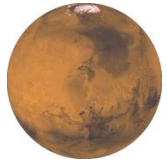

A Long-Range Vision for the Exploration of Mars

September 20, 2017

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(with help from Brandi Carrier[1])

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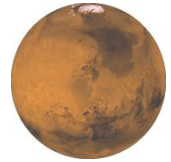
Based on content presented at the V2050 Workshop, Feb. 27-Mar. 1, 2017. This is not the report of a community consensus, but instead a compilation of the primary ideas presented/discussed there. The possible future missions have not been approved by NASA (or anybody else).

The Community's Vision for Mars: Common Strategic Elements



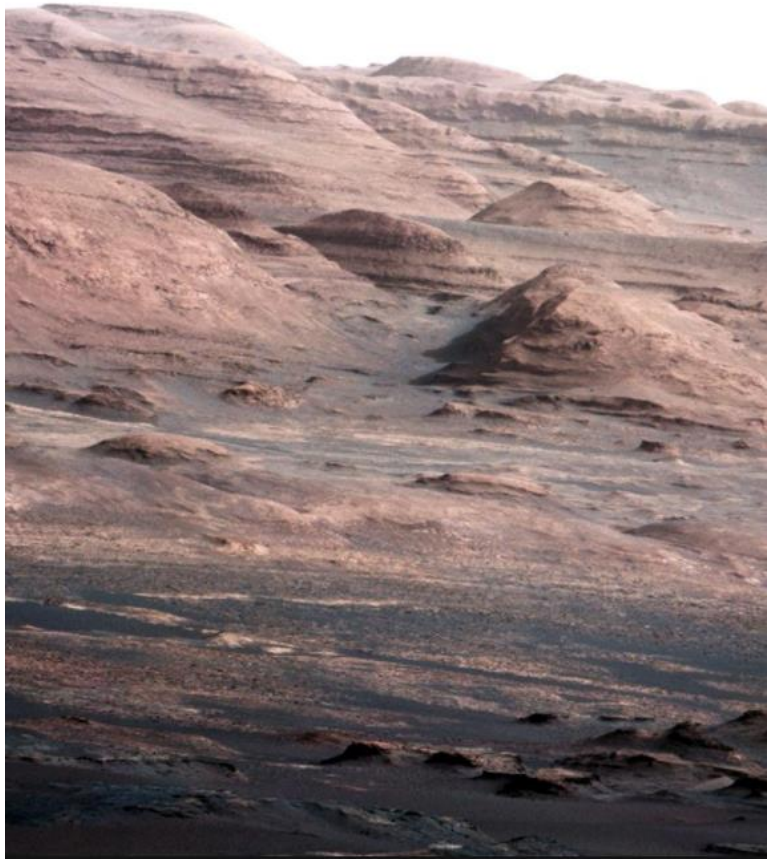
We have identified <u>three common strategic elements</u> that underlie the future vision of many members of the Mars community:

1. As part of a broader program of planetary science, we have high-priority long-term scientific objectives for Mars that will not be closed with the missions on the books.

The Community's Vision for Mars: Common Strategic Elements

We have identified three common strategic elements that underlie the future vision of many members of the Mars community:

2. We have made, and expect to make in the near future, a series of valuable discoveries that have/will raise important new questions that require follow-up.

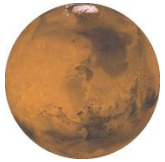


The Community's Vision for Mars: Common Strategic Elements

We have identified <u>three common strategic elements</u> that underlie the future vision of many members of the Mars community:

3. Mars remains the most coveted destination for the human spaceflight program. We need to plan for synergy between the robotic and human branches of Mars exploration.

Long-Term Motivations for Mars Exploration (1 of 2)



Key science considerations include:

A. Astrobiology: Life

We need to understand the biological pathways of Mars and the Earth.

I. If Mars had/has life, what was its character, and does it persist to the present?

II. If Mars never had life, why not? What are the essential points of divergence between it and Earth?

B. Workings and Astrobiology: Early Habitats

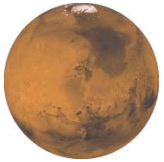
We need to understand the first billion years or so of Mars' geological history—This is a period that is almost entirely missing from Earth's geologic record and is crucial to understanding the earliest geological processes and environments available for life on Earth-like worlds

I. When and how was Mars' early thick atmosphere lost (stellar activity, magnetic field decline)?

II. How did heavy impact bombardment affect the atmosphere and surface (timing and response)?

III. How did the climate sustain liquid water in spite of a faint young sun?

Long-Term Motivations for Mars Exploration (2 of 2)



Key science considerations include:

C. Origins and Workings: Long-Term Evolution of Terrestrial Bodies

We need comparisons of the origin, evolution, and dynamics of the atmospheres of Mars, Venus, Earth that lead to quantitative predictive models (including climate and weather).

I. What can Mars' internal dynamics, crustal structure, volcanic history and processes, and variation in obliquity tell us about how physical processes are coupled?

II. Lessons from Mars are crucial for interpreting Earth-like exoplanets (with variable insolation, size, density, orbital parameters, atm. chemistry, etc.)?

D. Human Exploration of the Solar System

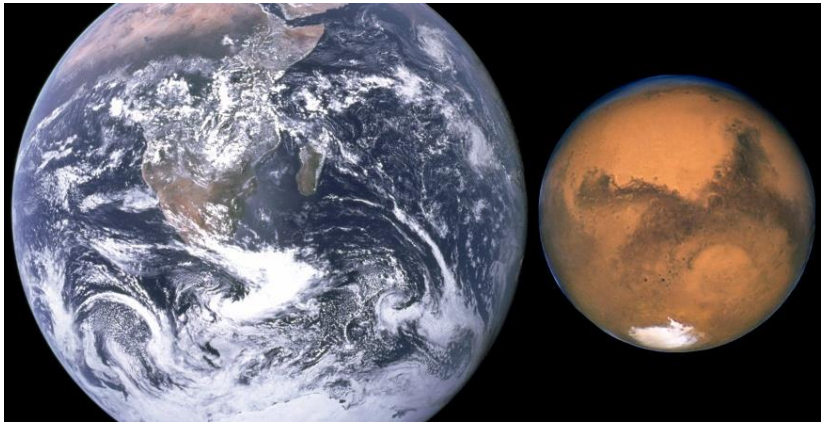
Mars is a crucial destination for potential future human exploration

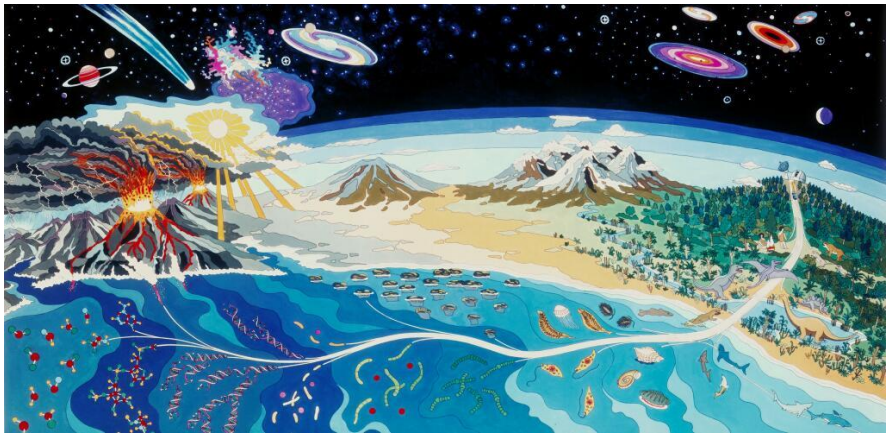
E. General

The MEPAG Goals document lists a number of high-level objectives that will not be closed by 2035, and that should be considered in long-range planning to 2050.

Possible Multi-Decade Mars Science Goals

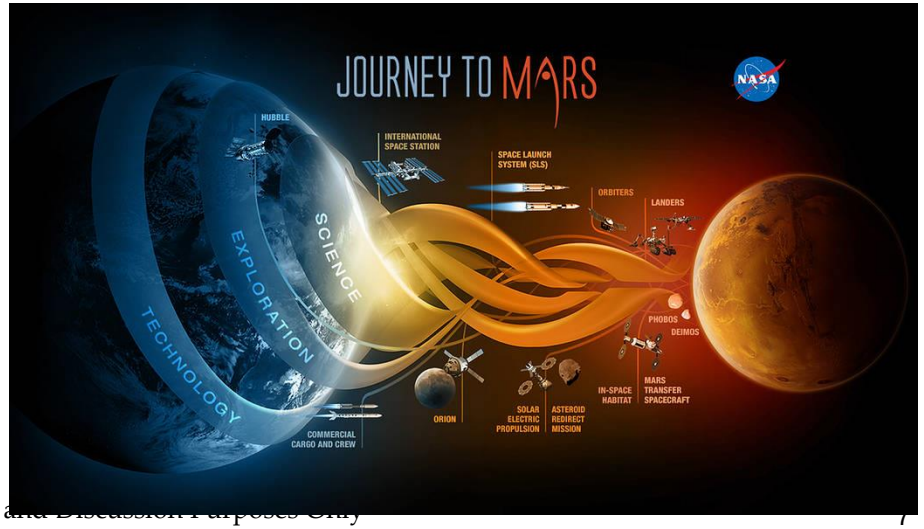
1. Understanding Earth-like Worlds in the Habitable Zone



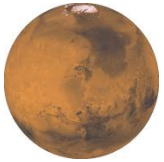


2. Searching for Life (Past & Extant)

3. A Destination for Human Solar System Exploration



Mars Planning: The Long View



LONG-TERM DRIVING MOTIVATIONS:

- *Understanding Earth-like Worlds in the Habitable Zone*
- *Searching for Life (Past & Extant)*
- *A Destination for Human Solar System Exploration*

2010s	2020s	2030s	2040s	2050

ODY, MER, MRO, MSL, MVN, TGO, MOM

DISCOVERIES

Mars-2020 (+intl. missions)

launch — *EM-1* — *Cache Depot #1* — *Cache Depot #2*

DISCOVERIES

2026-2028? — *Robotic or human-assisted* — *launch*

Sample Rtn Lander

Samples arrive 2031-2033?

Most likely outcome: *far better understanding of hab., preserv. pot., some candidate BioS, no definitive BioS, critical progress in petrogenesis, geochron., etc.*

Sample Analysis

initial *on-going*

DISCOVERIES

Key Fact: **Past, near-term, and far-term missions have made (and will make) multiple discoveries in the areas of life, origins, and workings that raise new high-priority questions that require follow-up.**

How can we best follow up on the discoveries?

1) Pathway for hypothesis-driven science to advance
2) Robotic and human exploration programs converge

Decadal Surveys

2020 **#3** 2022 — 2030 **#4** 2032 — 2040 **#5** 2042

ROBOTS

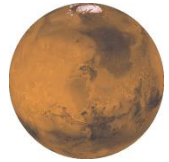
HUMANS, PREP

Possible future missions are notional

orbiter volatiles — *NF or SmallSat Scouts Dynamic Atm./Ices* — *multiple smaller landed missions, past and extant life?* — *rovers + sci. tools*

commercial lander? — *water resources* — *Comm. Network* — *ISRU lander?* — *std. comm. network replacement* — *Human Landing?*

The Importance of Discovery-Responsive, Hypothesis-Driven Science at Mars

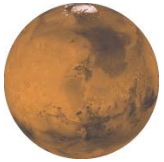


The engine that drives planetary (including for Mars) scientific exploration forward is discovery response and hypothesis formulation and testing. As previous questions about Mars are answered, they raise new questions that could not have been anticipated earlier. We have seen this play out for >200 years in the scientific exploration of the Earth. The exploration process is iterative, as it progresses forward and we understand the system at a deeper and more connected level.

- **CONCLUSION**: In the case of Mars, we have a critical opportunity to capitalize on our existing (and yet to come!) hard-earned discoveries that cannot be wasted.

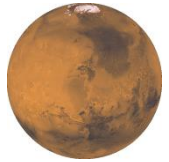
- **SCIENCE AND HUMANS**: Although many HEOMD- and science-driven measurement needs overlap, some science questions are fundamentally different from those solely in service of exploration.
  - Example: Rather than solely "what?" and "how much?", scientific questions about a hydrated mineral deposit are also "when?", "how?", and "why?".

Summary



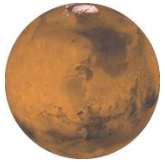
In summary, the best way to advance our understanding of Mars is to:

1. Provide a pathway for hypothesis-driven, discovery-responsive science to advance via robotic exploration
2. Plan for the robotic and human exploration programs to converge



Back Up Slides

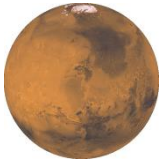
Discoveries/Questions That Require Follow-up as of 2017 (1 of 2)



Mars discoveries generate new scientific questions:

- Did Mars ever have **life**? Is it still there?
- Mars experienced **great transition(s)** from a much wetter environment to the cold, dry, oxidizing world of today: How, when, and how often did that happen? We have discovered **10+ distinct potential habitats,** comprising a key environmental record in the strata from first Gyr.
- How do early terrestrial planets like Mars respond to early processes like **giant impacts** and **warming of a faint young sun**? What is the **timing and intensity** of these processes in our solar system? How did different Mars habitats respond to these changes?
- Potential **water-related activity today**: Recurring Slope Lineae: what are these seasonally changing streaks? Gullies and Salts in last few Myr: How is water involved in their creation?
- **Massive polar traps of CO_2**: Do obliquity cycles raise atmospheric pressure and drive episodic modern water availability?
- **Methane** – How much? Does it really come and go? What is the nature of the source (biological or geochemical)? Why does it disappear quickly?

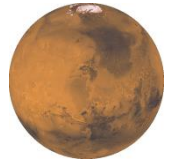
Discoveries/Questions That Require Follow-up as of 2017 (2 of 2)



Mars discoveries always leave more questions:

- What is the nature of **accessible water/ice** on Mars? Can it be used?
- Can humans live on Mars? Where are the **resources**? What are the **hazards**?
- We know some ways in which Mars is active today (methane, geomorphology, ice, water). **How do Martian processes compare in detail to the active processes on the Earth?**

NOTE: There are likely more discoveries than these that could be / should be followed up, and we encourage a more systematic, complete, compilation.



About This Package

This package was compiled from information and ideas about future Mars exploration from the Vision 2050 Workshop, Feb. 27-Mar. 1, 2017, including presentations/discussion that happened during the 3-day meeting and information in the written abstracts.

The V2050 Workshop was structured around themes, such as origins, life, and workings, not around planetary targets. Thus, the Mars content was scattered through the program.

This Mars compilation is what was observed by the authors, along with some editing help by several Mars-focused participants, of the primary Mars ideas presented/discussed and is not the report of a community consensus. This report was not chartered by, nor does not it reflect endorsement from, the V2050 organizers, NASA or the Mars Program Office.