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In-Situ Resource Utilization Experiment for the Asteroid Redirect Crewed Mission

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Abstract

The Asteroid Redirect Crewed Mission (ARCM) represents a unique opportunity to perform in-situ testing of concepts that could lead to full-scale exploitation of asteroids for their valuable resources [1]. This paper describes a concept for an astronaut-operated "suitcase" experiment to would demonstrate asteroid volatile extraction using a solar-heated oven and integral cold trap in a configuration scalable to full-size asteroids. Conversion of liberated water into H_2 and O_2 products would also be demonstrated through an integral processing and storage unit. The plan also includes development of a local prospecting system consisting of a suit-mounted multi-spectral imager to aid the crew in choosing optimal samples, both for In-Situ Resource Utilization (ISRU) and for potential return to Earth.

1. Introduction

Use of asteroid-based resources represents a truly "game-changing" strategy for the extension of human presence into space. The costs to launch resources from Earth to low-Earth-orbit (~$10,000/kg) and to loft them out of Earth's gravity well (~$30,000/kg) are high and likely to remain so considering that there have been no revolutionary advances in space launch capability in the past generation. High launch costs result in prohibitively high costs for advanced exploration missions that must carry all of their consumable resources (e.g., fuel and life support) from the Earth's surface. The Asteroid Redirect Robotic Vehicle (ARRV) is designed to retrieve as much as 1000 tons of volatile-rich asteroid into an accessible high orbit in the Earth–Moon system [1]. If 250 tons of volatiles could be extracted from such an object, and if ARRV-like vehicles could be refueled in orbit with 10 tons of propellant to perform each retrieval, then the cost of the resulting volatiles in high orbit would be $400 per kilogram – almost 2 orders of magnitude less costly than current practice. Such an advance would remove or reduce the cost of volatile transport as a significant barrier to human exploration of the Solar System.

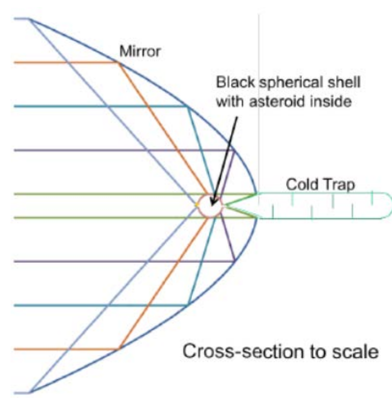

Figure 1: Mirror concentrates sunlight uniformly over sealed black sphere containing a sample (for the 1:75 subscale experiment) or an entire 10 m volatile-rich asteroid (for full-scale ISRU). The black sphere heats up to ~1100 K and "cooks" volatiles (mostly water) out of the asteroid. Hot volatile gases pass through a hole in the black sphere into a long coldtrap in the shadow of mirror that radiates into space to condense volatiles. Baffles in the cold-trap create graded-temperature zones for separation of volatile species.

Water is of primary interest as an in-situ resource. Typically ~10% of the mass of C-type carbonaceous asteroids is believed to be water in the form of hydrated minerals. Water can be used to produce hydrogen and oxygen required for chemical rockets. Hydrogen can also be used as propellant in nuclear-thermal or solar-thermal rockets. Both water and hydrogen also make excellent radiation shielding, and water and oxygen are essential for life support.

In 2013 and 2014, we built an experimental apparatus to heat samples in vacuum and to condense the volatiles in a cold trap and successfully tested the apparatus in the laboratory using a sample from the Murchison volatile-rich meteorite. For ARCM [2], a sub-scale (1:75) version of the full-scale apparatus depicted in Figure 1 would be deployed and operated by astronauts along with a resource processing and storage unit and an EVA-suit-mounted prospecting instrument.

2. Approach

2.1 Prospecting

Terrestrial field geologists (including those prospecting for resources) do not carry their laboratories into the field with them. Instead they select, acquire, and transport samples from the field to their laboratories for detailed analysis, and ARCM follows this same philosophy. However, field geologists and prospectors always bring a minimum set of portable instruments into the field to optimize sample selection (to be representative, avoid duplication, and capture the mineralogical diversity) and to document the context from which the samples were acquired. No geologist would think of leaving their hand lens, rock hammer, or acid (test for carbonates) behind, and modern additions to this standard field kit have also been proving their worth.

Infrared spectral imaging has a proven ability to assess and map mineralogy on Earth, the Moon, Mars, and the moons of Jupiter and Saturn. For ARCM extravehicular activities (EVAs), a suit-mounted multispectral infrared camera would map the mineralogy of the EVA workspace to improve sampling efficiency and optimize the value of the small set of samples that can be acquired in the limited time available. Cameras using infrared super-Bayer-patterned filters with custom spectral passbands (developed at JPL) acquire a complete multispectral 'image cube' in a single 'snapshot' – a capability essential for acquiring data from a freely-moving 'platform' (EVA crew in this case). The camera would operate continuously—placing no requirements on the crew. Data would be downlinked to the Mission Control Center, interpreted (with "back room" support) and used to guide the crew to select an optimal set of samples. Data rate would be similar to that of a visible color (RGB) video camera (more spectral bands but slower frame rate). The multispectral imagery would reveal the mineralogical diversity present in the EVA workspace and enable selection of samples that include at least one of each significant mineral and resource class present in the workspace, and would also document the context from which the samples were acquired.

2.2 Volatile Extraction and Separation

This experiment would demonstrate a subscale system based on the concept depicted in Fig. 1, carried on the ARCM in the Orion vehicle. The subscale apparatus would have a black spherical shell about 20 cm in diameter that opens like a clamshell and into which a crew member would insert the asteroid sample. The shell would seal when closed, with the exception of a single opening as a path for volatiles to escape to the cold trap/condenser tube. Volatiles liberated from the asteroid sample would successively condense along the length of the cold trap, according to their boiling points. Volatile composition would be measured by a mass spectrometer. Experiments at JPL support the hypothesis that volatiles will likely include numerous species in addition to water, so it is critical that the water collected in the cold trap be separated during the volatilization process, and subsequently collected in a manner that avoids cross contamination. One possible way to accomplish this separation involves a heating ring that would be mounted around the cold-trap to progressively transit forward from the back of the cold-trap to warm up and remove each of the collected species in sequence. A water electrolysis stack would be employed to splitting water into hydrogen and oxygen.

Acknowledgements

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Technologies for the Asteroid Redirect Robotic Mission

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Abstract

The Robotic segment of NASA's Asteroid Redirect Mission (ARM) will demonstrate key capabilities that will enable new frontiers of future human and robotic spaceflight. We introduce the current robotic mission concept, and detail the technologies and capabilities that will be demonstrated by the mission.

1. Introduction

The Asteroid Redirect Mission (ARM) consists of three major segments – a target identification campaign to characterize and select a target for the robotic mission, a robotic mission to capture and redirect asteroidal mass into a stable orbit around the moon, and a crewed mission in the mid-2020s to rendezvous with the returned vehicle, collect samples, and return them to earth.

ARM has five mission objectives:

1. Conduct a human exploration mission to an asteroid in the mid-2020s, providing systems and operational experience required for human exploration of Mars.
2. Demonstrate an advanced solar electric propulsion system, enabling future deep-space human and robotic exploration with applicability to the nation's public and private sector space needs.
3. Enhance detection, tracking and characterization of Near Earth Asteroids, enabling an overall strategy to defend our home planet.
4. Demonstrate basic planetary defense techniques that will inform impact threat mitigation strategies to defend our home planet.
5. Pursue a target of opportunity that benefits scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the mining of asteroid resources for commercial and exploration needs.

2. Robotic Mission

The ARM robotic segment will launch in the early 2020s, collect a boulder from the surface of a near earth asteroid, and return it to a stable, crew-accessible, lunar distant retrograde orbit (DRO) [1].

The robotic mission will use a high-power advanced Solar Electric Propulsion system to transit to the asteroid and to return home with a multi-ton boulder.

After arriving at the asteroid, the team will spend approximately four months characterizing the surface, selecting the candidate boulders, and checking out the key spacecraft systems.

Once a prime boulder has been selected, and all systems have been confirmed to be functioning properly, the operations team will command the vehicle to autonomously land, capture the boulder, and ascend to a safe distance.

Figure 1. Boulder Capture Illustration

The mission operations timeline includes up to five attempts at collecting a boulder at three different landing sites.

To accomplish this mission, the team designed the Asteroid Redirect Vehicle (ARV) consisting of a 5.5 meter SEP/Mission module and a 6 meter Capture module.

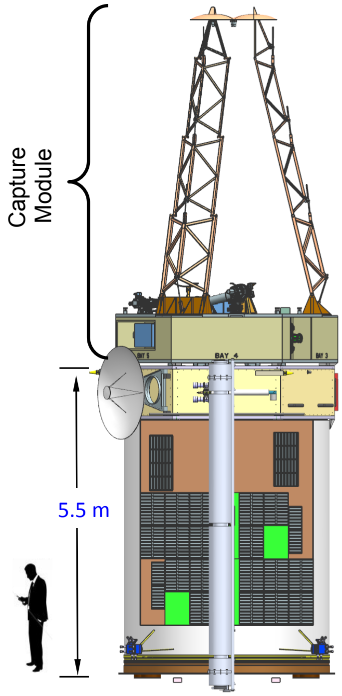

Figure 2: Notional Asteroid Redirect Vehicle

This vehicle can return boulders of up to 4 meter mean diameter.

3. Enabling Technologies

The ARM robotic segment will demonstrate key technologies and capabilities for NASA's future human missions to Mars and robotic missions throughout the solar system. These include:

Advanced Solar Electric Propulsion

The ARV includes a new 50 kW class Solar Electric Propulsion (SEP) system with up to 10 tons of Xenon propellant. This system will be capable of moving massive payloads throughout the solar system, ultimately including the systems required for a human expedition to Mars [2].

Autonomous Rendezvous and Docking

The ARV lands on the asteroid within 0.5 meters of the selected boulder using a precision Autonomous Rendezvous and Docking (AR&D) system. This system includes:

- A gimbaled camera platform that hosts narrow and medium field of view optical cameras for characterizing the landing site
- A deck mounted relative navigation sensor suite including redundant wide (60 degree) field of view optical cameras and redundant FLASH LIDARs
- Advanced Terrain Relative Navigation algorithms that autonomously process the optical and FLASH LIDAR data to determine relative position and attitude.

Micro Gravity Landing Systems

Three Contact and Restraint Subsystem (CRS) landing "legs" actively absorb the impact of landing on the asteroid, and perform the departure maneuver by pushing-off the asteroid surface after boulder collection. These same landing systems can be directly extended to enable missions to a wide range of airless bodies.

Multi-Mission Robotics

After landing on the surface of the asteroid, two seven degree-of-freedom robot arms reach out and "grab" the boulder using an innovative Microspine gripper.

These robotic elements will demonstrate key capabilities that can be used on future missions. For example the robot arms include a tool change out mechanism that allows for both mission specific tools to be mated to the multi-mission arms, and for tools to be changed during the mission. The Microspine gripper will demonstrate a novel approach to collecting natural rock samples that can be directly utilized on a range of future human and robotic missions.

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Asteroid Redirect Mission Overview and Potential Science Opportunities

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Abstract

The National Aeronautics and Space Administration (NASA) is developing the first-ever robotic mission to visit a large near-Earth asteroid, collect a multi-ton boulder from its surface, and redirect it into a stable orbit around the Moon. Once returned to cislunar space in the mid-2020s, astronauts will explore it and return to Earth with samples. This Asteroid Redirect Mission (ARM) is part of NASA's plan to advance the technologies, capabilities, and spaceflight experience needed for a human mission to the Martian system in the 2030s. Subsequent human and robotic missions to the asteroidal material would also be facilitated by its return to cislunar space. An overview of robotic and crewed segments of ARM will be provided along with a discussion of the potential science opportunities associated with the mission.

1. Introduction

NASA is developing the ARM, which includes the goal of robotically returning a multi-ton boulder (typically 2-4 meters in size) from a large near-Earth asteroid (NEA), 100 meters or greater in size, to cislunar space using an advanced 50 kW-class Solar Electric Propulsion (SEP) spacecraft designated the Asteroid Redirect Vehicle (ARV) [1]. An overview of the ARM robotic segment is shown in Figure 1.

After the ARV returns to a lunar distant retrograde orbit (LDRO) in the mid-2020s, initial astronaut exploration and sampling of the returned material will take place as part of ARM as depicted in Figure 2. Subsequent human and robotic missions to the asteroidal material would also be facilitated by its return to cislunar space and would benefit scientific and partnership interests, expanding our knowledge of small celestial bodies and enabling the demonstration of mining asteroid resources for commercial and exploration needs.

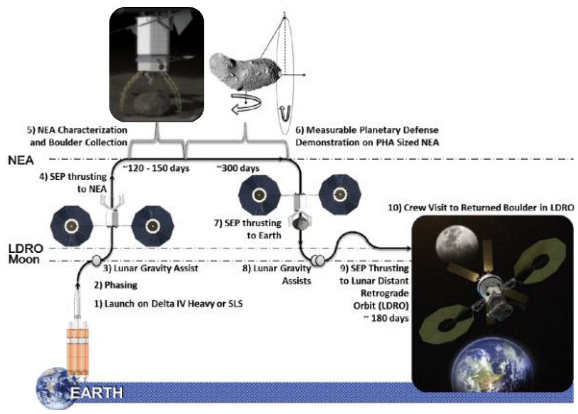

Figure 1: Robotic Segment Overview.

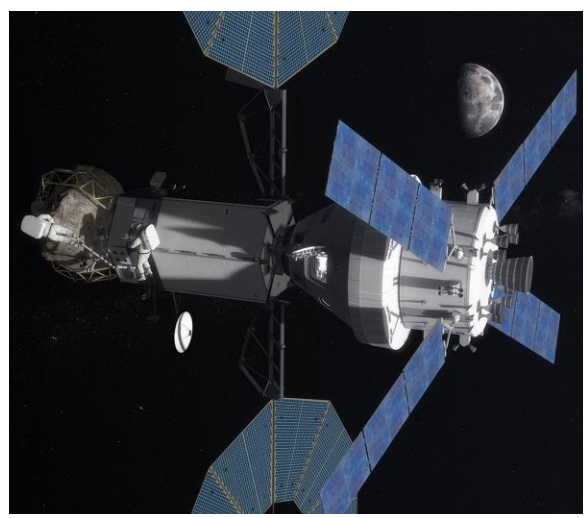

Figure 2: Crewed Segment Illustration.

The capabilities, systems, and operational experience developed and implemented by ARM and subsequent missions to the returned asteroidal material will advance NASA's goal of sending humans to deep-space destinations and eventually to the surface of Mars. The robotic segment would also permit the demonstration of planetary defense techniques on a hazardous-sized NEA.

2. Robotic Segment

The ARV will launch in the early-2020s and arrive at the NEA approximately two years later. After arriving, the ARV will spend approximately two months characterizing the surface and selecting three candidate boulders. During this time, the spacecraft will perform a series of seven-day reconnaissance passes over the surface at decreasing range, down to a final altitude of less than one kilometer. Over the following two months, the team will practice the operations right up to the low-gravity landing at the preferred boulder site as depicted in Figure 3. Once all systems have been confirmed to be functioning nominally, the operations team will command the ARV to autonomously land, capture the boulder, and ascend to a safe distance.

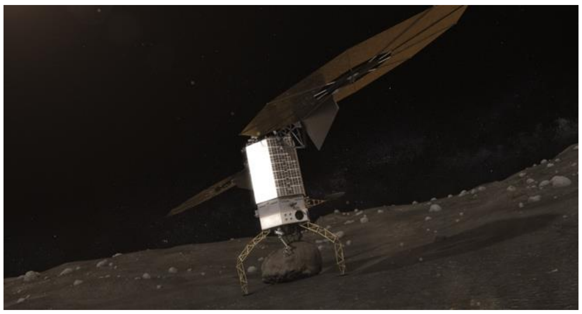

Figure 3: Boulder Capture Illustration.

After the boulder has been collected and secured, the ARV will be commanded to perform an Enhanced Gravity Tractor (EGT) planetary defense demonstration. During the EGT phase, the ARV will operate in a halo orbit around the target asteroid for up to two months, using the mass of the vehicle and boulder to slowly alter the asteroid's orbit [2]. Subsequently, the ARV and boulder would transit to the LDRO. The robotic segment asteroid will be selected a year before launch. To be a valid candidate, an asteroid must have an orbit that allows for a return in the mid-2020s, and have a confirmed or inferred presence of boulders on its surface. The team is currently assuming 2008 EV_5 as the reference target and is also evaluating Itokawa, Bennu, and 1999 JU_3.

3. Crewed Segment

In the mid-2020s, NASA's Orion spacecraft will launch on the agency's Space Launch System (SLS), carrying astronauts to rendezvous with the ARV and the returned boulder. The current concept for the crewed segment of ARM is a two-astronaut, 24-25 day mission. This crewed mission will further test many capabilities needed to advance human spaceflight for deep-space missions to Mars and elsewhere, including new sensor technologies and a docking system that will connect Orion to the ARV. Astronauts will conduct spacewalks outside Orion to study and collect samples of the asteroid boulder wearing new spacesuits designed for deep-space missions. Collecting these samples will help determine how best to secure and safely return samples during future human missions. Additionally, since asteroids are remnants from the formation of the solar system, the returned samples could provide valuable data for scientific research or commercial entities interested in asteroid mining as a future source of space-based resources.

4. Potential Science Opportunities

ARM provides numerous commercial, academic, and international partnership opportunities for payloads on the ARV (e.g., sensors or ride-along missions) and its launch vehicle during the robotic segment, or as secondary payloads on the SLS and possibly as part of the EVA operations during the crewed segment. These payloads may address scientific investigations, commercial interests such as asteroid resource prospecting, demonstration of planetary defense capabilities, or Strategic Knowledge Gaps (SKGs) for future human exploration. Science, planetary defense or commercial opportunities could also include precursor missions to potential target asteroids or the moons of Mars or independent small body missions.

Acknowledgements.

The images provided are credited to NASA/Analytical Mechanics Associates (AMA), Inc.

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Asteroid Impact and Deflection Assessment mission: the Double Asteroid Redirection Test (DART)

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Abstract

The Asteroid Impact & Deflection Assessment (AIDA) mission will be the first space experiment to demonstrate asteroid impact hazard mitigation by using a kinetic impactor. AIDA is a joint ESA-NASA cooperative project, which includes the ESA Asteroid Impact Mission (AIM) rendezvous spacecraft and the NASA Double Asteroid Redirection Test (DART) mission. The AIDA target is the near-Earth binary asteroid 65803 Didymos, which will make an unusually close approach to Earth in October, 2022. The ~300-kg DART spacecraft is designed to impact the Didymos secondary at 6.5 km/s and demonstrate the ability to modify its trajectory through momentum transfer. The primary goals of AIDA are (i) to investigate the binary near-Earth asteroid (65803) Didymos, (ii) to demonstrate asteroid deflection by kinetic impact and to characterize the deflection. The primary DART objectives are to demonstrate a hypervelocity impact on the Didymos moon and to determine the resulting deflection from ground-based observatories. The DART impact on the Didymos secondary will cause a measurable change in the orbital period of the binary.

1. Introduction

AIDA is a joint ESA-NASA cooperative project, which includes the ESA Asteroid Impact Mission (AIM) rendezvous spacecraft and the NASA Double Asteroid Redirection Test (DART) mission. AIM is in Phase A/B1 study at ESA as of early 2015 and continues until summer 2016. DART entered Phase A study at NASA in late spring 2015 until fall 2016.

The target of AIDA is the secondary member of the binary near-Earth asteroid (65803) Didymos, with the deflection experiment to occur in October, 2022. The DART impact on the secondary at ~6.5 km/s will alter the binary orbit period, which can be measured by Earth-based observatories. The AIM spacecraft will be launched in 2020 and arrive at Didymos in spring 2022. AIM will characterize the Didymos binary system by means of remote sensing and in-situ instruments both before and after the DART impact. The asteroid deflection will be measured to higher accuracy, and additional results of the DART impact, like the impact crater, will be studied in great detail by the AIM mission.

The joint mission AIDA will return vital data to determine the momentum transfer efficiency of the kinetic impact and key physical properties of the target asteroid.

2.AIDA/DART Science

The main objectives of the DART mission are to:

- Impact the secondary member of the Didymos binary system during its close approach to Earth in September-October, 2022
- Demonstrate asteroid deflection by kinetic impact and measure the period change of the binary orbit resulting from the impact, by ground-based observations
- Determine the impact location on the target asteroid, the local surface topography and the geologic context
- Develop and validate models for momentum transfer efficiency of kinetic impacts on an asteroid

DART will demonstrate a hypervelocity spacecraft impact deflection of a small near-Earth asteroid (NEA) and then measure the deflection caused by the impact. The DART mission includes ground-based optical and radar-observing campaigns of Didymos both before and after the kinetic impact, as well as modeling and simulation programs, in order to determine and understand the amount of deflection, as well as to develop and validate models for momentum transfer in asteroid impacts. In this way, DART helps us learn how to mitigate an asteroid threat by kinetic impact. AIM will further make detailed measurements of the DART impact and its outcome. AIDA will thus be the first fully documented impact experiment at real asteroid scale, allowing numerical codes to be tested and used for similar and other scientific applications at those scales.

DART is targeted to impact the smaller secondary component of the binary system [65803] Didymos, which has an 800 m primary and a 150 m secondary in an 11.9 hour orbit, from radar and optical observations [1,2]. The impact of the ~300 kg DART spacecraft at 6.5 km/s will produce a velocity change on the order of 0.4 mm/s, if the momentum is simply transferred to the target. However, production of crater ejecta, released back towards the incident direction, increases the momentum transferred to the target above that brought in by the incident projectile.

The momentum transfer efficiency of the spacecraft impact is characterized by the factor β, defined as the ratio of momentum transferred to the target to the incident momentum. The momentum transfer has been calculated using either well-known point source scaling relationships or numerical simulations [3-6]. Laboratory experiments have also measured the momentum transfer efficiency versus incident velocity in various target materials [7]. These studies predict β typically in the range 1.1 to 2.5 for a variety of target material properties, with lower β for low strength, porous targets, but higher values, even $\beta>4$, are predicted for very strong, non-porous targets.

The DART impact leads to a significant change in the mutual orbit of the binary, but only a minimal change in the heliocentric orbit of the system, because the target's velocity change from the impact is significant compared to its orbital speed ~17 cm/s, although it is quite small compared to the heliocentric orbit speed ~23 km/s. Thus the change in the binary orbit is relatively easy to measure compared with the change in the heliocentric orbit.

The DART mission will use ground-based observations to make the required measurements of the orbital deflection, by measuring the orbital period change of the binary asteroid. The DART impact is expected to change the period by ~0.5%, and this change can be determined to 10% accuracy within months of observations. The DART target is specifically chosen because it is an eclipsing binary, which enables accurate determination of small period changes by ground-based optical light curve measurements. In an eclipsing binary, the two objects pass in front of each other (occultations), or one object creates solar eclipses seen by the other, so there are sharp features in the lightcurves which can be timed accurately.

The DART payload consists of a high-resolution visible imager to support the primary mission objective of impacting the target body through its center. The DART imager is required to support optical navigation on approach and autonomous navigation in the terminal phase. The imager is derived from the New Horizons LORRI instrument [8] which used a 20 cm aperture Ritchey-Chretien telescope to obtain images at 1 arc sec resolution. The DART imager will determine the impact point within 1% of the target diameter, and it will characterize the pre-impact surface morphology and geology of the target asteroid and the primary to <20 cm/px.

3. Summary and Conclusions

DART will be the first full-scale demonstration of asteroid deflection by a spacecraft kinetic impact.

Acknowledgements

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Two radars for AIM mission: A direct observation of the asteroid's structure from deep interior to regolith.

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Abstract

Our knowledge of the internal structure of asteroids is, so far, indirect – relying entirely on inferences from remote sensing observations of the surface, and theoretical modeling. What are the bulk properties of the regolith and deep interior? And what are the physical processes that shape their internal structures?

Direct measurements are needed to provide answers that will directly improve our ability to understand and model the mechanisms driving Near Earth Asteroids (NEA) for the benefit of science as well as for planetary defense or exploration. Radar tomography is the only technique to characterize internal structure from decimetric scale to global scale.

This paper reviews the benefits of direct measurement of the asteroid interior. Then the radar concepts for both deep interior and shallow subsurface are presented and the radar payload proposed for the AIDA/AIM mission is outlined.

1. Asteroid's internal structure

The internal structure of asteroids is still poorly known and has never been measured directly. Our knowledge is relying entirely on inferences from remote sensing observations of the surface and theoretical modeling. Is the body a monolithic piece of rock or a rubble-pile, an aggregate of boulders held together by gravity? How much porosity it contains, both in the form of micro-scale or macro-scale porosity? What is the typical size of the constituent blocs? Are these blocs homogeneous or heterogeneous? The body is covered by a regolith whose properties remain largely unknown in term of depth, size distribution and spatial variation. Is it resulting from fine particles re-accretion or from thermal fracturing? What are its coherent forces? How to model its thermal conductivity, while this parameter is so important to estimate Yarkowsky and Yorp effects?

After several asteroid orbiting missions, theses crucial and yet basic questions remain open. Direct measurements of asteroid deep interior and regolith structure are needed to better understand the asteroid accretion and dynamical evolution and to provide answers that will directly improve our ability to understand and model the mechanisms driving Near Earth Asteroids (NEA) deflection and other risk mitigation techniques. There is no way to determine this from ground-based observation.

2. Radar observation

Radar operating from a spacecraft is the only technique capable of achieving this science objective of characterizing the internal structure and heterogeneity from submetric to global scale for the benefit of science as well as for planetary defense or exploration.

The deep interior structure tomography requires low-frequency radar to penetrate throughout the complete body. The radar wave propagation delay and the received power are related to the complex dielectric permittivity (i.e to the composition and microporosity) and the small scale heterogeneities (scattering losses) while the spatial variation of the signal and the multiple paths provide information on the presence of heterogeneities (variations in composition and/or porosity), layers, ice lens. A partial coverage will provide "cuts" of the body when a dense coverage will allow a complete tomography. Two instruments concepts can be considered: a monostatic radar like

Marsis/Mars Express (ESA) that will analyze radar waves transmitted by the orbiter and received after reflection by the asteroid, its surface and its internal structures; a bistatic radar like Consert/Rosetta (ESA) that will analyze radar waves transmitted by a lander, propagated through the body and received by the orbiter.

Imaging the first ~50 meters of the subsurface with a decimetric resolution to identify layering and to reconnect surface measurements to internal structure requires a higher frequency radar on Orbiter only, like WISDOM developed for ExoMars Rover (ESA) with a frequency ranging from 300 MHz up to 2.7 GHz. At larger observation distance, this radar working in SAR mode can map surface and sub-surface backscattering coefficient. In the frame of the AIDA mission, this is a unique opportunity to estimate regolith rearrangement in the impact area.

3. AIDA/AIM Mission

Both radars are presently under study in the frame of the ESA's Asteroid Impact Monitoring mission: AIM would be a stand-alone mission or constitute the Asteroid Impact & Deflection Assessment (AIDA) with the Double Asteroid Redirection Test (DART) mission under study by APL. The AIM objective is to characterize "Didymoon", the secondary body of the binary NEA (65803) Didymos and to contribute to the evaluation of impact mitigation strategies [1].

AIM will carry Mascot2, a lander inheriting from Mascot/Hayabusa to land on Didymoon. On Mascot2 and AIM, the bistatic radar will probe the Didymoon's internal structure at 60 MHz, with a typical resolution of 30 meters to characterize the structural homogeneity of the interior. The objective is to discriminate monolithic structure vs. building blocks, to derive the possible presence of various constituting blocks and to derive an estimate of the average complex dielectric permittivity, which relates to the mineralogy and porosity of the constituting material. Assuming a full 3D coverage of the body, the radar will determine Didymoon’s 3D structure: deep layering, spatial variability of the density, of the block size distribution, of the average permittivity.

When the AIM is combined with DART, the bistatic radar will be used to characterize possible structural modification induced by DART impact. It will also support mass determination and orbit characterization with range measurements during and after descent. Finally, it will contribute to the characterization of the primary body of the Didymos system (referred to as "Didymain").

On AIM mothership, the shallow subsurface radar’s objective is to determine the structure and layering of Didymoon and Didymain shallow sub-surfaces down to a few meters with a submetric resolution. The radar also will map the spatial variation of the regolith texture which is related to the size and mineralogy of the constituting grains and macro-porosity and spatial distribution of geomorphological elements (rocks, boulders, etc) that are embedded in the subsurface.

With DART, the shallow subsurface radar is a key instrument to assess the regolith tomography before and after impact in order to characterize the crater topography, the internal structure modifications and the mass loss. It should also be able to monitor the impact ejecta, generated by the collision with the DART spacecraft, in the vicinity of the secondary asteroid in order to estimate size distribution, speed, and total mass.

It will also contribute to shape modeling, mass determination and orbital characterization with altimeter mode. And finally, more prospective objectives will be considered, such as the support to ground-based radar measurements like Arecibo or Goldstone: orbital radar measurement is indeed a unique opportunity to cross-validate ground-based NEA characterization with radar signal in the same frequency range and with better resolution, better SNR and more favorable geometry.

References

[1] Michel, P. et al. Asteroid Impact and Deflection Assessment (AIDA) Mission: Science Return and Mitigation Relevance. Planetary Defense Conference 2015., Paper IAA-PDC-15-04-01.

[2] Herique, A. et al., A direct observation of the asteroid's structure from deep interior to regolith: why and how? Planetary Defense Conference 2015, Paper IAA-PDC-15-04-06.