Main challenges of Cubesat piggyback on an Interplanetary Mission: The HERA Cubesats, a technology demonstration case

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Abstract

Hera is a European Space Agency Planetary Defense mission part of the Asteroid Impact & Deflection Assessment (AIDA). AIDA is an international collaboration among scientists from Hera (ESA) and DART (Impact on 26 of September, 2022) science teams to demonstrate a deflection of a binary asteroid, Didymos, and perform close proximity observation of the outcome, while demonstrating technologies for future missions and addressing planetary defense. Hera will be launched in October 2024 and will arrive at Didymos in January 2027. The manuscript presents an overview of the main technical and programmatic challenges encountered, from the Hera spacecraft System perspective, to embark on the Deep Space Deployers, Milani and Juventas CubeSat. The Hera Cubesats are hosted inside the Hera Platform, therefore, presenting many dependencies on mechanical, thermal, electrical, and functional interfaces with the main Hera spacecraft. These dependencies create technical and programmatic challenges in the different domains that are amplified by the different development approaches followed by the traditional space Hera prime and the "New Space" Cubesat philosophy. The manuscript covers the proposed solutions to prevent failure propagation from the Cubesats to the main Hera platform; thermal, mechanical, and electrical integration inside the Deep Space Deployers, which host an umbilical for communications and battery conditioning during Cruise; the utilization of COTS inside a hi-rel platform; the SW interfaces to communicate during CRUISE and the nominal operations in Deep Space; and the Assembly Integration and Verification approach to streamline the development of both CubeSats.

Hera Mission and Platform Introduction

Hera is a planetary defense mission in ESA's Space Safety and Security program. Its primary mission goal is to characterize an asteroid in the 100-200 m size range, the range most relevant for planetary defense. For smaller objects, no deflection effort would be made, while larger objects have lower impact frequency with Earth. The target of Hera is the binary asteroid Didymos. The smaller component of the Didymos system, Dimorphos, will be impacted by NASA's Double Asteroid Redirection Test (DART) spacecraft four years before Hera's arrival. Both missions are mutually independent, however, their value is increased when combined. It is noted that Hera will be implemented with a different philosophy than a traditional science mission, such as Rosetta. This is characterized by three primary drivers: The overall financial budget for the mission is limited in comparison to a typical M- or even L-class ESA science mission for the spacecraft. Hera is not considered a science mission, instead, its mission objective is to advance our knowledge and capabilities in terms of planetary defense, while demonstrating new technologies. Hera Cubesats are considered opportunity payloads, hence, not fundamental for the achievement of the mission objectives.

Due to the orbit of Didymos, launch windows only occur about every two years, and the next favorable opportunity is in 2024.

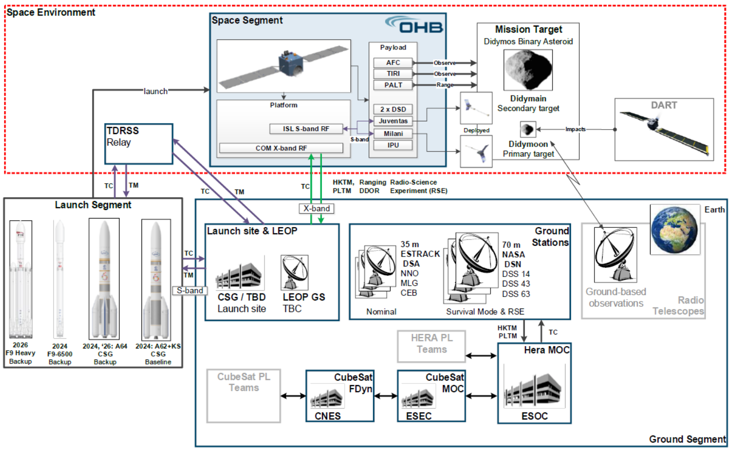


Figure 1 – HERA Mission architecture. Credit OHB Systems.

The baseline launch period of the Hera mission is 2024, with a cruise duration of approximately 820 days, and asteroid capture, by December 2026. Proximity operations will start in January 2027, with a planned end for operations in July-August 2027. Figure 2 provides, a not to scale, mission timeline.

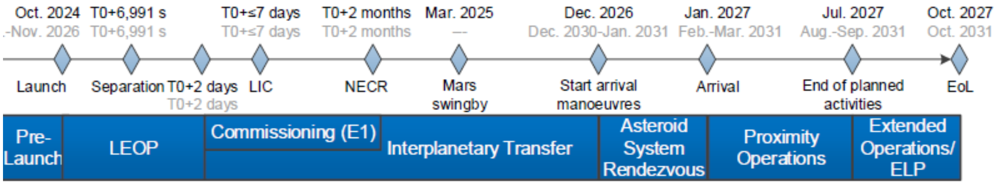


Figure 2- High-level HERA mission timeline for the 2024 Baseline Mission

The 2024 launch period requires an escape velocity of 5.1 km/s. The transfer has a duration of around 820 days and contains two deep space maneuvers and a Mars swingby. A 3D view of the transfer trajectory in ecliptic ICRF centered at the Sun is shown in Figure 3.

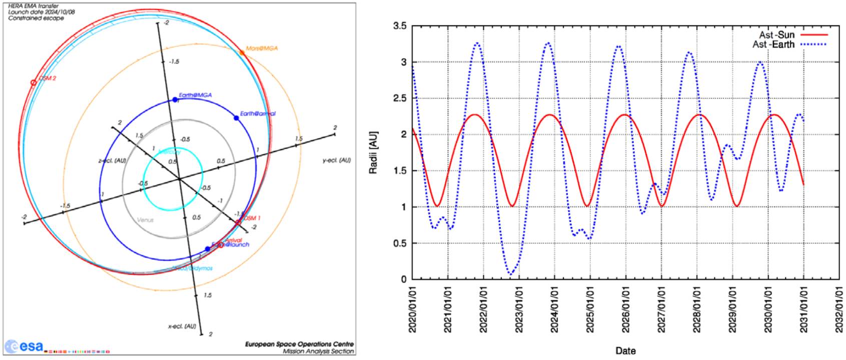


Figure 3 – 2024 Launch and Transfer plot for Hera Mission (left). Asteroid-Sun and Earth Distance from 2020 to 2030

Hera's mission target is the binary asteroid system 65803 Didymos (1996 GT). The Didymos system is classified as a near-Earth asteroid, as the system periodically approaches Earth (down to about 0.01 AU in 2022) and its perihelion is near 1 AU distance from the Sun. Compared to other asteroids, Didymos is reachable with a limited, but still high, Delta-v.

Diameter of Didymos	780 m
Shape of Didymos	Likely top-shaped, similar to 101955 Bennu
Diameter of Dimorphous	164 m (major axis, about half for minor axes)
Shape of Didymos	Likely ellipsoidal
The dynamic state of a system	➢ Didymos: rotating at about 2.26 rev / h ➢ Dimorphos: orbiting common barycentre at 11.9 h / rev. Moon rotating at the same rate, i.e. likely tidally locked to Didymos ➢ Orbit and Didymos rotation most likely in a retrograde direction, i.e. in opposite direction as Didymos orbit about Sun

Table 1 - Physical characteristics of Didymos. Rounded for simplicity

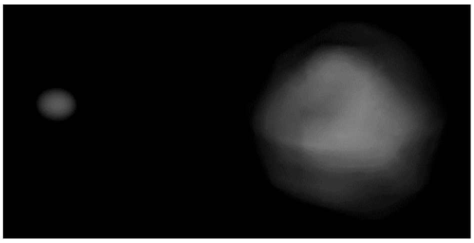
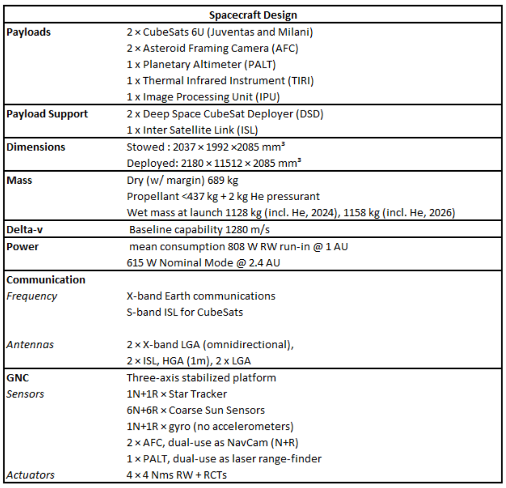


Figure 3: Reconstruction of the Didymos system, based on radar and light-curve measurements. Credits: Naidu et al., AIDA Workshop, 2016

The Hera platform is developed (Prime contractor) by OHB Systems. Figure 4 presents a short overview of the key spacecraft characteristics. The Hera spacecraft will host two 6U-XL Cubesats (Juventas and Milani) inside the Deep Space Deployer. Figure 4 shows the configuration of the Hera spacecraft upper deck, with both Cubesats in the Exposed configuration. Deep Space deployers are highlighted in the color orange.



Spacecraft Design	
Payloads	2 × CubeSats 6U (Juventas and Milani) 2 × Asteroid Framing Camera (AFC) 1 x Planetary Altimeter (PALT) 1 x Thermal Infrared Instrument (TIRI) 1 x Image Processing Unit (IPU)
Payload Support	2 x Deep Space CubeSat Deployer (DSD) 1 x Inter Satellite Link (ISL)
Dimensions	Stowed : 2037 × 1992 ×2085 mm^3 Deployed: 2180 × 11512 × 2085 mm^3
Mass	Dry (w/ margin) 689 kg Propellant <437 kg + 2 kg He pressurant Wet mass at launch 1128 kg (incl. He, 2024), 1158 kg (incl. He, 2026)
Delta-v	Baseline capability 1280 m/s
Power	mean consumption 808 W RW run-in @ 1 AU 615 W Nominal Mode @ 2.4 AU
Communication	
Frequency	X-band Earth communications S-band ISL for CubeSats
Antennas	2 × X-band LGA (omnidirectional), 2 × ISL, HGA (1m), 2 x LGA
GNC	Three-axis stabilized platform
Sensors	1N+1R × Star Tracker 6N+6R × Coarse Sun Sensors 1N+1R × gyro (no accelerometers) 2 × AFC, dual-use as NavCam (N+R) 1 × PALT, dual-use as laser range-finder
Actuators	4 × 4 Nms RW + RCTs

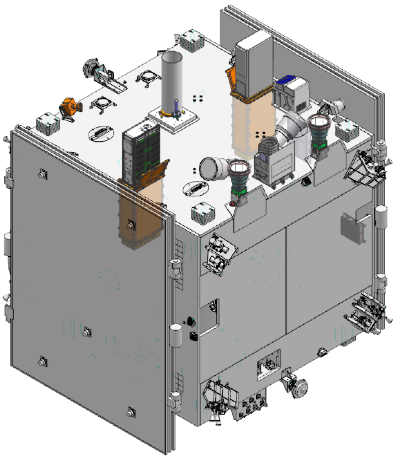


Figure 4 – Hera S/C characteristics (left) and Hera platform render in stowed (right) (Image Credit OHB Systems)

Hera Cubesats description

Milani Cubesat

The space segment for the Milani mission is integrated by the Milani Cubesat Platform bus (6UXL) developed by Tyvak International, a primary instrument (ASPECT), multispectral imager developed by a consortium led by VTT, a secondary payload (VISTA), developed by INAF, and Inter-satellite link (ISL) radio and S-band antennas developed by Anywaves. Figure 5 presents the stowed and deployed configuration of the 6UXL satellite. The Milani spacecraft includes sophisticated navigation optical sensors, including visible rage cameras, LIDAR for close-proximity range measurements, star-tracker and sun sensors, and a 6DOF chemical (Cold Gas) propulsion module developed by (T4I and Tyvak International) for rotational and translational maneuvers. The platform and instruments have been designed taking into account the expected space environment while combining redundancy, error correction codes, circuitry protections mechanisms, automotive-grade COTS, and rad-tolerant EEE parts.

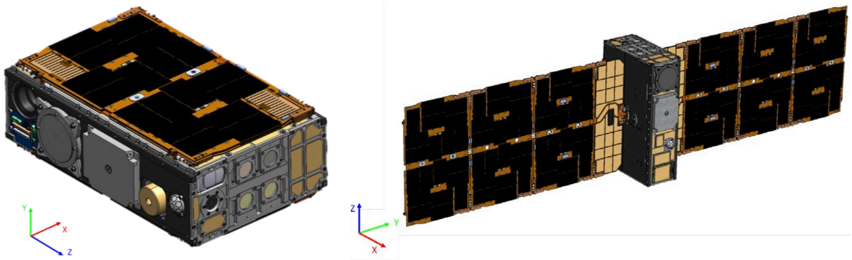


Figure 5. 6U Milani Cubesat stowed and deployed configurations (image credit: Tyvak International)

ASPECT payload is a hyperspectral imager operating in the visible and infrared parts of the electromagnetic spectrum. ASPECT imager covers the wavelength range of 500 - 2500 nm and has imaging capability between 500 and 1650 nm. The imager is split into three channels: VIS (500-900 nm), NIR (850 - 1650 nm), and SWIR (1600 - 2500 nm).

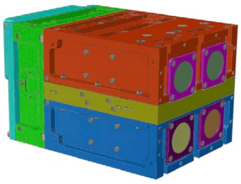


Figure 1. ASPECT Payload overview (Image credit of VTT)

The scientific goals of ASPECT are:

- To map the global composition of the Didymos asteroids
- To characterize the surface of the Didymos asteroids
- To evaluate space weathering and global shock effects on Didymos
- To identify local shock effects on Dimorphos caused by DART impact

Parameter	VIS channel	NIR1 channel	NIR2 channel	SWIR channel
Field of View [deg]	10 x 10	6.7 x 5.4	6.7 x 5.4	ca 5.85 circular
Spectral range [nm]	500 - 900	850 - 1250	1200 - 1600	1650 - 2500
Image size [px]	1024 x 1024	640 x 512	640 x 512	1 x 1
Pixel size	5.5 x 5.5 um	15 x 15 um	15 x 15 um	1 x 1 mm
No. spectral bands	Ca. 14	Ca. 14	Ca. 14	Ca. 30
Spectral resolution [nm]	< 20	< 40	< 40	< 40

Table 2. ASPECT Main parameters

The secondary payload on the Cubesat Mission is the Volatile In-Situ Thermogravimeter Analyser (VISTA), which scientific objectives, will accomplish the following scientific goals: Detect the presence of dust particles smaller than 10 µm (residual dust particles). Characterization of volatiles (e.g., water) and light organics (e.g., low carbon chain compounds) by using TGA cycles. i.e. heating controlled thermal cycles. Molecular contamination monitoring onboard the spacecraft

Figure 7. VISTA Payload (Image Credit: INAF)

Juventas Cubesat

The Juventas spacecraft is a 6U-XL form-factor CubeSat developed by a consortium led by GOMSpace Luxembourg. The CubeSat platform uses GomSpace satellite components but is improved for the expected harsh interplanetary environment. A group of EEE parts and electronic boards have been tested under high-energy protons and heavy ions. Main Juventas technical features are summarised in

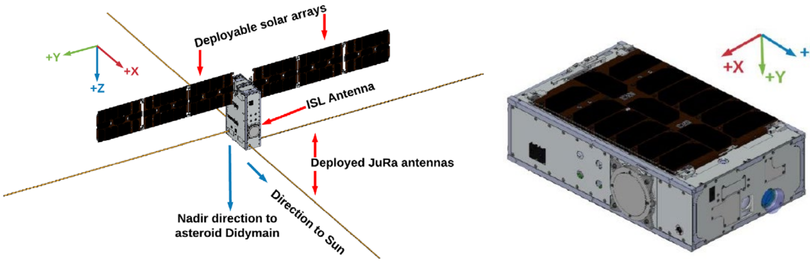


Figure 8 - Deployed and Exposed configuration of the Juventas satellite

Structure		6U-XL CubeSat bus
	Solar distance	1.02 – 1.71 AU (max 2.0 AU)
	Mission lifetime	2.2 years cruise and 3 months nominal proximity operations,
	Launch date	October 2024
Mass	*Mass*	Dry 10.4 kg , Wet Mass: 12 kg
Dimensions	*Stowed*	~130 x 246 x 366 mm
		~1420 x 910 x 366 mm including arrays and antennas
Payloads		Low-frequency radar and Gravimeter
Power	*Solar Array*	2x deployable wings, up to 35 W generation at 1.8 AU
	Bus	28V unregulated.
	Max consumption	~42W
Propulsion	*Delta-V*	10 m/s
	Thrusters	8x 1 mN thrusters
	Tanks	1x 420 g butane (5 bar MEOP)
Communication	*Frequency*	S-band ISL, 2,025 - 2,290 MHz
	Antennas	2x ISL patch (hemispherical coverage)
	Data rate	Variable, up to 460 kbps
	RF Chain	2W RF TX
ADCS & GNC		3-axis stabilized
	ADCS Sensors	7x Fine Sun Sensors, IMU, 2x star trackers
	GNC Sensors	Navigation Camera (w/payload) and Laser altimeter
	Actuators	4x GSW600-4P and RCS propulsion
Thermal		Mostly passive design with coatings and 2 heaters
Deployables table		Two solar array wings with 3 x 6U panels each, 4x low-frequency radar antenna with ~1.36 m deployed length

Table 3 – Juventas Cubesat technical characteristics

Juventas carries 1 main payload: a low-frequency radar (for radar science), and two secondary payloads: a high-rate accelerometer (for landing science), and a gravimeter (for surface science). This payload suite was selected to meet the scientific objectives of the mission and is presented below together with other supporting instruments.

The Low-Frequency Radar payload, named "JuRa" for Juventas Radar, is the primary payload onboard Juventas and will investigate the interior structure of asteroid Dimorphos. JuRa is a monostatic-coded synthetic aperture radar that is capable of penetrating depths of a hundred meters of the asteroid. The radar operates at a center carrier of 60 MHz with a default 20 MHz bandwidth, although the instrument can also operate in 10 MHz and 30 MHz bandwidth. The radar generates a binary phase-shift keying (BPSK) coded signal, amplifies it, and transmits it toward the target body through the radar antennas. It then receives the signal reflected by the surface and sub-surface structures. The signal is received on the same antenna in time-sharing (half-duplex), amplified, mixed-down, and digitalized by the Rx channel. An accumulation is performed on-board to improve the signal-to-noise ratio and then sent to platform telemetry. All these steps are clocked by the digital radar scheduler.

Figure 9 – Juventas Low-Frequency Radar EM (Image credit: IPAG and Emtronix Lux.)

Juventas is equipped with four radar antennas (developed by Astronika), each containing a deployable boom of approximately 1.26 m deployed length. The four booms can be fed to create horizontal-, vertical-, or circularly-polarized signals. The baseline antenna design is a flattened tape of curved copper-beryllium. The antenna is flattened inside the spacecraft and wound around a motorized reel. The motor can control the speed of deployment, and retraction if desired.

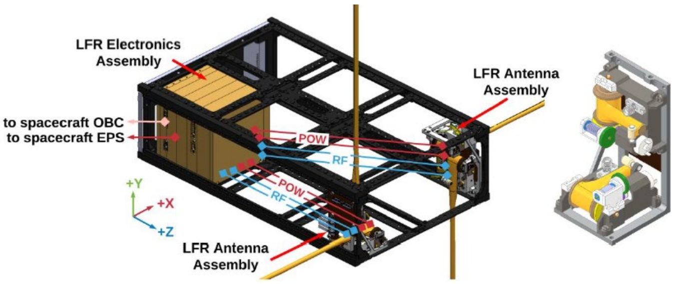


Figure 10. Low-Frequency Radar Antennas. (Image credit: GOMSpace and Astronika)

The gravimeter is used to measure the local dynamical environment at the landing site on the surface of Dimorphos, to constrain the self-gravitation, geological substructure (mass anomalies, local depth, and lateral variations of regolith), and the surface geophysical environment (tides, dynamic sloped and centrifugal forces). The instrument is developed by the Royal Observatory of Belgium and Emxys. The design consists of two orthogonal sensors that together obtain the magnitude and direction of the local surface acceleration. The gravimeter works by measuring the deflection/displacement of a flat spring in the presence of an external acceleration (net combination of gravity, centrifugal acceleration, and other sources). The position of the spring is recorded by a highly sensitive capacitor transducer.

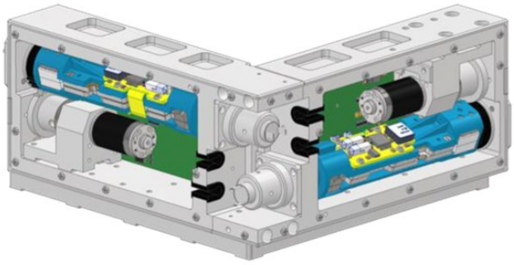


Figure 11. Juventas Gravimeter instrument (Image credit: Royal Observatory of Belgium and Emxys)

Mission Concept of Operations

The Hera Cubesats will be launched integrated inside the Deep Space Deployers (DSD), which will provide mechanical, electrical, and thermal housing for the Cubesats through the Cruise phase of the mission (2.2 years). The following sections of this manuscript will detail the different interfaces of the CubeSat to the Hera satellite. Both Cubesats will execute, every 2-3 months, functional health checks, maintenance procedures (e.g. reaction wheels spin), and battery conditioning. Throughout the entire mission, Hera S/C will serve as a communication relay to the Hera Mission Control Center (HMOC) and Cubesat Mission Control Center (CMOC). During Cruise, communications with Ground will be routed with the Hera S/C through UART ports available on the Cubesat umbilical interfaces.

After the Hera, S/C performs its rendezvous and capture maneuver, and the preliminary characterization phase of the Didymos system, the Cubesats will perform its final Stowed Check out tests, final battery charging, and Guidance Navigation and Control software updates (e.g. Didymos dynamical models, gravitational models, or estimated mass models). Ground control will decide to initialize the sequence for the Hera Payload Deployment Phase (PDP). The deployment of each CubeSat occurs in a three-step deployment sequence (approximately 1 week apart each) that is supported by the Deep Space Deployer (DSD):

1. In the first deployment step, each CubeSat is deployed from inside the DSD into the “exposed” configuration. In this configuration, the CubeSats are mechanically attached to the DSD, and thus the Hera S/C, but already exposed to the space environment. The umbilical connection routed through the DSD still provides data and power between the Hera and CubeSats. The umbilical connection allows for the initialization of the CubeSat sensors and establishes an RF communication link between the CubeSats and Hera.

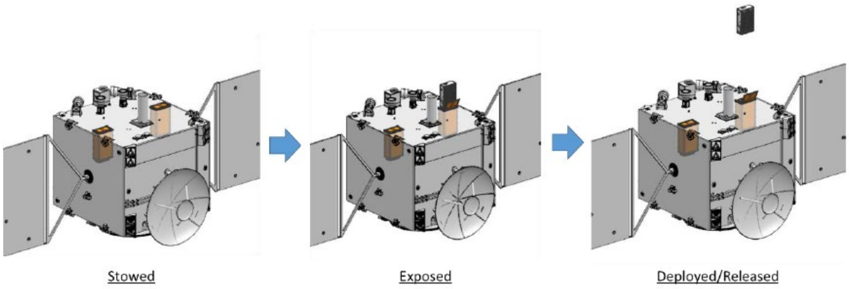


Figure 12: Illustration (Credit OHB Systems) of the two-step CubeSat deployment sequence. Left: The CubeSat is stowed inside the DSD (highlighted in orange). Middle: The CubeSat is ejected from the DSD into the exposed configuration, but still connected to the spacecraft for power and communication. In this configuration, the ISL RF communication link shall be established. Right: The CubeSat is released and separated from the spacecraft

2. After CubeSat initialization Exposed checkout and inter-satellite Link commissioning are confirmed from the ground, and the umbilical connection between Hera and the CubeSats is removed by ground command. The umbilical release is trigged via a dedicated command by HERA to the DSD, this configuration is referred to as “released”. In this configuration, the CubeSats are mechanically attached. This configuration will last only 2 seconds.

3. In the last step, the CubeSats are deployed from Hera S/C with the following release conditions: relative velocity to Hera equal to 3 cm/s with +/-1 cm/s dispersion and relative velocity direction error below 5 deg. The configuration after mechanical separation is referred to as the “Separated” configuration.

The above-mentioned steps are executed in specific Hera attitudes, following deployment requirements. The selected release arc to inject into the desired path is the resultant of the trade-off of several directions, sensitivity, and robustness analysis, which will allow the Cubesats to be injected into trajectories sensitive to injection velocities, phase angles, the margin of safety, and arcs durations. The selected injection arcs are the one that guarantees the closest distance to the following waypoint after a safe number of days of propagation

Dedicated mission analysis teams led by GMV (Juventas Flight Dynamics team) and Politecnico de Milano Teams (Milani Flight Dynamics team) have trade-off different injection scenarios and trajectory designs, to accomplish technical and scientific objectives.

The initialization procedure for each CubeSat is identical. Maximum operational duration of up to 7 days is foreseen for each CubeSat deployment sequence. An additional 7 days are allocated for the commissioning of the CubeSats after release. For safety reasons and to avoid collision risks, it is assumed that the deployment sequence for each CubeSat is performed sequentially with a sufficiently long period between the two deployments.

Each Cubesat, in the "free-flying" configuration, has its trajectory design which is briefly introduced.

For Juventas, assuming nominal conditions and the desired release direction, the SC arrives at the terminator plane after four days, where the first maneuver is scheduled. The duration of the arc is designed to be 4 days to match the natural week and ease the operations. This arc is in the terminator plane to allow simultaneous asteroid pointing and Sun pointing to the solar arrays.

Mission Phase	Initial Epoch	Final Epoch	Duration [days]
Preparation Phase (PREP)	23rd March 2027	26th March 2027	3
Commissioning Phase (COMP)	26th March 2027	30th March 2027	4
Insertion Phase (INSP)	30th March 2027	5th April 2027	6
Observations Phase (SSTO 3.3 km)	5th April 2027	5th May 2027	30
Observations Phase (SSTO 2.0 km)	5th May 2027	4th June 2027	30
End Of Life Phase (EOLP)	4th June 2027	5th June 2027	< 1
Total	23rd March 2027	5th June 2027	74

Table 4 - Mission timeline nominal case for Juventas Cubesat

The Observations Phase (see Table 4) is the scientific phase, in which the JURA instrument will nominal operate, through the execution of the desired measurements of Dimorphos. The proposed bassline trajectories are self-stabilized terminator orbits (SSTO). The SSTOs also called photo-gravitational orbits. The interest in these orbits lies in the scientific return obtained from them and the reduced number of operations required, reducing the cost of station-keeping maneuvers. The SSTOs arise from the existence of an equilibrium point that corresponds to a low-eccentricity orbit, offset from the center of the point mass along the direction x and perpendicular to this same direction, where the SRP perturbation is equal to the x-component of the gravitational force of the central body. Thus, it exists an equilibrium solution in the Hill Frame.

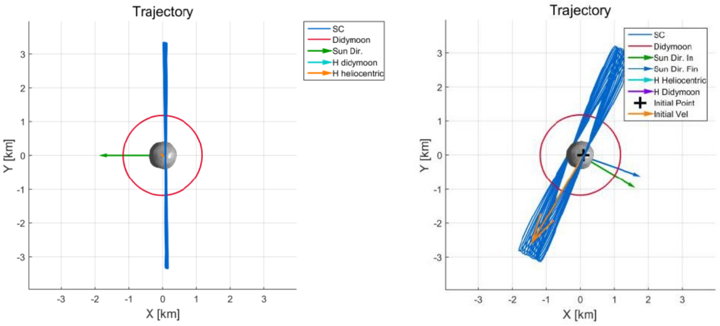


Figure 13 - 3.3 km SSTO in Hill frame (right) (Simulation credit GMV) and Ecliptic (left)

For Milani, all trajectory designs are driven by the scientific objectives and Safety (i.e. safety factors C>0), simplicity (i.e. reduced operational burden required to perform active operations on the CubeSat), robustness (i.e. robustness to the uncertainties due to system and dynamical environment, and inherently safe trajectories) and cost (i.e. in terms of the Delta-v).

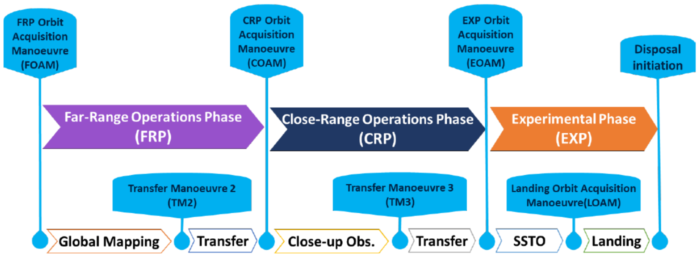


Figure 15 – Milani mission Phases

The operational orbit ranges are a consequence of the abovementioned factors and the ASPECT instrument observations. For the nominal operational orbits, a hovering loop trajectory with patched hyperbolic arcs is selected as baseline scientific orbits, allowing the observation of the poles of both bodies, while covering similar latitudes with slightly different phase angles.

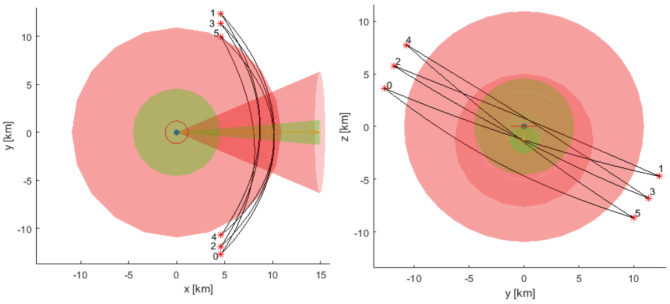


Figure 16 –Milani Cubesat FRP science orbit. (Simulation credit: POLIMI DART Team)

Interface challenges with the Main platform

The accommodation of Cubesats inside a larger spacecraft presents several technical interface challenges. To be able to mechanically and thermally house the CubeSats during long periods in interplanetary cruises, or being able to exchange telemetry and telecommands with the ground, a series of adaptations are required to standard low Earth Orbit developments. Given the nature of the different development approaches followed by the Hera platform prime, a traditional space actor, and the Cubesat providers, the programmatic development of the missions have a relevant role.

Mechanical and Thermal Integration

Juventas and Milani will be integrated inside the Deep Space Deployer, which is an ISISpace dedicated development for an interplanetary mission. The DSD design has been adapted to sustain higher mechanical and thermal loads, given the configuration of the units inside the main spacecraft. Both deployers are attached to the Hera central structure, and doors are exposed on the upper deck, next to other instruments.

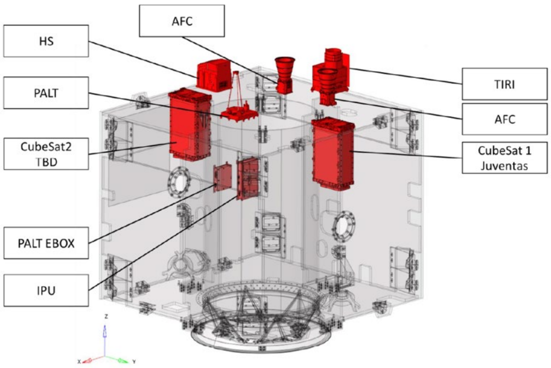


Figure 18 – DSD accommodation on HERA with other instruments on the upper deck (Image credit: OHB Systems)

The expected mechanical environment given the position of the deployers is more stringent for sine and quasi-static loads than in other traditional Cubesat launches onboard launch vehicles.

HERA-CS-MEC-051 Quasi-static qualification loads

The unit shall withstand the following qualification quasi-static loads:

- Out-of-Plane: ± 23 g
- In-Plane (IP-1): ± 23 g
- In-Plane (IP-2): ± 23 g

Verification Method: A, T

HERA-CS-MEC-052 Sine vibration qualification loads

The unit shall withstand the following qualification sine vibrations loads

Direction	Frequency [Hz]	Qualification Load [g]
IP-1	5	1
	18	12
	100	12
IP-2	5	1
	13	8
	100	8
OP	5	1
	13	8
	100	8

Verification Method**: A, T**

Figure 19 – QSL and Sine requirements on Cubesat Interface

The deployment of each CubeSat occurs in a three-step deployment sequence, as described in previous sections. To be able to deploy each of the Cubesats and expose them to the space environments, but remain attached to the Hera umbilical connection, the mechanical interface with Hera has been designed, on both the deployers and the Cubesats elements. Both CubeSats integrate the Cubesat Interface bracket (CIB) as structural elements on the Spacecraft, which allows supporting the exposed procedure, sustaining the shock loads during the deployment.

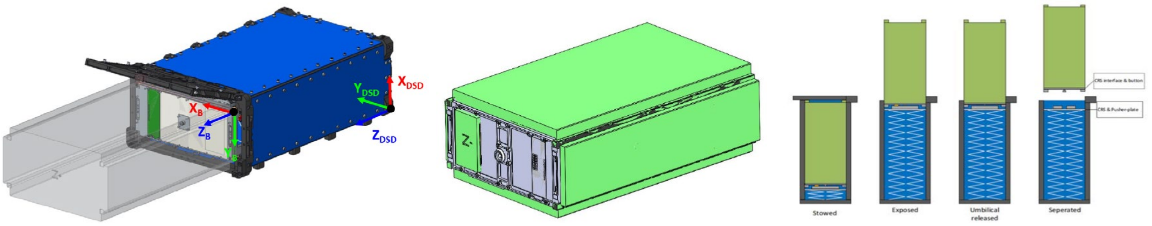


Figure 20 – Hera Deep Space Deployer (left) Dummy Cubesat configuration with CIB (center). Deployment sequence (right)

Deployers are not usually designed to host active Cubesats inside, given that Cubesats are off, during LV ascent, and deployment. On Hera, the Cubesats will be switched ON several times during the interplanetary Cruise phase, for the duration of the Stowed Health Check Test, which spans from 29 minutes to 45. Besides, the Cubesats will charge their batteries, to compensate for self-discharge, and keep safe states of charge. The thermal design of the Cubesat, plays a relevant role, in sizing the types of tests possible inside the deployer, its duration, and their heat dissipation profiles. Different from traditional LEO missions, the Cubesat Thermal Subsystems need to be sized accordingly for Stowed, Exposed, and Separated configurations.

The Hera SC, through Ground operations and telecommands sequences execution, has full controllability of the Cubesat while in a stowed configuration. Hera will command the switch On of the Cubesats, only if the Telemetry reading from the different Thermal Reference Points (TRP), installed outside the deployers and inside the deployers, are within pre-defined boundaries. To avoid ground intervention during each Nominal health check, autonomy mechanisms have been implemented onboard each Cubesat. This advanced mechanism will allow each satellite to be able to detect, and isolate recovery from failures or out-of-limit indicators, autonomously. A relevant example in the thermal domain is the ability of each Cubesat to react to any contingency (i.e. over-heating), by triggering an FDIR which will signal an electrical to Hera, which will switch Off the Cubesat immediately. Hera thermal control subsystem, dedicates active heaters to the deep space deployers, to keep the CubeSats within thermal boundaries.

One of the key thermal challenges in the design of the Hera Cubesats is during the Exposed configuration. Hera upper deck MLI will be in shadow, hence, very low temperatures. Sun aspect angle during deployment shall be >90 deg (Hera +Z and -X away from sun and +/-Y orthogonal to the sun-SC-asteroid plane). The Sun aspect angle requirement constraints the attitude of the HERA spacecraft during the Cubesat exposed scenario, to a minimum of 45 deg between the deployment direction and sun direction, hence, sun illumination during this phase is reduced. The Cubesats will rely on Hera power (through the umbilical connection), to operate their heaters, and keep the battery and other subsystems within operational ranges.

Electrical Integration

As described in previous sections, the CubeSats are connected to the Hera satellite, through an umbilical while in stowed and exposed configuration. On one hand, other Hera instruments are directly interfaced to the main platform avionics (i.e. Hera PCDUs, Hera Onboard Computers, or RTU) given that those are instruments developed with space-qualified hi-rel parts, Class 1 or Class 2, and the units have been designed, manufactured and tested, following ECSS and the tailored ECSS Hera requirements. On the other hand, the Cubesats are a mix of lower-class parts, that have been designed following ECSS tailored standards for Cubesats, with many parts being automotive COTS, screen COTS, or COTS+. These different EEE class levels on both sides of the interfaces entitle a higher risk for the Hi-rel avionics of the platform, if any electrical issue, propagates to the main platform. Therefore, to mitigate such technical compatibility, alleviate the level of requirements imposed on the Cubesat interfaces, and avoid any failure propagation from the Cubesats to the main Hera platform, the Cubesats are first interfaced with The Life Support Interface Board (LSIB) as described in Figure 21.

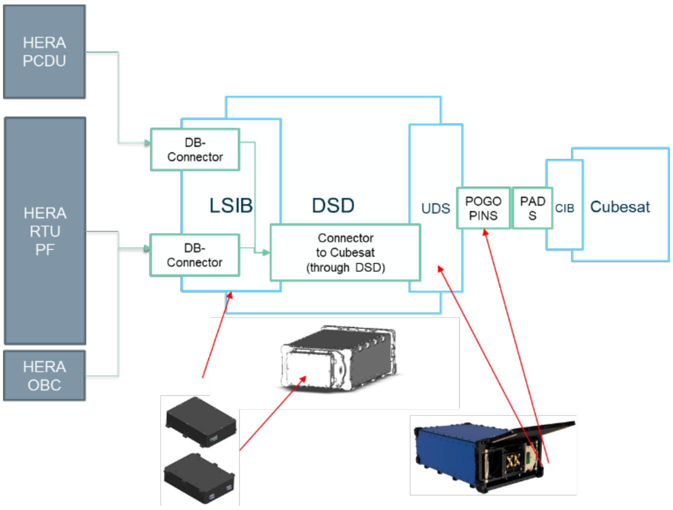


Figure 21 – LSIB electrical connection to Hera and Cubesat bus

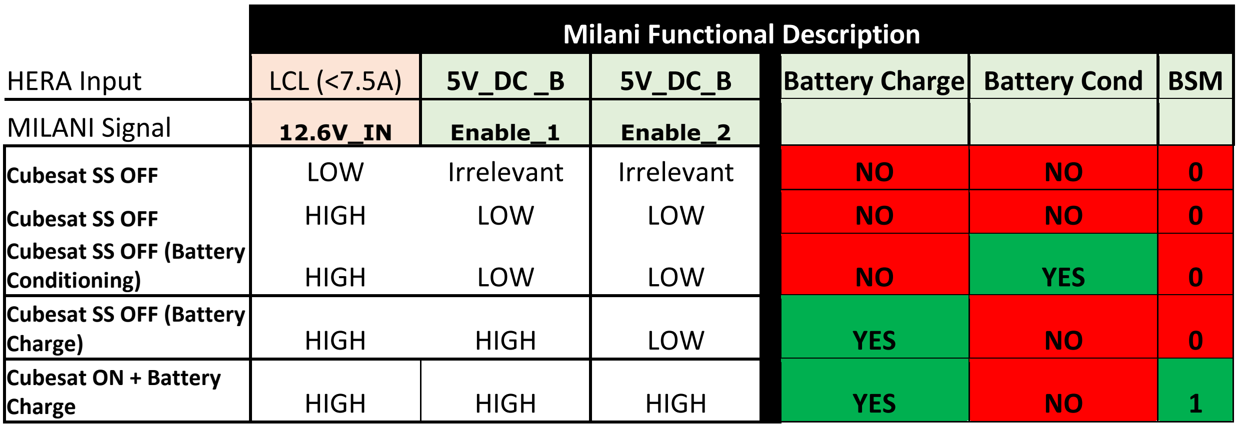
The LSIB is an electronic board (one per Cubesat) that provides power, and data I/F from the Hera spacecraft to each of the Cubesats, as well as power regulation functions, and selection of Cubesat operational modes. The LSIB galvanically isolates the Cubesat power and data lines from Hera and is developed with Hi-rel parts following ECSS for its developments, qualification, and test. Each LSIB is attached to the back of the DSD and interfaced with each Cubesat.

Signal	Source	Cubesat
Power Input (Unreg +28V)	HERA	Input Voltage Range: 12-28V
SDI over RS-422	Both	1 pair (nominal only)
5V_DC	HERA	CH1: Enable 1 CH2: Enable 2

BSM	Cubesat	CH1: Power Abort
TSM	Cubesat	CH1: LSIB temperature CH2: DSD temperature

Table 5 – LSIB electrical interfaces

The LSIB electrical interface definition is summarized in Table 5. The LSIB includes galvanically isolated DC/DC converters that regulate the Hera bus voltage to the Cubesat bus voltage. Each LSIB includes UART lines for the Cubesat to Hera communication, as well as 5V_DC lines, which can select the operational mode of the Cubesat, as described in Table 6, which allows the Cubesat to be switched ON, with battery charging, or be switched OFF and charge batteries, or be switched off and keep battery conditioning mode.



	Milani Functional Description					
HERA Input	LCL (<7.5A)	5V_DC _B	5V_DC_B	Battery Charge	Battery Cond	BSM
MILANI Signal	**12.6V_IN**	**Enable_1**	**Enable_2**			
Cubesat SS OFF	LOW	Irrelevant	Irrelevant	**NO**	**NO**	**0**
Cubesat SS OFF	HIGH	LOW	LOW	**NO**	**NO**	**0**
Cubesat SS OFF (Battery Conditioning)	HIGH	LOW	LOW	**NO**	**YES**	**0**
Cubesat SS OFF (Battery Charge)	HIGH	HIGH	LOW	**YES**	**NO**	**0**
Cubesat ON + Battery Charge	HIGH	HIGH	HIGH	**YES**	**NO**	**1**

Table 6 – Example of Milani Cubesat 5V_DC lines Hera actuation configuration table

Cubesat power consumption on the Stowed configuration is limited to 10-16 W, depending on the operational mode. When in exposed configuration, the power limiting is increased to 20W, to allow for heaters and extra onboard health checks.

Software and Intersatellite Link Communications

Traditional Cubesat onboard software's are usually not Packet utilization Standard (PUS-C) compatibles because, in LEO traditional missions, the End 2 End communication chain is usually controlled by the same user. In the Hera scenario, the Hera platform and Ground command only exchange PUS-C packets, therefore, to overcome the compatibility challenges in the software domain, both Cubesats had to adapt their on-board software interfaces to PUS-C. Several PUS-C services are implemented onboard the Cubesat (see table 7 for more details on Implemented services).

PUS-C Service	PUS-C Subservice
ST[1]	1,2,7,8
ST[3]	5,6,25,27,31
ST[5]	1,2,3
ST[9]	128
ST[17]	1,2
ST[20]	1,2,3
Mission Specific services [>230]	Different Subservices to encapsulate proprietary services

*Table 7 – Example of Hera Cubesat PUS-C implemented services and subservices_*

During the cruise phase, the PUS packets are routed through the UART interfaces to the Hera on-board computer and Ground. The benefit of using the same standard on Cubesats / Hera and Ground is that through PUS-C, ESOC (Hera Mission Operations Center, HMOC) can receive the packets, and monitor the basic Housekeeping telemetry before the TM reaches Cubesat Mission Control centers. Guidance and navigation control data (e.g. Navigation images of each Cubesat NAV Cameras), will be used by Ground Control to provide orbit determination solutions to the GNC teams. Given the time criticality of certain information, such as these navigation images, they will be directly received by ESOC (HMOC) and processed, without the need for pre-processing on the Cubesat MCCs. Besides, the Hera satellite, can also read on-board key TM points of the Cubesat and react accordingly through OBCP.

On the other hand, detailed telemetry packets download from the Cubesat to the ground, and telecommand sequences to be sent to the Cubesat are stored within Mission Specific services (see Table 7), and will be transparent to both HMOC and Hera central software. Cubesats will communicate to Hera while in a separated (e.g. free-flying) configuration, utilizing an Intersatellite Link (ISL) in S-Band. The ISL transponder also implements PUS-C, providing not only a communication channel, but also time synchronization services for the Cubesats and range, and range rate measurements, that will be used in several scenarios for navigation and operations purposes.

Besides, implementing PUS-C services, which already deviate from a standard or traditional Cubesats implementations, the Cubesat teams are exposed (for some of them for the very first time) to MIB (Mission information Base) and Satellite Reference databases (SRDB) implementations. Traditional space utilizes MIBs from very early in the development, to perform validation and verification of operational requirements, and exercise the operational scenarios. For the validation and verification phase, the MIB database is rather important to be fixed as soon as possible, to be able to test with mission simulators. The population of the SRDB is performed by each of the Cubesats and shared with the Hera prime, early on in the development process and utilize with ground support equipment as a Payload simulator, which allows the Cubesats to validate their interface developments, and the risk the subsequent IGSTs and SVTs (system validation tests)

Qualification and AIT

A traditional Cubesat development follows a Proto-flight Model approach, including the development of a flat-sat or Cubesat test bench, to de-risk HW interfaces with EM units, and support the SW development. On the Hera mission, the development philosophy requires the addition of more models to support the validation and verification together with the Hera mothercraft. Besides the challenges associated with the qualification of the Cubesat system, the developers are required to test the Cubesats integrated into the Hera platform during its proto-flight qualification, including vibration, thermal cycling, thermal balance, EMC, and all functional tests. Given the nature of the Hera Cubesats, which are considered opportunity payloads, hence, not fundamental for the achievement of the mission objectives. A delay on the Cubesat systems, shall not impact the development of any platform-related activity, therefore, a series of models (See Table 8) to retire risk from the Cubesat development, and avoid impacting the main spacecraft are introduced.

Model ID	Model Description
EM Flatsat	Flatsat with all spacecraft units on EM or QM configuration for Cubesat system tests, and operations. Mainly used as operational flatsat and validation of electrical, SW and functional interfaces.
Reduced EM	EM for HERA Test bench including a configuration of the Cubesat which is representative of the stowed and exposed configuration (OBC + PCDU + ISL + Load Simulator) + LSIB EM
STIM	Structural thermal interface Model including (STRUCT + SA + OBC + POWER + Thermal SIM) with flight representative quality.
PFM	Cubesat Protoflight Model. Fully qualified hardware: • FFT/RFTs • ISL Verification

	• Fit Checks • Dimensional and Mass Properties • Vibration test • Bakeout, TVAC • EMC testing
EQM	DSD Engineering Qualification Model, as the output of ESA activity, which undergoes full qualification (functional and environmental)
TEST POD EQM (TBC)	DSD Test POD to be utilized during Cubesat Environmental Test Campaigns (Vibration and TBT, fit checks, and Electrical Tests). It is expected that the EQM could be used for such a purpose
FM	DSD Flight Model + LSIB FM Flight Models
FM Spare	DSD Flight Model Spare. To be used for the ATB_V4 (TBC)
LSIB STM	Structural Thermal Model, to be used for the DSD Qualification
LSIB EQM	Engineering Models to be integrated with the Cubesats Reduced EM
LSIB PFM	Proto-flight models to be integrated on the DSD-FMs

Table 8 – Hera Cubesat Models developed for the Mission

To avoid over-testing of the Cubesat PFM, and after executing a Cubesat level qualification, re-run the qualification at Hera platform level, a new model is introduced: the STIM. The STIM (Structural Thermal Interface Model), has flight quality structural elements, flight quality OBC / PCDU and Battery subsystem, as well as thermally representative interfaces with the Hera platform. The STIM will be integrated inside Hera for its proto-flight qualification and is a functional representation of the stowed configuration. Besides the STIM the Cubesat providers are required to deliver a Cubesat reduced Engineering Model, to be tested with the Hera platform test bench, which will be used to rehearse all the functional tests to be executed with the PFMs.

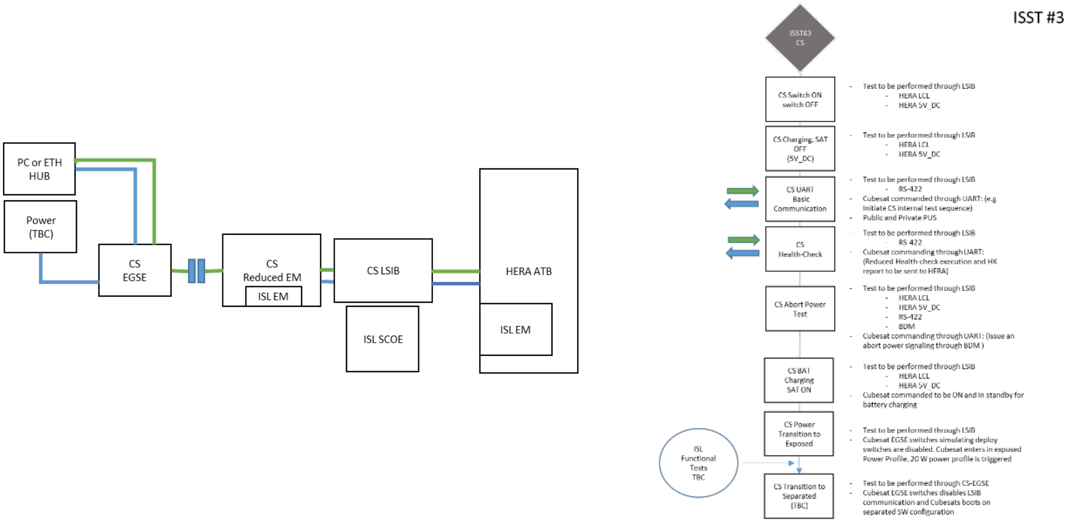


Figure 22 – Test setup configuration with Hera ATB and CubeSats reduced engineering model (left). Communication ISST procedure draft for Payload functional test on rEM (right)

Once Hera has finished its first section of the environmental test campaigns (EVT, vibration, and TVAC/TBT) the Cubesats PFM will be integrated into Hera, and the remaining part of the EVT including EMC and SVTs will be executed with the Cubesats PFMs.

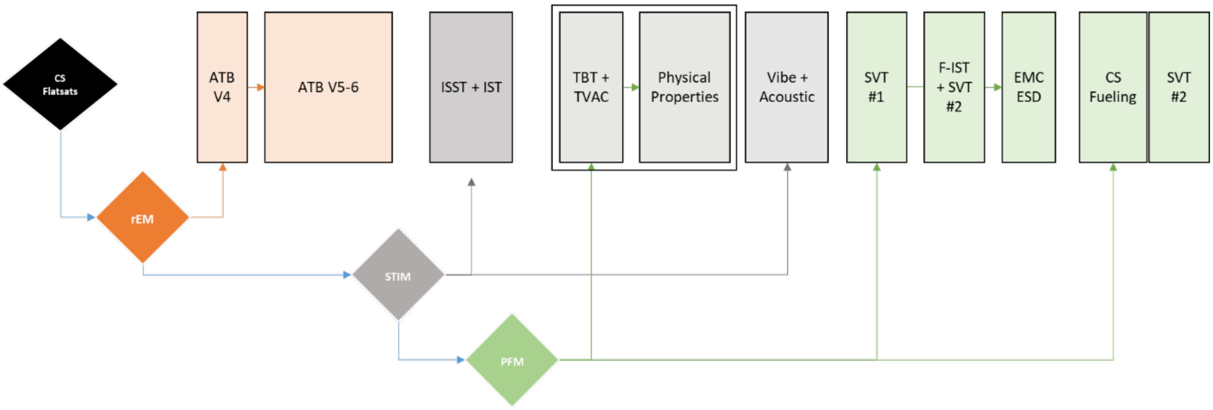


Figure 23 – Hera Cubesat models on Hera AIT.

Different from traditional Cubesat qualification campaigns, the need to integrate the Cubesats in and out of the Hera spacecraft, requires a set of Mechanical ground segment equipment (MGSE) dedicated to the mission are required. The GSE required span from integration handles on the Cubesat structural elements, which drives de structural design, to clean room cranes, to support the integration process on top of the main spacecraft. MGSE requires early planning, and coordination with the prime, to be able to execute all the required integration steps from clean room to launch site.

Conclusions

The Hera Cubesats are a technology demonstration opportunity payload on board Hera spacecraft, which will complement Hera mission objectives, by taking a higher risk and aiming to perform closer observations. Hera Mission objectives are not dependent on the CubeSats mission success. Juventas and Milani will be the first ESA deep space cubesats to be launched, and the first tandem mission on board a larger satellite, with propulsive capabilities. The development of deep space CubeSats is considered a technical challenge due to the harsh operational environment and the complexity of the operations through a relay system. Furthermore, the mechanical, thermal, electrical, and functional interfaces with the host spacecraft, increase the level of reliability and complexity of system interfaces that shall be overcome, to safely and successfully integrate a Cubesat inside a larger mission. Besides the technical challenges, programmatic has a relevant role when planning a similar mission. The confront in development approaches between traditional space prime contractors and the Cubesat developers shall be taken into consideration early in the development phase. To mitigate the risk of failure propagation from the Cubesats to the main spacecraft hi-rel units, electrical protection units such as the LSIB can be integrated, which will serve to isolate but also to off-load a series of complex requirements into a unit which will interface both worlds. Cubesats are a relevant tool to support exploration missions, since a higher risk profile can be accepted, without risking the main mission.