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Spacecraft Reconnaissance of Asteroid and Comet Interiors

On October 5 and 6, 2006, a group of engineers, scientists and space administrators convened at the University of California in Santa Cruz to attend the Workshop on Spacecraft Reconnaissance of Asteroid and Comet Interiors. The workshop's goal was to determine mission and instrument requirements for learning the global geology of small bodies. The meeting was timely, given that inquiry had reached an apex, and well-attended, filling the main hall of the University Center near town. It was organized by the Lunar and Planetary Institute and UCSC; abstracts are available at www.lpi.usra.edu/meetings/recon2006.

Key financial support was provided by NASA's Science Mission Directorate. Together with further support from ESA, JAXA, JPL, and APL, the workshop fostered international and inter-agency collaboration across a broad spectrum of scientific, engineering, and programmatic interests. As the resulting journal articles in this volume attest, our small celestial neighbors remain poorly understood, but there exist clever means of obtaining the required knowledge on a reasonable timeline.

An international approach is particularly well suited to the scientific reconnaissance of near-Earth objects, which are the asteroids and cometary nuclei most attainable by spacecraft. Focused scientific attention on these small bodies, when filtered by the popular press for the eyes of public and political scrutiny, is interpreted as interest in impact hazard mitigation, the costs of which cannot be the burden of any one nation. While science missions are cheap in comparison to moving asteroids around, and are required precursors, science missions to asteroids have so far cost in the 100s of millions of dollars. The sharing of flight hardware, launch opportunities, ground support, and research expertise across space agencies appears increasingly pragmatic and allows for richer and more diverse science missions and a deeper understanding of campaign targets.

The idea of learning enough to divert a hazardous small body was not the workshop's focus, although, as is often the case at small bodies meetings, it did provide a backdrop. At the forefront were the latest science mission results, notably from Hayabusa (http://hayabusa.sci.isas.jaxa.jp) which had just emerged from perilous and intensive operations about the ~500 m asteroid Itokawa—an object that is fated to have numerous close encounters with Earth. Camera images filled the conference display with spectacular pictures from an exotic new landscape dominated by house-sized boulders and gravely "seas." Also foremost on the workshop agenda were presentations and critical evaluations of high-tech instruments, orbiters, and landers for learning more about comets and asteroids, including penetrating radar—comparable to investigations in progress around Mars and the Moon—and landed seismometers of the sort deployed by the Apollo astronauts. Futuristic approaches, including peristaltic moles and crab-like subspacecraft, appeared to be the stuff of science fiction, although the latter were shown to be functioning as test-bench prototypes.

In this issue, Spitzer et al. describe and simulate a penetrometer to measure dielectric permittivity as an indicator of the stratification that is expected to result from regolith and dust transport, impact excavation and burial, and (in cometary bodies) from ice deposition and sublimation. Kohout et al. show how magnetic susceptibility of asteroids (a rock property) can be measured from orbit (through magnetometric analysis of solar wind induction) or from the surface using a coil. As for mechanical studies, Glaser and Ball examine the relative merits of drills, penetrators, impactors, and excavators, operating in the uniquely challenging microgravity environment of asteroids. Weissman and Lowry provide a detailed review of the physical properties of cometary nuclei as related to the challenges of penetrometry, impact studies, radar remote sensing, and sample return.

A number of papers consider what can be learned from global reconnaissance. Gaskell et al. describe their state-of-the art techniques for characterizing and navigating small bodies using standard imaging products. Samarasinha shows how measurements of rotational damping and excitation acquired through imaging, radar, or lidar can provide quantitative constraints on the body's rigidity and dissipation. Asphaug shows how the largest undegraded crater on an asteroid—something that can occasionally even be measured from Earth—might reveal its interior seismological properties. Carley and Heggy provide 3D modeling of the upcoming 90 MHz CONSERT radar experiment, to be deployed at comet 67/Churyumov-Gerasimenko in 2015. As they say, "a seven year wait must be endured until CONSERT returns its radar data," reminding us that in the business of solar system exploration, we are all in it for the long haul.

These are interesting times. Telescopic detection of asteroids and comets is accelerating at a breathtaking pace, whereas spacecraft visitation feels like it is crawling along. The culprit is budgetary: $300M will buy you a lot of glass—the startup budget for the LSST survey telescope that is recommended by the NRC and other panels to greatly improve detection and characterization of thousands of asteroids, and discover hundreds of thousands more. The same sum will, almost, buy you a Discovery-class spacecraft for a mission to a near-Earth object, or a flyby past a cometary nucleus. We are making widespread discovery among a population of millions of objects whose basic physics and chemistry we still do not understand, creating a situation where science becomes impatient, even apart from the hazardous nature of NEOs.

Detailed characterization of the global geology of asteroids and comets, whether for hazard mitigation or to satisfy our great natural curiosity, may require missions that touch the surface. For this reason, geophysical investigations and sample return missions may go hand in hand. Samples of some kind already exist in laboratory cabinets from almost every cosmic rock type that is out there, but the quality of the sample is best for those objects that are hardest, densest, commonest, and most refractory. The volatile and fragile objects which break up in Earth's atmosphere or dissolve under terrestrial weathering—the most primitive, that is—are grossly under-represented and frequently misinterpreted. The famous Tagish Lake meteorite could, on the basis of that logic, be worth close to $1B—an order-of-magnitude cost for a sample return mission to a comet—and one might wonder whether all the cost might not better be devoted to a program of thousands of civilians with special canisters to scoop up pristine samples whenever and wherever they fall.

The digression, while not entirely silly, is always trumped by the argument that unless we collect a sample in situ, we will not know that it is truly representative. The pristine sampling of tens or more grams of cometary material in cryogenic sealed conditions is now regarded as one of NASA's space exploration priorities, and that indicates the necessity for a flagship-class mission to a distant primitive body. One promising sign aligned with such a goal has been the development of sophisticated laboratories capable of unbelievably intensive nanoscale analysis of returned samples, the sort of push towards analytical sophistication that preceded the Apollo program.

The specific direction that NASA and other agencies take in missions to comets and asteroids remains to be seen. It is a relatively new exploration and has not yet been anchored in the kinds of long-term objectives enjoyed by, say, lunar and Mars exploration. The recent startup of the Small Body Assessment Group (SBAG, complementary to the LEAG, MEPAG, VEXAG, and OPAG assessment groups that exist for the Moon, Mars, Venus, and outer planetary exploration) could go a long way towards defining those mission priorities and defining a future for the long-term exploration of minor bodies. Along similar lines, the International Primitive Body Exploration Working Group met this January in Okinawa, in part to establish international exploration goals, collaborative methods, and priorities.

Considerable international and inter-agency efforts on many fronts—scientific, technical, and fiscal—will be needed before some of the fundamental questions surrounding small bodies in the solar system can be answered. The workshop on Spacecraft Reconnaissance of Asteroid and Comet Interiors was a small step forward in providing a forum for frank discussion of the science requirements and technological developments that will be needed to achieve these goals.

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