# DART: Double Asteroid Redirection Test

## The First Planetary Defense Test Mission

**Andrew Rivkin**
DART Investigation Team Lead
Johns Hopkins University Applied Physics Laboratory
Andy.Rivkin@jhuapl.edu

# September 26, 2022


2013/02/15 09:26:23

# Chelyabinsk, Russia February 2013

Impact of 20-25 m asteroid

Injured 1000+ people

# Fireballs Reported by US Government Sensors

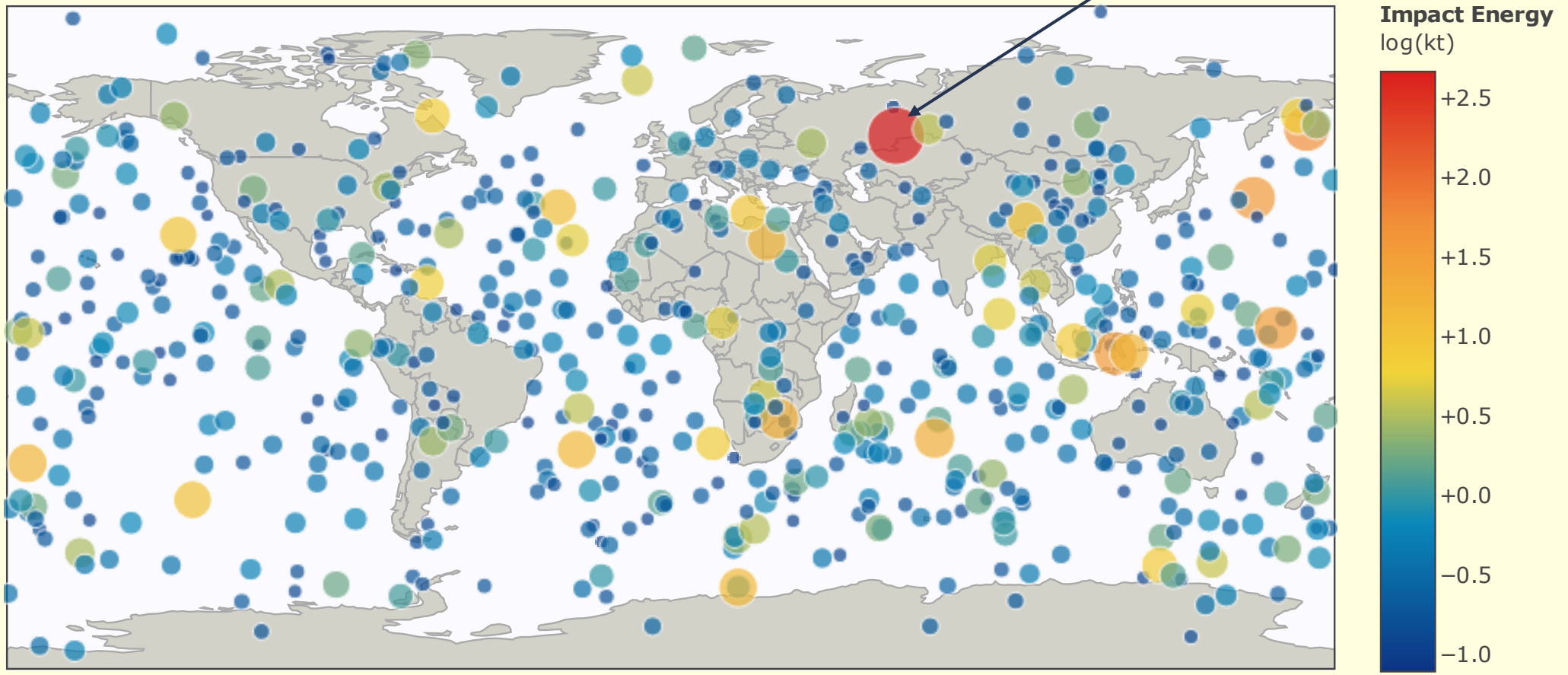
(1988-Apr-15 to 2023-Jan-09; limited to events >= 0.1kt)

**Chelyabinsk**

**Year:** 2013 **Diameter:** ~20 meters

**Equivalent to:** ~500 kilotons of TNT

**Frequency:** every few decades to centuries



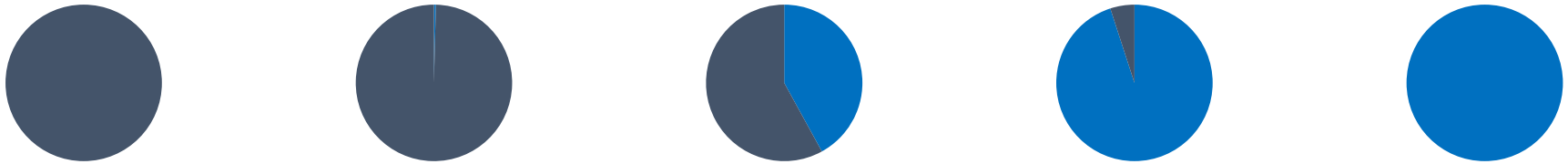

https://cneos.jpl.nasa.gov/fireballs/

Alan B. Chamberlin (JPL/Caltech)

# The Hazard by the Numbers

| Asteroid Size | 4 meters | 25 meters | 160 meters | 1,000 meters | 10,000 meters |
|---|---|---|---|---|---|
| Frequency | ~1 per **year** | ~1 per **100 years** | ~1 per **25,000 years** | ~1 per **500,000 years** | ~1 per **100-200 million years** |
| Impact | 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** |
| % Discovered | **< 0.1%** | **0.4%** | **42%** | **> 95%** | **100%** |

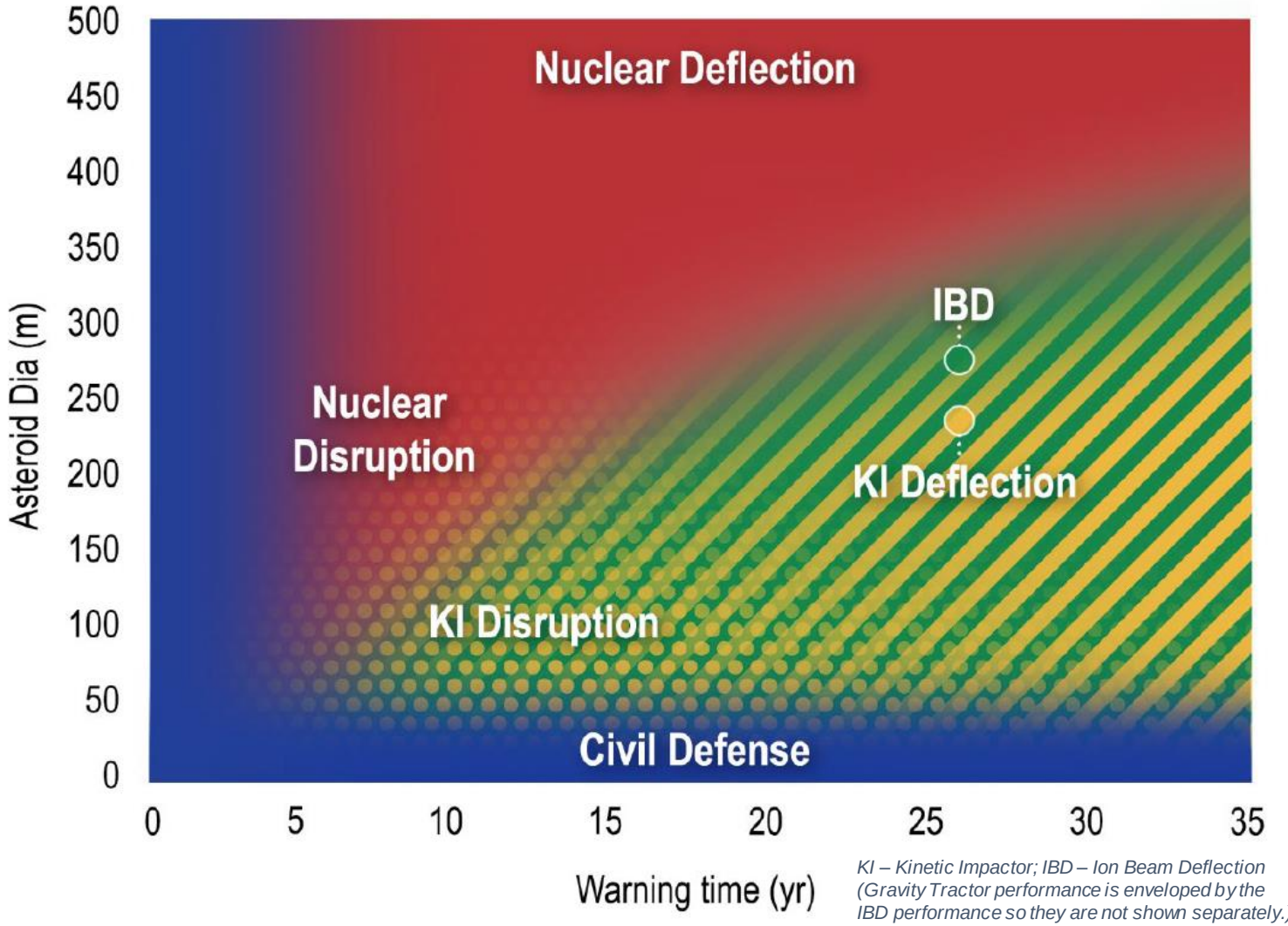
Located
Not located



# Top Priority for a Mitigation Mission

## Mitigation Techniques for Potentially Hazardous Asteroids

Animations from 360info.org




*KI – Kinetic Impactor; IBD – Ion Beam Deflection (Gravity Tractor performance is enveloped by the IBD performance so they are not shown separately.)*

# Launch

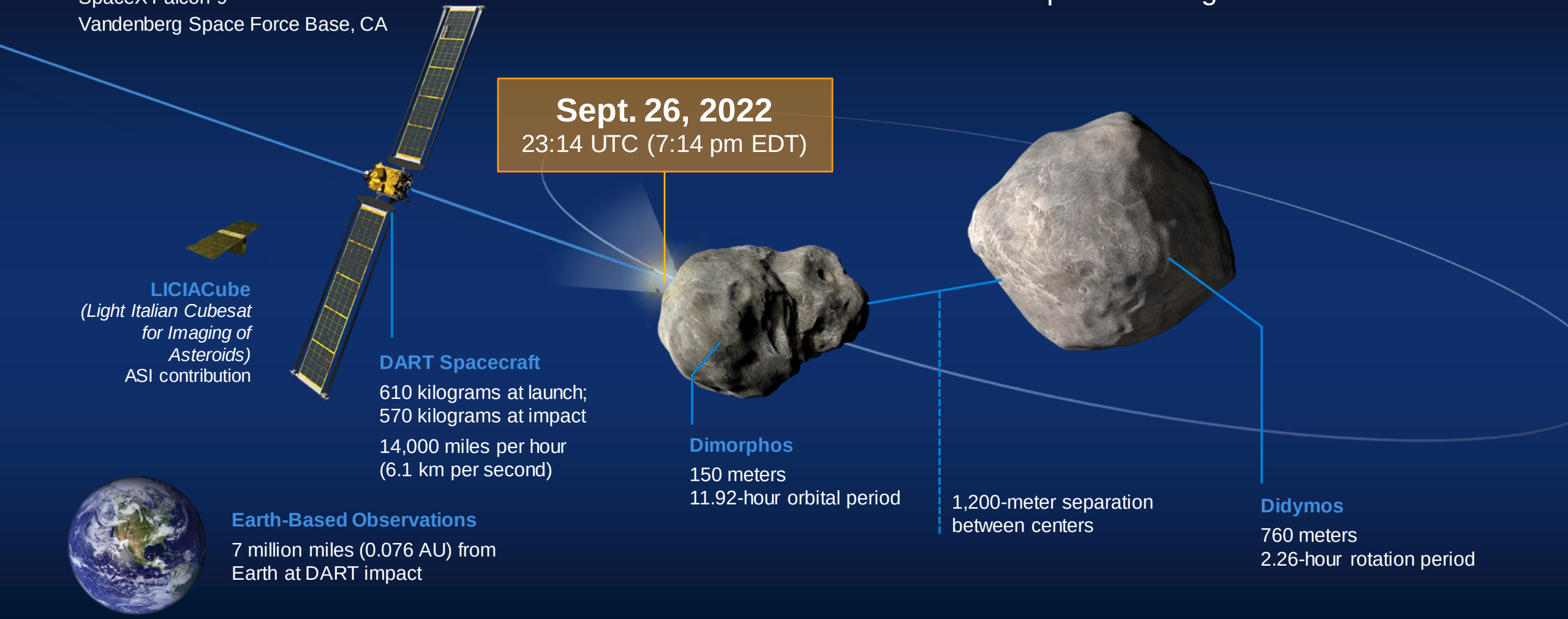
Nov. 24, 2021

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 km per second)

**Dimorphos**

150 meters
11.92-hour orbital period

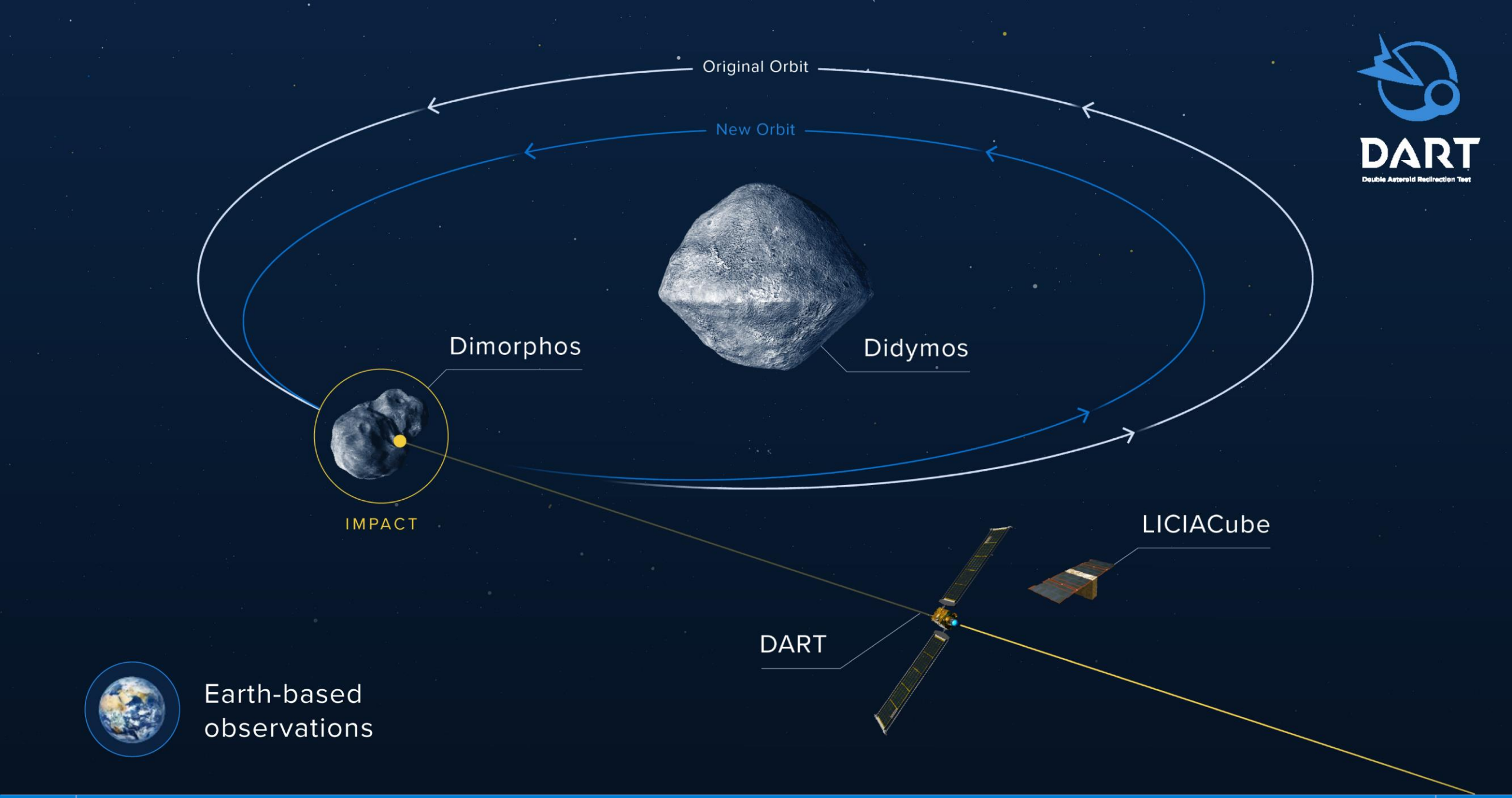
1,200-meter separation between centers

**Didymos**

760 meters
2.26-hour rotation period

**Earth-Based Observations**

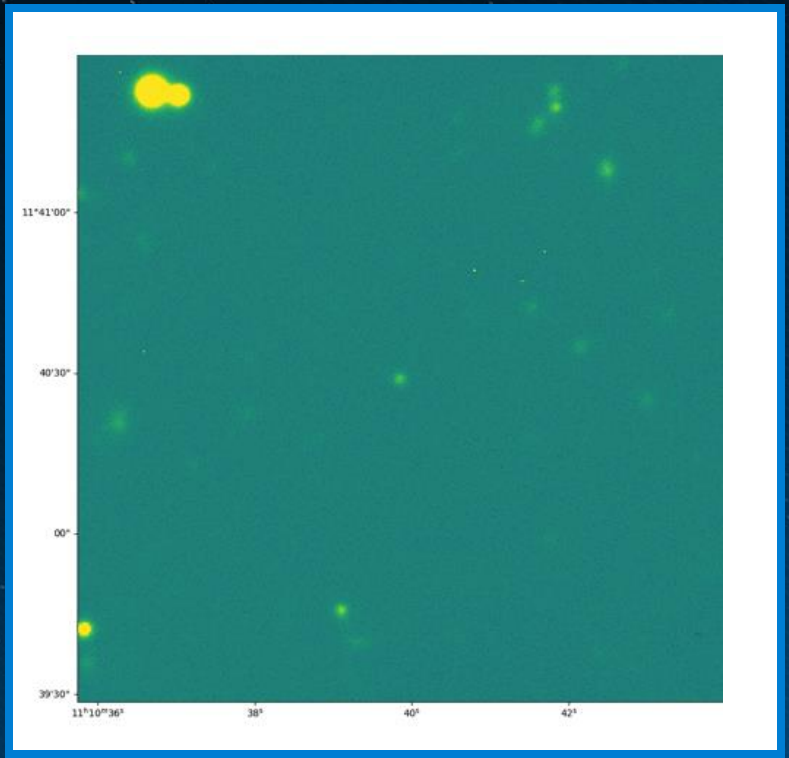
7 million miles (0.076 AU) from Earth at DART impact


Original Orbit
New Orbit
Dimorphos
Didymos
IMPACT
LICIACube
DART
Earth-based
observations

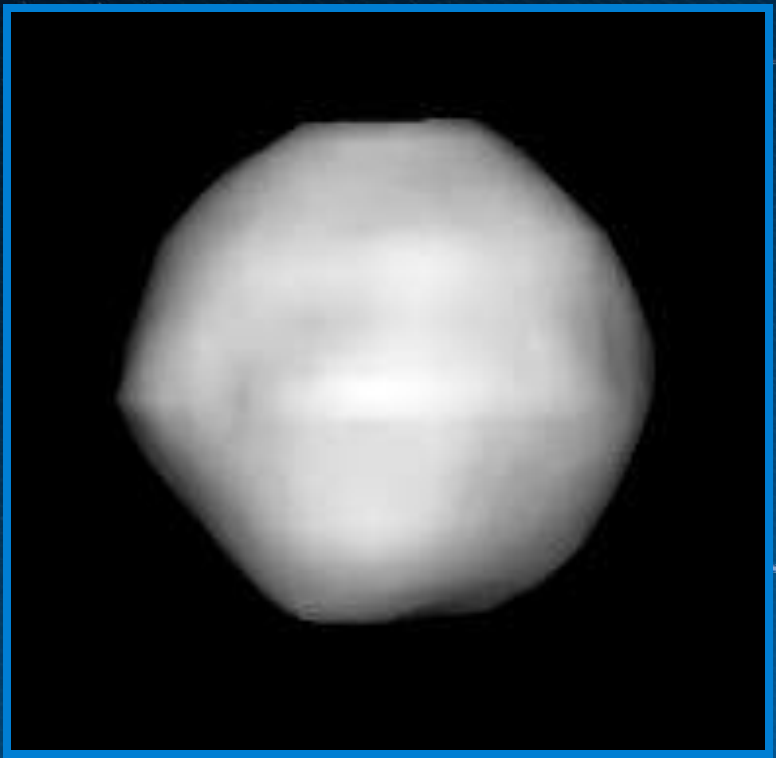
# DART Spacecraft

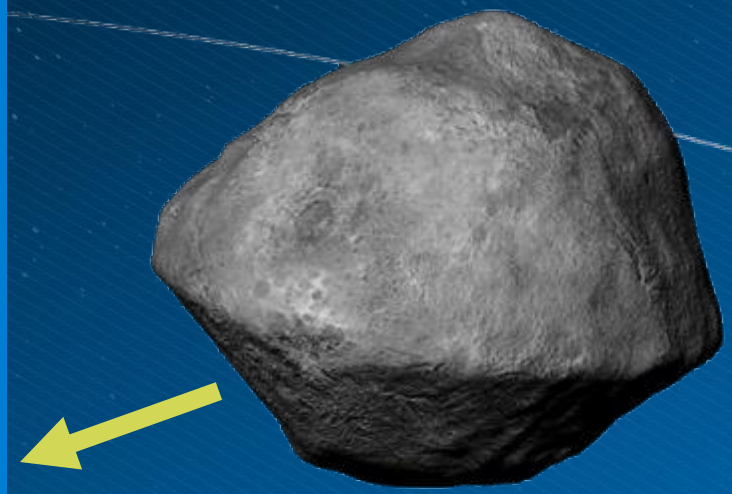

**Weight:**
1,345 pounds (610 kg) at launch
1,260 pounds (570 kg) at kinetic impact

# Understanding the pre-DART situation




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





Radar Shape Model

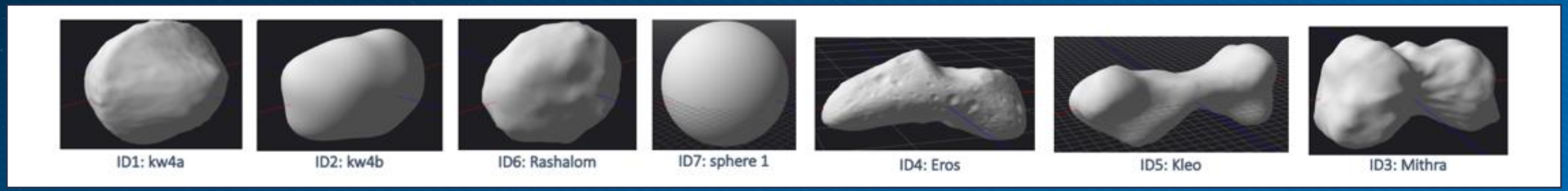
Preliminary shape model of the Didymos primary asteroid from combined radar and light curve data, diameter ~780 m.

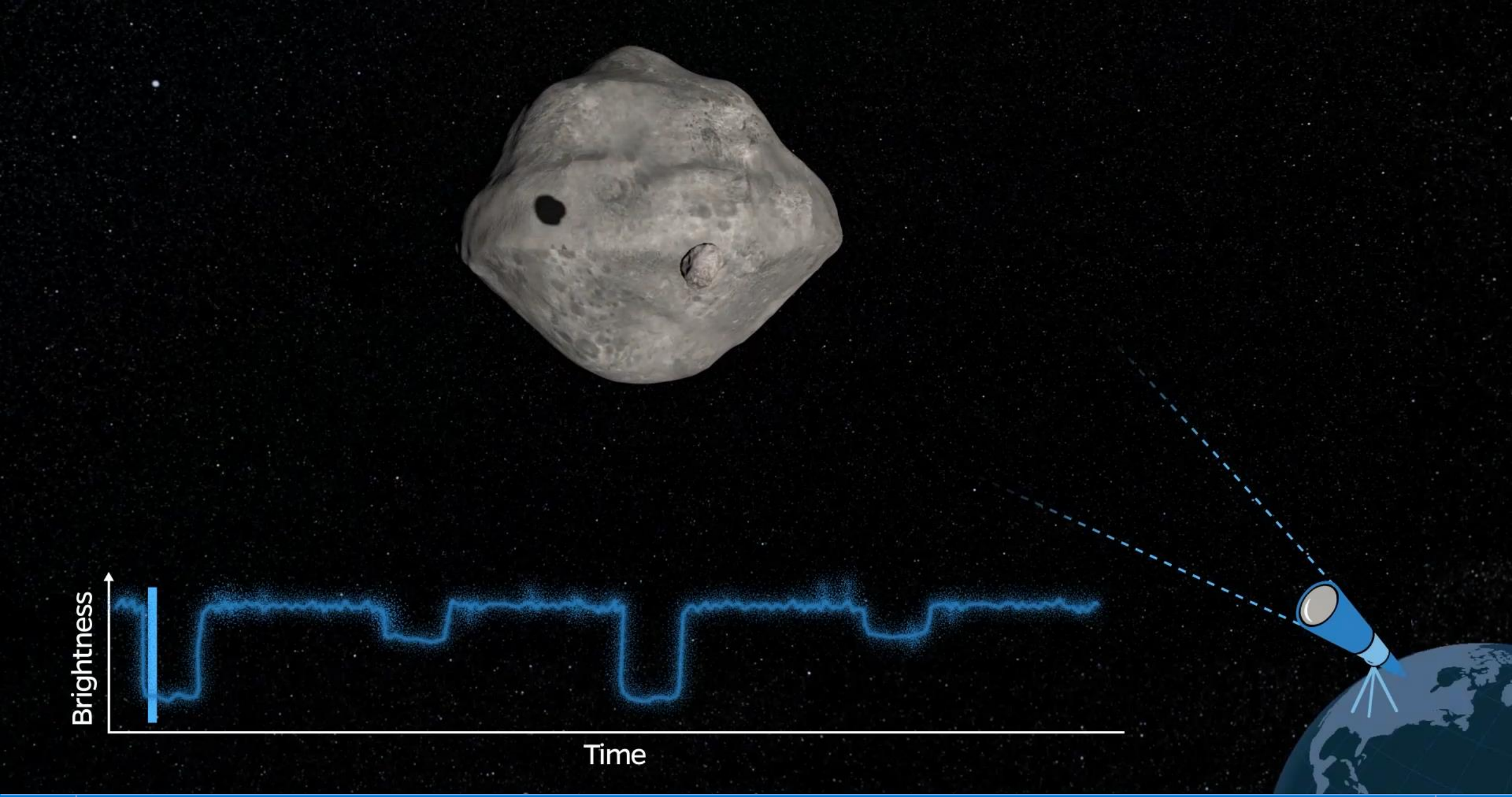
# We knew little about the object we were aiming for

## Dimorphos

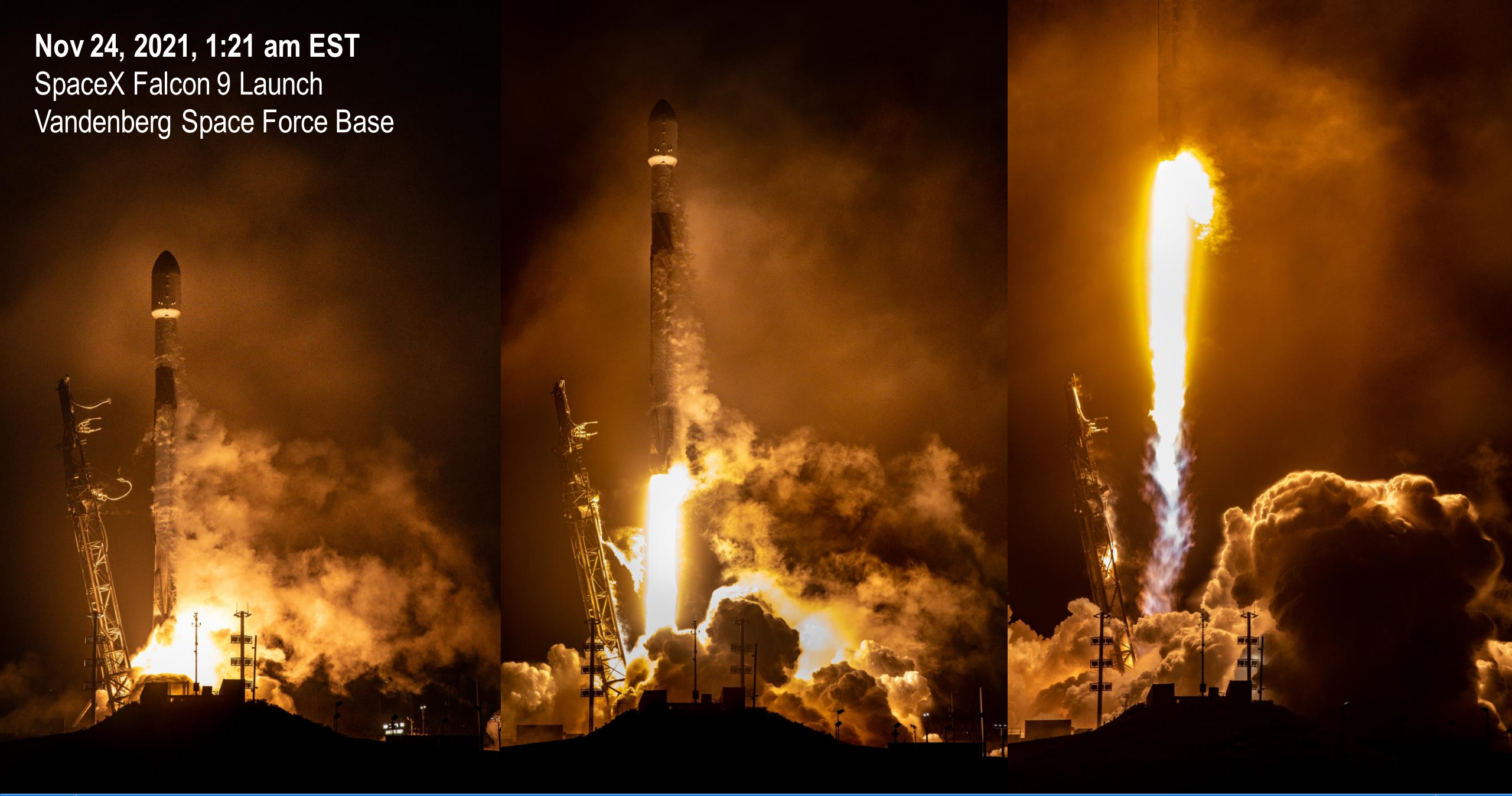
- Size estimate: 165 m
- Orbit period: 11 hr 55 min
- Composition: same as Didymos?

?



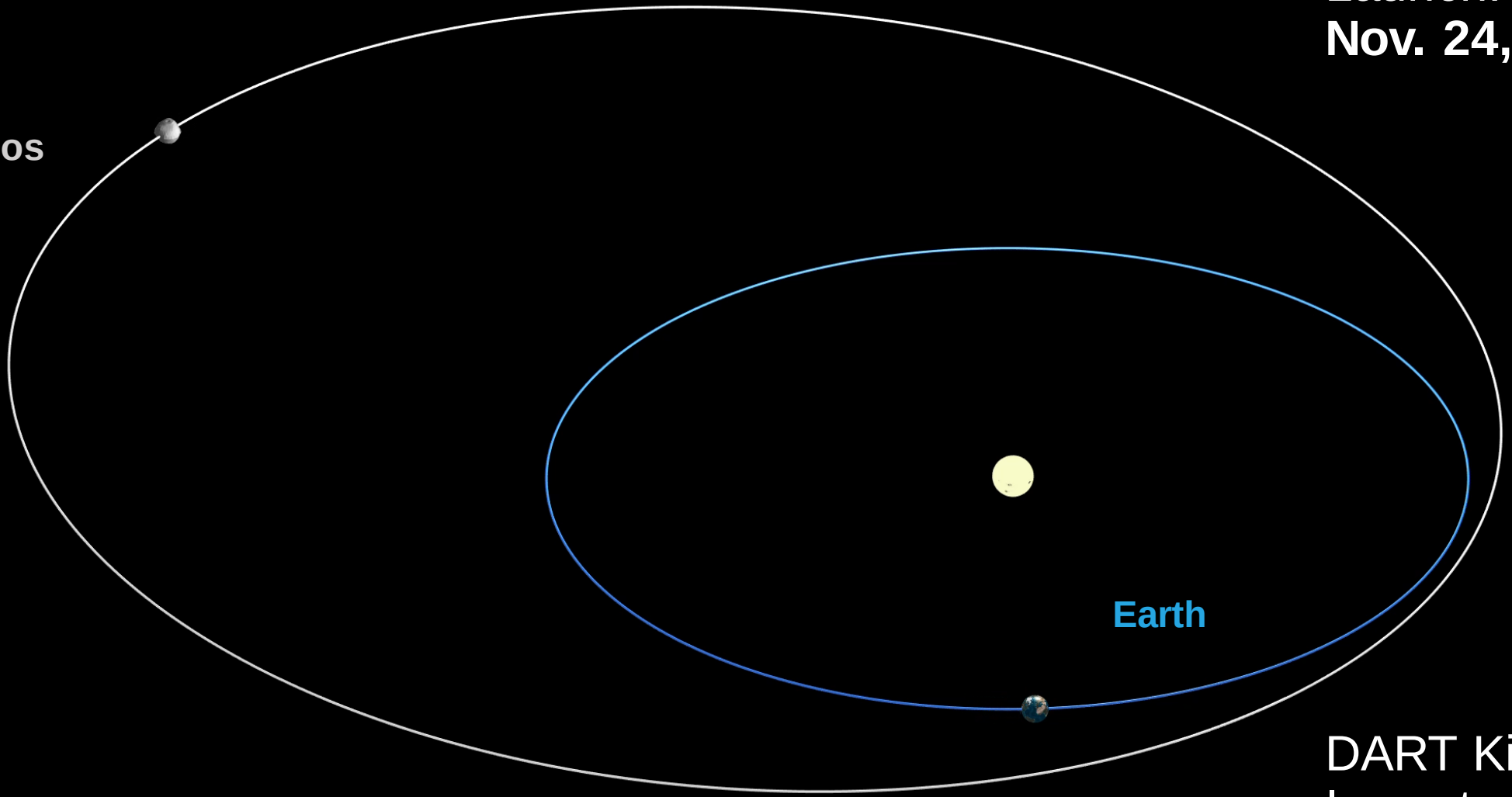

Brightness
Time

**Nov 24, 2021, 1:21 am EST**
SpaceX Falcon 9 Launch
Vandenberg Space Force Base



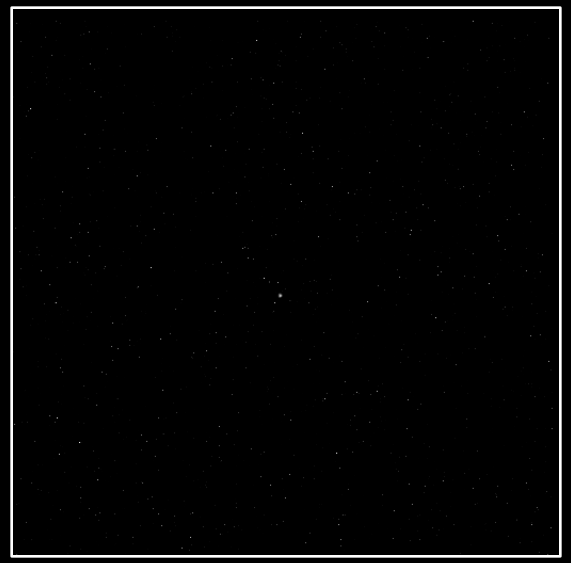
# The Ideal Time

Launch:
**Nov. 24, 2021**

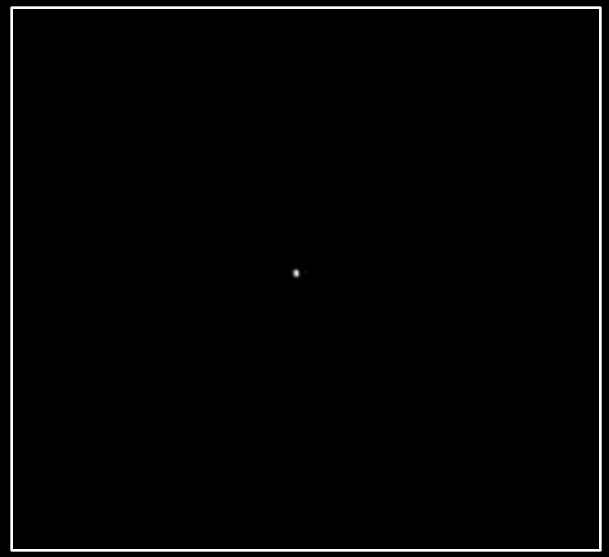



DART Kinetic Impact:
**Sept. 26, 2022**

# Autonomously Navigating to Asteroid Impact



**90,000 kilometers**
Started SMART Nav autonomous navigation



**27,000 kilometers**
First detection of Dimorphos

**930 kilometers**
SMART Nav maneuvering ended

**12 kilometers**
Last complete image

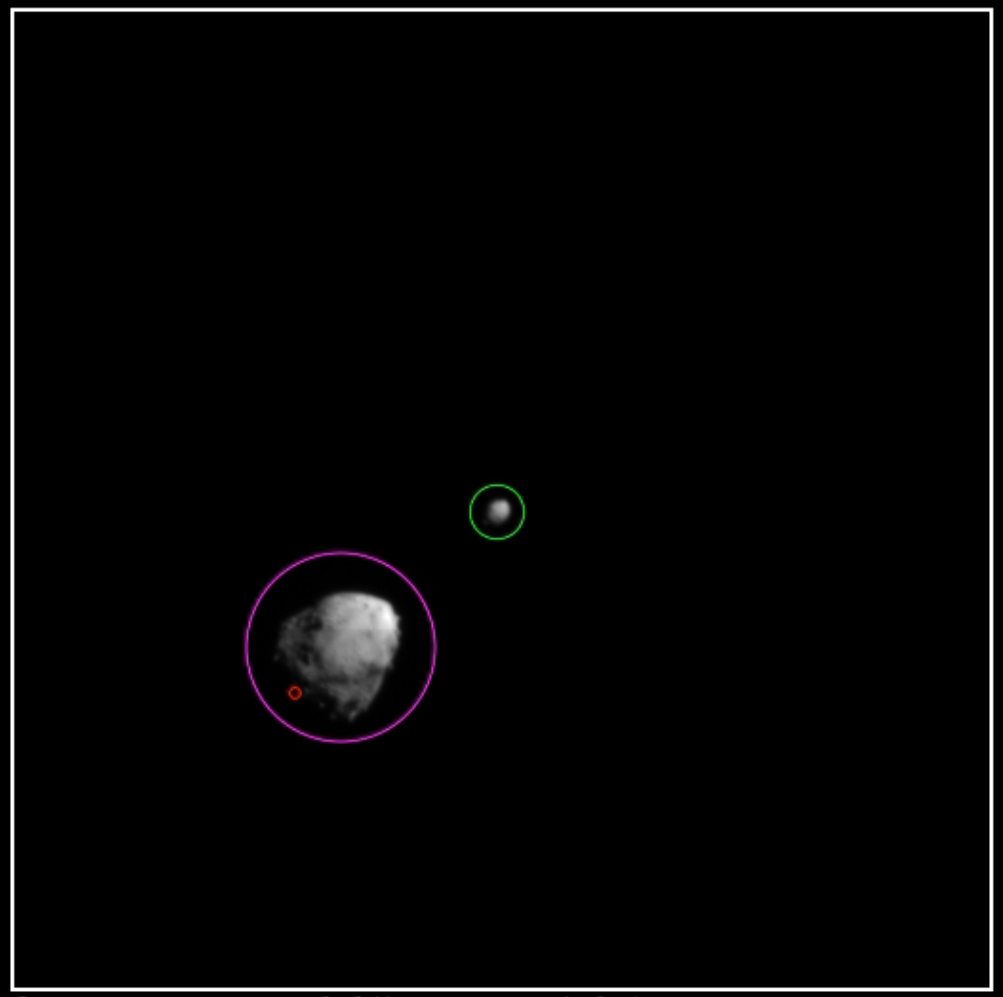
| 4 hours | 73 minutes | 2.5 minutes | 2 second |
|---|---|---|---|

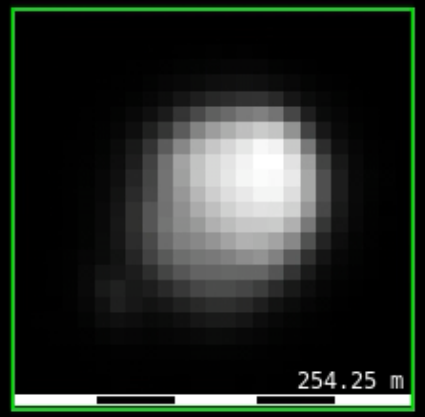
# DART DRACO

Final raw images as shown live, from last 5.5 min. Sped up x10, except for last 6 images

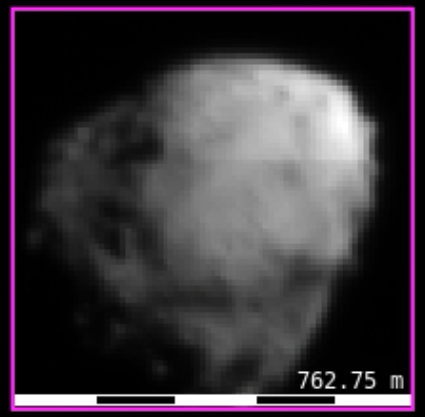
*Credit: NASA/Johns Hopkins APL*

# Autonomously Navigating to Asteroid Impact

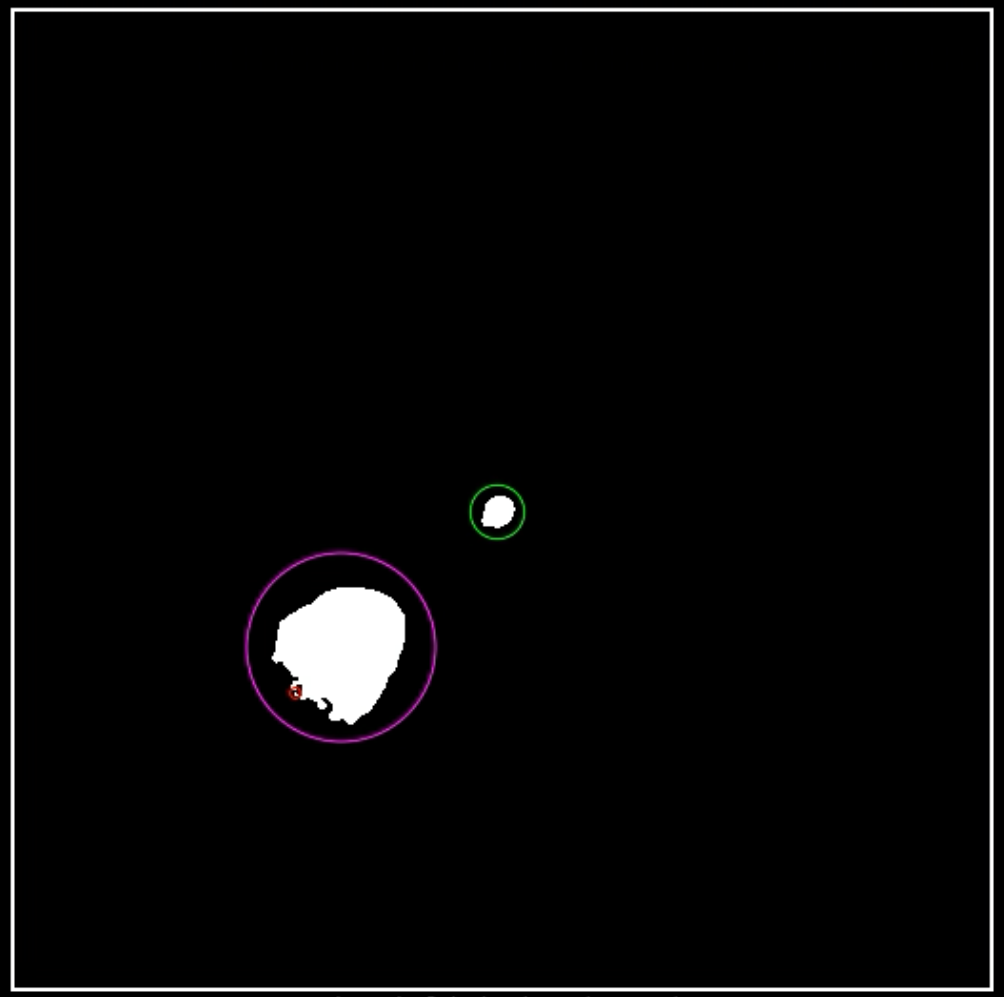



> DIMORPHOS <
numpix=225 | maxval=1147
total intensity=92818




> TRACK-6 (1st Largest) <
numpix=3454 | maxval=1626
total intensity=1851844



Thresholded View (DN=40)

# DART DRACO

Dimorphos and Didymos to scale
2.5 min. before DART's impact
580 miles (930 km) distance

*Credit: NASA/Johns Hopkins APL*

# DART DRACO

Dimorphos

11 seconds before DART's impact

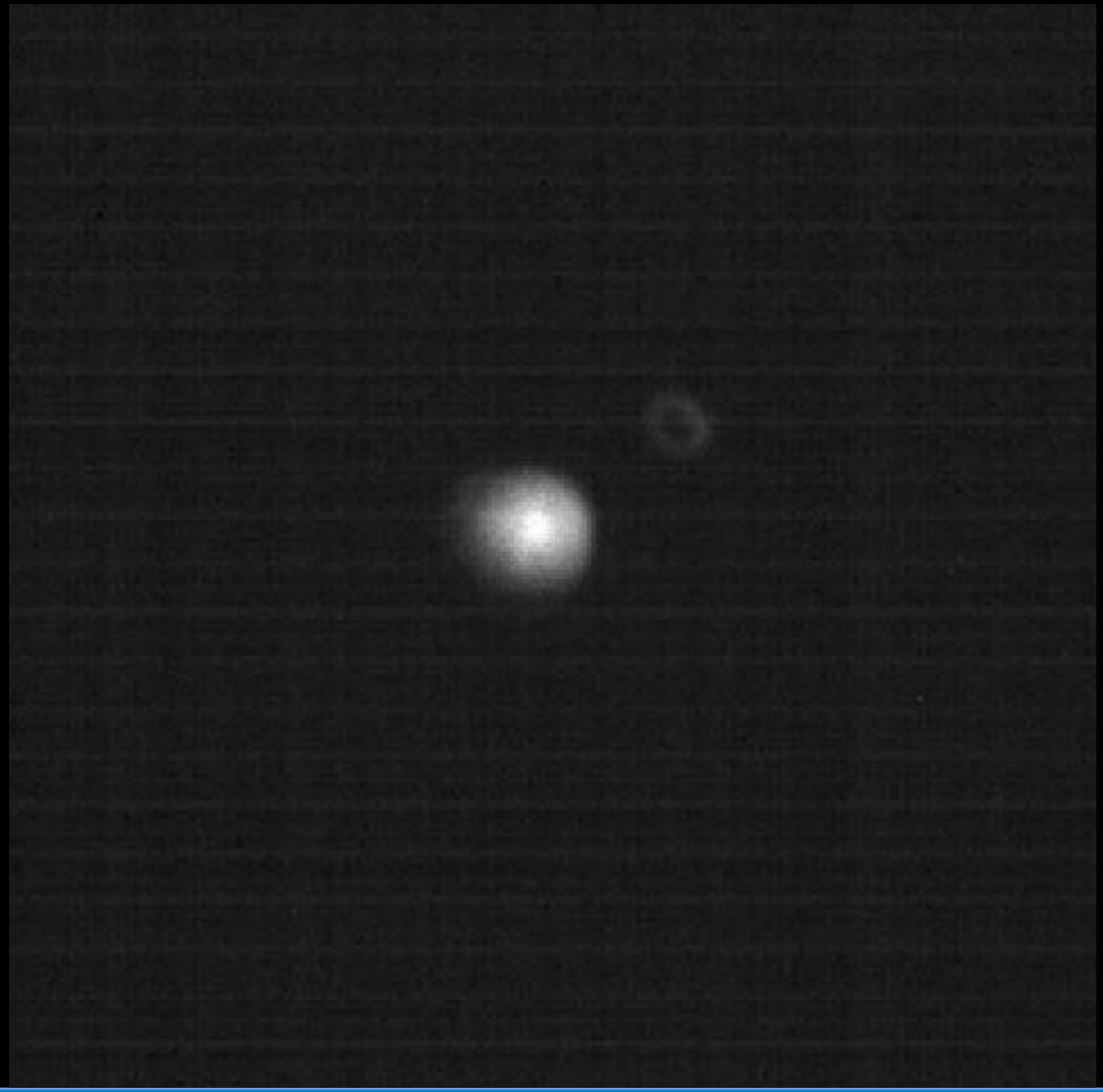
42 miles (68 km) distance

*Credit: NASA/Johns Hopkins APL*

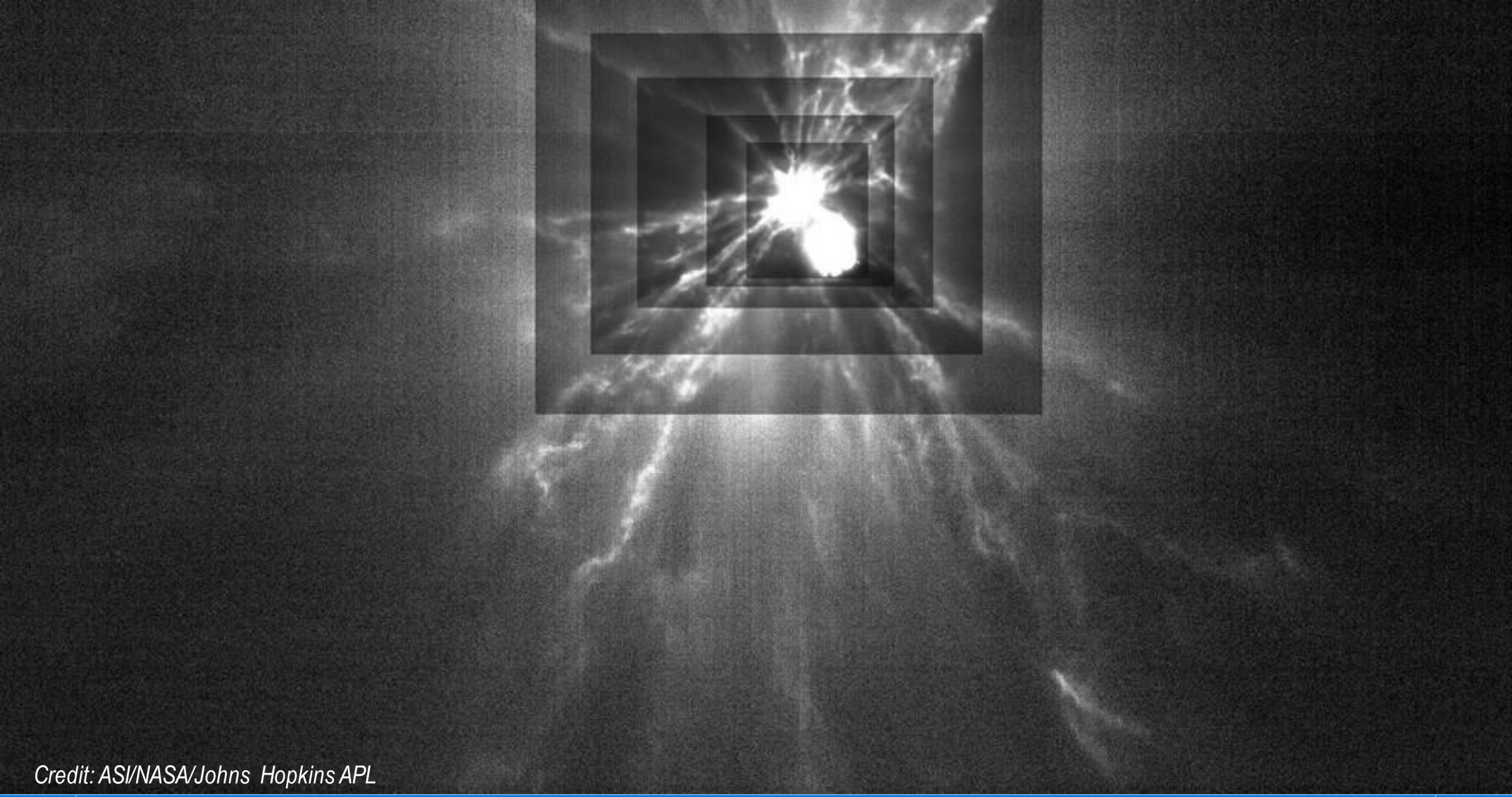
# LICIACube LEIA

Two images taken 6 seconds apart showing Dimorphos' brightness before and after impact

(LICIACube-Dimorphos distance = 1020 km)



*Credit: ASI/ NASA*



*Credit: ASI/NASA/Johns Hopkins APL*


WORLDWIDE OBSERVING CAMPAIGN 2022 2023
DART
Double Asteroid Redirection Test
Arizona
LDT (4.3 m)
Hall (1.1 m)
Spacewatch (0.9 m)
VATT (1.8m)
California
Goldstone
Palomar (5 m)
TMO (1 m)
Hawaii
IRTF (3 m)
ATLAS (0.5 m x 2)
Faulkes North (2 m)
Massachusetts
Sugarloaf Mt. (0.64 m)
West Virginia
Green Bank
Texas
LCOGT (1 m)
New Mexico
MRO (2.4 m)
Czechia
Ondřejov (0.65 m)
Italy
Asiago (1.8 m, 1 m)
Turkey
TUG (1.0 m, 0.12 m)
Canary Islands
TNG (3.5 m)
NOT (2.56 m)
LCOGT (1 m)
Morocco
TRAPPIST-North (0.6 m)
Slovakia
Stará Lesná (0.6 m)
Georgia
Abastumani (0.7 m)
Israel
Wise (0.71 m)
Uzbekistan
Maidanak (1.5 m)
Qatar
Qatar Univ. (0.3 m)
South Korea
BOAO (1.8 m)
Kenya
OPTiK (0.4 m)
Namibia
Drebach South (0.4 m)
Springbok (0.36 m)
Réunion
Les Makes (0.6 m)
Australia
LCOGT (1 m)
Chile
ALMA
VLT (8.2 m x 4)
Magellan (6.5 m)
SOAR (4.1 m)
La Silla (1.54 m, 0.6m)
LCOGT (1 m)
Swope (1 m)
ATLAS (0.5 m)
Argentina
Jorge Sahade (2.15 m)
EABA Bosque Alegre (1.5 m)
South Africa
LCOGT (1 m)
SAAO (1 m)
ATLAS (0.5 m)
SMARTnet (0.5 m)
Watcher (0.4 m)
Antarctica
ASTEP (0.4 m)
New Zealand
Mt. John (1.8 m)
HST
JWST
Lucy

September 26
23:26 UTC
(12 min. post-impact)

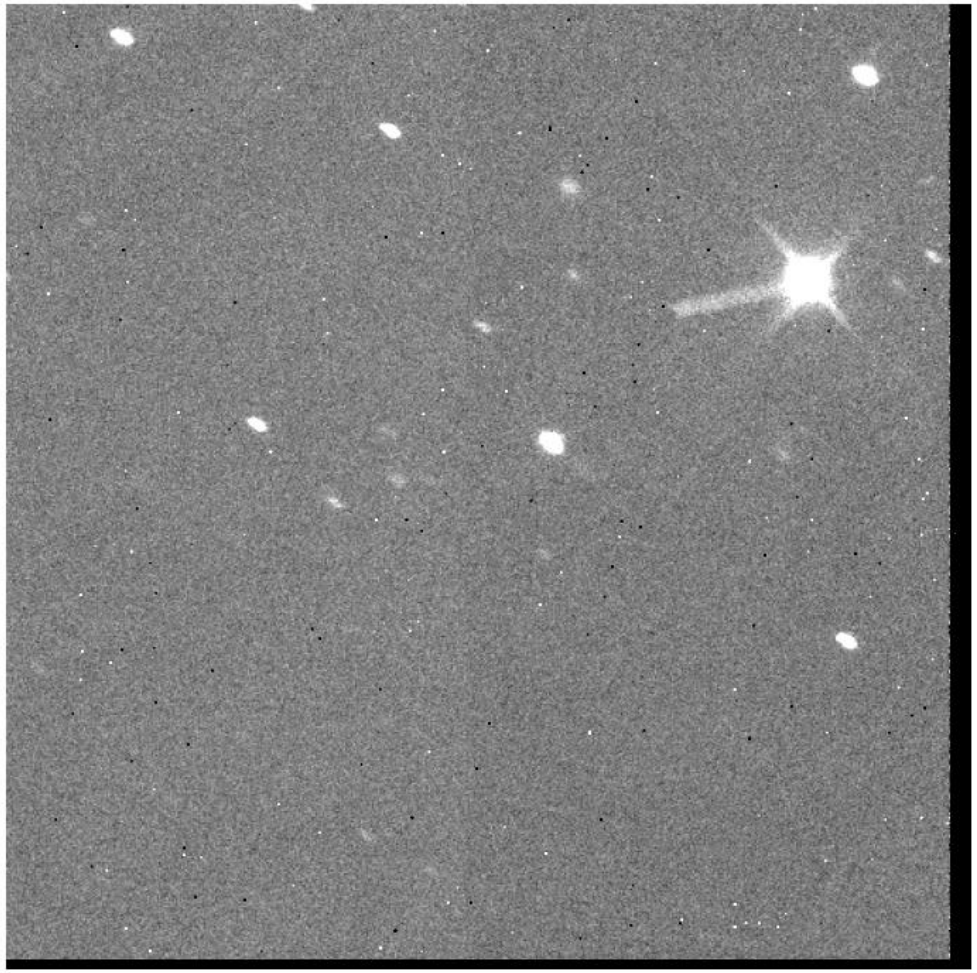
Vapor plume speed:
~1.5 km/s
~3300 mph

23:29 UTC
(15 min. post-impact)

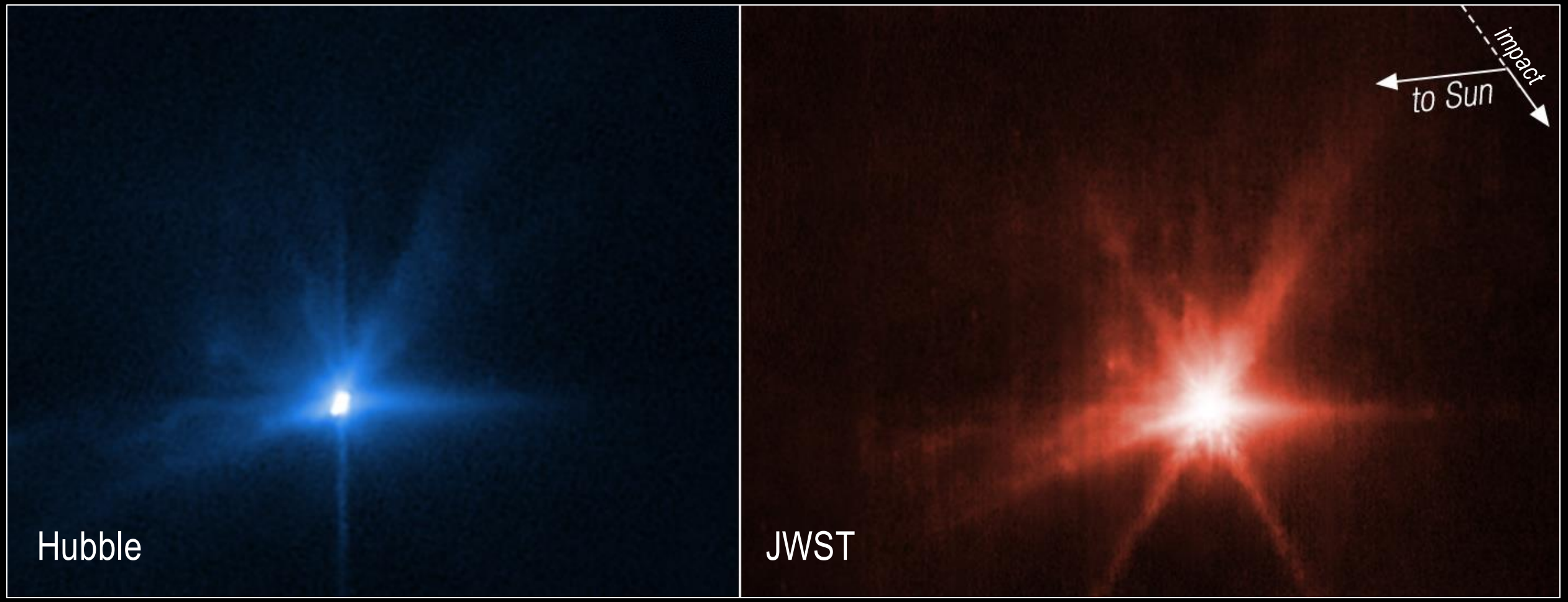
*Credit: Tim Lister, Joseph Chatelain, Rachel Street, Edward Gomez, Joseph Farah/Las Cumbres Observatory.*

LCOGT 1 meter Telescope at SAAO South Africa

UT Date: 09/26/2022 11:10:50 PM (1 of 50)



# September 27, 2022
## ~5 hours post-impact




*Credit: Science: NASA, ESA, CSA, Jian-Yang Li (PSI), Cristina Thomas (Northern Arizona University), Ian Wong (NASA-GSFC); image processing: Joseph DePasquale (STScI), Alyssa Pagan (STScI)*

September 26 – October 15, 2022
Hubble Space Telescope
1.3 hours before impact to 18.5 days post-impact

Sep 26 21:56:25 | T–1.3 hrs

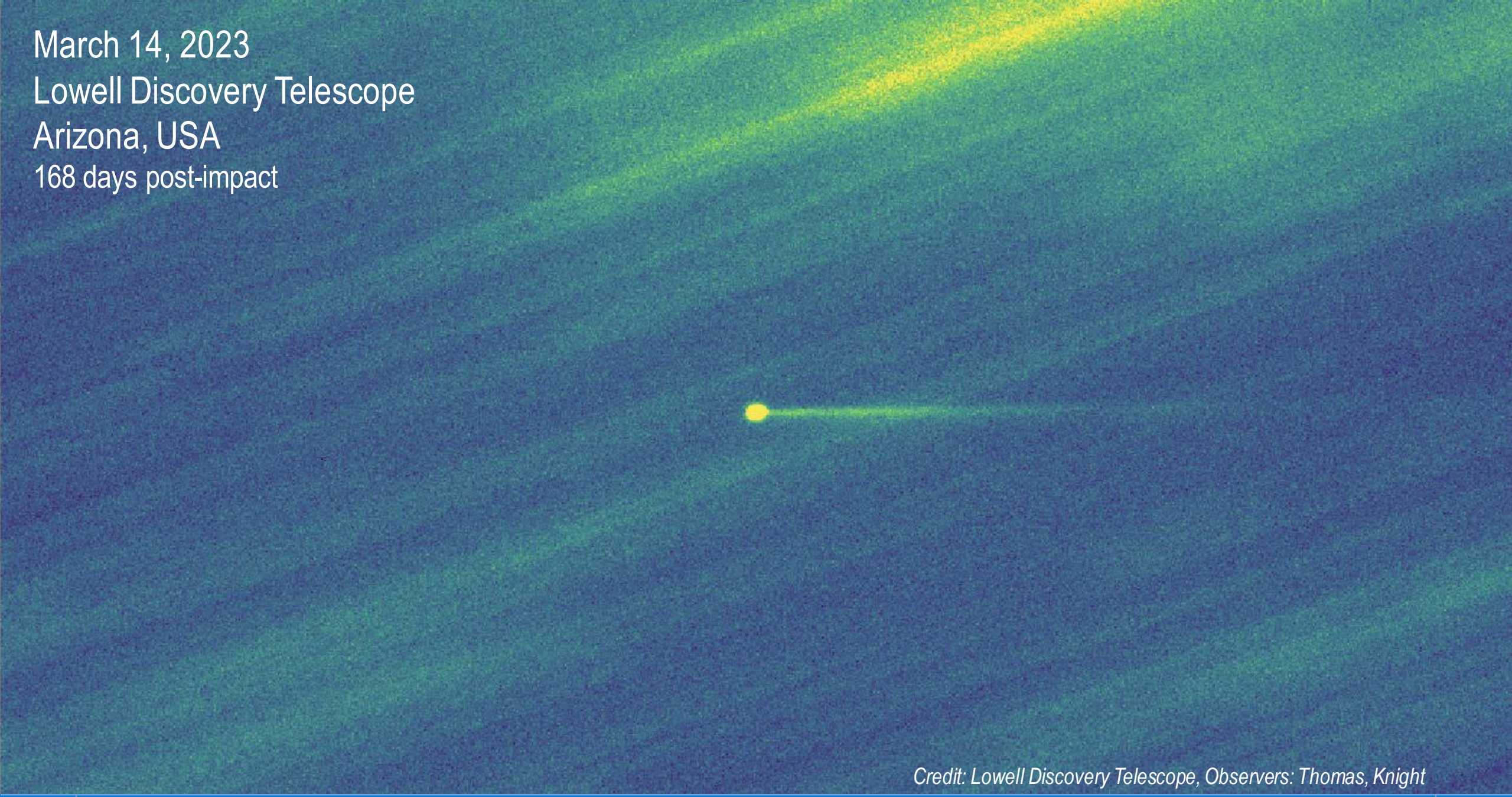
*Credit – Science: NASA/ESA/STScI/Jian-Yang Li (PSI); Video: Joseph DePasquale (STScI)*


September 27 – October 21, 2022
Ōtehīwai Mt. John Observatory in New Zealand
1 – 25 days post-impact

*Credit: University of Canterbury Ōtehīwai Mt. John Observatory / UCNZ*


November 18, 2022
Lowell Discovery Telescope
Arizona, USA
52 days post-impact
Credit: Thomas, Knight, Moskovitz

March 14, 2023
Lowell Discovery Telescope
Arizona, USA
168 days post-impact



*Credit: Lowell Discovery Telescope, Observers: Thomas, Knight*

# Dimorphos By Comparison

**Dimorphos itself is roughly as big as this building**

≃


**The debris tail stretches at least as far as the blue arc**

≃

**And has at least as much material to fill at least 6 rail cars (and perhaps as much as 60!)**

≃

Before DART's impact:
11 hrs 55 min

After DART's impact:
11 hrs 22 min

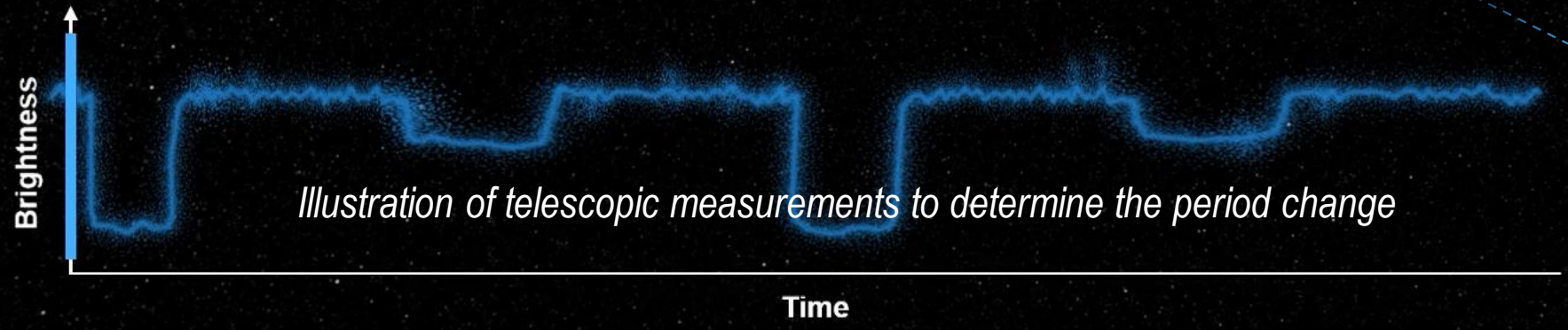
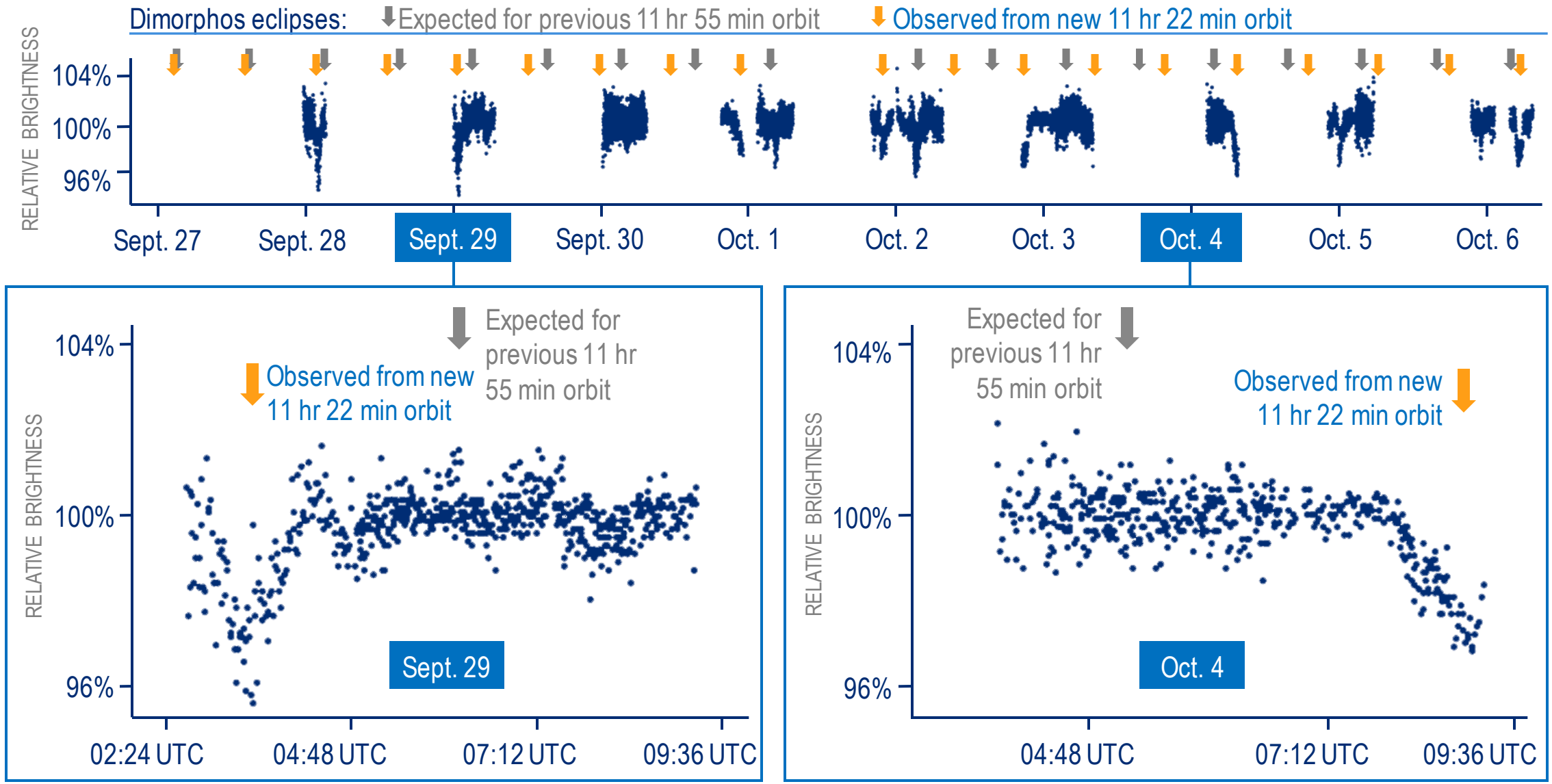


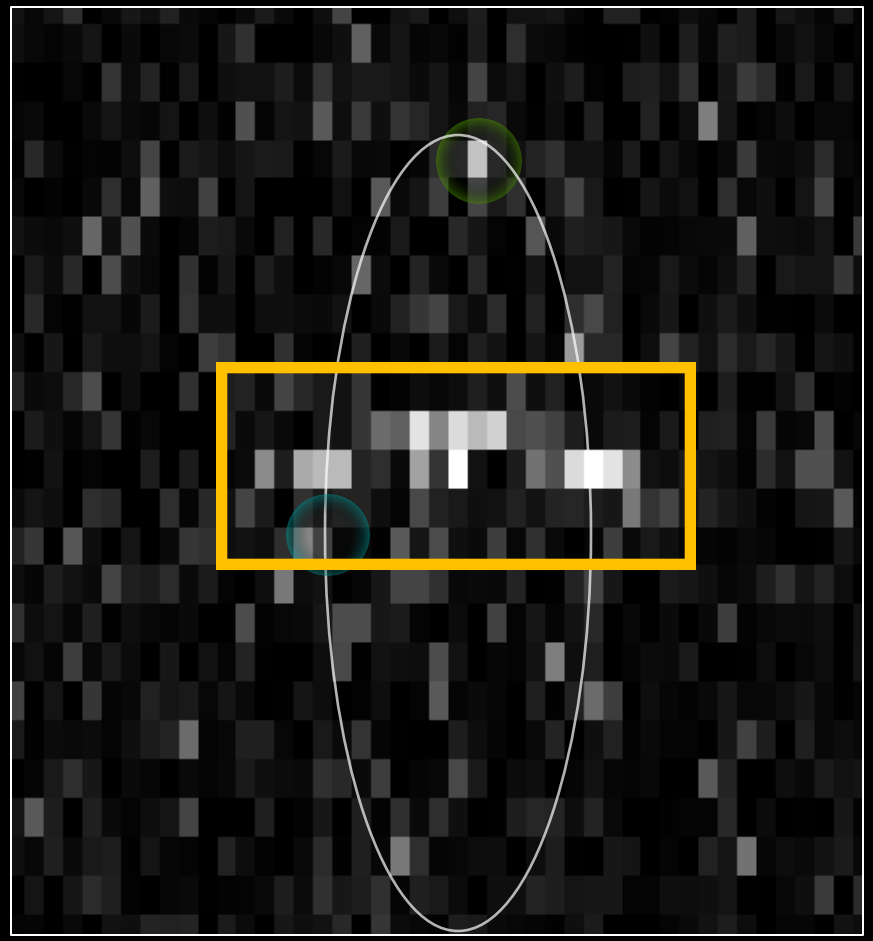

*Illustration of telescopic measurements to determine the period change*

# DART Impact Caused 33-Minute Period Change

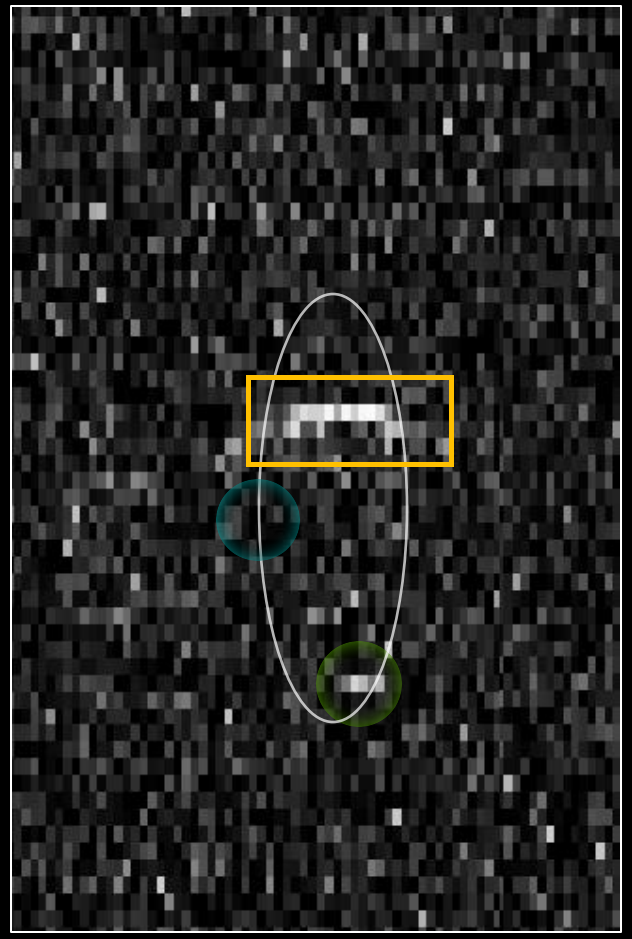



*Credit: NASA/Johns Hopkins APL/Astronomical Institute of the Academy of Sciences of the Czech Republic/Lowell Observatory/JPL/Las Cumbres Observatory/Las Campanas Observatory/European Southern Observatory Danish (1.54-m) telescope/University of Edinburgh/The Open University/ Universidad Católica de la Santísima Concepción/Seoul National Observatory/Universidad de Antofagasta/Universität Hamburg/Northern Arizona University*

# Radar images measure Dimorphos' new orbit



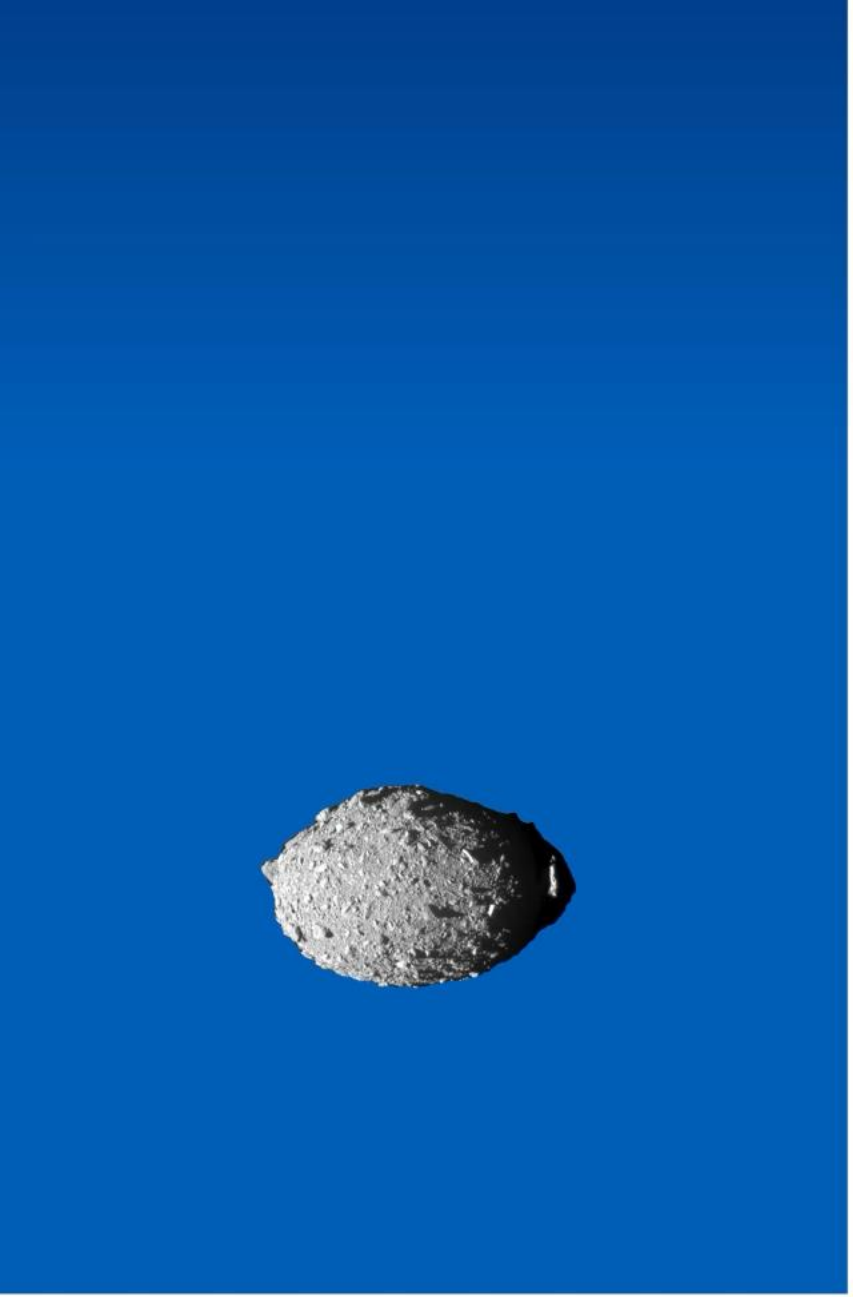
2022 Oct 04 11:55:39 UTC



2022 Oct 09 10:56:47 UTC

- Didymos
- Dimorphos
- Expected Dimorphos From 11 hr. 55 min. orbit
- Dimorphos orbit

*Credit: NASA/Johns Hopkins APL/JPL/NASA JPL Goldstone Planetary Radar/National Science Foundation's Green Bank Observatory*



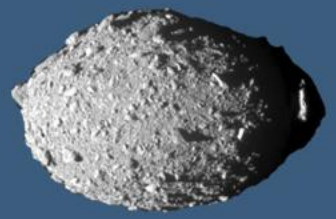
NO EJECTA

SOME EJECTA

LOTS OF EJECTA

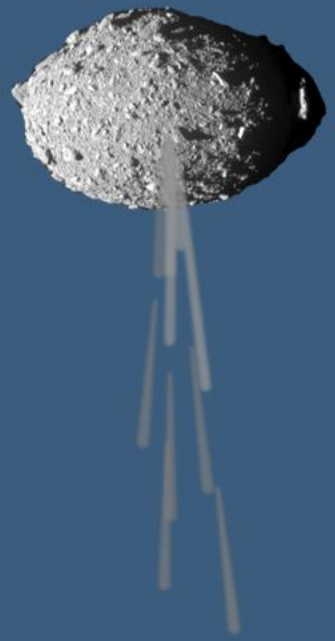
NO EJECTA

Momentum Enhancement Factor = 1



-7 minutes

SOME EJECTA

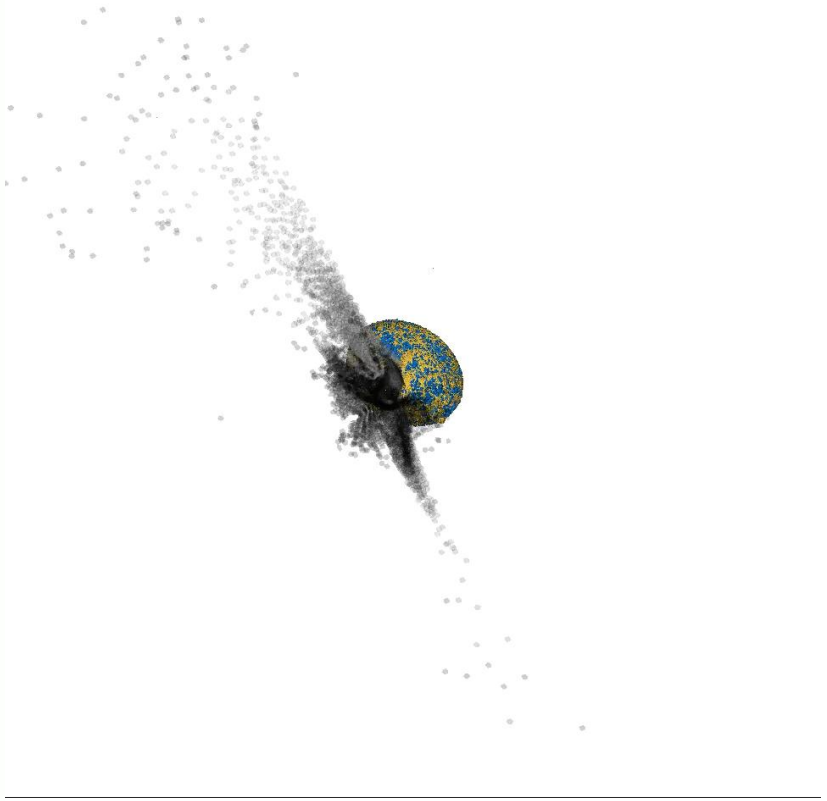


DART EJECTA

Momentum Enhancement Factor ~3.6

-33 minutes

LOTS OF EJECTA

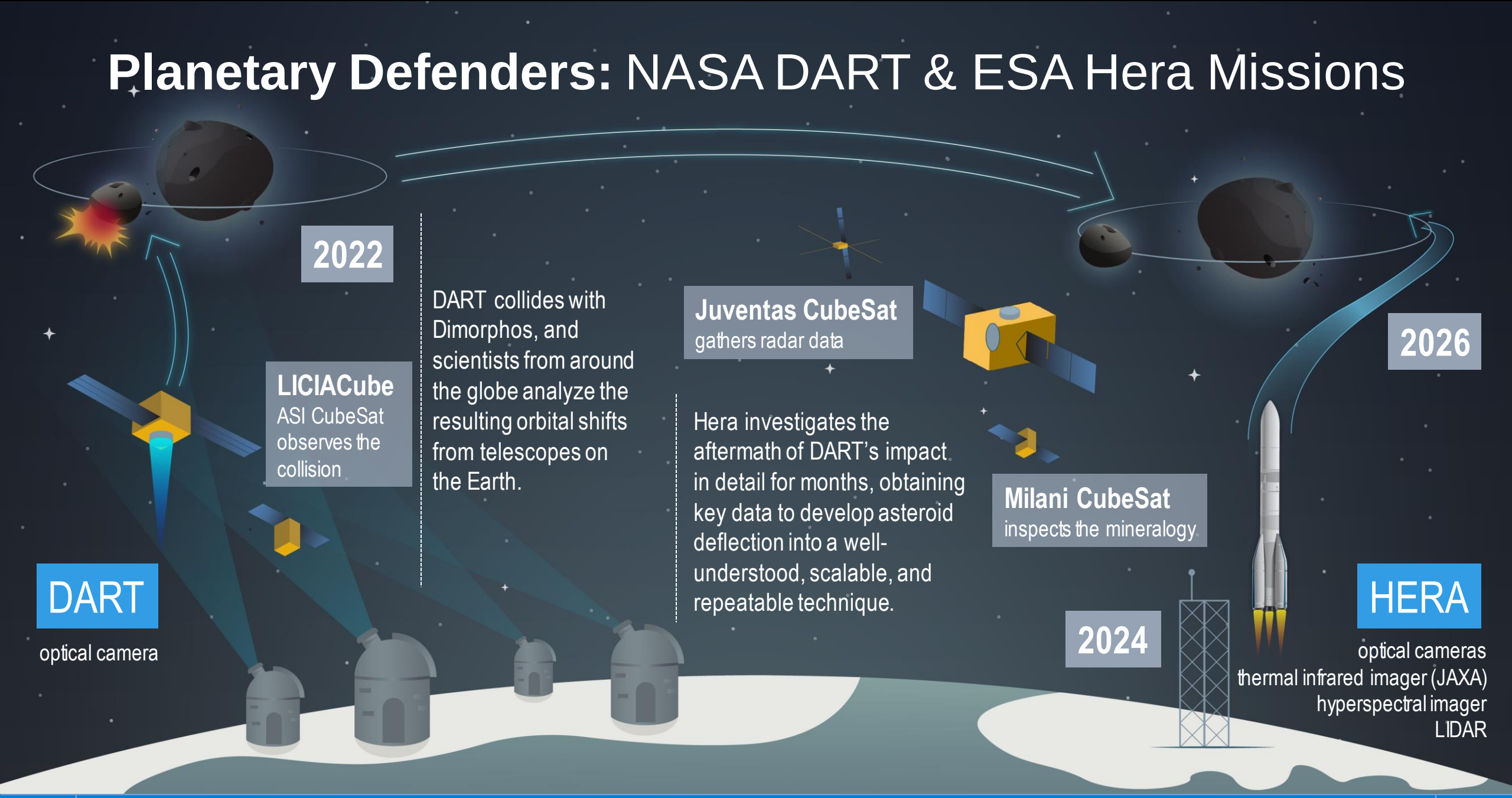



LLNL-VIDEO-845965


Nov. 9, 2022

44 days post-impact

# **Planetary Defenders:** NASA DART & ESA Hera Missions



# A Smashing Success: Humanity moves a celestial object for the first time

- DART demonstrated that kinetic impactor technology is a viable technique to potentially defend Earth, if necessary.
- The large orbit period change shows that ejecta contributed a significant amount of momentum to the asteroid beyond what the DART spacecraft carried.
- This means that a given kinetic impactor could be used on a larger object, or at a later time, than previously thought.

# DART

Double Asteroid Redirection Test