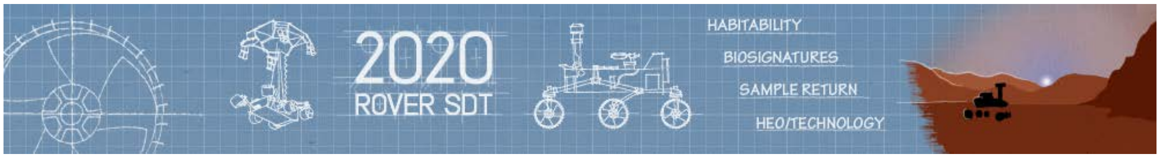

Appendices to the Report of the Mars 2020 Science Definition Team

J.F. Mustard, chair; M. Adler, A. Allwood, D.S. Bass, D.W. Beaty, J.F. Bell III, W.B. Brinckerhoff, M. Carr, D.J. Des Marais, B. Drake, K.S. Edgett, J. Eigenbrode, L.T. Elkins-Tanton, J.A. Grant, S. M. Milkovich, D. Ming, C. Moore, S. Murchie, T.C. Onstott, S.W. Ruff, M.A. Sephton, A. Steele, A. Treiman

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or

Mars 2020 SDT (2013), Committee members: Mustard, J.F. (chair), M. Adler, A. Allwood, D.S. Bass, D.W. Beaty, J.F. Bell III, W.B. Brinckerhoff, M. Carr, D.J. Des Marais, B. Drake, K.S. Edgett, J. Eigenbrode, L.T. Elkins-Tanton, J.A. Grant, S. M. Milkovich, D. Ming, C. Moore, S. Murchie, T.C. Onstott, S.W. Ruff, M.A. Sephton, A. Steele, A. Treiman: Appendix to the Report of the Mars 2020 Science Definition Team, 51 pp., posted July, 2013, by the Mars Exploration Program Analysis Group (MEPAG) at hthttp://mepag.jpl.nasa.gov/reports/MEP/Mars_2020_SDT_Report_Appendix.pdf.

Inquiries regarding this report should be directed to Jack Mustard, SDT Chair (John_Mustard@brown.edu), David Beaty, MED chief scientist (David.W.Beaty@jpl.nasa.gov), or Mitch Schulte, NASA SMD (mitchell.d.schulte@nasa.gov)

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Appendix 1. Charter: Science Definition Team For a 2020 Mars Science Rover

Summary Statement of NASA Intent

The NASA Mars Exploration Program (MEP) has made dramatic progress in the scientific investigation of the Red Planet, most recently with the landing and initial surface operations of the Mars Science Laboratory (MSL) *Curiosity* rover (Aug. 2012 to present). In combination with discoveries from the ESA Mars Express orbiter, the state of knowledge of Mars points to a planet with a rich geologic history of past environments in which liquid water has played a significant role. On the basis of the results achieved by the ongoing surface reconnaissance activities of the Mars Exploration Rovers and the initial findings of the MSL *Curiosity* rover, it is increasingly evident that the “scientific action” is at the surface. Furthermore, thanks to the comprehensive inputs by the broader science community, there is an emerging consensus that the search for signs of past life within the accessible geologic record via missions that include the ESA ExoMars rover (2018) and future NASA surface missions is a fertile exploration pathway for the next decade.

Thus, NASA plans to continue the pursuit of its “*Seeking the Signs of Life*” Mars Exploration Program science theme beyond the near-term missions that include *Curiosity* and MAVEN. The 2020 launch of a Mars science rover mission will focus on *surface-based geological and geochemical reconnaissance in search of signs of life*, with clearly defined preparation for eventual return to Earth of carefully selected materials. Supporting *in situ* measurements will be undertaken to address key questions about the potential for life on Mars via possible preservation of biosignatures within accessible geologic materials. This mission will enable concrete progress toward sample return, thereby satisfying NRC Planetary Decadal Survey science recommendations, and will provide opportunities for accommodation of contributed Human Exploration & Operations Mission Directorate (HEOMD) payload element(s), technology infusion, and international participation.

To support definition of the pre-Phase A 2020 mission concept, the 2020 Mars rover Science Definition Team (SDT) is formed within the framework described below.

Primary Objectives

A. 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. *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.

Primary Assumptions and Guidelines

- The mission will launch in 2020.
- The total cost of the instruments has a nominal cost limit of ~$100M (including margin/reserves). This includes the development and implementation costs of US instruments (~$80M) and the estimated costs of any contributed elements (~$20M), but not including surface operations costs. The cost of science support equipment, such as an arm, is budgeted separately and not included in this ~$100M/$80M limit for instruments.
- The mission will employ Mars Science Laboratory (MSL) SkyCrane-derived entry, descent, and landing flight systems, and *Curiosity*-class roving capabilities. Consideration of the scientific value and cost implications of improving access to high-value science landing sites should be provided by the SDT in consultation with the pre-project team.
- The mission lifetime requirement is surface operation for one Mars year (~690 Earth Days).
- Mission pre-project activities will provide additional constraints on payload mass, volume, data rate, and configuration solutions that will establish realistic boundary conditions for SDT consideration.
-

Statement of Task

The SDT is tasked to formulate a detailed mission concept that is traceable to highest priority, community-vetted scientific goals and objectives (i.e., *Vision and Voyages* NRC Planetary Decadal Survey and related MEPAG Goals/Objectives) that will be formally presented to the Mars Exploration Program and leaders of the Science Mission Directorate (SMD); any and all mission concepts must fit within available resources and associated levels of acceptable risk as provided by the pre-project team.

As such, the SDT shall:

1. Determine the payload options and priorities associated with achieving science objectives A, B, and C. Recommend a mission concept that will maximize overall science return and progress towards NASA's long-range goals within the resource and risk posture constraints provided by HQ.

2. Determine the degree to which HEOMD measurements or STP technology infusion/demonstration activities (Objective D) can be accommodated as part of the mission (in priority order), consistent with a separate (from SMD) budget constraint also to be provided by HQ.

3. Work with the pre-project team in developing a feasible mission concept.

4. For the favored mission concept, propose high-level supporting capability requirements derived from the scientific objectives, including both baseline and threshold values.

5. Develop a Level 0 Science Traceability Matrix (similar to those required for SMD mission Announcements of Opportunity) that flows from overarching science goals/objectives to functional measurements and required capabilities for the surface mission in 2020.

6. Define the payload elements (including both instruments and support equipment) required to achieve the scientific objectives, including high-level measurement performance specifications and resource allocations sufficient to support a competitive, AO-based procurement process:

   - Provide a description of at least one "strawman" payload as an existence proof, including cost estimate

- For both baseline and any threshold payloads, *describe priorities for scaling the mission concept either up or down (in cost and capability) and payload priority trades between instrumentation and various levels of sample encapsulation.*

Methods and Schedule

The following delivery points are specified:

- Interim results (presentation format) shall be delivered no later than 2 April 2013.
- A near-final summary presentation to be delivered by 31 May 2013, in which the essential conclusions and recommendations are not expected to change during final report writing.
- A final text-formatted report to be delivered by July 1, 2013.

The Mars-2020 pre-project engineering team at JPL has been tasked to support the SDT as needed on issues related to mission engineering.

The SDT report will be essential in formulating the HQ-approved set of 2020 Mars rover mission science goals and measurement objectives suitable for open solicitation via a NASA SMD Payload AO that is to be released for open competition in Summer 2013.

Point of contact for this task:

Dr. Mitchell Schulte, NASA Program Scientist for the 2020 Mars science rover mission

Email: mitchell.d.schulte@nasa.gov

References (see http://mepag.nasa.gov/reports/index.html)

- Vision and Voyages for Planetary Science in the Decade 2013-2022
- Mars Program Planning Group *Report* 2012
- "Baseline" arm- and mast-mounted measurement functionalities for Objective A as described in Appendix 6 of JSWG (2012) [see also MPPG Final Report Appendix A].
- Candidate measurements and priorities for HEO and OCT from MEPAG P-SAG (2012).
- Assume (as a one point of departure) the scientific objectives and priorities for returned sample science from the recent work of E2E-iSAG, 2018 JSWG, and MPPG (2012)

Appendix 2. Mars 2020 Science Definition Team Call for Applications, SDT Roster, and Independent Review Team (IAT) Roster

1. Mars 2020 Science Definition Team Call for Applications

Call for *Letters of Application* for Membership on the Science Definition Team for the 2020 Mars Science Rover

Solicitation Number:	NNH13ZDA003L
Posted Date:	December 20, 2012
FedBizOpps Posted Date:	December 20, 2012
Recovery and Reinvestment Act Action:	No
Original Response Date:	January 10, 2013
Classification Code:	A – Research and Development
NAICS Code:	541712 – Research and Development in the Physical, Engineering, and Life Sciences (except Biotechnology)

The National Aeronautics and Space Administration (NASA) invites scientists, technologists, and other qualified and interested individuals at U.S. institutions and elsewhere to apply for membership on the Science Definition Team (SDT) for the 2020 Mars science rover mission (hereafter Mars-2020). Mars-2020 is a strategic mission sponsored by NASA's Planetary Science Division, through the Mars Exploration Program, all of which are part of the Science Mission Directorate (SMD).

This mission will advance the scientific priorities detailed in the National Research Council's Planetary Science Decadal Survey, entitled "Vision and Voyages for Planetary Science in the Decade 2013-2022" (the Decadal Survey is available at http://www.nap.edu). Mars-2020 rover development and design will be largely based upon the Mars Science Laboratory (MSL) architecture that successfully carried the *Curiosity* rover to the Martian surface on August 6, 2012 (UTC). The 2020 rover is intended to investigate an astrobiologically relevant ancient environment on Mars to decipher its geological processes and history, including the assessment of its past habitability and potential for preservation of biosignatures within accessible geologic materials.

Furthermore, because NASA is embarking on a long-term effort for eventual human exploration of Mars, the mission should provide an opportunity for contributed Human Exploration Mission Directorate (HEOMD) or Space Technology Program (STP) participation via payload elements aligned with their priorities and compatible with SMD priorities for Mars-2020 (e.g., MEPAG P-SAG report, posted June 2012 to MEPAG website: http://mepag.jpl.nasa.gov).

The members of the Mars-2020 SDT will provide NASA with scientific assistance and direction during preliminary concept definition (Pre-Phase A) activities. Near-term activities of the SDT will include the establishment of baseline mission science objectives and a realistic scientific concept of surface operations; development of a strawman payload/instrument suite as proof of concept; and suggestions for threshold science objectives/measurements for a preferred mission viable within resource constraints provided by NASA Headquarters. The products developed by the SDT will be used to develop the NASA Science Mission Directorate (SMD) Announcement of Opportunity (AO) that will outline the primary science objectives of the baseline mission and the character of the payload-based investigations solicited under open competition via the AO. The SDT will be formed in January 2013, and disbanded after the work is complete approximately four months later.

All reports and output materials of the Mars-2020 SDT will be publicly available, and the SDT will be disbanded prior to any future Announcement of Opportunity (AO) for participation in the Mars-2020 mission, including provision of instrumentation and investigation support. Participation in the Mars-2020 SDT is open to all qualified and interested individuals. The formal NASA charter for the Mars-2020 SDT will be posted to the NASA Science Mission Directorate Service and Advice for Research and Analysis (SARA) website (http://science.nasa.gov/researchers/sara/grant-solicitations/).

DETAILS OF THIS CALL FOR SDT PARTICIPATION

Response to this Call for Membership in the Mars-2020 SDT is in the form of a *Letter of Application*. SDT members will be selected by NASA Headquarters senior officials from the pool of respondents and other qualified candidates. The selected members will have demonstrated expertise and knowledge in areas highly relevant to the Mars-2020 primary scientific goals and related technologies and instrumentation. The *Letter of Application* should provide clearly defined evidence of the candidate's demonstrated expertise in one or more areas associated with the preliminary mission description given above.

The *Letter of Application* may also contain a brief list of references to scientific or technical peer-reviewed papers the applicant has published that formally establish their position of scientific leadership in the community. The letter should also contain a statement confirming the applicant's time availability during the next three to six months to participate on the SDT, particularly if there are any major schedule constraints that may restrict full engagement in the significant amount of work that will be required in a reasonably short time frame. Applicants should indicate interest in serving as the chair or co-chair of the SDT.

Membership in the SDT will be determined by NASA after formal review of the *Letters of Application* solicited by this Call for Membership. Approximately 12-15 SDT members and an SDT Chair will be selected. The NASA Mars-2020 Program Scientist, the NASA Mars Exploration Program Lead Scientist, and possibly other Agency representatives will serve as *ex officio* members of the SDT.

Letters of Application are invited only from individuals, and group applications will not be considered. In addition, collaborations and teams will not be considered.

Each *Letter of Application* is limited to two pages, with 11-point font with 1-inch margins. *Letters of Application* submitted by E-mail are preferred, but may also be submitted by regular mail or fax. Responses to this invitation should be received by the Mars-2020 Program Scientist no later than January 10, 2013, at the address below.

The issuance of this Call for *Letters of Application* does not obligate NASA to accept any of the applications. Any costs incurred by an applicant in preparing a submission in response to this Call are the responsibility of the applicant.

Dr. Mitch Schulte

Planetary Sciences Division

Science Mission Directorate

National Aeronautics and Space Administration

300 E Street, SW

Washington, DC 20546

Phone: 202-358-2127

Fax: 202-358-3097

E-mail: mars2020-sdt@lists.hq.nasa.gov

2. Mars 2020 Science Definition Team Roster

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

3. Mars 2020 Independent Assessment Team

Name	***Professional Affiliation***	***Interest/Experience***
Chair		
Johnson, Jeff	JHU-APL	Remote sensing, Spectroscopy; MPF, MPL, MER, MSL, MEPAG
Members (n = 8)		
Cohen, Barbara	NASA MSFC	Geochemistry and mineralogy; impact history of the inner solar system, MER
Ehlmann, Bethany	Caltech/JPL	Remote sensing, Spectroscopy: MER, MSL
Ehrenfreund, Pascal	GWU	Astrobiology, Molecular Biology, Space Science; Exomars
Hecht, Michael	MIT Haystack	Geochemisty, Instrument development; PHX
Jakosky, Bruce	Univ of Colorado/LASP	Geology, Evolution of the martian atmosphere and climate; Viking, MO, MGS, MSL, MAVEN
McEwen, Alfred	Univ of Arizona	Planetary geology, MO, MRO
Retallack, Greg	Univ of Oregon	Paleontology, paleosols, astrobiology
Quinn, Richard	SETI Inst	Astrobiology, organic chemistry

Appendix 3: Acronym Glossary

Acronym	Definition
AGU	American Geophysical Union
AO	Announcement of Opportunity
APXS	Alpha Particle X-Ray Spectrometer, an instrument on both the 2003 MER mission and the 2011 Mars Science Laboratory mission
ARC	Ames Research Center, a field center within the NASA system
BPP	Biosignature Preservation Potential
CEDL	Cruise, Entry, Descent and Landing
ChemCam	Chemistry and Camera Instrument, an instrument on the 2011 Mars Science Laboratory mission
CHNOPS	Carbon, Hydrogen, Nitrogen, Oxygen, Phosphorous, Sulfur
CRIS	Confocal Raman Imaging Spectroscopy.A measurement technique/class of instrumentation
CRISM	Compact Reconnaissance Imaging Spectrometer for Mars, an instrument on the 2005 Mars Reconnaissance Orbiter mission.
DBS	Definitive Biosignature. Conclusive evidence of past life
DEM	Digital Elevation Model. Computerized "model" that shows terrain heights
DRT	Dust Removal Tool, a device on the 2011 Mars Science Laboratory mission
DSN	Deep Space Network. Network of world-wide satellite dishes to send spacecraft signals and receive data
DTE	Direct-to-Earth
E2E-iSAG	End-to-end International Science Analysis Group, a 2011 study team sponsored by the Mars Exploration Program Analysis Group (MEPAG)
EDL	Entry, Descent and Landing
EGA	Evolved Gas Analysis. A specific implementation of a differential scanning calorimetry experiment
ESA	European Space Agency
FIB	Focused Ion Beam. A measurement technique/class of instrumentation
FOV	Field of View
FTIR	Fourier Transform Infrared, a type of spectrometer
GWU	George Washington University
HAT	Human Spaceflight Architecture Team. Team charged with working the strategic vision for Human Spaceflight
HEO	Human Exploration and Operations
HEOMD	Human Exploration and Operations Mission Directorate, an organization within NASA
HGA	High Gain Antenna
HiRISE	High Resolution Imaging Science Experiment, an instrument on the 2005 Mars Reconnaissance Orbiter mission**.**
HIT	HEOMD Instrument Team. Team working to understand the priorities and possible implementation of instruments that will help pave the way for Human Exploration.
HQ	Headquarters (NASA)
IAT	Independent Assessment Team aka "Red Team" or supplementary review team for the 2020 Science Defintion Team
IMU	Inertial Measurement Unit. Spacecraft "gyroscope"
InSight	Interior Exploration using Seismic Investigations, Geodesy and Heat Transport, a Discovery mission to Mars in development for launch in 2016.
IR	Infrared Reflectance Spectroscopy. A measurement technique/class of instrumentation
ISRU	*In Situ* Resource Utilization. A general term that refers to making use of resources in space or on target objects.

JHU/APL	John Hopkins University/Applied Physics Laboratory
JPL	Jet Propulsion Laboratory, a field center within the NASA system
JSC	Johnson Space Center, a field center within the NASA system
JSWG	Joint Science Working Group. The International Science Team for the proposed (but not approved) 2018 Joint Mars Rover Mission
LaRC	Langley Research Center, a field center within the NASA system
LASP	Laboratory for Atmospheric Space Physics, an organization within the University of Colorado
LOD	Limit of Detection
MAHLI	Mars Hand Lens Imager, an instrument on the 2011 Mars Science Laboratory mission
MARDI	Mars Descent Imager, an instrument on the 2011 Mars Science Laboratory mission
MastCam	Mast Camera, an instrument on the 2011 Mars Science Laboratory mission
MAV	Mars Ascent Vehicle. The spacecraft that could "blast off" from the martian surface
MAVEN	Mars Atmosphere and Volatile EvolutioN, a Mars orbiter mission to be launched in 2013
MAX-C	Mars Astrobiology Explorer-Cacher. The name of a mission proposed in the MRR-SAG study, which was in turn sponsored by MEPAG.
MEDLI	Mars Science Laboratory Entry, Descent, and Landing Instrument, an instrument on the 2011 Mars Science Laboratory mission
MEDLI+	Mars Entry, Descent, and Landing Instrumentation Plus, the next generation of MEDLI
MEP	Mars Exploration Program
MEPAG	Mars Exploration Program Analysis Group, an analysis group affiliated with NASA's Planetary Science Subcommittee
MER	Mars Exploration Rovers, a dual Mars rover mission launched in 2003
MI	Microscopic Imager, an instrument on the 2003 MER mission
micro-XRF	ultraminiaturized X-Ray Fluorescence Spectrometer, an instrument in development
Mini-TES	Miniature Thermal Emission Spectrometer, an instrument on the 2003 MER mission
MIT	Massachusetts Institute of Technology
MMC	Macromolecular Carbon
MMI	Mars Microscopic Imager, an instrument in development
MMRTG	Multi-Mission Radioisotope Thermoelectric Generator
MOLA	Mars Orbiter Laser Altimeter, an instrument on the 1996 Mars Global Surveyor mission
MPF	Mars Pathfinder, a Mars rover mission launched in 1996
MPO	Mars Program Office
MPPG	Mars Program Planning Group, a Mars planning team active in 2012
MRO	Mars Reconnaissance Orbiter, a Mars orbiter mission launched in 2005
MRR-SAG	Mars Mid Range Rover Science Analysis Group, a 2009 study team sponsored by MEPAG
MSFC	Marshall Space Flight Center, a field center within the NASA system
MSL	Mars Science Laboratory, a Mars rover mission launched in 2011
MSR	Mars Sample Return
MSR-SSG	Mars Sample Return - Science Steering Group sponsored by MEPAG
MSSS	Malin Space Science Systems
NanoSIMS	Nano Secondary Ion Mass Spectroscopy. A measurement technique/class of instrumentation
NASA	National Aeronautics and Space Administration
ND-SAG	Next Decade Science Analysis Group, a 2008 study team sponsored by MEPAG
NRC	National Research Council
OCSSG	Organic Contamination Science Steering Group, a study team sponsored by MEPAG. Findings were used to set the contamination standards for MSL.
OM	Organic Matter
P-SAG	Precursor Strategy Analysis Group

PBS	Potential Biosignature
PDR	Preliminary Design Review
PHX	Phoenix Mars Lander, a Mars lander mission lauched in 2007
PP (Category)	Planetary Protection
ppb	parts per billion
ppm	parts per million
PSG	Project Science Group
Pyr/CELAS	Pyrolysis/Cavity-Enhanced Laser Absorption Spectroscopy. A measurement technique/class of instrumentation
Pyr/GC-MS	Pyrolysis/Gas Chromatography Mass Spectrometry. A measurement technique/class of instrumentation
Pyr/MS	Pyrolysis/Mass Spectrometry. A measurement technique/class of instrumentation
RT	Range Trigger. A technology for improving EDL capabilities
RAT	Rock Abrasion Tool, a tool on the 2003 MER mission
ROI	Regions of Interest. Operational term used to define geographic areas where robotic actions may be grouped
RSL	Recurring Slope Lineae, a surface feature on Mars
SA	Sample Acquisition
SAED	Selected Area Electron Diffraction, a measurement technique/class of instrumentation
SAG	Science Analysis Group
SAM	Sample Analysis at Mars, an instrument on the 2011 Mars Science Laboratory mission
SDT	Science Definition Team
SKG	Strategic Knowledge Gap. Term for areas that need additional study**.**
SMD	Science Mission Directorate, an organization within NASA
SPaH	Sample Processing and Handling System, a device on the 2011 Mars Science Laboratory mission
STMD	Space Technology Mission Directorate, an organization within NASA
STP	Science Technology Program. Now known as STMD
TGO	Trace Gas Orbiter, a Mars orbiter to be launched in 2016
THA	Terminal Hazard Avoidance. A technology for improving EDL capabilities
THEMIS	Thermal Emission Imaging System, an instrument on the 2001 Mars Odyssey mission
TIR	Thermal Infrared
TRL	Technology Readiness Level
TRN	Terrain Relative Navigation. A technology for improving EDL capabilities
TWTA	Traveling-Wave Tube Amplifier
UCIS	Ultra-compact Imaging Spectrometer, an instrument in development
UHF	Ultra High Frequency
UV	Ultraviolet
V&V	Validation and Verification
VISIR	Visible and Infrared

Appendix 4: Possible Instrument Concepts

This table is the result of a survey of potential instruments for a Mars surface mission. This survey primarily draws from concepts publicly presented at two recent conferences: the International Workshop on Instrumentation for Planetary Missions (IPM-2012) held on Oct. 10-12, 2012 in Greenbelt, MD (http://ssed.gsfc.nasa.gov/IPM/) and the Concepts and Approaches for Mars Exploration Workshop held on June 12-14 in Houston, TX (http://www.lpi.usra.edu/meetings/marsconcepts2012/). From all the instrument concepts presented in these venues, we selected the subset relevant for a Mars surface mission. The survey also includes a number of heritage instruments.

This table indicates the instrument name, acronym/short name, category, and a more detailed measurement description. We have also listed references to the specific papers or presentations used to compile this database.

Acronym	Instrument Name	Instrument Category	Measurement Description	References
AOTF Point Spec.	Acousto- optic tunable filter point spectrometer	Fine Scale Mineralogy	Identify minerals associated with aqueous environments at sample scales of ~ 1 mm; as well as organic molecules and volatiles (notably H2O and CO2 ice)	Chanover, N. J., D. A. Glenar, K. Uckert, D. G. Voelz, X. Xiao, R. Tawalbeh, P. Boston, W. Brinckerhoff, S. Getty, and P. Mahaffy (2012), Miniature Spectrometer for Detection of Organics and Identification of their Mineral Context, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1142, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1142.pdf
APXS	Alpha Particle X-Ray Spectrometer	Fine scale elemental chemistry	Bulk elemental abundance	Gellert, R., J. L. Campbell, P. L. King, L. A. Leshin, G. W. Lugmair, J. G. Spray, S. W. Squyres, and A. S. Yen (2009), The Alpha-Particle-X-Ray-Spectrometer APXS for the Mars Science Laboratory MSL Rover Mission, in 40th Lunar and Planetary Science Conference, p. Abstract #2364, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/lpsc2009/pdf/2364.pdf
ChemCam	Chemistry Camera	Fine scale elemental chemistry; Microscopic Imaging	Remote Fine scale elemental chemistry; panchromatic, focusable, remote microscopic imaging	Maurice, S. et al. (2012), The ChemCam instrument suite on the Mars Science Laboratory MSL rover: science objectives and mast unit description, Space science reviews, 170, 95–166, doi:10.1007/s11214-012-9902-4. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9902-4 Wiens, R. C. et al. (2012), The ChemCam instrument suite on the Mars Science Laboratory MSL rover: Body unit and combined system tests, *Space science reviews*, *170*, 167–227, doi:10.1007/s11214-012-9902-4.
CHEMSENS	Chemical analysis system	Redox Potential; Regolith/Dust Properties	Measure aqueous geochemical soil properties: Ca2+, Mg2+, K+, Na+, NH4+, Cl-, Br-, I-, NO3-, pH, and Ba2; electrical conductivity; oxidation-reduction potential; anodic stripping voltammetry; chronopotentiometry; cyclic voltammetry	Kounaves, S. P., J. M. Bayer, K. M. McElhoney, G. D. O'Neil, and M. H. Hecht (2012), CHEMSENS: A Wet Chemical Analysis Laboratory for Mars, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1010, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1010.pdf
Chirality	Chirality Experiment	Sample Organic Detection	Chirality	Vandendriessche, S., V. K. Valev, and T. Verbiest (2012), Detecting and Analyzing Molecular Chirality on Mars, in Concepts and Approaches for Mars Exploration, p. Abstract #4048, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4048.pdf
CLUPI	Close-Up Imager	Microscopic Imager	Microscopic imager	Josset, J., F. Westall, B. Hofmann, C. Cockell, M. Josset, E. Javaux, and others (2011), CLUPI: the High-Performance Close-up Camera System on board the 2018 ExoMars Rover, in EGU General Assembly 2011, vol. 13, pp. 2011–13365. [online] Available from: http://orbi.ulg.ac.be/bitstream/2268/87493/1/EGU2011-13365.pdf
CW-CRDS	Continuous Wave-Cavity Ring-down Spectrometer	Atmospheric Trace Gas Detection; Isotopic Ratios	Isotopic composition of methane	Chen, Y., T. C. Onstott, K. K. Lehmann, Y. Tang, S. L. Yang, P. Morey, P. Mahaffy, J. Burris, B. Sherwood Lollar, and G. Lacrampe-Couloume (2012), Measurement of the 13C/12C of Atmospheric CH4 Using Near-IR Cavity Ring-Down Spectroscopy, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1109, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1109.pdf
ECAM	ECAM	Context or Descent or Microscopic Imaging	Modular imaging system. A single DVR can control up to four camera heads. A variety of camera heads are available.	Schaffner, J. A., M. A. Ravine, and M. A. Caplinger (2012), Reducing Space-Based Science Instrument Cost and Mass with a Modular Off-the-Shelf System, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1130, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1130.pdf
ECHOS	Electrostatic Charging Hazards Originating from the Surface of Mars	Regolith/Dust Properties; Meteorology; Atmospheric Electricity	Determine electrical properties of saltation clouds; Wind speed/direction near surface; detect lightning; Determine rate of dust devil occurrence; determine atmospheric breakdown potential; define discharge hazards for sharp corners	Farrell, W. M., J. R. Marshall, and G. T. Delory (2012), Electrostatic Charing Hazards Originating from the Surface ECHOS of Mars with Applications to Other Surface/Atmosphere Interfaces, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1060, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1060.pdf
FARCAM	FARCAM	Context Imaging	Imaging	Robinson, M. S., and M. A. Ravine (2012), Telephoto Reconnaissance Imaging for Lunar Rover Applications, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1064, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1064.pdf
Geochronology	In Situ Geochronology	Geochronology; Isotopic Ratios	Geochronology	Plescia, J. B. (2012), In Situ Absolute Age Dating: Sample Return Science at a Discovery Price, in Concepts and Approaches for Mars Exploration, p. Abstract #4159, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4159.pdf
GORILA	Geochemical and Organic analysis by Raman Imaging and Laser Autofluorescence	Fine Scale Mineralogy; Organic Detection	High sensitivity analysis of organic compounds in their mineralogical and spatial context	Bhartia, R., W. F. Hug, L. P. DeFlores, M. D. Fries, R. D. Reid, A. Allwood, W. Abbey, E. C. Salas, and L. Beegle (2012), Finding the Organics: A Compact Non-Conact, Non-Invasive Trace Organic and Mineralogical Mapping Arm Instrument, in Concepts and Approaches for Mars Exploration, p. Abstract #4188, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4188.pdf
GPR	Ground Penetrating RADAR	Subsurface Characterization	Subsurface characterization	Kim, S. S., S. R. Carnes, and C. T. Ulmer (2012), Miniature Ground Penetrating Radar GPR for Martian Exploration: Interrogating the Shallow Subsurface of Mars from the Surface, in Concepts and Approaches for Mars Exploration, p. Abstract #4094, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4094.pdf
In-situ luminescence instrument	In-situ luminescence instrument	Radiation Environment; Geochronology; Sample Mineralogy	Geochronology, mineral identification (mineralogy), and radiation measurements	DeWitt, R., S. W. S. McKeever, M. Lamothe, S. Huot, A. Bell, M. Vila, and K. Zacny (2012), A Mars In-Situ Luminescence Reader for Geochronology, Mineral Identification, and Radiation Measurements, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1019, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1019.pdf
K-Ar Dating Instrument	Laser Ablation Isochron K-Ar Dating Instrument	Geochronology; Isotopic Ratios	Geochronology	Cho, Y., Y. N. Miura, and S. Sugita (2012), Development of a Laser Ablation Isochron K-Ar Dating Instrument for Landing Planetary Missions, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1093, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1093.pdf
K-Ar Geochronology Instrument	In-situ K-Ar Geochronology Instrument	Geochronology; Isotopic Ratios	Geochronology	Hurowitz, J. A., K. A. Farley, N. S. Jacobson, P. D. Asimow, J. A. Cartwright, J. M. Eiler, G. R. Rossman, and K. Wallenberg (2012), A New Approach to In-Situ K-Ar Geochronology, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1146, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1146.pdf

Acronym	Instrument Name	Instrument Category	Measurement Description	References
KArLE	Potassium-Argon Laser Experiment	Geochronology; Isotopic Ratios; Fine scale elemental chemistry	Measure K-Ar isotope Ratios for geochronology	Cohen, B. A., Z.-H. Li, J. S. Miller, W. B. Brinckerhoff, S. M. Clegg, P. R. Mahaffy, T. D. Swindle, and R. C. Wiens (2012), Development of the Potassium-Argon Laser Experiment KArLE Instrument for In Situ Geochronology, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1018, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1018.pdf
LD-MAPI	Laser Desorbtion - Martian Atmospheric Pressure Ionization Mass Spectrometer	Sample Organic Detection; Atmospheric Trace Gas Detection	Detection and identification of potential biomarker compounds	Johnson, P. V., R. Hodyss, and J. L. Beauchamp (2012), Mars Atmospheric Pressure Ionization MAPI of Biomarkers for Mass Spectrometry, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1048, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1048.pdf
LD-TOF-MS	Laser desorption / ionization time-of- flight mass spectrometer	Sample Organic Detection; Sample Mineralogy	Mineralogy, organic detection	Getty, S. A. et al. (2012), Laser Time-of-Flight Mass Spectrometry for Future In Situ Planetary Missions, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1100, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1100.pdf
LMC	Life Marker Chip	Sample Organic Detection	Detect organic molecules in the form of biomarkers	Sims, M. R. et al. (2012), The Life Marker Chip LMC Instrument: Antibody-Based Detection of Organic Molecules and Biomarkers in Martian Samples, in Concepts and Approaches for Mars Exploration, p. Abstract #4306, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4306.pdf
MAA	Mars Acoustic Anemometer	Meteorology	Wind speed, temperature	Banfield, D., and R. W. Dissly (2012), Mars Acoustic Anemometer, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1090, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1090.pdf
MAHLI	Mars Hand Lens Imager	Microscopic Imager	Color imaging at microscopic to landscape-scale using a focusable macro lens.	Edgett, K. S. et al. (2012), Curiosity's Mars Hand Lens Imager MAHLI Investigation, Space science reviews, 170, 259–317, doi:10.1007/s11214-012-9910-4. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9910-4
MastCam	Mast Camera	Context Imaging	Focusable, fixed focal-length, color imaging; stereo possible but focal length limits stereo coverage.	Malin, M. C. et al. (2010), The Mars Science Laboratory MSL Mast-mounted Cameras Mastcams Flight Instruments, in 41st Lunar and Planetary Science Conference, p. Abstract #1123, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/lpsc2010/pdf/1123.pdf
MEEMA	Mars End-to-End Microfluidic Analyzer	Sample Organic Detection	Quantitative compositional analysis of organic material	Willis, P. A., A. M. Stockton, M. F. Mora, M. L. Cable, E. C. Jensen, H. Jiao, and R. A. Mathies (2012a), Mars End-to-End Microfluidic Analyzer MEEMA for Solids, Liquids, and Gases, in Concepts and Approaches for Mars Exploration, p. Abstract #4291, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4291.pdf
MI	Microscopic Imager	Microscopic Imager	Panchromatic, fixed-focus microscopic imaging	Herkenhoff, K. E. et al. (2003), Athena Microscopic Imager investigation, Journal of Geophysical Research: Planets, 108, n/a–n/a, doi:10.1029/2003JE002076. [online] Available from: http://dx.doi.org/10.1029/2003JE002076
Micro-XRF	Micro X-Ray Fluorescence	Fine scale elemental chemistry	High spatial resolution elemental composition	Allwood, A. C., R. Hodyss, and L. Wade (2012), Micro-XRF: Elemental Analysis for In Situ Geology and Astrobiology Exploration, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1138, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1138.pdf
MicrOmega	MicrOmega	Fine Scale Mineralogy	Fine grain structure & mineralogy	Leroi, V., J.-P. Bibring, and M. Berthe (2009), MicrOmega/IR:Design and status of a near-infrared spectral microscope for in situ analysis of Mars samples, *Planetary and Space Science*, *57*, 1068–1075, doi:10.1016/j.pss.2008.12.014. Pilorget, C., J. P. Bibring, M. Berthe, and V. Hamm (2010), MicrOmega IR, An Infrared Hyperspectral Microscope for Space Exploration, in *International Conference on Space Optics*, Rhodes, Greece. Pilorget, C., J. P. Bibring, M. Berthe, and others (2011), MicrOmega: An IR Hyperspectral Microscope for the Phobos Grunt Lander, in *42nd Lunar and Planetary Science Conference*.
MIMA	MIMA Infrared Fourier Spectrometer	Context Mineralogy	Context Mineralogy	Belluccia, G. et al. (2007), MIMA, a miniaturized Fourier infrared spectrometer for Mars groundexploration: part I, concept and expected performance, *Proceedings of SPIE*, *6744*, doi:10.1117/12.737896. Fonti, S., G. A. Marzo, R. Politi, G. Bellucci, and B. Saggin (2007), MIMA, a miniaturized infrared spectrometer for Mars ground exploration: part II, optical design, *Proceedings of SPIE*, *6744*, doi:10.1117/12.737912.Bellucci, G. et al. (2008), MIMA, a miniaturized infrared Fourier spectrometer for Pasteur/ExoMars, in *EGU General Assembly*.
MIMOS IIa	Mossbauer and X-Ray Fluorescence spectrometer	Fine Scale Mineralogy	Characterization of Fe-bearing mineralogy, Fe oxidation states, magnetic properties and chemical composition	Klingelhofer, G., C. Schroder, M. Blumers, R. V. Morris, B. Bernhardt, J. Bruckner, and P. Lechner (2012), MIMOS IIA: A Combined Mossbauer and X-Ray Fluorescence Spectrometer for the In-Situ Analysis of the Moon, Mars, Asteroids and Other Planetary Bodies, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1079, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1079.pdf
Mini-TES	Mini Thermal Emission Spectrometer	Context Mineralogy	Context Mineralogy	Christensen, P. R. et al. (2003), Miniature Thermal Emission Spectrometer for the Mars Exploration Rovers, Journal of Geophysical Research: Planets, 108, ROV 5.1–23, doi:10.1029/2003JE002117. [online] Available from: http://dx.doi.org/10.1029/2003JE002117
MMI	Multispectral Microscopic Imager	Fine Scale Imaging and Mineralogy	Multispectral microscopic imagery; mineralogy	Nunez, J. I., J. D. Farmer, and R. G. Sellar (2012), The Multispectral Microscopic Imager: A Compact, Contact Instrument for the In Situ Petrologic Exploration of Planetary Surfaces, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1158, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1158.pdf
MMRS	Mars Microbeam Raman Spectrometer	Fine Scale Mineralogy	Identify and characterize organic and inorganic molecules; fine grained mineralogy	Wang, A., and J. L. Lambert (2012), Characterization of Planetary Surface Materials by In Situ Laser Raman Spectroscopy, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1157, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1157.pdf
MOMA	Mars Organic Molecule Analyzer	Sample Organic Detection	Detect organic molecules, at ppb to ppt concentrations. Establish the biotic or abiotic origin of molecules by molecular identification in terms of chirality.	Brinckerhoff, W. B., F. H. W. van Amerom, R. M. Danell, V. Pinnick, R. Arevalo, M. Atanassova, X. Li, P. R. Mahaffy, R. J. Cotter, and M. Team (2012), Mars Organic Molecule Analyzer Mass Spectrometer for 2018 and Beyond, in Concepts and Approaches for Mars Exploration, p. Abstract #4236, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4236.pdf Steininger, H., E. Steinmetz, D. K. Martin, B. Lustrement, F. Goesmann, W. B. Brinckerhoff, P. R. Mahaffy, F. Raulin, R. J. Cotter, and C. Szopa (2012), Mars Organic Molecule Analyzer MOMA Onboard ExoMars 2018, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1116, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1116.pdf

Acronym	Instrument Name	Instrument Category	Measurement Description	References
NERNST	Next Generation Wet Chemical Laboratory	Redox Potential	Cation & halide concentrations, pH, Oxidation-reduction potential	Quinn, R. C., A. D. Aubrey, M. H. Hecht, F. J. Grunthaner, M. C. Lee, G. D. O'Neil, and L. DeFlores (2012a), MECA Wet Chemistry: The Next Generation., in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1143, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1143.pdf
NetStation GPR	NetStation Ground Penetrating RADAR	Subsurface Characterization	Conduct geologic and volatile-related investigations of planetary environments in both the near- and deep-subsurface (~10 - 1000 m); in-situ water or water ice resources; stratigraphy and structure of the subsurface;	Ciarletti, V., S. M. Clifford, D. Plettemeier, A. LeGall, and M. Biancheri-Astier (2012b), The NetStation GPR: A Tool for Conducting Lander-Based 3-D Investigations of Planetary Subsurface Structure, Stratigraphy, and Volatile Distribution, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1053, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1053.pdf
NS	Miniature Nuclear Spectrometer	Fine scale elemental chemistry	Bulk elemental composition	Lawrence, D. J., P. N. Peplowski, R. C. Elphic, J. O. Goldsten, and K. T. Tyagi (2012a), Miniature Nuclear Spectrometers for Measuring Surface Composition and Near-Surface Composition Stratigraphy, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1096, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1096.pdf Lawrence, D. J., P. N. Peplowski, R. C. Elphic, J. O. Goldsten, and K. T. Tyagi (2012b), Miniature Nuclear Spectrometers For Measuring the Surface Composition and Near-Surface Composition Stratigraphy on Mars and its Moons, in Concepts and Approaches for Mars Exploration, p. Abstract #4340, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4340.pdf
OA-ICOS	Off-Axis Integrated Cavity Output Spectroscopy	Atmospheric Trace Gas Detection; Isotopic Ratios	Measure methane and hydrocarbons (similar to Tunable Laser Spectrometer)	Bebout, B. M., N. E. Bramall, C. A. Kelley, J. P. Chanton, A. Tazaz, J. Poole, B. Nicholson, A. Detweiler, M. Gupta, and A. J. Ricco (2012), Methane as an Indicator of Life on Mars: Necessary Measurements and Some Possible Measurement Strategies, in Concepts and Approaches for Mars Exploration, p. Abstract #4205, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4205.pdf
Pancam	Panoramic Camera	Context Imaging	Color stereo imaging	Bell, J. F. et al. (2003), Mars Exploration Rover Athena Panoramic Camera Pancam investigation, Journal of Geophysical Research: Planets, 108, doi:10.1029/2003JE002070. [online] Available from: http://dx.doi.org/10.1029/2003JE002070
Phase Contrast X-Ray Micro-Imager	Phase Contrast X-Ray Micro-Imager	Microscopic Imager	Nondestructive, high sensitivity imaging of microscopic textures and biosignatures. Mapping of trapped water.	Hu, Z. W. (2012), Phase Contrast X-Ray Micro-Imaging: A Potentially Powerful Tool for In Situ Analysis and Sample Return Missions from Mars, Asteroids, Comets, and the Moon, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1148, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1148.pdf
PING	Probing In situ with Neutrons and Gamma rays	Fine scale elemental chemistry	Measure bulk elemental composition of the subsurface to a depth of 0.3 - 1 m	Parsons, A. M. (2012), Complete Subsurface Elemental Composition Measurements with PING, in Concepts and Approaches for Mars Exploration, p. Abstract #4279, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4279.pdf Parsons, A. M., J. G. Bodnarik, L. G. Evans, T. P. McClanahan, M. Namkung, S. F. Nowicki, J. S. Schweitzer, R. D. Starr, and J. I. Trombka (2012), High Sensitivity Subsurface Elemental Composition Measurements with PING, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1089, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1089.pdf
PISCES	Planetary In-Situ Capillary Electrophoresis System	Sample Organic Detection	Perform a suite of chemical analyses with parts per trillion sensitivity; amine, amino acid, short peptide, aldehyde, ketone, carboxylic acid,	Willis, P. A., A. M. Stockton, M. F. Mora, M. L. Cable, N. E. Bramall, E. C. Jensen, H. Jiao, E. Lynch, and R. A. Mathies (2012b), Planetary In Situ Capillary Electrophoresis System PISCES, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1038, Lunar and Planetary Institute, Houston. [online] Available from:
PROMIS	Portable, Rugged Optical and Mass Instrument Suite	Fine scale elemental chemistry; Sample Mineralogy; Contact organic detection	Fully integrated, multi-functional, miniature laboratory that incorporates laser-induced fluorescence (LIF), Raman, laser-induced breakdown spectroscopy (LIBS), and mass spectrometry for both solids (i.e., laser desorption (LD)) and gases (i.e., gas chromatography (GC))	Scott, J. R., B. Beardsley, G. S. Groenewold, S. Lammert, E. Lee, T. R. McJunkin, G. Ritchie, J. Almirall, and L. Becker (2012), Integrated Portable, Rugged Optical and Mass Instrument Suite PROMIS for Geologic, Biologic, and Organic Signature Characterization for Space Exploration, in Concepts and Approaches for Mars Exploration, p. Abstract #4255, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4255.pdf
RAD	Radiation Assessment Detector	Radiation Environment	Measure neutrons with directionality	Hassler, D. et al. (2012), The Radiation Assessment Detector RAD investigation, Space science reviews, 170, 503–558, doi:10.1007/s11214-012-9913-1. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9913-1
Raman/LIBS	Combined Raman & Laser Induced Breakdown Spectrometer	Fine Scale Mineralogy	Mineralogy	Blacksberg, J., Y. Maruyama, M. Choukroun, E. Charbon, and G. R. Rossman (2012), Combined Raman and LIBS for Planetary Surface Exploration: Enhanced Science Return Enabled by Time-Resolved Laser Spectroscopy, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1044, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1044.pdf
RASIR	Reactivity Analyzer for Soil, Ices, and Regolith	Sample Organic Detection; Redox Potential	Measure organic content and chemical reactivity of surface samples	Quinn, R. C., A. J. Ricco, P. Ehrenfreund, F. Grunthaner, O. Santos, A. Zent, J. W. Hines, and E. Agasid (2012b), Reactivity Analyzer for Soil, Ices, and Regolith, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1127, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1127.pdf Quinn, R. C., A. J. Ricco, P. Ehrenfreund, F. Grunthaner, O. Santos, A. Zent, J. Hines, and E. Agasid (2012c), Reactivity Analyzer for Soil, Ices, and Regolith RASIR, in Concepts and Approaches for Mars Exploration, p. Abstract #4177, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4177.pdf
Rb-Sr Dating & Life Detection Instrument	In-Situ Rb-Sr Dating & Life Detection Instruments	Sample Organic Detection; Isotopic Ratios; Geochronology	Analysis of biotic & abiotic chemistry; Rb-Sr isotope Ratios for geochronology; mineralogy; K-AR isotope Ratios for geochronology; organic molecule detection; chirality	Anderson, F. S., J. H. Waite, J. Pierce, K. Zacny, G. Miller, T. Whitaker, K. Nowicki, and P. Wilson (2012), An In-Situ Rb-Sr Dating and Life Detection Instrument for a MER+ Sized Rover: A MSR Precursor, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1152, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1152.pdf
REMS	Rover Environmental Monitoring Station	Meteorology	Pressure at surface	Gómez-Elvira, J. et al. (2012), REMS: the environmental sensor suite for the Mars Science Laboratory rover, Space science reviews, 170, 583–640, doi:10.1007/s11214-012-9921-1. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9921-1
SAM	Sample Analysis at Mars	Sample Organic Detection; Atmospheric Trace Gas Detection	Habitability investigation; abundance of C, H, N, O, P, S; identify carbon compounds; geochemistry	Mahaffy, P. R. et al. (2012), The sample analysis at Mars investigation and instrument suite, Space science reviews, 170, 401–478, doi:10.1007/s11214-012-9879-z. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9879-z

Acronym	Instrument Name	Instrument Category	Measurement Description	References
SETG	Search for Extraterrestrial Genomes	Sample Organic Detection	In-situ metagenomic or targeted sequencing of RNA, DNA, or other nucleic acid polymers	Carr, C. E., G. Ruvkun, and M. T. Zuber (2012), Beyond RNA and DNA: In-Situ Sequencing of Informational Polymers, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1136, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1136.pdf
Strata	Strata Ground Penetrating RADAR	Subsurface Characterization	Subsurface characterization, properties, subsurface imaging	Grant, J. A., C. J. Leuschen, and P. S. Russell (2012a), The Strata Ground Penetrating Radar: Constraining the Near Surface Properties of Mars, in Concepts and Approaches for Mars Exploration, p. Abstract #4074, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4074.pdf Grant, J. A., C. J. Leuschen, and P. S. Russell (2012b), The Strata Ground Penetrating Radar: Constraining the Near Surface Properties of Solar System Bodies, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1003, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1003.pdf
TDEM	Time-Domain Electromagnetic Sounder	Subsurface Characterization	Large-scale and shallow sub-surface structure	Grimm, R. E. (2012), Low-Frequency Electromagnetic Methods for Multi-Scale Subsurface Planetary Exploration, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1031, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1031.pdf
TLS	Miniature Tunable Laser Spectrometer	Atmospheric Trace Gas Detection	Atmospheric trace gasses	Webster, C. R., G. J. Flesch, L. Christensen, D. Keymeulen, and S. Forouhar (2012), Miniature Tunable Laser Spectrometers for Quantifying Atmospheric Trace Gases, Water Resources, Earth Back-Contamination, and In Situ Resource Utilization, in Concepts and Approaches for Mars Exploration, p. Abstract #4229, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4229.pdf
TLS	Tunable Laser Spectrometer	Atmospheric Trace Gas Detection; Isotopic Ratios	Atmospheric composition: detection of H_2O, CO_2, and CH_4; some isotopic Ratios	Mahaffy, P. R. et al. (2012), The sample analysis at Mars investigation and instrument suite, Space science reviews, 170, 401–478, doi:10.1007/s11214-012-9879-z. [online] Available from: http://dx.doi.org/10.1007/s11214-012-9879-z
TLS + AA	Tunable Laser Spectrometer + Acoustic Anemometer Turbulent Eddy Flux Instrument	Meteorology; Atmospheric Trace Gas Detection; Isotopic Ratios	Temperature, humidity, wind, turbulent eddy heat flux, methane flux, moisture flux	Rafkin, S., D. Banfield, R. Dissly, J. Silver, A. Stanton, E. Wilkinson, W. Massman, and J. Ham (2012), An Instrument to Measure Turbulent Eddy Fluxes in the Atmosphere of Mars, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1119, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1119.pdf
TOF MS	Time of Flight Mass Spectrometer	Sample Organic Detection; Atmospheric Trace Gas Detection; Isotopic Ratios	Mass spectra of ions	Miller, G. P., J. H. Waite, and D. T. Young (2012), A High-Resolution, Multipass Time-of-Flight Mass Spectrometer for Investigation of Elemental, Isotopic and Molecular Compositions, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1144, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1144.pdf
Triboelectric Sensor	Triboelectric Wheel Regolith Sensor	Regolith/Dust Properties; Atmospheric Electricity	Amount of electrical charge that develops on a polymer through frictional contact as the rover wheel rolls over the Martian regolith, regolith surface charge density as the rover wheel rolls over the Martian surface.	Calle, C. I. (2012), Sensors to Characterize the Properties of the Martian Regolith, in Concepts and Approaches for Mars Exploration, p. Abstract #4206, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4206.pdf
UCIS	Ultra-Compact Imaging Spectrometer (Vis/NearIR Spectrometer)	Context Mineralogy	Context Mineralogy	Blaney, D. L., P. Mouroulis, R. O. Green, J. Rodriquez, G. Sellar, B. Van Gorp, and D. Wilson (2012), The Ultra Compact Imaging Spectrometer UCIS, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1105, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1105.pdf
VNIS	Visible/Near IR Spectrometer	Fine Scale Mineralogy	Mineralogy	Liu, B., J. Z. Liu, G. L. Zhang, Z. C. Ling, J. Zhang, Z. P. He, and B. Y. Yang (2012), Reflectance Conversion Methods for the VIS/NIR Imaging Spectrometer VNIS Aboard the Chang'E-3 Lunar Rover: A Preliminary Investigation, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1007, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1007.pdf
WISDOM	Water Ice Subsurface Deposit Observation on Mars	Subsurface Characterization	Investigate Mars subsurface stratigraphy and presence of water ice	Ciarletti, V., S. M. Clifford, D. Plettemeier, N. Mangold, E. Petinelli, A. Herique, W. Kofman, and E. Heggy (2012a), Analyzing the Shallow Martian Subsurface with the WISDOM GPR, in Concepts and Approaches for Mars Exploration, p. Abstract #4201, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4201.pdf Ciarletti, V., D. Plettemeier, S. M. Clifford, P. Cais, A. Herique, W. Kofman, and S. E. Hamran (2012c), WISDOM a GPR for the ExoMars Rover Mission, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1126, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1126.pdf
XRF	Ultra-trace X-Ray Fluorescence	Fine scale elemental chemistry	Measure all elements from Na+	Tickner, J. R., G. J. Roach, J. O'Dwyer, and Y. Van Haarlem (2012), Ultra-Trace X-Ray Analysis of Martian Rocks and Soils Using Low-Cost Commodity Hardware, in Concepts and Approaches for Mars Exploration, p. Abstract #4120, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/marsconcepts2012/pdf/4120.pdf
		Sample Organic Detection; Isotopic Ratios	Measure isotopic fractionation and chirality in organic molecules	Waite, J. H. J., and M. Libardoni (2012), Multi-Dimensional Life Detection, in International Workshop on Instrumentation for Planetary Missions, p. Abstract #1128, Lunar and Planetary Institute, Houston. [online] Available from: http://www.lpi.usra.edu/meetings/ipm2012/pdf/1128.pdf

Appendix 5: Strawman Payload

1. Straw Payload Example Instruments

Fine-Scale Imaging Options		
	MArs Hand Lens Imager (MAHLI)	Multispectral Microscopic Imager
Sensitivity	Ability to determine fine rock and regolith textures (grain size, crystal morphology), detailed context, in color, day or night.	Identify selected mineral classes, especially Fe-bearing phase; submilimeter scale details, texture & structure
Field-of-View / Spatial Resolution	• CCD format 1600 x 1200 pixels • adjustable focus at working distances 2.1 cm to infinity *examples* • 14 µm/pixel and 21 x 17 mm coverage at 2.1 cm. • 31 µm/pixel and 50 x 37 mm coverate at 6.8 cm. • 95 µm/pixel and 152 x 114 mm coverage at 25 cm. • 360 µm/pixel and 574 x 431 mm at 1 m.	40 x 32 mm FOV 640 x 512 pixels 62.5 µm/pixel
Wavelength Range / Spectral Resolution	395 nm – 670 nm bandpass with red, green, blue Bayer Pattern microfilters	0.45 – 1.75 µm; 21 bands with multiwavelength LED illuminator
Operational Constraints		Sunshade required to shade from direct sunlight
Dependencies	Standoff required	Standoff; current design is fixed focus

Spectroscopic Organic Measurement Techniques				
	Green Raman	Laser Induced Native Fluorescence	UV/Vis	FTIR
Detection Limit (weight C / weight sample)	10 – 100 ppm (~0.001 ppb if using resonance effects of specific molecules)	Single bacterial Cell 0.001 ppb	~20ppm	~> 100 ppm
Detectable types of OM	Molecular bonds C=O, C-C, C-H etc	Molecular bonds Compound specific fluorescence i.e.PAHs	Molecular bonds Compound specific information (PAHs, pigments)	Molecular bonds C=O, C-C, C-H etc
Spatial Resolution	~20 micron spot	~1 micron	~ millimeter range	~20 micron
Operational Constraints	Low light levels/overnight; needs more-flat surface	Low light levels/overnight; needs more-flat surface		
Dependencies	Objective, wavelength and power dependent. Molecule dependent resonance effects.	Objective and power dependent. Molecule dependent resonance effects.	Developed for remote deployment. Coupled to LINF.	Reflection systems integration time dependent

Remote/Recon Mineralogy Instruments			
	Thermal Emission Spectrometer	Vis/NIR Imaging Spectrometer	Fourier Transform IR Spectrometer
Sensitivity	5% mineral abundances	Ability to identify mineralogy(clays, sulfates, carbonates, etc.) (TBD sensitivity)	Identify carbonates, sulphates, phyllosilicates, evaporites and phosphates, manganese oxides and carbonates.
Spatial Resolution	8 mrad (Point measurement)	512 mrad x 2 mrad FOV 2 mrad/pixel	~55 mrad (Point measurement)
Wavelength Range / Spectral Resolution	5—29 µm; 5 cm^{-1} spectral resolution	0.5 – 2.6 µm; 210 bands, 10 nm spectral resolution	2 – 25 µm; 5 cm^{-1} spectral resolution for atmospheric sounding, 10 cm^{-1} spectral resolution for geologic mapping
Operational Constraints		~30 min integration time for full panorama	
Dependencies		Detector cooling	

Fine Scale Fine scale elemental chemistry Instruments			
	Alpha Particle X-Ray Spec.	Laser-Induced Breakdown Spec.	X-Ray Fluorescence Spec.
Sensitivity	Na – Ba with ~20-100 ppm sensitivity • 100 ppm for Ni and ~ 20 ppm for Br in 3 hours; • ~ 0.5% abundance, such as Na, Mg, Al, Si, Ca, Fe, or S, can be done in ~10 minutes	Sensitive to nearly all elements (H-Pb) • < 100 ppm for alkali and alkali earth elements (e.g. Li, Sr, and Ba) • ~5-10% for halogens (Cl, F, etc.)	Na-U with ~10 ppm sensitivity
Field-of-View / Spatial Resolution	15 mm point meas.	RMI: 19 mrad FOV, 1024 x 1024 pixels; LIBS: 0.3 to 0.6 mm spot size	100 – 200 µm point meas. (Can be scanned to build up grid)
Wavelength Range / Spectral Resolution	768 bands, 0.5 keV to 25 keV	240—850 nm spectral range; 6144 bands; 0.09 to 0.30 nm spectral resolution	TBD
Operational Constraints	3 hour integration time for 100 ppm; 10 minutes for ~0.5% abundance	Short integration time; requires precise mast movement	Short integration time
Dependencies	Standoff distance; X-ray source intensity	Standoff distance, laser power	Standoff distance; power of X-ray source; raster scanning capability

Fine Scale Elemental Mineralogy Measurement Options		
	Green Raman (Compact Integrated Raman Spectrometer - CIRS)	Near Infrared Microscope (MicrOmega)
Sensitivity	Identify major, minor, and trace minerals, obtain their approximate relative proportions, and determine chemical features (e.g., Mg/Fe ratio) and rock textural features (e.g., mineral clusters, amygdular fill, and veins)	Identify, at grain scale, most potential constituents: silicates, oxides, salts, hydrated minerals, ices and frosts, as well as organic compounds, discriminating between specific members in each family
Field-of-View / Spatial Resolution	Raman: <20 μm spot size; ~1 cm linear traverse; Camera: 15-20 micron/pixel	5mm x 5mm FOV 256 x 256 pixels 20 μm/pixel
Wavelength Range / Spectral Resolution	200–4000 cm^{-1} spectral range; ~7 cm^{-1} spectral resolution; 532 nm laser source	0.9 to 3.5 μm, and its spectral sampling of ~ 20 cm^{-1}
Operational Constraints	Sunshade or nighttime operations may be needed	
Dependencies	Thermal cycling for arm-mounted laser; Radiation degradation of optics (due to RTG radiation source)	Redesign from lab-contained instrument

Organic Measurement Techniques		
	Green Raman	Deep UV Raman
Detection Limit (weight C / weight sample)	10 – 100 ppm (~0.001 ppb if using resonance effects of specific molecules)	TBD
Detectable types of OM	Molecular bonds C=O, C-C, C-H etc	Molecular bonds, hydrated minerals, complex organics
Field-of-View / Spatial Resolution	Raman: <20 µm spot size; ~1 cm linear traverse; Camera: 15-20 micron/pixel	100 micron spot size
Wavelength Range / Spectral Resolution	200–4000 cm^{-1} spectral range; ~7 cm^{-1} spectral resolution; 532 nm laser source	Laser wavelength: <250 nm; Spectral resolution: up to 1 cm^{-1}
Operational Constraints	Low light levels/overnight; needs more-flat surface	Low light levels/overnight
Dependencies	Thermal cycling for arm-mounted laser; Radiation degradation of optics (due to RTG radiation source)	Objective and power dependent. Molecule dependent resonance effects.

2. In-Situ Resource Utilization (ISRU): Oxygen Production from Atmosphere

Description

- Dust filtration & non-intrusive measurement during Mars carbon dioxide (CO_2) capture
- CO_2 collection via CO_2 freezing (Option: rapid-cycle adsorption pump)
- Oxygen (O_2) and fuel production from CO_2 via Reverse Water Gas Shift/Water Electrolysis and Sabatier (Options: Microchannel reactors and Solid Oxide Electrolysis)
- Produce small quantities of O_2 and analyze O_2 purity (TBD instrument)

Rationale

- ISRU can greatly reduce mass transported to the Martian surface.
- Mars carbon dioxide can be acquired at all locations on Mars with technologies similar to life support

Measurement detail

- CO_2 collection rate: 0.011 - 0.045 kg/hr.
- Analyze dust particle size/shape and number density during CO_2 collection
- O_2 production rate: 0.015 kg/hr

Resources needed

- Mass: 10-20 Kg
- Power: 50-150 W
- Cost: $20 -25M for Dust/$CO_2$ Capture
- $50-55M for Dust/$CO_2$ Capture & O_2/Fuel production
- Operational concept: Operate 7 to 8 hrs per sol.
- Operate as many Sols as possible

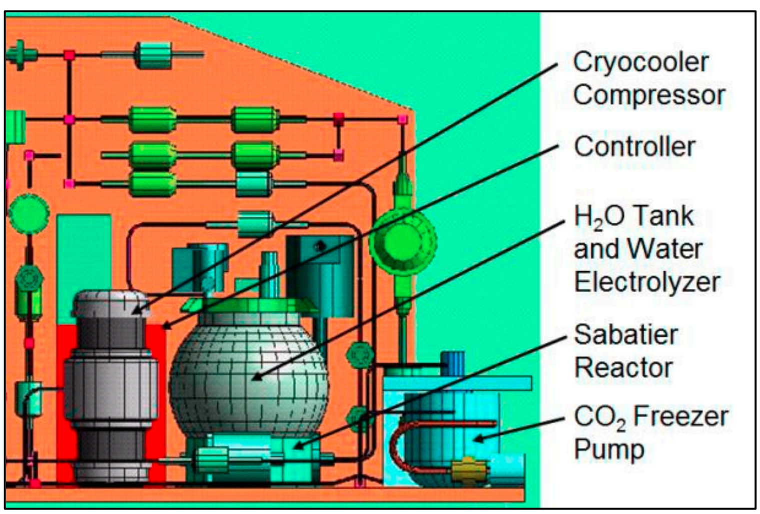


Figure Appx 5-1. Instrument concept for ISRU

3. MEDLI+

Description

- Reflight of MEDLI with some pressure and temperature sensors moved to afterbody.
- Corroborate MEDLI data in areas where the results were contrary to original predictions.
- Add new technology sensors (surface heat flux, catalysis, time-dependent recession).
- Uplooking camera to observe parachute inflation (optional)

Rationale

- Validate Mars atmospheric models and thermal protection system performance to design aerocapture, EDL, aerobraking and launch systems

Measurement detail

- Temperature, pressure, and recession sensors on heat shield and afterbody

Resources needed

- MEDLI as built:
    - Mass: 15.1 kg
    - Power: 10 W
    - Cost: $19.7M; $30M with camera
- Operational concept: Operates during EDL

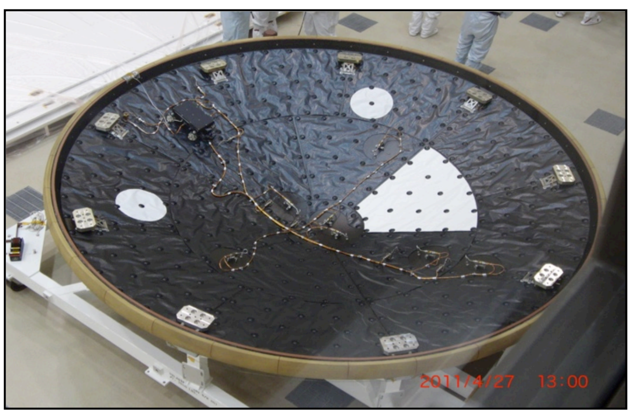


Figure Appx 5-2. MEDLI on MSL heat shield

4. Biomarker Detector System

Description

- Signs of Life Detector (SOLID) has been developed to detect extant life in planetary bodies.
- Sample processing involves solvent extraction of molecular biomarkers by means of sonication in the Sample Preparation Unit (SPU). Measurement is based on fluorescent antibody microarray technology in the Sample Analysis Unit (SAU). Large heritage from research, clinical and biotech sectors.
- Capability to interrogate for more than 500 molecular biomarkers in a single assay, starting from a particulate sample (soil, sediment or ice).
- SOLID has proven sensitivities down to 1-2 ppb (ng/mL) for peptides and proteins, and 10^3-10^4 cells or spores per mL.
- SOLID can be used for extraterrestrial life detection by targeting universal biomarkers such as amino acids, polymers, polysaccharides, whole cells and microbial spores.
- SOLID can also be used for Planetary Protection to monitor forward contamination during robotic/human operations in an extraterrestrial.

Rationale

- Determine if Martian environments contacted by humans are free of biohazards that might have adverse effects on exposed crew, and on other terrestrial species if uncontained Martian material would be returned to Earth.
- Do not know extent to which terrestrial contaminants introduced at a possibly inhospitable landing site could be dispersed into more hospitable sites.

Measurement detail

- Detect biomarkers present in Earth life (e.g., amino acids, peptides) that might also be components of Mars life, at concentrations relevant to contamination limits for Mars Sample Return

Resources needed

- Mass: 7.4 kg
- Volume: 10 L
- Power: 12 W avg; 50 W peak
- Requires sampling system
- Cost: $26M ($13M NASA; $13M co-funding from Spain)

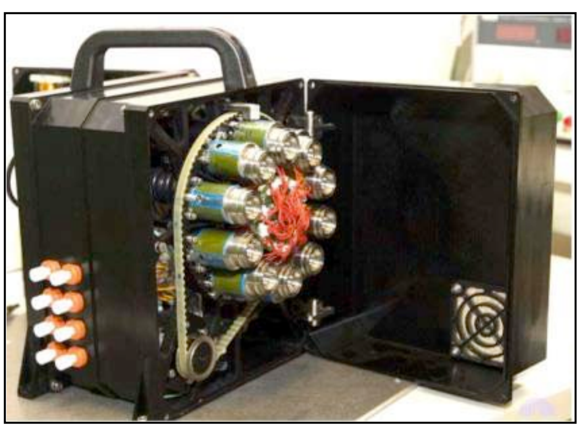


Fig. Appx 5-3. Biomarker Detector System. Left: SOLID Sample Preparation Unit. Right: SOLID Sample analysis unit

5. Surface Weather Station

Description

- REMS follow on for P, T, winds, humidity.
- Mini-TES or MCS like instrument for vertical T profiles. Deck or mast mounted, upward looking.
- Pancam with sun filters for total aerosols.
- LIDAR for aerosol profiles.

Rationale

- Provide density for EDL and ascent profiles, and validation data for global atmosphere models, in order to validate global model extrapolations of surface pressure
- Provide local-surface and near-surface validation data for mesoscale and large eddy simulation models in order to validate regional and local model atmospheric conditions.

Measurement detail

- Surface Pressure with a precision of 10^{-2} Pa; Surface meteorological packages (including T, surface winds, relative humidity, aerosol column); both for Full diurnal cycle, Sampling rate > 0.01 Hz, for multiple Martian years.
- Upward-looking, high vertical resolution T & aerosol profiles below ~10 km; Sun tracking visible (near UV/IR) filters

Resources needed

- REMS as built:
    - Mass: 1.3 kg
    - Power: 19 W
    - Data Volume: ~1.6 MBytes/sol
    - Cost: $19.3M
- Operational concept: Sampling (approximately 24 times a day)

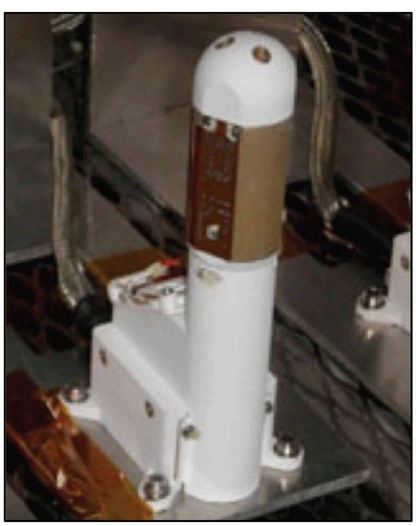


Fig Appx 5-4. Rover Environmental Monitoring Station (REMS)

6. Instrument Cost Estimation

A key constraint specified by the SDT charter was that the total cost of the instruments should be less than $100M (of which it is assumed for planning purposes that share of this budget to come from SMD would be $80M, with $20M contributed from some other entity). In order to build the strawman payload (Table 5-3 above), the SDT therefore required instrument cost estimates. As requested by the charter, the SDT turned to the Mars 2020 Project team for notional instrument costing assessments. For the purpose of this planning, it makes no difference which instruments are contributed, and which are U.S.-sourced, so neither the SDT nor the Project speculated on this.

Cost Estimation Procedure

For instruments that had very clear heritage (examples included APXS and Mastcam), the as-built/as-flown costs were inflated and adjusted based on available heritage or new functionality. Most of the other instruments were assessed using mass and power characteristics inputs into the NASA Instrument Cost Model (NICM) (Version 5 May 2012) database. NICM is a standard NASA instrument costing tool with a database of 140 instruments. Where previous costing work existed (examples include Green Raman), and/or where other analogous instrument data was available, that information was considered as well. In each case, the payload and project management adjusted costs based on our best understanding of TRL levels, technology challenges, MSL heritage compatibility, and previous development experience. The Project also had access to two additional costing models, PRICE and SEER, in the event that NICM and as-built analogs were not available or appropriate references - however, the Project did not find the need to use these models.

The estimated costs were targeted to be reasonable ROMs, but not worse case. The estimates included anticipated expenditure of reserve, although this was easier to estimate on instruments with clear as-built analogies. Accommodation assessments included mass, volume, and power margins based on instrument maturity. However, the cost to the flight system for accommodation was not included in the payload cost. Where instruments appeared to be incompatible with MSL heritage systems, alternate instruments were selected or the instrument cost estimates were increased under the assumption that significant modifications may be required.

Two alternate instrument payload suites were submitted for cost estimation (see Table 5-3 above). The estimated cost of the two suites were identical within the estimated error of the assessment. This provided a notional cross-check on the total aggregated costs for the totality of the instrumentation required to meet the stated objectives. In general, while any individual instrument cost assessment may have been too high or too low, the likelihood of the aggregated suite of instruments being substantially higher or lower than the estimated costs would be more limited.

The cost of the HEOMD candidate payloads was estimated by HEOMD personnel, not by the Mars 2020 Project. The Project did not review any cost estimation work done by either HEOMD or STMD. The project did make an estimate a $5M+ for accommodation costs of the IRSU CO2 experiment. This is likely to be the lowest possible accommodation cost for this instrument based on MSL RAD costs. Since the SDT charter does not place a constraint on the maximum amount of money to be contributed by either HEOMD or STMD, the estimated cost of these payloads played no role in SDT deliberations.

Appendix 6: Candidate Landing Site Supporting Information

Maps of Mars showing the distribution of candidate landing sites proposed and evaluated for MSL and additional sites proposed to calls for future missions (top) and sites proposed to MSL indicating the final four candidate sites for that mission (bottom). These sites were reviewed to establish the Reference Sites for the 2020 mission. Red lines in the top panel help define where proposed sites occur relative to latitudes of 30 degrees north and south of the equator. Areas indicated as black in the top panel are above +1 km elevation, whereas those in the lower panel are above 0 km elevation. The sites indicated by numbered dots in the top panel are listed in Table A6-1 that follows.

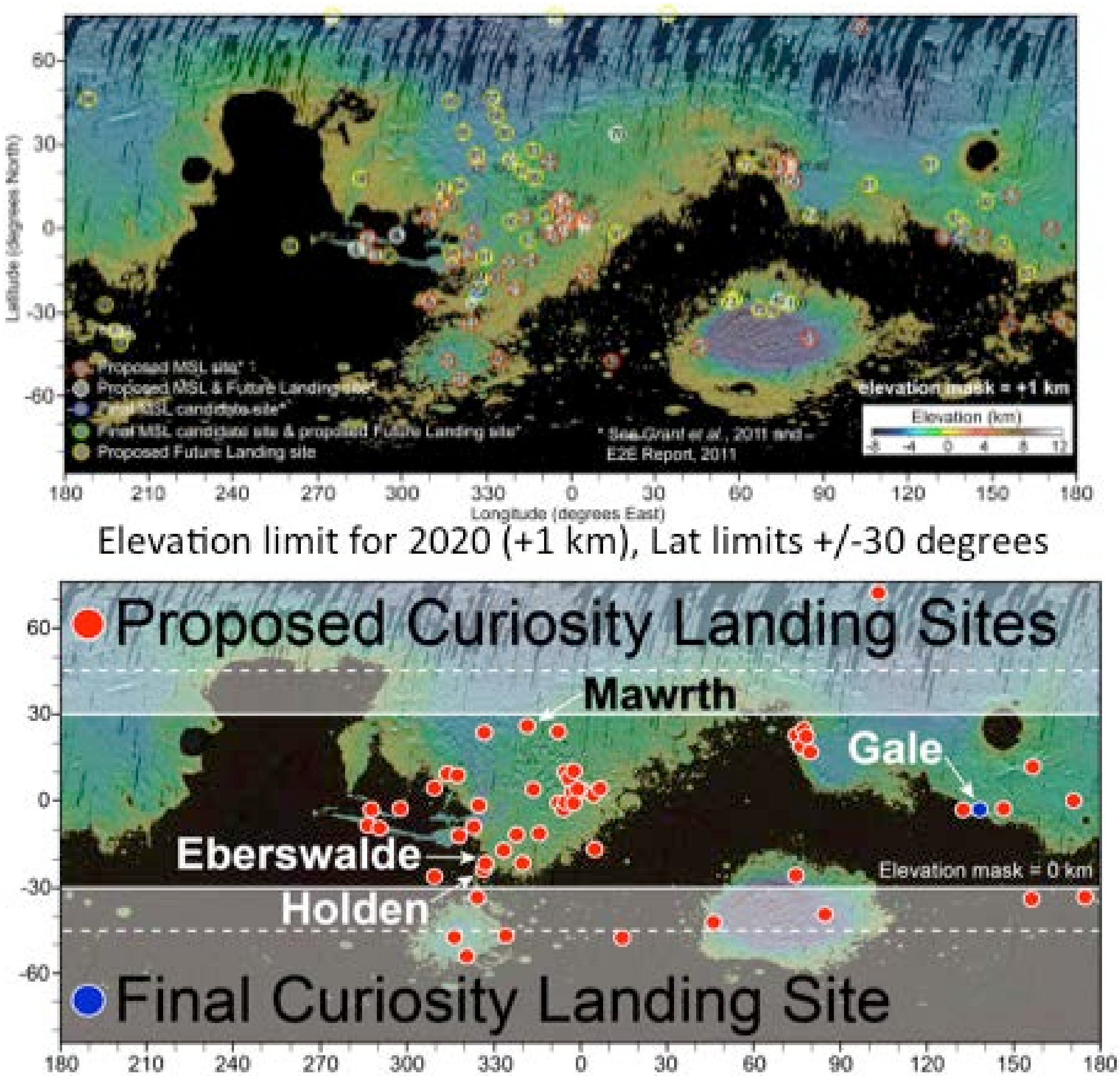


Table A6-1 lists the candidate landing sites for MSL and proposed to calls for candidate sites for future missions that were reviewed to establish Reference Sites for the proposed 2020 mission. Table A6-1 indicates the number corresponding to the dot in the map above, the site name (and multiple ellipses where applicable), site location, elevation, and brief description of the target materials and is generally sorted by lowest to highest elevation. Exceptions exist, however, where relief in the vicinity of a candidate site results in multiple elevations for the site or for some sites proposed for future missions (at the end) where the elevation was not available.

Table A6-1. Candidate Landing sites proposed for MSL and for future missions.

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
76	N. Hellas rim	-29.537	70.844	-6	resolve layering along northern rim of Hellas, correlate with Terby layers
		-29.875	71.844	-5.9	correlate layers on northern rim of Hellas with Terby
51	Dao Vallis	-38.9	81.2	-6.0	valley terminus, layered deposits
		-39.5	82.7	-6.0	
		-41.2	84.4	-6.0	
		-40.7	85.6	-5.4	
		-41.7	85.8	-5.4	
		-43.3	86.8	-5.4	
3	Eastern Melas Chasma	-11.6	290.5	-5.8	layered deposits
75	N. Hellas rim	-29.0545	67.628	-5.8	layered deposits
		-29.1215	66.701	-5.4	
97	Coprates Chasma	-12.3575	295.958	-5	landing ellipse; exposure of light toned layered floor material
		-12.167	295.647	-5	central Mons of the canyon exposing crustal bedrock enriched in Low Calcium Pyroxenes and possibly in phyllosilicates Iimage is located 2 kilometers north to the landing ellipse.
		-12.588	296.087	-5	landing ellipse; exposure of light toned layered floor material
42	Terby crater	-27.4	73.4	-4.7	hydrated layered deposits (lacustrine?), fluvial and ice-related morphology
		-27.6	74.0	-4.7	
		-28.0	74.1	-4.5	ancient basin bedrock
67	Acidalia Mensa	44.74	331.72	-4.8	Mound (interpreted as mud volcano) cut by polygon
		46.7	331.12	-4.5	
49	Nili Fossae	21.9	78.9	-4.5	layered phyllosilicates under sulfates

	carbonate plains	2.17544	78.6099		western carbonate plains
		21.6013	78.5413		
		21.5093	78.6511		
		21.7416	79.0604		
		21.9456	78.6978		
54	Gale crater[i]	-4.6	137.4	-4.5	layered deposits, exhumed channels
		-5.7	137.6	-3.6	
68	Acidalia Planitia	40.08	333.27	-4.5	Densly occurring mounds (mud volcanoes)
		40.67	332.32	-4.5	
		44.53	317.3	-4	thumbprint terrain (mud volcanoes)
Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
87	Northeast Chryse: Diapiric Mounds - Ghost Crater	33	336.63	-4.1	large mounds associated with rim of ghost crater may represent hydrothermal diapirism in lacustrine setting, possibly involving involve fluid movement from great depth.
		32.91	336.76	-4.1	
95	Amazonis	46.16	188.79	-4.03	Subsurface access into ground ice; Mid-Amazonian age outflows.
14	Valles Marineris	-3.8	324.6	-4.0	floor/walls
52	Vastitas Borealis	70.5	103.0	-4.0	salt, ice/impact tectonics
66	Northern Chryse	32.2	322.7	-4	mud flow mounds
85	Northern Chryse: Diapiric Mounds - Ghost Crater (site 1)	33.87	321.86	-3.95	large possible diapiric mounds
84	South Central Chryse: Diapiric Mounds - Simud Chaos (site 2)	33.84	322	-3.95	large mounds (thought to be diapiric in nature)
		14.77	320.86	-3.9	Large mounds associated with rim of ghost crater may represent hydrothermal diapirism in lacustrine setting, possibly involving fluid movement from great depth.
86	Central Chryse: Linear Trend of Diapiric Mounds	25.06	327.01	-3.893	large possible diapiric mounds
		26.3	326.27	-3.887	
		25.98	326.31	-3.887	
12	Eos Chasma	-10.7	322.0	-3.8	quartz or silica-rich materials, aqueous geomorphology
17	Tiu Valles	22.9	327.8	-3.8	fluvial and lacustrine deposits
79	Libya Montes Layered Coastal Cliffs	3.62	85.89	-3.7	Layered coastal cliffs of Arabia "shoreline"
		3.53	85.99	-3.7	
		3.44	85.94	-3.7	

25	Becquerel crater	21.5	351.4	-3.6 to -3.8	layered deposits
		21.3	352.5	-3.6 to -3.8	
100	Trouvelot crater	16.1345	347.049	-3.62	central uplift, possible hydrothermal activity
		15.76	347.264		
		15.185	347.142		landing ellipse and southern crater rim
		15.863	346.817		fluidized ejecta from the inner crater, which may have excavated hydrothermally altered material from the main Trouvelot uplift region
9	Eos Chasma Alluvial	-13.4	317.5	-3.5	alluvial fan
50	Western Isidis	14.2	79.5	-3.5	escarpment, volatile sink
		18.0	79.6	-3.5	
69	North Pole C (Gemini Lingula)	82.86	354.5	-3.3	Polar layered deposits, ice

Dot[a]	Site Name[b]		Center of Proposed Ellipse			Target
			Lat (°N)	Lon (°E)	Elev (km)	
77	Libya Montes		3.58	84.1	-3.3	Carbonates, phyllosilicates, basalt
			3.68	85.62	-3.11	
			3.57	84.43	-2.5	
22	Marwth Vallis[f]	site 0	24.5	338.9	-3.0	Noachian layered phyllosilicates
		site 1	24.7	340.1	-3.1	
		site 2	24.0	341.0	-2.3	
		site 3	23.2	342.2	-3.4	
		site 4	24.9	339.4	-3.4	
			25.415	339.728	-3.14	Jarositic deposit, Phyllosilicate-bearing layered deposits, Impactites
			25.3465	339.81	-3.14	
70	Ismenius Cavus		33.5	17	-~3	Paleolake. Phyllosilicates in crater breached by Mamers Vallis. Well formed delta on NE wall
			33.84	17.275		
71	North Pole B (the saddle)		85.21	34.6	-3	Polar layered deposits, ice
78	Libya Montes Layered Deposits		2.83	85.7	-2.8	1) Fe/Mg phyllosilicates and olivine mixtures in intermontane deposits 2) delta front with bright polygonally fractured material, Al phyllosilicates
93	Cerberus Palus		6.623	147.227	-2.72	Putative basement rock to investigate water/lava interactions. Possible hydrothermal site. Dikes
			6.7635	146.53		
			6.77	146.45		
			6.793	146.367		

94	Sabrina Delta	11.681	313.169	-2.72	delta stratigraphy
		11.7145	313.247	-2.72	delta stratigraphy
		11.8805	313.378	-2.72	landing ellipse and traverse to putative delta
		11.9905	313.443	-2.72	Center of proposed landing ellipse to access putative delta
96	Firsoff crater	2.63579	350.398	-2.7	equatorial layered deposits (ELDs, spring deposits), Mud Volcanoes, Sulfates
		2.865	350.473	-2.7	
		2.17752	350.947	-2.7	
23	Iani Chaos	-2.1	342.3	-2.8	Hematite- and sulfate-rich layered sediments
		-2.6	342.2	-2.7	
		-1.6	341.8	-2.5 to -2.8	
11	Argyre	-56.3	318.0	-2.7	glacial/lacustrine features
		-55.2	322.4	-2.7	
41	Hellas	-44.0	46.0	-2.6	ancient basin bedrock

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
4	Juventae Chasma	-4.8	296.8	-2.7	sulfates
		-4.5	297.5	-2.0	layered sulfates
	Juventae Plateau	-4.6	296.4	2	Sulfates, silica, aqueous deposits
15	Holden crater[d]	-26.7	325.0	-2.0	Layered fluvial and lacustrine materials, fans
		-26.4	325.1	-1.9	
		-26.4	325.1	-1.9	
		-26.9145	326.452	-2.198	Layered materials, Delta, Prodelta, Channels, Probable phyllosilicates
		-26.8535	326.346	-2.198	
44	Northeast Syrtis Major	16.3	78.0	-3.2	Hesperian volcanic, Noachian layered deposits
		16.4	77.4	-2.8	
		16.1	76.7	-2.2	
		17.1	75.4	-1.1	
		16.2	76.6	-2.1	diverse mafics, Noachian layered phyllosilicates
		17.8	77.1	-2.6	diverse aqueous alteration minerals on Noachian-Hesperian boundary
46	Nili Fossae crater (Jezero)	18.4	77.6	-2.6	fan, layered deposits, inverted channels
		18.5187	18.673		western fan
		18.518	18.884		fan
		18.4718	77.8217		possible fluvial bedforms in fan

		19.0336	77.3795		feeder channel for fan
		18.6996	78.1389		possi le bedforms indicative of flow direction
		18.1563	78.2007		possible volcanic feature?
		18.7035	77.8958		relationship between fan, eastern channel, possible volcanic deposits
81	Utopia Region Seismic Network	23.3695	127.6816	-3.956	Mars geophysical network to investigate interior structure and proceses and determine present level of volcanic/tectonic activity
		3.6229	136.4472	-2.638	
		15.6195	105.7068	-2.539	
		-11.33	329.5589	-0.82	
83	Chryse Region Seismic Network	14.79	320.73	-3.9	Mars geophysical network to investigate interior structure and proceses and determine present level of volcanic/tectonic activity
		27.7446	347.0187	-2.634	
		10.6068	316.7862	-2.504	
		-16.5306	162.7855	-0.517	
65	North Pole A	88	275.6	-2.58	Polar layered deposits, ice
7	Northern Xanthe	11.4	314.7	-2.6	Hypanis Vallis highlands, valley walls
		8.0	312.7	-1.0	
		6.9	312.8	-1.0	

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
57	Athabasca Vallis	10.0	157.0	-2.5	dunes, streamlined forms, fissures
58	Elysium (Avernus Colles)	1.4	168.7	-2.5	iron-rich materials at valley terminus
		-3.1	170.6		
		-3.1	170.7		
		0.2	172.5		
13	Hale crater	-35.7	323.4	–2.4	gullies
82	Aeolis Meanders	-5.71438	153.495	-2.35	meandering inverted channels. Possible oxbow lakes and floodplain overbank deposits, Channels, MFF materials
		-5.82915	153.734	-2.35	
53	Aeolis Region	-5.1	132.9	-2.3	lobate fan delta
55	Northwestern slope valleys	-4.9	146.5	-2.3	flood, fluvial morphology
73	crater SW of Neisten crater	-28.282	56.818	-2.2	layers exposed in crater on northern rim of Hellas
20	Margaritifer basin	-11.7	337.3	-2.2	Fluvial deposits
		-12.8	338.1	-2.1	

18	Ladon basin	-18.8	332.5	-2.1	chloride and nearby phyllosilicates
45	Nilo Syrtis	23.0	76.0	<-2.0	Phyllosilicates
6	Xanthe Terra	2.3	309.0	-2.0	delta deposit
27	Miyamoto crater[g], Southwestern Meridiani (formerly Runcorn)	-1.8	352.4	-2 to -1.7	layered deposits, hematite
		-3.4	352.6	-2.0	phyllosilicates, sulfates, adjacent to hematite-bearing plains
		-3.5	352.3	-1.9	layered phyllosilicates and chloride deposits, inverted channels
1	Melas Chasma	-9.8	283.6	-1.9	Paleolake, sulfates
31	Vernal crater (Southwest Arabia Terra)	6.0	355.4	-1.7	layered deposits (fluvio-lacustrine?), methane, spring deposits
74	Neisten crater	-28.0865	58.118	-1.7	layered deposits
		-27.6335	57.803	-1.5	
88	Southern Mawrth Vallis	19.814	342.654	-1.65	Smectites (Fe, Mg) and phyllosilicates (Al)
		19.72	342.85	-1.65	
35	Northern Sinus Meridiani	2.6	358.9	-1.6	layered deposits
26	Chloride west of Miyamoto crater (site 17)	-3.2	351.6	-1.6	chloride salts

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
30	South Meridiani Planum	-3.3	354.4	-1.6	sulfate plains and phyllosilicate uplands
		-3.1	354.6		
36	Northern Sinus Meridiani	2.4	3.5	-1.5	layered deposits
		1.9	0.4	-1.4	
		3.1	3.3	-1.4	
33	Northern Sinus Meridiani crater lake	5.5	358.1	-1.5	layered deposits
34	West Arabia Terra	8.9	358.8	-1.5	layered deposits
48	Nili Fossae carbonate	21.7	78.8	-1.5	phyllosilicates, carbonates
16	Eberswalde crater[e]	-23.9	326.7	-1.5	layered deposits, fan delta, channels
		-23.0	327.0	-1.5	
		-24.0	325.6	-0.6 to -0.4	

		-23.8	327.0	-0.7 to -0.6	
29	Meridiani Planum bench	8.3	354.0	~-1 to –1.5	Hematite- and sulfate-rich layered sediments
		7.9	354.0		
		8.4	354.5		
8	ShalbatanaVallis	7.0	317.0	-1.3	phyllosilicates
28	East Margaritifer Terra	-5.6	353.8	-1.3	chlorides, phyllosilicates
32	Northern Sinus Meridiani	1.6	357.5	-1.3	layered deposits, ridges, hematite
37	East Meridiani	0.0	3.7	-1.3	sulfate and hydrated materials, phyllosilicates in region
5	Ritchey crater	-28.3	308.9	-1.2	clays, alluvial/fluvial deposits
24	Margaritifer Terra Chloride Site 10	-13.1	345.3	-1.2	chloride salts
47	East Nili Fossae	21.8	78.6	-1.2	phyllosilicates, mafics
39	Northern Sinus Meridiani	2.4	6.7	-1.1	layered deposits
21	Samara Vallis	-23.6	339.8	-1.0	valley networks, fluvio-lacustrine basin
99	Crater North of Echus Chaos	15.0995	284.688	-0.0725	central crater mound sediments, crater rim materials
		15.31	284.838	-0.0725	
		15.1755	284.54	-0.0725	
59	Ariadnes Colles	-35.0	174.2	-0.1	phyllosilicates, possible sulfates
98	Schiaparelli Crater	-3.0185	13.7125	-0.15	Hydrated minerals, Rock specimens from rim of Schiaparelli
		-4.2415	13.378	-0.15	

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
19	Wirtz crater	-49.0	334.0	-0.6	gullies
43	Nili Fossae Trough[h]	21.0	74.5	-0.6	Noachian phyllosilicates, bedrock, clay-rich ejecta, Hesperian volcanics
		20.691	74.505		
63	Avire crater	-41.25	200.14	-0.77	Gullies, mid-latitude fill material, layered lobate features, dunes
72	Antoniadi crater	24.07	63.07	0.1	Granitoid, phyllosilicates, zeolites
		20.471	62.83	0.1	
		20.34	62.91	0.1	
38	Chloride Site 15	-18.4	4.5	0.2	chloride salts
56	South Terra Cimmeria	-36.0	156.0	0.4	gullies
		-35.0	156.0		

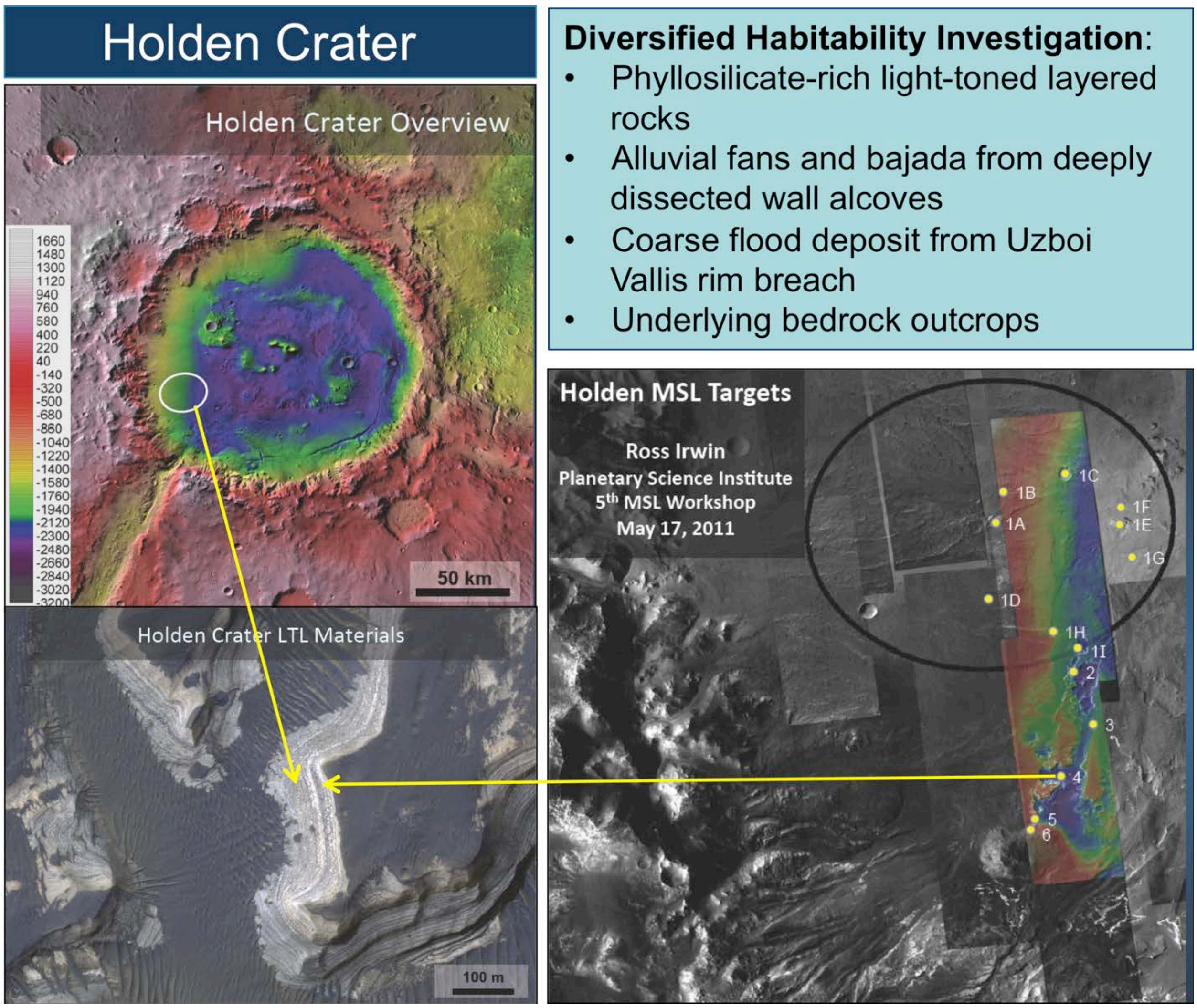
40	Southern mid-latitude (SML) craters	-49.0	14.0	0.5	viscous flow features, gullies, patterned ground, dissected mantles
60	Columbus Crater	-28.8	194	0.9	layered deposits, kaolinite, smectites, jarosite, mono- & polyhydrates sulfates
2	Western Candor Chasma	-5.5	284.5	2.0	sulfates, layered deposits
		-5.5	284.5	2.0	
64	Noctis Labyrinthus	-6.798	260.956	2.2	Smectites, gypsum, opal, light toned deposits
		-6.854	261.052	2.2	
		-6.843	261.151	2.2	
61	Kamnik crater	-37.49	198.13	2.3	Gullies, mantling material, mid-latitude “fill”
62	Naruko crater	-36.55	198.2	2.7	Gullies, mantling material, mid-latitude “fill”
10	Argyre	-49.7	316.0	--	ancient basin bedrock
89	Ladon Vallis	-20.4775	329.86		light toned material
		-20.178	329.79		
		-20.4775	329.86		
		-19.6455	327.6		central landing ellipse
		-19.6455	327.503		western landing ellipse
		-19.638	327.689		eastern landing ellipse
90	Ladon Basin	-19.638	327.689		eastern portion of landing ellipse
		-19.6455	327.6		central portion of landing ellipse
		-19.6455	327.503		western portion of landing ellipse
91	Aram Chaos	2.21	339.1015		western portion of landing ellipse
		2.214	339.1945		central portion of landing ellipse
		2.199	339.29		central portion of the ellipse
		2.21	339.38		eastern portion of the ellipse
92	Crater in SE Eos Mensa	-11.36	317.1		carbonate-beaing crust, LCP mafic rocks
		-11.44	316.9		
		-10.99	317.06		

Dot[a]	Site Name[b]	Center of Proposed Ellipse			Target
		Lat (°N)	Lon (°E)	Elev (km)	
92	Crater in SE Eos Mensa	-11.36	317.1		carbonate-beaing crust, LCP mafic rocks
		-11.44	316.9		
		-10.99	317.06		
80	Hashir crater	3.601	84.909		
		3.526	84.855		

		3.412	84.882		
		3.306	84.779		
		3.219	84.862		
		3.144	84.713		
		3.420	84.589		
101	McLaughlin crater	21.696	337.588		
		21.920	337.650		
		22.099	337.672		
		21.929	337.851		
		21.912	337.441		
		22.130	337.900		
		21.495	337.387		
		21.498	337.582		
		21.498	337.774		
102	Candidate landing site in northern Hellas region	-29.139	78.116		

Appendix 7: Reference Landing Site Summary Characteristics

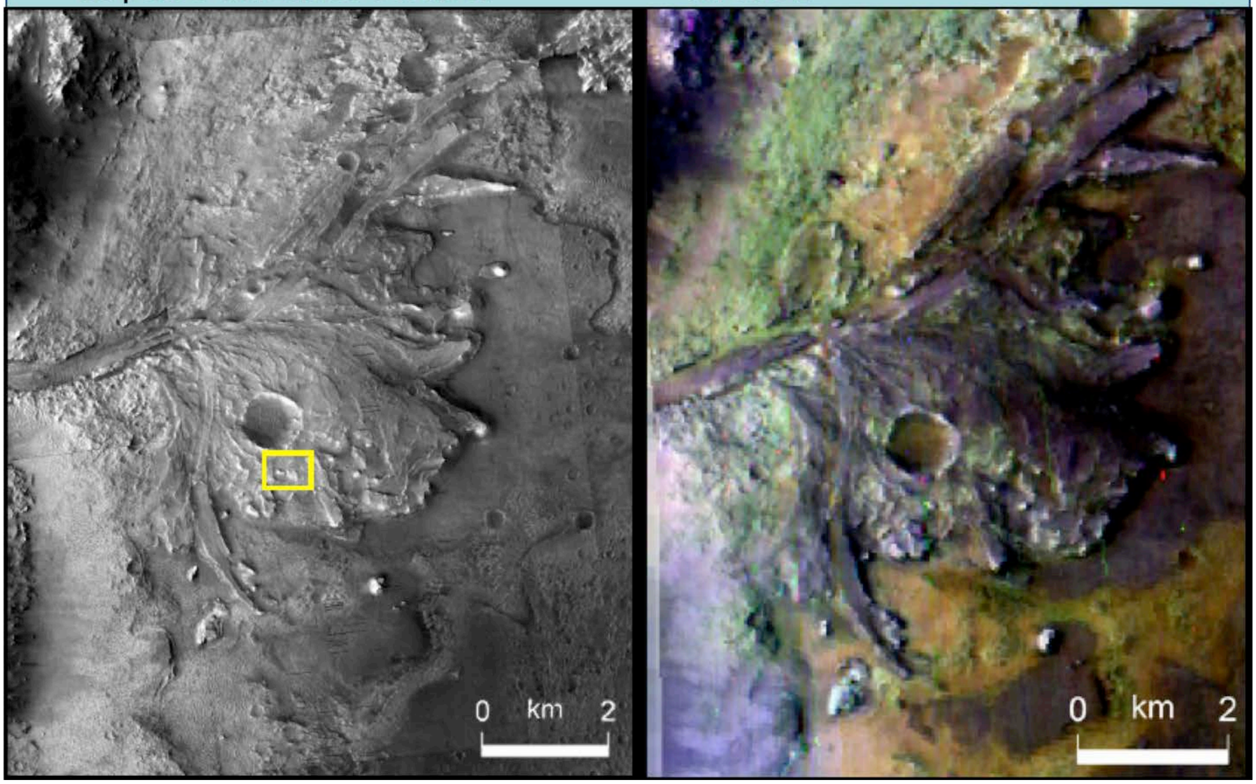
All figures in this appendix are adapted from presentations given during the community landing site selection workshops for MSL.



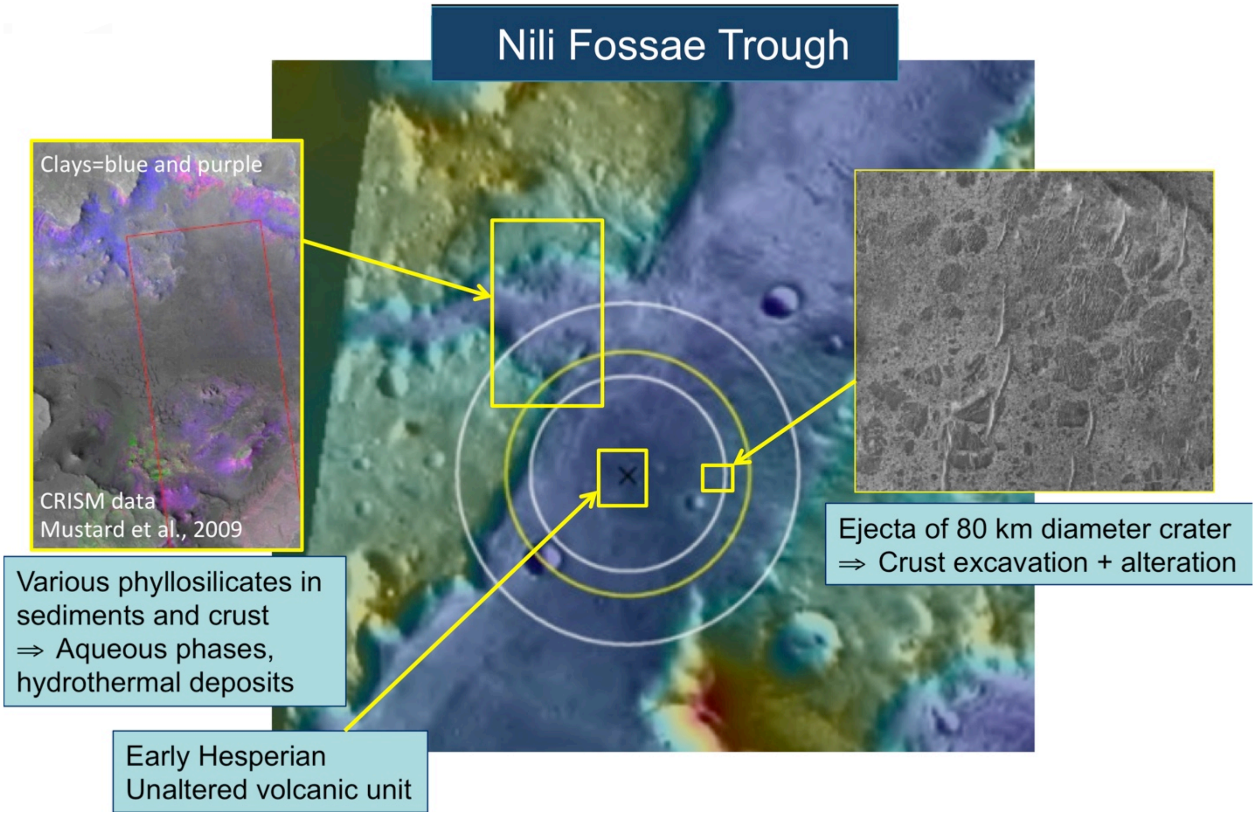
Reference Site: Holden Crater. Description from MSL landing site selection community workshop, Ross Irwin, John Grant, James Wray

Jezero Crater

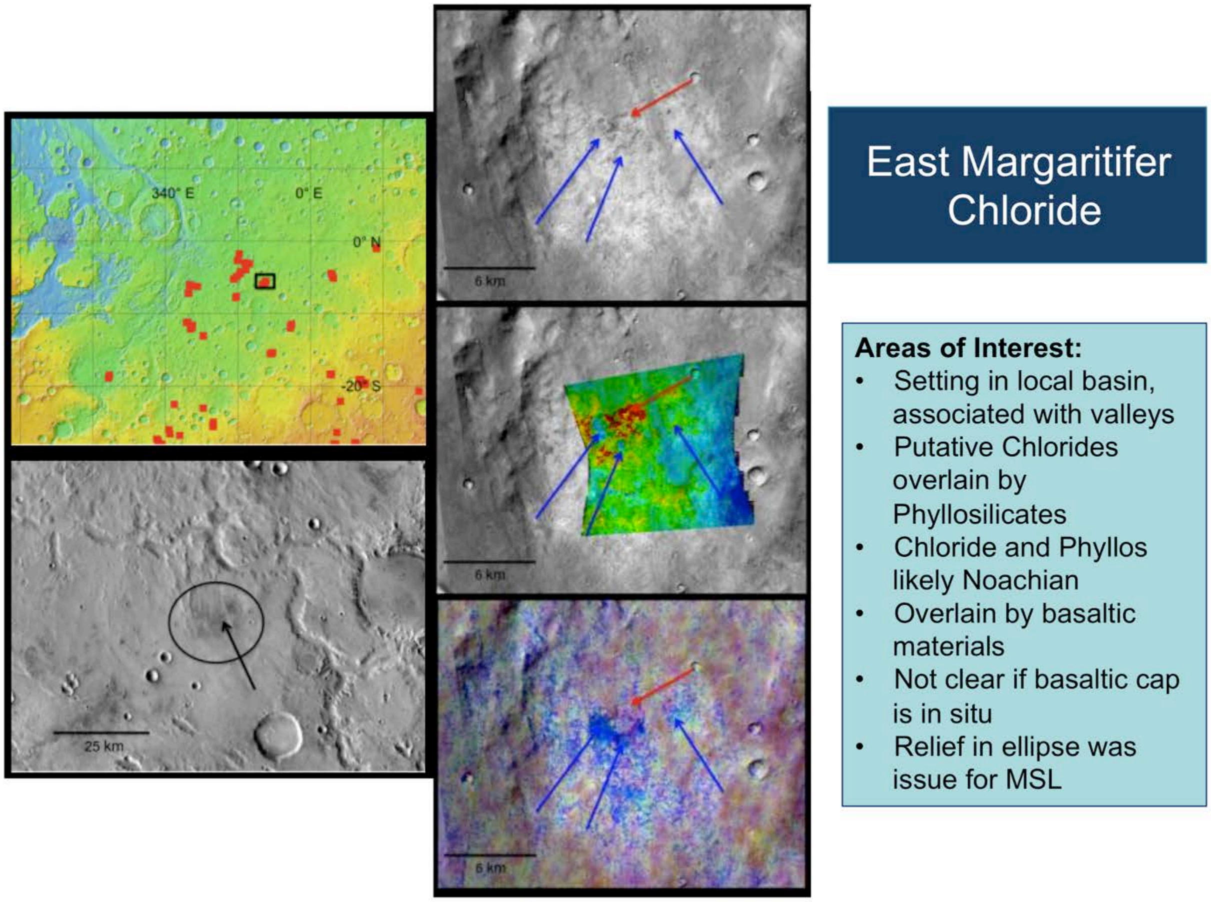
- Phyllosilicates in Delta
- Volcanic sands adjacent
- In place volcanics on floor
- Bottomset beds buried?
- Rocky surface in ellipse an issue for MSL



Reference Site: Jezero Crater. Fassett, Ehlmann, Harvey and others

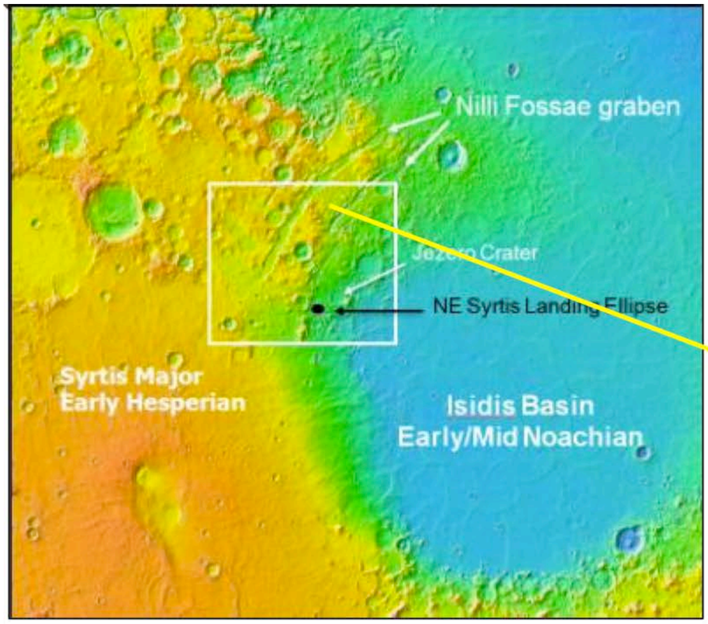


Reference Site: Nili Fossae Trough. After Mustard et al.



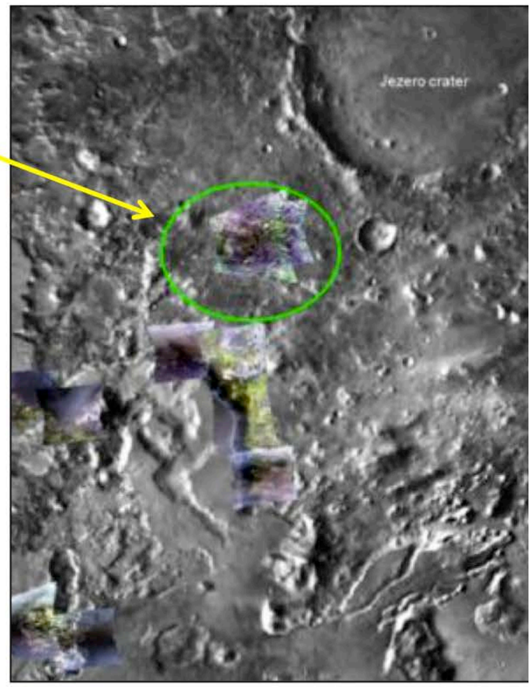
Reference Site: East Margaritifer Chloride. From presentation by Christensen et al. 5/2010

NE Syrtis Major



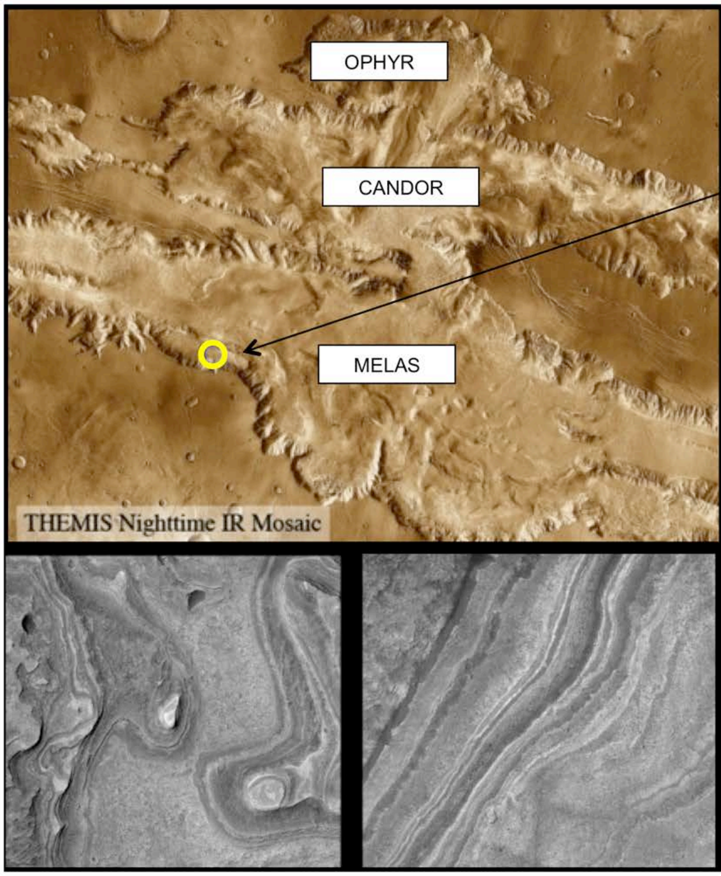
Areas of Interest

- Noachian-Hesperian boundary
- Bedrock strata represent 4 distinct enviroments of aqueous alteration
  - Basement Fe/Mg smectites
  - Carbonate/serpentine/olivine
  - Layered phyllosilicates
  - (Sedimentary?) acid sulfate formation
- volcanic flows



Relief an issue for MSL

Reference Site: NE Syrtis Major. From Presentation by Mustard, Ehlmann, and Skok 5/2010



Melas Chasma

Areas of Interest

- The proposed landing ellipse is located on layered beds in a postulated paleolake in a basin along the wallrock in SW Melas Chasma
    - Drainage network in lake
    - Probable sublacustrine fan
    - No phyllosilicates identified
- W of ellipse are extensive Hesperian-aged valley networks; likely formed by precipitation over kyrs
- Folded beds, sulfate deposits, depositional fans adjacent to ellipse

Possible concerns related to slope winds and/or ellipse size

Reference Site: Melas Chasma. After Weitz, Quantin, Metz et al

Appendix 8: Surface Operations Scenario Modeling

1. Model Overview and Assumptions

The conclusions presented in Section 7 were informed by the results of a detailed model of the Mars 2020 mission operations system. This model incorporates estimates of the flight system and ground system capabilities based on the Mars Exploration Rover (MER) and Mars Science Laboratory (MSL) missions to Mars.

The model makes certain assumptions about the characteristics of the Mars 2020 mission, including:

- The surface mission lifetime would not exceed 1 Martian year (669 sols).
- The mission would use MSL-like communications and operations strategies; specifically:
    a. Fixed local mean solar time X-band windows in the Martian morning for commanding (uplink) communications.
    b. Two UHF relay orbiter passes per Sol; with the UHF pass in the Martian afternoon having sufficient volume for decisional data and low latency for return of the data to Earth.
    c. Eight-hour ground planning cycle, which includes analysis of received telemetry; determination of plans for the next sol; generation, validation, and review of command products to implement the next sol's plan; and delivery of command products for radiation. For comparison, MSL's current planning cycle duration is 10 hours; at landing, MSL's cycle duration was 16 hours.
    d. Some fraction of the mission would be performed in "Mars Time" operations. So-called "Mars Time" assumes that scheduling of the ground data analysis and uplink planning cycle follows the procession of the receipt of telemetry (downlink) and the deadline for commanding (uplink) as they "walk" around the Earth clock due to the phasing of Earth time and Mars time. This scheduling strategy yields the highest number of sols that permit reactive operations.
- The "commissioning" phase, during which the various rover subsystems would be checked out and science instruments would be commissioned, is assumed to take 60 sols. By way of comparison, MSL's commissioning phase consisted of 25 sols of rover subsystem checkouts before the rover was ready to initiate nominal science operations. In addition, first-time activities required additional scrutiny, resulting in reduced science efficiency for those periods. First time activities on MSL included first use of the scoop, first use of the CHIMRA, first use of the drill, among others.
- The margin policy is that 25% of the mission duration is "unproductive", i.e., does not directly contribute towards meeting science objectives (This is consistent with MSL's operational margin policy at launch). The margin is intended to cover:
    a. Communication problems (e.g., outages in the Deep Space Network, relay asset safing, long latencies);
    b. Non-determinism of *in situ* operations (including repeating operations that failed);
    c. Increases in activity time or energy needs during operations;
    d. Increases in the time required for activities due to data volume constraints (which are not currently included in the model);
    e. Increases in time or energy required for activities due to better understanding of rover and instrument design during development;
    f. Flight software uploads during surface operations;
    g. Anomaly diagnosis and resolution.

- No operations occur during the period subtending < 2° Sun-Earth-Mars angle (i.e., Solar Conjunction, which spans 11 sols during the Mars-2020 Primary Mission).
- The rover and cache do not have to be at a specific location, for eventual retrieval and return to Earth, at the end of the Primary Mission. That is, no time would be spent driving the cache to a specific location; the entire Primary Mission period would be available for addressing the mission's science objectives, including sample caching.
- The cache would be capable of holding a minimum of 31 samples, a minimum of 2 of which are blanks that would be cached during the Commissioning phase of the mission.

The model divides the mission into three major activities – traverse (driving), fieldwork, and coring/caching.

2. Traverse Model (Sols spent driving)

Notionally in the model, the activities contained within a single "driving sol" consist of:

- Driving
- Post-drive contextual imaging and mineralogy measurements
- Post-drive go-and-touch fine-scale imaging and close-up fine scale elemental chemistry measurements.

Note: "Go-and-touch" capability has been demonstrated on MER. Parts of this capability—specifically, the ability to track and traverse to visual targets autonomously, and the ability to analyze workspace images for hazards and autonomously unstow the arm—are either currently or planned to be part of the MSL flight software before the conclusion of MSL's prime mission.

There are four different types of driving Sols in the model, based on the type of terrain and the proximity to scientific targets.

Long-Traverse Sols are the "workhorse" drive sols for covering distances between Regions of Interest (ROI's), and from landing to the first ROI. They include:

- Traverse an average of 100 m/Sol – which is the current estimate for MSL. (For comparison, MER averaged 59 m/Sol.)
- Mid-drive contextual science imaging and mineralogy measurements.
- Traverse documentation imaging.
- Imaging to support planning of next traverse.
- Opportunistic contextual imaging and mineralogy measurements (as fits into plan).

Terrain-Limited Traverse Sols are just like Long Traverse sols, but cover a shorter distance due to difficult terrain. They include:

- Traverse up to 50 m (MER averaged 23 m/short traverse sol).
- Traverse documentation imaging.
- Imaging to support planning of next traverse.
- Opportunistic contextual imaging and mineralogy measurements (as fits into plan).

Time-Limited Traverse Sols traverse a shorter distance than Long Traverse sols, because time is needed for remote observations in order to characterize the ROI being approached. They include:

- Traverse up to 50 m (MER averaged 23 m/short traverse sol).
- Traverse documentation imaging.
- Imaging to support planning of next traverse.
- Contextual imaging panorama.
- Contextual mineral measurements.
- Contextual imaging of candidate contact targets.

Target-Limited Traverse Sols are shorter traverses because targets for approach can only be selected within a limited range due to instrument fields of view. These sol types contain:

- Traverse up to 20 m (end with target within instrument workspace).
- Traverse documentation imaging.
- Imaging to support planning of next traverse.
- Imaging to support planning of in-situ science.

Note that Target-Limited Traverse Sols are not counted as separate sols within the current model; instead the model assumes "go and touch" autonomy on the rover (which has been demonstrated on MER and parts of which are already or are planned to be included in the MSL flight software by the conclusion of its prime mission), which effectively combines these "approach" activities into the fieldwork sol types.

3. Fieldwork Model (Sols spent conducting fieldwork)

The focus in this modeling effort has been on determining the robotic actions necessary to characterize the geology to an extent that it would be possible to select materials for coring and caching. As articulated elsewhere in this report, the measurements necessary to cache samples are the same as the measurements required to fulfill Objectives A and B. These robotic actions are combined into the so-called "fieldwork" section of the mission duration breakdown, and can be defined as the activities necessary to understand the geology, habitability, and biosignature detection and preservation potential of a site.

In the model, "fieldwork" consists of:

- Contextual imaging measurements.
- Contextual mineralogy measurements.
- Targeted fine scale imaging, mineralogy, close-up fine scale elemental chemistry, and organic detection measurements.
- Rock surface brushing and abrading.
- Re-do (on abraded/brushed surface) of fine scale imaging, mineralogy, close-up fine scale elemental chemistry, and organic detection measurements.

Depending on the geological complexity and scientific richness of a site, this process would be iterated a number of times.

There are three sol types in the fieldwork model: Simple Surface Contact, Abraded Contact, and Context Measurement. In the model, it was assumed that there was a set number of each of the three fieldwork sol types per core acquired and cached; the ratios of each sol type assumed was determined from the E2EiSAG (2011) findings, which were in turn derived from experiences with Spirit and Opportunity. The ratios used were as follows:

- 4.5 Context Measurement sols per core collected and cached.
- 5 Simple Surface Contact sols per core collected and cached.
- 2 Abraded Contact sols per core collected and cached.

Simple Surface Contact Sol is an example approach for initial characterization of a target, which may lead to a decision to prepare the surface (by brushing or abrading it) for acquiring the 2020 rover's fine-scale imaging, fine-scale mineralogy, close-up fine scale elemental chemistry, and organic detection measurements. This sol type includes:

- Context imaging.
- Fine scale image mosaic of target.
- Overnight close-up fine scale elemental chemistry measurement (which is not considered decisional data for the next sol's plan).

To proceed to the next (Abraded) sol type in operations, ground-in-the-loop would be needed for science selection of the abrasion target, and to construct the command sequence for the robotic arm to perform abrasion on the selected target.

Abraded Contact Sol is an example approach (brushing would be another) for preparing a rock surface and then acquiring key fine-scale imaging, fine-scale mineralogy, close-up fine scale elemental chemistry, and organic detection measurements. This sol type includes:

- Abrade target patch.
- Context imaging of abraded patch.
- Context mineral measurement of abraded patch.
- Fine-scale image mosaic of abraded patch.
- Fine-scale organic, mineralogy, and elemental chemistry measurements of abraded patch.
- Overnight fine-scale fine scale elemental chemistry measurement.

For the two straw payloads (Blue and Orange) considered for the current model, the assumption was that the time required to both acquire all of the decisional data and return it to Earth took longer than a single sol. Thus, this "sol type" was assumed to take 4 sols for the Blue straw payload, and 3 sols for the Orange straw payload (both described in Table 5-3).

To proceed to the coring/caching sol type in operations, ground-in-the-loop would be needed for science selection of where to acquire the core, and to construct the command sequence for the robotic arm to perform coring and caching of the selected target.

Context Measurement Sol is a sol in which context measurements—which require neither arm motion nor mobility—are collected to aid in future fine scale context measurements or target selection. This sol type could be planned without decisional data; thus, it can be (and on MER and MSL is) used during sols when reactive operations (i.e., ground-in-the-loop) is not possible (known as "restricted sols") due to, for example, communications/ground schedule phasing. In the model (with the current communications and operations schedule assumptions), this sol type is not counted separately in the number of sols for fieldwork, since it replaces sols that would otherwise be “unproductive” due to restricted sols. This sol type includes:

- Targeted context imaging and mineralogy measurements.

4. Coring and Caching Model (Sols spent coring and caching)

Notionally in the model, “coring and caching” consists of

- Coring.
- Post-coring context and fine-scale imaging of the borehole and tailings.
- Post-coring contextual, fine-scale and close-up mineralogical, organic and fine scale elemental chemistry measurements of the borehole and its tailings.
- Insertion of encapsulated core sample into cache.

There is only a single **Core and Cache Sol** type. On that sol the following activities are performed:

- Acquire core sample.
- Cache sample.
- Visual documentation imaging.
- Fine-scale image measurement of core site.
- Context mineral measurement of core site.

Of note, the model does not include any specific provisions for sample change-out (i.e., removal and replacement of a cached sample). The model also assumes that the core sample is not examined by the science instruments before it is encapsulated and cached. The model further does not assume that any cores will be extracted which are not cached.

5. Free Parameters

Given the assumptions described above, there is some flexibility to adjust the following aspects of the scenario in order to meet the science objectives (which correspond to different points in the triangular trade-space in Figure 7-2):

- The total traverse distance.
- Adjustments to the E2E-iSAG (2011) ratios of the fieldwork sol types per sample (expressed as number of cores per “unit” of fieldwork).
- The number of cached samples.

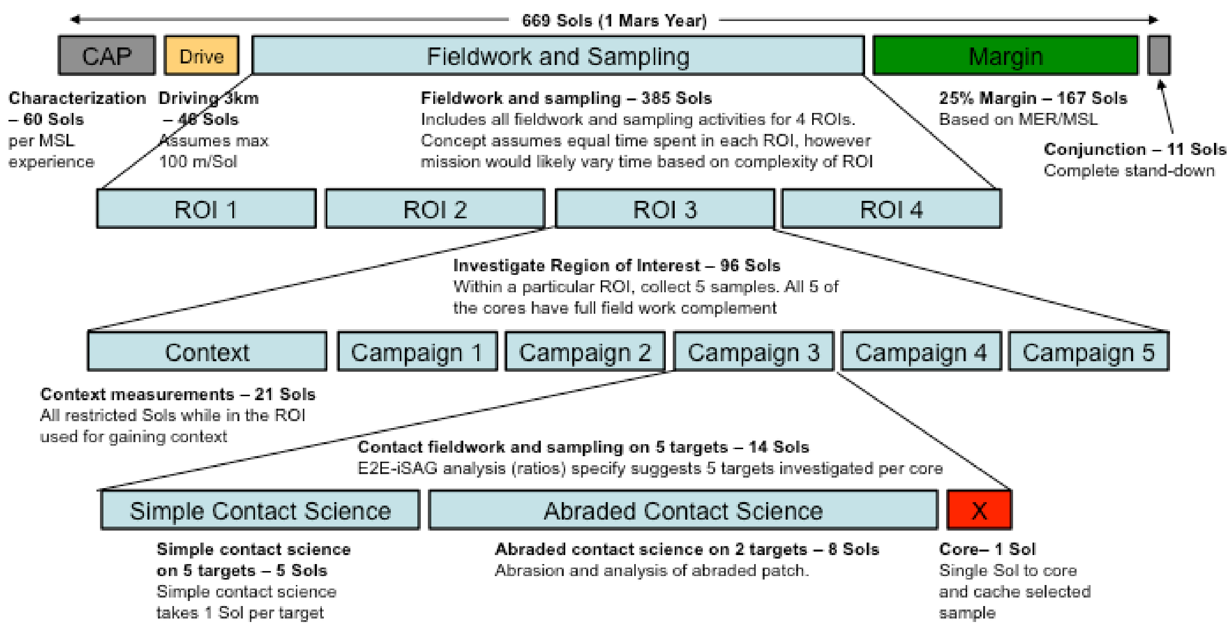
In addition, the model permits adjustments to many of the assumptions described above, which was used to help assess sensitivity to changes in the assumptions. For example:

- The long-traverse rate (expressed as average number of meters traversed per long traverse sol).
- The number of Sols spent working Mars time.
- The number of Sols spent working 7-day Earth time operations.
- The number of Sols spent working 5-day Earth time operations (includes holidays off).

6. Model results

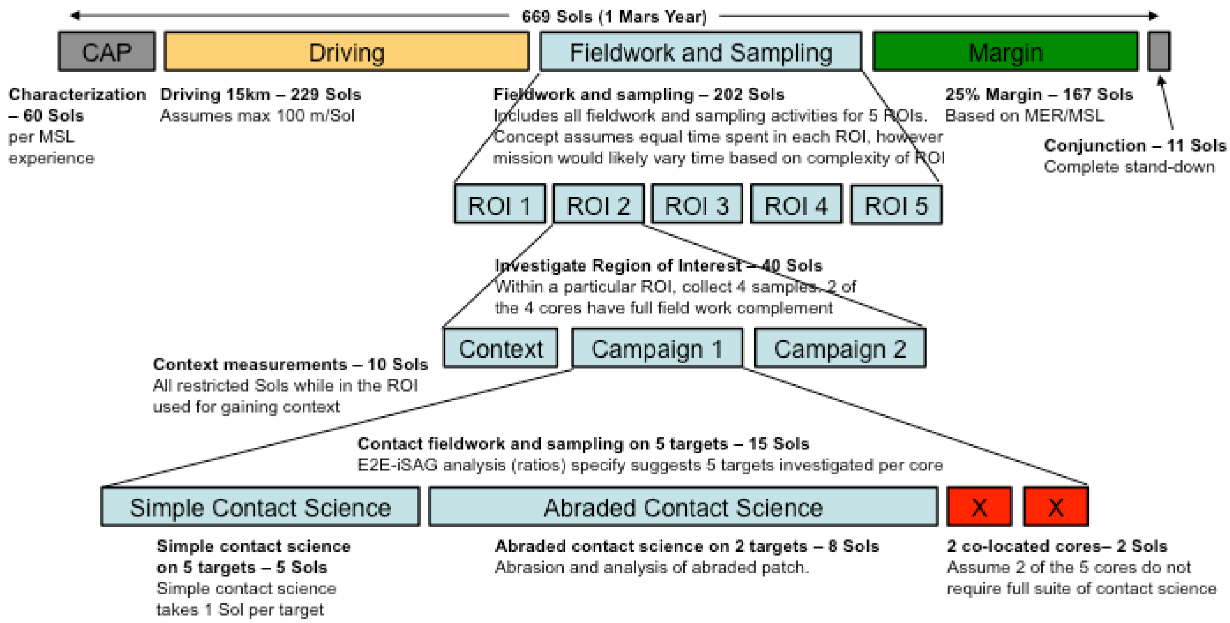
In addition to the point design (Figure 7-4) from the interior of the triangular trade-space illustrated in Figure 7-2, scenario models were built for cases illuminating the points of the trade-space: maximizing, in turn, fieldwork, driving, or coring/caching. These scenario models are shown here:

a) More Fieldwork (and less driving and coring/caching)
The following concept collects 5 cores from 4 Regions of Interest separated by 3 km total in 1 Mars year. This assumes a MSL operations model (Mars time through Sol 90, 7-day ops through Sol 180, 5-day ops afterwards), and no augmentations to MSL baseline capability.



b) More Driving (and less fieldwork and coring/caching)

The following concept collects 4 cores from 5 Regions of Interest separated by 15 km total in 1 Mars year. Assumes MSL operations model (Mars time through Sol 90, 7-day ops through Sol 180, 5-day ops afterwards), and no augmentations to MSL baseline capability.



c) More Coring/Caching (and less driving and fieldwork)

The following concept collects 8 cores from 4 Regions of Interest separated by 5 km total in 1 Mars year. Assumes MSL operations model (Mars time through Sol 90, 7-day ops through Sol 180, 5-day ops afterwards), and no augmentations to MSL baseline capability.