The ESA Hera mission: Detailed Investigation of the NASA DART Impact Ouctome and Characterization of the Binary Asteroid Didymos

Dr. Patrick Michel

On behalf of the Hera Science Team

Hera mission Principal Investigator

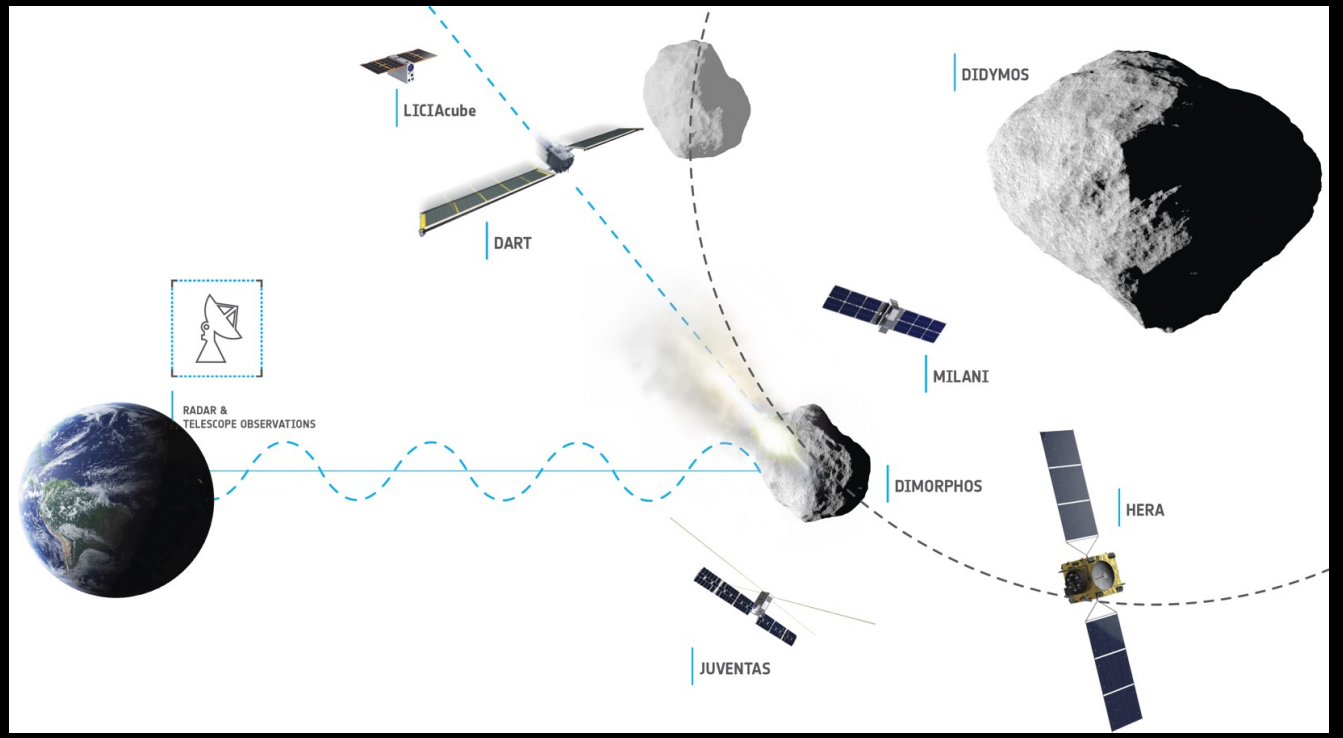
Univ. Côte d'Azur, Obs. Côte d'Azur, CNRS, Lagrange Lab.

Michel, P. et al. 2022. Planet. Sci. J. 3, 160

(PSJ Special Issue DART/Hera pre-arrival)

8th IAA Planetary Defense Conference, April 2023

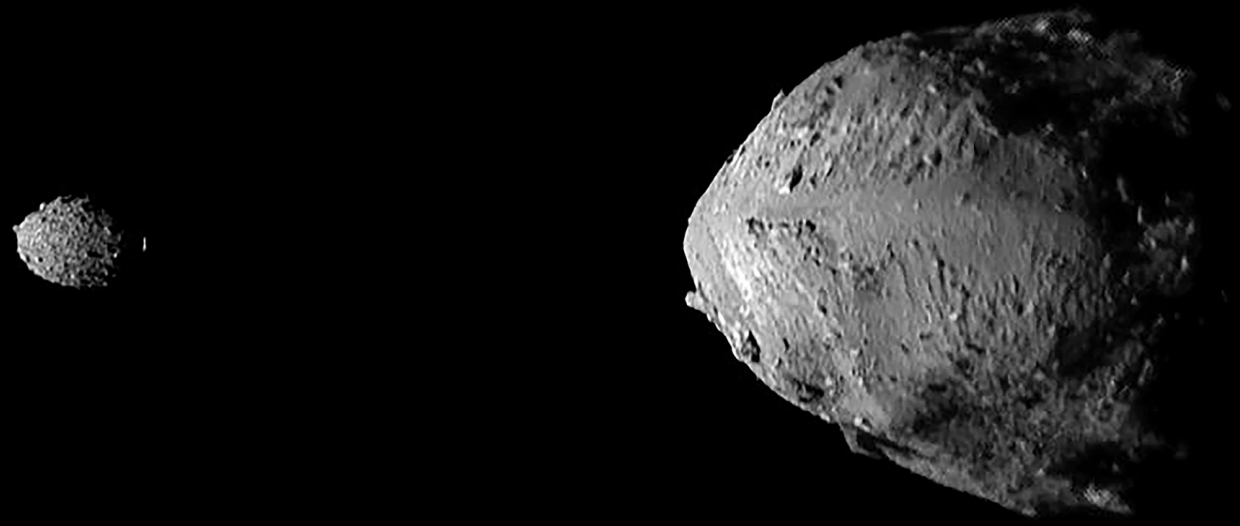
AIDA collaboration for planetary defense



Successful impact on September 26th at 23:14:24 UTC

LICIACube successful imaging of the ejecta

Big questions!
Didymos& Dimorphos shapes



Observations of the two components on all sides are missing!!

↓

Strong implications for binary formation

Credit: NASA/Johns Hopkins APL

Dimorphos

What is its mass?
Is it an aggregate?

Credit: NASA/Johns Hopkins APL

Strong implications for binary formation, small body geophysics & impact physics

What does Dimorphos look like after impact?

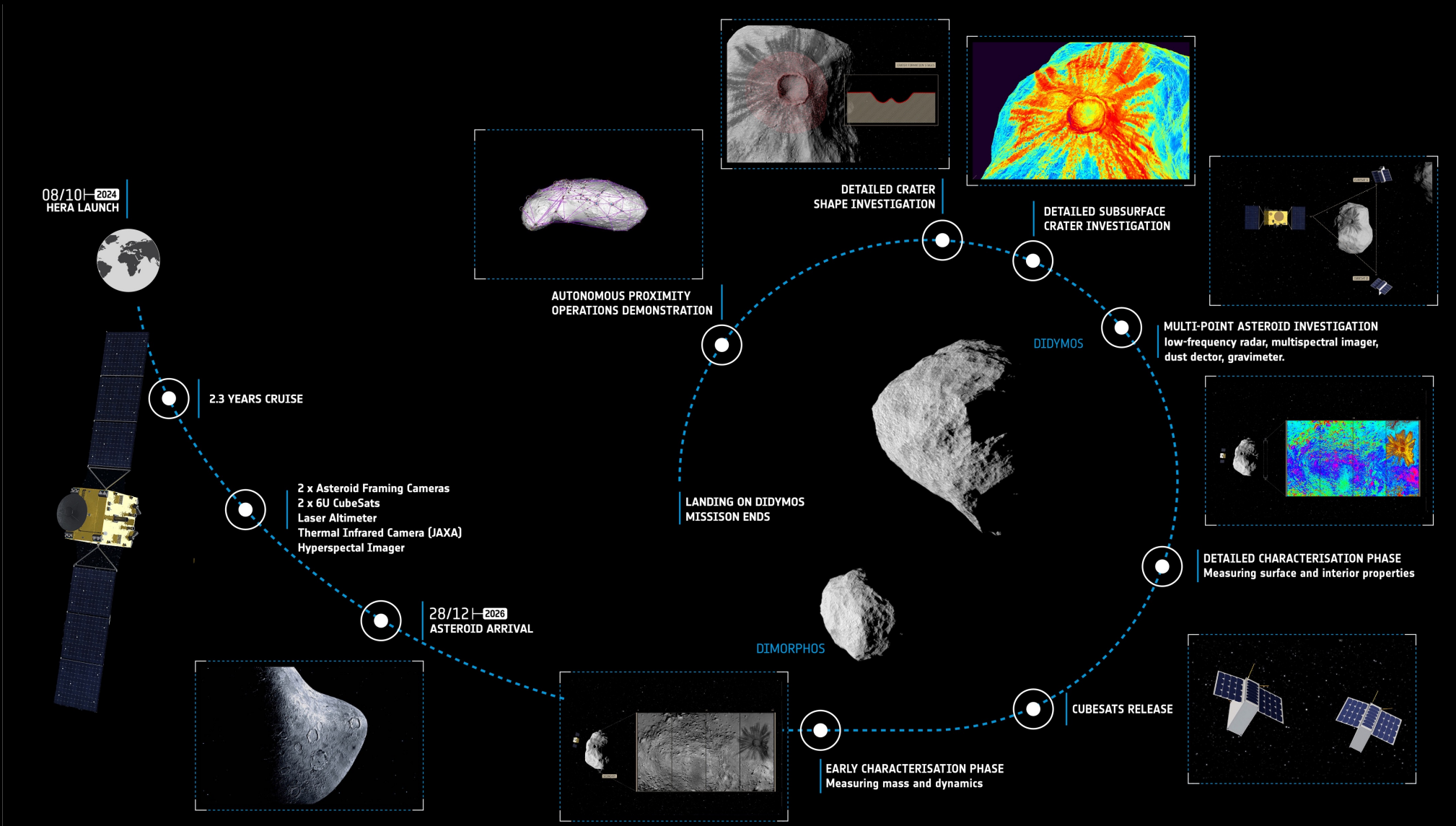
Seeing the « final » Dimorphos

Credit: NASA/ESA/STScI/Hubble

Credit: ASI/NASA

Only way to interpret DART impact, to understand the response of such small rocks in space & to validate impact models

Hera mission

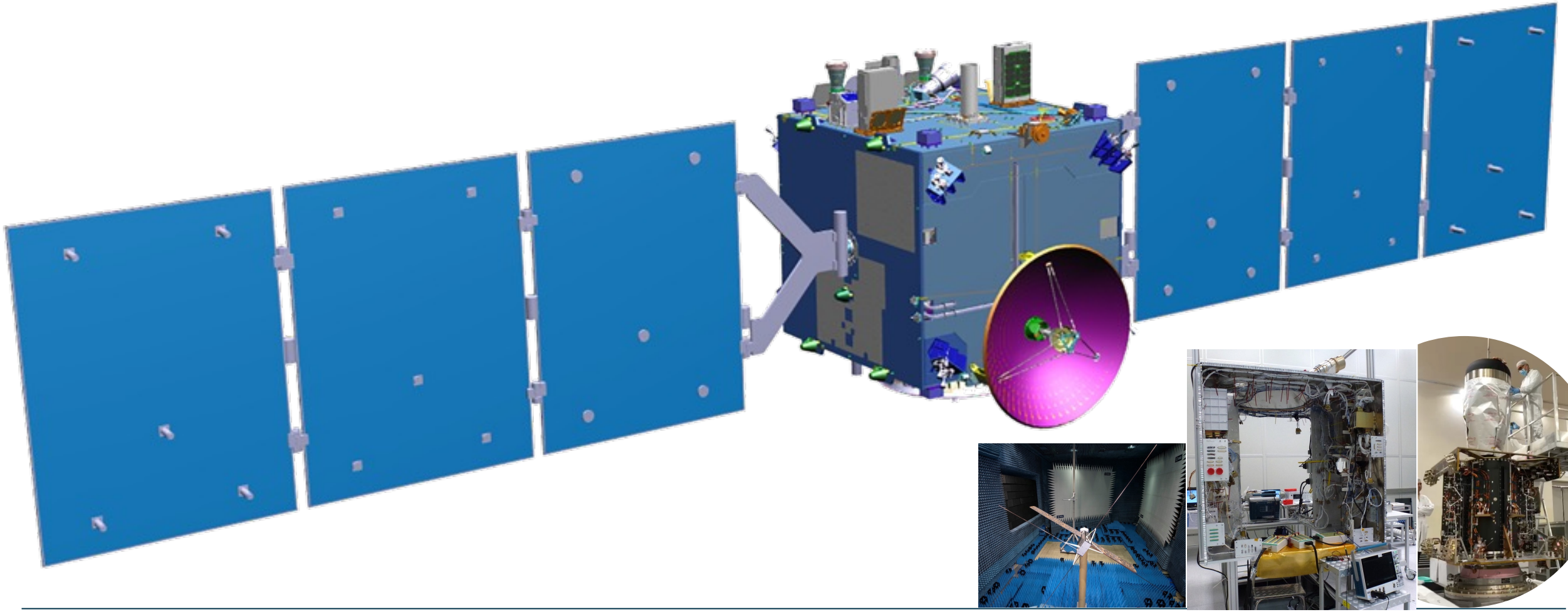


- First mission to rendezvous with a binary asteroid and smallest asteroid ever visited
- First radar tomography of an asteroid
- First full-scale cratering physics experiment investigation
- First deep-space CubeSat for very close asteroid inspection

Hera spacecraft

Launch: 8 Oct 2024
Satellite integration completed in 2023
Tests at ESTEC in 2023/24

Mass: 1215 kg
Power: 826 W
Size: 2m × 11m × 2m
Countries: 17 EU + Japan

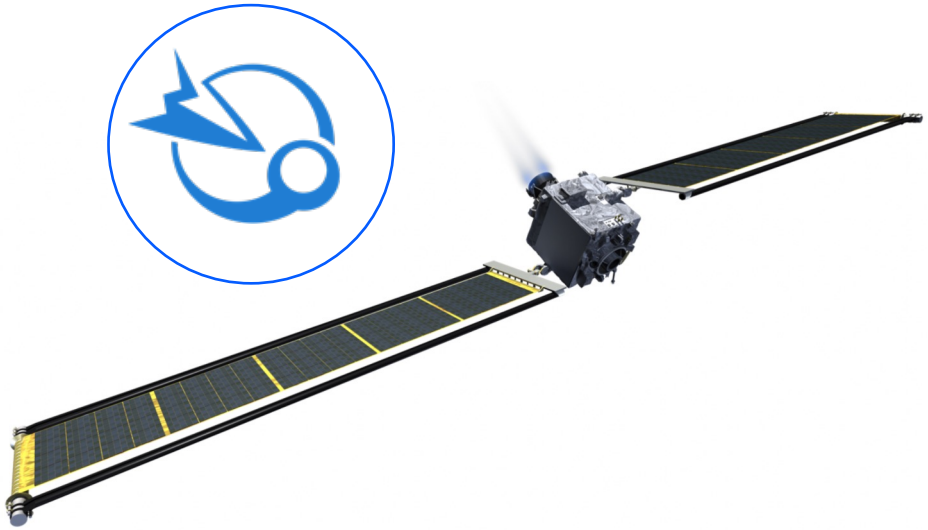


DART & Hera: First fully documented impact experiment on a 160 m-size asteroid at asteroid collision speed

Target properties

- Cohesive strength - not known
- **Mass - not known** → momentum transfer efficiency
- Bulk density / porosity - not known
- Internal structure - not known

Impact conditions



- Impact velocity - known
- Impact angle - known
- Impactor mass/shape - known

Hera + detailed impact outcome

Hera mission objectives

CORE asteroid investigation requirements

- Mass of Dimorphos
- Global properties (volume, linear scale, density)
- Size distribution of surface material
- Dynamical properties of the Didymos system
- Shape and volume of DART impact crater
- Size distribution of excavated material

OPPORTUNITY asteroid investigation requirements

- Surface strength
- Interior structure of Dimorphos
- Composition of Dimorphos
- Transport of impact ejecta from Dimorphos to Didymos

Hera Payloads

Core Payload

Asteroid Framing Cameras (AFC)

jenaoptronik

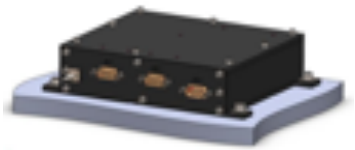
Visible camera for GNC and asteroid science

Qty 2 (Nom + Red)

Opportunity Payloads

Planetary ALTimeter (PALT)

efacec



Small Monitoring Camera (SMC)

TSD Space

Deep Space Deployer (DSD)

ISISPACE

Low velocity deployer for CubeSats

Inter-Satellite Link (ISL)

TEKEVER

S-band comms between Hera and CubeSats, with ranging and radio science

Image Processing Unit (IPU)

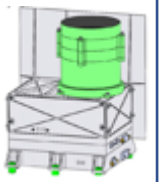
gmv

Experimental aid for on-board autonomous GNC

Thermal InfraRed Imager (TIRI)

JAXA

Thermal infrared camera with filter wheel



Hyperscout-H

cosine | hyperscout

2D snapshot hyperspectral imager

CubeSat "Juventas"

GOMSPACE

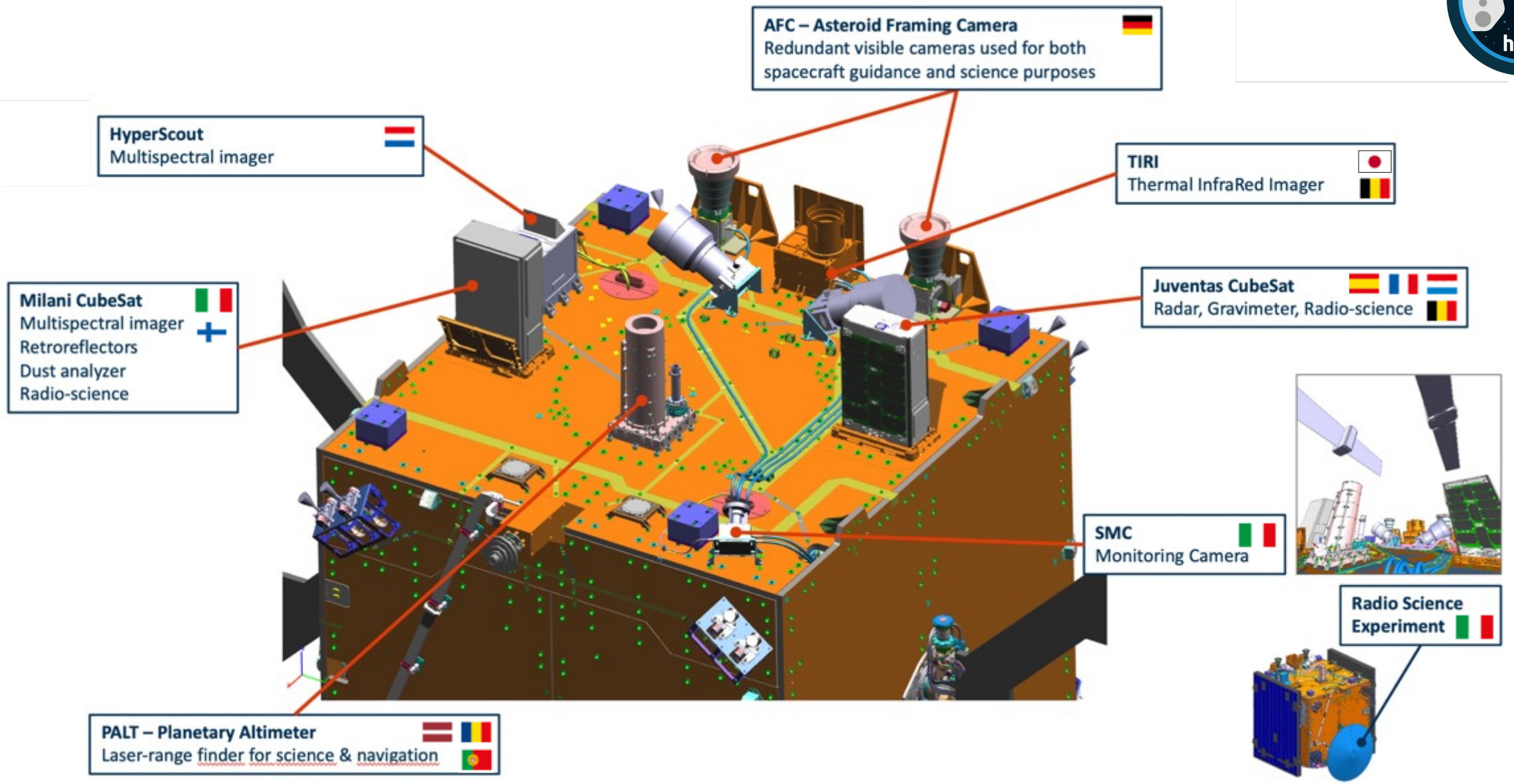
CubeSat with low-frequency radar and gravimeter, incl. radio science with ISL

CubeSat "Milani"

Tyvak International

CubeSat with multispectral imager and dust analyzer payloads

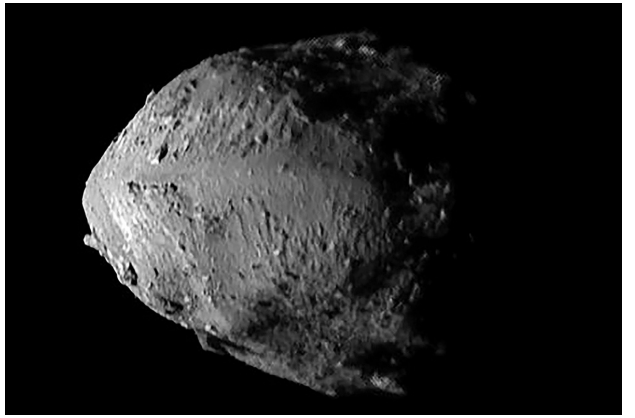
Hera instruments



First detailed investigation of a binary asteroid

15% of NEAs are binaries

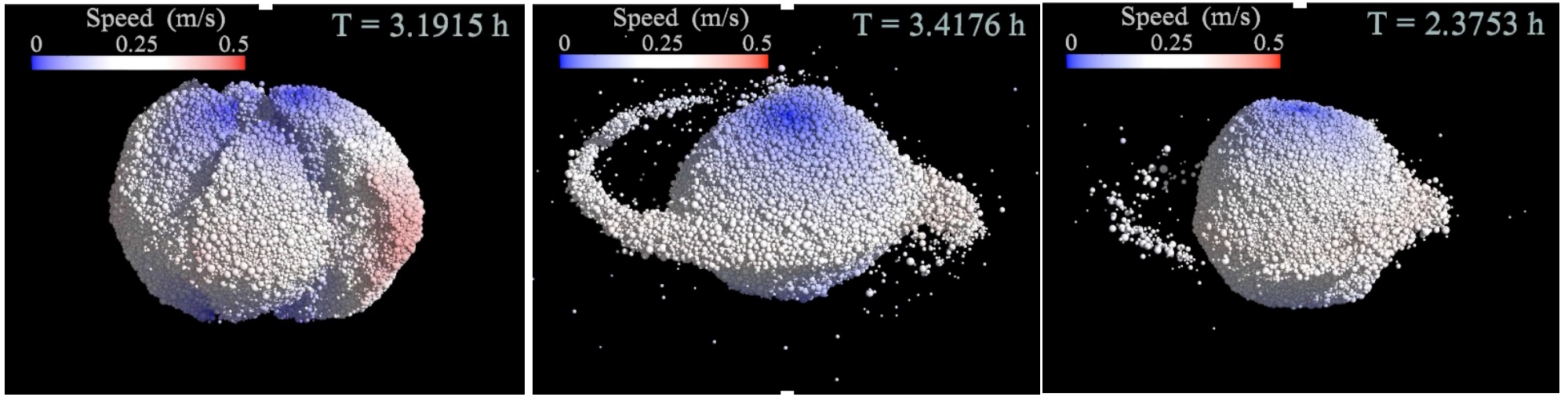
- Are Didymos and Dimorphos rubble piles?
- Why does Dimorphos have an oblate spheroidal shape?



Credit: NASA, APL

Structural processes and evolutions

- First asteroid visited that may be at the limit of structural stability (**Didymos spin period is 2.26 hr**)
- Insights on the geophysics of fast spinning tops



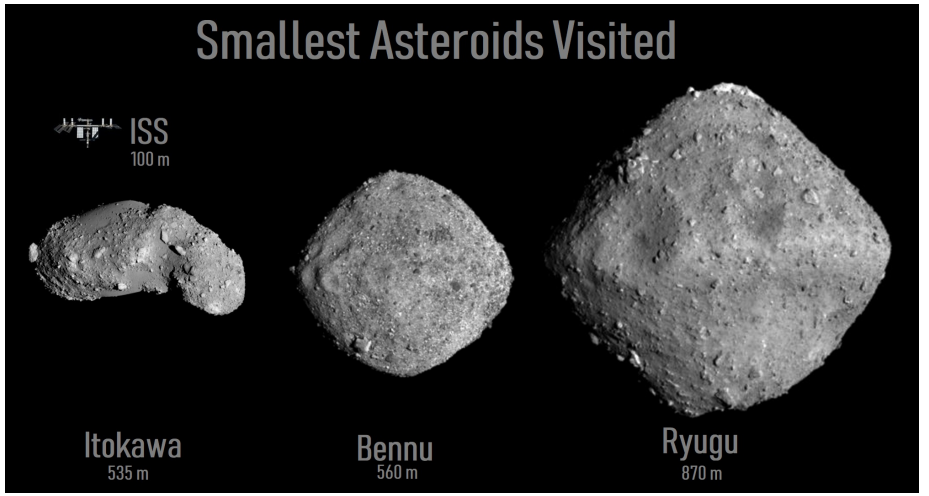
Zhang, Michel, Richardson, et al. 2021, Icarus 362

Structural stability and spinup outcome depends on cohesion, at the level of 1 Pa!!

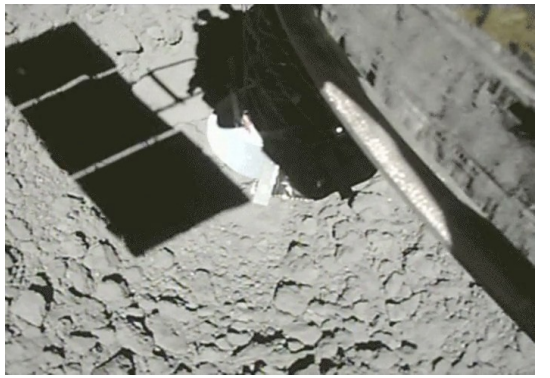
First geophysical data on a 160 m-size object

- **H2 and O-REx : 1st detailed characterization and surface response of 2 primitive asteroids in different gravity conditions**

  - Ryugu is 900 meter wide
  - Bennu is 500 meter wide



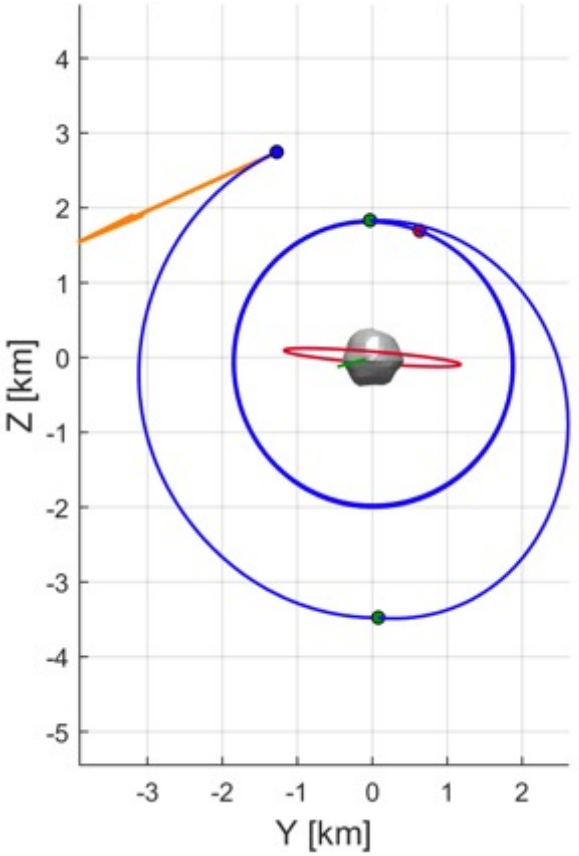
NASA, Univ. Arizona

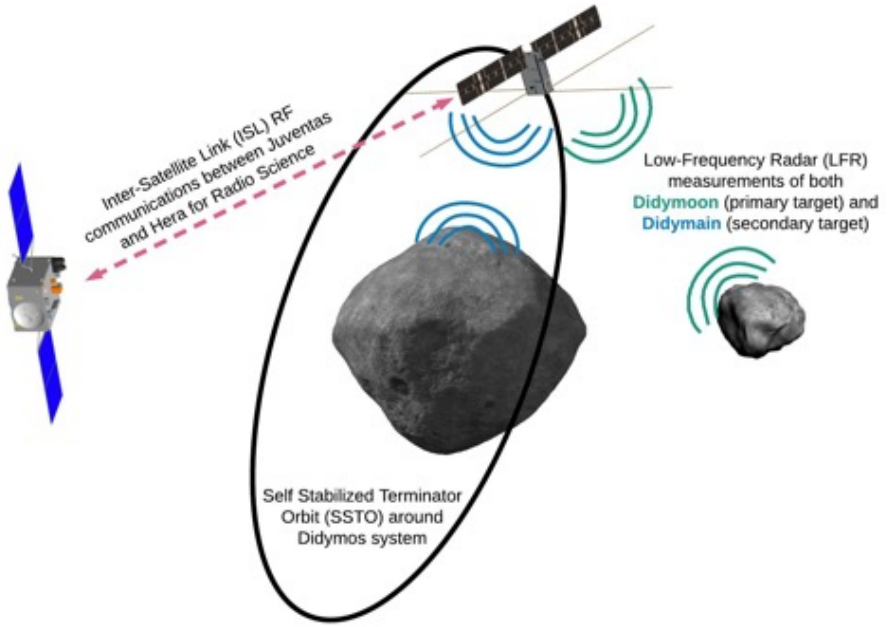


JAXA, Univ. Tokyo and Co

- **Dimorphos is ~ 3 times less wide than Bennu**
  - Possibility to understand how some processes scale with gravity down to the low-g of Dimorphos

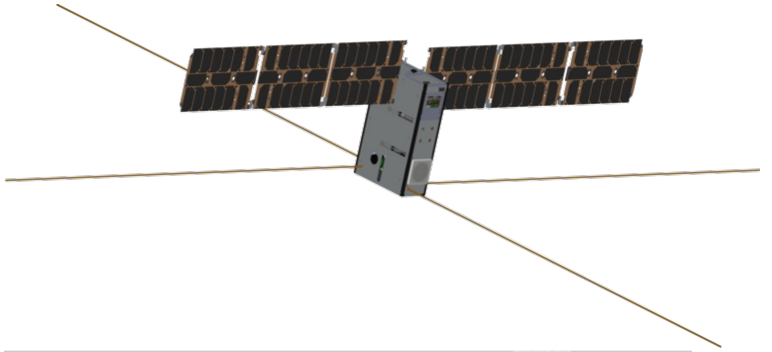
First internal probing of an asteroid

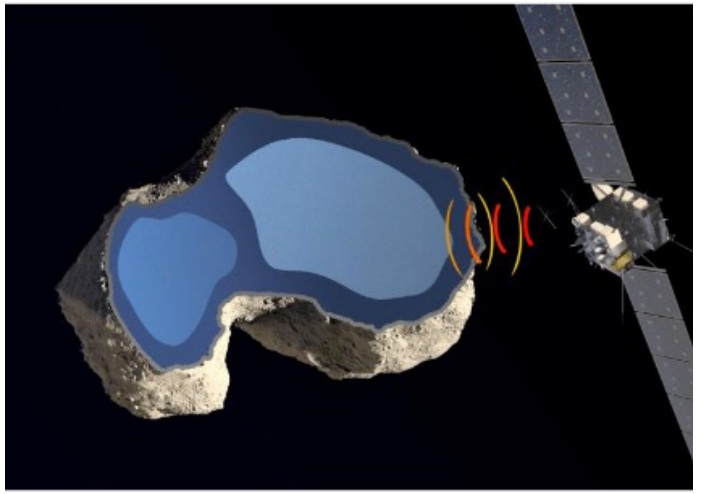




Asteroid interior probing by radar tomography (a first)

JUVENTAS





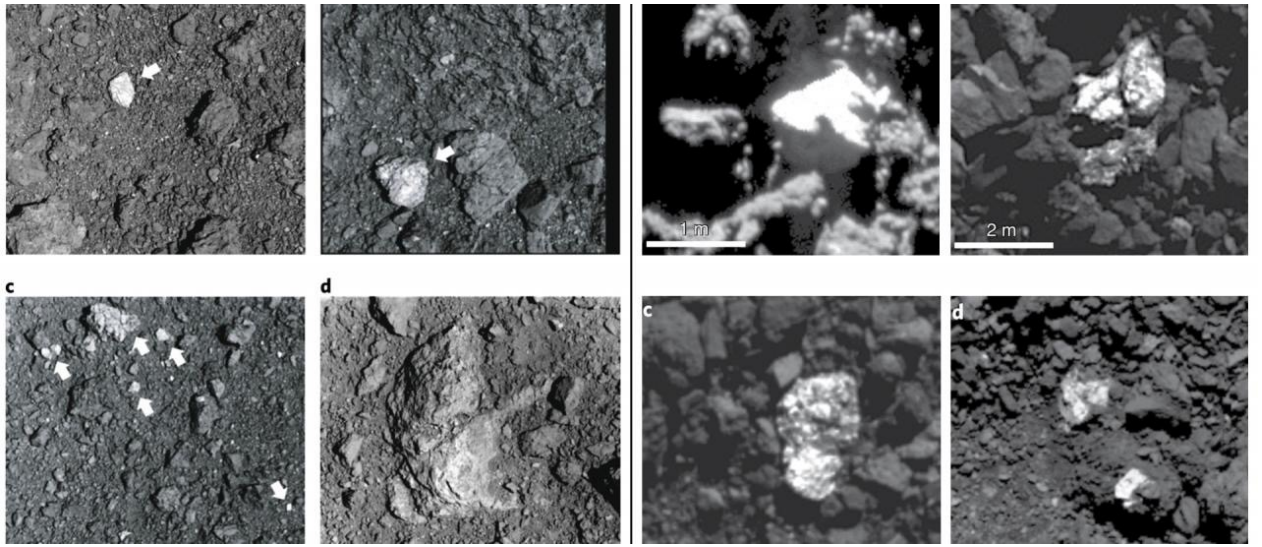
What is the level of heterogeneity in the interior of Dimorphos?

First mineralogical study of a 160m-size objects and its subsurface revealed by the DART impact

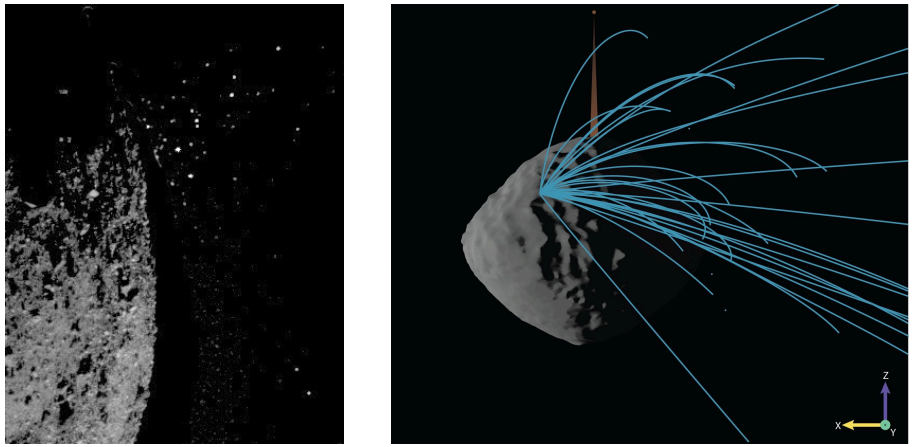
Milani Cubesat will investigate in details the mineralogy and possible surrounding dust

- **Is the composition homogeneous?**

- **Is there dust in the system?**
  - Exchange of material between Didymos and Dimorphos
  - Micrometeorite impacts

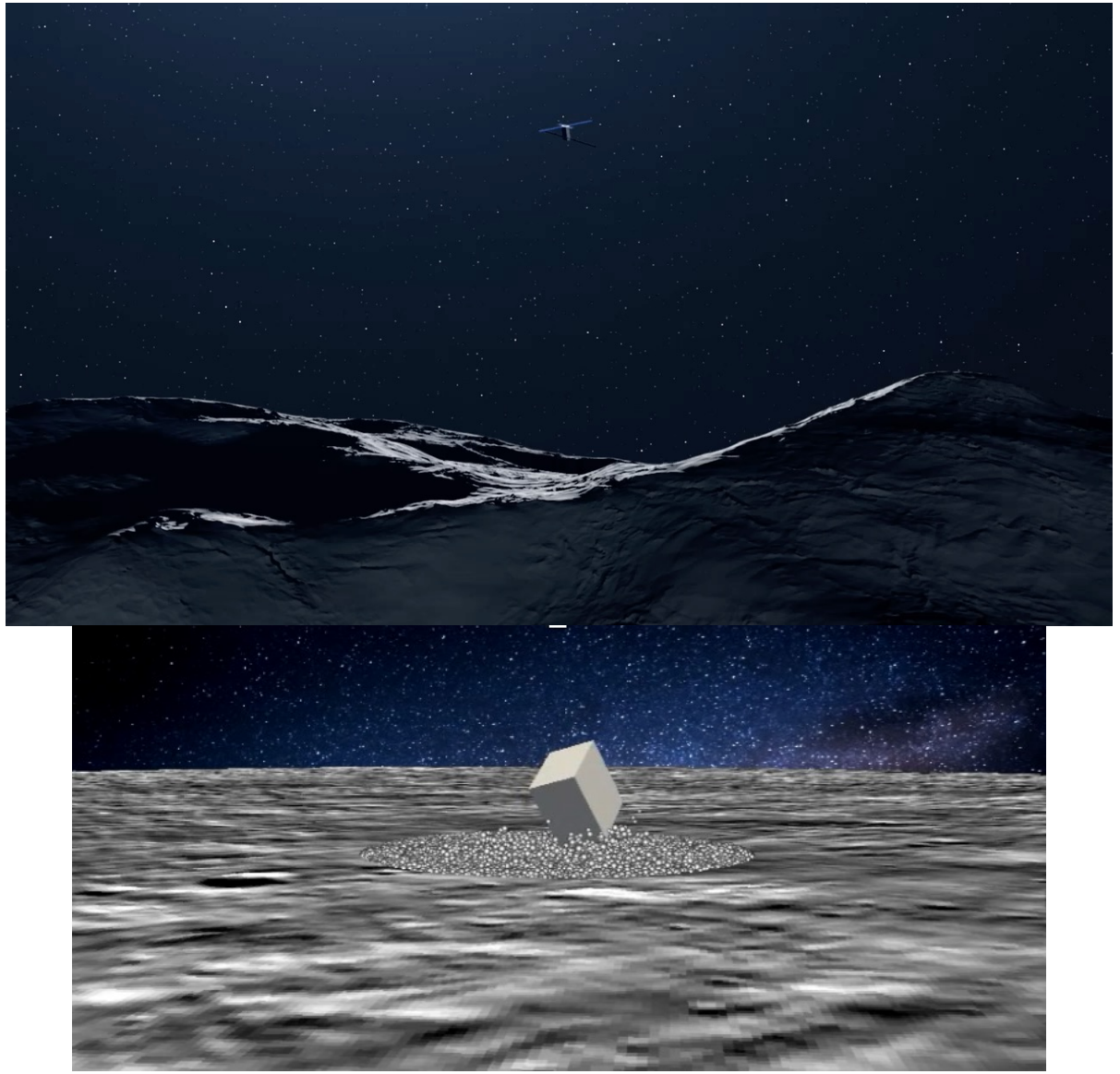


Exogeneous material on Ryugu & Bennu



Dust ejected from Bennu

First landing on a 160 m-size object



Thuillet, Michel et al. 2019

Cubesats Juventas & Milani

Landing on Dimorphos

- Bouncing properties

➢ Only way to determine the response of these bodies in their low gravity environment

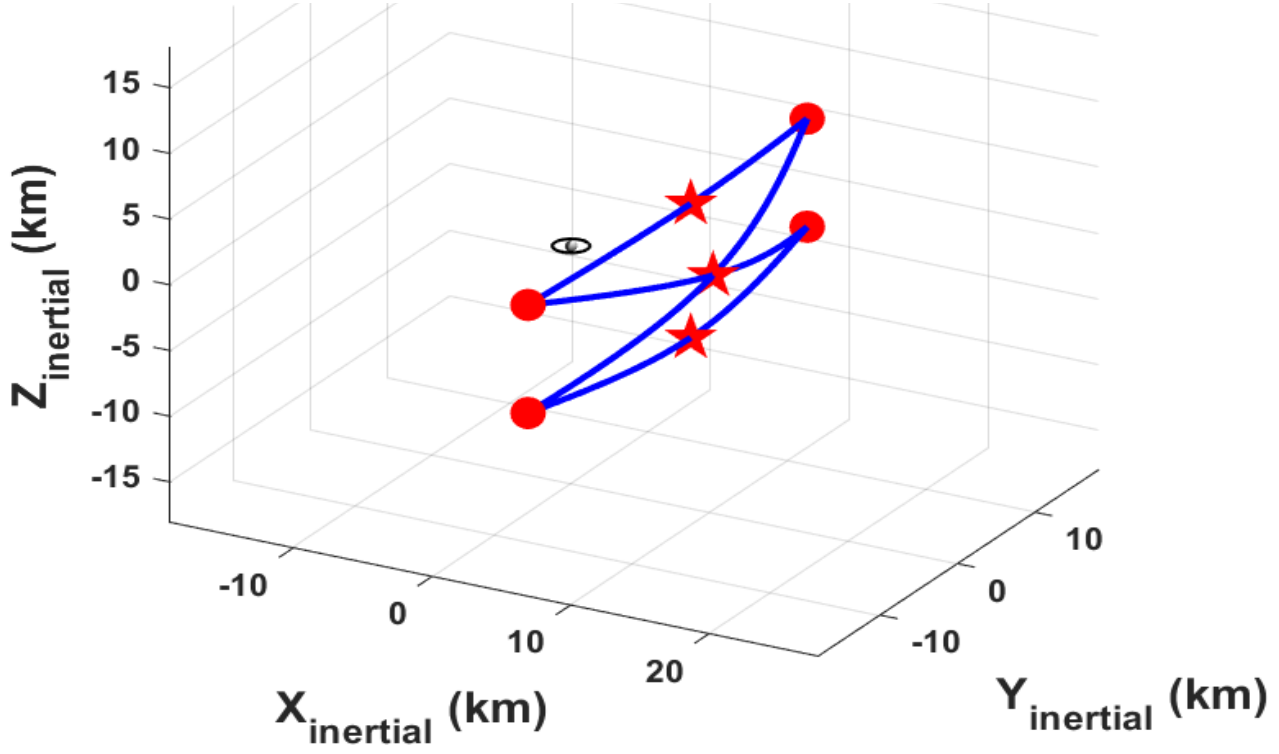
➢ Implications for science, planetary defense and mining

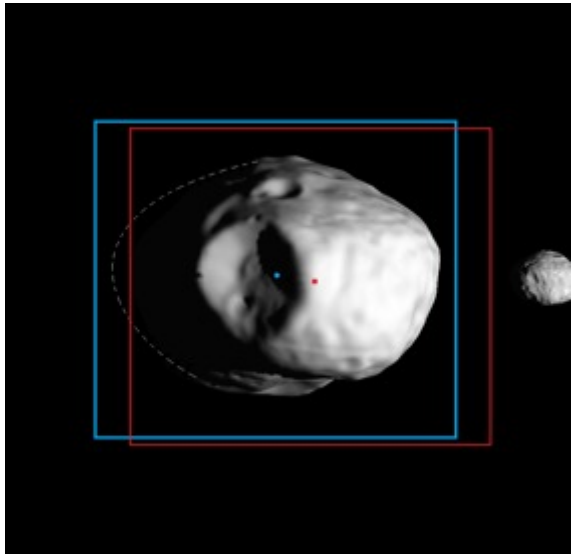
Close-ops timeline

1. **Early Characterization Phase (ECP)**
   - Distance ~20-30 km (entire system in FOV of AFC)
   - Ground-controlled SC ⇒ ensure observations of Didymos system
2. **Payload Deployment Phase (PDP)**
   - Release of CubeSats from passively safe trajectory similar to ECP
3. **Detailed Characterization Phase (DCP)**
   - Distance ~9-20 km
   - Autonomous navigation based on AFC only (Didymos LOS navigation)
   - CubeSats operations (multi-point measurements)
4. **Close Characterization Phase (COP)**
   - Distance ~4-22 km (Didymos and/or Dimorphos LOS navigation)
   - Dimorphos high-resolution imaging and full characterization of DART´s impact crater
5. **Experimental Phase (EXP)**
   - Very low altitude fly-bys ~1km (autonomous delta-V to lower pericentre)
   - PALT + feature tracking below ~2km distance

HERA Detailed Characterization Phase (DCP)

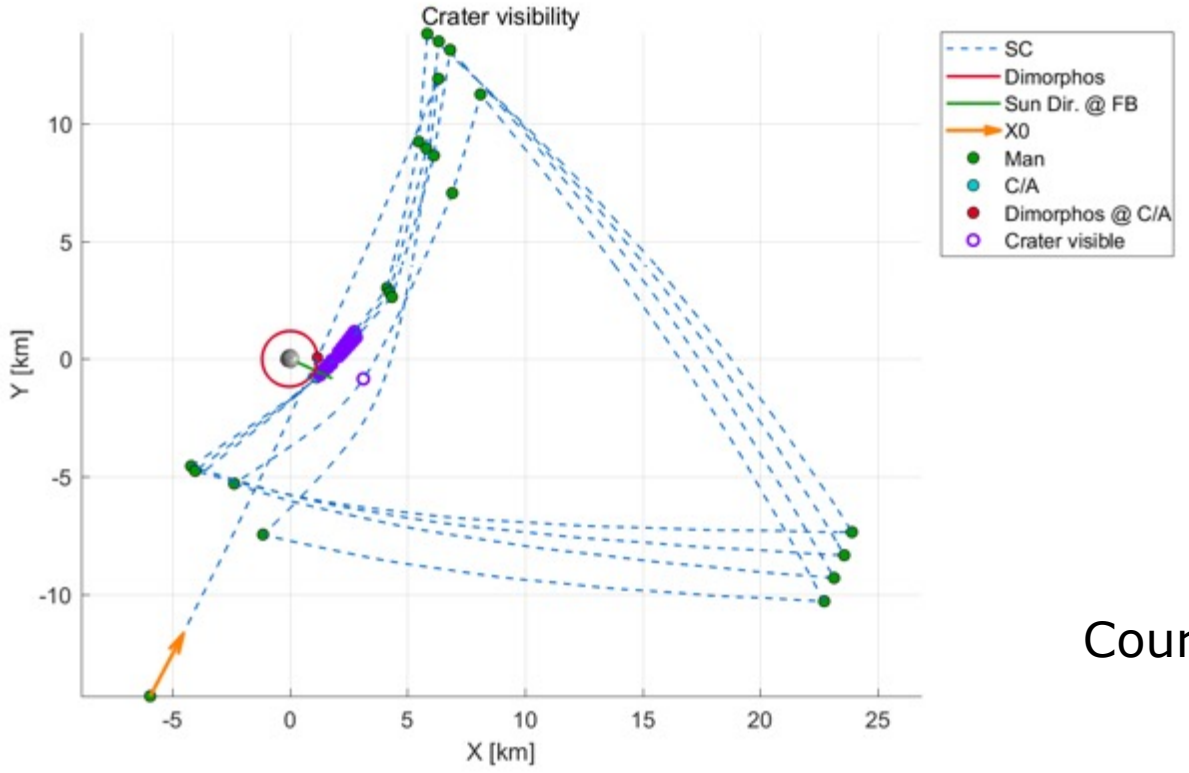
- Change trajectory shape to reach lower distances keeping constraints
- Autonomous Pointing ⇒ autonomous navigation
  - Pericenter around 10km to have full Didymos in FOV



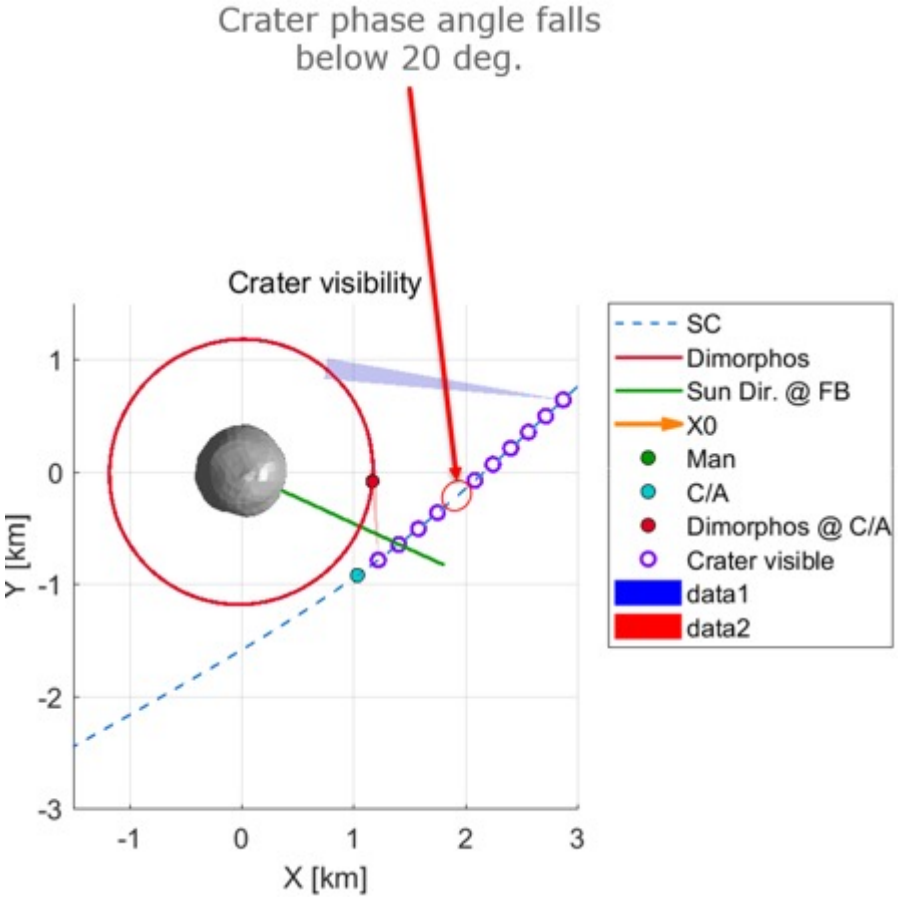


HERA Experimental Phase (EXP)

- Pericentre is very close to Dimorphos orbit to reach crater imaging resolution
- Very-close fly-bys reaches night side and optical navigation is interrupted
- GNC must ensure that can take images back in the day side to recover

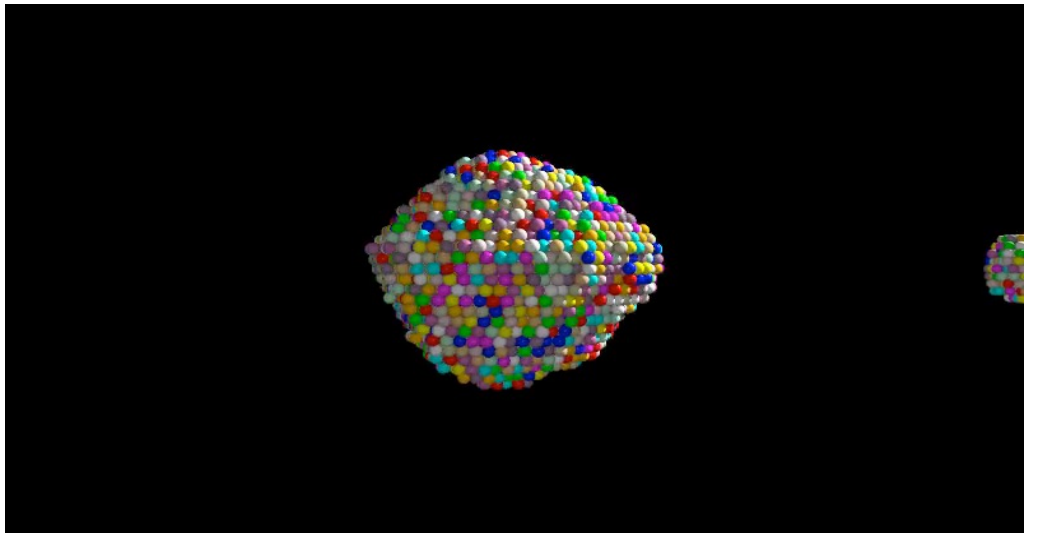


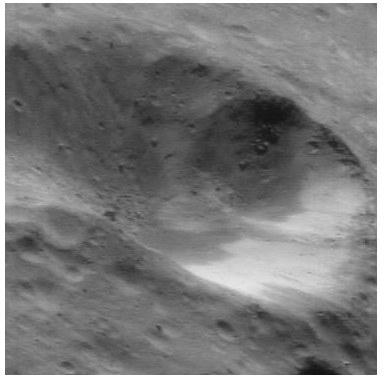
Courtesy GMV



Hera: a mission full of « firsts »

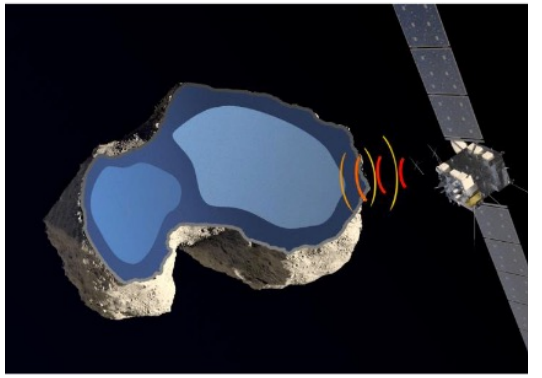
- **1st** rendezvous with a binary & smallest visited asteroid (Dimorphos)
- **1st** detailed outcome of an impact at a speed of 6 km/s
- **1st** Deep Space CubeSats & **close inspection of composition & internal, subsurface and surface structures**
- **1st** landing on an asteroid of 160 m in diameter





Credit: NASA/JPL/JHUAPL

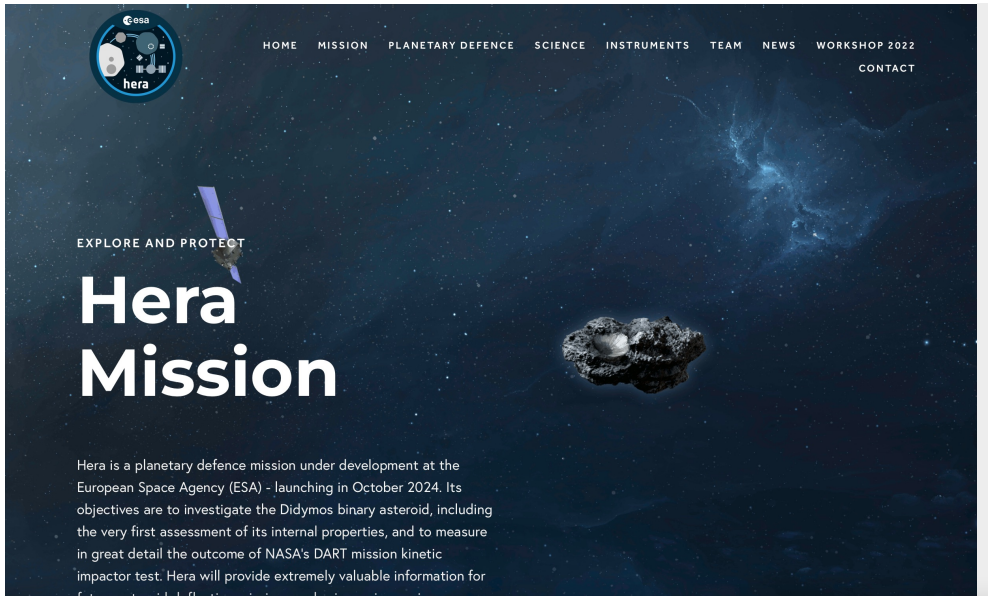
Analysis of the size and interior of a crater

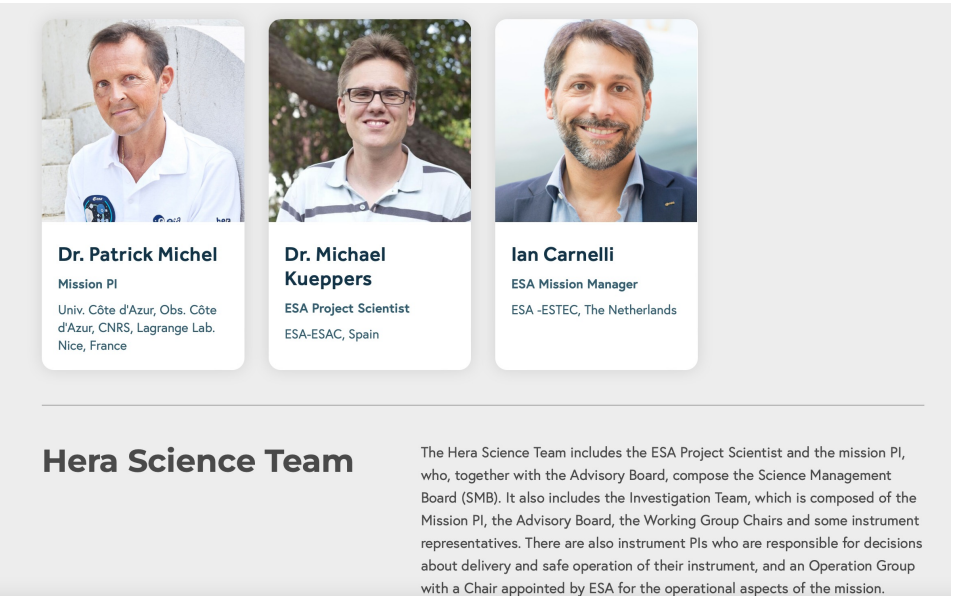


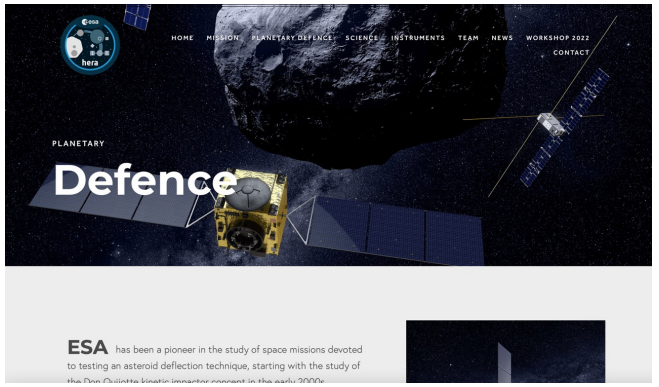
Analysis of the interior of an asteroid

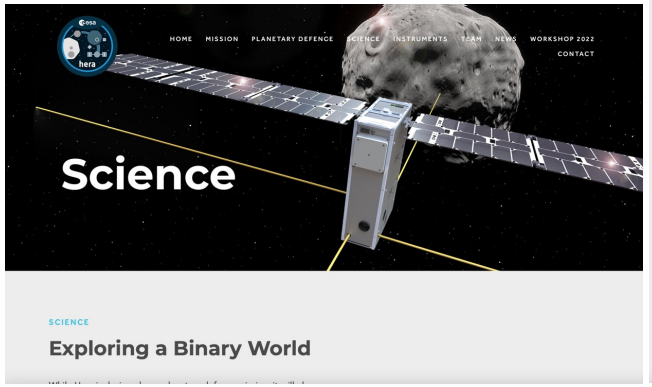
The structural analysis and measurement of the response to a surface interaction in low-gravity conditions are crucial knowledge for many purposes

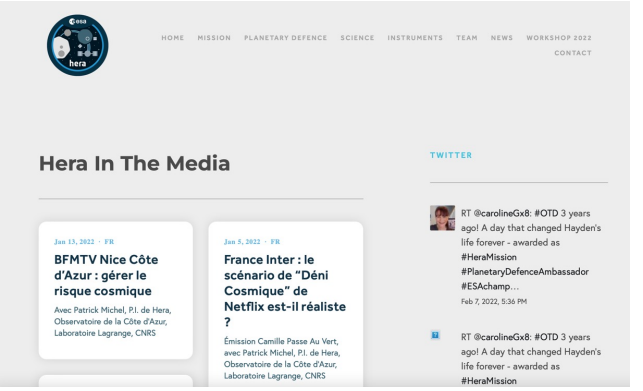
Hera Community Website











https://www.heramission.space

Conclusions

- Hera spacecraft development progressing at fast pace, **on schedule to launch in October 2024 onboard Falcon-9**

- Baseline trajectories achieve multiple geometries and observation conditions of the binary asteroid considering all constraints

  - With the assumption of tidally locked Dimorphos, almost half of Dimorphos surface can be imaged with a resolution of 40 cm or less
  - Rotation around Sun direction can allow deviations from hypotheses

- Great international team and synergy with DART promising breakthroughs in our knowledge