Mining Asteroids and Exploring Resources in Space

Puneet Bhalla

Exploration is intrinsic to mankind which has forever sought newer frontiers, primarily for scientific discovery and for economic gains. Extra-terrestrial missions beyond the Earth orbit into deeper space have until now pursued the former. However, with a growing realisation of depleting natural resources on Earth, the focus has shifted equally to seeking celestial bodies that can be mined for further use. Until now seen mostly in the realm of science fiction, today, space mining is being brought closer to reality through advanced technologies and directed investments. Scientists have been studying asteroids by analysing meteorite samples found on Earth and by telescopic studies. Asteroids are rocky bodies, varying from a few metres across to the largest Ceres (averaging 952 km in diameter, also called a 'dwarf planet'), orbiting the sun. Most of the millions of asteroids in the solar system are found between the orbits of Mars and Jupiter in the 'main asteroid belt'. Among asteroids outside this belt, astronomers have discovered more than 10,000 near Earth asteroids (more of them continue to be discovered) whose orbital trajectories bring them close to Earth. Of these, nearly 9,000 are known to be larger than 150 ft in diameter.

Group Captain **Puneet Bhalla** is Senior Fellow, Centre for Land Warfare Studies, New Delhi.

Spectrographic tests on asteroids have indicated mainly three types that have been classified as:[1]

- C Type – 75 percent of asteroids. Rich in carbon and water.
- S-Type – stony. Mixture of rock and metal mixed together.
- X-Type – metallic. Highly concentrated deposits of precious metals.

Exploration of asteroids offers a number of benefits for humans. A number of space agencies have launched missions to asteroids with a view to gather information that would answer questions regarding the origins and evolution of the solar system. For the National Aeronautics and Space Administration (NASA), the Galileo probe, on its way to Jupiter, provided the first close-up photographs of an asteroid in 1991. In 2001, the first dedicated asteroid probe, NEAR Shoemaker, landed on 433 Eros. Japan's Hayabusa (Falcon) mission, launched in May 2003, collected dust samples from a small asteroid named Itokawa and returned them to Earth in June 2010. NASA's Dawn space probe was launched in September 2007 with the mission to study two of the known 'big four' asteroids, Vesta and Ceres. From July 2011, it orbited Vesta for 14 months before leaving for Ceres whose orbit it entered in March this year. The European Space Agency's (ESA's) Rosetta probe, launched in 2004, was in the news because of its lander module Philae, that carried out the first successful landing on a comet, the 67P/Churyumov–Gerasimenko (67P) in November last year. Most of these probes also provided information on other heavenly bodies of interest that they flew by. China joined the club in 2012, when its lunar orbiter Chang'e 2, after having completed its primary mission, flew close to asteroid 4179 Toutatis while proceeding deeper into space.

Hayabusa 2, the second Japanese asteroid probe was launched successfully in December last year for a six-year round-trip to the nearly kilometre-wide C-type asteroid 1999 JU3. The probe is expected to arrive at the asteroid in June 2018 and spend eighteen months around it before returning to Earth around the end of 2020. Once there, it will blast a crater using a 2 kg copper impactor, allowing collection of sub-surface samples that are less weathered by the space environment or heat, through a complex touch-and-go manoeuvre. It will also deploy three rovers and a German and French made MASCOT lander to study the surface in detail. Meanwhile, in March this year, NASA confirmed that it had started building the Origins, Spectral Interpretation, Resource Identification, Security Regolith Explorer (OSIRIS-Rex) spacecraft. The OSIRIS-Rex mission is expected to be launched in September 2016, aimed for a 500 metre (m) sized asteroid, Bennu, with the planned landing in 2019. It is expected to collect rock samples and return them to Earth by 2023.

The vast amount of resources available on asteroids has also stimulated interest in their commercial exploration, with a number of studies conducted on accessing and harvesting the near-Earth asteroids. While the Moon and Mars have garnered much attention, mining asteroids provides relatively better opportunities as most of them are easier to reach, do not have high gravity to be countered and also have higher concentrations of resources like:

- Water is a valuable commodity in space but the costs associated with launching it from Earth are huge. Besides human sustenance, it has utility in radiation shielding of spacecraft and astronauts. It could also be broken down into its hydrogen and oxygen components, which can then be used to form the basic building blocks of rocket fuel. Its availability in space would considerably reduce the fuel component of the gross weight at launch, allowing for more mission related load to be carried.
- The asteroids could provide a vast supply of high value minerals that, if economically extracted, could provide solutions to the Earth's resource depletion worries. This is especially true of the platinum group and other rare metals that are found in low

concentrations on Earth but are available in abundance on some asteroids.[2]

Space-based processing facilities would have to be set up to segregate the minerals from the ore. While the most precious ones would then be transported back to Earth, others would be employed for In Situ Resource Utilisation (ISRU), to optimally utilise them for satellite life extension, enable sustainable presence and expanded robotic and human exploration of the solar system, support future space colonisation and to make mining ventures self-sustaining.

Asteroid Mining: The low gravity of the asteroids makes them easy to move around in a low gravity theatre like space, requiring minimal fuel for altering their trajectory to bring them to a high Earth orbit. [3] Here, closer to Earth, useful resources can be extracted, processed and even stored for further use. A study ordered by NASA has estimated the cost of capturing an asteroid and returning it to a low lunar orbit to be about $2.6 billion.[4] The very low surface gravity of an asteroid necessitates mining processes that are radically different from those on Earth or those envisaged for the Moon or Mars. However, issues related to temperature extremes and operating machinery in a vacuum might remain the same as those of other bodies in space, necessitating novel solutions.[5] NASA's first-ever Asteroid Redirect Mission (ARM) aims to launch a robotic capture probe in 2020 that would pluck a boulder off a near-Earth asteroid,[6] then drag the rock into orbit around the Moon at a distance of 61,500 km, which is very stable and requires relatively little energy to reach.[7] Solar Electric Propulsion (SEP)[8], providing continuous low thrust, rather than chemical propulsion that depends on short high thrust bursts, is expected to power this mission. Once there, it would be analysed by robotic probes and by visiting astronauts in 2025. The ARM would also demonstrate a planetary defence technique – for deflecting an asteroid – to be used against potentially hazardous asteroids in the future. The whole mission itself would provide important inputs for planetary defence. In addition, it would test a number of new capabilities that would contribute to future space exploration missions, including those to Mars.

Recent years have also seen the increased interest of, and participation by, the private industry, backed by tech billionaires, in space ventures and their growing acceptance in this traditionally government dominated sector. These companies are looking at revolutionising the sector through more entrepreneurial and cost-effective ways of doing things. Asteroid mining is a high risk, high returns venture, something ideally suited for private investment. In the US, NASA has contracted two private space firms, Planetary Resources Asteroid Mining Company and Deep Space Industries (DSI), to prepare for, and, ultimately, undertake, missions to asteroids. This would offload major tasks and risks to private enterprise, easing pressure on NASA's already constrained budget, while allowing it to gain from the projects' achievements.

Planetary Resources, a company backed by Google's Larry Page and luminaries like film-maker and explorer James Cameron, revealed its intention to mine near-Earth asteroids for commercial gains in 2012. In July this year, the company deployed its Arkyd 3 Reflight (A3R) spacecraft from the International Space Station (ISS) for its 90-day mission during which it will validate core technologies for the mission. It aims to follow this up later this year with the Arkyd-6 for further testing of spacecraft systems as well as sensors. The company subsequently would launch its Arkyd series of space telescopes for detection and characterisation of resources – the prospecting phase of the project to help identify the most profitable targets for further exploration and eventual resource extraction. There are further plans of towing the asteroids back to the vicinity of Earth, for low cost robotic resource extraction and delivery of the commercially viable resources to Earth at a later date.

Deep Space Industries (DSI), starting 2016, plans to send tiny 'Firefly' CubeSats on reconnaissance missions to potentially mineable near-Earth asteroids. It intends to follow up with the larger Dragonfly spacecraft for collecting asteroid materials and returning them to Earth for experimentation, processing, and mineral extraction. Much later, the Harvestor tug would be developed, for towing entire asteroids back to the Earth's geo-stationary orbit and harvesting them for resources. Its microgravity foundry would then use these materials to create vital components needed to maintain machinery in space through 3D printing. Its propellant refinery will harvest the water and hydrocarbons found in asteroids and refine them into propellant and usable water. Besides development of space vehicles and other associated systems, DSI has also been contracted by NASA to develop stimulants for terrestrial testing of technologies for excavation and processing of asteroid soil and to investigate methods to manufacture propellant from asteroid materials.[9] DSI is also experimenting with harvesting solar power to support its space-based operations.

The excitement of the initial missions notwithstanding, asteroid mining is an ambitious project. Presently, the technologies and correspondingly the economics are not adequately developed to support the envisaged large scale operations. Revolutionary changes are required in launch and propulsion technologies that would also bring down launch, space transportation and other associated costs for deep space operations. Technologies in related fields such as artificial intelligence and robotics need much progression, while those for harvesting and utilising asteroid resources need to be developed. Sceptics continue to highlight the downsizing of original plans and extension of timelines of most projects as also the delays in other ongoing commercial space ventures. Others question the commercial prospects of such missions when large unexploited deposits are available on Earth itself. Paradoxically, bringing in vast amounts of rare metals might itself result in steep depreciation in their value, making such missions economically unviable.

Initiation of the commercial mining ventures has simultaneously stimulated debates on the associated legal issues. At the very outset is the issue of space property rights. The Outer Space Treaty (OST) of 1967, an agreement signed or ratified by most space-faring nations, has called space the "province of mankind", free for access by all states and for exploration.[10] At the same time, its Article II states, "Outer space, including the Moon and other celestial bodies, is not subject to national appropriation by claims of sovereignty, by means of use or occupation, or by any other means." This has led to some interpretations that while the physical space cannot be claimed by any state, the resources are open to be exploited. Samples collected from the Moon by various nations are cited as examples. Another point of contention has been the status of private entities with respect to the treaty. However, Article VI of the OST clearly states that nations would be responsible for all activities in space including those carried out by their non-governmental entities, implying that all private parties would also be governed by this treaty.

The Moon Treaty of 1979, drafted after the experience of the lunar endeavours and drawing inspiration from the United Nations Convention on the Law of the Sea, is more unambiguous on resource utilisation in space. It has labelled outer space as "common heritage of mankind" and provides for equitable sharing by all states parties in the benefits derived from those resources.[11] However, such laws are seen as an impediment to space exploration as no government or private company would invest in such capital intensive and time consuming ventures without the incentive of economic benefits. Consequently, the Moon Treaty has been ratified by 16 states only. There has been a growing clamour in the US to challenge the existing space regime in order to promote commercial space endeavours. Towards endorsing private asteroid exploration and protecting the interests of these companies, on May 21, 2015, the US House of Representatives passed the Spurring Private Aerospace Competitiveness and Entrepreneurship (SPACE) Act. It states that "any asteroid resources obtained in outer space are the property of the entity that obtained such resources, which shall be entitled to all property rights thereto, consistent with applicable provisions of federal law." The applicability of the Act has been questioned as being contradictory to the existing space regime. However, while debating the Act, the Chairman of the US House Committee on Science, Lamar Smith, reportedly said, "There is nothing in this Act that violates the law. The Outer Space Treaty is a series of guiding principles subject to legal interpretation, not a binding law."[12]

It is evident that the extant space regime would have to be revisited in response to the changed realities in space. While most nations would be loath to replacing the OST, the ambiguities related to space exploration could be cleared while following a more pragmatic approach to property rights. This would ensure more active global participation in mining of asteroids and other celestial bodies. Laws are required not just for appropriation of space resources but also to ensure that a legal vacuum does not result in lawlessness that has been associated with many previous terrestrial exploratory efforts, such as the Californian Gold Rush.[13] As private participation in space continues to grow, comprehensive international laws would have to be accompanied by the establishment of a global authority to regulate all commercial ventures into space. With the legal and bureaucratic communities across the world already finding it hard to catch up with the fast pace of technological advancement, commencement of such efforts can wait no longer.

Over half of the 28 proposals that NASA received for a $450 million robotic solar-system mission launching in 2021, seek to explore small bodies such as comets, asteroids or tiny moons.[14] However, sustenance of interest and further investments would depend on the success of the pioneering missions as well as on a favourable space regime. Governments would do well to stand firmly behind these initial programmes for they would lay the foundation for ventures that would one day allow commercial asteroid mining operations to support a bustling space exploration industry, with the associated economic vigour. It must be remembered that most audacious explorations of the past, when they started out, had also seemed highly risky and capital intensive and had long developmental timelines.

Notes

1. There is a number of classification schemes, depending on the criteria chosen. However, these major classes are generally mutually accepted by the most widely used schemes.
2. Ellie Kaufman, "The Next Great Gold Rush Won't Be Taking Place on Earth", Science.Mic, in collaboration with ULA, April 21, 2015, available at http://mic.com/articles/115786/the-next-great-gold-rush-won-t-be-taking-place-on-earth
3. For more details, see Brooks Hays, "NASA Contracts Two Firms to Work on Asteroid Mining", *United Press International*, November 24, 2014, at http://www.upi.com/Science_News/2014/11/24/NASA-contracts-two-firms-to-work-on-asteroid-mining/5301416856690/
4. Mike Wall, "The Evolution of NASA's Ambitious Asteroid-Capture Mission", available at http://www.space.com/28963-nasa-asteroid-capture-mission-history.html, March 30, 2015.
5. For more details, see "Mining the Lunar Surface", at http://www.permanent.com/mining-the-moon-for-lunar-resources.html
6. Selected in March 2015 against the other option that envisaged capturing a small asteroid in a bag and towing it to Earth's orbit.
7. David Szondy, "NASA Outlines Asteroid Redirect Mission", *Gizmag*, March 28, 2015, available at http://www.gizmag.com/nasa-asteroid-initiative/36725/
8. This uses solar panels to power ion thrusters that provide a very low, constant thrust for years on end by charging xenon atoms and accelerating them. The system is currently being used on NASA's Dawn mission to Ceres and would be employed in Mars missions.
9. Simulants are needed in order to adequately test equipment and processes prior to launch to an actual asteroid. The simulant may need to adequately reproduce the physical characteristics of an asteroid to validate sampling techniques, anchoring methods, or to test hazards such as dust production. See n. 5.
10. Article 1 of the 1967 Outer Space treaty states, "The exploration and use of outer space, including the Moon and other celestial bodies, shall be carried out for the benefit and in the interest of all countries… and shall be the province of all mankind… Outer space, including the Moon and other celestial bodies, shall be free for exploration and use by all States without discrimination of any kind… and there shall be free access to all areas of celestial bodies."

11. The Moon Treaty states: "Neither the surface nor the sub-surface of the Moon [or any other celestial bodies], nor any part thereof or natural resources in place, shall become the property of any State, international inter-governmental or non-governmental organization, national organization or non-governmental entity or of any natural person. The placement of personnel, space vehicles, equipment, facilities, stations and installations on or below the surface of the Moon [or any other celestial bodies], including structures connected with its surface or sub-surface, shall not create a right of ownership over the surface or the sub-surface of the Moon, [or any other celestial bodies] or any areas thereof".
12. Jason Koebler, "The US Mulls Breaking an International Treaty so Americans Can Mine Asteroids", *Motherboard,* May 14, 2015, available at http://motherboard.vice.com/read/the-us-mulls-breaking-an-international-treaty-so-americans-can-mine-asteroids
13. Matthew Feinman, "Mining the Final Frontier: Keeping Earth's Asteroid Mining Ventures from Becoming the Next Gold Rush", *Pittsburgh Journal of Technology Law & Policy*, Vol. 14, No. 2, Spring 2014.
14. Dan Leone, "Small Bodies Dominate NASA's Latest Discovery Competition", available at http://spacenews.com/small-bodies-dominate-nasas-latest-discovery-competition/#sthash.odYXZPe3.dpuf, July 07, 2015.