AFFORDABLE MSR: CONSTRAINING REQUIREMENTS ON SAMPLING AND SAMPLE PRESERVATION.
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Introduction: A Mars sample return (MSR) mission has been a serious objective since at least the 1970's, but has not yet been realized because the expectation value for its cost has exceeded the justification for its need. In the meantime, many of the technologies and mission segments have been demonstrated by other space missions, including the return of space samples using affordable robotic return vehicles. At the same time, the renaissance in new missions to Mars have made discoveries for which MSR is scientifically more important than ever before. Many mission elements remain uncertain, however, such as sample preservation, the ascent vehicle, rendezvous pickup in Mars orbit, and planetary protection. To ultimately achieve an overall affordable MSR, it will be necessary to constrain development and implementation costs of these new elements.

Historical Precedents: The space program began with the most modest of scientific exploration objectives. Indeed, academia at first turned its back for the most part. The van Allen belts were discovered with the crudest form of radiation spectrometer, a few shielded Geiger-Mueller counters. Spatial resolution of most missions to Mars was poor by orders of magnitude compared to the meter- and submeter-scale resolution of images eventually achieved on MGS, MEx, and MRO. Virtually every instrument flown on a space science mission has known limitations in terms of sensitivity, resolution, baseline offsets, cross-coupling and absolute accuracy. Calibrations are mostly ground-based, and there is little independent verification of results by independent means of measurement. Yet, instrument developers are strong, enthusiastic advocates for each mission they propose to become part of, even as they prepare on the drawing boards the next generation instrument that will put to shame all that has gone before it. Clearly, these flight-savvy instrumentation guru's are not hesitant to propose only what they can accomplish, affordably, in order to be selected for the next flight. A "perfect" remote or in situ sensing mission never has and never can be flown, because the instruments are usually behind the state-of-the-art by the time of launch. This has not prevented mission-after-mission, each extending and improving on the discoveries of the last. The instrumentation community has learned its lessons and learned them well.

KISS: For the first MSR to be affordable and remain non-cancelable, it must avoid stumbling blocks. Previous cancellations of major missions by NASA are quickly forgotten, but include such notable cases as Halley/Tempel 2, CRAF, Apollo 18-20, much of the science of ISS, and for a brief while, DAWN. New lunar science missions became non-existent after Apollo; Mars exploration suffered a great hiatus after Viking. To keep first-MSR as affordable as possible and to assure the likelihood of "staying in the cost box", it must embrace the principle of KISS (keep it simple, son). Once an MSR capability is developed, it will become time to promote improvements and refinements of capabilities, hopefully building extensions on the same hardware and operating plan so as to keep costs of future MSR's competitive. It could be unwise to impose Ultimate MSR capabilities as requirements that should be levied on Initial MSR capabilities.

Sample segregation vs hermetic sealing: Some martian samples might contain volatiles, at least H2O and possibly some CO2. Ideally, such samples would be collected at the coldest time of the sol and their temperature maintained at that appropriately cold temperature. Problems in implementing this idealized requirement are manifold. The thermal gradient on Mars is extraordinarily steep from the surface of the soil through the first few centimeters. It is beyond the physical resolution of practical sampling devices and their implementation to take samples from only one temperature zone. Even the soil temperature gradient has never been satisfactorily measured by any mission on Mars and even if so, such gradients would vary dramatically in different specific locations as a function of soil thermal insulation (particle sizes, shapes, compositions; pore spaces; cementation of grains) as well as exposure to solar insolation (e.g., anti-sunward vs pro-solar slopes) and presence or absence of large rocks.

One concern has been that if each and every sample is not individually hermetically sealed, the ones that contain volatiles would release their gases once the sample time-temperature product was high enough, and that this would not only change the mineral phases but also potentially induce artificial alteration of pristine samples. Unfortunately, providing hermetic seals for all samples will impose a significant weight penalty and worse, a set of potentially costly requirements difficult to assure in a dusty, desert environment. Technologies from elastomeric to malleable metals or explosive welding will need to be considered, but application to each and every sample will be the challenge.

The GRS instrument on Odyssey has amply demonstrated the existence of forms of H2O in soils and sediments at virtually all latitudes on Mars. Some of this H_2O is thought to be loosely bound, and responds to changes in the temperature-humidity environment on seasonal and even diurnal cycles. Where $MgSO_4$ is present, adsorbed layers and several mineral hydrated states are possible and laboratory experiments demonstrate the ready conversion between states as a function of environmental fluctuations on times scales of days or sometimes hours [2, 3]. The only way to capture these hydration states and preserve them on the way back to Earth is to seal the samples hermetically (no gas exchange) and keep them at least as cold as that at the time of collection. What, however, does that accomplish. The same sample will in fact have transitioned to other states while on Mars, depending on time of season and/or day/night. Thus, such samples have no canonical state that is representative of their in situ existence. Those minerals just a few mm deeper or shallower will experience different environments, both thermally and in terms of water activity. A “representative” sample may not strictly exist. In other cases, the H_2O may be bound tightly into the mineral structure as OH, such as in smectites, kaolinite and other clay minerals. Release of constitutional OH occurs only at temperatures of several hundreds of deg C, and there is no danger of inadvertent release even if the samples are unsealed.

A potential method of easing these requirements is to provide an in situ DSC/EGA instrument on future missions to measure labile H_2O, but with multiple-use ovens so as to not be limited to 8 samples as with the TEGA instrument on the Phoenix lander. Such an instrument could analyze far more samples than could be sealed and transported back to Earth.

Investigation Centrism: In the “Requirements Flowdown” scheme favored by NASA in justifying missions, science is cast in terms of discipline investigations. For example, “Follow the Water” is a typical investigation theme for Mars exploration. More pragmatically, missions are generally formulated by a combination of science questions and measurement feasibilities, embodied in the end as a specific suite of Instruments. Generally, these is no unique isolated one-to-one correspondence between Disciplines and Instruments. Cameras and IR spectrometers, for example, serve multiple purposes to multiple disciplines, ranging from the various subsets of geological to atmospheric sciences.

It is likewise possible to formulate sampling requirements for MSR based on disciplines and specific hypotheses, or to formulate them on the basis of a suite of laboratory instruments that will be brought to bear on the returned samples. One instrument lab often conducts multiple investigations. For example, stepped temperature volatile release can be used to study everything from the forms of chemical and physically bound H_2O, to organics, to trapped gases.

Many previous sample return missions, from Apollo to Stardust, allocated very small quantities of very specific sub-samples for analysis and then competitively evaluated proposals from various laboratories in part on their ability to squeeze the most science out of the least amount of material consumed or contaminated.

Sample Consumption: For previous sample return missions, only a fraction of the returned material was made available for near-term analysis. The remainder has been kept carefully stored and archived for future analytical capabilities and investigations. Thus, for a nominal 500 g of sample first returned from Mars, perhaps only 100 or 200 g will be available in the proximate future. Assuming the rover-based sampling missions are successful in locating and sampling one dozen (e.g., MER Opportunity at Meridiani) or two dozen (e.g., MER Spirit at Gusev) diverse samples of high priority, there will be as little as 5 or 10 g total per sample type. These quantities are far below that typically requested just for back contamination assessments and for martian toxicity analyses to prepare for human exploration. There will be precious little material for replicate studies, except for micro-analyses. The samples will be far more useful if on the other hand, (1) planetary protection can concentrate on high-likelihood samples, (2) toxicity be derived from the extraordinarily extensive data that will be collected on composition by geochemists and organic chemists, and (3) multi-discipline investigations be carried out in a single laboratory and/or round-robin samples. Atmospheric sampling could be mainly opportunistic, other than perhaps a modest dedicated sampling tube. Instead, future missions could include highly sophisticated mass spectrometers.

MSR vs Mars: Although sample return is essential to advancing our knowledge beyond the intrinsic limitations of all other types of missions, it must be kept in mind that the quantum increase in costs of MSR is in competition with other avenues of investigating the red planet. For example, if MSR indeed turns out to be a 3+ B$ mission, how will it be justified when the same total expenditure could accomplish any of a number of broad, multiple mission sets. How can MSR be justified compared to having three more MER rovers and two more Phoenix landers, all for the same price and peppered at five intriguing sites on Mars? Or another long-lived MSL with alternative science payload, and one each of MER and PHX? Keeping MSR below 2 B$ would a wise move to enhance survivability of the project.