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A Long-Range Vision for the Exploration of Mars

D.W. Beaty (1) and Bethany Ehlmann (2)
(1) Mars Program Office, Jet Propulsion Laboratory, California Institute of Technology, (2) GPS/Caltech and Jet Propulsion Laboratory / California Institute of Technology (David.W.Beaty@jpl.nasa.gov)

Abstract

In response to a request from NASA's Planetary Science Division, a large community group met Feb. 27-Mar. 1, 2017 to develop a collective vision of planetary science research and exploration in the decades until 2050. The workshop was organized around themes (Life, Workings, Origins, Defense and Resources, Policies, Technologies) and not by destination solar system objects. However, after the workshop, we compiled the primary ideas from all of the themes that relate to Mars. Thus, this document does not describe a set of positions that have been validated via widespread discussion and debate, but instead a reporting of various aspects of a Mars vision as presented in the abstracts, posters, and oral talks at the Vision 2050 workshop (e.g., 1-5).

1. 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:

- 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 currently planned (i.e., launches planned through 2020).
- We have made—and expect to continue to make in the near future from ongoing and planned missions—scientific discoveries that have/will raise important new questions that require follow-up. In particular, this includes substantial new knowledge since 2010 on the environmental diversity of ancient Mars, possibly late periods with liquid water (driven by obliquity cycles), large reservoirs of water and CO_2 volatiles as ices, and unexplained methane generation and destruction.
- Mars remains the most coveted destination for the human spaceflight program. As such, on a multi-decadal timescale, we need to plan for synergy between the robotic and human branches of Mars exploration.

2. Long-Term Motivation for Mars Exploration

A critically important aspect of formulating a vision for the future exploration of Mars is to establish the long-term motivations.

Key science considerations include:

- <u>Astrobiology: Life</u>. We need to understand in detail the biological pathways of Mars and the Earth. If Mars had/has life, what was its character; does it persist to the present? If Mars never had life, why not, and what are the key points of divergence between it and Earth?
- <u>Workings and Astrobiology: Early Habitats</u>. We need to understand the first billion years or so of Mars' geological history—a period that is almost entirely missing from the Earth's geologic record. When and how was Mars' early thick atmosphere lost (stellar activity, magnetic field decline)? How did heavy impact bombardment affect the atmosphere and surface (timing and response)? How did the climate sustain liquid water in spite of a faint young sun? This is crucial to understanding the earliest geological processes and environments available for life on Earth-like worlds. It is a record only accessible on Mars.
- <u>Origins and Workings: Long-Term Evolution of Terrestrial Bodies</u>: Comparisons of the atmospheres of Mars, Venus, Earth that lead to quantitative predictive models for climate and weather are important for understanding the origin, divergent evolution, and modern dynamics of these three terrestrial planets. How are geophysical and atmospheric processes coupled, as revealed by study of Mars' internal dynamics, crustal structure, volcanic history, and variation in obliquity? Lessons from Mars (and

Venus) are crucial for interpreting Earth-like exoplanets (with variable insolation, size, density, orbital parameters, atm. chemistry, etc.).

Additional considerations associated with the broader space exploration enterprise include:

- Human Exploration of the Solar System: Mars is a crucial destination for potential future human exploration. It is of interest to national space agencies of multiple countries as well as commercial entities. It is the only destination with the potential for long-term inhabitation from in situ resources.
- **Technology**: Sample return technologies (MAV, fetch rover) have reached a level of maturation suitable for implementation of sample return. Miniaturization—partially driven by the CubeSat revolution—has resulted in new enabling technologies for networks of Mars weather/comm. satellites, highly capable but low-mass landed payloads on small rovers or helicopters, and higher capability orbiter instruments at equivalent or low mass.
- 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.

3. The Importance of 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 were answered, they raised 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. In the case of Mars, we have a critical opportunity to capitalize on our existing hard-earned discoveries that cannot be wasted.

Although many human- and science-driven measurement needs overlap, some science questions are fundamentally different from those solely in service of exploration.

- Example #1: Rather than solely "what?" and "how much?", scientific questions about a hydrated mineral deposit are also "when?", "how?", and "why?".
- Example #2: Measurements for understanding the timing and processes behind early planetary evolution fall largely within the province of science alone.

As such, a science-driven robotic and sampling program at Mars can and should continue, independent of but complementary to activities related to the human spaceflight program, incorporating the enhancements that human capabilities can provide as they become available.

4. Summary and Conclusions

In summary, the best way to follow up on the discoveries that have been and will be made is:

1) Provide a pathway for hypothesis-driven science to advance
2) Plan for the robotic and human exploration programs to converge

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