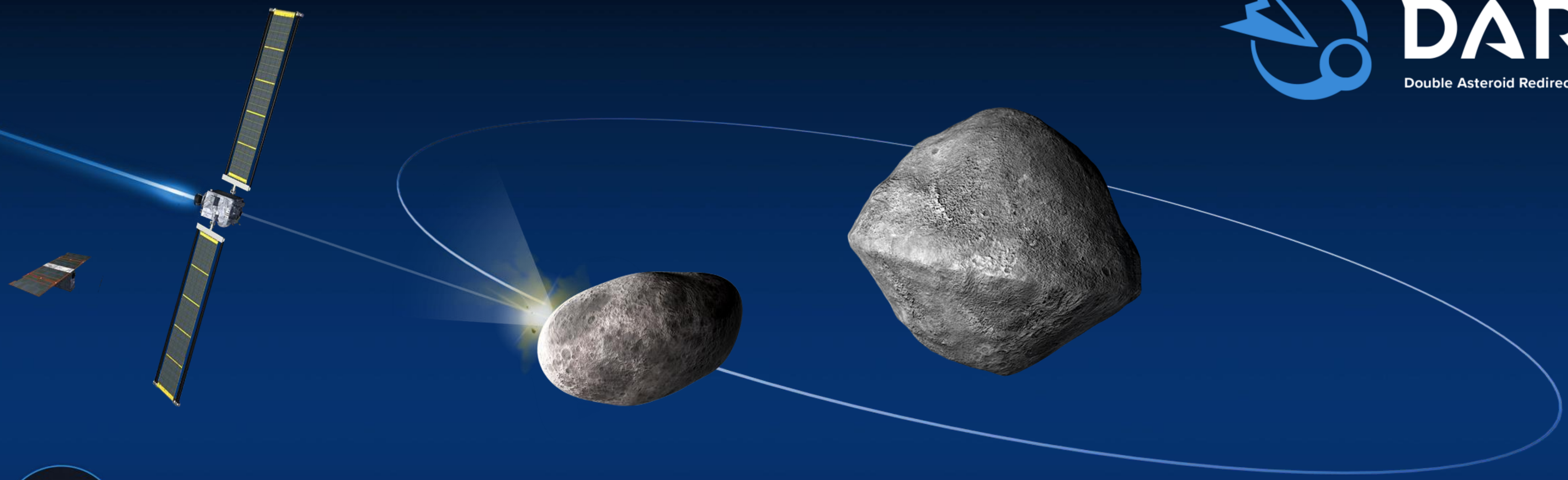
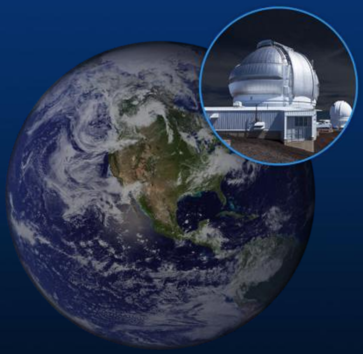




DART
Double Asteroid Redirection Test

Double Asteroid Redirection Test (DART) - NASA's First Planetary Defense Mission

Deane Sibol, Ground Data System Lead
Johns Hopkins Applied Physics Laboratory

NASA
Goddard Space Flight Center
Johnson Space Center
Langley Research Center
Glenn Research Center
Marshall Space Flight Center
Planetary Defense Coordination Office

APL Johns Hopkins Applied Physics Laboratory

Jet Propulsion Laboratory
California Institute of Technology

Aerojet Rocketdyne

Lawrence Livermore National Laboratory

Auburn University

University of Colorado Boulder

University of Maryland

NAU Northern Arizona University

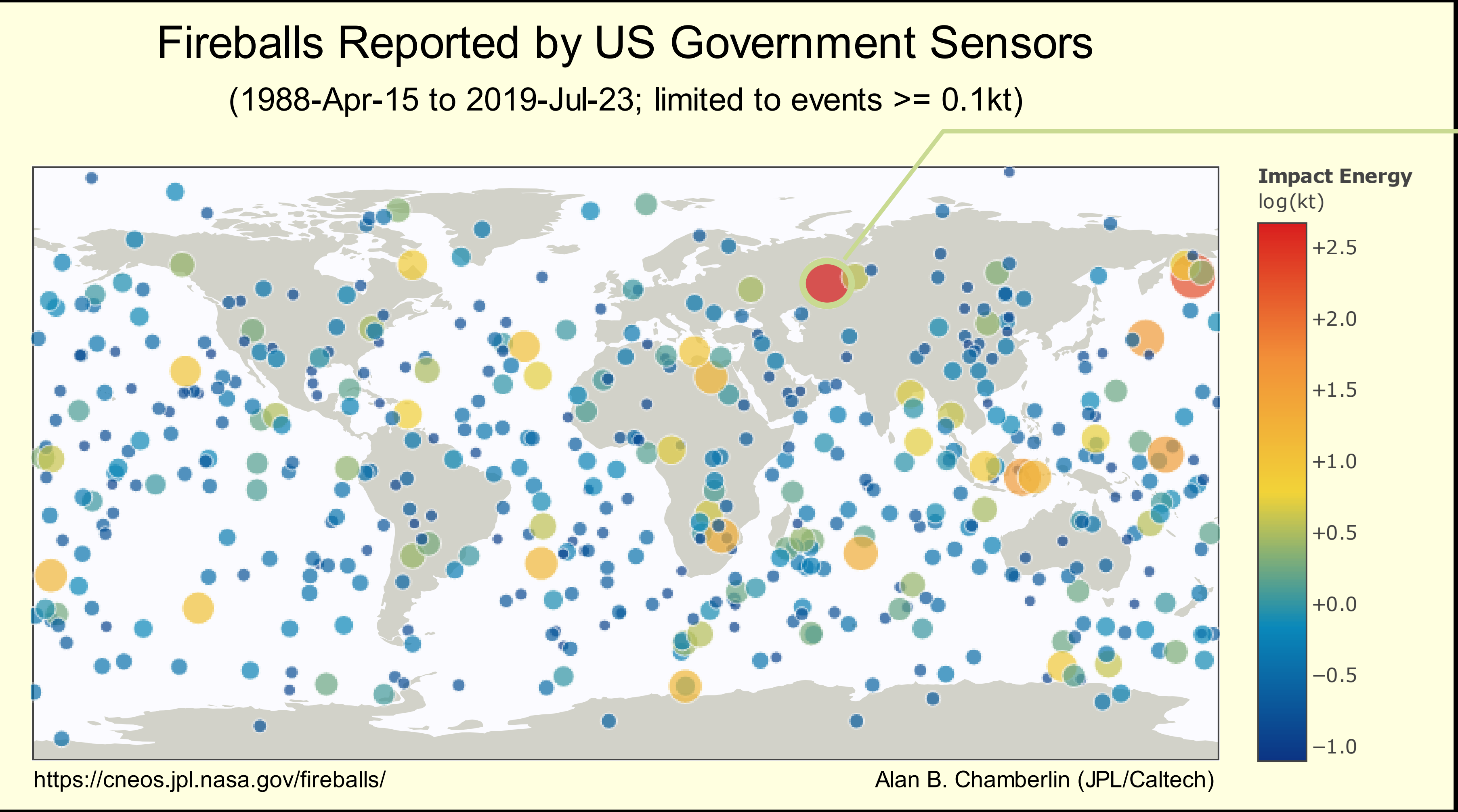
Planetary Science Institute

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

DART

Planetary Defense: Mitigation of Asteroid Hazards, a Global Concern

Small asteroids hitting Earth, 1988–2019



Chelyabinsk-sized

Diameter: ~20 m

~500 kilotons TNT

2013, every few decades

Tunguska-sized

Diameter: 60–190 m

~5 megatons TNT

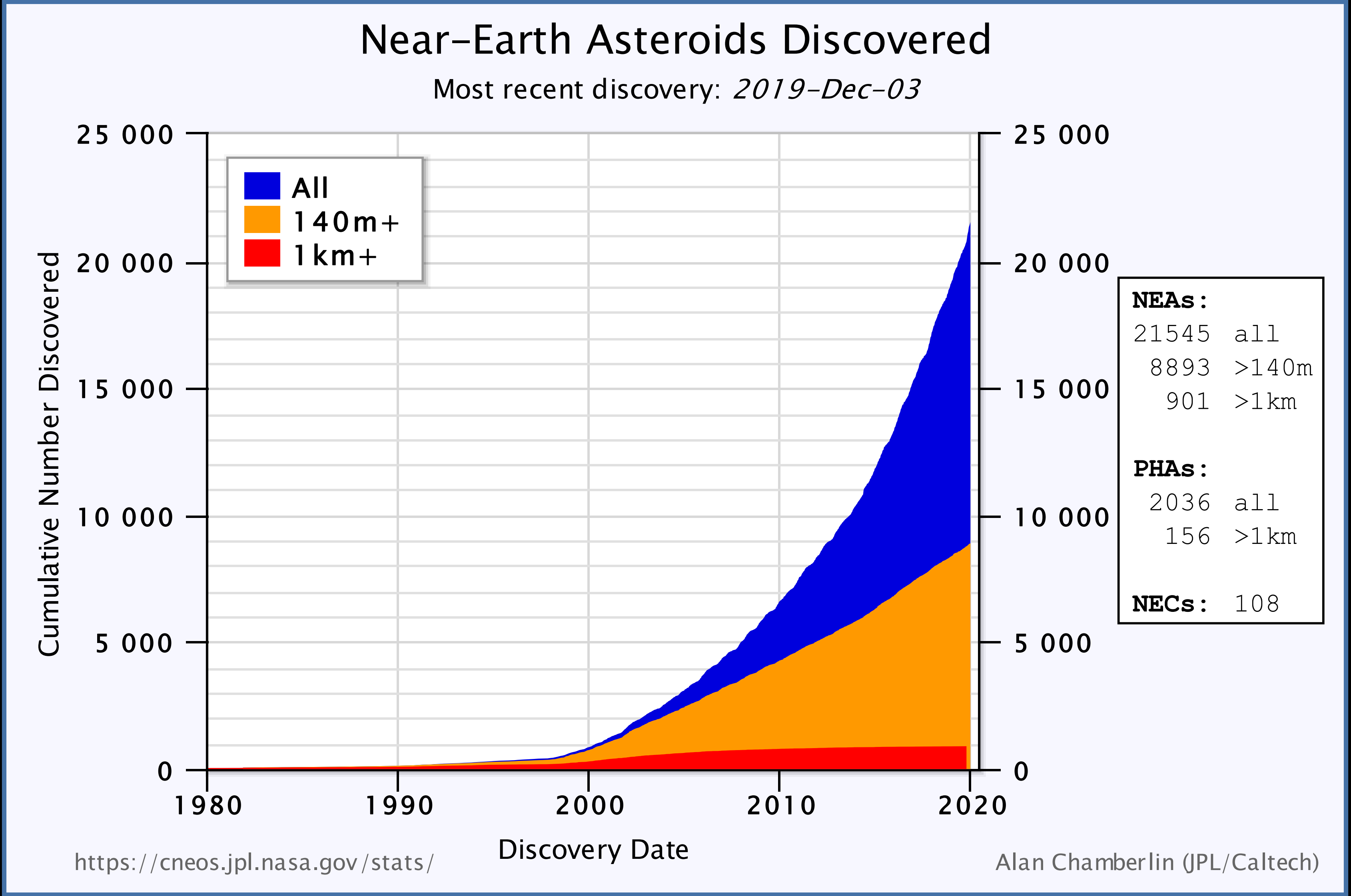
1908, every few centuries

Chicxulub-sized “dinosaur killer”

Diameter: 10–15 km

65 million years ago

DART


Near-Earth Asteroids Discovered
Most recent discovery: 2019-Dec-03
All
140m+
1km+
Cumulative Number Discovered
25 000
20 000
15 000
10 000
5 000
0
1980
1990
2000
2010
2020
Discovery Date
NEAs:
21545 all
8893 >140m
901 >1km
PHAs:
2036 all
156 >1km
NECs: 108
https://cneos.jpl.nasa.gov/stats/
Alan Chamberlin (JPL/Caltech)


ASSESS
[CENTER FOR NEAR EARTH OBJECT STUDIES]
IAU
Minor Planet Center
SEARCH, DETECT & TRACK
[GROUND-BASED & SPACE-BASED OBSERVATIONS, IAWN]
PLANETARY DEFENSE
MITIGATE
[DART, FEMA EXERCISES]
CHARACTERIZE
[NEOWISE, GOLDSTONE, ARECIBO, IRTF]
PLAN & COORDINATE
[SMPAG, PIERWG, DAMIEN IWG]
NASA
NASA Planetary Defense Coordination Office (PDCO): established 2016

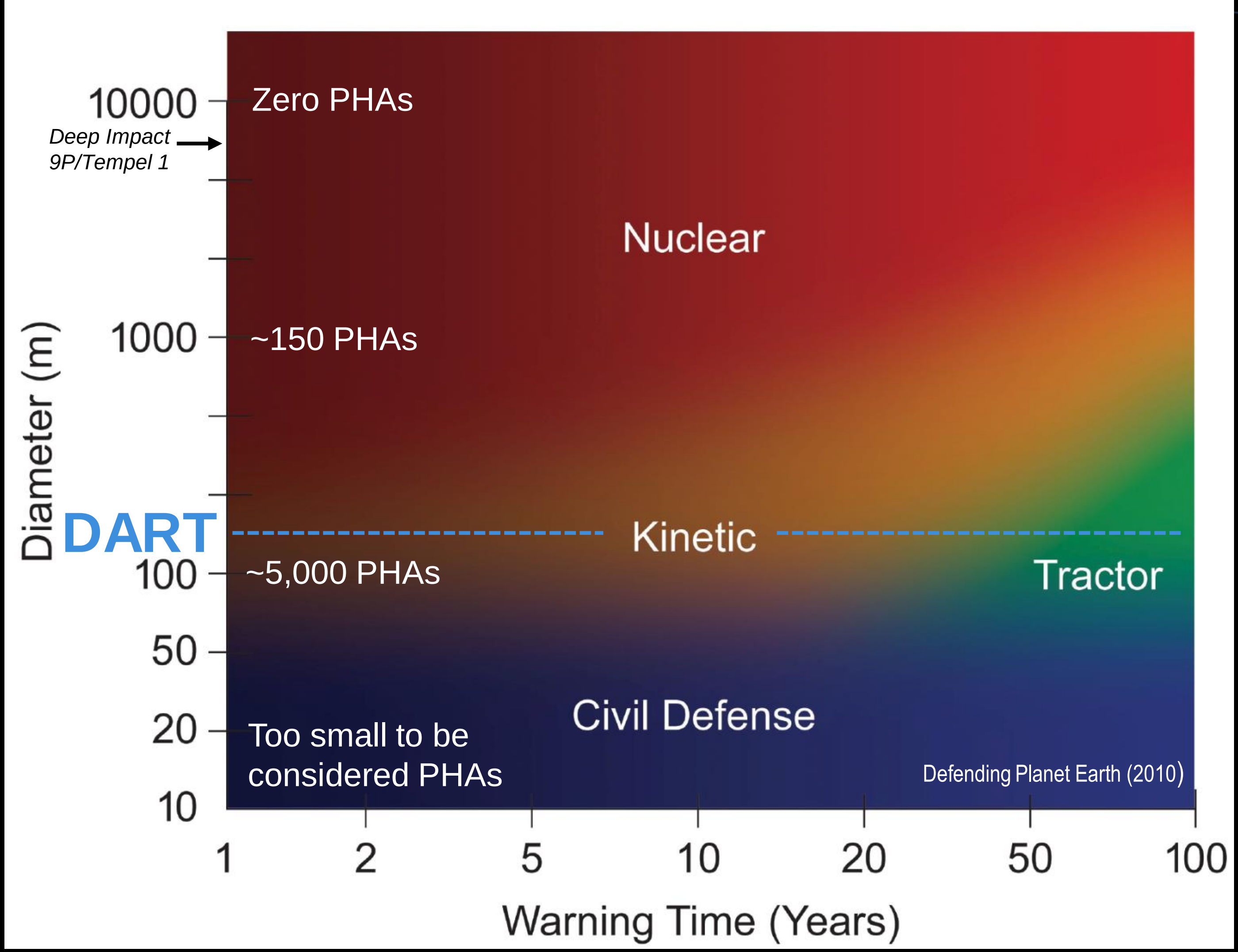
Top Priority for a Mitigation Mission

Defending Planet Earth (2010) National Academy of Sciences

Recommendation:
"the first priority for a space mission in the mitigation area is an experimental test of a kinetic impactor"

DART is the first kinetic impact test at a realistic scale for planetary defense

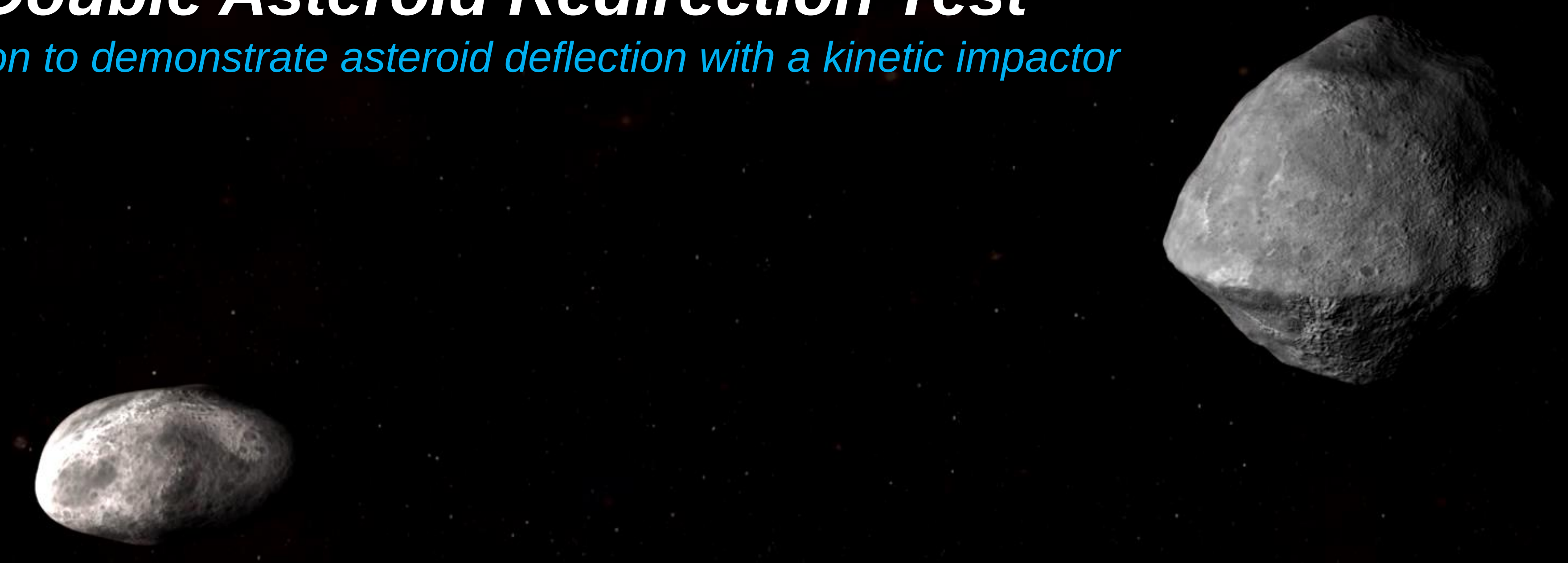
Mitigation Techniques for Potentially Hazardous Asteroids (PHA)



DART

DART – Double Asteroid Redirection Test

The first mission to demonstrate asteroid deflection with a kinetic impactor



NASA
Goddard Space Flight Center
Johnson Space Center
Langley Research Center
Glenn Research Center
Marshall Space Flight Center
Planetary Defense Coordination Office

Johns Hopkins Applied Physics Laboratory

Jet Propulsion Laboratory
California Institute of Technology

Aerojet Rocketdyne

Lawrence Livermore National Laboratory

Auburn University

University of Colorado Boulder

University of Maryland

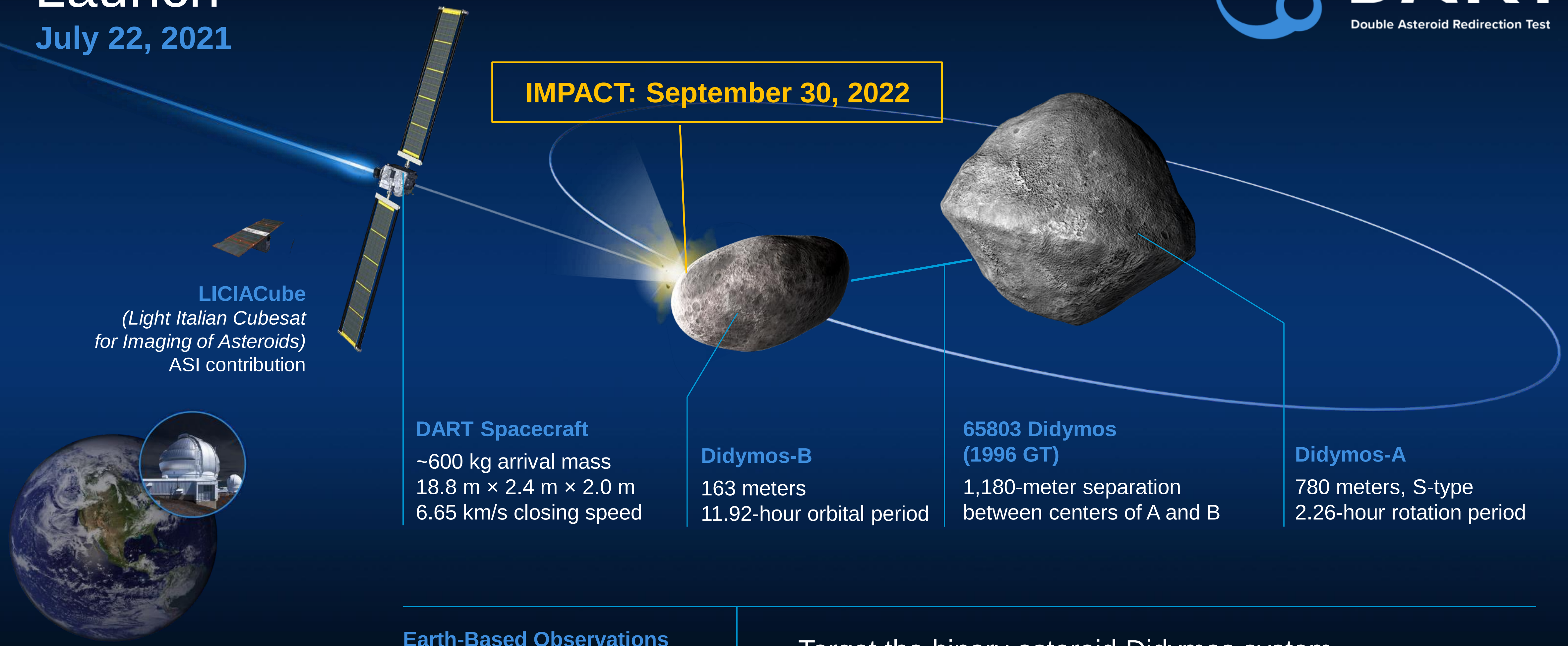
NAU Northern Arizona University

Planetary Science Institute

DART

Launch

July 22, 2021



Earth-Based Observations

0.07 AU range at impact
Predicted ~10-minute change
in binary orbit period

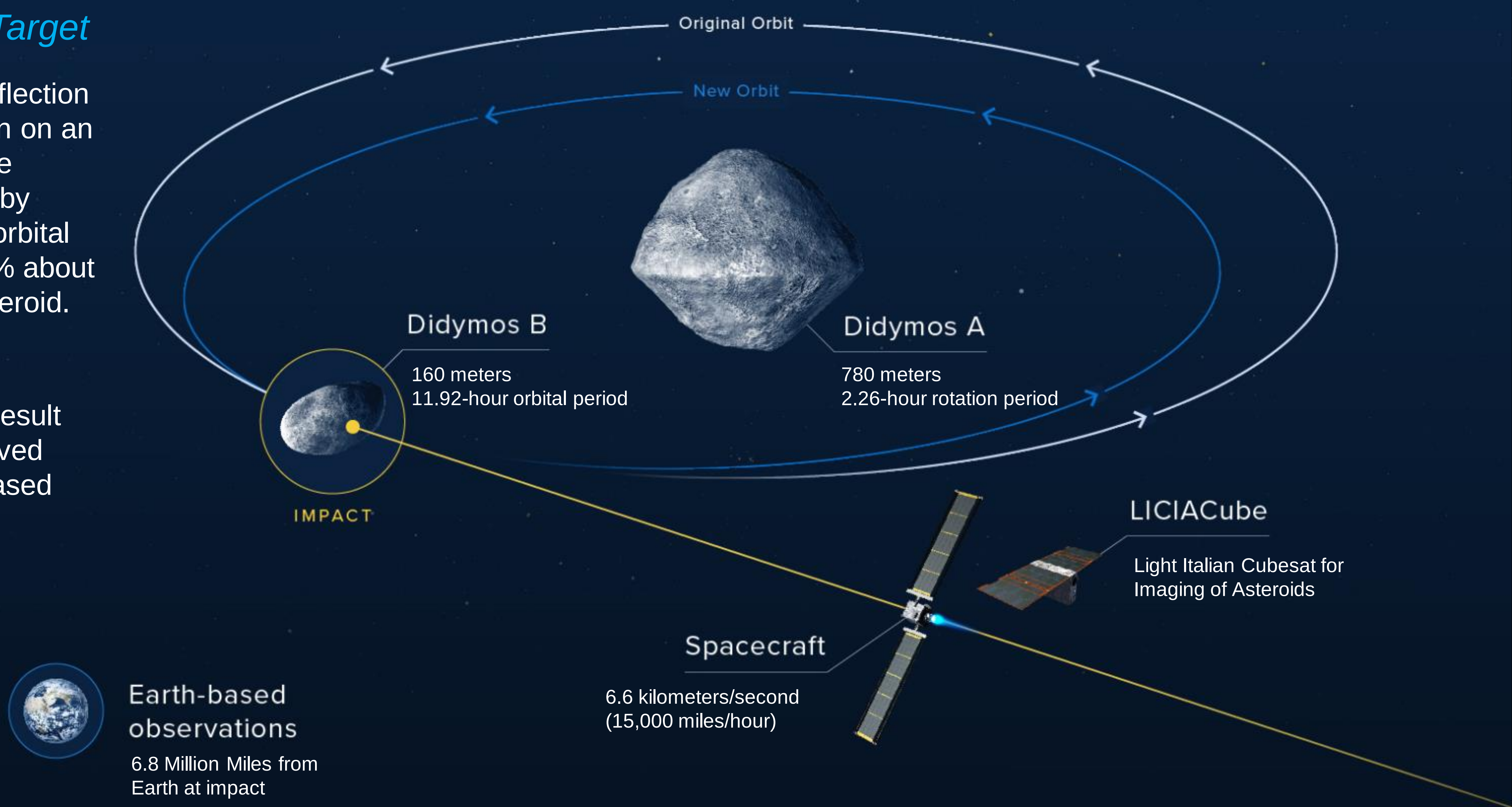
- Target the binary asteroid Didymos system
- Impact Didymos-B and change its orbital period
- Measure the period change from Earth

Didymos:

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.

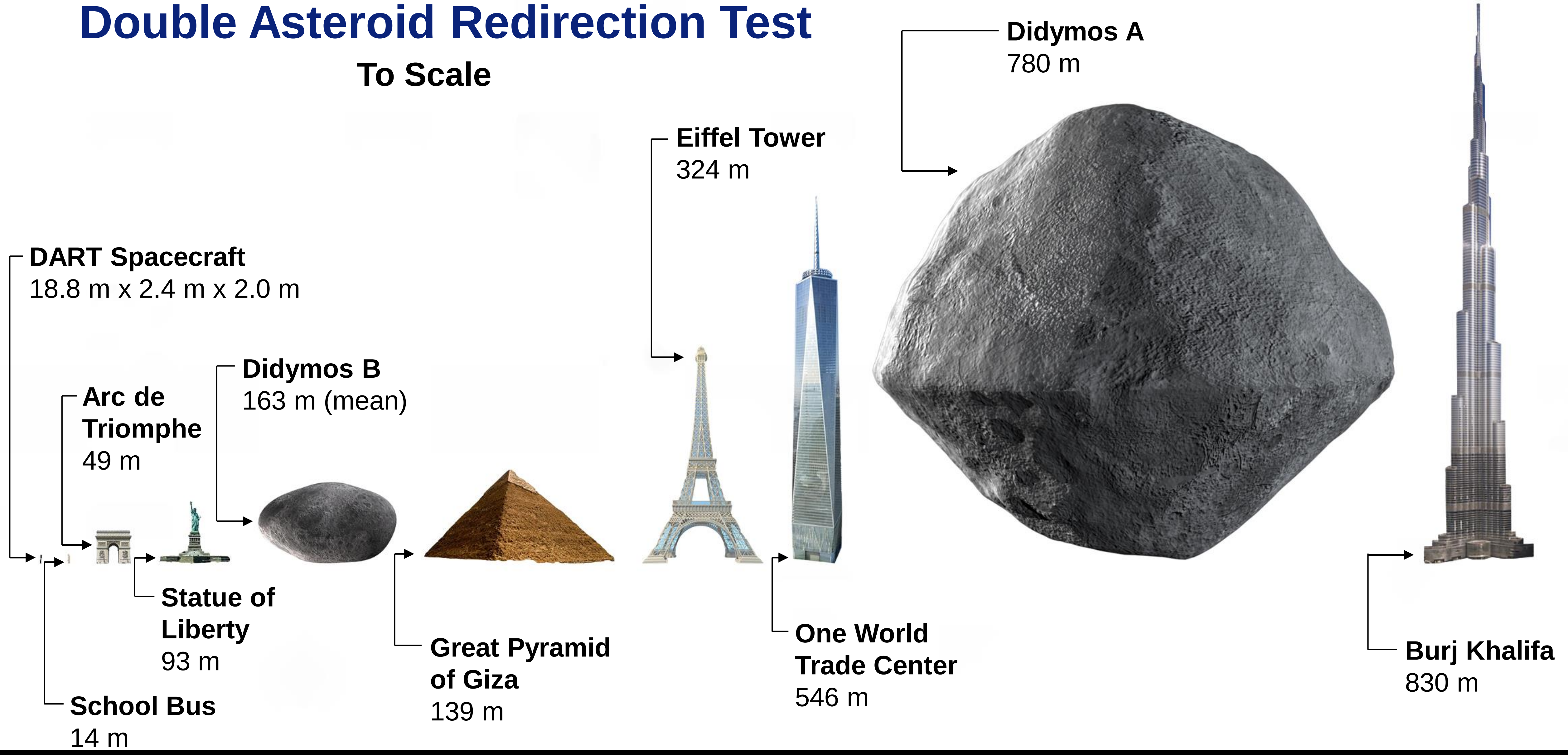
In 2022, the result can be observed from Earth-based telescopes.



DART

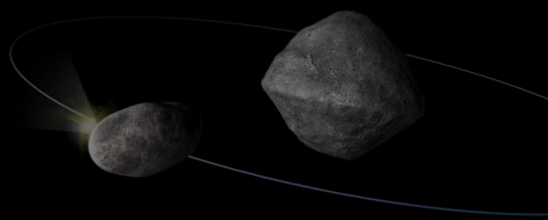
Double Asteroid Redirection Test

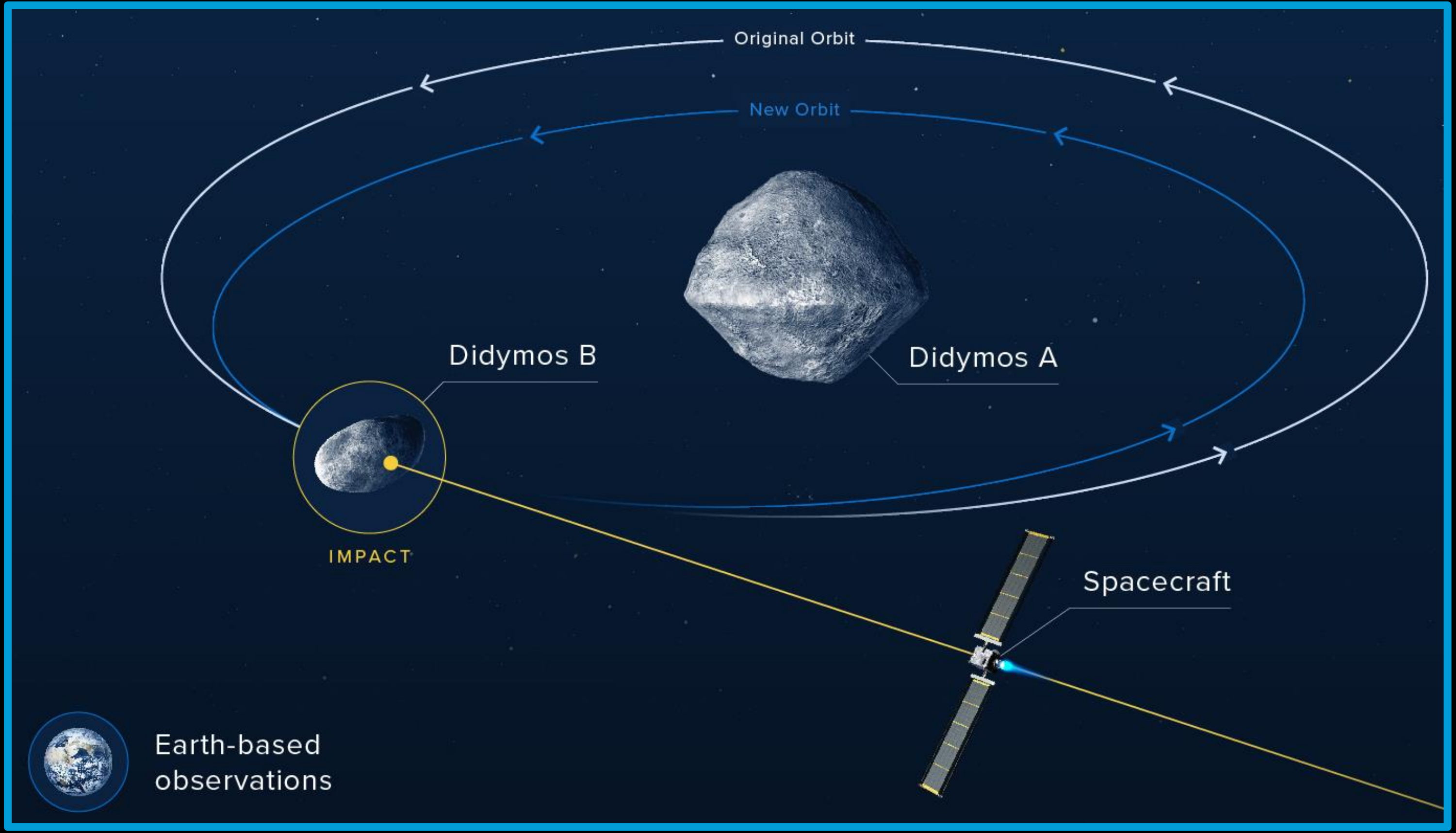
To Scale



DART-1: DART shall intercept the secondary member of the binary asteroid (65803) Didymos as a kinetic impactor spacecraft during its September to October, 2022 close approach to Earth.

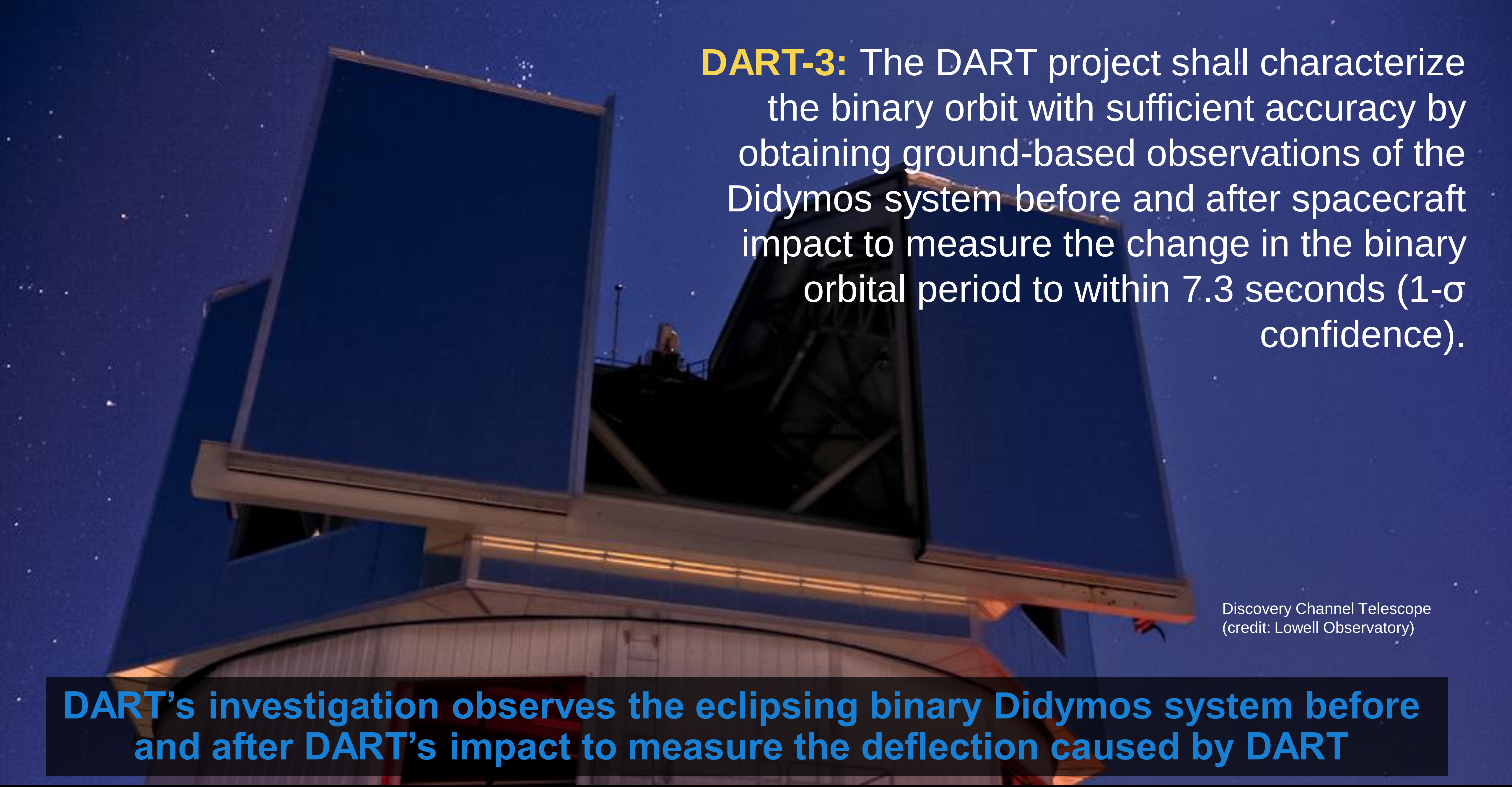
DART-2: The DART impact on the secondary member of the Didymos system shall cause at least a 73-second change in the binary orbital period.





DART intercepts Didymos B, designing the impact to maximize the deflection to the orbit of Didymos B about Didymos A

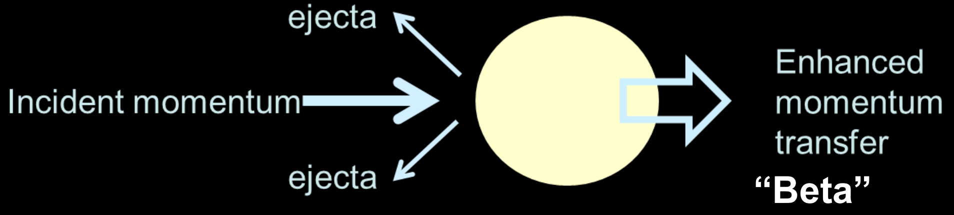
DART-3: The DART project shall characterize the binary orbit with sufficient accuracy by obtaining ground-based observations of the Didymos system before and after spacecraft impact to measure the change in the binary orbital period to within 7.3 seconds (1-σ confidence).

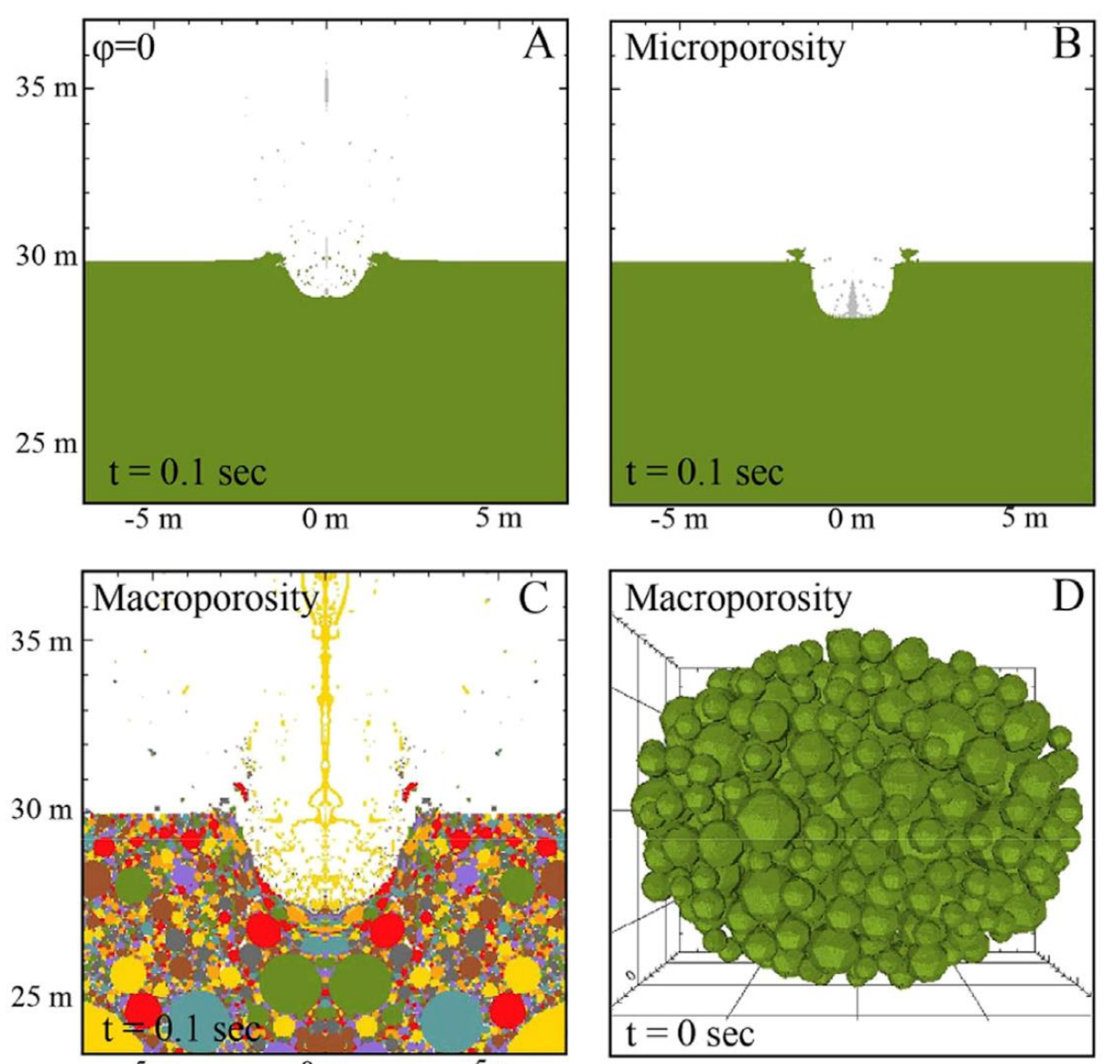


Discovery Channel Telescope
(credit: Lowell Observatory)

DART's investigation observes the eclipsing binary Didymos system before and after DART's impact to measure the deflection caused by DART

DART-4A: The DART project shall use the velocity change imparted to the target to obtain a measure of the momentum transfer enhancement parameter referred to as “Beta” (β) using the best available estimate of the mass of Didymos B.

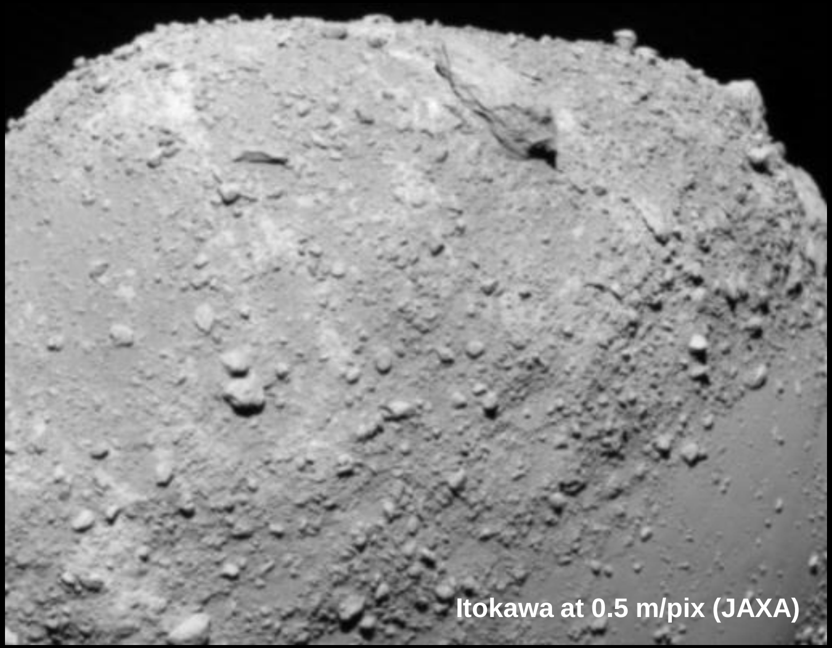


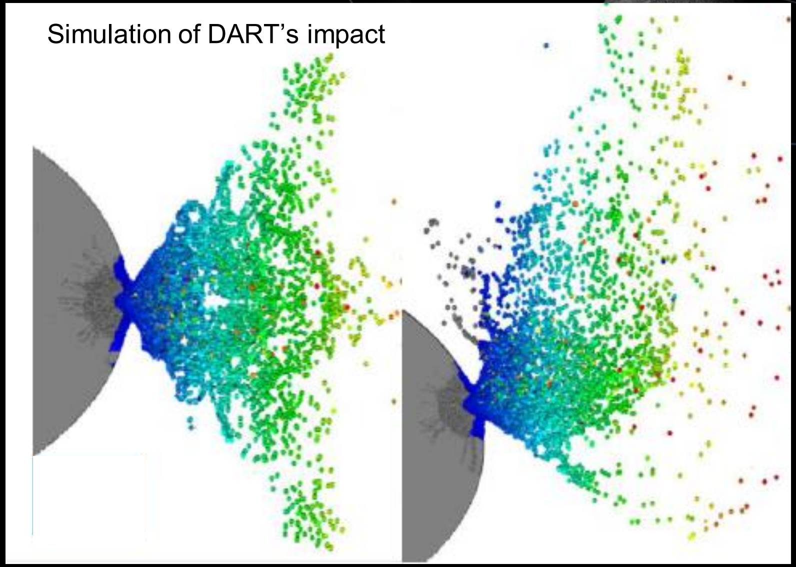


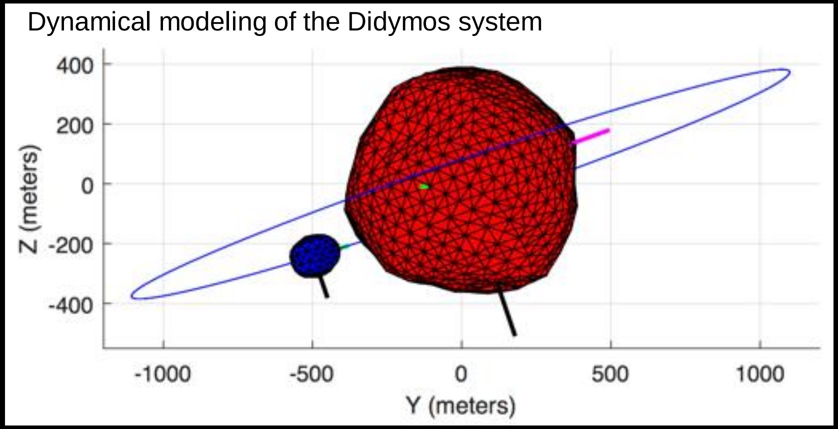
(Stickle et al., 2017)

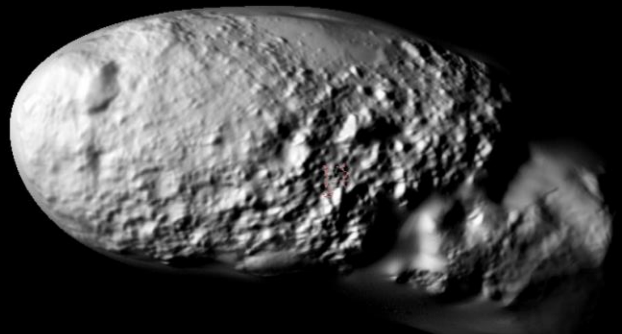
DART’s investigation determines and interprets the momentum transfer resulting from the DART impact

DART-4B: The DART project shall obtain data, in collaboration with ground-based observations and data from another spacecraft (if available), to constrain the **location and surface characteristics of the spacecraft impact site** and to allow the estimation of the **dynamical changes in the Didymos system** resulting from the DART impact and the coupling between the body rotation and the orbit.









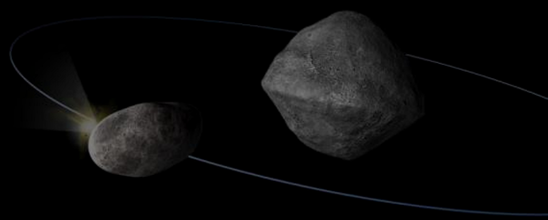
Reconstructed shape model

DART's investigation characterizes the impact site, dynamical effects, and ejecta to fully evaluate the results of DART's kinetic impactor mission

DART

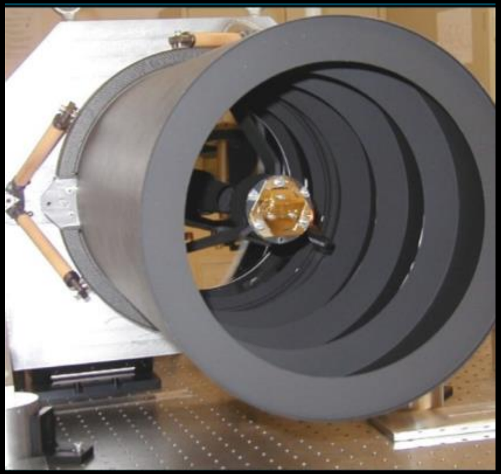
DART: Key Technologies

DART will demonstrate key technologies for future planetary defense missions.



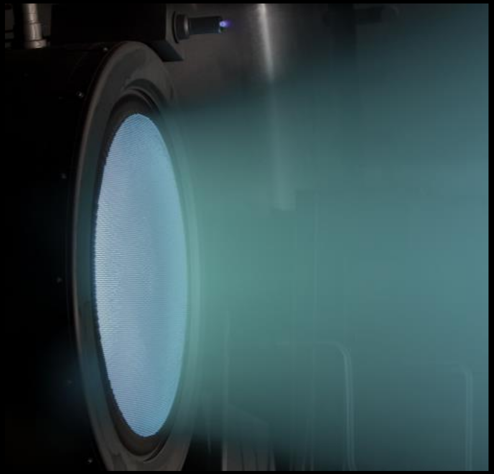
Autonomous SMART Nav System

SMART Nav autonomously directs DART to impact Didymos-B, leveraging decades of missile guidance algorithm development and experience at APL.



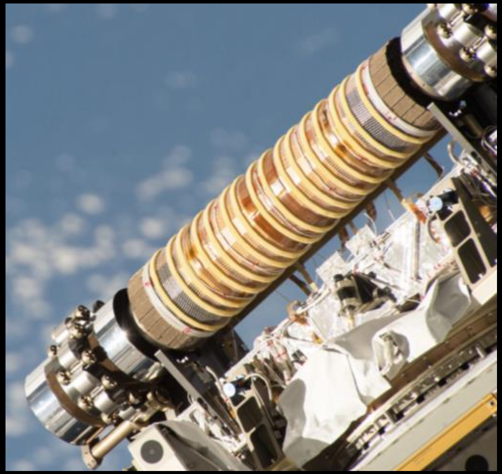
DRACO Imager, modified from LORRI

DRACO (Didymos Reconnaissance and Asteroid Camera for Opnav) is a modification of the LORRI instrument used on the New Horizons mission to Pluto and the Kuiper Belt.



NEXT-C Ion Propulsion Engine

DART will be the first flight of NASA's Evolutionary Xenon Thruster-Commercial (NEXT-C) ion propulsion engine and be about 3x as powerful as the ion engine on the Dawn mission.

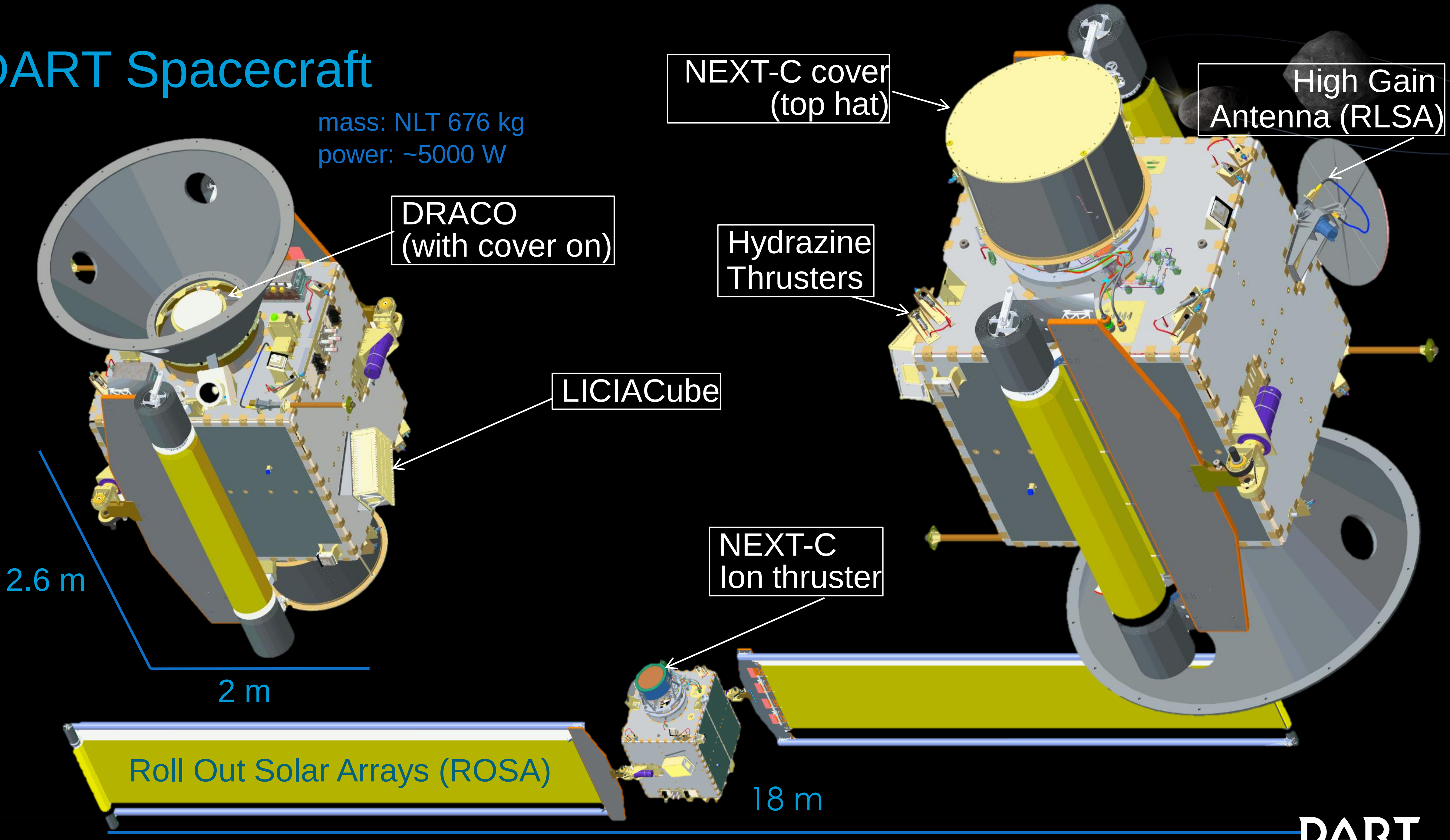


ROSA – Roll Out Solar Arrays

NASA's newly developed ROSA arrays will provide a compact form and light mass for launch and be deployed in space to reach 19 meters from tip to tip.

DART Spacecraft

mass: NLT 676 kg
power: ~5000 W

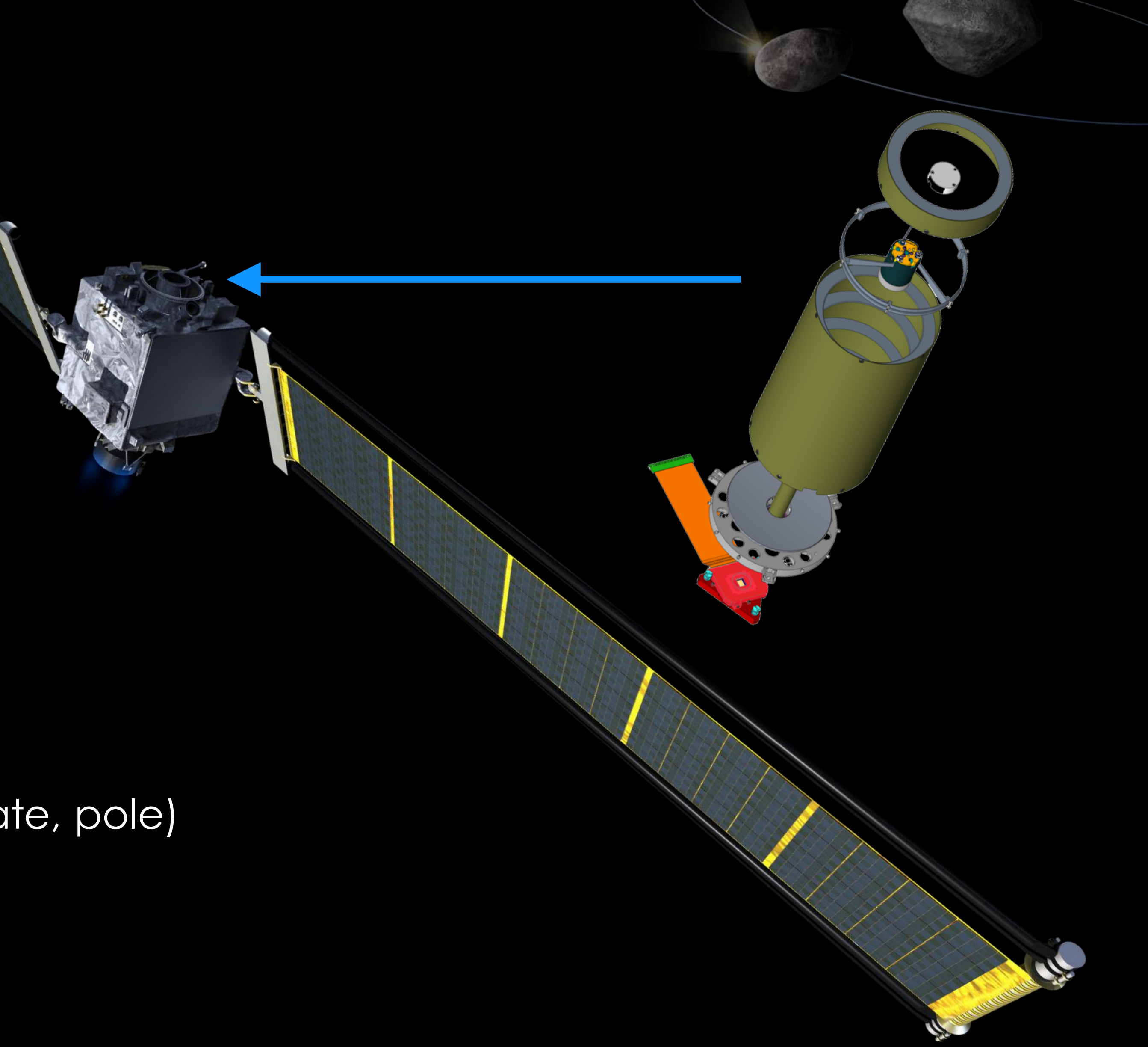


DART

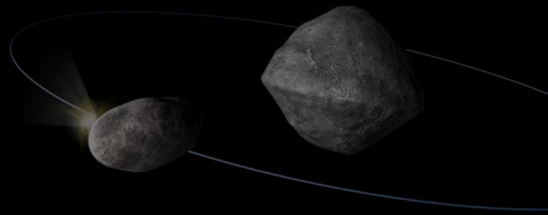
Didymos Reconnaissance and Asteroid Camera for OpNav (DRACO)

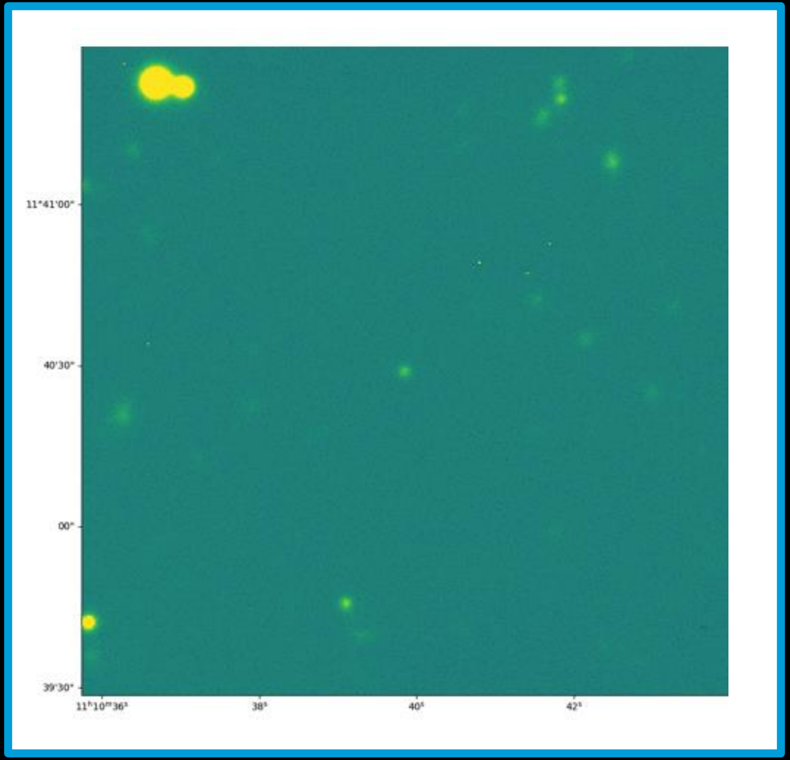
- DRACO *is* the DART payload
  - Derived from LORRI on New Horizons
  - IFOV is 4.96 µrad binned (2.48 µrad unbinned)
  - Full FOV is 0.29 degree
  - CMOS detector
  - Panchromatic

- DRACO is designed to support several tasks
  - Optical navigation of the spacecraft (OpNav)
  - Ensure impact with Didymos B (SmartNav)
  - Refine system properties (e.g., orbit, rotation rate, pole)
  - Constrain the location of the impact site
  - Characterize the surface of Didymos B
  - Determine the shape of Didymos B

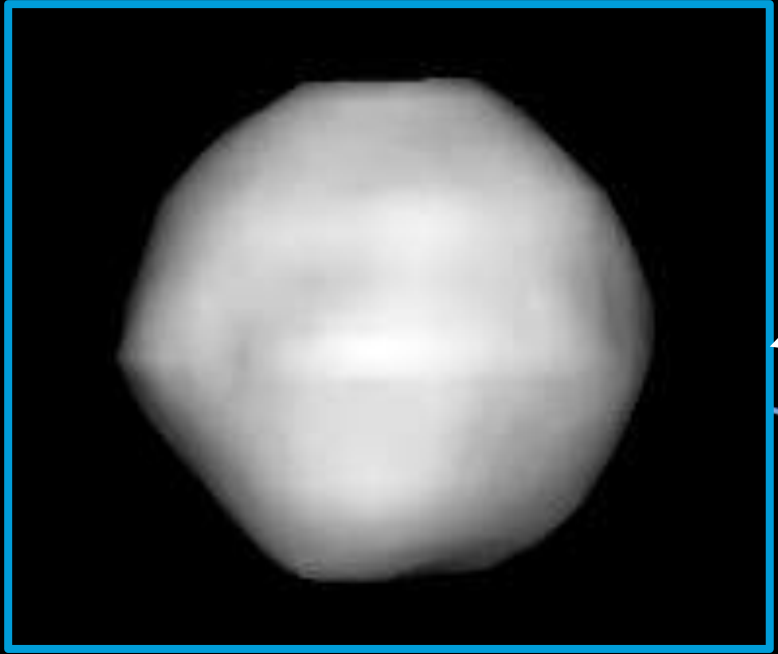


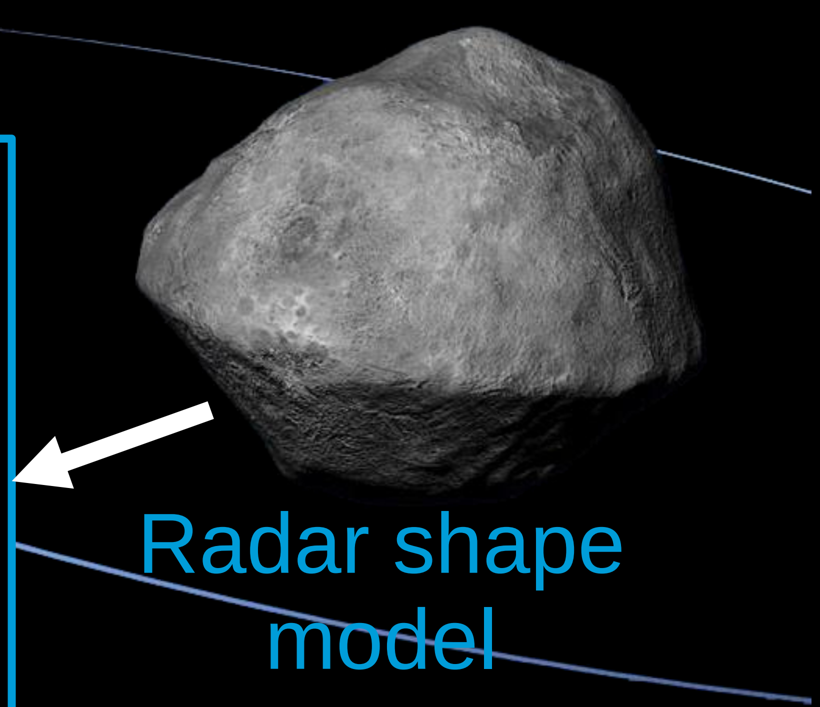
Know little about the object we are trying to hit





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



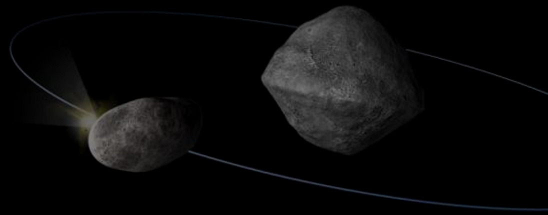


Radar shape model

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

DART

… and won't know in time to hit it



timeline not to scale

30 days

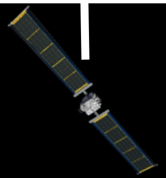
Camera detects Didymos system

10 days

Continuous ground antenna coverage

8 hours

Begin pre-terminal phase

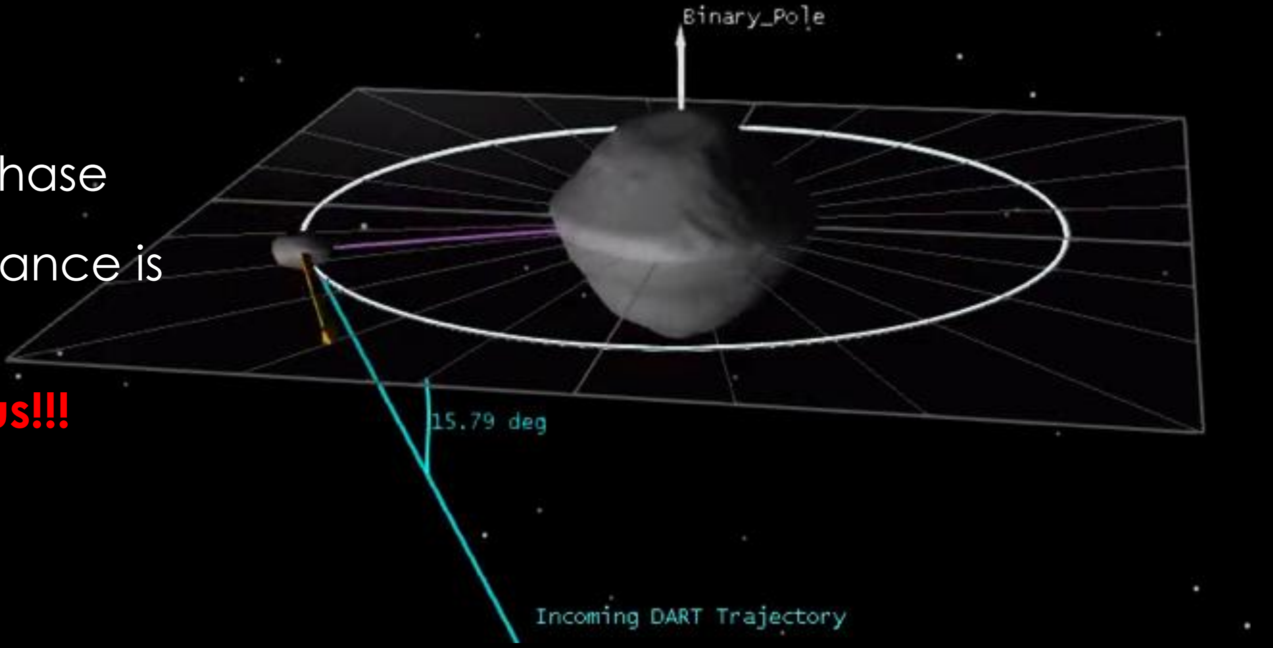


4 hours out

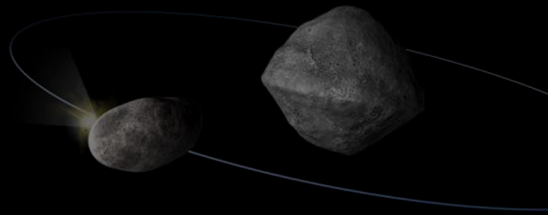
Begin terminal phase

SMART Nav guidance is enabled.

Fully Autonomous!!!



Terminal Phase Timeline



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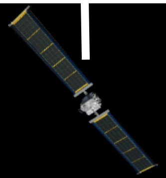
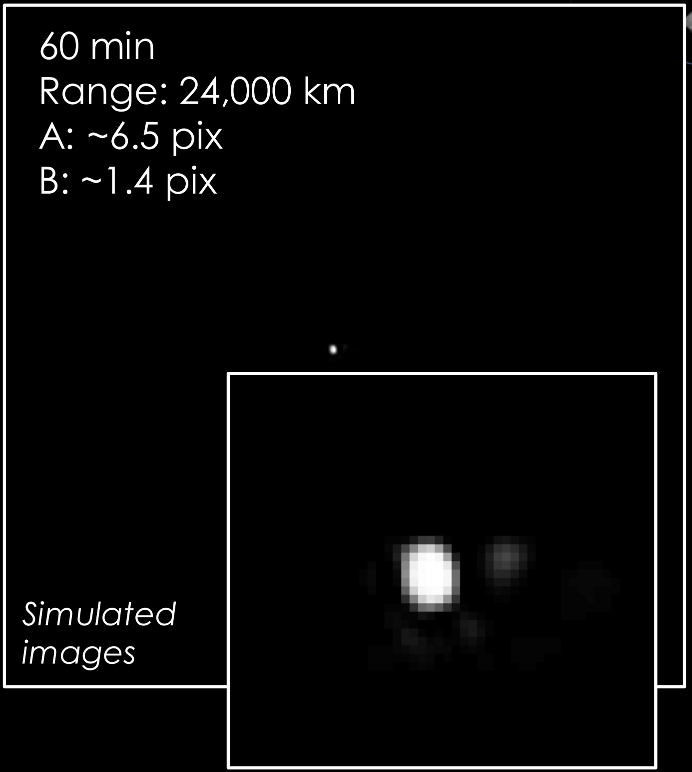


60 minutes out

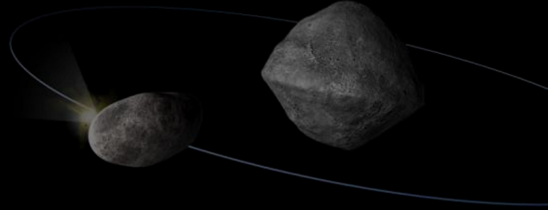
SMART Nav begins to target Didymos B instead of primary



Simulated images

DART

Terminal Phase Timeline



timeline not to scale

30 days

Camera detects Didymos system

10 days

Continuous ground antenna coverage

8 hours

Begin pre-terminal phase

4 hours

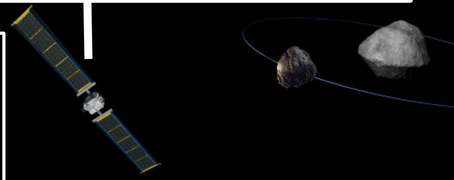
Begin terminal phase

60 minutes

Locked on target

4 min
Range: ~1,600 km
A: 99 pix
B: 21 pix

Simulated images

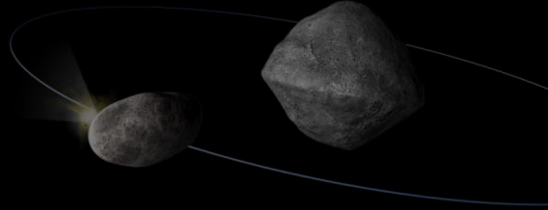


4 min out

Last image to contain all of Didymos A

DART

Terminal Phase Timeline



timeline not to scale

30 days

Camera detects Didymos system

10 days

Continuous ground antenna coverage

8 hours

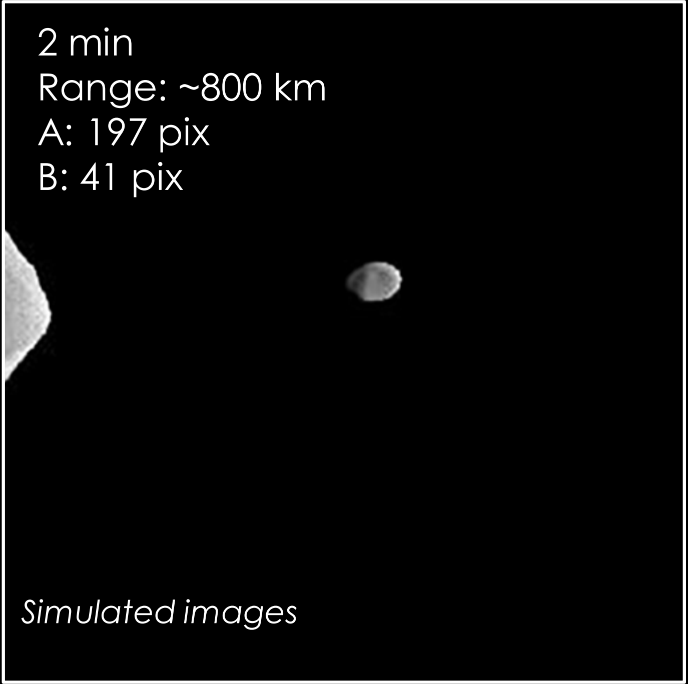
Begin pre-terminal phase

4 hours

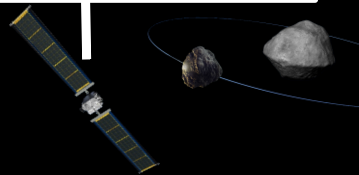
Begin terminal phase

60 minutes

Locked on target



Simulated images

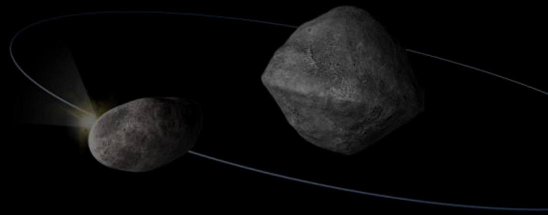


2 min out

SMART Nav maneuvers completed, intercept course achieved

DART

Terminal Phase Timeline



timeline not to scale

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Camera detects Didymos system

10 days

Continuous ground antenna coverage

8 hours

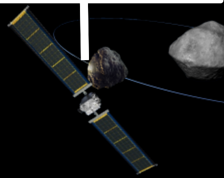
Begin pre-terminal phase

4 hours

Begin terminal phase

60 minutes

Locked on target



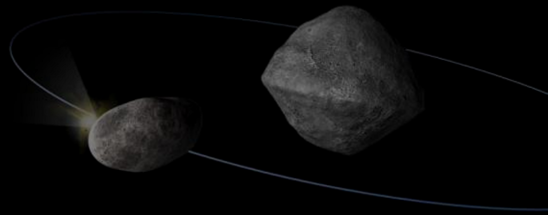
20 s out

Range: ~120 km
Required image resolution satisfied

Didymos B will fill ~60% of the camera frame

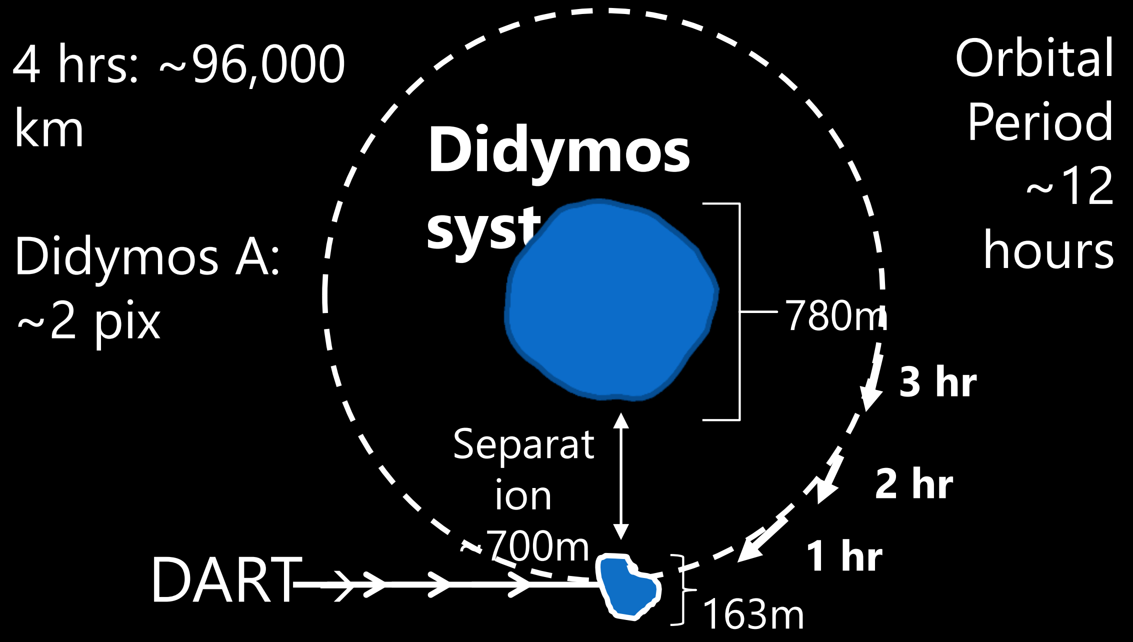
DART

Only “sort of know” where the object is



Needle in the haystack

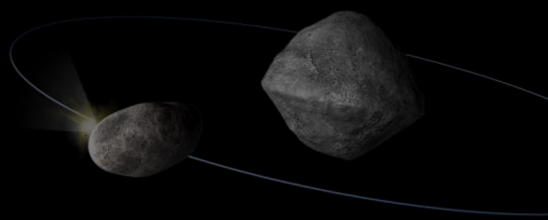
... and you have to thread that needle

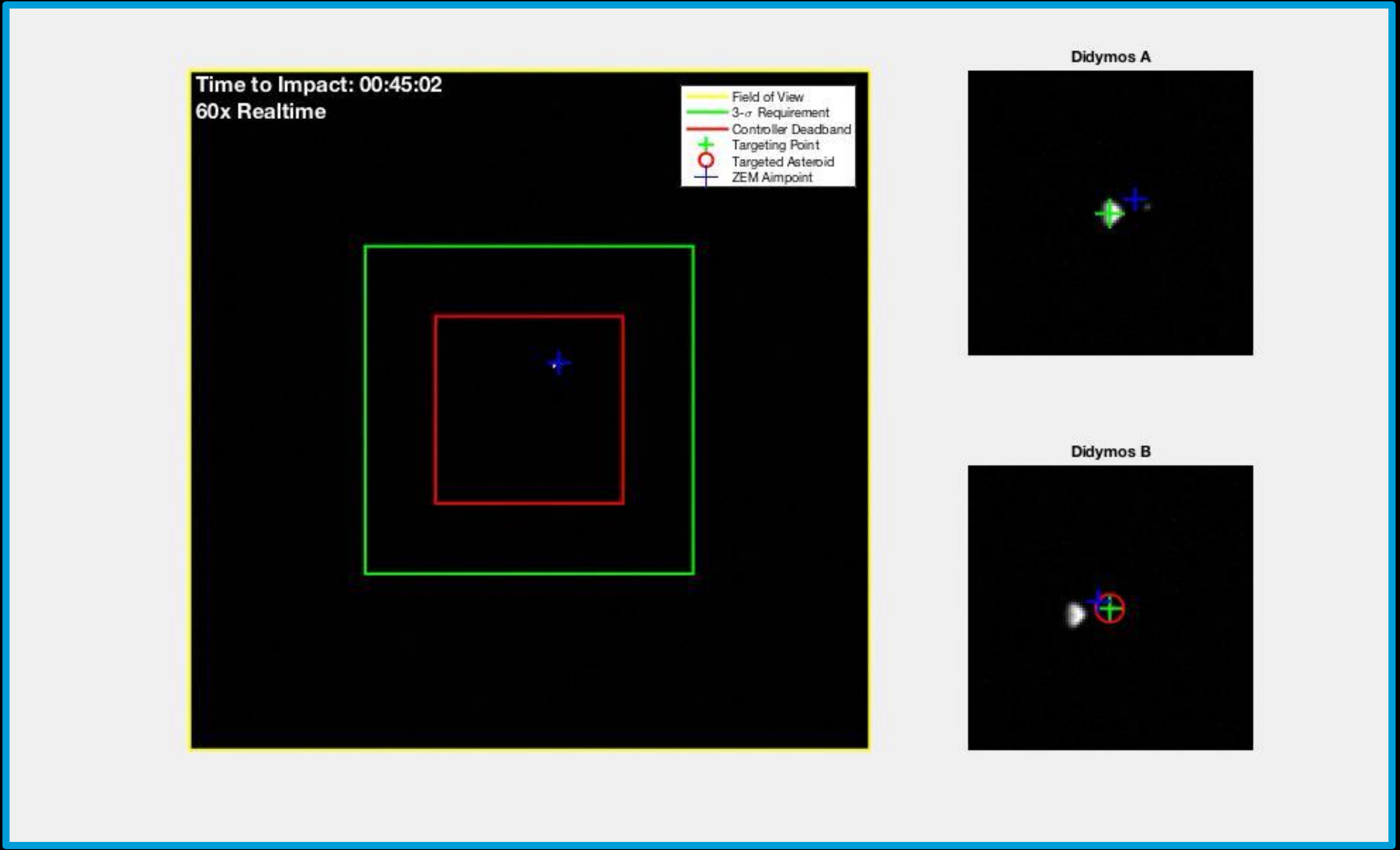


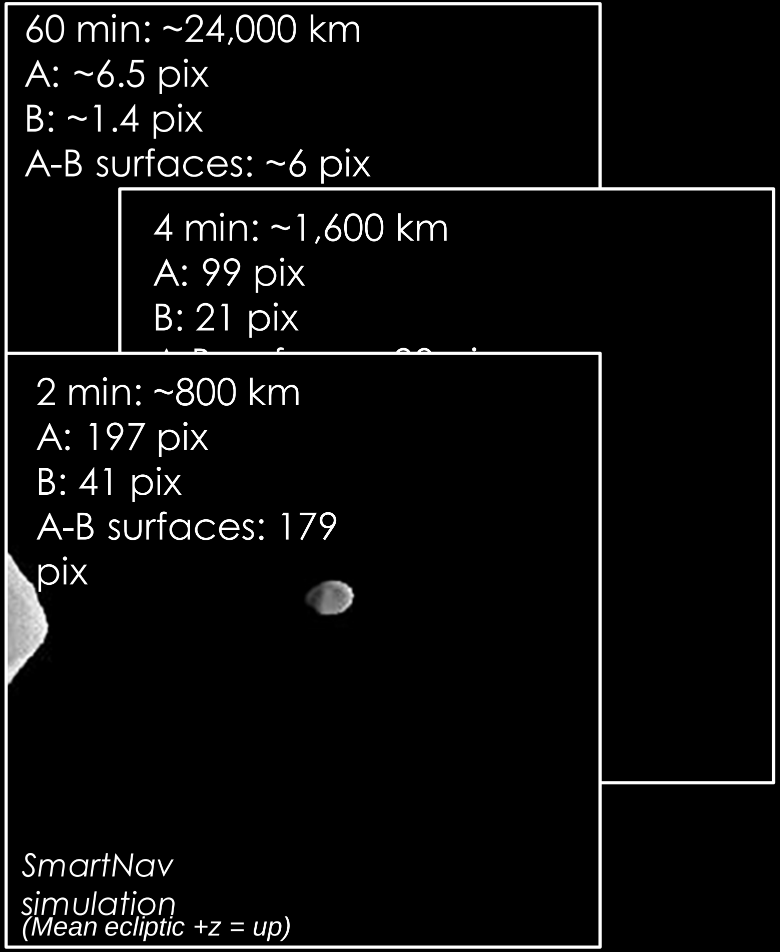
DART

DART - Through the Eyes of DRACO

Small-body Maneuvering Autonomous Real-Time Navigation SMART Nav)

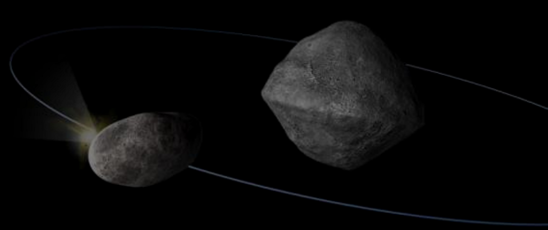






DART

How do we know SMART Nav works?



On the ground

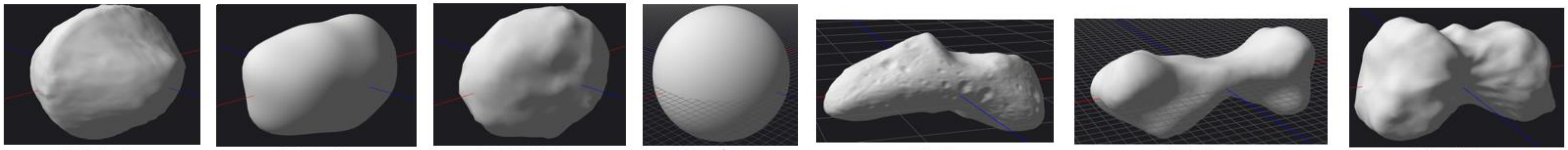
Row_names
Orbit Phase Angle (deg)
Target Shape File
Primary Shape File
Target Albedo
Primary Albedo
Target Radius (m)
Primary Radius (m)
Target Spin Rate (period, hrs)
Target Orbit Radius (km)
2nd Moon Present Flag
2nd Moon Radius (m)
2nd Moon Orbit Radius (km)
2nd Moon Shape File
2nd Moon Albedo
2nd Moon Spin Period
2nd Moon Orbit Period
2nd Moon Orbit Phasing (deg)
2nd Moon Orbit Inclination (deg)

Vary the moon

Vary the Spacecraft

Run simulations on high fidelity testbeds (hardware & emulations of spacecraft)

Category	Parameter
Mass Properties	CM position error
	Inertia principal axis misalignment
	Inertia principal moment error
Mass Property Knowledge	CM position knowledge error
IMU	Gyro bias per axis (post-cal)
	Gyro scale factor error per axis (post-cal)
	Gyro rotational misalignment per axis (post-cal)
	Gyro non-orthogonality per axis (post-cal)
	Accel bias per axis (post-cal)
	Accel scale factor error per axis
	Accel rotational misalignment per axis
	Accel non-orthogonality per axis
ST	Star tracker misalignment (post-cal)
LPS	LPS thruster coefficient scale factor error per thruster
	Thruster misalignment



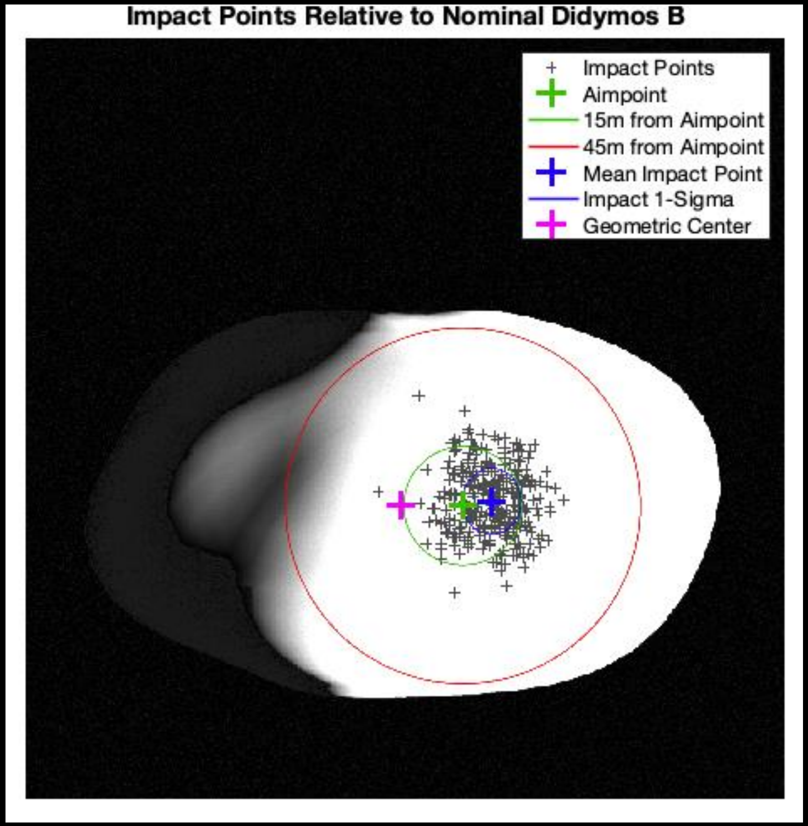
ID1: kw4a ID2: kw4b ID6: Rashalom ID7: sphere 1 ID4: Eros ID5: Kleo ID3: Mithra

DART

How do we know SMART Nav works?

On the ground

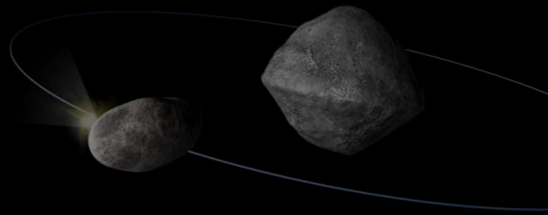
Goal: Hit the center



15 meter (1-σ) miss distance is satisfied. All cases hit within 45 meters of aimpoint

DART

Testing SMART Nav

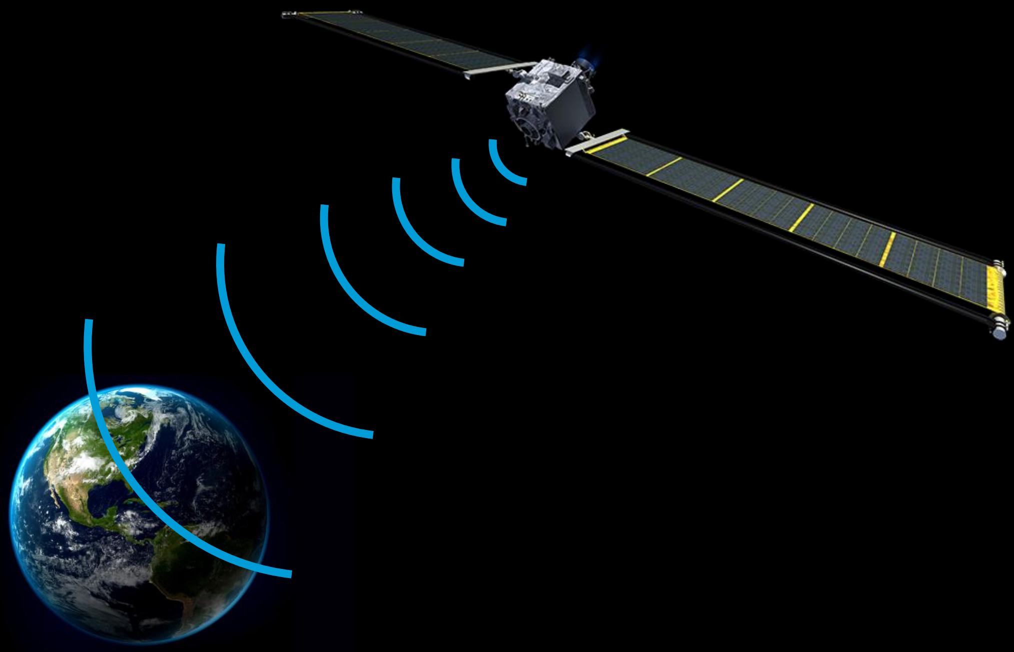


In Flight:

23 and 60 days after launch and again 100 days prior to impact

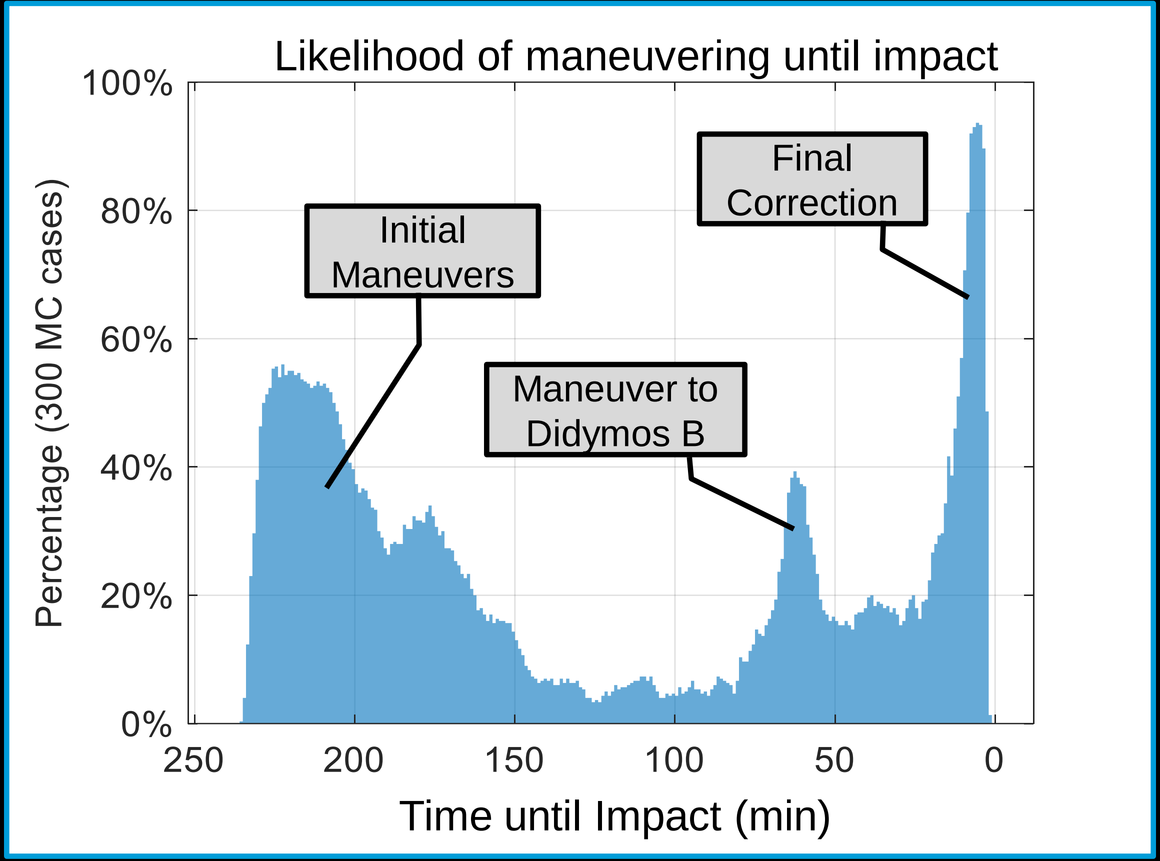
Practice on moons of Jupiter

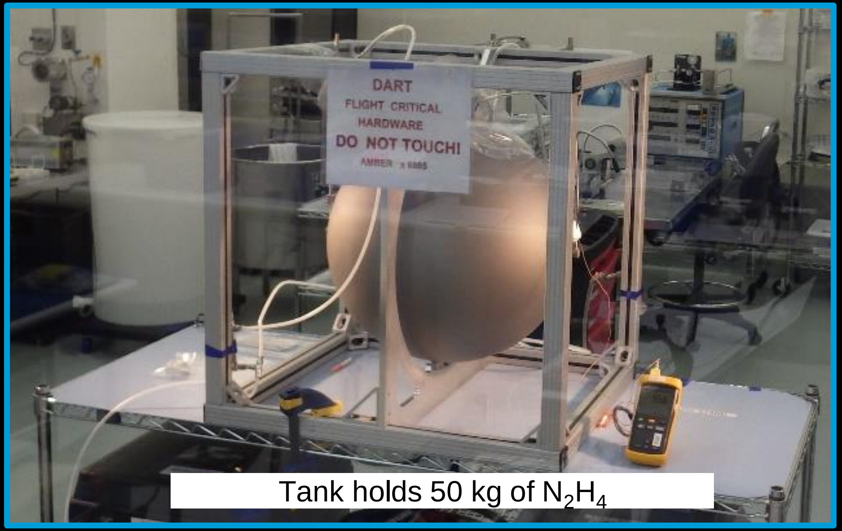
Do image processing, guidance and navigation, and send data to Earth real time



DART

Prerequisite to Impact: Don't run out of fuel at the end





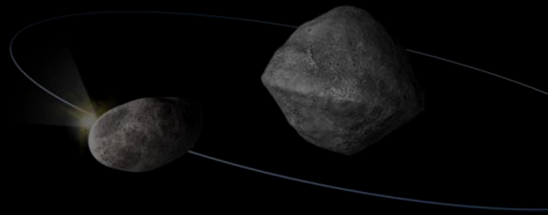
Tank holds 50 kg of N_2H_4

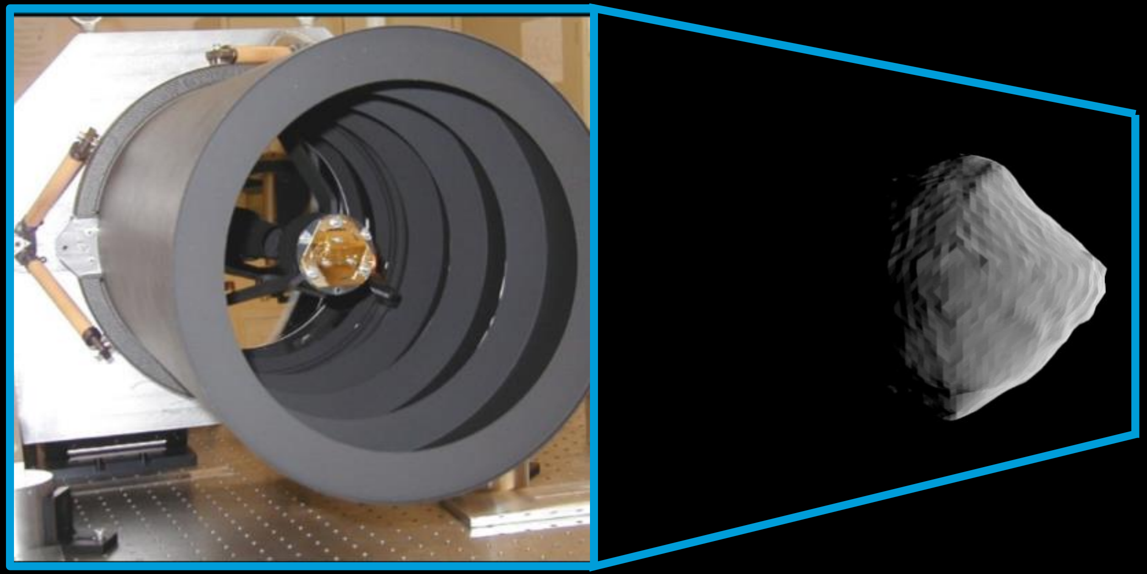
Most of the fuel is used early on in the mission

Early simulations show that we maneuver ~65% of time Terminal Phase (last 4 hours)

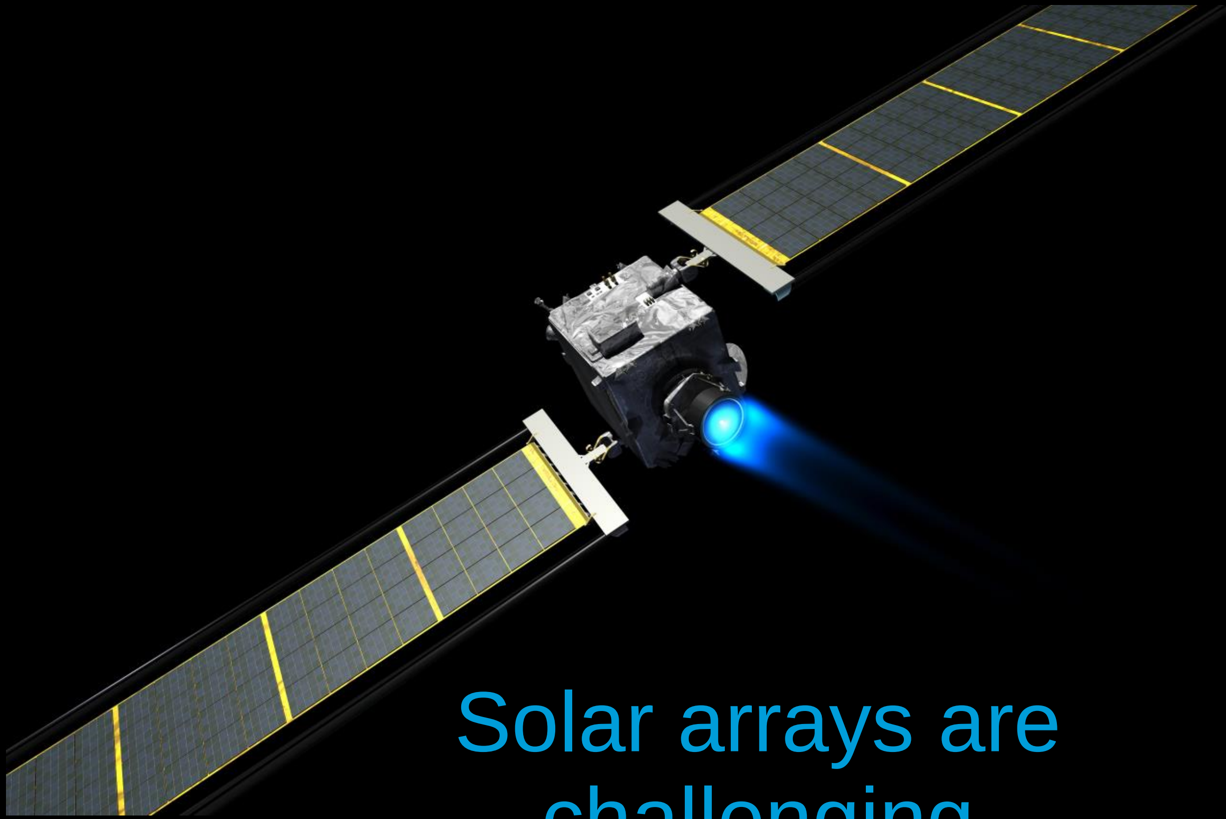
Prerequisite to Impact: Image that asteroid!

It sure won't be happening after impact…



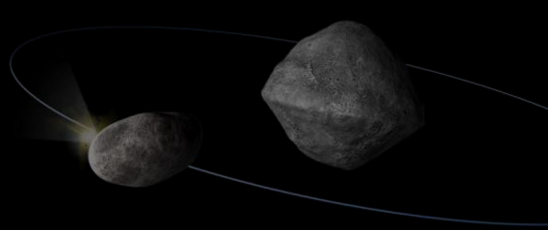


Point this camera
(telescope)
at Didymos



Solar arrays are
challenging

Light Italian CubeSat for Imaging Asteroids



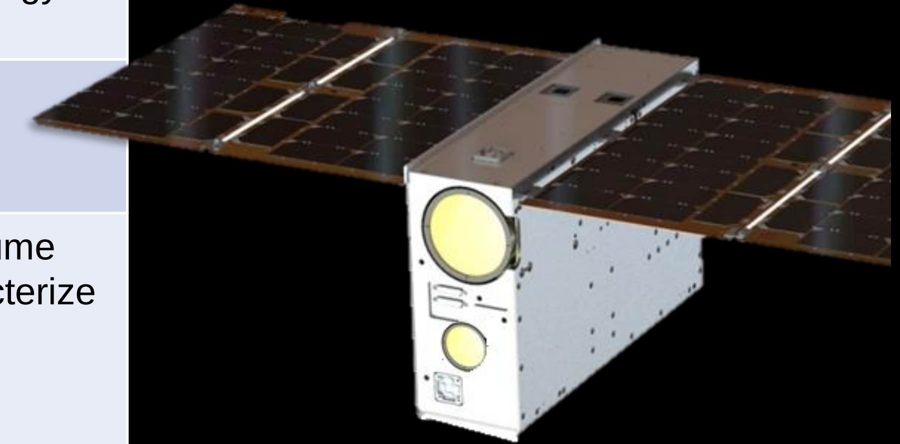
LICIACube

LICIACube Goals	Description
1- Impact ejecta plume evolution	Obtain multiple (at least three) images of DART impact ejecta plume over a span of times and phase angles, to allow estimation of plume density structure
2- Impact crater	Obtain multiple (> 3) images of DART impact site having sufficient resolution to allow measurements of impact crater size and morphology
3 - Non-impact hemisphere	Obtain multiple (at least three) images of the non-impact hemisphere of Didymos B
4 - Color/ spectral imaging plume & Didymos	Obtain images of the ejecta plume and of 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)

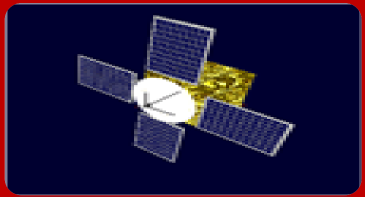
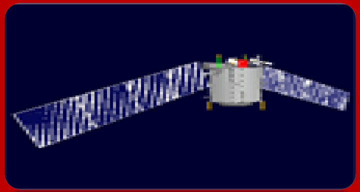


Current conops includes flyby of Didymos ~ 5 min after DART impact and downlinking data after event

argotec our boost to your future

agenzia spaziale italiana

Ground Software Heritage

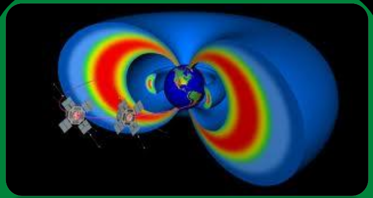

1990s

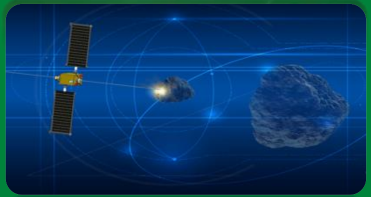
One-Off Systems



2000s

Common Ground Architecture



2010s

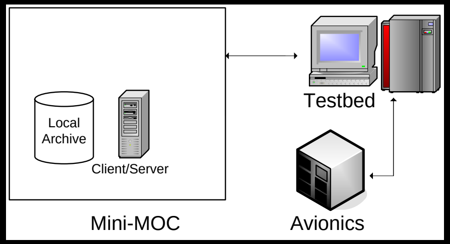
Mission / System Independent Architecture

DART

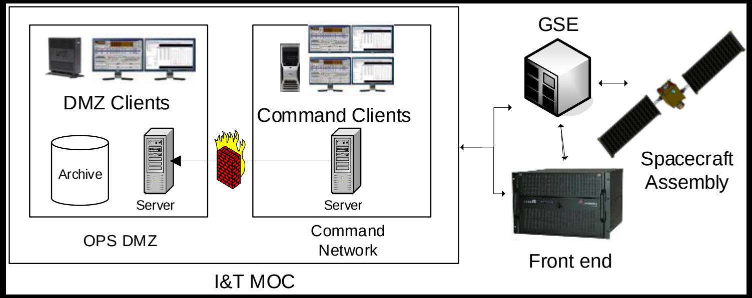
Ground Software
Mission Operations Center (MOC*) Configurations

The same set of software is used in each configuration

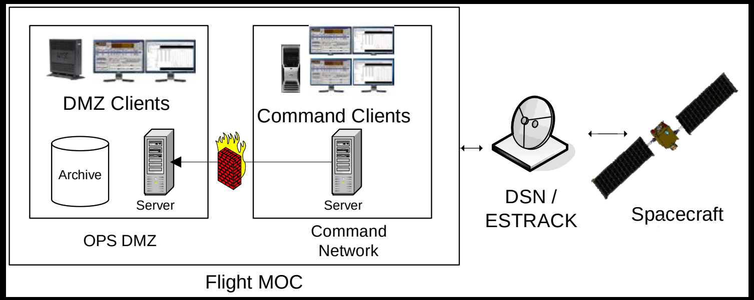
- Mini-MOC / Hardware-In-The-Loop Simulator
  - Supports local test of a spacecraft processor subsystem and avionics via a single computer
  - Provides primary user interface for the testbed (commanding and telemetry)
  - Local archive



- I&T MOC
  - Supports spacecraft I&T, allowing users to send commands to and receive telemetry from the spacecraft under test and GSE
  - Central archive in the OPS DMZ
  - Other users may view status and telemetry information simultaneously from client workstations connected to controlling I&T MOC workstation and in the OPS DMZ

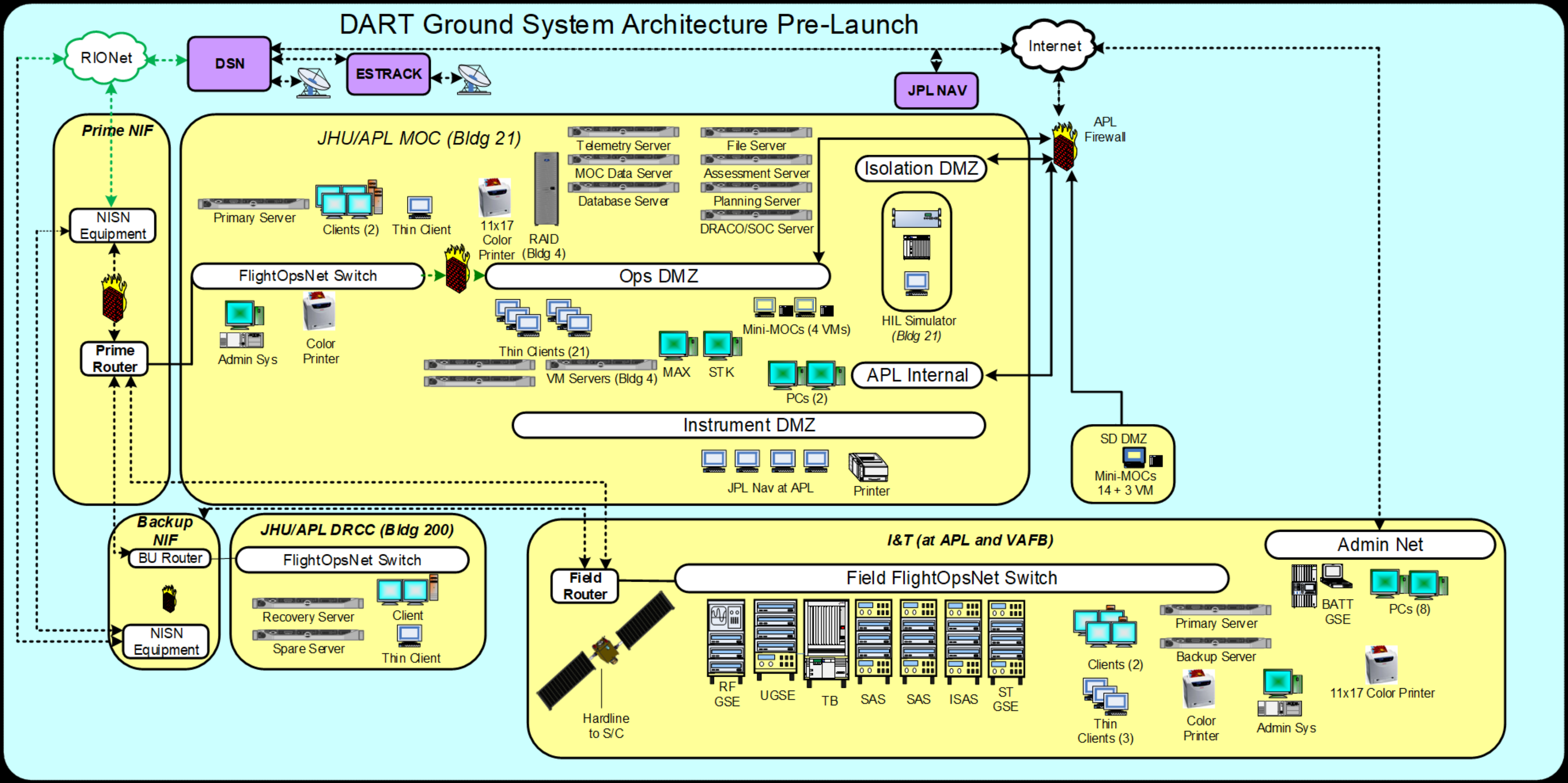


- Flight MOC
  - Supports mission simulations, launch and operations, including via ground stations
  - Central archive in the OPS DMZ
  - Other users may view status and telemetry information simultaneously from client workstations connected to controlling Flight MOC workstation and in the OPS DMZ



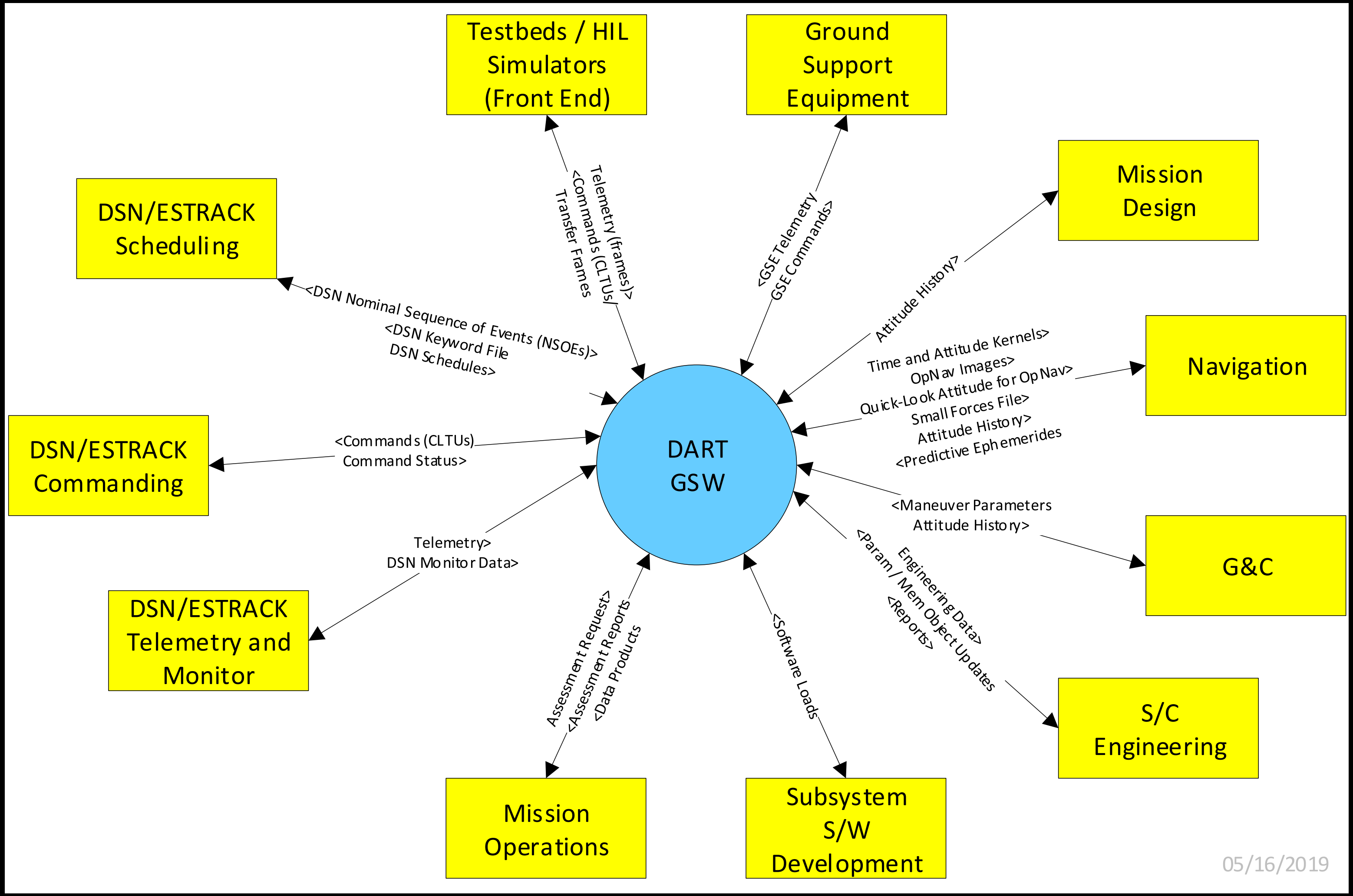
*Mission Operations Center (MOC) =~ Satellite Operations Center

Typical Ground System Architecture



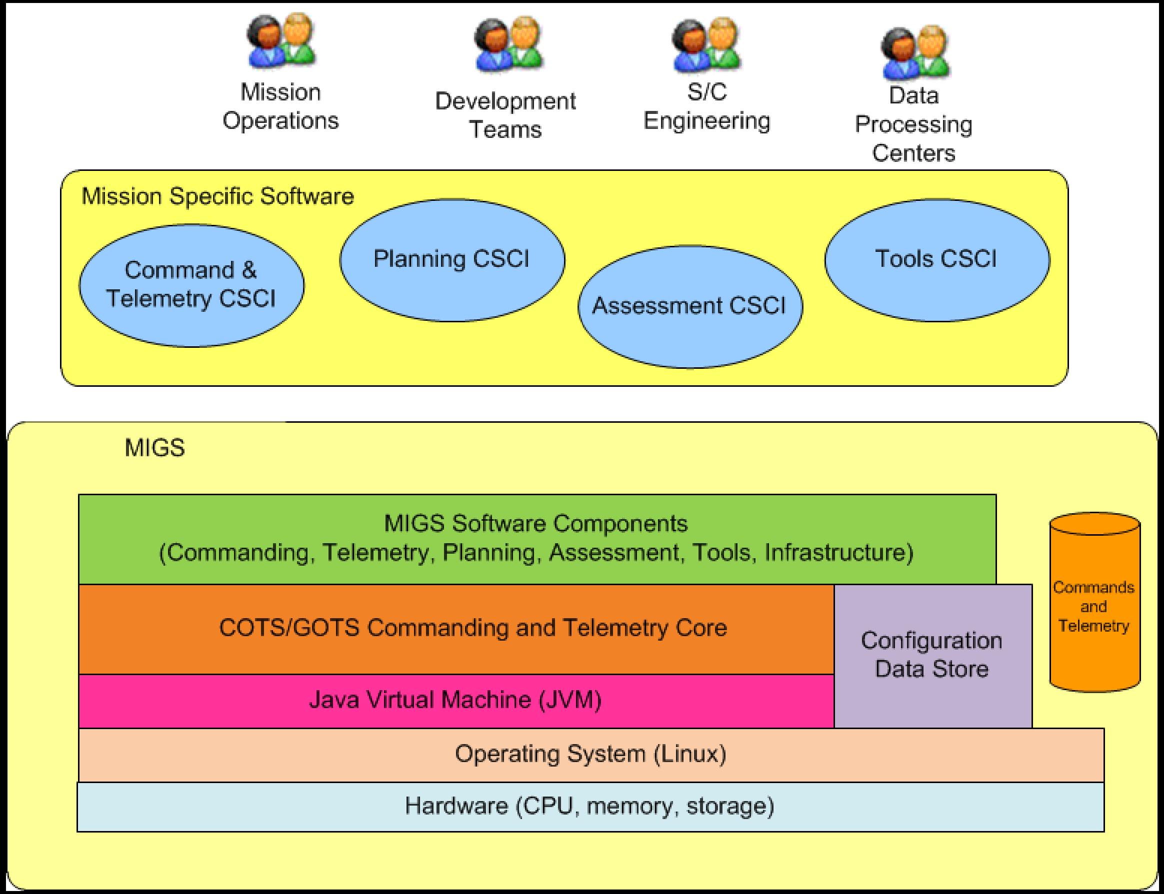
DART

Typical Ground Software Context



DART

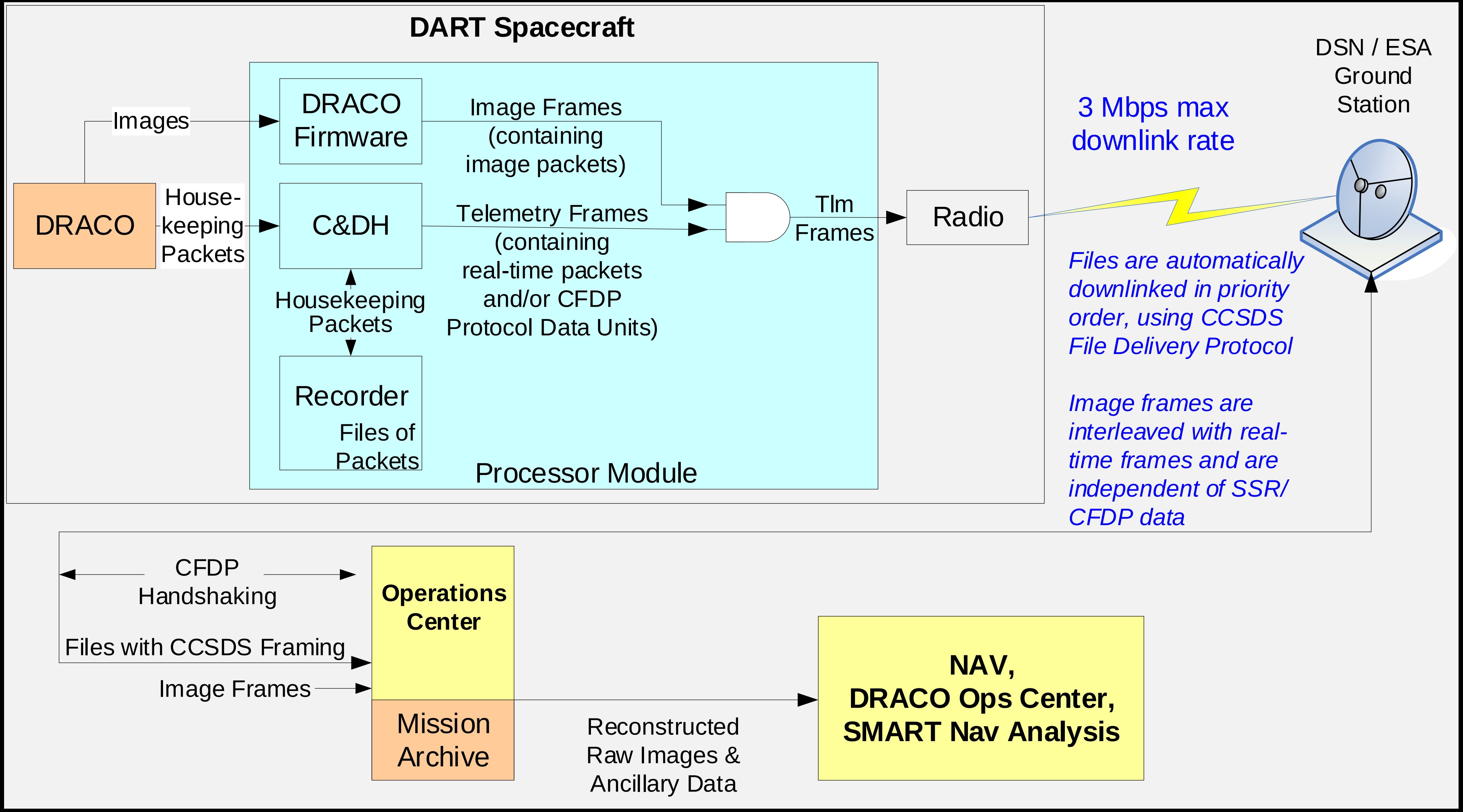
Mission / System Independent Architecture



- DART's Ground Software consists of 71 Computer Software Components (CSC)s
  - Most CSCs are java applications that run in separate JVM processes or application server
  - ~40 CSCs are on-line applications running with an L3Harris InControl-NG Telemetry and Commanding system
  - Remainder are off-line planning or assessment applications
- Code is shared across missions and used with mission specific configuration

High (94%) Re-use = Inexpensive DART ground solution

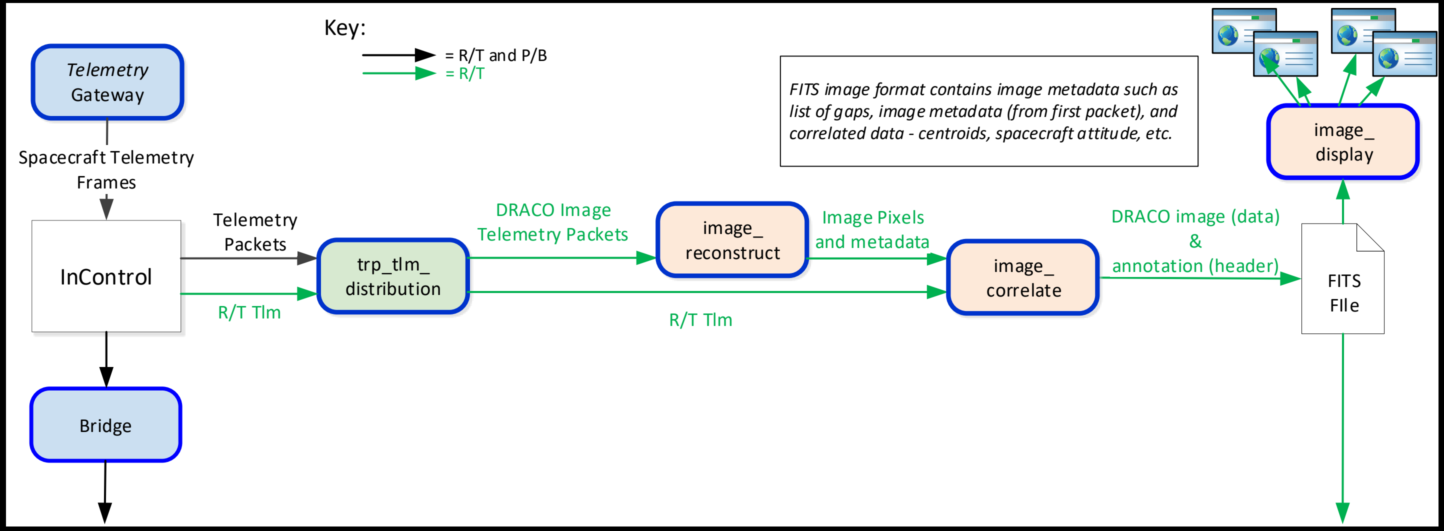
Downlink Flow:
Many Sources = Lots of Telemetry Virtual Channels!



DART

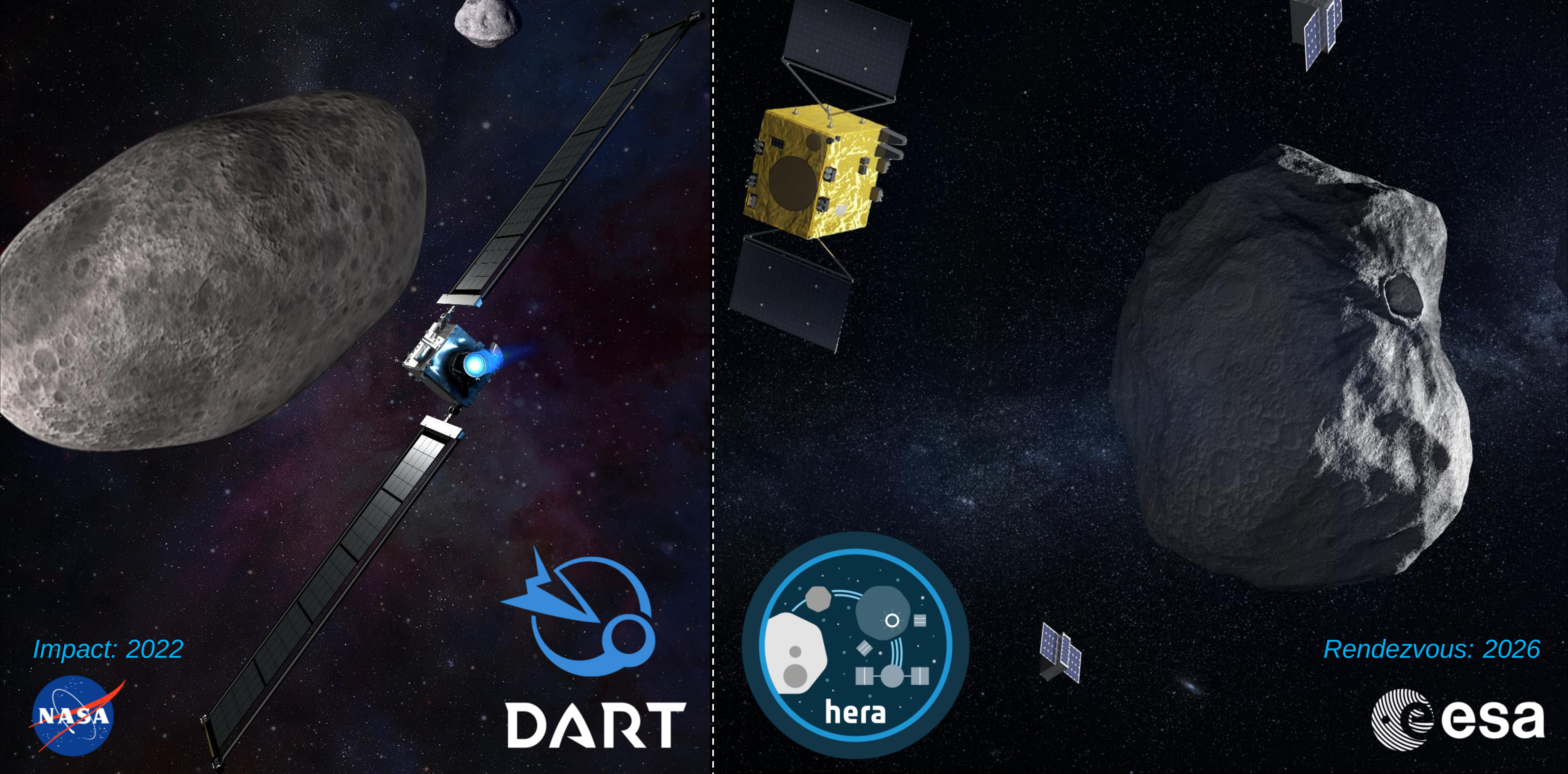
Ground Software: Unique Features for DART

- Receive Telemetry Frames from DSN / ESTRACK @ 3 Mbps
- Extract image packets from frames and reconstruct image in near-real-time @ 1 image / second during Terminal Phase
- Correlate additional flight data with reconstructed image in near-real-time
- Overlay image with applicable correlated data and display to users in 2 different networks
- Separately, support timely OpNav processing of recorded images to Navigation Team



AIDA – Asteroid Impact & Deflection Assessment

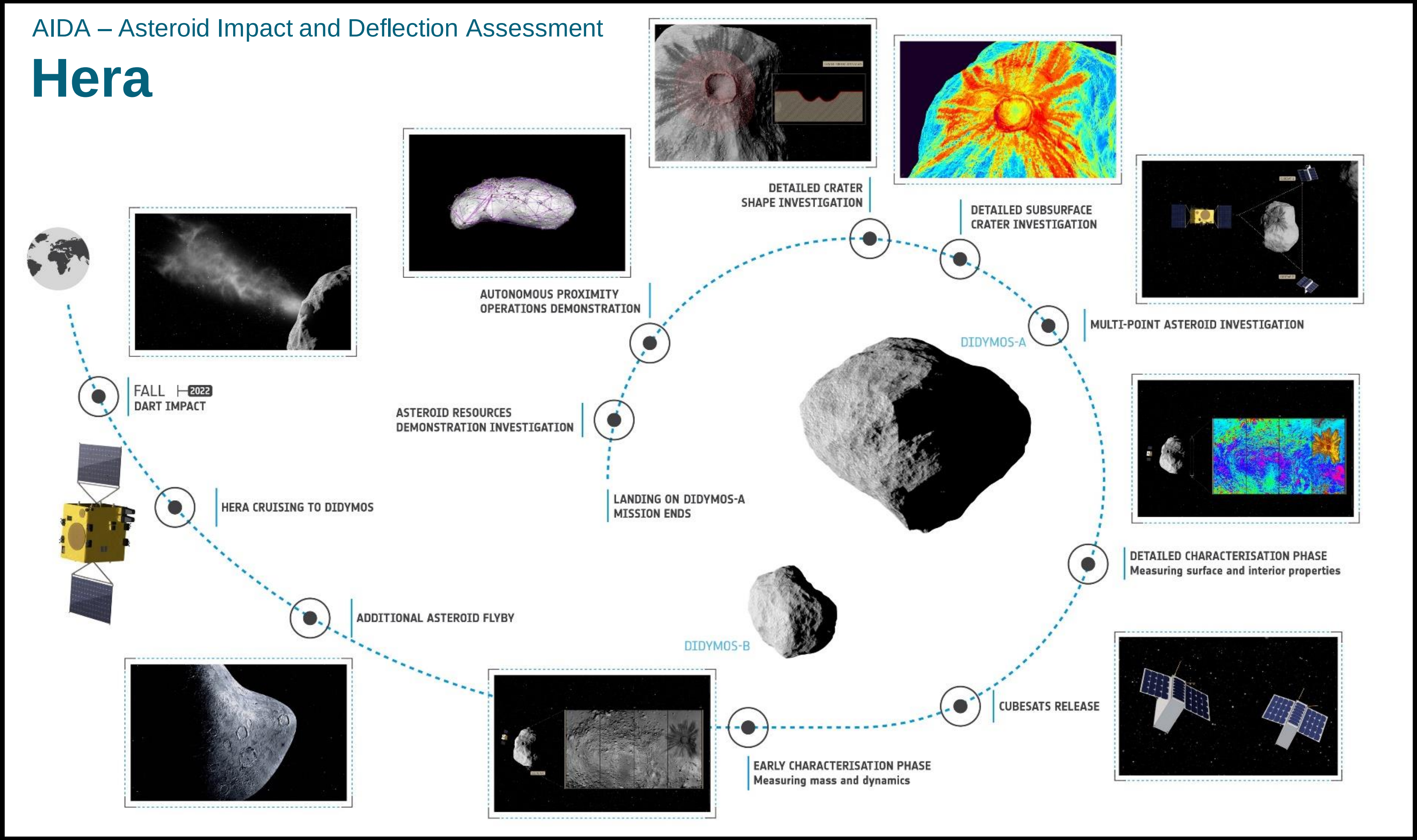
International Cooperation for an International Issue



AIDA – International Collaboration for Planetary Defense

Hera Advances the Planetary Defense Test that DART Begins

- Hera would launch in 2024, arrive at Didymos in 2026, and conduct a 6-month survey, including:
  - Directly measuring the Didymos B mass to determine momentum transfer
  - Investigating the DART impact crater depth and diameter to understand target physical property effects
- These measurements can be made four years after the DART impact without loss of value



DART


DART

JOHNS HOPKINS

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