DART: Double Asteroid Redirection Test

The First Planetary Defense Test Mission

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September 26, 2022
Impact of 20-25 m asteroid

Injured 1000+ people
Chelyabinsk
Year: 2013  Diameter: ~20 meters  Equivalent to: ~500 kilotons of TNT  Frequency: every few decades to centuries
# The Hazard by the Numbers

<table>
<thead>
<tr>
<th>Asteroid Size</th>
<th>Frequency</th>
<th>Impact</th>
<th># of NEOs</th>
<th>% Discovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 meters</td>
<td>~1 per year</td>
<td>Bright flash, no ground effects, but could leave meteorites</td>
<td>~500 million</td>
<td>&lt; 0.1%</td>
</tr>
<tr>
<td>25 meters</td>
<td>~1 per 100 years</td>
<td>Air burst explosion, could cause widespread injuries if over populated area</td>
<td>~5 million</td>
<td>0.4%</td>
</tr>
<tr>
<td>160 meters</td>
<td>~1 per 25,000 years</td>
<td>Crater of 1-2 kilometer diameter, deadly over metro areas/states, mass casualties</td>
<td>~20,000</td>
<td>42%</td>
</tr>
<tr>
<td>1,000 meters</td>
<td>~1 per 500,000 years</td>
<td>10-kilometer crater, global devastation, possible collapse of civilization</td>
<td>~900</td>
<td>&gt; 95%</td>
</tr>
<tr>
<td>10,000 meters</td>
<td>~1 per 100-200 million years</td>
<td>100-kilometer crater, global devastation, mass extinctions of terrestrial life</td>
<td>4</td>
<td>100%</td>
</tr>
</tbody>
</table>
Top Priority for a Mitigation Mission
Mitigation Techniques for Potentially Hazardous Asteroids

Animations from 360info.org

KI – Kinetic Impactor; IBD – Ion Beam Deflection
(Gravity Tractor performance is enveloped by the IBD performance so they are not shown separately.)
Launch
Nov. 24, 2021
SpaceX Falcon 9
Vandenberg Space Force Base, CA

Sept. 26, 2022
23:14 UTC (7:14 pm EDT)

DART Spacecraft
610 kilograms at launch; 570 kilograms at impact
14,000 miles per hour (6.1 km per second)

Dimorphos
150 meters
11.92-hour orbital period

Didymos
760 meters
2.26-hour rotation period

Earth-Based Observations
7 million miles (0.076 AU) from Earth at DART impact

LiCIACube
(Light Italian Cubesat for Imaging of Asteroids)
ASI contribution

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

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The Ideal Target

Earth-based observations

Original Orbit

New Orbit

Dimorphos

Didymos

IMPACT

DART

LICIACube
DART Spacecraft

Weight:
1,345 pounds (610 kg) at launch
1,260 pounds (570 kg) at kinetic impact

27.9 feet long

ROSAR (Roll-out Solar Array)

RLSA (Radial Line Slot Array)

TRANSFORMATIONAL SOLAR ARRAY

LI CIACUBE

NEXT-C

SMART NAV

DRACO
Understanding the pre-DART situation

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

Preliminary shape model of the Didymos primary asteroid from combined radar and light curve data, diameter ~780 m.
We knew little about the object we were aiming for Dimorphos?

- Size estimate: 165 m
- Orbit period: 11 hr 55 min
- Composition: same as Didymos?
Nov 24, 2021, 1:21 am EST
SpaceX Falcon 9 Launch
Vandenberg Space Force Base
The Ideal Time

Launch: Nov. 24, 2021

DART Kinetic Impact: Sept. 26, 2022
### Autonomous Navigating to Asteroid Impact

<table>
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<tr>
<th>Time</th>
<th>Distance</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 hours</td>
<td>90,000 km</td>
<td>Started SMART Nav autonomous navigation</td>
</tr>
<tr>
<td>73 minutes</td>
<td>27,000 km</td>
<td>First detection of Dimorphos</td>
</tr>
<tr>
<td>2.5 minutes</td>
<td>930 km</td>
<td>SMART Nav maneuvering ended</td>
</tr>
<tr>
<td>2 seconds</td>
<td>12 km</td>
<td>Last complete image</td>
</tr>
</tbody>
</table>

- Started SMART Nav autonomous navigation at 90,000 kilometers.
- First detection of Dimorphos at 27,000 kilometers.
- SMART Nav maneuvering ended at 930 kilometers.
- Last complete image at 12 kilometers.
DART DRACO
Final raw images as shown live, from last 5.5 min. Sped up x10, except for last 6 images

Credit: NASA/Johns Hopkins APL
Autonomously Navigating to Asteroid Impact
DART DRACO
Dimorphos and Didymos to scale
2.5 min. before DART’s impact
580 miles (930 km) distance

Credit: NASA/Johns Hopkins APL
DART DRACO
Dimorphos
11 seconds before DART’s impact
42 miles (68 km) distance

Credit: NASA/Johns Hopkins APL
LICIACube LEIA
Two images taken 6 seconds apart showing Dimorphos’ brightness before and after impact

(LICIACube-Dimorphos distance = 1020 km)

Credit: ASI/ NASA
September 26
23:26 UTC
(12 min. post-impact)

Vapor plume speed:
~1.5 km/s
~3300 mph

23:29 UTC
(15 min. post-impact)

Credit: Tim Lister, Joseph Chatelain, Rachel Street, Edward Gomez, Joseph Farah/Las Cumbres Observatory.

LCOGT 1 meter Telescope at SAAO South Africa
UT Date: 09/26/2022 11:10:50 PM (1 of 50)
September 27, 2022
~5 hours post-impact

Credit: Science: NASA, ESA, CSA, Jian-Yang Li (PSI), Cristina Thomas (Northern Arizona University), Ian Wong (NASA-GSFC); image processing: Joseph DePasquale (STScI), Alyssa Pagan (STScI)
September 26 – October 15, 2022
Hubble Space Telescope
1.3 hours before impact to 18.5 days post-impact

Credit – Science: NASA/ESA/STScI/Jian-Yang Li (PSI); Video: Joseph DePasquale (STScI)
September 27 – October 21, 2022
Ōtehīwai Mt. John Observatory in New Zealand
1 – 25 days post-impact

Credit: University of Canterbury Ōtehīwai Mt. John Observatory / UCNZ
November 18, 2022
Lowell Discovery Telescope
Arizona, USA
52 days post-impact

Credit: Thomas, Knight, Moskovitz
March 14, 2023
Lowell Discovery Telescope
Arizona, USA
168 days post-impact

Credit: Lowell Discovery Telescope, Observers: Thomas, Knight
Dimorphos By Comparison

Dimorphos itself is roughly as big as this building

The debris tail stretches at least as far as the blue arc

And has at least as much material to fill at least 6 rail cars (and perhaps as much as 60!)
Before DART's impact:
11 hrs 55 min

After DART's impact:
11 hrs 22 min

Illustration of telescopic measurements to determine the period change
DART Impact Caused 33-Minute Period Change

Dimorphos eclipses:
- Expected for previous 11 hr 55 min orbit
- Observed from new 11 hr 22 min orbit

- Sept. 27
- Sept. 28
- Sept. 29
- Sept. 30
- Oct. 1
- Oct. 2
- Oct. 3
- Oct. 4
- Oct. 5
- Oct. 6

RELATIVE BRIGHTNESS

- 104%
- 100%
- 96%

Sept. 29

Credit: NASA/Johns Hopkins APL/Astronomical Institute of the Academy of Sciences of the Czech Republic/Lowell Observatory/JPL/Las Cumbres Observatory/Las Campanas Observatory/European Southern Observatory/Danish (1.54-m) telescope/University of Edinburgh/University of Edinburgh/Universidad Católica de la Santísima Concepción/Seoul National Observatory/Universidad de Antofagasta/Universität Hamburg/Northern Arizona University
Radar images measure Dimorphos’ new orbit

Credit: NASA/Johns Hopkins APL/JPL/NASA JPL Goldstone Planetary Radar/National Science Foundation’s Green Bank Observatory

- Didymos
- Dimorphos
- Expected Dimorphos From 11 hr. 55 min. orbit
  - Dimorphos orbit

2022 Oct 04 11:55:39 UTC

2022 Oct 09 10:56:47 UTC
NO EJECTA

Momentum Enhancement Factor = 1

-7 minutes

SOME EJECTA

DART EJECTA

Momentum Enhancement Factor ~3.6

-33 minutes

LOTS OF EJECTA
Credits: ASI/NASA
Distance [km]: 777
Nov. 9, 2022
44 days post-impact
DART collides with Dimorphos, and scientists from around the globe analyze the resulting orbital shifts from telescopes on the Earth.

Juventas CubeSat gathers radar data.

Hera investigates the aftermath of DART’s impact in detail for months, obtaining key data to develop asteroid deflection into a well-understood, scalable, and repeatable technique.

Milani CubeSat inspects the mineralogy.
A Smashing Success: Humanity moves a celestial object for the first time

- DART demonstrated that kinetic impactor technology is a viable technique to potentially defend Earth, if necessary.
- The large orbit period change shows that ejecta contributed a significant amount of momentum to the asteroid beyond what the DART spacecraft carried.
- This means that a given kinetic impactor could be used on a larger object, or at a later time, than previously thought.