DART

NASA

APL JOHNS HOPKINS APPLIED PHYSICS LABORATORY

Double Asteroid Redirection Test (DART): Earth Strikes Back

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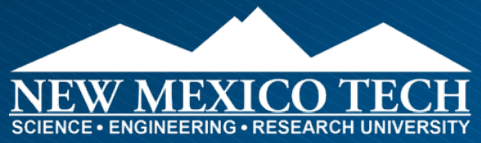
Glenn Research Center
Goddard Space Flight Center
John F. Kennedy Space Center
Johnson Space Center
Langley Research Center
Marshall Space Flight Center
Planetary Defense Coordination Office

Jet Propulsion Laboratory
California Institute of Technology

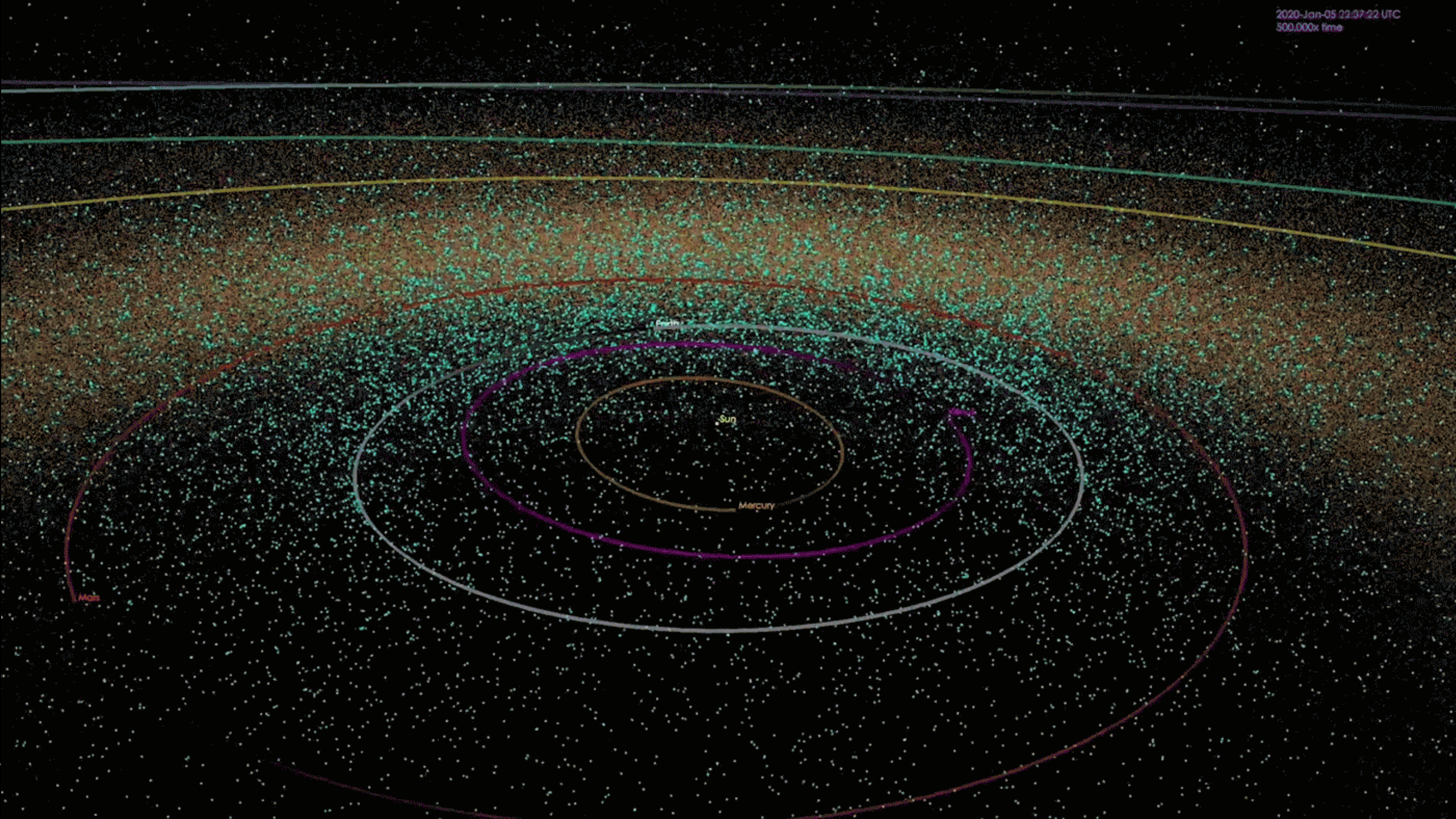
University of Colorado
Boulder

Lawrence Livermore
National Laboratory

UNIVERSITY OF
MARYLAND

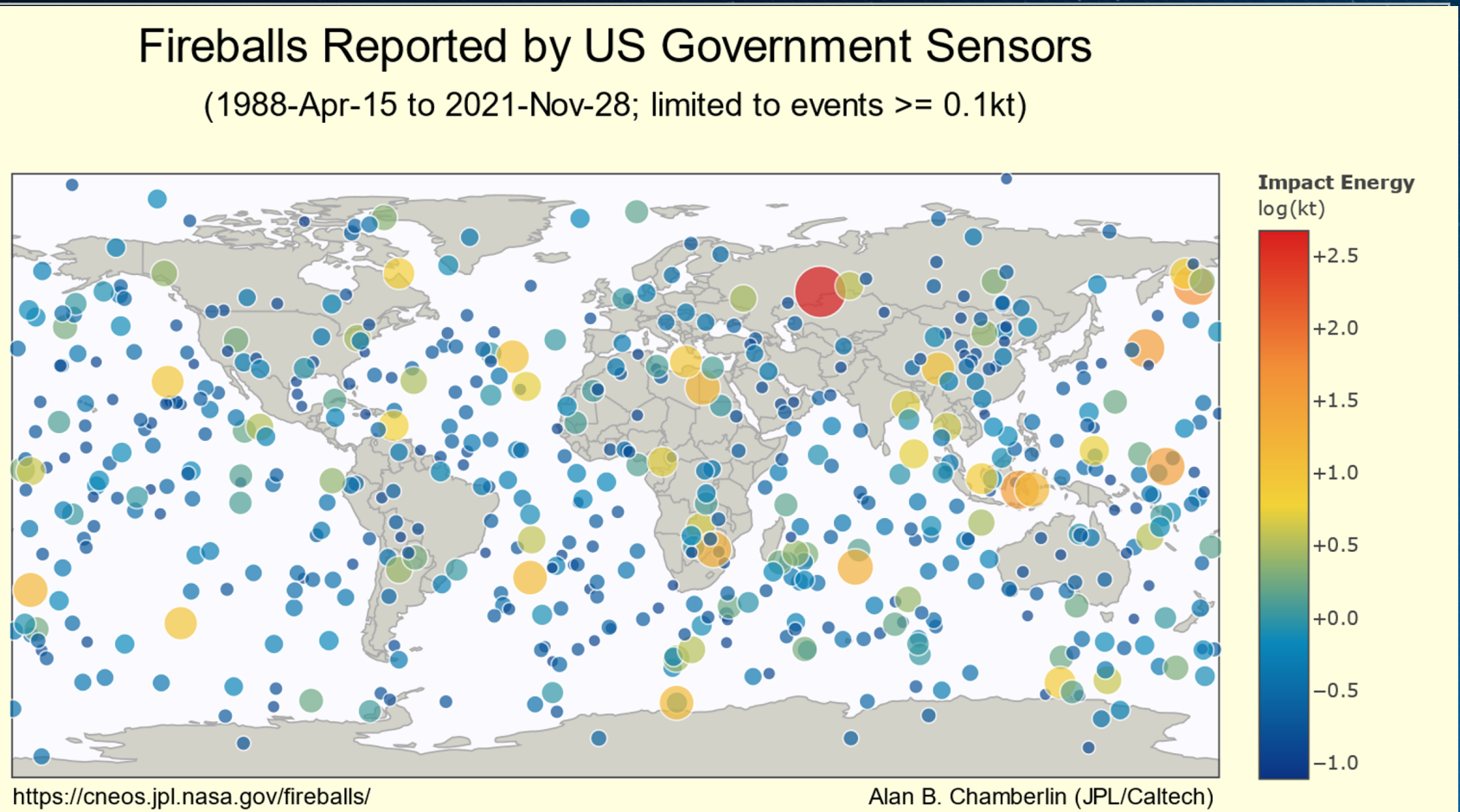


Planetary Science
Institute


2020-Jan-05 22:37:22 UTC
500,000x time
Earth
Sun
Mercury
Mars

https://www.businessinsider.com/no-one-saw-chelyabinsk-meteor-over-russia-coming-could-happen-again-2016-4

Small Asteroids Hitting Earth, 1988 – Now



Chelyabinsk-sized

Diameter: ~20 meters

Equivalent to: ~500 kilotons of TNT

Last known: 2013

Frequency: every few decades to centuries

Tunguska-sized

Diameter: 60–190 meters

Equivalent to: ~5 megatons of TNT

Last known: 1908

Frequency: every few centuries to millennia

Chicxulub-sized

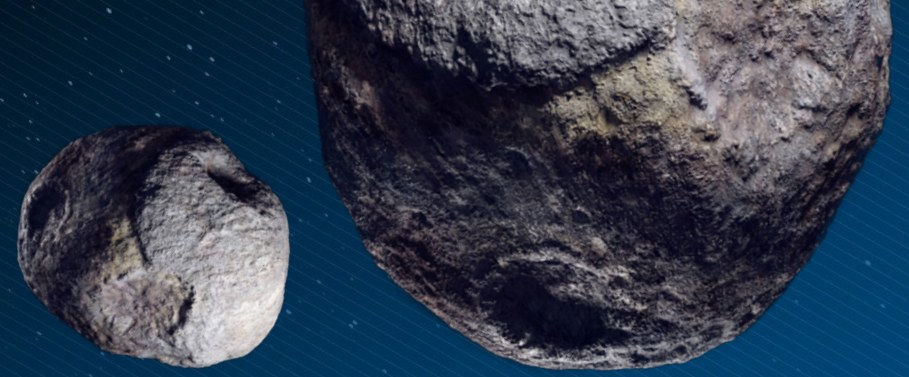
Dinosaur Killer

Diameter: 10–15 kilometers

Last known: 65 million years ago

Frequency: every few 100 million years

Hazard by the Numbers



How big?	4 meters	25 meters	160 meters	1,000 meters	10,000 meters
How often?	~1 per **year**	~1 per **100 years**	~1 per **25,000 years**	~1 per **500,000 years**	~1 per **100-200 million years**
How bad?	Bright flash, no ground effects, but could leave meteorites	Air burst explosion, could cause widespread injuries if over populated area	Crater of 1-2 kilometer diameter, deadly over metro areas/states, mass casualties	10-kilometer crater, global devastation, possible collapse of civilization	100-kilometer crater, global devastation, mass extinctions of terrestrial life
# of NEOs	**~500 million**	**~5 million**	**~20,000**	**~900**	**4**
How many found?	**< 0.1%**	**0.4%**	**42%**	**> 90%**	**100%**

Located
Not located

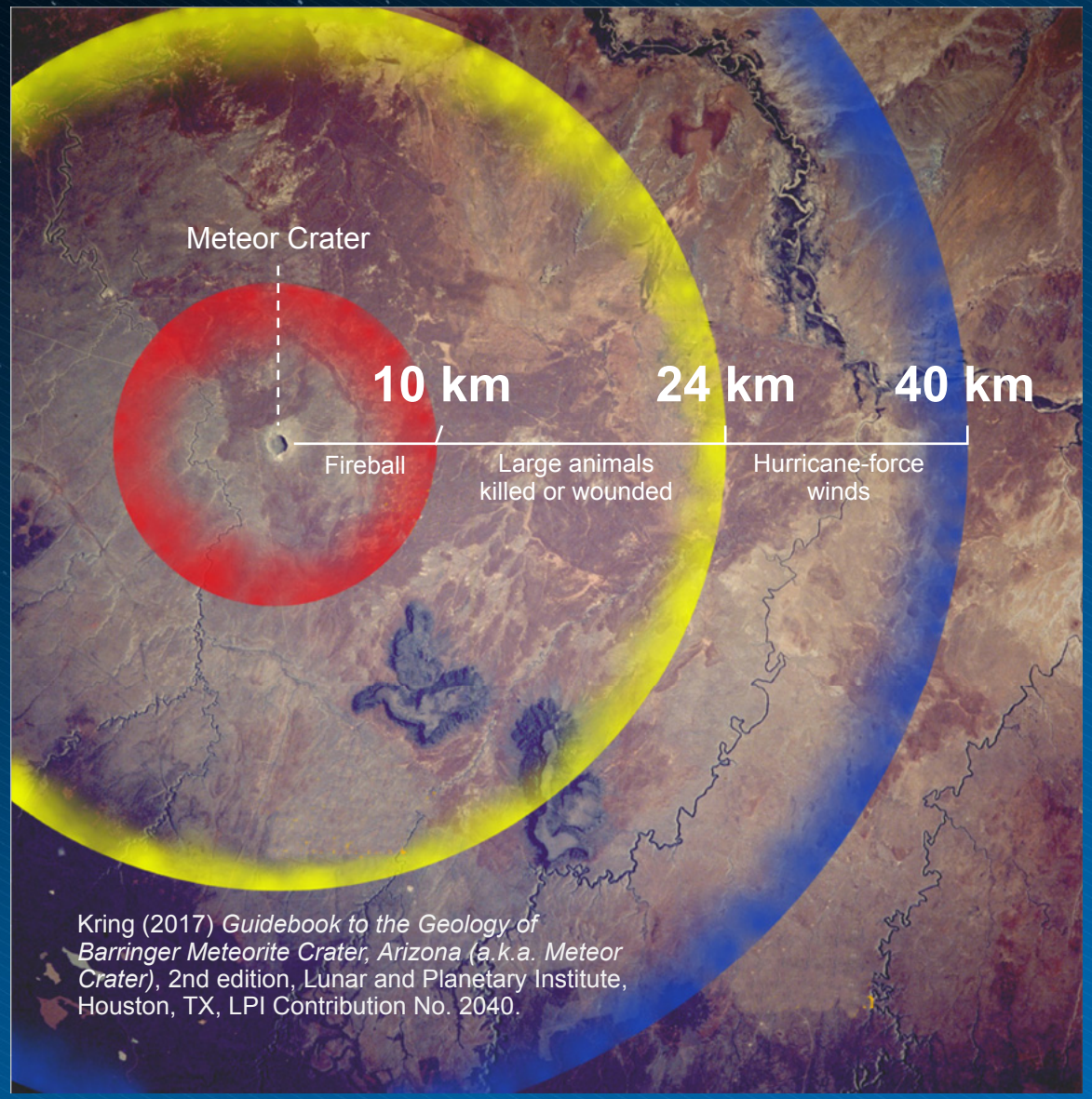




Barringer (“Meteor”) Crater

Arizona

- Formed ~50,000 years ago by a **~50-meter-diameter** metallic asteroid
- Crater is 1.2 kilometers in diameter and ~180 meters deep
- Devastation = tens of kilometers



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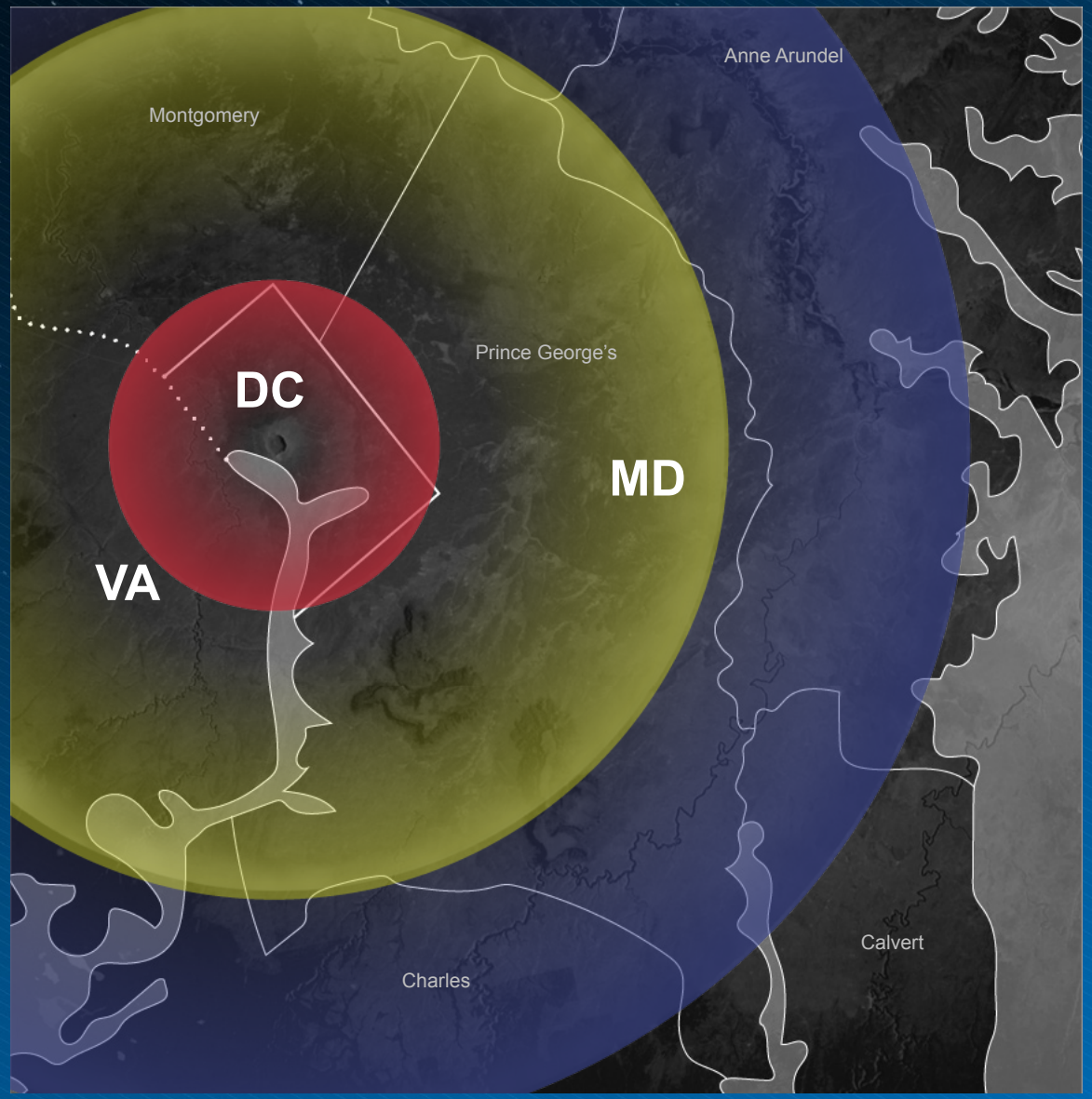
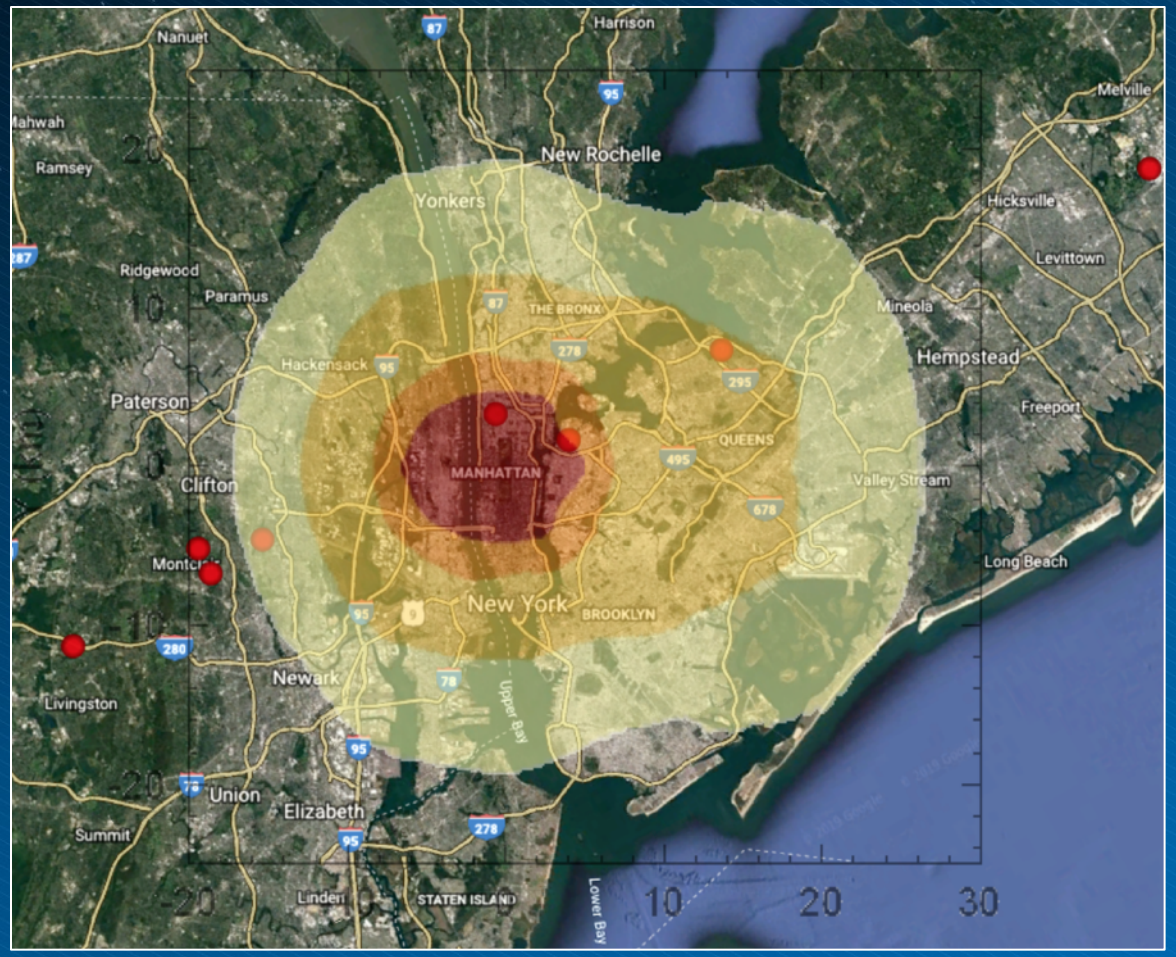


2019 IAA Planetary Defense Conference

April 29 – May 3, 2019, College Park, MD, USA

Conference exercise shows the projected damage zones if a 60-meter asteroid were to impact in Manhattan

- 1,000 times more powerful than the atomic bomb dropped on Hiroshima
- **Red zone** = “un-survivable”
- **Orange** = most residential structures would collapse, and clothing would ignite




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]
NASA
NASA Planetary Defense Coordination Office (PDCO): established 2016

Part of a Larger Strategy

National Near-Earth Object Preparedness Strategy and Action Plan

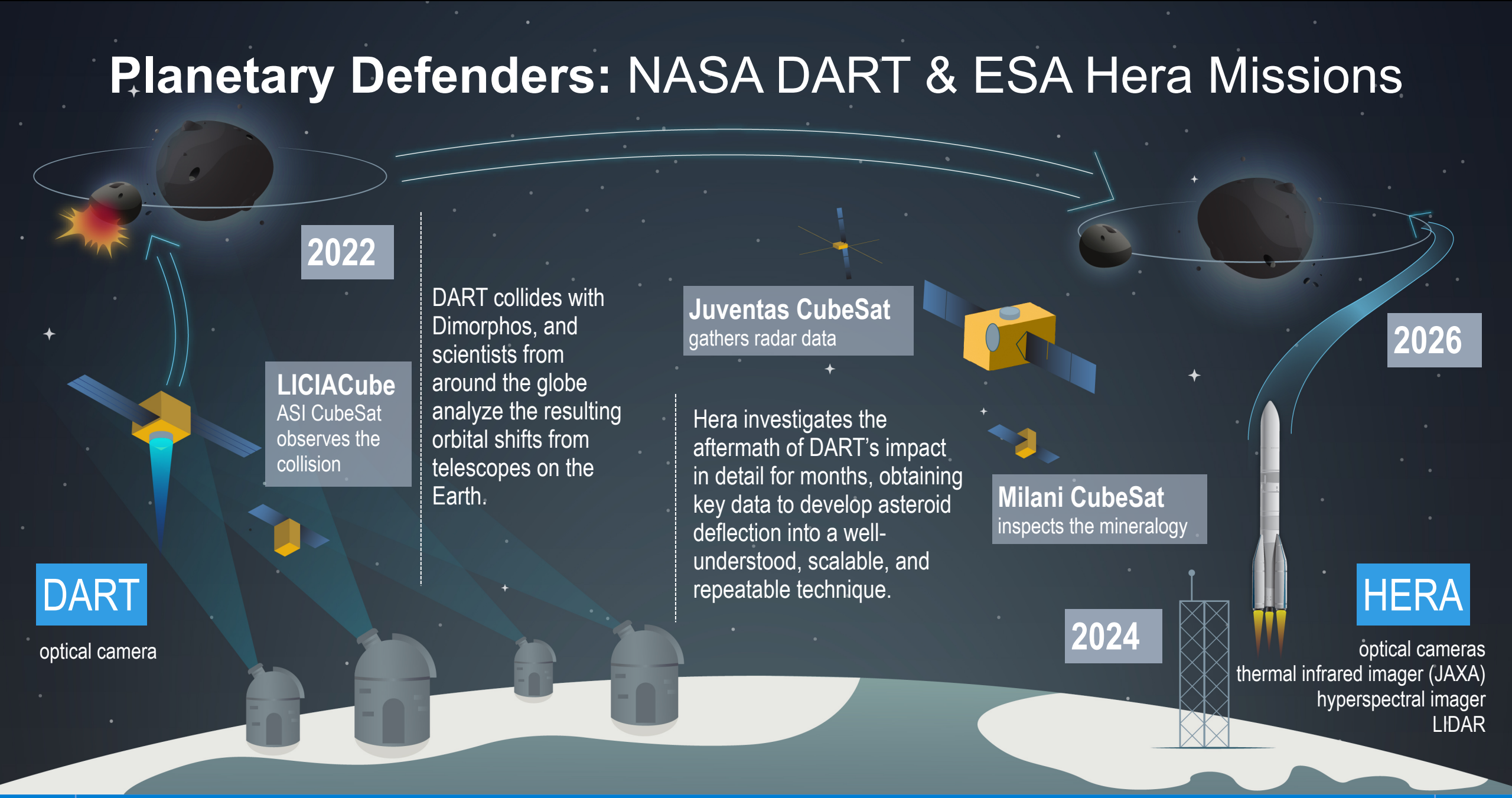
A Report by the Interagency Working Group for Detecting and Mitigating the Impact of Earth-Bound Near-Earth Objects *of the* National Science & Technology Council, June 2018

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 – Asteroid Impact & Deflection Assessment

International Cooperation for an International Issue

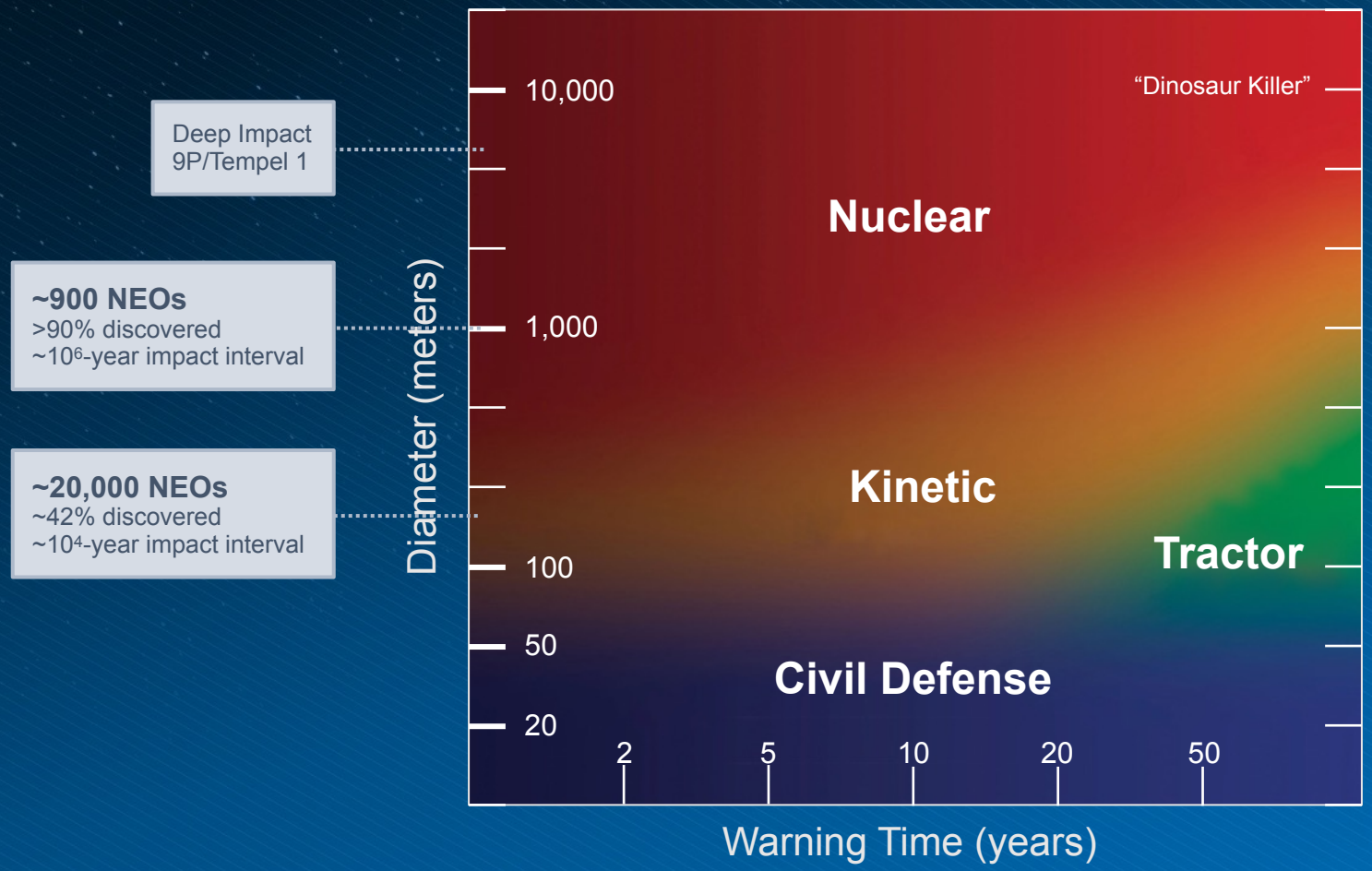
Planetary Defenders: NASA DART & ESA Hera Missions



Mitigation Techniques for Potentially Hazardous Asteroids

*"The **first priority** for a space mission in the mitigation area is an **experimental test of a kinetic impactor**."*

— from *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies*
published in 2010 by the
National Academy of Sciences



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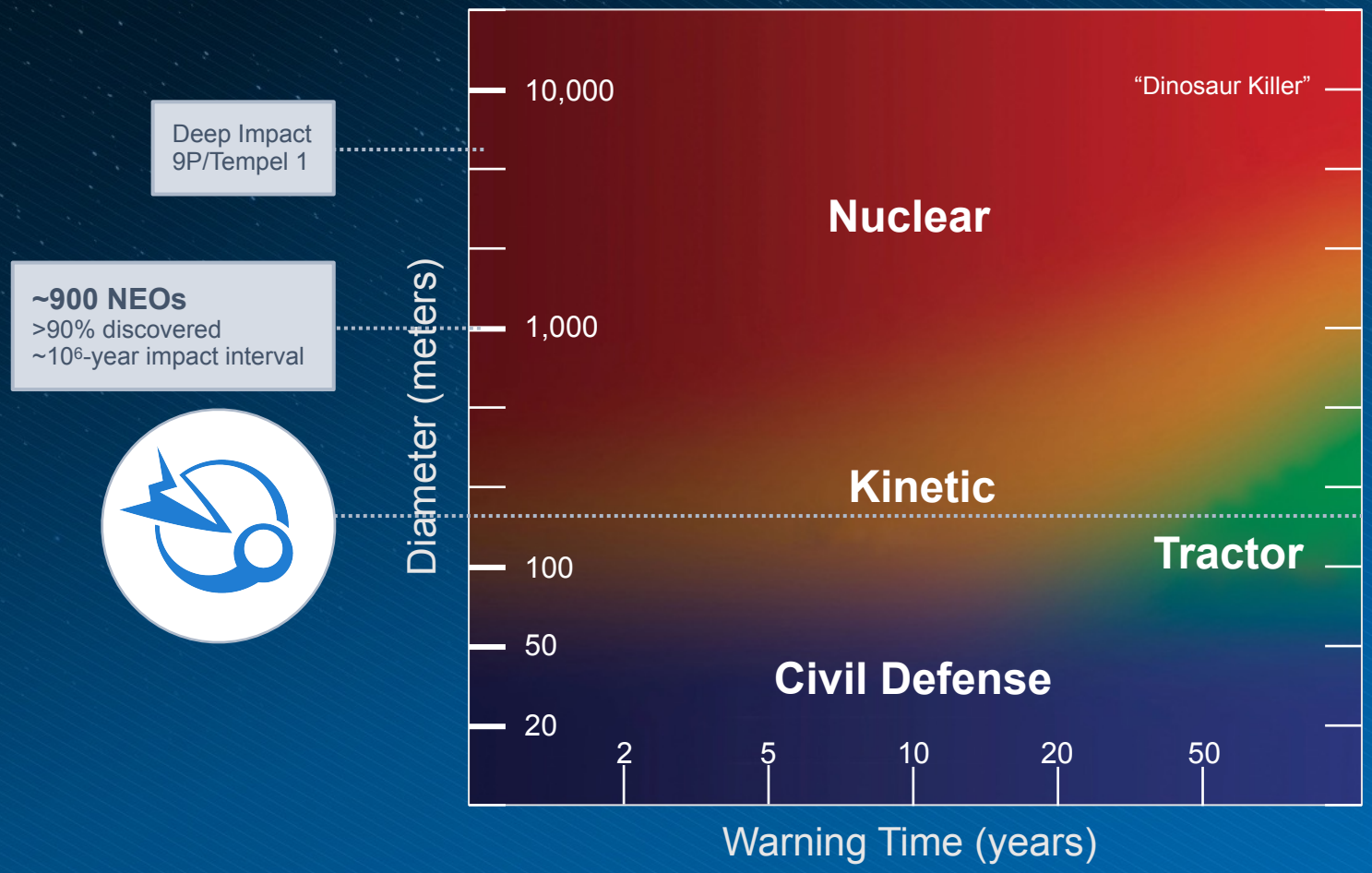


Launch

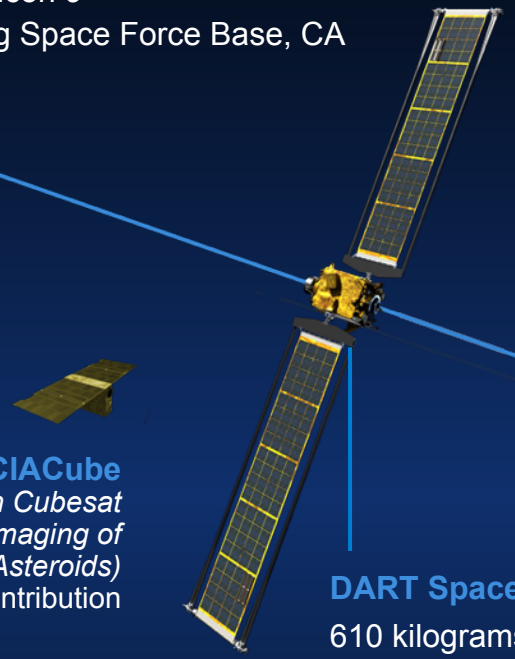
Nov. 23, 2021, 10:21 pm PST

SpaceX Falcon 9

Vandenberg Space Force Base, CA

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

Sept. 26, 2022
23:14 UTC (7:14 pm EDT)



LICIACube
(Light Italian Cubesat for Imaging of Asteroids)
ASI contribution

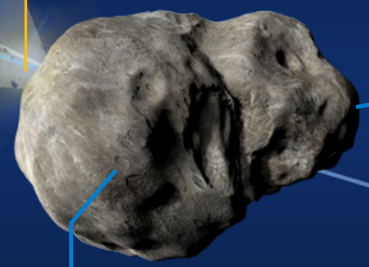
DART Spacecraft

610 kilograms at launch;
~570 kilograms at impact

14,000 miles per hour
(6.1 kilometers per second)

Earth-Based Observations

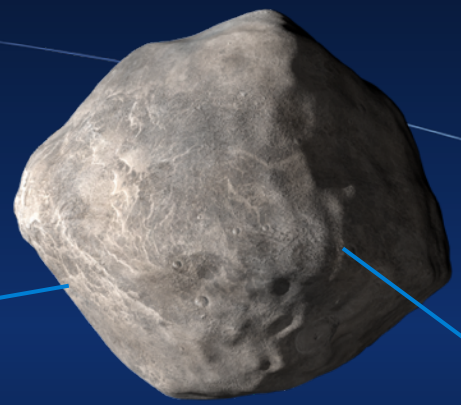
6.7 million miles (0.07 AU) from Earth at DART impact



Dimorphos

160 meters
11.92-hour orbital period

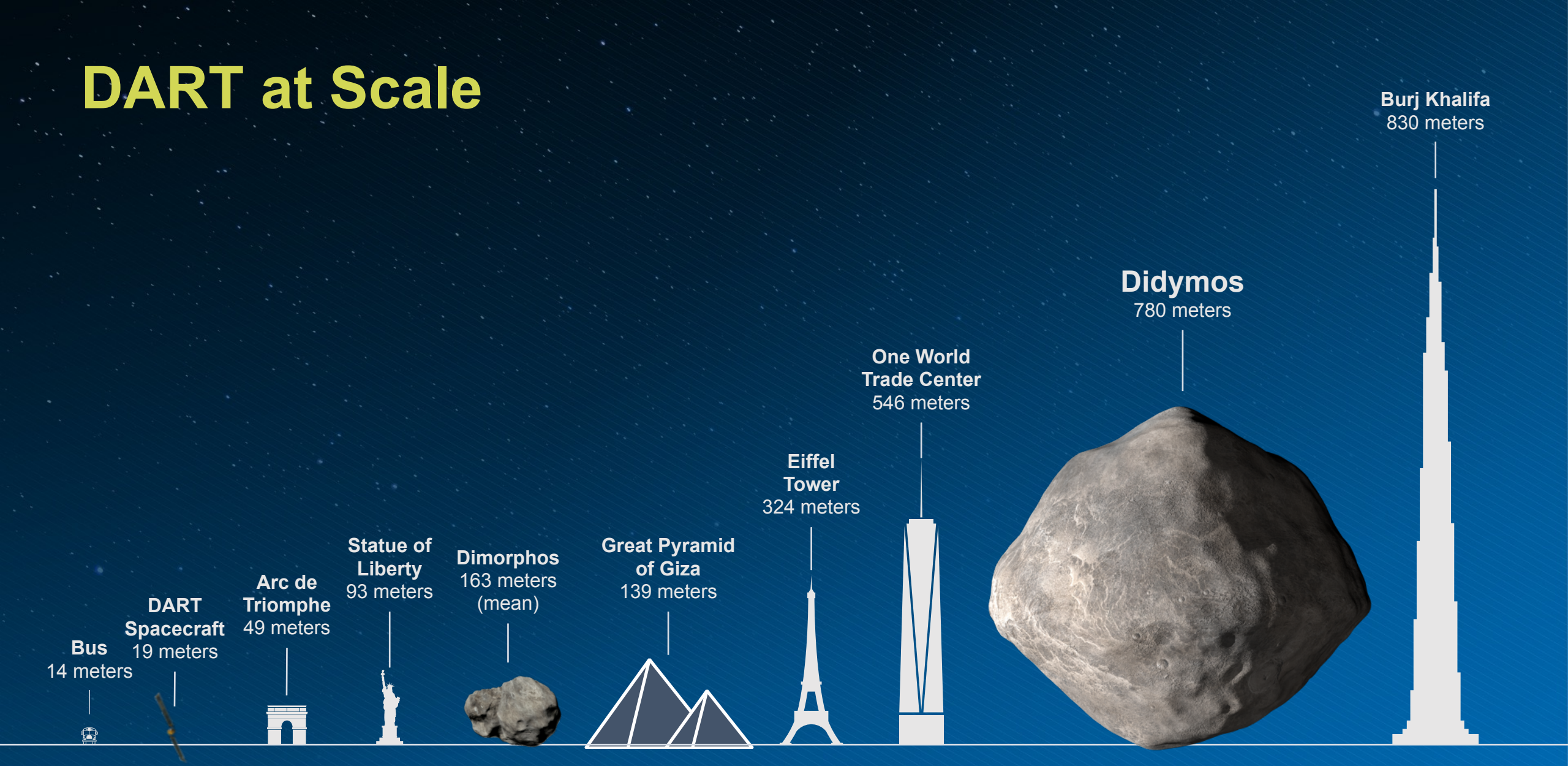
1,180-meter separation between centers



Didymos

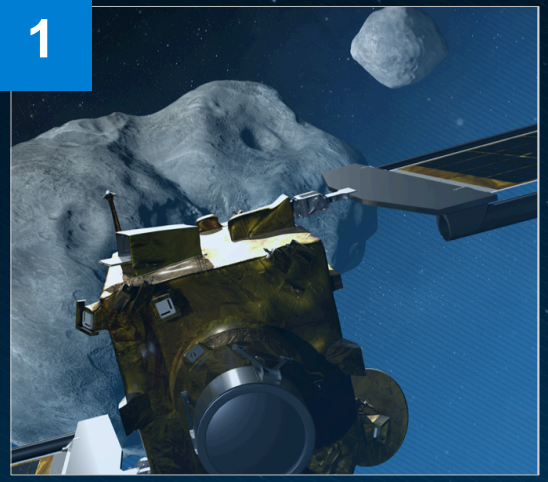
780 meters
2.26-hour rotation period

DART at Scale



What will DART do? Aka, DART Level 1 Requirements

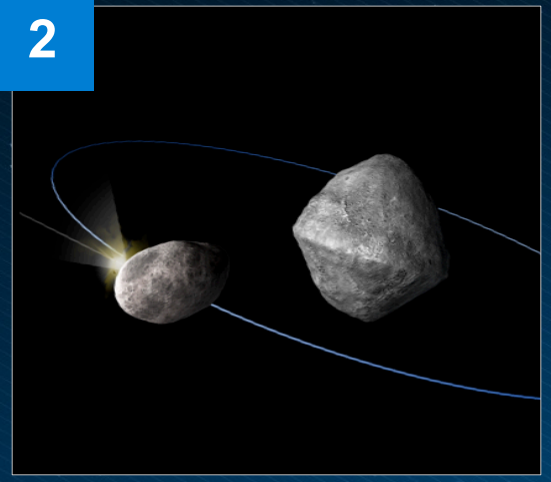
1



Impact Dimorphos

During its Sept /Oct 2022 close approach to Earth

2



Change the binary orbital period

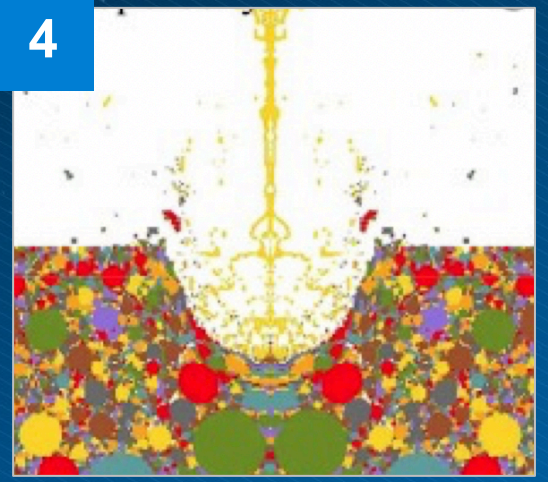
Cause a ≥73-second change in the orbital period of Dimorphos

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*

The Ideal Time

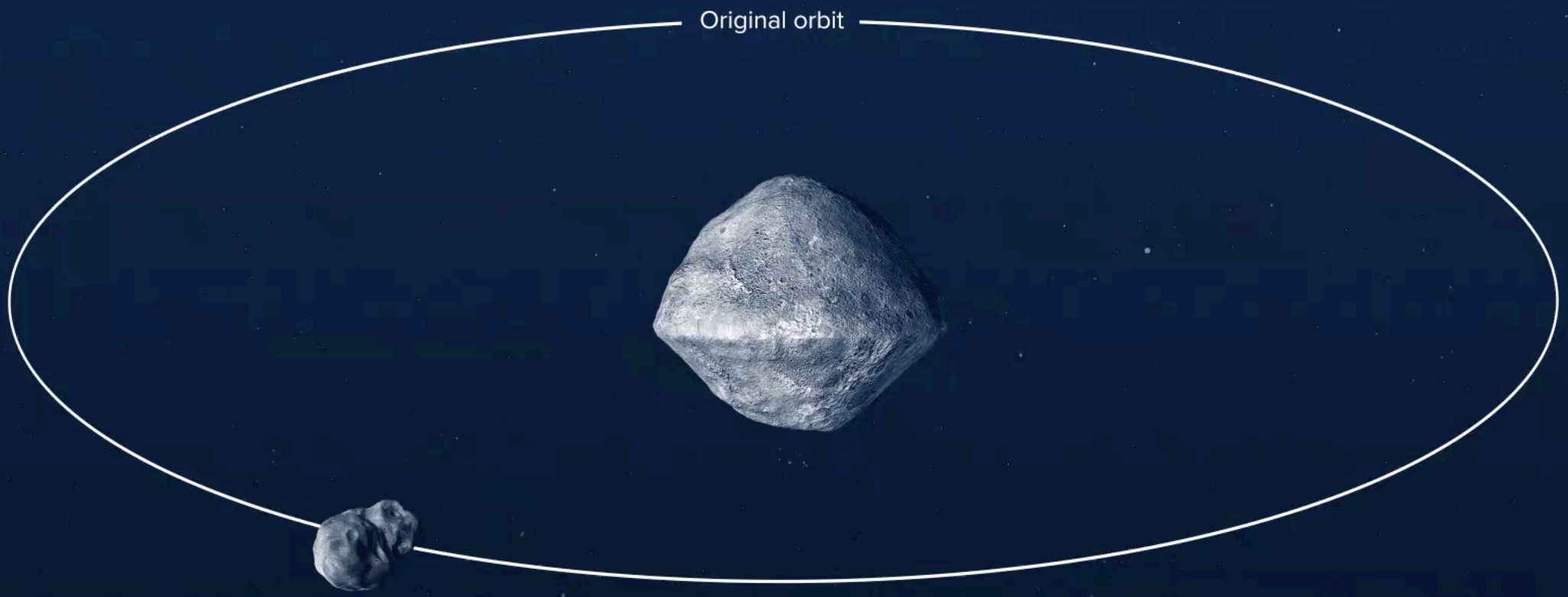
Launch:
Nov. 23, 2021

DART Kinetic Impact:
Sept. 26, 2022

DART
Double Asteroid Redirection Test

The Ideal Target

It allows a deflection demonstration on an asteroid of the relevant size by changing its orbital period by ~1% about the larger asteroid.



Earth-based observations

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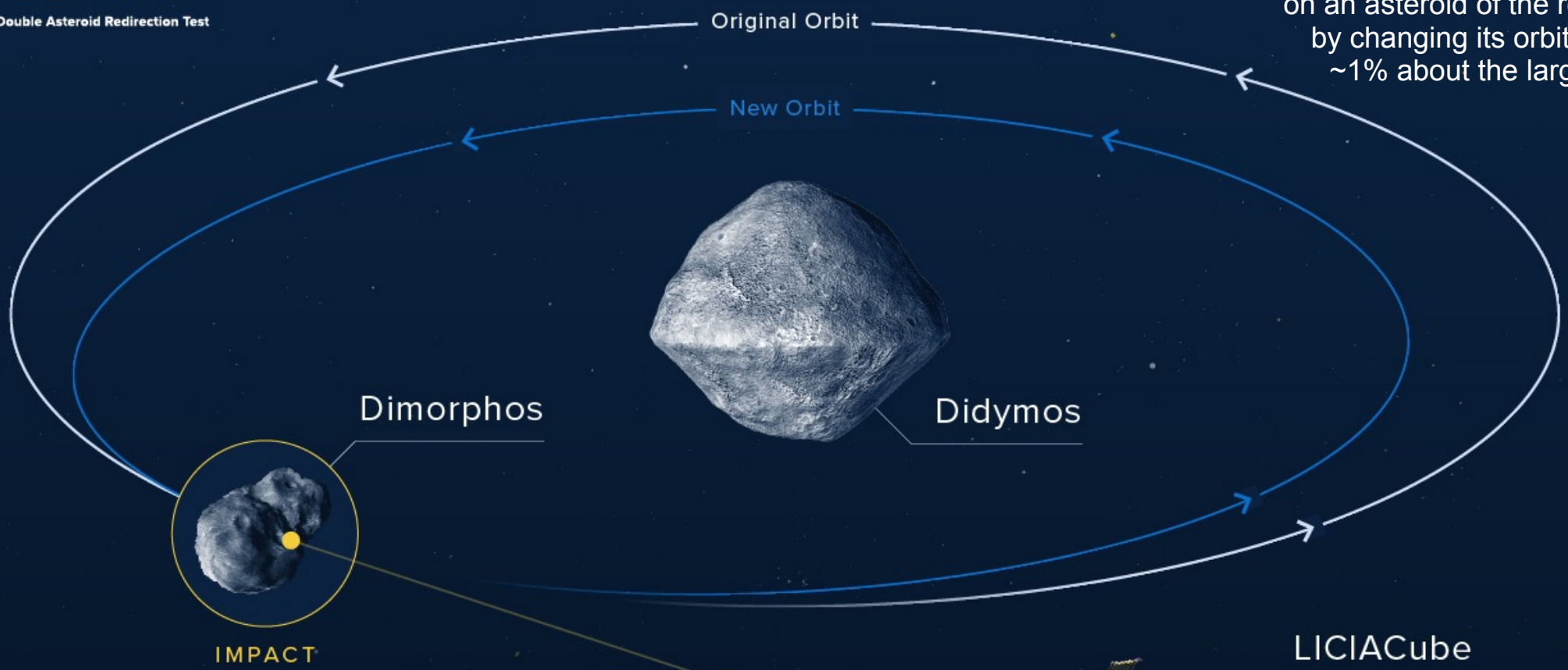
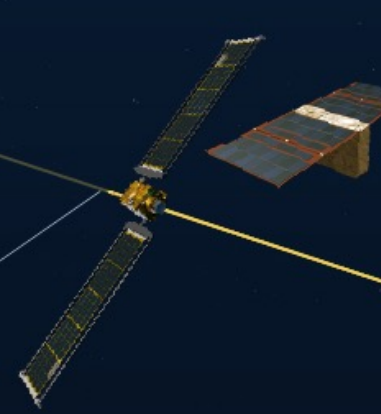
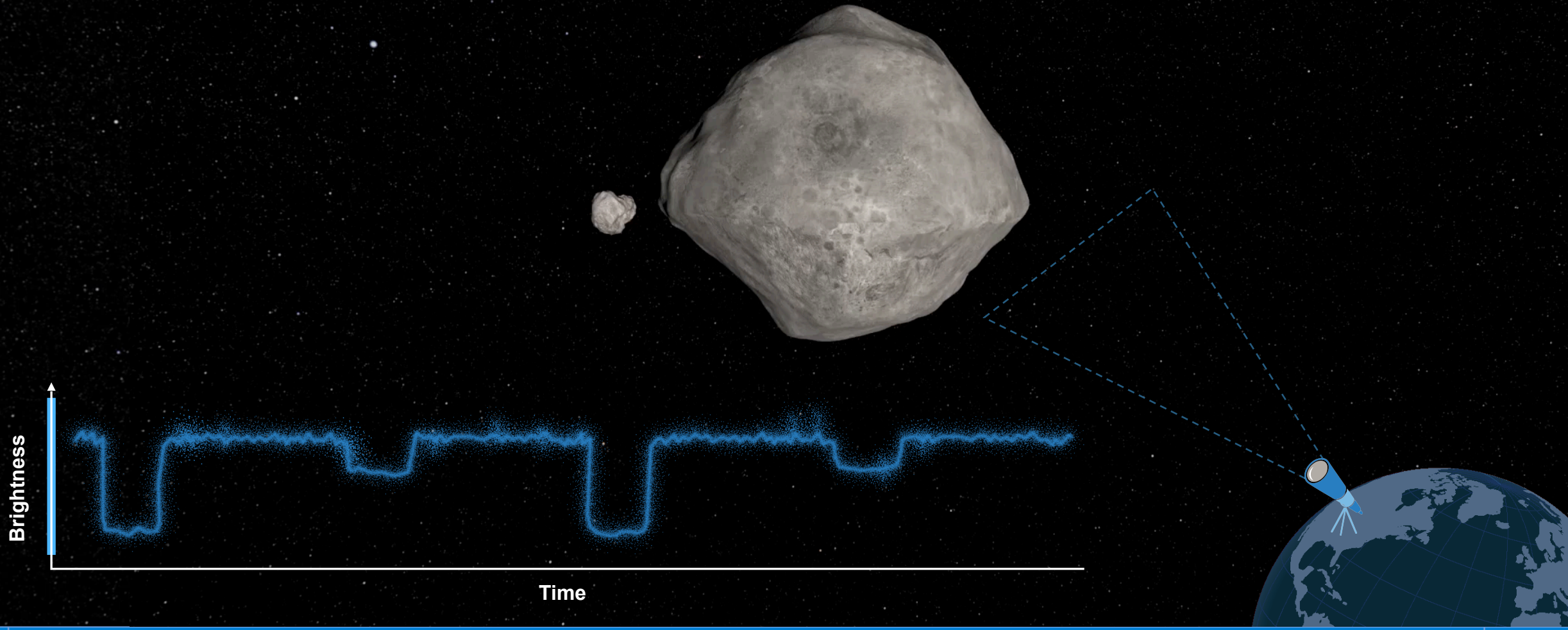
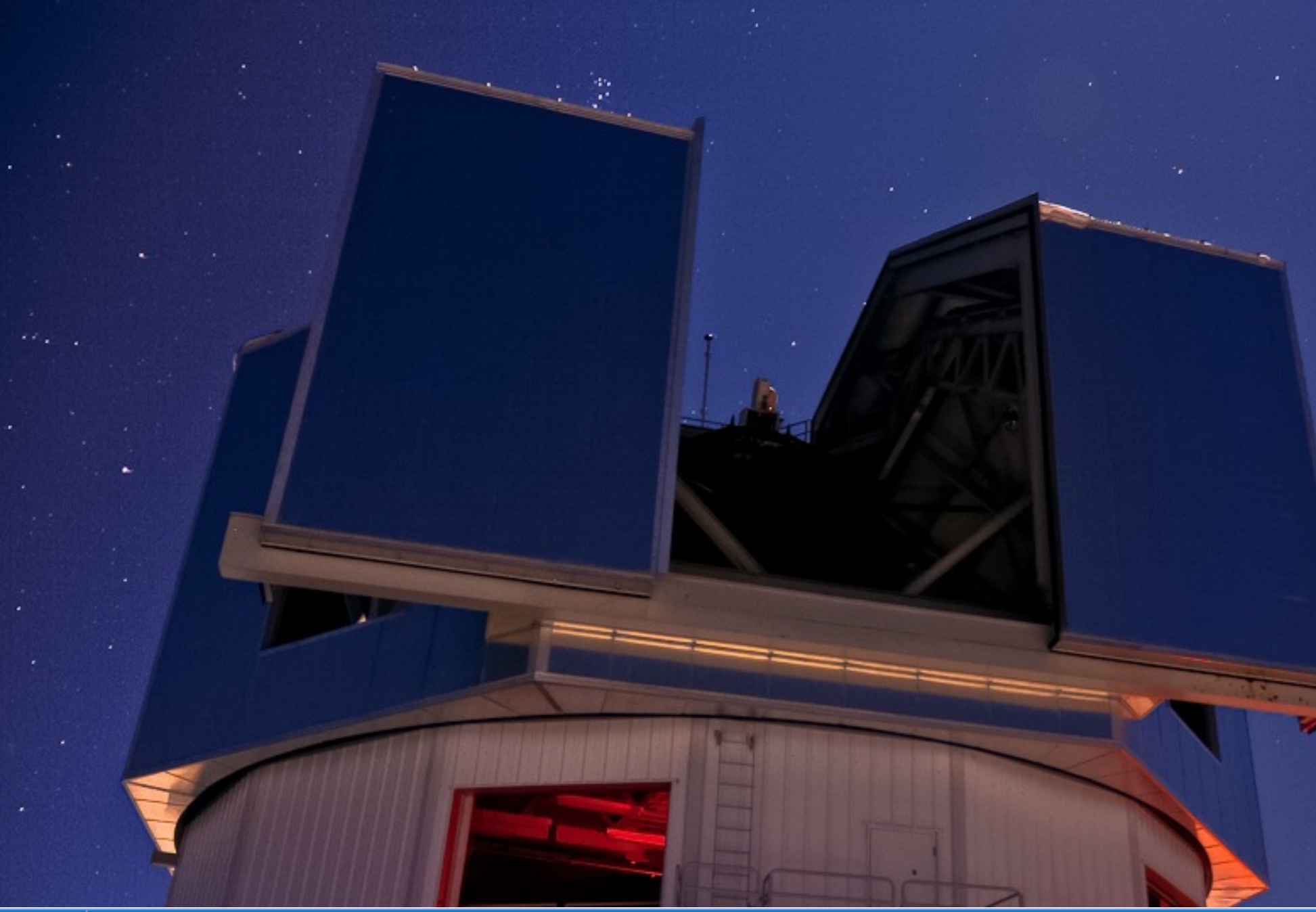




Earth-based observations

Measuring result of the impact: new orbit for Dimorphos





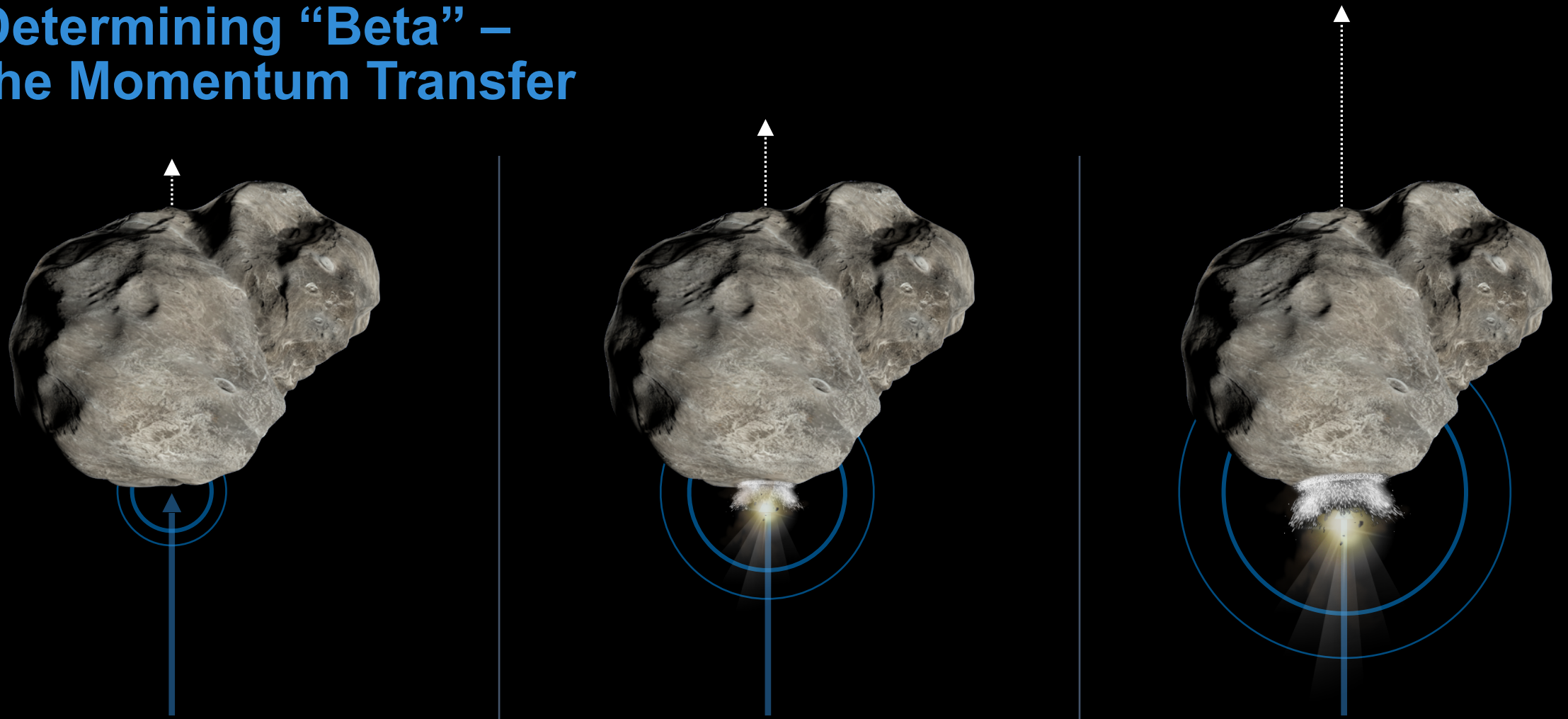
Post-Impact Didymos Observations:

- *Lowell Discovery Telescope (AZ, US)*
- *Magdalena Ridge Observatory (NM, US)*
- *Las Campanas Observatory (Chile)*
- *Las Cumbres Global Observatory Network (TX, US; Chile; Spain; Israel; South Africa; Australia)*

- *Goldstone Solar System Radar*
- *Hubble Space Telescope*
- *James Webb Space Telescope*
- *VLT (Chile)*
- *IRTF (Hi, US)*
- *Mount John (New Zeland)*

Lowell Discovery Telescope
(credit: Lowell Observatory)

Determining “Beta” – the Momentum Transfer



Beta = 1
No ejecta and small momentum increase

Beta = 2
Moderate ejecta and momentum increase

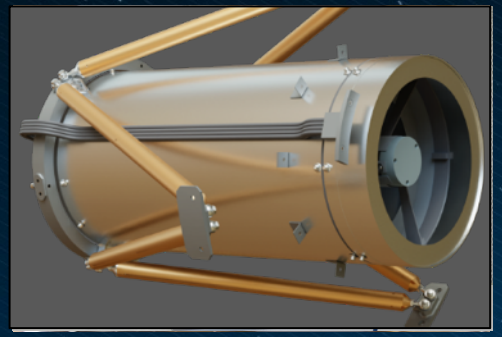
Beta = 4
Heavy ejecta and large momentum increase

DART: Key and New Technologies

DART will mature key technologies for future planetary missions

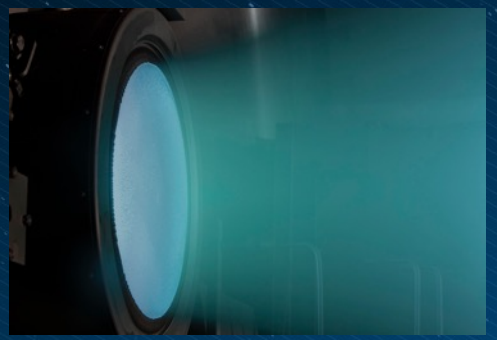
Autonomous SMART Nav System

Autonomously directs DART to impact Dimorphos, leveraging APL missile guidance experience



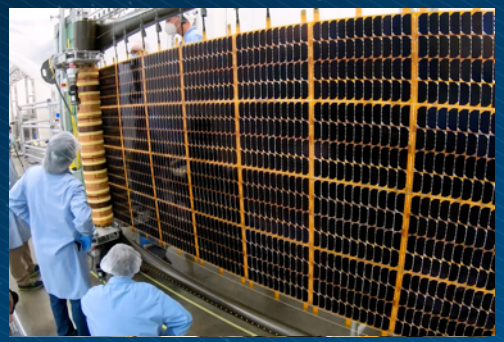
DRACO Imager

Didymos Reconnaissance and Asteroid Camera for Opnav. Modification of LORRI on New Horizons



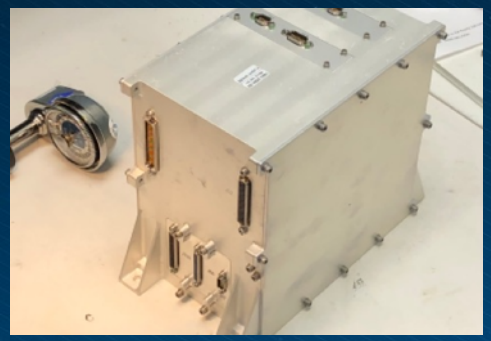
NEXT-C Ion Propulsion Engine

NASA's Evolutionary Xenon Thruster-Commercial ion propulsion engine, 3x as powerful as Dawn



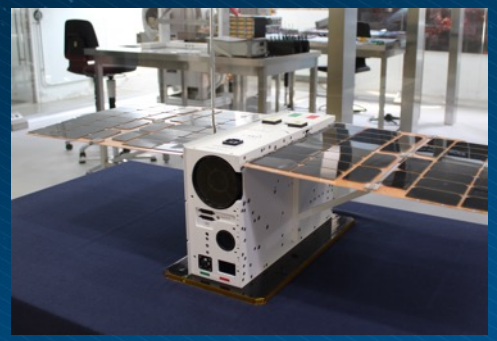
ROSA – Roll-Out Solar Arrays

Compact form and light mass, deployed in space



Coresat Avionics

Integrated system with FPGA-based electronics

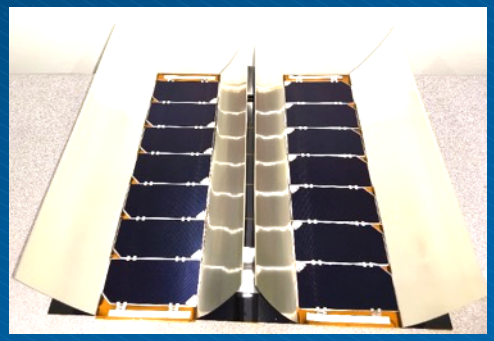


LICIACube Cubesat

6U CubeSat provided by Agenzia Spaziale Italiana (ASI)

Radio Line Slot Array

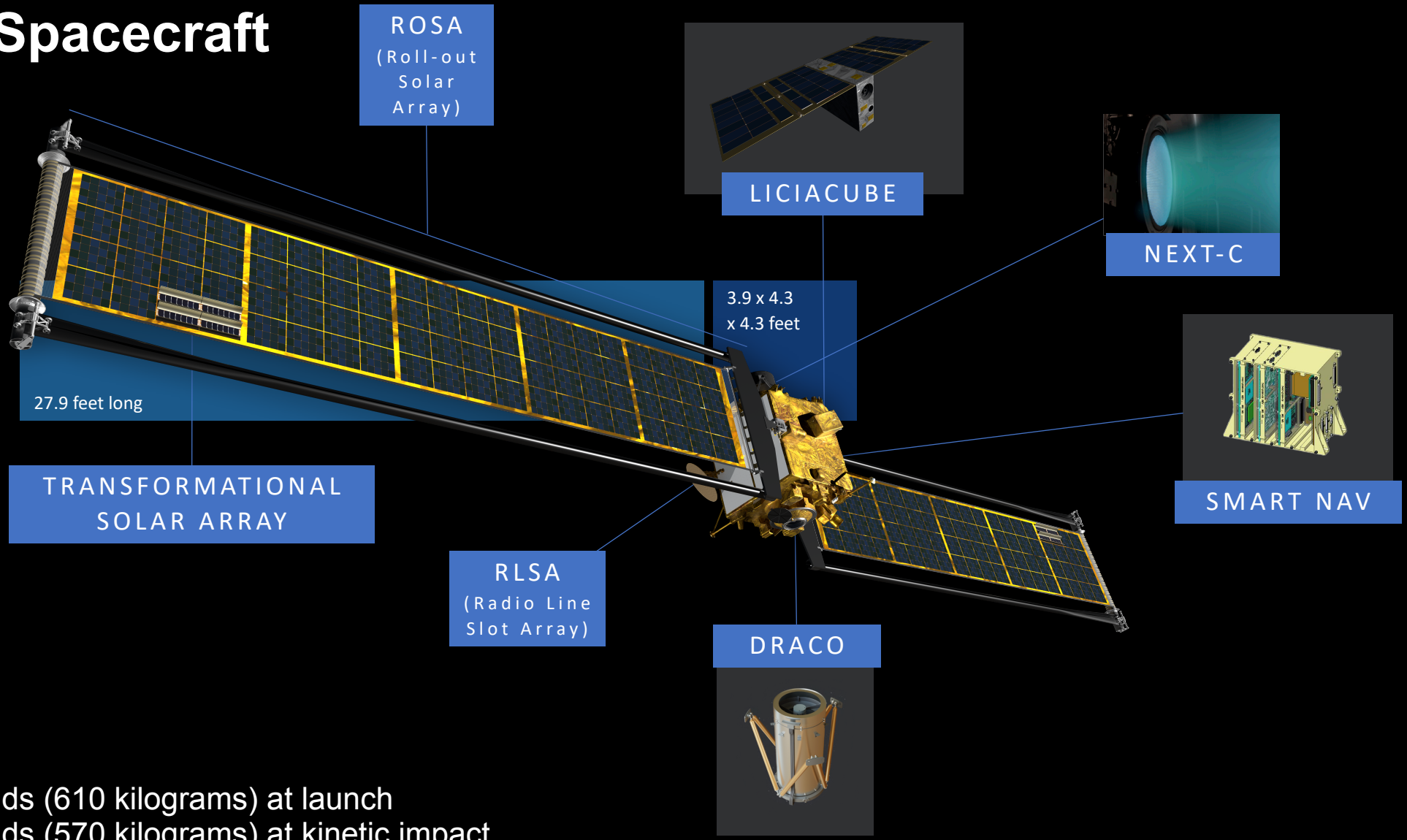
Planar, low-cost, high-efficiency high gain antenna



Transformational Solar Array Concentrators

High-efficiency cells, reflective concentrators

DART Spacecraft

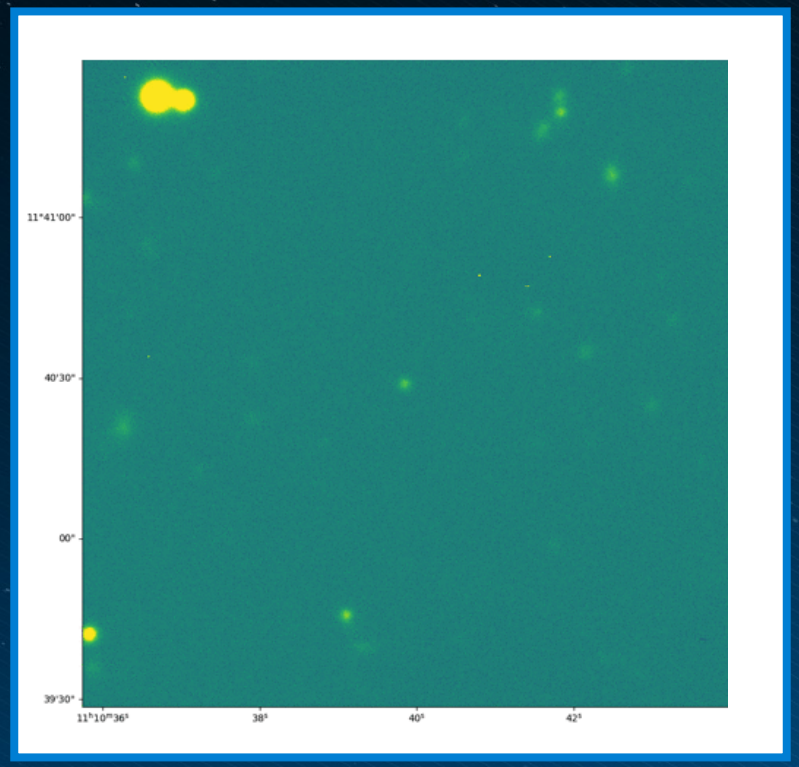


Weight:
~1,345 pounds (610 kilograms) at launch
~1,210 pounds (570 kilograms) at kinetic impact

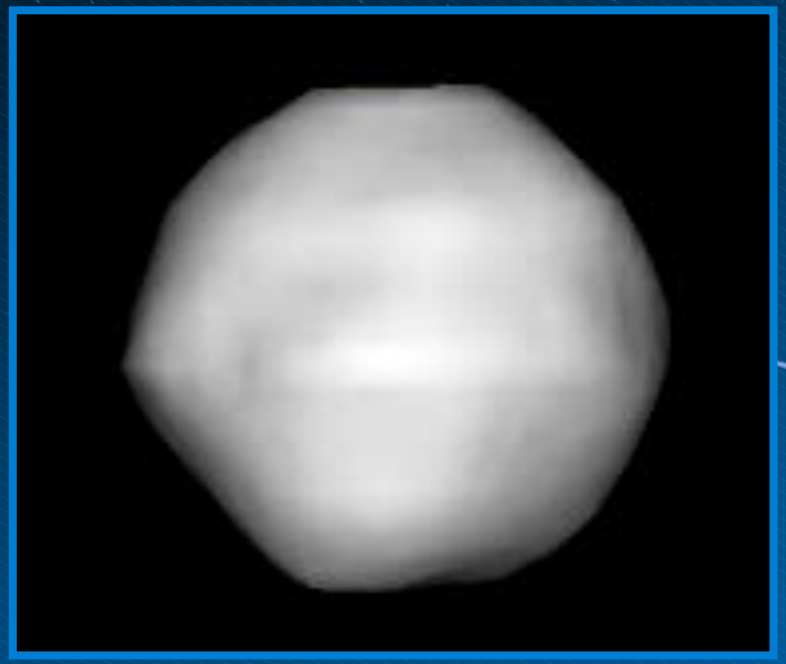
Our eyes:
DRACO Instrument

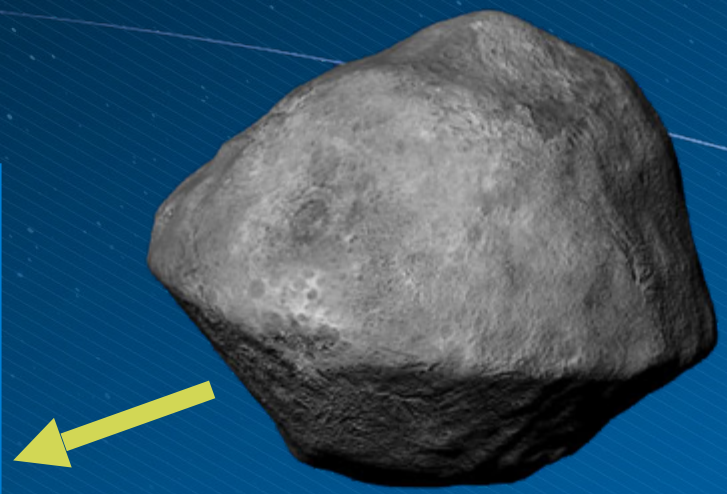
June 2022, Jovian Moons test for SMARTNav

Know little about the object we are going to hit



Images centered on Didymos, moving through star fields
Taken from VLT in Chile, March/April 2019





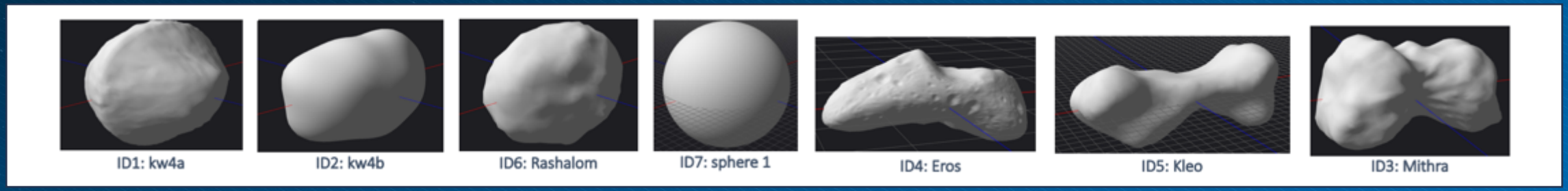
Radar shape model

Preliminary shape model of the Didymos primary asteroid from combined radar and light curve data, diameter ~780 m.

Know little about the object we are going to hit

Dimorphos

?

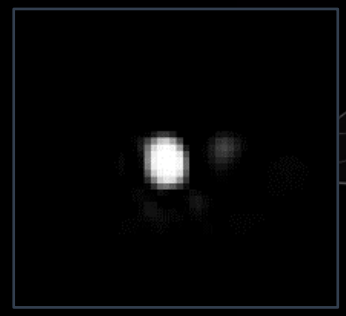


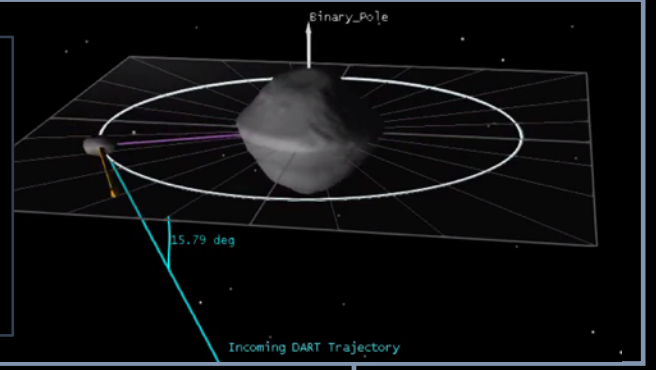
And won’t know it in time to hit it!

Fully Autonomous

Begin terminal phase

SMART Nav guidance is enabled





Camera detects Didymos system

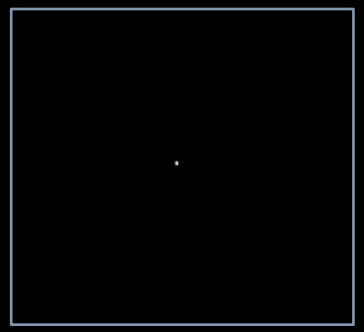
Continuous ground antenna coverage

Begin pre-terminal phase

30 days	10 days	8 hours	4 hours

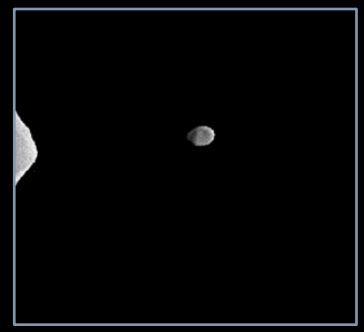
30 days | 10 days | 8 hours | 4 hours | 60 minutes | 4 minutes | 2 minutes | 20 seconds

And won’t know it in time to hit it!



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



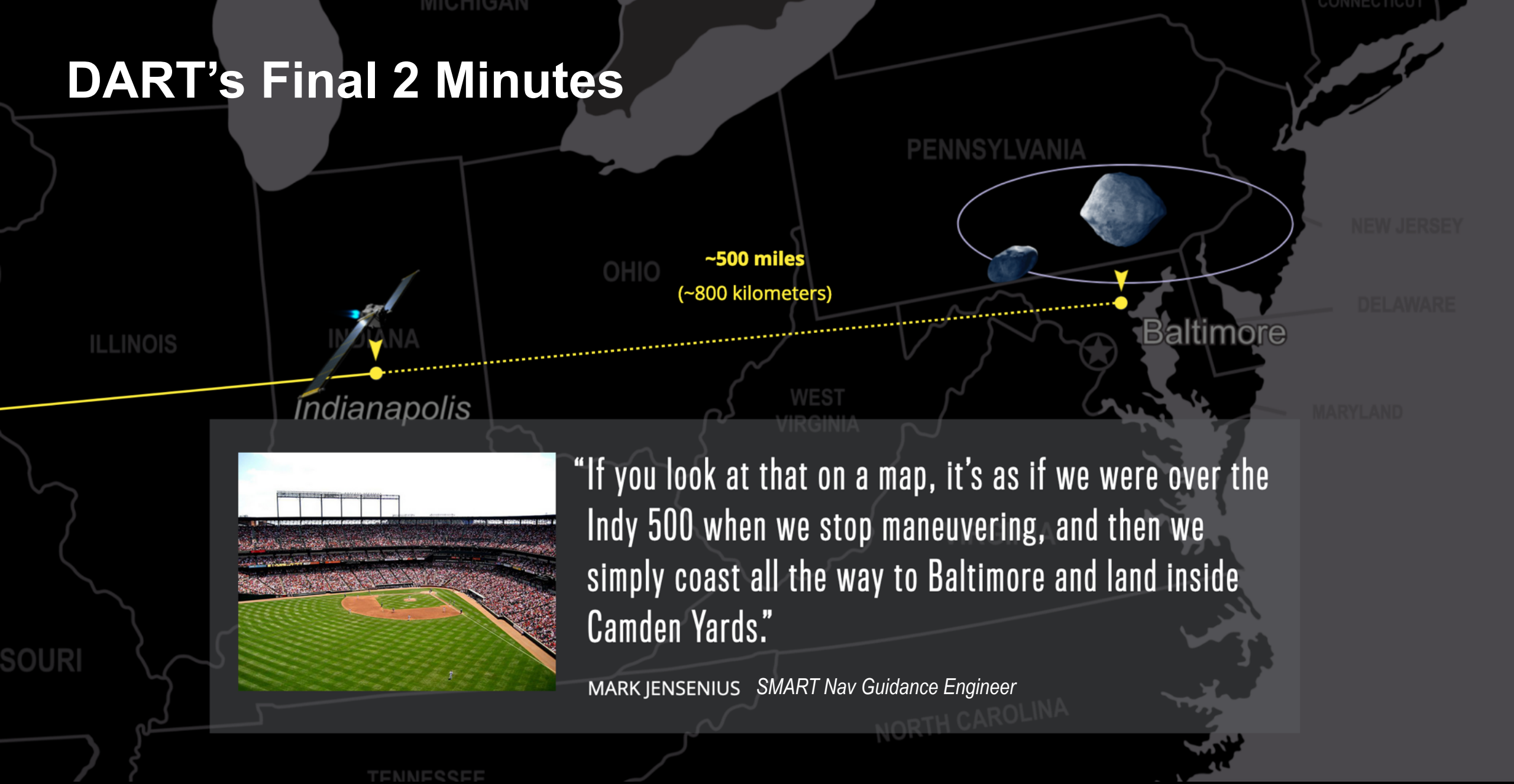
800 kilometers
Didymos – 197 pixel
Dimorphos – 41 pixel
Divert maneuvers complete, drift to impact

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**

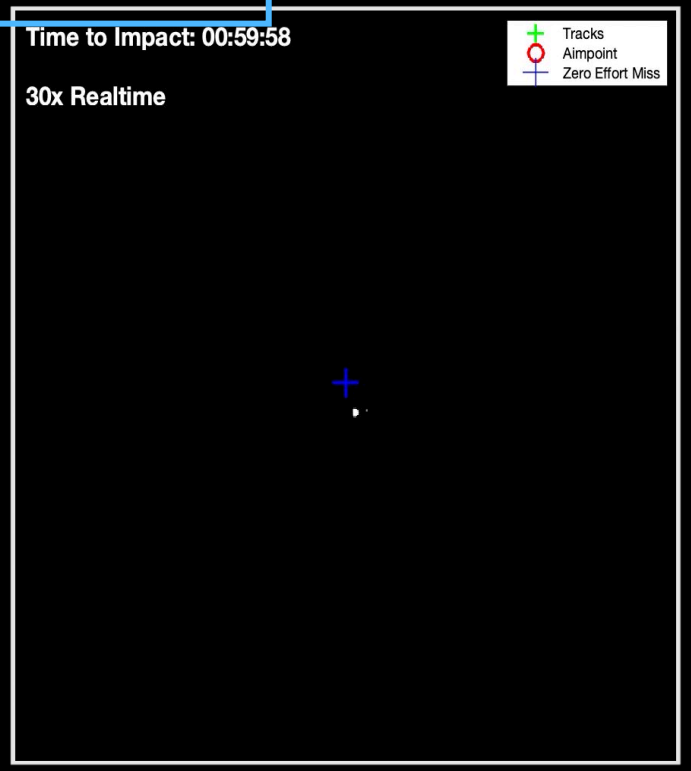
DART's Final 2 Minutes



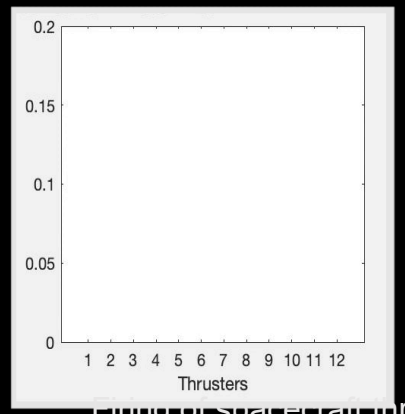
"If you look at that on a map, it's as if we were over the Indy 500 when we stop maneuvering, and then we simply coast all the way to Baltimore and land inside Camden Yards."

MARK JENSENIUS *SMART Nav Guidance Engineer*

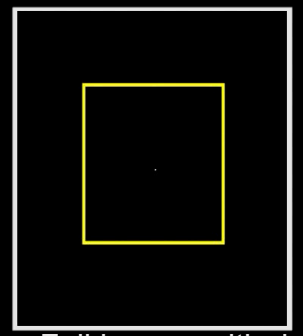
SMART Nav Simulation



Downlinked information



Firing of spacecraft thrusters

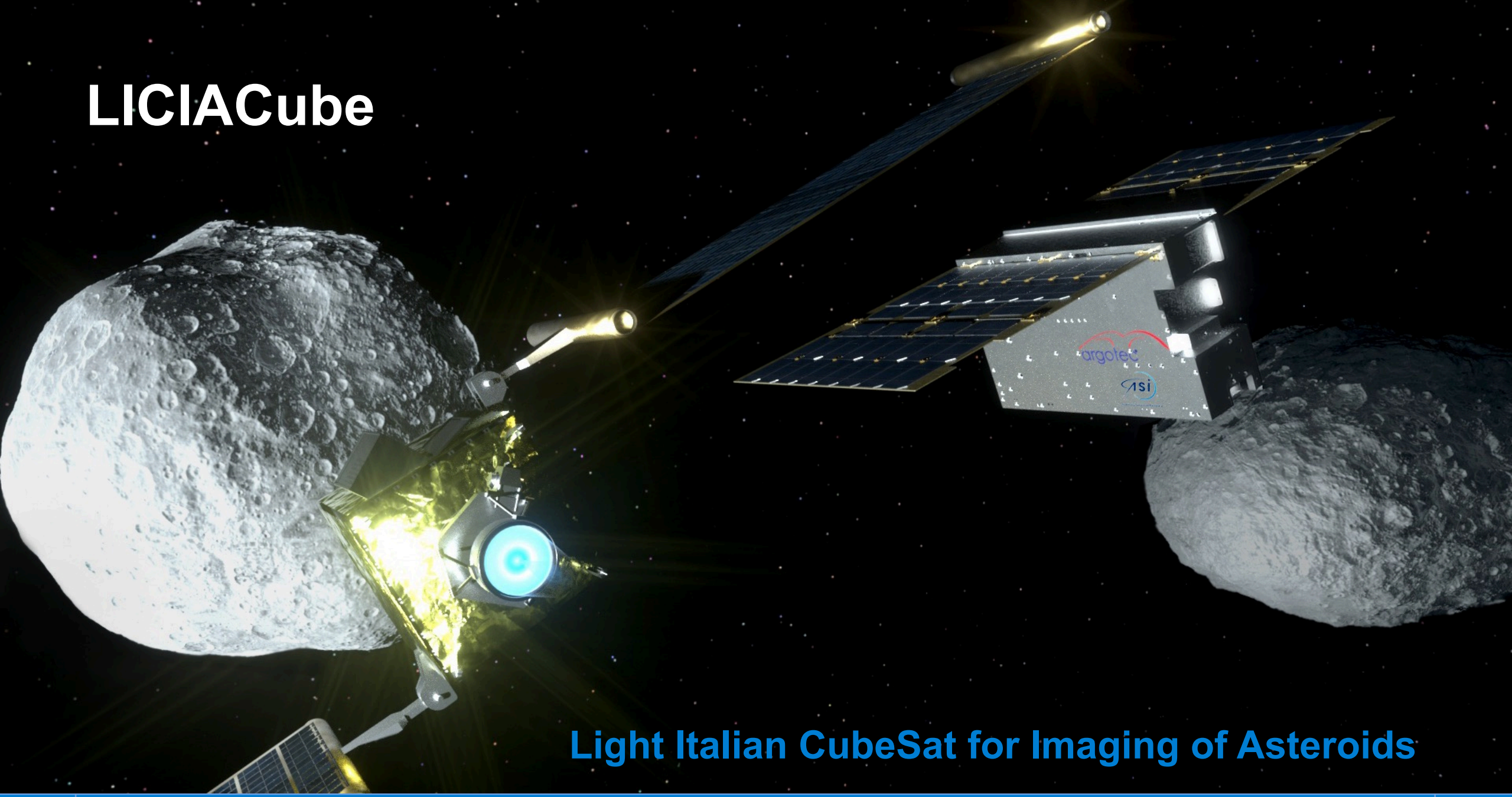


Full image, with downlinked portion in yellow

DRACO
(Didymos Reconnaissance and Asteroid Camera for Opnav)

DRACO view of Didymos and Dimorphos one hour before impact

LICIACube



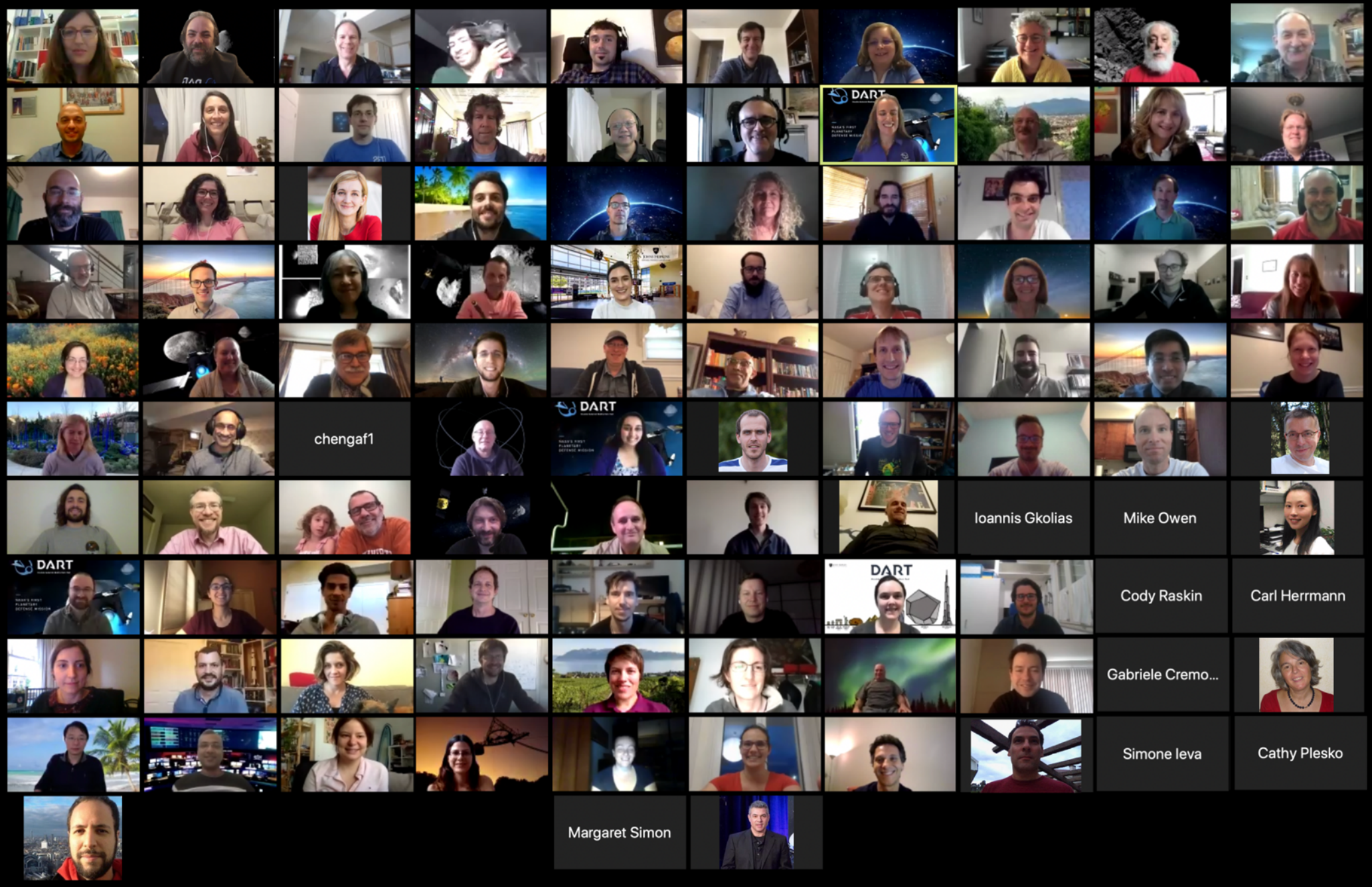
Light Italian CubeSat for Imaging of Asteroids

DART

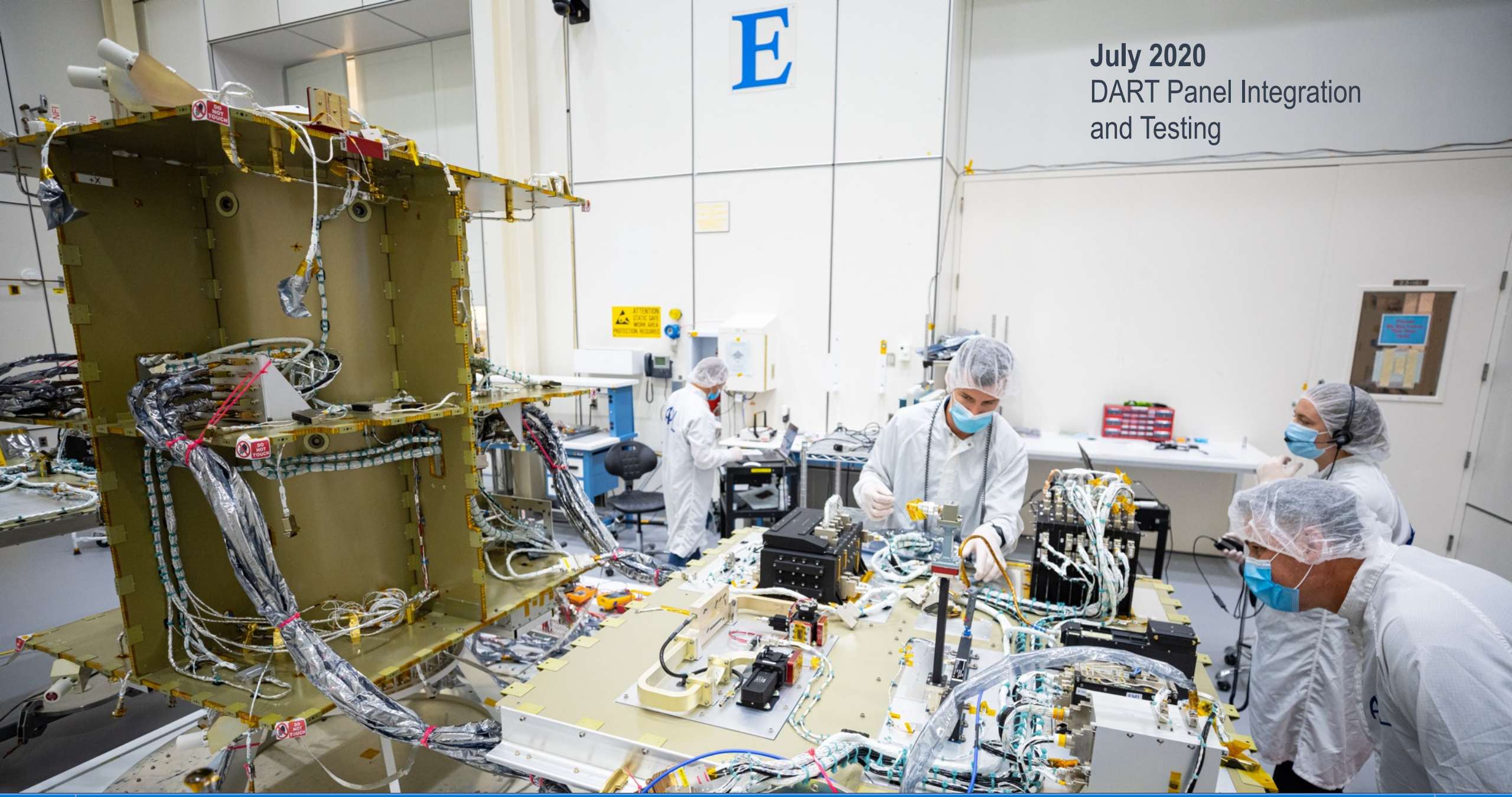
Double Asteroid Redirection Test

Investigation Team Meeting

May 2020

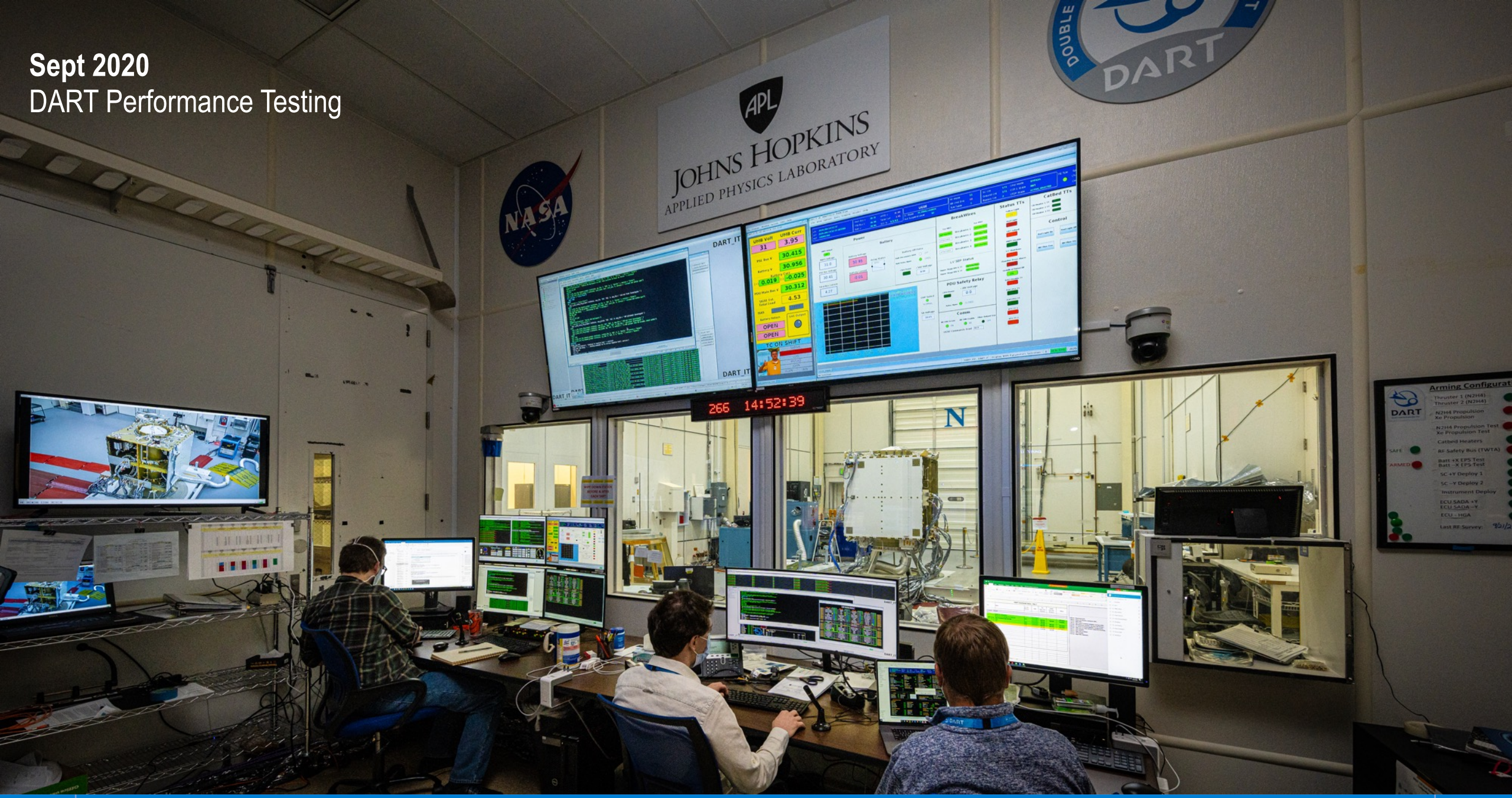


May 2020
Spacecraft Structure
in Clean Room


July 2020
DART Panel Integration
and Testing

Sept. 2020
DART Panel Closeout

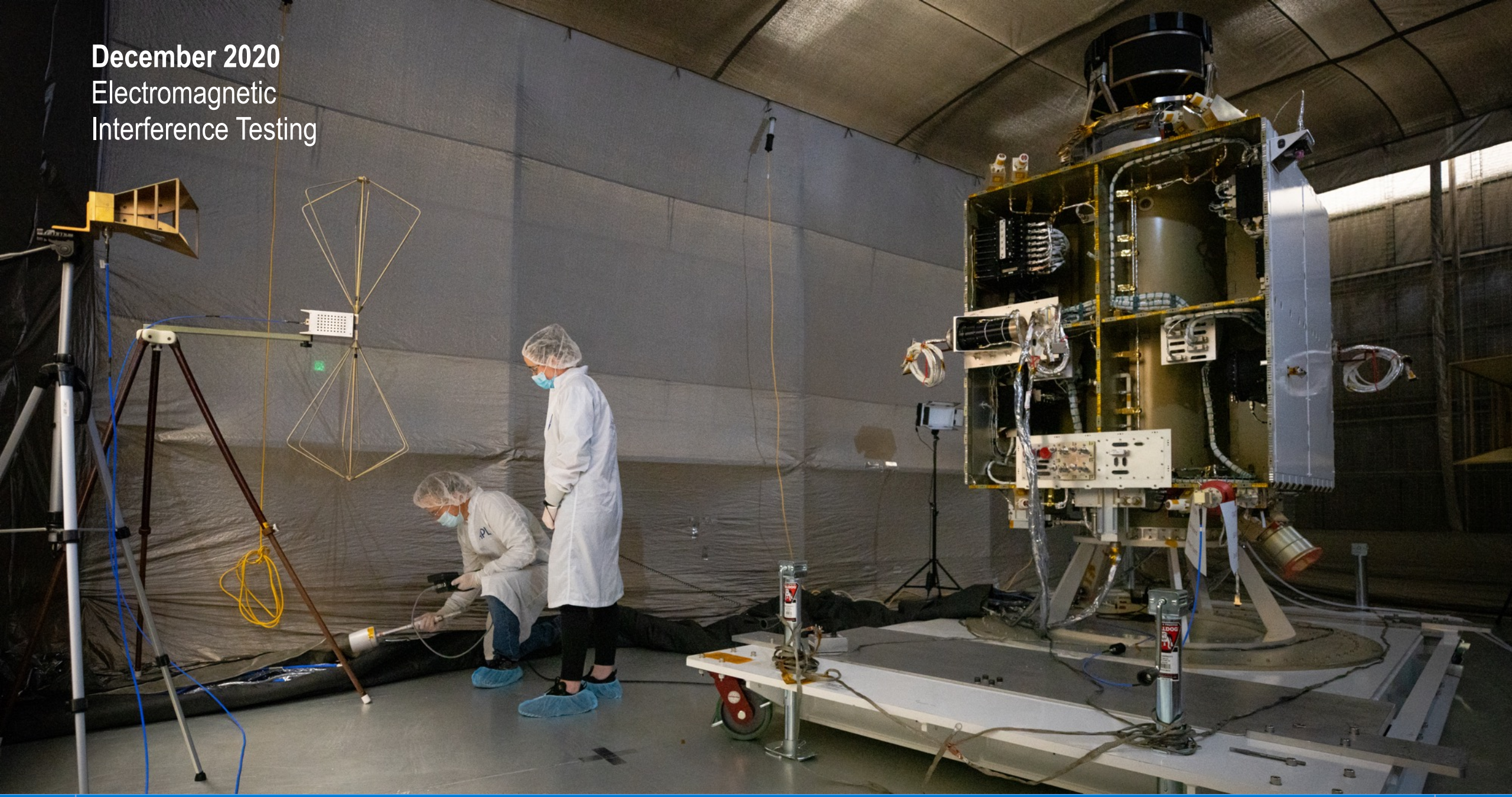
Sept 2020
DART Performance Testing



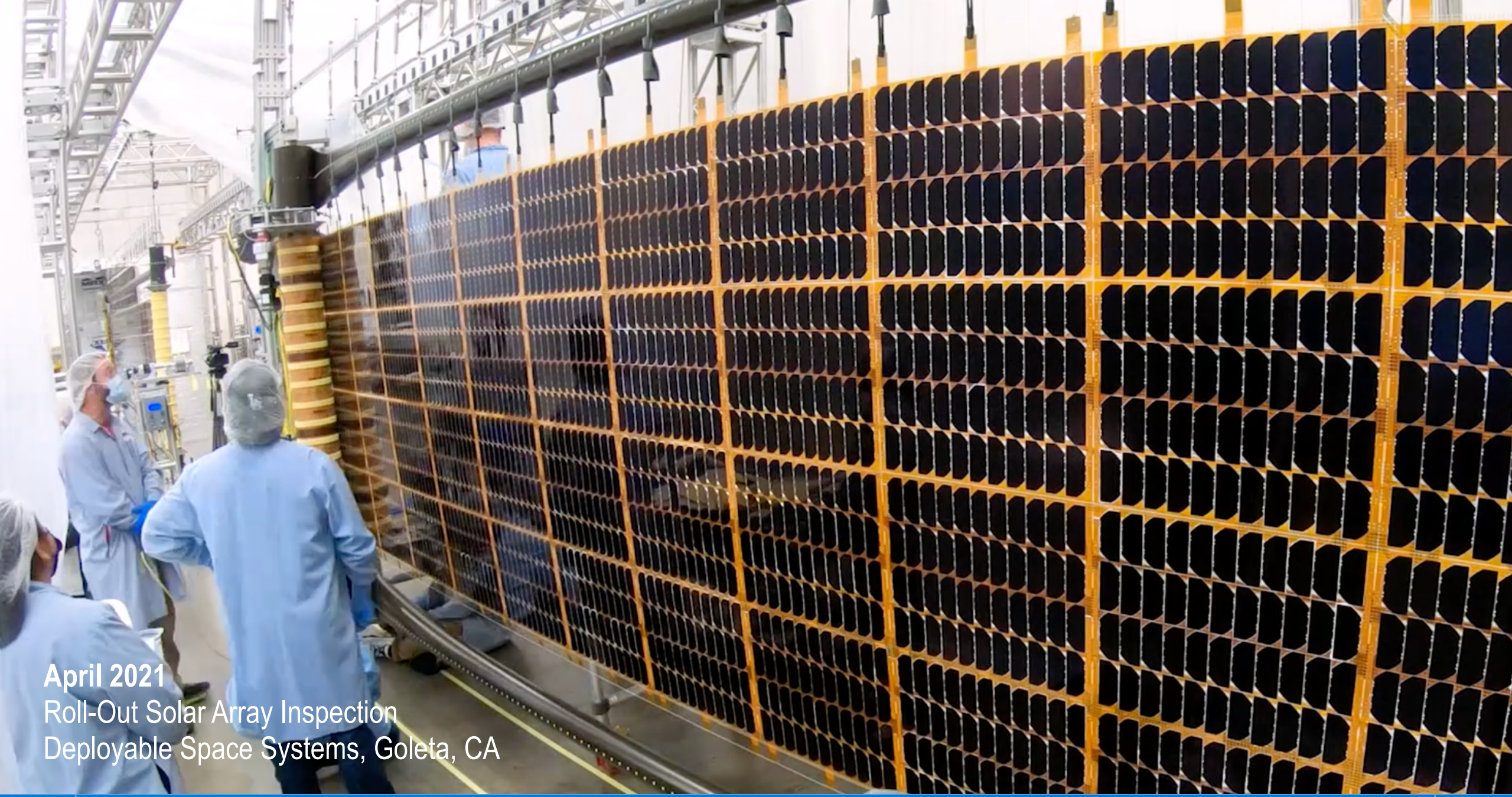
Nov 2020
RLSA Installation


Nov. 2020
NEXT-C Installation
APL
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
APL

December 2020
Electromagnetic
Interference Testing



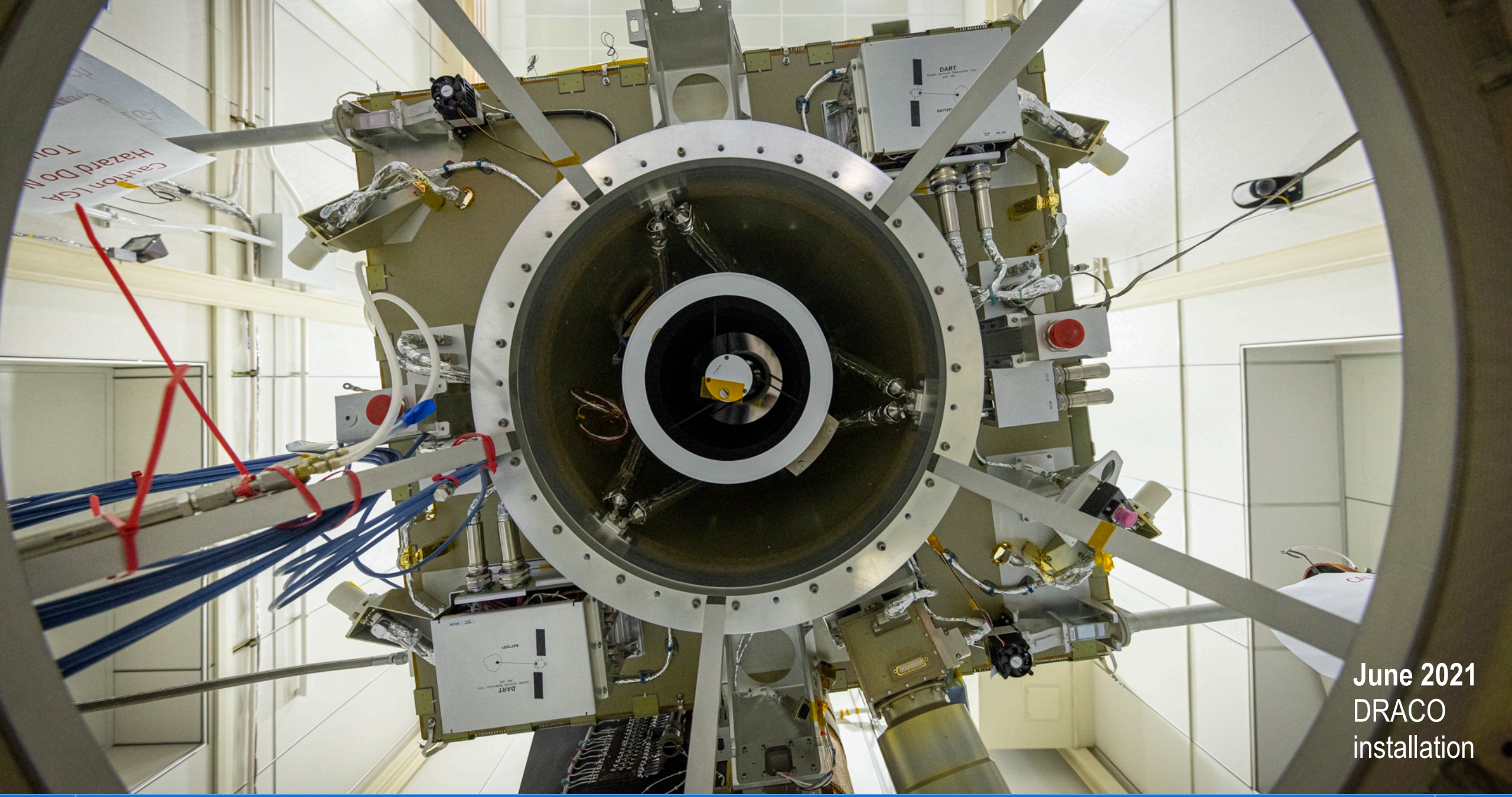

Jan 2021
Thermal Vacuum
Testing



April 2021
Roll-Out Solar Array Inspection
Deployable Space Systems, Goleta, CA

May 2021
Solar Array Installation

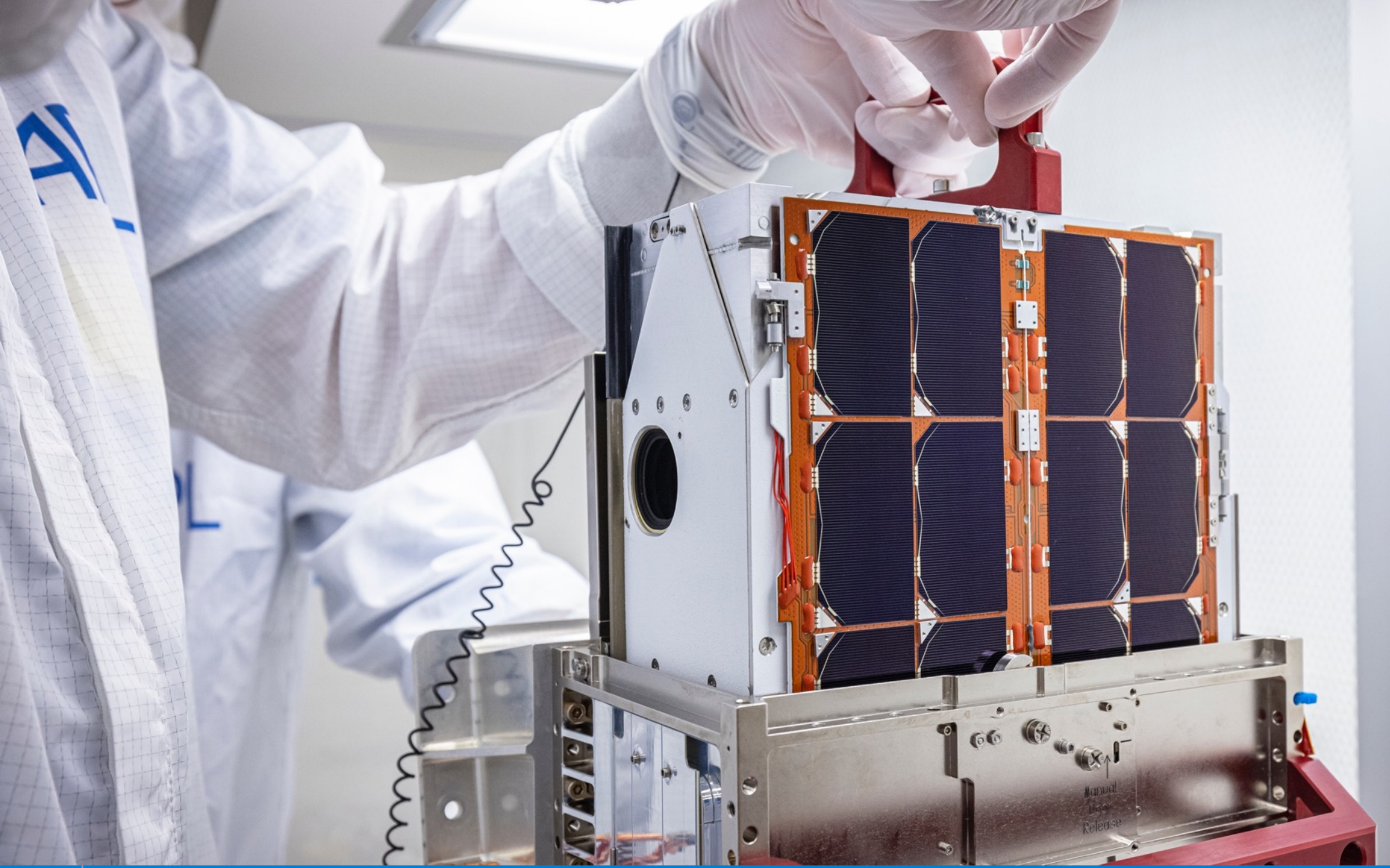
June 2021
DRACO
installation



June 2021
DRACO
installation


July 2021
Pre-vibration
testing inspection
DART

July 2021
Vibration testing

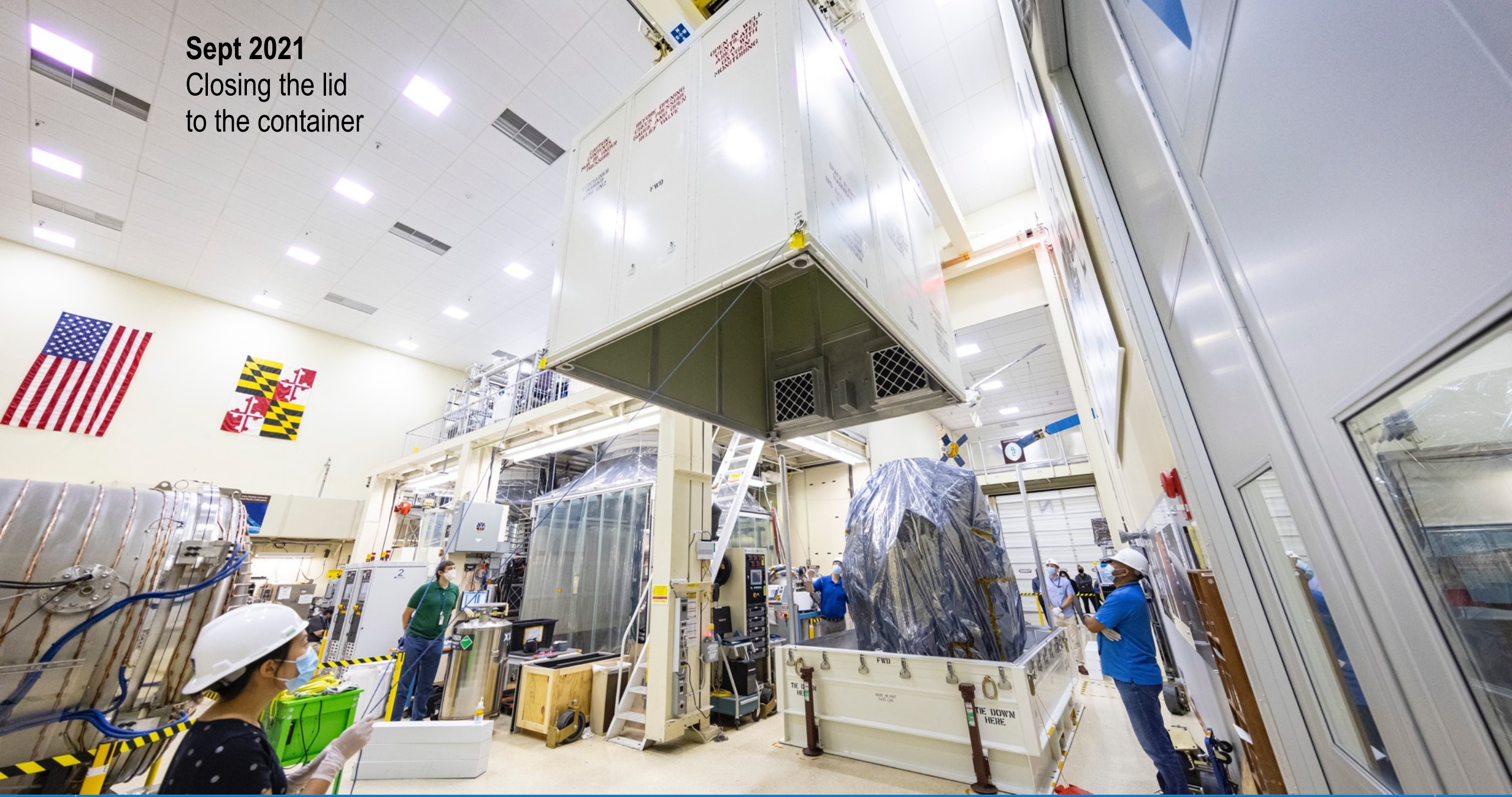


Aug. 2021
LICIACube arrives at APL

Sept. 2021
LICIACube
Integration

Sept. 2021
Pre-ship inspection

Sept 2021
Lift to the container


Sept 2021
Closing the lid
to the container
FWD
TIE DOWN HERE

Sept 2021
Transportation to Vandenberg Space Force Base

Oct 2021
SpaceX facility on Vandenberg Space Force Base

Nov 2021
Vandenberg Space Force Base

Bill Ingalls/NASA

Bill Ingalls/NASA


Nov 23, 2021, 10:21 pm PST
SpaceX Falcon 9 Launch
Vandenberg Space Force Base
NASA
LIVE
NLM POLL
PROP LOAD
LC POLL
LIFTOFF
MECO
1st STAGE SEP
ENGINE START 1
FAIRING JETTISON
ENGINE CUTOFF 1
ENGINE START 2
ENGINE CUTOFF 2


Nov 23, 2021, 11:17 pm PST
DART Spacecraft Separation

DART

Double Asteroid Redirection Test

https://dart.jhuapl.edu/

I am a Planetary Defender

https://dart.jhuapl.edu/Planetary-Defender/

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Hashtags:
#DARTMission
#planetarydefense