Asteroid Impact & Deflection Assess mission to the binary NEA Didymos

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First japanese to visit France in 1615

TSUNENAGA HASEKURA

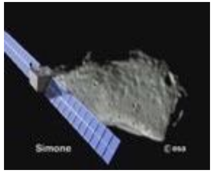
EUROPEAN BACKGROUND

ESA has been studying the role of space missions with respect to the NEO impact hazard since 1998 (Euneos, Nero, Earthguard, Simone, Ishtar, Don Quijote, Sancho, Proba-IP):

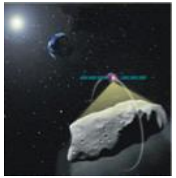
Euneos

Nero

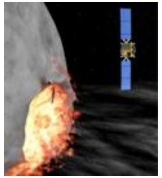
Earthguard



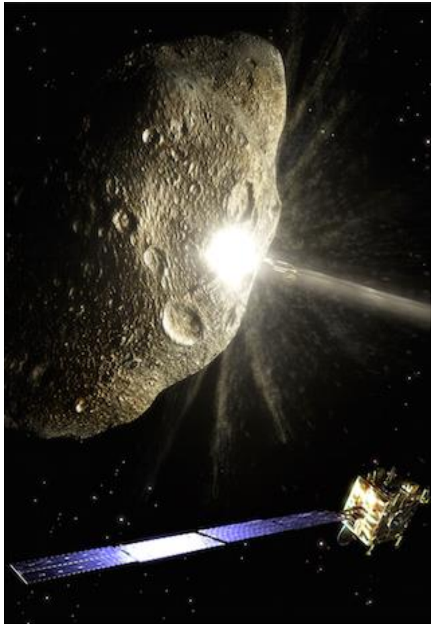
Simone



Ishtar



Don Quijote



- ESA Agenda 2015 calling for "…**initiating a planetary defence mission (possibly in cooperation with non-European partners) [which] would increase Europe's competitiveness since such a mission would require the development of new technologies also relevant to other missions.**"
- Leveraging on ESA systems and technology activities in several programmes: from Science to Mars Robotic Exploration, Lunar Lander as well as relevant activities in national Agencies (e.g. CNES, DLR). Numerous developments and lessons learned from past missions applicable to AIM (e.g. Rosetta, Proba…).

AIDA COOPERATION **Asteroid Impact & Deflection Assessment**

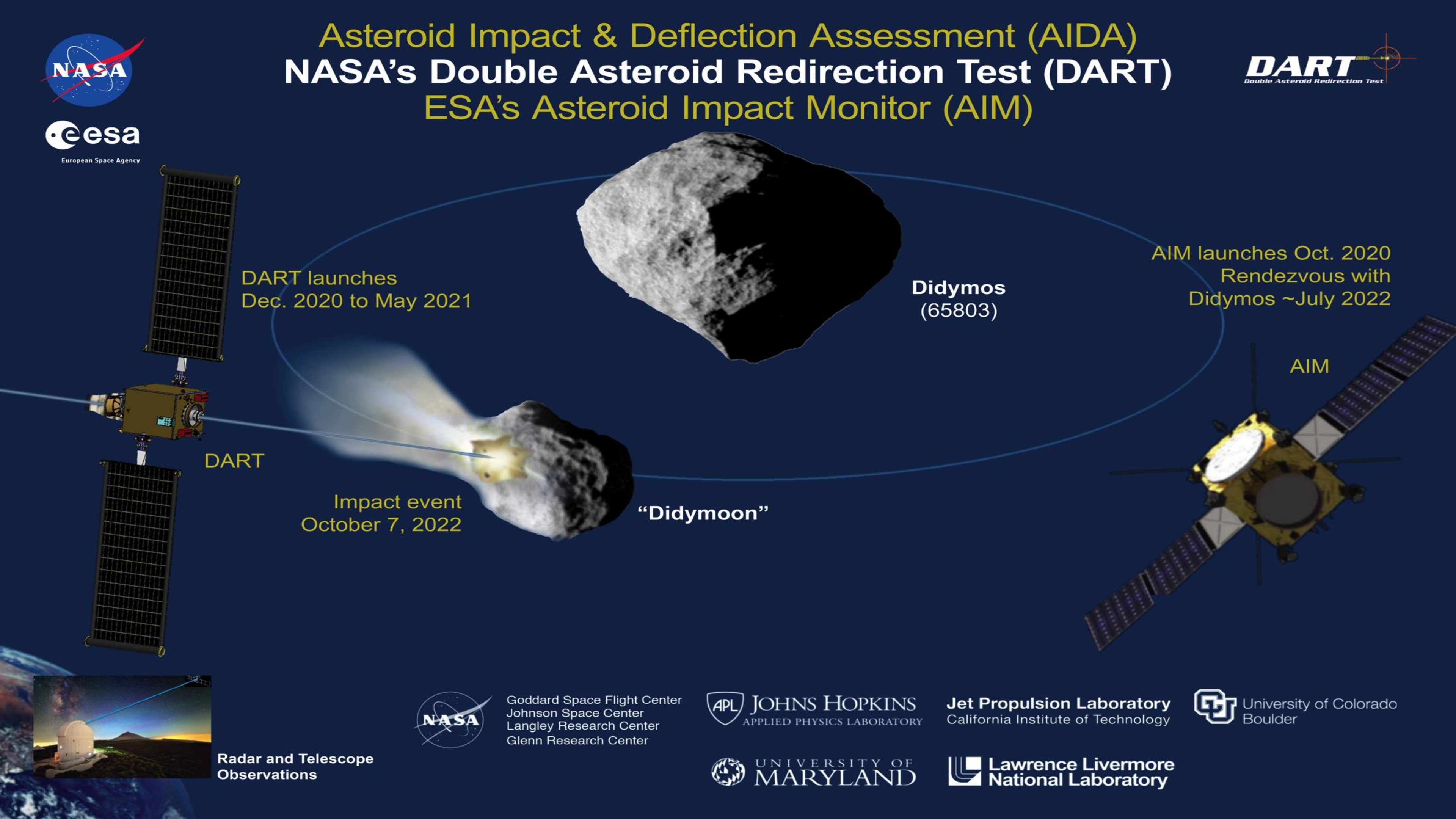
Two **simple**, **independent** and **self-standing** mission developments operated in coordination:

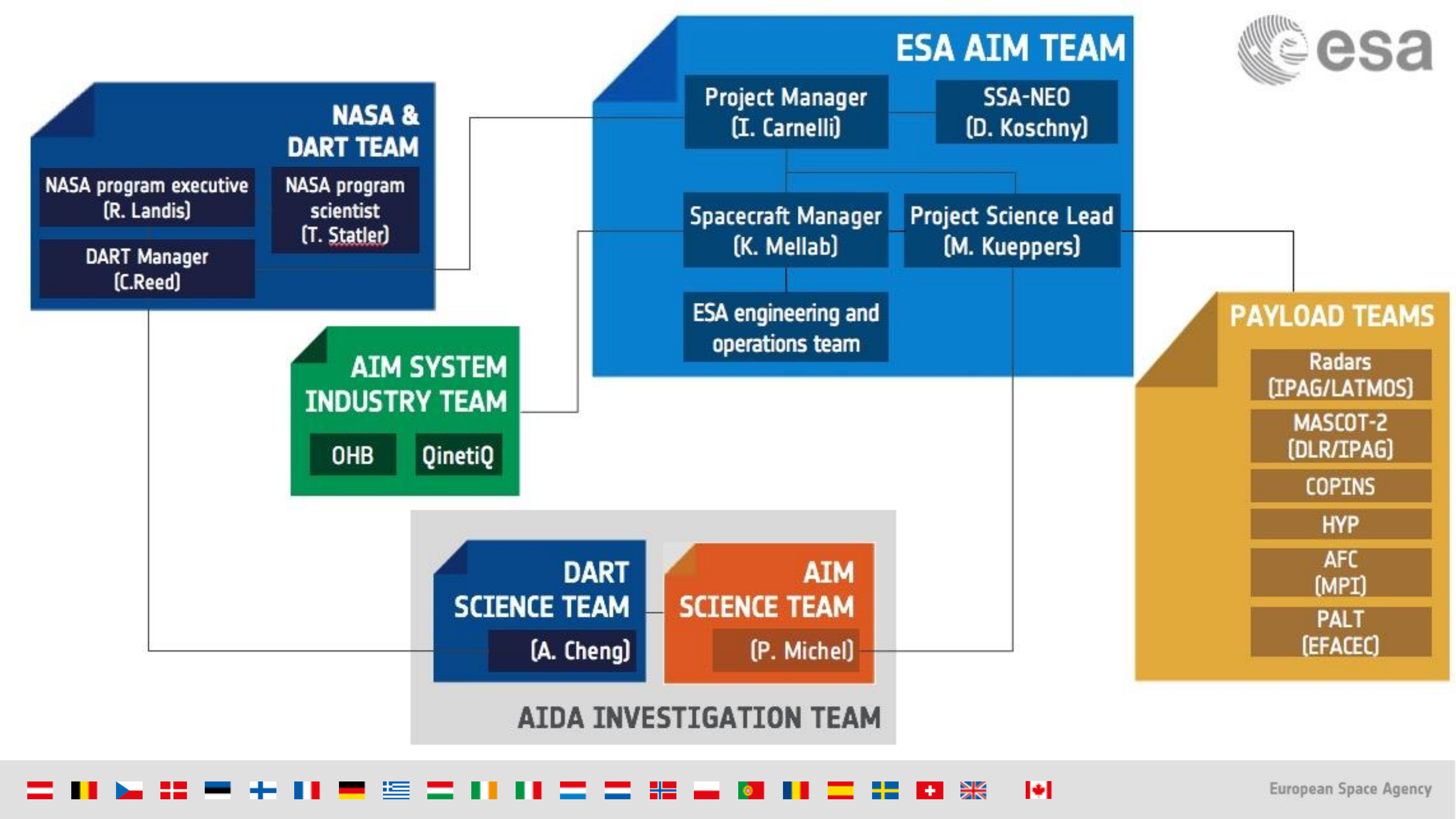
- demonstrate the ability to **modify the orbital path of Didymoon** and measure the deflection by monitoring the binary´s orbital period change
- measure all scientific and technical parameters to **interpret the deflection** and extrapolate results to future missions or other asteroid targets

aida

aim

dart


Asteroid Impact & Deflection Assessment (AIDA)
NASA's Double Asteroid Redirection Test (DART)
ESA's Asteroid Impact Monitor (AIM)
NASA
esa
European Space Agency
DART
Double Asteroid Redirection Test
DART launches
Dec. 2020 to May 2021
Didymos
(65803)
AIM launches Oct. 2020
Rendezvous with
Didymos ~July 2022
AIM
DART
Impact event
October 7, 2022
"Didymoon"
Radar and Telescope
Observations
Goddard Space Flight Center
Johnson Space Center
Langley Research Center
Glenn Research Center
JOHNS HOPKINS
APPLIED PHYSICS LABORATORY
Jet Propulsion Laboratory
California Institute of Technology
University of Colorado
Boulder
UNIVERSITY OF
MARYLAND
Lawrence Livermore
National Laboratory



ESA AIM TEAM
Project Manager (I. Carnelli)
SSA-NEO (D. Koschny)
Spacecraft Manager (K. Mellab)
Project Science Lead (M. Kueppers)
ESA engineering and operations team
NASA & DART TEAM
NASA program executive (R. Landis)
NASA program scientist (T. Statler)
DART Manager (C.Reed)
AIM SYSTEM INDUSTRY TEAM
OHB
QinetiQ
PAYLOAD TEAMS
Radars (IPAG/LATMOS)
MASCOT-2 (DLR/IPAG)
COPINS
HYP
AFC (MPI)
PALT (EFACEC)
DART SCIENCE TEAM
(A. Cheng)
AIM SCIENCE TEAM
(P. Michel)
AIDA INVESTIGATION TEAM
European Space Agency

OVERLAPPING GOALS OF NEO MISSIONS

Planetary Defense
Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties

Science
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition

AIDA
Deflection demonstration and characterization
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Sub-surface properties

Human Exploration
Orbital state
Rotation state
Size, shape, gravity
Geology, surface properties
Density, internal structure
Composition (mineral, chemical)
Radiation and Dust environment

Resource Utilization
Geology, surface properties
Density, internal structure
Sub-surface properties
Composition (mineral, chemical)

AIDA target: The binary asteroid Didymos

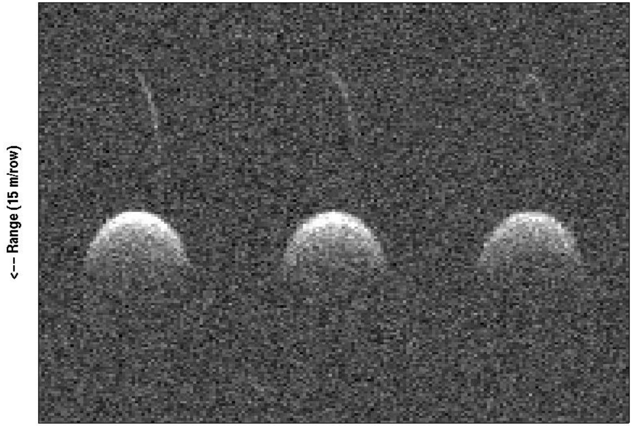
AIDA Target

The binary Near-Earth Asteroid 65803 (1996 GT) Didymos

- **Discovered in April 1996**
  - Perihelion distance 1.01 AU
  - Aphelion distance 2.3 AU
  - **Close approach to Earth in Oct 2022**
  - 0.07 AU range provides opportunity for ground observation of impact event

- **(YORP spin-up) binary system**
  - 770 m primary (rotation period 2.26 hr)
  - **163 m secondary** (synchronous?)
  - Secondary in 11.9-hr orbit
  - Distance between primary's and secondary's centers: 1.1 km

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



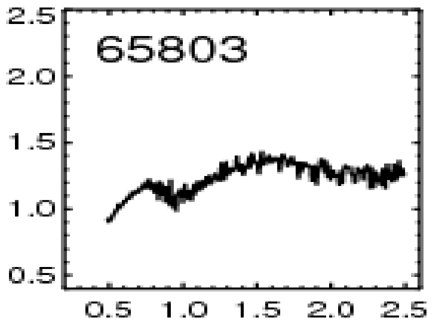
Radar image of Didymos
From L. Benner, Arecibo, Nov. 2003

Primary: Didymain
Secondary: Didymoon

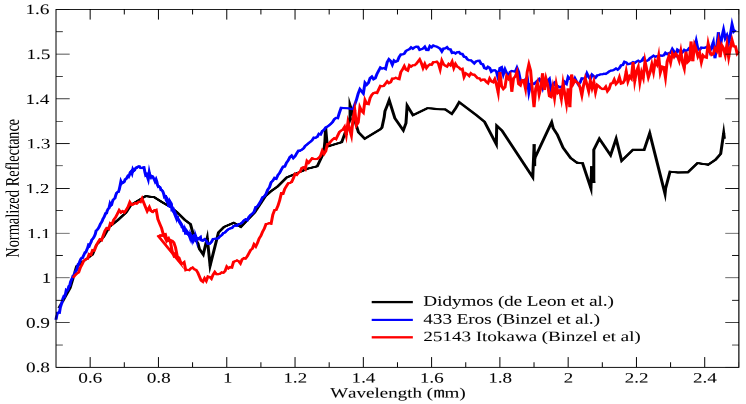
AIDA

Didymos: Spectral type

- Limited wavelength coverage by Binzel et al. (2004)
  - Classified as Xk
- Expanded coverage by de León et al. (2010)
  - Pretty clearly **S type**
  - Not exotic or new type
  - Context for Eros/Itokawa
- Likely meteorite analog: Ordinary Chondrite
  - Very common meteorite



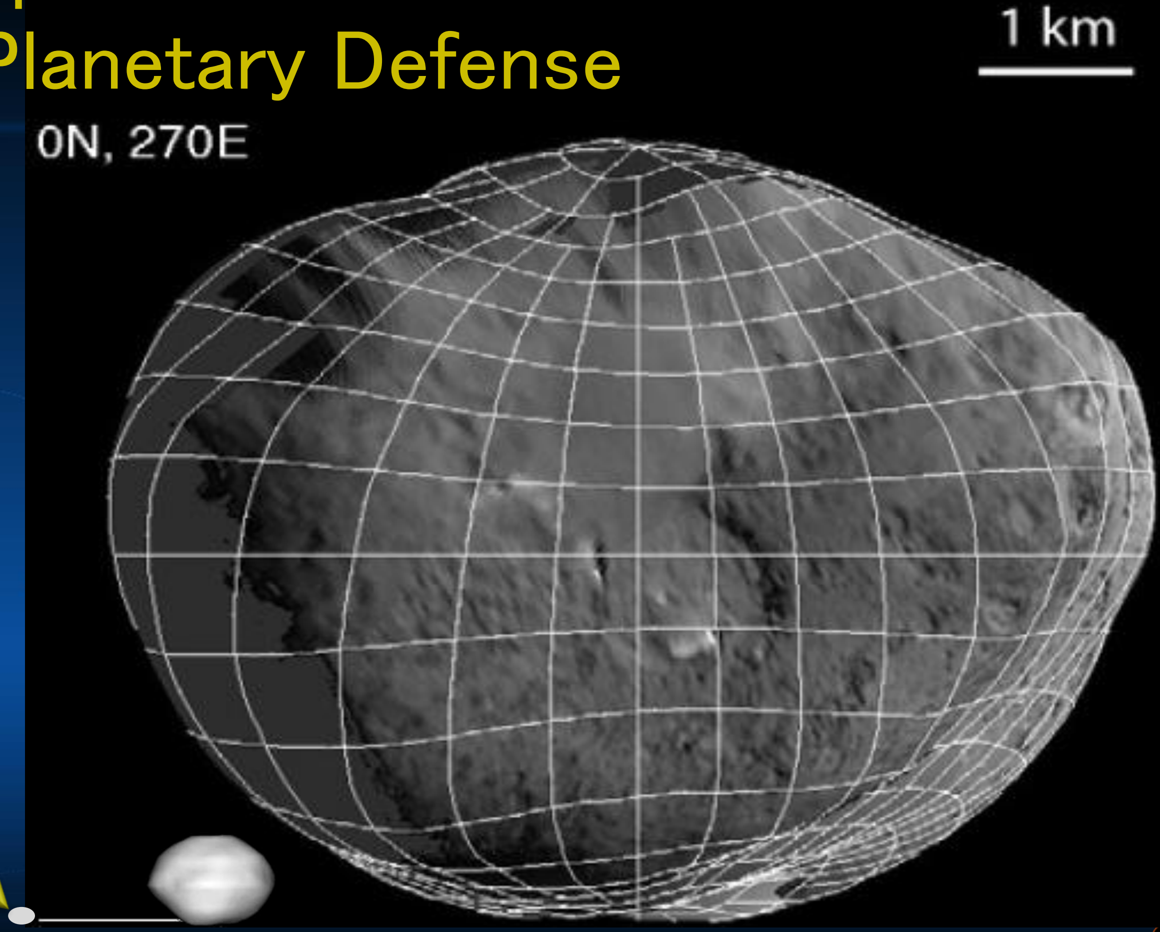
de León et al. (2010)



AIDA

First Kinetic Impact Test at Realistic Scale for Planetary Defense

DART target much smaller than the Deep Impact target

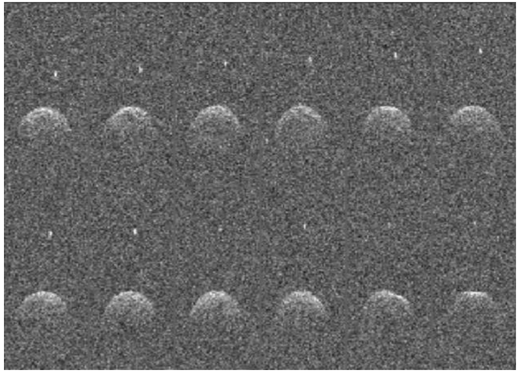


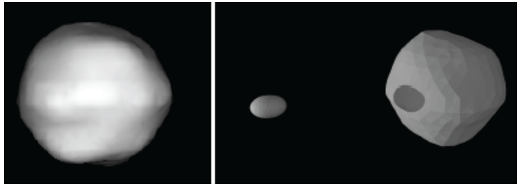
Comet 9P/Tempel 1
Deep Impact target

DART target
Didymos moon

DIDYMOS: A PERFECT TARGET

- Asteroid observed by ground telescopes and radars
- Heliocentric orbit well known
- Shape and size of primary well known (not Didymoon)
- Orbit plane orientation to be confirmed in 1Q 2017 (observations planned with European observatories)
- Didymoon size representative of a potentially hazardous object (generating casualties independently from impact location on Earth)



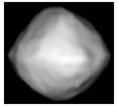


Chelyabinsk meteor (Feb 2013): 1500 injuries, 7200 damaged buildings

OSIRIS-REx and Hayabusa 2

- First detailed characterization and surface response of two primitive asteroids in different gravity conditions
  - Ryugu is 900 meter wide

  - Bennu is 500 meter wide

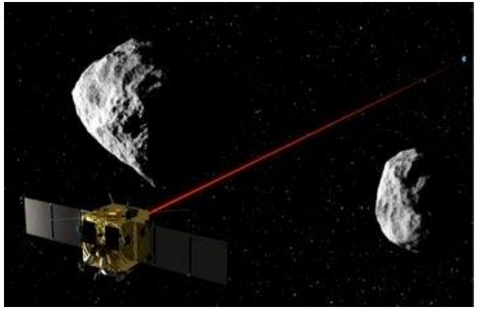


- **Didymos is ~ 3 times less wide than Bennu**
  - Another step in low gravity levels
  - **Possibility to understand how some processes scale with gravity down to the low-g of Didymoon (targets for mining)**

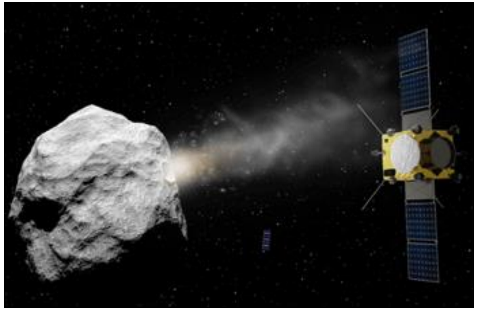
ASTEROID IMPACT MISSION (AIM)

Small mission of opportunity to explore and demonstrate technologies for future deep-space missions while addressing planetary defence objectives and performing asteroid scientific investigations.

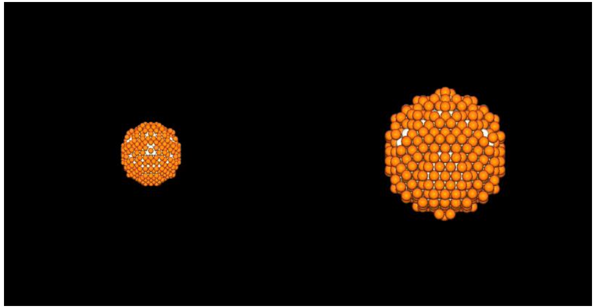
TECHNOLOGY DEMONSTRATION



ASTEROID IMPACT MITIGATION

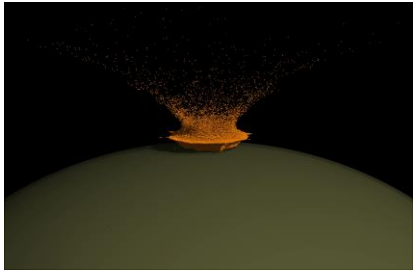


SCIENCE

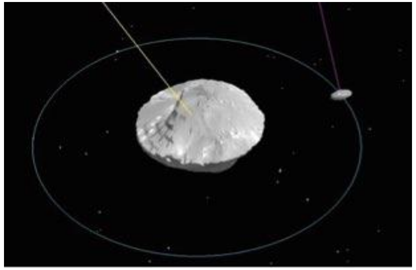


AIM "FIRSTS"

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** and **characterize asteroid deflection** by determining the "ejecta momentum amplification factor" of a kinetic impactor.



First mission to **study a binary asteroid,** its **origins** and sound the **interior structure** providing clues of its formation process.

AIM MISSON OBJECTIVES

- Demonstrate technologies for future deep-space missions:
  - **Deep-space optical communication**
  - **Deep-space inter-satellite links** with CubeSats/µlander
  - **Semi-autonomous operations** in low-gravity

- Demonstrate the ability to **modify the orbital path of Didymoon** and measure the deflection by monitoring the binary´s orbital period change
  - Measure all scientific and technical parameters to **interpret the deflection** and extrapolate results to future missions or other asteroid targets
  - **Correlate ground-based observations with in-situ measurements**

- Answer fundamental questions on our Solar system:
  - Are parameters (scaling laws) used in **collisional models** valid?
  - what physical processes lie behind the **formation of binary asteroids**?
  - what is the **internal and subsurface structure** of the natural satellite of a binary NEA?
  - what **links** can be established **between subsurface and the surface properties?**
  - what are the **mechanical properties** of a small asteroid's surface? **Cohesion**?

AIM (alone) PRIMARY SCIENCE OBJECTIVES

PARAMETER	RELEVANCE	SUPPORTING INSTRUMENTS
S#1 **Didymoon size, mass, shape, density**	Mass => momentum size => shape, volume, gravity density => internal structure	Camera (VIS), LIDAR (OPTEL-D), radio tracking
S#2 **Didymoon dynamical state**	Momentum transfer Indirect constraints on interior structure	VIS
S#3 **Geophysical surface properties, topology, shallow subsurface**	Composition, mechanical properties, thermal inertia =>Interpretation of impact	VIS, Thermal Infrared Imager (TIRI), High Frequency Radar (HFR), Accelerometer on MASCOT
S#4 **Deep-internal structure of the moonlet**	Interpretation of the impact Origin of binarity	Low Frequency Radar (LFR)
S#5 **Optical, IR, Radar calibration**	Simultaneous ground and space-based measurements to calibrate ground-based observations and extrapolate to other objects observed from the ground.	VIS, TIRI, HFR

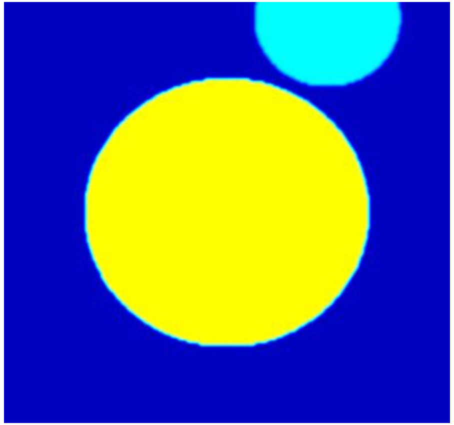
AIM (with DART) SECONDARY SCIENCE OBJECTIVES

PARAMETER	RELEVANCE	SUPPORTING INSTRUMENTS
S#6 **Didymoon post-impact characterisation**	Changes due to impact	All
S#7 **Didymain characterisation**	Origin of the system	VIS, TIRI, HFR, LFR
S#8 **Impact ejecta**	Porperties of ejected dust	VIS, TIRI, HFR
S#9 **Ambient dust**	Dust in Didymos environment	VIS, TIRI, HFR
S#10 **Chemical and mineralogical composition**	Asteroid classification, origin of the system	VIS (TBC), TIRI, MASCOT-2 lander

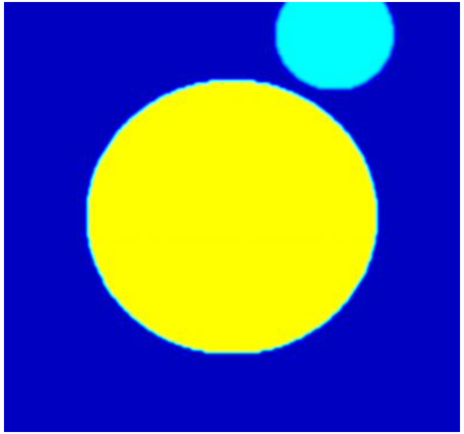
MAIN OBJECTIVES RELATED TO MITIGATION

First mission to measure properties to interpret an impact (DART) and inform mitigation:

- Target's mass and shape
- Dynamical state of the target(before/after impact)
- Surface and subsurface properties (FIRST TIME)
- Deep interior properties (FIRST TIME)

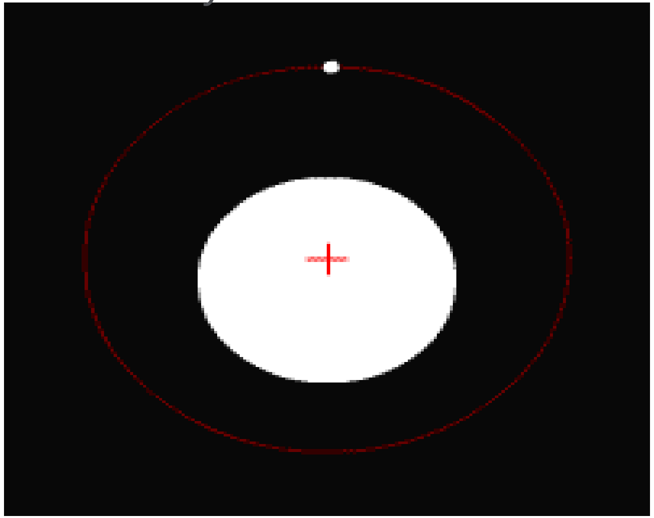


Non-Porous vs. Porous Structure

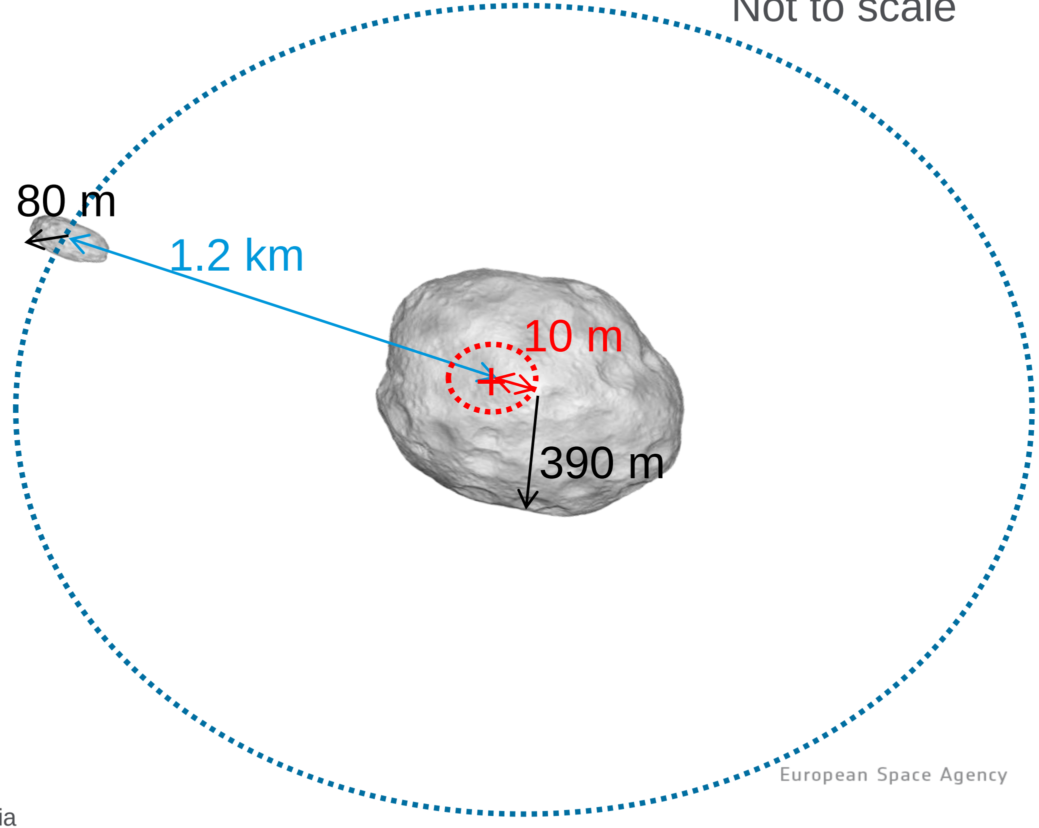


MASS DETERMINATION OF A SMALL ASTEROID MOON

- Mass measured to an accuracy of 10 % required to
  - Scale the impact experiment
  - Interpret the observations by AIM to constrain the mechanism of binary formation
- Translates to wobble measurement with accuracy of about 1m

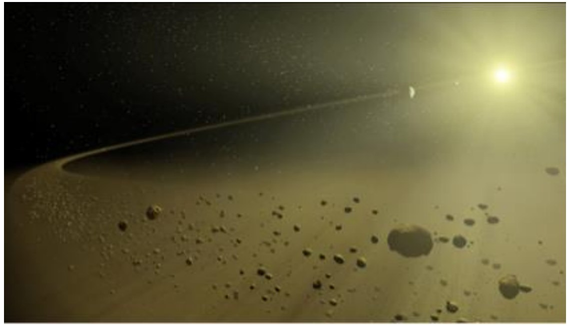


Source: Wikipedia



ROLE OF COLLISIONS IN THE SOLAR SYSTEM

Planetesimal formation

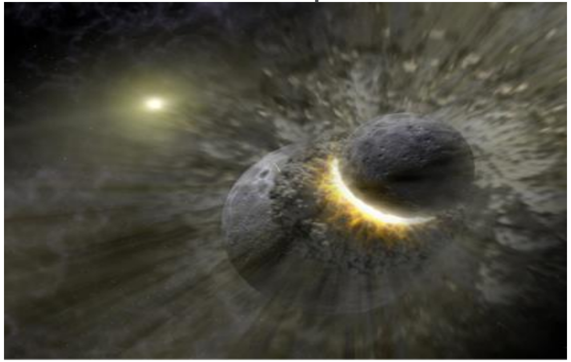


Collisional accretion

EARLY PHASES

Planet formation

Giant impacts



Collisional disruption

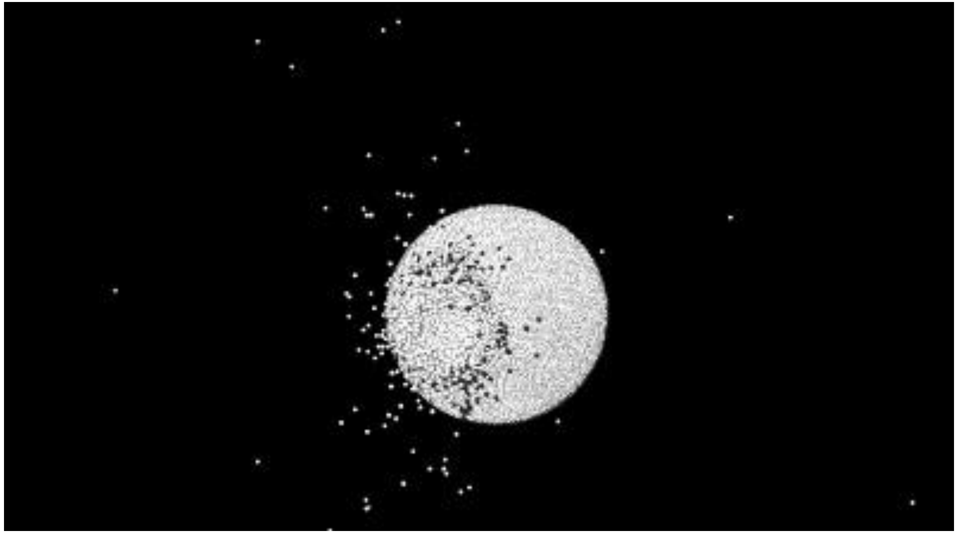
LATE PHASES

Asteroid disruption

COLLISIONS AND INTERNAL STRUCTURE KNOWLEDGE

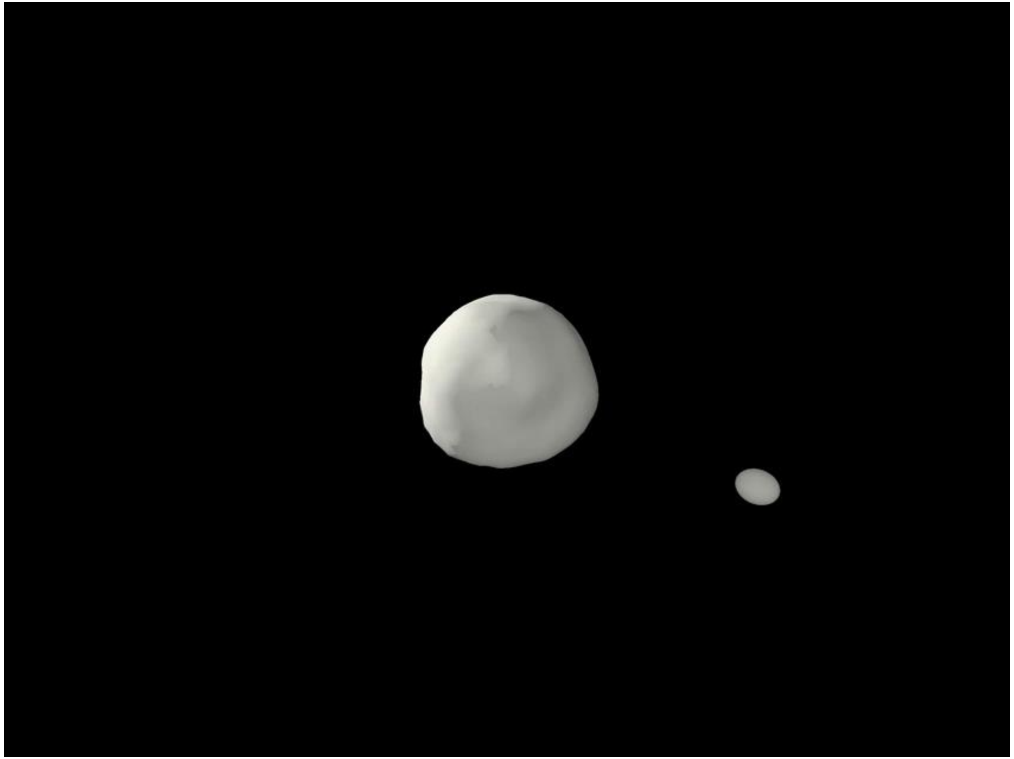
A big step in our understanding of the geophysics of small asteroids:

- Asteroid structures are tracers of the origin and evolution of the Solar System
- Asteroids formation and evolution glean insights into the history and properties of debris disks and planetary systems around other stars



FATE OF CRATER EJECTA IN A BINARY SYSTEM

AIDA will allow us to check/refine our understanding of impact physics at asteroid scale



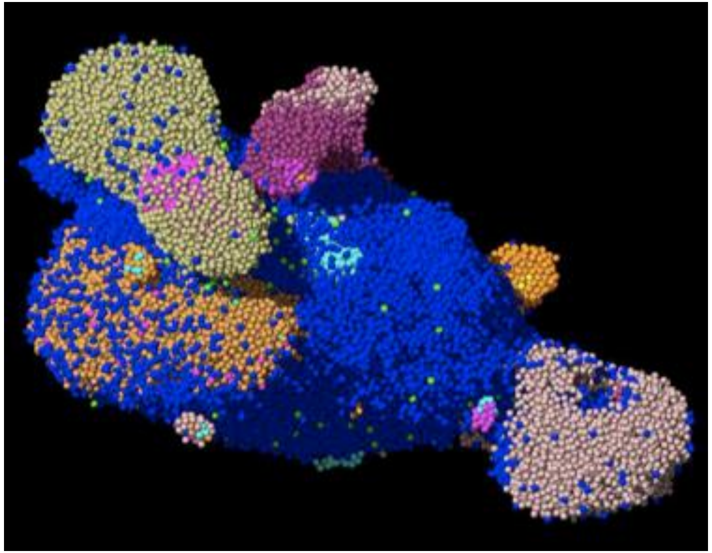
Ejecta evolution under:

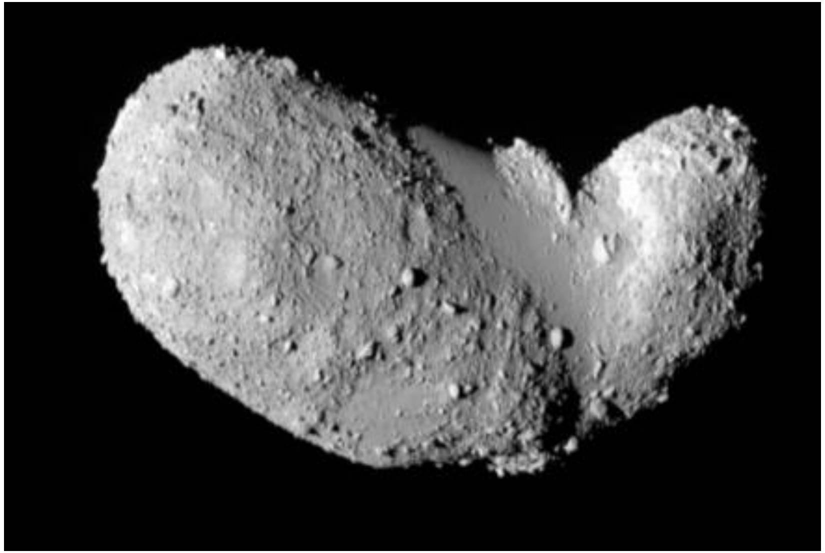
- Didymos' gravity
- Solar tides
- Solar radiation pressure

Yu, Michel, Schwartz 2016. Icarus, in press

INTERNAL STRUCTURE

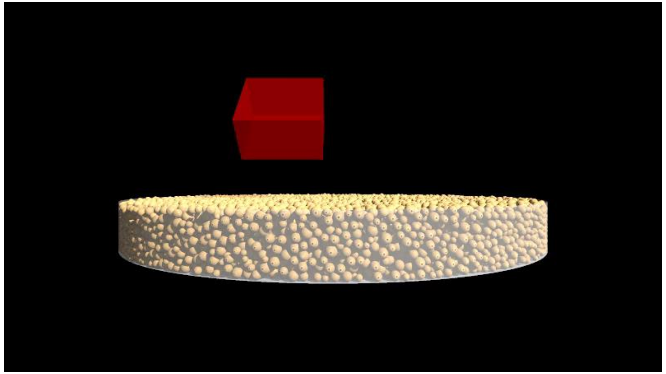
Current knowledge from both observations and modeling suggest that larger NEOs (> 200m BUT <50km) are rubble piles (or are at least heavily shattered)



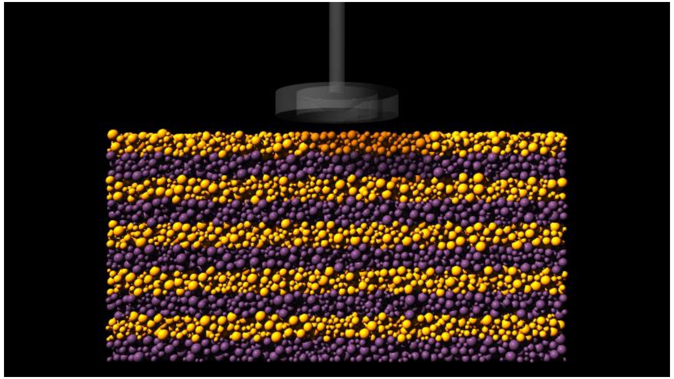


→ NO DIRECT MEASUREMENT AVAILABLE !

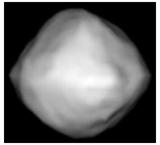
Surface interaction (lander, sampling device, impact) in low-g environment?

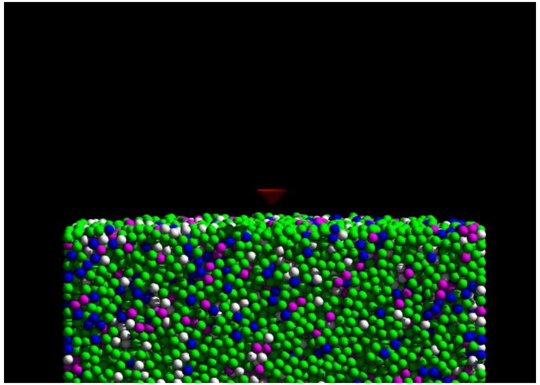


H-2 MASCOT lander bouncing
Ryugu (900 m) g-conditions
(C. Maurel, P. Michel, R.L. Ballouz)



O-REx TAGSAM compliance
Bennu (500 m) g-conditions
(R.L. Ballouz, P. Michel, D.C. Richardson)

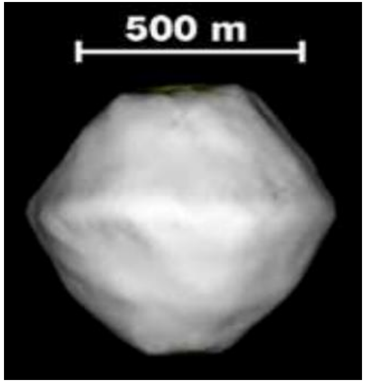




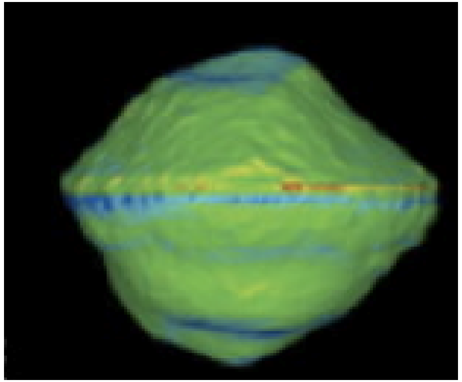
H-2 sampling mechanism
Ryugu (900 m) g-conditions
(S. Schwartz, P. Michel,
D.C. Richardson)

Modeling efforts have not been validated with an experiment in same conditions

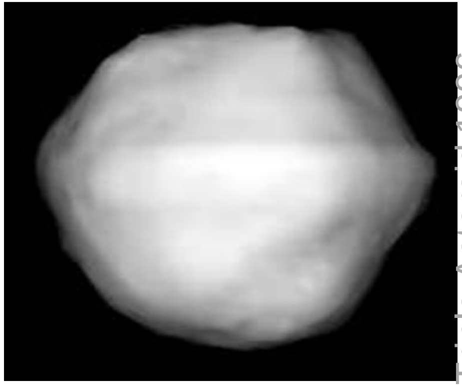
PREVALENCE OF "TOP SHAPES"



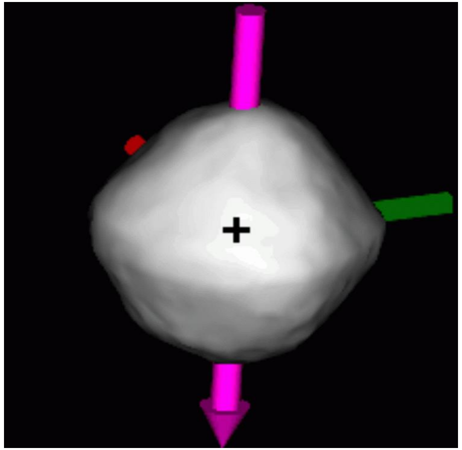
Triple Asteroid 1994 CC
Brosovic et al. 2011



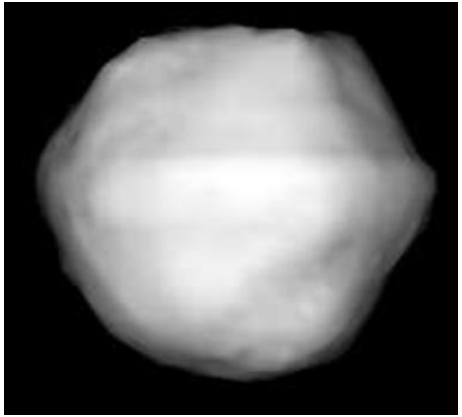
Binary Asteroid 1999 KW4
Ostro et al. 2005



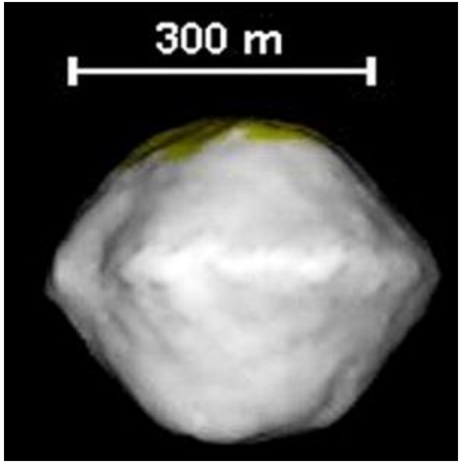
Triple Asteroid 1996 SN263
Becker et al. 2008



Single Asteroid Bennu
Howell et al. 2008, ACM



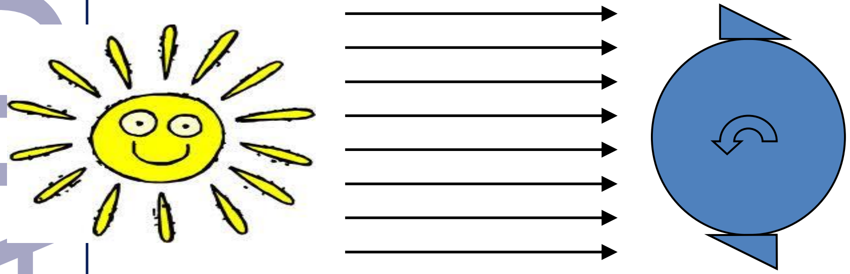
Binary Asteroid 2004 DC
Taylor et al. 2008, ACM

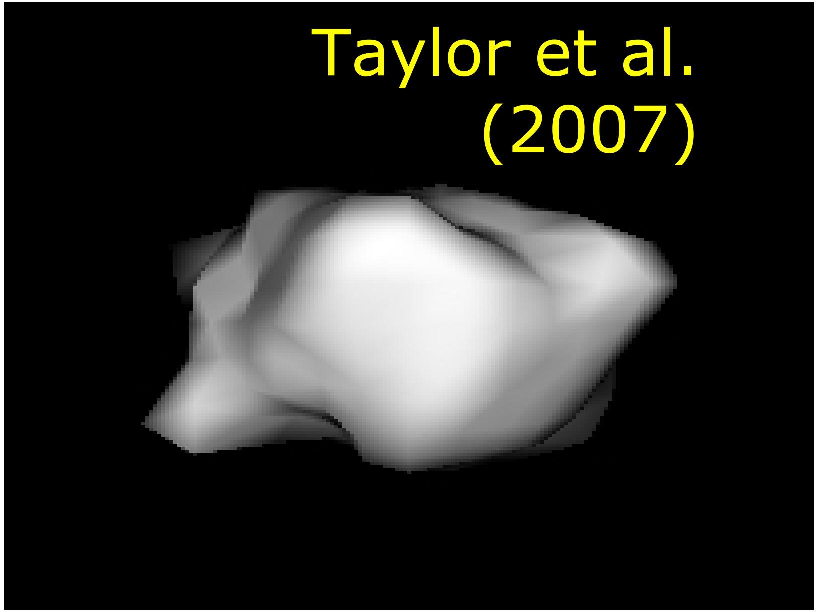


Single Asteroid 2008 EV5
Busch et al. 2011

Binary formation: Spin–up by YORP?

- Spin state change due to reflectance/re-emission of absorbed solar radiation.
- Depends on body size and distance from Sun.
- Spin-up timescale ~Myr.





54509 YORP: 12.2-minute rotation and speeding up…

Binary formation: Spin–up by YORP?

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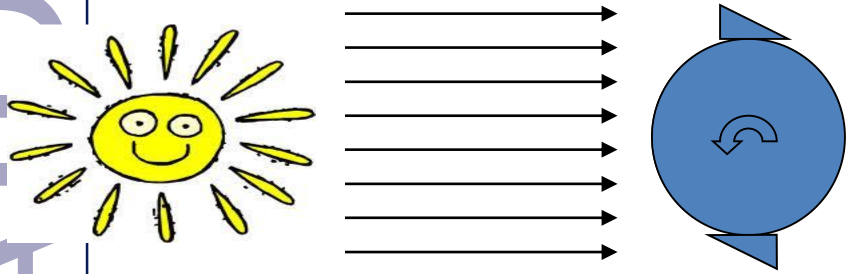
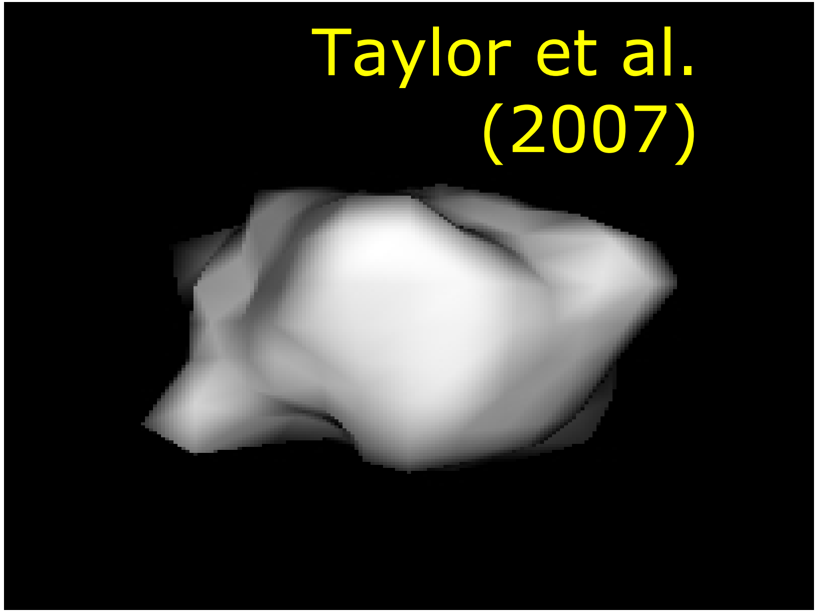




54509 YORP: 12.2-minute rotation and speeding up…

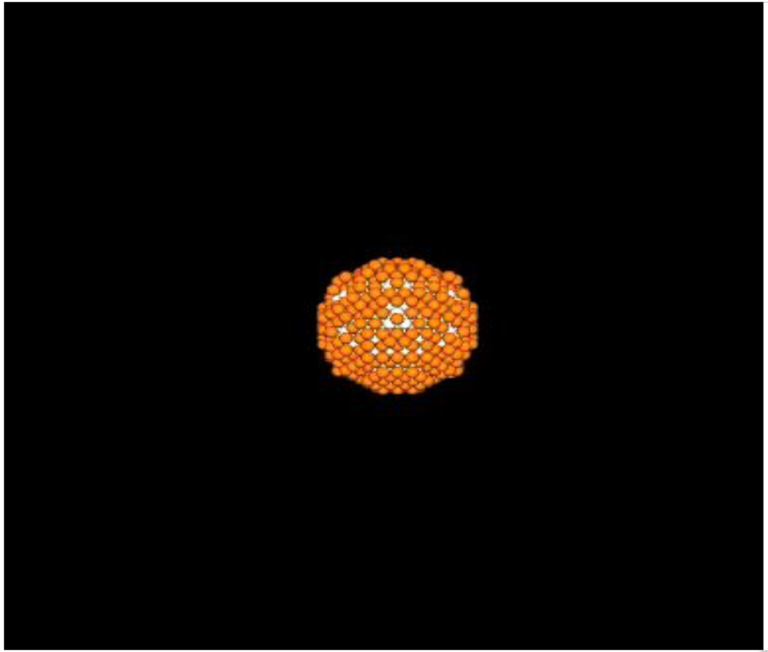
AIDA

Simulating binary formation by YORP

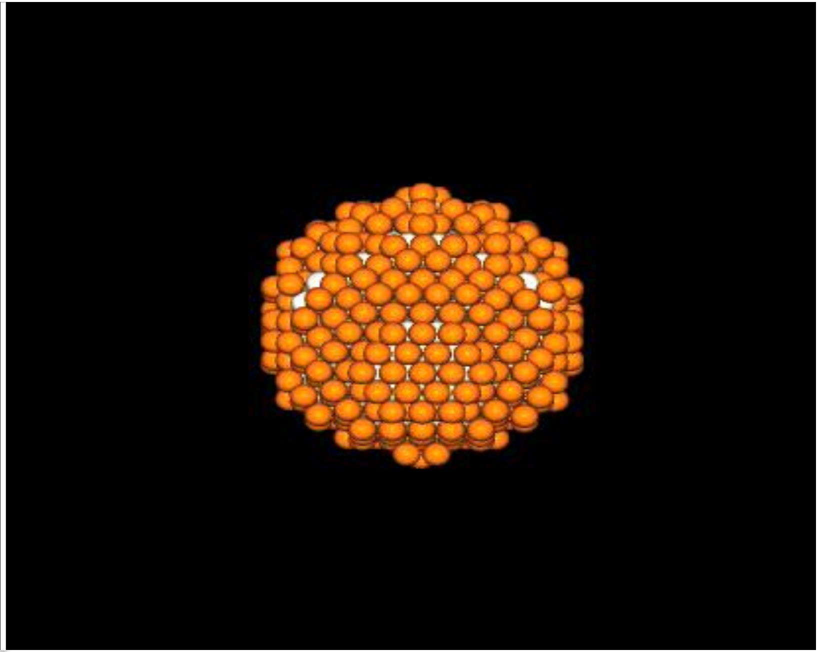
nature International weekly journal of science
LETTERS
Vol 454 | 10 July 2008

Rotational breakup as the origin of small binary asteroids

Kevin J. Walsh[1,2], Derek C. Richardson[2] & Patrick Michel[1]

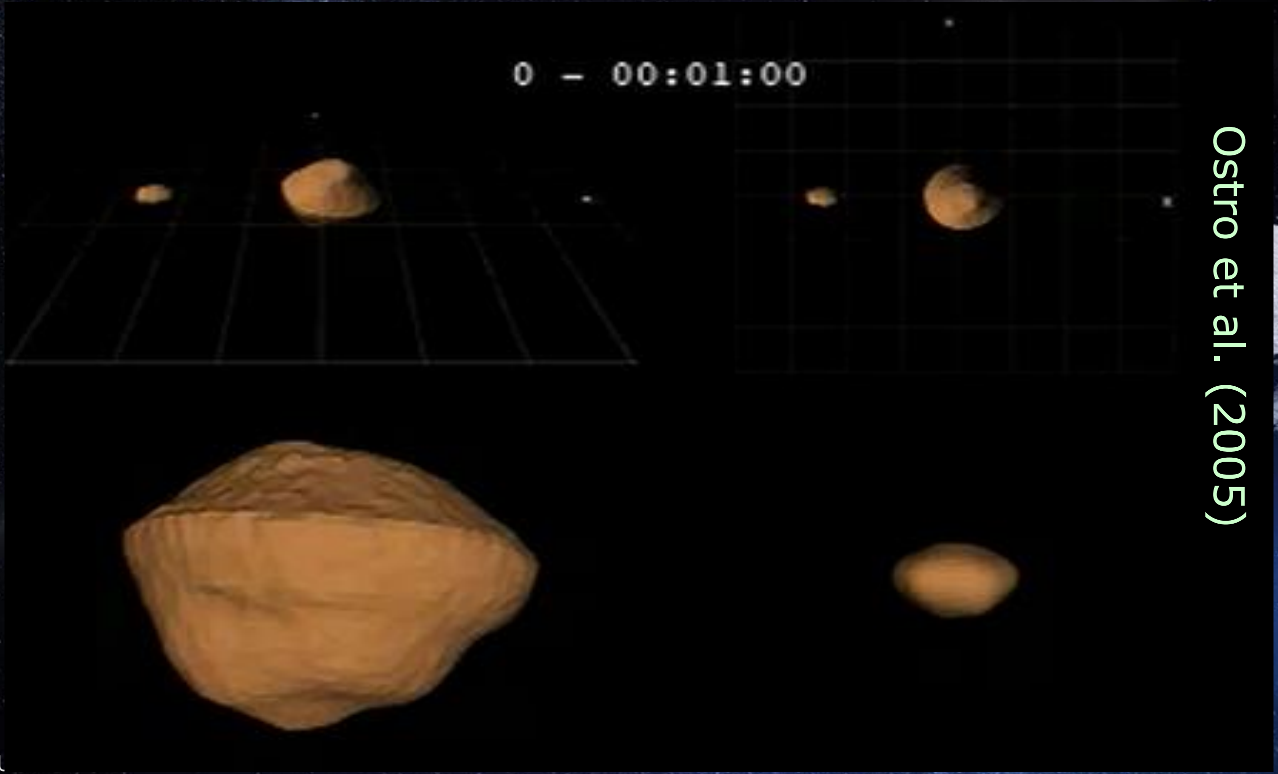


Top view



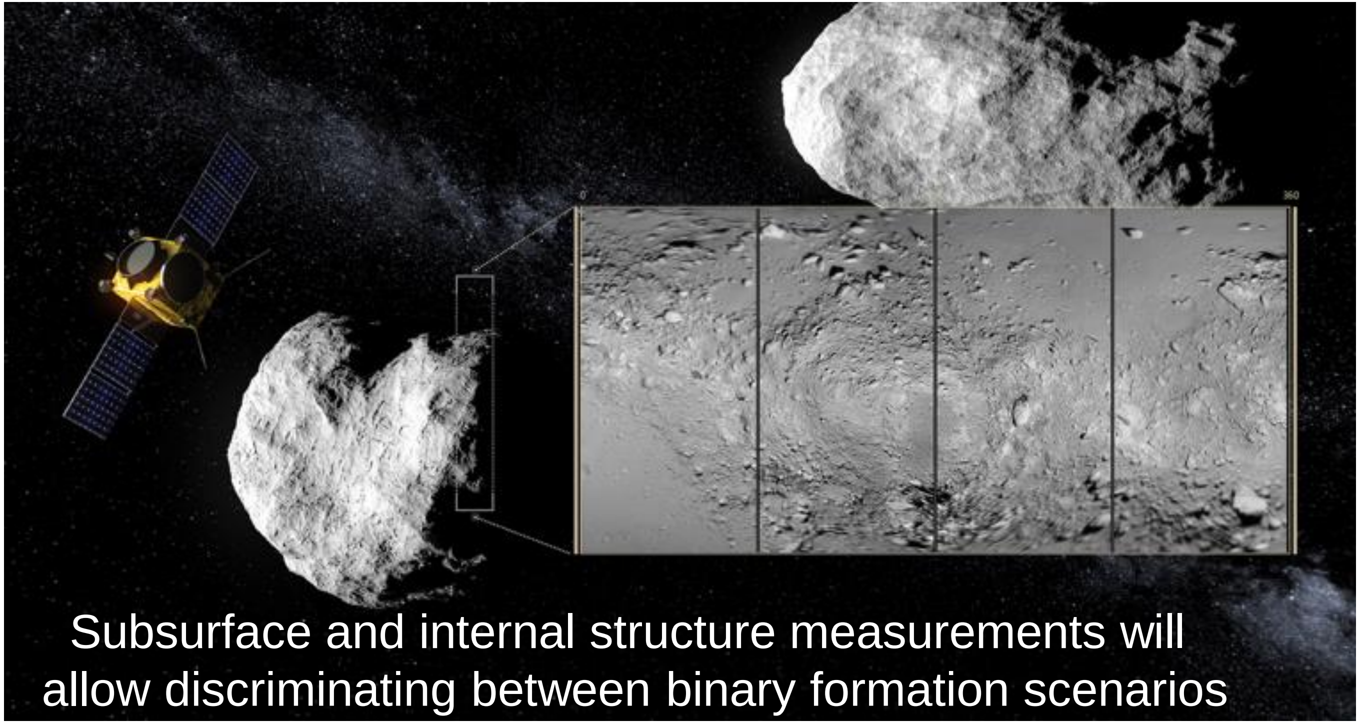
Side view

YORP spinup can explain the top shape of the primary and secondary/primary size ratio



Ostro et al. (2005)

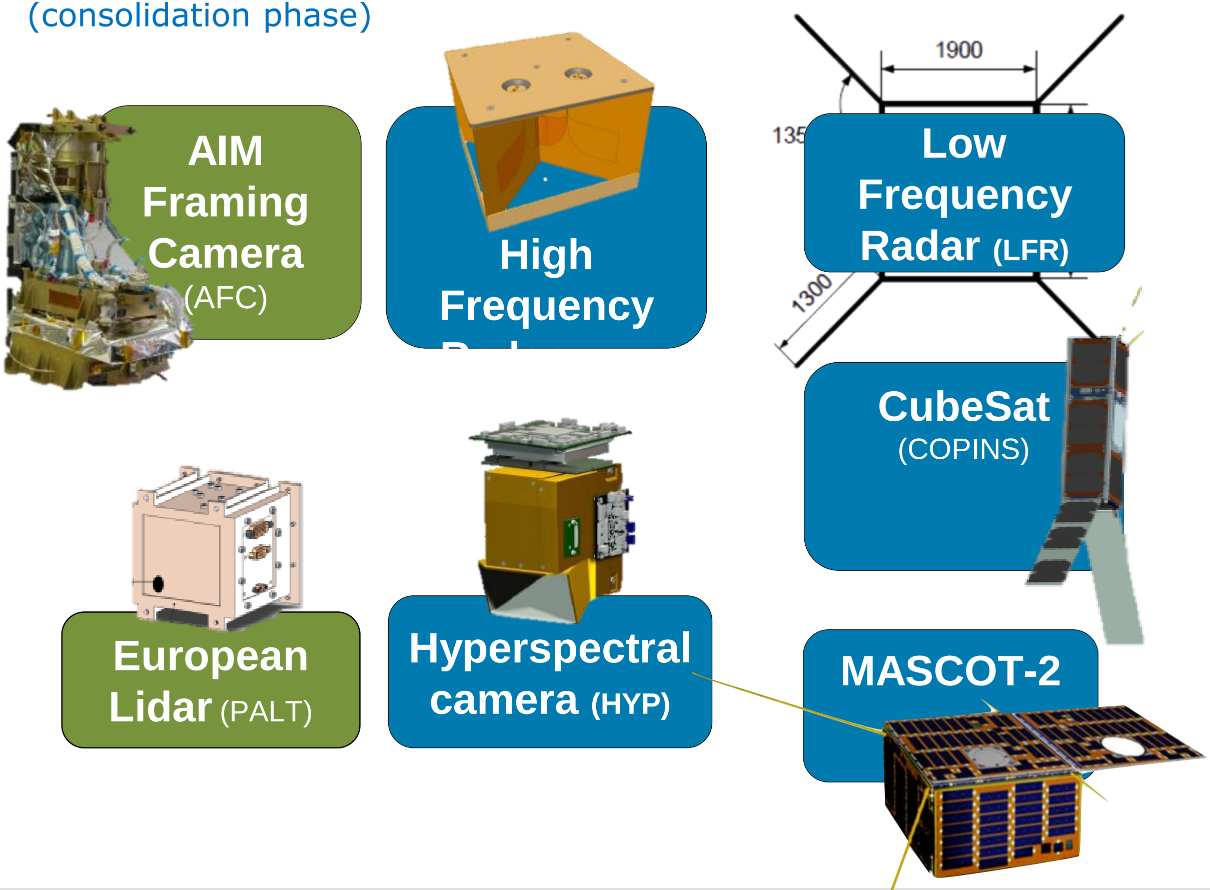
BREAKTHROUGH IN UNDERSTANDING BINARIES FORMATION



→ Mainly: two different models are proposed to form binaries

AIM REFERENCE PAYLOAD

(consolidation phase)



- Several options studied in detail to prepare for proper **interfaces** and **proximity operations**.
- Announcement for payload opportunities to be released in **Jan 2017** (after CM16).

Legend: Potential provider companies (country)

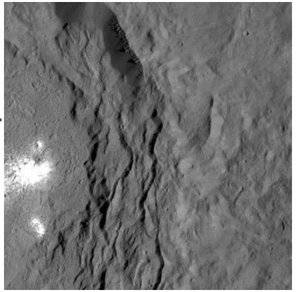
Built-in AIM S/C (GNC subsystem)

AIM Framing Cameras (AFC), Hyperspectral Imager

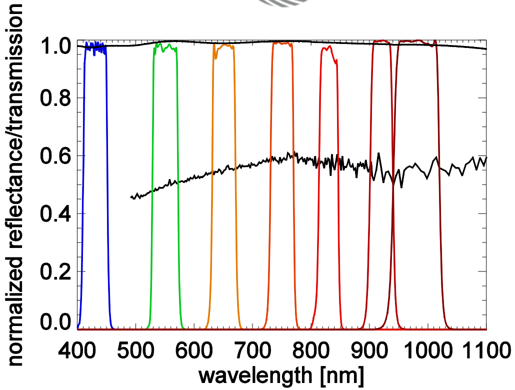
Flight Spares of the DAWN cameras

(5.5° FOV, 93.7 µrad/pixel, 400-1000 nm, 7 filters)

- spacecraft GNC system, provided by MPI for solar system research
- Used for spacecraft navigation but also science
- Navigation currently being tested at GMV with QM

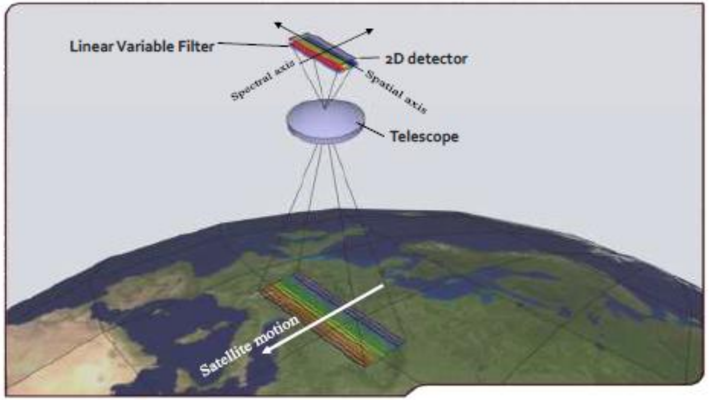


DAWN FC image of Ceres

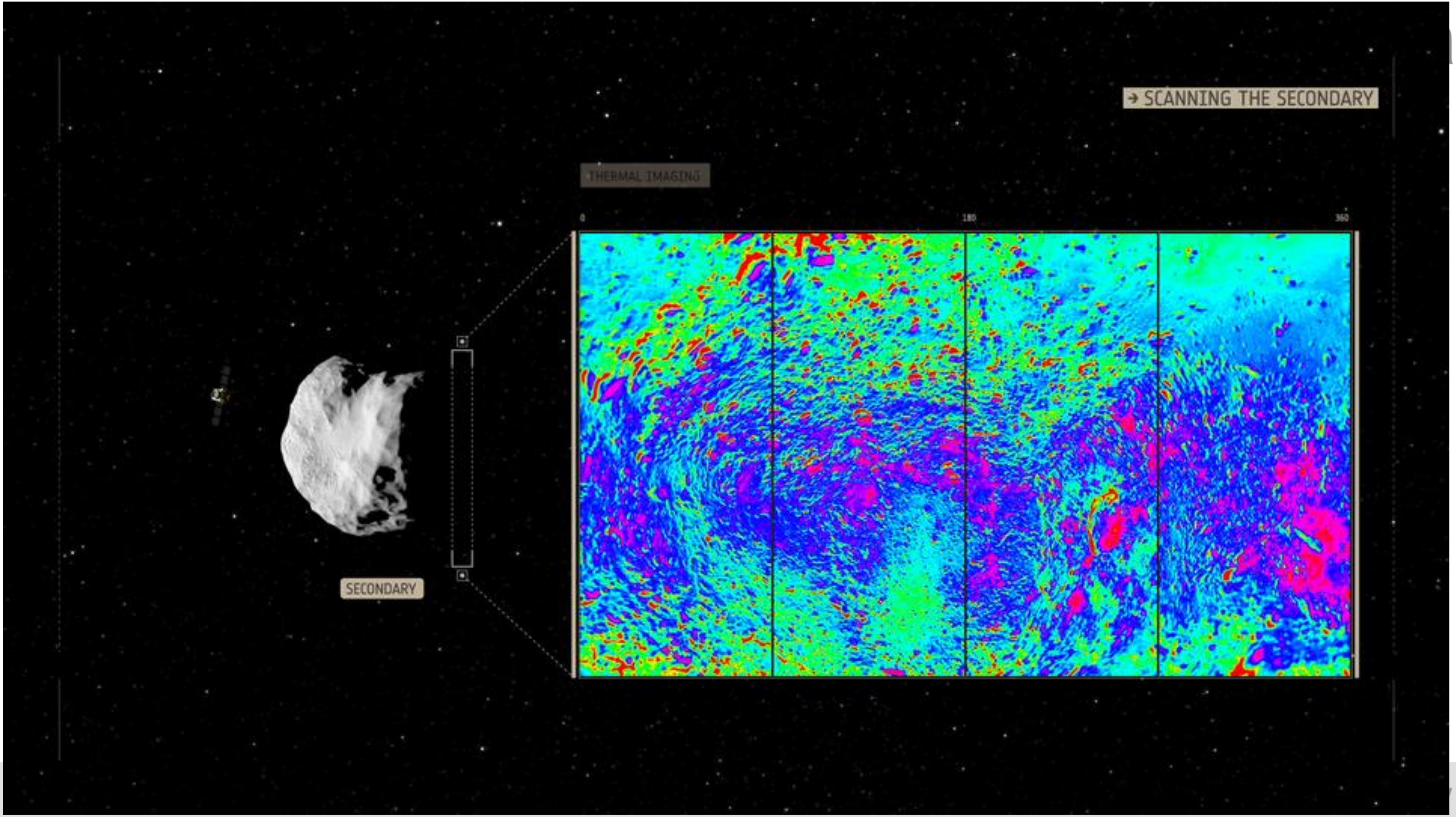


Compact Hyperspectral imager

- Grating spectrometer or linear filter fixed on CMOS detector
- Large detector, 7 x 9 deg. FOV at 8 arcsec/pix
- Spectral resolution 5-10 nm
- Wavelength range 470-950 nm
- Developed for Earth observation

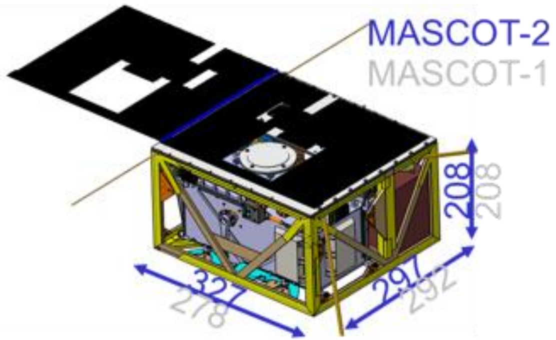


PLANETARY RESOURCES INC. (LUX), AMOS (BE), VITO (BE), COSINE (NL)



→ SCANNING THE SECONDARY
THERMAL IMAGING
0
180
360
SECONDARY

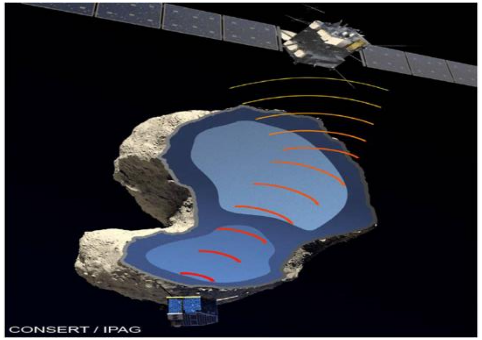
MASCOT-2 μLANDER, LOW-FREQUENCY RADAR



MASCOT-2 μlander

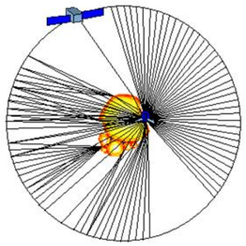
- Development based on MASCOT-1 currently on JAXA's Hayabusa-2 mission
- Size: 33 x 30 x 21 cm
- Mass: 15 kg
- Deployable solar generator cover (supports orientation)
- 3 months operational lifetime
- Carries: μ-camera (CAM), low-frequency radar (LFR), radiometer (MARA), accelerometer (DACC)

DLR (DE), SSC (SE), Cobham Gaisler (SE), CBK (PL), Astronika (PL), COSINE (NL), CGS (I), SELEX (I), POLIMI (I), Space-X (CH), CSEM (CH), MCSE (CH)



Instrument design based on CONSERT (Rosetta)

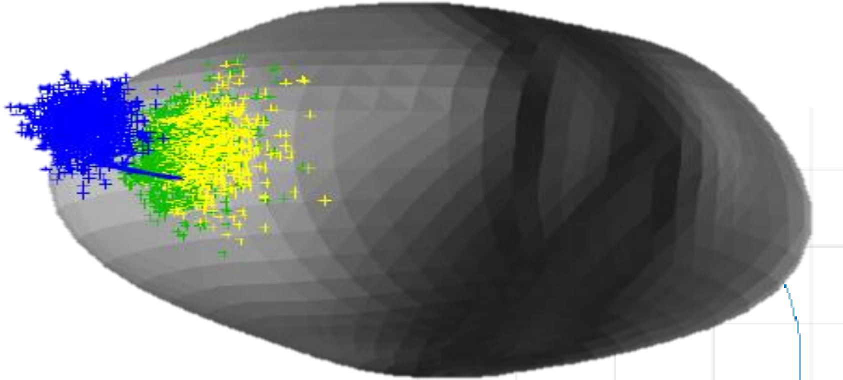
- Spare components available and TRL6
- Radar type: Bistatic radar (between AIM and MASCOT-2)
- Carrier frequency: 60 MHz
- Bistatic operation through the secondary asteroid

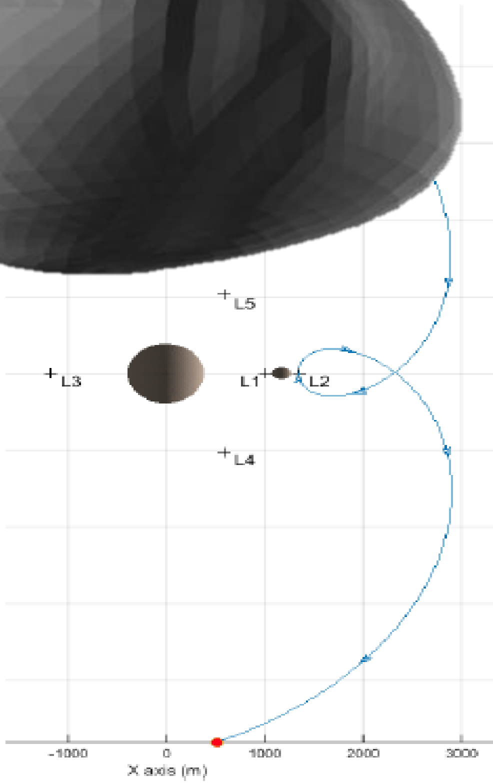


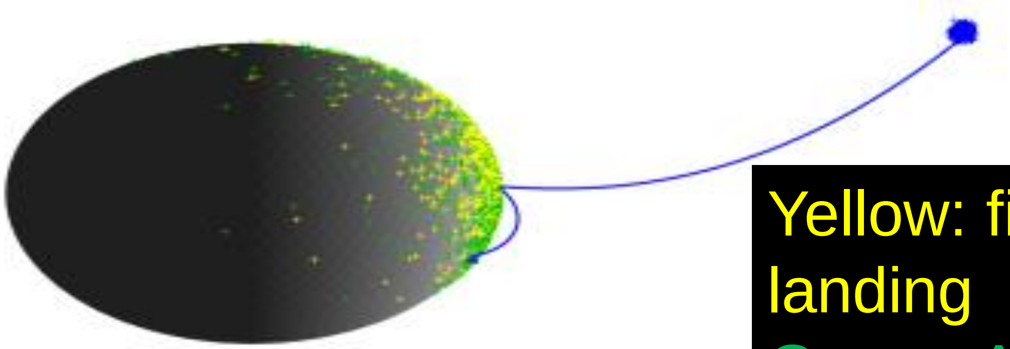
IPAG (FR), LATMOS (FR), Univ. Dresden (DE), ROB (BE), Antwerp Space (BE), Astronica (PL), CBK (PL)

LANDING ON A SMALL ASTEROID MOON

- Needs accurate (position and velocity) release from close distance (200 m max.) due to proximity of primary asteroid
- Low gravity implies bouncing -> low landing velocity needed







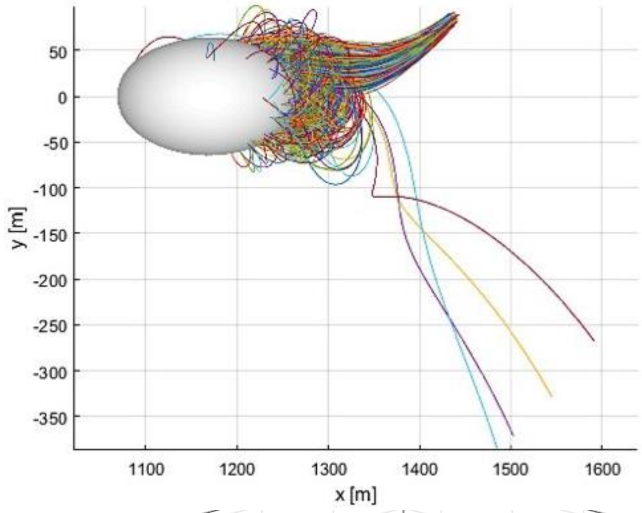
Credit: S. Biele, S. Ulamec

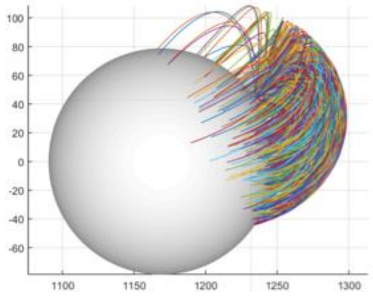
Yellow: first landing
Green: After bouncing

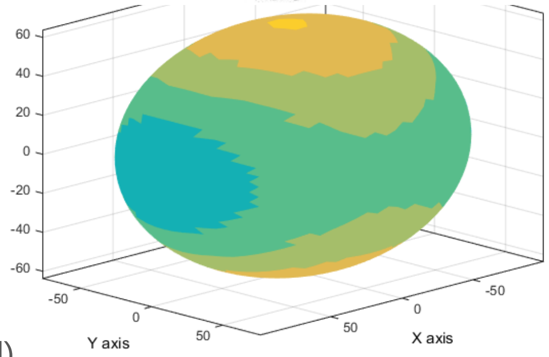
LANDING ON A SMALL ASTEROID MOON

MASCOT-2 RELEASE

1. The main perturbation due to the uncertainty on Didymos gravity field
2. The minimum TD velocity from outside Didymoon SOI 5.14 cm/s (L2)
3. Robust landing solutions have TD velocities on the order of 6 cm/s
4. Uncertainty on first touch down dispersion depends mainly on uncertainty on release velocity
5. No targeting possible when releasing from outside SOI
6. 96% landing probability from 200m with 10 m relative position error, 1 cm/s, 0.9 restitution coeff.

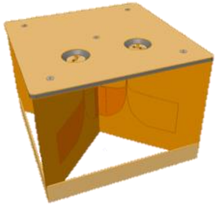






Escape velocity from L2, ranging from ~4 to ~6 cm/s (S. Tardivel)

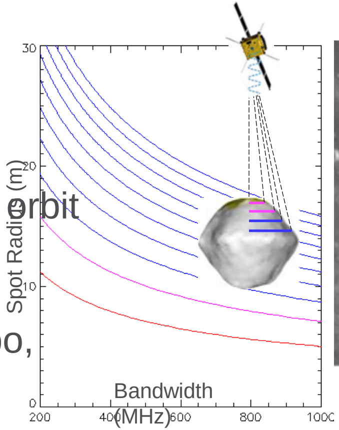
HIGH-FREQUENCY RADAR (HFR)

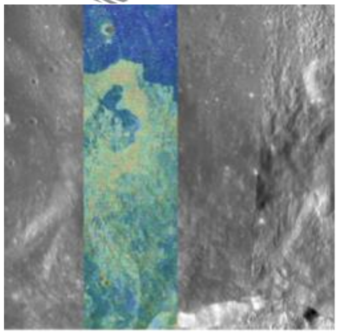


Stepped high-frequecy frequency radar

(300MHz to 2.4GHz, 108W power, 2.86kg, 37 x 37 x 27 cm3)

- determine structure and layering of shallow sub-surface
- support asteroid mass determination, shape modelling and orbit characterisation
- observe ejecta cloud
- support ground-based bi-static radar measurements Arecibo, Goldstone, SRT





IPAG (FR), LATMOS (FR), Univ. Dresden (DE), ROB (BE), Antwerp Space (BE), Astronica (PL), CBK (PL)

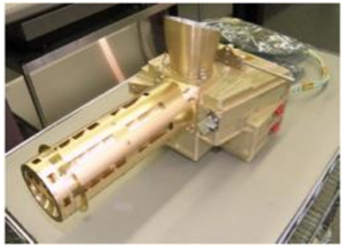
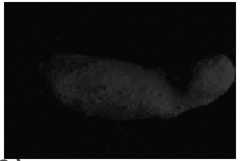


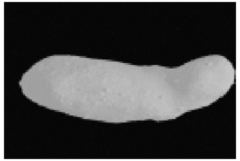
Figure: MERTIS

TIRI strawman design

- Heritage: MERTIS (Bepi-Colombo), MAIR, HIBRIS, AMS
- Temperature range: 200 K – 450 K
- Spectral range: 8 µm – 13 µm (spectral resolution 0.3 µm)
- Spatial resolution (goal): 2 m @ 10 km
- Field of view: ~5 deg., similar to cameras
- Thermal and physical surface properties



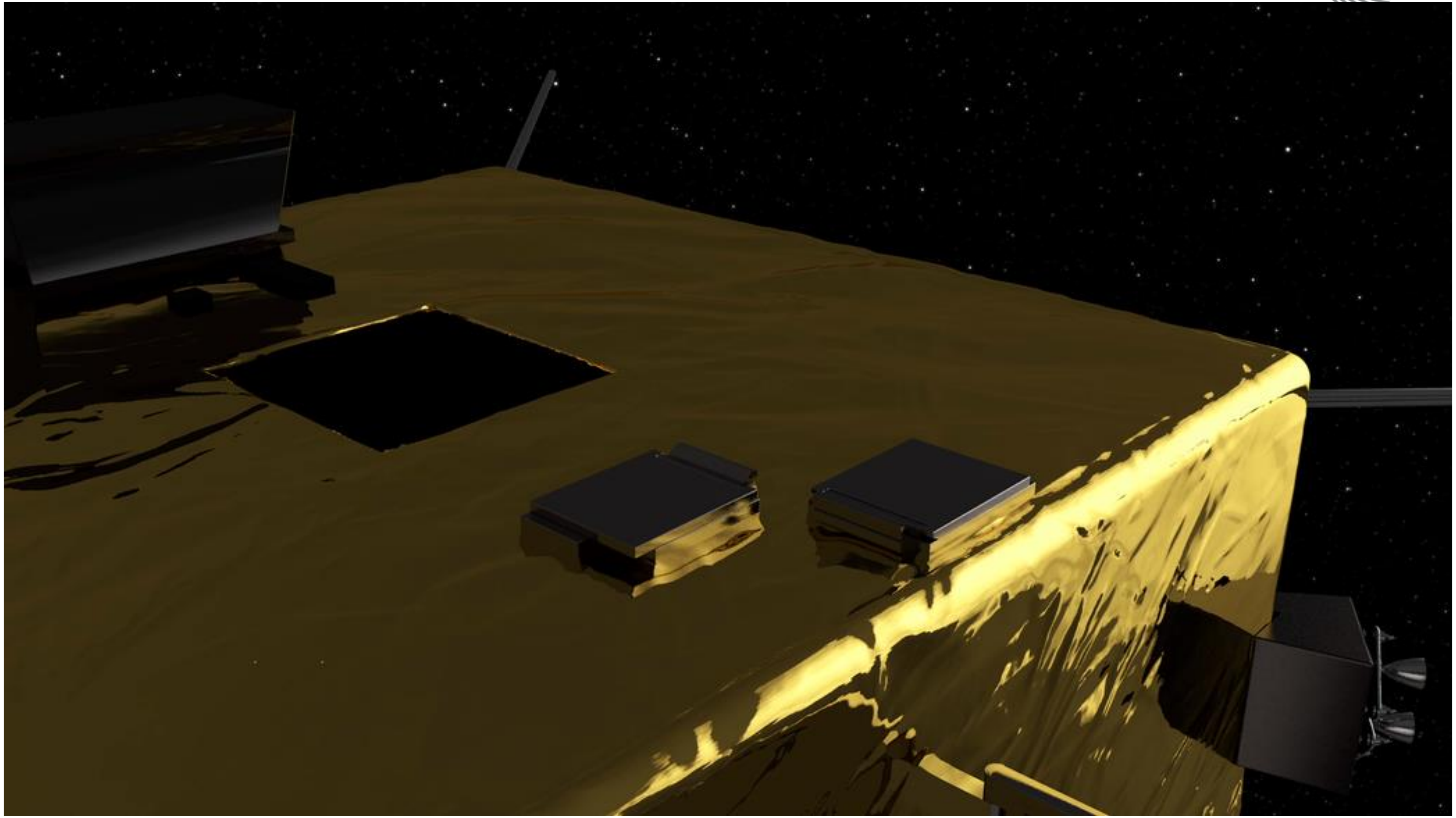
VISUAL @ 5 km



IR @ 5 km

COSINE (NL), GMV (PT), GMV (RO), SODERN (F), MPI (D), DLR (D)

CubeSats and inter-satellite link



COPINS: A CASE FOR CUBESATS IN DEEP SPACE

ASPECT

- Vis-NIR imaging spectrometer
- Space Weathering
- Shock experiment
- Plume

VTT (FI), Univ. Helsinki (FI), Aalto Univ. (FI), CAS (CZ)

AGEX

- Mechanical properties of surface material
- Seismic properties of sub-surface
- Determine kinematics prior and

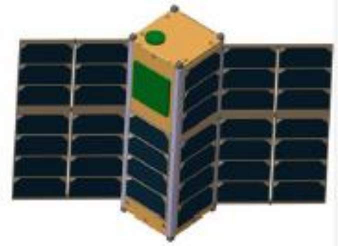
ROB (BE), ISAE (FR), Antw. Space (BE), EMXYS (ES)

PALS

- Characterize magnetization
- Composition of volatiles
- Volatiles released from DART impact
- Super-resolution imaging
- DART collision and plume observation

IFR (SE), AAC (SE), DLR (DE), IEEC (ES), KTH (SE)

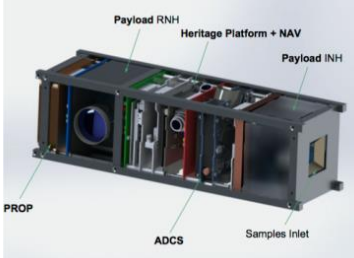
CUBATA



- Gravity field
- Observe DART impact
- Perform seismology
- Velocity field of the ejecta

GMV (ES), Sapienza Univ. Roma (IT), INTA (ES)

DUSTCUBE



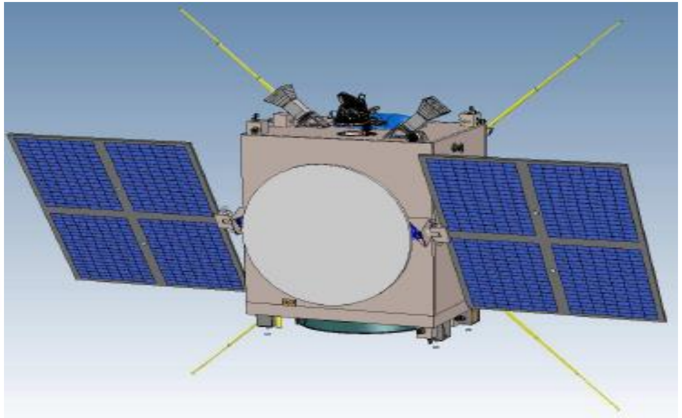
- Dust properties with Nephelometer
- Mineralogical composition
- Compliment com demo
- Reflectance of the

Univ. Vigo (ES), Micos (CH), Univ. Bern (CH)

AIM PLATFORM DESIGN

QinetiQ
Prime Contractor
QuinetiQ Space (B)

gmv
Sub-contractor
GMV (E)

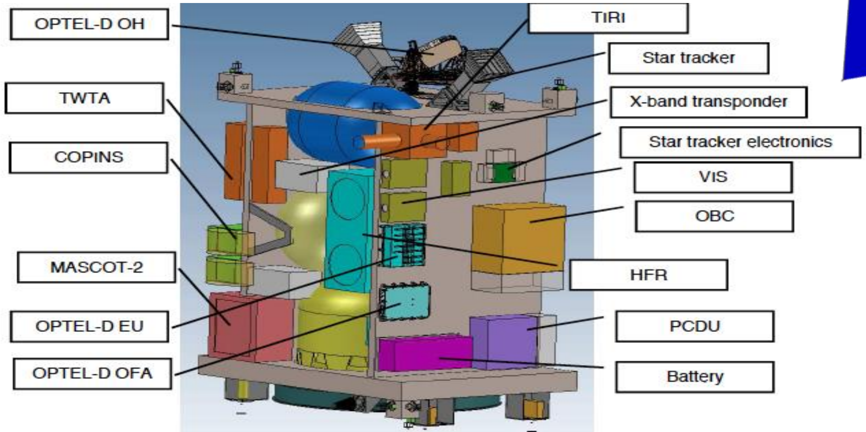


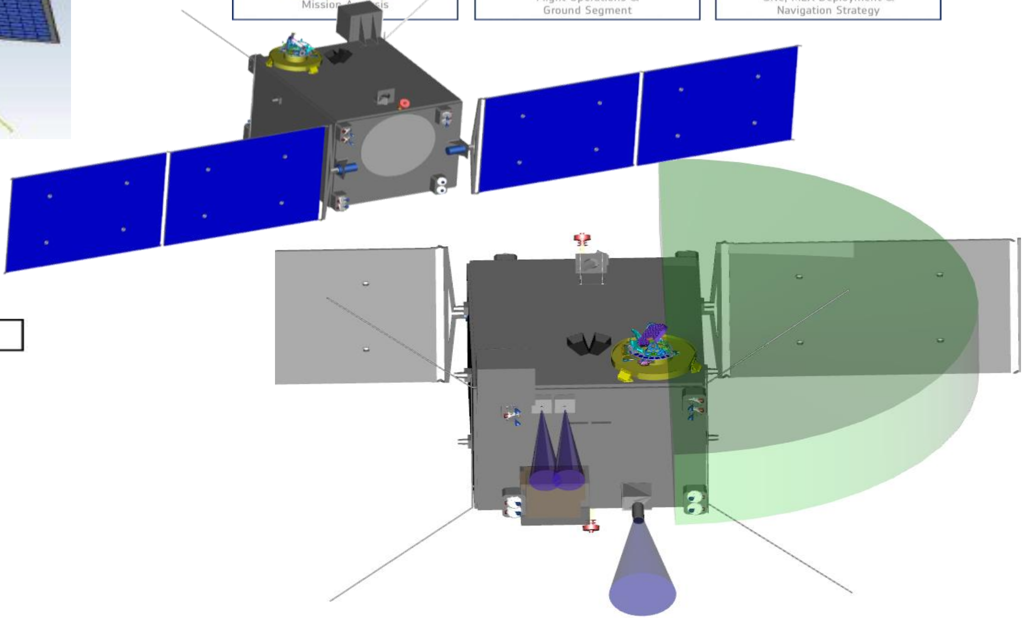
OHB
Prime Contractor
Requirements, mission and spacecraft design, payload operations, product development & programmatics

Politecnico di Milano
Sub−contractor
Mission [illegible]

Telespazio
A Finmeccanica/Thales Company
Sub−contractor
Flight Operations & Ground Segment

spin.works
Spin.Works
GNC, MEX Deployment & Navigation Strategy

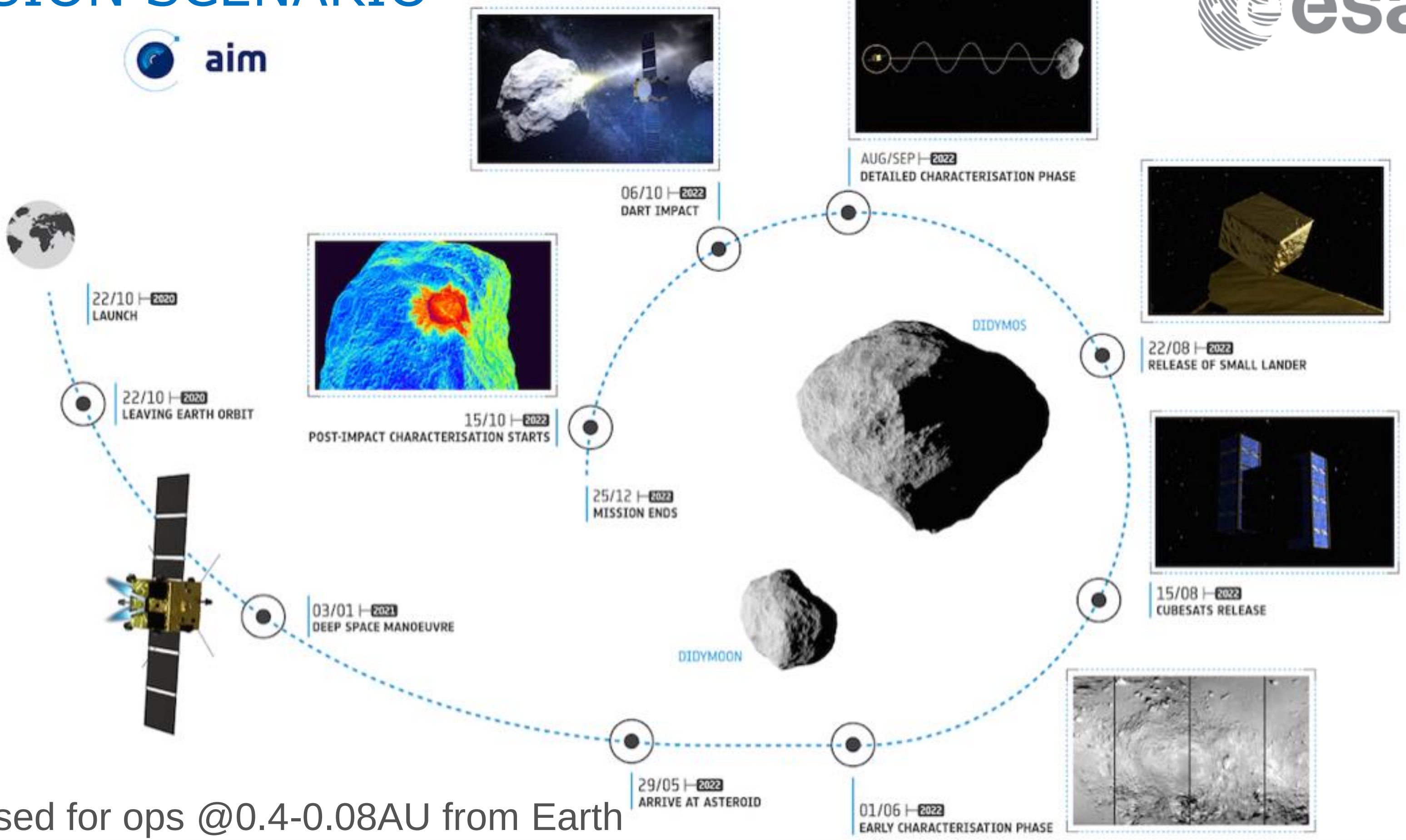




AIM MISSION SCENARIO

aim

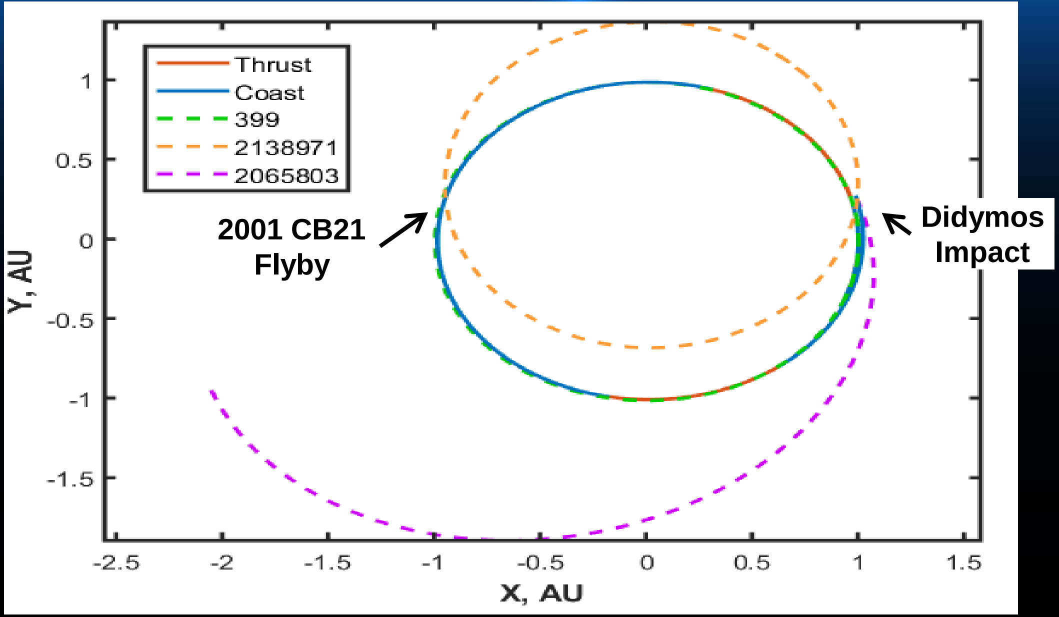
Ariane 6
maiden flight
under study



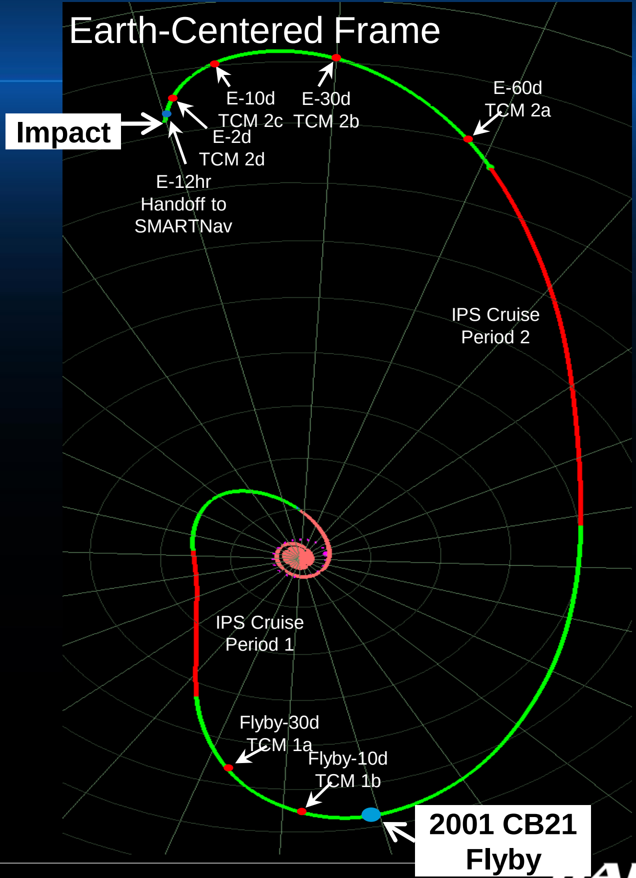
Direct escape
1.5 years cruse
0.5 years ops
Platform optimised for ops @0.4-0.08AU from Earth

DART Baseline Trajectory (Deep Space)

Flyby: Mar 03 2022, 640 kg, 11.37 km/s (67 day coast arc)
Impact: Oct 07 2022, 529 kg, 5.92 km/s (82 day coast arc)

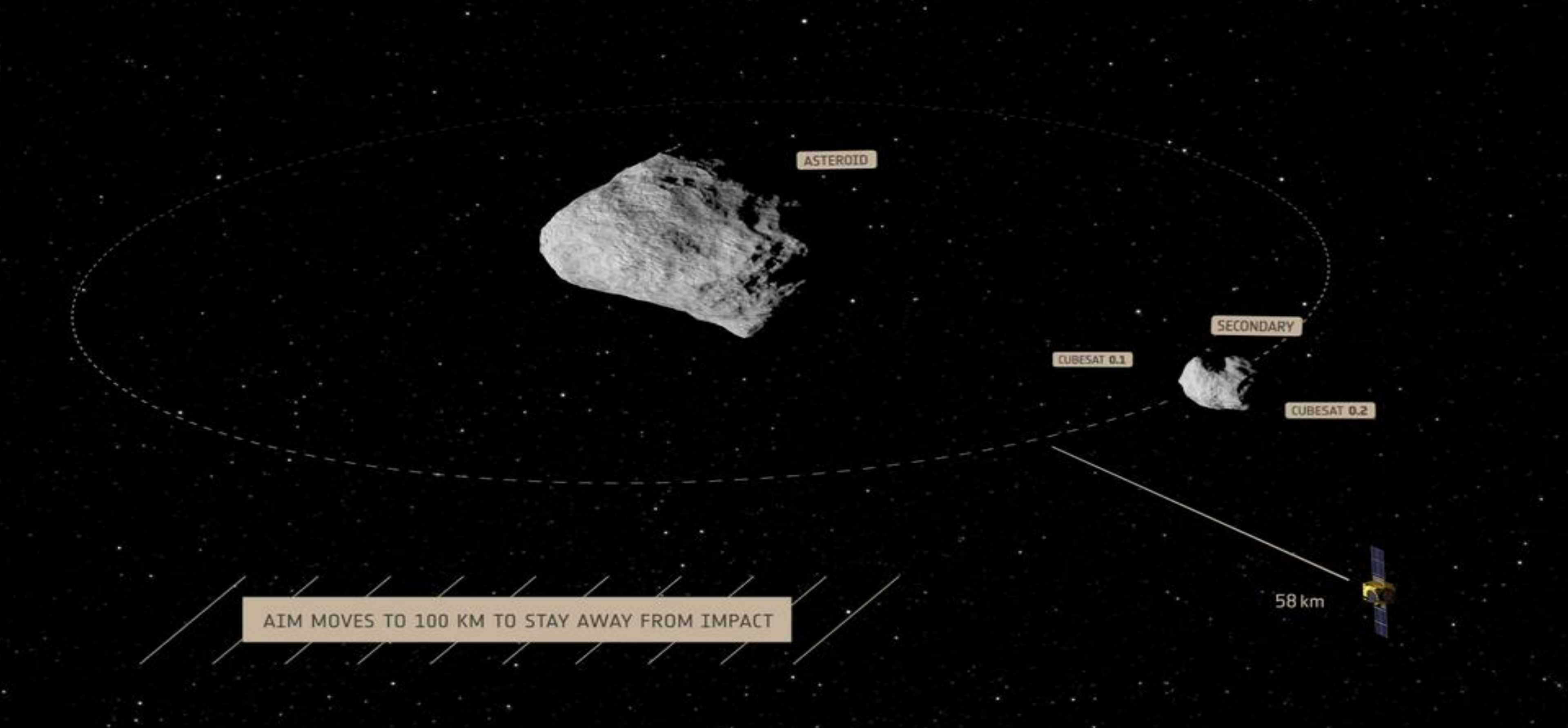


Sun-Centered Inertial Frame



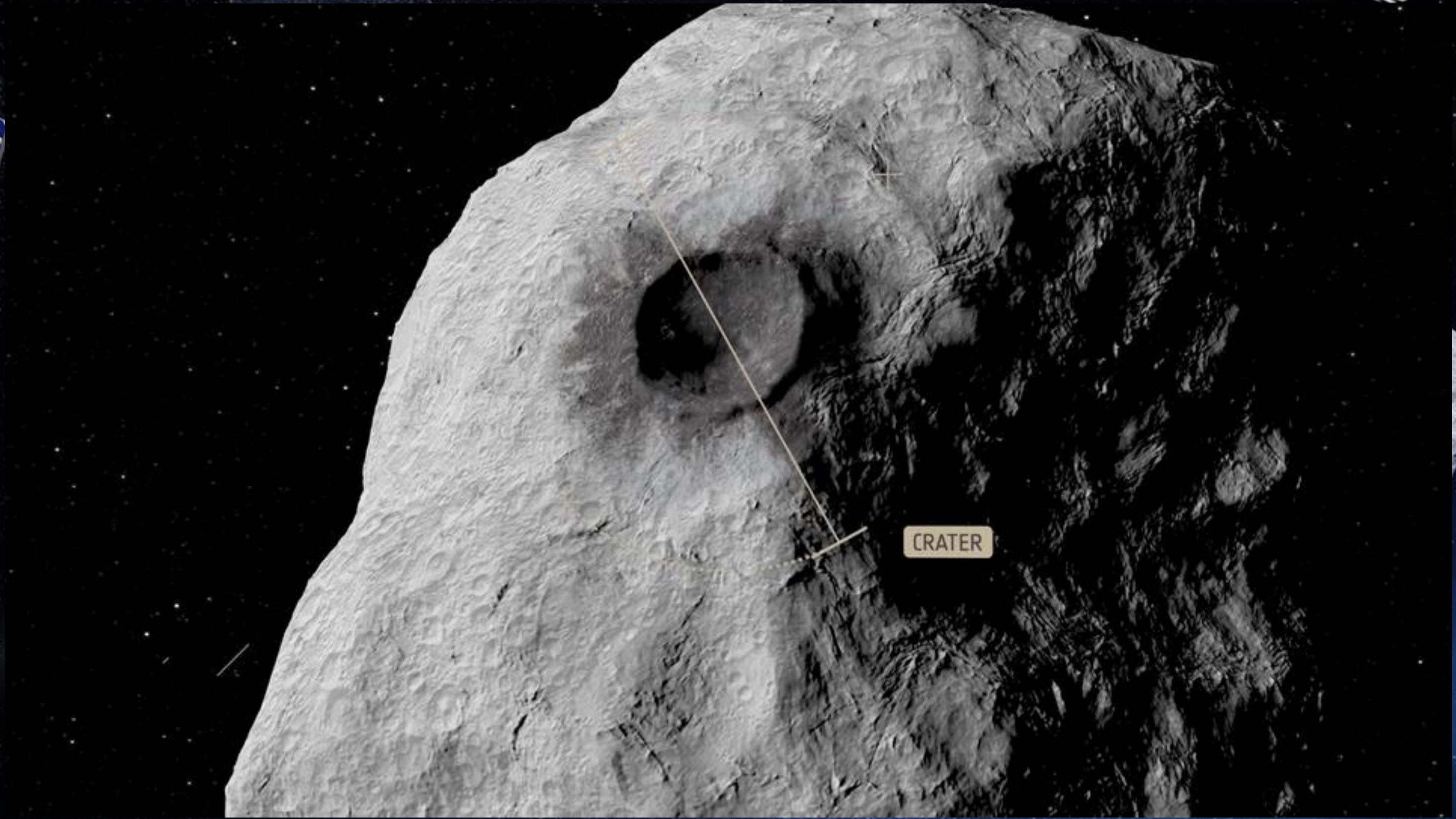
*All planned, deterministic maneuvers are accomplished with IPS
*Zero planned, deterministic, impulsive ΔV by mission design in baseline reference trajectory

Impact



ASTEROID
SECONDARY
CUBESAT 0.1
CUBESAT 0.2
58 km
AIM MOVES TO 100 KM TO STAY AWAY FROM IMPACT

Crater



What will DART achieve?

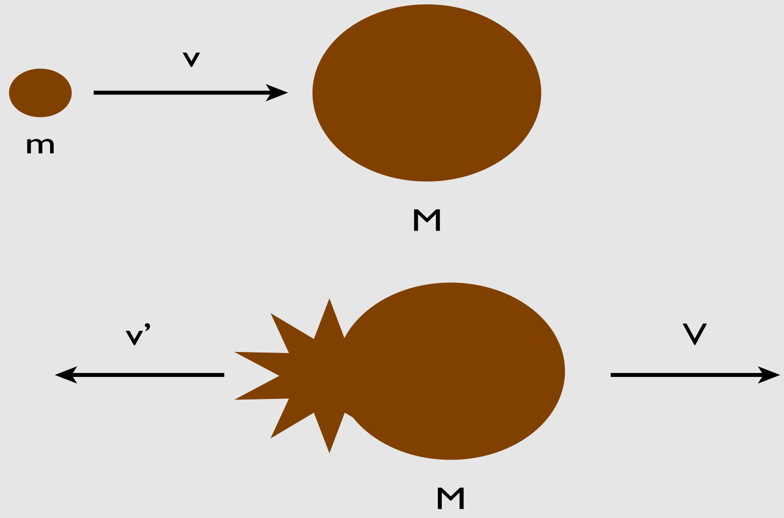
Before DART-AIDA

- Theoretical understanding of kinetic impactor mitigation
- Impact codes necessary for mitigation planning untested in relevant physical regime
- Realistic-sized hazardous asteroid response to impact mitigation poorly constrained in important ways

After DART-AIDA

- “Dress Rehearsal” on appropriately-sized object of most common NEO composition, demonstrating ability to intercept
- Impact codes validated and cross-referenced, allowing confident predictions in relevant situations
- Vastly improved understanding of important asteroidal physical parameters

Kinetic impactor method



Momentum transfer:

$$\vec{P}_{target} = \vec{P}_{projectile} + \vec{P}_{ejecta} > \vec{P}_{projectile}$$

AIDA

Momentum transfer

- Normalized with the momentum of the projectile:

$$P_{target} = 1 + P_{ejecta} \equiv \beta \geq 1$$

- Change of the target velocity

$$\Delta V = \frac{P_{target}}{M_{target}} = \beta \times \frac{P_{projectile}}{M_{target}}$$

AIDA

Momentum transfer

- Momentum multiplication factor

$$\beta = ?$$

Target structure
Material characteristics
Impact velocity
Target size etc.

from scaling laws:

$$\beta \sim \left(\frac{\rho U^2}{Y}\right)^{(3\mu-1)/2}$$

AIDA

Modeling and understanding the outcome of the DART kinetic impact

		Expected range for AIDA experiment		
	Non-porous, strong	Low porosity, moderate strength	Very high porosity, weak	High porosity, weak
β	3.32	1.1	1.23	1.3
Crater Size [m]	4.89	3.06	8.47	5.7
Orbiting fraction	<1%	<1%	32%	<1%
Material Analog	Basalt	Weakly Cemented Basalt	Perlite /Sand	Sand / Fly Ash

Cheng, Michel et al. (2016) PSS 121:27

- Porous target cases predict of ~1.1 to ~1.3 consistent with simulations, Jutzi & Michel (2014)
- Non-porous case ("Basalt") not expected to apply because of binary formation scenario
- Deflection result of kinetic impact is not appreciably affected by gravity of binary companion
- AIM measurement of crater radius is important for finding target properties

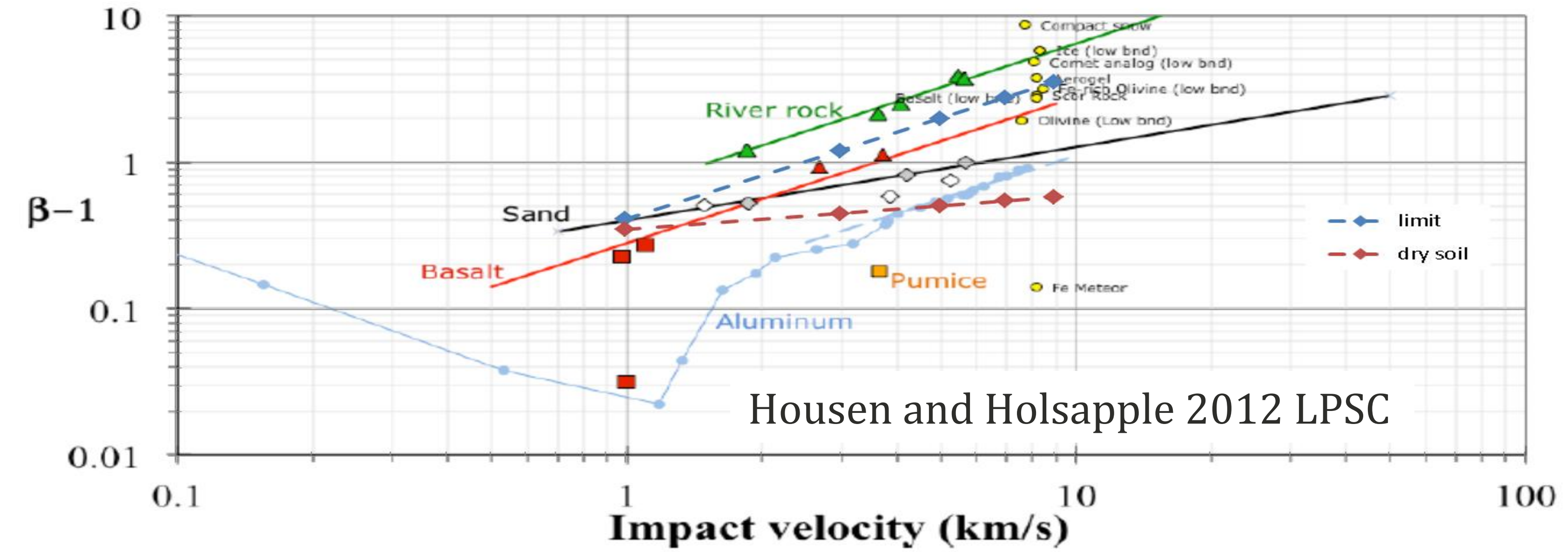
Orbiting fraction is the ejecta mass fraction captured into temporary binary orbits

The modeling and simulation effort produces predictions of parameters that can be verified by ground-based and AIM observations

Velocity Scaling of β from Lab Data and Scaling Laws

AIDA

The DART impact is at 6.5 km/s



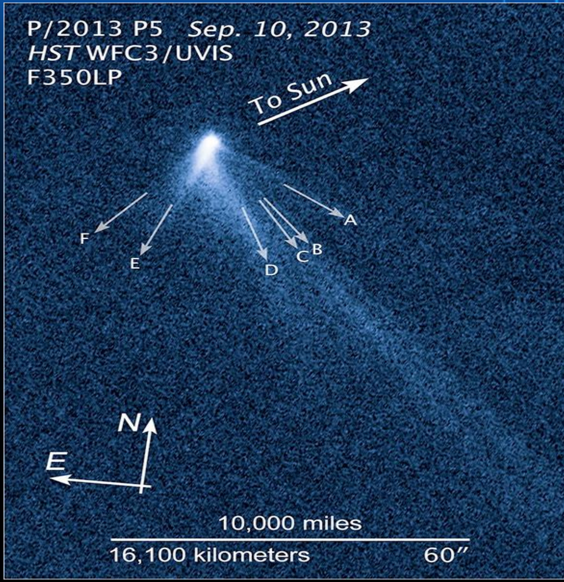
Blue dashes, scaling law model with μ= 0.66, K= 0.12, Y= 18 MPa
Red dashes, scaling law model with μ= 0.41, K= 0.132, Y= 0.18 MPa
Scaling law models assume 300 kg DART impacts

Didymos 2022 Impact Observing Campaign

- DART impact during excellent apparition: Didymos at V ~ 14-15, very well placed for Chile, observable from other observatories
- Didymos primary and secondary are separated by up to 0.02 arcsec when 0.08 AU from Earth
  - Marginally resolvable with ALMA (sub-mm), Magellan adaptive optics
- Post-impact brightening and ejecta stream as extended object (“coma”) may be observable from Earth

Brightness of coma from ejecta released by DART kinetic impact.

	Basalt C2	WCB C3	PS C8	SFA C7
Didymos brightening (mag)	−0.08	−0.02	−0.38	−0.12
Coma, integrated V mag	17.3	18.8	15.5	16.8



P/2013 P5 ~250 m, observed at 1.1 AU Earth distance

Cheng, Michel et al. (2016) PSS 121:27

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
- AIDA has additional handles on the scaling parameter μ
  - Estimation from ejecta velocity distribution and from observing the ejecta distributions over time
  - If crater growth can be observed, determine μ

AIDA

SCI on Hayabusa 2

SCI ON AIM?

- DART: 529 kg at 5.92 km/s
- SCI: 2 kg at 2 km/s
  - Two different impact velocities would allow us to much better constrain the μ scaling law parameter ….

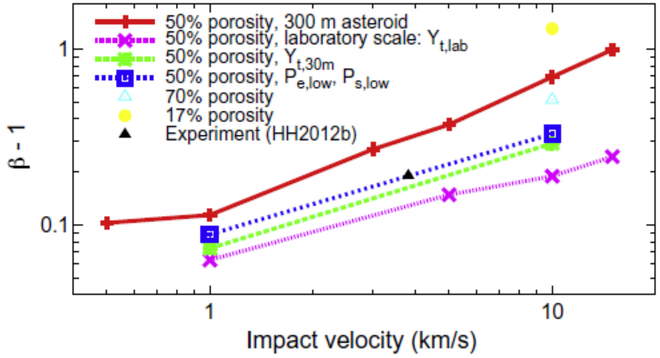


Fig. 6. Momentum multiplication factor $\beta - 1$ as a function of impact velocity using target structure (a) and considering various strengths and porosities. Unless indicated, the nominal values for Y_t and P_e, P_s are used (see Table 1). The result of an impact experiment using a pumice target (Housen and Holsapple, 2012) is also shown.

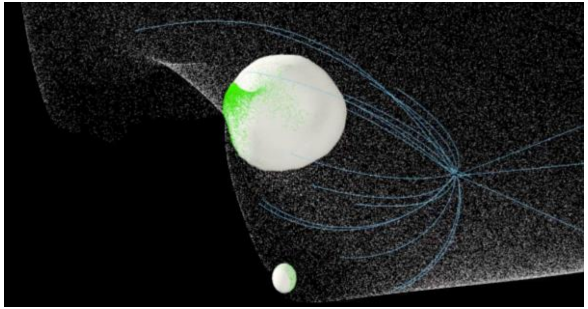
From Jutzi & Michel 2014

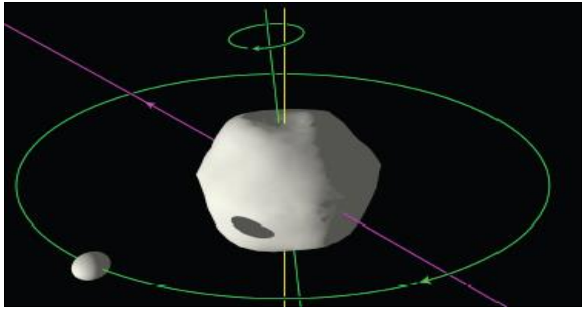
AIDA INVESTIGATION TEAM

DART SCIENCE (A. Cheng)

AIM SCIENCE (P. Michel)

AIDA INVESTIGATION TEAM





W1 Modelling and simulation of impact outcomes
(A. Stickle/JHU-APL, P. Miller/LLNL, R Schwartz/OCA)

W2 Remote sensing observations
(A. Rivkin/JHU-APL, P. Pravec/Ondrejov Obs.)

W3 Dynamical and physical properties of Didymos
(D. Richardson/Univ. Maryland, K. Tsiganis/Univ. Thessaloniki, A. Bagatin/Univ. Alicante)

W4 Science proximity operation
(S. Ulamec/DLR, O. Barnouin/JHU-APL)

Working Group 1 (Chairs: Stickle A., Miller P., Schwartz S.R.)

Modelling and simulation of impact outcomes

Name	Affiliation
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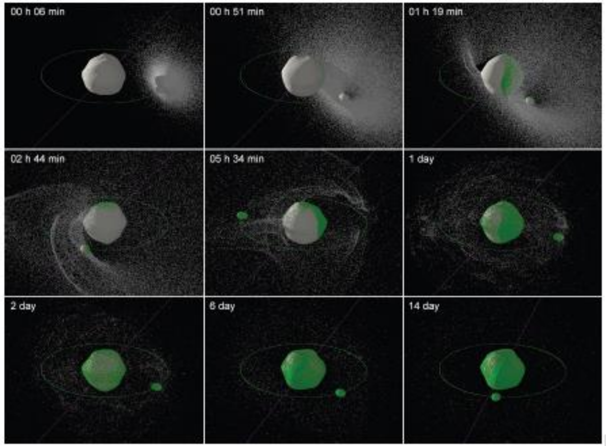
Julie Bellerose	JPL
Olivier S. Barnouin	JHU-APL
Megan Bruck-Syal	LLNL
Andrew Cheng	JHU-APL
Steve Chesley	JPL
Gareth Collins	Imperial College
Dan Durda	SWRI
Charles El-Mir	JHU
Carolyn M. Ernst	JHU-APL
Eugene Fahnestock	JPL
Galen Gisler	LANL
Nicole Güldemeister	MfN
Douglas Hamilton	UMD
Keith Holsapple	UW

Name	Affiliation
Kevin Housen	Boeing
Daniel S. Jontof-Hutter	PSU
Robert Luther	MfN
Paul Miller	LLNL
Patrick Michel	OCA
Naor Movshovitz	UCSC
Nilda Oklay	MPS, MPG
J. Michael Owen	LLNL
Cathy Plesko	LANL
Mark Price	University of Kent
Emma S. G. Rainey	JHU-APL
K.T. Ramesh	JHU
Jim Richardson	Arecibo
Eileen Ryan	NMT
Peter H. Schultz	Brown

Name	Affiliation
Gonzalo Tancredi	Fisica
Keomenis Tsiganix	AUTH
Jean-Baptiste Vincent	MPS, MPG
Kai Wünnemann	MfN, Leibniz
Yang Yu	OCA

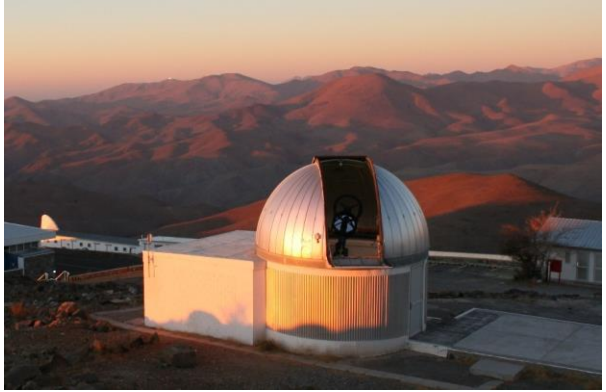


Working Group 2 (Chairs: Pravec P., Rivkin A.)

Remote sensing observations

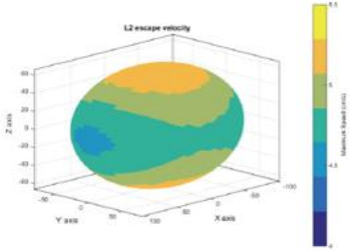
Name	Affiliation
Paul Abell	NASA
A. Campo Bagatin	U. Alicante
Lance Benner	NASA/JPL
Michael Busch	UCLA
Humberto Campins	UCF
Andy Cheng	APL
Steve Chesley	JPL
Julia De Leon	IAC
Marco Delbo	OCA
Elisabetta Dotto	INAF
Emily Kramer	UCF
Matthew Knight	U Maryland
Jian-Yang Li	U Arizona
Javier Licandro	IAC
Tim Lister	LCOGT
Colin Snodgrass	Open U

Name	Affiliation
Amy Mainzer	NASA/JPL
Patrick Michel	OCA
Nick Moskovitz	Lowell Obs
Shantanu Naidu	UCLA
Michael Nolan	
Dave Osip	
Dagmara Oskiewicz	
David Polishook	
Petr Pravec	
Derek Richardson	
Andy Rivkin	
Elieen Ryan	
William Ryan	
Petr Scheirich	
Amanda Sickafoose	
Emmanuel Jehin	FNRS



Working Group 3 (Chairs: Campo Bagatin A., Richardson D.C., Tsiganis M.)

Dynamical and physical properties of Didymos



Name	Affiliation
Asphaug	ASU
Barbee	NASA/GSFC
Barnouin	JHU/APL
Bellerose	NASA/JPL
Benner	NASA/JPL
Biele	DLR
Bottke	SwRI/Boulder
Campo Bagatin	U Alicante
Cheng	JHU/APL
Chesley	NASA/JPL
Fahnestock	NASA/JPL
Hamilton	U. Maryland
Hartzell	U. Maryland
Hestroffer	Obs. Paris
Hirabayashi	Purdue

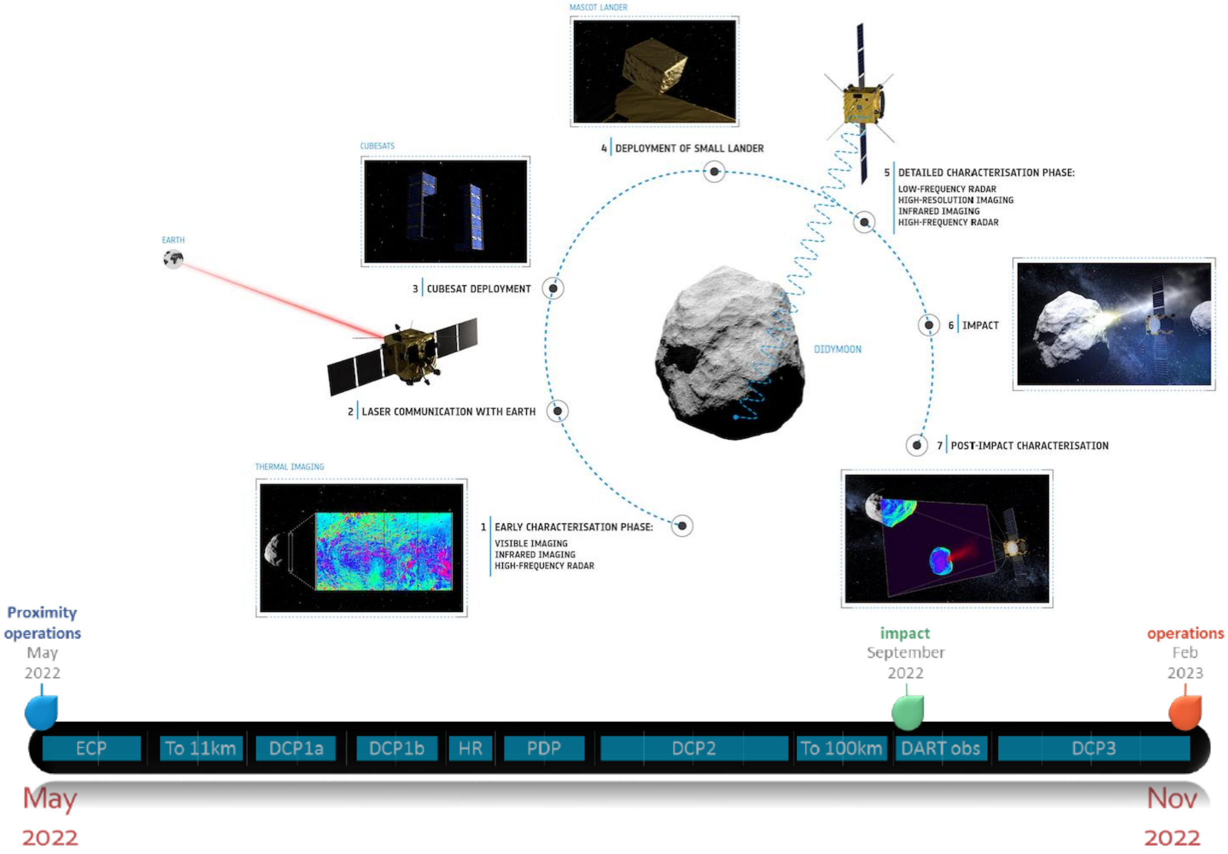
Name	Affiliation
Jacobson	U. Nice/OCA
Mardling	Monash U
Maurel	ISAE-SUPAERO
McMahon	U. Colorado
Michel	U. Nice/OCA
Fernando	IAA
Murdoch	ISAE-SUPAERO
Naidu	NASA/JPL
Penttilä	U. Helsinki
Pravec	AICAS
Richardson	U. Maryland
Rivkin	JHU/APL
Rosenblatt	OMA
Rossi	IFAC-CNR
Sánchez	U. Colorado

Name	Affiliation
Sarid	UCF
Scheeres	U. Colorado
Scheirich	AICAS
Schwartz	U. Nice/OCA
Siegfried	IMCCE
Tancredi	Ciencias
Tanga	U. Nice/OCA
Tardivel	NASA/JPL
Tsiganis	Aristotle U/Th
Vincent	MPS
Voyatzis	Aristotle U/Th
Walsh	SwRI Boudler
Yu	U. Nice/OCA
Zhang	U. Maryland

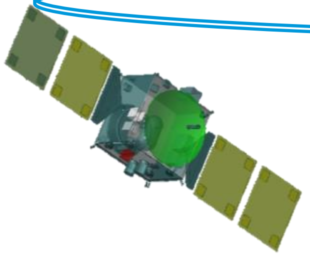
Working Group 4 (Chairs: Barnouin O., Ulamec S.)

Proximity operations

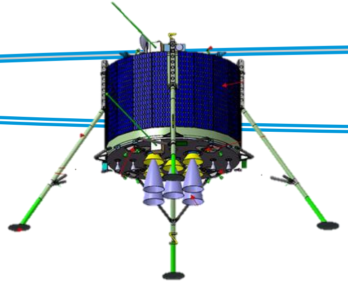
Name	Affiliation
Olivier Barnouin	JHU/APL
Stephan Ulamec	DLR
Michael Kueppers	ESA
Jean-Baptist Vincent	OCA
Alain Herique	IPAG
Valerie Ciarletti	U. Versailles
Simon Green	Open Univ.
Bjoern Grieger	ESA
Andy Rivkin	JHU/APL
Andy Cheng	JHU/APL
Kieran Carroll	GEDEX



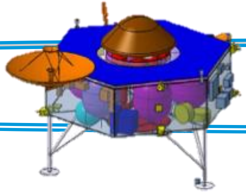
BUILDING ON STRONG EUROPEAN HERITAGE



Proba-IP
(2011)

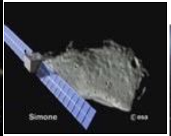


Lunar Lander
(2010)

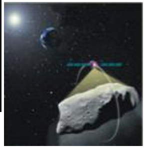


MarcoPolo
(2008)

Don Quijote
(2001)



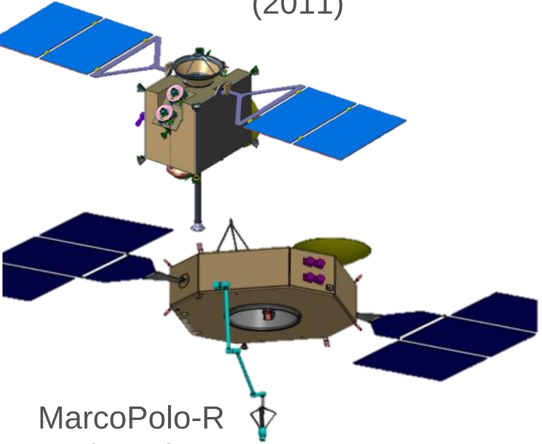
Simone
(2000)



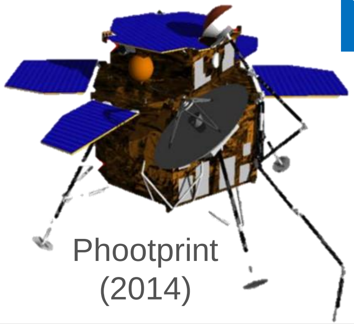
Ishtar
(2000)

> 83 M€ investments in relevant
- system studies (GSP, SCI, MREP)
- technology (CTP, ETP, TRP, GSTP, ARTES)

70+ industries involved



MarcoPolo-R
(2013)



Phootprint
(2014)

aim

In study at ESA since 2011 based extensive heritage

TO DATE: 40+ companies/R&D   15 Member States

OBSERVATOIRE DE LA COTE DAZUR OCA
DLR - German Aerospace Center

UNIV JOSEPH FOURIER GRENOBLE
QINETIQ SPACE NV

GMV AEROSPACE AND DEFENCE, SA
OHB SYSTEM AG
SPINWORKS
POLITECNICO DI MILANO

TELESPAZIO VEGA DEUTSCHLAND GMBH

CNRS - DELEGATION ALPES - INSTITUT

RUAG SCHWEIZ AG, RUAG SPACE
KAYSER ITALIA
INST ASTROFISICA CANARIAS
Gooch & Housego Ltd
AXCON APS
VTT TECHNICAL RESEARCH CENTRE OF FINLAND LTD
UNIVERSITY OF HELSINKI
AALTO UNIVERSITY FOUNDATION Aalto University Foundation

MICOS ENGINEERING GMBH
OBSERVATOIRE ROYAL
INSTITUT SUPERIEUR AERO ET ESPACE
Antwerp Space N.V.
EMBEDDED INSTRUMENTS AND SYSTEMS SL
ASTEROID INITIATIVES LLC
SWEDISH INST SPACE PHYSICS
CSIC-IEEC
HBM-BENELUX
AAC MICROTEC ABFORMERLY ASTC
ARIANESPACE
SPACE EXPLORATION INSTITUTE (SPACE-
ISIS-INNOVATIVE SOLUTIONS IN SPACE
INSTITUTE OF SPACE SCIENCE – ISS (INFLPR) Space Science and Technology

SPACE RESEARCH CENTRE POLISH ACADEMOF SCIENCES
ASTRONIKA SP. Z O.O.
COSINE RESEARCH BV
GMV INNOVATING SOLUTIONS SRL
GMVIS SKYSOFT S.A.
DTU
University of Bologna

POTENTIAL PLATFORM CONTRIBUTIONS

esa

Spacecraft platform (OHB), TT&C (ADS, TESAT), AOCS (Jena Optronic, RCD, STI), OBDH (ADS), Power (TAS, ADS, ETCA), propulsion (ADS, MTA)

RTU (TERMA), AOCS (DTU, TERMA, MOOG), SW (TERMA), POWER (TERMA)

OBC (RUAG), AOCS (ACREO), DHS (SSC), Power (RUAG)

AOCS (Bradford, TNO, MOOG), Power (DutchSpace)

AOCS (SENSONOR), Software (DNV), HDRM (KONGSBERG)

AOCS, onboard Software (SFF), Power (PATRIA)

Spacecraft platform (QS), OBC (QS), Power (TAS), GSE, onboard software (AWS), TT&C (TAS), DHS (Spacebel)

Structure (Eurocomp.), Power

Structure (SSTC), HDRM (ASTRONIKA), Software, GNC (GMV, Optinav), TT&C, SADMs

Propulsion (MOOG), AOCS (SSTL, SELEX), IMU (TAS), TT&C (ADS, QQ, SSTL, ComDev), Power (ABSL)

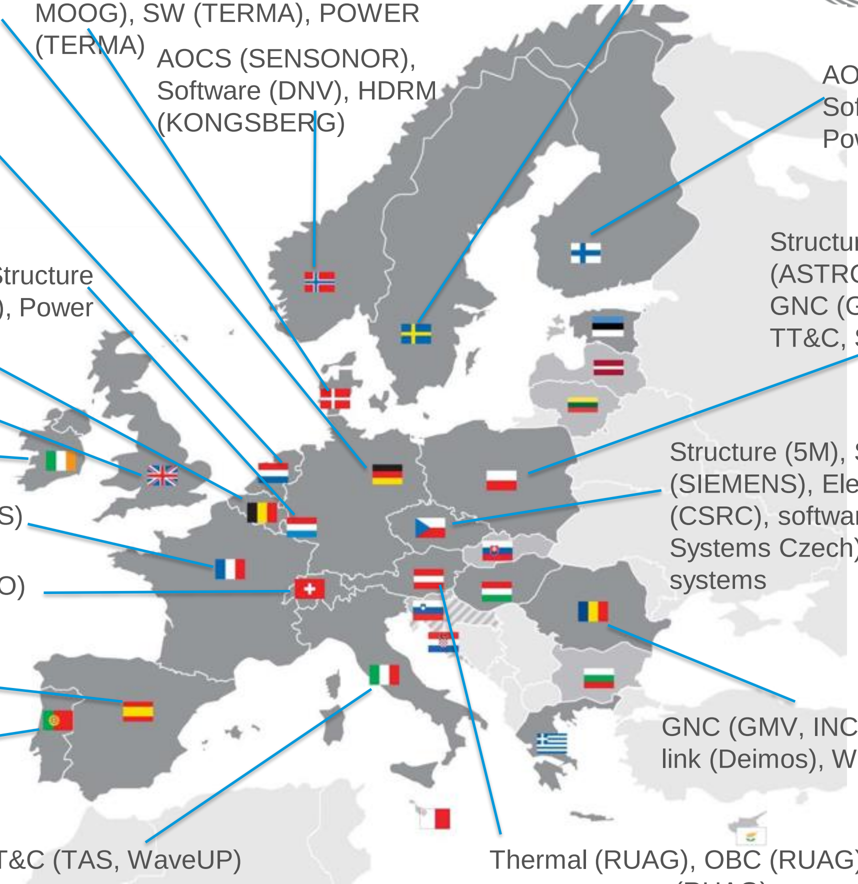
Software (CAPTEC), Structure (Eirecomposites)

Structure (5M), SCOS/EGSE (SIEMENS), Electronics (CSRC), software (Space Systems Czech), MGSE, power systems

Inter-satellite link (SYRLINKS)

GNC (GMV), Thermal (SENER), Structure (CASA), Software (INDRA), TT&C (TAS, RYMSA), Power (CRISA, MIER)

Structure (RUAG, APCO)



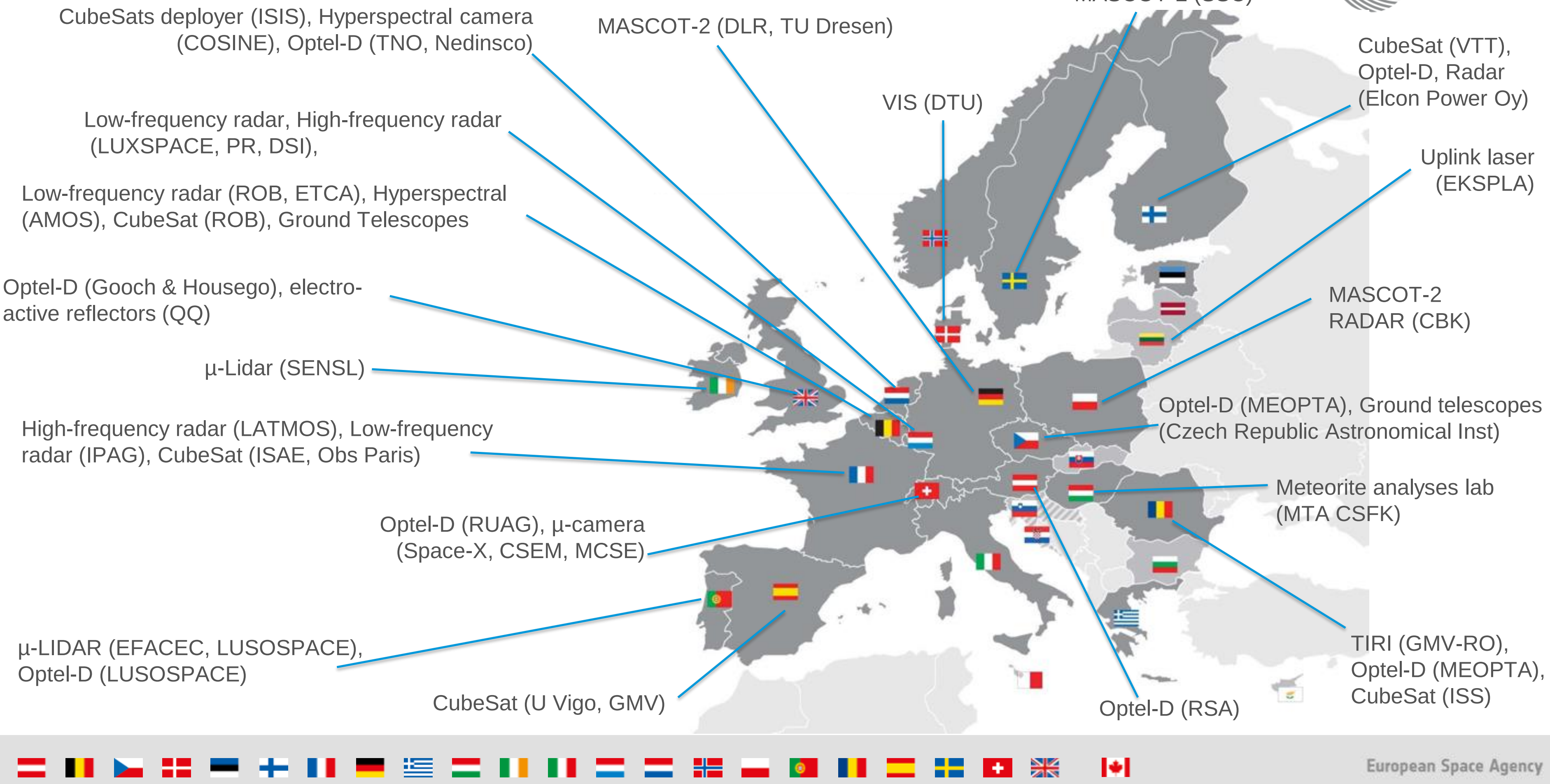
GNC (GMV, INCAS), Inter-satellite link (Deimos), W-AIV (NIRD)

GNC (Spin.Works), Inter-satellite link (TEKEVER), Onboard software (Critical Software), thermal (HPS)

TT&C (TAS, WaveUP)

Thermal (RUAG), OBC (RUAG), Power (RUAG)

POTENTIAL PAYLOAD CONTRIBUTIONS



SYSTEM ACTIVITIES: PHASE B1 COMPLETED

2015 PHASE-A 2016 PHASE-B1

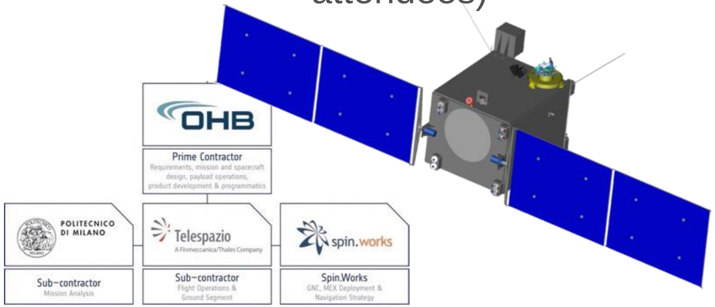
KO	PM1 KO+2	PM2 KO+4	PM3/OMC KO+6	PRR KO+9	PM4 PRR+3	ISRR PRR+6
ESTEC 19 March	8 & 13 May	3 & 6 July	ESAC 21 & 22 Sept	ESOC ESTEC 12 - 29 Jan	8 & 11 April	ESTEC 11 July - **13 Sept**

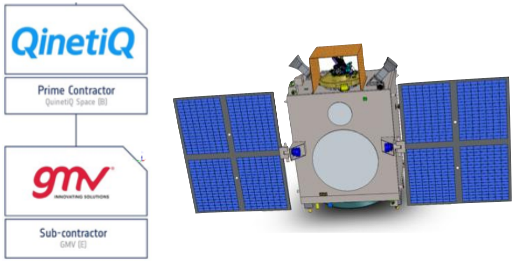
Payload/Spacecraft colocation

Operations/Spacecraft colocation

Industry days (100+ attendees, IOV/IOD)

Science workshop (90+ attendees)





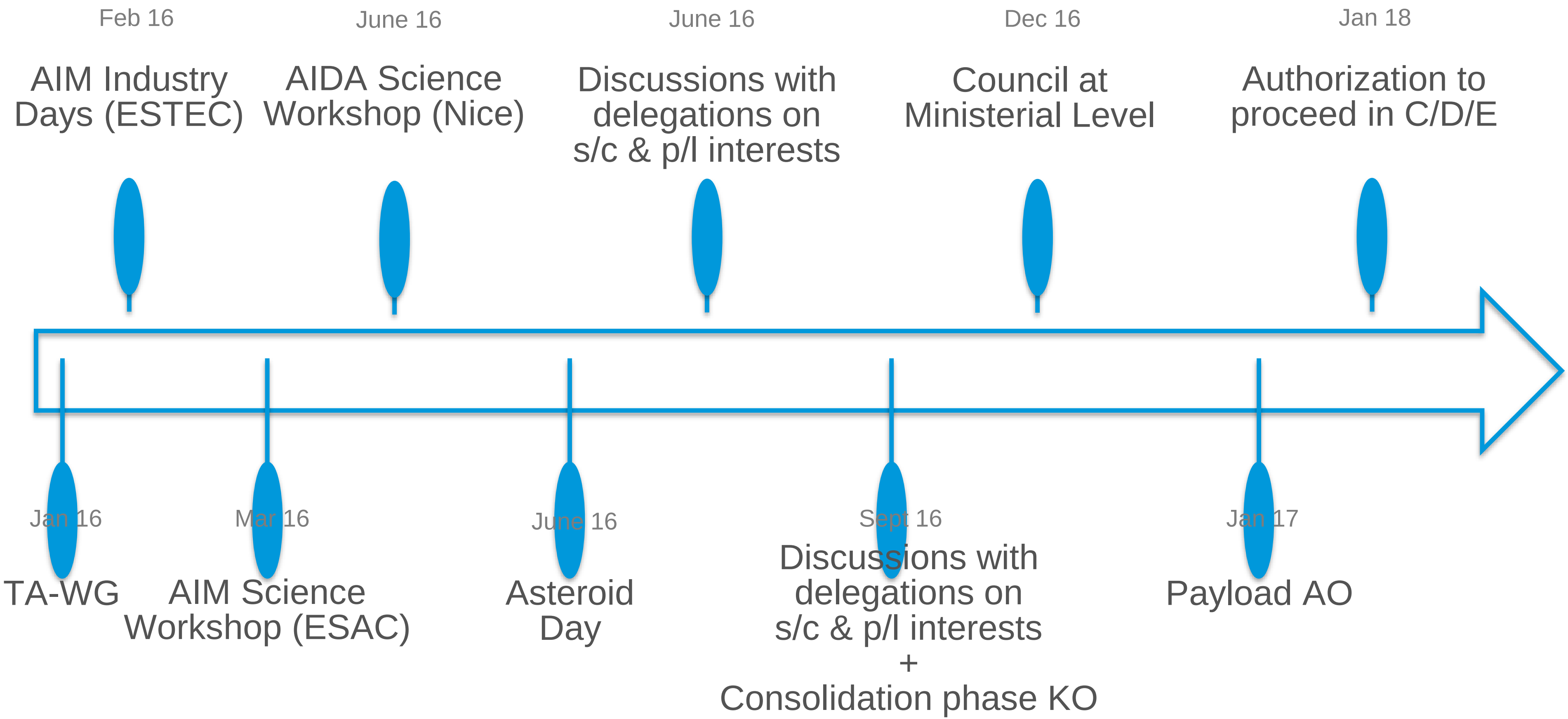
→ ENABLING APPROACH

- Preliminary feasibility confirmed

→ ENABLING APPROACH

- Cost and schedule driven
- Platform and payload “integrated” teams
- Early OPS and FDyn teams support (Rosetta)
- Early GNC testing and validation in lab
- Reuse of flight spares (e.g. DAWN framing camera)

AIM PROJECT PREPARATION



AIM SCHEDULE & STATUS

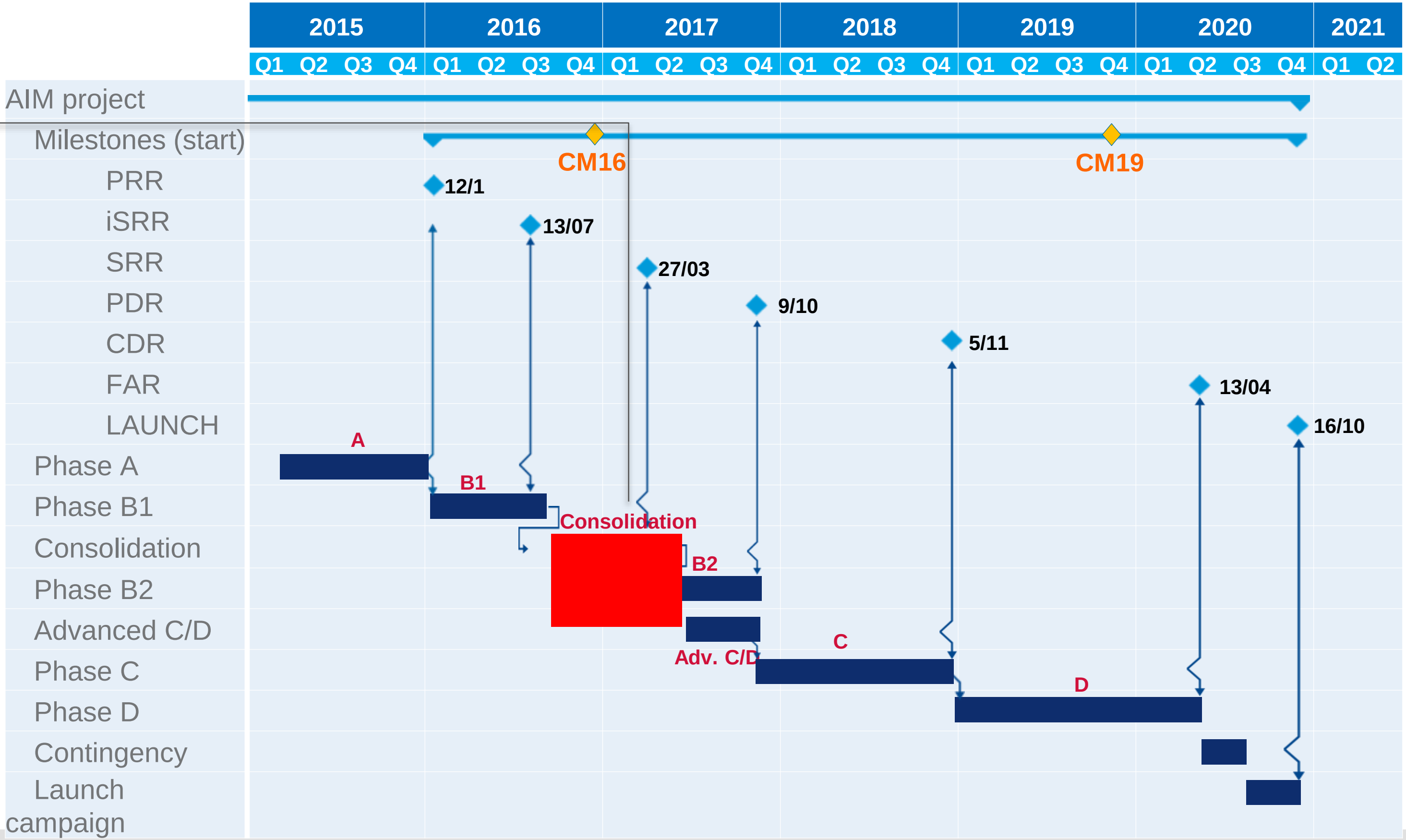
→ NEXT STEPS

ITT Consolidation Phase published
(4.5M€)

- Spacecraft design consolidation
- Team organization
- Consolidation of CaC and implementation plan

Part 1 (750k€) supported by:

- Germany
- Belgium
- Spain
- Portugal
- Romania
- Poland



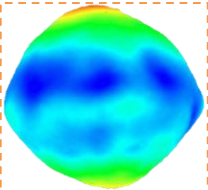
AN OPPORTUNITY

→ SPEED

Fast “return on investments”, 2 years from launch (Ariane 6.2)
Asteroid operations: 6 months, favourable to constraint cost
Demonstrate new platform-payload-operations teams integrated approach for faster implementation

→ TECHNOLOGY

New technology “firsts” applicable to future missions based on activities already funded in ESA: laser comm, on-board autonomy, cubesats, advanced GNC, inter-satellite comm and metrology, distributed systems
New industries to demonstrate capabilities in deep-space



→ SCIENCE

Answer fundamental questions on Solar System formation
Understand impact dynamics beyond laboratory scale
Probe the interior structure of small bodies (first time)
Provide “ground-truth” for observations (radar, optical, meteorites)

→ INSPIRATION

Addressing planetary defence objectives
Public engagement and outreach similar or even beyond Rosetta
Opportunity to provide visibility to space programmes at large
Opportunity to enhance governments support in space activities

INSPI TION AND OUTREACH (416.000 results on Google for “as ”)

AI

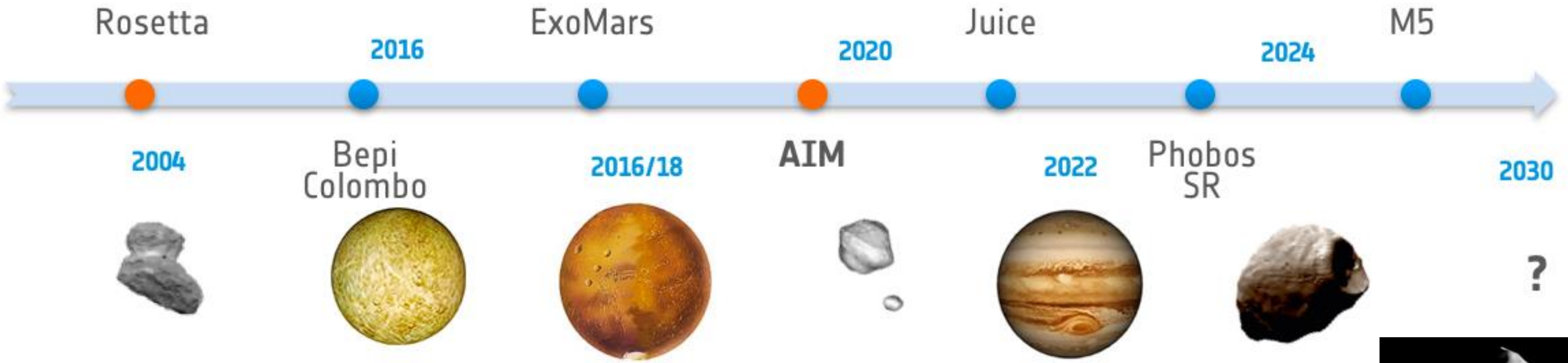
conf AIM @ planetarii Astr

016)

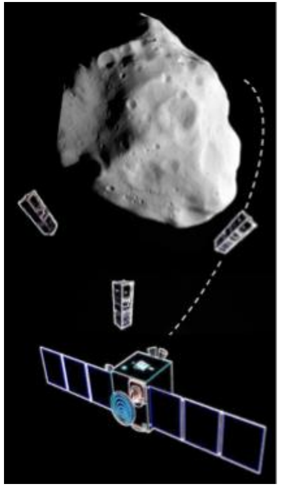
2015)

Astero Day (Bucharest, 2015

AIM in the context of future planetary missions



- **AIM will be the first ESA mission to a small body (●) since 2004 launch of Rosetta and the only opportunity in the next 20 years**
- Benefit from the wealth of expertise and experience of Rosetta, in particular for close-prox operations and deployment of the first lander since Philae
- Operations in low gravity environment relevant to e.g. Phobos-SR
- COPINS operations relevant for Mars sample return architecture (canister)
- Communications technologies enabling future missions with high-data volumes (e.g. human exploration, L-observatories, deep-space data relays)
- Platform concept applicable to deep-space missions (e.g. Space Weather)



Conclusions

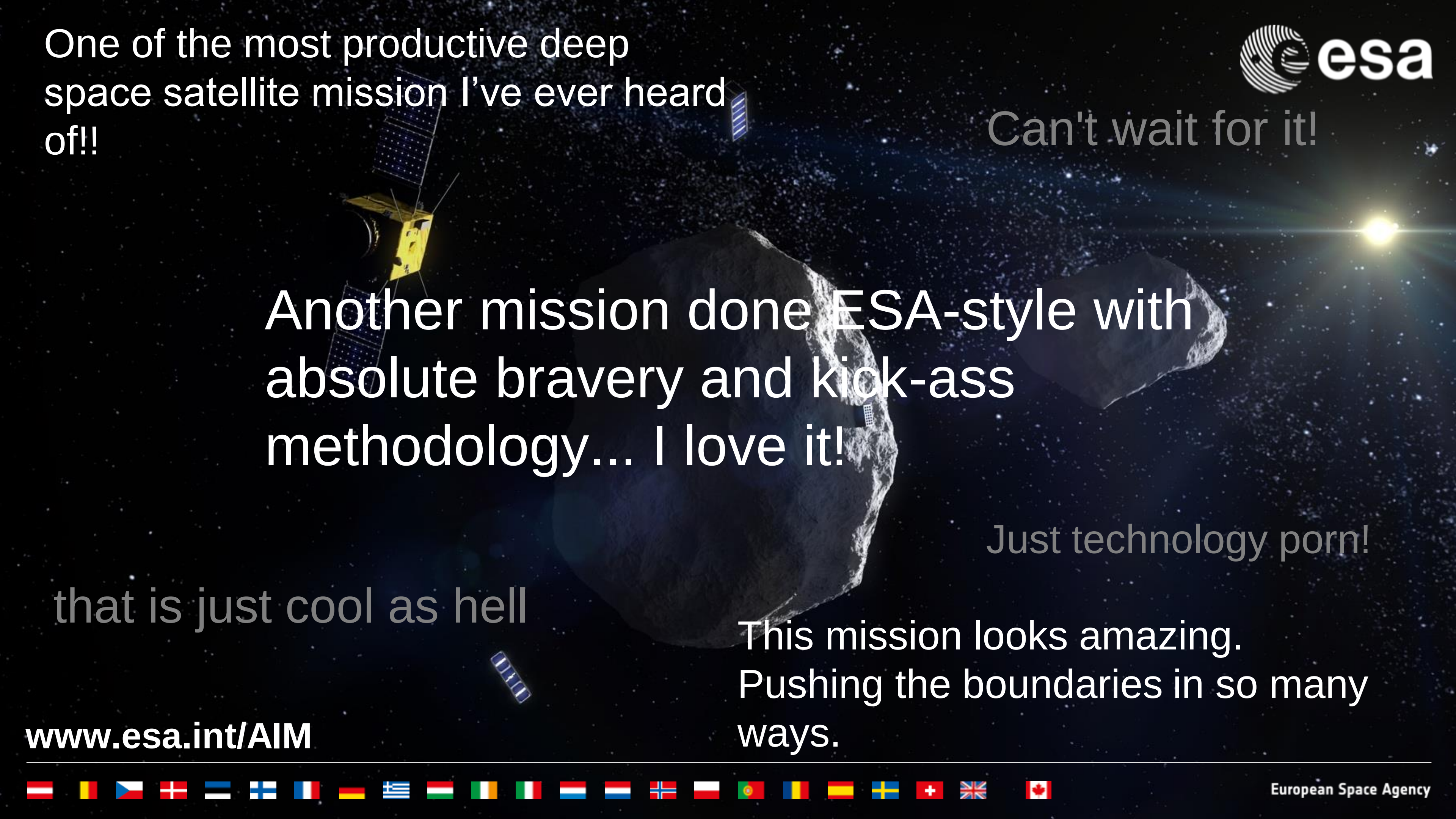
- AIDA will combine US and European space experience and expertise to address an **international challenge**, **the asteroid impact hazard** (planetary defense)
- AIDA is **the first well documented impact experiment** at asteroid scale
- AIDA will return **fundamental new science data on an asteroid's surface properties, internal structure, strength, with great implications in Solar System science**
- AIDA is a high-value-return innovative, international, low-cost small satellite mission with high potential for public interests
- AIM is the **only European opportunity** for a small body mission, addressing high level scientific questions **within the next 15-20 years.**

AIDA

For more information

www.oca.eu/michel/AIDA/

www.esa.int/AIM


One of the most productive deep space satellite mission I’ve ever heard of!!
esa
Can't wait for it!
Another mission done ESA-style with absolute bravery and kick-ass methodology... I love it!
Just technology porn!
that is just cool as hell
This mission looks amazing. Pushing the boundaries in so many ways.
www.esa.int/AIM
European Space Agency