THE PROMISE OF LUNAR SCIENCE WITH SMALL SPACECRAFT.

M. Bicay[1], S.P. Worden[1], Y.J. Pendleton[1], and J.L. Heldmann[1], [1]NASA Ames Research Center, Moffett Field, CA 94035

Introduction: Emerging lunar science issues can be addressed effectively and expeditiously with small spacecraft. In the present context, we shall define 'small' to be missions with total costs less than $100 million, including launch, spacecraft, science payload(s) and operations. This loosely translates into payload instrumentation of a few kg to a few tens of kg.

Conducting science with small satellites requires one to embrace a mission philosophy of rapid development timescales and the potential use of commercial-off-the-shelf technologies. Such schedule compression and use of heritage makes it possible, with modest funds, to implement a series of low-cost small satellite launches as often as every six months.

Here we introduce research topics that are gaining increased prominence due to NASA's planned return to the Moon. We introduce <u>illustrative examples</u> of science experiments that can be addressed using small satellites or landed probes. These concepts are by no means comprehensive, but are intended to illustrate that focused lunar science experiments can be implemented at modest cost. Moreover, the experiments described herein could be rapidly developed or adapted from existing prototypes, enabling valuable scientific data to be gained from the Moon with small payloads – as soon as 2008.

The Search for Water: Following up LRO and LCROSS: The presence or absence of frozen water ice in the permanently shadowed regions of the Moon is still a controversial – and unresolved – issue. Currently available data are inconclusive.

The Lunar Reconnaissance Orbiter (LRO) and its piggyback Lunar Crater Observation and Sensing Satellite (LCROSS) will be launched in late 2008, and should provide the most definitive hydrogen measurements yet. In the event that LRO and LCROSS both detect water ice (or if the results are ambiguous), small follow-up probes could expand the search to a wider variety of geographic and topological features. These probes would measure abundance of H_2O within a sample within a range of 100 to 100,000 ppm (0.01% to 10%) per unit mass with a resolution of 100 ppm. They would sample a minimum of 1 meter column depth at intervals of 1 cm. A mast-mounted H_2O remote sensor (e.g., neutron spectrometer) on a landed probe would be highly desirable both for locating optimum sample target(s), and surface-orbit based observation reconciliation (ground truthing). Depending on the cost cap, some ground mobility -- or a network of inexpensive sensors -- might be feasible.

Physics and Dynamics of Dust: Early measurements from the Surveyor, Lunokhod, Clementine, and Apollo missions to the Moon each returned evidence suggestive of the levitation of dust particles above the lunar surface, perhaps to altitudes of 100 km [1, 2, 3, 4]. Subsequent theoretical modeling of these experimental results suggests that such levitation is possible due to the differential charging of the lunar surface [5, 6]. Theory predicts that dust levitation events should be correlated with the day-night transition on the Moon and indeed most data indicates that dust activity increases near the terminator. There are no extant data from the polar regions (i.e., near a permanent terminator), where the electrostatic dynamics may be more pronounced. To the extent that future human presence may be preferentially located near the poles, small probes could provide invaluable data on the extent of the dust and its dynamics in the near future.

The phenomenon of dust levitation is therefore of high scientific interest and additional data are required to more fully understand the cause and effect of the dust transport mechanism. A fuller understanding of the extent and frequency of dust levitation is important for assessing the viability of lunar astronomy (particularly at infrared and optical wavelengths), in assessing the potential health risks to crew members engaged in long-durations visits to the lunar surface, and in understanding its effects on mechanical systems on or near the surface.

A thorough study of these effects requires a coordinated remote and on-site sensing program (and perhaps sample return activities). NASA's Ames Research Center is formulating a series of low-cost lunar orbiters and landed probes that will measure the solar wind environment in the lunar exosphere and the distribution and dynamics of levitated dust. Proposed measurements will detect, sample and analyze lofted dust, providing information about the size, mass, electric charge and chemical reactivity of the dust particles. More specifically, the data would reveal the vertical distribution of lofted dust, the time dependence of dust-lofting rates and the impact direction correlated with the lunar day/night cycles, and the infall rates of cometary and asteroidal interplanetary dust particles. Furthermore, the relationship of particle size and composition to the dust adhesion would be characterized.

The Biological Toxicity of Dust: The unique features of lunar dust, only partly understood from

Apollo-era studies, indicate that it may have serious human health effects [7]. Lunar dust is formed by micrometeorite bombardment of the lunar surface, which results in the formation of glass agglutinates, with high surface-to-volume ratio, sharp, jagged edges with high amounts of trapped (reduced) iron. Particle sizes down into the sub-micron range can be deposited deeply into the lungs, with the potential for pulmonary toxicity. Eye and skin toxicity are also an issue, with the added concern that the abrasive nature of lunar dust may pose risk for mechanical damage to the skin, with both operational and health consequences to the crew.

Because of the long lead-time in developing engineering approaches to dust mitigation, it is logical to attempt to obtain as much specific knowledge about lunar dust as soon as possible. Specifically, the strategy for studying lunar dust should be to obtain high-priority information in all three areas of interest: physical, chemical and biological properties.

Key physical measurements include size distribution and shape of particles, particularly in clouds formed during regolith surface disturbances; surface charge; and surface affinity for water, as well as material interactions/adhesion. Key chemical measurements include surface reactivity and surface chemistry. Key biological measurements include effects on bio-viability of dormant cells (activation), activation of oxidative stress and other stress-responsive genes, and membrane damage and integrity.

Life on a Lifeless World: Science experiments designed to investigate the Moon's combined environmental effects on biological organisms are well matched to the constraints inherent in a small lunar surface probe. Such studies are likely to yield important new insights affecting crew health during long-duration visits on the lunar surface. Based on previous heritage gained through payloads on free-flyers and the International Space Station, we know there are many <10 kg experiments of biological interest. Incorporating multiple experiments on a single small lunar lander is not only feasible, but practical.

Researchers will study the combined effects of radiation, low gravity, dust, light and thermal conditions on a variety of life forms, ranging from genes, proteins and microbes to Drosophila (fruit flies) and plants. These experiments will yield data relevant to membrane damage, cell growth, and DNA damage in the space environment. Environmental parameters can be controlled autonomously and lunar surface experiments would require only modest adaptation of existing payloads.

Enabling Lunar Astronomy: There is vigorous and ongoing debate within the scientific community over the advantages and disadvantages of conducting astronomical research from the Moon [8, 9, 10, 11]. However, the extent to which lunar dust may scatter light at optical and ultraviolet wavelengths, or introduce added thermal effects at infrared wavelengths, remains unknown. Small satellites can play a vital and cost-effective role in conducting site surveys of possible telescope sites near the lunar poles. Some of the experiments described earlier in this paper could lay the foundation for researching the effects of levitated dust on telescope optics and mechanical systems. These data should be enhanced by a dedicated and sustained effort to assess the accumulated dust on and near the lunar surface. A notional concept for a lander with a <10 kg payload would determine the sky brightness at optical and infrared wavelengths, determine the dust environment through deployment of a liquid test cell, incorporate fish-eye visible-light cameras, and a radiatively cooled mid-infrared zenith camera. To assess the feasibility of a very low frequency (VLF) radio telescope on the lunar farside, a small satellite in lunar orbit, equipped with simple dipole antennas, could offer a preliminary assessment of the VLF environment. A more comprehensive experiment would require a small lander since the extent to which the Moon serves as a true interference shield depends upon the tenuous lunar ionosphere and diffraction. The former requires knowledge about the electron density profile, while the latter depends upon the lunar sub-surface. Neither is well understood. One mission concept would deploy a pair of 10 kHz to 500 kHz dipoles to measure the actual interference on the lunar far side.

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