Universitat d'Alacant
Universidad de Alicante

Grupo "Ciencias Planetarias" (Astronomía y Astrofísica)
Depto. Física, Ingeniería de Sistemas y Teoría de la Señal (Escuela Politécnica Superior)
Instituto de Física Aplicada a las Ciencias y la Tecnología.
Universidad de Alicante

Miembros del grupo:

Adriano Campo Bagatin (TU)
Paula G. Benavidez Lozano (AYU DOC)
Rafael A. Alemañ Berenguer (Col. H. + Doctorando)

Principales líneas de investigación:

- **Estructura interna pequeños cuerpos SS**
- **Rotación/fisión y formación de sistemas binarios**
- **Dinámica del 'regolito' en pequeños asteroides en rotación rápida**
- **Colaboración en misión espacial AIDA**
- Evolución colisional poblaciones de pequeños cuerpos (Asteroides, EKB)
- Experimentos colisión
- Observación y estudio TNOs

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IU FACyT

Principales colaboraciones

- **IAA (J. L. Ortiz, F. Moreno)**
- **Obs. Côte d'Azur (Niza, F) (P. Tanga, S. Schwartz)**
- **Southwest Research Institute (Boulder, CO, USA) (D.D. Durda)**
- **Universty of Maryland (College Park, MD, USA) (D.C: Richardson)**

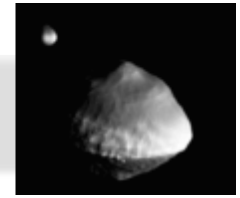
Fuentes financiación:

Desde enero 2015:
Remanentes de fondos DFISTS + IUFACyT ~ 4000 €/año

La misión espacial AIDA al asteroide binario Didymos

Adriano Campo Bagatin
DISTS – IUFACyT. Universidad de Alicante

AIDA = AIM + DART



Target: Didymos in 2022

AIDA: Asteroid Impact and Deflection Assessment
AIM: Asteroid Impact Mission
DART: Double Asteroid Redirection Test

- ESA AIM rendezvous spacecraft
  - Orbiter payload to characterize Didymos dynamical system and study impact results
  - Asteroid proximity operations, lander release on secondary asteroid, deep-interior analysis
  - Deep-space optical communication demonstration

- NASA DART interceptor and Earth-based observing
  - Measure asteroid deflection to within 10%
  - Return high resolution images of target prior to impact
  - Autonomous guidance with proportional navigation to hit center of 150 meter target body

AIDA: Asteroid Impact & Deflection Assessment

AIDA Coordination Committee:	
Patrick Michel, AIM Advisory Team chair	Obs de la Cote d'Azur
Andy Cheng, DART Science Definition Team chair	APL
Derek Richardson	Univ Maryland
Adriano Campo Bagatin	Univ Alicante
Olivier Barnouin	APL
Stephan Ulamec	DLR
Angela Stickle	APL
Andy Rivkin	APL
Paul Miller	LLNL
Kleomenis Tsiganis	Univ. Thessaloniki
Steven Schwarz	Obs de la Cote d'Azur
Peter Pravec	Czech. Acad. Science

Ian Carnelli	**ESA**
Lindley Johnson	**NASA HQ**
Cheryl Reed	**APL PM**

AIM Advisory Team	
Patrick Michel	Obs de la Cote d'Azur
Simon Green	Open University
Jean-Baptiste Vincent	MPS
Petr Pravec	CAS
Marco Delbo	Obs de la Cote d'Azur
Pascal Rosenblatt	Royal Obs Belgium
Juergen Blum	TU Braunschweig
Kleomenis Tsiganis	Aristotle Univ Thessaloniki
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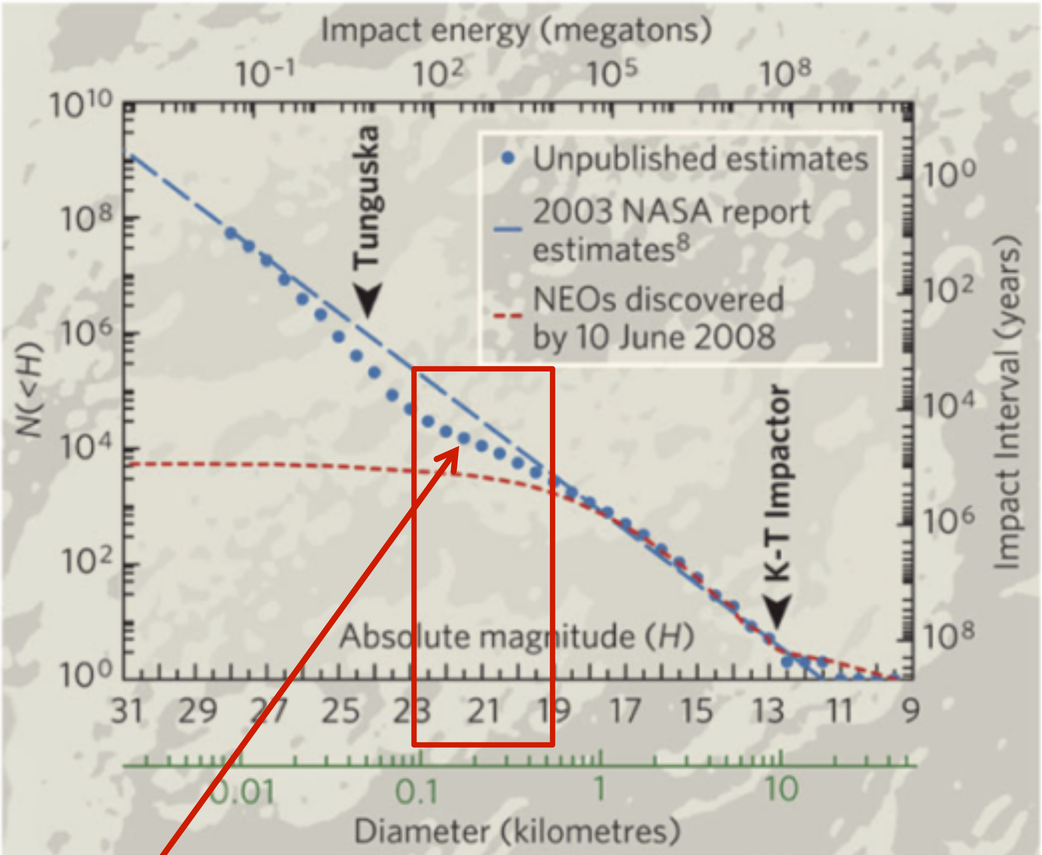
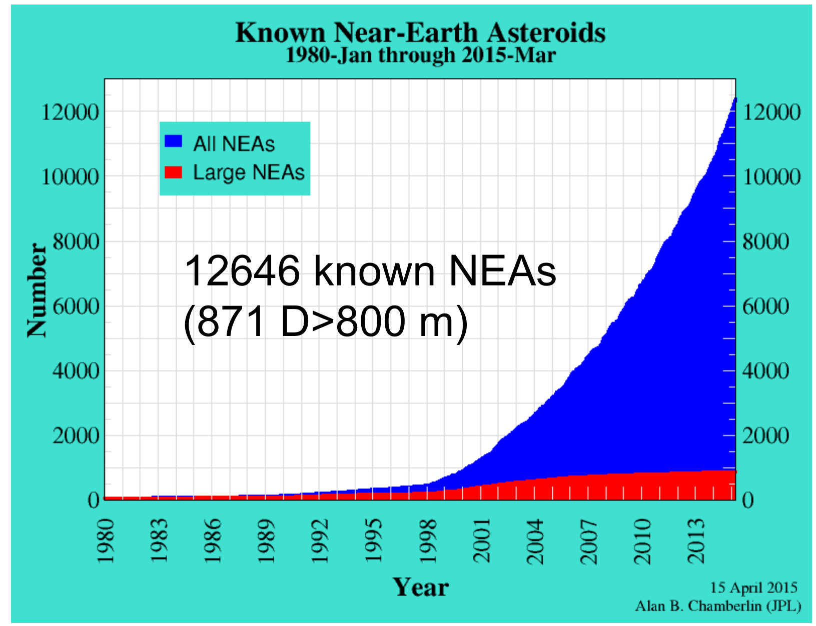
Alain Herique	IPAG
Valerie Ciarletti	Université Versailles

DART Science Definition Team	
Andy Cheng	APL, Chair
Paul Abell	JSC
Brent Barbee	GSFC
Olivier Barnouin	APL
Lance Benner	JPL
Steve Chesley	JPL
Carolyn Ernst	APL
Andy Rivkin	AP
Dan Scheeres	Univ. Colorado
Angela Stickle	APL

Why an impact test mission on a small NEO?





- **Less than 20% of NEAs in the 100-500 m range are known!**
- Earth atmpsphere has no effect at this size.
- Larger objets are >90% known.

65803 Didymos: AIDA target

Measurable deflection of the asteroid moon without risk of deflecting the asteroid into a dangerous heliocentric orbit

- Discovered in April 1996
- Near Earth Asteroid (Apollo)

  Perihelion distance:1.01 AU

  Aphelion distance: 2.3 AU

  Close approach to Earth: Oct 2022

  0.07 AU range: opportunity for ground observation of impact event
- (YORP spin-up ?) Binary system

  800 m primary

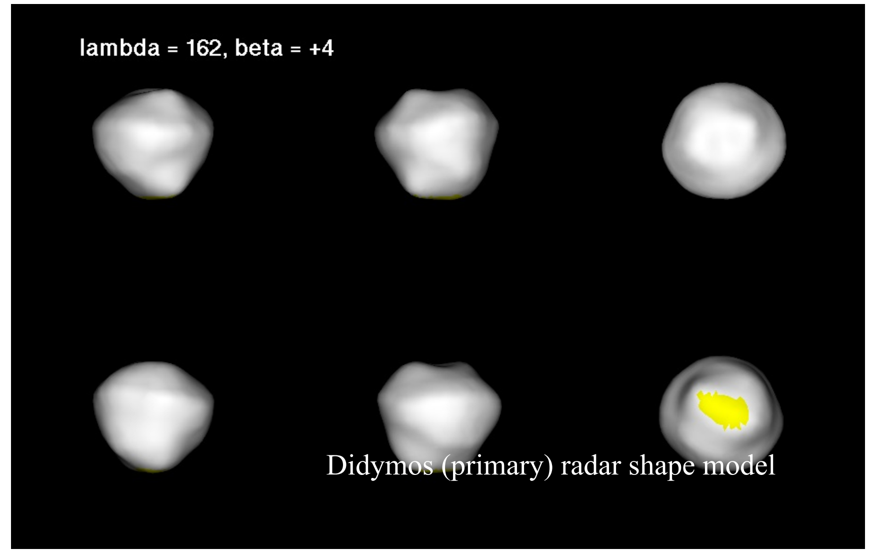
  Primary spinning at 2.26 hr

  150 m secondary

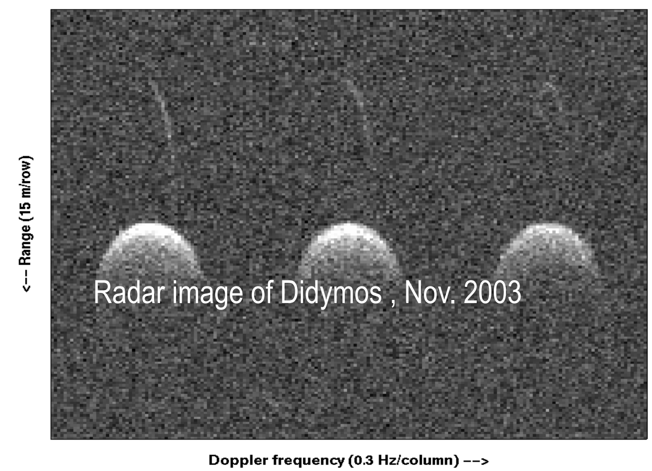
  Separation: 1100 m

  Secondary: 11.9-hr orbit

  C type.



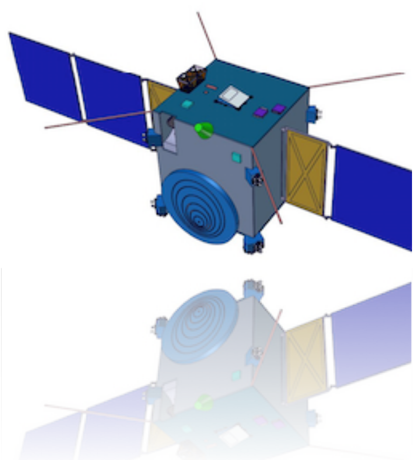
ARECIBO RADAR IMAGES OF 65803 DIDYMOS: 2003 NOV. 23, 24 & 26



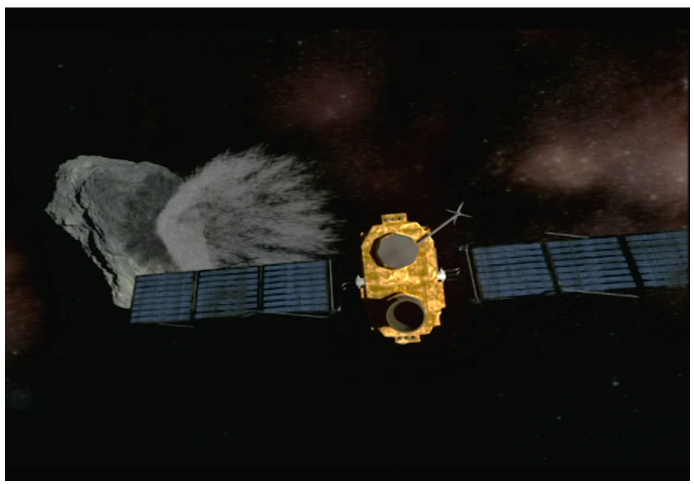
Asteroid Impact Mission (AIM)

Small mission of opportunity to demonstrate technologies for future missions
+ addressing planetary defense objectives
+ performing asteroid scientific investigations

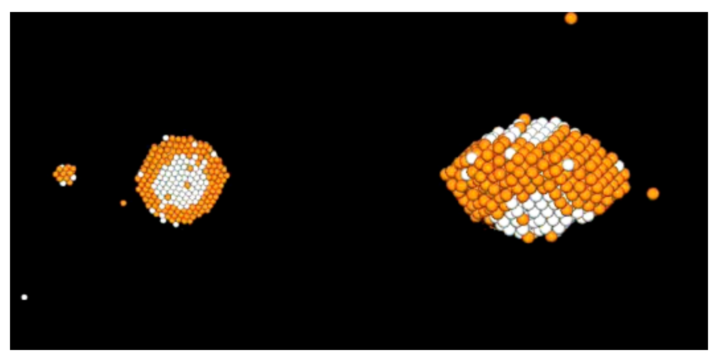
Technology demonstration



Asteroid impact mitigation

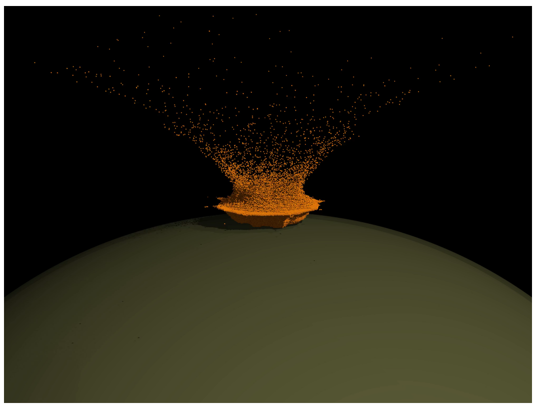


Science

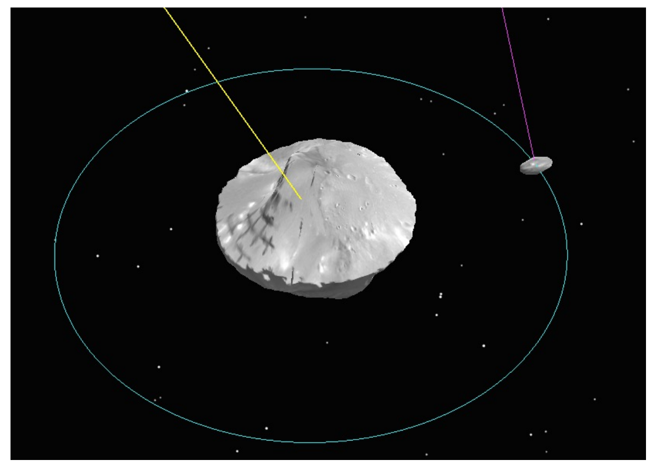


AIM “firsts”

First mission to demonstrate **interplanetary optical communication** and **deep-space inter-satellite links with CubeSats** and a **lander** in deep-space.



First mission to **measure asteroid deflection** by determining the “ejecta momentum amplification factor” of a kinetic impactor.



First mission to **study a binary asteroid,** its **origins** and sound its **interior structure**

AIM mission objectives

Primary objectives

① Determine the binary asteroid **orbital and rotation dynamics**, as well as its **mass, geophysical properties, surface and subsurface structure**.

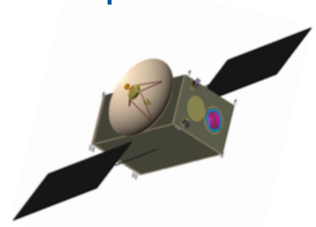
② Carry out a **Telecommunication Engineering eXperiment** (TEX), a **Moonlet Engineering eXperiment** (MEX) deploying the **MASCOT-2 asteroid lander**;

③ Test **inter-satellite network link** with **COPINS** (Cubesat Opportunity Payload Intersatellite Network Sensors) and the **MASCOT-2 lander.**

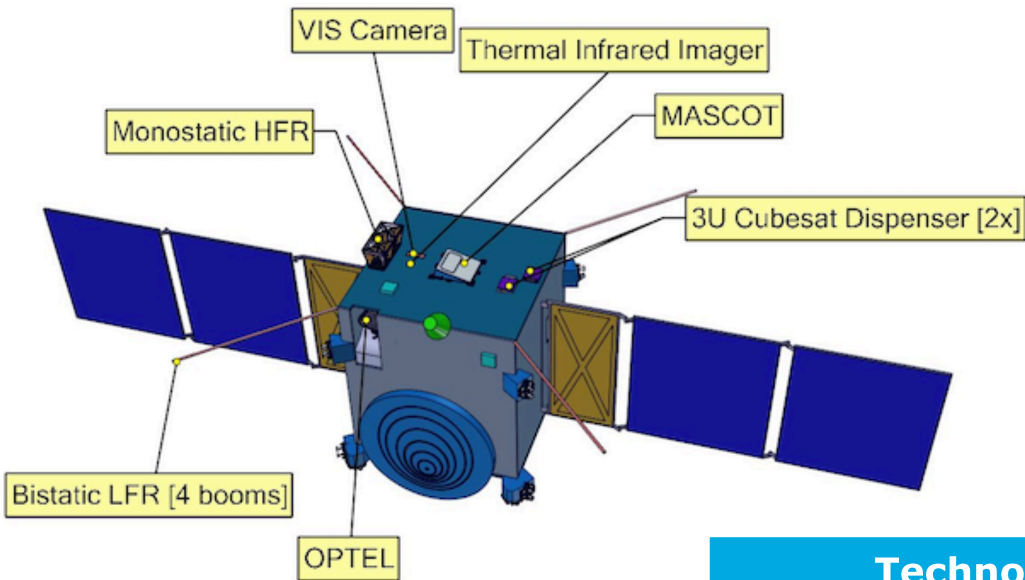
Secondary objectives

④ **Determine the momentum transfer** resulting from the DART impact, by measuring the **variation of the asteroid satellite's** period, its **rotation state** and by imaging the **resulting impact crater**. An optional extension of this primary objective is the imaging the **asteroid ejecta** resulting from the impact.

⑤ **Characterise the asteroid deep interior structure**.

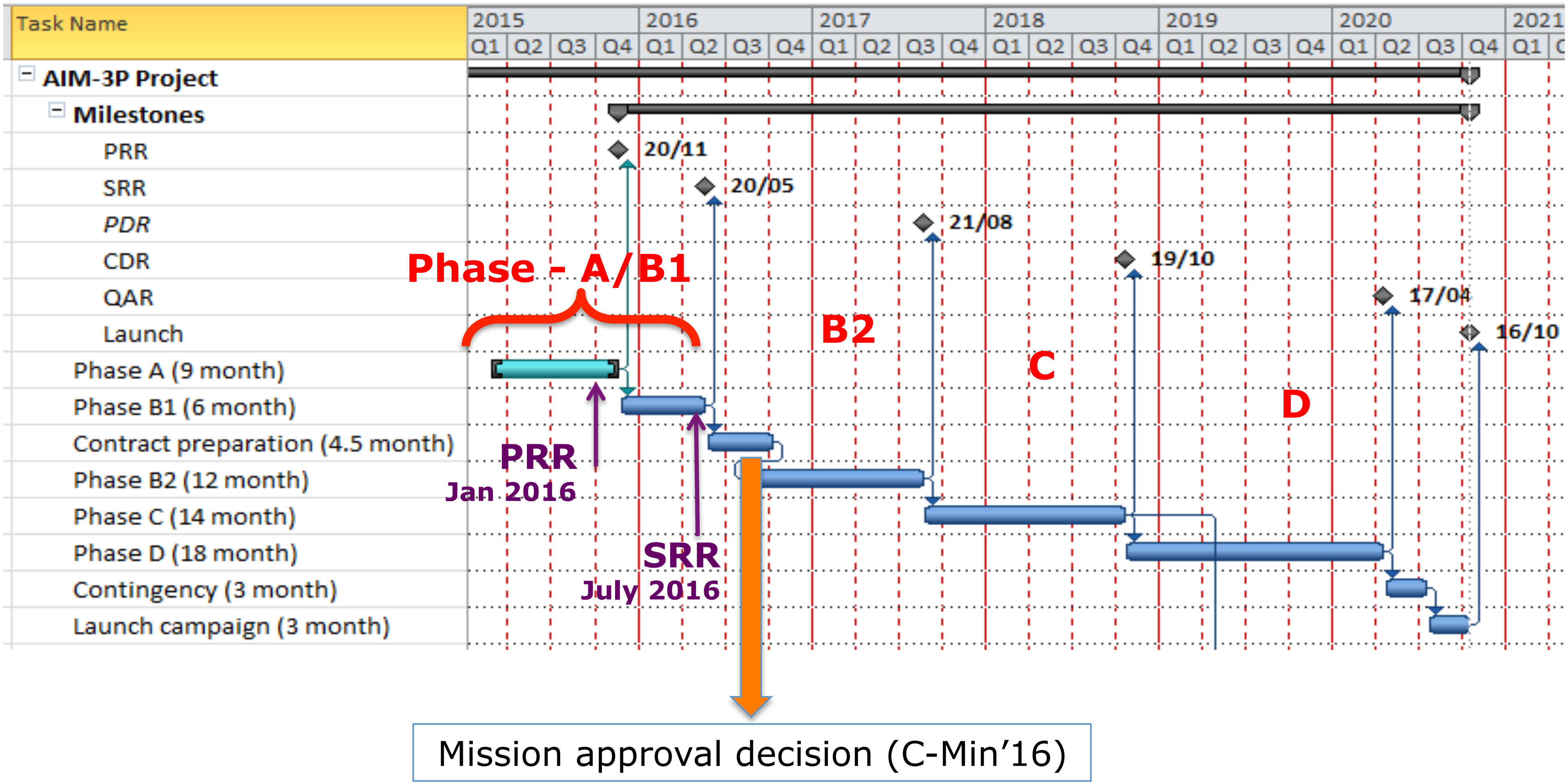


AIM main elements



Technology Payload	Mass
OPTEL-D (Optical terminal)	39.3
MASCOT-2 (incl. low-frequency radar)	13
COPINS	13.2
Asteroid Research Payload	**Mass**
Thermal Infrared Imager	3.6
Monostatic High Frequency Radar	1.7
Bistatic Low Frequency Radar (Orbiter)	1.2
Visual Imaging Camera	2.4

AIM baseline schedule

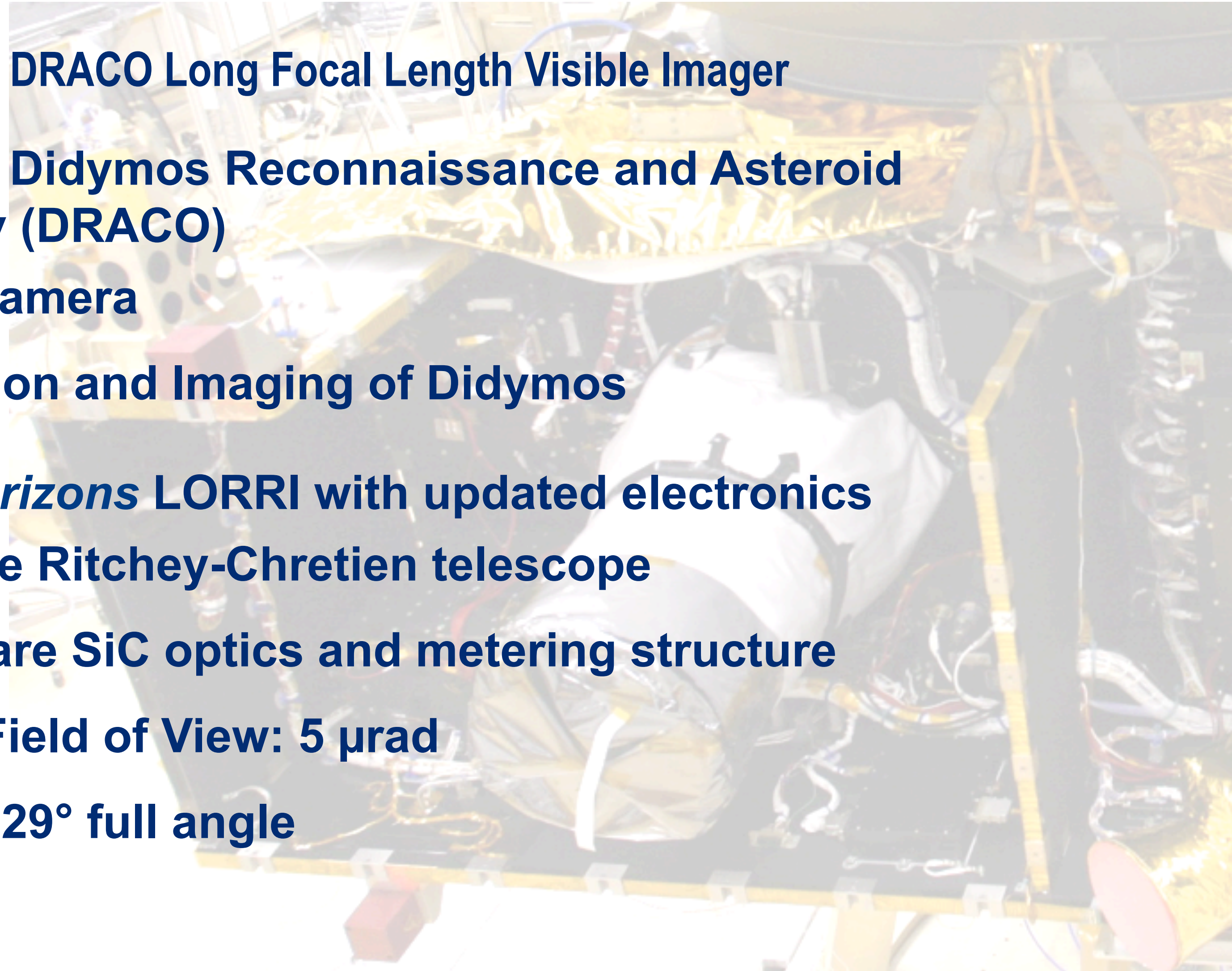


DART mission Objectives

	Objectives	Measurements and Analyses
Planetary Defense	**Demonstrate the spacecraft kinetic impact mitigation technique**	Target an asteroid large enough to qualify as a PHA (larger than 100 m)
	Measure asteroid deflection	Target Didymos binary system; measure the binary period change to within 10% (Earth-based optical and radar observations)
	Learn how to mitigate an asteroid by kinetic impact: validate models for momentum transfer in asteroid impacts	Determine energy transfer; infer β; determine crater size and ejecta distributions [with AIM] and constrain cratering models
Science and Exploration	**Understand asteroid collision effects to infer physical properties of asteroid surface and subsurface**	Light curve and radar observations of the binary for sizes and density; infer density, porosity, strength from cratering and from β [with AIM]
	Study long-term dynamics of DART impact ejecta	Observe and model transient disk and debris tail formation and evolution

$\beta = transferred\ momentum / incident\ momentum$

DART Payload Instrument



DRACO Long Focal Length Visible Imager

- Single Instrument: Didymos Reconnaissance and Asteroid Camera for Op-nav (DRACO)
  - Narrow Angle Camera
  - Optical Navigation and Imaging of Didymos
- Rebuild of *New Horizons* LORRI with updated electronics
  - 203 mm aperture Ritchey-Chretien telescope
  - Use of flight spare SiC optics and metering structure
  - Instantaneous Field of View: 5 μrad
  - Field of View: 0.29° full angle

DART Impact Results

Understanding and modeling the DART impact

Parameter β is defined as momentum change divided by momentum input

$$\beta = \frac{transferred\ momentum}{incident\ momentum}$$

If no ejecta, then $\beta = 1$

Ejecta *enhances* momentum transfer, $\beta > 1$

$$M\Delta V = \beta M_i V_i$$

M is target mass, ΔV is velocity change

β depends on the incident velocity and momentum, on target size and target material properties such as strength and porosity

Expected changes (nominal values, head on collision in satellite velociiy direction):

ΔV = 0.4 mm/s for β = 1

Binary orbit period change of some 270 sec

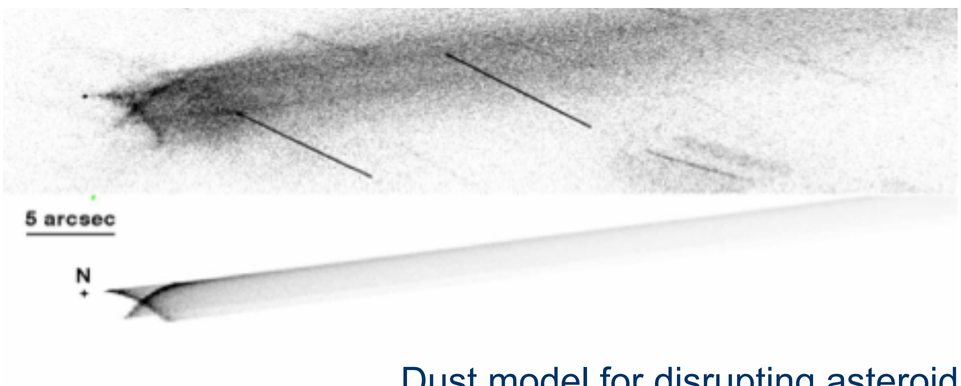
Post-Impact Observing Prospects

Observation and Modeling of DART ejecta

- Didymos and Didymoon are separated by up to 0.02 arcsec when 0.08 AU from Earth

  Marginally resolvable with ALMA (sub-mm), Magellan adaptive optics.

- Observe and model post-disruption dust evolution, as done with active asteroids



Dust model for disrupting asteroid P/2010 A2, Agarwal et al. (2013):
Object is ~200 m across, observed 1 AU from Earth.
HST image (top) vs. model (bottom)

La misión espacial AIDA al asteroide binario Didymos

Adriano Campo Bagatin
DISTS – IUFACyT. Universidad de Alicante

Binary Period from Light Curve Observations

Observe Mutual Events of Didymos

- **Binaries often discovered by light curve observations**
- **Large telescopes not needed**

  Magdalena Ridge 2.4-m (Ryan)

  Ondrejov 0.65-m (Pravec)

  Palmer Divide 0.5-m (Warner)
- **Mutual event observations constrain sizes, rotation rate, and binary orbit**
- **Some ambiguities remain!**

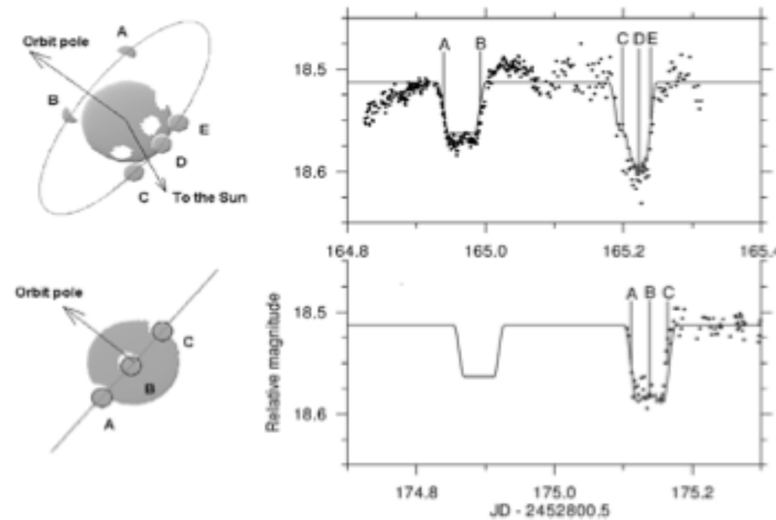


Fig. 4. The model of the system of (65803) Didymos as seen from Earth on 2003-11-22.0 and 2003-12-2.2. There are plotted the observational data (points) as well as the best-fit synthetic lightcurve of the prograde solution (curve). The other, mirror solution (retrograde) gives a nearly identical curve. The letters A to E denote particular positions of the secondary in its orbit and corresponding phases in the lightcurve. In this figure, the minima are shown in an order opposite to Fig. 1. Outside the minima, there is apparent a lightcurve variation caused by the secondary rotation that we did not model numerically.

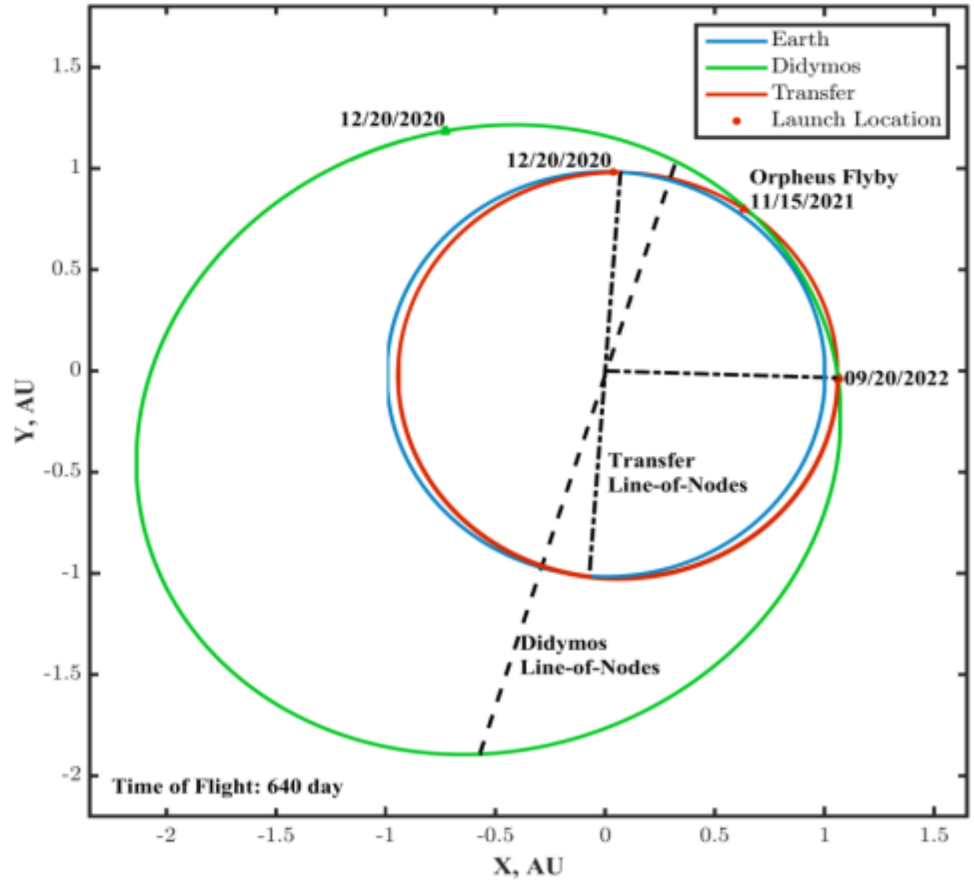
Modeling the Impact, Inferring Surface Physical Properties

Scaling relations and numerical simulations model the hypervelocity impact

- DART measurement of deflection without AIM constrains β and yields qualitative inferences of target properties
- With AIM, precise measurements of β and crater size better separate porosity and strength effects, but may still not be unique
- However, AIDA has additional handles on μ
  - Estimation from ejecta velocity distribution and from observing the ejecta distributions over time
  - If crater growth can be observed, determine μ
- A second impactor, at a different (smaller) impact velocity, would strongly constrain cratering models

DART: 2022 Didymos Intercept

- DART trajectory remains near 1 AU from Sun, Earth distance < 0.20 AU.
- Impact velocity 6.5 km/s
- Impact event in Sept-Oct, 2022, occurs under excellent Earth-based viewing conditions including radar
- NEA flyby 10 months before Didymos encounter



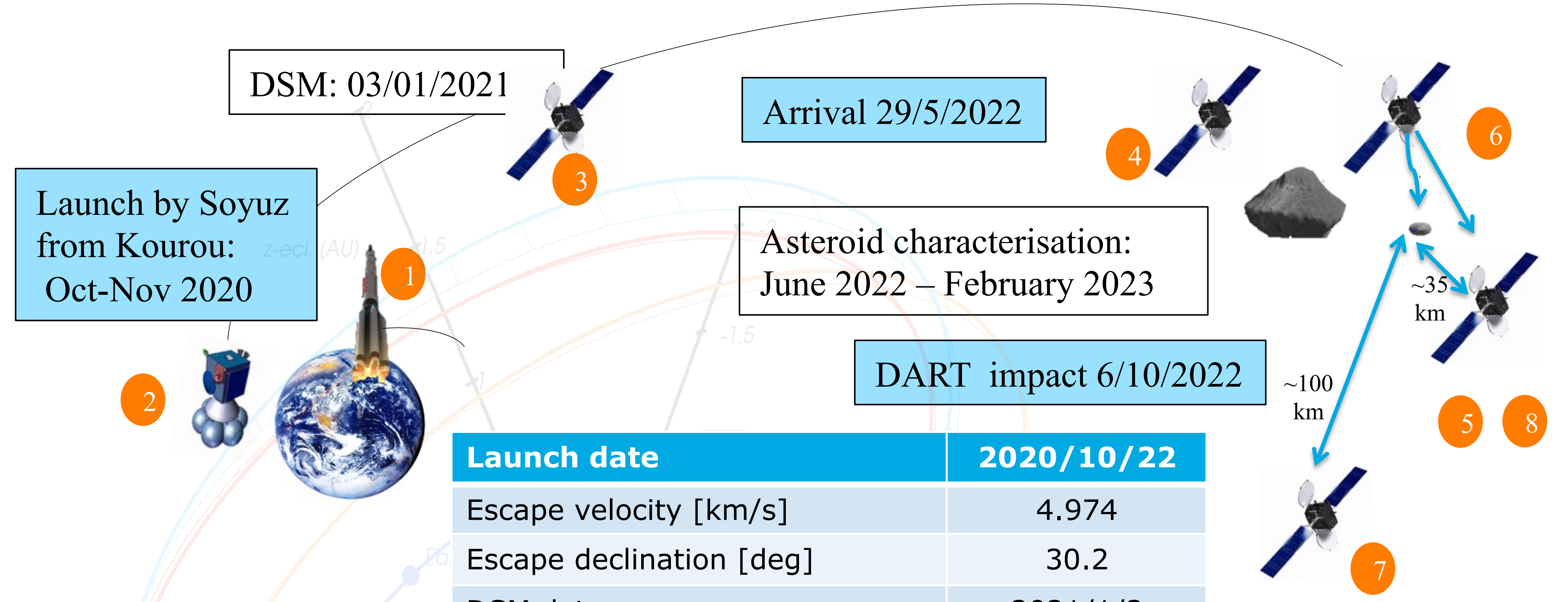
DART launches in Dec 2020 and intercepts Didymos on Sept 20, 2022

AIM Asteroid Research Objectives

P#	Parameter	Relevance to goal	Supporting instrument(s)
S#1	**Didymoon size, mass, shape, density**	Mass key to momentum, size to shape, volume, gravity and density to internal structure, operations	• Mass from binary orbit, spacecraft tracking (**RSE, Optel-D**) • Shape model from Visual Imaging System (**VIS**), laser altimetry (**Optel-D**)
S#2	**Dynamical state of Didymoon** (period, orbital plane axis, spin rate and spin-axis)	Key to determine momentum, indirect constraints on the internal structure	• **VIS**
S#3	**Geophysical surface properties, topology, shallow subsurface**	Bulk composition, material mechanical properties, and surface thermal inertia, key to determine momentum as shallow subsurface drives the efficiency of the impact shock wave propagation, data point to validate kinetic impact simulations	• **VIS** for surface features • Thermal InfraRed Imager (**TIRI**) for surface roughness • Hi-frequency radar **HFR** for shallow subsurface structure • **Accelerometer** on lander
S#4	**Deep internal structure of Didymoon**	Interior can affect absorption of impact energy, "data point" to validate asteroid mitigation models. Key to distinguish between scenarios of binary origin	• Low-frequency radar **LFR** • Drift-bys to estimate gravity field

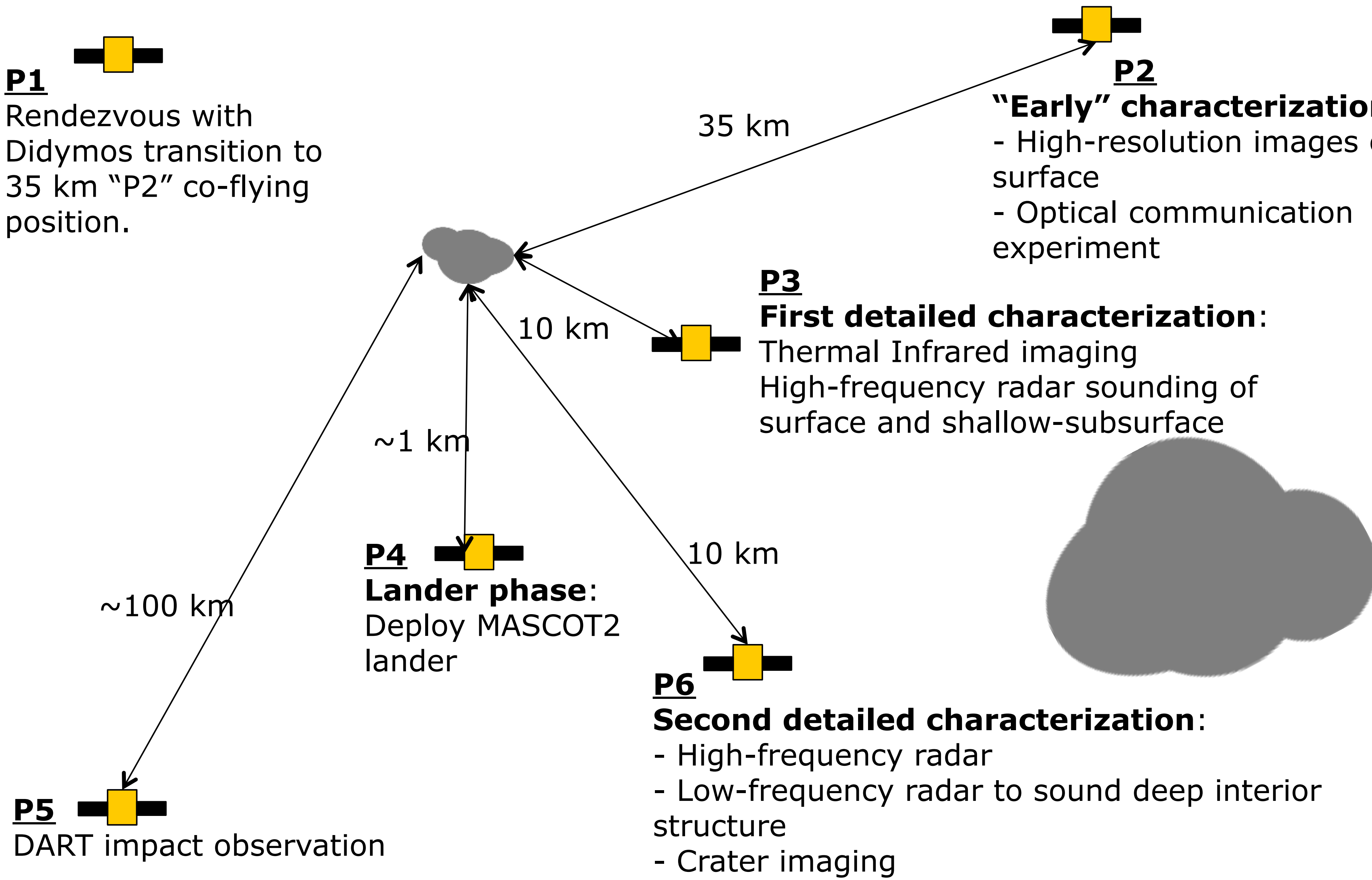
P#	Goal	Comment
T#1	**Qualify an end-to-end 2-way deep-space optical communications system for small missions**	• Primary goal transmit full asteroid 1m resolution map before DART arrival (goal, transmit images of the impact) • Components and operations representative of terminal developed for commercial applications. • Maximum platform independence: inertial pseudo-star pointing, mirror-stabilization, power-limited modes 135 W nominal @ 0.11 AU and 50 w power limited mode @ 3.3 AU max distance
T#2	**Demonstrate deep-space inter-satellite communication network for independent CubeSat-based sensors (COPINS)**	• Deploy up to two 3U cubesats (or any combination of units) • Demonstrate inter-satellite link network between AIM, COPINS and MASCOT-2 lander
T#3	**Demonstrate asteroid landing and extended operations in the secondary component of a binary system**	• Demonstrate landing on small (170 m) asteroid and inter-satellite link in deep-space • Test long-lived payload operation i.e. transmission radar and surface imaging, possibly other if resource allow.

AIM mission scenario



Launch date	2020/10/22
Escape velocity [km/s]	4.974
Escape declination [deg]	30.2
DSM date	2021/1/3
DSM size [m/s]	246
Asteroid arrival	2022/5/29
Duration [d]	584
Time to DART impact [months]	5
Arrival manoeuvre [m/s]	1004
Total Delta-v [m/s]	**1250**

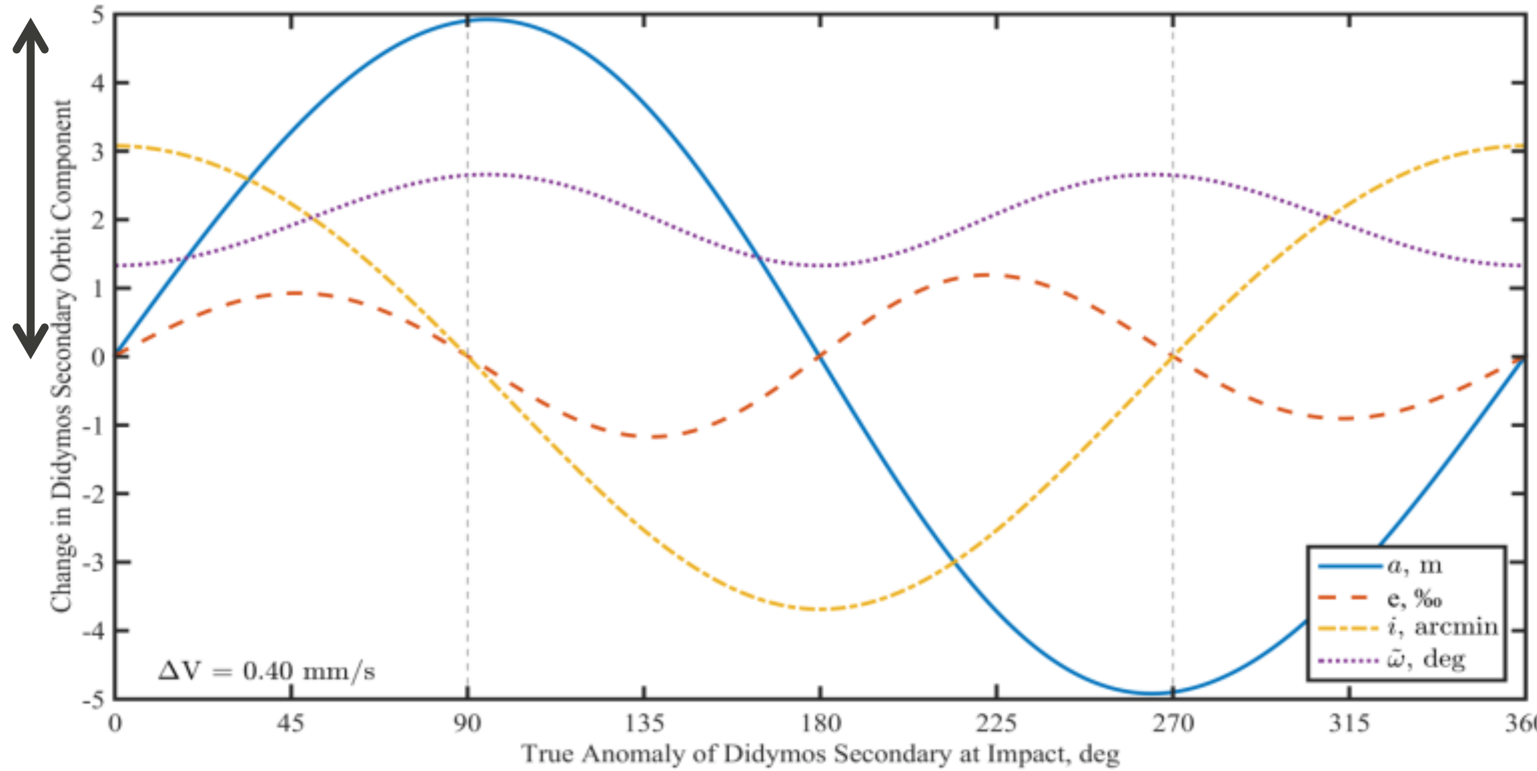
Close proximity Asteroid Operations: 29 May 2022 – 25 December 2022



Changes in Didymos Binary Orbit

DART will target true anomaly near 270°

Binary orbit period change of 273 sec



$\Delta V = 0.4$ mm/s for $\beta = 1$

Changes in Kepler orbit parameters of the Didymos binary from the DART impact, assuming the velocity change is along the incident momentum. These changes depend on true anomaly at the impact.