Comments On The 2017 Humans To Mars Report (H2MR'17)

1. Preface

This essay is a personal commentary on a document published by Explore Mars, Inc. in conjunction with The Humans to Mars Summit 2017 during May 2017 and titled "The Humans To Mars Report 2017: Landing Humans on Mars by 2033". This document is referred to as "H2MR'17" herein. A copy of H2MR'17 may be obtained from https://www.exploremars.org/wp-content/uploads/2017/05/H2MR_2017_Final_webv1.pdf (accessed 26 May 2017). The essay author's opinions as an unaffiliated astrodynamics consultant are expressed herein with intent to stimulate further discussion among colleagues and the public of what this author views to be absent, arguable, questionable, unexpected, or unsupported information, strategies, or predictions in H2MR'17.

Commentary on H2MR'17 is organized in subsequent paragraphs according to major section-specific themes or concepts running through the document or absent from it. Page *n* references to H2MR'17 are therefore not in any ordered numeric sequence and are of the format "p. *n*". External references with respect to H2MR'17 are cited in square brackets and detailed in the References section at the end of this essay. Other informal external references appear in footnotes.

2. Mars As A Critical Off-Earth Human Destination

On p. ii, Mars is termed "a critical destination that will enable exploration and development of space". The takeaway message from this remark, and indeed from the Explore Mars mission statement, is the surface of Mars offers a uniquely hospitable off-Earth destination for <u>human</u> exploration and development. As stated on p. iv, "Explore Mars was created to advance the goal of sending humans to Mars within the next two decades."

Subsequent to p. ii, the concept of Mars as a critical human destination is neither further defined nor supported with any substantial evidence. Why is the surface of Mars humanity's preeminent 21st Century off-Earth destination? Readers of H2MR'17 are being asked to tacitly accept this assertion without even so much as a reference to consult.

The words "critical" and "enable" in the p. ii quotation convey an impression that off-Earth exploration and development cannot occur without humans on the martian surface. This impression is misleading[i], as demonstrated by human activity in low Earth orbit since 1961 and by crewed Apollo Program lunar landings from 1969 into 1972.

3. Landing Humans On Mars By 2033

This theme is H2MR'17's subtitle, and the associated deadline year is justified on p. ii with the statement: "the 2033 date is close enough to maintain public and political support for Mars

[i] The verb "mislead" is defined as imparting an incorrect idea or impression. It is beyond the scope of this essay to conclude whether or not H2MR'17 *intentionally* misleads any of its readers.

exploration, particularly when coupled with appropriate pre-cursor missions." To the contrary, history demonstrates such urgency is completely unfounded. Widespread public support for a human presence on Mars has existed at roughly current levels for more than 100 years, commencing long before any robotic Mars reconnaissance began with Mariner 4's flyby in 1965. On p. 2, H2MR'17 affirms this contention without qualifying its time of inception: "Public support for Mars has always been strong and, within the United States, Mars is broadly viewed as the next natural step for human space exploration." This contradicts rationale for the 2033 deadline year and calls any such deadline into question.

A vast body of science fiction literature appears to be the primary motivating factor giving rise to perennial support for humans on Mars. The associated bibliography begins with *The War of the Worlds* (by H. G. Wells, published in 1897) and *Under the Moons of Mars* (by Edgar Rice Burroughs, published in 1912). It continues to the present day with *The Martian* (by Andy Weir, self-published in 2011). Conglomerated with this fictional literature are highly speculative accounts on the suitability of Mars for human habitation with a basis in science and technology at the time of publication. These accounts have been fundamentally discredited by subsequent research, but they include *Mars and Its Canals* (by Percival Lowell, published in 1906) and *Das Marsprojekt* (by Wernher von Braun, published in 1952).

It is worth noting that von Braun's technical research, serving as the basis for *Das Marsprojekt*, was conducted in 1948 [1]. The assumed launch year for his crewed Mars expedition is 1965, two decades in the future and remarkably similar to lead time advocated in H2MR'17. It can be argued *Das Marsprojekt* gave birth to the mantra "We're always 20 years away from landing humans on Mars." This mantra has persisted to the present and is but another indication public support for the idea will not wane if a deadline is not set or met. Well motivated or not, a human presence on the surface of Mars is in our cultural DNA regardless of efforts from advocacy groups like Explore Mars.

The 20-year mantra is reiterated at the top of H2MR'17 p. 20, where readers are informed: "The overall sense of Congress, as evidenced by the *NASA Transition Authorization Act of 2017* and the unambiguous policy statements therein, is that the nation must focus its human space flight efforts on achieving human surface missions to Mars within the next two decades." Nowhere in the *NASA Transition Act of 2017* [2], hereinafter called "NTAA'17", is the imperative "must" from this H2MR'17 p. 20 quote imposed on NASA by law. Only NASA studies and plans are actually authorized by NTAA'17. This act of Congress artfully dodges an actual commitment to landing humans on Mars.

For example, the "HUMAN EXPLORATION ROADMAP" sanctioned by NTAA'17 requires "an integrated set of exploration, science, and other goals and objectives of a United States human space exploration program to achieve the long-term goal of human missions near or on the surface of Mars in the 2030s" [2, Sec. 432(b)(2)(A), PDF p. 39]. The NTAA'17 also authorizes a 2-month study to be contracted before August 2017 "with an independent, non-governmental systems engineering and technical assistance organization to study a Mars human space flight mission to be launched in 2033" [2, Sec. 435(a), PDF p. 43]. Note the precise destination for this mission (near to or on the surface of Mars) is again unspecified. Need for such a study indicates NASA's ability to land humans on Mars in the 2033 timeframe within pertinent funding constraints is very much an open question. Is it coincidence this study focuses on the same mission year as in H2MR'17's subtitle? Like H2MR'17, the NTAA'17 gives no rationale for a year 2033 deadline pertaining to any human spaceflight mission with Mars as its destination. The 2-month study is only authorized to estimate funding necessary to meet the arbitrary 2033 deadline [2, Sec. 435(b)(2), PDF p. 43]. Changes to this deadline are not authorized.

Rationale for human exploration of Mars in NTAA'17 rests completely with the "Pathways to Exploration" report [3] as detailed in Sec. 431 [2, PDF p. 38]. The Pathways report focuses on Mars as a human space exploration "horizon goal", but it provides no compelling rationale for this choice vice other Solar System destinations. From cultural observations earlier in this section, Mars fixations in the Pathways report, NTAA'17, and H2MR'17 appear to rest on a common "house of cards" rationale built from over a century of science fiction literature, limited data, intuition, and poorly informed research at the dawn of The Space Age.

4. Mars Exploration Strategy

Missing from the table titled "Future Mars Science Missions Can Provide Key Answers for Human Exploration" on H2MR'17 p. 6 is any in situ study of the outer martian moon Deimos.[ii] A JAXA mission study with an objective to return samples from inner martian moon Phobos is cited in this table. This is the Martian Moons eXploration mission (MMX), planned for a launch in 2022.[iii] Unfortunately, MMX only performs flybys of Deimos after Phobos samples are autonomously obtained during the mission phase likely incurring highest risk. The implication that Phobos exploration can serve as a proxy for understanding the physical properties of Deimos is dubious. Mars exploration strategies consistently rank Deimos at lower priority than Phobos, but no compelling rationale is given for this preference. The following five substantive reasons favor Deimos over Phobos as a strategic destination from which humans can most inexpensively, safely, and efficiently explore Mars.

1) Deimos is more accessible from interplanetary space than is Phobos, and interplanetary space is more accessible from Deimos than from Phobos.
2) The Sun and Earth are eclipsed less by Mars at Deimos than at Phobos. From high Deimos latitudes near the local summer solstice, the Sun and Earth are continuously in view for months. Mars eclipses the Sun and Earth for some interval during every 7.656-hour Phobos orbit.
3) Proximity operations with respect to Deimos are easier because Mars tidal effects are less dominant than in proximity to Phobos. Mars tides on Deimos are also likely to create less severe surface instabilities than on Phobos.
4) A fixed location on the surface of Mars can be kept in view for days from Deimos in its slightly super-synchronous 30.312-hour orbit. Continuous viewing from Phobos is limited to hours.
5) Higher latitudes on the surface of Mars can be viewed from Deimos than from Phobos.

[ii] No explicit mention of Deimos appears in H2MR'17.
[iii] Reference http://spaceref.com/news/viewsr.html?pid=48736 (accessed 29 May 2017).

A strategy with which humans could explore Mars from Deimos, from another closer Mars orbit, or from a subsurface Mars habitat is called low-latency telepresence (LLT). From Deimos, humans can continuously control robotic surface proxies at a single location on Mars with line-of-sight communications for intervals of nearly 60 hours. If but two other such proxies are emplaced at roughly 120° intervals in martian longitude, full-time LLT exploration of Mars would be possible. Participants at a Keck Institute for Space Studies workshop held in October 2016[iv] were asked what planetary science objectives on the surface of Mars could not be accomplished via LLT. The consensus response was "none". This workshop concluded LLT could be particularly advantageous to three off-Earth exploration strategies.[v]

1) LLT may be the only way to conduct the highest-quality field science in extreme environments where presently available technology will not offer suitable protection for on-site humans.
2) LLT may be necessary to observe transient events (e.g., cryovolcanic eruptions, or atmospheric phenomena such as dust devils) whose durations preclude effective study by high-latency telerobotics.
3) LLT may permit more effective teleoperation of spatially distributed robotic assets on a planetary surface, enabling rapid, large-scale reconnaissance to guide more detailed exploration.

A comprehensive survey of current and planned high-latency robotic missions to Mars is made on H2MR'17 pp. 3-6. Only brief mention of LLT, in connection with Lockheed Martin and Boeing mission concepts, appears on p. 9. No mention is made of the potential for LLT to minimize cost and risk, while maximizing productivity, as humans explore the surface of Mars through nearby robotic proxies.

The "MARS SURFACE SYSTEMS" section on H2MR'17 p. 14 adopts a conventional human "boots on the ground" approach to Mars exploration without any aid from LLT. This strategy is affirmed by the section's opening statement: "Surface systems needed for Mars include habitats, power, surface transportation, and surface Extra-Vehicular Activity (EVA) and must support a crew for up to 500 days on the surface." No mention is made about a subsurface habitat to minimize human exposure to radiation. Furthermore, illustrations of routine Mars surface EVA on pp. 15-16 and p. 25 indicate a lack of concern for radiation exposure during a 500-day surface sojourn. They may be less picturesque, but illustrations showing humans in well-shielded subsurface Mars habitats [4, pp. 258-259 and 266-267] would impart a more ethical attitude to H2MR'17 regarding Mars human explorers' welfare. There is also no mention of how Mars surface systems support more than a single 500-day sojourn. These systems represent on the order of 50 metric tons (t) of mass transported to the surface of Mars. Will these systems be abandoned in favor of another location? If not, how are they resupplied? Finally, no mention is made of Mars "special regions" (likely sites of native life if it exists) and how these will be protected from contamination by human presence on the martian surface. Only brief mention is

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[iv] Reference the LLT workshop website at http://www.kiss.caltech.edu/new_website/workshops/telepresence/telepresence.html (accessed 29 May 2017).

[v] Reference the LLT Part II workshop website overview at http://www.kiss.caltech.edu/new_website/workshops/telepresence/telepresence2.html (accessed 29 May 2017).

made on H2MR'17 pp. 5-6 of robotic Mars sample return missions protecting Earth from possible infection by any extant Mars life forms.

At the end of p. 8, H2MR'17 concludes human missions to the Moon "would be dress rehearsals for the Mars missions, just as Apollo 10 was a dress rehearsal for Apollo 11." This analogy requires qualification to avoid misleading readers. The Apollo 10 Lunar Module was a virtual duplicate of the Apollo 11 Lunar Module that first landed humans on the Moon. Both missions flew similar trajectories in the same environment only two months apart with similar support teams. But Mars descent/ascent vehicles will use fundamentally different designs from Moon descent/ascent vehicles due to the differing environments and mission architectures associated with human logistics to these distinctly different destinations. Physical and programmatic constraints will likely dictate any lunar "dress rehearsal" be flown years before a Mars landing is attempted. When preparing to land humans on Mars, better experience and training would be gained at far less expense with a high-fidelity Mars mission simulator as opposed to regarding lunar missions as relevant dress rehearsals. As stated on H2MR'17 p. 11, "systems designed only for the Moon are not compatible with the exploration of Mars."

Yet in the same p. 11 paragraph, H2MR'17 argues "There is value in all space exploration and every effort can help contribute to the goal of humans on the surface of Mars in the 2030s." How can incompatible lunar exploration systems also contribute to Mars exploration? Additional doublethink abounds in the previous p. 11 paragraph: "Efforts in cislunar space can help enable NASA’s Mars effort but NASA should not lead or fund exploration of the lunar surface." As an LLT-based strategy would suggest, exploration of the lunar surface is indeed possible from cislunar space. But the same strategy would apply to exploring the surface of Mars. Furthermore, the enhanced probability of extant native martian life, as opposed to life on the Moon, would discourage human landings on Mars. Until Mars is proven to be sterile, humans on Mars will threaten epidemics and extinctions, both there and back on Earth. As for why NASA should lead/fund Mars exploration while ignoring the Moon, rationale appears confined to H2MR'17's arbitrary 2033 deadline. Per Section 3 in this essay, there is no rational basis for this deadline.

The Human Research Program (HRP), in which spaceflight human factors issues are being researched, is described on H2MR'17 pp. 17-18. A list of "biomedical challenges" is provided near the end of p. 18. Among these is "Optimizing human health in a partial gravity environment". If this challenge is posed by human adaptation to Mars surface gravity, no details are supplied on how this optimization is to be accomplished before humans land on Mars for a 500-day sojourn by 2033. Completely missing from the list of HRP challenges is how humans will survive direct entry into Earth's atmosphere with accelerations of ~10 Gs after some 900 days in reduced gravity.

5. Affordability And Sustainability For Human Landings On Mars

At the top of H2MR'17 p. 9, "affordability" is defined as "the ability to bear cost and return value commensurate with that cost." From this definition, it is unclear whether or not "cost" includes loss of crew during or as a consequence of Mars exploration. Requisite programmatic funding must include adequate crew safety margins, or costs will exceed affordability and schedule milestones will be delayed beyond sustainable programmatic limits. At the bottom of p. 13, readers learn new deep space habitat technologies "will help enable safe and affordable Mars vehicles." This implies H2MR'17 authors do not consider safety to be a component of affordability, but the two attributes are inextricably linked. Without adequate safety, no human Mars exploration program will be affordable, nor will it ultimately be sustainable. The Space Shuttle was a remarkable spacecraft, but the financial costs and schedule delays to operate it with adequate crew safety margins were not affordable, and the program was not sustainable after two fatal mishaps.

Also at the top of H2MR'17 p. 9 is a somewhat contradictory statement: "Affordability must be considered at all stages of architecture development and leads to sustainable human space exploration." Affordability is certainly a necessary attribute of sustainable human space exploration, but it is not sufficient for such sustainability. As observed in the other p. 9 quote, an affordable exploration program must also return sufficient value to become sustainable. Specific rationale for the compelling value humans on the surface of Mars will return, in contrast to their presence at other off-Earth destinations, appears to be beyond the scope of H2MR'17. A p. 10 "FINDINGS" bullet is therefore all too pertinent: "Mars exploration architectures must consider and address affordability, including how the architecture will return appropriate value to its stakeholders, as a fundamental requirement for credibility."

6. Miscellaneous Questionable Statements

In H2MR'17's p. 10 "SPACEX Mars Architecture" sidebar, readers are informed, "Full reusability is fundamental to the architecture, and leverages the extensive experience base from SpaceX's Falcon 9 first stage and Dragon spacecraft reuse." As of 1 May 2017, SpaceX had recovered 10 Falcon 9 first stages intact, both at the launch site and on ocean-based drone ships.[vi] Of these recovered stages, only the one launched 8 April 2016 has been launched a second time (on 30 March 2017).[vii] As of May 2017, no Falcon 9 second stage had been recovered intact, no Dragon spacecraft had been reused on multiple launches (the first reused Dragon was launched on 3 June 2017), and no Dragon had flown humans into space. In the lexicon of space operations, this Falcon 9 and Dragon flight history does not equate to an "extensive experience base".

The list of "FINDINGS" on p. 10 of H2MR'17 begins with "The wide range of architectures for the exploration of Mars and the credibility of the institutions and companies producing them demonstrate both the wide interest in Mars exploration and the positive opinions of the viability of current technology to achieve it." None of the major elements in these human Mars exploration architectures has flown in space, let alone for the 1000 days required to conduct a meaningful human roundtrip to Mars. Institutions and companies proposing these paper-based architectures may be credible, but the cost, risk, and return on investment associated with such proposals are highly uncertain. Readers of H2MR'17 should recognize that technological leaps, like landing humans on Mars, must rely on immature architectures at their inception. The

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[vi] Reference https://en.wikipedia.org/wiki/List_of_Falcon_9_and_Falcon_Heavy_launches#Flights_by_landing_outcome (accessed 30 May 2017).
[vii] Reference https://en.wikipedia.org/wiki/SpaceX_CRS-8 (accessed 30 May 2017).

credibility, affordability, and sustainability of such architectures must therefore be regarded as low in 2017. Bringing these attributes to Mars-ready status in anything like 16 years is a formidable challenge.

At the end of H2MR'17's p. 10 "FINDINGS" list is the opaque statement "Mars is achievable." Perhaps an elaboration such as "Human landings on Mars by 2033 are achievable." might be more aligned with this report's theme and scope. But in the context of other items in the "FINDINGS" list, the "achievable" statement is poorly support at best. Those other items constitute a litany of concerns such as insufficient affordability, uncertain partnerships, lack of consensus for science objectives, immature technology/architecture, and insufficient landing site reconnaissance. At no point in the list is crew safety explicitly cited.

Regarding crew safety, the "RADIATION" sidebar on H2MR'17 p. 11 conveys a mixed message. The sidebar begins by observing that radiation "is a known risk of space travel and travel beyond low Earth orbit increases this risk to astronauts." But this statement must be qualified by a subsequent sidebar remark: "the combined, long term impact of space radiation is not yet well characterized." Human radiation exposure during a Mars roundtrip is little more than a known unknown, with the amount of shielding mass required to adequately protect a crew very much an open question. If current human radiation exposure standards are to be relaxed to minimize shielding mass for missions to Mars, the anticipated value of such missions should exceed that provided by atomic energy and nuclear medicine workers who are subject to these current standards.

On H2MR'17 p. 26, the statement "American industry has committed to Mars more decisively than at any other time in history." is true but not very substantive. There is little incentive for private firms to commit any more than studies and reports to the "enterprise" of landing humans on Mars. Most of this research is performed under NASA grants and other funding sources or with the motive of obtaining such funding in the future. Furthermore, motivation for private firms to exercise initiative in exploring Mars is slim. Beyond communications satellites stationed in geosynchronous Earth orbit, prospects for a viable off-Earth business plan are poor. The overhead of human spaceflight further detracts from these prospects. Where is the "unobtanium" on Mars requiring an in situ human presence to yield a profit?

The H2MR'17's p. 26 "RECOMMENDATIONS" list begins with: "The question ‘Why Mars?[']' needs to be better articulated by the space community." This is probably true, but the answers to that question will be far more important. As pointed out in Sections 2 and 3 of this essay, along with other remarks, there is no compelling rationale for selecting Mars as the preeminent off-Earth human destination for the 21st Century. A habitat ~50 km above the surface of Venus is arguably more habitable and accessible than the surface of Mars.[viii]

Also in H2MR'17's p. 26 "RECOMMENDATIONS" list is the imperative: "Dispel the $1 trillion myth: Recent studies have shown that human missions to Mars will only cost a fraction of this amount." The referenced studies are conducted by organizations trying to profit from or promote human missions to Mars and are therefore highly suspect. An effort akin to the magnitude of

[viii] Reference the High Altitude Venus Operations Concept (HAVOC) at http://sacd.larc.nasa.gov/branches/space-mission-analysis-branch-smab/smab-projects/havoc/ (accessed 15 June 2017).

interplanetary human spaceflight can, at its outset, be estimated to cost one-tenth of its ultimate price tag. In particular, the sustainability attribute of Mars exploration advocated by H2MR'17 will greatly inflate this effort's cost. The ISS has a mass of ~400 t and cost the U.S. with its international partners $100 billion to fabricate and assemble in low Earth orbit.[ix] Assuming a crew of 3, efficient in-space propulsion, and a high degree of reusability, each human roundtrip to Mars orbit will require launching an ISS-similar mass from Earth [5]. It will therefore be likely less than 10 human roundtrips to Mars orbit will cost more than $1 trillion, particularly if a crew larger than 3 is to be transported. Without warp drive and proven highly accessible resources at Mars, far less than 10 roundtrips to the surface of Mars could easily exceed a cost of $1 trillion. Are a handful of Mars landings delivering no foreseeable return on investment a sustainable enterprise?

The H2MR'17 p. 26 "RECOMMENDATIONS" list also observes "NASA and the space community regularly collaborate with the entertainment industry, but these ties need to be strengthened to amplify the messaging for human missions to Mars." Enlisting "Hollywood" as an advocate for human spaceflight to Mars can be a double-edged sword. As observed in Section 3 of this essay, books and movies do indeed help sustain interest in humans exploring Mars, as they have for over the past century. But above all else, the entertainment industry aims to earn a profit through popular storytelling. In this process, spaceflight reality is often compromised, and false expectations can be raised among readers or moviegoers. An example would be the continuous Mars surface activity protagonist astronaut Mark Watney endures for 549 martian days in the book [6, p. 340] and movie titled *The Martian*. Without spending the bulk of this 1.54 Earth years in an adequately shielded subsurface Mars habitat, Mark would likely develop a fatal cancer from acute radiation exposure.

In the "CONTINUING RECOMMENDATIONS FROM 2016" list on H2MR'17 p. 26, readers are told "Special emphasis should be made to inform the public that landing humans on Mars by 2033 is an achievable goal." This statement requires qualification because it leaves the cost, risk, and sustainability of reaching the goal open to question. Is a one-off stunt being advocated? If so, the unqualified statement is inconsistent with affordability, safety, and sustainability claims made throughout H2MR'17.

Also in the "CONTINUING RECOMMENDATIONS FROM 2016" list on H2MR'17 p. 26 is the questionable statement: "increased education needs to be undertaken to articulate why lunar surface operations are not the best path to Mars". As pointed out primarily in Sections 2 and 3 of this essay, the superiority of Mars with respect to the Moon as an off-Earth human destination is very much an open question. In our current state of ignorance concerning the habitability or profitability of the Moon and Mars in association with sustained human activity, we are in no position to provide authoritative "education". Only weakly supported arguments bordering on propaganda are possible in favor of any specific off-Earth human destination.

[ix] Reference https://www.space.com/9435-international-space-station-worth-100-billion.html (accessed 15 June 2017).

7. Summary

As this year's update to an annual publication by the Explore Mars, Inc. advocacy group, H2MR'17 likely fulfills its authors' intent. It contains some useful information about progress, both political and technological, toward the goal of landing humans on Mars. But readers should in general regard H2MR'17 with suspicion regarding its objectivity as a roadmap for off-Earth human exploration.

The notion of Mars as a "critical" destination for human spaceflight is introduced early in H2MR'17, but this terminology is never rigorously defined. Furthermore, no objective evidence is presented or cited by H2MR'17 from which readers can conclude why Mars is a more compelling destination than others, particularly those yet to be explored by spacecraft to the extent Mars has since 1965.

The H2MR'17 theme of landing humans on Mars by 2033 may well have its inception in 1948, when Wernher von Braun planned an initial human Mars landing 17 years in the future. Since then, humanity has been planning its first footsteps on Mars about 20 years in the future without more than a brief hiatus. The H2MR'17 argument that public interest will wane if this 20-year mantra isn't maintained fails to recognize the "footsteps on Mars" vision is supported by more than a century of science fiction literature and movies. Although helpful to keeping the dream of interplanetary spaceflight alive, this fantasy-based "cultural DNA" can cloud selection of humanity's spaceflight priorities with an unjustified Mars fixation. Dispelling this fixation or citing a compelling argument to justify it is evidently contrary to H2MR'17's purpose.

Although H2MR'17 pays homage to utilizing the moons of Mars in the planet's exploration by humans, only the inner moon Phobos is specifically mentioned. This preference for Phobos over the outer moon Deimos echoes virtually all mission planning, human or robotic, involving the moons of Mars. There is no logical basis for this preference beyond insubstantial arguments based on Phobos being larger in diameter and closer to Mars than Deimos. Section 4 of this essay cites five compelling arguments favoring Deimos over Phobos as a human spaceflight destination. Failure to recognize these arguments demonstrates H2MR'17 tendency to parrot "the party line" on Mars exploration strategy without offering a perspective independent from NASA or its international counterparts.

Whether humans explore Mars from a proximal orbit or from a subsurface habitat adequately shielded from radiation, the LLT strategy reduces cost and risk while increasing productivity. Although H2MR'17 briefly associates LLT with existing concepts confining humans to Mars orbit, it fails to recognize this strategy's payoffs for humans in adequately shielded Mars subsurface habitats. After humans land on Mars, H2MR'17 describes and illustrates their activities in above-surface habitats, rovers, or EVA garb. This irresponsible strategy fails to minimize radiation exposure risks to human health from a 500-day sojourn on Mars.

Affordability and sustainability of human spaceflight to Mars are themes running throughout H2MR'17. Although H2MR'17 doesn't clearly define affordability in monetary or human costs, this attribute is certainly a necessary condition for sustainability. The lack of rigor in H2MR'17's affordability accounting may have led to its poorly supported "$1 trillion myth" contention. For example, how many humans will land on Mars before the sustainable enterprise transporting them expends more than $1 trillion? How many lives will be lost or significantly compromised in the process? What will the return on this investment be? Unfortunately, H2MR'17 provides at best minimal insight to those who would honestly and responsibly address these questions.

References

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[xi] This Act is available at https://www.congress.gov/bill/115th-congress/senate-bill/442/text (accessed 11 June 2017).

[xii] This publication is available at http://www.nap.edu/catalog/18801/pathways-to-exploration-rationales-and-approaches-for-a-us-program (accessed 12 June 2107).

[xiii] This paper is available at http://www.sciencedirect.com/science?_ob=ArticleListURL&_method=list&_ArticleListID=-1219107740&_sort=r&_st=4&md5=3b12fea25e56f574aef1fcc45f79580f&searchtype=a (accessed 15 June 2017).