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The Hera Data Hub

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Abstract

The Hera Data Hub serves as the central repository for all data related to the Hera mission and its realization is funded by ESA. It manages raw data collected by the Hera spacecraft and its cubesats, Milani and Juventas, as well as all processed data generated on the ground to achieve the mission's scientific objectives. This paper outlines the designed data flows within the Hera mission, focusing on the role of the Hera Data Hub. It provides a technical overview of the Hera data products, detailing the technical aspects of data model, and highlights the requirements for data access and visualization. Additionally, it explains the design and implementation decisions made by ALTEC in developing the system.

Hera is a ESA planetary defence mission in the Space Safety and Security Program of the European Space Agency launched on 7 October 2024. It will rendezvous in 2026 with the binary asteroid (65803) Didymos and in particular its moon, Dimorphos, which was impacted by NASA's DART spacecraft on 2022 September 26 as the first asteroid deflection test. The main goals of Hera are the detailed characterization of the physical properties of Didymos and Dimorphos and of the outcome of the DART impact, as well as measurement of the momentum transfer efficiency resulting from DART's impact.

The Hera Data Hub receives raw and calibrated data from the Instrument Team, which in turn obtains payload data from the Hera Mission Operations Centre (HMOC) hosted at ESOC. Raw data is typically delivered within 1-5 days after reception, while calibrated data is provided following a calibration and validation period, expected to last no more than a few months. The Hera Data Hub will make the received data available to the Hera Investigation Team immediately and to the public after the calibration and validation period according to the ESA data access policy.

Members of the Hera Investigation team will create (multi-instrument) high-level products, which will also be delivered to and archived by the Hera Data Hub. At the conclusion of the Hera mission, all data will be transferred from the Hera Data Hub to ESA's Planetary Science Archive.

The Hera Data Hub system is based on the ASDTR data management framework that is a distributed data management framework that offers a range of native functionalities, such as automated data product crawling, uploading, and downloading; customization of data models; integration of diverse data product types; enhancement of metadata descriptions; support for multiple data storage solutions; and comprehensive management and monitoring of data flows.

The availability of this framework, coupled with a well-established tailoring process based on agile methodology, allows for the rapid implementation of the Hera Data Hub in a remarkably short time.

Keywords: hera, data system, framework, planetary data, ASDTR

Nomenclature

None

Acronyms/Abbreviations

Aerospace Logistics Technology Engineering Company (ALTEC), ALTEC Space Data Transformation and Repository (ASDTR), Application Programming Interface (API), Comma-Separated Values (CSV), European Space Agency (ESA), European Union (EU), Graphical User Interface (GUI), Hera Data Hub (HDH), , JavaScript Object Notation (JSON), Planetary Data System version 4 (PDS4), Asteroid Framing Cameras (AFC), Spectral Imager (HSH), Thermal Infrared Imager (TIRI), Planetary Science Archive (PSA), Observatory de la Cote D'Azur (OCA)

1. Introduction

Hera is a ESA planetary defense mission of the Space Safety and Security Program of the European Space Agency launched on 7 October 2024. The Hera mission objectives are to investigate from late 2026 December a binary asteroid, including its subsurface and interior properties, and to measure in great detail the outcome of a kinetic impactor test, thus providing extremely valuable information for asteroid impact threat mitigation, mining, and science purposes.

It will rendezvous in 2026 with the binary asteroid (65803) Didymos and in particular its moon, Dimorphos, which was impacted by NASA's DART spacecraft on 2022 September 26 as the first asteroid deflection test. The main goals of Hera are the detailed characterization of the physical properties of Didymos and Dimorphos and of the outcome of the DART impact, as well as measurement of the momentum transfer efficiency resulting from DART's impact [1].

1.1 Hera Payload and Data Products

To achieve its objectives and provide valuable planetary defence and scientific insights, the Hera spacecraft will be equipped with several advanced instruments [1]. These instruments are designed to support the mission's key goals and provide essential data for the study of asteroid Dimorphos. The onboard instruments of the Hera mission include:

- Two Asteroid Framing Cameras (AFCs)
- Spectral Imager (Hyperscout-H)
- MicroLIDAR (PALT)
- Thermal Infrared Imager (TIRI)
- An X-band Transponder (X-DST) and a Hera-to-CubeSats Intersatellite Link (ISL) transceiver for the radio science experiment (RSE).
- Small Monitoring Cameras (SMC) for monitoring the cubesat release

In addition to these core instruments, Hera will deploy two CubeSats at close proximity to Dimorphos, which will communicate with the spacecraft through the ISL transceiver. The two CubeSats are:

1. Juventas, composed of the low-frequency monostatic radar JuRa, which will perform the first direct measurement of an asteroid interior, as well as the gravimeter for small solar system objects (GRASS), an accelerometer, and the ISL.
2. Milani, composed of the near-infrared imager ASPECT, the VISTA microthermogravimeter, a Navigation Camera and the ISL.

These payloads collectively enable Hera to carry out a wide range of scientific experiments, contributing crucial data for planetary defense and advancing our understanding of small celestial bodies. Each Hera instrument will acquire scientific telemetry, which will be processed to generate Level 1 (L1), Level 2 (L2), and Level 3 (L3) data products. These products will then be ingested into the Hera Data Hub for accessing, analysis and distribution.

1.2 Hera Mission Ground Segment

The Hera Data Hub receives raw and calibrated data from the Instrument Team, which in turn obtains payload data from the Hera Mission Operations Centre (HMOC) hosted at ESOC. Raw data is typically delivered within 1-5 days after reception, while calibrated data is provided following a calibration and validation period, expected to last no more than a few months. The Hera Data Hub will make the received data available to the Hera Investigation Team immediately and to the public after the calibration and validation period according to the ESA data access policy.

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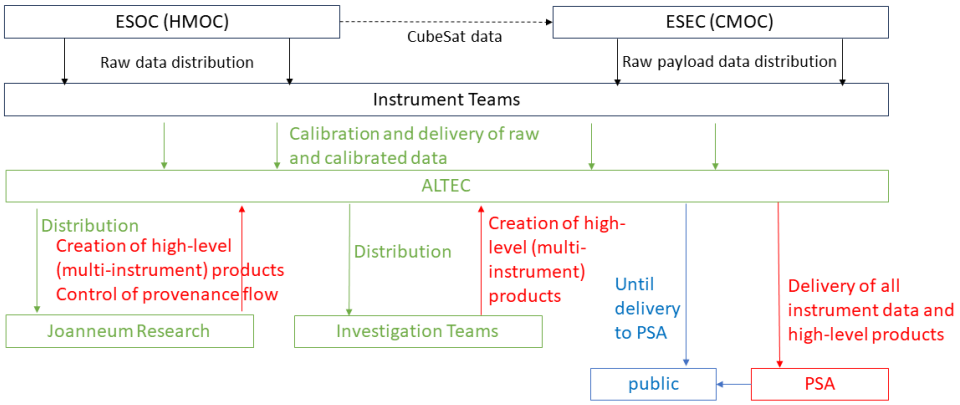

Figure 1 - HERA Ground Segment

2. The Hera Data Hub

The Hera Data Hub is a comprehensive data management system designed to support the data handling needs of the Instrument Teams and the Science Team throughout the execution of the Hera mission. It also facilitates the preparation of final data products for archiving in the PSA. This section provides a detailed overview of the Hera Data Hub architecture and its key capabilities.

Under the Observatory de la Cote D'Azur (OCA) contract, ALTEC is responsible for the development, deployment, and hosting of the Hera Data Hub, ensuring the collection, management, and distribution of all Hera mission data products. ALTEC is developing the system following an agile approach with sprint reviews with the HERA team every 3 weeks and with a direct involvement of users to shape capabilities according to the real user needs.

2.1 Objectives

The Hera Data Hub mission objectives concern the provision of a data system to be used during mission operations to fulfil the following points:

- Retrieval and ingestion of all data products defined and generated by each Instrument Teams and Scientist Teams in their facilities;
- Ingestion of all data products generated on ground for calibration purpose;
- Management, secure storage and cataloguing of ingested data products with proper metadata included versioning information;
- Authenticated and controlled access to data products based on user roles and privileges;
- Support for data exploration and retrieval through user-friendly interfaces and APIs;
- Facilitation of data sharing and collaboration among mission stakeholders;
- Preparation and support to validation of final data products bundle for archiving in the Planetary Science Archive (PSA);
- Monitoring and logging of data system activities to ensure traceability and integrity;
- Ensure high availability and reliability of the data services throughout the mission lifecycle.

Figure 2 illustrates the Hera Data Hub context, highlighting its central role in the data flow. On the left side, the Data Hub interacts with external systems, including data sources from the Instrument Teams—such as the BME repository for the AFC and HYPERSCOUT instruments, and the TIRI repository for the TIRI instrument—as well as the PSA as the final data distribution target. On the right side, the Data Hub interfaces with users through the provided Human-Machine Interface (HMI) and REST API, enabling access to data and services.

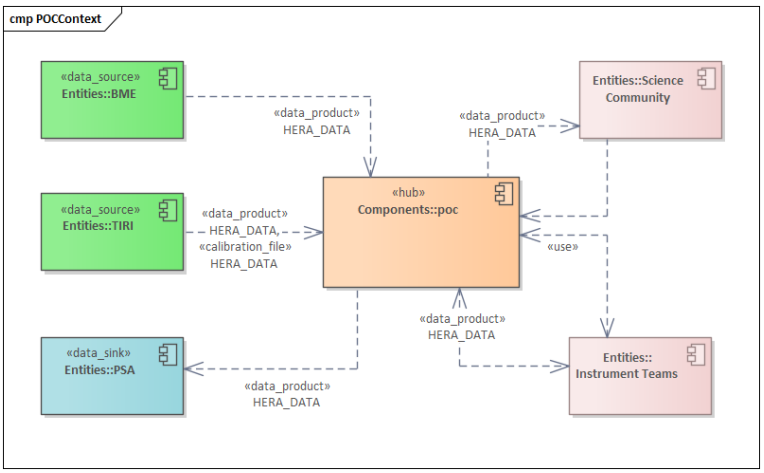

Figure 2 - Hera Data HUB Context

2.2 Architecture

The HERA POC is a distributed software system composed of several containerized applications running on ALTEC cloud platform leveraging container and Kubernetes technologies. *Figure 3* shows the high level architecture of the Hera Data Hub. The identified components are the following:

- **Front-End**: it will act as the web entry point for accessing and exploring the data stored in the data hub, as well as for exploiting the services exposed by other subsystems to the end-users;
- **Back-End**: it stores all Hera data products and their metadata, providing an access layer for data retrieval, ingestion into the internal data stores and distribution from/to internal and external endpoints; it is also in charge of exposing public REST API to enable machine-to-machine integration with the Hera Data Hub.
- **Infrastructure & Services**: it is the infrastructure backbone and it provides lower level access to resources and services. It manages authentication and authorization flows, as well as collecting statistics and metrics about the other S/Ss. It also manages the logging mechanisms and the notification flows.

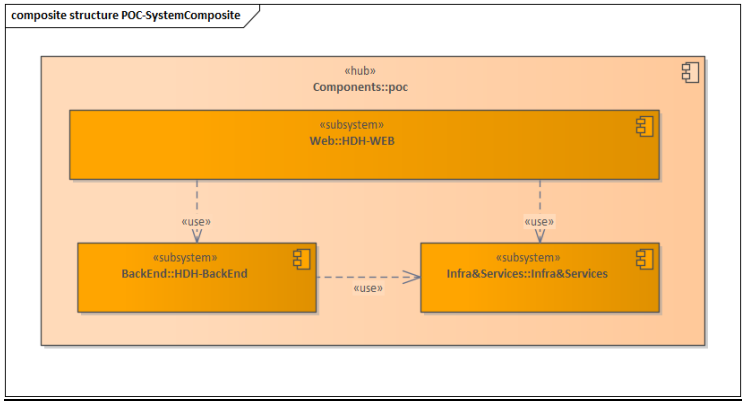

Figure 3 - HERA Data Hub composite view

2.3 Input Data Flows

The population of the Hera Data Hub system occurs through two mechanisms: (1) authorized end-users can upload data products via the web GUI by completing a form with the necessary product details; and (2) the system can automatically or manually ingest data products from pre-configured data sources allowing data products access through standard protocols such as HTTPS and SFTP. The second mechanism is generally preferred, as it enables machine-to-machine integration, allowing for the configuration and testing of the data retrieval process that will be executed repeatedly over time. However, the first mechanism is also robust, as it shares the same ingestion workflow with the automated approach. The main difference lies in how data products are delivered to the system's back-end—manually by users in the former, and automatically from predefined sources in the latter.

The core part of the input data flow is data products cataloguing based on the metadata extraction and enrichment. The system adopts a structured approach to data organization by introducing the concept of data type, which is used to

categorize data products during the ingestion phase. Each data type is defined by a set of key metadata elements—such as the *instrument name, observation ID, and processing level*—that are automatically extracted from the FITS file headers at the time of ingestion. This categorization enables a logical segmentation of data within the internal archive, significantly enhancing the efficiency of data retrieval, management, and manipulation. The presence of above fields allows the ingestion system to derive the correct data type for each product, ensuring consistency and traceability across the data repository. In the current phase, data products are generated as FITS files with metadata fields available in the header. However, all data collected within the Hera Data Hub will be compliant with the PDS4 (Planetary Data System, version 4 [2]) standard for data archiving.

2.4 Output Data Flows

The output data flow involves the extraction of data products managed within the Hera Data Hub, either through user-initiated download requests based on specific queries, or via automated system processes designed to prepare and deliver data product packages to the PSA.

The Hera Data Hub enables users to download data products through an intuitive interface accessible after login. From the "Products Page," users can search and filter data products using a query builder with customizable fields and logical operators. Each product entry provides key details such as instrument, observation ID, and processing level.

Users can interact with individual products to:

- View product details, including images and metadata;
- Download metadata in JSON or XML formats.

There are three main download options:

- Single Download: Accessed from the action panel of a specific product, this provides a ZIP archive containing the product and its metadata.
- Multiple Download: Users can select multiple products using checkboxes and initiate a grouped download via the "Download Selected" option. Resulting files are available on the SFTP server.
- Total Download: By clicking "Download All," users retrieve all search results matching the applied filters.

Additional options include exporting metadata to CSV, copying to clipboard, and resetting filters. Notifications inform users of download completion or errors during the process.

In line with long-term mission data preservation requirements, all data collected within the Hera Data Hub will ultimately be delivered to PSA at the conclusion of the mission. Although the data currently ingested into the Hera Data Hub do not yet conform to the PDS4 standard, they will be transformed accordingly prior to delivery to ensure compatibility with the PSA infrastructure and standards.

2.5 HMI Interface

To access HERA's functionalities, users must log in to the HERA GUI at https://heradatahub.altecspace.it/. However, the public landing page is accessible without logging in, allowing users to explore general information about the HERA Mission. Upon logging in with the standard username and password, users are directed to the dashboard, which displays statistics about the archive and provides a quick overview of the most recently ingested data products, sorted by their latest update time.

Figure 4 - HERA Landing Page

2.6 REST API Interface

The Hera Data Hub functionalities provided are also available through the public web API at https://public-api.heradatahub.altecspace.it. This API is a subset of the endpoints exposed by the system backend and offers users programmatic access to HERA's data and services. To ensure secure access, the API requires authentication through the OpenID Connect (OIDC) flow, utilizing JWT tokens. Each endpoint is protected by HERA's authentication layer, meaning that no invocation can be performed by unauthenticated clients. The system backend will validate the token, extract the user's information, and fulfill the request based on the user's roles.

2.7 Public Access

The Hera Data Hub has been designed and implemented to allow public access for any user that will complete the registration process and accept the "Hera Science Team and Data and Publication Policies" [3]. Users that are not member of Instrument Teams and Science Community can access to the web GUI and explore data products having the same access rights of the scientists group but with some time restrictions, the data will be available for public access 30 days later after the ingestion into the system.

4. ALTEC Data Management Framework

The Hera Data Hub system is based on the ASDTR (ALTEC Space Data Transformation and Repository) data management framework. ASDTR streamlines dataset management and utilization in ground segment projects, providing a robust technical solution deployed across various ALTEC science data centres [5,6]. ALTEC offers a portfolio of data system frameworks that can be easily tailored and deployed on various infrastructure layers. This portfolio is assorted, including frameworks designed and developed by third parties, such as the European Space Agency, as well as systems created by ALTEC [4]. ALTEC developed frameworks were introduced either when no suitable external solutions were available or when a common software platform was needed to support multiple ground segment projects led by the company. The selected third parties software are used for mission control system, operational simulator system and flight dynamics system. The ALTEC developed data system framework are AMPS (ALTEC Mission Planning System) for mission planning system, ASDP (ALTEC Space Data Processing) for data processing system and ASDTR for data management.

4.1 ASDTR

ASDTR is a versatile data management framework to augment ground segment with efficient and effective product management capability. It was initially conceived as a distributed product management framework. It offers functionalities such as data product crawling, uploading, and downloading, customisation of data models, integration of diverse data product types, enhancement of metadata descriptions, utilization of various data stores and management and monitoring of dataflows. The framework's versatility enables its usage across various space domains. Its modularity allows to select and change the metadata model, facilitating the description of products. Additionally, a tailored mechanism is foreseen to accommodate project customization needs.

Now, the framework is evolving to encompass the management of software products and machine learning models. This expansion aims to standardize product data access and establish lineage among heterogeneous products.

The framework offers multiple interfacing capabilities, facilitating seamless integration of external repositories as data sources, sinks, or both, using secure protocols for data discover and transmission. For end-users, the framework is equipped with a user-friendly web front-end, offering easy data access. Additionally, it features a secure API access layer, enabling seamless machine-to-machine integration.

ASDTR is already utilized across various ALTEC ground segment projects beyond the Hera Data Hub, including:

- Metis Operations Facility (MOF) for the Metis instrument of Solar Orbiter (a coronagraph on board the ESA/NASA Solar Orbiter [7]) where the framework is used to implement the Mission database for TM, TC, planning and science data products.
- ERFNet (European Radiation Facilities Network ERFNet) Data Hub, which serves for the collection of space radiation data in a centralized repository, the exploitation of all collected data product and the support of various end-user activities [4].
- Furthermore, ASDTR will be utilized in implementing new data management systems in space weather domain.

3. Data Operations

3.1 Organization

The Hera Data Hub operations officially began on March 12th. Under the supervision of the ALTEC team, data ingestion is actively ongoing. Instrument teams are responsible for delivering the data products to the Hera Data Hub, while the ALTEC team oversees account creation, ingestion operations, ensuring accuracy and compliance with mission standards. The process includes both manual and automated ingestion from multiple data sources, as well as the management of data retractions when necessary. Currently, the following L1A/L1B data products are available and being ingested into the Hera Data Hub:

- AFC1 (Asteroid Framing Camera 1)
- AFC2 (Asteroid Framing Camera 2)
- HSH
- TIRI

To facilitate efficient issue reporting and resolution, a dedicated Helpdesk service is available to all end-users. For general inquiries that do not require ticketing or support intervention, users can reach the ALTEC Hera Team via the dedicated mailing list.

3.2 Earth To Moon

Following its successful launch on 7 October 2024, the Hera spacecraft entered its Near-Earth Commissioning Phase, during which its instruments were powered on for the first time. As part of this phase, on 10 and 11 October, spacecraft's scientific payloads was oriented back toward Earth. From a distance of over one million kilometres, three of Hera's instruments AFC (*Figure 5*), HSH and TIRI captured their first images of Earth and the Moon, marking a key milestone in verifying the spacecraft's observational capabilities. Most of the Earth to Moon data is already available and accessible within the Hera Data Hub.

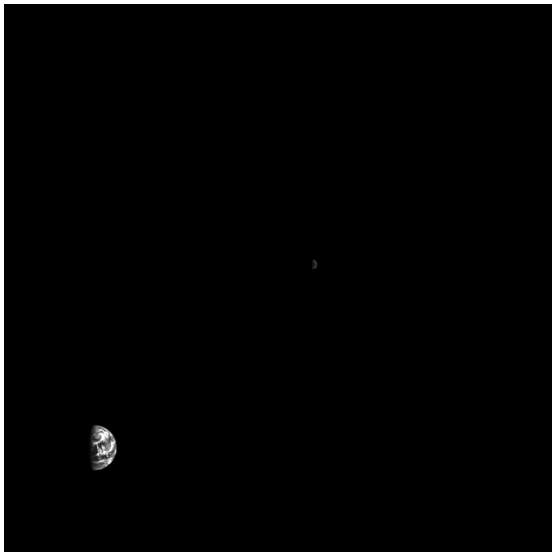

Figure 5 - Hera's AFC captured this farewell image of Earth (bottom left) and the Moon (centre) ©ESA

3.2 Mars Fly By

As part of its trajectory toward the Didymos-Dimorphos binary asteroid system, the Hera spacecraft performed a gravity-assist flyby On 12 March . This manoeuvre allowed Hera to adjust its trajectory and gain the necessary velocity to reach its final destination efficiently. During the flyby, the spacecraft came around 5600 km from the surface of Mars and 300 km from Deimos, several of Hera's instruments were activated to perform early in-flight calibrations and collect valuable science data, particularly from the AFC, HSH (*Figure 7*), and TIRI (*Figure 6*) instruments. These observations did the opportunity to obtain images of its two moons, Deimos (during the approach) and Phobos (when departing Mars) and also served as a critical test of the spacecraft's payload, operations, and data handling capabilities, including the end-to-end data processing pipeline via the Hera Data Hub. Most of the Mars swing-by data is already available and accessible within the Hera Data Hub.

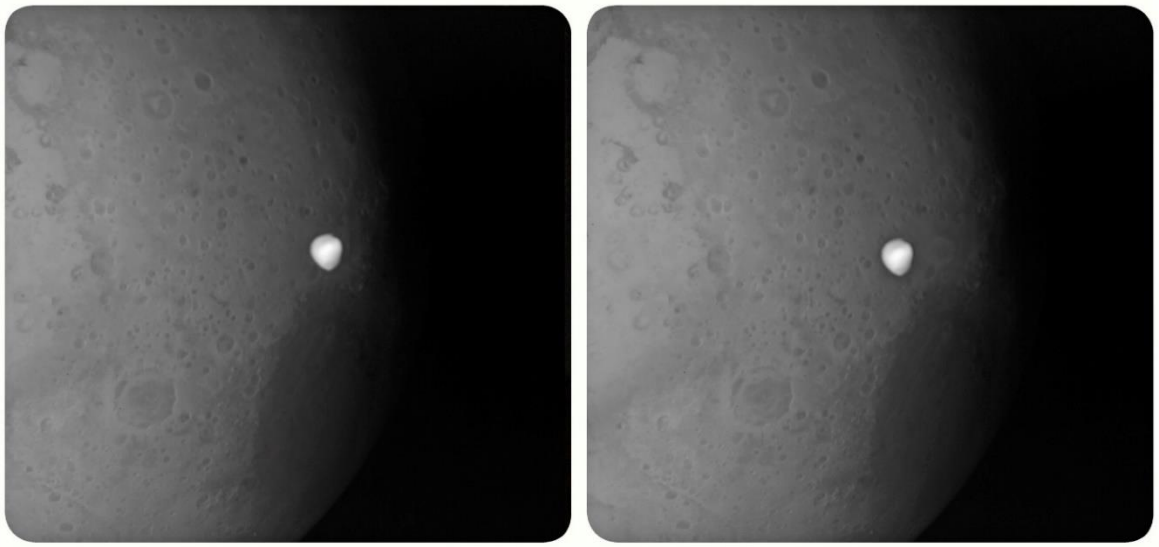

Figure 6 - Pair of images from the (TIRI) Hera payload ©ESA/JAXA/BM

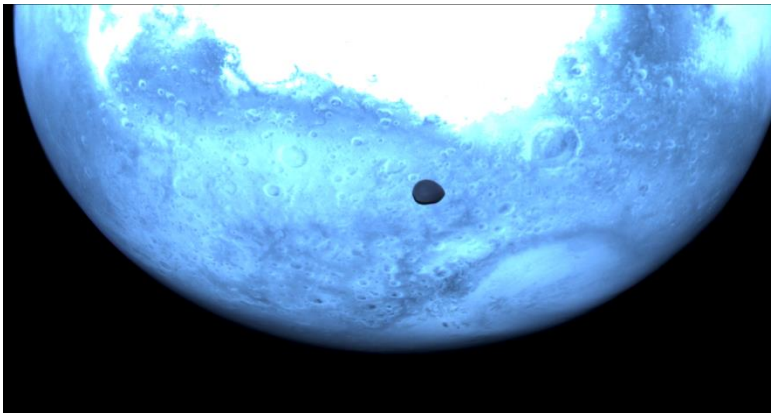

Figure 7 - Mars and Deimos viewed by Hera's Hyperscout H ©ESA

6. Conclusions

The Hera Data Hub is now online and fully operational, supporting Hera mission operations in achieving its scientific objectives and enabling global data distribution to anyone interested in exploring asteroids, as well as the planet Mars and its moons.

The decision to build the data system on top of the ALTEC data management framework has proven highly effective. In just six months, the first version of the Hera Data Hub was released and deployed in production, offering a robust set of capabilities already validated in other scientific data centres.

Over the next twelve months, development will continue to further enhance the system's data management features and to introduce advanced data visualization and exploitation tools. The final version of the Hera Data Hub will not only be instrumental in fulfilling the mission's objectives but will also be readily reusable, with minimal adaptation, for future planetary defence missions.

Acknowledgements

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ALTEC team gratefully acknowledge ESA and OCA for the constructive cooperation and the support in setting up this project.

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