A Techno-Economic Assessment of the Asteroid Mining Development and its Ethical Ramifications

Amandin T. Chyba Rabeendran

Department of Applied Mathematics, Colorado School of Mines, Golden

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ABSTRACT

Science fiction movies such as Armageddon have seen astronauts exploring and landing on asteroids to save humanity. This type of scenario might actually be in a closer future than most of us think. A first step in that direction already undertaken by agencies such as NASA include robotics missions for asteroid mining. This paper will discuss the motivation behind what can be viewed as extravagant endeavors, discussing the gain and economical impact of these missions as well as their ethical issues. Additionally, we will explore an "Asteroid Retrieval Feasibility Study" by KISS (Keck Institute for Space Studies) which covers a conceptual plan to reduce costs of capturing and mining near-Earth Asteroids. This paper will cover their plan to bring back an asteroid possibly worth billions back to a high-lunar moon orbit by 2025. Rendezvous with asteroids including landing and return of samples is exciting and might even save us. However, is space conquest an economically viable solution to our problems and do we understand all of its consequences?

KEYWORDS
Asteroid; Mining; Space; Exploration; Natural-Resources; Universal-Expansion; Feasibility

INTRODUCTION

1. Asteroids as sources of raw materials

1.1. Why asteroids?

Asteroids are small irregular shaped bodies of rock that travel through space by orbiting the sun with a speed that will avoid orbit degradation. Due to their size and composition, they have often been referenced as planetoids or minor planets. Asteroids are left over from the formation of our solar system, and therefore their composition is often the center of attention and mainly depend on their distance to the Sun. From "volatile-rich bodies to metallic bodies with high concentrations of rare metals" [8], asteroids can contain gold, silver, platinum, iron, nickel, and water, just to name a few.

1.2. Past and future attempts at asteroid exploration

In 1991, NASA's Galileo spacecraft took the first close-up images of asteroids and in 2001, NASA's NEAR spacecraft made the first successful land on an asteroid. Nine years later Japan's Hayabusa returned asteroid samples to Earth that are currently under study. NASA's Dawn mission orbited Vesta and Ceres and revealed it is still geologically active. There are several ongoing and future missions to study asteroids for possible mining to exploit their raw material, indeed sample return is currently really at the forefront of scientific exploration. One of these ongoing missions is NASA’s OSIRIS_REx which is currently studying a near-Earth asteroid named Bennu. OSIRIS_REx launched over 8 years ago and is scheduled to reach Bennu’s orbit and collect samples without landing within 4 years where “the spacecraft’s robotic arm, the TAGSAM instrument, will actually make contact with the asteroid” [11]. NASA plans to retrieve the sample by bringing the spacecraft back to Earth. NASA also has several future missions planned that will explore asteroids in further detail. For example, Lucy is expected to launch in October 2021 and planned to “explore six Trojan asteroids, a unique family of asteroids that orbit the Sun in front of and behind Jupiter” [12]. Lucy is special since “No other space mission in history has been launched to as many different destinations in independent orbits around our sun” [12]. To accommodate such an ambitious goal, NASA plans to take advantage of the Jupiter-Sun Lagrangian points, locations in space where the combined gravitational forces of two large bodies will allow a third object to maintain an equilibrium position relative to the other two large bodies, surrounding Jupiter among others in our solar system. Lagrangian points have often been called “parking spots for spacecraft” [14] due to their nature and convenience.

2. Potential applications

2.1. The economic value of asteroids

The most obvious direct reward that would come from mining asteroids is the value of the elements that could be extracted from the asteroids. Asteroids containing platinum and gold could fetch a very hefty price on Earth due to their scarcity. For example, “one 500-meter-wide platinum-rich asteroid could contain nearly 175 times the annual global platinum output” [8] which could be used to fund more missions to asteroids. Another component that may not be as obviously valuable is water. Not only is water a common resource found on asteroids which would be “expected to become central to a space economy” [3], it could also be used as fuel through the conversion of hydrogen while its oxygen component would be used as air, possibly for longer missions. Similarly, silicon, nickel, and iron could be used directly during the mission rather than being brought back to Earth. These raw materials could be used for “space manufacturing” including space stations and “solar power systems” [8]. The opportunity to use some of the raw materials collected from mining these asteroids directly in space could play a crucial part in how viable asteroid mining might become. According to Mark Kaufman of National Geographic, “Mars exploration would be much cheaper, and more efficient, if some of the fuel could be picked up en route” [3].

Philip Metzger, an academic researcher with experience working with companies like DSI (Deep Space Industries) and Planetary Resources, explains the economic issues that would come with introducing such large quantities of rare materials back on Earth. The sudden increase in rare materials such as gold or platinum could “crash the market, reducing the valuation of the asteroid” [5]. There is also the problem of bringing materials from space back to Earth since “the most expensive and resource-intensive aspect of space travel is pushing through the Earth's atmosphere” [3]. Therefore, the main goal of mining asteroids should not be to bring back rare ores, but rather the use of them in space for other missions and projects. The demand for space infrastructure including satellites for wireless data transfer will increase past the amount that can be supplied through terrestrial methods and cheaper methods will need to be adopted. It would be much more efficient for the resulting materials of asteroid mining to “remain in space, transmitting precious data down into the digital market” [5].

2.2. How asteroids could help resolve energy and environmental concerns

Energy generation and the current environmental situation are major concerns for human sustainability and survival on Earth where asteroid mining could provide a solution. According to J. O. McSpadden in “Space solar power programs and microwave wireless power transmission technology” [10], energy transmission from space to Earth, although not documented and researched to the desired degree, could provide a much cheaper alternative than any known method derived from Earth resources. In the meantime, relocating our energy production would “unburden the planet of the environmental impacts of energy generation” [5] including wind and solar farms, nuclear power plant incidents, and CO2 emissions from fossil fuels. Philip Metzger goes so far as to say that “off-planet energy generation could eliminate one-quarter of the human industrial footprint by 2100” [5] based on estimates used in his own paper “Space development and space science together, an historic opportunity” published by Elsevier in August 2016.

2.3. Fulfilling our thirst for knowledge

On another note, one must not forget about the potential data and information that may be gathered from asteroid mining should not be underestimated. NASA reveals the potential of what could be learned by explaining the motivation behind an ongoing mission involving the exploration and close up study of an asteroid named Bennu. The agency explains that studying Bennu and its particle plumes, asteroid dust left in space throughout its travel, could hold information about “the origins of our solar system, the sources of water and organic molecules on Earth, the resources in near-Earth space, as well as improve our understanding of asteroids that could impact Earth" [7].

3. The economic and ethical dilemma

3.1. Is asteroid mining too ambitious for investors?

Although there are many advantages of asteroid mining, it still poses the question: is the world prepared for this type of technical, economical, and social leap? Due to the amount of unknowns in asteroid mining, the timeline of such a project and eventual mission would seem extremely long to investors. "Timing challenges are particularly difficult for asteroid mining, given that the timing of cash flows is largely dependent on the mission timeline" [4]. Another source of concern for investors is the lack of any solid laws governing asteroid mining and space real estate. Asteroid mining requires a lot of money as made clear in Figure 1. and "It is likely that we will require different types of insurance throughout the various phases of the venture to manage operational and market risks." [4] including pre-launch, launch, landing, and post-launch. In DSI's case, an interview with an ex-employee tells us they "were only $10 million away from hitting that point" [2] after they had already spent several tens of millions in preparation, research, and planning.

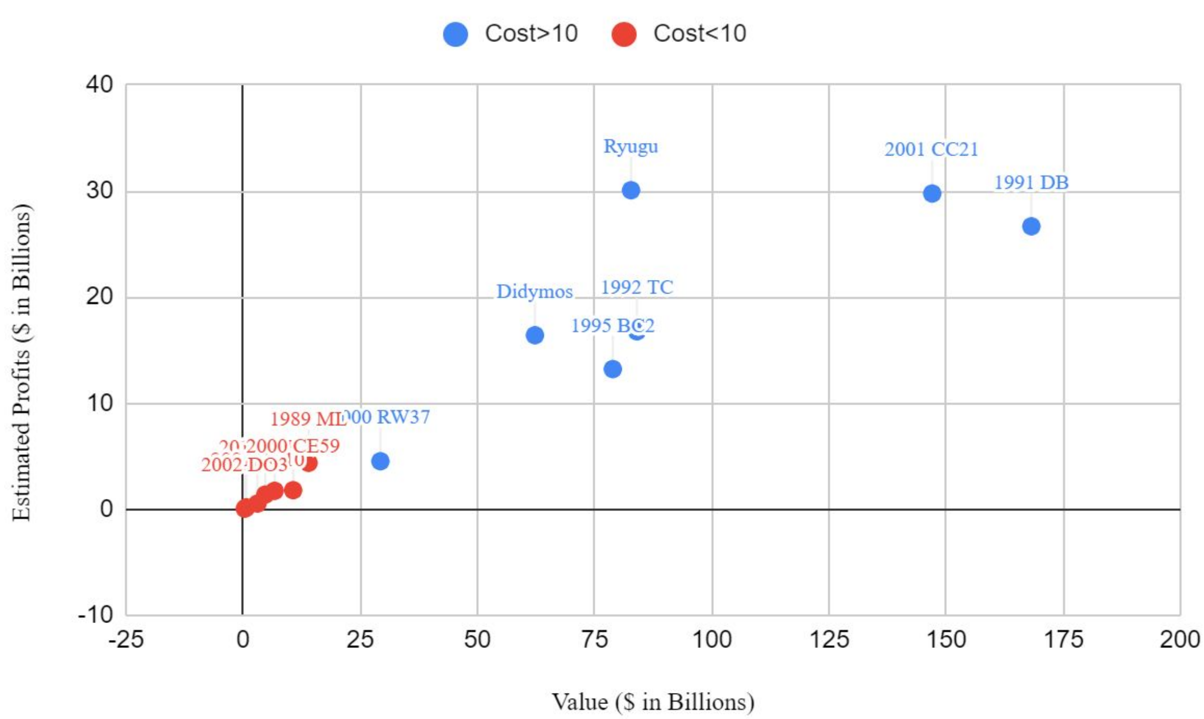

Figure 1: *Current top 15 most cost-effective asteroids.* This scatter plot was designed with the intention of displaying/highlighting the potential gain in billions of U.S. dollars of a single asteroid while tracking the realistic costs of each mission. It should be noted that for the purpose of clarity, the asteroid Anteros was removed from the data set due to its absurd values (estimated value of 5.57 trillion and profit of 1.25 trillion) as it would have been ranked 7th in terms of cost-effectiveness. (Raw data was gathered from the "Asterank database" [18])

3.2. Some ethical concerns

The ethical concerns that revolve around asteroid mining vary greatly. Due to the unknown and mystery of outer space, many of these ethical dilemmas are philosophical. Additionally, the scale of these issues and their potential permanent impact make asteroid mining a very delicate subject for debate. One of the main ethical worries surrounding asteroid mining is the risk of losing human lives. Advances in technology and robotics has allowed the world to attain a new level of autonomy that could reduce human exposure to danger in space. Robots are "much faster at processing information than humans" [4] and can be designed to complete "specific tasks" with low probability of error. However, the necessity of humans aboard space missions for non-linear decision making is an obstacle that is yet to be overcome. The mental and biological issues that threaten humans in space are "many magnitudes greater than those experienced on Earth" [4] including "galactic cosmic rays and ionizing radiation result in an increased risk of cancer, infertility, and potentially loss of years of life". The uncertainties that surround space exploration make it quite difficult to send humans on these kinds of long term missions even with consent. Perhaps the consent of the astronaut is not enough to send him into outer space with all the known and unknown dangers that may befall him or her. It is also not too difficult to think of a situation where keeping information from the astronaut may increase his or her chances of success.

A more aggressive yet not impossible hypothesis is the idea of alien contact through the exploration of asteroids. There is a scientific hypothesis named Panspermia that explains the distribution of life in space and its movement. It identifies asteroids, meteors, and many other space objects as possible "transfer vehicles for life through space" [17]. As suggested by ASTRA (ASteroid mining, Technologies RoadMap, and Applications) [4], the same process of life migration could happen in reverse, also known as "backward contamination" [4]. By making contact with an asteroid and bringing components of it back to Earth, we could allow the infestation of new microorganisms on our planet.

There is also the ever-so hypocritical problem solving process of mining a new region, space, due to the current lack of natural resources on Earth. By mining asteroids and space materials the same way as we do on Earth, we may be depleting the amount available to "future generations and to nations that are currently less developed" [16]. However, from a logical point of view, it is "very improbable" [16] that we will ever use up all the resources that space has to offer, especially considering that there are some 9,000 near-Earth Asteroids [3]. Nonetheless, there are philosophical questions about our place as living beings in the universe and our right to impact the space outside of Earth's boundaries. Humans have adopted many environmentally negative habits such as fracking and the overuse of fossil fuels as we thirst for more comfortable lives, but "the disruption of a global common is not the right of any one individual or State" [16]. Ignoring this warning could result in permanent damage on not just the global scale, but to the universe and all that exists within.

3.3. The meaning and force of change of these consequences

As presented in Figure 2., the concerns highlighted above will have many impacts in different areas, some of which are more obvious (medical and environmental) than others (social). A major variable that should be taken into account when we talk about space exploration is society's willingness to send humans/robots out to space. The hefty cost of asteroid mining can only be achieved through the motivation of the public and the individuals that have the opportunity to fund these types of missions. Successful human directed asteroid missions could result in "valuable benefits in the areas of cultural inspiration and increased mission performance" [4]. The same mentality can be applied to unsuccessful asteroid mining missions, where the already hard to reach cost of asteroid mining would become impossible to reach as the public fails to see it as a viable solution. There are several health concerns that must be addressed as well, including microgravity posing "physiological challenges to cardiovascular, musculoskeletal, endocrine, immunological and neuro-cognitive systems" [4] and different types of radiation such as "cosmic rays (GCRs), ionizing radiation, and solar particle events (SPEs)" [4] which could severely impact the medical condition of astronauts. We have already seen the negative effects of certain mining methods, such as fracking, on Earth and we can only assume that there are side effects of mining in space that which we are "currently not cognizant" [16] of.

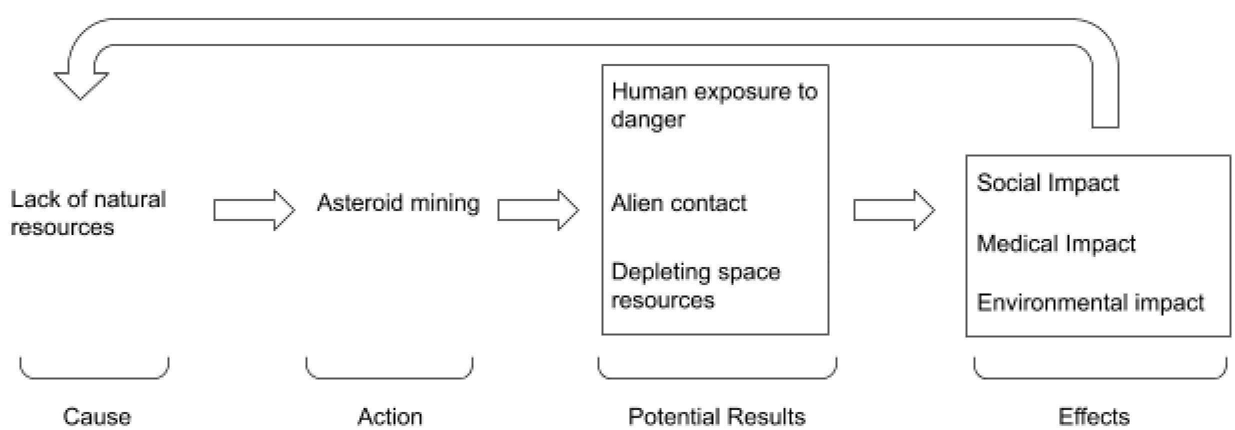

Figure 2: *The ethical cause-effect cycle of space natural resources extraction.* This hypothetical timeline highlights some potential courses of action asteroid mining might take and the long/short term effects it

could have on Earth and on Humans. The impact of some of the ethical concerns listed under "Potential Results" could have far-reaching consequences including motivation for future space exploration and permanent damage to local/universal ecosystems. These results could lead to an even more desperate environmental situation on Earth which might force us to search for external solutions once again restarting the cycle.

SOLUTION

4. The Asteroid Capture-and-Return mission

4.1. The plan

The asteroid capture-and-return mission that we will examine as a possible solution to the high-cost and unreliability of space exploration/asteroid mining was sponsored by KISS (Keck Institute for Space Studies). Their plan includes either the full retrieval of a 500,000 kg asteroid ("Get a Whole One approach" [19]) or partial retrieval ("Pick Up a Rock approach" [19]) in case the target asteroid size is larger than can possibly be extracted. In their executive summary, they state that it would be feasible to retrieve an asteroid "roughly 7 m in diameter" by 2025 and bring it to a Lagrange point near the Moon. It should be assumed that the asteroid would be a near-Earth asteroid to fit the timeline they have produced.

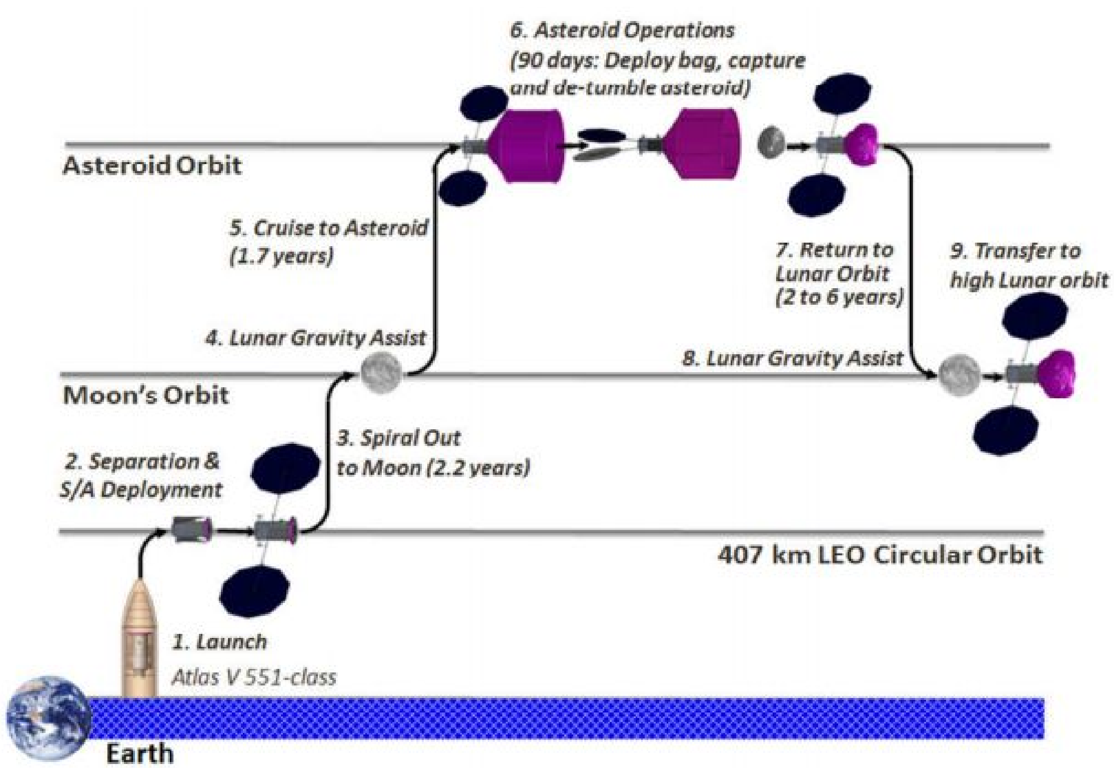

Figure 3: *Asteroid capture-and-return mission concept/timeline.* The diagram above shows the step-by-step process that Keck Institute for Space Studies has designed in hopes of capturing an asteroid whole for mining and examination. The following timeline begins with the spacecraft on Earth and ends with the Spacecraft on a high Lunar orbit/Lagrange point revolving around the moon. This specific mission concept is planned to take around 7-11 years. (The image comes from the Keck Institute for Space Studies report "Asteroid Retrieval Feasibility Study", 2012 [19])

4.2. Exploiting solar array systems and solar electric propulsion systems

KISS explains that the feasibility of capturing and mining an asteroid depends on 3 key factors, one of which we will explore in economic and technical detail. The first key component is the ability to locate and classify an asteroid as a "sufficiently small near-Earth asteroids for capture and return" [19]. The second is the capability to engineer and integrate "powerful solar electric propulsion systems" [19]. Thirdly, we must have humans in space in preparation of the spacecraft's return with the asteroid for immediate study. Since this paper was written with the purpose of illustrating direct plans to mine asteroids and their effective costs, we will be exploring KISS's plan to reduce the cost of this asteroid retrieval mission using solar array and propulsion systems.

Although KISS highlights the possibility of capturing and studying an asteroid within a few years, they are not hesitant to address the issue that current technology may not be enough. As part of their plan to reduce costs, they feature the necessity of further research in solar electric propulsion (SEP) technology. According to KISS, SEP is the most efficient and "most cost-effective technology" [19] for exiting Earth's atmosphere. Unfortunately, the "end of life power level" of current SEP systems are too low for their plan to reach a near-Earth asteroid under certain costs. In addition to the SEP systems, KISS reveals the importance of solar array systems. In their design they scheme of using "rigid-panel arrays" [19] with specific beginning-of-life power levels which are currently available commercially. These solar arrays would generate the amount of power needed for the solar electric propulsion systems to work. With their current plan, they estimate a cost of around 2.647 billion U.S. dollars [19]. This may seem like an inhumane amount, but their cost estimation includes NASA insight/oversight and other preparation fees which would also make future missions cheaper. Note that the possible value of a fully captured asteroid could be worth magnitudes more than the initial cost.

According to KISS's plan, capturing an asteroid is economically possible. However, this plan/solution does not address many of the ethical, social, and sustainability problems that were mentioned in the introduction. This plan is one of the most revised plans to be released to the public on asteroid rendezvous thus far and yet it fails to be concrete enough for testing or further investigation.

CONCLUSION

Although numerous near-Earth asteroids are valued at over 1 billion U.S. dollars, the process of bringing it back into Earth's atmosphere for study and resources could bring many more negative side effects than advantages including crashing the economic market due to over-supply of a certain rare material. Therefore, the best course of action would be to capture and preserve an asteroid in the Lagrange points that cluster our solar system for space manufacturing and supply stations for future space missions. However, there are many philosophical questions that have yet to be explored including our right to interfere with the space ecosystem and although low risk, still relevant possibility of permanent damage to space resources. KISS plan to bring a full asteroid and "park" it in a high lunar moon orbit using some of the most cutting edge technology including solar array systems for energy generation and solar electric propulsion system to efficiently exit Earth's atmosphere which could end up greatly saving on the hefty initial cost that asteroid mining brings to the table.

Asteroid mining isn't quite here yet but as KISS and some simple models have shown us, with continuous research in spacecrafts, we may reach a point in the near future where the resulting profits heavily outweigh the initial costs. By relating the possible results that a cheaper/quicker asteroid mining mission might have on the social, economic, and environmental situation of Earth and humans we can assume that the most important mission will be the first one due to the impression it will leave on the general public and investors. We should also expect development in the medical and environmental areas including radiation and possible alien contact if an asteroid exploration project such as KISS's theoretical mission were to succeed and lead to more projects. Perhaps expanding our reach past our planet is a necessary process that will lead to new discoveries, but the vast quantity of unknowns suggests a dangerous future full of social, economic, technical, ethical, and environmental issues.

NOTES ON REFERENCES

Not all of the references were directly referenced in this paper, but all of them were used as sources of inspiration, data, or background knowledge.

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