AIDA Concept Overview

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Chelyabinsk Meteor on 15 February 2013
Asteroid Impact & Deflection Assessment (AIDA)

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

July 29, 2014
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
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

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

<table>
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<th>Baseline Objectives</th>
<th>Measurements</th>
<th>Payload Examples</th>
<th>Knowledge Gains</th>
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<tr>
<td><strong>Surface/ Sub-surface physical properties</strong></td>
<td>Surface strength, porosity, density, mechanical properties, subsurface properties, thermal inertia</td>
<td>WAC/NAC + filters, impactor or hopper with accelerometer (interacting tool with the surface; e.g. penetrometer), in-situ imaging, thermal infrared spectrometer</td>
<td>Local properties, resource utilization, human exploration; Yarkovsky &amp; YORP effects. <em>Momentum transfer (impact)</em></td>
</tr>
<tr>
<td><strong>Surface chemical, mineralogical properties</strong></td>
<td>Elemental, chemical, mineralogical composition. Volatiles?</td>
<td>WAC/NAC + filters, Visible photometry, NIR spectrometer, in-situ IR spectrometer, APX/LIBS (on a surface package)</td>
<td>Compositional properties of a NEA; resource utilization; <em>impact science (melting etc.); optional because of “low” impact speed</em></td>
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<tr>
<td><strong>Global characteristics</strong></td>
<td>Mass, shape, high resolution DTM, rotational properties, bulk composition, global subsurface properties, internal structure</td>
<td>Radio Science (RF tracking), seismometers, radar sounding, LIDAR, WAC/NAC</td>
<td>CoG position; YORP; detailed physical properties of a NEA; <em>damping of impact energy</em></td>
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<tr>
<td><strong>Orbital parameters</strong></td>
<td>State of binary orbit, heliocentric orbit</td>
<td>WAC, NAC Radio Tracking</td>
<td>Dynamical properties of a binary; <em>momentum transfer</em></td>
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</table>
| **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.

Taylor et al. (2007)

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

54509 YORP: 12.2-minute rotation and speeding up!
Preliminary Radar Shape Model for the Primary: Principal Axis Views

\[ \lambda = 162, \beta = +4 \]

From L. Benner
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

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

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<tr>
<th></th>
<th>Primary</th>
<th>Secondary</th>
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<tbody>
<tr>
<td>Rotational Period</td>
<td>$2.2593 \pm 0.01,\text{h}$</td>
<td>Orbital Period = 11.9 h (synchronous)</td>
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<tr>
<td>$\Delta m$</td>
<td>0.08 mag $\rightarrow$ low elongation</td>
<td>$\Delta m = 0.6,\text{mag} \rightarrow$ elongated</td>
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**PRIMARY**
Rotation period: $2.259\,\text{h}$ (Scheirich and Pravec 2009)

Pole 1
$(\lambda, \beta) = (162, +4) \pm 20\,\text{deg}$
$x, y, z = 0.84 \times 0.82 \times 0.79\,\text{km}$
$Deff = 0.79\,\text{km}$

Pole 2
$(\lambda, \beta) = (300, -60) \pm 20\,\text{deg}$
$x, y, z = 0.78 \times 0.79 \times 0.74\,\text{km}$
$Deff = 0.75\,\text{km}$

**SECONDARY**
$D = 100-150\,\text{m}$, elongated

**ORBIT**
Semimajor axis: $1.18 \pm 0.04 - 0.02\,\text{km}$
Mass: $5.3 \pm 0.5 \times 10^3\,\text{kg}$
Bulk density: $2.4 \pm 0.5\,\text{g/cm}^3$
Orbital period: $11.9\,\text{h}$ (Scheirich and Pravec 2009)

**DISK-INTEGRATED PROPERTIES**
Radar albedo: $0.24 \pm 0.05$
SC/OC: $0.22 \pm 0.02$

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 $\rho > 3$ 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?
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
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 $\beta p$ where the enhancement factor $\beta$ 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 $\sim0.5$ mm/s and the period change $\Delta P$ is $\sim400$ s, or $\Delta P/P \sim 1\%$
- Measurement of deflection to $<10\%$ in light curves requires $(\Delta P/P)*(t/P) > 0.1$
  - Corresponds to mean anomaly change $36^\circ$ over time span $t$, for better than $10\%$ measurement with observational error $\sim3^\circ$
  - 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

Orbital velocity: 15.4 cm/s
Momentum Transfer and Beta

- Momentum transferred to the target:
  \[ \frac{P_{\text{target}}}{P_{\text{projectile}}} = 1 + \frac{P_{\text{ejecta}}}{P_{\text{projectile}}} = \beta \geq 1 \]
  If no ejecta then \( P_{\text{ejecta}} = 0 \) \( \Rightarrow \beta = 1 \)

\[ \Delta V = \frac{P_{\text{projectile}}}{M_{\text{target}}} \times \beta \]

**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 $\Gamma$ is not known.

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
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

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. The fate of small ejecta is simulated with the code COSSIM, accounting for solar radiation pressure (Vincent et al. 2010). The worst-case scenario is that 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 ranges are:

- 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
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)
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.

AIDA Workshop:
15-17 October, 2014, at APL/JHU, Laurel, MD
http://www.oca.eu/michel/AIDAWorkshop2014

Due Sept 1