ENHANCING MARS SCIENCE WITH AN ORBITAL-BASED "MARS BASE CAMP".
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Introduction: The NASA vision for human missions to Mars involves selecting a region to be designated the Exploration Zone (EZ) for establishing surface facilities. Within this zone, sorties with pressurized rovers will enable detailed study by astronauts out to a range of approximately 100 km. The selected EZ is expected to contain at least three locations with high-priority science targets within them.

The first mission to Mars by human explorers may have only minimal infrastructure for a long-term surface stay. However, with a science-capable orbital facility plus the human-rated telecommunications infrastructure, and with surface assets strategically placed at other scientifically important sites, greatly enhanced progress in the rate and thoroughness of the exploration of Mars will be facilitated.

Mars Base Camp (MBC) Concept: Prior to the first landed mission by humans on Mars, a precursor human mission to Mars orbit is proposed for establishing a Mars Base Camp [1, 2], in analogy to the base camps put into place when exploring new territories or ascending major mountain peaks. This could be accomplished early, before the full development and test cycle is completed for all landed elements. To minimize propulsion requirements, the astronauts would be in a 1-sol elliptical orbit, similar to the approach of the Viking orbiter-lander mission. In addition to their Habitat module, there would be a dedicated Laboratory module which would be equipped with large-aperture, advanced remote sensing systems and analytical instrumentation for study of samples launched from the surface for rendezvous with the MBC vehicle. Concepts for a system to support transportation and study of the martian satellites and for a reusable single stage lander/ascent vehicle have also been developed for follow-on missions to the first orbital mission.

Fig. 1. Mars Base Camp Spaceship

Advantages of Human Presence: With astronauts at Mars, there will be several inherent benefits of the mission as well as the proximity of humans to the robotic assets for exploring Mars.

Telecommunications. Unlike current robotic missions at Mars where communications are aperiodic, opportunistic and with relatively low bandwidth, the nature of the human missions and their levels of reliability and safety assures that there will be in place a high data rate with continuous (24/7) communications between Mars and Earth, except for solar occultations. Any node where human presence is occupied for any significant length of time will have access to the telecommunications network that will be supporting their mission. Science data could and should occupy a significant fraction of this capability, resulting in ten- or hundred-fold greater downlink data rate, and even higher increases in data volume when taking into account the continuity of transmissions.

Reduced Latency in Teleoperations. Because of minimum light travel times of 4 to 24 minutes, there has always been a significant latency between ground commands from Earth and their execution in robotic assets at Mars. However, in practice the typical operational latency for ground assets, such as rovers and landers, is far greater. This is because these assets are serviced by polar orbiting spacecraft, which pass within radio transmission range of any given asset only once or rarely twice each day. Thus, most planning cycles for such missions are on a daily, or multi-day basis, rather than in near real time. With astronauts in the high elliptical orbit proposed for the MBC architecture, they can communicate directly with more than one-half of the planet at a latency of a few seconds for most of local daylight (and with the entire planet if additional relay satellites are deployed).

Operation of Rovers. The combination of higher data rate and negligible latency enables a whole new paradigm for operation of rovers and other complex assets at Mars. Although rover safety will still be a concern, it is expected that lower-cost simpler rovers will be provided by multiple agencies and institutions, and that the interaction with a virtually real-time driver will enable much longer traverses per sol when desired, and enormously enhanced imaging frequency and content. Walkabouts can be much more common.

Enhancements, Compared with Past Robotic Missions: Rover missions to Mars have greatly increased our knowledge of the past habitability on the planet. Although it is not possible to *a priori* predict the degree of enhancement to science, there are certain metrics that can be evaluated relative to past and current missions.

Rover Traverse Rates: Several missions to the moon and Mars may be used as benchmarks for previous success.

Opportunity Mars Exploration Rover (MER). The Opportunity Rover completed its primary mission in a relatively local region, visiting several craters. It then trekked from Endurance crater to Victoria crater, a distance of 6 km. Driving the rover was the main goal, but required 600 sols to complete the traverse (during which time 30 rocks were chemically analyzed), averaging only 10 meters per sol. Later, traversing from Victoria to its current target of Endeavour crater consumed another 1000 sols (to traverse 19 km and analyze 7 samples).

Spirit Mars Exploration Rover (MER). The Spirit rover drove from its landing site area to the Columbia Hills with an average rate of 45 meters per sol. One hindrance to attempts to extract the rover from the soil trap it was mired in was the limited data and especially the latency in oprations, such that when a promising solution in driving technique was found the rover was already irreversibly succumbing to cold temperatures that could not be remedied because of the orientation of its solar arrays with respect to the sun angle.

Curiosity Mars Science Laboratory (MSL) Rover Mission. Because of its landing location with respect to a line of hazardous dune fields, the first thousand sols of driving were to get to the base of Mt. Sharp, averaging about 10 meters per sol. Although valuable science was obtained, the primary goal of reaching the stacked beds of sediment that characterize Gale Crater was delayed.

Lunokhod 2 Rover on the Moon. This rover landed by Soviet scientists and engineers was driven a distance of 42 km in only 4 months, for an average traverse rate of 350 meters/day, using technologies available to them 45 years ago. This mission is analogous to the operation of Mars rovers by astronauts in the MBC architecture in the sense that latency can be as low as 3 seconds between driver and rover. However, imaging technology was relatively primitive for the Lunokhod mission compared to Mars exploration today and the even greater expectations for the era of human exploration. Nonetheless, the crews were able to drive a bulky, balky rover at a much higher average traverse rate than current Mars rovers.

Apollo Lunar Rover. The three Lunar Rover missions (Apollo 15, 16 and 17) each averaged 11 km of travel per EVA from the LEM module. This traverse rate is the order of one thousand times greater than the average for Mars rovers.

Data Return: The Curiosity rover averages approximately 500 Mbits of data downlink to Earth per sol. The MER rovers have an earlier version of the UHF relay system and achieve less. If the link between MBC and a rover asset can achieve 2048 kbps continuous, there would be up to 100 times the number of images per sol returned to Earth.

Geological Science Enhancement: The massive increase in imaging, combined with the greater mobility, will allow far more extensive high resolution and stereo coverage of the surrounding and traversed terrain. This, in turn, will enable major advances in both macro and micro reconnoitering of the geologic setting, and hence the context of the various samples analyzed and selected for possible return to Earth.

Other Mars Science Opportunities: Many other science disciplines could greatly benefit from the capabilities of humans at Mars in the MBC concept. Exploration and sample return from the natural satellites, Phobos and Deimos, would be possible. High-rate meteorological data could be transmitted routinely. High-volume spectral data (Raman, LIBS, IR reflectance, x-ray microanalysis, etc.) could be obtained and returned on a larger number of samples.

Samples from rover missions could be packaged and sent to Mars orbit for retrieval by astronauts. Those samples could, in principle, be subject to a certain level of preliminary analysis inside the MBC Laboratory module which may inform the remaining goals of the rovers still operating on the surface.

At the scale of human missions, the MBC spaceship can accommodate large, relatively massive remote sensing instrumentation with high data volume to construct spectral image cubes of greater surface coverage than achievable before.

Conclusion: By taking advantage of the enhanced Mars-Earth telecommunications that will be required to support human missions, and the dramatic reduction in latency for operating space assets in the Mars system, the Mars science community can achieve quantum gains in the rate and depth of exploration at locations remote from the human Exploration Zone. By stationing astronauts in high elliptical Mars orbit, the MBC Architecture will enable major advances in the breadth and depth of Mars exploration and the continued search for the evidence of past life.

References: [1] Cichan, T. et al. (2017). New Space, *5*, 4. [2] Cichan, T. et al. (2017) IEEE Aerospace Conf., Big Sky, MT.