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Response to call for white papers, NASA Strategic Roadmap

Meteorites, Asteroids, Planets, and the Exploration Vision Strategy

Meteorites, including interplanetary dust particles (IDPs), are our primary evidence of early solar system history, the formation and composition of asteroids and comets, Martian geologic processes, and the chemical evolution of the galaxy. They sample the solid feedstocks for in-situ resource utilization (ISRU). Sudy of IDPs and meteoritic grains formed around other suns has driven instrument development so we can now analyze rare isotopes in sub-micron volumes of rare materials. Meteorite studies have driven the educations of many talented young cosmochemists and planetary geologists eager to participate in the next stages of exploration of space.

The capabilities roadmap and the strategic roadmap (NASA APIO RFI 01, Attachment 1) indirectly acknowledge the importance of chemical and textural studies of extraterrestrial materials already (!) in our possession, e.g.-meteorites, IDPs, and lunar samples. Such studies are key to calibration and testing of sensors carried by robotic and human missions, and to characterizing potential resources in near earth space. We have demonstrated that the extraterrestrial rocks and supporting display materials in our Museums are wonderful entry points to bringing NASA activities to the public, and inspiring excitement in students and teachers. It is the hands-on study of extraterrestrial rocks by curators involved in NASA-sponsored research that brings meteorites to life in these venues.

Many of the studies involving meteorites specialists are interdisciplinary. Some examples include:

- **combined hydrodynamic and chemical studies of impact processes**: Impacts shape all planets, and may transfer biological material between them. The grain size, apparent chemistry, and bulk chemsistry of regoliths of bodies large and small are, as is the moon, very strongly affected by impacts. Hydrodynamic codes tell us the volumes of vaporized, melted and shocked material, and where they travel, for particular impact parameters. Chemical thermodynamic simulations yield predictions of what mineral species, liquid droplets, and vapor molecules contain how much of each chemical element after the impact.
- **laboratory calibration of ultraviolet spectra for extraterrestrial materials**: Ultraviolet spectra are not nearly so well-calibrated in the laboratory as are infrared spectra. We need to be able to interpret ALL of the spectrum of light reflected by objects in space. Calibrating uv spectra requires close collaboration between specialists in petrology, mineralogy and chemistry; with instrument design engineers and physicists engaged in remote sensing studies. Laboratory materials must be provided which are chemically and texturally well-characterized, and cover the appropriate spectrum of materials expected in remote sensing. Calibration of uv spectra may allow much better characterization of asteroid types, grain sizes of regolith on airless bodies, and ice chemistry on icy moons. All of these science goals have obvious application to exploration, particularly ISRU capabilities.
- **chemistry of extrasolar disks**: Extrasolar planets are of obvious interest, however, the disks in which planets form are larger, easier targets that can tell us a great deal about how,

where, when and why habitable planets form. Our solar system is a single datum; we need points of comparison. It is critical that observers (e.g.-coronagraphic or interferometric imagers, and instrument builders) collaborate with disk modelers, and with cosmochemists who have first-hand knowledge of the 'left-overs' of our own solar disk. The collaboration of experts in astronomy, astrophysics and cosmochemistry is essential to success in combining all these lines of evidence into a clear picture of our origins.

- **experimental planetary chemistry**: Experimental work is necessary to address many questions not anticipated by the terrestrial experimental petrology community. This is not surprising, given the 'bizarre' pressure-temperature regimes, and bulk chemical compositions of solids and liquids on other planets. For example, there is a critical lack of good laboratory data on the low-temperature thermodynamic properties of clathrates that may be important constituents of the Martian cryosphere. The study of systems like these requires both experimental expertise, and expertise in classical thermodynamics to identify the critical data necessary. Collaboration with physical modelers (e.g.-glaciologists) would follow, integrating chemical and rheological laboratory-based models, with the appropriate gravitational, thermal, and insolation fields, to predict conditions and resource locations on other bodies (e.g.-Mars). This is the preliminary work necessary for engineering missions to these locations, and ISRU at them.

- **instrument development and meteorite study**: The disciplines of analytical chemistry, mineralogy, petrology (geology), and physical chemistry (thermodynamics) are combined in the ongoing study of extraterrestrial samples of all kinds. This enterprise is at the core of many NASA roadmap focus areas. Missions such as GENESIS, STARDUST, and Opportunity and Spirit MERs all connect these core disciplines with solar physics, solar system, and planetary science objectives. Instruments on these and other missions derive from cutting-edge work in the core disciplines. While each mission is important, it is the continued, steady support by NASA of these core competencies, in the study of extraterrestrial samples already in hand, that continually rejuvenates the human infrastructure.

Interdisciplinary studies in support of particular pre-formed questions are vital to the future of the space exploration vision. There must also be continued support for the basic sciences that underpin all such targetted interdisciplinary projects. We use analytical chemistry, mineralogy, petrology, and physical chemistry to understand meteorites, IDPs, lunar samples, and other extraterrestrial materials as they become available. Discoveries such as the finding of presolar dust grains formed around other stars result from continued, steady support of diligent inquiry by dedicated investigators over long time periods. Development of instruments such as the CHARISMA mass spectrometer appear to occur in a similar way.

It is my hope that strategic focus areas be described broadly enough to continue NASA support for the basic sciences that has led to such a recent explosion of knowledge about our solar system. The big divides between disciplines appear to be chemistry < > physics, and science < > engineering. Focus areas should be structured so as to encourage bridging these divides.

References:
call for white papers: http://fellowships.hq.nasa.gov/apio/rfi.pdf
CHARISMA instrument: Geochimica et Cosmochimica Acta 67, 3215-3225 (2003); http://cosmochemistry.uchicago.edu/

submitted 10-Dec-2004.
Primary NASA focus area: Sustained program of solar system exploration.
Secondary NASA focus area: Explore the origin, evolution, structure and destiny of the Universe.