COMMON GROUND:
Asteroid Mining and Planetary Defense

BY JAMES C. HOWE

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Defending Earth from collisions with asteroids and comets emerged as a serious issue less than two generations ago, as the science community increased its understanding of the Near-Earth Object (NEO) population within the Solar System. Interest in planetary defense grew as evidence showed that a large asteroid strike 65 million years ago led the dinosaurs to extinction, and was enhanced during observation of the fragmented comet Shoemaker-Levy 9 crashing into Jupiter in 1994. The asteroid that exploded above Chelyabinsk, Russia, in 2013 rekindled debate, showing once again the vulnerability of our planet to celestial impacts.

More recently, a nascent space mining industry has begun to take shape, with several commercial entities taking concrete steps to develop the systems needed to harvest water and mineral resources from asteroids and comets, as well as from the Moon. While neither planetary defense nor asteroid mining operations have yet been conducted, both disciplines may prove vital to humanity: the first by protecting the planet from a devastating collision, and the second by developing new sources of precious metals, raw material for in-space manufacturing, and water for use as hydrogen- or oxygen-based rocket fuel, expanding mankind's reach into the Solar System.

Finding Synergies

At first glance, planetary defense and asteroid mining appear to be markedly different activities, the first designed to deflect or destroy a hazardous asteroid and the second to recover its resources. However, an examination of the operational, logistical, and technological attributes of these two disciplines shows a striking amount of commonality. Like fraternal twins, planetary defense and asteroid mining look different but share much of their DNA.

Notionally, most planetary defense and asteroid mining scenarios involve five discrete steps. The first step, detection, locates previously undiscovered asteroids and comets from among the vast catalog of known celestial objects. An estimated billion asteroids and trillion comets revolve around the Sun: more than half a million of them have diameters greater than 30 meters and orbits that pass through the inner Solar System. Planetary defense practitioners concentrate on those that will pass within 0.05 Astronomical Units (7.5 million kilometers) of Earth's orbit, posing the greatest threat of collision.

To date, terrestrial and Earth-orbiting telescopes have discovered more than 12,000 NEOs: the ground-based LINEAR, Catalina Sky Survey, and Pan-STARRS telescopes being the most successful. New technologies are poised to greatly expand this number. The B612 Foundation's proposed Sentinel space telescope, if launched as planned into a Venus-like orbit, should become the most prolific asteroid hunter in history. NASA's NEOCam satellite, still on the drawing board, could be a close second as it looks outward from its planned station at the Earth-Sun L1 Lagrange Point.

The same processes and procedures used for detecting potentially hazardous objects in space apply to the detection of possibly resource-rich asteroids or comets. While the space mining industry may eventually develop a robust detection capability of its own, relying on existing NEO detection programs should serve it well into the future.

This is true also for the second step in both endeavors, the long-term tracking and accurate determination of an asteroid or comet's orbit, and projections of when it will pass through the inner Solar System. Three main variables affect orbit calculation accuracy: the number of observations, the time span over which they are conducted, and whether observations from optical telescopes or the far more precise, but range-limited, Goldstone and Arecibo radar telescopes are included in the data. For the planetary defense community, a precise orbit is needed to determine which asteroids constitute a potential threat, with the goal of identifying a hazard several decades before a forecast collision.

For miners, knowing a precise orbit allows cost-benefit calculations as to which asteroids can be reached most advantageously: many mineral-or ice-laden bodies may have orbital parameters that preclude a cost-effective interception, while more than 2,500 known asteroids can be reached using less fuel than is needed to fly to and land on the Moon. NASA and other organizations publish the orbital parameters of all known NEOs—information that is available at no cost to the space mining community.

The third general shared attribute of both activities is the remote characterization of NEOs. This step is essential in planetary defense, as it provides important information for guiding a mitigation strategy for asteroids or comets bound for collision with Earth. Optical and radar telescopes, when within range, are employed to determine the body's size, mass, shape, density, composition, albedo, and spin characteristics, a process that sometimes can take years, depending on the orbital track of the object and the number and quality of the observations. Once these characteristics have been established, decisions regarding the type of mitigation effort—a nuclear explosion, a kinetic impact, or one of many "slow push" techniques, such as laser ablation, gravity tractors, or mass drivers—can be made. Without knowing the characteristics of the body, any deflection or fragmentation strategy would face a very high risk of failure.

The mining community also depends on knowing the detailed characteristics of an asteroid or comet, and would use remote characterization to winnow the field of potential targets. Small NEOs that may not be considered a serious hazard to Earth could be ideal targets for resource exploitation. Conversely, many asteroids that at first glance seem like likely mining targets may be discounted due to high spin rates, loose structures, or awkward shapes that make mining impractical. Precise remote characterization will help the asteroid mining industry determine the most suitable candidates for further exploration and, potentially, resource extraction.

The fourth common step, in situ exploration, builds upon the data collected through remote characterization. For most planetary defense deflection or fragmentation efforts, information beyond what can be determined remotely will be necessary for finalizing operational planning for the mission. Robotic fly-bys, close orbits, or contact exploration can determine a number of vital parameters, such as the amount of rubble orbiting near a threatening asteroid, the seismological characteristics and internal structure of a body, and the depth of regolith on a body's surface. Assuming a hazardous asteroid is discovered well in advance of collision, in situ exploration is essential for assessing the physical characteristics that will help drive the exact mitigation tactics to be employed.

In situ exploration is also vital for the asteroid mining industry, as it would allow detailed analysis of a body's chemical make-up, geological composition, and thermal structure. Additionally, mechanical testing could establish the effectiveness of anchoring, surface excavation, drilling, or scooping—information that would be essential for assessing if an otherwise tempting asteroid is indeed suitable for metal, mineral, or water extraction.

Proximity operations constitute the fifth, and broadest, shared attribute of national planetary defense and asteroid mining activities. These operations involve orbiting, hovering, landing/launching, anchoring, and extracting material, all in a micro- or milli-gravity environment. The technical challenges of operating near a small celestial body are extreme: witness the Japanese Hayabusa mission to the asteroid Itokawa in 2005, and the European Space Agency's ongoing mission to Comet 67P/Churyumov-Gerasimenko, both which encountered severe difficulties with landing and, in the later case, anchoring on the asteroid or comet.

Progress in Proximity

Extensive and prolonged proximity operations will be an essential element of most types of planetary defense mitigation missions. The most technologically mature method for fragmentation or deflection of a hazardous object is through a surface, subsurface, or stand-off nuclear explosion: The tremendous impulsive force of the blast and resulting surface ablation could, in one moment, deliver the necessary velocity change to the body to miss its future collision with Earth. Time permitting, to assure exact positioning and maximum deflective or fragmentation effect, the nuclear device would be buried, anchored to the surface, or orbiting just above the asteroid, an effort that would involve precise proximity operations.

On the opposite end of the spectrum for deflecting an inbound body are the "slow push" methods, which would deliver a minute but steady deflective force to the asteroid or comet, over time providing a cumulative change in velocity. With few exceptions, every proposed slow push technique would be dependent on extended operations in close proximity to the body. Gravity tractors would hover a spacecraft near the asteroid for years or decades, slowly imparting a deflective gravitational force; an enhanced gravity tractor would first collect boulders or regolith from the threatening body, to increase the mass and gravitational pull of the spacecraft. Laser or solar ablation methods would require the stationing of a spacecraft near the asteroid to direct the ablative beam. Using thrusters or a space tug would require direct physical contact with the body for years on end, nudging it to alter its velocity. Mass driver systems would land and anchor a robotic mining apparatus on the asteroid's surface, to cast a steady stream of regolith into space and produce a minute but steady deflective counterforce.

Similarly, asteroid or comet mining would rely entirely on the ability to conduct reliable, long-term, repetitive proximity operations. Several mining concepts have been analyzed. The most common concept would land and anchor robotic mining and support systems on the asteroid or comet; these systems would methodically drill, scrape, crush, lift, or scoop the desired minerals or ice from the body. Support systems would discard unwanted tailings and transport the ore to a processing station or collection facility. The mining operation could occur on the surface, in pits, or in caverns cut into the interior of the asteroid or comet.

Alternative mining methods include leaching minerals through the injection of high pressure steam, fully encapsulating a small asteroid or comet and capturing the escaping water as the container is heated by the Sun, and collecting water vapor from a passing comet using a spacecraft stationed in a trailing position behind it. Each of these activities would require the ability to operate on and near the surface of the body for long periods.

The commonalities between planetary defense and asteroid mining are extensive for the wide range of proximity operations. For both endeavors, hovering, orbiting, landing, and anchoring on the space body are essential competencies. The same base technologies that can be used to mine metals could be employed in burying a nuclear device to fragment an asteroid, or as a mass driver apparatus used in deflection. The technologies that could be employed to secure thrusters or a solar sail to a tumbling asteroid to change its orbit could be adapted to anchor a full suite of mining equipment to the surface of a resource-rich body.

Advancing Two Fields

From initial detection to detailed characterization to operations on and around a NEO, the twin disciplines of planetary defense and asteroid mining share a host of common attributes. Because of this, advances in one field also will lead to advances in the other. Building a robust space mining industry and developing the technologies and techniques to conduct extended operations in a micro-gravity environment would yield tremendous benefits for future planetary defense operations. Likewise, advances in planetary defense-related detection, orbit calculation, characterization, and mitigation capabilities would provide a similar boost to the fledgling mining industry.

A constructive path forward would see increased cooperation and collaboration between the planetary defense and asteroid mining communities, the former overseen primarily by governments and academia, and the latter spearheaded by the private sector. While collaboration currently exists, it is piecemeal and poorly resourced, with very limited government funding being used to develop collision mitigation technologies or kick-start the space mining industry. Considering the consequences of a major asteroid or comet strike, as well as the immense promise of commercial mining in space, a greater focus on this connectivity could be extremely beneficial to the long-term health, wealth, and survival of our species.

First Steps Forward

In September 2014, NASA took an important step forward by holding a conference at the Ames Research Center titled "The Economics of NEOs," bringing together leaders from the space mining community, academia, and government to explore the contours of the industry, identify overlap with other federal activities, and find areas for further collaboration.

The conference summary included a list of key findings, the first of which very effectively framed the issue: "Great synergies exist between planetary defense, scientific research, space exploration, and commercial space activities—including mining of minerals and volatiles—that could be strengthened through public-private partnerships." Further, the findings noted that government must play a central role in nurturing the fragile asteroid mining industry, by serving as the "first customer" for water and minerals harvested in space. Finally, the conference established that the significant technological challenges faced in operating on and near small space bodies, by both the planetary defense and asteroid mining communities, were achievable in the near term, assuming a properly focused effort.

A first necessary action would be to increase detection capabilities, particularly for smaller asteroids and comets down to 30 meters in diameter. While these bodies cannot generate civilization-ending collisions, they constitute the vast majority of NEOs, can inflict significant regional damage, and strike Earth far more frequently than larger bodies; further, they represent a population ripe for resource exploitation. Terrestrial and Earth-orbiting telescopes, while having performed admirably in this quest, should be augmented by much more effective infrared telescopes placed into orbit around the Sun. At a minimum, ensuring that the B612 Foundation's Sentinel and NASA's NEOCam spacecraft receive the private and public funding needed for deployment is vital.

A second enhancement would more deeply intertwine mitigation and mining technological development with government space operations. The planned Asteroid Redirect Mission (ARM), in which NASA will capture a small asteroid—or part of one—and place it into lunar orbit, could yield significant technological advances for both the mining and planetary defense communities. Increasing the involvement of the asteroid mining industry in this endeavor could help jumpstart efforts to develop the landing, anchoring, and extraction technologies essential for successfully harvesting resources in space. Further, focusing specific activities of ARM and future NASA missions on planetary defense capabilities could generate major operational and technological breakthroughs, such as perfecting close-aboard orbiting and hovering techniques, key attributes of gravity tractor and other deflection methods.

Third, government research activities related to planetary defense and asteroid mining activities should be increased dramatically over current levels, which barely exceed $1.0 million per year—an almost invisible sum by federal standards. Vast improvements need not break the bank: an aggressive program dedicated to developing asteroid mitigation, proximity operations, and mining technologies could involve cooperative cost-sharing arrangements between industry and government, all for far less than what is spent annually by NASA on agency management (about $365 million last year).

Building a functional space mining industry will yield more robust planetary defense capabilities, and developing the enhanced technologies and methods to protect Earth from collision could enhance the growth of a commercial sector dedicated to harvesting the resources found on asteroids and comets. Through close, continual, and expanded collaboration between these two fields of endeavor, the synergies of planetary defense and asteroid mining can best be leveraged to yield benefits for all mankind.

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