Astronomy from the vicinity of Mars

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Introduction: As the human exploration of Mars matures, we will both learn more about Mars itself, and also begin using Mars as a platform for outward-looking observations, to learn more about the rest of the solar system, and beyond. In this presentation, we will briefly describe some of the observations that can be made from the vicinity of Mars, which strongly complement those made from the vicinity of Earth.

In the late Renaissance, as telescopes were exported from Europe throughout the rest of the world, it quickly emerged that making similar observations, from multiple, well-separated locations, provided more information than could be obtained at a single site. This pattern will hold true, in an even more spectacular way, when the separation distances are several AU, rather than mere fractions of an Earth radius.

We will now describe several scenarios, in which assets deployed at Mars can be used to better observe and understand solar system phenomena.

MSL astronomy: Relatively simple observing systems, on or near Mars, can make observations pertinent to other bodies, and beyond what can be done from Earth. This was first demonstrated by the Viking Lander and Orbiter observations of the shadow of Phobos **[1, 2]** and direct imaging of Phobos and Deimos **[3].** Since then, rovers and orbiters have made sporadic observations of Phobos and Deimos **[4].** With the arrival of MSL at Mars, we will have a camera system, and a nuclear power supply, which fairly begs to be used during the night, looking up at the Mars sky.

Phobos and Deimos are easy targets, both because of brightness and predictability. Earth-based observations are made only near inferior conjunctions and spacecraft encounters are irregularly spaced in time. In the 135 years since discovery, there has never been a systematic, rapid cadence, long duration program of astrometric observations of Phobos and Deimos. This would be easy to accomplish with MSL, and would provide much improved knowledge of the orbits of these bodies, which would in turn provide more information about the internal structure of Mars **[5].**

There are many other observations which could be made, including searches for near-Mars asteroids and dust rings about Mars, associated with Phobos and Deimos **[6, 7],** determining the styles, times and intensity of meteor showers **[8],** optical tracking of artificial satellites, and monitoring climate driven changes in the rotation rate of Mars **[9].**

The main point is that even very modest optical instruments can achieve significant scientific results if deployed in the right location. For example, in searching for circum-Mars dust rings, the MSL mast-cam system has greater potential sensitivity than the Hubble Space Telescope, because it is so much closer to the object of investigation.

Solar system laser ranging: The observational backbone solar system dynamics is provided by Earth-Mars range measurements, which had 10 m accuracy in the Viking era, and currently have 1 m accuracy **[10, 11].** Among the benefits of the current accuracy level is that many asteroids perturb the orbit of Mars by small but measurable amounts, and their masses can thus be determined **[12, 13].**

We now briefly examine how future measurements can be used to improve our understanding of asteroid masses, though it should be noted that this is only one example of the types of information which will accrue from the proposed measurements

In very general terms, we envision three types of improvements to the Earth-Mars range measurement paradigm. Simplest is to just continue the existing time series. Next is to improve the accuracy of the Earth-Mars range measurements. Third, and somewhat more ambitious, is to also measure the Venus-Mars range. This could be done by having a pair of spacecraft, one orbiting Mars, the other orbiting Venus, each equipped with laser transmitters and optical detectors. This could, in principle, be done in association with other planetary mission objectives. Sub-meter accuracy laser range measurements have already been made over interplanetary distances **[14, 15].**

If all 3 legs of the triangle were simultaneously measured in both directions, we would have, in effect, a very large laser ring gyroscope **[16]** with area (and hence sensitivity) of order a square AU. That would yield parts-per-billion sensitivity to the rotation rate of the Venus-Earth-Mars triangle, and could help better tie the solar system reference frame to the International Celestial Reference Frame (ICRF).

An orthogonal component of information could come from a regular program of VLBI observations of spacecraft in orbit about Mars. The range and angular measurements are obviously complementary, but an assessment of their combined utility in asteroid mass determinations is currently lacking.

While the present observational constraints on planetary orbits are clearly adequate for interplanetary navigation purposes, there are many scientific benefits which would result from improved measurements of the orbital motions of Venus, Earth, and Mars. Using them as test particles to measure the masses of perturbing asteroids is only an illustrative example.

The situation is quite analogous to the lunar laser ranging program, which has, in the 40 years of its operation, improved knowledge of the Earth-Moon distance from km level, at the beginning, to sub-cm level today **[17, 18].** As the measurement accuracy has increased, the number of dynamical processes which can be resolved has continued to increase. We can, and should, do a similar job of better understanding solar system dynamics.

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