# 7th IAA Planetary Defense Conference

26-30 April 2021, Online Event

Hosted by UNOOSA in collaboration with ESA

# Session 3: DART

Chairs: Andy Rivkin | Dawn Graninger

Presenters: T. Statler, NASA | E. Adams, JHU/APL | E. Dotto, INAF | A. Rivkin, JHU/APL | A. Cheng, JHU/APL

DART

# Overview of the DART Mission
# Seven Months to Launch

**Dr. Thomas S. Statler**
DART Program Scientist
Planetary Defense Coordination Office
NASA Headquarters
Washington, DC

# NASA's Planetary Defense Coordination Office (PDCO)

- Established January 2016 at NASA HQ
- Manages planetary defense related activities across NASA
- Coordinates with U.S. interagency and international efforts in planetary defense

## Mission Statement

- Lead national and international efforts to:
- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

ASSESS
[CENTER FOR NEAR EARTH OBJECT STUDIES]
IAU
Minor Planet Center
SEARCH, DETECT & TRACK
[SPACE-BASED & GROUND-BASED OBSERVATIONS, IAWN]
PLANETARY
DEFENSE
MITIGATE
[DART, FEMA EXERCISES]
CHARACTERIZE
[NEOWISE, GOLDSTONE, IRTF]
PLAN & COORDINATE
[SMPAG, PIERWG, NITEP IWG]


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DART is the first full-scale flight demonstration of an asteroid deflection technology: kinetic impact
PLAN & COORDINATE
[SMPAG, PIERWG, NITEP IWG]

# Part of a Larger Strategy

## *National Near-Earth Object Preparedness Strategy and Action Plan*

*A Report by the* Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects *of the* National Science & Technology Council, June 2018

**Goal 1:** NEO Detection, Tracking, Characterization

**Goal 2:** NEO Modeling and Information Integration

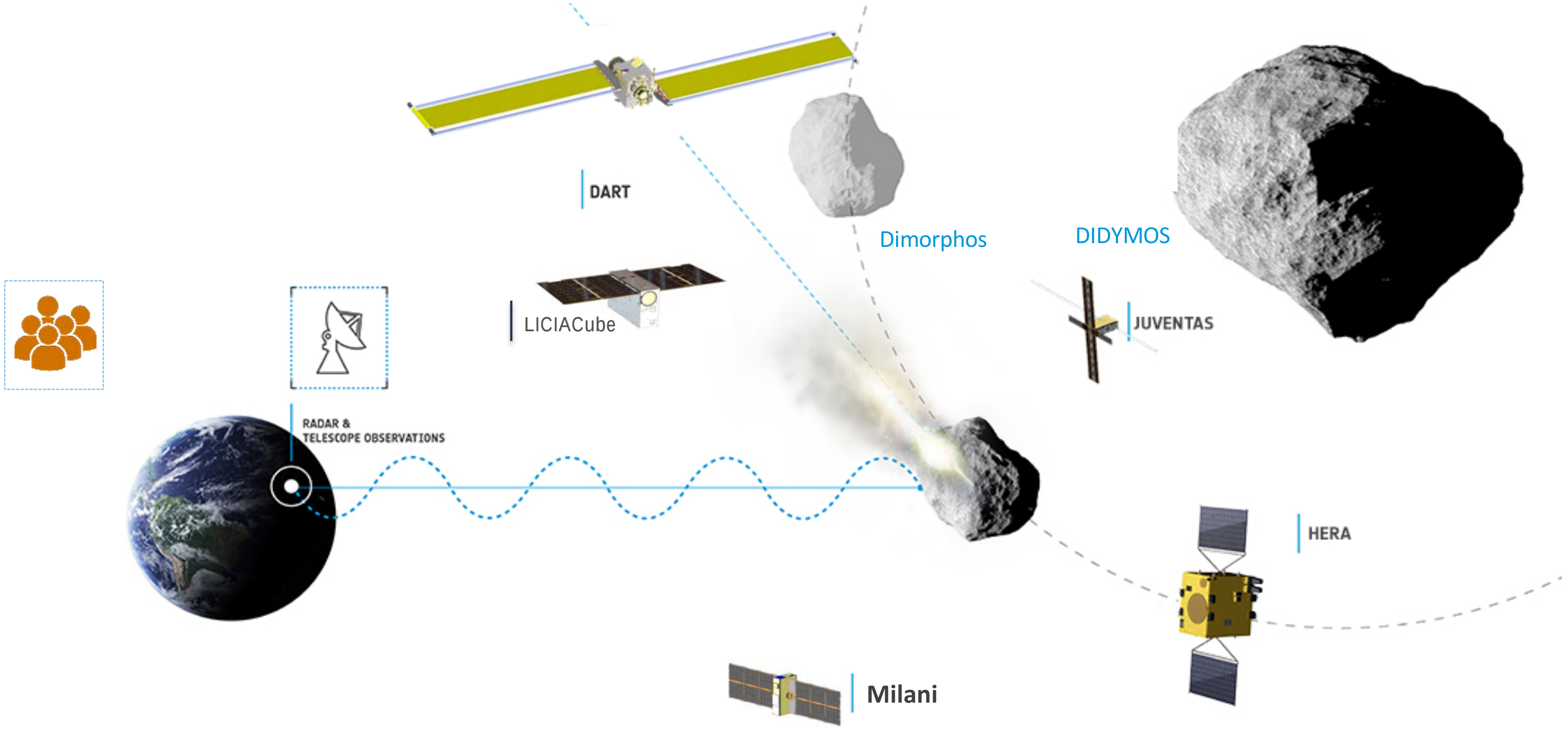
**Goal 3:** NEO Deflection and Disruption Mitigation

**Goal 4:** Increase International Cooperation

**Goal 5:** Strengthen and Exercise Impact Protocols

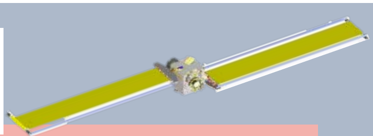
**DAMIEN (Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects) Membership:** Department of Commerce, Department of Defense, Department of Energy, Department of Homeland Security, Department of the Interior, Department of State, NASA, National Science Foundation, Office of the Director of National Intelligence, National Security Council, Office of Management and Budget, Office of Science and Technology Policy

# AIDA international collaboration



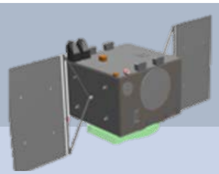

AIDA

DART



LICIACube

hera



Synergy from

First demonstration of asteroid deflection by kinetic impact on Dimorphos, to change its orbit

with

First prompt imaging of the impacted surface, ejecta plume evolution and of the non-impacted hemisphere of Dimorphos

+

Mass of Dimorphos
Detailed dynamical characterization
Detailed investigation of final crater
Overall characterization of the asteroids

# DART = Double Asteroid Redirection Test

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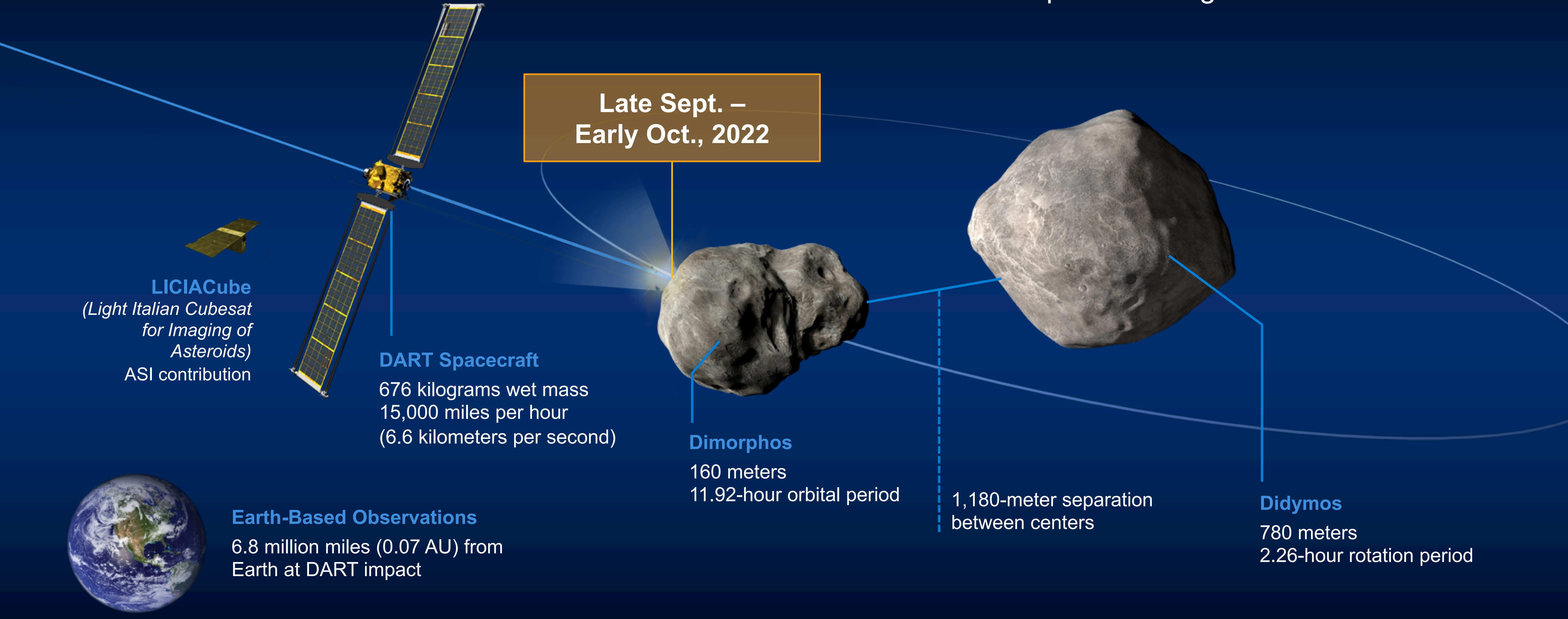
- **There is no known asteroid that poses an actual impact risk to Earth.**
- The current impact hazard comes from asteroids not yet discovered.
- The test is being conducted to develop a deflection capability, in case one is needed in the future.

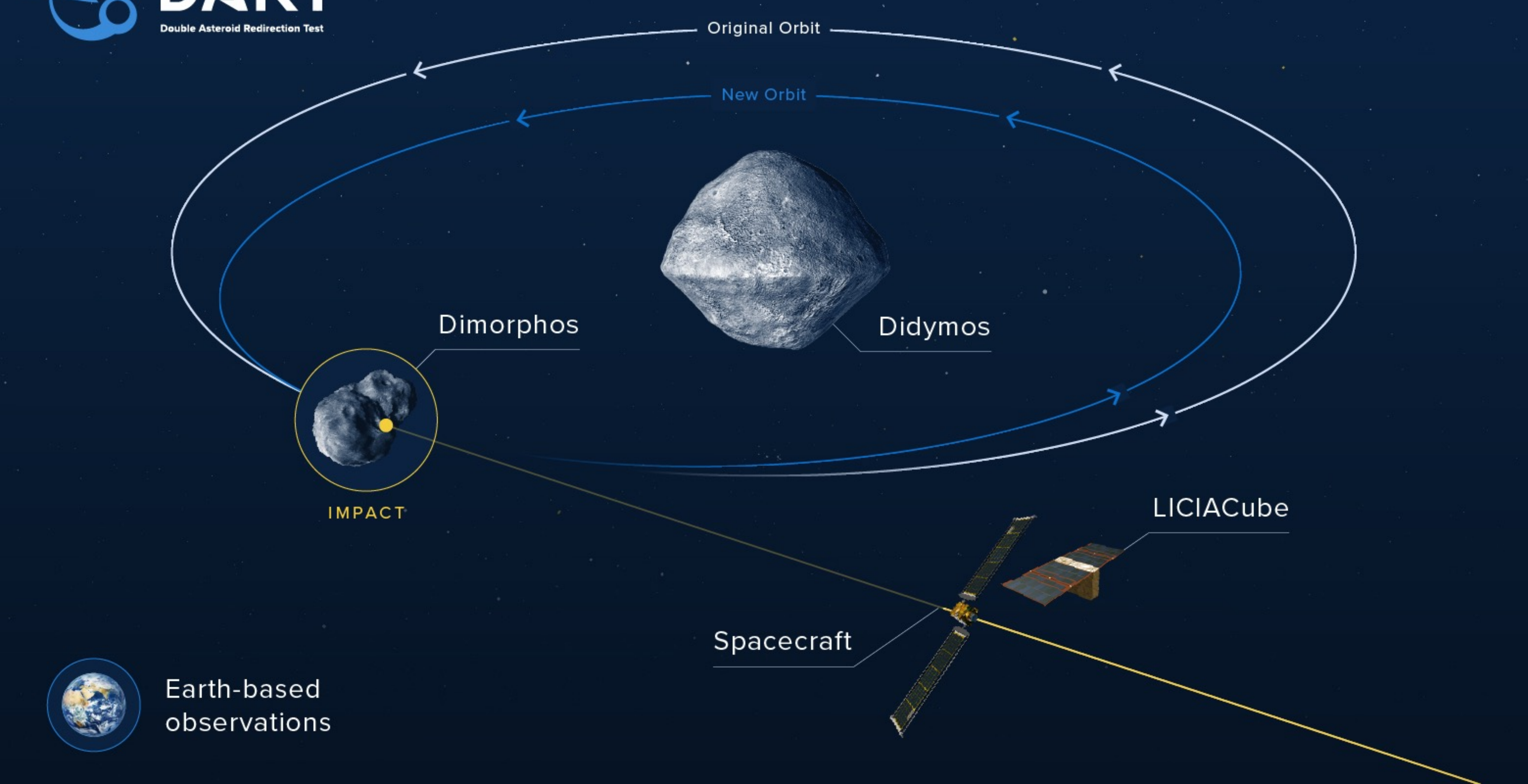
# Launch Window

Nov. 18, 2021 – Feb. 15, 2022

- Target the binary asteroid Didymos system
- Impact Dimorphos and change its orbital period
- Measure the period change from Earth

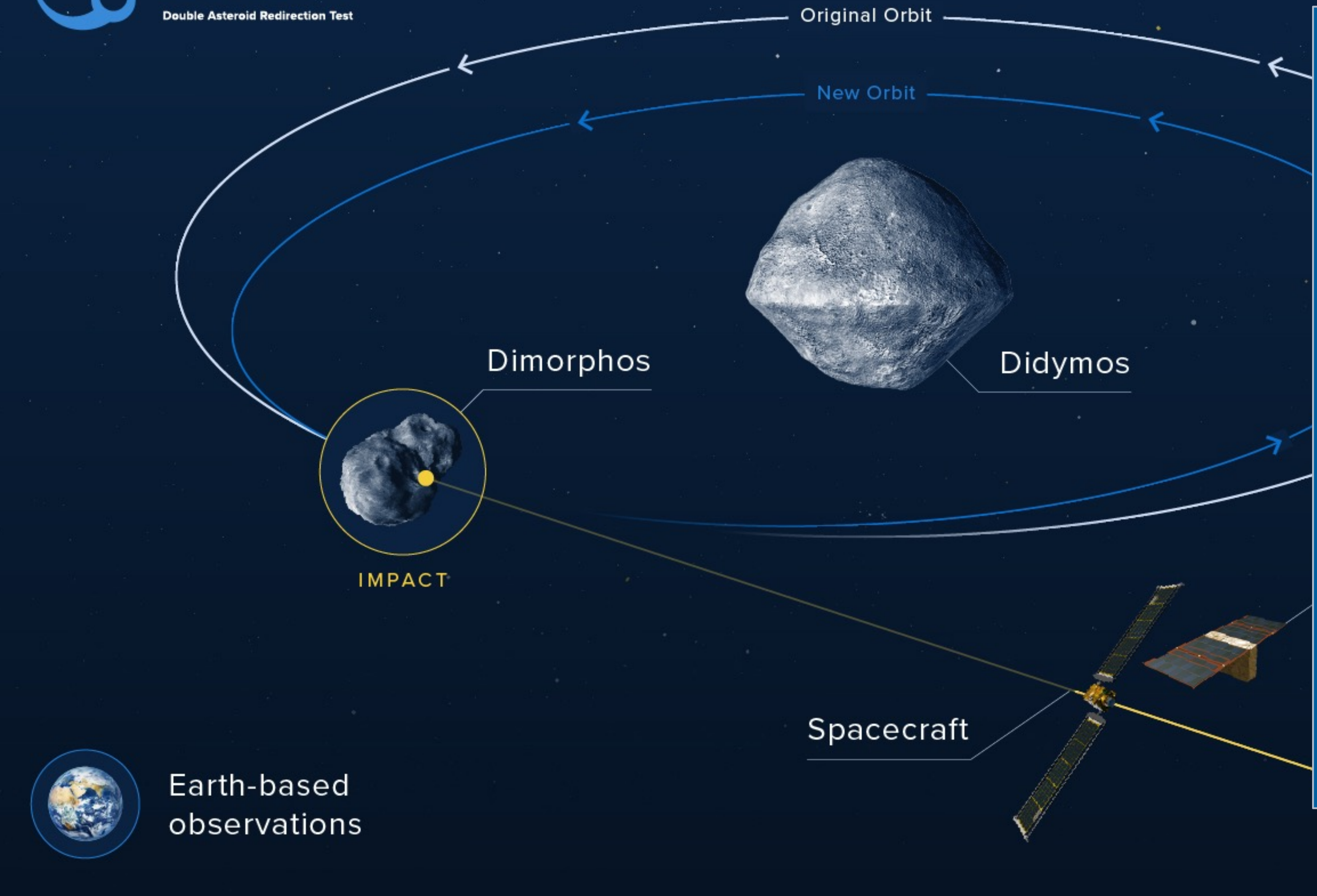


# The Ideal Target: A Natural Laboratory



DART
Double Asteroid Redirection Test

# The Ideal Target: A Natural Laboratory

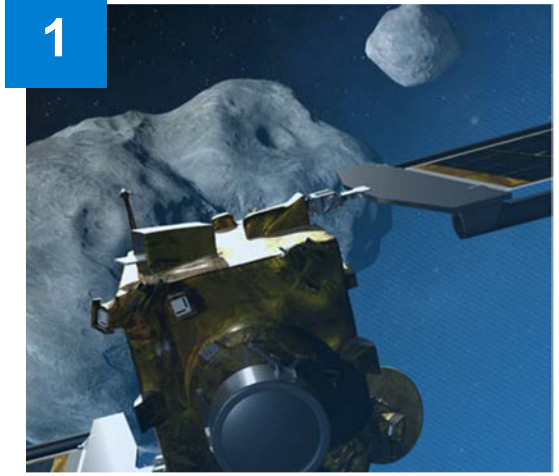



- A binary asteroid allows a detectable deflection of an asteroid of relevant size.
- DART’s kinetic impact will change the orbital period about the larger asteroid by ~1%.
  - Detectable in weeks to months.
- Same kinetic impact on a non-binary asteroid would change the orbital period about the Sun by ~0.000006%.
  - Would take many years to detect.

# DART's Level 1 Requirements

Defining the Mission's Planetary Defense Investigation

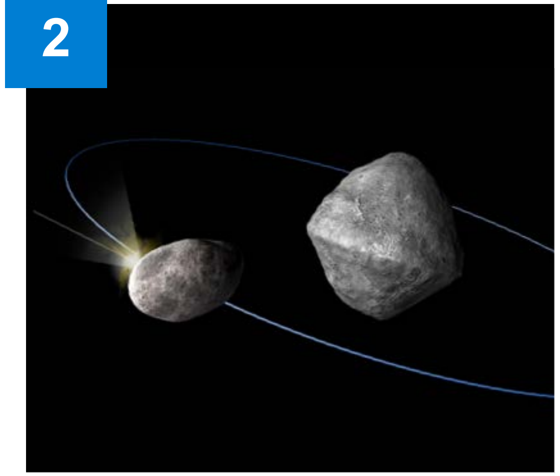
1



## Impact Dimorphos

During its Sept/Oct 2022 close approach to Earth

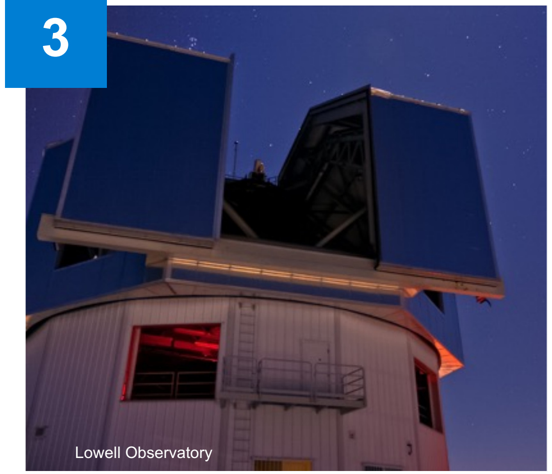
2



## Change the binary orbital period

Cause a ≥73-second change in the orbital period of Dimorphos

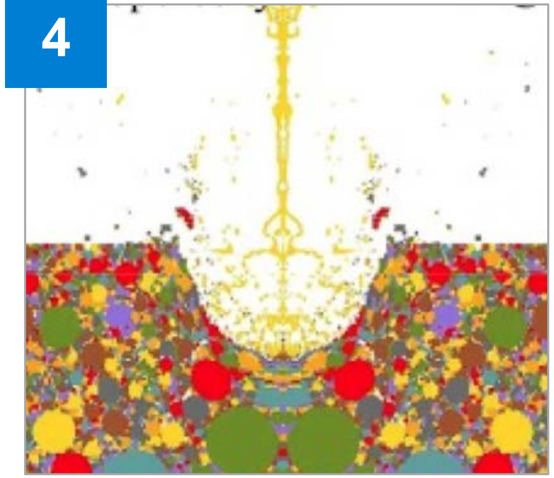
3




## Measure the period change

To within 7.3 seconds, from ground-based observations before and after impact

4



## Measure "Beta" and characterize the impact site and dynamics

***Beta*** = *the momentum enhancement factor*

# DART's Level 1 Requirements

## Defining the Mission's Planetary Defense Investigation

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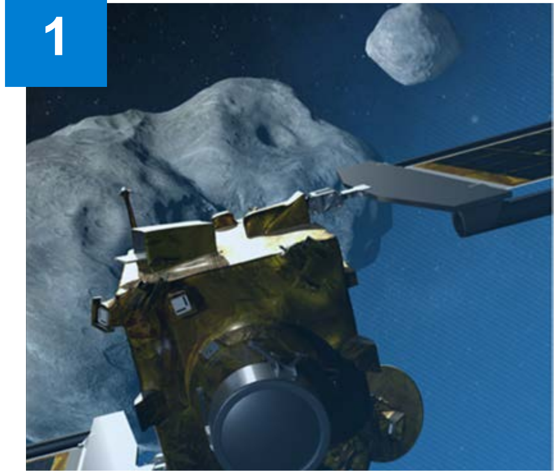
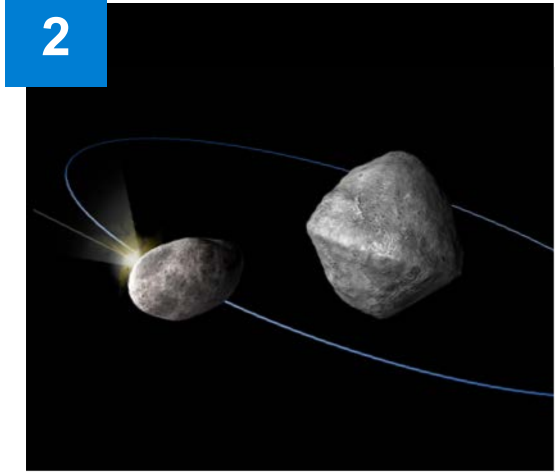


### Impact Dimorphos

During its Sept/Oct 2022 close approach to Earth

2



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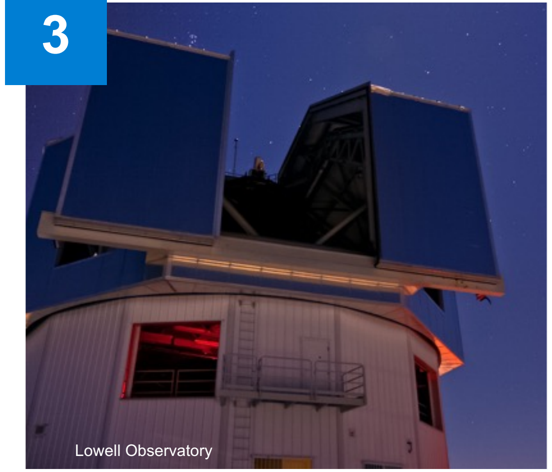


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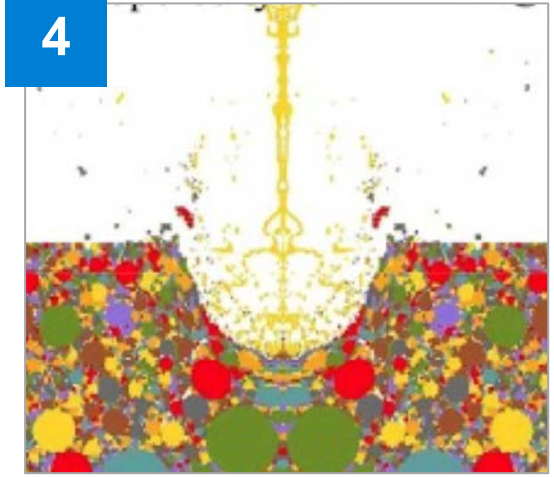

### Measure "Beta" and characterize the impact site and dynamics

***Beta*** *= the momentum enhancement factor*

DART spacecraft ops → | No DART spacecraft ops →

# DART = Double Asteroid Redirection Test

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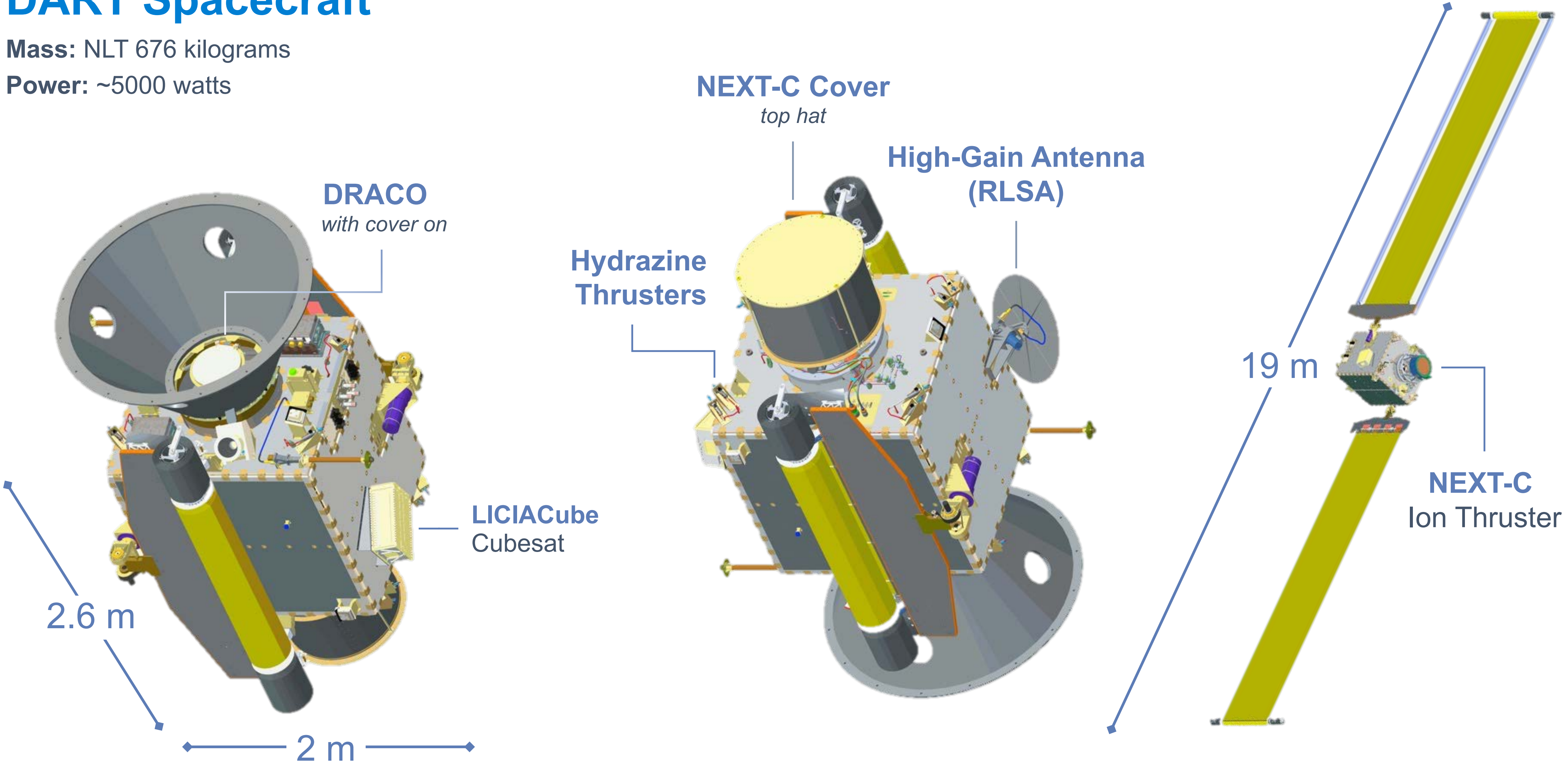
1. **Test the ability to achieve a kinetic impact on a real asteroid**
2. **Test how a real asteroid responds to a kinetic impact**

Test 1 ends, and Test 2 begins, at the moment of impact.

# DART Spacecraft

**Mass:** NLT 676 kilograms

**Power:** ~5000 watts



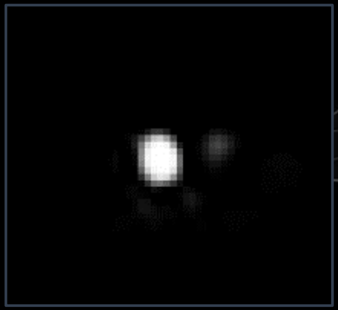
# DART Operations

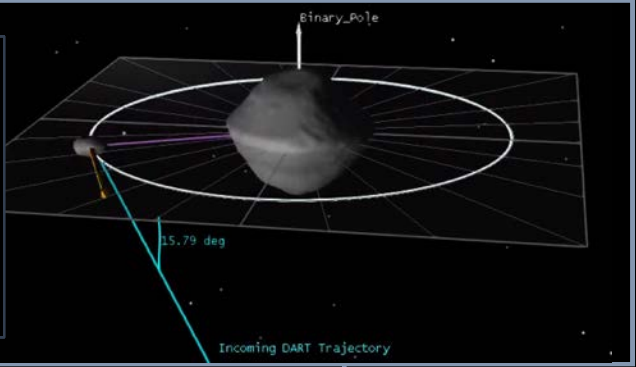
## How DART targets Dimorphos

**Fully Autonomous**

Begin terminal phase

SMART Nav guidance is enabled



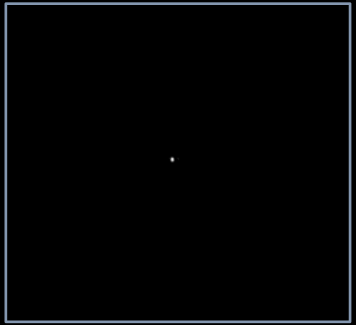



| Camera detects Didymos system | Continuous ground antenna coverage | Begin pre-terminal phase | Fully Autonomous: Begin terminal phase; SMART Nav guidance is enabled |
|---|---|---|---|
| 30 days | 10 days | 8 hours | 4 hours |

30 days · 10 days · 8 hours · 4 hours · 60 minutes · 4 minutes · 2 minutes · 20 seconds

# DART Operations

## How DART targets Dimorphos



**24,000 kilometers**
Didymos – 6.5 pixel
Dimorphos – 1.4 pixel
Secondary becomes observable

**1600 kilometers**
Didymos – 99 pixel
Dimorphos – 21 pixel
Final divert maneuver corrections

**800 kilometers**
Didymos – 197 pixel
Dimorphos – 41 pixel
Divert maneuvers complete, drift to impact


**130 kilometers**
Didymos – N/A
Dimorphos – ~300 pixel
Pixel-scale requirements met

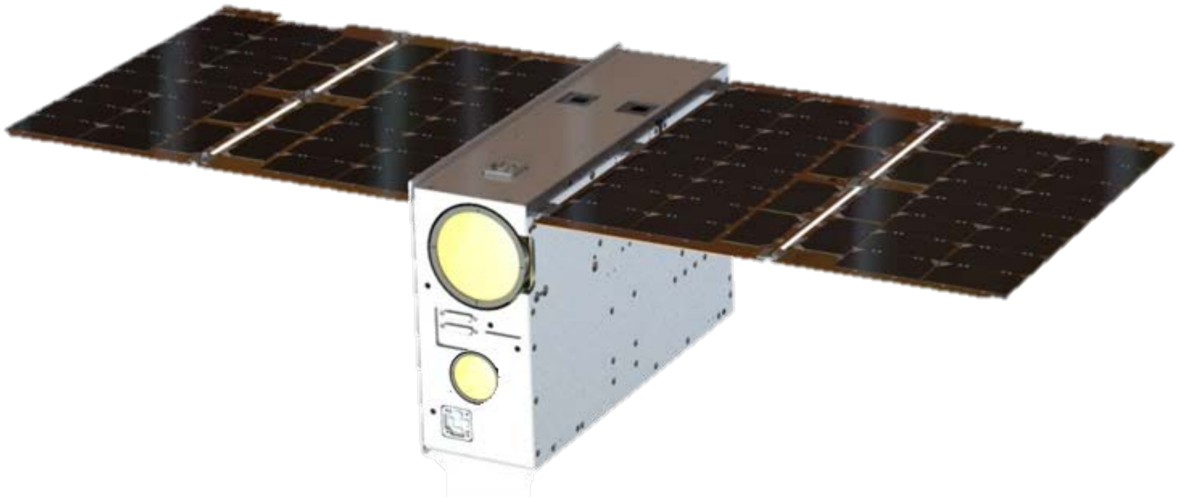
| 60 minutes | 4 minutes | 2 minutes | 20 seconds |
|---|---|---|---|

30 days — 10 days — 8 hours — 4 hours — **60 minutes** — **4 minutes** — **2 minutes** — **20 seconds**

# Light Italian CubeSat for Imaging of Asteroids

## LICIACube Goals

1. Obtain multiple (at least three) images of the DART impact ejecta plume over a span of times and phase angles, to allow estimation of plume density structure
2. Obtain multiple (more than three) images of the DART impact site with sufficient resolution to allow measurements of impact crater size and morphology
3. Obtain multiple (at least three) images of the non-impact hemisphere of Dimorphos
4. Obtain images of the ejecta plume and of the asteroid target to characterize color and spectral variations



Capable 6U CubeSat provided by Agenzia Spaziale Italiana (ASI)

Based on Argomoon CubeSat that will be flying on EM-1 mission (first flight of SLS in 2020)

Two cameras (goal of 2 m/pixel resolution imagery)

*Current concept of operations includes flyby of Didymos ~3 minutes after DART impact and downlinking data after event*

# From Kinetic Impact to Beta – Looks Easy, but Isn't!

$$\beta = \frac{\frac{M}{m_{sc}}\Delta V_T - \vec{V}_{\infty_{\perp n}} \cdot \hat{e}_T + V_{\infty_n}\vec{\epsilon} \cdot \hat{e}_T}{V_{\infty_n}(\hat{n} + \vec{\epsilon}) \cdot \hat{e}_T}$$

# From Kinetic Impact to Beta – Looks Easy, but Isn't!

$$\beta = \frac{\frac{M}{m_{sc}}\Delta V_T - \vec{V}_{\infty \perp n} \cdot \hat{e}_T + V_{\infty_n} \vec{\epsilon} \cdot \hat{e}_T}{V_{\infty_n}(\hat{n} + \vec{\epsilon}) \cdot \hat{e}_T}$$

- Determined directly from ground-based measurement of period change
- Known spacecraft & binary asteroid parameters
- Constrained by DART & LICIA imaging of Dimorphos and impact site
- Constrained by impact simulations and LICIA imaging of ejecta plume

- DART is 7 months from launch, and 17 months from its kinetic impact on Dimorphos.
- DART will be a historic first test, both of humanity’s ability to deflect a real asteroid and of a real asteroid’s response to a deflection.
- DART will enlarge our understanding of NEOs for planetary defense and planetary science, both on its own (along with LICIACube) and synergistically with Hera.

DART

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

# Double Asteroid Redirect Test (DART) Mission Status

Dr. Elena Adams
Elena.Adams@jhuapl.edu
26 April, 2021

# Launch

November 18, 2021 – February 15, 2022

- Target the binary asteroid Didymos system
- Impact Dimorphos and change its orbital period
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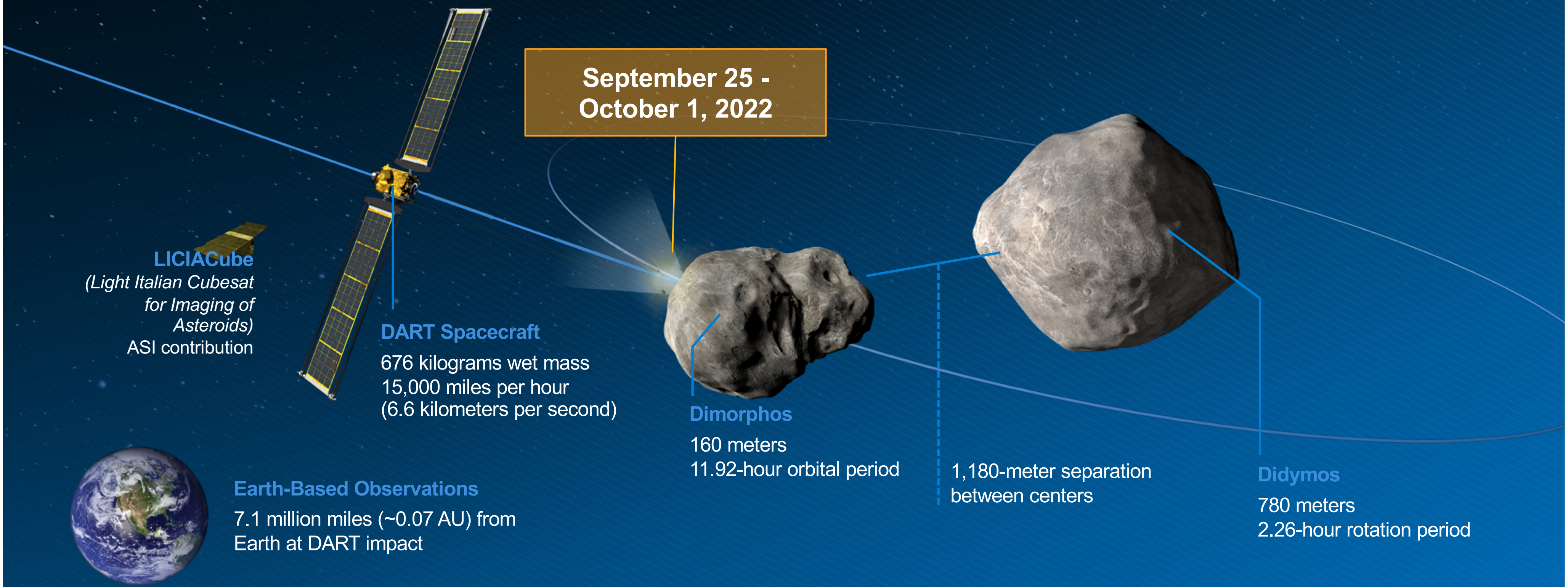
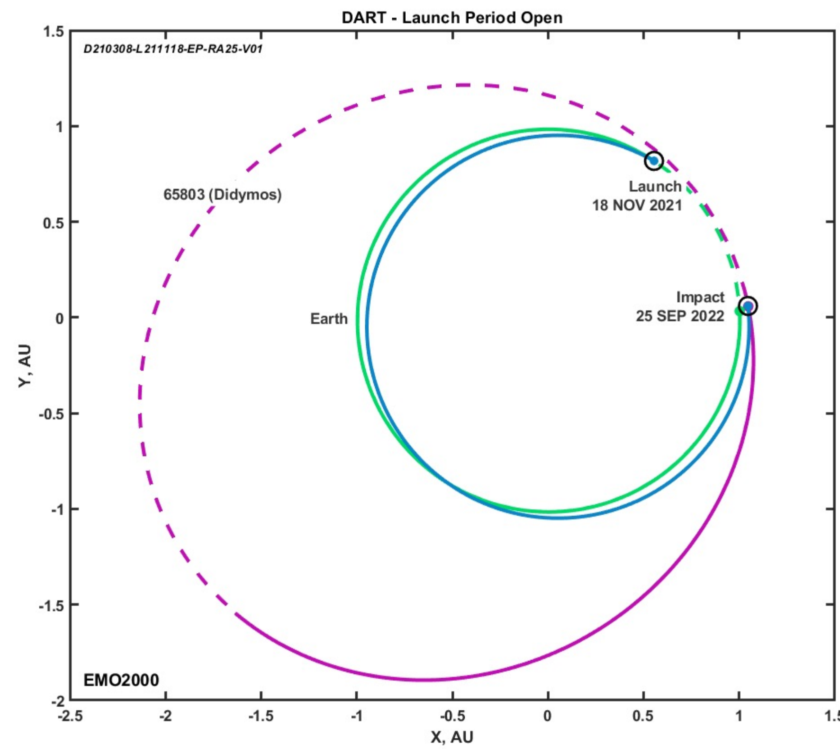


# DART moves to the secondary launch opportunity

- DART was directed by NASA to move to secondary launch opportunity with baseline **launch readiness date: 18 November, 2021**

- This secondary opportunity allows DART to meet its launch and objectives
  - Launch ground coverage becomes simpler, as DART will have a good contact with ESTRACK's New Norcia ground station
  - Cruise portion of the mission is a few months shorter
  - Impact geometry and velocity is comparable
  - Spacecraft still arrives at Dimorphos near the asteroid's closest approach to Earth, and guarantees good ground telescope and radar coverage
    - New impact dates: 25 Sept, 2022- 01 Oct, 2022



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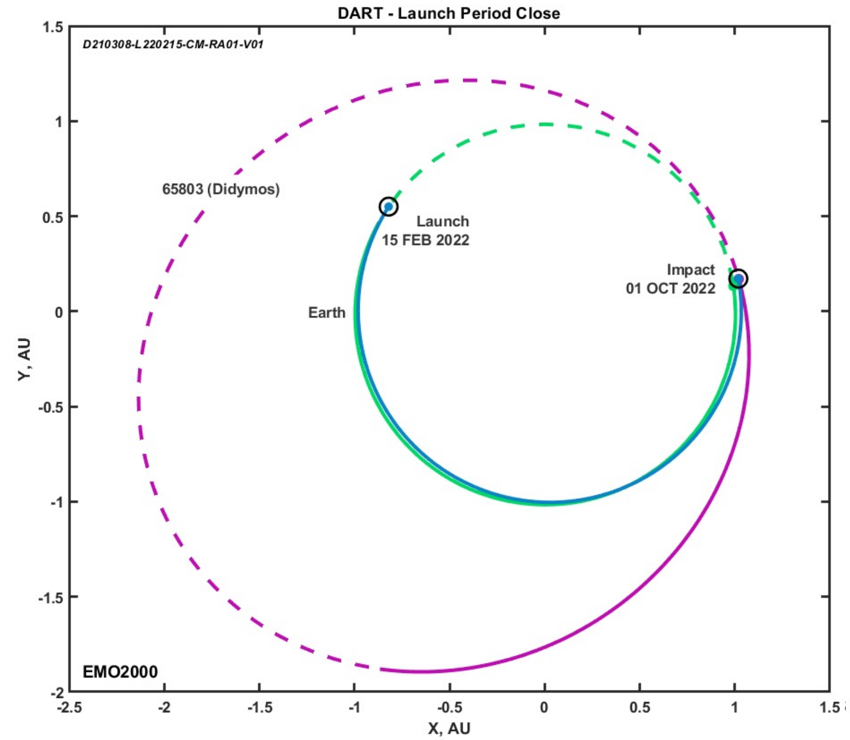

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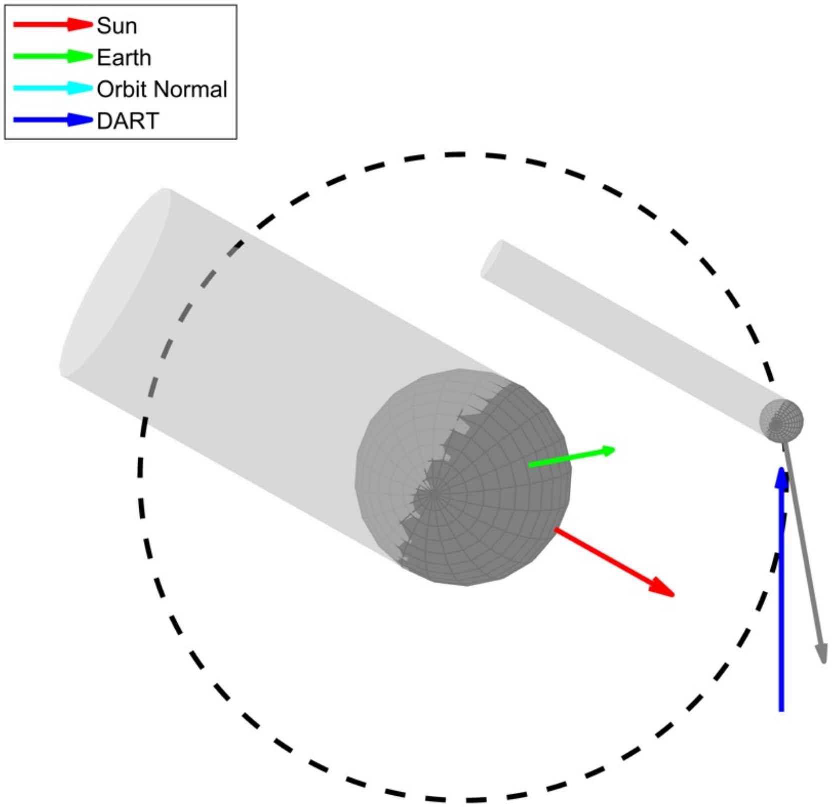
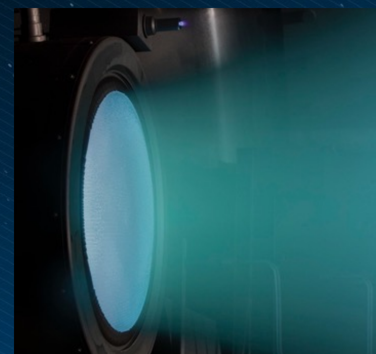


# DART: Key and New Technologies

DART will mature key new technologies for future planetary missions

**Autonomous Navigation using SMART Nav**

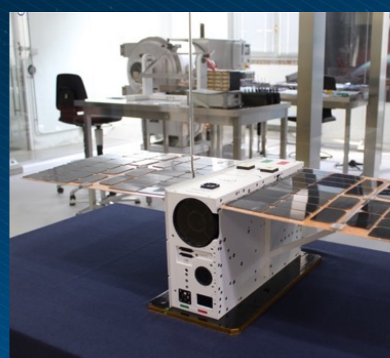
**DRACO Telescope**



**Ion Propulsion Engine (NEXT-C)**

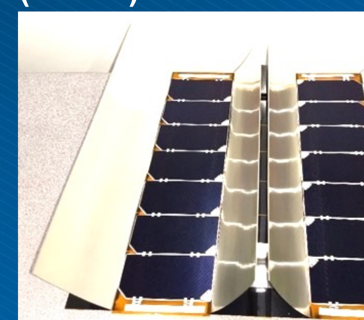
**Roll Out Solar Arrays (ROSA)**

**Coresat Avionics**



**LICIACube Cubesat**

**Radio Line Slot Array**

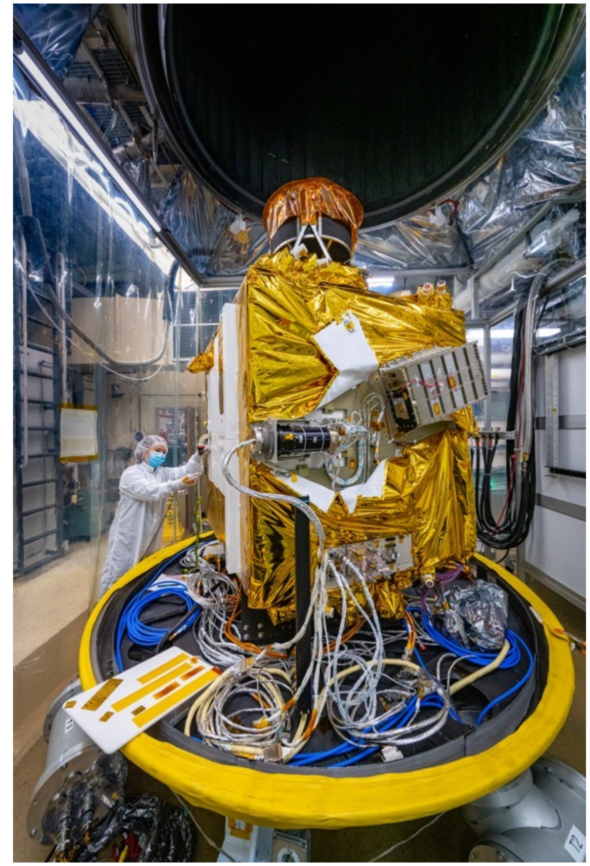


**Transformational Solar Array Concentrators**

# Integrating and Testing Spacecraft Getting Ready for Launch This Year

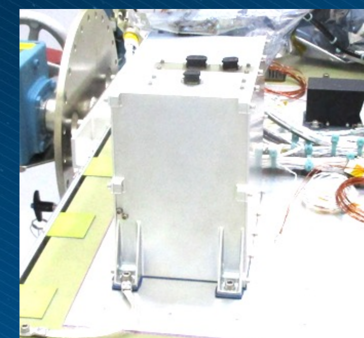

# DART mission status overview

- **Spacecraft integration and test is proceeding, even in COVID-19 environment**



DART in thermal chamber

# Timeline to Launch

**Integration Readiness Review** ✓
March 2020

**NEXT-C Delivered** ✓
April 2020

**Panels/Harness Delivered, I&T began!** ✓
April 2020

**Spacecraft Core Delivered** ✓
May 2020

**Coresat Avionics Delivered and Integrated** ✓
June 2020

# Timeline to Launch

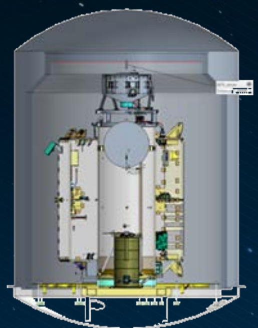

- **Solar Arrays Engineering Unit Deployed** (@ DSS) ✓ — Jul 2020
- **Comprehensive Performance Test (CPT) 1** ✓ — Aug 2020
- **Mission Simulation (MSIM) 1** ✓ — Aug 2020
- **Closed S/C Panels** ✓ — Sept 2020
- **DSN Compat Testing** ✓ — Oct 2020
- **NEXT-C Integration** ✓ — Oct 2020
- **CPT 2 MSIM 2** ✓ — Dec 2020
- **PER** ✓ — Jan 2021

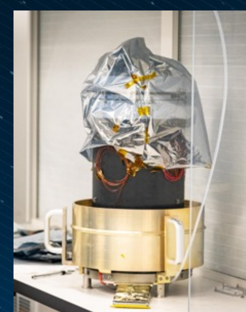
# DART mission status overview

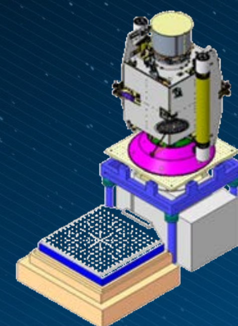
- **Spacecraft integration and test is proceeding, even in COVID-19 environment**
- Move to the secondary launch opportunity is caused by waiting on two hardware articles to be delivered to the spacecraft: the DRACO telescope and the Solar Arrays
  - Spacecraft structural testing cannot commence without them
- DRACO telescope had a mirror failure during vibration of a spare flight telescope, and the failure investigation board concluded that the flight telescope mirror mounts needed redesign to ensure that the flight telescope survives spacecraft testing and launch. Redesign was completed, and new mirror mounts manufactured. **Telescope is expected to arrive for integration in June 2021**
- **Rollout Solar Arrays (ROSA)** have experienced delays in the build due to COVID and as part of the new technology development, but now **have been received at APL for integration on the spacecraft in May 2021**

DART in thermal chamber

# Timeline to Launch







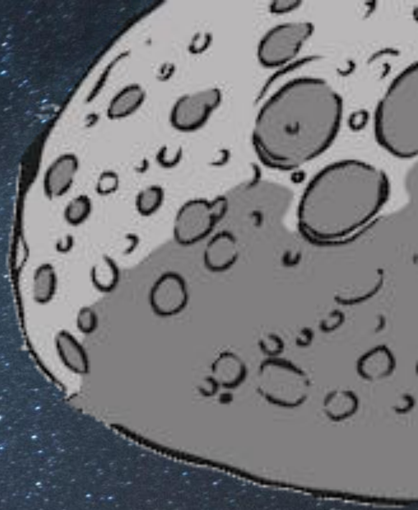
| | |
| --- | --- |
| Thermal ✓ Tests (CPT3, MSIM3) | Feb-Mar 2021 |
| Solar Array ✓ Delivery | Apr 2021 |
| DRACO telescope Delivery | Jun 2021 |
| Structural Tests (Vibe, Shock) | July 2021 |
| Pre-Ship Review | Sept 2021 |
| Ship to Vandenberg Air Force Base | Oct 2021 |
| Launch! | Nov 2021 |

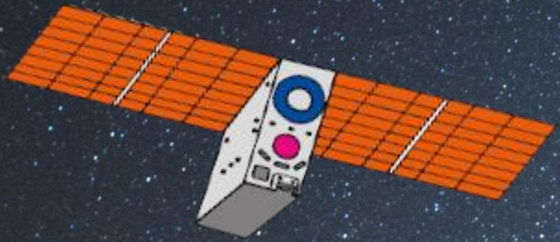
# DART

Double Asteroid Redirection Test

LICIA

Light Italian Cubesat for Imaging of Asteroids





# LICIACube

## the Light Italian Cubesat for Imaging of Asteroids

Elisabetta Dotto (INAF-OAR)
on behalf of the LICIACube Team

PDC– April 2021

DART

Double Asteroid Redirection Test

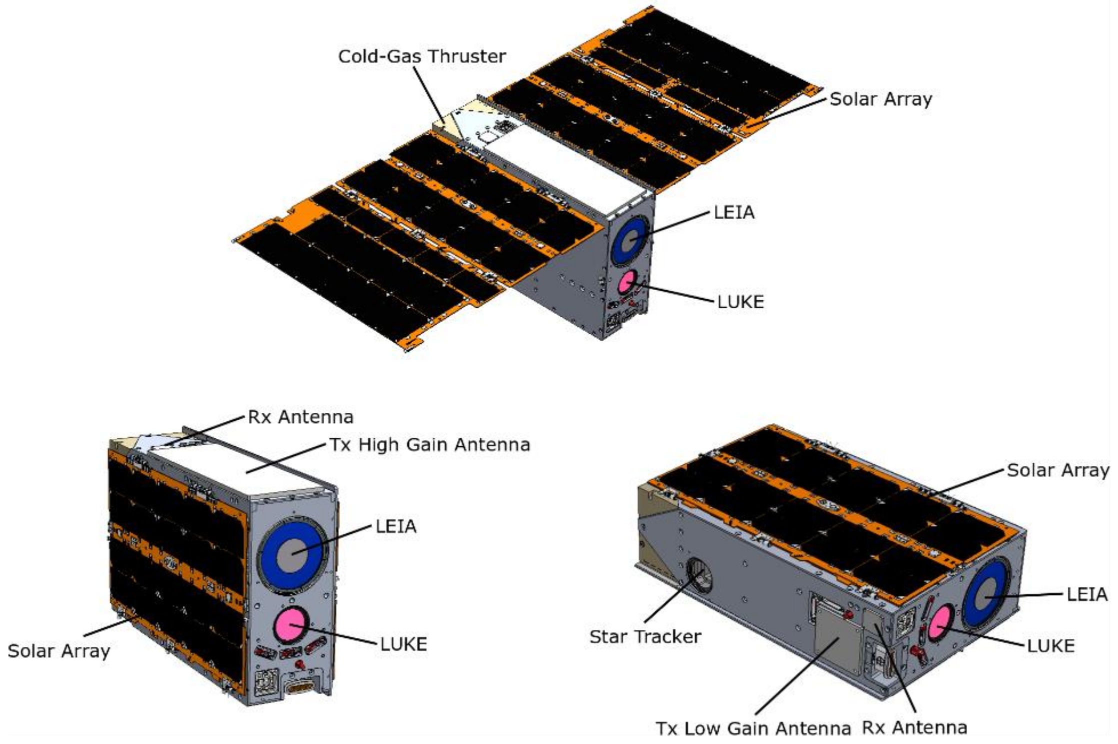
# The LICIACube team:

| | |
|---|---|
| **INAF:** | E. Dotto *(Science Team Lead)* |
| | V. Della Corte *(Instrument Team Lead)* |
| | E. Mazzotta Epifani *(WP Observations Lead),* S. Ieva, D. Perna |
| | J.R. Brucato *(WP Laboratory experiments Lead*), A. Meneghin, G. Poggiali |
| | S. Ivanovski *(WP Ejecta Lead)* |
| | A. Lucchetti *(WP Impact Simulation Lead),* G. Cremonese, E. Simioni |
| | M. Pajola *(WP Proximity Lead)* |
| **IFAC-CNR:** | A. Rossi *(WP Dynamics Lead)* |
| **Politecnico Milano:** | M. Lavagna *(WP Mission Analysis Lead),* A. Capannolo, G. Zanotti |
| **Univ. Bologna:** | M. Zannoni *(WP Orbit determination Lead),* P. Tortora, D. Modenini, I. Gai |
| **Univ. Parthenope:** | P. Palumbo, I. Bertini, |
| **Argotec:** | V. Di Tana *(Argotec Program Manager),* S. Simonetti *(System Engineer),* |
| | B. Cotugno, F. Miglioretti |
| **ASI:** | S. Pirrotta *(Program Manager),* M. Amoroso, G. Impresario, |
| **ASI SSDC:** | A. Zinzi *(SOC Lead)* |

# LICIACube



**Orbit:** Heliocentric (~10M km from the Earth)
**Mass:** 14 kg
**Volume:** 6U+
366 mm x 239 mm x 116.2 mm (stowed)
911.5 mm x 366 mm x 239 mm (deployed)



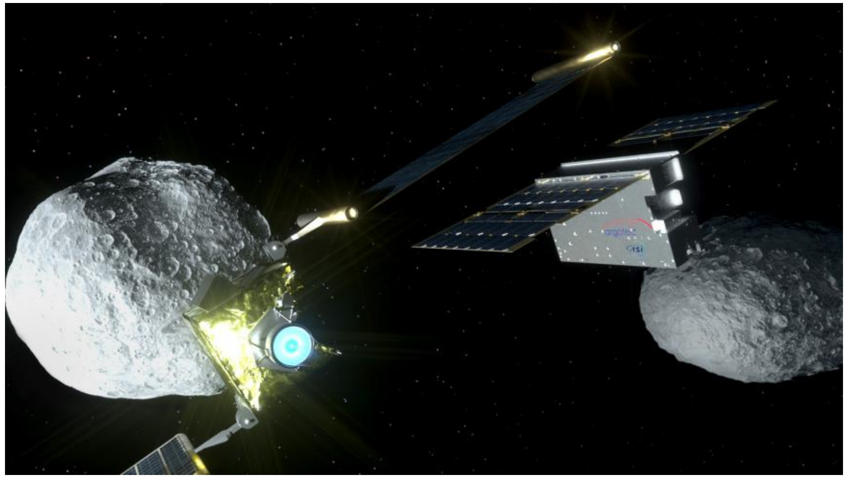

| | Focal length (mm) | FoV (°) | IFoV (µrad/px) | Spat. scale at 55.2km (m/px) |
|---|---|---|---|---|
| LEIA | 220 | ± 2.06 | 25 | 1.38 |
| LUKE | 70.55 | ±5 | 78 | 4.31 |

**LEIA:** a catadioptric camera
spatial scale at C/A (~55km) 1.38 m/px

**LUKE**: a camera with a RGB Bayer pattern filter

E. Dotto and the LICIACube team

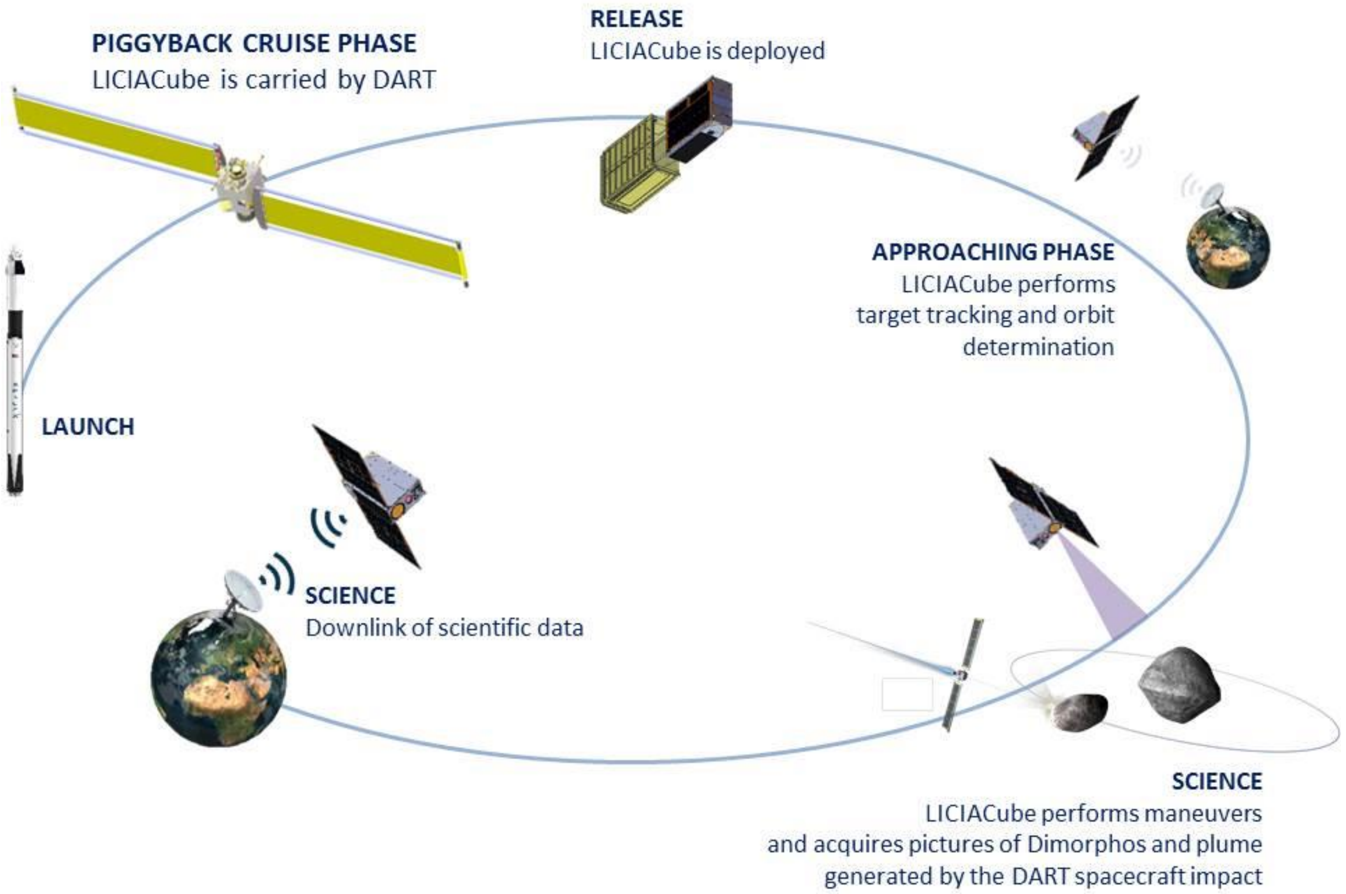
# LICIACube



LICIACube is carried by DART until close to Didymos and then released to perform a fly-by of Dimorphos after DART impact.

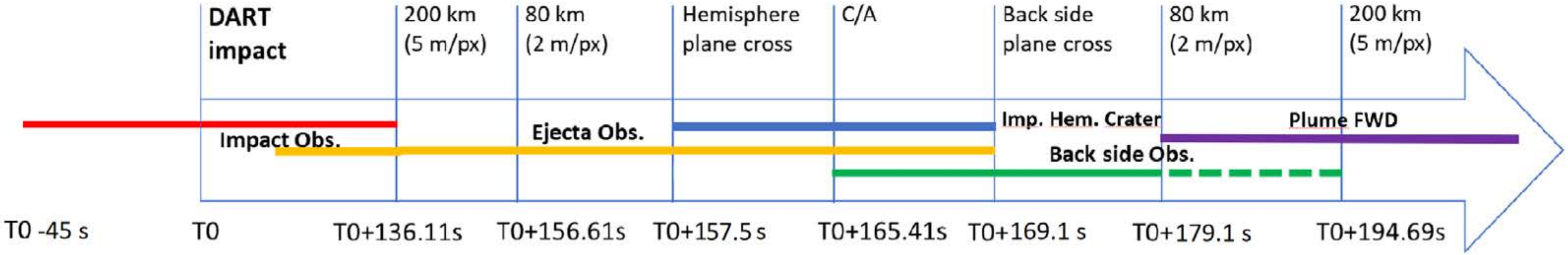
LICIACube downlinks images directly to Earth after the target fly-by.

E. Dotto and the LICIACube team



# LICIACube acquisition strategy

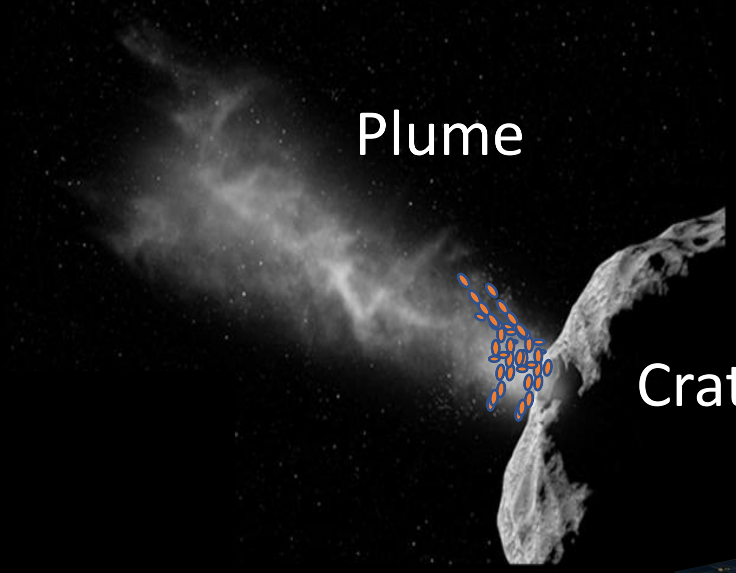
| Phase | Start | End | LEIA | LUKE |
|---|---|---|---|---|
| 1 – DART Impact | -45 s to T0 | T0+136.11 s | yes | Not operative |
| 2 - Ejecta Observation | -25 s to T0 | T0 + 169.1 s | yes | yes |
| 3 - High resolution (surface properties/crater) observation | T0 + 157.5 s | T0 + 169.1 s | yes | yes |
| 4 – Non-impact hemisphere observation | T0 + 165.41s | T0 + 179.1 s | yes | yes |
| 5 – Plume evolution in forward scattering | T0 + 179.1 s | T0 + 600 s | yes | yes |

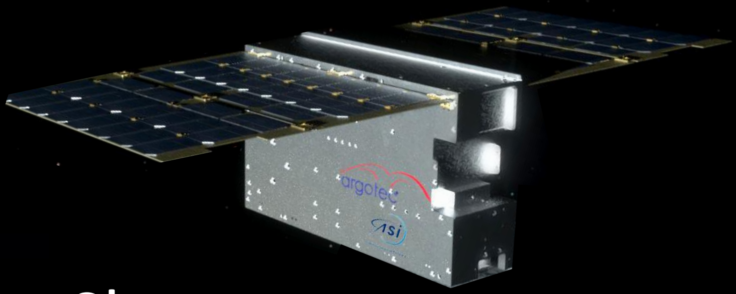


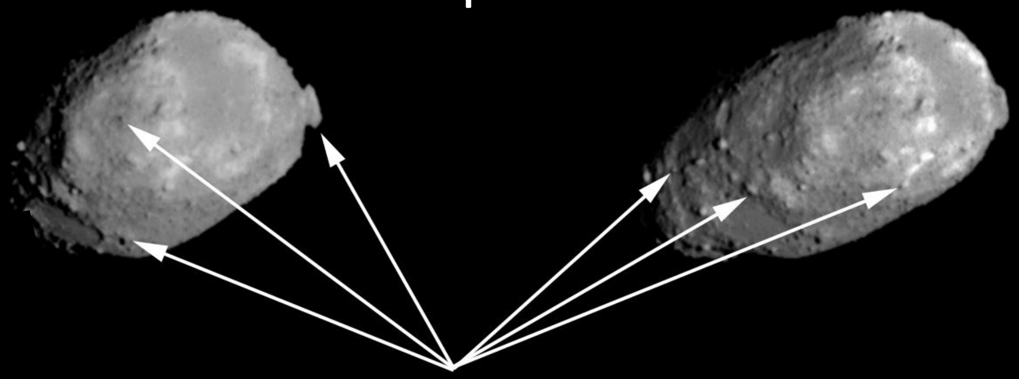

E. Dotto and the LICIACube team

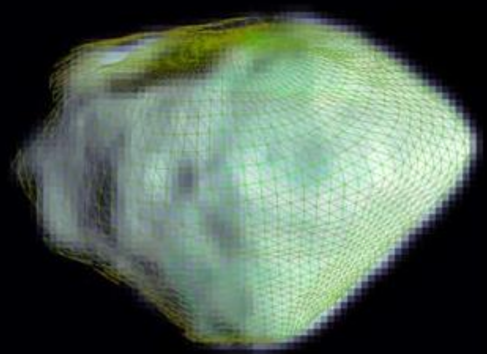
# Scientific Objectives

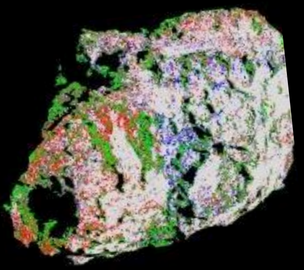
Geological and morphological analysis





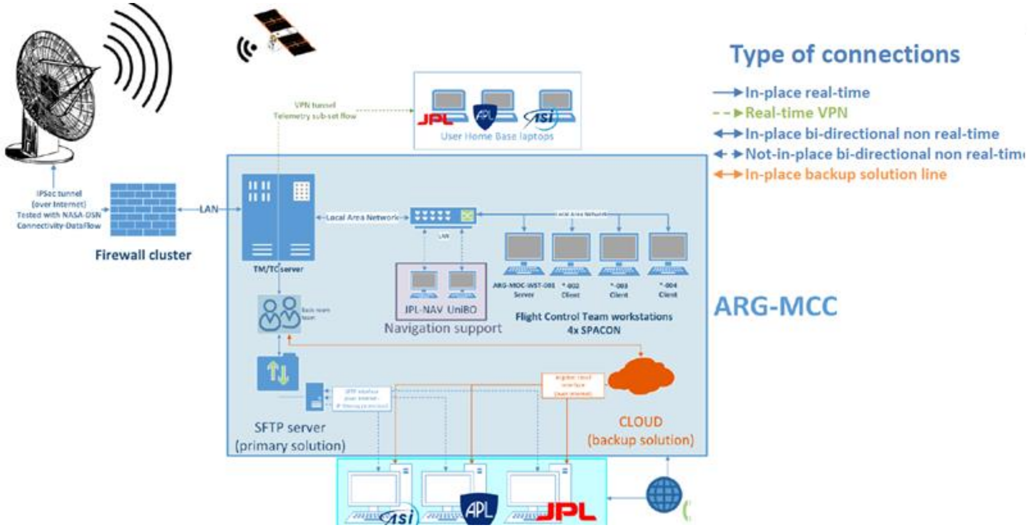




E. Dotto and the LICIACube team

# Ground Segment

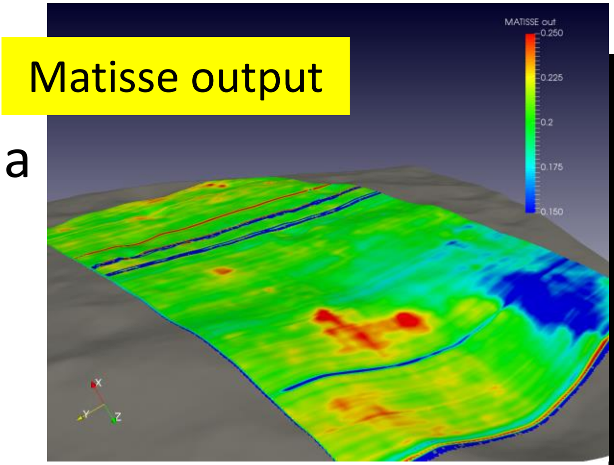
The mission Ground Segment architecture includes DSN antennas and the two main elements located in Italy:

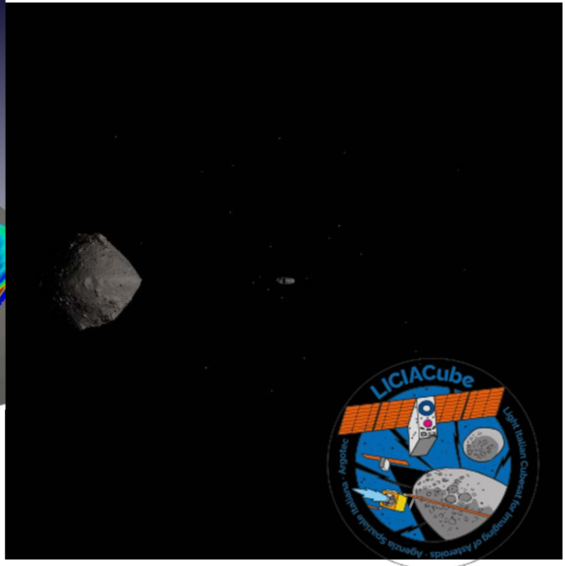
- Mission Control Center (MCC): @ Argotec (Turin)
- Science Control Center (SOC): @ ASI SSDC (Rome) https://www.ssdc.asi.it/liciacube/




The raw data, coming from MCC, will be calibrated by SOC, using the calibration procedure provided by INAF.

A PDS4 archive will be designed, populated and released to the public after the end of the mission.



Data will also be accessible (first of all to the team and in a second time to public) by means of the SSDC MATISSE webtool (https://tools.ssdc.asi.it/Matisse), with advanced 2D and 3D visualization capabilities.

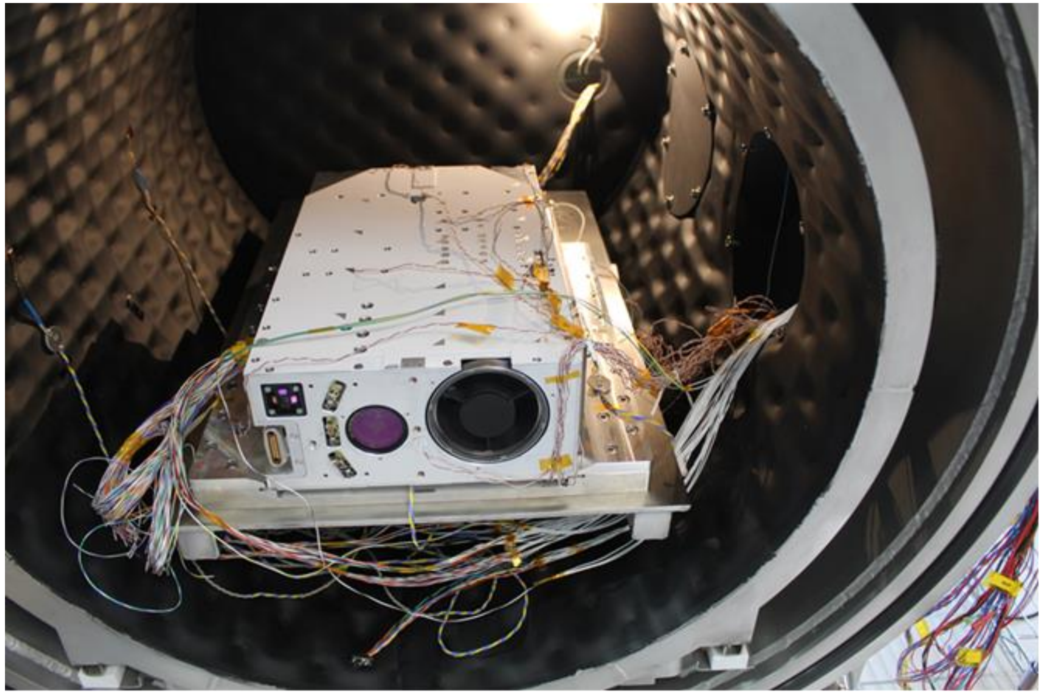
E. Dotto and the LICIACube team

# Status of the Project

- Qualification test campaign at Cubesat level in progress:
  - Full funtional test succesfully completed;
  - TVAC test succesfully completed;

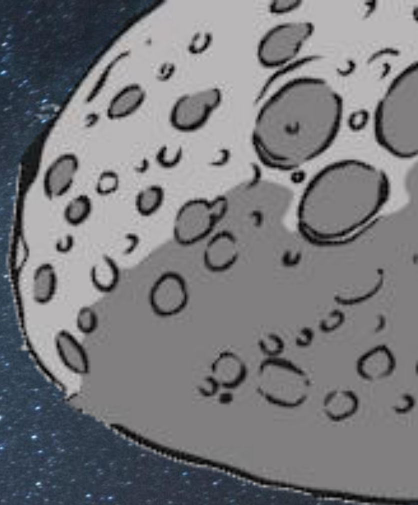
- Integration into the dispenser, expected on 12th May
- Qualification and Acceptance test campaign at System level (cubesat + dispenser + EBC)
  - Vibrations test
  - Deployment test
  - Thermal balance test

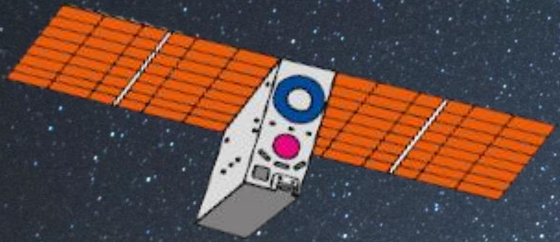
- Readiness of the System, expected on mid June
- Reviews and logistics
- Delivery to APL in Baltimore, expected on 23rd July



**LICIACube spacecraft in TVAC chamber, after test**

LICIA
Light Italian Cubesat for Imaging of Asteroids





# LICIACube

## the Light Italian Cubesat for Imaging of Asteroids

Elisabetta Dotto (INAF-OAR)
on behalf of the LICIACube Team

PDC– April 2021

DART
Double Asteroid Redirection Test

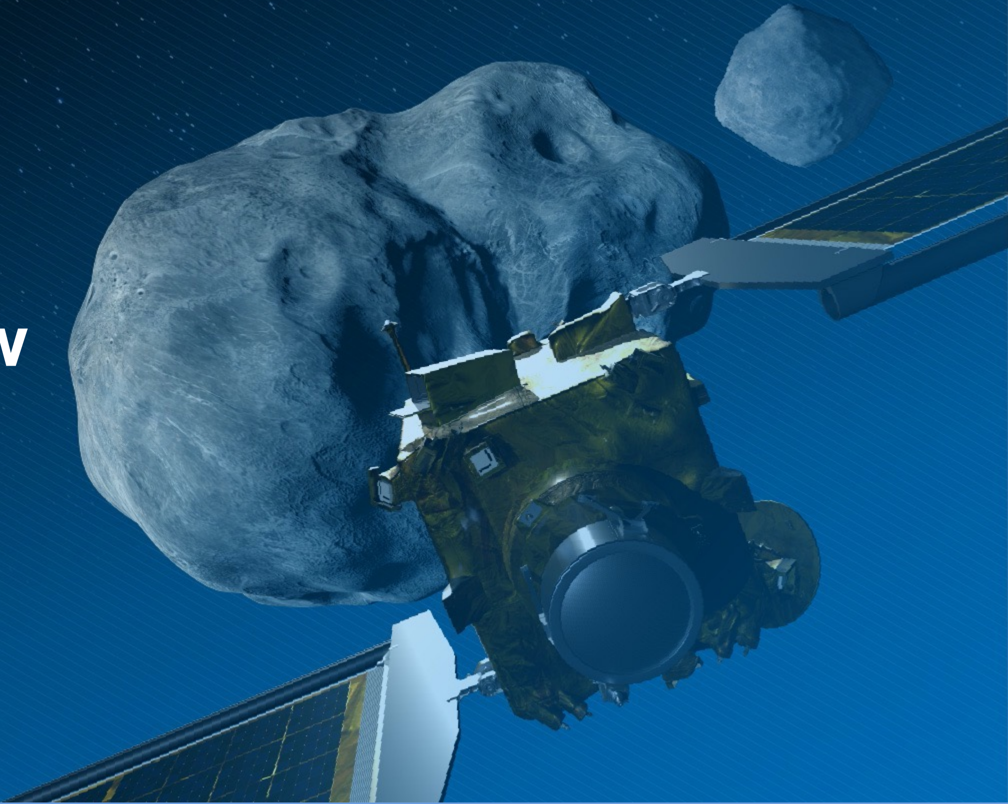
DART

NASA

JOHNS HOPKINS APPLIED PHYSICS LABORATORY

# DART: How will we know what we've done?

## Observations and Dynamics

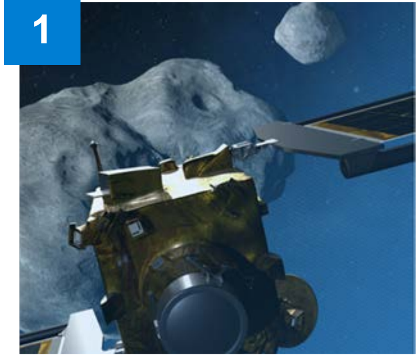


Andy Rivkin
DART Investigation Lead

# DART's Level 1 Requirements

Defining the Mission's Planetary Defense Investigation

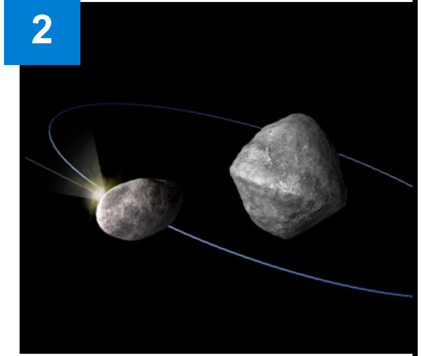
1



## Impact Dimorphos

During its Sept/Oct 2022 close approach to Earth

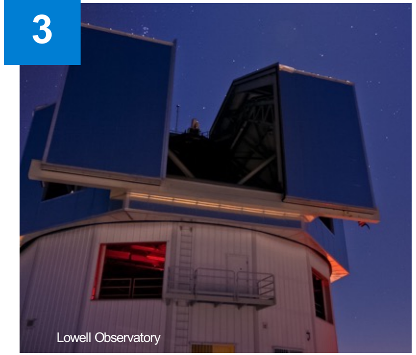
2



## Change the binary orbital period

Cause a ≥73-second change in the orbital period of Dimorphos

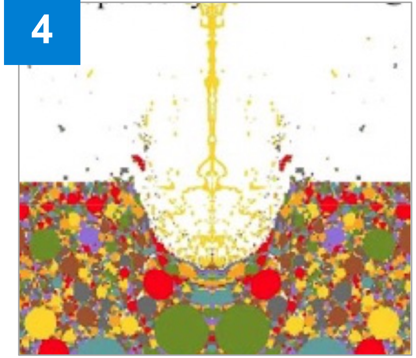
3




## Measure the period change

To within 7.3 seconds, from ground-based observations before and after impact

4



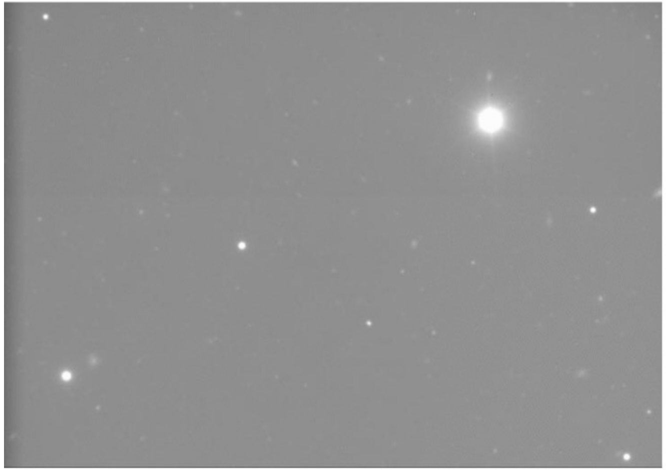
## Measure "Beta" and characterize the impact site and dynamics

***Beta*** *= the momentum enhancement factor*

I'll be talking mostly about #3, just touch on #4

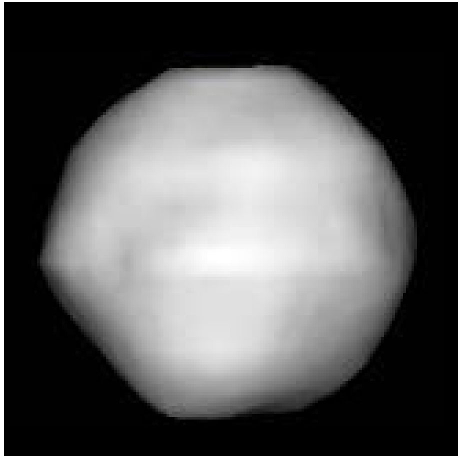
# Current Knowledge about Didymos

## Lightcurves



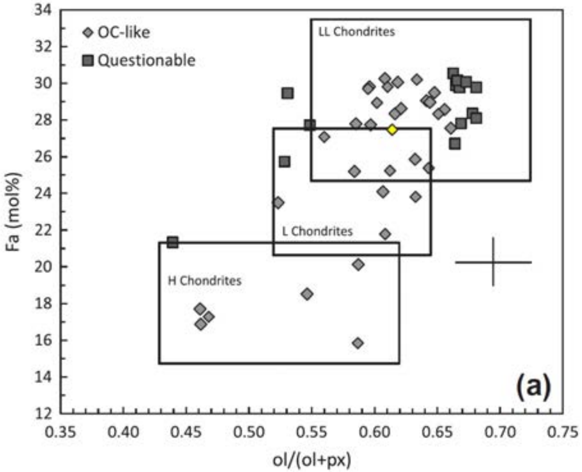
Didymos, moving through star field
*Taken from Keck Observatory, January 2021*

## Radar Shape Model



Shape model of the Didymos primary asteroid from combined radar and light curve data (Naidu et al. 2020)

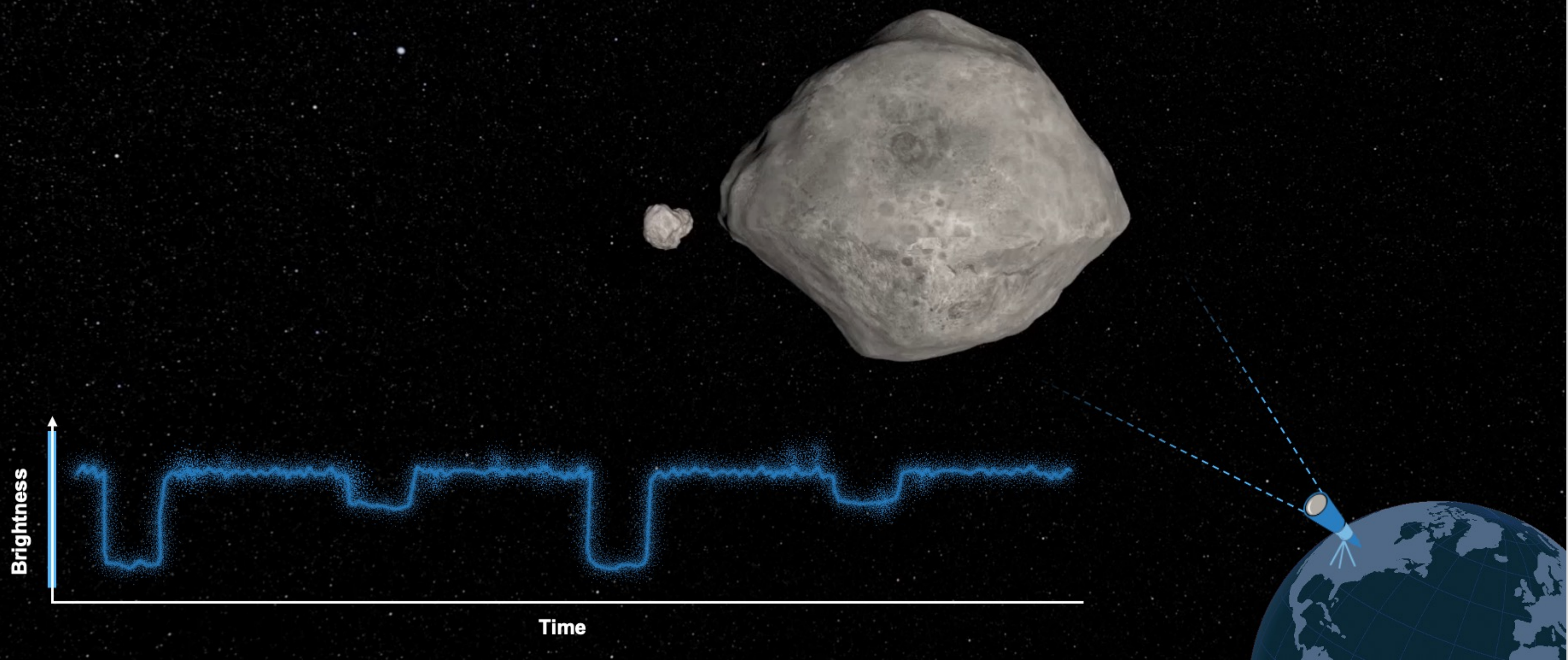
## Composition



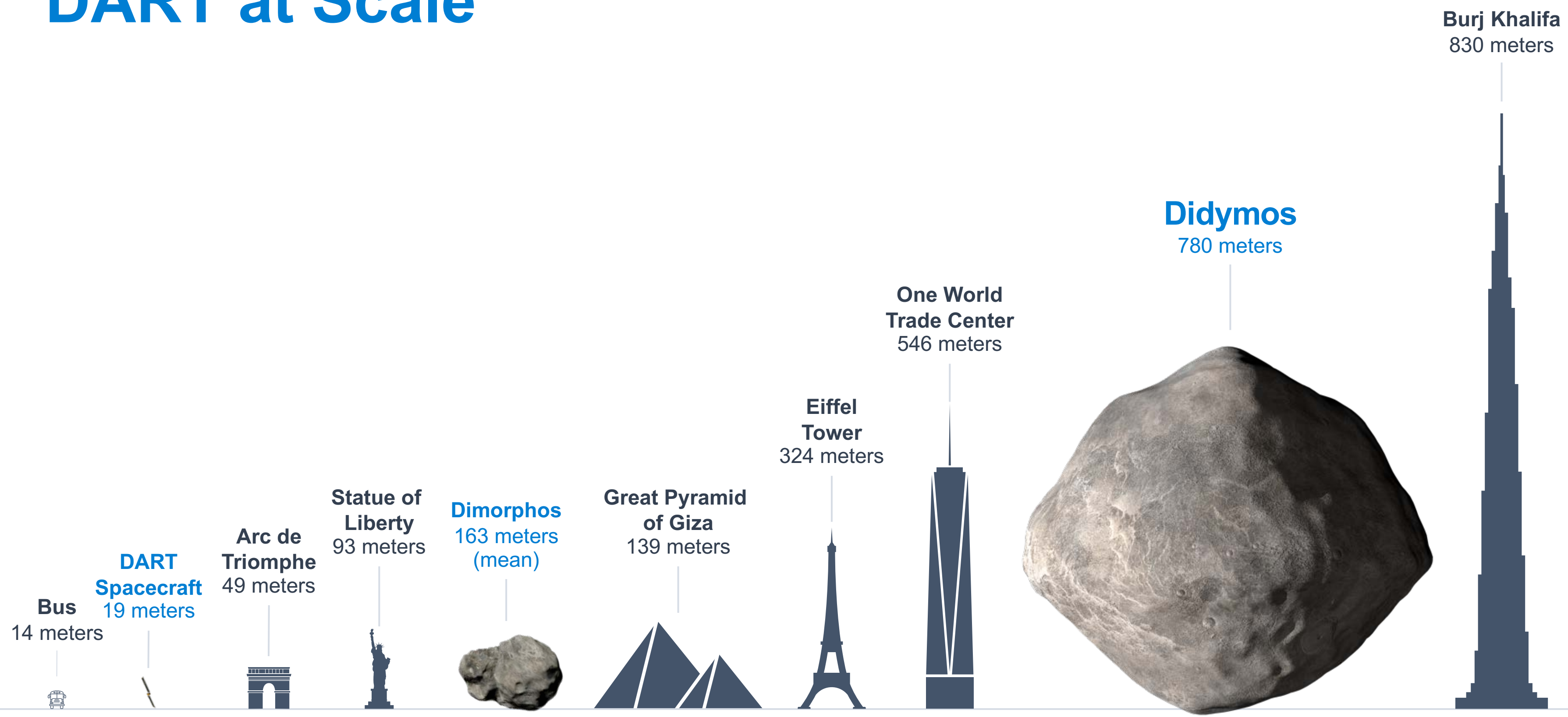

Spectral parameters from observations by de Leon et al. (2009) (yellow diamond) found by Dunn et al. (2014) to be most consistent with L/LL meteorites.

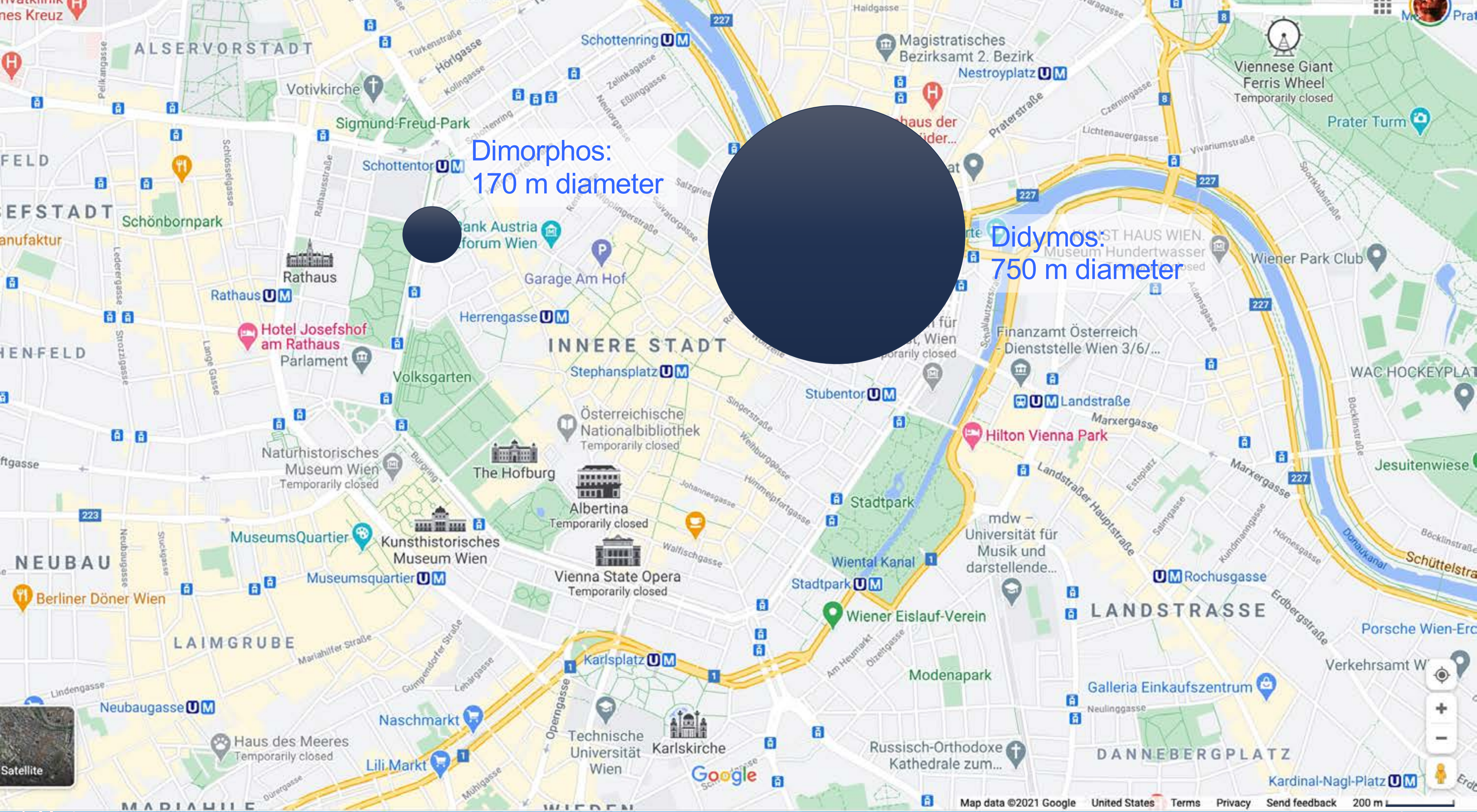
# Measuring the Binary Asteroid System from Earth

Dimorphos Orbiting about Didymos



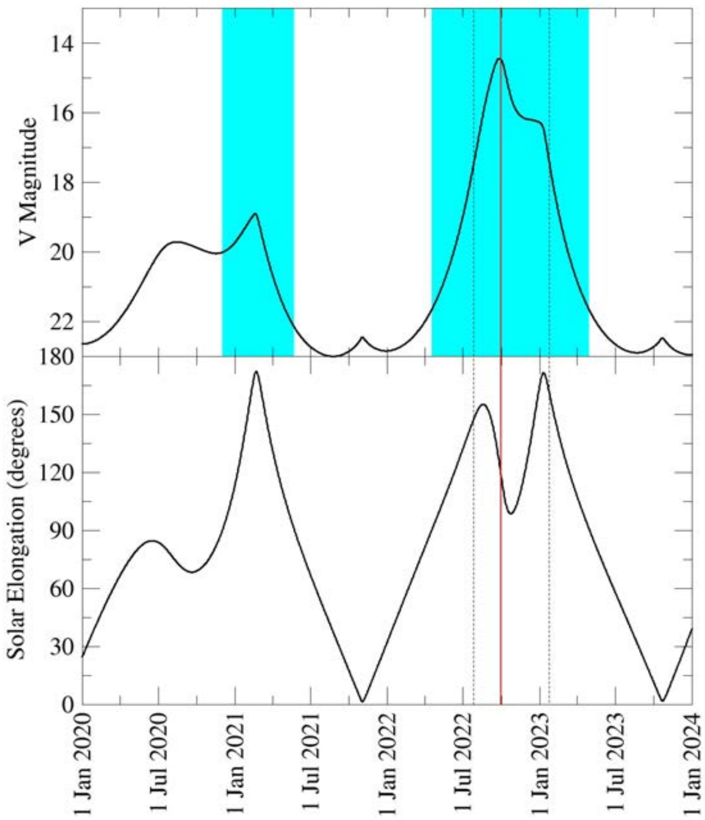
# DART at Scale




Dimorphos:
170 m diameter
Didymos:
750 m diameter
ALSERVORSTADT
Schottenring
Magistratisches Bezirksamt 2. Bezirk
Nestroyplatz
Viennese Giant Ferris Wheel
Temporarily closed
Votivkirche
Sigmund-Freud-Park
Prater Turm
Schottentor
Schönbornpark
Bank Austria Forum Wien
Rathaus
Garage Am Hof
Wiener Park Club
Herrengasse
Hotel Josefshof am Rathaus
Parlament
INNERE STADT
Finanzamt Österreich - Dienststelle Wien 3/6/...
Volksgarten
Stephansplatz
Stubentor
WAC HOCKEYPLATZ
Landstraße
Österreichische Nationalbibliothek
Temporarily closed
Hilton Vienna Park
Naturhistorisches Museum Wien
Temporarily closed
The Hofburg
Albertina
Temporarily closed
Stadtpark
Jesuitenwiese
MuseumsQuartier
Kunsthistorisches Museum Wien
mdw – Universität für Musik und darstellende...
NEUBAU
Wiental Kanal
Museumsquartier
Vienna State Opera
Temporarily closed
Stadtpark
Rochusgasse
Berliner Döner Wien
Wiener Eislauf-Verein
LANDSTRASSE
LAIMGRUBE
Porsche Wien-Erdberg
Karlsplatz
Verkehrsamt Wien
Modenapark
Galleria Einkaufszentrum
Neubaugasse
Naschmarkt
Haus des Meeres
Temporarily closed
Technische Universität Wien
Karlskirche
Russisch-Orthodoxe Kathedrale zum...
DANNEBERGPLATZ
Lili Markt
Kardinal-Nagl-Platz
Satellite
Google
Map data ©2021 Google
United States
Terms
Privacy
Send feedback
200 m

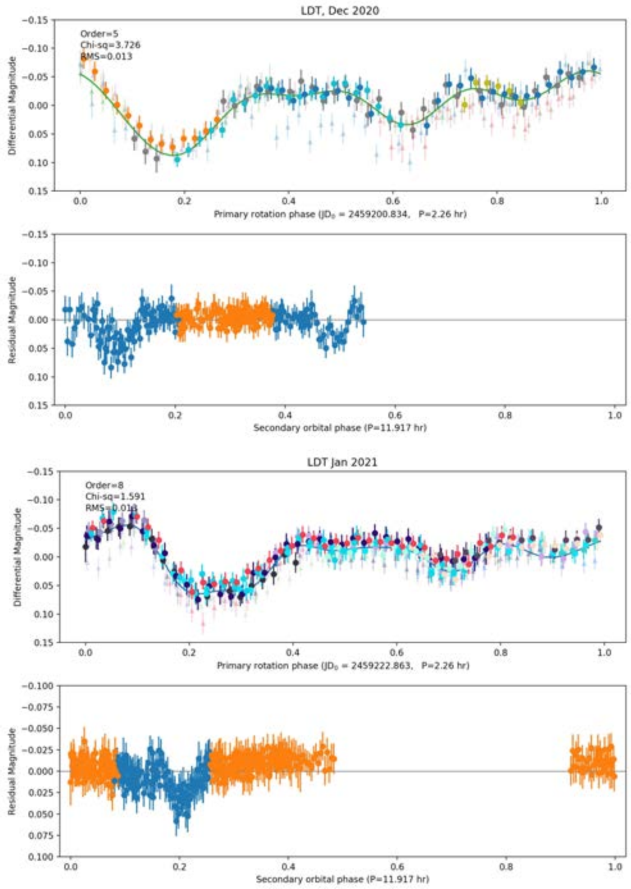
# The 2020-2021 Apparition

- Focused on improving precision of Dimorphos' orbit to allow extrapolation and targeting of a particular orbit phase at time of DART arrival
- Observing season December 2020—March 2021
  - Early observations only had short observing window per night
- Deadline-driven data analysis included observations from LDT and Keck
  - Only data reduced through mid-January included in current fits
  - Additional observations still under analysis



# The 2020-2021 Apparition

- New data reduces the uncertainty on Dimorphos’ orbit period to 0.01 seconds
- 3-$\sigma$ uncertainty on Dimorphos orbit phase < 7° when extrapolated to time of DART arrival
- GM value corresponds to mass of roughly 5.5 x $10^{11}$ kg
  - 95%+ of mass in Didymos, remainder in Dimorphos
  - Density 2170 ± 350 kg/$m^3$
- Best estimate for binary YORP (“BYORP”) is small but non-zero.




Lowell Discovery Telescope, December 2020 & January 2021
Nick Moskovitz, Matthew Knight, Tony Farnham

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| Parameter | Value | 1$\sigma$ uncertainty |
|---|---|---|
| $M_0$ (°) | 78.9 | 1.9 |
| Period (h) | 11.9216287 | 0.0000031 |
| $n_0$ (rad $s^{-1}$) | 1.46400235e-04 | 0.00000038e-4 |
| $\dot{n}$ (rad $s^{-2}$) | 4.9e-18 | 1.1e-18 |
| Epoch (TDB) | 2011-08-21.5 | |
| $\chi^2$ | 20.0 | |
| $\chi^2_\nu$ | 0.42 | |
| $(\lambda, \beta)^\circ$ | $(320, -79)^\circ$ | |
| $GM_{sys}$ ($m^3$ $s^{-2}$) | 37.0362739237411501789 | |

# The 2020-2021 Apparition

- New data reduces the uncertainty on

**Also see e-Lightning Talks:**

“Constraining the Orbital Parameters of the Didymos-Dimorphos System: Lightcurve Observations in Preparation for AIDA/DART” by Thomas et al.

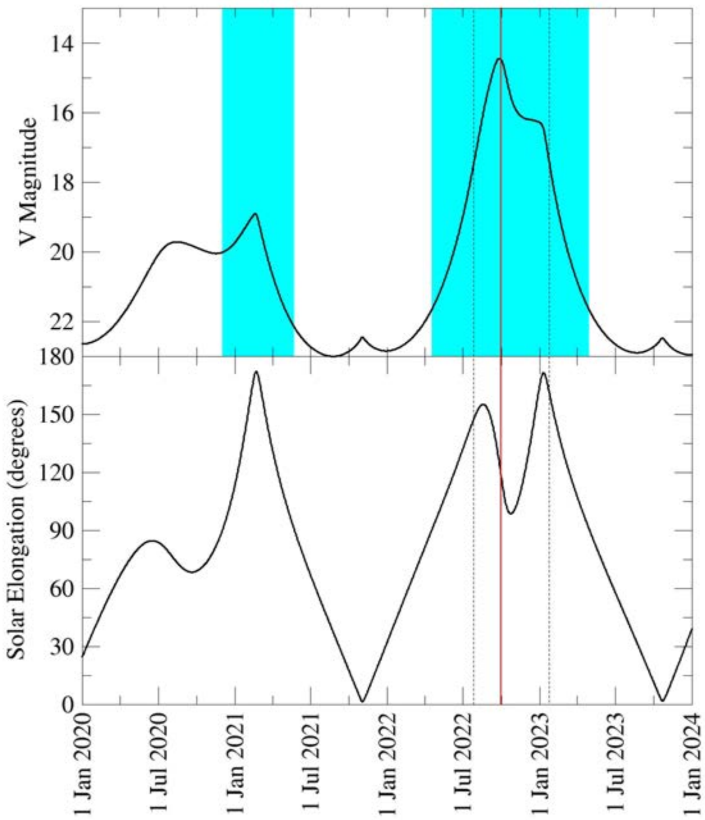
“Estimation of orbital parameters of Dimorphos from lightcurve mutual events” by Naidu et al.

  Dimorphos
  - Density 2170 ± 350 kg/m$^3$

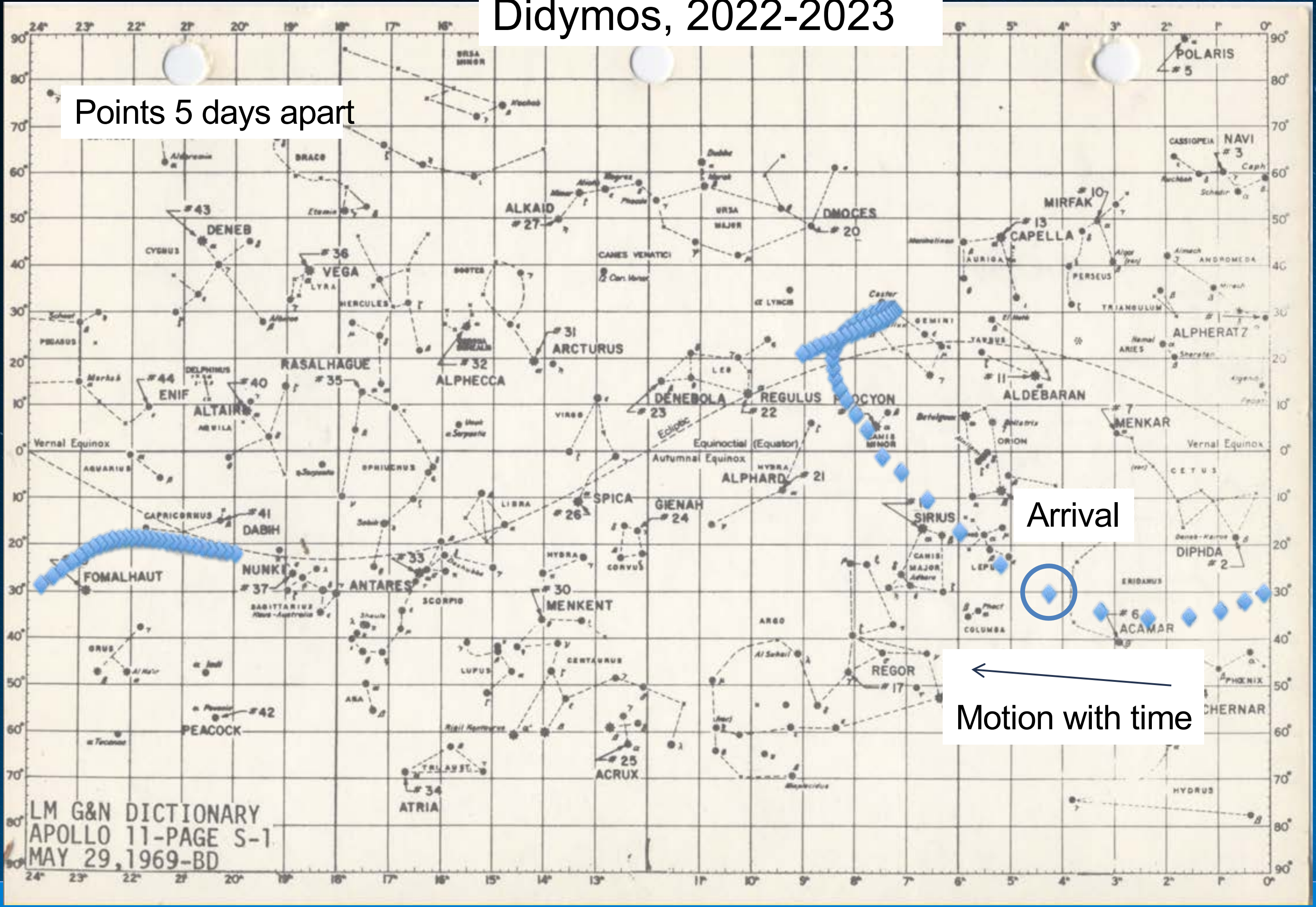
- Best estimate for binary YORP (“BYORP”) is small but non-zero.

# The 2022-2023 apparition

- Didymos spends very long period at >90° solar elongation, roughly 6 months at V < 17.5
  - At V < 17.5 should be able to get good lightcurve data with m-class telescopes
- DART supporting observations from 4 observatories
  - Lowell Observatory
  - Magdalena Ridge Observatory
  - Las Cumbres Observatory (network)
  - Las Campanas Observatory
- Access to additional observatories through team membership around the world
- At time of DART arrival, Didymos is in southern skies. It moves north rapidly over following weeks
  - Distribution of supported telescopes allows good coverage during entire period
- Anticipate reaching required precision on period change by end of calendar year 2022



# Didymos, 2022-2023



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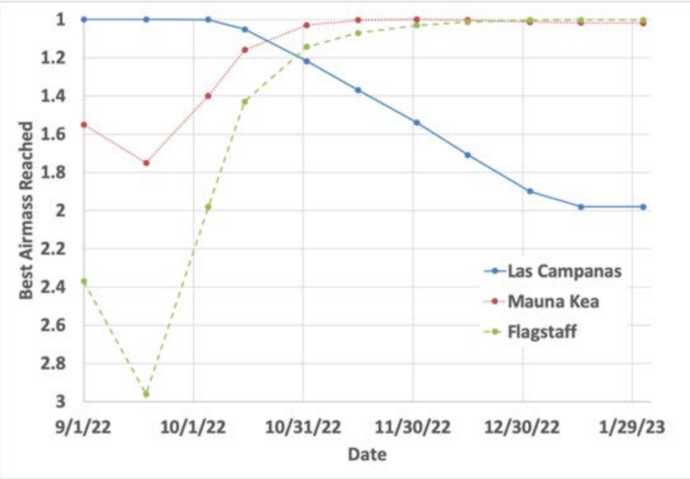
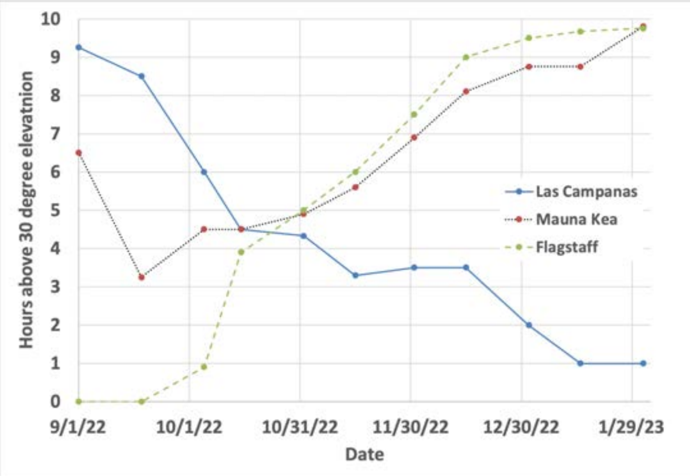


# Additional measurements

- Radar: High SNR measurements available from Goldstone 2-16 October 2022, 150 m/pixel monostatic, 75 m/pixel bistatic with Green Bank possible.
  - Can potentially measure offset between Dimorphos position and unperturbed position within a few days of DART impact
- Ejecta:
  - Visualization models still being run for LICIACube and other observing platforms
  - Expect brightening of system while ejecta is still unresolved within same pixel as Didymos (duration dependent upon imaging system used as well as ejecta model)
  - Hope to study the ejecta evolution from Earth-based systems, which will help constrain particle sizes and ejecta mass

# Additional measurements

- Radar: High SNR measurements available from Goldstone 2-16 October 2022, 150 m/pixel monostatic, 75 m/pixel bistatic with Green Bank possible.
  - Can potentially measure offset between Dimorphos position and unperturbed position within a few days of DART impact

**Also see e-Posters:**
“Dynamics of ejecta plume after the DART impact on Dimorphos” by Ferrari et al.;
“Non-spherical dust dynamics of the ejecta plume in support of DART/LICIACube mission” by Ivanovski et al.
“Incorporating a gravity field model based on radar observations into the rebound ejecta dynamics package” by Larson et al.
**e-Lightning talks:** “Simulating planned LICIACube imagery of DART impact ejecta based on ejecta dynamics simulation output” by Fahnestock et al.;
“Influence of the body composition on the evolution of ejecta in the Didymos-Dimorphos binary system” by Rossi et al.

# Dynamical Possibilities

- The impact into Dimorphos will inevitably cause librations
  - Even if perfectly circular/perfectly tidally locked pre-arrival, DART will cause some amount of eccentricity and thus libration
- The amount of libration is dependent upon Dimorphos' shape
  - Not clear if likely amounts of libration will be observable from Earth
  - May be observable with Hera's arrival
  - If observable, will provide information about Dimorphos' interior
- Dynamics of system very sensitive to initial conditions, shape of Didymos and Dimorphos
  - Close enough to one another that they do not appear as point sources for gravitational purposes
- Hera's visit to Didymos will enable dynamical models to be tested
  - Another case were the combined data sets will be "more than the sum of parts"

# Dynamical Possibilities

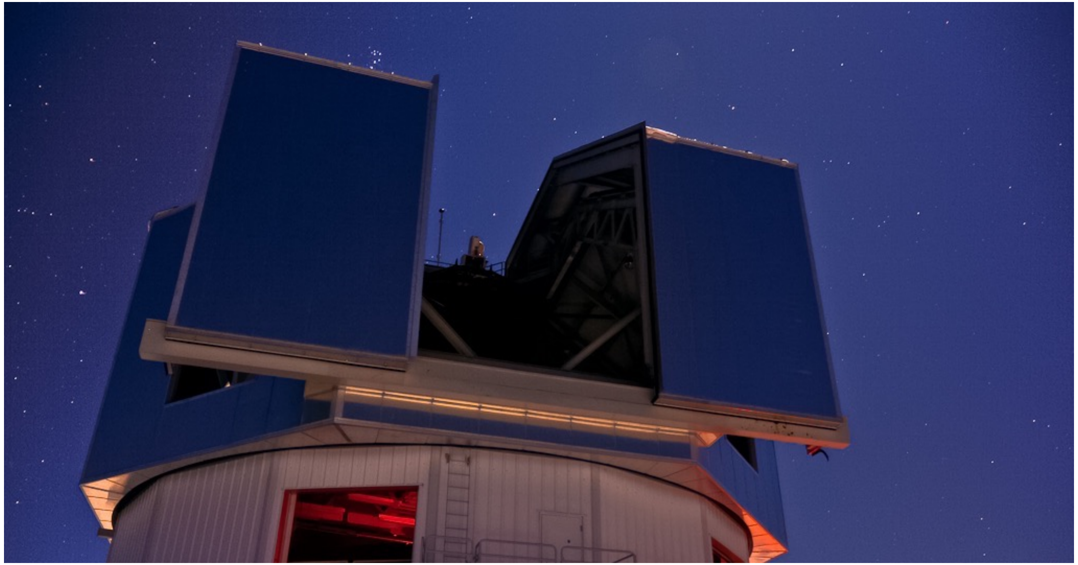
- The impact into Dimorphos will inevitably cause librations

**Also see e-Lightning talks:**
“Consequences of the DART impact on Dimorphos’ spin state and surface mass”, Benavidez et al.;
“On the post-impact spin state of the secondary component of the Didymos-Dimorphos binary asteroid system” by Agrusa et al.;
“Changing the heliocentric orbit of the Didymos system with DART” by Makadia et al.

- Hera’s visit to Didymos will enable dynamical models to be tested
  - Another case were the combined data sets will be “more than the sum of parts”

# Summary

- Telescopic observations of the Didymos system are integral to the DART project
- Dynamical studies have been showing what can/can't be extrapolated or determined from 1st principles, and studying the lifetime of DART effects
- Observations prior to DART's arrival are necessary to characterize its undisturbed nature and to enable targeting at a desired Dimorphos orbit phase
- Observations subsequent to DART's arrival are how the experiment will be evaluated
- Preparations for the 2022-2023 observations are beginning, with opportunity to participate



Lowell Discovery Telescope (credit: Lowell Observatory)

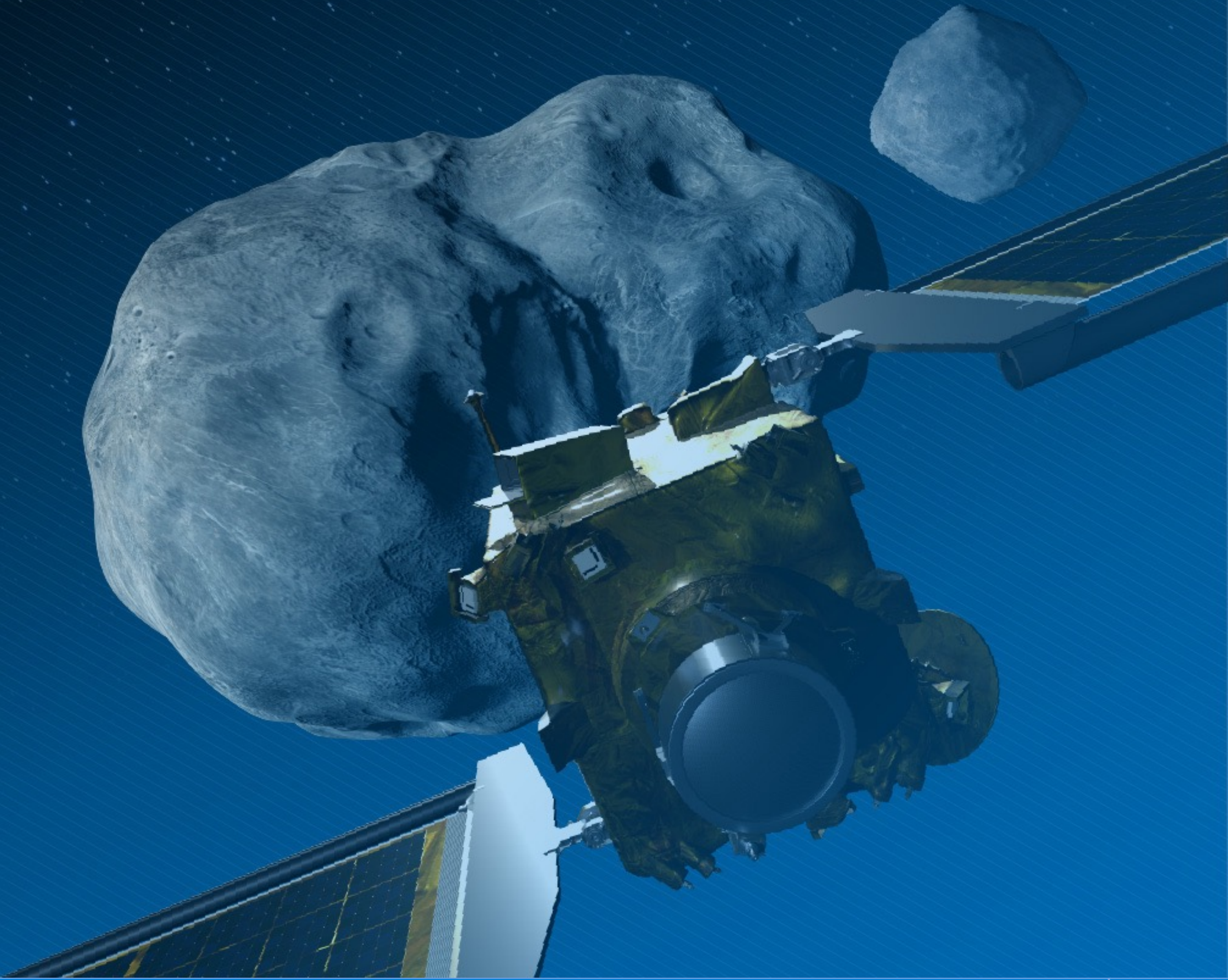
# DART

Double Asteroid Redirection Test

# DART Legacy: Determination of beta, data archive

*Kinetic Impactor Demonstration*

Andrew Cheng
andy.cheng@jhuapl.edu



# DART

*Kinetic impactor demonstration at Didymos*

- Demonstrate orbital deflection of a representative threat asteroid
- The DART target is a realistic-sized asteroid (160 m) of the most common NEO composition (S-type)
- A controlled impact experiment to increase confidence of kinetic impact predictions and improve understanding of asteroid physical properties and high-speed collisions

**Impact Dimorphos**

During its Sept/Oct 2022 close approach to Earth

**Change the binary orbital period**

Cause a ≥73-second change in the orbital period of Dimorphos

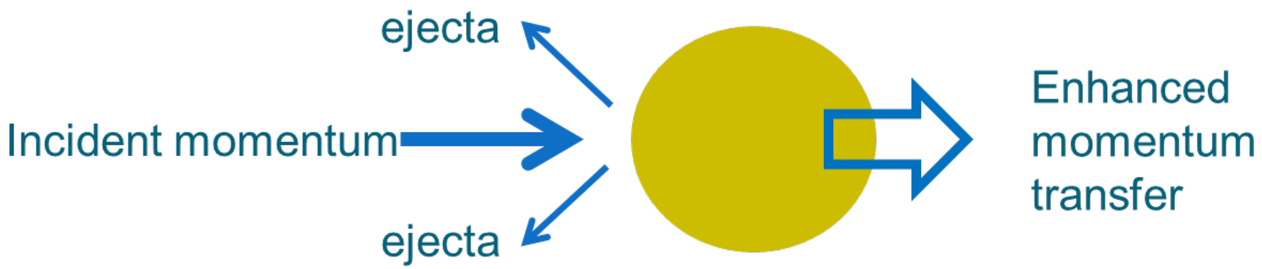
**Measure the period change**

To within 7.3 seconds, from ground-based observations before and after impact

**Measure “Beta” and characterize impact site and dynamics**

***Beta*** = *the momentum enhancement factor*

# Beta: Momentum Transfer Efficiency




in 1D:

$$\beta = 1 + \frac{p_{\text{ejecta}}}{p_{DART}}$$

- $\beta$ is defined as momentum transfer divided by momentum input
  - **If no ejecta, then $\beta = 1$**
  - **Ejecta release *enhances* momentum transfer, $\beta > 1$**
- Momentum transfer from kinetic impact is enhanced by impact ejecta
- Estimation of $\beta$ important for asteroid deflection. How large a kinetic impact is needed, or how many kinetic impacts are needed, depend on $\beta$

For DART impact in 3D:

$$\Delta\vec{v} = \frac{m}{M}\left(\vec{u} + (\beta - 1)(\hat{n} \cdot \vec{u})\hat{n}\right)$$

$$\beta = \frac{M(\hat{n} \cdot \Delta\vec{v})}{m(\hat{n} \cdot \vec{u})}$$

$\beta$ is the transferred momentum component along $\hat{n}$ divided by the incident momentum component along $\hat{n}$.

With some assumptions, the vector $\hat{n}$ is the target surface normal

# DART Beta determination

- Measure transverse component of velocity change (from period change)
- Use full 2-body numerical modeling of Dimorphos binary dynamics to relate period change to vector velocity change and beta (using mass)
- Determine size, shape and volume of Dimorphos to infer mass (with assumed density given by bulk density of Didymos)
  - DART approach imaging of approach hemisphere
  - LICIACube imaging of approach and departure hemispheres
- Determine DART impact site location, and geology and topography of impact site, from DART approach imaging
- LICIACube plume observations to constrain plume direction $\hat{n}$
- Use impact simulations for
  - Effects of spacecraft geometry
  - Effects of impact site topography, slopes, rubble structures
  - Estimation of uncertainty

# DART Data Archive

DART, LICIACube and Ground-based telescopic data

| Data Source | Dataset | Derived data | Archive |
|---|---|---|---|
| DART DRACO | Monochrome imaging | Mosaics, light curves, image backplanes, shape models, facet data | PDS SBN |
| LICIACube LEIA | Monochrome imaging | Image backplanes | PDS SBN |
| LICIACube LUKE | 3-color imaging | Image backplanes | PDS SBN |
| Las Cumbres | Ground-based 2m/spectral images | Light curves | PDS SBN |
| Las Campanas | Magellan/IMACS images | Light curves | PDS SBN |
| Lowell | DCT/LMI images | Light curves | PDS SBN |
| Magdalena Ridge | 2.4m images | Light curves | PDS SBN |
| Radio Science | Doppler and ranging | | PDS SBN |
| SPICE data | Ancillary data | | NAIF |

# Anticipating Hera science at Didymos

*AIDA: DART and Hera joint studies of kinetic impact demonstration results*

- Hera ESA mission to Didymos, arriving late 2026, will
  - Measure mass of Dimorphos
  - Measure DART impact crater
  - Study spins, search for shape changes, and measure librations excited by DART impact
- Didymos telescopic observations
  - Light curve observations of mutual events, spins and orbital period
  - Ejecta imaging from Earth to study activation of comet-like dust tails by DART impact
- Impact simulations
  - DART crater predictions
  - Modeling of spacecraft structure and target structures (rubble, boulders, topography)
  - Inference of Dimorphos target properties (like strength, porosity, friction, crush properties), with Hera data
  - Beta determination and uncertainties, with Hera data
- Didymos binary system dynamics
  - Inference of interior structures
  - Tidal interactions and BYORP

# DART Legacy

- DART demonstrates planetary defense capability
  - Showing that a kinetic impactor accomplishes asteroid deflection
  - Demonstrating kinetic impactor technology and concept of operations
- DART determines momentum transfer efficiency for a target asteroid of representative size and most common spectral type
- DART improves and validates models of kinetic impact deflection
  - More reliable predictions of kinetic impactor effects on other asteroids
- DART informs planetary defense decision and policy definition processes and reduces risks

# DART

Double Asteroid Redirection Test

# Q&A

## Session 3 - DART

# 7th IAA Planetary Defense Conference

## 26-30 April 2021, Online Event

### Hosted by UNOOSA in collaboration with ESA

# Break

Up Next: Session 4 - OSIRIS-REx