AIT and System Level Verification for ESA Interplanetary Cubesats (Juventas and Milani), ready to piggyback on the ESA Hera Mission

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Abstract

Hera is a European Space Agency Planetary Defense mission and 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) teams to demonstrate a deflection of a binary asteroid, Didymos. The mission will perform proximity observations 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 October/November 2026. The manuscript presents an overview of the Assembly, Integration and Verification of the Interplanetary Cubesats (Milani and Juventas which are the first ESA Deep Space Cubesats) and the Deep Space Deployer, being this the first time that such a detailed and comprehensive AIT campaign has been performed for CubeSat companions. The manuscript and presentation will be focused on the System level tests executed together with the Hera PFM, including: Cubesats inside Hera during PFM vibration, and Thermal Vacuum Cycling. Cubesats PFM on Electromagnetic Characterization Testing with Hera PFM, on ESA Maxwell anechoic chamber. ISL Testing with Hera PFM and Cubesats PFMs. Software and interface functional Tests inside Hera PFM and within the Hera OHB Avionics Test Bench environment. Hot deployment tests and CubeSat integration on the Hera PFM and Launch site activities planned for October 2024. The manuscript provides an overview of the proposed solutions for System Level testing and verification with the main Hera platform, covering all different mission phases and environmental scenarios.

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, was 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.

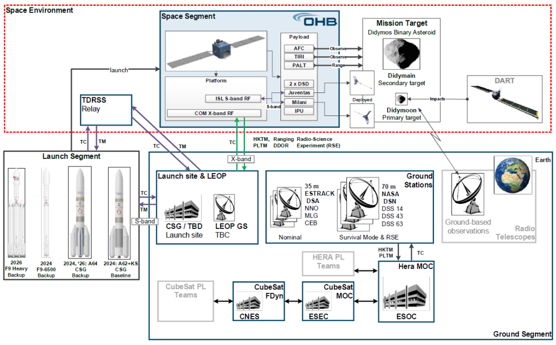

Figure 1 – HERA Mission architecture. Credit OHB Systems.

The baseline launch period of the Hera mission is 2024, with a cruise duration of approximately 820 days, and asteroid capture, by October 2026. Proximity operations will start in DEC 2026, with a planned end for operations in July-August 2027.

The 2024 launch period requires an escape velocity of 5.1 km/s. The transfer has a duration of around 790 days and contains two deep space manoeuvres and a Mars swingby. A 3D view of the transfer trajectory in ecliptic ICRF centered at the Sun is shown in Figure 3.

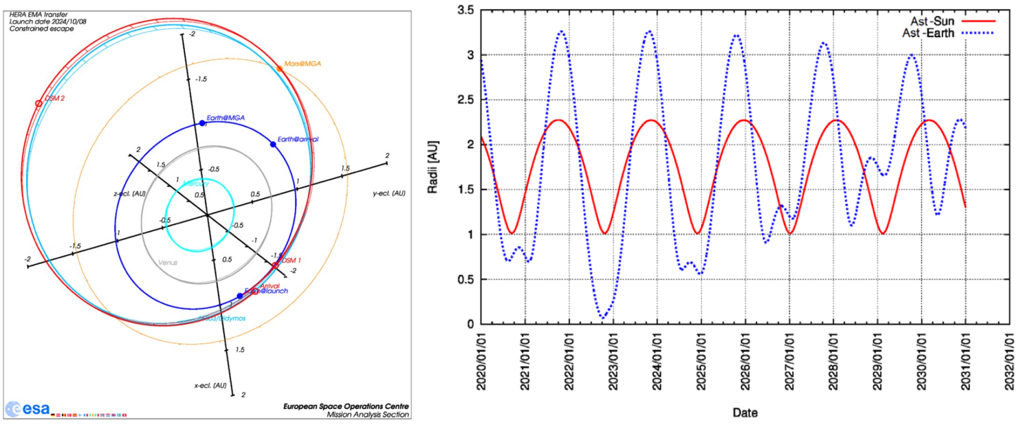

Figure 2 – 2024 Launch and Transfer plot for Hera Mission (left). Asteroid-Sun and Earth Distance from 2020 to 2030

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, which makes not feasible to be reached by a Stand-alone Cubesats by means of their own propulsion, justifying the need for a rideshare on-board a larger S/C.

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: DART Mission Images (Credit NASA/APL), 2022

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 and 4a shows the configuration of the Hera spacecraft asteroid deck, with both Cubesats in the Exposed configuration.

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

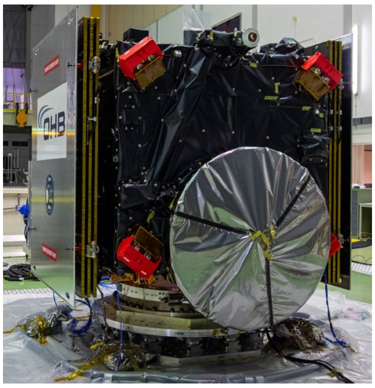

Figure 4 – Hera S/C characteristics (left) and Hera platform during vibration testing (right) (Image Credit OHB Systems)

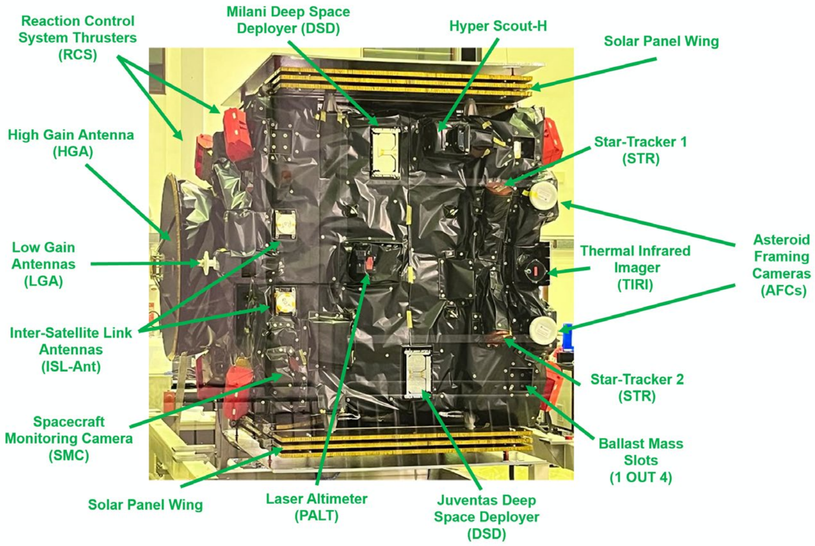

Figure 4a. Hera S/C Instruments description, on Asteroid deck (Image Credit OHB Systems/ESA-2024)

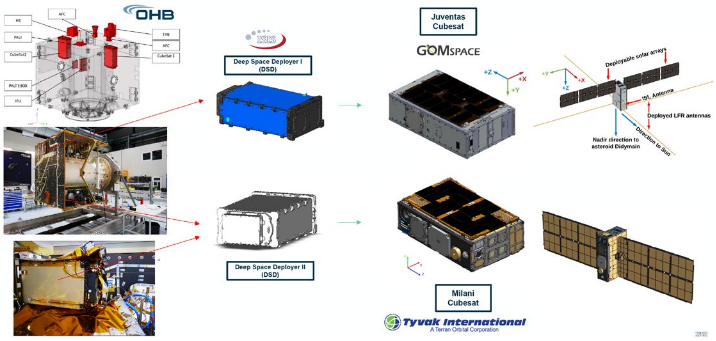

Figure 4b. Deep Space Deployers and CubeSat accommodation on Hera

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 [1], 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 manoeuvres. 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.

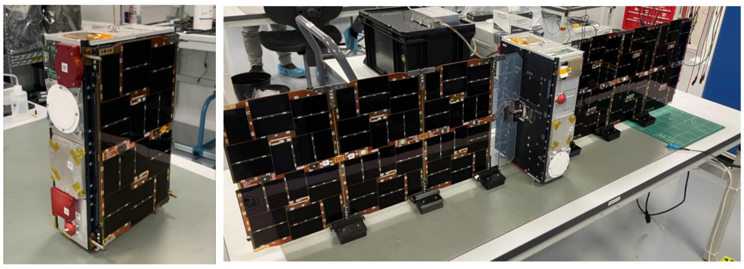

Figure 5. 6U-XL Milani CubeSat (Flight Units) stowed and deployed configurations (image credit: Tyvak International)

The 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).

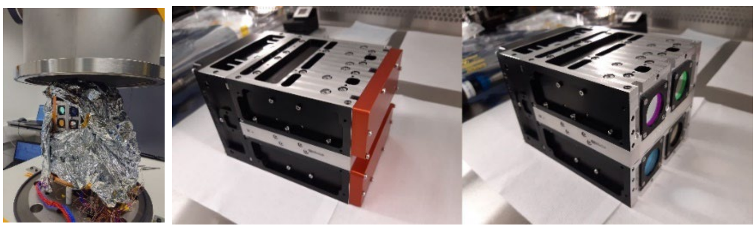

Figure 1. ASPECT Payload Flight Unit (Image credit of VTT)

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 Flight Unit (Image Credit: INAF)

Hera 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

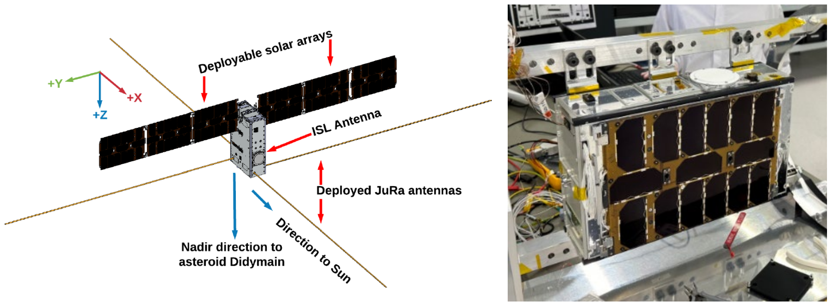

Figure 8 – Deployed (Render, Left) and Stowed (Flight Unit, right) configuration of the Juventas satellite

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
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

Table 3 – Juventas Cubesat technical characteristics

Juventas carries a 6DOF Chemical propulsion subsystem developed by GOMSpace Sweden (see Figure 8b), which is capable of a delta-v of 10 m/s and has 8 MEMs thruster of 1mN.

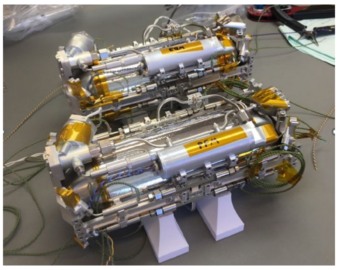

Figure 8a – Juventas QM and PFM PROPUlsion subsystems (Image Credit GOMSpace SE)

Juventas carries one 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 on-board 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.

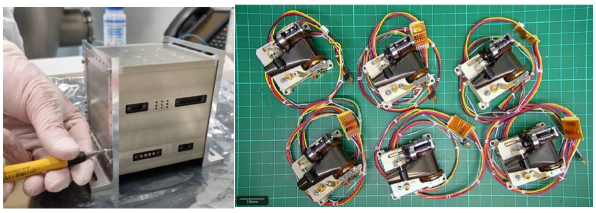

Figure 9 – Juventas Low-Frequency Radar Flight Unit(left) (Image credit: IPAG and Emtronix Lux.). Low-Frequency Radar Antennas Flight Models (Right). (Image credit: Astronika)

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.

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. 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.

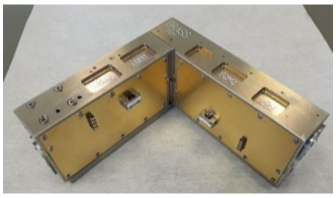

Figure 11. Juventas Gravimeter instrument (Image credit: Royal Observatory of Belgium and Emxys)

Deep Space Deployer (DSD)

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 years). The deployment of each CubeSat occurs in a three-step deployment sequence, 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.

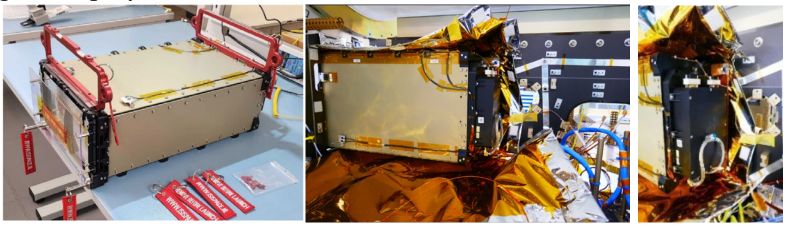

Figure 11b – Deep Space Deployer (Stand-alone, Image Left credit ISISpace NL). Deep Space Deployer + LSIB integrated inside Hera S/C (image in the right, credit OHB Systems)

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.

Life Support interface Board (LSIB)

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 (tested in proton and heavy-ion), 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 11c. Figure 11d shows a simple electrical schematic of the LSIB, DSD and Hera avionics.

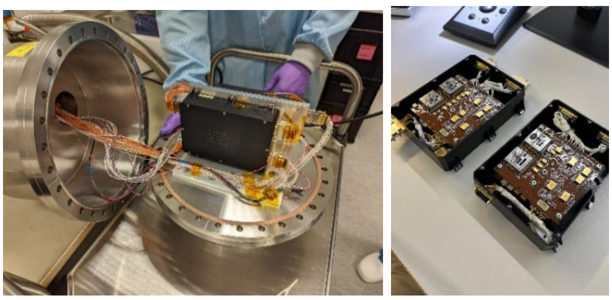

Figure 11c – Juventas and Milani Life Support Interface Board (LSIB) FMs serving as interface with the Hera Satellite.

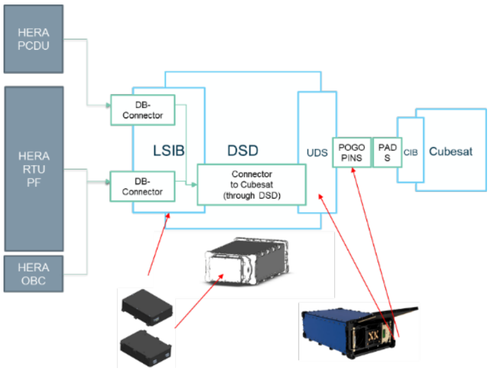

Figure 11d –LSIB+DSD+Hera high level schematics.

Concept of Operations

After the Hera, S/C performs its rendezvous and capture manoeuvre, 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.

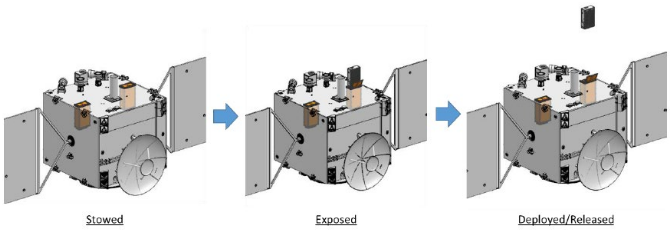

Figure 12: Illustration (Credit OHB Systems) of the two-step CubeSat deployment sequence. Left: The CubeSat is stowed inside the DSD (highlighted in orange). Middle: The CubeSat is ejected from the DSD into the exposed configuration, but still connected to the spacecraft for power and communication. 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.

Joint AIT with Main Hera Platform

The Hera Cubesats, unlike standalone LEO or deep-space Cubesats, required a relatively complex testing phase with the Hera satellite, to verify all the interfaces requirements, as per the Hera CubeSat Interface Requirement Document, to full-fill Hera System level requirements. The testing campaign, utilised several Cubesats models, following and representatives' incremental approach, allowing both the Hera satellite, and the Cubesats mature, until both Hera PFM and Cubesats FMs met on the E2E and EMC testing (see Figure 13).

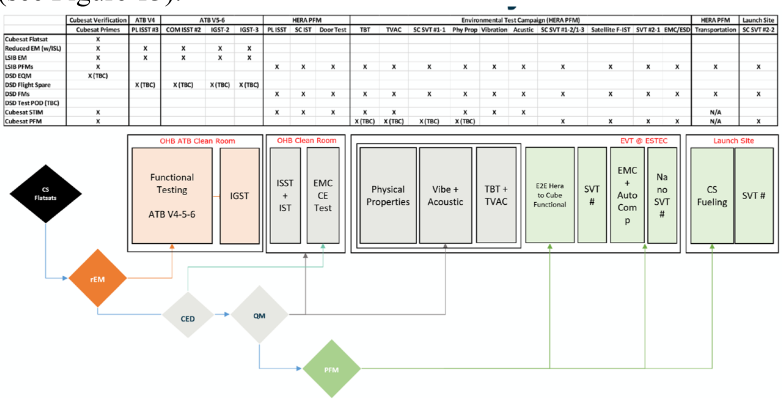

Figure 13. Hera AIT Flow Vs Hera CubeSat Models. Reduced Engineering Model (rEM), Conducted Emission Model (CED), Qualification Mode (QM)l, Proto-Flight Models (PFM)

Avionics Test Bench EM Testing

The testing campaign started on the Hera ATB (Avionics Test Bench) where all Hera units are represented in Engineering Model configuration, including the Cubesats with the so-called rEM's (Reduced Engineering Models) see Figure 14. The rEM includes an EM of the main platform avionics of the CubeSats (i.e OBC, PCDU, Battery and Backplanes) and they are able to perform exactly the same functionalities as the FM Cubesats in STOWED configuration (configuration during the CRUISE Phase to the asteroid), and the Exposed configuration. This includes electrical and SW functionalities (through the LSIB connection) such as Cubesats Battery Charging, CubeSat Switch ON, performance of functional checks (i.e Are you alive tests, Health check tests, SW updated, etc). The ATB setup is fully representative of the CRUISE phase, and will be kept as an operational ATB during all the mission operations after launch.

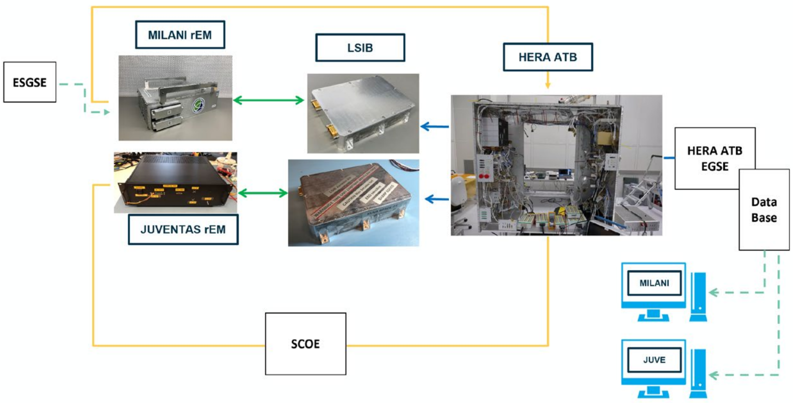

Figure 14 – Milani and Juventas rEMs connected to the Hera ATB at OHB Bremen Clean Room (Image Credit OHB Systems/ESA)

Each CubeSat (both Milani and Juventas) has developed their own full "FlatSat/C-ATB" (see Figure 15) in order to perform electrical, functional, SW and harness testing, and will be used during the operation phases of the Mission.

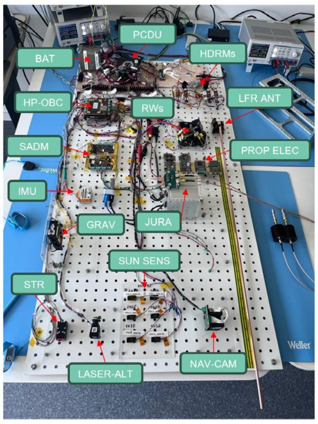

Figure 15 – Juventas Flatsat at GOMSpace Luxembourg (Image credit: GOMSpace LUX and ESA)

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. A series of models (See Table 2) 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 2– Hera Cubesat Models developed for the Mission

CubeSats Qualification Models Integration on Hera Satellite

In order to prevent over-testing of the CubeSats FMs, and in order to avoid dependencies on the development schedules of the Cubesats FM with the Hera platform AIT flow, from the beginning of the project the Cubesats QM models were design and built (see Figure 16). The Cubesats Qualification Models are fully representative of the Mechanical, Thermal, and functional interfaces, except for the capability of Intersatellite link with Hera. The QMs include Flight quality avionics and mechanical sub-assemblies. The qualification units of the Cubesats have been fully qualified at CubeSat level first, and then integrated into the Hera satellites (see figure 16) to be tested through Hera environmental tests for Vibration and thermal vacuum cycling.

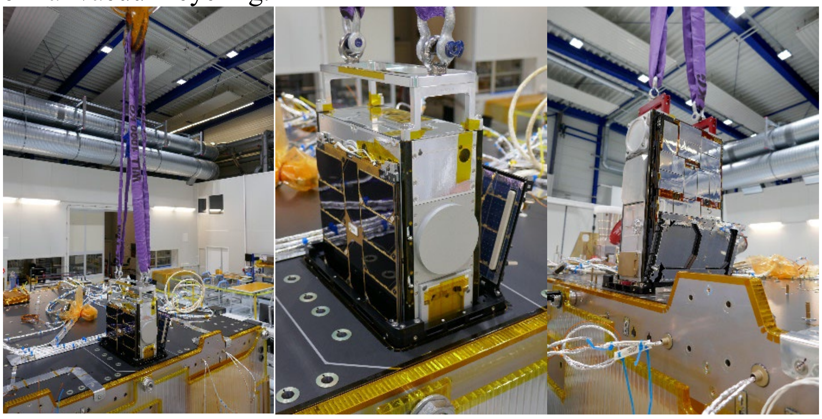

Figure 16 – Milani (right image) and Juventas (2xleft) Qualification Models being integrated on the Hera platform, showing its integration MGSE and utilising the clean room crane (Image credit OHB Systems/ESA)

Hera Vibration Testing with CubeSats QMs

The Hera satellite, in preparation to its launch on-board of a SpaceX Falcon-9 rocket, has been subjected to vibration testing. Given the configuration of the Deep Space deployers with regards the Hera structural elements on the Central tube and shear web panels, the loads on the Hera Interface are amplified through the Hera structure and after reaching the mechanical interface with the Deep Space Deployers, these mechanical loads are again modified (amplified and dumped depending on the frequency range) until they reach the CubeSat interface (through the rails). Given the level of integration and dependencies with rather complex transfer functions (i.e. Input-to-Hera + Hera-to-DSD + DSD-to-CubeSat) the Cubesats, were qualified at relatively high loads for a regular piggyback launch-type CubeSat (see Figure 17 for input loads at CubeSat qualification level, both QMs and FMs).

QM Loads Specification		
Random Vibration (Qualification)		
	Frequency (Hz)	PSD (g2/Hz)
	20	0.026
	150	0.16
	800	0.16
	2000	0.026
Reference Frame	BRF	
Direction	X,Y,Z	
Duration	120 Seconds	
GRMs (g)	9.8	
Tolerances	3dB	

PFM Loads Specification		
Random Vibration (Qualification)		
	Frequency (Hz)	PSD (g2/Hz)
	20	0.011
	150	0.08
	800	0.08
	2000	0.013
Reference Frame	BRF	
Direction	X,Y,Z	
Duration	60 Seconds	
GRMs (g)	9.8	
Tolerances	3dB	

Sine Vibration (Qualification)		
Direction	Frequency (Hz)	Qualification Load (g)
IP2-X	5	1
	12.2	8
	40	8
	45	8
	100	8
OOP-Y	**5**	1
	12.2	8
	35	8
	50	8
	55	8
	70	8
	80	8
	100	8
IP1-Z	5	1
	17.25	12
	35	12
	40	12
	90	12
	92	12
	100	12

Sine Vibration (Qualification)		
Direction	Frequency (Hz)	Qualification Load (g)
IP2-X	5	10mm
	12.2	6
	40	6
	45	3
	100	3
OOP-Y	**5**	10 mm
	12.2	6
	35	6
	50	2
	55	1.6
	70	1.6
	80	3.5
	100	3.5
IP1-Z	5	10mm
	17.25	12
	35	12
	40	5
	90	5
	92	3
	100	3

Figure 17 – Cubesats QM Qualification Loads Environments utilised for CubeSat qualification (Left) and CubeSat PFM Loads utilised for the PFM testing.

As can be observed in Figure 17, the loads were heavily reduced from the QM to the FM campaign, given than the Hera PFM level testing took place in between, and the Deep Space Cubesats were instrumented, in that campaign. The results (see figure 18) were utilised in order to justify the reduction of the loads for the FM campaign.

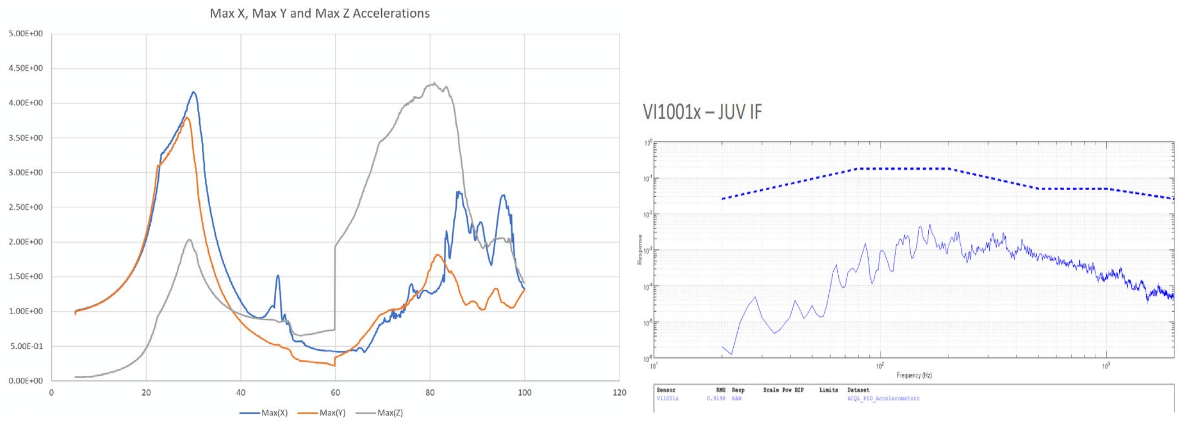

Figure 18 – Example of Sine loads on the OOP/IP1/IP2 axis derived from the Accelerometers mounted on the Deep Space Deployers during Hera environmental test Campaign (Left). Random profile derived from the Hera Acoustic Test, on the DSD instrumentation (right)

The derivation of reduced loads and confidence in the load levels was possible because all CubeSat testing was done in QM of the DSD models, hence fully representative, and the acceleration and frequency response were measured (Cubesats instrumented) during all campaigns.

Hera TVAC/TBT with Cubesats inside

As the described on the previous sections, the CubeSats' qualification models have been utilised during the Hera level Bake-out, Thermal Vacuum Tests, and Thermal Balance Tests. During the campaign (see Figure 19), both Cubesats executed several functional tests on Cold and Hot plateaus, including full functional tests (as per scenario defined for the Cruise phase), battery charging, etc, while constantly acquiring data through the Hera On-board Computer. Several requirements were validated on the TVAC campaign, including Failure detection, Isolation and Recovery requirements. Both Cubesats implements and FDIR strategy during CRUISE, in which, in case of overheating (Battery and main core avionics reaching a pre-defined temperature thresholds) inside the deployers, the Cubesats can request Hera to switch them OFF, signalizing through a BSM line (to the Hera OBC) identified as the "abort line", in case the Cubesats are being utilised for CRUISE functional tests.

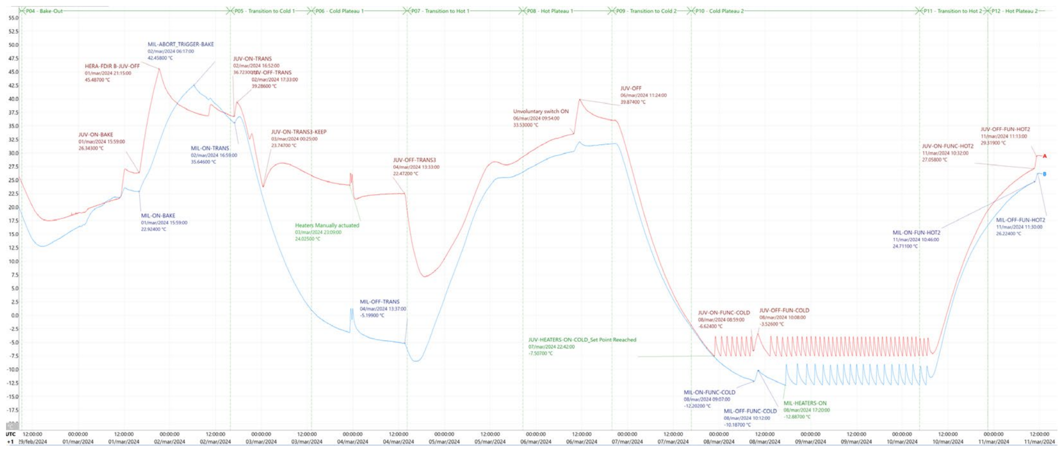

Figure 19 – Temperature reading of the Thermocouples on the Deep Space Deployers Temperature Reference Points (TRP's) through the full Thermal campaign. The Active bake-out phase was used to verify the FDIR abort line triggering.

As shown in Figure 19, the autonomous functionality of the Hera heaters, that might be active during the CRUISE phase, in case the CubeSat TRP temperatures go below a predefined set-up, have been exercised and verified.

End to End Hera DSD Hot Deployment and Cubesats FMs Testing

After the Hera level Vibration and TVAC tests campaigns were finalised, the Hot Deployment of the mechanisms were performed. This campaign was focused on commanding the DSD Hold down release mechanism (HDRMs), including the doors, the Umbilical Disconnect System (UDS) and the CubeSat Release System (CRS). The commands were executed using the full electrical and functional chain with the flight commands to verify that the mechanism actuation, command firing and status read-out work after exposure to the environmental loads on the Hera PFM. Within Figure 20, the full AIT flow, including all the intermediate functional tests and the Mechanical reconfiguration are depicted. The mechanisms were fired with nominal and redundant HDRMs, and also the commands and sequences to fire with the nominal and redundant Hera RTUs were exercised.

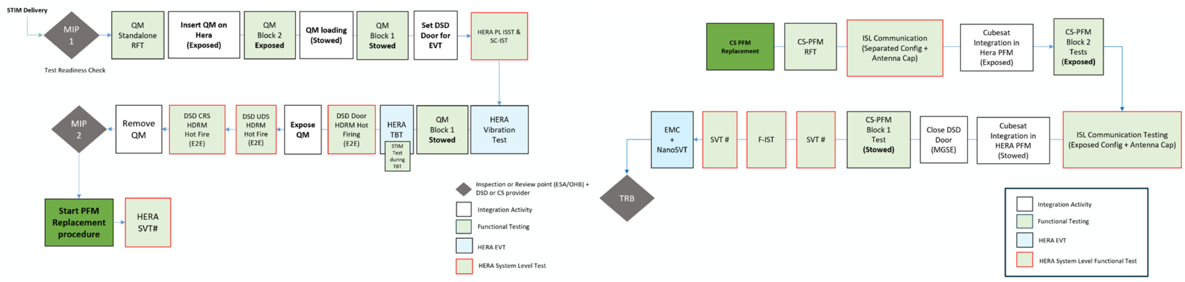

Figure 20. CubeSat-Hera AIT flow for QM (left) and FMs (right)

For the first time on the full AIT flow, the Hera PFM S/C and the Cubesats PFM S/C were interface together, in order to perform a full E2E test including Intersatellite Link in separated configuration (see next section), and Full functional tests of the Cubesats in Exposed configuration and STOWED configuration through the Hera umbilical UARTs inside the DSDs. Figure 21 shows both Cubesats PFMs, and Hera PFM in exposed configuration during the execution of the Exposed Checkouts.

Figure 21. Hera Cubesats PFMs in Exposed Configuration during the Exposed Checkouts functional tests at ESA Rosetta clean room (Image credit OHB Systems and ESA). MGSE + Slings + Clean room crane used as off-loading system during the Hot deployment of the CRS

The Cubesats ISL were tested directly communicating with the Hera ISL, through tests caps and RF harness. A variety of tests were executed including Ranging Tests, PING tests, House-Keeping TM exchange from CubeSat to Hera, and from Hera to CubeSat, at different data rates.

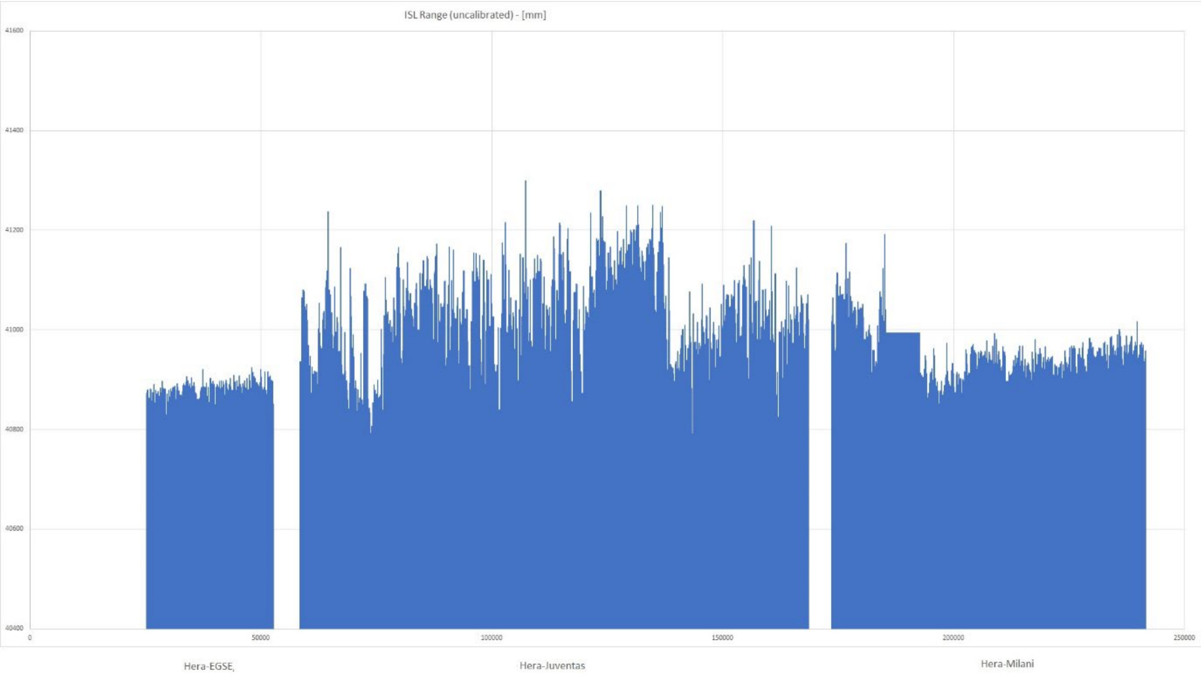

Figure 21a. Ranging Measurement obtained from Hera ISL while connected to Hera Cubesats on TestCaps, without any post-processing or calibration.

Hera EMC and Auto-compatibility with Cubesats FMs

The Hera Cubesats are brought into the ESA Maxwell anechoic chamber, the objective is to verify that Hera can operate with the CubeSats in ON state. The CubeSat susceptibility to electromagnetic emission was verified a-priori as part fo the CubeSat stand-alone test campaign. After the EMC, the Auto-Compatibility (i.e. Hera – Cubesats) test campaign takes place following different test configuration that can be summarized on the Figure 22. The auto compatibility tests are all performed inside the Anechoic chamber, radiating with the ISL and the Hera X-Band transponder over the air (OTA). The tests are performed in three different mechanical configurations:

- Configuration 1: Both Cubesats in separated (free flying) simulating the Cubesats at distance of 60 km, while radiating OTA,
    - CONF 1-A: Hera Transponder ON
    - CONF 1-B: Hera transponder OFF

- Configuration 2: Juventas in Exposed Configuration, while Milani is stowed. Juventas is operating and communication both through the UARTs/Umbilical and the ISL.
    - CONF 1-A: Hera Transponder ON
    - CONF 1-B: Hera transponder OFF

- Configuration 3: Milani in Exposed Configuration. Milani is operating and communication both through the UARTs/Umbilical and the ISL.
    - CONF 1-A: Hera Transponder ON
    - CONF 1-B: Hera transponder OFF

After tall these configurations were tested, a NanoSVT is performed. The NanoSVT is a System Validation Test in which ESOC (European Space Operations Centre) who is the part of ESA responsible of the Satellite operations, connects to the clean room in remote, and through Hera exercise the UARTs and ISL links, while validating several TCs. The setup for the NanoSVT is MOC (Hera Mission Operations Center) -> NDIU (Network Data Interface Unit) -> RF SCOE -> Hera -> ISL (Intersatellite Link) -> CubeSat ISL

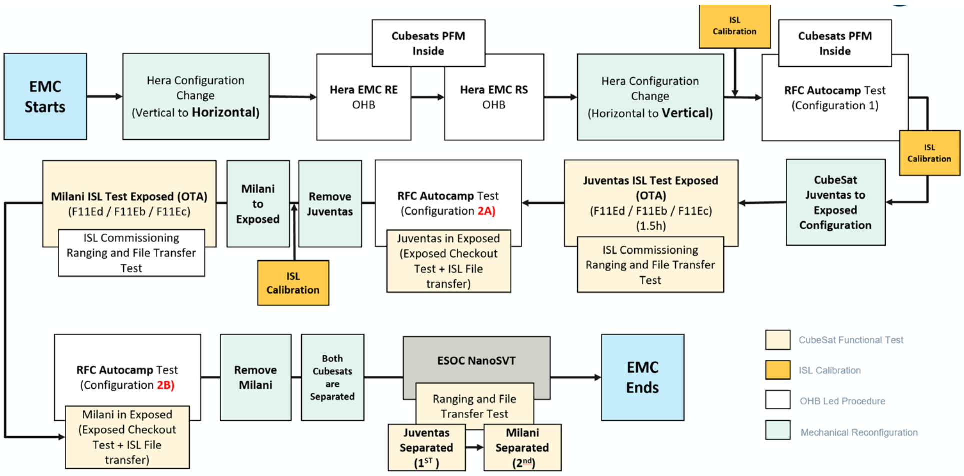

Figure 22. EMC and Auto-compatibility testing flow for Hera and the Hera Cubesats. Tests executed at the ESA Maxwell Anechoic chamber facility.

Conclusions

The Hera Cubesats are a technology demonstration opportunity payload on board the 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 (October 2024), 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 complexity of system interfaces that shall be verified, to integrate a CubeSat safely and successfully inside a larger mission. The stand-alone qualification cubesats and the EVT campaign performed in join operations with Hera have been completed. Vibration testing, Thermal Vacuum Cycling, EMC, Auto-compatibility testing , Hot deployment tests, and several functional tests were the objective of the verification campaign which has been successfully completed. Several lessons learnt have been derived from the Hera-Cubesats campaign which will be gather together with the already existing for future ESA interplanetary missions involving Cubesats as secondary passengers.

Bibliography

[1] M.Cardi, et.al Hera Milani CubeSat – 4S Conference Paper