SSC19-WKIV-05

The Juventas CubeSat in Support of ESA's Hera Mission to the Asteroid Didymos

Hannah R. Goldberg
GomSpace A/S
Langagervej 6, 9220 Aalborg Øst, Denmark; +45 8172 7727
hrg@gomspace.com

Özgür Karatekin, Birgit Ritter
Royal Observatory of Belgium
Avenue Circulaire 3, 1180 Uccle, Belgium
ozgur.karatekin@observatory.be

Alain Herique
Institut de Planétologie et d'Astrophysique de Grenoble
414 Rue de la Piscine, 38400 Saint-Martin-d'Hères, France
alain.herique@univ-grenoble-alpes.fr

Paolo Tortora
Università di Bologna
Viale Risorgimento 2, I-40136 - Bologna, Italy
paolo.tortora@unibo.it

Claudiu Prioroc
GMV
Etaj 32, Calea Floreasca 246C, București 077190, Romania
cprioroc@gmv.com

Borja Garcia Gutierrez, Paolo Martino, Ian Carnelli
European Space Agency, ESTEC
Keplerlaan 1, PO Box 229, Noordwjik, Netherlands
Borja.Garcia.Gutierrez@esa.int

ABSTRACT

The European Space Agency's planetary defense Hera mission will launch to the Didymos binary asteroid system in 2023 (with bodies nicknamed Didymain and Didymoon). Once in vicinity of the asteroid, two 6U CubeSats will be deployed to contribute to the asteroid research and mitigation assessment objectives of the Hera mission. This paper will describe the Juventas CubeSat, equipped with a low frequency radar payload to characterize the internal structure of Didymoon. Juventas is designed to be operated using the Hera mothercraft as a proxy. This mission architecture creates a new paradigm for CubeSats, requiring high levels of mission autonomy while operating in the challenging environment of a small-body binary asteroid. Juventas will utilize the inter-satellite link to Hera for performing radio science experiments, augmenting the characterization of the asteroid gravity field. Once the radar science and radio science observation objectives have been met, Juventas will perform an attempted landing on the surface of Didymoon to research its dynamical properties.

INTRODUCTION

Juventas is a 6U CubeSat designed for the Hera mission. Hera is ESA's contribution to the international Asteroid Impact and Deflection Assessment (AIDA) mission and will travel to the Didymos binary asteroid system to survey the results of the impact resultant from the NASA DART mission[1,2,3]. DART, the Double Asteroid Redirect Test will impact the smaller Didymoon of the Didymos binary asteroid system in 2022. The Hera spacecraft will follow, arriving in 2027 to characterize the formation of the impact crater with its primary payload, the Asteroid Framing Camera (AFC),[4,5].

After a few months of initial asteroid characterization, Hera will deploy two 6U CubeSats, Juventas and APEX, each equipped with their own suite of payloads to gain additional data on Didymoon.

Juventas and APEX will relay information through the Hera spacecraft for the continued phases of proximity operations at the asteroid.

The AIDA mission through DART, Hera, Juventas, and APEX will contribute to the scientific knowledge of the understanding on the formation processes of binary asteroids and assess kinetic impact for the purpose of future planetary defense evaluation.

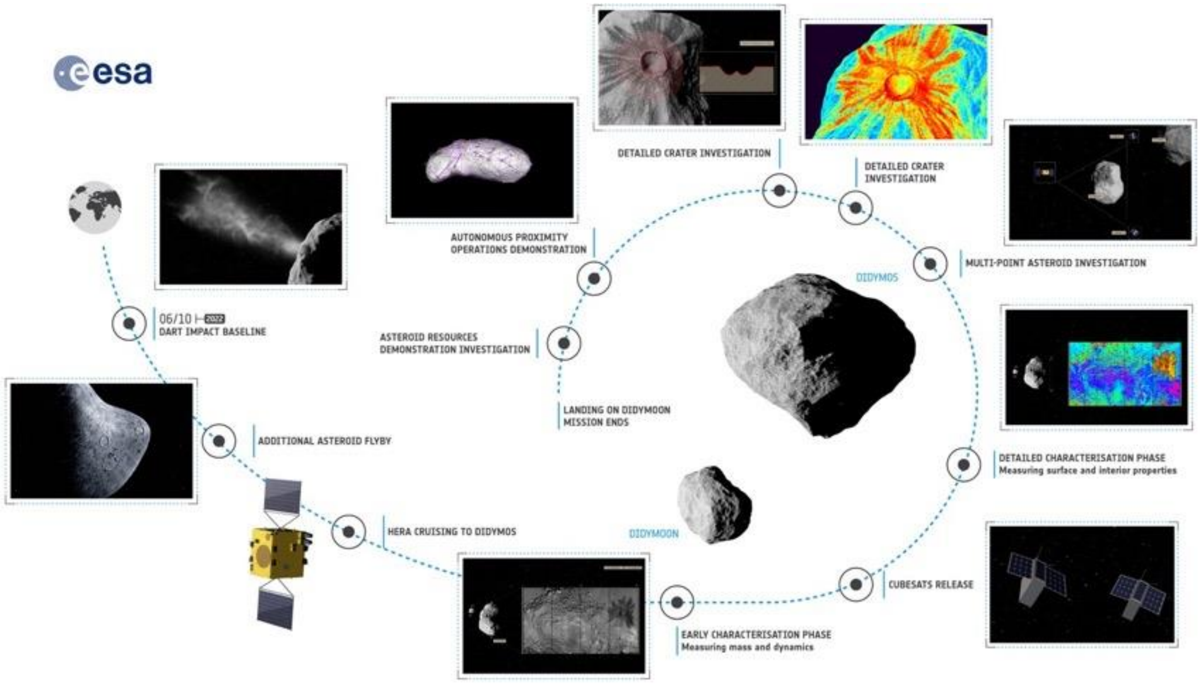

Figure 1: Overview of the Hera Mission Phases (Credit: ESA)

SCIENCE OBJECTIVES

Juventas was created for the purpose of contributing to the asteroid research and mitigation assessment objectives of the Hera mission. The following scientific objectives have been constructed as the basis of the proposed Juventas mission. These objectives are to:

- Determine the gravity field of Didymoon
- Determine the interior structure of Didymoon
- Determine the surface properties of Didymoon
- (Secondary) Determine the dynamical properties of Didymoon

The first three are considered primary objectives with the last identified as a secondary objective for the mission. These objectives have been broken down into investigations and measurements required in order to define the payload suite of the CubeSat as well as the basis behind the definition of mission conops. The science objectives were selected to further the understanding of the evolution of asteroids.

The payload suite selected to meet the stated objectives includes a Low Frequency Radar (LFR), 3-axis gravimieter, Inter-Satellite Link (ISL) radio, visible camera, and IMU (accelerometers and gyros).

MISSION DESIGN

Juventas will be transported to the Didymos system carried within a launch canister located within the Hera spacecraft. Hera has the ability to communicate with Juventas during the cruise phase of the mission, ensuring all systems remain healthy, but primarily Juventas will remain in a dormant state during this time. Once separated from Hera is when the operational portion of the Juventas mission begins. The operational period of the mission plans to last between 3-6 months near the asteroid.

The Juventas mission is divided into three phases: Commissioning, Observations, and Impact/Landing.

Hera will release the Juventas CubeSat from a safe distance (~10km) from the Didymos asteroid system, with a small release velocity (few cm/s) and low tip-off rates. The separation event will power on the Juventas spacecraft and immediate check-out of subsystems will occur. One week of operations is estimated in order to commission the spacecraft and begin payload observations. The goal for reduced commissioning time is driven by the fact that the asteroid system is moving farther from the sun throughout the proximity operations phase meaning an overall reduction in power over time. More payload operations are enabled with more power and shorter commissioning times. The trajectory of Juventas during this commissioning phase will remain at a safe distance from the asteroid, in hyperbolic arcs similar to the design for Hera.

Once Juventas has been deemed operational, it will navigate to inject itself to a Self-Stabilized Terminator Orbit (SSTO) around Didymain, at a range beyond that of the orbit of Didymoon. The SSTO orbit is along the sun-terminator of Didymain, approximately perpendicular to the plane of Didymoon and the ecliptic. This orbit is chosen because it is inherently stable and is favorable for the purposes of radio science as a means of gravity field measurements. The orbit stability minimizes the delta-V required to maintain the orbit stationkeeping as well as reduces mission operations costs due to complex planning required by ground flight dynamics and navigation teams.

The SSTO orbit will be approximately 2-5km from Didymain, keeping outside the orbit of Didymoon for safety.

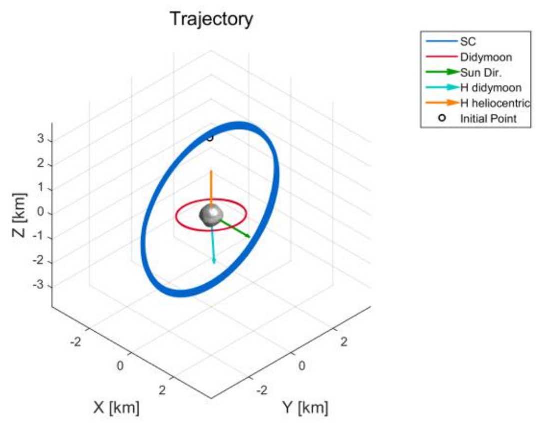

Figure 2: Juventas Self-Stabilizing Terminator Orbit (SSTO) around Didymos

Juventas will remain in the SSTO orbit during the observation phase of the mission. During this time, the CubeSat will exercise its primary Low-Frequency Radar (LFR) as well as performing radio science experiments via the Inter-Satellite (ISL) radio link with the Hera mothercraft. The radar and radio science measurements contribute to the primary objectives of Juventas. The SSTO orbits, combined with the range and range-rate measurements achieved through the ISL link will allow for the calculation of higher order terms of the gravity field reconstruction. The Low-Frequency Radar will make measurements for determining the internal structure of Didymoon. The LFR has large penetration depths due to its low frequency, allowing to see whether the Didymoon is a monolithic object or heterogeneous in nature.

The nature of the SSTO orbits perpendicular to the Didymoon orbit allows for radar measurements that vary in range and angle with respect to Didymoon. Even though Didymoon is the primary target for radar science, due to the omnidirectional pattern of the radar signal, measurements will also be collected for the Didymain asteroid, furthering still our knowledge of asteroid interior composition.

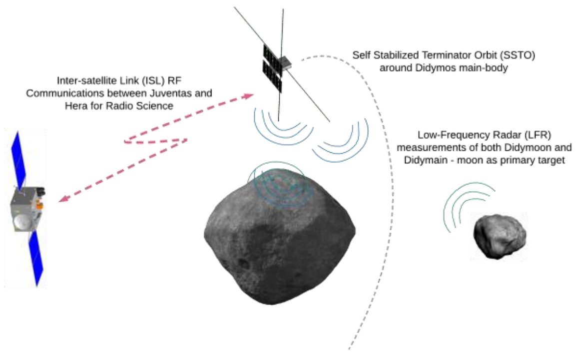

Figure 3: Juventas Observation Phase for Radar and Radio Science

Preliminary mission analysis of SSTO orbits show that >95% coverage of Didymoon can be achieved within 60 days of operations. Full coverage is not possible however, due to mission geometries and the assumption that Didymoon is tidally locked to Didymain, meaning there will be a permanently unobservable zone.

To simplify operations, orbit periods of the SSTO orbit can be constructed to be integer multiples within one week time. This leads to repeatable planning for the ground operations team, potentially reducing cost[6].

The observation phase of the mission will contribute to the majority of operational time of Juventas. Once it has been determined that sufficient payload data has been collected for radar and radio science observations, Juventas will proceed with its final and most risky mission phase – an attempted landing on the surface of Didymoon.

The Juventas CubeSat will initiate a series of maneuvers in order to transition from the SSTO orbit to one that intercepts Didymoon. As the CubeSat is not designed to be a lander[7], there is no site selection or targeting necessary. The CubeSat will try to keep the impact speed below 10 cm/s through the trajectory established in the mission design.

Juventas will use its on-board visible context camera to image Didymoon and potentially the DART landing site at ranges closer than is reasonable with the larger Hera spacecraft and its larger Asteroid Framing Cameras. The intent is that surface features imaged by the visible camera will give clue to Didymoon surface properties.

In its final descent, Juventas will turn on its 3-axis gravimeter, accelerometers, and gyros and record the dynamics from the impact or landing event. High rate recording of accelerometer and gyro data will give the ability to reconstruct the relative dynamics of the spacecraft with the asteroid surface and can be used to reconstruct the regolith surface Coefficient of Restitution (CoR) as previously studied with the AIM CubeSat study AGEX[8,9].

Once Juventas has settled to rest on the Didymoon asteroid surface, and assuming it is still operational, Juventas will use its gravimeter payload, coupled with attitude measurements from the star tracker and sun sensors to relay information back to the Hera mothercraft. The goal of the surface portion of the mission operations is to stay operational for one day, which equates to approximately two orbits of Didymoon around the Didymain. This data contributes to the science objectives related to the local gravity field of Didymoon, but also contributes to the secondary science objective of determining the dynamical properties of Didymoon.

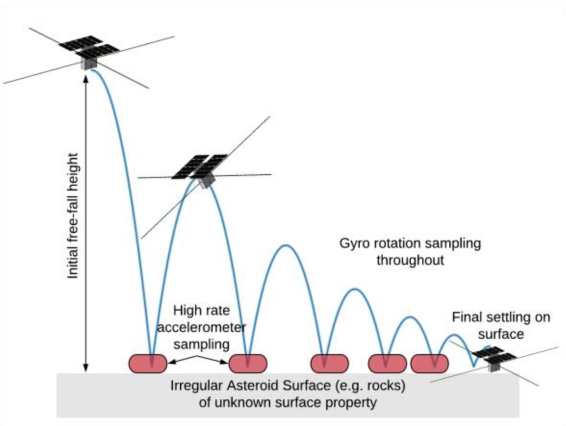

Figure 4: Representation of Juventas Impact/Landing on Didymoon Surface

Although Juventas has ambitious science objectives, it is the appropriate platform to take such risks for the benefit of contribution to asteroid formation knowledge.

SPACECRAFT OVERVIEW

Juventas is a 6U CubeSat with a wet mass of approximately 12 kg in order to fit within the deployment pod located in the Hera mothercraft for cruise to the Didymos asteroid. In addition the standard rail interface, the structure will host a specific deployer interface to enable the low-velocity requirements of separation.

Once separated from Hera, Juventas will deploy two large solar arrays as well as long deployable booms for the LFR radar payload. The large solar arrays are needed to cover operations across a wide range of operation across varying solar ranges. The radar antennas extend 1.5 meters from the CubeSat to support the low-frequency of the radar operation.

The spacecraft structure is derived from the standard GomSpace NanoStructure 6U platform, used in many previous missions including ESA's GOMX-4B. This allows for a flexible internal configuration of spacecraft subsystem components across the electrical power subsystem, command and data handling, guidance, navigation and control, propulsion, and the payloads.

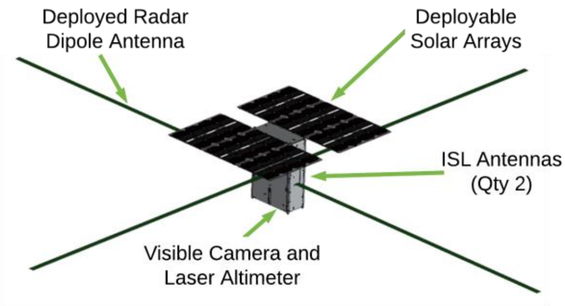

Figure 5: Juventas in the Deployed Configuration

The subsystem elements draw heritage from GomSpace developed products.

The EPS subsystem is enabled by the NanoPower P80 and NanoPower BP8 products. The P80 is the EPS core, providing the function of power conversion and distribution. The unit features independent latch-up protected output switches to the downstream devices. The system also includes the peak power tracker hardware and software to support regulation from the solar array input to the batteries. The BP8 is the battery pack used for the EPS, consisting of lithium ion cells. The battery pack features autonomous heater control and also includes protection by means of over-voltage, under-voltage, and over current protections. Each battery pack has a capacity of more than 80 W-hr. Although during most operations, Juventas will orient its solar arrays to the sun, the battery life is required to ensure sufficient operation while on the surface as the orientation of the solar arrays with respect to the sun will not be known in order to sufficiently rely on their power generation capabilities.

The command and data handling subsystem is based on the GomSpace housekeeping service of requesting and monitoring telemetry from other subsystem nodes that otherwise have the capability of operating independently from each other. Simple scheduled events are executed through the mission flight planner service as planned from the ground and relayed through Hera to Juventas.

Attitude determination is built from heritage GomSpace components, including the star tracker, sun sensors, and gyros. Reaction wheels are the primary means of attitude control, however as typical GomSpace CubeSats operate in a low-Earth Orbit environment, they typically rely on magnetorquers to dump the momentum of the reaction wheels. Juventas will use its on-board propulsion system as a reaction control system for means of dumping momentum of the wheels. The reaction wheels are the GomSpace developed GSW-600 comprised of four wheels in a pyramid configuration, currently flying on the GOMX-4 mission.

The same gyros used for AOCS will also be used for meeting the mission science objectives during the impact and landing phase of the mission. The addition of the accelerometers allows the dual use of the IMU for both spacecraft platform function as well as science contribution. The same is true for the platform attitude determination system during surface operations.

The propulsion subsystem is a butane cold-gas system, derived from similar GomSpace propulsion units, currently flying on GOMX-4B. The modifications made specifically for the deep space missions, including Juventas include the ability for the propulsion subsystem to act as reaction control in purely rotational motion as well as navigation maneuvering delta-V operations that require translational propulsive burns. This added capability is new to CubeSats in the 6U form-factor.

Juventas hosts a visible camera and laser rangefinder for the purpose of assisting in relative navigation to the asteroid target. Primary navigation will take advantage of the ISL radio link, however as Juventas will attempt to land on the Didymoon surface, the camera and laser rangefinder provide added information to contribute to the success of the final mission phases. In addition to being a navigation aid, the visible camera may be used as a means of providing context and imaging the asteroid surface in contribution to the scientific objectives. Images downlinked will be limited based on data constraints through Hera.

Inter-Satellite Link

The Inter-Satellite Link (ISL) is the radio link between the Juventas CubeSat and the Hera mothercraft. Juventas does not have a direct-to-Earth communication system, therefore it relies on Hera in order to relay its data and commands to operations centers on the ground. In addition to the TMTC link, the ISL subsystem also provides navigation data to Juventas through range and range-rate measurements. Estimated accuracies are 1m range and 1mm/s range-rate.

The ISL subsystem is provided to the Juventas CubeSat in order to be similar across Hera and the APEX CubeSat. The design is based on the Proba-III mission and operates in the S-band frequencies. With 2W of RF power, the link has a variable data rate, up to 460 kbps, as the relative geometries (attitude and range) are constantly varying during operations. The Juventas ISL has two patch antennas located on opposing sides of the spacecraft body in order to provide quasi-hemispherical coverage. This reduces the need for the ISL system to know the relative direction of Hera (e.g no specific spacecraft pointing is required for the link).

Juventas will utilize the navigation functions of the ISL link in order to enable radio science investigations. While in the SSTO observation orbits, the ISL data recorded can be transmitted to the ground for reconstruction of flight dynamics to see the gravitational effects of the asteroid to the Juventas CubeSat orbit. This measurement enables higher order terms of the gravity field to be derived.

LFR Payload

The Low Frequency Radar is the primary payload of Juventas. The design is derived through heritage of the CONSERT radar flown as part of the Rosetta/Philae mission[10]. As CONSERT was a bistatic radar, coordinating between the two spacecraft, the LFR for Juventas will be a monostatic design meaning that Juventas is both transmits and receives the radar signal.

The LFR operates at a frequency of 60 MHz in order to have high penetration depth to investigate the deep interior of the asteroid. The measurements give insight to the composition and porosity of the asteroid body. The monostatic radar quantifies the returned power of the emitted signal to determine the scale of heterogeneity. If the radar penetrates through the entire asteroid body, information on permittivity can be determined.

The radar works by emitting a BPSK PN-signal and digitizing the return. Multiple signals can be aggregated in order to improve signal-to-noise measurements as the relative dynamics of the CubeSat orbit is slow. The output power of the radar is approximately 10W, which means the total power draw of the LFR is approximately as high as 50W peak. Due to this high power, the measurements are spaced in time over the Juventas SSTO orbit, giving varying viewing geometries of the target Didymoon.

The LFR payload is made up of an electronics box consisting of the analog electronics of the transmit and receive chains, the digital electronics with signal processing algorithms, and a power interface board. The mechanical packaging is designed to dissipate the heat generated from the payload to the CubeSat structure.

The LFR payload also includes the deployable elements of the radar antenna. Operating at 60 MHz, each antenna element is 1.5 meters in length. The radar signal is circularly polarized in support of data reconstruction due to the differing geometries of measurement. The radar antennas are stowed within the CubeSat body interior and release via a burn-wire initiated by the Juventas power subsystem.

Gravimeter Payload

For local measurements of the asteroid gravity field while on the surface, Juventas has a 3-axis gravimeter payload. The payload was developed for ESA's MMX mission and will be adapted for Juventas.

The gravimeter is a long flat spring with two capacitor electrodes. As the spring deflects due to gravity, the deflection is measured via the electrodes. A motor is present to rotate the orientation of the spring within the payload housing.

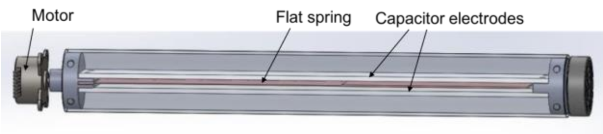

Figure 6: Gravimeter Payload Component Elements

Sensitivity of the instrument is estimated at 0.001 mGal, with an overall measurement range of 1000 mGal. This is achieved in a small package, with a power consumption of <0.3W.

The gravity of Didymoon may vary across its surface, however only one location at the point of landing will be measured. The operation of the gravimeter throughout the orbit of Didymoon will show the gravitational attraction, centrifugal force and tidal forces.

MISSION OPERATIONS

Mission operations will be conducted from a dedicated CubeSat operations center separate from the larger ESA ESOC facility. This is to reduce cost and complexity of operations in the overhead inherent in those facilities used for larger missions.

As Juventas relays its data through the ISL link of Hera to the ground, the CubeSat MOC will receive that data from the ESOC parsed from Hera telemetry. CubeSat operations require flight dynamics functions, which are assumed to remain separate from Hera. The CubeSat MOC will interface with the Juventas science and payload teams for the purpose of scheduling and planning as well as data distribution and dissemination. The CubeSat MOC will coordinate the operations sequence plan and upload that to Juventas, through the Hera relay.

The system architecture is being developed such that the function of the data relay is transparent to the CubeSat operations team, therefore commands sent from the CubeSat MOC, will be received in the same manner on the CubeSat. This allows for Hera and the ISL to be developed without dependencies driven by CubeSat operations. It also does not impose requirements to the CubeSats to follow strict compatibility standards typical for larger ESA missions, a simplified ICD is able to describe the relevant interface.

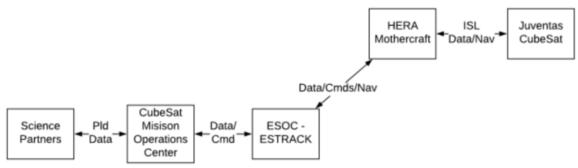

Figure 7: Operations Data Flow

Even though the two CubeSats on Hera are different designs and operate independently from each other, coordinate operations are another method in reducing overall operations costs as it minimizes the number of interfaces required to maintain.

CONCLUSION

Juventas is a complex mission with ambitious goals, however it is the ideal platform to provide benefit to the Hera mission. Through its payload measurements achieving the scientific objectives outlined, Juventas will contribute to the overall knowledge of asteroid formation.

The low-cost nature of CubeSats and their ability to accept a higher risk posture opens the opportunity provided to the mission design. The Juventas spacecraft is built from existing CubeSat subsystems and products and will prove the viability of deep space CubeSats in support of larger missions providing added benefit.

Acknowledgments

This work was performed in support of the European Space Agency's Hera project. The authors wish to acknowledge contribution from the Juventas team including collaborators at ESA, GomSpace, the Royal Observatory of Belgium, GMV, the University of Grenoble-Alpes, TU-Dresden, the University of Bologna, Brno University of Technology, Astronika, as well as the entire Hera mission team.

References

1. Cheng, A.F., Michel, P., M. Jutzi, et al., "Asteroid impact and deflection assessment mission: kinetic impactor," Planet. Space Sci, 121, pp 27-35. 2016.
2. Michel, P., Küppers, M., Carnelli, I., "The Hera mission: European component of the ESA-NASA AIDA mission to a binary asteroid," 42nd COSPAR Scientific Assembly, Pasadena, CA, July 2018.
3. Michel, P. Küppers, M., et al, "European component of the AIDA mission to a binary asteroid: Characterization and interpretation of the impact of the DART mission," Adv. Space Res. 62, 2261-2272. 2018.
4. Küppers, M. et al, "Exploration of the binary asteroid 65803 Didymos by the payload of the Hera mission", 32nd ISTS and 9th NSAT Joint Symposium, June 2019.
5. Karatekin, O. et. al., "HERA planned mission and payload operations at close proximity of the Didymos binary asteroid system after DART impact," Planetary Defense Conference, Washington DC, April 2019.
6. Goldberg, H. et al, "Low-cost asteroid science with a CubeSat – an overview of the Juventas CubeSat for the HERA mission,", Low Cost Planetary Missions, Toulose, June 2019
7. Goldberg, H. O. Karatekin, B. Ritter, C. Prioroc, "Juventas – Attempting to Land a CubeSat on Didymoon for the Hera Mission," International Planetary Probe Workshop, Oxford, UK, July 2019.
8. Karatekin, O., et al, "The Asteroid Geophsycial Explorer (AGEX) to Explore Didymos," iCubeSat, Oxford, UK, 2016.
9. Murdoch, N., Sanchez, P, Schwartz, S.R., Miyamoto, H., Asteroid surface geophysics. Asteroids IV. University of Arizona Press, Tuscon, pp 767-792. 2015.
10. Herique, A., et. al, "Direct observations of asteroid interior and regolith structure: Science measurement requirements," Adv. Space Res. 62, 2141-2162. 2017.