SMALL SATELLITE-DERIVED MICROFLUIDIC AND MICROANALYTICAL TECHNOLOGIES FOR MARS SURFACE BIO/CHEMICAL HAZARDS ASSESSMENT.

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Introduction: Small satellites including cubesats and nanosatellites offer increasingly sophisticated analytical measurement capabilities in small (0.5 – 6 L), low-mass (1 – 10 kg), low-power (0.5 – 8 W), low-cost ($1 – 10 million) packages that are readily adaptable to a range of spaceflight and planetary applications [1]. Since 2006, NASA/Ames has demonstrated, by successful spaceflight missions, 1U and 2U payload systems (one "U" = 10-cm cube) to measure (a) bacterial gene expression via fluorescent proteins and light scattering [2]; (b) antifungal drug dose dependence monitored via 3-color measurements of microbe population and metabolic activity (Figure 1) [3]; (c) spore and extremophile survival in space via 3-wavelength absorbance [4]. Additional 2U spaceflight instruments are presently under development to monitor photosynthetic efficiency in algae and cyanobacteria as a function of gravitational level, and to study antibiotic resistance changes in uropathogenic bacteria subjected to microgravity. Spectrometers in the 1/3- to 1.5-U range that consume 0.2 – 1.5 watts have been developed and flown for the UV, visible, and near-IR spectral domains [5, 6].

Such microanalytical systems harness recent advances in microfluidics, microelectromechanical systems (MEMS) including sensors and actuators, polymer microfabrication technologies, low-power microelectronics, miniature high-efficiency motors, advanced materials, and integrated/fiber optics including micro/miniature light sources, cameras, and spectrometers. In addition to suitability for application on landers, the ruggedness and minimal mass of many integrated technologies enables them to survive shocks associated with penetrator technology.

Applications on Mars: For the specific Challenge Areas of this Mars Exploration workshop, small satellite microanalytical systems would be readily adapted in the near-, mid- and long-term for Mars hazard as-

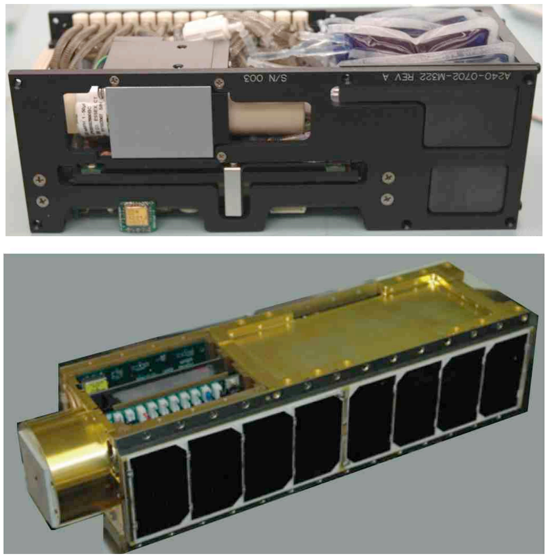

Figure 1. ***(Top)*** *PharmaSat fluidic system prior to integration (~ 7x7x20 cm), including 2 pumps, a dozen active valves, 8 reagent and waste bags, and 48-well microfluidic card;* ***(Bottom)*** *Mostly-integrated PharmaSat. Spaceflight mass 5.1 kg; size 10x10x34 cm. This technology can be adapted to the measurement of Mars surface reactivity.*

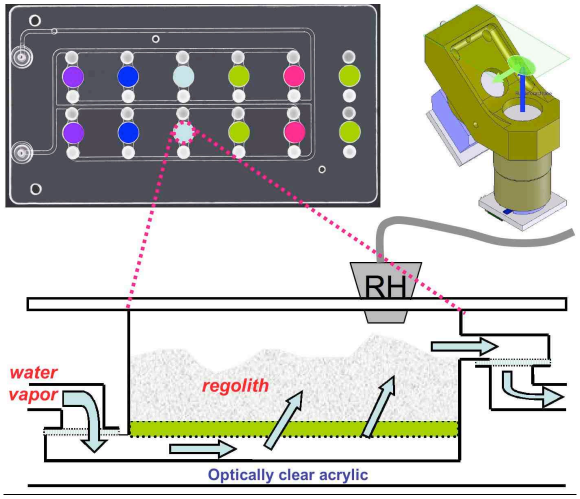

Figure 2. Mars dust reactivity measurement concept showing ***(top left)*** *a 10-well microfluidic card with a range of reactivity indicator dyes;* ***(top right)*** *integrated fluorescence-and-absorbance optical unit (~30 cm^3) dedicated to one well;* ***(bottom)*** *cross-sectional view of one well showing indicating film (green layer) in contact with regolith (gray) and fluidic connections to add water, stimulating reaction.*

sessment and human health risk reduction.

(1) *Near-Term Instrumentation and Investigation Approaches* for in-situ interrogation of the shallow subsurface of Mars using samples provided by drilling or excavating, when such technologies are available. Importantly, however, microliter analytical volumes also enable "passive" surface sample delivery using the ubiquitous martian dust storms to fill a microfabricated capture screen, with sensors indicating delivery of sufficient sample for analysis. This approach could be combined with a multiwavelength array of suitable wet-chemical indicator reactions supporting a sensitive assay of the biochemical reactive hazards of local surface environments. A tradeoff is available between a few standardized assays implemented in a small (~1U) system in many locations, and more sophisticated analysis with a larger system in fewer locations. This technology also provides an embodiment of lightweight, low-cost in-situ instrumentation to identify and triage high-priority materials for analysis.

(2) *Mid-Term Instrumentation and Investigation* concepts for detection of trace-level organic matter in dust. A suitable lab-on-a-chip technology for this need is isotachophoresis, an electrokinetic sample preconcentration method that provides million-fold concentration enhancement using microcapillary networks in microfludic devices [7, 8]. The device can include a dried-in derivatization/labeling reagent (which in some cases would also add charge to a neutral analytical target) to enable preconcentration, identification via retention time, and fluorescent detection with no other processing of a (wind-delivered) dust sample. Extremes and gradients of pH are readily generated by on-chip electrodes, facilitating the extraction of trace organics from many different types of mineral surfaces.

In the mid-term, the biochemical hazard assay described above could be tuned to provide in-situ sample analysis for purposes of human health risk reduction through the use of increasingly sophisticated biochemical reagents and assays, including electrophoretic analysis where separation of a moderate to large number of targets or indicators is necessary.

Both near- and mid-term lab-on-chip technologies described above could be adapted to support "smart sample acquisition" for eventual return by providing localized detailed analysis of reactivity and other key characteristics.

(3) *Long-Term Instrumentation and Investigation* for human health risk reduction. While terrestrial living organisms would *not* be included with near- or mid-term robotic lander missions, preparation for human habitation could include risk mitigation strategies based on "biosentinel" organisms. The unique martian environmental combination of reactive (oxidizing/toxic) dust, reduced gravity, and greater-than-terrestrial levels of ionizing radiation provide an integrated environment with the potential to affect living organisms in a manner not predictable from separate consideration of these perturbations.

Microfluidic culture-and-analysis systems descended from those flown on GeneSat, PharmaSat, and O/OREOS would support bioengineered organisms, in some cases tailored with human genes and sharing mammalian repair mechanisms, in order to study such biomolecular risks as double-strand DNA breaks, cell membrane damage, general oxidative damage, and protein modification. The biosentinel approach could also provide martian-ground-truth validation of models of the biological efficacy of radiation shielding strategies. Moreover, the potential for microbes and microbial ecologies that offer zero or minimal threat to human health and performance under terrestrial conditions could be evaluated for changes in pathogenicity, toxin output, and antimicrobial dose dependence under the actual conditions of a future martian surface habitat.

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