AIDA Concept Overview

Chelyabinsk Meteor on 15 February 2013

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Asteroid Impact & Deflection Assessment (AIDA)

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Web Site: http://www.oca.eu/michel/AIDA/

Asteroid Impact & Deflection Assessment (AIDA) Background

- AIDA is an international cooperation to learn how to mitigate an asteroid impact threat
- AIDA is a low cost demonstration of the kinetic impactor technique to divert a potentially hazardous asteroid
  - Use a spacecraft impact to push an asteroid off its dangerous path
- AIDA is currently in parallel, pre-Phase A studies in the US and in ESA
  - AIM study of rendezvous monitoring spacecraft at ESA
  - DART study of kinetic impactor spacecraft at APL

AIDA = AIM+DART

Asteroid Impact & Deflection Assessment (AIDA)

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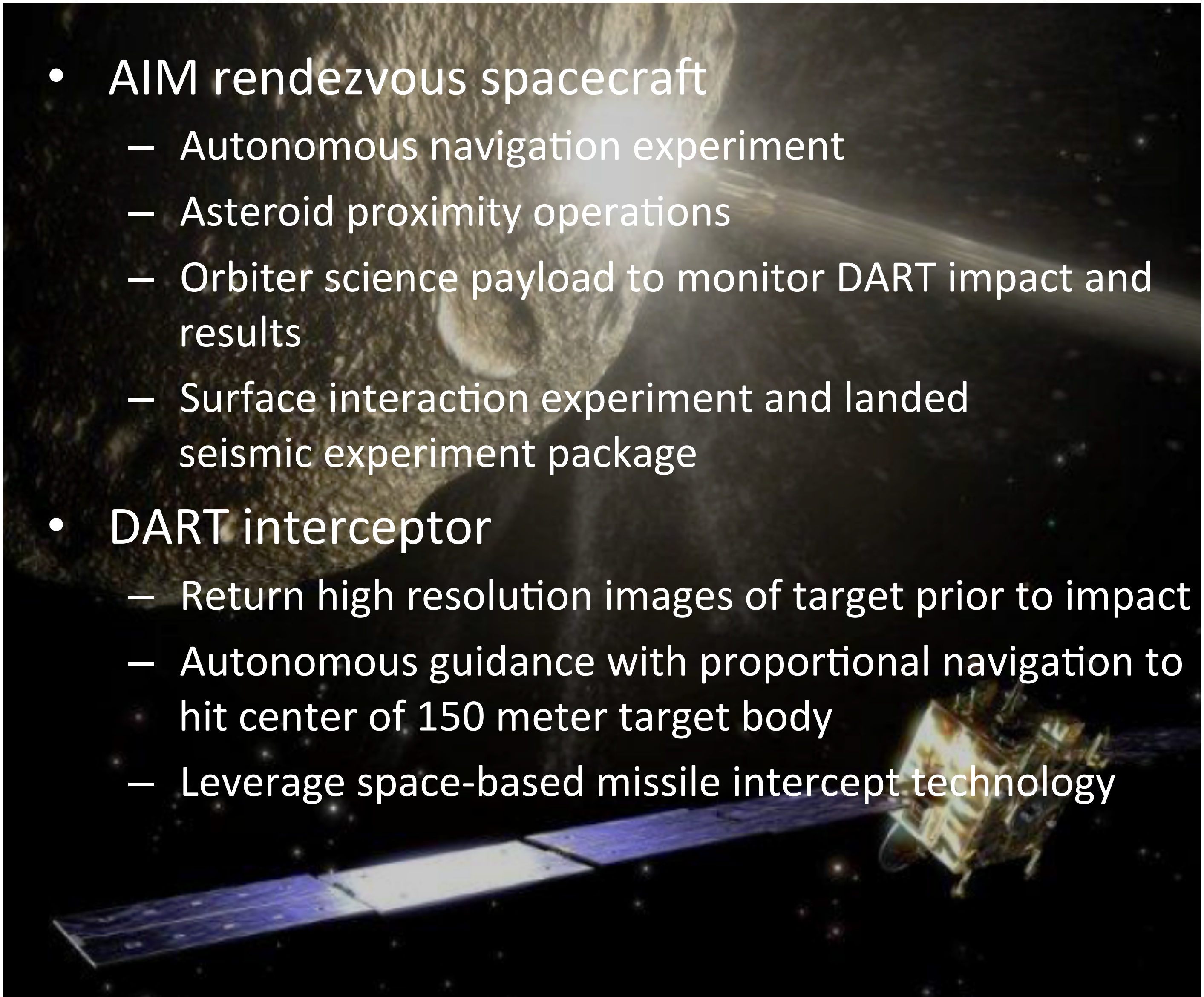
- AIDA will demonstrate asteroid deflection by spacecraft kinetic impact
- AIDA: a joint US and European mission:
  - European rendezvous spacecraft, the Asteroid Impact Monitor (AIM) mission
  - US kinetic impactor, the Double Asteroid Redirection Test (DART) mission
- The DART mission will intercept the secondary member of the binary Near-Earth Asteroid Didymos in October, 2022

→ AIDA = AIM+DART

AIDA = AIM+DART



- AIM rendezvous spacecraft
  - Autonomous navigation experiment
  - Asteroid proximity operations
  - Orbiter science payload to monitor DART impact and results
  - Surface interaction experiment and landed seismic experiment package
- DART interceptor
  - Return high resolution images of target prior to impact
  - Autonomous guidance with proportional navigation to hit center of 150 meter target body
  - Leverage space-based missile intercept technology

Science Objectives- Level 1 DART Requirements

DART Requirements	Rationale
DART shall intercept the secondary member of the binary asteroid 65803 Didymos as a kinetic impactor spacecraft during its October, 2022 close approach to Earth	Target asteroid is large enough (mean diameter > 100 m) to be a Potentially Hazardous Object
	Target is an eclipsing binary asteroid to enable ground-based observers to measure the energy transfer from the kinetic impact
	The October, 2022 close approach of Didymos to Earth is the best ground-based observing opportunity for optical and radar techniques
DART shall impact on the Didymos secondary asteroid and cause at least a 0.17% change in the binary orbital period	The period change shall be measureable by ground-based observing within one month by small aperture optical telescopes
DART shall demonstrate asteroid deflection and shall measure the change in the binary orbital period to within 10% precision	This measurement determines the kinetic energy transfer to within 6.7%
DART shall impact no earlier than September 30, 2022	Ground-based observations are more difficult prior to September 30, 2022
DART shall autonomously impact the secondary asteroid through its center of figure with a miss distance of less than 15m (TBR)	The central impact reduces uncertainty in determination of momentum transfer
DART shall impact such that the night side of the secondary is illuminated by reflected light from the primary	DART can target the center-of-figure including the night side of the approach hemisphere
DART shall determine the impact location within 1 m	Understanding and interpretation of momentum transfer require knowledge of impact location
DART shall determine local surface topography and geologic context of impact site to meter scale (TBR)	Knowledge of local surface geology and topography required to interpret momentum transfer and to understand impact effects

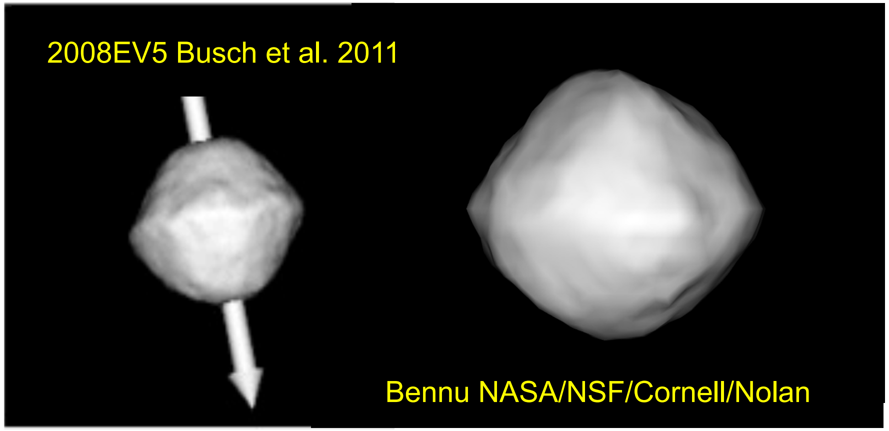
AIM Requirements/Traceability

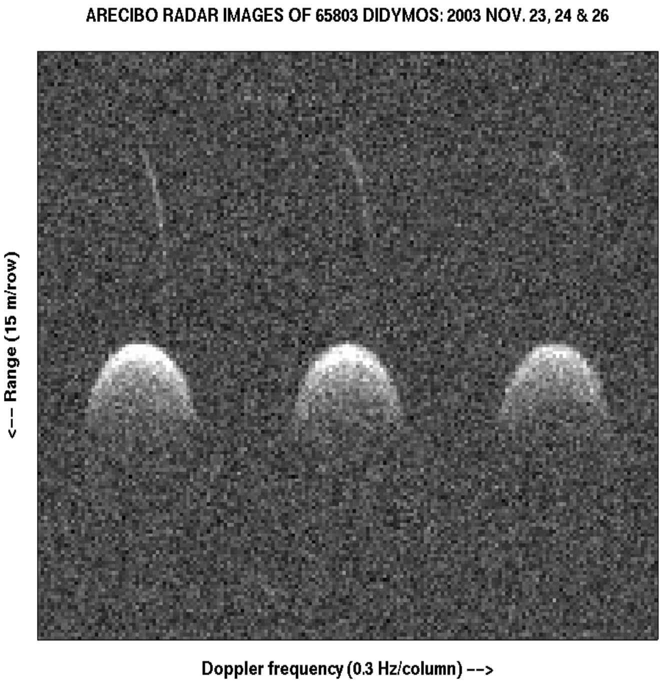
Baseline Objectives	Measurements	Payload Examples	Knowledge Gains
Surface/ Sub-surface physical properties	Surface strength, porosity, density, mechanical properties, subsurface properties, thermal inertia	WAC/NAC + filters, impactor or hopper with accelerometer (interacting tool with the surface; e.g. penetrometer), in-situ imaging, thermal infrared spectrometer	Local properties, resource utilization, human exploration; Yarkovsky & YORP effects. *Momentum transfer (impact)*
Surface chemical, mineralogical properties	Elemental, chemical, mineralogical composition. Volatiles?	WAC/NAC + filters, Visible photometry, NIR spectrometer, in-situ IR spectrometer, APX/ LIBS (on a surface package)	Compositional properties of a NEA; resource utilization; *impact science (melting etc.); optional because of "low" impact speed*
Global characteristics	Mass, shape, high resolution DTM, rotational properties, bulk composition, global subsurface properties, internal structure	Radio Science (RF tracking), seismometers, radar sounding, LIDAR, WAC/NAC	CoG position; YORP; detailed physical properties of a NEA; *damping of impact energy*
Orbital parameters	State of binary orbit, heliocentric orbit	WAC, NAC Radio Tracking	Dynamical properties of a binary; *momentum transfer*
Impact event	*Dust production/properties* *Crater size, depth, morphology;* *Composition in the crater*	*Dust monitor,* *Camera (stray light detection)* *IR spectrometer*	*Impact outcome* *Test of numerical models & scaling laws; sub-surface properties*

In italics, relevant to AIDA only

AIDA Target Properties

- The target is the binary Near-Earth Asteroid 65803 (1996 GT) Didymos: a YORP spin-up binary with an equatorial ridge on the primary

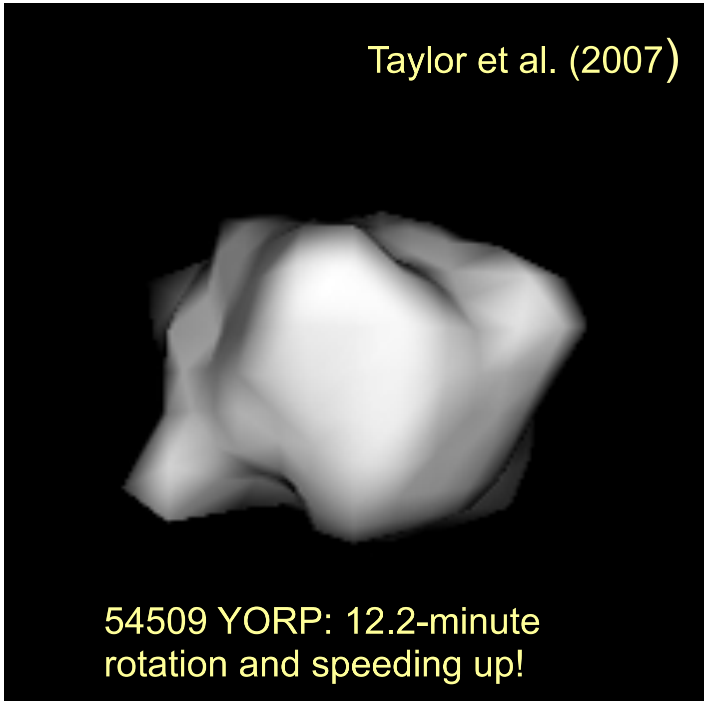


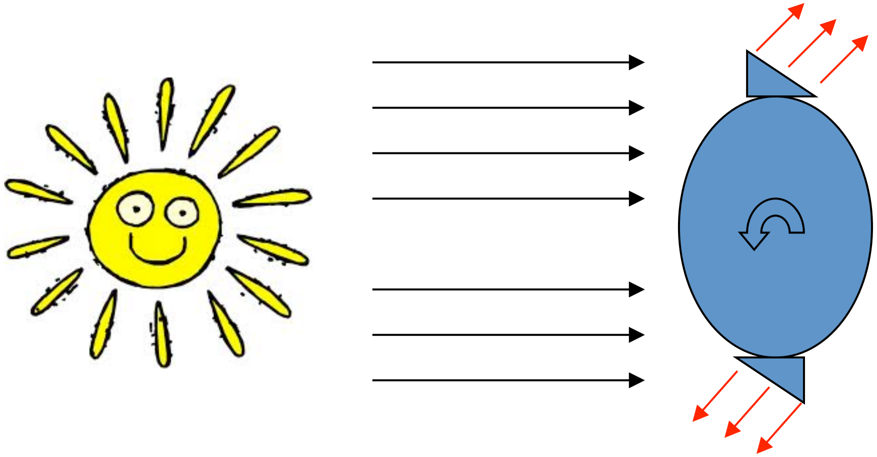


Radar image of Didymos
From L. Benner, Arecibo, Nov. 2003

YORP spin-up

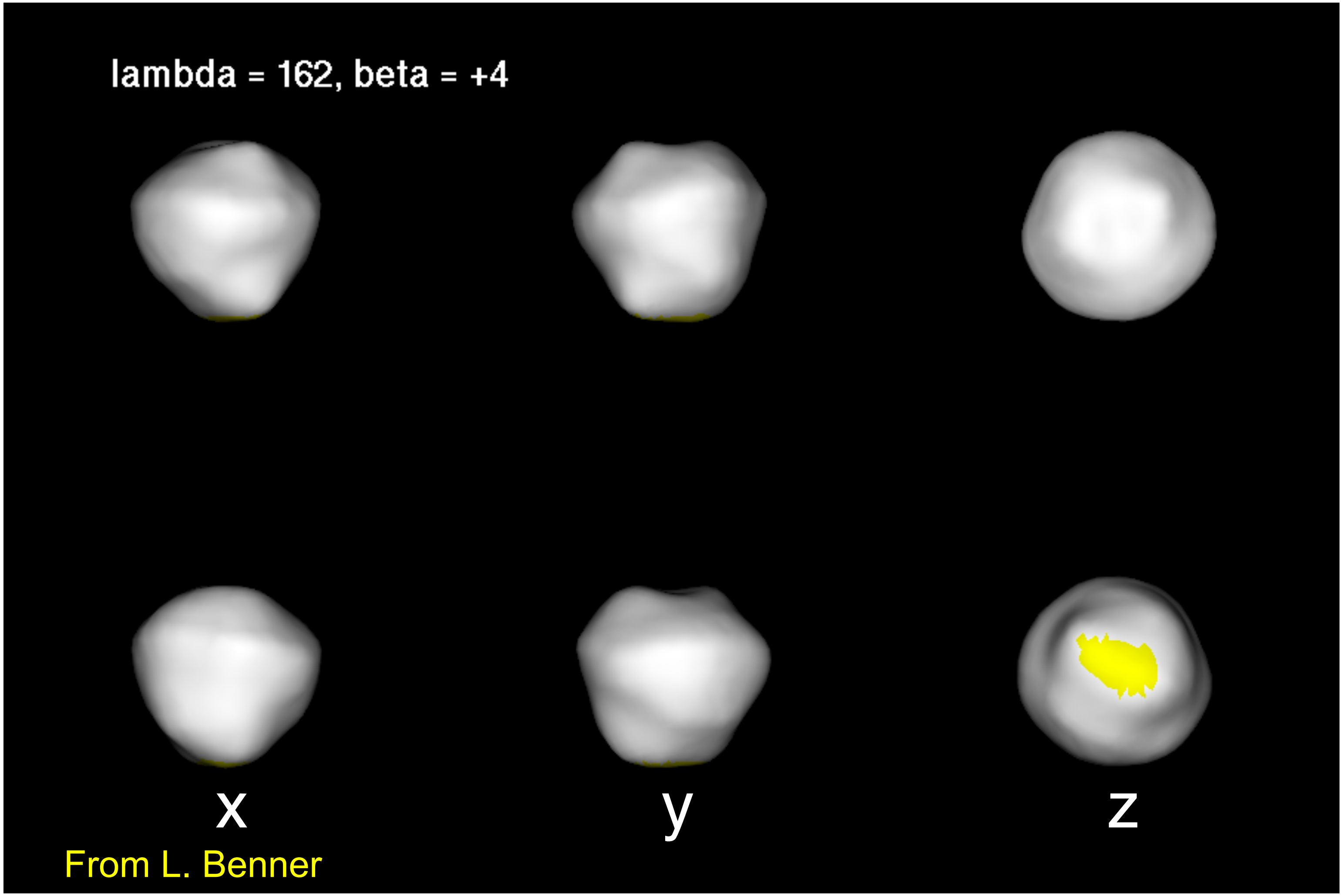
- Even sunlight, such as the "YORP" effect, can spin-up and disrupt asteroids.
  - Asymmetric re-radiation of thermal energy
- Depends on body size and distance from Sun.
- Spin-up timescale ~Myr.





Not all internal structures lead to a binary from YORP spin-up

Preliminary Radar Shape Model for the Primary: Principal Axis Views



Other Radar Observations

Secondary member of binary: dimension not well constrained, bandwidths and visible extents are consistent with synchronous rotation, no estimate of secondary's mass and density.

Radar albedo is consistent with silicates but is inconsistent with pure metal.

Near-surface roughness is lower than NEA average and somewhat less than on Eros, Itokawa, and Toutatis.

Didymos Properties from Light Curves

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Physical and Dynamical Properties from Optical Observations:

- Spin periods (two pole solutions)
- Orbital properties
- Since object is a binary, also mass and density

Binary System: discovered by light curves and radar	
Primary	Rotational Period = 2.2593 ± 0.01 h
	Δm = 0.08 mag → low elongation
Secondary	Orbital Period = 11.9 h (synchronous)
	Δm = 0.6 mag → elongated

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PRIMARY
Rotation period: 2.259 h (Scheirich and Pravec 2009)
Pole 1
(λ, β) = (162,+4) +-20 deg
x, y, z = 0.84 x 0.82 x 0.79 km
Deff = 0.79 km

Pole 2
(λ, β) = (300,-60) +-20 deg
x, y, z = 0.78 x 0.79 x 0.74 km
Deff = 0.75 km

SECONDARY
D = 100-150 m, elongated

ORBIT
Semimajor axis:  1.18 +0.04-0.02 km
Mass:            5.3  +- 0.5 E11 kg
Bulk density:    2.4  +- 0.5     g/cm3
Orbital period:  11.9 h (Scheirich and Pravec 2009)

DISK-INTEGRATED PROPERTIES
Radar albedo:    0.24 +- 25%
SC/OC:           0.22 +- 0.02
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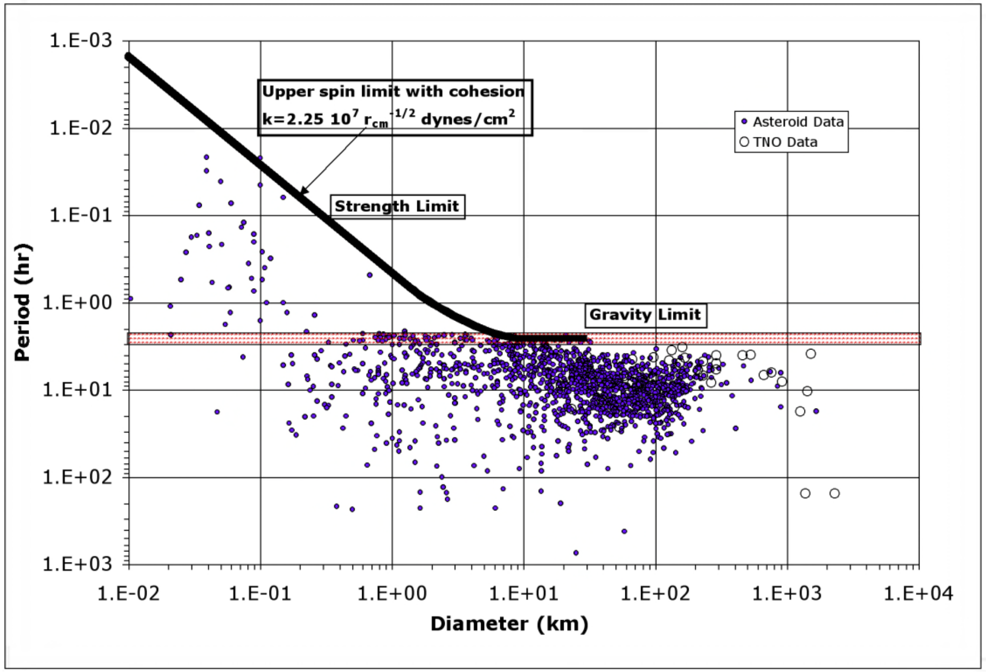
Pravec et al. (2006), Scheirich and Pravec 2009)

Rotation period and Internal Structure

Rotation period of the primary = 2.26 hrs

- ~30% above the limit for a purely cohesionless body (unless ρ > 3 g/cm^3).
- Must have some global cohesion
- Surface velocity > orbit speed at the equator:
  - What happens to loose material formed on the surface from impacts or thermal fragmentation?
  - Can debris fall back onto the primary or accrete onto the secondary?



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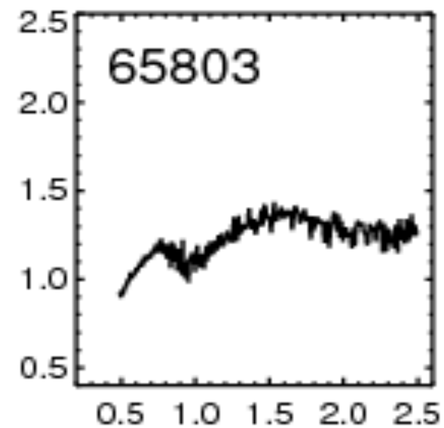
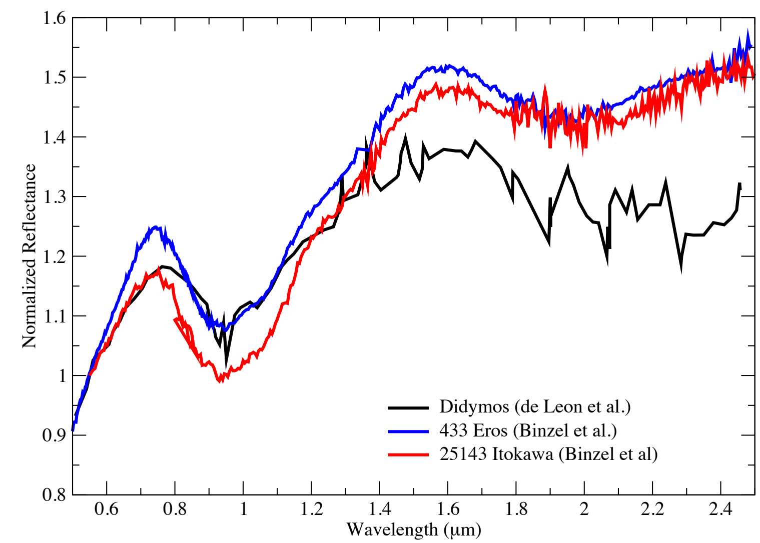
Didymos: Spectral type

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



de León et al. (2010)



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AIDA Impact Experiment

- DART impact transfers momentum to the secondary and changes binary relative orbit
  - Orbital period change measurable by Earth-based observatories
- If impactor relative momentum is ***p***, the impulse transferred to target is β***p*** where the enhancement factor β is uncertain
  - Likely $\beta>1$ because of impact ejecta
  - With $\beta=1$ and 400 kg impactor at 6 km/s onto Didymos secondary along orbital motion, the orbital velocity change is ~0.5 mm/s and the period change ΔP is ~400 s, or $\Delta P/P \sim 1\%$

Orbital velocity: 15.4 cm/s

- Measurement of deflection to <10% in light curves requires $(\Delta P/P)*(t/P) > 0.1$
  - Corresponds to mean anomaly change 36° over time span t, for better than 10% measurement with observational error ~3°
  - If t is 14 days, then $(\Delta P/P)*(t/P) \sim 0.26$
- Deflection measurement requirement is expected to be met within a few weeks of the encounter
  - Impact won't disrupt the secondary or unbind the binary

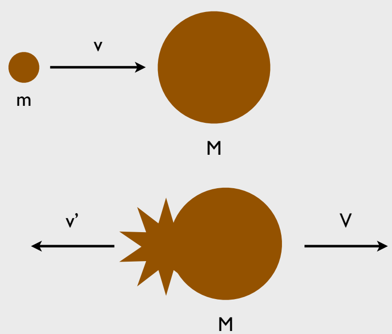
Momentum Transfer and Beta

- Momentum transferred to the target:

$P_{target} / P_{Projectile} = 1 + P_{ejecta} / P_{projectile} = \beta \geq 1$

If no ejecta then $P_{ejecta} = 0 \rightarrow \beta = 1$

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



Momentum transfer:

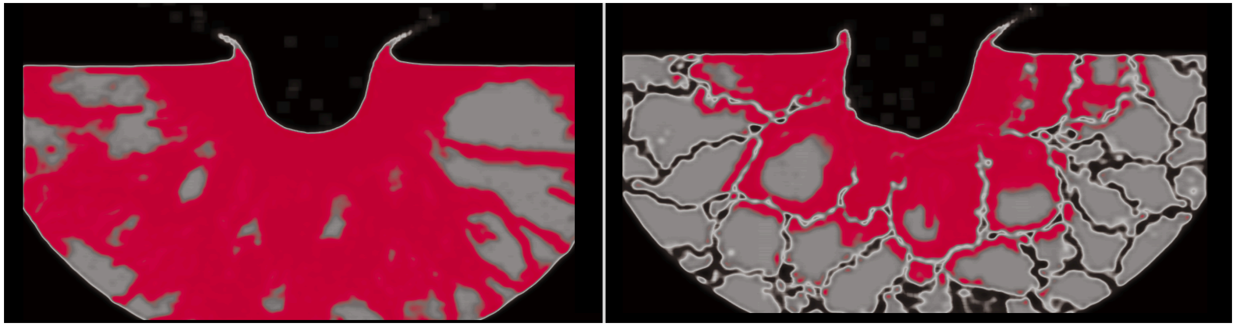
$$\vec{P}_{target} = \vec{P}_{projectile} + \vec{P}_{ejecta} > \vec{P}_{projectile}$$

- ➡ Target structure
- ➡ Material Properties
- ➡ Impact velocity
- ➡ Target size etc.

Objectives: to observe and characterize newly formed crater, to determine beta from effects of the known impact, and to infer target physical properties

Simulations of Spacecraft Impact

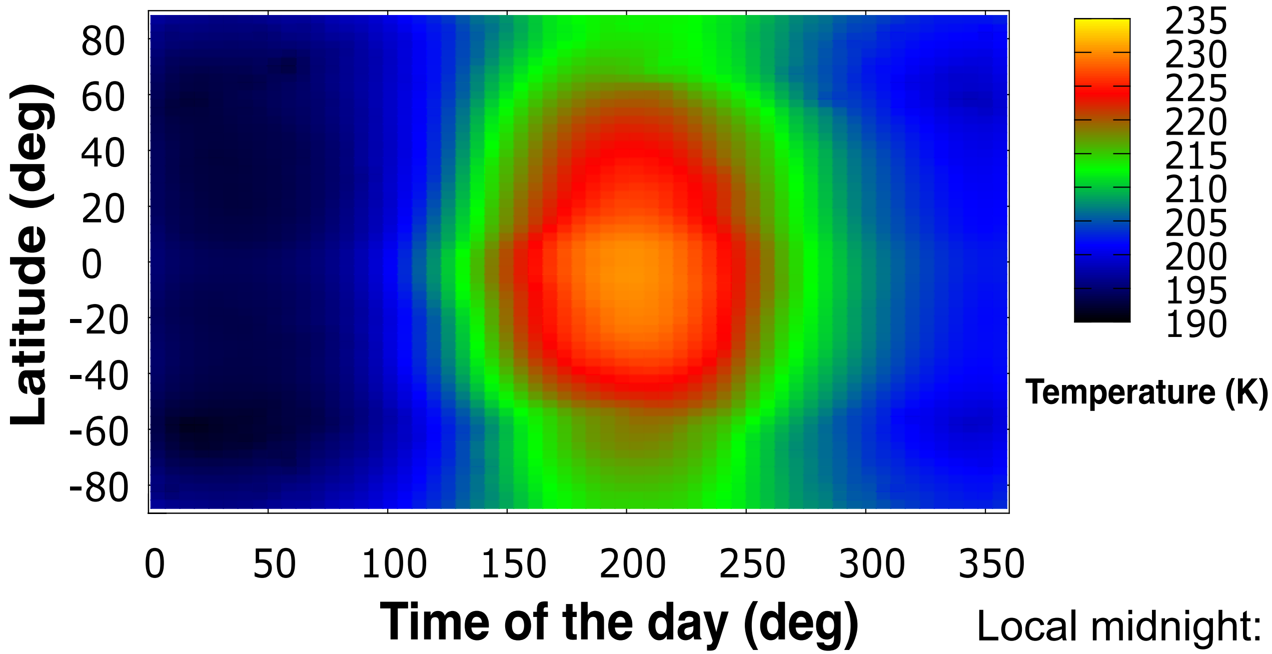
- From impact simulations (SPH hydrocode), using the DART impact conditions and a porous internal structure:
  - Predicted crater diameter: about 15 meters
  - Large scale (body's size) restructuring is unlikely
  - Regolith displacement (lift off) in the crater's vicinity may occur but difficult to assess
- Computed β factor is highly uncertain, depending on porosity, other target physical properties, and internal structure



Jutzi & Michel 2014

Thermal Properties

- Due to faintness of Didymos before 2022, thermal IR measurements are difficult; thermal inertia Γ is not known



Local midnight: 0°

Temperature distribution model on Didymos' primary at 1.664 AU from the Sun, assuming: $\Gamma = 100\ J\ m^{-2}\ s^{-0.5}\ K^{-1}$, bolometric bond albedo of 0.1, emissivity of 0.9, spin perpendicular to the Sun

Calculated by M. Delbo

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What is the fate of small ejecta?

- The DART impact may stimulate creation of a transient debris disk in the Didymos system
- A dust/particulate tail or trail may be created that can be monitored by Earth-based observatories
  - Computed with the code COSSIM accounting for solar radiation pressure (Vincent et al. 2010)
  - Worse case scenario: dust grains are ejected just above the escape speed of the secondary
  - Particles leaving the volume corresponding to a distance of 100 km for different size range:

1-10 microns:	6 hours
10-100 microns:	1 day
0.1-1 mm:	3 days
1-10 mm :	10 days
1-10 cm :	> 30 days

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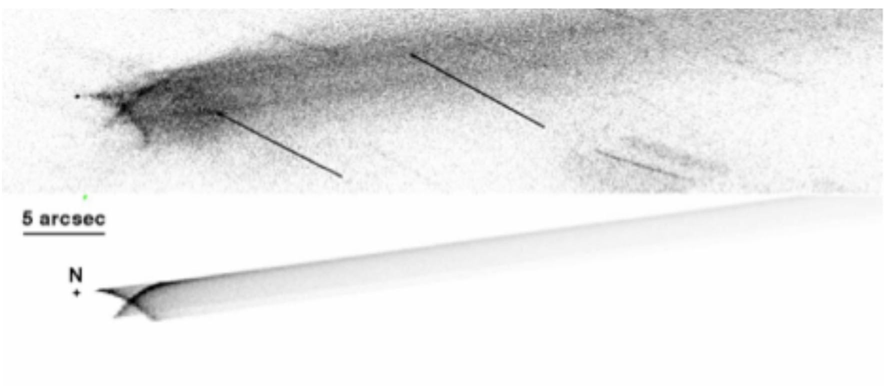
Post-Impact Observing Prospects

- Didymos and satellite are separated by up to 0.02 arcsec when 0.08 AU from Earth
  - Edge of doable with ALMA (sub-mm), Magellan adaptive optics?
- Detect/model post-disruption dust evolution, as done with active asteroids?
- *Preliminary, ballpark* estimates suggest dust production could brighten Didymos by 3+ magnitudes



Dust mode 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)

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AIDA: International Cooperation for Planetary Defense

Abstracts solicited for AIDA Workshop:
Didymos binary system; binary origins, dynamics, evolution; impact observing strategies; impact and ejecta modeling and simulation; science opportunities for impact demonstration payloads.

Due Sept 1

AIDA Workshop:

15-17 October, 2014, at APL/JHU, Laurel, MD

http://www.oca.eu/michel/AIDAWorkshop2014

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