Planetary Defense Missions
Post-DART/NEOSM

Presented to the Decadal Survey on Planetary Science and Astrobiology:
Panel on Small Solar System Bodies

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- The views expressed herein are those of the presenter and do not represent an official position of NASA, Goddard Space Flight Center, or the Planetary Defense Coordination Office.

Future Spacecraft Missions for Planetary Defense Preparation

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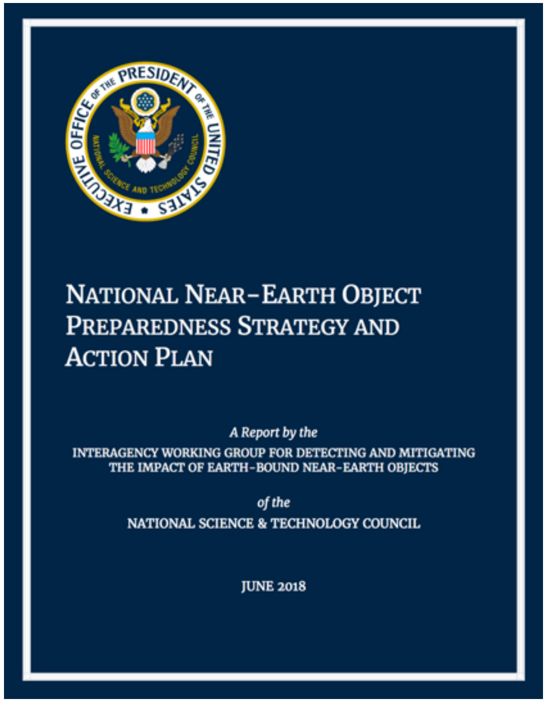
Assumptions and Background

- Assumption: NASA's Double Asteroid Redirection Test (DART) mission launches as planned in July 2021 and is successful.
- The next priority for Planetary Defense missions after DART is NASA's NEO Surveillance Mission (NEOSM).
- Assumption: NEOSM is developed, deployed, and operates successfully.
- The US National Near-Earth Object Preparedness Strategy and Action Plan (NNPSAP) describes post-DART/NEOSM Planetary Defense mission priorities.


EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES
NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

NATIONAL NEAR-EARTH OBJECT PREPAREDNESS STRATEGY AND ACTION PLAN

A Report by the
INTERAGENCY WORKING GROUP FOR DETECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS

of the
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

JUNE 2018

https://www.whitehouse.gov/wp-content/uploads/2018/06/National-Near-Earth-Object-Preparedness-Strategy-and-Action-Plan-23-pages-1MB.pdf

The following describes the Planetary Defense missions that are recommended to occur after DART and NEOSM.

PD Mission Priorities Post-DART/NEOSM

1. Rapid Response In Situ NEO Reconnaissance Demonstration Mission

NNPSAP 3.1 **Assess technologies and concepts for rapid-response NEO reconnaissance missions.** This assessment should include dedicated reconnaissance via spacecraft flyby or rendezvous, as well as mission concepts in which the reconnaissance spacecraft could also carry out deflection or disruption. The assessment should consider both commercial-off-the-shelf parts and new hardware development.

NNPSAP 3.3 **Create plans for the development, testing, and implementation of NEO reconnaissance mission systems.** These plans should lead to establishment of operational NEO reconnaissance capabilities, including rapid-response. Planning could include developing a system to automatically calculate possible trajectories for planetary defense spacecraft to reach potentially hazardous NEOs.

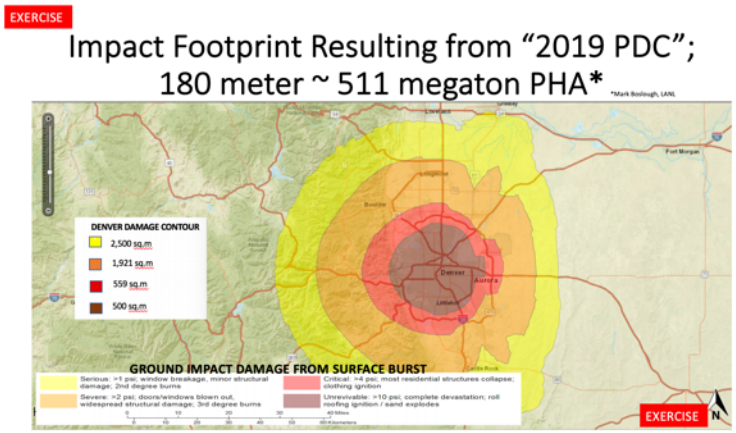
2. Combination Kinetic Impactor / Nuclear Explosive Device ***System*** Demonstration Mission

(*does not include an actual nuclear device*)

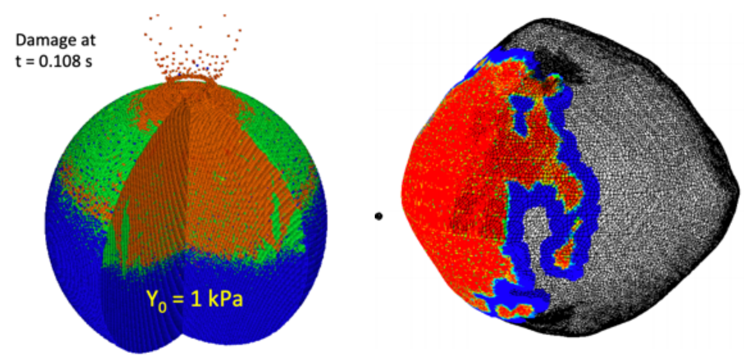
NNPSAP 3.7 **Conduct a series of flight demonstrations to validate NEO deflection and disruption system concepts.** These flight demonstrations would focus on harmless NEOs to test and validate deflection/disruption system concepts and identify design issues for correction. Any flight demonstrations relevant to nuclear explosive techniques would not incorporate an actual nuclear device or involve any nuclear explosive testing. Results would inform decision-making processes during an actual NEO threat scenario. **Thorough flight testing of a deflection/disruption system prior to an actual planetary defense mission would substantially decrease the risk of mission failure.**

The Need For Rapid Response In Situ NEO Reconnaissance

- When an NEO with a sufficiently concerning near-term probability of Earth impact is discovered, it will be important to acquire data about the NEO as quickly as possible using both remote observations and in situ spacecraft reconnaissance missions.
  - Quickly confirm whether Earth impact will occur.
  - Enable earlier mitigation actions and prevent drawn-out impact uncertainty.
  - Inform modeling of Earth impact effects, mitigation options, etc.



https://cneos.jpl.nasa.gov/pd/cs/pdc19/pdc19_briefing3c.pdf



Credit: Megan Bruck Syal

Credit: J. Michael Owen

https://www.lpi.usra.edu/sbag/meetings/jun2016/presentations/barbee.pdf

Rapid Response NEO Recon Characteristics

- Relatively small but sufficiently capable, able to be rapidly readied for launch and deployed quickly during an operational planetary defense scenario
  - How small? (how expensive?), how capable? (and, capable how?), how rapid/quick?, how architected?, etc., etc., are all TBD via ongoing research
- NEO rendezvous is preferable for recon, but in some scenarios only high-speed NEO flybys may be available, so both rendezvous and flyby recon should be supported by the recon spacecraft
- Spacecraft instrumentation should be informed by ongoing research into prioritized NEO characterization needs for planetary defense purposes

NEO Characterization Needs for Planetary Defense

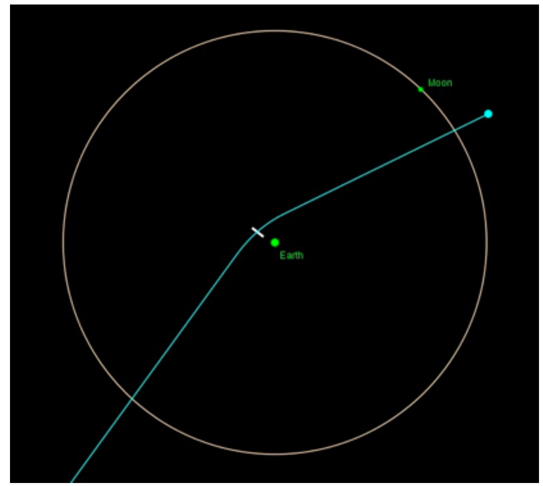
<u>Notionally*</u> Prioritized High-Level NEO Characteristics To Inform Mitigation Options/Decisions (in order of decreasing notional priority):

- Orbit (i.e., heliocentric inertial orbital state (position and velocity vectors) at reference epoch(s))
  - **Precise orbit of NEO**
    - **Impact location** (sets requirements and/or informs minimum amount of deflection needed)
- Physical Properties
  - **Mass**: most important to know for a deflection/disruption attempt
  - **Binarity**: special considerations are required for deflecting/disrupting binary NEOs
  - **Shape**: with mass, we can then solve for bulk density
  - **Rotation:** may affect response to deflection/disruption attempt
  - **Strength**: influences NEO response to deflection/disruption attempt, cratering during Kinetic Impactor (KI) deflection, etc.
  - **Internal structure including porosity:** influences NEO response to deflection/disruption attempt, cratering during KI deflection, etc.
  - **Mineral composition**: particularly the iron fraction in the first few mm to cm of the NEO's surface (influences deflection/disruption method)
  - **Detailed surface topology**: relevant for predicting how the ejecta from a deflection attempt might influence the achieved deflection; may inform understanding of internal structure through boulder distribution analyses, regolith presence, etc.

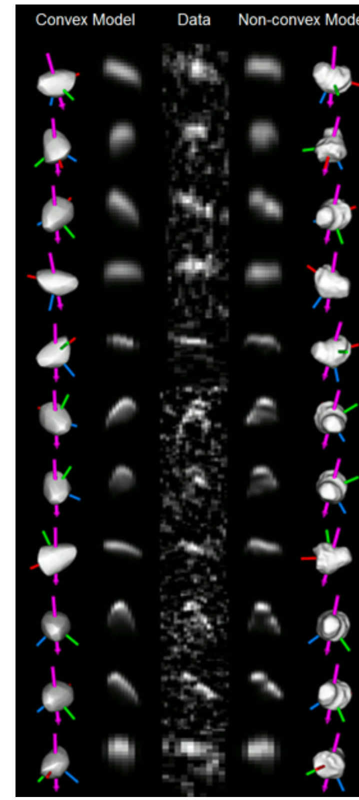
**Research on NEO characterization priorities is ongoing, and priorities may vary between different types of planetary defense scenarios.*

Deploying a NEO Recon Demo Mission to Apophis Offers Many Synergies

- Apophis is ~340 meter size PHA that will make an historic close approach to Earth on April 13, 2029 within ~31,300 km of Earth's surface (closer than geosynchronous satellites)
  - Apophis will not hit Earth during this 2029 encounter.
- This is an exceedingly rare opportunity to observe planetary encounter effects on minor planet.
  - Changes in asteroid spin state, possible shape changes, seismic activity, regolith refreshing, etc.
- There will be significant worldwide public attention on this historic event.
- It would be useful to learn about Apophis in case there are any post-2029 Earth impact possibilities and mitigation missions are eventually called for.



Trajectory of Apophis during April 2029 Earth close approach. Image credit: NASA/JPL-Caltech

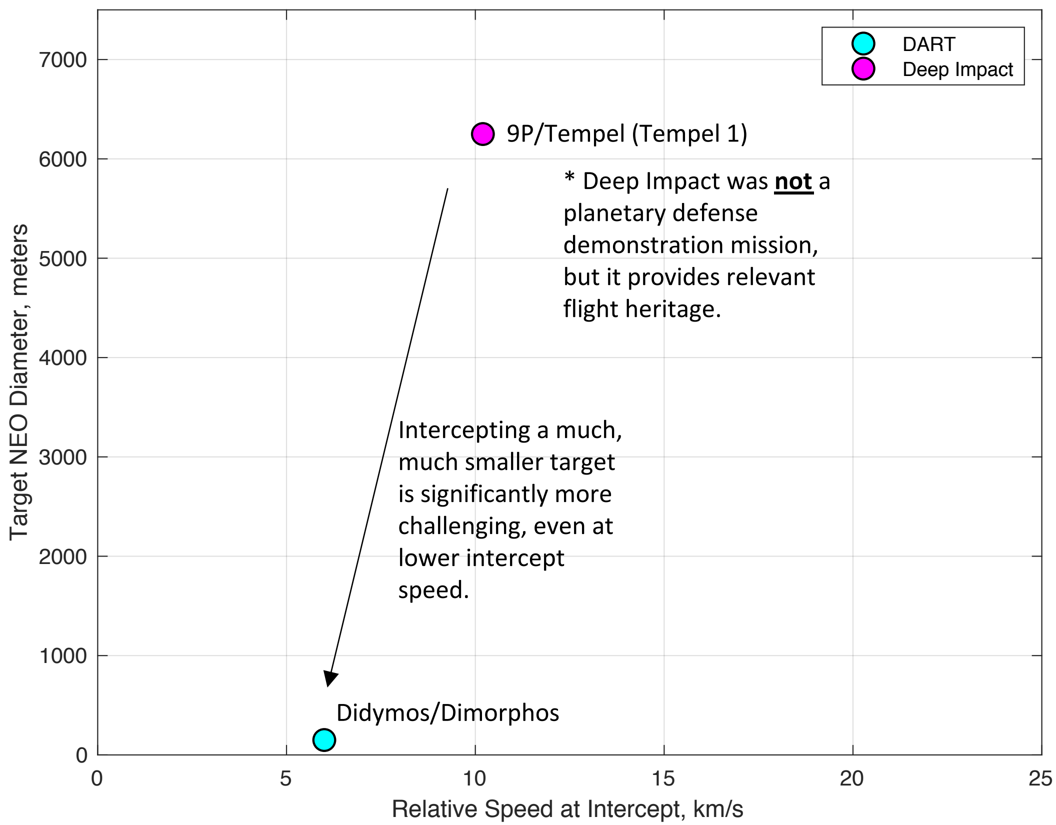


Apophis shape model fitting to radar data; from Brozović et al., Goldstone and Arecibo radar observations of (99942) Apophis in 2012–2013, Icarus Vol 300, 15 January 2018, pp. 115-128.

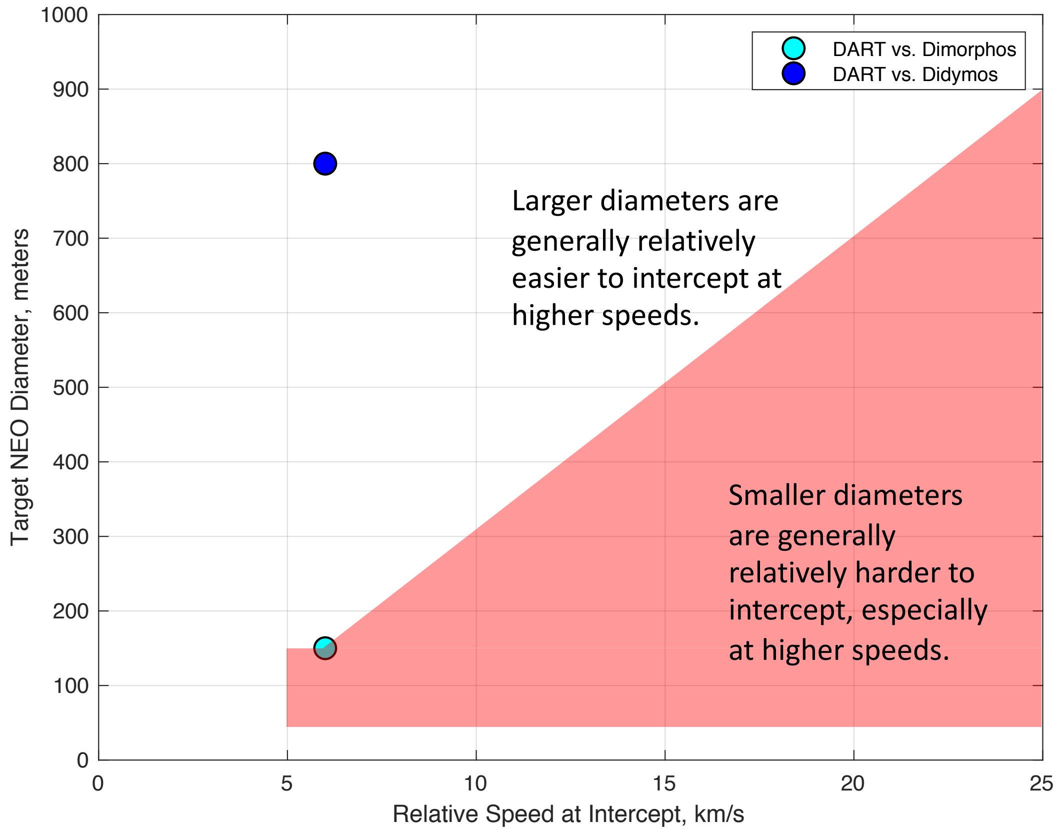
Building Upon DART's Legacy

- The DART mission currently planned for launch during summer 2021 will demonstrate the capability to acquire, track, and intercept a ~150-m-size NEO target—Dimorphos, the smaller secondary member of the Didymos binary NEA system—with a relative speed at intercept of ~6 km/s.
- The DART mission is intended to produce a diagnostic change in the secondary body's orbit about the primary body within the binary asteroid system, *not* an Earth deflection-scale change in the binary asteroid's heliocentric orbit
- The DART mission will also provide our first insight into the momentum enhancement factor ("beta," β) expected from NEO material ejected from the crater made in the NEO's surface by the kinetic impactor spacecraft
- The β effect can change the NEO's velocity beyond basic conservation of linear momentum effects; however, β is currently not well understood due to lack of any in situ testing and characterization on NEOs.
- Understanding the expected behavior of β is important for accurately planning attempts to deflect NEOs via kinetic impactor spacecraft.
- DART has established a strong international collaboration for planetary defense that should be maintained and strengthened over time.
- **Just like DART, all subsequent planetary defense missions should be designed to interact with non-Earth-threatening NEOs in a 'do no harm' manner, and demonstrate through analyses that no impact threats to Earth might be caused by the missions.**

Deep Impact and DART



High-Speed Intercept of Smaller Target NEOs Is Challenging

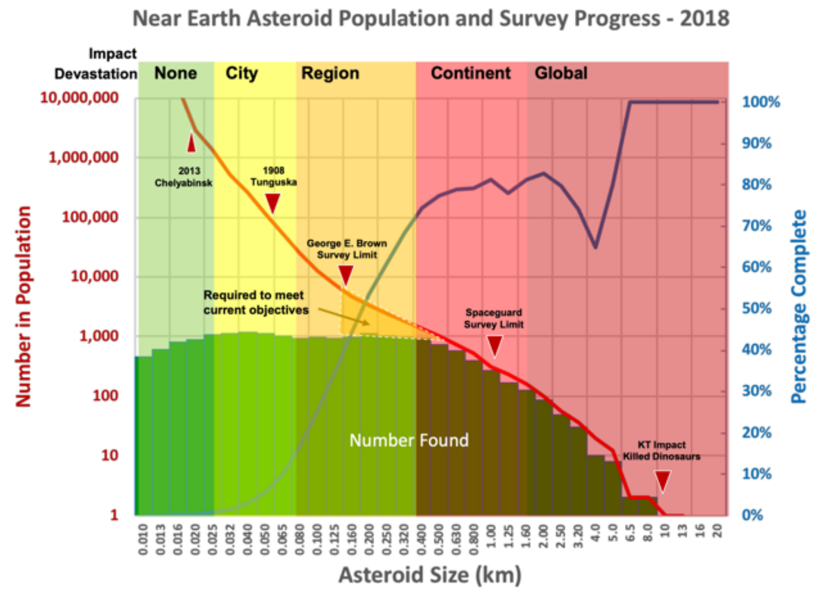


Comet intercept speeds can be much higher (e.g., up to 40-60 km/s+); Preparation for this should be undertaken in the future.

DART advances our NEO intercept capabilities and creates a legacy upon which we should build.

We Need to Be Prepared for High-Speed Intercept of Smaller NEOs

- NEOs on the smaller end of the size scale can still cause significant damage that would warrant in-space mitigation of the NEO.
- Smaller NEOs are exponentially more numerous than larger NEOs, creating an elevated likelihood of being faced with an impact threat from a small NEO.
- Although NEO recon/mitigation via rendezvous spacecraft is preferable, the circumstances of a scenario may force us to perform recon and/or mitigation via high-speed NEO flyby/intercept.
- NEO mitigation via nuclear deflection or disruption may be required in some scenarios.
- **Therefore, we should be prepared for the stressing case of high-speed intercept of even relatively small NEOs, e.g., down to ~50-100 m size.**
- **We should also be prepared for the further challenge of performing nuclear deflection/disruption of an NEO during a high-speed intercept.**



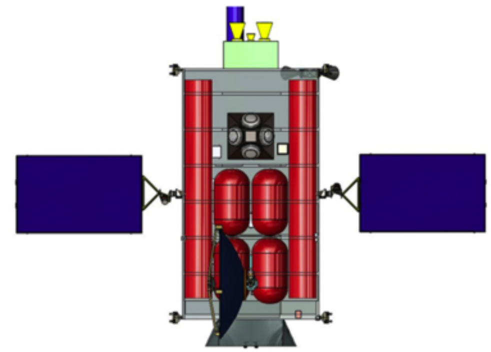
Fast, K., Near-Earth Object Observations Program, 21st Meeting of the NASA Small Bodies Assessment Group, June 24–25, 2019, College Park, MD, https://www.lpi.usra.edu/sbag/meetings/jun2019/presentations/Fast.pdf

Standoff Nuclear Detonation via High-Speed Intercept is Challenging

- Performing standoff nuclear detonation after rendezvous with NEO is preferable.
- However, in some scenarios NEO rendezvous won't be possible and so a standoff nuclear detonation may need to be performed via high-speed flyby.
- Standoff nuclear detonation via high-speed NEO intercept is very challenging, and we must be prepared to do it reliably in case the need ever arises.
- In order to impart the correct amount of DV to an NEO (for deflection or disruption purposes), a NED must detonate within +/- several tens of meters of the ideal distance from the NEO's surface.
- At high intercept speeds of >5 km/s (up to several tens of km/s), **detonation must therefore occur within <u>+/- several milliseconds</u>** of the moment at which the NED is actually at the ideal detonation location.
- This imposes very challenging requirements on the spacecraft sensors, detonation circuitry, etc.
  - And those requirements are on top of the already very challenging guidance, navigation, and control requirements associated with successfully bringing the spacecraft to the detonation coordinates at high speed in the first place.
- These challenges are even more extreme when the target NEO is small (e.g., <100 m), all else being equal.

Combination Kinetic Impactor / Nuclear Explosive Device System Demonstration Mission

- The next mission after DART to demonstrate increasing NEO mitigation capabilities should be a combination kinetic impactor / nuclear explosive ***system*** demonstration mission.
- No nuclear material will be included, only an inert mass simulator for a nuclear device.
  - Same interfaces, circuitry, mass properties, dimensions, etc.
  - Same processes, procedures, security, command/control, etc.
  - Same high-speed intercept sensing/detonation control systems & instrumentation.
- Build upon DART heritage by making this a larger spacecraft targeting a smaller NEO at higher intercept speed.
- Acquire additional data on the momentum enhancement factor (β).
- Make further progress in addressing the challenges of high-speed intercept of smaller target NEOs with the precision systems needed to carry out reliable standoff nuclear detonation if ever required.
- Prioritize systems suitable for short warning response (e.g., high-speed intercept), so that we are prepared for such situations as soon as possible.
  - Work on systems suitable for longer warning scenarios (e.g., gravity tractors) can then be performed later.



Conceptual KI / NED delivery spacecraft: HAMMER (Hypervelocity Asteroid Mitigation Mission for Emergency Response) spacecraft design; from Barbee, et al., Options and uncertainties in planetary defense: Mission planning and vehicle design for flexible response, Acta Astronautica, Vol 143, 2018, pp. 37-61, http://www.sciencedirect.com/science/article/pii/S0094576517307919

Developing and demonstrating capabilities to rapidly response stressing cases with short warning prepares us to handle those <u>and</u> all the less stressing cases (e.g., rendezvous rather than high-speed flyby, longer warning, etc.).

Progression of Performance

DART has established a strong international collaboration that should be maintained in future planetary defense missions.

DART

~6 km/s

~600 kg

~150 m target NEO

Measurable change in binary NEO mutual orbit

First data point for β

No rendezvous observer spacecraft

➡

KI/NED Sys. Demo

>6 km/s (e.g., **~10-15 km/s?**)

>600 kg (e.g., **~1000-2000 kg?**)

<150 m target NEO (e.g., **~50-100 m?**)

Measurable change in a solitary NEO's heliocentric orbit, sized to be representative of deflection that would be required in an actual PD scenario <10 years from Earth encounter

Demonstrates standoff NED detonation *system* (no nuclear device)

Second data point for β

Opportunity to include a rendezvous observer spacecraft

➡

Other KI/NED Sys. Demos

Other combinations of intercept relative speed and target NEO size, type, etc. that demonstrate performance throughout the relevant envelopes

Measurable change in solitary NEO's heliocentric orbit, sized to be representative of deflections that would be required in various actual PD scenario timelines

Refines standoff NED detonation capabilities

Additional data points for β

More opportunities to include rendezvous observer spacecraft

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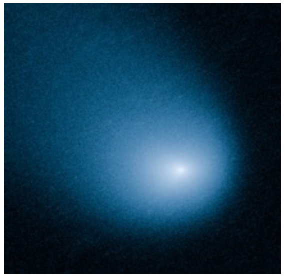
Develop and demonstrate increasing levels of capability - Towards future comet mitigation capabilities …



NASA, ESA, and J.-Y. Li (PSI)
https://www.nasa.gov/sites/default/files/14-090-hubble-comet_0.jpg

Comet C/2013 A1 (Siding Spring) nearly hit Mars at 56 km/s on Oct. 19, 2014.

Rendezvous observer spacecraft can also serve as demos/refinements of rapid response NEO recon spacecraft designs …

Summary of Recommendations

- **Establish an ongoing line of space missions and research activities dedicated to planetary defense.**
- **Develop and fly a rapid response in situ NEO reconnaissance mission.**
  - Deploy this mission to rendezvous with the PHA Apophis in order to observe it in situ before, during, and after its historic Earth close approach in April 2029.
  - **Helps address NNPSAP Actions 3.1 and 3.3.**
- **Develop and fly a combination kinetic impactor / nuclear explosive device (NED) *system* demonstration mission *using a simulated NED* (containing *no* nuclear material) to demonstrate:**
  - Increased guidance, navigation, and control capabilities under more challenging high-speed NEO intercept circumstances;
  - A larger-than-DART scale impact providing additional data to build understanding of the momentum enhancement factor (β);
  - Operational factors, instrumentation, sensing, commanding, security, etc., for a successful standoff NED detonation during high-speed NEO intercept, but without involving an actual nuclear device or nuclear material (in-space testing of NEDS is deliberately deferred to future discussions).
  - **Helps address NNPSAP Actions 3.4, 3.6, and (especially) 3.7.**
- **Planetary defense missions should always operate in a 'do-no-harm' manner and never have any possibility of posing risks to Earth.**