JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Planetary Defense Spacecraft Missions

Past, Present, and Future

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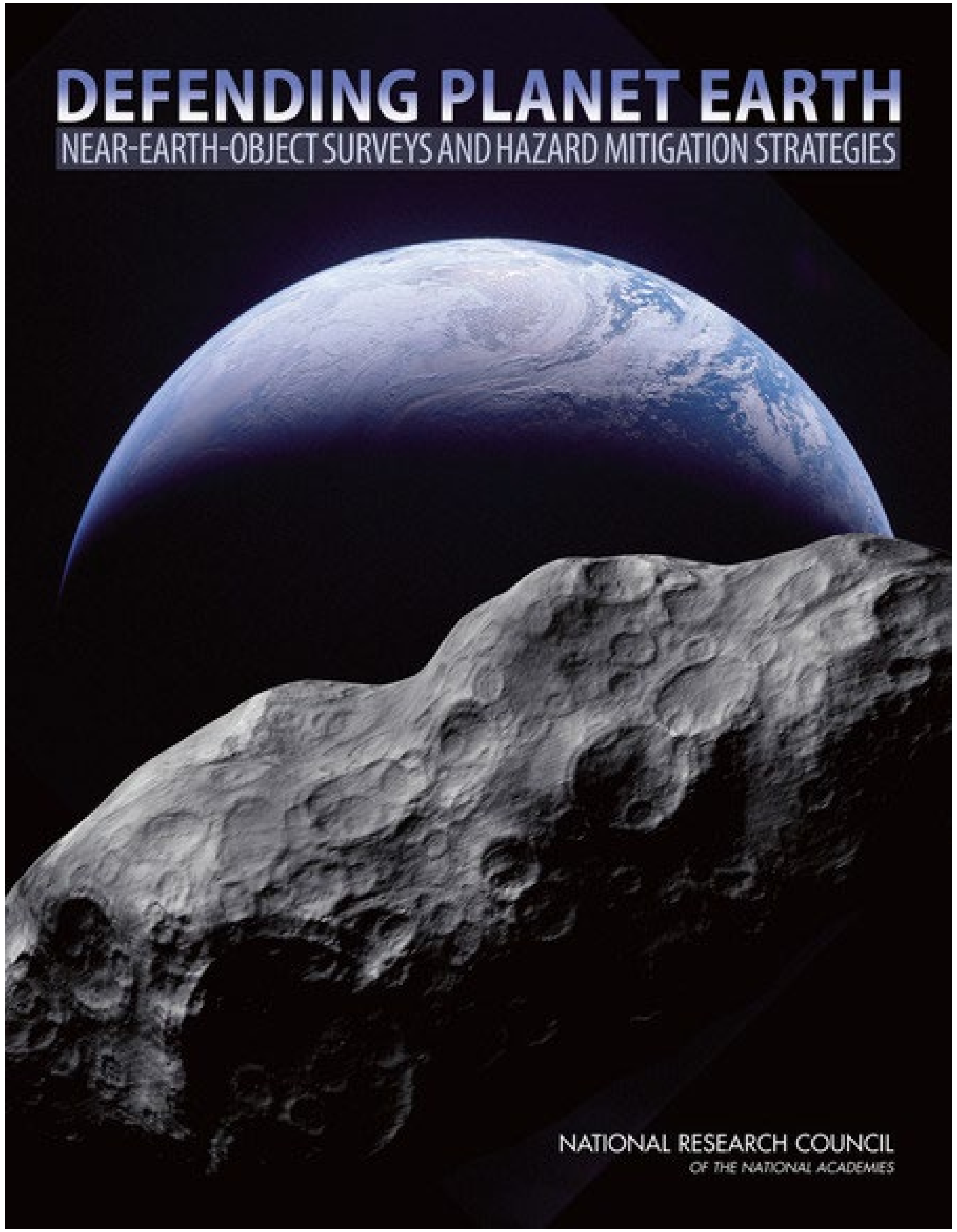
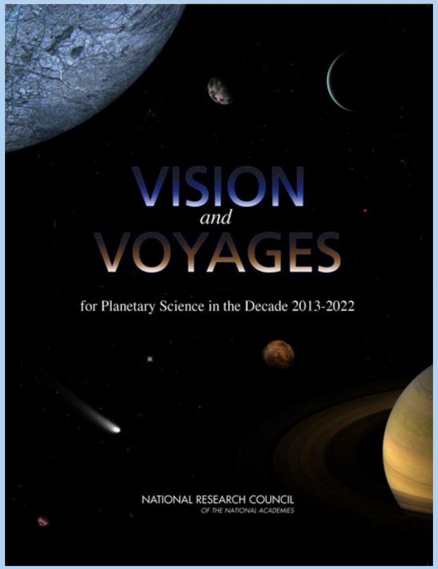


Defending Planet Earth – 2010

Tasked with assessing:

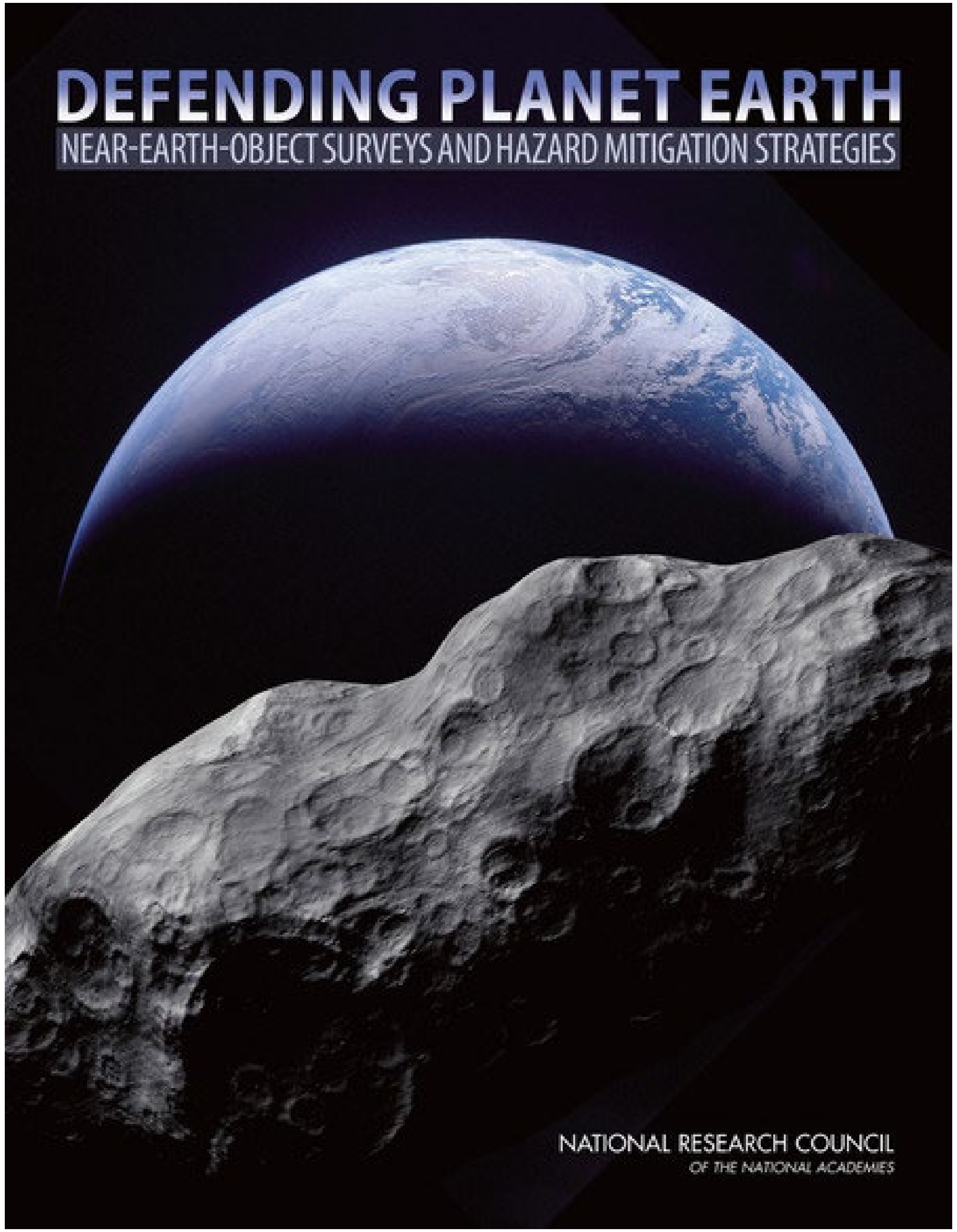
1. Near-Earth Object (NEO) Surveys
2. NEO Hazard Mitigation



Vision and Voyages – 2011

The following topics are not addressed in this report:

Issues relating to the hazards posed by near-Earth objects and approaches to hazard mitigation. Relevant material on the hazard issue is contained in *Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies.*

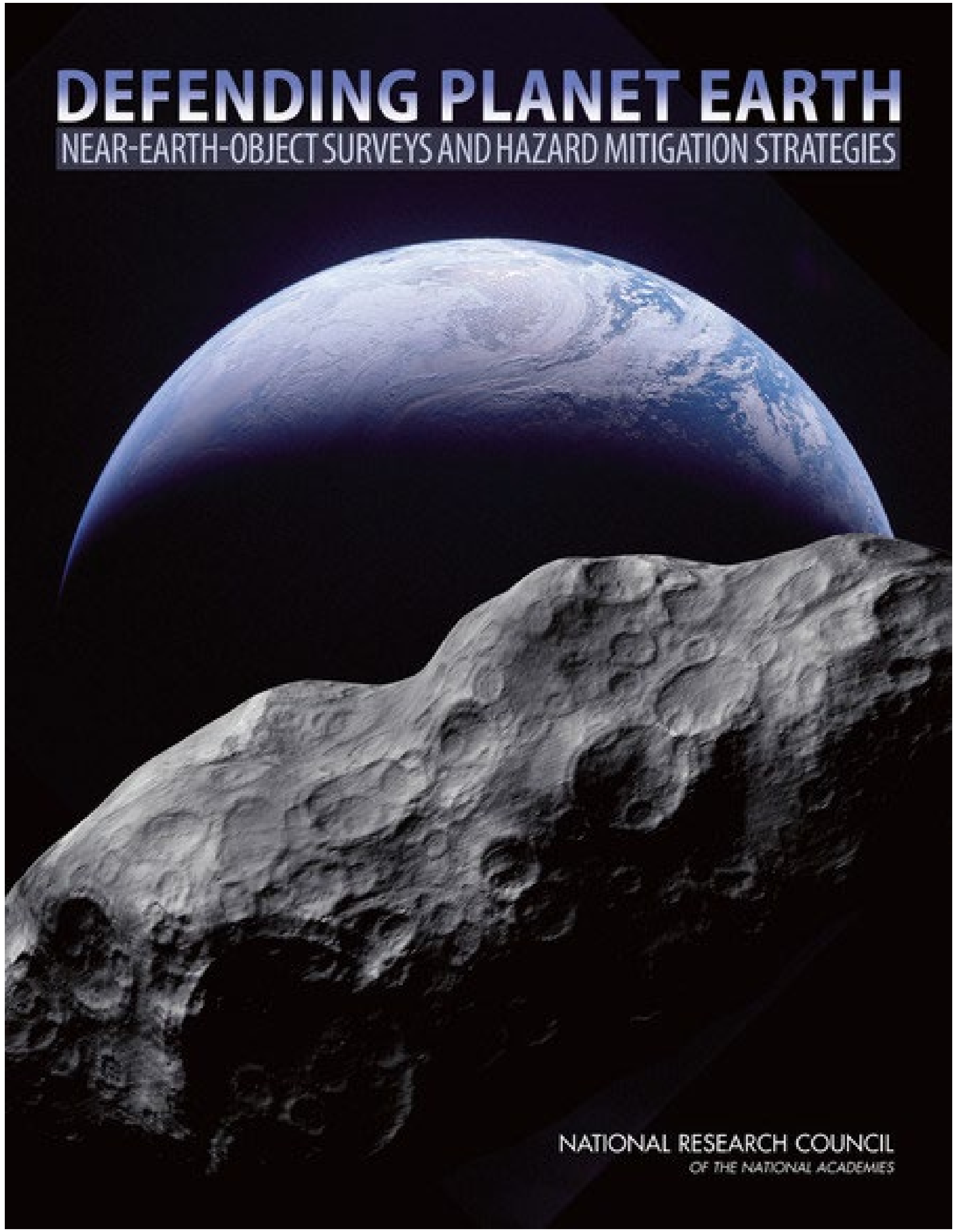


Defending Planet Earth – 2010

Task 1. NEO Surveys

Finding: The current near-Earth object surveys cannot meet the goals of the 2005 George E. Brown, Jr. Near-Earth Object Survey Act directing NASA to discover 90 percent of all near-Earth objects 140 meters in diameter or greater by 2020.

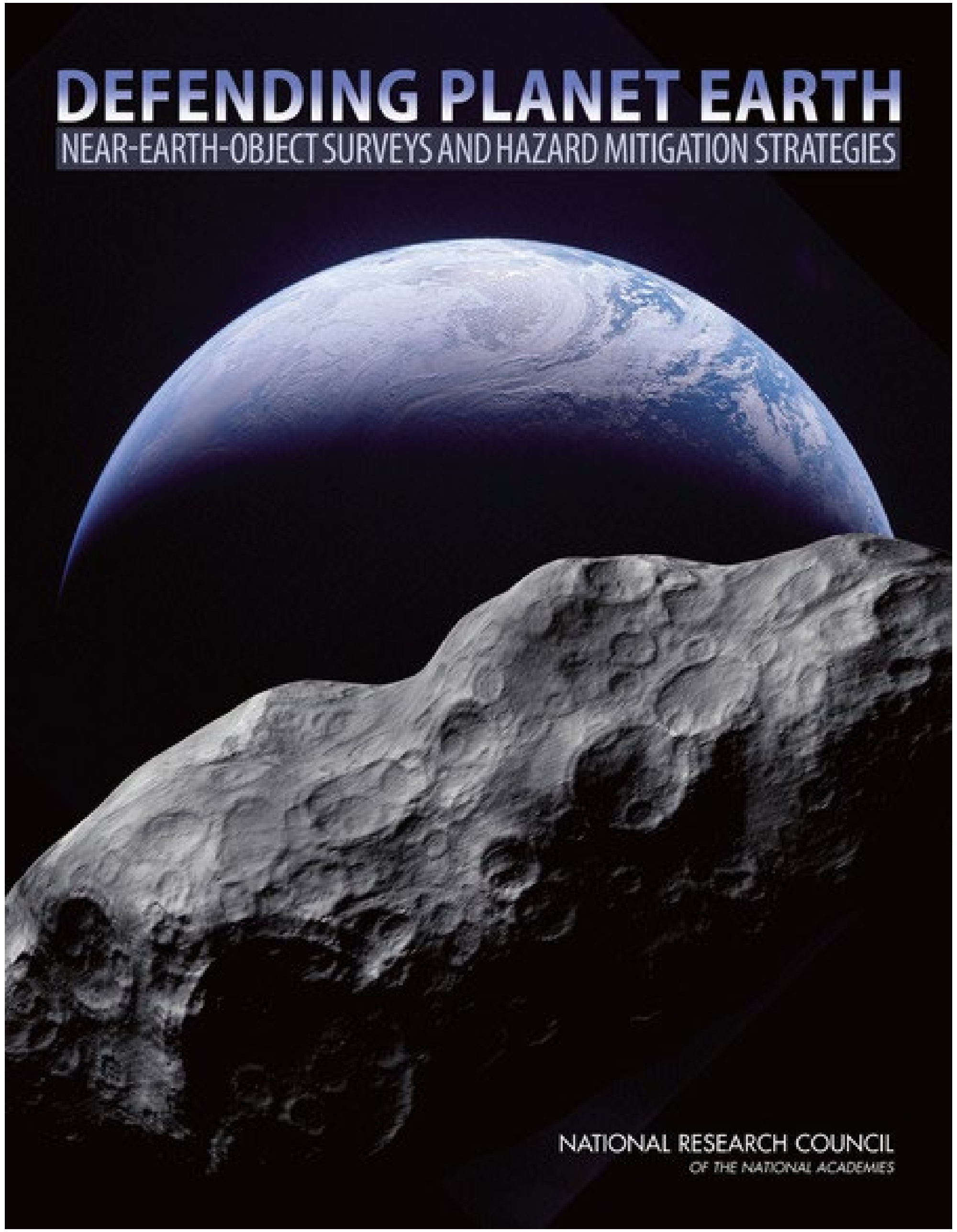
Recommended that a space mission was the fastest way to complete the NEO survey of ≥140-m objects.



Defending Planet Earth – 2010

Task 2. NEO Hazard Mitigation

Recommendation: The first priority for a space mission in the mitigation area is an experimental test of a kinetic impactor.



Defending Planet Earth – 2010

Task 2. NEO Hazard Mitigation

Recommendation: The first priority for a space mission in the mitigation area is an experimental test of a kinetic impactor.

Chelyabinsk impact: 15 Feb. 2013

SMPAG: Space Mission Planning Advisory Group – 2013

UNITED NATIONS
Office for Outer Space Affairs

The UN Committee on the Peaceful Uses of Outer Space recommended and endorsed the creation of SMPAG in 2013.

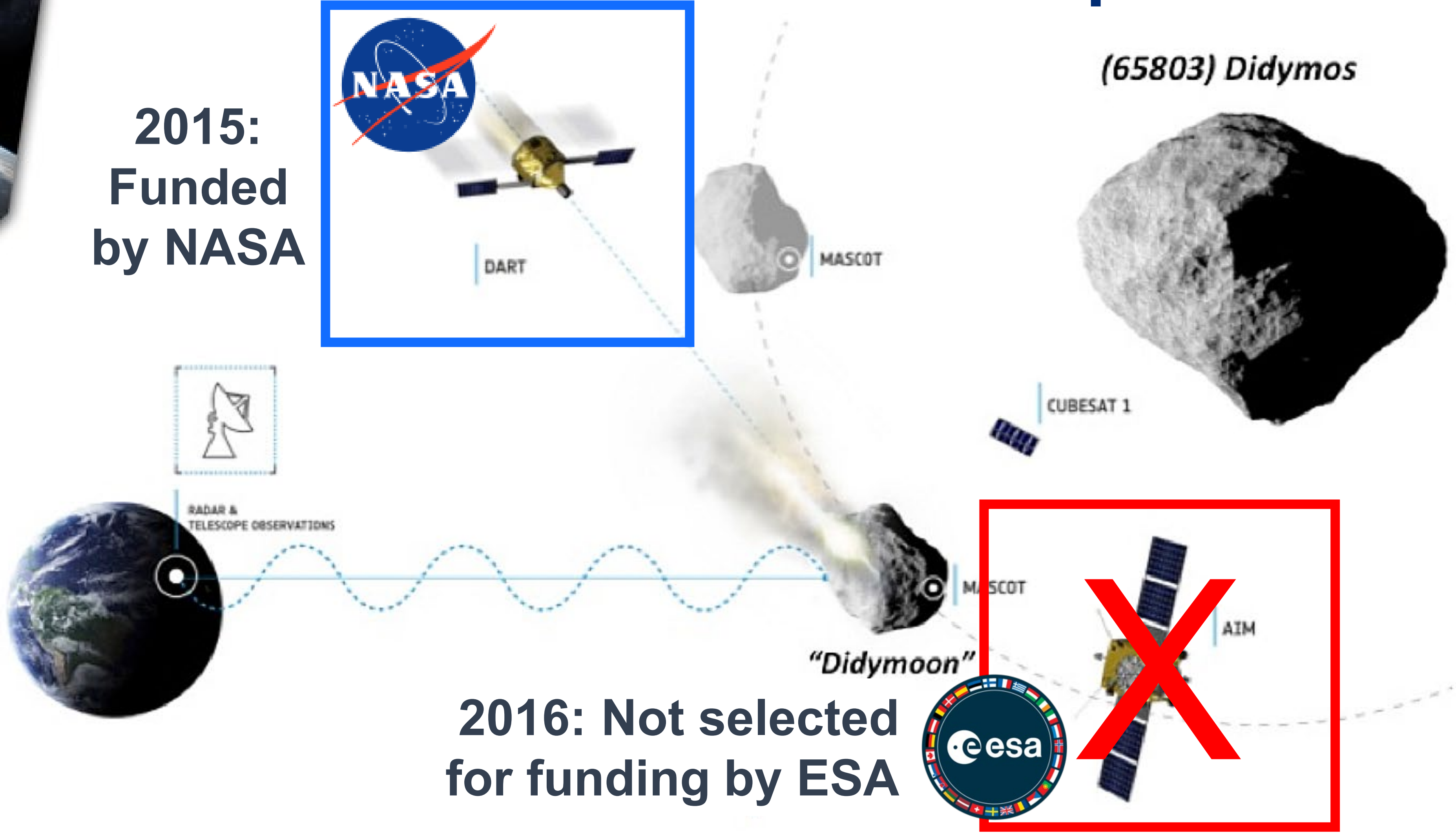
SMPAG Objectives as per the Terms of Reference:
The purpose of the SMPAG is to prepare for an international response to a NEO impact threat through the exchange of information, development of options for collaborative research and mission opportunities, and NEO threat mitigation planning activities.

SMPAG, Feb. 2016: Statement on Asteroid Orbit Deflection Demonstrations
SMPAG has identified the need to gain sufficient confidence in the viability of any proposed technique to deflect an asteroid from an impact trajectory. **The SMPAG encourages actual demonstration of the kinetic impactor technique with a space mission**, as it appears at this point in time to be the most technologically mature method of asteroid deflection.

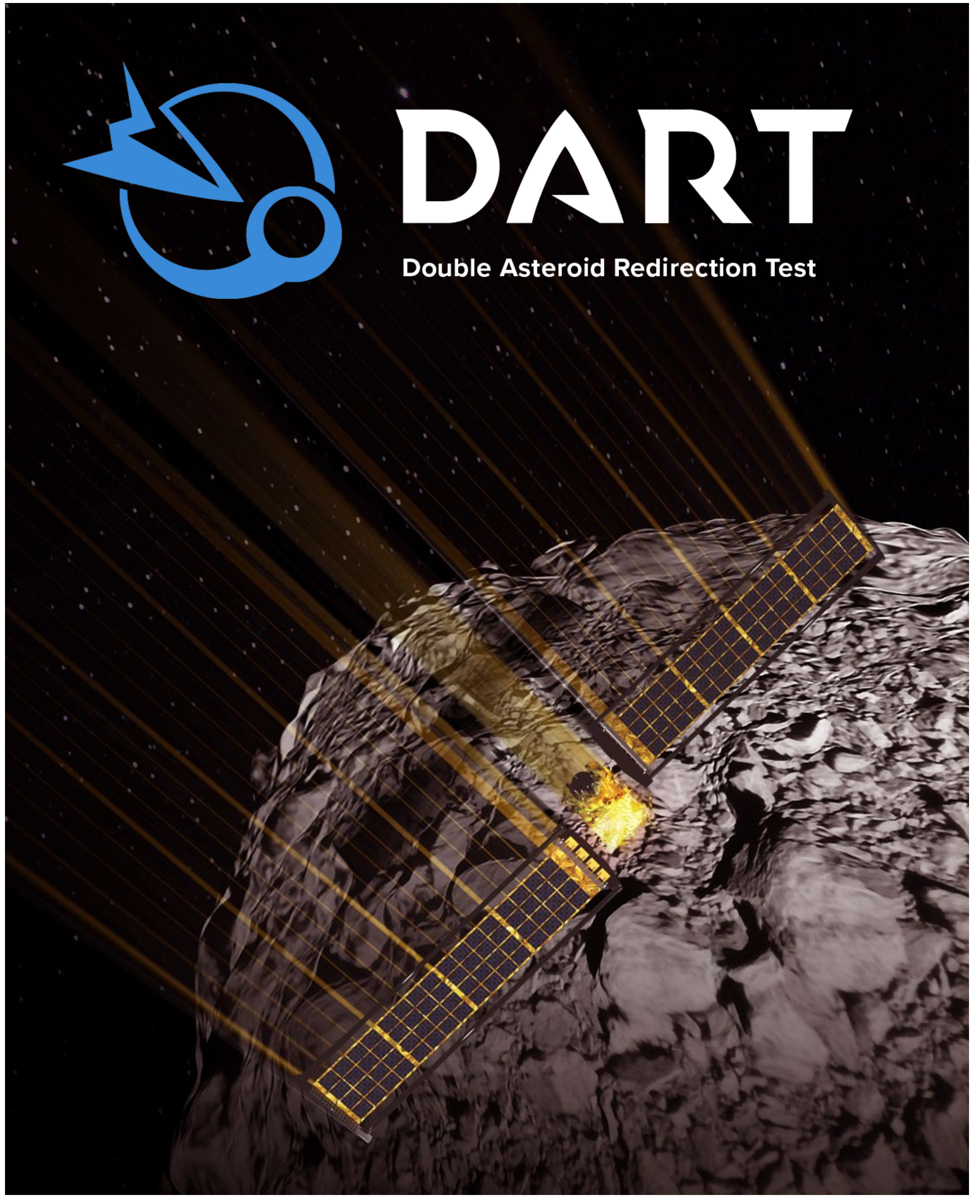
SMPAG members as of Feb. 2022: List of SMPAG Members as of 10 Feb 2022: AEM (Mexico); ASE (Association of Space Explorers - status as observer); ASI (Italy); BELSPO (Belgium); Czech Republic; CNSA (China); CNES (France); COSPAR (status as observer); DLR (Germany); ESA (current Chair); ESO (status as observer); FFG - Austrian Research Promotion Agency (Austria); IAA (status as observer); IAU (status as observer); IAWN (ex-officio); ISA (Israel); JAXA (Japan); KASI (Korea); NASA (USA); ROSA (Romania); ROSCOSMOS (Russian Federation); SSAU (Ukraine); SWF (status as observer); SUPARCO (Pakistan); UK Space Agency (UK); UN Office of Outer Space Affairs (OOSA - Status as observer)

AIDA: Asteroid Impact & Deflection Assessment Mission Concept

2015: Funded by NASA



2016: Not selected for funding by ESA



DART Mission

A planetary defense kinetic impactor technology demonstration mission

Cost and Schedule

- **2015** – DART Phase A begins
- **2017** – Phase B
- **2018** – Preliminary Design Review
- **2019** – Critical Design Review
- **2021** – Launch
- **2022** – Kinetic impact into Dimorphos
- **2023** – DART Phase F ends

$327 Million total mission cost

$67 M for Space X Falcon 9 launch
$260 M for Phases A–F (2105–2023)

NASA PDCO: Planetary Defense Coordination Office – 2016

In 2016, NASA established the Planetary Defense Coordination Office (PDCO) to manage the agency's diverse and rapidly growing efforts in the "applied planetary science" of Planetary Defense, including:

- **Finding Possible NEO Threats**
- **Warning of Possible NEO Impacts**
- **Coordinating Global Planetary Defense Efforts**
- **Studying Technologies to Mitigate Against NEO Impacts with Earth**

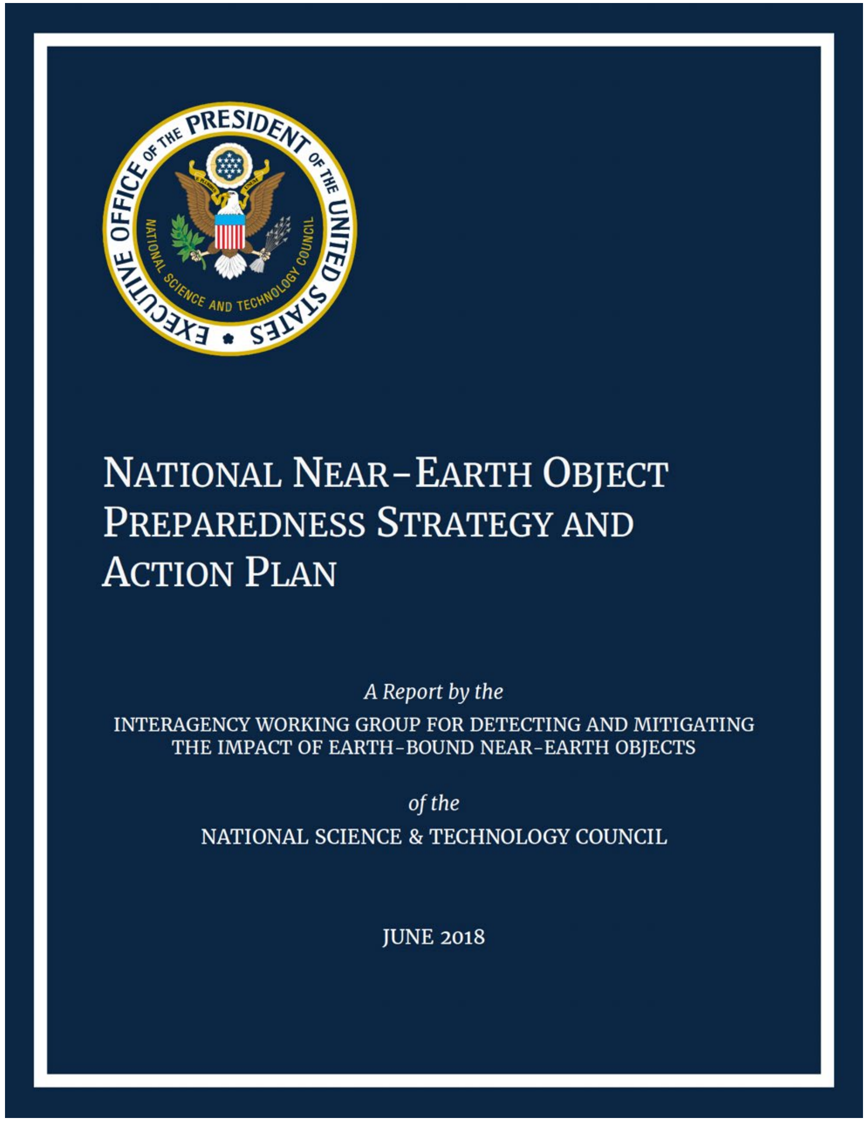
Hera – selected for ESA funding – 2018

Rendezvous with the Didymos system

2024 Launch
2026 Arrival
2027 Operations

TIRI instrument
contributed by JAXA

US National Plan – 2018


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

Goal 1:
Enhance NEO detection, tracking, and characterization capabilities

Goal 2:
Improve NEO modeling, prediction, and information integration

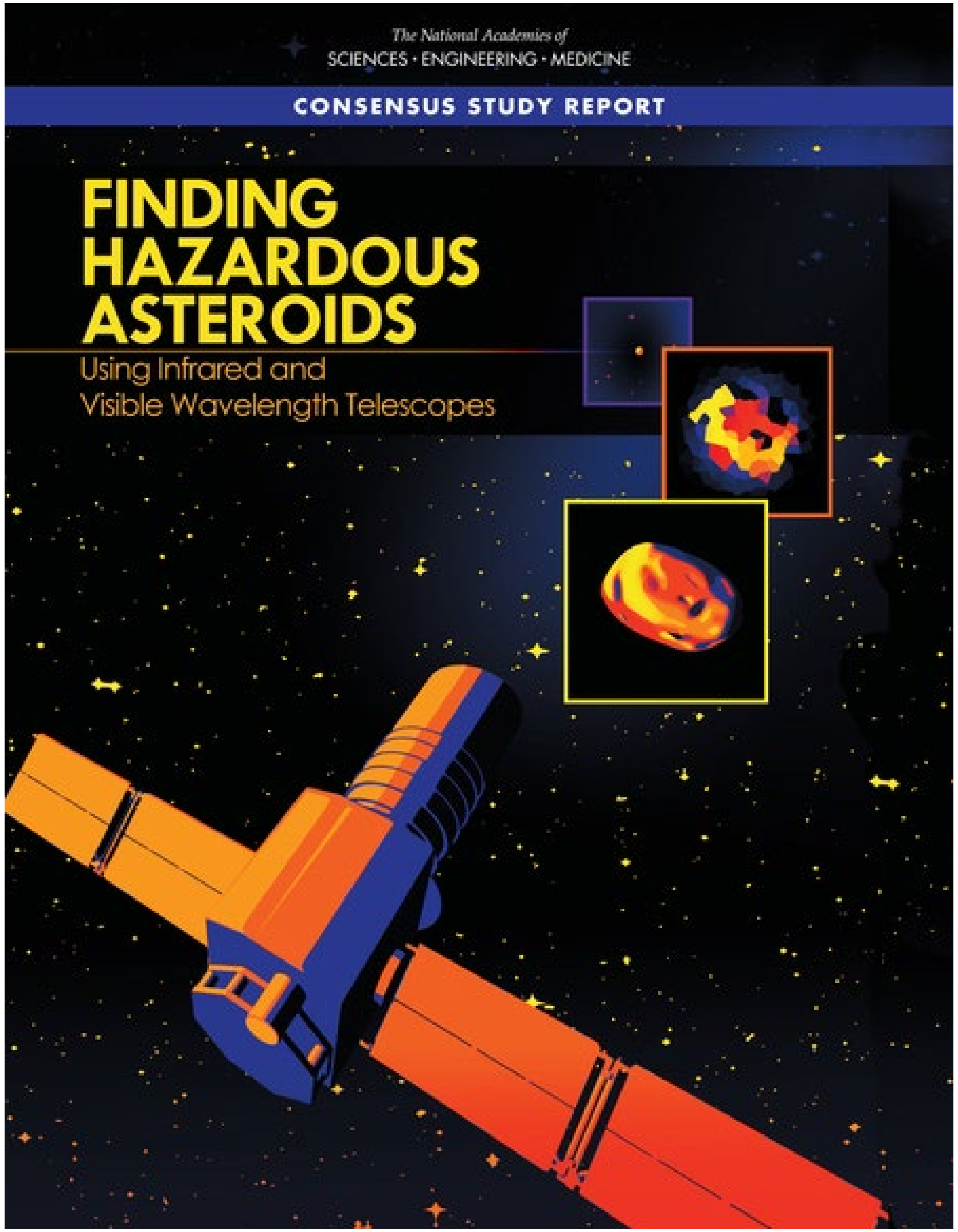
Goal 3:
Develop technologies for NEO deflection and disruption missions

Goal 4:
Increase international cooperation on NEO preparedness

Goal 5:
Strengthen and routinely exercise NEO impact emergency procedures and action protocols

An interagency endeavor: Product of an interagency working group of the National Science & Technology Council

(With members from: OSTP, NASA, DHS/FEMA, DOC, DOC/NOAA, DOD/JCS, DOD/USSPACECOM, DOD/OSD(R&E), DOD/USSF, DOE, DOS, DOI/USGS, NSF, NSpC, OMB)



Finding Hazardous Asteroids – 2019

In 2018, NASA requested NASEM to establish an ad hoc committee to investigate and make recommendations about a space-based telescope's NEO survey capabilities

- **Recommendation:** If the completeness and size requirements given in the George E. Brown, Jr. Near-Earth Object Survey Act are to be accomplished in a timely fashion (i.e., approximately 10 years), **NASA should fund a dedicated space-based infrared survey telescope.**
- **Recommendation: Missions meeting high-priority planetary defense objectives should not be required to compete against missions meeting high-priority science objectives.**

SMPAG: Space Mission Planning Advisory Group – 2019

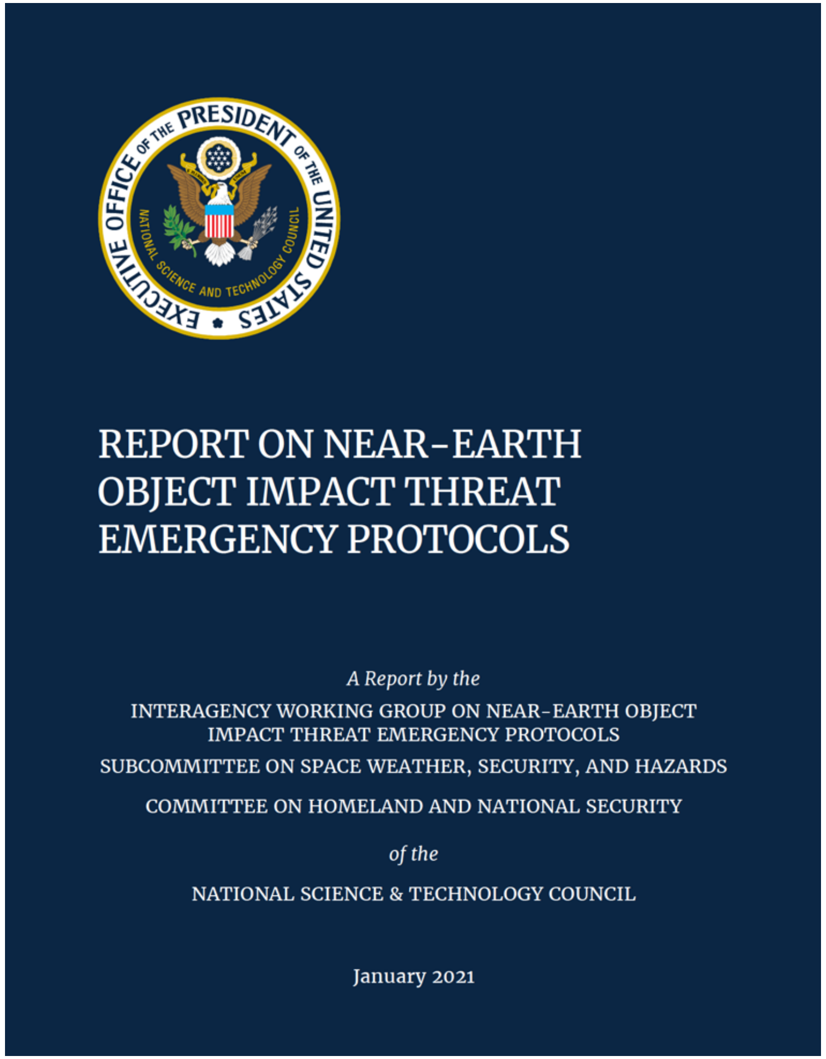
UNITED NATIONS
Office for Outer Space Affairs

The UN Committee on the Peaceful Uses of Outer Space recommended and endorsed the creation of SMPAG in 2013.

SMPAG, Sept. 2019: Recommendation to perform a demonstration of a rapidly deployable flyby or rendezvous mission to collect critical information on a threatening asteroid or comet

The Space Mission Planning Advisory Group (SMPAG) recommends that small-scale NEO flyby or rendezvous demonstration missions be performed to test and verify our ability to characterize a potential impactor when needed.

Report on NEO Impact Threat Emergency Protocols – 2021


EXECUTIVE OFFICE OF THE PRESIDENT OF THE UNITED STATES

NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

REPORT ON NEAR-EARTH OBJECT IMPACT THREAT EMERGENCY PROTOCOLS

A Report by the

INTERAGENCY WORKING GROUP ON NEAR-EARTH OBJECT IMPACT THREAT EMERGENCY PROTOCOLS

SUBCOMMITTEE ON SPACE WEATHER, SECURITY, AND HAZARDS

COMMITTEE ON HOMELAND AND NATIONAL SECURITY

of the

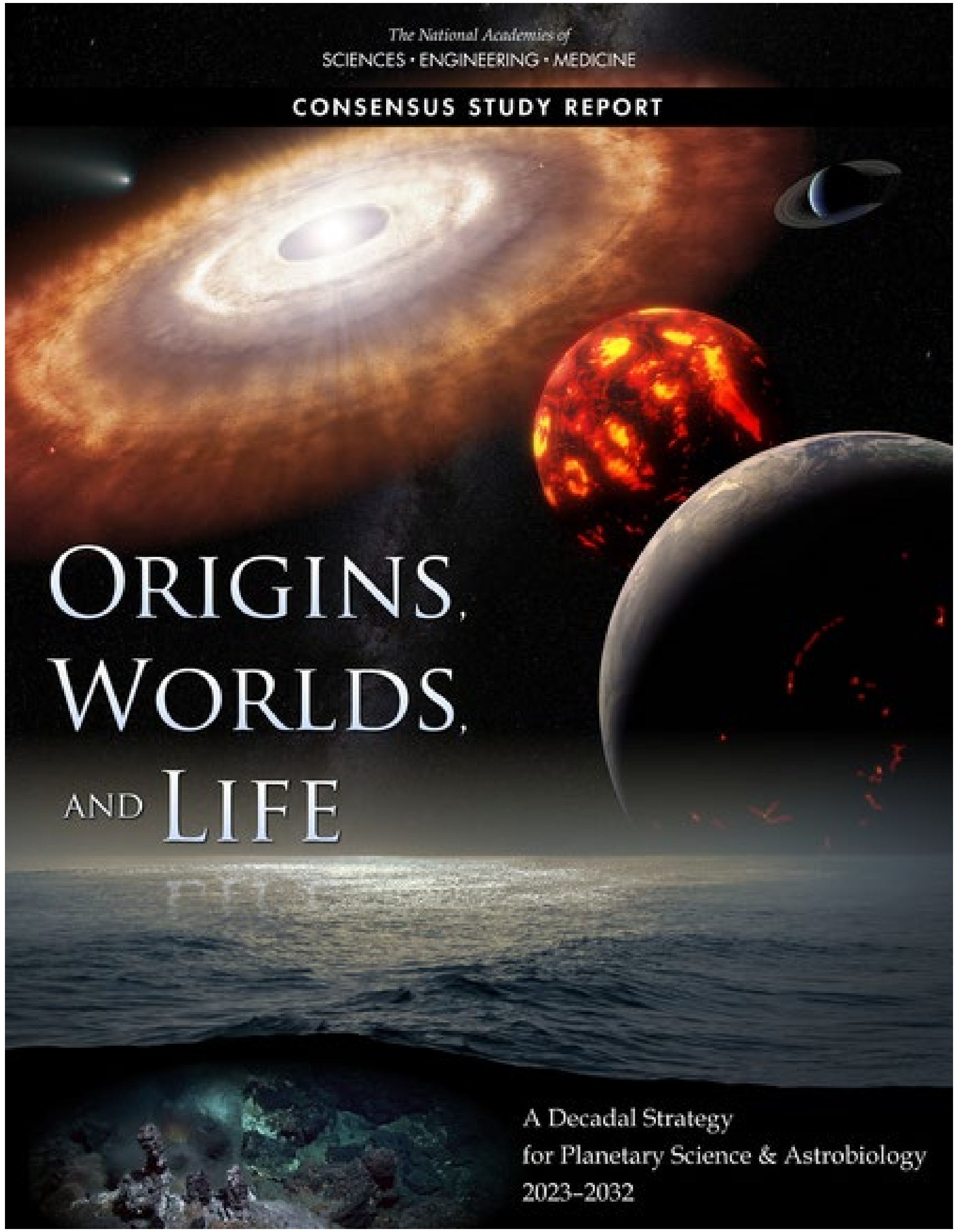
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

January 2021

With members from: DoD, DoC, DHS, Dept. of State, NASA, NSF, OMB

Focused on five actions within the *National NEO Strategy and Action Plan* associated with **Goal 5: Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols:**

- **Action 5.2.** Establish a procedure and timeline for conducting and updating a **threat assessment** upon detection of a potential NEO impact.
- **Action 5.3.** Revisit and validate the current **notification protocol chain-of-command** for NEO threats.
- **Action 5.4.** Develop **protocols for notifying** the White House and Congress, State and local governments, the public, foreign governments, and other international organizations regarding NEO threats.
- **Action 5.6.** Establish a procedure and timeline for conducting a risk/benefit analysis for **space-based mitigation mission options** following a NEO threat assessment.
- **Action 5.7.** Develop benchmarks for determining **when to recommend NEO reconnaissance, deflection, and disruption missions.**

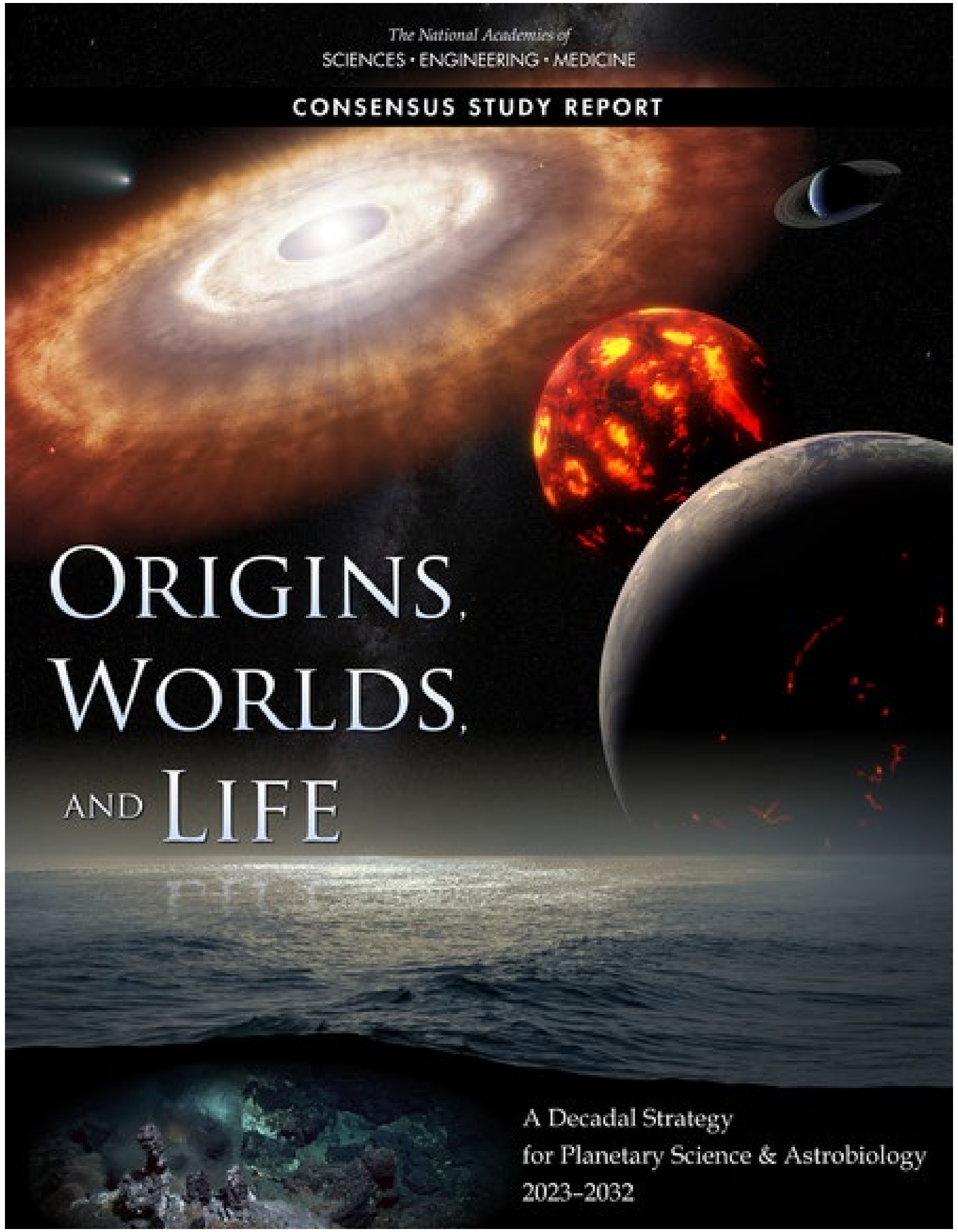


Origins, Worlds, and Life – 2022

Chapter 18:
Planetary Defense: Defending Earth through Applied Planetary Science

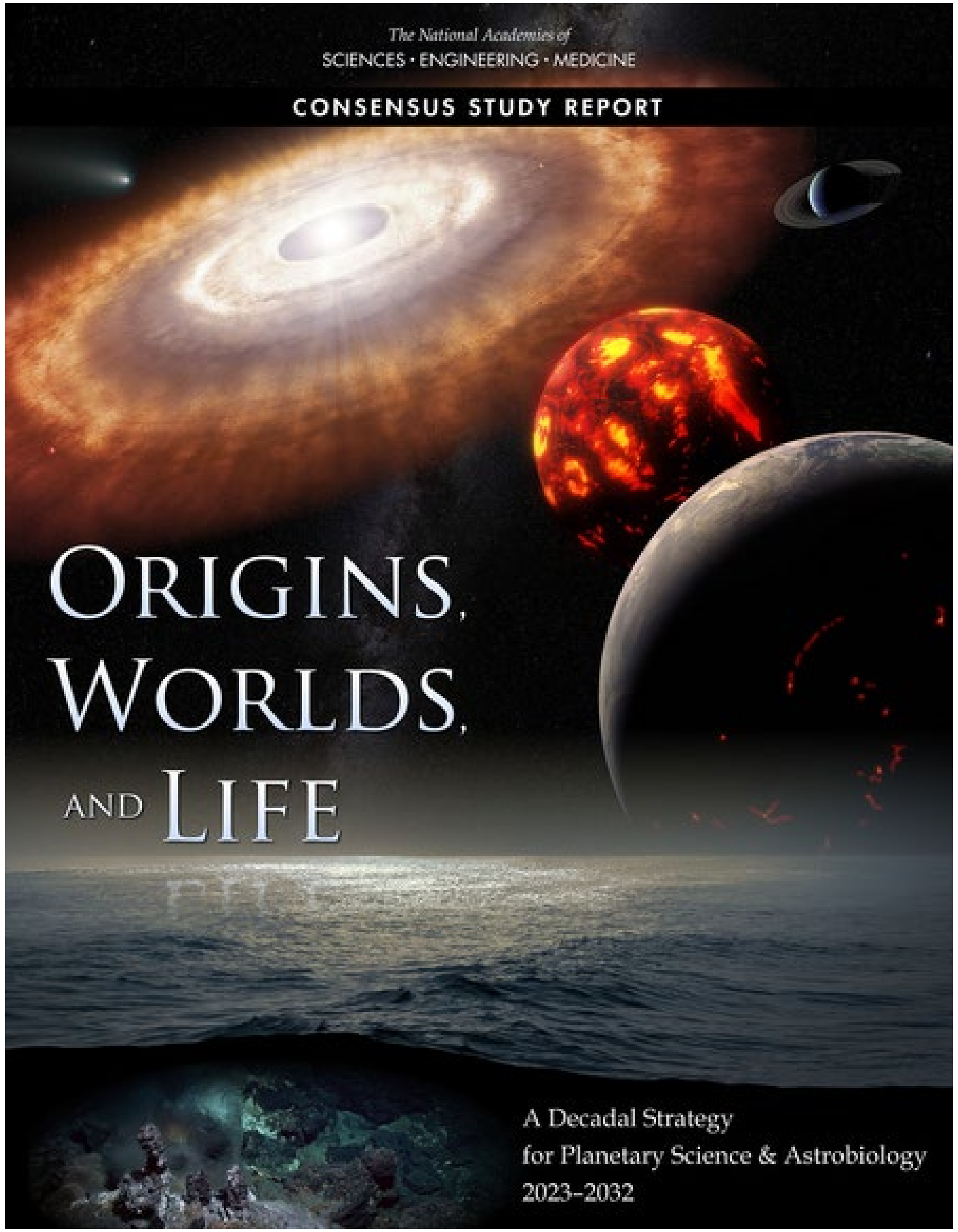
Paul Abell (NASA JSC) – Co-Lead
Tom Jones (ASE) – Co-Lead
Nancy Chabot (APL)
Carol Raymond (JPL)
Richard Dissly (Ball Aerospace)
Daniel Scheeres (UC Boulder)
Edgard Rivera-Valentín (LPI*)
Megan Bruck Syal (LLNL)
James Crocker (Lockheed Martin, Retired)
William Bottke (SWRI)

** now APL*



Origins, Worlds, and Life – 2022

Recommendation: NASA should fully support the development, timely launch, and subsequent operation of NEO Surveyor to achieve the highest priority planetary defense near-Earth object survey goals.

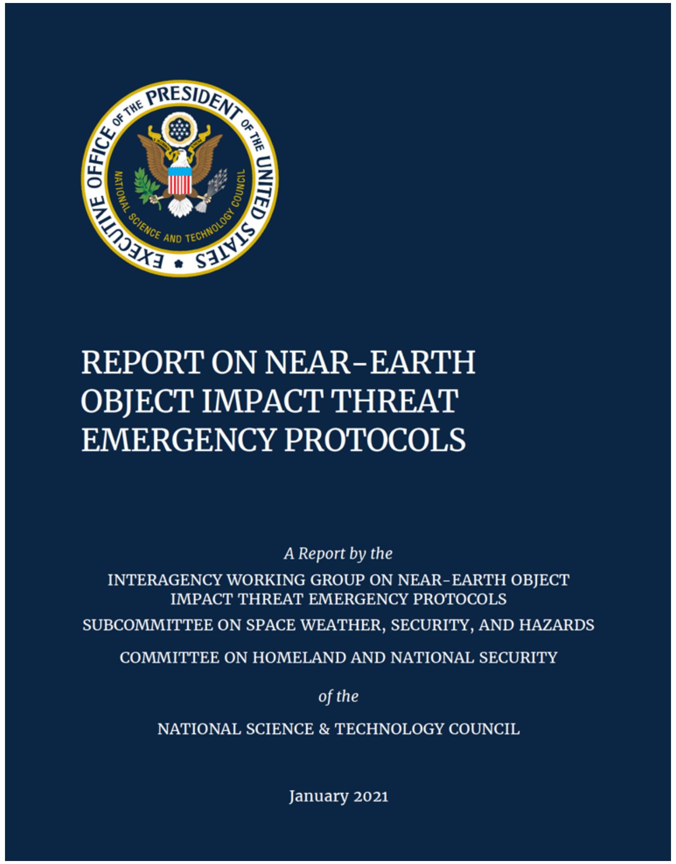


Origins, Worlds, and Life – 2022

Recommendation: The highest priority planetary defense demonstration mission to follow DART and NEO Surveyor should be a **rapid-response, flyby reconnaissance mission targeted to a challenging NEO, representative of the population (~50 to 100-m in diameter)** of objects posing the highest probability of a destructive Earth impact. Such a mission should assess the capabilities and limitations of flyby characterization methods to better prepare for a short-warning-time NEO threat.

Why ~50 to 100 m?

Same as the SMPAG 2017 recommendation:
>50 m, >1% impact probability within <50 years



REPORT ON NEAR-EARTH OBJECT IMPACT THREAT EMERGENCY PROTOCOLS

A Report by the

INTERAGENCY WORKING GROUP ON NEAR-EARTH OBJECT IMPACT THREAT EMERGENCY PROTOCOLS

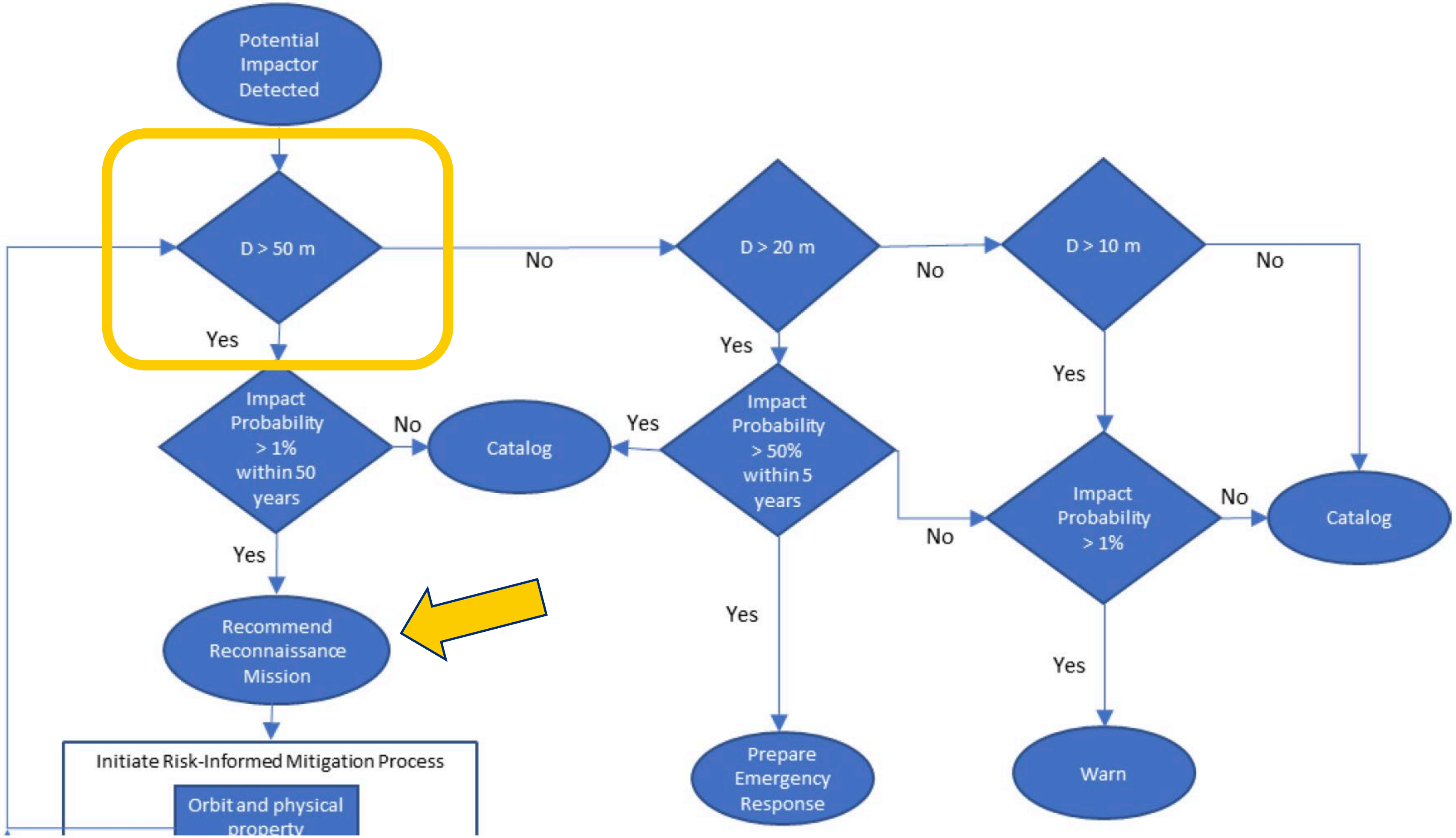
SUBCOMMITTEE ON SPACE WEATHER, SECURITY, AND HAZARDS

COMMITTEE ON HOMELAND AND NATIONAL SECURITY

of the

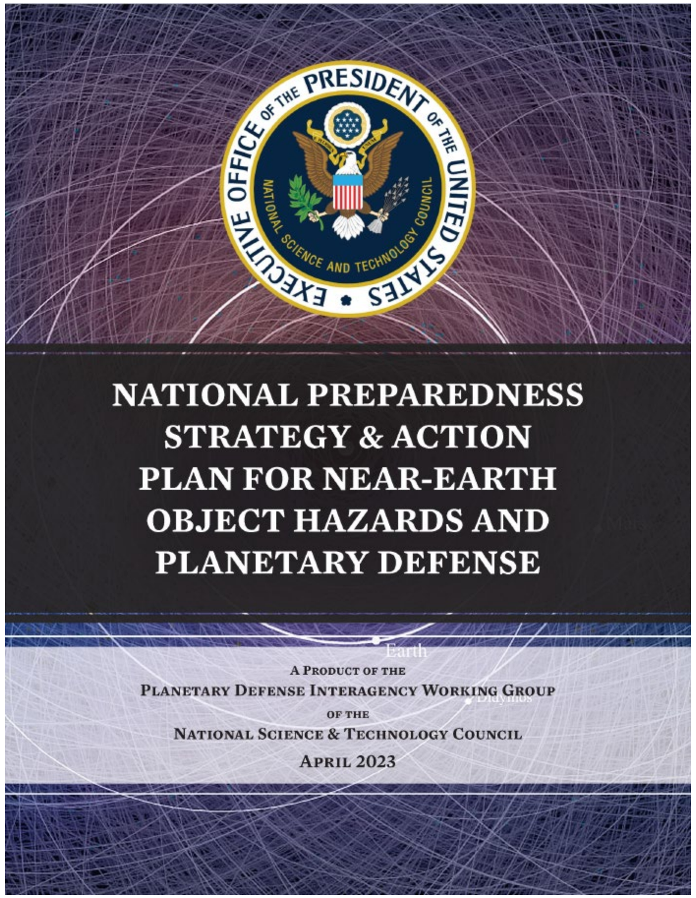
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

January 2021



A 50-m object is the smallest for which a reconnaissance mission is recommended in the US and SMPAG protocols

Why ~50 to 100 m?



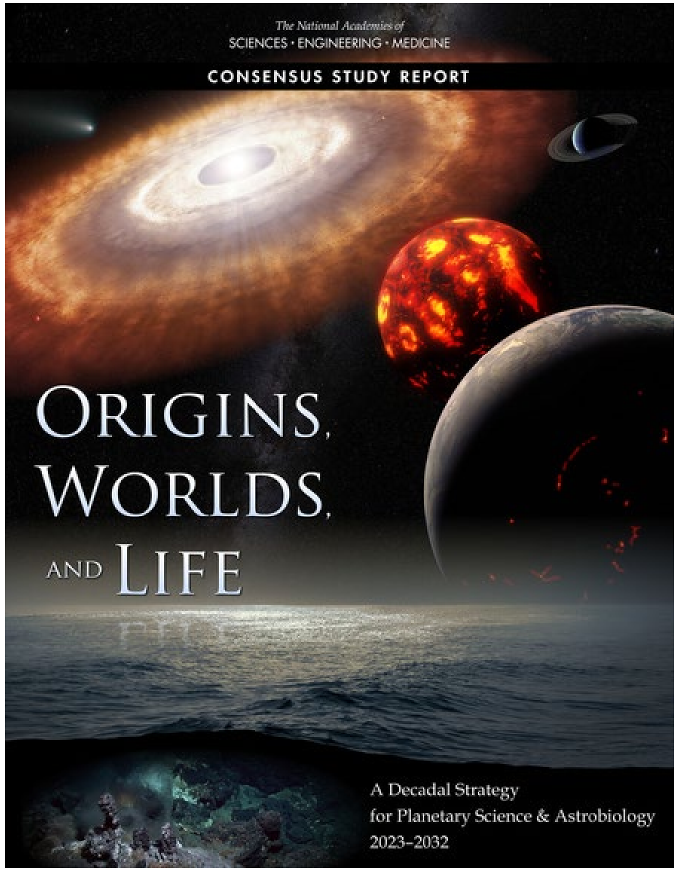
The Hazard by the Numbers

How Big?	10 meters	50 meters	140 meters	1000 meters	10,000 meters
How Often?	~1 per decade	~1 per 1000 years	~1 per 20,000 years	~1 per 700,000 years	~1 per 100 million years
How Bad?	Very bright fireball, strong sonic boom could break windows if close to habitation	Local devastation, regional effects, may or may not leave an impact crater	Crater of 1–2 kilometers in diameter, deadly over metro areas/states, mass casualties	10-kilometer crater, global devastation, possible collapse of civilization	100-kilometer crater, global devastation, mass extinctions of terrestrial life
Approx. impact energy (megatons)	0.1	10	300	100,000	100,000,000
How Many?	~45 million	~230,000	~25,000	~900	4
% Discovered	0.03%	7%	40%	95%	100%

Figure 2: NEO size, frequency of Earth-impact, and hazard. (Credit: Johns Hopkins University/Applied Physics Laboratory)

50-m sized objects impact the Earth much more frequently than larger objects, making a 50-m object the most likely size that would trigger a space-based mission

Why ~50 to 100 m?

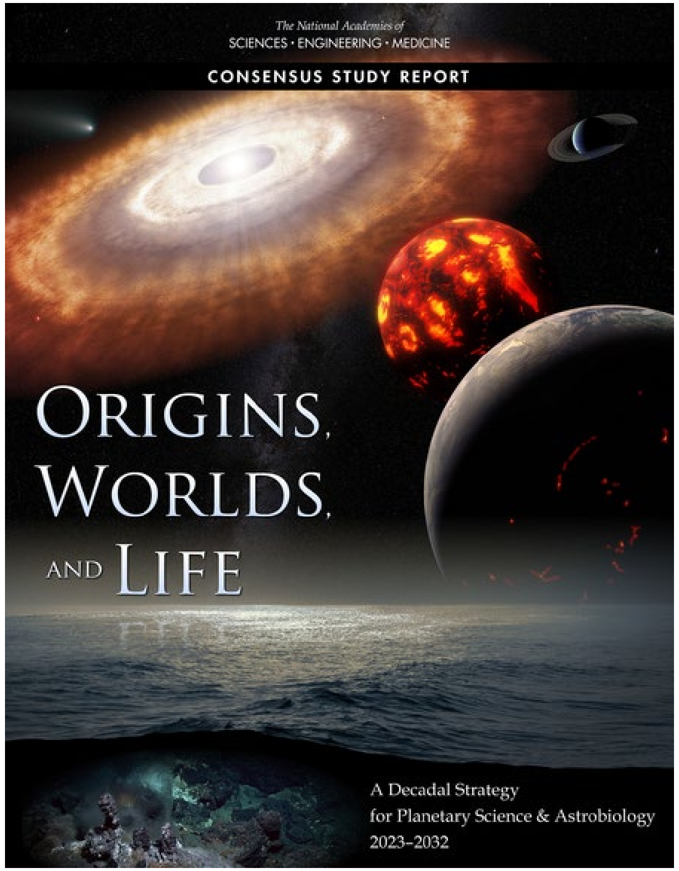


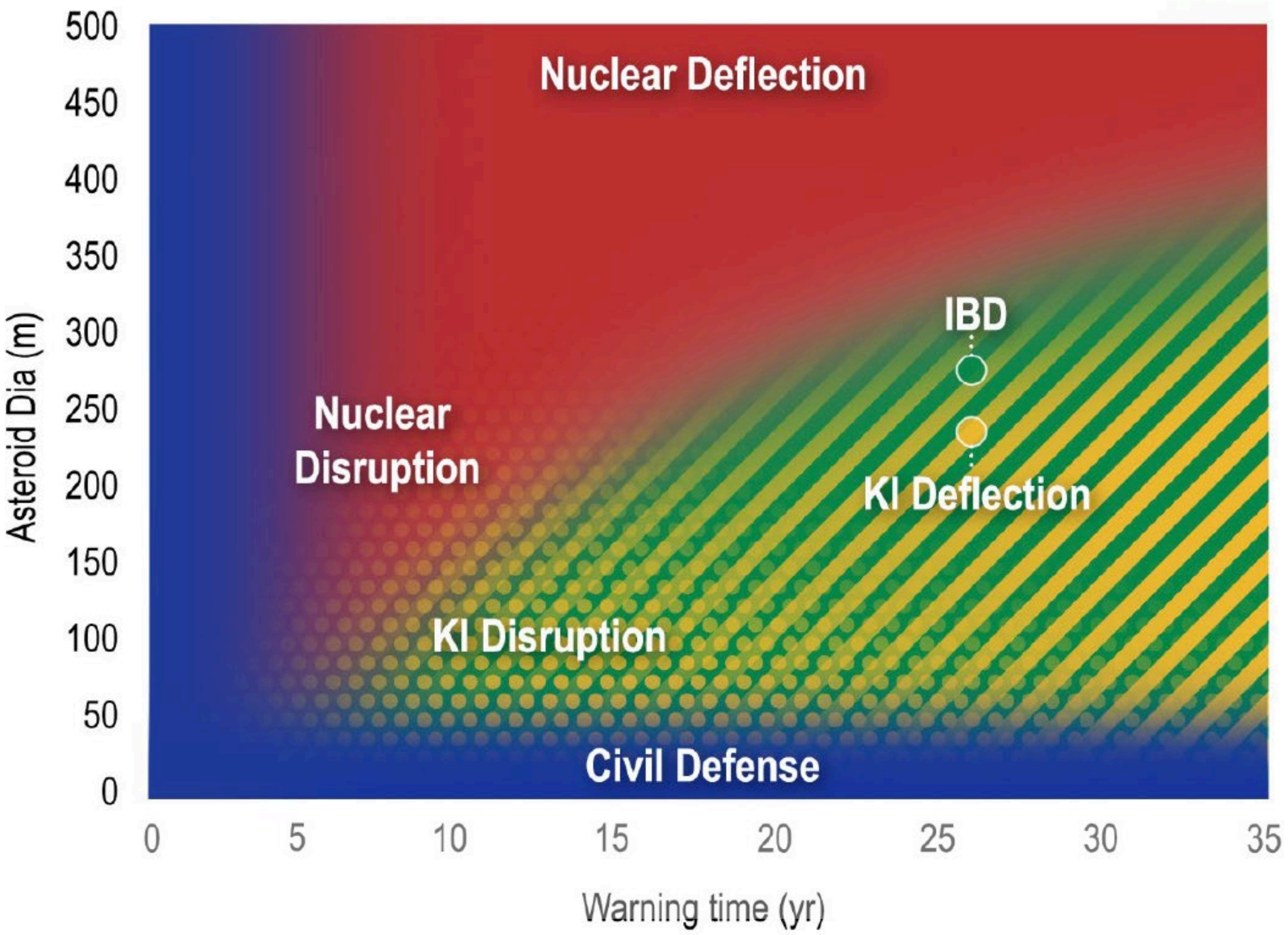
Permission Pending

Chapter 18
Figure 18.4

Warning time is a key factor in mitigation options.

Why ~50 to 100 m?

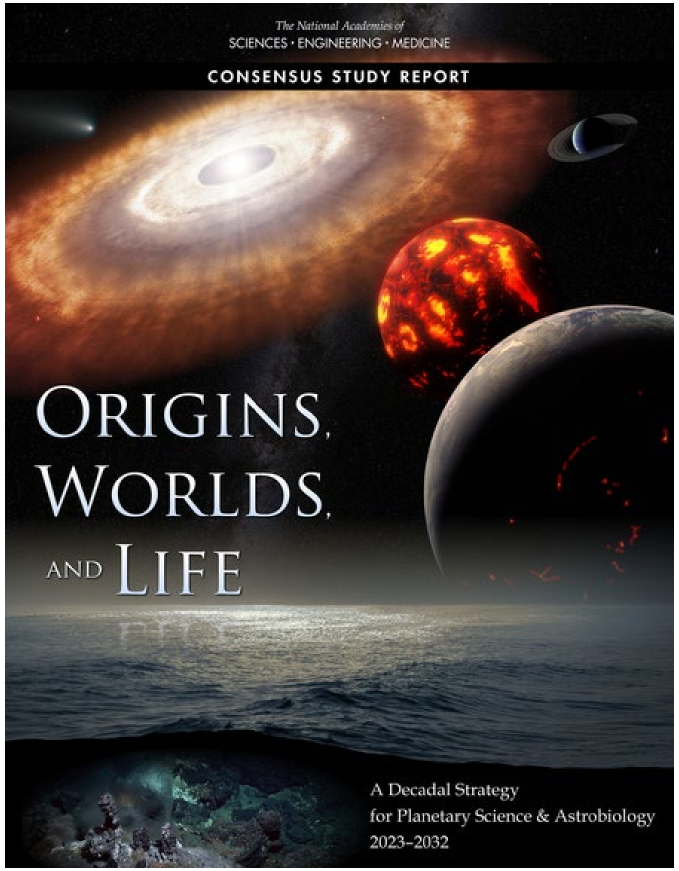




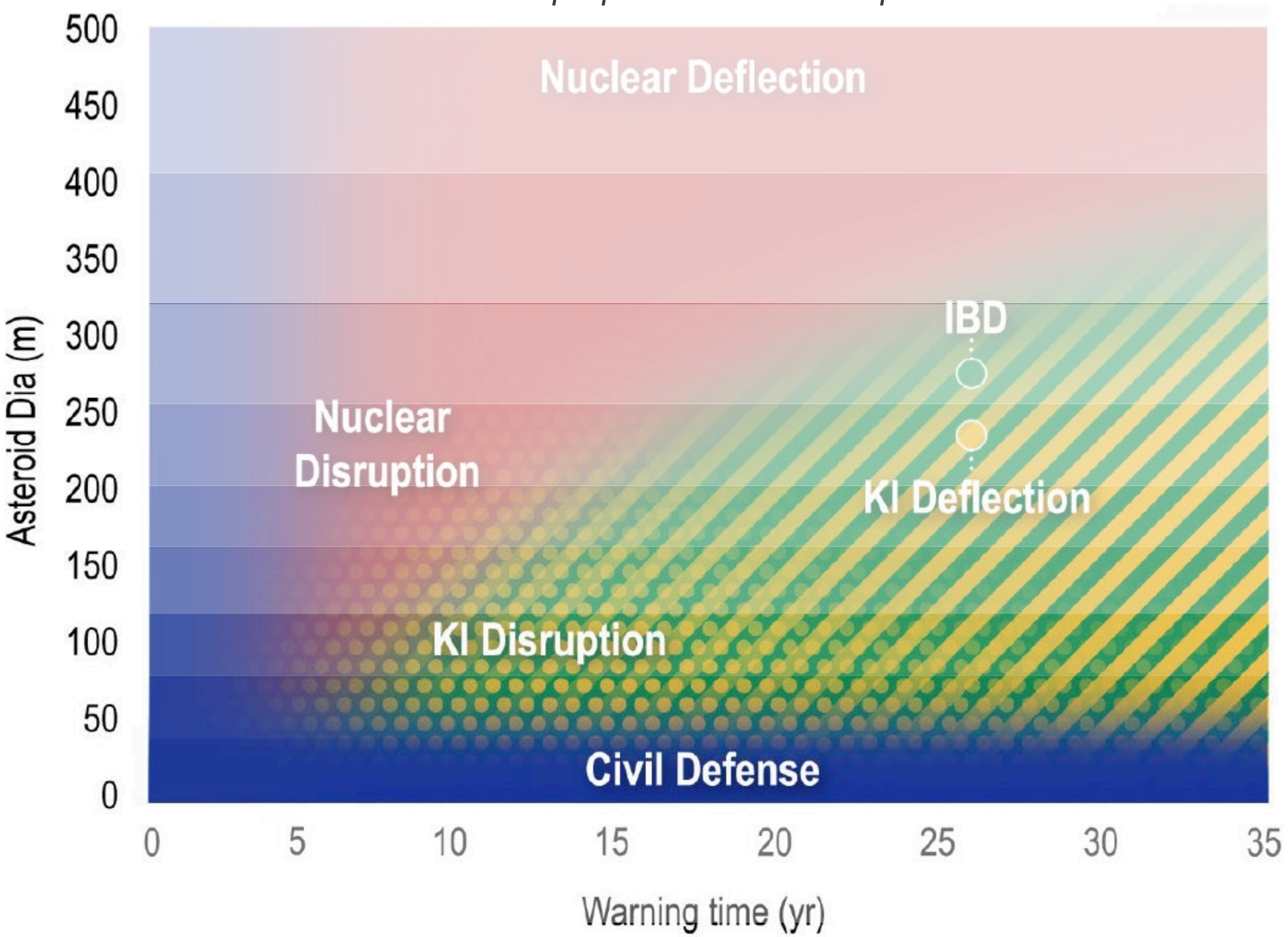
Chapter 18
Figure 18.4

Warning time is a key factor in mitigation options.

Why ~50 to 100 m?



Shaded with opaqueness = the completeness



Current Survey Completeness

84% @ 500 m

78% @ 398 m

70% @ 316 m

62% @ 251 m

53% @ 200 m

44% @ 159 m

34% @ 126 m

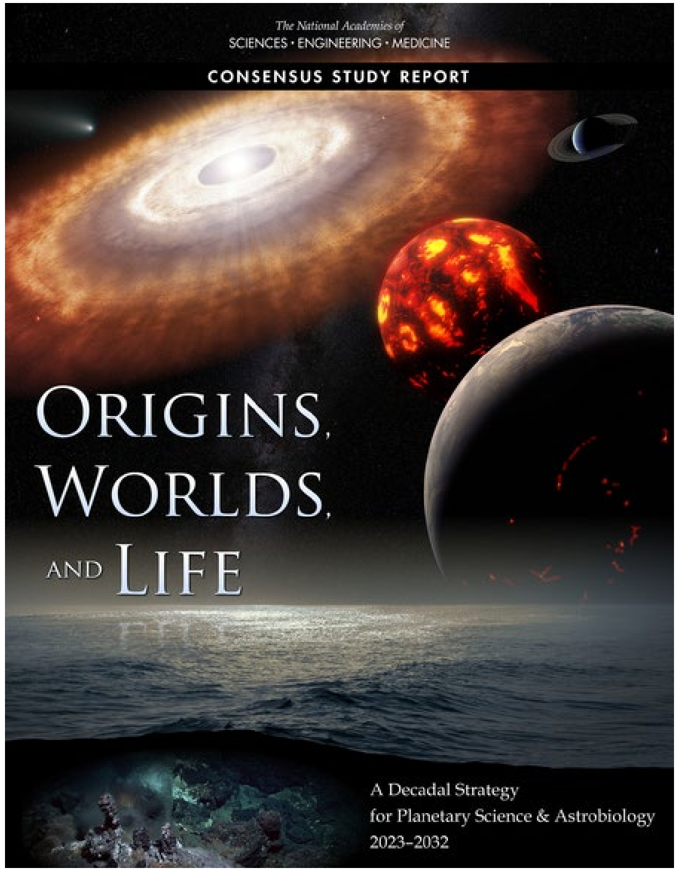
16% @ 79 m

5% @ 50 m

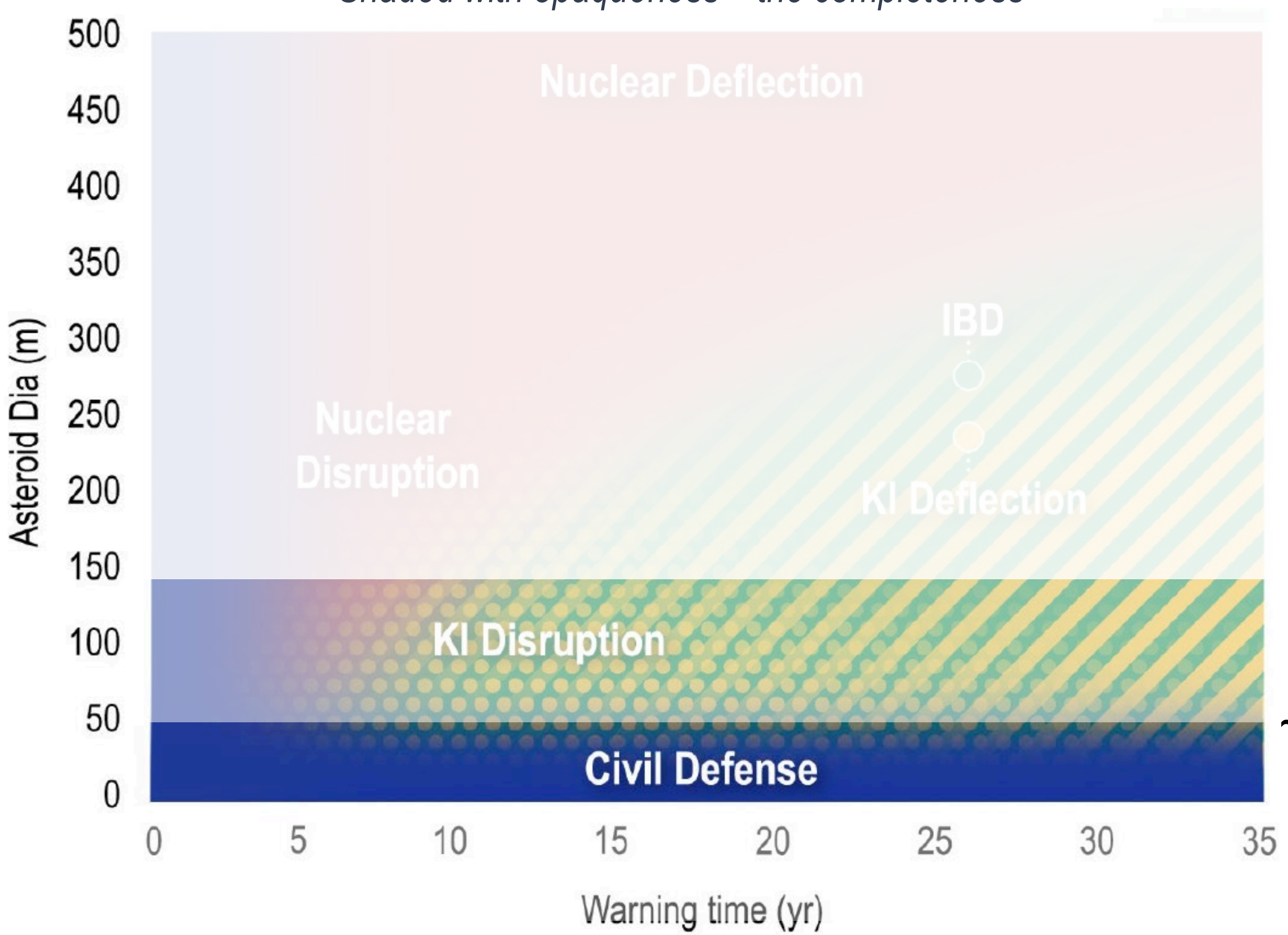
(Harris and Chodas, 2021)

Warning time is a key factor in mitigation options.

Why ~50 to 100 m?



Shaded with opaqueness = the completeness

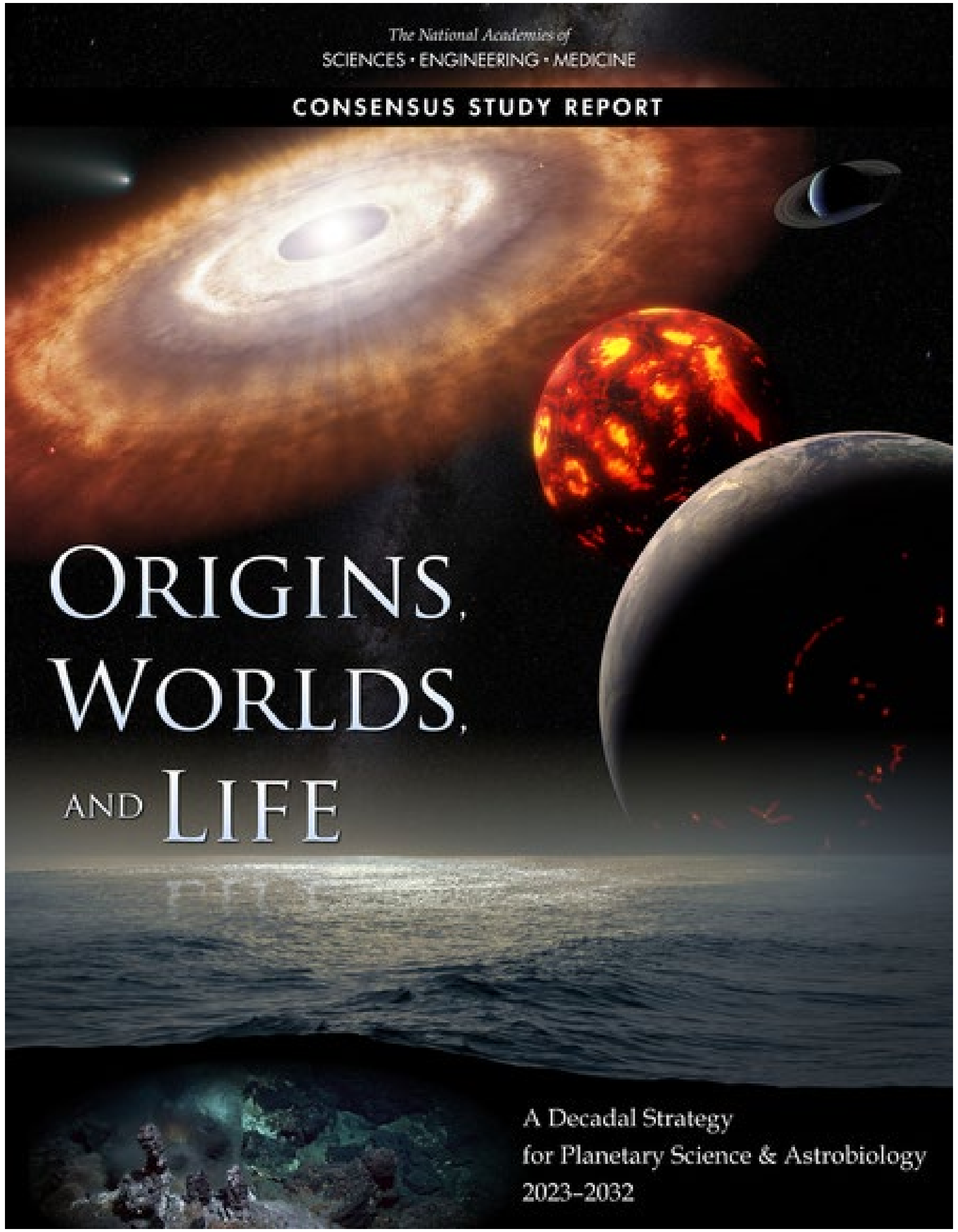


After 10-years with NEO Surveyor:

90% @ ≥ 140 m

~50% @ 50 m

Warning time is a key factor in mitigation options.
Objects ~50–100 m in size are the ones that would still need a rapid flyby mission to inform decision makers.



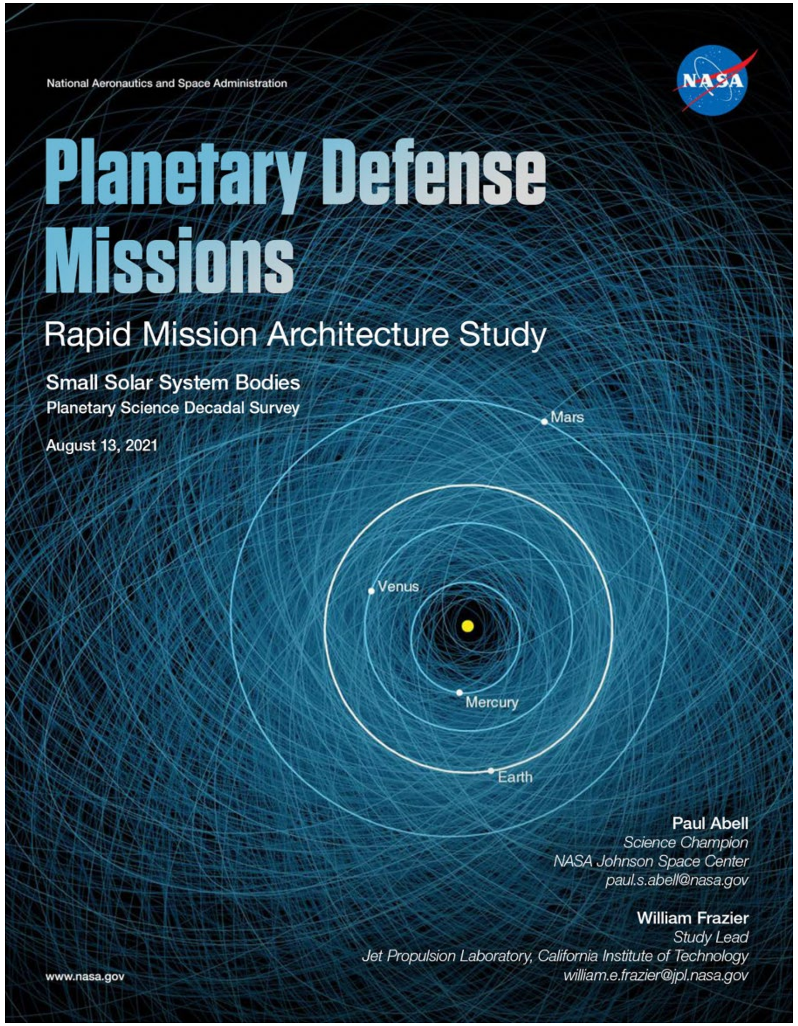
Origins, Worlds, and Life – 2022

Recommendation: Following a rapid-response, flyby reconnaissance mission demonstration, the next highest priority planetary defense mission would be a characterization and/or mitigation mission. The suggested candidates are, in no particular order:

- A **characterization tour mission** to exercise characterization capabilities and gain characterization information required for future deflection/disruption missions across a range of NEO targets.
- A **kinetic impact mission on a smaller NEO** and at a higher closing speed than DART to acquire experience needed for more challenging mitigation missions.
- A **slow-push/pull mitigation demonstration**, such as ion beam deflection, to develop several different technologies that may be employed against future hazardous objects.

Finding: *Mission concepts that address multiple characterization and mitigation objectives in future planetary defense technology demonstrations would potentially maximize results.*

Planetary Defense Missions:
Rapid Mission Architecture Study – 2022



186 page report studying planetary defense missions as part of the Decadal Survey effort

Consideration of 17 different architectures for planetary defense technology demonstration missions for their costs and benefits

Lead:
Paul Abell (NASA JSC)

Science Team:
Nancy Chabot (APL)
Carol Raymond (JPL)
Megan Bruck Syal (LLNL)
Richard Dissly (Ball Aerospace)
Tom Jones (ASE)
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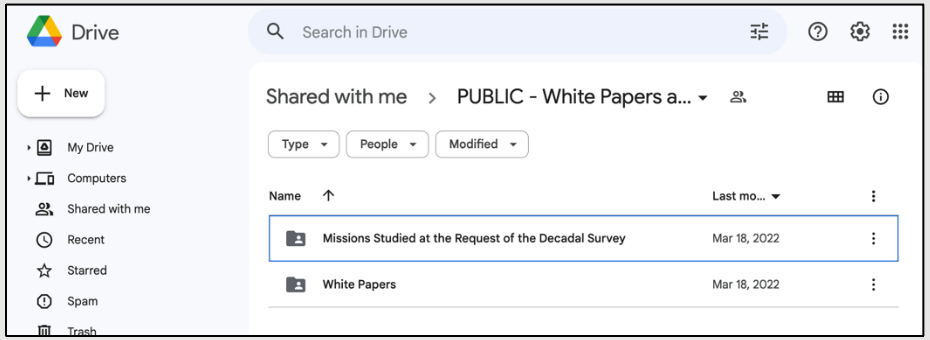
Jonathan Murphy – Systems
Robert Kinsey – Deputy Systems
Melora Larson – Instruments
Charles Reynerson – Mission Design
Ronald Hall – Power
Matthew Kowalkowski – Propulsion
Mason Takidin – Cost

** now APL*

JPL Study Team:
William Frazier – Study Lead/ Systems Engineering
Paul Chodas – Center for Near Earth Objects Studies
Steve Chesley – Center for Near Earth Objects Studies
Reza Karimi – Mission Design
Jack Maydan – Literature Survey and Data Base

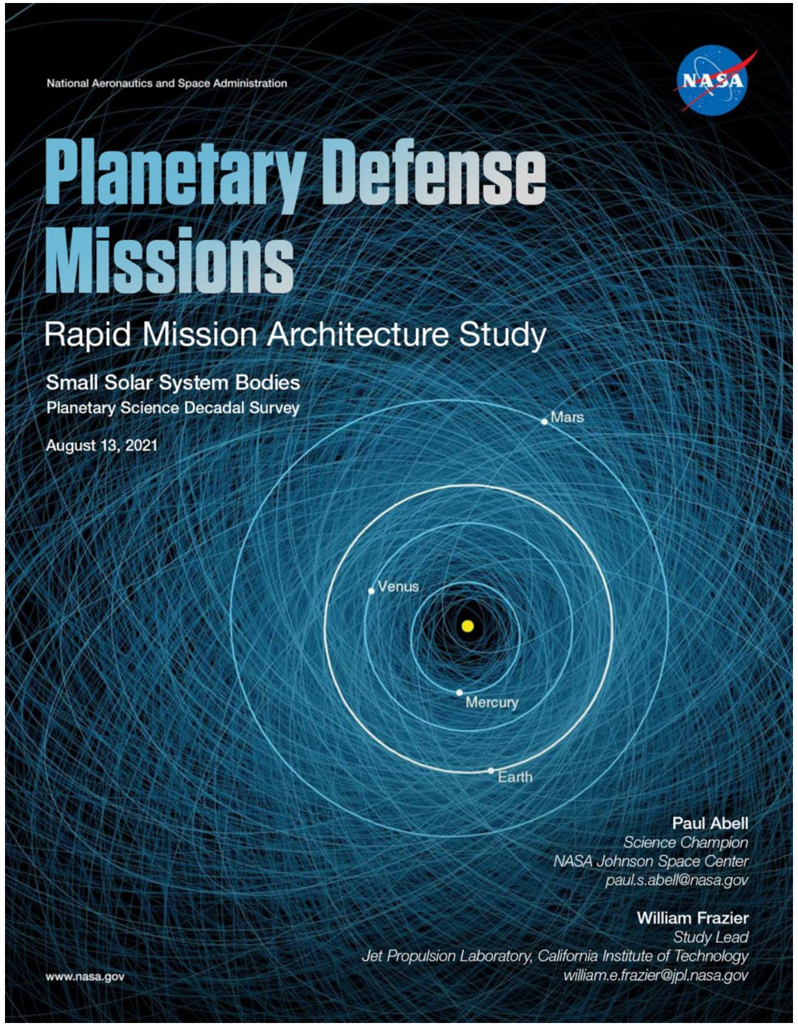
The only way to access this report is by following the footnote on the bottom of Appendix C, page C-3, which gives this link: https://tinyurl.com/2p88fx4f



Can NASEM post this study (and the others too!) in a proper archive or on the Decadal Survey website?

Planetary Defense Missions: Rapid Mission Architecture Study

Full mission costs (A thru F + LV) for flyby concepts are ~$200M to $400M (FY25 $)



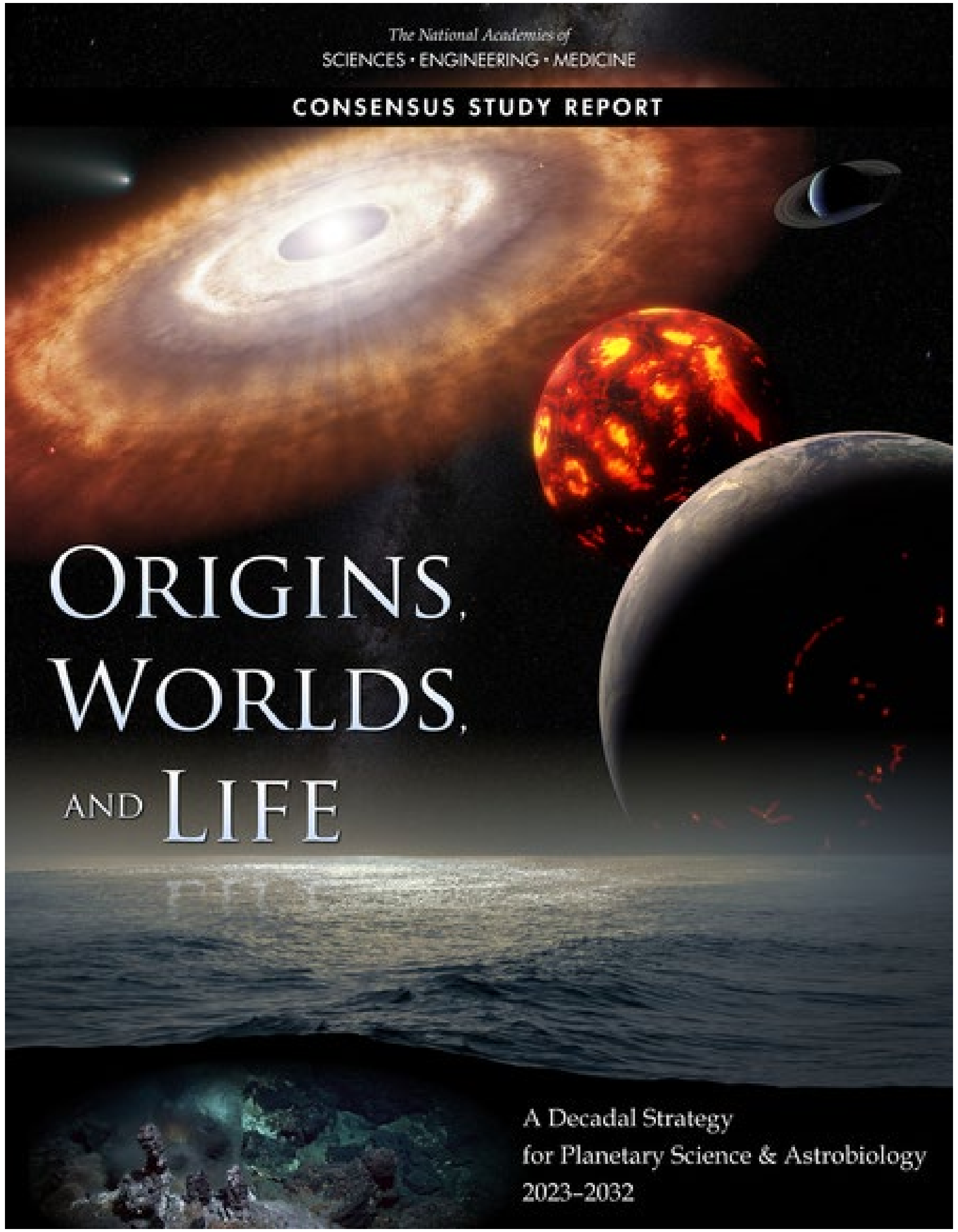
186 page report studying planetary defense missions as part of the Decadal Survey effort

Table F-3. Time-phased costs for each option

Trade Study Mission Number	Mission Description	Mission Type	Est Cost, Best LV ($M FY 2025)	Mission $M per phase				
				A	B	C	D	E/F
1	Flyby Recon	Flyby	199	9.95	39.8	59.7	69.65	19.9
2	Rendezvous Low ΔV (2 km/s)	Rendezvous	352	17.5	70	87.5	105	70
2-E	Rendezvous Solar Electric Propulsion (SEP) Low ΔV	Rendezvous	310	15.4	61.6	77	92.4	61.6
3	Rendezvous High ΔV (4 km/s)	Rendezvous	349	17.35	69.4	86.75	104.1	69.4
4	Rendezvous with Expanded Payload	Rendezvous	597	29.75	119	148.75	178.5	119
4-E	Rendezvous SEP with Expanded Payload	Rendezvous	465	23.15	92.6	115.75	138.9	92.6
5	Rendezvous High ΔV with Big Sat Components	Rendezvous	434	21.6	86.4	108	129.6	86.4
6	Rendezvous with Deployed Lander/Rover	Rendezvous	626	31.2	124.8	156	187.2	124.8
6-E	Rendezvous SEP with Deployed Lander/Rover	Rendezvous	472	23.5	94	117.5	141	94
7	Flyby Tour with a single spacecraft to 4 NEOs	Flyby	206	10.3	41.2	61.8	72.1	20.6
8-1	Flyby Tour with 2 spacecraft to 4 NEOs	Flyby	279	13.95	55.8	83.7	97.65	27.9
8-2	Flyby Tour with 3 spacecraft to 4 NEOs	Flyby	339	16.95	67.8	101.7	118.65	33.9
8-3	Flyby Tour with 4 spacecraft to 4 NEOs	Flyby	430	21.5	86	129	150.5	43
9	Flyby Tour Mothership with 4 CubeSats (1/per target)	Flyby	363	18.15	72.6	108.9	127.05	36.3
10-MP	Intercept (Mono-Prop) w/ NED Simulator	Flyby	352	17.6	70.4	105.6	123.2	35.2
10-BP	Intercept (Bi-Prop) w/ NED Simulator	Flyby	359	17.95	71.8	107.7	125.65	35.9
11	Rendezvous with NED Simulator	Rendezvous	438	21.8	87.2	109	130.8	87.2
11-E	Rendezvous SEP with NED Simulator	Rendezvous	326	16.2	64.8	81	97.2	64.8
12	Rendezvous with Deployed NED Simulator (2 elements)	Rendezvous	512	25.5	102	127.5	153	102
12-E	Rendezvous SEP with Deployed NED Simulator (2 elements)	Rendezvous	376	18.7	74.8	93.5	112.2	74.8
13	Kinetic Impact w/ 2 elements (like Deep Impact)	Flyby	361	18.05	72.2	108.3	126.35	36.1
13-DART	Kinetic Impact w/ 2 elements (like DART w/CubeSat)	Flyby	298	14.9	59.6	89.4	104.3	29.8
14	Kinetic Impact w/ 2 elements (Rendezvous SC + Impactor SC)	Rendezvous	621	30.95	123.8	154.75	185.7	123.8
15 A-M	Ion Beam w/MaSMi Thruster (32 kg Xe)	Rendezvous	336	16.7	66.8	83.5	100.2	66.8
15 B-M	Ion Beam w/MaSMi Thruster (150 kg Xe)	Rendezvous	390	19.4	77.6	97	116.4	77.6
15 C-M	Ion Beam w/MaSMi Thruster (600 kg Xe)	Rendezvous	598	29.8	119.2	149	178.8	119.2
15 A-S	Ion Beam w/SPT-140 Thruster (32 kg Xe)	Rendezvous	499	24.85	99.4	124.25	149.1	99.4
15 B-S	Ion Beam w/SPT-140 Thruster (150 kg Xe)	Rendezvous	555	27.65	110.6	138.25	165.9	110.6
15 C-S	Ion Beam w/SPT-140 Thruster (570 kg Xe)	Rendezvous	666	33.2	132.8	166	199.2	132.8
16	Gravity Tractor	Rendezvous	430	22.4	89.6	112	134.4	89.6
17	Ion Beam & Gravity Tractor	Rendezvous	443	22.05	88.2	110.25	132.3	88.2

Flyby:
90 months total mission

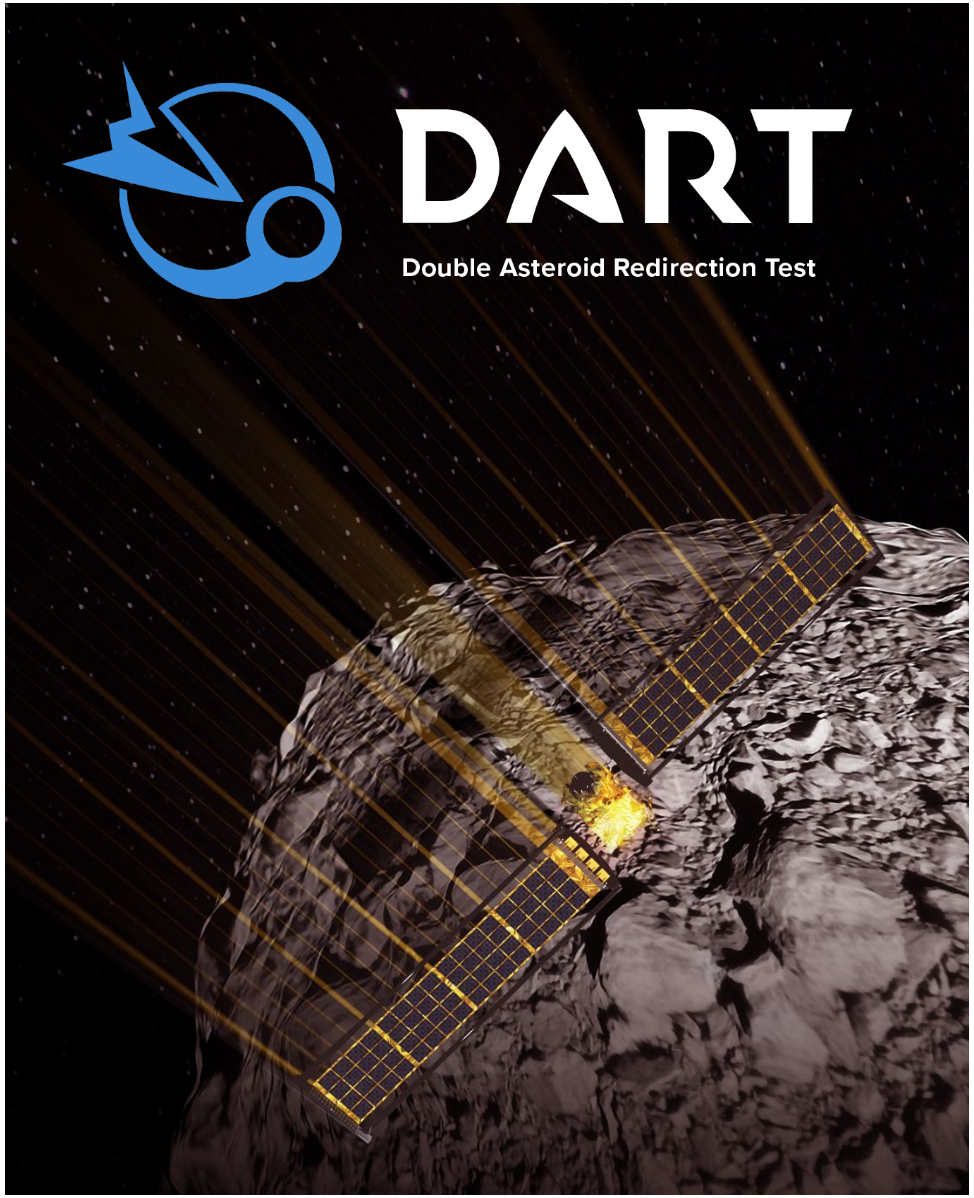
Rendezvous:
105 months total mission



Origins, Worlds, and Life – 2022

Recommendation: NASA's Planetary Defense Coordination Office should be funded at adequate levels to conduct a robust program of necessary planetary defense-related activities, technologies, and **demonstration missions launching on a regular cadence**.

Finding: *The recommendation of the 2019 NASEM report, Finding Hazardous Asteroids Using Infrared and Visible Wavelength Telescopes, remains valid and important to follow for the next decade and beyond:* ***"Missions meeting high-priority planetary defense objectives should not be required to compete against missions meeting high-priority science objectives."***



DART Mission

A planetary defense kinetic impactor technology demonstration mission

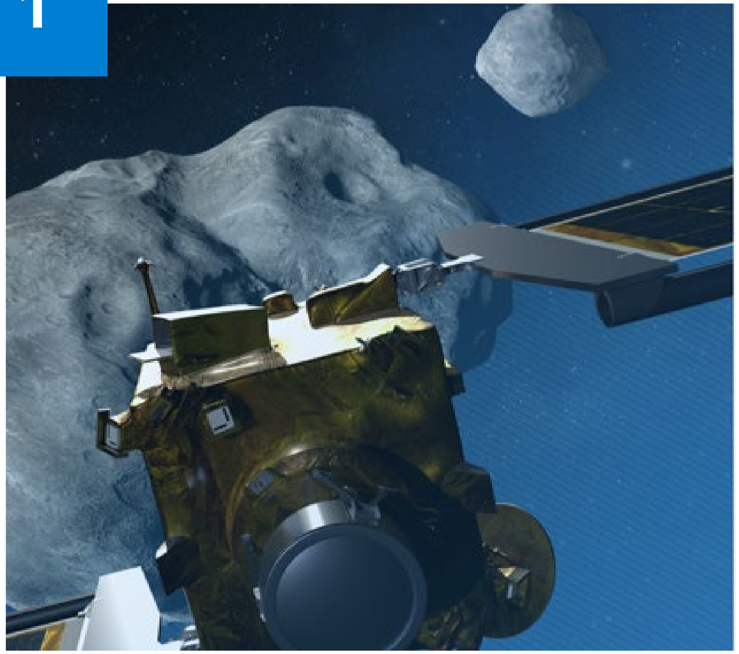
Cost and Schedule

- **2015** – DART Phase A begins
- **2017** – Phase B
- **2018** – Preliminary Design Review
- **2019** – Critical Design Review
- **2021** – Launch
- **2022 – Kinetic impact into Dimorphos**
- **2023** – DART Phase F ends

$327 Million total mission cost
$67 M for Space X Falcon 9 launch
$260 M for Phases A–F (2105–2023)

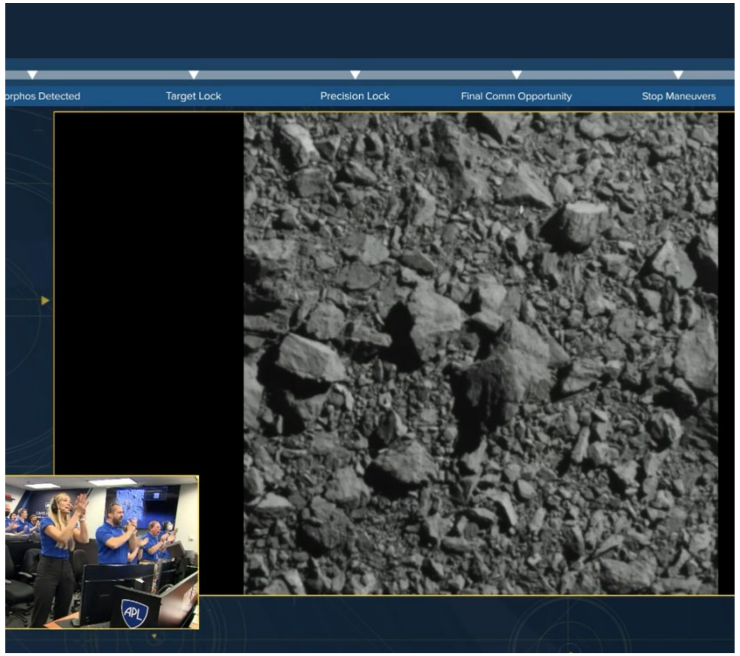
DART’s Level 1 Requirements: #1

1



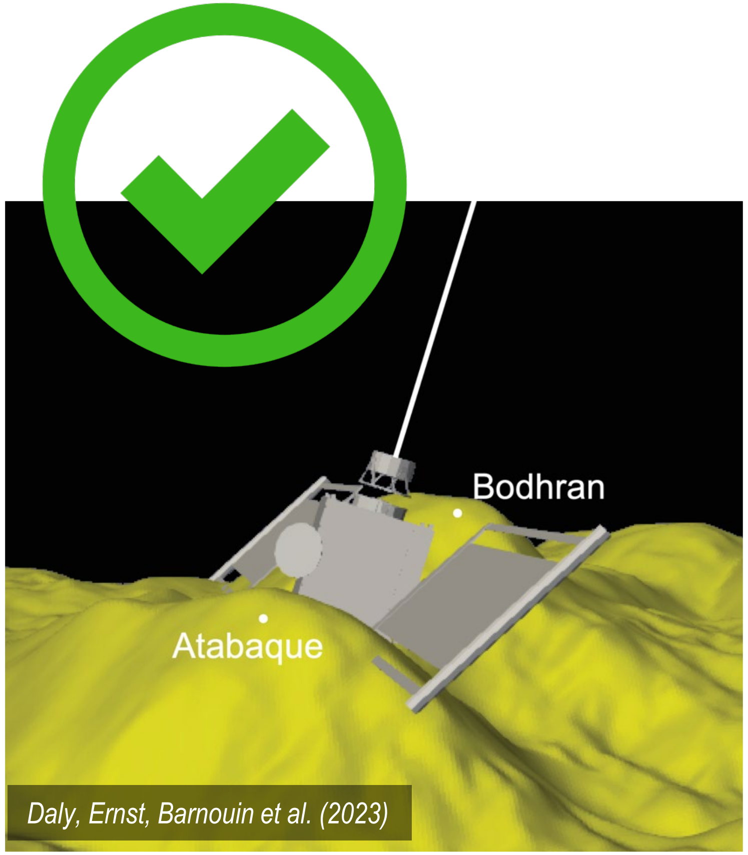
Impact Dimorphos

During its Sept/Oct 2022 close approach to Earth



September 26, 2022

DART impacted Dimorphos, with more than a million concurrent viewers watching the live NASA broadcast.



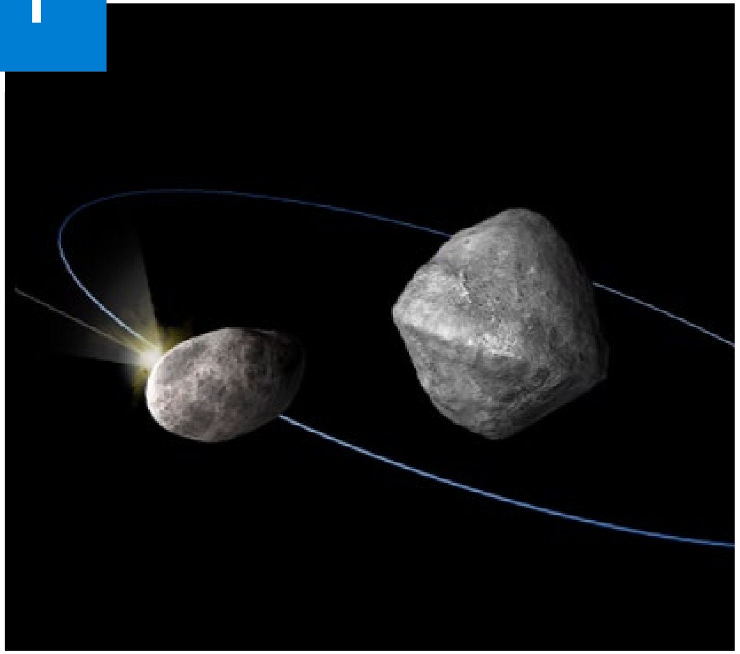
Publications

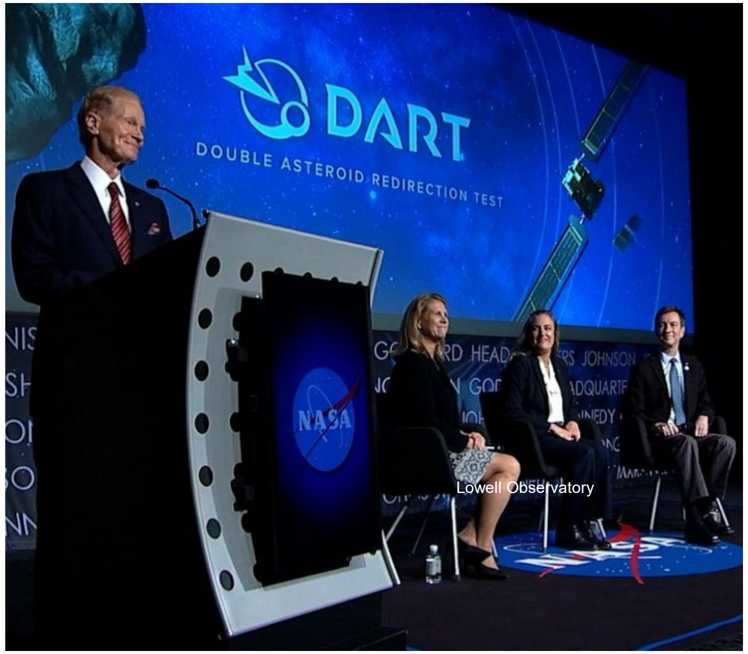
Daly, R.T., Ernst, C.M., Barnouin, O.S. et al. (2023) Successful Kinetic Impact into an Asteroid for Planetary Defense. *Nature*, 616, 443–447.

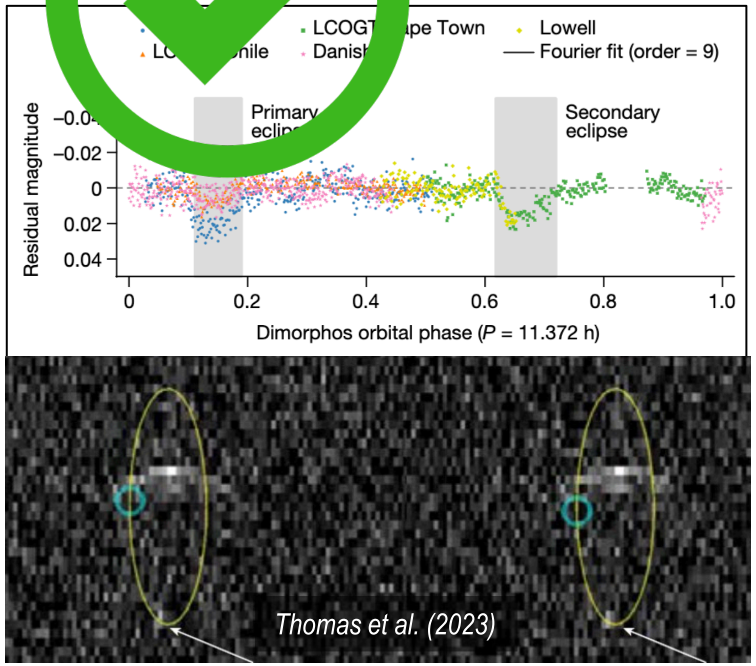
+ *many others documenting the engineering design, development, and operations*

DART’s Level 1 Requirements: #2

1







Change the Binary Orbital Period

Cause a ≥73-second change in the orbital period of Dimorphos

October 11, 2022

NASA announced that DART shortened the orbital period of Dimorphos, with the initial data indicating a change of -32 ±2 min.

Publication

Period change of -33 ±1 minute.

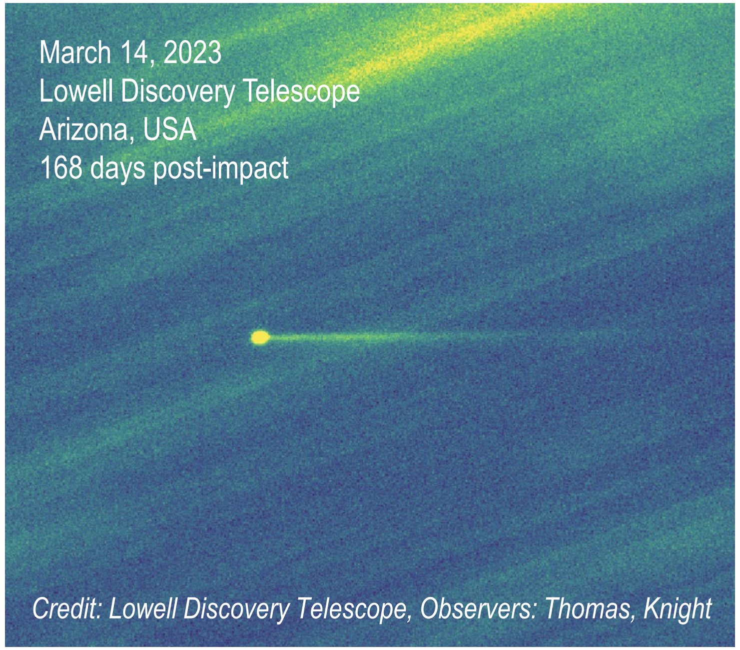
Thomas, C.A., Naidu, S.P., Scheirich, P. et al. (2023) Orbital Period Change of Dimorphos Due to the DART Kinetic Impact. *Nature* 616, 448–451.

DART’s Level 1 Requirements: #3

3

Measure the Period Change

To within 7.3 seconds, from ground-based observations before and after impact



Five Months of Telescopic Data

Two independent analysis models determined a final period change of -33.24 min. ±1.4 sec., surpassing the required precision.

Publications

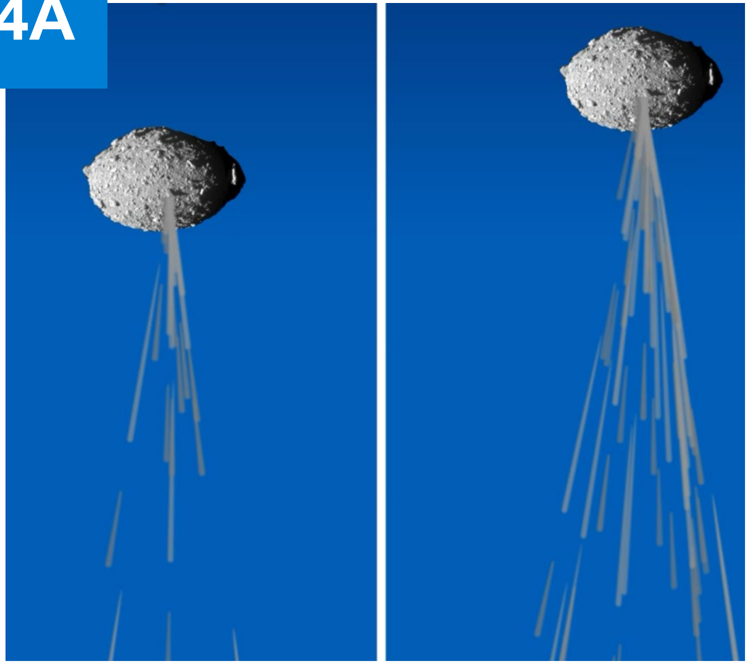
Moskovitz, N., Thomas, C., Pravec, P. et al. (2023) Photometry of the Didymos system across the DART impact apparition. *Planetary Science Journal*, submitted.

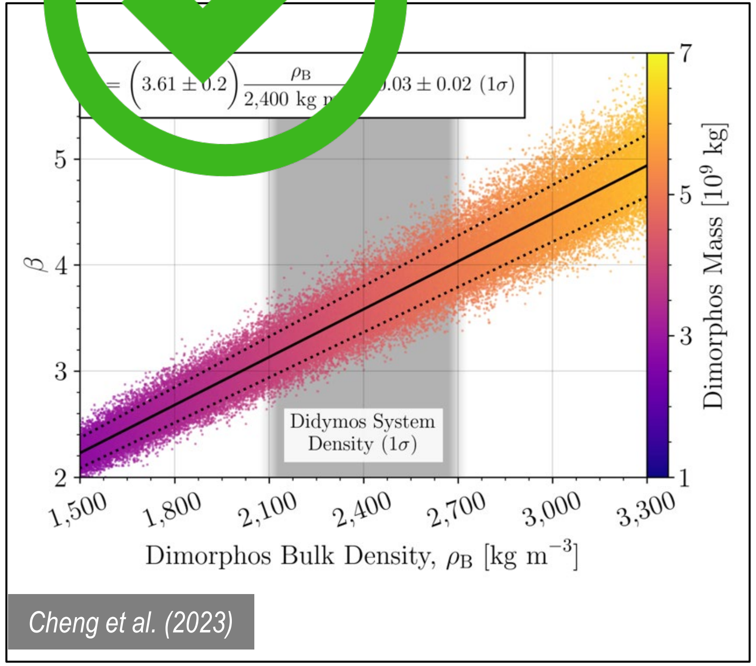
Naidu, S. P., Chesley, S. R., Moskovitz, N. et al. (2023) Orbital and physical characterization of Dimorphos following the DART impact. *Planetary Science Journal*, submitted.

Scheirich, P. Pravec, P., Meyer, A. J. et al. (2023) Dimorphos orbit determination from mutual events photometry. *Planetary Science Journal*, submitted.

DART’s Level 1 Requirements: #4A

4A





Measure “Beta”

Using the velocity change and the best available estimate of the mass of Dimorphos

December 15, 2022

At a press conference at AGU, the DART team announced a determination of Beta of ~3.6, using a density of Dimorphos of 2400 kg m^{-3}

Publication

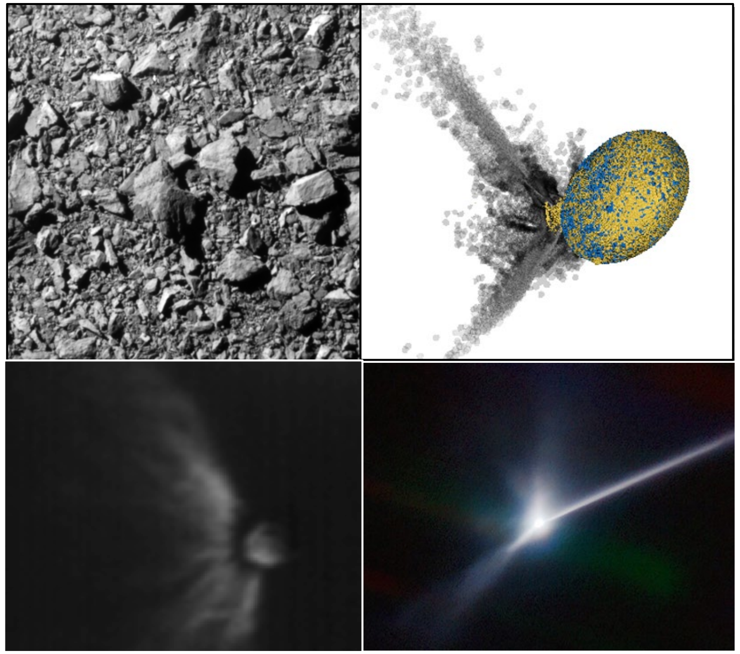
Cheng, A.F., Agrusa, H.F., Barbee, B.W. et al. (2023) Momentum Transfer from the DART Mission Kinetic Impact on Asteroid Dimorphos. *Nature,* 616, 457–460.

DART's Level 1 Requirements: #4B

4B

Characterize the Surface, Impact Site, and Dynamical Changes in the Didymos System

With ground-based observations and data from another spacecraft (if available)



Data from DART, LICIACube, and Telescopic Observations Inform Models and Simulations

Combined work of >300 members from 29 different countries on the DART Investigation Team

Publications

Bagnulo et al. (2023) *ApJL,* 945:L38

Dotto & Zinzi (2023) *NatCo,* 14: 3055

Kareta et al. (2023) *ApJL, in press*

Li et al. (2023) *Nature*, 616, 452-456

Lin et al. (2023) *A&A*, 676, A116

Meyer et al. (2023) *PSJ*, 4, 141

Moreno et al. (2023) PSJ, 4, 138

Opitom et al. (2023) *A&A*, 671, L11

Rivkin et al. (2023) *PSJ, in press*

Rivkin & Cheng (2023) NatCo, 14: 1003

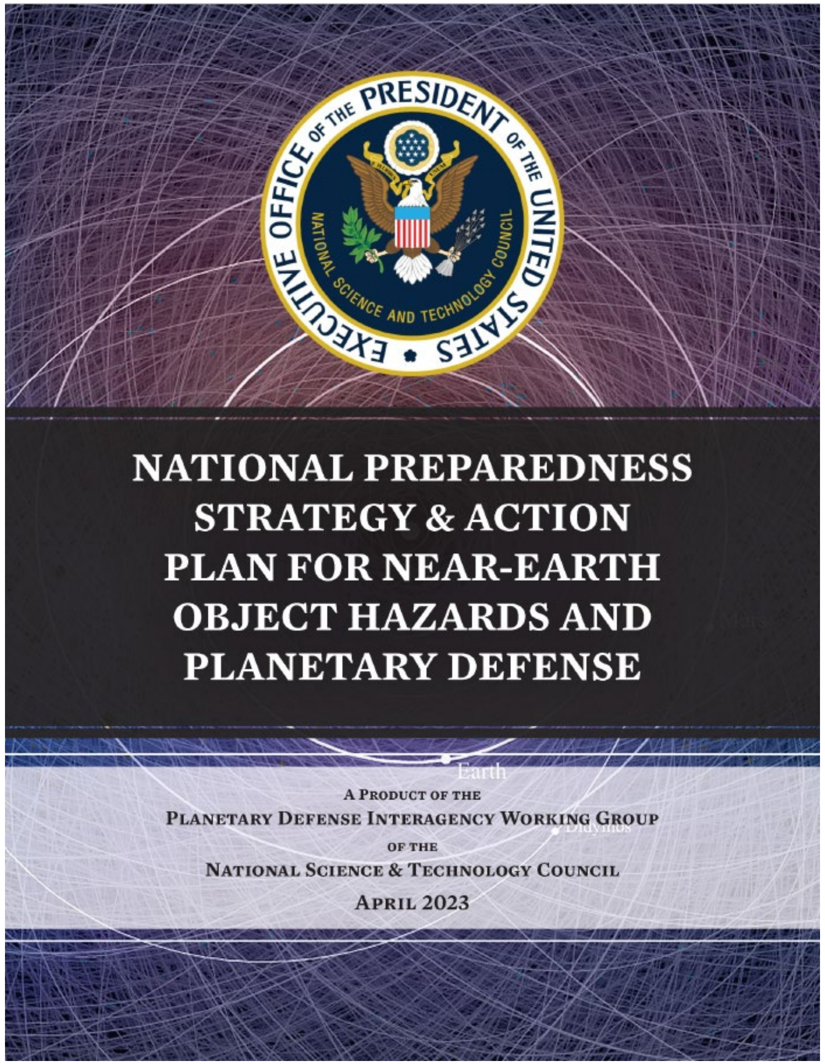
Roth et al. (2023) *PSJ, in press*

+ 34 others currently submitted

WORLDWIDE OBSERVING CAMPAIGN 2022 2023

DART
Double Asteroid Redirection Test

US National Plan – 2023



Goal 1:
Enhance NEO detection, tracking, and characterization capabilities

Goal 2:
Improve NEO modeling, prediction, and information integration

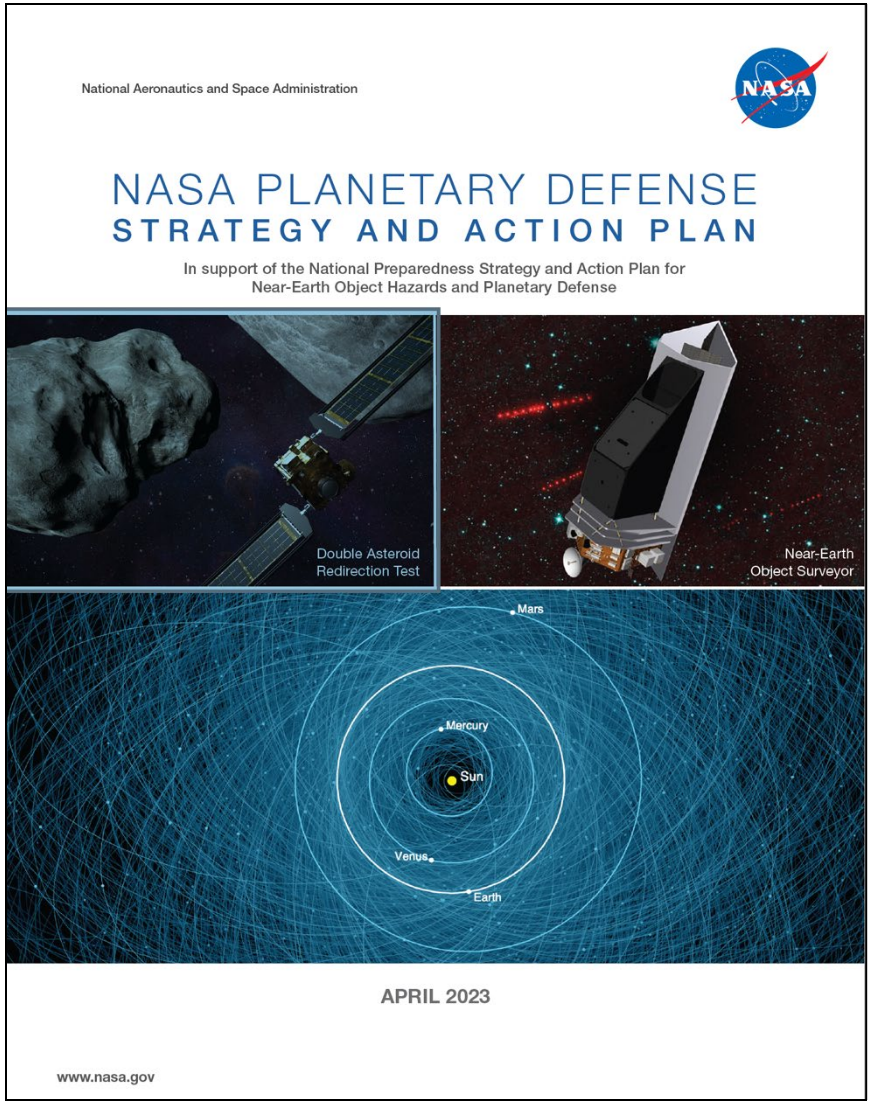
Goal 3:
Develop technologies for NEO **reconnaissance**, deflection, and disruption missions

Goal 4:
Increase international cooperation on NEO preparedness

Goal 5:
Strengthen and routinely exercise NEO impact emergency procedures and action protocols

NEW **Goal 6:**
Improve U.S. management of planetary defense through enhanced interagency collaboration

NASA Plan – 2023



Goal 1:
Enhance **NASA** NEO detection, tracking, and characterization capabilities

Goal 2:
Improve **NASA coordination on** NEO modeling, prediction, and information integration

Goal 3:
Develop technologies for NEO **reconnaissance**, deflection, and disruption missions

Goal 4:
Increase **NASA contributions to** international cooperation on NEO preparedness

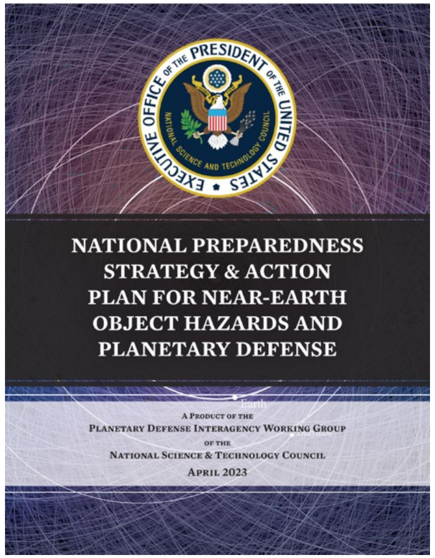
Goal 5:
Coordinate with FEMA and other agencies to strengthen and routinely exercise NEO impact emergency procedures and action protocols

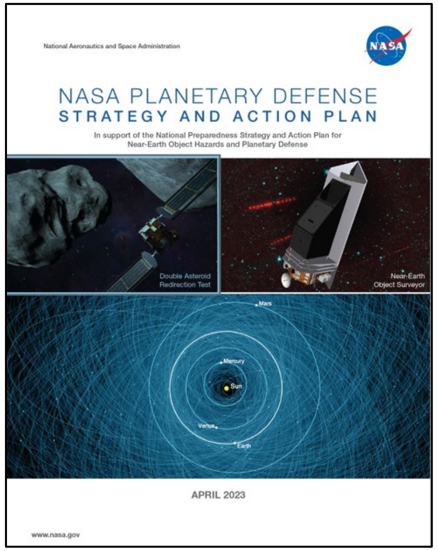
Goal 6:
Improve **NASA contributions to ongoing** interagency collaboration on planetary defense

Goal 7:
Improve organization of NASA's planetary defense activities

Goal 8:
Enhance strategic communications related to planetary defense

2023

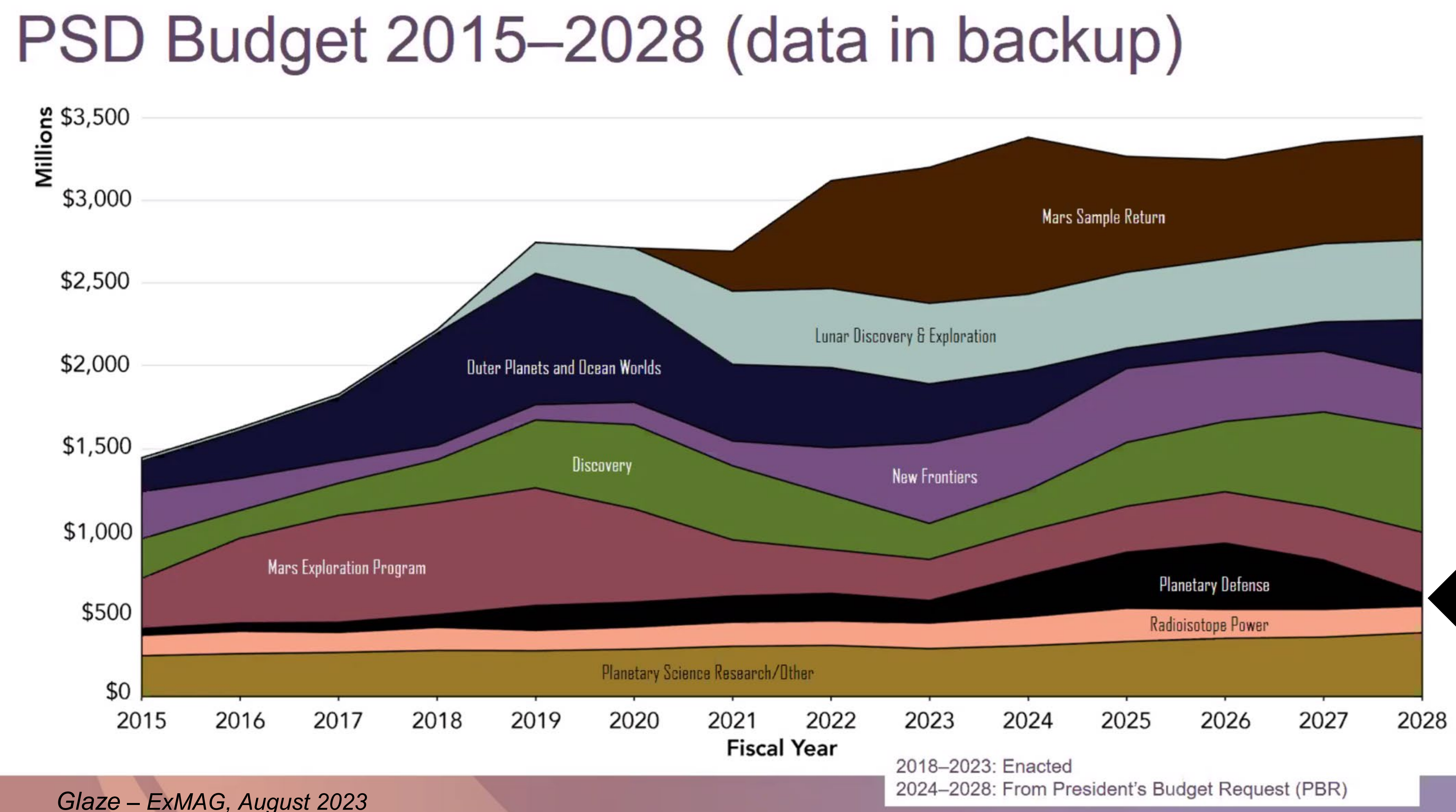




Goal 3: Develop technologies for NEO reconnaissance, deflection and disruption missions

Actions	Timeframe	
3.1 Collaborate with interagency partners on technologies for rapid response, reconnaissance, and characterization of in-space objects. Evaluate the capabilities of current and projected launch vehicle infrastructure to support short-warning planetary defense missions.	Short term	rapid-response NEO reconnaissance missions
3.2 Create plans for the development, testing, and implementation of NEO reconnaissance mission systems.	Short term	
3.3 Develop preliminary mission designs for future NEO deflection mission campaigns. Identify, assess the readiness, estimate costs, and propose development paths for key technologies required by NEO impact prevention concepts. Perform a risk analysis on planetary defense mission success under varying assumptions and circumstances.	Medium term	NEO deflection and disruption missions
3.4 Continue the study of circumstances when only use of a nuclear explosive device would provide the necessary force to mitigate an impending NEO impact threat, and the technologies, capabilities and operational considerations required for use of such devices. Assess the legal and national policy implications of such an option.	Medium term	
3.5 Continue flight demonstrations to validate NEO deflection and disruption system concepts.	Long term	

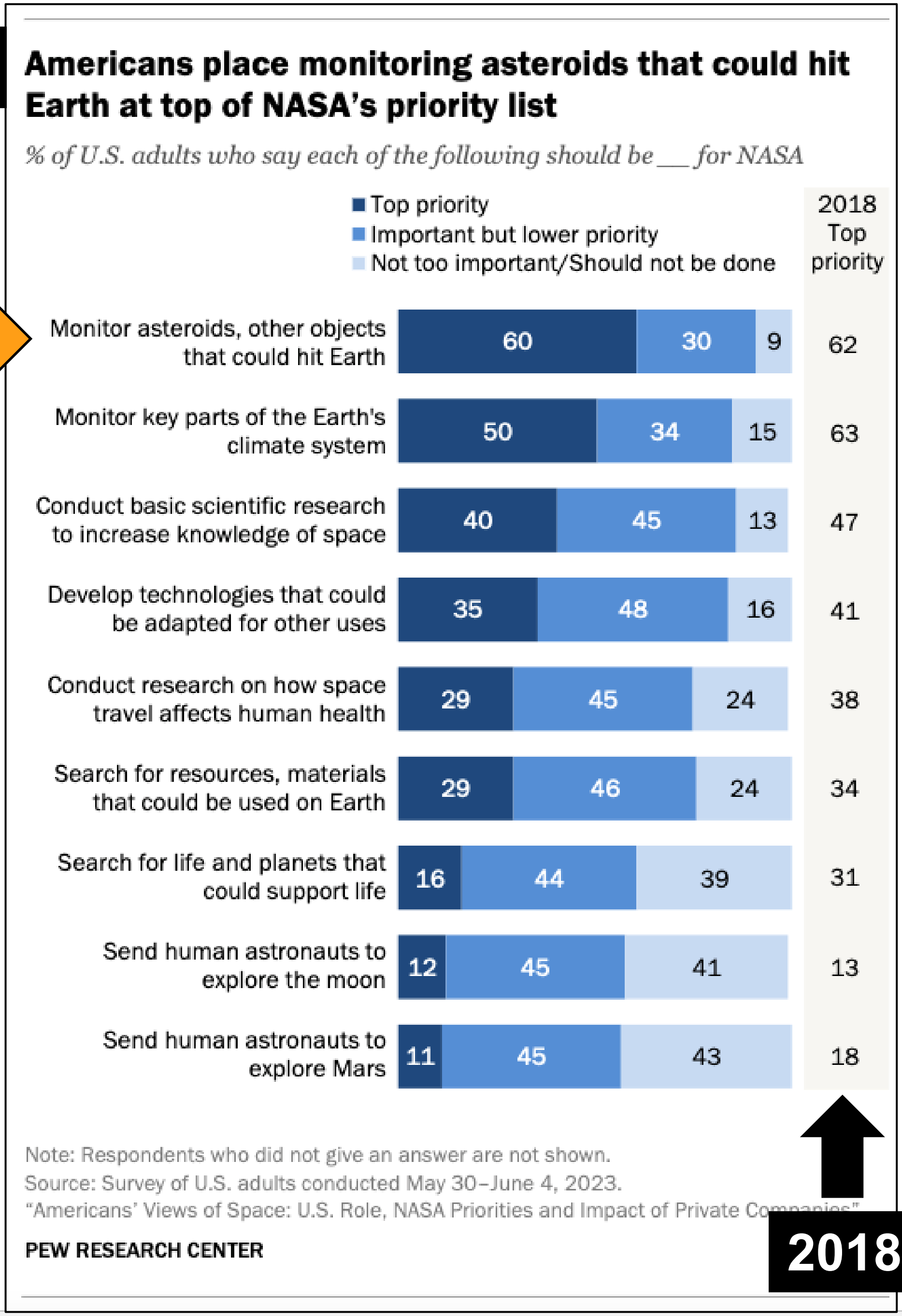
PSD budget slide



Glaze – ExMAG, August 2023

The 2028 President's Budget Request is not positioned to support a sustained cadence of technology demonstration missions for planetary defense

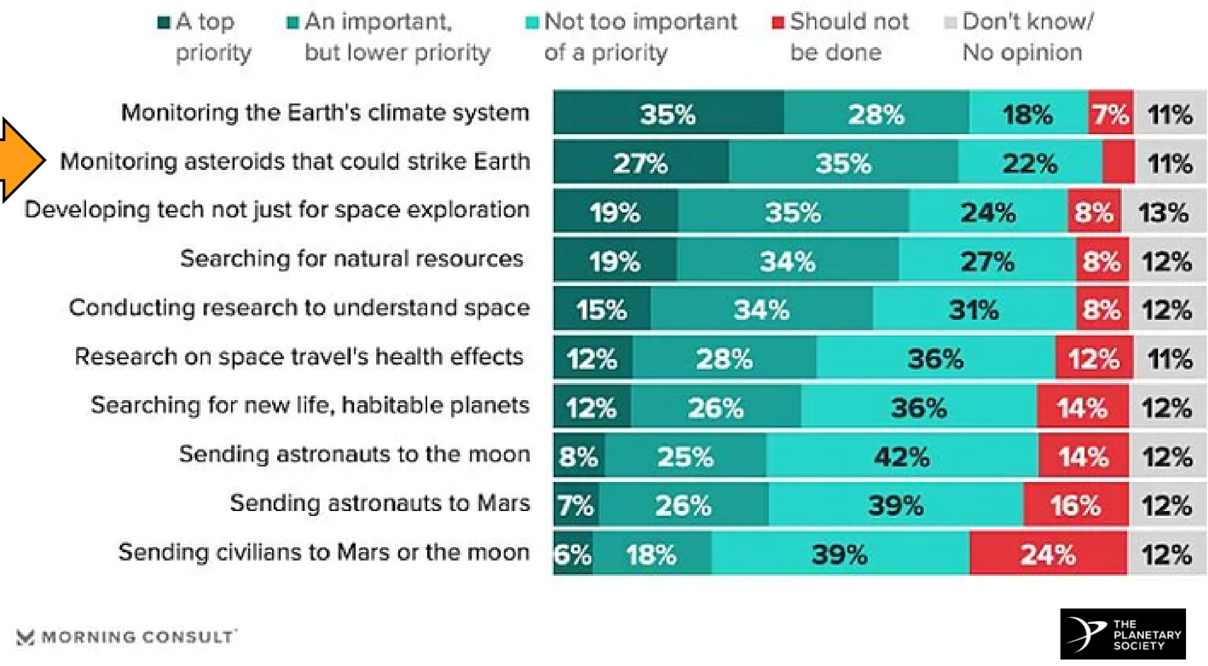
2023



2018

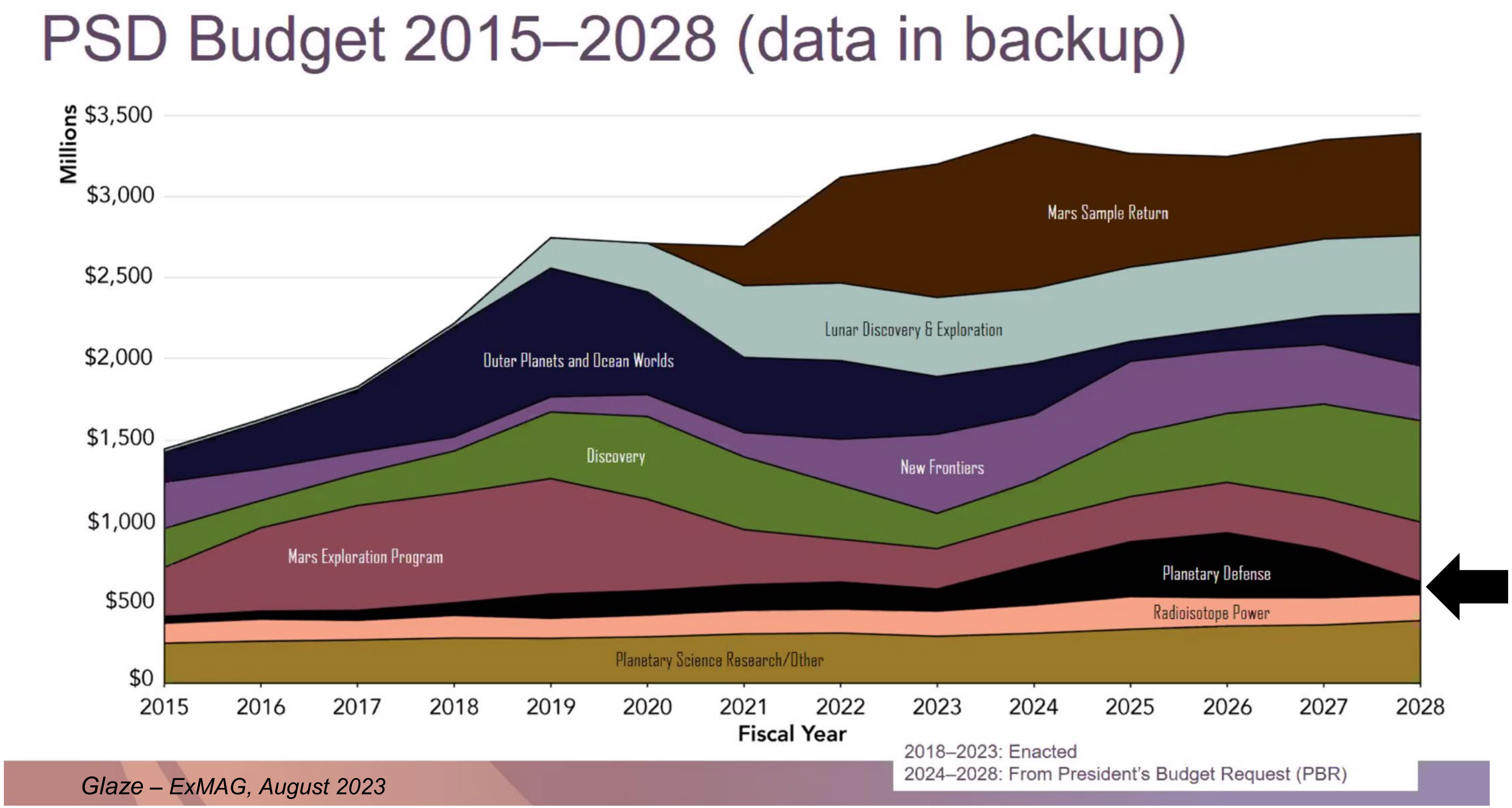
2021

Polling data supports planetary defense activities



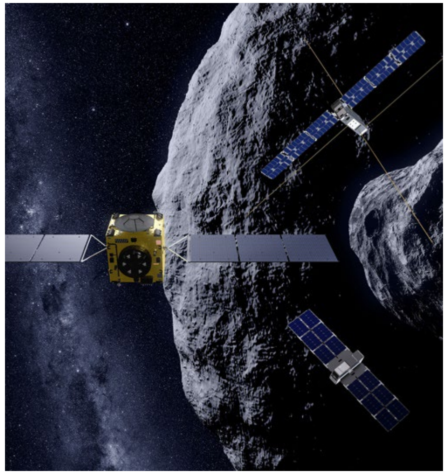
POLLING DATA SUPPORTS PLANETARY DEFENSE ACTIVITIES This 2021 poll from Morning Consult shows strong public support for planetary defense (asteroid detection) activities by NASA. Poll conducted Feb. 12-15, 2021 among 2,200 U.S. adults, with a margin of error ± 2%. *Morning Consult*

PSD budget slide



The 2028 President's Budget Request is not positioned to support a sustained cadence of technology demonstration missions for planetary defense

Planetary Defense Spacecraft Missions – Future



Hera

ESA mission to follow DART and rendezvous with the Didymos-Dimorphos system, with **TIRI contributed by JAXA**

Future

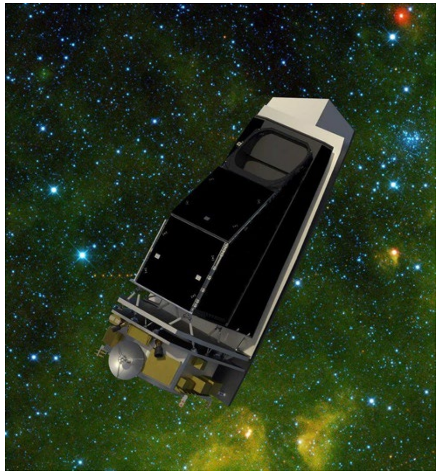
Launch: 2024

Mission to 2019 VL5

Chinese two spacecraft mission to 2019 VL5 (~30-m), with an observer and an impactor spacecraft (6.4 km/s)

Future

Launch: 2025

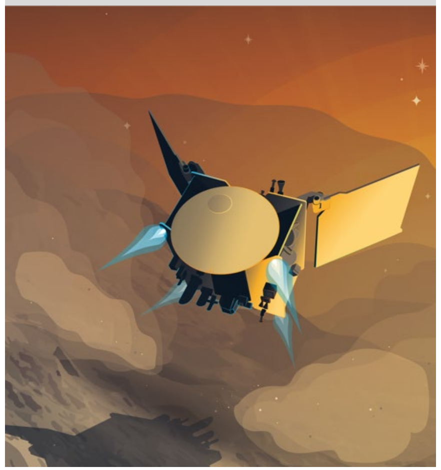


NEO Surveyor

NASA infrared space telescope mission to find NEOs, with capabilities to find the ≥140-m population

Future

Launch: NET 2027



OSIRIS-APEX

Extended mission of NASA OSIRIS-REx spacecraft to rendezvous with Apophis (340-m)

Future

Rendezvous: 2029

Hayabusa2#

Extended mission of JAXA Hayabusa2. Flyby of 2001 CC21 (500-m) in 2026. Rendezvous with 1998 KY26 (30-m, 10 min spin period).

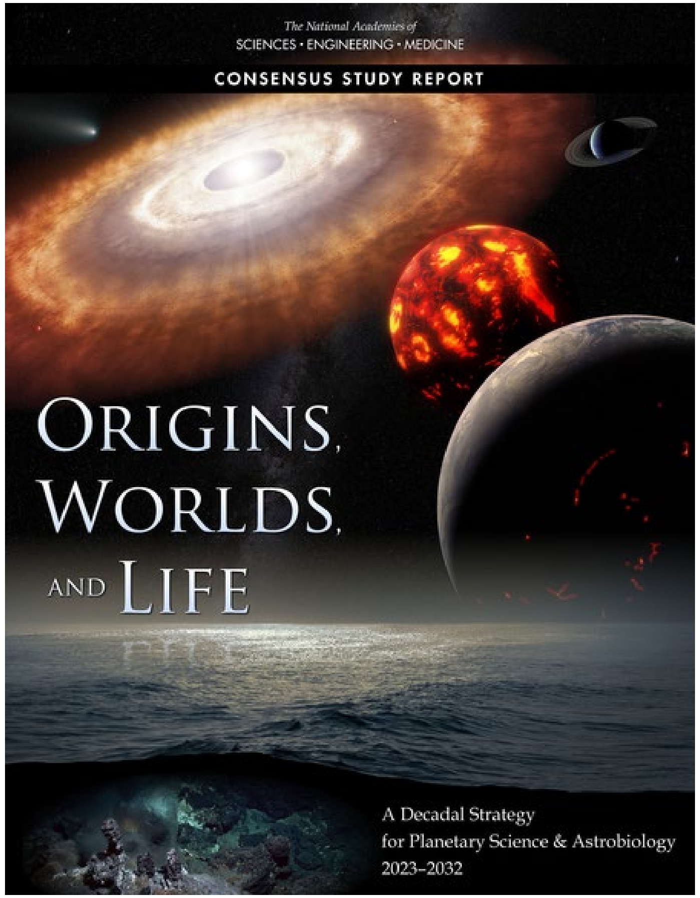
Future

Rendezvous: 2031

Apophis – 2029

Apophis (340 m) will pass within 32,000 km of Earth's surface on Friday, April 13, 2029.

There is no risk for Earth impact in the next century.



Chapter 18 section:

Apophis, a Unique Characterization Opportunity in the Coming Decade

Recommendation: NASA should study all relevant observing opportunities surrounding the unique Apophis encounter, using both ground and space-based assets. To maximize the scientific and planetary defense return, NASA should develop plans for making the best use of these identified assets during the Apophis encounter and support international cooperation in carrying out these valuable observations.

Apophis – 2029

Apophis (340 m) will pass within 32,000 km of Earth's surface on Friday, April 13, 2029.

There is no risk for Earth impact in the next century.

Specific Action Team formed by SBAG at the request of NASA PSD

Apophis Specific Action Team Report

Jessie L. Dotson,[1,*] Marina Brozovic,[2] Steven Chesley,[2]
Stephanie Jarmak,[3,*] Nicholas Moskovitz,[4] Andrew Rivkin,[5]
Paul Sánchez,[6] Damya Souami,[7] and Timothy Titus[8,*]

Report: 9 Nov., 2022, 59 pgs

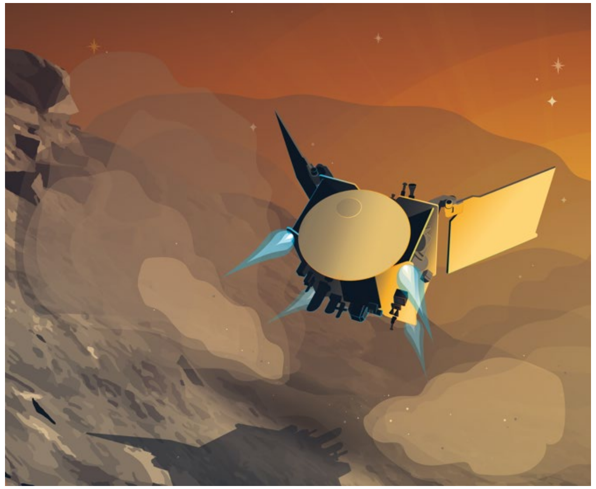
Top Priority Opportunities –
Direct Observations of Geophysical Processes

The close encounter of Apophis presents a unique opportunity to observe geophysical processes contemporaneously, rather than infer them after the fact. One or more spacecraft with a high resolution, multi-band optical-NIR imager in close proximity to Apophis **before and after** the close encounter would be sufficient to make direct observations of this effect.

Before Earth encounter:

Potential concepts being discussed by ESA and others, pursuing international collaboration, but nothing is currently planned

After Earth encounter:



OSIRIS-APEX will orbit Apophis

Nov. 14–16, 2023

NEO WARP 3

The Near-Earth Object Workshops to Assess Reconnaissance for Planetary defense (NEO WARP) 3 will take place on November 14th-16th, 2023, at the University of Arizona Center in Washington DC.

11/14/2023
11/15/2023
11/16/2023 (half-day)

University of Arizona Center:
1301 Pennsylvania Avenue, NW,
Washington, D.C. 20004
and virtual

$ Free Event

*** Registration Deadline is Nov. 5th ***

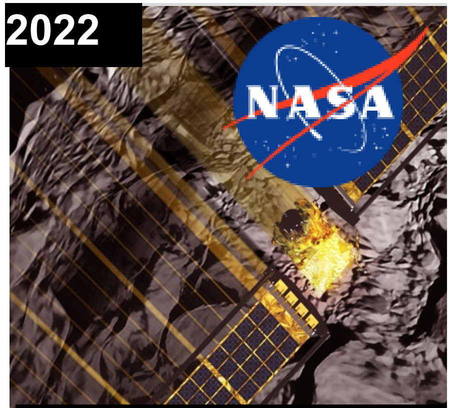
https://science.gsfc.nasa.gov/690/neowarp3/

April 22–23, 2024

https://www.hou.usra.edu/meetings/apophis2024/

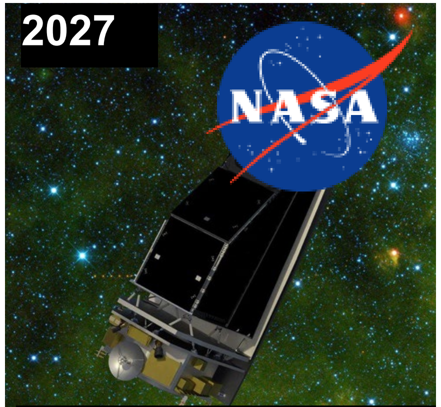
Planetary Defense Spacecraft Missions – Past, Present, & Future


2013
NEOWISE


2022
DART


2024
Hera

2025
Mission to 2019 VL5


2027
NEO Surveyor


2029
OSIRIS-APEX

2031
Hayabusa2#

Decadal Recommendation: NASA's Planetary Defense Coordination Office should be funded at adequate levels to conduct a robust program of necessary planetary defense-related activities, technologies, and **demonstration missions launching on a regular cadence**.

JOHNS HOPKINS

APPLIED PHYSICS LABORATORY