The Hera Milani mission

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Abstract. Hera is the European part of the Asteroid Impact & Deflection Assessment (AIDA) international colaboration with NASA who is responsible for the DART (Double Asteroid Redirection Test) kinetic impactor spacecraft. Hera will be launched in October 2024 and will arrive at Didymos in January 2027. The Hera mothercraft will accommodate two 6U Nanosatellite, Milani and Juventas. The Milani Nanosatellite is developed by Tyvak International leading a consortium of European Universities, Research Centers and Firms from Italy, Czech Republic, Finland. During the cruise to the Asteroid (+2 years), Milani Nanosatellite will be hosted inside the Hera mothercraft, periodically checked for health and charged. At arrival it will be deployed and commissioned while HERA is performing the Didymos detailed characterization phase, at about 10 to 20 km distance from the asteroid. The Milani mission objectives are defined as to add scientific value to the overall Hera mission: i) Map the global composition of the Didymos asteroids, ii) Characterize the surface of the Didymos asteroids, iii) Evaluate DART impacts effects on Didymos asteroids and support gravity field determination, iv) Characterize dust clouds around the Didymos asteroid, enhancing the scientific return of the whole HERA mission. The scientific payloads supporting the achievement of these objectives are the main Payload "ASPECT" (developed by VTT, Finland), a SWIR, NIR and VIS imaging spectrometer and the secondary Payload "VISTA" (developed by INAF, Italy), a thermogravimeter aiming at collecting and characterizing volatiles and dust particles below 10µm. The Milani mission and the project team is facing challenges such as, among others, the use of COTS components in deep space environment, optical navigation implementation, interfaces management with the HERA mothercraft since the very beginning of the design up to the mission. Tyvak International work focuses on the development and integration of the Milani vehicle, including mission specifics development enabling the mission and vehicle models enabling early interface testing with Hera mothercraft.

Introduction

In 2027, the Hera spacecraft will rendezvous with the binary asteroid 65803 Didymos as the European contribution to the AIDA (Asteroid Impact and Deflection Assessment) international collaboration. NASA is responsible for the Double Asteroid Redirection Test (DART) kinetic impactor spacecraft. Hera and DART have been conceived to be mutually independent, however, their value is increased when combined. Indeed, Hera is a planetary defense mission aimed to investigate the effect of DART impact, with clear scientific objectives as a bonus. In proximity to the target, Hera will release two 6U Nanosatellites called Milani and Juventas. The two nanosatellites will be the first Nanosatellites to orbit in the close proximity of a small body and the first to perform scientific and technological operations around a binary asteroid.

Tyvak International is responsible for the Milani system development and is leading (as Prime Contractor) a large consortium made by 10+ entities from Italy, Czech Republic and Finland. Milani will contribute to the scientific value of the Hera planetary defense mission, mainly through the visual inspection of the asteroid (main payload: ASPECT) and dust detection (secondary payload: VISTA).

Didymos properties

Didymos is a binary Near-Earth Asteroid (NEA) of S-type discovered in 1996 formed by Didymos, or D1 (the primary) and Dimorphos, or D2 (the secondary). Up-to-date data about Didymos and Dimorphos are reported in the following tables:

Table 1. Binary system parameters (semi-major axis, eccentricity, inclination, revolution period)

System parameters			
a 1.66446 AU	e 0.3839	i 3.4083 deg	T 770 days

Table 2. Didymos and Dimorphos mass and spin periods properties

System parameters			
M1 5.226×10^{11} kg	M2 4.860×10^{9} kg	T1 2.26h	T2 11.92h

The orbital properties are retrieved from the up-to-date kernels of the Hera mission. In the up-to date reference model, Dimorphos and Didymos are assumed to share the same equatorial plane on which their relative motion occurs and Dimorphos is assumed to be in a tidally locked configuration with Didymos. In this work, two reference frames are used. "DidymosEclipJ2000" is a quasi-inertial reference frame, centered in the system barycenter with the axis directed as the inertial EclipJ2000 reference frame. This frame can be considered inertial for intervals of time negligible with respect to Didymos heliocentric motion. "DidymosEquatorialSunSouth" is a non-inertial reference frame in which the trajectories are shown. It is centered in the system barycenter and has the X-Y plane on the asteroid equatorial plane. The X axis is aligned with the projection of the Sun vector on the equatorial plane and the Z-axis is aligned to the south pole of Didymos.

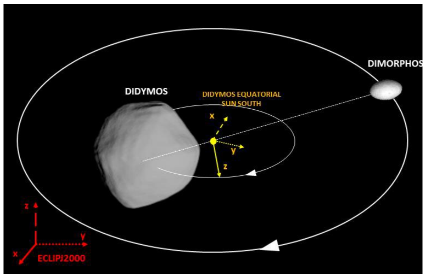

Figure 1. Didymos geometry. The reference frames are highlighted. The red frame is the inertial Eclip2000 which corresponds to the quasi-inertial DidymosEclipJ2000 when centred in the system barycentre. The yellow frame is the Didymos Equatorial Sun South (Courtesy: Politecnico di Milano)

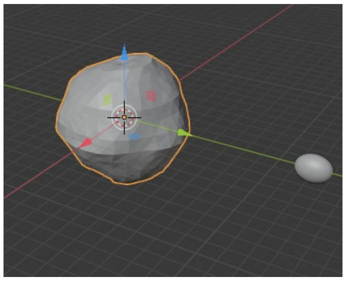

*Figure **2**. Didymos system geometry: polyhedral radar shape model of D1 and triaxial ellipsoidal model of D2 in D1_Body reference frame. (Courtesy: Politecnico di Milano)*

Scientific goals and operational constraints

Milani scientific phases design has been mostly driven by its main payload, ASPECT. ASPECT is a passive payload, equipped with a four-channel visible to near-infrared hyperspectral imager and will be used on Milani to perform global mapping of the asteroids with detailed observation of the DART crater on Dimorphos. ASPECT main scientific goals can be summarized in three actions:

1. Imaging both the asteroids with a spatial resolution better than 2 m/pixel
2. Imaging the secondary asteroid with a spatial resolution better than 1 m/pixel
3. Imaging the DART crater with a spatial resolution better than 0.5 m/pixel at phase angle (Sun-Asteroid-Milani angle) in the range [0-10] deg and [30-60] deg.

In terms of trajectory design, spatial resolution requirements drive the maximum range at which scientific observations can be performed. From an operational point of view, Milani's communication with ground will be performed via Inter-Satellite Link (ISL) using Hera as data relay. For this reason, data downlink and uplink must be performed within the same communication windows used by Hera. Operations will be scheduled considering:

- Hera mission operations requirements
- Milani Nanosatellite mission operations requirements
- Mission Data downlink (Milani-to-Hera)
- Communication window (Hera-to-Earth)

In order to avoid open-loop manoeuvres, Milani needs to select the manoeuvring frequency to be as close as possible to Hera's pattern (4-3 days). This is not mandatory, however, it ensures the compatibility of the strategy with the requirement on the Turn-Around time (TAT)1 of 48 h.

Scientific goals and operational constraints are the results of an initial phase of requirements definition and consolidations, led by Politecnico di Torino team and have been the main driver for the detailed design of the main phases of Milani's mission: Far Range Phase (FRP) and Close Range Phase (CRP). The scientific goals that mostly drove the mission design of Milani have been derived from its main payload, ASPECT, presented in the following sections.

Milani Mission profile and Concept of Operations (ConOps)

The Milani Mission is designed by Politecnico di Milano (PoliMI). Milani trajectory design has been mainly driven by the main scientific goals of the mission, but it has also been influenced by both technical and operational constraints. Due to the low gravity environment around the asteroids, selecting Keplerian orbits as nominal trajectories would require a demanding station keeping strategy to counteract the SRP effect. For this reason, a patched-arc manoeuvring strategy that leverages the SRP acceleration to target pre-selected waypoints has been implemented. This strategy has flight heritage in small-body environment. It is the one currently envisaged by the Hera spacecraft during its operational phases and previously performed by the Rosetta spacecraft during its initial scientific phase, after rendezvous with comet 67-P/Churyumov-Gerasimenko. The waypoints selection has been mostly influenced by the passive nature of Milani's payload as well by the on-board navigation strategy, which forces the Nanosatellite to avoid the night-side. The resulting trajectories are loop orbits with manoeuvres points placed as far away from each other as possible to maximize the time spent in proximity to the system. Main Milani mission phases are hereafter presented:

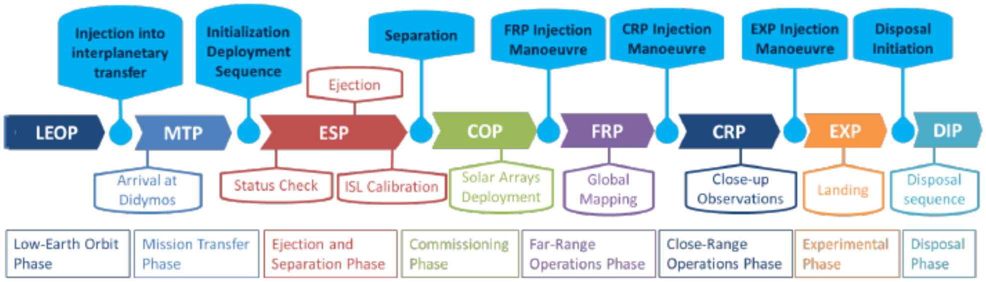

Figure 3. Milani mission phases

- **Low Earth Orbit Commissioning Phase (LEOP)**, will be done on Hera spacecraft upon launch; a specific list of checkout tests will be executed also on Milani Nanosatellite to verify the basic functionalities that can be verified in stowed and integrated Configurations
- **Mission Transfer Phase (MTP)**, or interplanetary cruise, will be characterized by regular checkout tests to be executed on Milani Nanosatellite to verify the basic functionalities
- **Ejection and separation phase (ESP)**, will start upon arrival to the asteroids and will be characterized by checkout test in stowed configuration, ejection of Milani Nanosatellite outside Hera, pre-deployment checkout in exposed configuration, Milani Nanosatellite separation from Hera
- **Commissioning Phase (COP)**, checkout, stabilization, and calibrations
- **Far Range Operations Phase (FRP)**, transfer to the operative orbits, first global mapping, and technologies demonstration
- **Close Range Operations Phase (CRP)**, transfer to the operative orbits closer to the asteroids, Close-up observation of Didymos bodies, additional technology demonstration, observation of the DART impact crater
- **Experimental Phase (EXP)**, foreseeing the landing on the asteroids or transfer on a heliocentric graveyard orbit, currently under evaluation
- **Disposal Phase (DIP)**, Passivation

System Overview

The Nanosatellite leverages on Tyvak Trestles platform architecture, avionics technology Mark II. This is a standard platform, however, some customizations were made specifically for Milani mission. In the following figure, the vehicle configuration is shown.

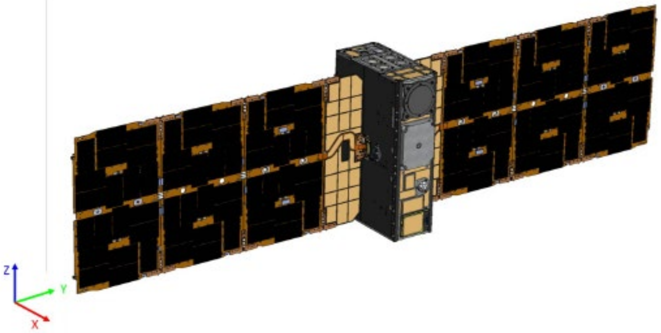

Figure 4. Milani nanosatellite – Deployed configuration

The system is composed of the following elements:

- Avionics (Tyvak Mark II technology), including Flight Computer, Electrical Power System, ADCS
- Primary Payload (ASPECT)
- Secondary Payload (VISTA)

- Cold-gas propulsion system, enabling technology
- External Inter-satellite link (ISL) radio + antennas
- Navigation Camera
- COTS components
- Mission Specific Interfaces (such as Payload Interface Board, PIB)
- Interfaces with the Hera mothercraft:
  - Milani is integrated into the Deep Space Deployer (DSD) developed by ISIS, providing also a specific CubeSat Interface Board to interface the Milani CubeSat with the DSD
  - The main interface with the assembly constituted by the DSD and Milani Nanosat with the Hera mothercraft is the Life Support Interface Board (LSIB), developed by KUVA Space and allowing the exchange of power and data between the two spacecraft and so the execution of the checkout tests during the stowed and exposed configuration.

A radiation-related analysis was executed to mitigate risks associated to the execution of the mission in deep space environment. The radiation analysis effort was led by Politecnico di Torino team and included both fault injection approaches and dedicated radiation testing on a subset of components identified as critical for the mission.

Conclusions

To date, the Milani project is in Assembly Integration and Test phase. Upon successful vehicle qualification, a System Validation Testing (SVT) Phase will be foreseen aiming at testing the end-to-end communication with the Hera mothercraft at ESTEC. A risk mitigation approach was implemented during the project through the reduced EM and Structural and Thermal Interface Model (STIM) development and delivery.

Acknowledgement

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