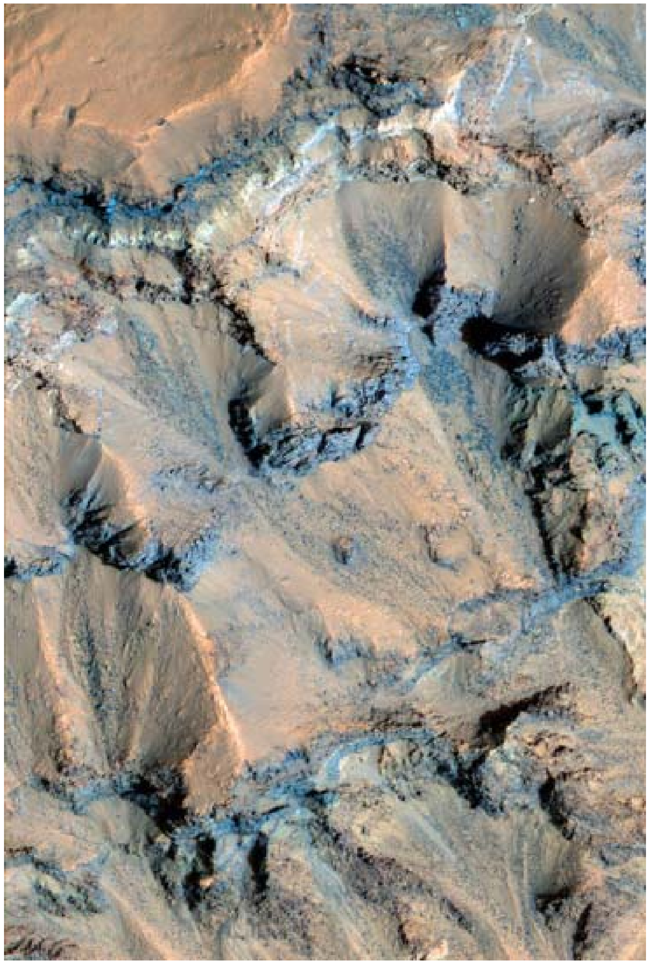
- Is methane being emitted from the subsurface and if so, what is the nature of the source(s)? Are methane emissions seasonal, episodic, or persistent?
- Is the source of methane abiotic or biotic (related to present or past life?)?
- Are other reduced gases (e.g., H_2S, $(CH_3)_2S$, H_2, CO, C_nH_{2n}+2) associated with methane? Are other proposed biogases present in the vicinity (N_2O, O_2, O_3)?
- What is the lifetime and destruction mechanisms of methane in the atmosphere?



Map of methane concentrations on Mars Credit: Mike Mumma, NASA press release.

Radiometric Dating (Priority #5)

- Determine the absolute ages of a sequence of igneous and/or sedimentary rocks of fundamental scientific importance
- Evaluate stratigraphic models such as the concept of "mineral epochs"
- Determine absolute age of a globally significant stratigraphic boundary
- Provide calibration for crater counting chronology



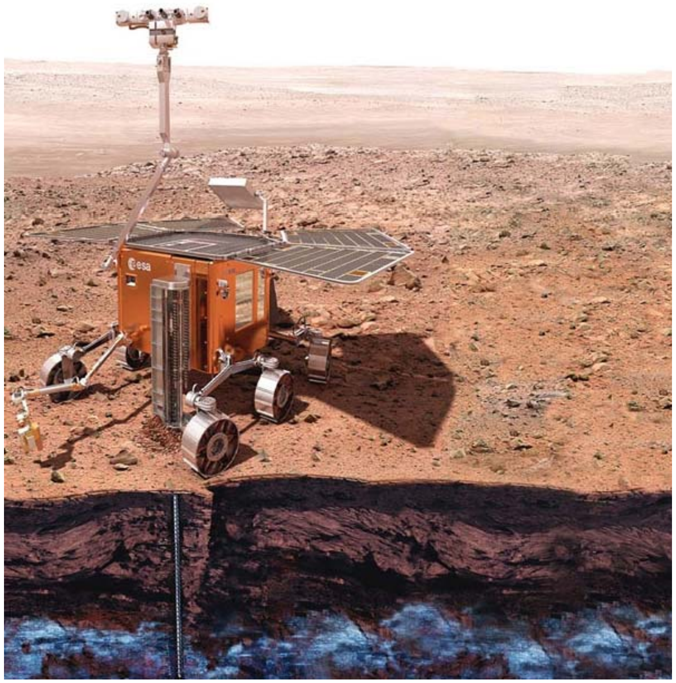
Interbedded unaltered lava (blueish enhanced colors) and deposits with hydrous alteration (light-toned units) on a steep slope in Asimov crater.

Portion of HiRISE color image PSP_004091_1325.
Credit: NASA/JPL/University of Arizona

Concept #6

Deep Drilling (1-2 m depth) (Priority #6)

- What is the extension of the superficial oxidation layer and the processes acting in the near subsurface?
- How is oxidation progressing and what is causing it?
- What is the fate of the meteoritic carbon?
- What is the nature and origin of organics on Mars?



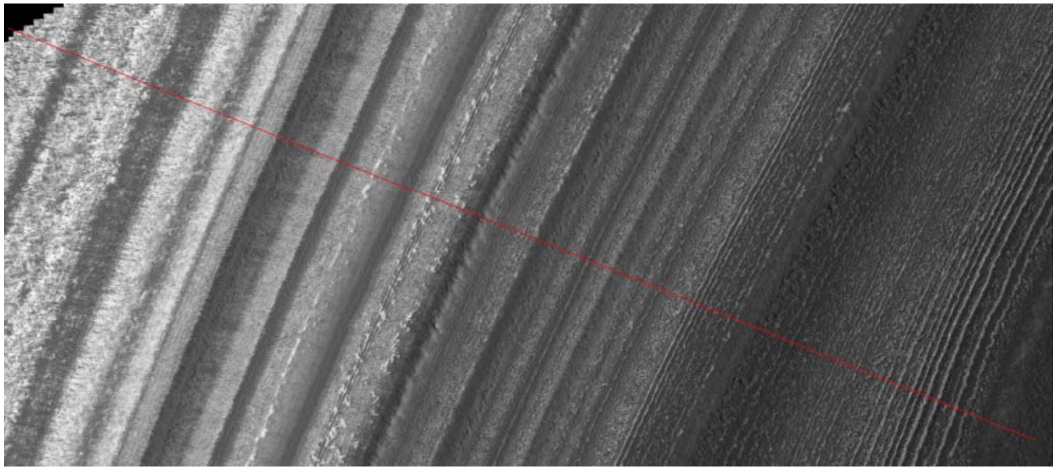
Artist's depiction of a deep drilling mission (ExoMars). Credit: ESA/AOES Medialab.

- Is there any evidence of life in the near subsurface?
- What is the paleoclimate history of Mars?
- What kinds of environments and geologic settings are/were present on Mars?

Concept #8

Polar Layered Deposits (Priority #7)

- Do the PLD contain a record of recent global climate changes and other episodic events? If so, what are the mechanisms by which climate changes are recorded?



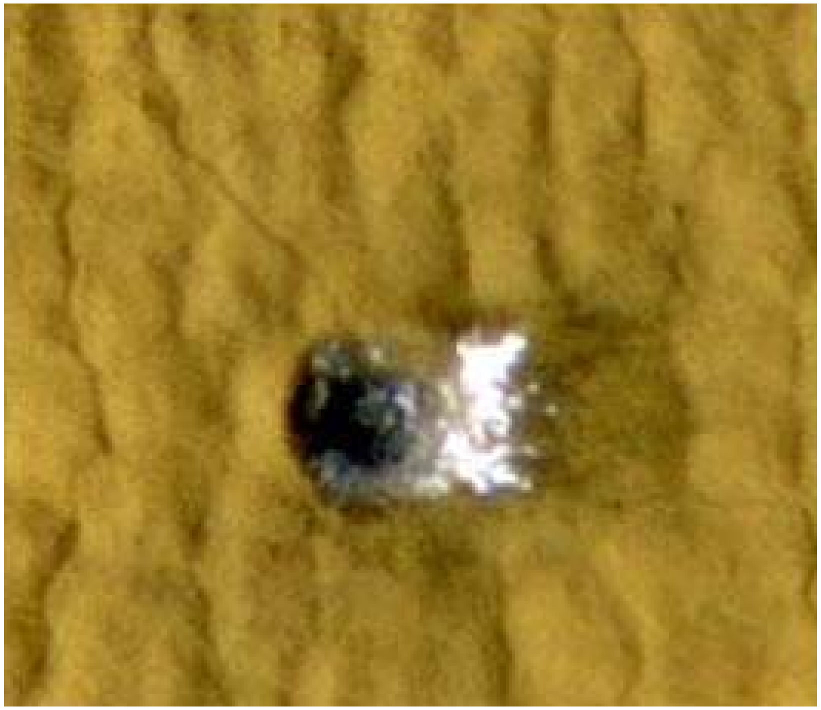
Exposure of PLD with example rover traverse. HiRISE image PSP_001738_2670. Credit: NASA/JPL/University of Arizona.

- What could be inferred about the secular evolution of water on Mars from the PLD record?
- Are recent global climate variations dominated by astronomical (orbit/axis) forcing?
- How do recent global climate changes on Mars compare with those on Earth?

Concept #1

Mid-Latitude Shallow Ice (Priority #8)

- What are the characteristics of mid-latitude periglacial sites and their relationship to obliquity cycles?
- What is the habitability of mid-latitude ice, and how does perchlorate affect the present day habitability of Mars?
- Could mid-latitude ice provide a resource for *In Situ* Resource Utilization (ISRU)?



Portion of HiRISE image of Phlegra Montes showing an impact crater formed in 2008 at 46°N latitude, which excavated a shallow layer of very pure water ice. Crater diameter is 12 m; depth is 2.5 m. HiRISE image ESP_011494_2265. Credit: NASA/JPL/University of Arizona.