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ROBOTIC MISSIONS TO SMALL BODIES AND THEIR POTENTIAL CONTRIBUTIONS TO HUMAN EXPLORATION AND PLANETARY DEFENSE

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Introduction: Robotic missions to small bodies will directly address aspects of NASA's Asteroid Initiative and will contribute to future human exploration and planetary defense. The NASA Asteroid Initiative is comprised of two major components: the Grand Challenge and the Asteroid Mission[1]. The first component, the Grand Challenge, focuses on protecting Earth's population from asteroid impacts by detecting potentially hazardous objects with enough warning time to either prevent them from impacting the planet, or to implement civil defense procedures. The second component, the Asteroid Redirect Mission (ARM), involves sending a large robotic spacecraft using solar electric propulsion (SEP) to retrieve a boulder from the surface of a 100+ meter near-Earth asteroid, conduct one or more planetary defense demonstrations at the NEA, and then return the boulder to a lunar distant retrograde orbit (LDRO). Once the boulder is securely in the LDRO, two astronauts will travel in an Orion capsule and rendezvous with the robotic capture vehicle to conduct two 4 hour extravehicular activities (EVAs). During the EVAs, the astronauts will study the boulder in detail, deploy engineering and scientific equipment, and collect various types of samples from multiple locations on the boulder. Both components of the ARM will help develop the technologies and experience required for conducting future human exploration missions to other NEAs and of the Martian system, which includes Phobos and Deimos, and possibly provide new insights for developing planetary defense techniques.

Robotic Precursor Missions: Prior to the launch of the robotic capture system for the ARM, robotic precursor spacecraft will be launched and will have rendezvoused with two NEAs. The Hayabusa2 and OSIRIS REx missions will investigate asteroids 1999 JU_3 and Bennu, respectively, both of which are under consideration as possible ARM targets. The science and technical data obtained from these robotic precursor missions, which will investigate the surface and interior physical characteristics of their respective targets, will help identify the pertinent physical properties that will maximize operational efficiency and reduce mission risk for both robotic assets and/or crew operating in close proximity to, or at the surface of, a small body. This information will not only be invaluable for the ARM, but will also provide crucial data for any other mission planning to rendezvous with a NEA whether for future human exploration or planetary defense purposes. Given the current state of knowledge about small body physical and geotechnical properties, robotic precursor missions are required in order to understand the essential characteristics of those targets that are of interest for human exploration and planetary defense. The data from these missions will help fill crucial strategic knowledge gaps (SKGs) concerning asteroid physical characteristics that are relevant for human exploration considerations at similar small body destinations. These data can also be used for gaining an appreciation of pertinent small body physical characteristics that will be beneficial for formulating future impact mitigation procedures.

Small Body Strategic Knowledge Gaps: For the past several years NASA has been interested in identifying the key strategic knowledge gaps (SKGs) related to future human destinations. These SKGs highlight the various unknowns and/or data gaps of targets that the science and engineering communities would like to have filled in prior to committing crews to explore the Solar System. An action team from the Small Bodies Assessment Group (SBAG) was formed specifically to identify the small body SKGs under the direction of the Human Exploration and Operations Missions Directorate (HEOMD), given NASA's recent interest in NEAs and the Martian moons as potential human destinations[2]. The action team organized the SKGs into four broad themes:

1) *Identify human mission targets*;
2) *Understand how to work on and interact with the small body surface*;

3) *Understand the small body environment and its potential risk/benefit to crew, systems, and operational assets*; and
4) *Understand the small body resource potential*.

Each of these themes were then further subdivided into categories to address specific SKG issues. Of these four SKG themes, the first three have significant overlap with planetary defense considerations. The data obtained from investigations of small body physical characteristics under these three themes can be directly applicable to planetary defense initiatives. The fourth theme may be irrelevant or applicable (either directly or indirectly) contingent on the type of planetary defense technique to be considered and the resource present in the object (e.g., volatiles, metal, etc.).

Potential Robotic Precursor Contributions to SKGs: A properly instrumented robotic precursor mission that performs a rendezvous with the object and interacts with its surface can address specific aspects related to all of the SKG themes. Theme 1 deals with the identification of human mission targets within the NEA population. The current guideline indicates that human missions to certain types of asteroids or those with certain configurations may be too risky to conduct successfully from an operational perspective. For example, binary NEAs and extinct/dormant comets among the near-Earth object population (NEOs) are currently classified as targets that would be excluded from consideration as potential future human targets based on the perceived operational complexities. Currently no spacecraft mission has been to a binary NEA or a NEO that is actually an extinct/dormant comet. Hence the information that robotic precursors would gather on these objects could be used to reassess the current restriction concerning them as potential human destinations. At the same time, the information collected would be helpful for understanding the basic physical characteristics of these objects, which may be necessary in order to select and implement the most effective deflection technique. It should be noted that the most accessible NEAs are also by definition are among the most hazardous.

Data addressing SKGs from themes 2 and 3 are undoubtedly where the robotic precursor mission will return the most value from the standpoint of human exploration and planetary defense. Theme 2 addresses the concerns about interacting on the small body surface under microgravity conditions, and how the surface and/or sub-surface properties affect or restrict the interaction. A robotic precursor spacecraft should have a suite of remote sensing instruments (e.g., visible and thermal imagers, radar transmitter, radio science receiver, etc.) that can characterize the surface of the target to a high degree and provide the appropriate global geological context. These instruments can also be used to infer or measure some of the interior properties of the binary asteroid system. In addition, the robotic precursor should have one or two packages/rovers that are planned for deployment for local *in situ* characterization of the surface. These elements will be able to gather vital information on the geotechnical and compositional properties of the target's surface and near-surface regimes. The combination of the remote sensing instrument suite and the *in situ* payloads with their local perspective will provide good insight into the target's surface and subsurface properties. This knowledge will be useful in planning and designing the systems required for astronauts to explore and work on the surface of a small body. This information will also be useful for understanding the internal structure of the object, which will allow higher fidelity modelling of specific planetary defense mitigation techniques that rely on such parameters as the object's density and its internal mass distribution.

SKG theme 3 deals with the environment in and around the small body that may present a nuisance or hazard to any assets operating in close proximity. Robotic precursor spacecraft are aptly suited to contribute to the SKGs related to this particular theme. Robotic spacecraft will be able to image the object(s) of interest and constrain the size of any particulates that may be present that would pose a risk to a subsequent human exploration or planetary defense mission. Such spacecraft could also be used to image the impact of another spacecraft (either previously deployed or co-manifested) and monitor the response of the object/ system to the kinetic impact. The information gained on the crater formation processes, the amount of ejecta released during the impact, and the ejecta response over time would address issues related to particle longevity, internal structure, and the near-surface mechanical stability of the object/system. Understanding or constraining these physical characteristics is also important for future human mission planning. It would also provide a much needed data point on the efficiency of kinetic impacts and the magnitude of any delta V that was imparted to the object/system for planetary defense.

Evidence from remote sensing observations of small bodies and the examination of materials from the terrestrial meteorite collections suggests that some portion of the NEA population may be resource-rich[3,4,5]. Robotic spacecraft mission data may be used to determine whether potential resources exist on the surface of these targets or at depth. This would address the SKG theme 4 and help identify the protocols necessary for understanding the resource potential of small bodies. Resources such as volatiles and water would be extremely valuable for future human exploration, but may also have some value for future development of planetary defense techniques that would take advantage of the presence of volatiles and/or water to enhance the effects of the mitigation technique by activating specific source regions on the object (e.g., exposing volatile material to solar insolation).

Conclusions: Robotic missions to investigate small bodies can address the four strategic knowledge gap themes and contribute to the overall success for human exploration missions to asteroids and the Martian moons. In addition, such reconnaissance of small bodies can provide a wealth of information relevant for implementation of planetary defense missions to hazardous NEAs.

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