INTERACTIVE SCIENCE ON MARS.

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Introduction: Cargo transportation systems being developed for the human exploration of Mars could substantially alter the way we conduct science at Mars . The current paradigm is to send individual highly-capable science rovers, with which a competitively-selected science team designs a traverse making intensive science investigations at a series of sequential stops. We propose shattering this investigation paradigm. Solar electric propulsion systems enable the delivery of large payloads to the Mars surface, and further provide a means to power very high capability communications systems that can transmit unprecedented data rates. This combination opens the door to the deployment of large numbers of small rovers for Mars exploration. The high communications bandwidth will allow a constellation of rovers to put together a high-fidelity, detailed model of the surface, allowing 3-D augmented reality exploration of the surface by professional and citizen scientists across the world, and opening up the excitement of walking across the Mars surface to interested amateurs and non-scientists. The result would be a new baseline: “Mars is for everybody.”A candidate conceptual mission design that we’ve analyzed would deliver 93 small rovers to three locations, with high data-rate communications limited only by the allocated spectral bandwidth and the number and size of Earth-based receiving terminals. It would be cost prohibitive to pay for 93 science teams, so citizen scientists could be employed to conduct specific science observations using an augmented reality gaming infrastructure. An augmented reality interface would simultaneously register high resolution images in an accurate areospatial map and provide an intuitive data interface to assist both professional and amateur scientsits. It could also be seamlessly integrated into gaming activities that could be developed for commercial products.

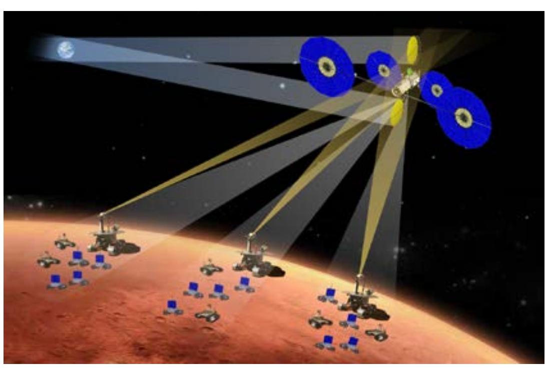

Figure 1. High Power SEP communications relay for distributed rover swarms on the surface of Mars.

Science opportunities: Previous missions have shown the high value of color stereo visual imagery in science investigations, validating the observation of Yogi Berra, “you can observe a lot just by looking.” Addition of multichannel hyperspectral bands allows adding mineralogy as well as geomorphology capabilities to visual imagery. Camera technologies have been rapidly evolving, and visual cameras are small, cheap, and highly capable; with limitations set entirely by the downlink bandwidth, rather than camera limits. For more focused science, the small rovers can serve as scouts for subsequent misisons with larger, more capable instrument suites. They could search for interesting minerals and geologic formations using small imagers and spectrometers such as an evolved version of the 2.4-kg, 5.6-W miniature thermal emission spectrometer deployed on the Mars Exploration Rovers. Searching for hydrated minerals, and detecting for instance clays, sulfates, and anhydrous ferric oxides would help to understand the water distribution across the surface of a region. Rovers equipped with small manipulators could collect and cache samples. Rovers regions could be separated by hundreds of kilometers to create a meterological network and conduct seismology studies. The regions could be placed so that two groups lie within magnetic fields and one group does not; small magnetomers could then be used to study local magnetic effects and determine, for instance, if there is correlatation of these effects with aurorae. Local methane variations could be monitored to determine baseline background levels to help assess whether levels identified in other regions might have geological or biotic origins. Depending on the level of planetary protection that could be cost-effectively achieved by these small rovers, they could be constrained to regions that are highly unlikely to harbor life or they could explicitly be sent in search of life. Although we are focused on Mars, this concept could be applied to the Moon as well. The software developed for this application could also be used for terrestrial Earth science campaigns (e.g., measuring ice sheet thickness or soil water content).

Spacecraft concept: We envision using a high-power (150-kW at Earth) solar electric propulsion (SEP) spacecraft to deliver dozens of small (<100-kg) rovers to Mars. To ensure a high level of interactivity from a nearly continuous view of a large portion of the Mars surface, we will position the spacecraft in areo-synchronous orbit 17,000 km (11,000 mi) above the Mars equator. The large solar arrays used to power the SEP spacecraft during the trip to Mars will then be used to power a high-capacity communications system to transmit data back to Earth. The high-power SEP could be built by retrofitting NASA's Asteroid Redirect Mission SEP vehicle with a second set of solar arrays, thrusters, and propellant tanks to boost the power level from 50 to 150 kW. This spacecraft will deliver 30 t to Mars and will fit within the mass and volume constraints of a Space Launch System (SLS) launch vehicle. Two designs exist for solar arrays large enough (50 kW each) to serve as the retrofit power source. The number of electric thrusters (12.5-kW each) will be increased from 4 to 12 without requiring a technology change, and 8 additional tanks will bring the total amount of xenon propellant to 16 t. We will use two large (nominally 7-m) deployable mesh Ka-band antennas to relay data to and from Earth. These antennas will use novel radio-frequency power-combining techniques that draw on a small portion of the unprecedented 8 kW of power from the large solar arrays, power-combining the signals from 200-W amplifiers using opposite polarizations on two simultaneous links to return the most data possible to Earth. This allows the transmission of over 60 Mbps of data for at least 8 continuous hours every day to each region on Earth as it rotates, except for a few days each year when the Sun encroaches the line of sight to Mars. Data rates as much as 25 times higher may be possible during Mars opposition when the red planet is 5 times closer to Earth. Even with this high return-link data rate, users will still have to accommodate the 6- to 44-min round-trip time delay from forward links imposed by speed-of-light communications. Nonetheless, 10 to 80 interactions each day will be possible.

We start with three types of rovers for this mission: one optimized for surface communications between the other rovers and the areosynchronous-relay satellite, one for surveying, and a third for excavating and building. Groups of these three types of rovers can be deployed to individual sites, such as 5-km craters, to both contain the play and provide interesting visuals on the horizon. A 50-kg rover based on a low-cost lunar prospecting concept serves as the starting point for the surveyors, and for the builders we start with a 95-kg excavator based on another lunar concept. Each surveyor has two-motor skid-steer tweels (airless radial tires) capable of up to 15 cm/s speeds on less than 30° inclines, with power provided by 50-W solar arrays and 400-W-hr rechargeable batteries. Each excavator is a tracked vehicle with a center-mounted linearly actuated bucket that is capable of lifting its own weight in regolith while drawing only 100 W of power provided by 18 A-h batteries recharged by solar arrays. The communications rover has a mass of about 285 kg—similar to that of the Mars Exploration Rover—and communicates to the other rovers via space-qualified WiMax or Electra Lite Radios, and to the orbiter via an X-band antenna. Splitting the 30-t payload into three sites and using rough mass estimates of heat-shield technology and lander concepts being developed by NASA for large-scale operations to support Mars human exploration, we estimate that about 2.2 t of the three landed 10-t payloads could be allocated to rovers. This will allow 1 communications rover, 20 surveyors, and 10 builders at each site—93 rovers total in one launch—to initiate the mission. Rover operations would be public, and the science capabilities will both influence and be influenced by the rover designs.

Citizen engagement: The popular Zooniverse website has demonstrated that citizens have high interest in engaging in science activities. Applications such as Comet Hunters permit people with very little formal training to mine datasets in search of scientist-determined features of interest. A game-based science mission that provides everyone on Earth with the opportunity to operate Mars rovers could initiate and foster a new public-private partnership model for planetary science.

Synergy with Human Exploration: This interactive Mars concept will demonstrate high-power SEP, heat-shield technology for landing large payloads, high-capacity communications, and autonomous systems—all identified as being necessary for NASA's Journey to Mars. This mission could serve as an Earth-independent pathfinder mission on NASA's Journey to Mars, simultaneously reducing the risk of critical technologies and emplacing a communications infrastructure that could be used for astronaut communications on future missions. NASA's investment in the infrastructure could be followed by commercial investments in games, additional rovers, rover instruments, and a host of other options.

Summary: A direct, interactive experience with Mars will change space science—transforming it from a spectator sport into a personal activity available to anyone on Earth. The interactive Mars science mission would leverage technologies needed for human space exploration and provide a new planetary science capability.