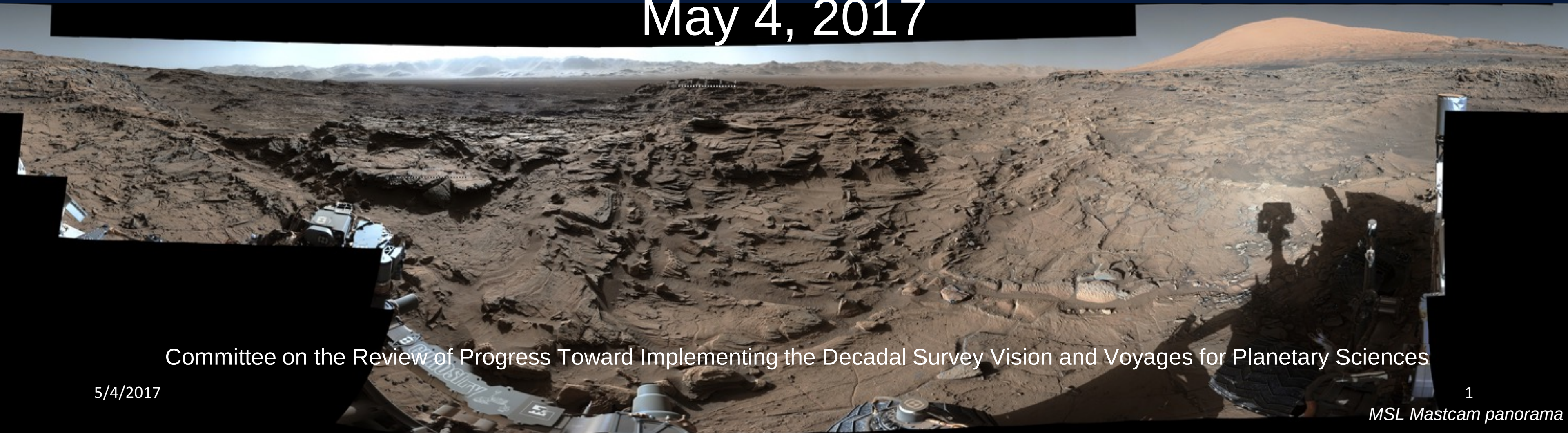
Mars Exploration Program Analysis Group (MEPAG)

chartered by NASA HQ to assist in planning the scientific exploration of Mars

Mars Exploration Program Analysis Group (MEPAG) Perspectives on Mid-Term Decadal Survey Review

Jeffrey R. Johnson, MEPAG Chair

May 4, 2017



Committee on the Review of Progress Toward Implementing the Decadal Survey Vision and Voyages for Planetary Sciences

MSL Mastcam panorama

Outline

- MEPAG overview
- Review of Mars in the *Visions and Voyages for Planetary Science in the Decade 2013-2022* (***V&V 2011***)
- Progress made at implementing the ***V&V 2011*** Mars goals
- New discoveries since the ***V&V 2011*** that have relevance to NASA's current and future planetary science program
- Views on the committee's statement of task, and requested comments
  - Actions that should be undertaken to prepare for the next decadal survey
  - New Frontiers 4 comment
  - Mars Architecture Assessment comments

What is MEPAG? (1 of 5)

https://mepag.jpl.nasa.gov/about.cfm

MEPAG is responsible for providing science input needed to plan and prioritize Mars exploration activities. MEPAG serves as a community-based, interdisciplinary forum for inquiry and analysis in support of Mars exploration objectives. To carry out its role, the MEPAG updates goals, objectives, investigations and required measurements for robotic and human exploration of Mars in response to new discoveries and directions on the basis of the widest possible community outreach.

Curiosity reaching the southern part of Murray Buttes - sol 1435 - NASA/JPL-Caltech/MSSS/Thomas Appéré

What is MEPAG? (2 of 5)

Community: MEPAG meetings are open to all members of the planetary exploration community, particularly those scientists, engineers, project and program personnel, theoreticians and experimentalists, instrument scientists, and modelers who are interested in Mars exploration.

International participation is welcomed and solicited as appropriate, including reports of activities by the various space agencies.

Artist's concept of an astronaut to scale with Murray buttes, Curiosity right Mastcam, sol 1436 NASA / JPL / MSSS / Seán Doran

What is MEPAG? (3 of 5)

Procedure: The MEPAG maintains the Goals Document and conducts analysis activities on topics of relevance to Mars-related exploration.

http://mepag.nasa.gov/reports.cfm

- 4 Main Goals Aligned with *V&V 2011*: 1) Life, 2) Climate, 3) Geological Sciences, 4) Preparation for Humans (not prioritized)
- Prioritized Hierarchy within Each Goal: Objectives, Sub-objectives, and Investigations
- Cross-cutting and interdisciplinary themes identified and articulated

- Analysis tasks may be requested by NASA, including its Mars Exploration Program (MEP), its Science and Human Exploration & Operations Mission Directorates (SMD, HEOMD), and its advisory committees, such as the ~~Planetary Science Subcommittee (PSS)~~ Planetary Science Advisory Committee (PAC).
- Tasks may also be requested through NASA by committees of the National Academy of Sciences (NAS) Space Sciences Board. MEPAG may choose to organize Science Analysis Groups (SAGs) to deal with specific issues; these SAGs report their findings to the full community. Findings are reported to the requestors and posted to the community on the MEPAG website, and status reports are routinely made to MEP and ~~PSS~~ PAC.

What is MEPAG? (4 of 5)

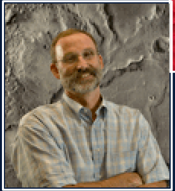
Organization:

- Chair: appointed by the MEPAG Executive Committee in consultation with NASA Headquarters.
- MEPAG Executive Committee consists of: MEPAG Chair (lead), the previous MEPAG Chair, the MEP Lead Scientist, the Mars Program Office Chief Scientist, the Goals Committee Chair, and up to 5 additional members of the MEPAG community.
- HEOMD Chief Scientist for Exploration is an ex officio member.
- Goals Committee nominally has two members for each of the four goal areas, in addition to its Chair.
- Membership of the Executive and Goals Committees are solicited from the MEPAG community and determined by the Chair and Executive Committee.
- Typical terms ~2-3 years depending on activity
- Logistical and organizational support to the MEPAG, including its analysis groups, is provided through the Mars Program Office, located at the Jet Propulsion Laboratory.

Executive Committee

Jeff Johnson, Chair, JHU-APL

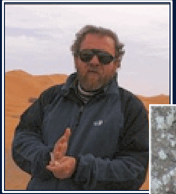
Lisa Pratt, Past Chair, IU



Phil Christensen, ASU

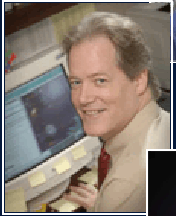
Don Banfield,
Goals Committee Chair,
Cornell Univ.

Scott Hubbard, Stanford



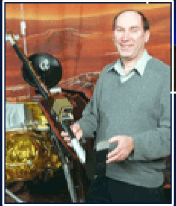
Gian Gabriele Ori, IRSPS

Dave Beaty, JPL



Michael Meyer, NASA HQ

Ben Bussey, NASA HQ

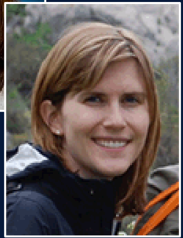


Rich Zurek, JPL

Goals Committee

Don Banfield, Goals Committee Chair, Cornell Univ.

Jen Eigenbrode NASA GSFC, Goal 1 (Life)

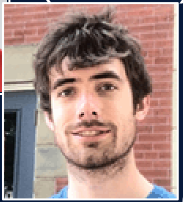


Sarah Stewart Johnson Georgetown, Goal 1 (Life)

Steve Ruff, ASU, Goal 3 (Geology)

R. Aileen Yingst, PSI, Goal 3 (Geology)

Paul Withers, Boston University, Goal 2 (Climate)



Robin Wordsworth Harvard University, Goal 2 (Climate)

Ryan Whitley, NASA JSC, Goal 4 (Prep. for Humans)

Jacob Bleacher, NASA GSFC, Goal 4 (Prep. for Humans)

What is MEPAG? (5 of 5)

MEPAG Reports/updates since 2011

https://mepag.jpl.nasa.gov/reports.cfm

- Report from Mars International Collaboration SAG (MIC-SAG) 3/2017
- Report from Next Orbiter SAG (NEX-SAG) 12/2015
- Candidate Scientific Objectives for Human Exploration of Mars, and implications for the identification of Martian Exploration Zones (HSO-SAG) 7/2015
- Mars Science Goals, Objectives, Investigations and Priorities (Update) 6/2015
- New Analysis of Mars 'Special Regions': Findings of the 2nd MEPAG Special Regions SAG (SR-SAG2) 11/2014
- Humans to the Martian System Summary of Strategic Knowledge Gaps (SKGs) P-SAG (joint between MEPAG and SBAG) 6/2012
- Is Mars Sample Return Required prior to Sending Humans to Mars? 2012

Supported by MEPAG:

- Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study 4/2016
- ISRU & Civil Engineering Needs for Human Mars Missions (ICE-SAG) 10/2015
- The Value of Participating Scientist Programs to NASA's Planetary Science Division 5/2017

Mars in the V&V (2011)

TABLE 6.1 Major Accomplishments of Studies of Mars in the Past Decade **2001-2011**

Major Accomplishment	Mission and/or Technique
Provided global mapping of surface composition, topography, remanant magnetism, atmospheric state, crustal structure	Mars Global Surveyor, Odyssey, Mars Express, Mars Reconnaissance Orbiter
Mapped the current distribution of near-surface ice and the morphologic effects of recent liquid water associated with near-surface ice deposits	Odyssey
Confirmed the significance of water through mineralogic measurements of surface rocks and soils	Mars Exploration Rovers, Phoenix
Demonstrated the diversity of aqueous environments, with major differences in aqueous chemistry, conditions, and processes	Mars Express, Odyssey, Mars Reconnaissance Orbiter, Mars Exploration Rovers
Mapped the three-dimensional temperature, water vapor, and aerosol properties of the atmosphere through time; found possible evidence of the presence of methane	Mars Global Surveyor, Odyssey, Mars Express, Mars Reconnaissance Orbiter, and ground-based telescopes

Mars in the V&V (2011)

Over the past decade the Mars science community, as represented by the Mars Exploration Program Analysis Group (MEPAG), has formulated three major science themes that pertain to understanding Mars as a planetary system:

- *Life*—Understand the potential for life elsewhere in the universe;
- *Climate*—Characterize the present and past climate and climate processes; and
- *Geology*—Understand the geologic processes affecting Mars's interior, crust, and surface.

From these themes, MEPAG has derived key, overarching science questions that drive future Mars exploration. These include the following:

- What are the nature, ages, and origin of the diverse suite of geologic units and aqueous environments evident from orbital and landed data, and were any of them habitable?
- How, when, and why did environments vary through Mars history, and did any of them host life or its precursors?
- What are the inventory and dynamics of carbon compounds and trace gases in the atmosphere and surface, and what are the processes that govern their origin, evolution, and fate?
- What is the present climate and how has it evolved on timescales of 10 million years, 100 million years, and 1 billion years?
- What are the internal structure and dynamics, and how have these evolved over time?

Mars in the V&V (2011)

- “The next decade [2013-2022] holds great promise for Mars Exploration”:
  - Mars Science Laboratory (Curiosity)
  - MAVEN mission
  - ESA-NASA Mars Trace Gas Orbiter (TGO)
- “Following these missions, the highest-priority science goal will be to address in detail the questions of habitability and the potential origin and evolution of life on Mars.”
  - “The major focus of the next decade will be to initiate a Mars Sample Return (MSR) campaign, beginning with a rover mission to collect and cache samples…”
  - “These samples can be collected and returned to Earth in a sequence of three missions that collect them, place them into Mars orbit, and return them to Earth.”

Mars in the V&V (2011)

- Three high-priority science goals for the exploration of Mars in the [2013-2022] decade:
  1) Determine if life ever arose on Mars
     - If yes, it will be important to know where and for how long life evolved, and how the development of life relates to the planet's evolution
  2) Understand the processes and history of climate
     - The key to understanding how the planet may have been suited for life and evolution of the surface features
     - Relevant to our understanding of the past, present, and future climate of Earth
     - Necessary for the safe implementation of future robotic and human spacecraft missions
  3) Determine the evolution of the surface and interior of an evolving, Earth-like planet
     - Is fundamental to understanding the solar system as a whole, providing context for Earth history/processes
     - Requires analyses of heat flow, loss of a global magnetic field, pathways of water-rock interaction, and sources and cycling of volatiles including water, carbon dioxide and hydrocarbons
     - ➢ Mars has a rich and accessible geologic record of the igneous, sedimentary, and cratering processes that occurred during the early history of the solar system

Mars in the V&V (2011)

The importance of Mars Sample Return (MSR)

- Site Selection and context
  - diversity of sedimentary/igneous environments with potential biosignature preservation
- Sample criteria
  - diverse products of igenous/aqueous processes
  - encapsulated samples fully isolated from atmosphere, with documented field context
- Planning for sample handling, curation, analysis, telecommunications
- Technical implementation and feasibility using a 3-step strategy:
  1) A caching rover, the Mars Astrobiology Explorer-Cacher (MAX-C)
     - collection and caching of samples from a site with the highest potential to study aqueous environments, potential prebiotic chemistry, and habitability
     - exploring a site on a diverse planet with a science payload similar to MER will significantly advance our understanding of the geologic history and evolution of Mars, even before the cached samples are returned to Earth
  2) A Mars Sample Return Lander (MSR-L) that would include a rover to fetch the sample cache and a Mars Ascent Vehicle (MAV)
  3) Rendezvous and return by a Mars Sample Return Orbiter (MSR-O)

Mars in the V&V (2011)

Technology Development needs in the [2013-2022] decade

- High priority to develop technologies for MSR
  - Sample coring, collection, caching system
  - MAV thermal control, autonomous launch operations, ascent/guidance in Mars conditions
    - "It is essential that these elements receive *major investments* during the coming decade in order to ensure that they will reach the necessary maturity to be used by the end of the coming decade or early in the decade after that"
  - Tracking, rendezvous, capture of orbital sample (OS)
  - Planetary protection to ensure requirements are met for back-contamination (contamination of Earth by martian materials) by isolating sample cache
  - Mars returned sample handling (MRSH) facility definition and architecture development to verify the required level of isolation, planetary protection, and sample characterization.

Mars in the V&V (2011)

New Frontiers Missions studied (but not considered high enough priority compared to other medium-class mission concepts):

- Mars Geophysical Network
  1) Measure crustal structure/thickness, and core size, density, and structure, and investigate mantle compositional structure and phase transitions.
  2) Characterize the local meteorology and provide ground truth for orbital climate measurements.
- Mars Polar Climate Mission
  1) Follow-on to Phoenix lander (2008), to explore polar layered deposits (PLD)

Discovery Missions

- ***Mars Scout*** program terminated after MAVEN mission, but Mars options for Discovery included:
  - A one-node geophysical pathfinder station
  - A polar science orbiter
  - A dual satellite atmospheric sounding and/or gravity mapping mission
  - An atmospheric sample-collection and Earth return mission
  - A Phobos/Deimos surface exploration mission
  - An in situ aerial mission to explore regions of the atmosphere and remanent magnetic field that are not easily accessible from orbit or from the surface

Mars in the V&V (2011)

Summary

Flagship missions —The major focus of the next decade should be to initiate the Mars Sample Return campaign. The first and highest-priority element of this campaign is the Mars Astrobiology Explorer-Cacher.

New Frontiers missions —Although the committee looked at both the Mars Geophysical Network and the Mars Polar Climate missions (see Appendixes D and G), due to cost constraints neither was considered a high priority relative to other medium-class missions (see Chapter 9).

Discovery missions —Small spacecraft missions can make important contributions to the study of Mars.

Technology development —The key technologies necessary to accomplish Mars sample return include the following: the Mars ascent vehicle; the rendezvous and capture of the orbiting sample-return container; and the technologies to ensure that planetary protection requirements are met. Continued robust support for the development of instruments for future in situ exploration is appropriate.

Research support —Vigorous research and analysis programs are needed to enhance the development and payoff of the orbital and surface missions and to refine the sample collection requirements and laboratory analysis techniques needed for Mars sample return.

International cooperation —While Mars sample return could proceed as a NASA-only program, international collaboration will be necessary to make real progress. The 2016 Mars Trace Gas Orbiter mission is an appropriate start to a proposed joint NASA-ESA Mars program.

Progress made at implementing the *V&V 2011* Mars goals

- **Large Missions**: The concept of ESA-NASA MAX-C/ExoMars dual rovers landed by a single NASA vehicle was terminated in 2011. MAX-C was reborn as the 2020 Mars Rover with the specific astrobiology/geology/sampling caching objectives recommended by *V&V 2011*.
  - *2020 Mars Rover has passed Critical Design Review (CDR) and is on schedule and within cost*
  - Landing site finalists are: Jezero Crater, NE Syrtis, Columbia Hills.
- **Medium Missions (New Frontiers)**:
  - ESA continued work on Mars Network; no follow-up mission defined.
  - NEX-SAG considered polar climate science in its future orbiter study, finding considerable overlap of decadal survey ice science and resource assessment objectives.
- **Small Missions (Discovery):**
  - *Trace Gas Orbiter* (TGO): NASA pulled out of joint orbiter mission (2012); ROSCOSMOS/IKI filled in with launch vehicle and instruments. *TGO is now in orbit, aerobraking into final science orbit (3/2018)*
    - *NASA participation is "Electra" telecommunication radios*
  - *InSight* (Mars single station seismometer and heat probe) selected in Discovery program for 2016 launch; slipped but *on schedule for launch in 2018*.

Progress made at implementing the *V&V 2011* Mars goals

- **Technology Development**: The Mars Exploration Program has invested in technology studies critical to a successful return, if authorized, of carefully selected, scientifically credible samples to be cached by the 2020 Mars Rover.
- These ongoing background studies are reported to include:
  - Industry studies with multiple commercial providers regarding the possible provision of solar-electric-powered (SEP) spacecraft for Mars missions (2016).
  - NEX-SAG report on the range of payloads possible with various SEP orbiters (2015)
  - Ongoing studies of the Mars Ascent Vehicle (MAV) needed to loft a fetched sample cache into Mars orbit.
  - Ongoing studies of the rendezvous and orbital capture systems (ROCS) needed to catch an orbited cache of samples.
  - Discussions with ESA concerning collaboration on Earth Entry (return) Vehicle to bring the captured samples back to Earth.

New discoveries since the DS that have relevance to NASA's current and future planetary science program

- Ancient Habitable Mars
  - Solid evidence that Mars was habitable early in its history
  - First in-situ rock and surface exposure age dating on another planet
  - Diversity of water-related environments; warm/wet vs. cold/wet early Mars
  - Compelling evidence that much of the ancient Mars atmosphere has been lost to space
- Ice Ages and Climate Change in more Recent Geologic Times
  - CO_2 ice buried in South Polar Cap could double present atmospheric mass
  - Internal stratigraphy of the polar caps
  - Inference of massive volumes of subsurface ice, including very shallow ice (exposed by recent impacts)
- Dynamic Processes on Modern Mars
  - Extensive surface change triggered by seasonal CO_2 frost; effects of seasonal snowfall
  - Dust storm pathways and temporal patterns of regional dust storms; moving sand dunes
  - Possible briny flows of water on Mars today (RSL)
  - Transient methane plumes in Gale Crater

New relevant discoveries since *V&V 2011 (1 of 6)*

- ***Life***
  - **Prior**: Minerals had been detected on Mars that must have formed in a diverse set of early aqueous environments
  - **Now**: Solid, *in situ* analytic evidence of habitability from MSL
    - *John Klein* site appears to have been at the end of an ancient stream system or within an intermittently wet lake bed.
    - The mineralogy indicates sustained interaction with liquid water that was low salinity & not too acidic or alkaline; conditions were not strongly oxidizing
    - Key chemical ingredients for life are present (C, H, N, O, P, S).
    - The presence of minerals in various states of oxidation would provide a source of energy for primitive organisms.

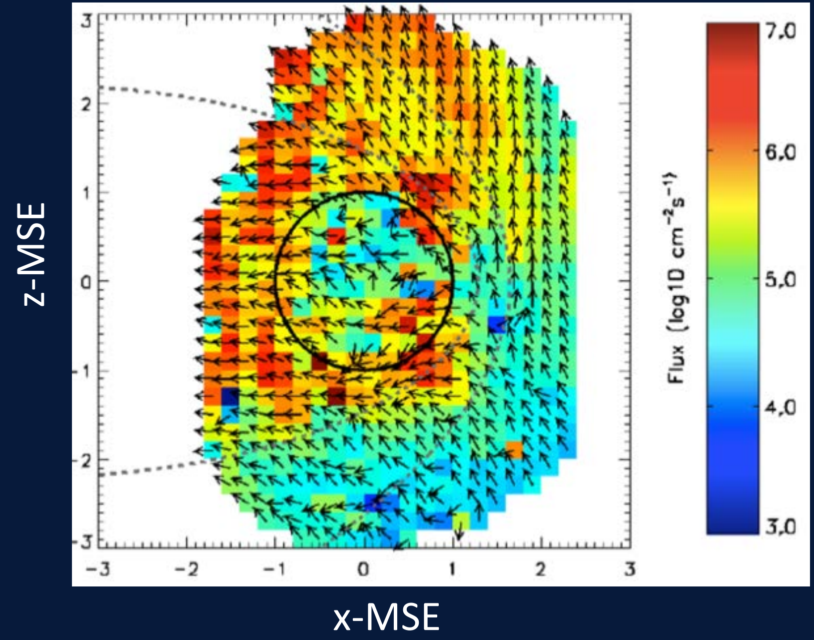
  - **Now**: Additional evidence that water was active in both the surface and subsurface and that it was episodic, with multiple wet regimes
  - **Now**: Sporadic enhancements of methane in Gale Crater: geochemical or biogenic?

Mars was habitable! (Was it inhabited?)

New relevant discoveries since *V&V 2011 (2 of 6)*

- *Climate and Geology--Ancient Mars*
  - **Prior**: Enormous channels and extensive valley networks pointed to a warm, wet Mars
  - Now: The ancient climate may have been cold and wet for extended and/or intermittent periods
    - If there was an early massive CO_2 atmosphere (with greenhouse gases like H_2), it did not leave massive carbonate beds. The total surface inventory of CO_2 today (carbonate and buried CO_2 ice) can account for ~10 x the current atmospheric amount.
    - However, much of the CO_2 and other gases may have escaped to space:
      - At a minimum, isotopic measurements of Argon indicate the loss of ~2/3 of atmospheric neutrals
      - Although highly uncertain when present rates are extrapolated to early Mars, (ionized) CO_2 loss was much greater than this.
      - D/H of water extracted from clays in ancient rocks by Curiosity was already increased by 3x
        - » indicates early, substantial loss of water

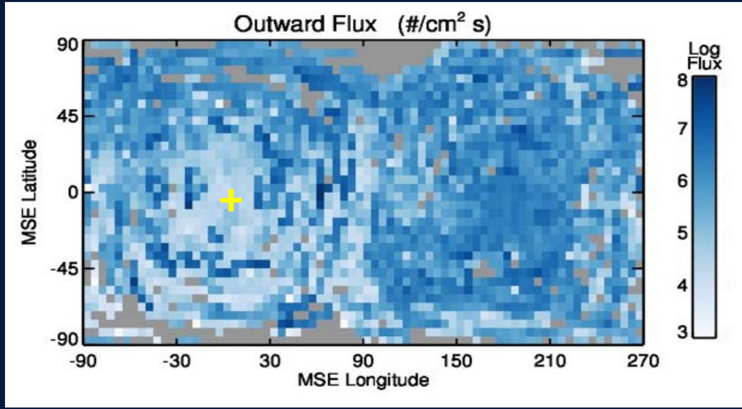
Quantifying Atmospheric Escape, Past and Present



Ion density and flow direction projected onto X-Z plane in solar coordinates. Note polar plume and ion escape down the tail

Goals for Extended Missions

- Observe during a different phase of the solar cycle
- Characterize response to new solar events
- Quantify inter-annual variability
- Fill in the 3-D global coverage of space surrounding the planet



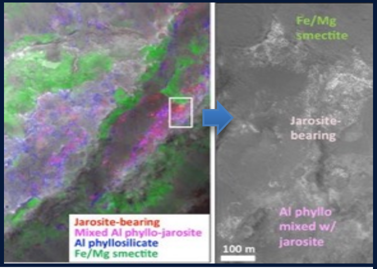
Map View: Escaping flux of ions mapped onto a sphere centered on Mars in solar coordinates

New relevant discoveries since *V&V 2011 (3 of 6)*

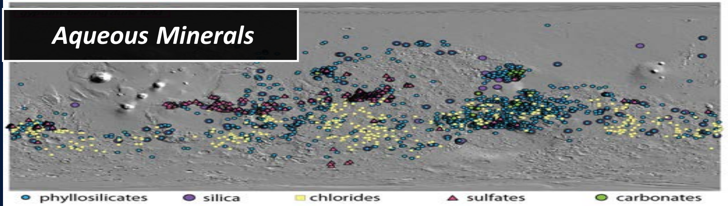
- ***Climate and Geology—Middle Mars***
  - **Prior**: Warm-wet conditions occurred mainly in the Hesperian era
  - **Now**: A cold-wet ancient climate may have occurred episodically
    - Modeling of an "Icy Highlands" scenario can account for many, but not all geologic features formed on early Mars
    - An ice-melt hydrology in the post-Hesperian era is suggested by recent mapping of widespread, paleolake-associated, fresh shallow valleys in mid-latitudes
  - **Prior**: Layered polar terrains suggest ice ages driven by obliquity changes; indications of near-surface ice in mid-latitudes
  - **Now**: Radar profiling of the polar caps reveals non-uniform "packets" of reflectors which models can relate to obliquity changes
    - Modeling of the topmost layer suggests the last ice age was ~ 370,000 years ago
    - Digital terrain maps show better correlation of segments than of albedo changes
    - Correlated radar and imaging show extensive volumes of mid-latitude ice
    - New impact craters have revealed clean, shallow ice (< 2 m) at lower latitudes

Four Goals to Study *Mars in Transition*

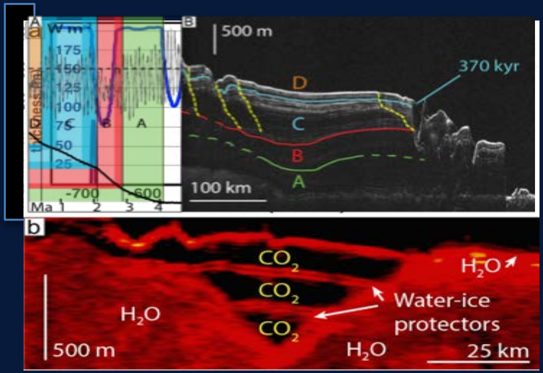
1. Ancient Mars: Environmental Transitions and Habitability



Aqueous Minerals



2. Amazonian Mars Climate: Ice and Volcanism

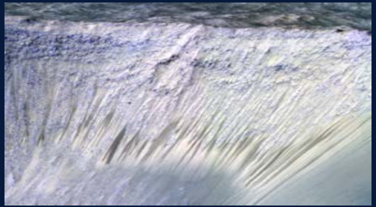


Ice Ages

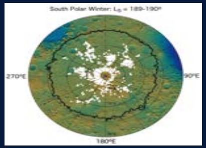
Volatile Reservoirs

Climate Change

3. Modern Mars: Surface Changes and Implications



Volatiles

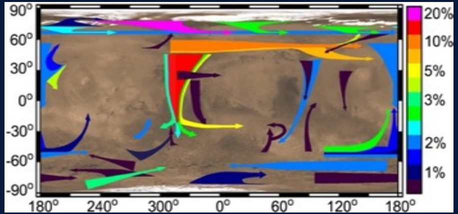


Water Environments?

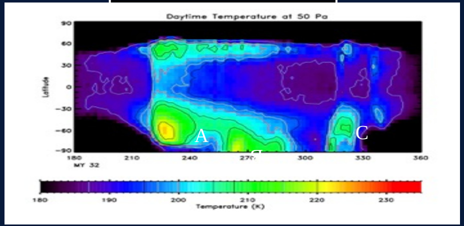
New Impacts

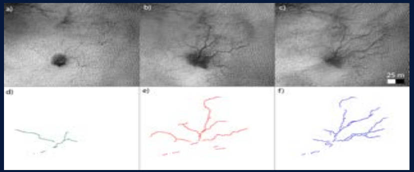
4. Modern Mars: Atmospheric and Polar Processes

Storm Tracks



Dust Storms



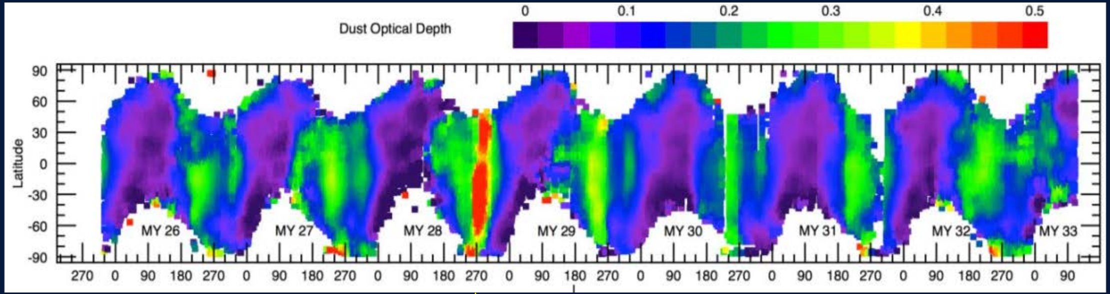


Polar Changes

New relevant discoveries since *V&V 2011 (4 of 6)*

- *Climate and Geology—Modern Mars*
  - **Prior**: There is little surface change in the present climate
  - **Now**: There is extensive change on modern Mars
    - High-resolution, long period monitoring has revealed movement of many dunes, including those observed up close by Curiosity. This suggests surprising Earth-like erosion rates in some locales.
    - At high latitudes, the seasonal cycle of CO_2 has been observed to produce significant surface change (e.g., dunes on gullies, “spiders”) and has even been suggested to be a “trigger” for avalanching and/or Recurring Slope Lineae.
    - Recurring Slope Lineae (RSL) —dark, thin surface streaks that extend downslope during warm seasons and then fade away, only to recur in the next Mars year—have been suggested as evidence of brine flows; surface thermal inertial estimates suggest only very little water could be present at the surface.
    - Almost a Mars decade of atmospheric dust and temperature measurements have revealed an interesting pattern of regional dust storms during southern spring and summer. Interestingly, no planet-encircling storm has occurred since 2007.

New Perspectives in Mars Climate

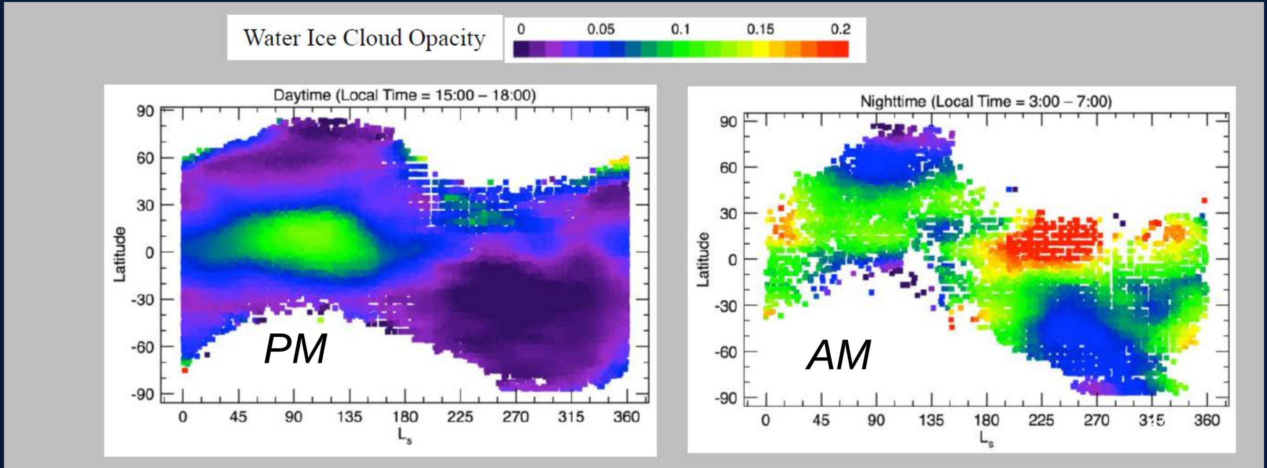


Inter-annual Variability of dust over a Mars Decade

MGS, ODY, MRO

(2007)

Mars Odyssey



Atmospheric and Surface Variations with Local Time

Recurring Slope Lineae (RSL): An Example of Change on Modern Mars

McEwen et al. (2011, 2014):

∗ RSL are narrow (0.5-5 m), dark markings on steep slopes (>25°)

∗ Originally detected in southern hemisphere (32°S to 48°S), favoring equator-facing slopes, but also seen in areas like Valles Marineris on sun-facing slopes.

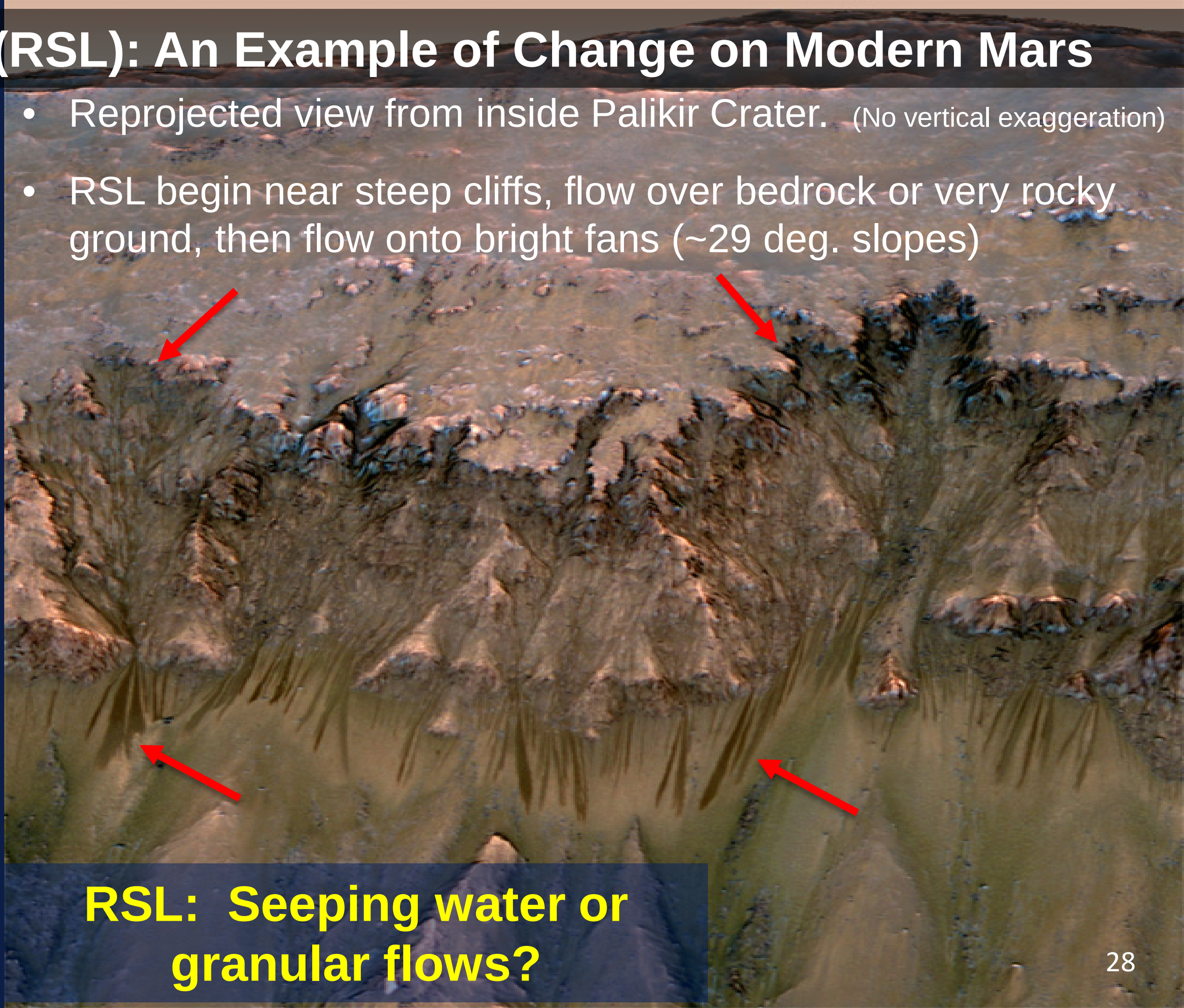
∗ Form and incrementally grow in late spring to summer, then fade or disappear in late summer to fall.

∗ Reform at nearly same locations in multiple Mars years.

∗ Extend downslope from bedrock outcrops or rocky areas; often associated with small gullies.

∗ RSL active in *seasons* when peak temperatures > 250 K.

∗ Behavior similar to water tracks in Antarctica (Levy et al, 2012)



- Reprojected view from inside Palikir Crater. (No vertical exaggeration)
- RSL begin near steep cliffs, flow over bedrock or very rocky ground, then flow onto bright fans (~29 deg. slopes)

RSL: Seeping water or granular flows?

RSL Summary

- Hypothesis: Water plays some role in RSL activity
  - Temperature dependence, albedo changes
  - Hydrated salts (e.g., perchlorates, Ohja et al., 2015, 2016)
- However:
  - Amount of water in near surface may be small (e.g., Edwards and Piquex, 2016)
  - RSL are perfectly confined to slopes at, or steeper than, the “dynamic angle of repose” for cohesion-less granular materials (Dundas et al., in review)
    - Indicates that the basic flow mechanism is dry
- Water may trigger granular flow in some way
  - Boiling of small amounts of water triggers grain flows [Masse et al., 2016]
  - Changes in hydration affects cohesion
  - Subsurface deliquescence destabilizes overlying grains
- New results imply low water activity, so habitability is difficult
  - Currently treated like Special Regions for Planetary Protection
- *Recurrence is difficult to explain in all models to date*
  - Something is being depleted that has to be replenished annually (ice, water, grains, salt)
    - Grimm et al. (2014)
  - More research and observations are needed, including lab and theoretical work

Summary of new relevant discoveries since *V&V 2011*

- *Mars was habitable. The question remains: Was it inhabited?*
  - Exposures of aqueously altered rocks point to possible preservation of organics.
- *The Martian climate and surface/subsurface changed over time, with diverse environments (some acidic, some not) and with episodic periods of water activity*
  - The early climate may often have been cold and wet—not warm.
  - While escape processes have removed much of the atmosphere, considerable volumes of water are still present in the caps and in the ground, with significant transfers between the poles and lower latitudes (ice ages) in more recent geologic time.
- *The Mars climate today still is dynamically active*
  - The wind and volatility of CO_2 ice are major agents of change today.
  - The question of whether water is liquid for specific times and places on modern Mars, perhaps as a brine, remains open.
  - A decade of atmospheric observations provides partial validation for climate models.

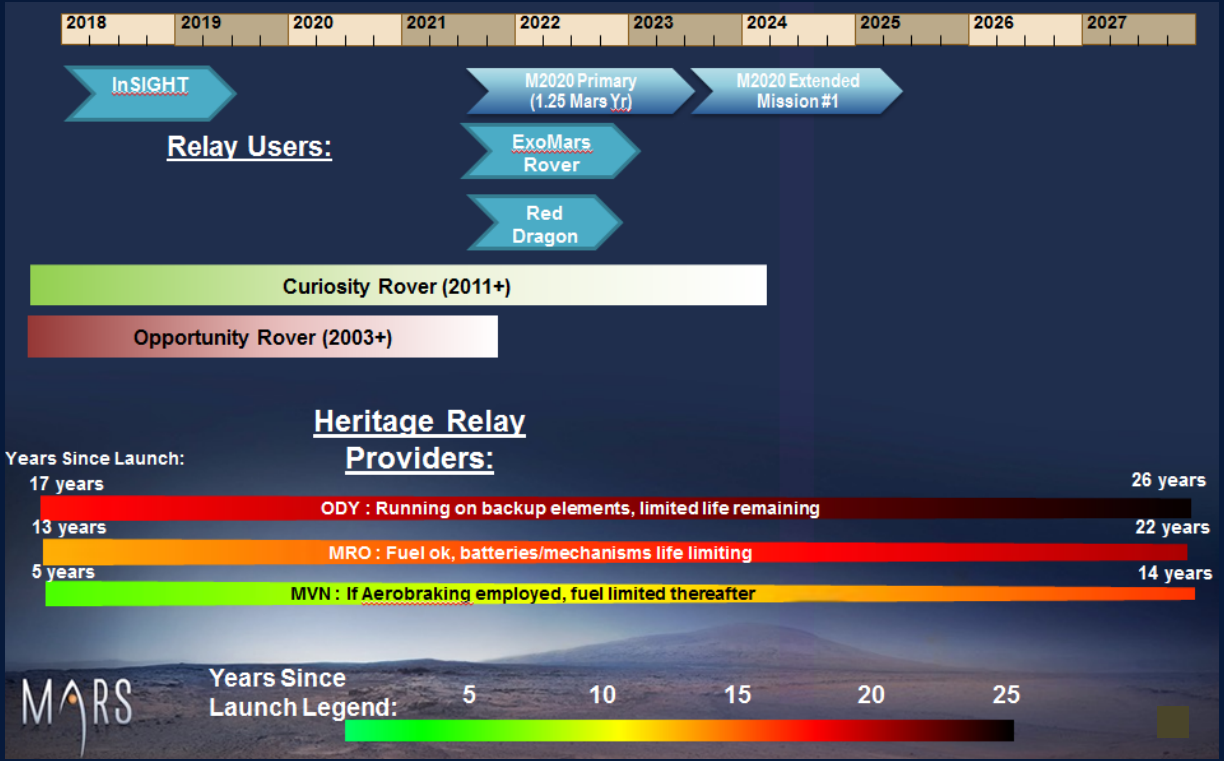
New relevant discoveries/activities since *V&V 2011 (5 of 6)*

- *Preparation for Humans*
  - ***V&V2011***: "It is vital to maintain the science focus of such peer-reviewed missions and not to incorporate human exploration requirements after the mission has been selected and development has begun"
  - ***MEPAG***: Has worked to identify Strategic Knowledge Gaps (SKGs) and Gap Filling Activities prior to mission definition. Examples:
    - Precursor Strategy Analysis Group (P-SAG, 2012) study results were incorporated into revisions of the MEPAG Goals Document
      - These aspects of Goal IV have been communicated by participation in workshops and studies looking at the "tall-pole" challenges to human exploration (e.g., Affording Mars-IV conference)
    - NEX-SAG was directed to study synergies/overlap between Decadal Survey science objectives and resource detection objectives in the context of future Mars orbiters

New relevant discoveries/activities since *V&V 2011 (6 of 6)*

- ***Preparation for Humans***
  - MEP: Discoveries addressing SKGs:
    - Detection from orbit of subsurface ice and hydrated minerals points to possible *in situ* resources for future Mars missions
    - Ongoing characterization of Martian climate and weather have provided partial (incomplete) constraints on engineering models for the design and simulation of future missions
    - Rover operations have characterized surface environments and gained practical operational experience in Mars environments

MEPAG Concerns: 1--MEP Infrastructure is Nearing Exhaustion



MEPAG Concerns: 2

- A prime frustration of the MEPAG community is the absence of high-level discussion of future Mars missions to follow the 2020 caching rover now in development. With the Agency seemingly unable or unwilling to even discuss next steps, sample return seems to be “on hold” indefinitely, and opportunities to further understand the diverse environments of a complex planet have not been pursued.
- A second major frustration of the U.S. portion of the MEPAG community is the seeming absence of competed opportunities for U.S. investigators to address outstanding questions in Mars science (e.g., polar climate science) in lieu of, or even as part of, the orbiter and rover missions required to return samples to Earth.

MEPAG Concerns: 3

- MEPAG still supports the conclusion of past Decadal Surveys that well-characterized sample return is the highest-priority next step
  - Provides ability to address fundamental questions of past life, changing climate and planetary processes of a habitable terrestrial planet
- However, the absence of committed missions of any kind in a program architecture is most troublesome if we are to understand Mars and what it can tell us about all planets, including our own.
- The V&V 2011 recommendation for "major investment" in MSR technologies (MAV thermal control, autonomous launch operations, ascent/guidance in Mars conditions) has not yet been met ($10M+ reportedly spent thus far)

Response: MEPAG reaction to addition of 2 new targets to the NF4 list

- There was a reaction in the hallways at the MEPAG meeting at this out-of-Decadal sequence, although most took it as a reasonable response to new discoveries by Cassini.
- But the question was raised (there and in the MEPAG Executive Committee) as to why there was still no Mars NF candidate, even though Mars has also had significant discoveries (e.g., RSLs, mid-latitude/polar ice).
- Thus, this has now became part of Executive Committee discussions as to whether and how Mars could be brought into a NF list.
  - Previously, it had not occurred to MEPAG that the NF list could be amended without Decadal Survey approval.

Preparations for the Next Planetary Decadal Survey (2023-2032)

Mars Architecture for the Decade 2023-2032

Factors in the Next Mars Architecture

- New and ongoing missions, including *TGO* and *InSight*, are likely to make additional new discoveries
- Science-driven Mars Sample Return remains a high priority for Mars & Planetary Science
  - Need to plan the next missions, and a Sample Receiving Facility (SRF) is required to finish MSR
- Mars has become a frequent target for many space agencies and now for commercial entities as well
  - NASA, ESA, ISRO, CSA, JAXA, China, UAE, Space X, etc.
- New capabilities are coming into play (e.g., Solar Electric Propulsion (SEP), small sats)
- There are several non-MSR science objectives which could and should be pursued (e.g., polar science, RSL)
- Major uncertainties include: 1) the FY18 budget and beyond, and 2) the relationship of the robotic and human Mars exploration activities
  - Dual-purpose missions? Robotic precursors? Assimilation?

MEPAG Roles in the Next Mars Architecture (1 of 2)

- Continue support for the 2020 Mars rover and press for comprehensive planning of the next missions needed to complete Mars sample return
- Look for opportunities to pursue non-MSR science, including R&A
  - Mars is a complex planet. The scientific questions now being asked require new analysis, new laboratory work on volatile and aqueous processes, and continued work on/in Earth analog field sites, all of which the community is prepared/excited to pursue.
    - Presently, missions well past their prime phases are carrying some of the R&A load; this will change as these missions end and more will have to be done in the data analysis programs
  - Update the Goals Document to maintain consistency with new discoveries
  - Identify possible New Frontiers candidates to be approved in the next Decadal Survey
  - Study those candidates and the MSR follow-on missions, once defined, for opportunities to fly science instruments/investigations

MEPAG Roles in the Next Mars Architecture (2 of 2)

- Look for opportunities (*continued*)
  - Look at small satellite and commercial space opportunities for flight of science instruments; look to facilitate synergy and coordination
    - Study possibility of competed, PI-led small satellite missions carried to Mars by strategic missions with data returned through those missions (e.g., the next Mars orbiter, Red Dragon)
- In both the MSR and non-MSR mission context, help facilitate international cooperation at the payload and mission level
- Look for ways to assist planning for human missions, including dual missions supporting both science and exploration generally
  - The question is: What does the agency want to do?

Discoveries/Questions That Require Follow-up as of 2017

- Did Mars ever have life? Is it still there?
  - Science-driven sample return is critical to answering this question.
- How, when, and how often did Mars experience great transition(s) from a much wetter environment to the cold, dry, oxidizing world of today?
  - We have discovered 10+ distinct potential habitats, comprising a key environmental record in the strata from first billion years. How many more of these habitats are there and what is their time history? Need to characterize and date materials from many different locations.
- How do terrestrial planets like Mars respond to early processes like giant impacts and warming from a faint young sun in our solar system?
  - What is the timing/intensity of these processes? How did different Mars habitats respond to these changes?
- How is water involved in the near-surface today?
  - RSLs: what are these seasonally changing streaks? Gullies and salts in last few million years?
- Do obliquity cycles raise atmospheric pressure and drive episodic modern water availability?
  - Massive polar traps of CO_2
- What does water ice on Mars tell us about the earlier climate and environmental changes?
- What is the temporal variability, amount, and source of methane?
  - What is the nature of the source (biological or geochemical)? How can it disappear so quickly?

Preparations for Humans

- ***Mars is the logical destination for humans in deep space***
  - What do we need to know to make that journey possible while minimizing cost and risk?
  - Can humans live on Mars? Where are the resources? What are the hazards?
    - Where can water be extracted? From shallow ice? From hydrated minerals?
    - Planetary protection policy must be addressed if these resources are to be used.
    - What are the nature of the hazards and how can they be mitigated?
  - What should humans do on Mars to advance our understanding of Mars, Earth, and all planets?

- ***MEPAG stands ready to assist in exploring answers to these questions***
  - A human flight architecture is needed to set priorities in precursor missions, but MEPAG feels strongly that analysis of returned samples would be a great benefit.
  - Joint workshops are an excellent way to bring the most relevant questions and plans into focus (e.g., the Human Landing Site workshop)
  - Existing and future orbital remote sensing can contribute
  - Much can be done with analysis and new approaches to existing data

MEPAG Roles in preparation for the next Decadal Survey (2023-2032)

- Involve the Mars/planetary/commercial community through SAGs and at least one annual face-to-face meeting per year
- Update the Goals Document as new discoveries and new research shape our understanding of Mars
  - Build on major conferences and topical analysis groups
- Investigate new ways of doing missions; e.g., with international partners, commercial entities, or missions of opportunity
- Debate and build consensus
- Suggest specific items for detailed study by MEP
- Encourage the community to participate as members of the Decadal Committees and as authors of white papers
  - this provided vital input to the Decadal committees during the last Decadal Survey

Summary

- New and ongoing discoveries have challenged many previous views of Mars–this will continue, given new and long-lived assets at Mars, supported by data analysis
- Progress is being made toward Mars Sample Return
  - 2020 Mars caching rover is on schedule and budget, with a capable payload for selecting samples and providing their geological context
  - Key technical studies are in progress to help lower the cost and cost risk of the future missions that are needed to complete sample return, but at low levels that need to be accelerated
- Major concerns for both sample return and Mars science are:
  - An aging infrastructure and a lack of a confirmed post-2020 architecture, including no identified opportunities for competed flight investigations that often make the key discoveries
  - The missing element seems to be the will to proceed on the part of the agency and administration
- There remains much exciting science to do at Mars, and community momentum is strong to address fundamental questions about planetary evolution and origin of life
  - MEPAG remains ready to respond to calls for assistance to help implement the plans