7

Asteroid Impact and Deflection Assessment Mission (AIDA): Space Mining Concepts

Tom James

Introduction

Originated by NASA, the Asteroid Impact and Deflection Assessment (AIDA) mission concept has been tabled by an international collaboration between the US space agency, the ESA, Observatoire de la Cote d'Azur (OCA) and the John Hopkins University Applied Physics Laboratory (JHU/APL).[1]

It represents a world first and consists of a guided missile, which is aimed at a chosen asteroid with the agenda of quantifying and demonstrating the kinetic effects of an 'impactor' space vehicle into an asteroid moon, and to measure any resultant change in the regolith's trajectory. It is intended to assess whether or not such a mission might successfully deflect an asteroid away from, or onto, a direct course towards Earth.

This sounds like an alarming concept, however, the theory behind a premeditated effort to put an asteroid on a collision course with the Earth would be to bring it closer for mining operations, reducing technological necessities and the fiscal investment needed to mine NEAs that aren't that near Earth. Conversely it could be implemented to remove a potential hazardous space rock.

Any AIDA mission would likely be composed of two spacecrafts:

[1] NASA Planetary Defense, Edited by Tricia Talbert, Last updated 14 September 2017, "Asteroid Impact and Deflection Assessment (AIDA) Mission", https://www.nasa.gov/planetarydefense/aida

T. James (✉)
NR Capital & Deep Space Technologies, Singapore, Singapore

T. James (ed.), *Deep Space Commodities*,
https://doi.org/10.1007/978-3-319-90303-3_7

- Asteroid Impact Mission, or 'AIM', which would orbit the asteroid.
- Double Action Redirection Test, or 'DART', which might impact its moon.

Besides the observation of the change to a chosen asteroid's orbital parameters, the observation of the plume, the crater and the freshly exposed material is expected to give decipherable and distinctive data for future asteroid deflections to the astrophysical, scientific and mining communities.

AIDA is, at its core, a science-driven test of developing Earth technologies for preventing the impact of hazardous asteroids. However, for mining purposes, controlling asteroids for easier resource mining is advantageous. AIDA's primary mission is to deflect the near-Earth binary asteroid 65,803 Didymos, which will be in unusually close proximity to Earth, relatively speaking, in October 2022.

The 300-kilogram DART space vehicle is designed to affect the Didymos at 7 kilometres per second and exhibit the ability to transform its course through momentum transfer, NASA states.

AIDA will be the primary demonstration of the kinetic impact technique to alter the motion of an asteroid in space. AIDA is a dual-mission conception, involving two freelance space vehicles: NASA's DART and ESA's AIM. The DART mission is in 'Formulation phase A', led by JHU/APL and managed by the Planetary Missions Program workplace at Marshall Space Flight Center for NASA's Planetary Defense Coordination workplace. AIM, managed by ESA's European Space Research and Technology Centre (ESTEC), is in 'Preliminary Definition phase B1'.

As of 2016, the missions were in formative planning stages, with a projected launch for AIM in October 2020, and for DART in July 2021. DART would commence operations to alter Didymos' trajectory around October 2022. As of December 2016, the AIM space vehicle component of AIDA had yet to be funded. Regardless, NASA plans to continue with its part of the programme.

Didymos consists of a primary body around 800 metres across and a secondary body, or 'moonlet', whose 150-metre size is typical of the dimensions of asteroids that would create a hazard to Earth.

The resultant effects of any kinetic impactor to an asteroid are poorly understood at present as to date only a few studies have been dedicated to the process. However, it is of great significance because:

1. It contributes to the understanding of the working environment for improved risk management of space rocks.

2. It provides crucial information for the ground-based observation of the impact outcome, which is planned for AIDA.
3. It contributes to the theoretical understanding of small binary formation mechanisms with a wealth of empirical data.
4. It can be used to estimate the momentum transferred to the impacted body.

Designing an Asteroid Mission

Didymos is a 'binary asteroid system' where one asteroid, in this case Didymos, is orbited by a smaller one. The first asteroid is approximated to be 800 metres (2,600 feet) in diameter; its tiny satellite is measured at 150 metres (490 feet) in diameter in an orbit of 1.1 kilometres from the primary asteroid. Didymos isn't an Earth-crossing asteroid, and there's no chance from preliminary calculations that the proposed deflection experiment would produce resultant danger to our Blue Planet. The assessment continues.

As already mentioned, under the current tabled proposal, AIM would launch in October 2020, and DART in July 2021. AIM would orbit the larger asteroid and study the composition of it and its moon. DART would then impact the laze in October 2022. AIM would study the result on the asteroid moon's orbit round the larger asteroid.

AIDA can give information on the asteroid's strength, surface physical properties and its internal structure. There's likely to be a wealth of information gleaned from the ensuing impact crater created by DART.

DART + AIM = A

Although DART and AIM are independent missions, together they will provide the first measurements of a planetary-scale impact experiment with controlled impact conditions on a well-researched and quantified target body.

DART

- NASA's DART mission[2] is currently a Phase A study. DART is a strategic technology demonstration that will launch in 2020 and impact the second-

[2] NASA, Edited by Tricia Talbert, Last updated 30 August 2017, "Double Asteroid Redirection Test (DART) Mission", https://www.nasa.gov/planetarydefense/dart/

ary rock of the Didymos binary system in 2022. DART will be a full-scale demonstration of asteroid deflection by kinetic impact.
- DART will develop our understanding of the impact effects at large scales, provide information of a given asteroid's properties and study long-term dynamics of impact ejecta.
- DART will use ground-based observations to measure the binary period change from kinetic impact with an accuracy of 10 percent.
- DART will return high-resolution images of the target prior to impact to determine the impact site and its geologic context.

AIDA: Critical Test of Asteroid Mitigation by Kinetic Impact

- The asteroid threat is simulated to be international, of global proportions. Initially following the discovery of a hazardous asteroid, its impact location is uncertain, spanning borders and continents. Eventually the predicted impact is to be pinpointed to a specific geographical and political point, but even then, its effects will likely be global. Prevention, preparation and recovery must be coordinated internationally to benefit from worldwide resources and expertise.
- Techniques for deflecting a hazardous asteroid require demonstration and validation prior to implementation against a real threat. Kinetic deflection facilitated by launching a rocket at an asteroid to move it off course has been identified as the most capable method of deflecting most asteroids, except for rare objects that may appear suddenly or are of an extremely large size.
- Sophisticated models exist for simulating kinetic deflection, but the predicted amount of deflection depends on physical properties that have never been measured on any asteroid, which is what the AIDA project is designed to measure.
- The scale of a kinetic deflection event is much larger than can be accessed in laboratory experiments, and occurs in a microgravity geology, so Earth-based experiments are helpful but insufficient.
- Until kinetic deflection models are benchmarked via data from actual asteroid/s, their predictions will have unknown uncertainties and the possibility of unexpected behaviour will persist.
- AIDA will characterize the physical properties and internal structure of the target asteroid prior to the kinetic impact, providing solid science for making quantitative predictions of deflection.

- AIDA will provide an end-to-end test of the integrated technology required to carry out an asteroid deflection mission.

DART Impact During Excellent Apparition

- Didymos at V~14–15 is very well placed for Chile and observable from other observatories.
- Didymos primary and secondary are separated by up to 0.02 arcseconds when 0.08 AU from Earth. Marginally resolvable with ALMA (sub-mm), Magellan adaptive optics.
- Post-impact brightening and ejecta stream as extended object (coma) may be observable from Earth.
- Debris cloud analogous to YORP-driven main belt comets (MBCs)?

A list of the investigation working groups is given in Table 7.1

Current Status

Together AIM and DART were given a green light for Phase A/B1 study in February of 2015 for a period of 15 months.

Baseline payloads for AIM include a navigation camera, a lander (based on DLR MASCOT heritage), a thermal infrared imager, a monostatic high frequency radar, a bistatic low frequency radar (on the orbiter and on the lander), and some opportunity payloads based on CubeSat standards. AIM is conceived as a small and simple platform with no mechanisms providing a flight opportunity to demonstrate technologies to advance future small and medium missions.

As such, AIM will also demonstrate for the first time the use of deep-space optical communication. It will allow for the first time accessing direct infor-

Table 7.1 AIDA investigation working groups

WG 1	Modelling and Simulation of Impact Outcomes	Angela Stickle, Paul Miller, Steven Schwartz
WG 2	Remote Sensing Observations	Andy Rivkin, Petr Pravec
WG 3	Dynamical and Physical Properties of Didymos	Derek Richardson, Kleomenis Tsiganis, Adriano Campo-Bagatin
WG 4	Science Proximity Operations	Stephan Ulamec, Olivier Barnouin

mation on the internal and subsurface structures of a small asteroid, and with DART, determining the influence of those internal properties on the impact outcome. The DART mission will use a single spacecraft to impact the smaller member of the binary near-Earth asteroid (NEA) Didymos in October 2022. DART uses a simple, high-technology-readiness and low-cost spacecraft to intercept Didymos. DART carries no scientific payload other than an imager for targeting and data acquisition. The impact of the >300-kilogram DART spacecraft at 6.1 kilometres per second will change the mutual orbit of these two objects. By targeting the smaller, 150-metre diameter member of a binary system, the DART mission produces an orbital deflection which is both larger and easier to measure than would be the case if DART targeted a typical, single NEA so as to change its heliocentric orbit. It is important to note that the target Didymos is not an Earth-crossing asteroid, and there is no possibility that the DART deflection experiment would create an impact hazard.

The DART asteroid deflection demonstration targets the binary asteroid Didymos in October 2022, during a close approach to Earth. The DART impact will be observable by ground-based radar and optical telescopes around the world, providing exciting opportunities for international participation in the mission, and generating tremendous international public interest, in the first asteroid deflection experiment.

Germany offered to cover 35 million of the 60 million required for the AIM portion to continue, but this wasn't enough to continue development. However, National Aeronautics and Space Administration will still continue with an alternative portion of the mission, DART, thus overall AIDA will continue in a way. The director has aforesaid that he may also be able to revive the AIM portion of the mission in future before the timeline for meeting the launch window passes. It's technically potential for the DART mission to continue, however, it's going to need a lot of support from the bottom, and therefore the AIDA programme overall would be empty information that AIM would supply.

The DART space vehicle can succeed the kinetic impact by deliberately colliding with the moonlet at roughly 6 kilometres per second, with the help of an aboard camera and an advanced autonomous navigation software package. The speed of the moonlet in its orbit around the main body will be altered by a fraction of 1 percent—large enough to be measured by exploitation telescopes on Earth. By targeting the little moonlet in an exceedingly binary numeration system, the AIDA mission set up makes these exact measurements achievable and makes sure that there's no probability of the impact unknowingly producing a hazard to Earth.

The DART space vehicle can utilize the National Aeronautics and Space Administration evolutionary Xenon Thruster–industrial and commercial

(NEXT-C) solar electrical propulsion system as its main in-space propulsion system. NEXT-C—developed at NASA's Glenn centre in Cleveland, Ohio—is the next generation system that has supported the Dawn space vehicle system. The use of electrical propulsion means that DART is ready to realize important flexibility to the mission timeline and expand their launch window.

The AIM space vehicle, with its in-depth collection of scientific instruments, should reach Didymos before DART's impact. It will then perform the first close-up study of a binary asteroid, supplying high-resolution images of the surfaces of the positional notation in addition to measurements of the densities, masses and shapes of its two bodies. AIM will be able to move to a secure distance from which to watch DART's impact and examine ejected material within the ensuing plume. AIM's instruments can observe the consequences of the collision and create precise conclusions of the momentum transferred to the moonlet.

AIM can investigate potential mass transfer between the two bodies, live crater formation and material distribution after the impact, and it can constrain the inner structure and make-up of this interesting binary asteroid. A surface package, MASCOT-2 (Mobile Asteroid Surface Scout), will be deployed by AIM to characterize the moonlet before, during and after the DART impact. AIM will be the primary space vehicle to demonstrate heavenly body visual communications.

This distinctive double mission situation incorporates the launch of ESA's AIM artificial satellite in October 2020. A meeting with the Didymos system will follow in 2022. The launch of NASA's DART artificial satellite will be in late 2020 and it will intercept Didymos' moonlet in early October 2022, when the Didymos system is less than 11 million kilometres from Earth. This will make facultative observations by ground-based telescopes and planetary radio detection and ranging possible.

Key benefits if AIDA data

AIDA can return fundamental new information on the mechanical response and impact cratering method at real asteroid scales, and consequently on the collisional evolution of asteroids with implications for planetary defence, human space travel and near-Earth object science and resource utilization. AIDA is able to return distinctive data on an asteroid's strength, surface physical properties and internal structure. Supporting numerical simulation studies and laboratory experiments are going to be required to understand the potential benefits of AIDA and these can be an integral a part of the mission.

Mining Concepts: Deflected or Not

Asteroid mining will shift from being relegated to the realms of enthusiastic sci-fi dreams to world-changing reality a lot quicker than one might think, as key participants in the push to mine all those regoliths, orbiting tantalizingly close to our technological capability, forge ahead with exploratory missions and flex their space muscles.

Whether we choose to deflect these space rocks a little closer for comfort or not, one company at the forefront of researching these asteroids is Planetary Resources. The company has deployed its first space vehicle from the International Space Station (ISS), the beginning of this Washington-based asteroid-mining concern's plans to launch a series of increasingly capable probes over the coming years.

Its goal is to find a rock containing sufficient water content to convert into a rocket propellant within a decade and eventually to reap valuable and helpful platinum-group metals from NEAs.

"We have every expectation that delivering water from asteroids and making an in-space fueling economy are a few things that we'll see within the next ten years … even within the half of the 2020s," Chris Lewicki, Planetary Resources President and Chief Engineer, claims.[3]

Talking about the timeline for going after asteroid metals, Lewicki commented: "After that, I believe it's progressing to be how the market develops".[4]

"If there is one factor that we have seen repeat throughout history, it's [that] you tend to over predict what'll happen within the next year, however you tend to immensely under predict what's going to happen within the next ten years", he added.[5]

Degrading and Exploiting the Resources of Space

Planetary Resources and Deep Space Industries (DSI) both aim to assist humanity in extending its stellar footprint out into the solar system by tapping asteroid resources.

[3] Space.Com, by Mike Wall, 11 August 2015, "Asteroid Mining May Be a Reality by 2025", https://www.space.com/30213-asteroid-mining-planetary-resources-2025.html

[4] Space.Com, by Mike Wall, 11 August 2015, "Asteroid Mining May Be a Reality by 2025", https://www.space.com/30213-asteroid-mining-planetary-resources-2025.html

[5] Space.Com, by Mike Wall, 11 August 2015, "Asteroid Mining May Be a Reality by 2025", https://www.space.com/30213-asteroid-mining-planetary-resources-2025.html

This whole concept relies upon harvesting water, which is in plentiful supply in a category of rock called carbonaceous chondrites. Asteroid-derived water may do much more than merely quench an astronaut's thirst, mining advocates say. It can be used to shield them from dangerous radiation and, once split into its constituent chemical element and oxygen, enable voyaging spaceships to replenish their fuel tanks whilst in transit.

The technology to locate and extract asteroid water isn't significantly difficult or overtly expensive to implement, so Planetary Resources has found out. Its exploratory scientific space vehicles have discovered this most precious liquid on celestial bodies—and obtaining this fluid from an asteroid may merely involve partitioning the strata of an asteroid containing water and exposing it to the heat of the Sun for collection.

Carbonaceous chondrites also usually contain metals such as iron, which is traditionally used in construction, so targeting these asteroids may permit miners to begin building off-Earth structures. That's the logical next step in the chain of opportunities derived from exploiting water.

The gold at the tip of the rainbow will be the extraction and exploitation of platinum-group metals that are rare here on Earth but extremely necessary to the manufacturing of differing sophisticated products.

Ultimately, what Planetary Resources wishes to try to do is produce a space-based business that is an economic engine that will actually reveal space to the remainder of the economy.

So far, every frontier that we've unfolded on our planet Earth has either been within the pursuit of resources, or we've been ready to keep in this frontier as a result of the native resources that were offered to us.

Why should space be any different?

Asteroid Mining Probes

As yet nobody is mining asteroids, however, companies like Planetary Resources and DSI do have some hardware in space. Planetary Resources Arkyd-3R CubeSat completed a 90-day mission to check astronautics, software and alternative key technology following its launch on 16 July 2015 from the ISS.

Planetary Resources is currently working on its next space vehicle, which may be a 6 U CubeSat known as Arkyd-6. One "U", or "unit", is the basic CubeSat building block, as was previously noted, a cube measuring 4 inches, or 10 centimetres, on its sides.

The Arkyd-6, was successfully launched into orbit from SpaceX's Falcon 9 rocket on 18 January 2018. It featured advanced astronautics and electronics, also acting as a colloquially-termed 'selfie cam' that was funded by a so-called Kickstarter Project years back. The CubeSat carried associated instruments designed to find water and water-bearing minerals for Planetary Resources.[6]

The data obtained from the Arkyd-6 will be valuable in the development of the Arkyd-301, the company's next spacecraft—marking the beginning of Planetary Resources' space resource exploration programme according to information provided by Brian L. Wang, MBA, a long-time futurist and lecturer at the Singularity University (and an author for internet portal Nextbigfuture.com).

In the process of engineering the Arkyd-6, the Planetary Resources' team was able to modify commercial hardware to be used in space, allowing for the possibility of deep-space missions at greatly reduced costs. This process also allows for control at every stage of development and production, resulting in a reliable and innovative product.

"The success of the Arykd-6 will validate and inform the design and engineering philosophies we have embraced since the beginning of this innovative project", said Lewicki.[7] "We will continue to employ these methods through the development of the Arkyd-301 and beyond as we progress toward our Space Resource Exploration Mission."

Out of 17 elements that will be tested during Arkyd-6's flight, one of the most crucial technologies is the on-board mid-wave infrared (MWIR) imager. The technical team qualified a commercial sensor to collect pixel-level data and integrated custom optics, creating the world's first commercial MWIR instrument to be used in space. Based on the findings from this initial flight, Planetary Resources will further develop this sensor technology into the most advanced water resource detection hardware available, which will be incorporated into Arkyd-301.

Chris Voorhees, Chief Engineer at Planetary Resources, said, "If all of the experimental systems operate successfully, Planetary Resources intends to use the Arkyd-6 satellite to capture MWIR images of targets on Earth's surface, including agricultural land, resource exploration regions, and infrastructure for mining and energy. In addition, we will also have the opportunity to perform specific celestial observations from our vantage point in low Earth orbit.

[6] Next Big Future, By Brian Wang, 12 January 2018, "Planetary Resources Arkyd-6 launched and deployed successfully", https://www.nextbigfuture.com/2018/01/planetary-resources-arkyd-6-launched-and-deployed-successfully.html

[7] Planetary Resources company site article 12th January 2018. https://www.planetaryresources.com/2018/01/planetary-resources-launches-latest-spacecraft-in-advance-of-space-resource-exploration-mission/

Lessons learned from Arkyd-6 will inform the company's approach as it builds on this technology to enable the scientific and economic evaluation of asteroids during its future Space Resource Exploration Mission."[8]

Arkyd-6 will be testing additional technologies such as power generation, attitude determination, instrument operation and two-way communication. Although the spacecraft is fully autonomous and able to execute all functions independently, it will continue to communicate with Mission Control through every critical check point.

Also in the mining mix, for its part, DSI is also building a space vehicle and aims to launch its initial resource-harvesting mission before 2020, company representatives have said.

The Competition to Mine Asteroids

It's still barely the beginning of the twenty-first century and already the personal space business is starting to take shape. Elon Musk's SpaceX has launched the world's first in private developed spacecraft, the Dragon, to dock with the ISS. Meanwhile, different private firms are developing space vehicles, and even toying with plans to send individuals to Mars. Several of those ideas are still barely past their origination, however, they are being taken seriously by the likes of NASA and Musk.

The two asteroid mining firms featured in this chapter, DSI and Planetary Resources, have an identical primary objective, however, their strategies are somewhat different. Planetary Resources is presently developing small, low-cost telescopes to survey asteroids from Earth orbit. They later plan to develop two larger styles of prospecting craft.

The aggressively named Interceptor can act as a prospector, with the ability to intercept any asteroids that come inside 10–30 times the Earth-moon orbit, a phenomenon which occurs quite frequently. Interceptor missions will allow Planetary Resources to quickly acquire data on several so-called NEAs.

Ultimately, the 'rendezvous prospector' spacecraft would be able to travel halfway across the inner system to assemble elaborate information regarding asteroids, in addition to cataloguing their size, shape, rotation and density. The company plans to develop craft to gather samples from and eventually mine whole asteroids, however, these plans have yet to reach the public arena.

[8] Planetary Resources website, Press release 12 January 2018, "Planetary Resources Launches Latest Spacecraft In Advance Of Space Resource Exploration Mission", https://www.planetaryresources.com/2018/01/planetary-resources-launches-latest-spacecraft-in-advance-of-space-resource-exploration-mission/

Conversely DSI is taking a more forthright approach. As already reported, it currently has two planned space vehicles. The first is the Firefly, which will prospect for appropriate asteroids to mine. Then its larger Dragonfly spacecraft comes in to play, designed to mine materials from the target asteroid.

The operations of private corporations such as SpaceX are funded by significant investment from NASA, unlike the billionaire backer behind Planetary Resources. It's notable, though, that several of the goals of the asteroid-mining corporations also are in line with NASA's existing science and exploration objectives. Rock samples taken from asteroids may prove very helpful in scientific research.

Where Might This All Lead?

Asteroid mining is already seen as becoming a necessity for the future of humankind, fuelled by advancing technologies that continue to facilitate the increasing consumption of Earth's resources. Asteroids are plentiful and jam-packed with usable metals and alternative resources, which means that any asteroid-mining venture stands to become terribly rich.

Couple this with the fact that proposed orbital fuel depots and off-planet construction facilities may considerably scale back the inherent problem of costs associated with space exploration, making things that bit easier. The net result could be that gathering resources from asteroids might not solely boost the economy here on Earth but become a key driver for the exploration of the solar system.

Reduced prices, the orbital production and accessibility of materials in space will likely facilitate the establishment of distant parts of the solar system and by the close of this century pundits suggest the space industry could see outposts, not that different in principle to the ISS, in remoter parts of the solar system.

The end of this century might even see an 'asteroid rush' not dissimilar to the gold rushes of the nineteenth century in the Klondike, where an estimated 100,000 prospectors flocked to the region of the Yukon in north-western Canada between 1896 and 1899.

Yet the hard truth is that, whereas it has overwhelming potential, asteroid mining is fraught with difficulties and obstacles. To date, only one space probe has ever successfully retrieved and returned a sample of asteroid material; others have tried unsuccessfully. Much of the technology required by DSI and Planetary Resources does not exist, but there is an inevitability to it. Development continues regardless.

Add on Materials

Earth's resources are becoming more and more scarce. For example, the push for oil, gas and valuable minerals happening within the Arctic is the result of an amalgamation of world shortages, inflation and technical advances. Most commentators expect the Arctic to play a key role in meeting the world's energy needs throughout the twenty-first century.

The United States Geological Survey estimates that the Arctic holds 30 percent of the world's undiscovered gas and that 80 percent of that lies underneath the glaciers and waves offshore. On land, the areas exploited for minerals or hydrocarbons are likely to remain comparatively small.

So, it's high time to look off of our planet for essential resources, even deflecting the bounty towards us. There are still decades until the development of asteroid mining reaches a feasible and economically viable stage. Our scientific and technological developments will eventually see humankind expand, breaching the limits of our native star system.

Other Useful Information Resources

http://www.esa.int/Our_Activities/Space_Engineering_Technology/Asteroid_Impact_Mission/Asteroid_Impact_Deflection_Assessment_mission

https://hal-insu.archives-ouvertes.fr/insu-01282898

http://www.space.com/30213-asteroid-mining-planetary-resources-2025.html

https://www.seeker.com/asteroid-mining-booming-21st-century-gold-rush-1766444290.html

https://www.quora.com/Is-there-anything-of-worth-on-the-planets-in-our-solar-system-like-gold-or-something-like-helium-3

http://www.planet-science.com/categories/over-11s/space/2012/04/mining-in-space.aspx

https://astronaut.com/developing-an-off-planet-mining-industry/