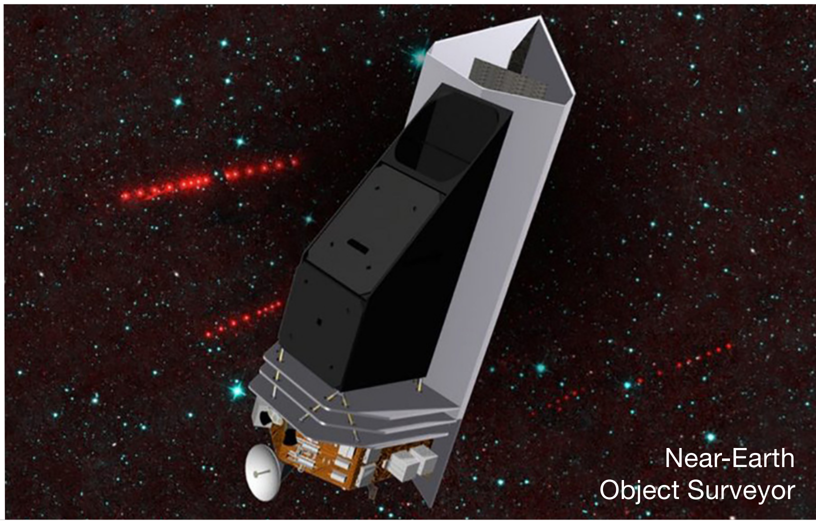
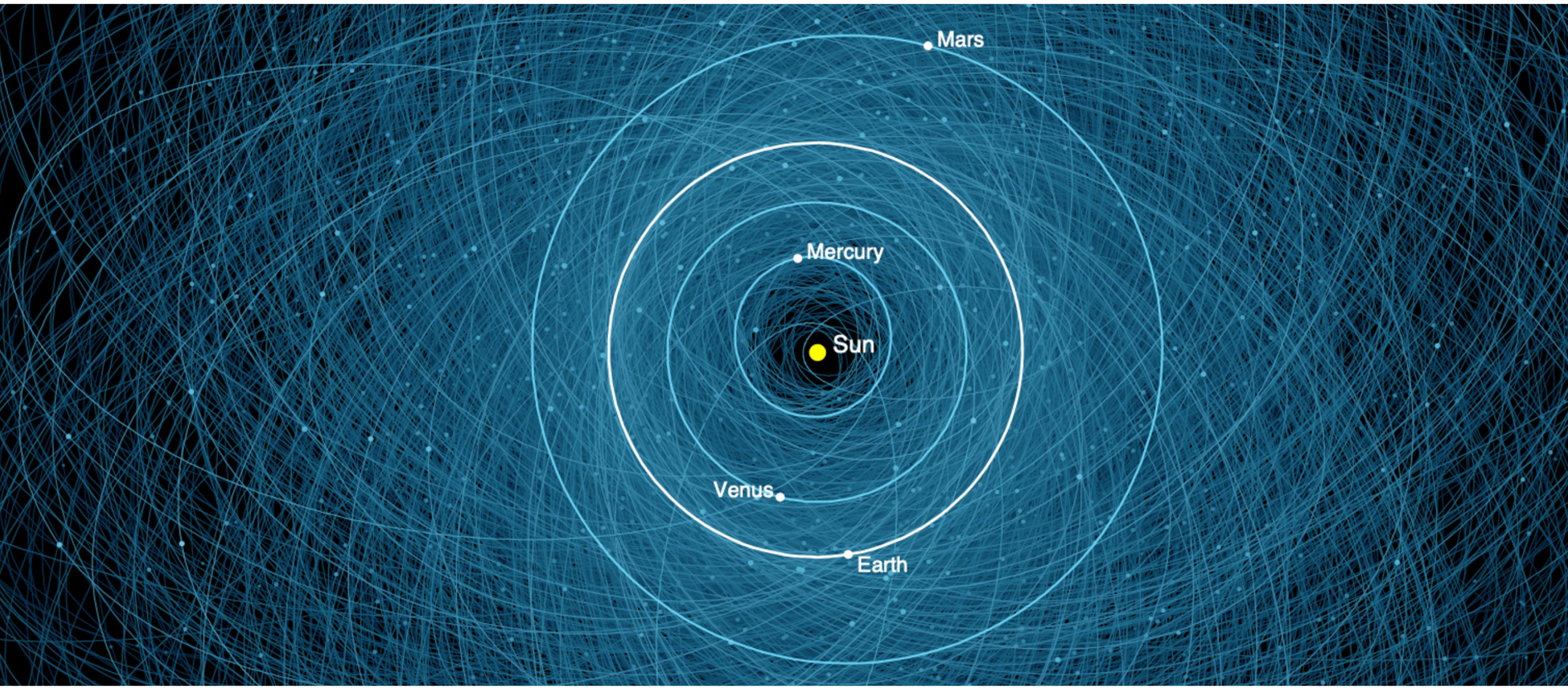
National Aeronautics and Space Administration

NASA PLANETARY DEFENSE
STRATEGY AND ACTION PLAN

In support of the National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense





APRIL 2023

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In support of the National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense

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Summary of the 2023 National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense

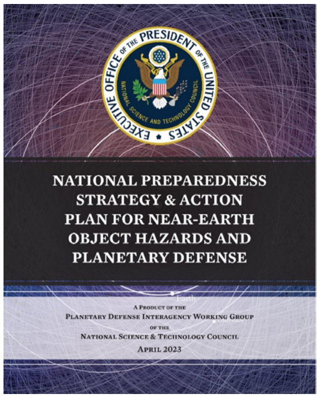


Figure 1: *National Planetary Defense Strategy. available online.*[1]

In April 2023 the United States government released the *National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense* (National Planetary Defense Strategy)[1] to improve the United States' preparedness to address the hazard of NEO impacts over a 10-year period, primarily by helping organize and coordinate interagency NEO-related efforts.

The 2023 National Planetary Defense Strategy updates the United States' first comprehensive Near-Earth Object Preparedness Strategy and Action Plan released in 2018. It builds on existing efforts by Federal Departments and Agencies to address the hazard of NEO impacts, includes evaluation of where progress has been made since 2018, and focuses future work on planetary defense across the U.S. government.

The National Planetary Defense Strategy provides a road map for a collaborative and federally coordinated approach to developing effective technologies, policies, practices, and procedures for decreasing U.S. and global vulnerability to NEO impacts.

When implemented, the National Planetary Defense Strategy will improve detection, research, mission planning, emergency preparedness and response, international engagement, and internal U.S. government coordination on planetary defense.

NEOs are asteroids and comets that come close to or pass across Earth's orbit around the Sun. They range in size from small "meteoroids" only a few meters across, to much larger bodies several kilometers wide. When NEO orbits bring them into Earth's atmosphere, smaller objects harmlessly fragment and disintegrate, while larger objects can cause local damage or even global devastation.

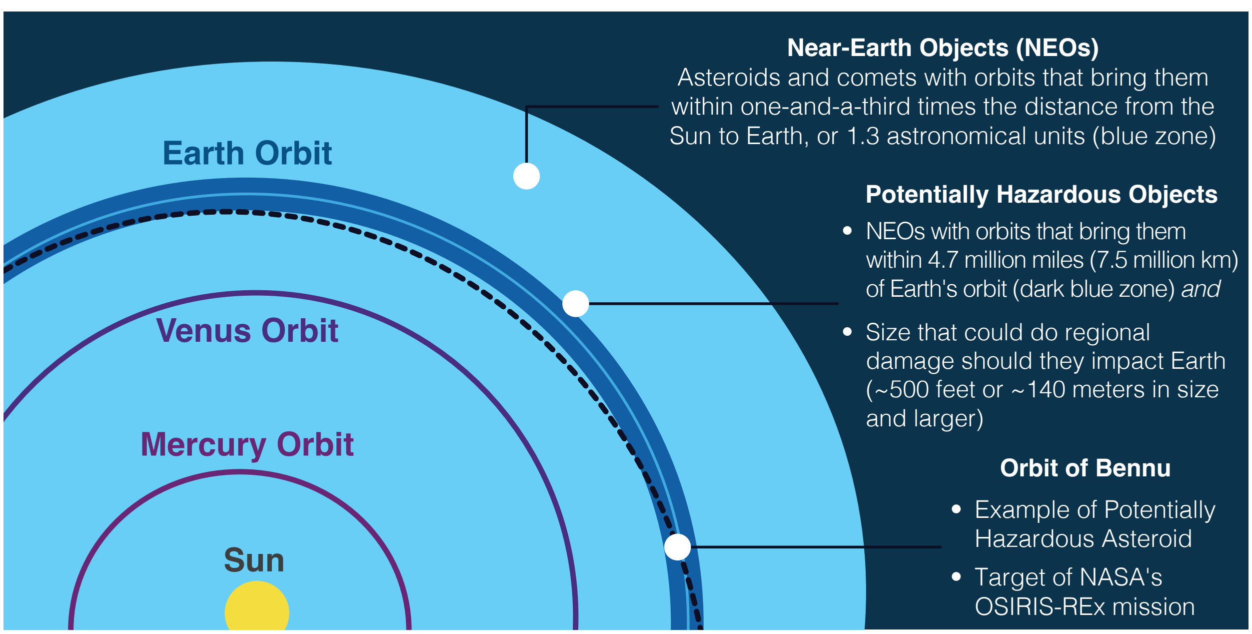


Figure 2: *Near-Earth objects in the Solar System. (Source: NASA)*

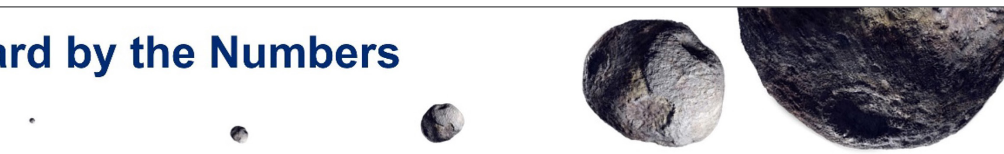
1 https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

The threat exists because our planet orbits the Sun amidst millions of objects that cross our orbit – asteroids and comets. Even a rare interstellar asteroid or comet from outside our solar system can enter Earth's neighborhood.

Characteristics of the estimated NEO population:

- Around 1,000 NEOs greater than one kilometer in size that are potentially capable of causing global impact effects. Approximately 95 percent of these bodies have been found and none are a current threat.
- Around 25,000 objects larger than 140 meters in size, capable of causing regional devastation, are believed to exist. Less than 50 percent have been detected and tracked to date.
- An estimated 230,000 or more objects exist that are equal to or larger than 50 meters in size and could destroy a concentrated urban area. It is estimated that fewer than eight percent of these have been detected.
- Tens of millions of smaller NEOs exist. While most are small enough to likely break up in Earth's atmosphere during an impact, those larger than 10 meters in size could potentially cause some surface damage. Less than one percent of these small bodies have been discovered.[2]

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 3: *NEO size and hazard. (Credit: Johns Hopkins University / Applied Physics Lab)*

2 National Academies of Science Planetary Science Decadal Survey 2023-2032

Executive Summary

In April 2023 the United States released the ***National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense*** (National Planetary Defense Strategy).[3] This NASA strategy responds to the U.S. National Planetary Defense Strategy, and focuses Agency-level activities within NASA, describing existing efforts to survey the Near-Earth Object (NEO) population, assess risks and develop approaches to prevent or mitigate NEO impacts on Earth. It provides guidance to improve current efforts and charts a robust yet realistic path forward for planetary defense activities at NASA.

NASA has been engaged in NEO research since 1998. In 2016, NASA formalized its planetary defense efforts with the establishment of the Planetary Defense Coordination Office (PDCO), under the Planetary Science Division (PSD) in NASA's Science Mission Directorate, to oversee the ongoing NEO research and to coordinate activities with U.S. government agencies and international participants. The PDCO manages the NEO Observations Program and coordinates requirements for planetary defense missions, such as the Double Asteroid Redirection Test (DART) and the NEO Surveyor missions.

In 2022, the National Academy of Sciences' *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032* prominently featured a section on planetary defense, noting that NASA's PDCO was "the critical organization to advance U.S. planetary defense capabilities and initiatives in the next decade and beyond."

Significant progress in NEO detection has been made in recent years and the recently approved NEO Surveyor mission, designed to improve detection capabilities to greater than 90 percent of NEOs 140m or larger within about a decade of being launched in 2028, will roughly triple our current capability.

Despite this impressive progress, key challenges remain:

- **Survey, detection, characterization and assessment:** The global community wants a complete NEO survey catalog and sufficient ability to fully characterize NEOs. The ability to assess the risks that NEOs may pose to Earth, and support any mitigation efforts, could be significantly improved by a sufficient set of ground and space-based observations, modeling and prediction capabilities. (NASA Strategic Goals 1 and 2, see table below)
- **Mitigation:** Technological preparedness would be improved with follow-on reconnaissance and mitigation demonstration missions. (NASA Strategic Goal 3)
- **International cooperation:** With the expansion of international capabilities related to NEO survey and mitigation, planetary defense is poised to become a global effort. To realize this vision, NASA plans to foster greater international collaboration and engagement. (NASA Strategic Goal 4)
- **NASA support for interagency coordination:** The National Planetary Defense Strategy recognizes a need for more stable, coordinated planetary defense activities across the United States government. NASA has a key role to play in spearheading this ongoing interagency coordination. (NASA Strategic Goals 5 and 6)
- **NASA organization:** While the NASA PDCO benefits greatly from the close coordination with planetary science activities by being part of NASA PSD, competing priorities in the Planetary Science portfolio, which currently includes development of several large missions, may limit opportunities for expanding planetary defense activities. However, competition for funding is likely to be an issue regardless of where the program is situated. (NASA Strategic Goal 7)

3 https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

- **Strategic communications:** NASA should better integrate and disseminate information regarding NEO survey and mitigation work. (NASA Strategic Goal 8)

In support of the National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense, NASA developed this NASA Planetary Defense Strategy and Action Plan. It also complements the 2022 National Cislunar Science & Technology Strategy (e.g., Objective 3). The NASA strategy is organized around the paradigm of architecting from the right: envisioning desired end states, identifying key challenges and then developing actions to address them. Embedded within are the six National goals and two additional NASA-specific goals (NASA Strategic Goals 7 and 8).

The NASA strategy provides additional details related to the Agency's planetary defense work and specific actions to be completed by NASA organizations in response to the National Strategy and Action Plan (consistent with the leading/supporting agency roles identified in the National plan).

NASA Strategic Goals and Actions

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

Actions	Timeframe
1.1 Continue to identify opportunities in existing and planned space domain awareness programs to improve detection and tracking by enhancing the volume and quality of current data streams, including from ground-based and space-based optical, infrared, and radar facilities.	Short term and ongoing
1.2 Identify technology and data processing capabilities and opportunities in existing and new telescope programs to enhance characterization of NEO composition and dynamical and physical properties.	Short term
1.3 Continue and enhance multi-agency efforts to detect large meteoroids and small asteroids entering Earth's atmosphere and provide rapid public notification.	Short term
1.4 Identify opportunities to leverage existing and planned cislunar space domain awareness capabilities to support detection, tracking, and characterization of NEOs, including through data sharing with planetary defense databases.	Short term
1.5 Support an interagency assessment to explore interest from key stakeholders in the coordinated development of current and future deep space radar facilities and identify where these facilities may be useful for planetary defense.	Short term
1.6 Use the information developed in Actions 1.1, 1.2, 1.3, and 1.4 to inform investments in space domain awareness programs and technology improvements to enhance completeness and speed of NEO detection, tracking, and characterization.	Long term

1.7 Advance concepts for rapid characterization of a potentially hazardous NEO.	Short term and ongoing
1.8 Support analysis of emerging challenges in NEO survey and characterization in the upcoming decade, as well as solutions for mitigating and overcoming these challenges.	Long term and ongoing
1.9 NASA should seek to apply maturing commercial capabilities to the challenge of planetary defense survey, characterization, and mitigation efforts.	Medium term and ongoing
1.10 Consider strengthening planetary radar partnerships, beginning with a study of desired capabilities in collaboration with National Science Foundation (NSF) and/or United States Space Force (USSF).	Medium term
1.11 Consider potential designs for a bolide detector tech demonstration, such as a hosted sensor on a mission, which could be developed in partnership with other U.S. organizations.	Medium term

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

Actions	Timeframe
2.1 Continue to support an interagency working group for coordination and enabling dissemination of the results of NEO threat modeling and analysis.	Ongoing
2.2 Ascertain what information each participating organization requires for threat analysis on what timeframe. Identify gaps and develop recommendations for modeling improvements.	Short term
2.3 Continue development and validation of a suite of computer simulation tools for assessing the outcome of deflection or disruption techniques applied to a NEO.	Medium term
2.4 Improve a suite of computer simulation tools for assessing the local, regional, and global risks associated with an impact scenario. Continue to assess the sensitivities of these models to uncertainties in NEO dynamical and physical properties.	Medium term
2.5 Develop an impact risk data pipeline to inform decision makers on results from integrated modeling of potential impact threats.	Medium term
2.6 Continually assess the adequacy and validity of modeling and analysis of impact effects through annual exercises, test problems, comparison to experiments, and peer review activities.	Ongoing

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
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
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

Goal 4: Increase NASA contributions to international cooperation on NEO preparation	
Actions	**Timeframe**
4.1 Continue to engage and inform foreign governments of the need for a collaborative and coordinated approach to preparing for a NEO event.	Ongoing
4.2 Continue to demonstrate U.S. leadership in technical international NEO organizations, and increase awareness among all countries, in particular space agency officials, of the need to address NEO issues in major international bodies.	Ongoing
4.3 Continue to improve international collaboration on observation infrastructure and data sharing, as well as numerical modeling and scientific research.	Ongoing
4.4 Support development of a plan for improving NEO monitoring through enhanced coordination (and potential expansion) of U.S. and key country ground-based telescopes.	Short term
4.5 Continue to encourage countries to initiate and continue programs to develop space- and ground-based telescopes to detect, track, and characterize NEOs and coordinate via participation with the International Asteroid Warning Network (IAWN).	Ongoing

4.6 Continue to strengthen the IAWN and the Space Mission Planning Advisory Group (SMPAG) as the primary international technical bodies for addressing hazardous NEO response planning and mitigation.	Ongoing
4.7 Support and encourage participation in tabletop and physical exercises with global partners regarding preparedness, prevention, response, and recovery efforts.	Medium term
4.8 Conduct exploratory discussions with international partners regarding U.S. participation and cooperation with upcoming foreign flight missions to NEOs such as a potential reconnaissance mission to Apophis.	Ongoing
4.9. NASA will leverage existing and new research to develop long-term principles for NASA's planetary defense activities that maximize transparency, multilateral cooperation, and promote the benefits of applied planetary science for all humanity.	Short term and ongoing

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

Actions	Timeframe
5.1 Support maturation of a set of real-world scenarios based on credible impact threats with observable parameters to inform planning and procedure development.	Medium term
5.2 Continue to improve protocols for notifying The White House and Congress (including briefing appropriate subcommittees), federal interagency, state and local governments, the public, foreign governments, and other international organizations, regarding NEO threats.	Ongoing
5.3 Develop and share informational material for different audiences providing basic education, information on NEOs, impacts, uncertainties, and the scope of NASA's role.	Short term
5.4 Improve procedures and timeline for conducting a risk/benefit analysis for space-based mitigation mission options following a NEO threat assessment.	Short term

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

Actions	Timeframe
6.1 Convene an ongoing interagency group on planetary defense to address more detailed implementation issues than is common for a White House-level interagency working group.	Short term
6.2 Work with agencies substantially involved with cooperation and collaborations outlined in the National Strategy and Action Plan to identify offices and points of contact (POCs) (expected to be only part-time for most agencies) tasked with responsibility and authority to address and advance the activities supporting planetary defense called for within the Action Plan.	Short term

6.3 Establish a small study effort to explore existing authorities and legislation (e.g., Economy Act) that could be leveraged to improve and enhance implementation of interagency collaborations related to planetary defense.	Short term
Goal 7: Improve organization of NASA's planetary defense activities	
Actions	**Timeframe**
7.1 Conduct an independent assessment of the organization of planetary defense activities at NASA.	Short term
7.2 Formulate a budget and organizational plan to support the long-term sustainment, development and maturation of survey and mitigation capabilities.	Short term
Goal 8: Enhance strategic communications related to planetary defense	
8.1 Prepare a strategic communications plan related to planetary defense.	Short term
8.2 Enhance leadership messaging of planetary defense to increase scientific knowledge, raise awareness and improve preparedness when addressing general public, Congress, media and partners.	Ongoing

This effort seeks to outline priorities and needs that would advance NEO physical characterization capabilities, pursue mitigation and prevention strategies beyond the DART demonstration, and coordinate planetary defense activities across the U.S. government, U.S. commercial industry, and with international partners.

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Background for Planetary Defense at NASA

The 2023 NASA Planetary Defense Strategy and Action Plan focuses NASA efforts within the National Planetary Defense Strategy, providing additional details on NASA's specific actions and the Agency's current and future planetary defense work.

Planetary defense encompasses all the capabilities needed to detect and warn of potential asteroid or comet impacts with Earth and then to either prevent or mitigate their possible effects. The effort involves:

- Finding and tracking NEOs that pose a hazard of impacting Earth (>10m);
- Characterizing each NEO to determine its precise trajectory, and also size, shape, mass, composition, rotational dynamics, and other parameters to assess the likelihood and severity of devastation if it has a potential Earth impact;
- Warning of the impact timing and potential effects, and advise of possible means to mitigate the impact; and
- Planning and implementation of measures to deflect or disrupt (break up) an object on an impact course with Earth, or to mitigate the effects of an impact if it can be prevented. Mitigation measures that can be taken on Earth to protect lives and property include evacuation of the impact area and movement of critical infrastructure.

Figure 4: ***Planetary defense as a decision cycle:*** *planetary defense can be described as a cycle akin to the observe, orient, decide, act, and assess (OODAA) loop. This strategy and action plan entails efforts to detect and characterize NEOs, integrate information, plan action protocols, develop technologies to mitigate NEO hazards, and coordinate responses. Each of the six goals in this strategy address parts of the loop where the most impact can be made. (Source: NASA PDCO)*

The hazard of NEO impacts is challenging to assess when we do not have a complete NEO survey catalog. New survey projects, such as the space-based mid-infrared NEO Surveyor mission, would dramatically improve our risk assessment. When paired with new mitigation approaches, such as rapid-response reconnaissance missions and targeted deflection missions, they can form the basis for a credible set of capabilities in response to actual NEO impact threats.

By statute, NASA is the lead U.S. Government agency for planetary defense. The 2005 George E. Brown Near-Earth Object Survey Act (51 USC Chapter 711) amended the NASA Act of 1958 to indicate that in the interest of U.S. "general welfare and security," NASA will detect, track, catalogue, and characterize Near-Earth Asteroids (NEAs) and Near-Earth Comets (NECs) "in order to provide warning and mitigation of potential hazard of such near-Earth objects impacting the Earth." This legislation also directed NASA to find at least 90 percent of NEOs that are at least 140 meters by 2020, however appropriations were not provided at the time to support this goal.

The 2017 NASA Authorization Act (Public Law 115-10) reiterated these goals, adding that NASA should "submit recommendations for carrying out the Survey program and an associated proposed budget, analyze options for diverting an object on a collision course with Earth, and provide the status of cooperation with other nations in a mitigation strategy in the event of a NEO threat." The 2022 NASA Authorization Act (Public Law 117-167) further emphasized that NASA "shall continue the development of a dedicated space-based infrared survey telescope mission, known as the 'Near-Earth Object Surveyor,' on a schedule to achieve a launch-readiness date not later than March 30, 2026, or the earliest practicable date, for the purpose of accomplishing the objectives . . ." of the Survey.

The roles and responsibilities of the PDCO and NASA's responsibilities to provide timely notification to the White House Office of Science and Technology Policy (OSTP) of close approaches of NEOs that may cause damage to the surface of the Earth are featured in NPD 8740.1. The Planetary Defense Officer leads the efforts of the PDCO.

Significant progress in NEO detection has been made in recent years and the recently approved NEO Surveyor mission, designed to improve detection capabilities to greater than 90 percent of NEOs 140m or larger within about a decade of being launched in 2028, will roughly triple our current capability. In 2022, NASA's DART mission successfully impacted an asteroid almost 7 million miles from Earth, altering its orbit and demonstrating our ability to respond to a potential asteroid threat for the first time via a kinetic impactor spacecraft.

In 2023, NASA established a Planetary Defense Strategy Working Group (PDSWG) co-led by the NASA's Office of Technology, Policy & Strategy (OTPS) and PDCO to develop this first-ever NASA Planetary Defense Strategy in support of the 2023 National Planetary Defense Strategy

Challenges

The PDSWG identified several motivating challenges that this strategy aims to address:

- **Survey, detection, characterization and assessment:** The global community wants a complete NEO survey catalog and sufficient ability to fully characterize NEOs. The ability to assess the risks that NEOs may pose to Earth, and support any mitigation efforts, could be significantly improved by a sufficient set of ground and space-based observations, modeling and prediction capabilities. (NASA Strategic Goals 1 and 2, see table below)

- **Mitigation:** Technological preparedness would be improved with follow-on reconnaissance and mitigation demonstration missions. (NASA Strategic Goal 3)
- **International cooperation:** With the expansion of international capabilities related to NEO survey and mitigation, planetary defense is poised to become a global effort. To realize this vision, NASA plans to foster greater international collaboration and engagement. (NASA Strategic Goal 4)
- **NASA support for interagency coordination:** The National Planetary Defense Strategy recognizes a need for more stable, coordinated planetary defense activities across the United States government. NASA has a key role to play in spearheading this ongoing interagency coordination. (NASA Strategic Goals 5 and 6)
- **NASA organization:** While the NASA PDCO benefits greatly from the close coordination with planetary science activities by being part of NASA PSD, competing priorities in the Planetary Science portfolio, which currently includes development of several large missions, may limit opportunities for expanding planetary defense activities. However, competition for funding is likely to be an issue regardless of where the program is situated. (NASA Strategic Goal 7)
- **Strategic communications:** NASA should better integrate and disseminate information regarding NEO survey and mitigation work. (NASA Strategic Goal 8)

Strategic Goals and Action Plan

- **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 preparation
- **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 coordination on planetary defense
- **Goal 7:** Improve organization of NASA's planetary defense activities
- **Goal 8:** Enhance NASA's strategic communications related to planetary defense

A set of strategic actions support each goal within NASA. Each action includes a desired timeline for completion and a list of relevant mission directorates and offices within NASA, with the recommended lead organization listed first. The timeline is described as **short term** for less than two years, **medium term** for two to five years, **long term** for five to ten years, and **ongoing** if expected to be repeated within the ten-year horizon of this NASA strategy and action plan. The lists of relevant organization are not meant to be exhaustive or limiting. The commitment of resources to support activities outlined in this document will be determined through the regular budget process and subject to the availability of appropriated funds.

Goal 1

Enhance NASA NEO Detection, Tracking, and Characterization Capabilities

Why is this important?

Early detection and characterization of hazardous NEOs provide the greatest leverage to adequately respond in time to prevent loss of life and damage to critical infrastructure. Providing years to decades of warning increases the time available to make decisions and take effective mitigating action, enabling use of more benign options to prevent the impact. Once detected, early characterization of objects that are potential impact threats is key to reducing uncertainties, providing critical information for decision making, and developing an informed mitigation strategy.

What is NASA doing?

NASA has conducted a NEO survey and research program since 1998 and is the global leader in detecting, tracking, and characterizing NEOs. NASA PDCO's Near-Earth Object Observations Program currently sponsors and leverages largely competed projects that use ground- and space-based telescopes around the world to search for NEOs, track them to determine their orbits, and study the characteristics, such as size, shape, rotation, and physical composition. Current major projects include the Catalina Sky Survey (CSS) and the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) for NEO detection and tracking, Spacewatch for NEO follow-up, and NASA's Infrared Telescope Facility and Goldstone Solar System Radar for NEO physical characterization. Critical data management and analysis facilities include the Minor Planet Center and the Center for Near-Earth Object Studies. A more comprehensive list of current and planned NEO detection, tracking, and characterization projects and missions with NASA involvement can be found in Appendix B.

What are the challenges?

While these projects have enabled significant advances in the field of planetary defense, less than half of the estimated 25,000 NEOs that are 140 meters and larger in size (capable of causing regional devastation) have been detected and tracked to date. A complete NEO survey catalog and sufficient ability to fully characterize NEOs is required in order to detect and understand all potential impact threats.

How we will solve challenges

The ability to assess the risks that NEOs may pose to Earth, and support any mitigation efforts, can be significantly improved by a sufficient set of ground and space-based observation, modeling and prediction capabilities. In the next decade, NASA will significantly improve national capabilities for NEO detection, tracking, and characterization to reduce current levels of uncertainty and aid in more accurate modeling and more effective decision-making. A mix of ground-and space-based assets are required, and completion of planned ground and space-based wide-field sky survey assets will enable achievement of this goal.

New survey projects, such as the space-based mid-infrared NEO Surveyor mission, launching not later than 2028, would dramatically improve our risk assessment. NEO Surveyor is designed to improve detection capabilities to greater than 90 percent of NEOs 140m or larger within about a decade of being launched (roughly tripling the current capability).[4]

4 Additionally, the Vera C. Rubin Observatory, a joint National Science Foundation (NSF) and Department of Energy (DOE) multi-disciplinary facility, is slated for first light in 2024, with full operations in 2025. NSF: https://www.nsf.gov/about/budget/fy2023/pdf/37_fy2023.pdf.

The ability to more rapidly characterize objects that represent potential impact threat once detected is also critical. To realize this, existing radar capabilities could be augmented with a next generation deep space radar for potentially hazardous object (PHO) ranging and imaging, which may require interagency collaboration and partnership.

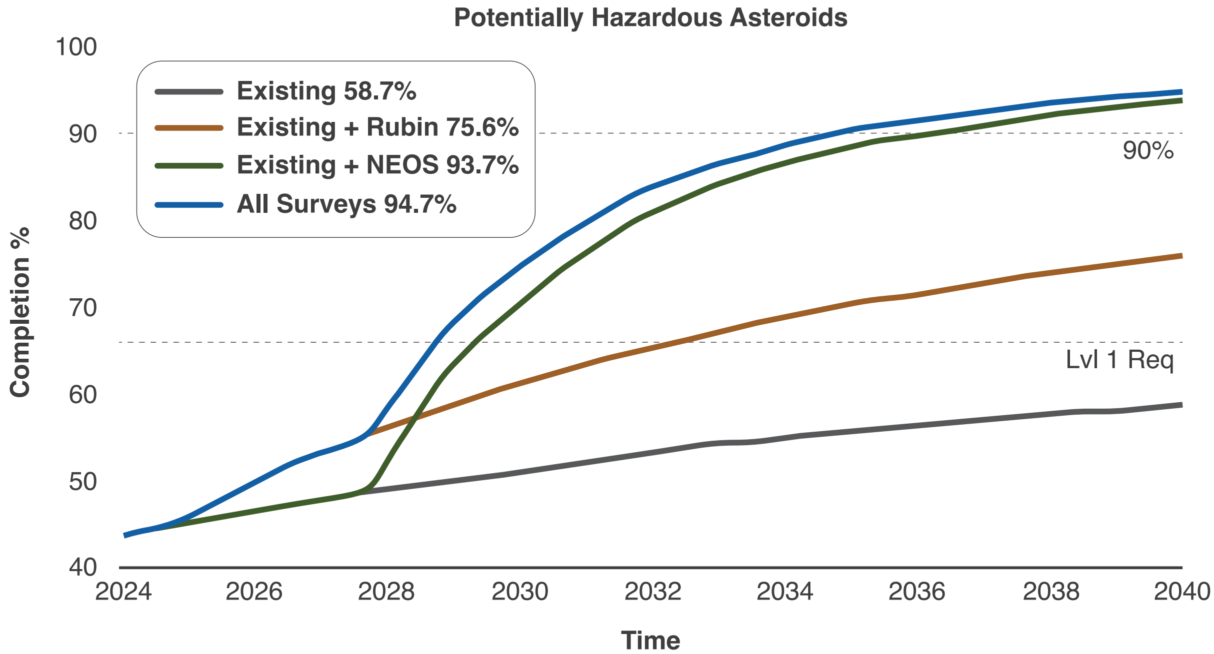

Figure 5: *Predicted NEO survey completeness, combining current capabilities with projected contribution by the Vera Rubin Observatory and then NEO Surveyor after 5 years of operations. (Source: NASA PDC)*

NASA Action Plan

The following actions support Goal 1:

Improve NASA capabilities for NEO detection, tracking, and remote characterization

1.1 Continue to identify opportunities in existing and planned space domain awareness programs to improve detection and tracking by enhancing the volume and quality of current data streams, including from ground-based and space-based optical, infrared, and radar facilities. Existing and planned space situational awareness assets, including commercial systems and public-private partnerships, can also contribute to accelerate NEO detection and tracking. Existing and planned telescope programs should include those designed exclusively for NEO detection, tracking, and characterization and those that can be leveraged for this purpose. Solicit proposals for relevant capabilities through the ROSES Yearly Opportunities for Research in Planetary Defense peer review cycle. [Short term and Ongoing; PDCO]

1.2 Identify technology and data processing capabilities and opportunities in existing and new telescope programs to enhance characterization of NEO composition and dynamical and physical properties. Continue efforts to leverage opportunities in automation and analytical software, deployed sensor systems, data processing capabilities, and investigation into any existing national capabilities that could aid in asteroid characterization. Improving these capabilities will inform NEO impact threat assessments and enhance decision-making by aiding better estimation of size, shape, rotation period, pole orientation, mass, mineralogical composition, hydration state, internal structure, and other properties. Continue investigation of approaches to use data from disparate and diverse sensors, in a standardized and defined format, into a database that is accessible to the widest available section of science, academic, government, and commercial entities, as applicable, allowing for development and use of evolving data analytics or emergent behaviors. Solicit proposals for relevant capabilities through the ROSES Yearly Opportunities for Research in Planetary Defense peer review cycle. [Short term; PDCO, Office of International and Interagency Relations (OIIR)]

1.3 Continue and enhance multi-agency efforts to detect large meteoroids and small asteroids entering Earth's atmosphere and provide rapid public notification. These events occur worldwide a few times per month and create very bright meteors called bolides, aka "fireballs," detectable by a variety of monitoring systems. These events provide opportunities to collect more extensive information on the very nearest-to-Earth natural objects. Rapid notification of such events to the world-wide science community enables further data collection, provision of information to calm the general public, and potential for timely collection of meteoritic samples of the object before contaminated by the terrestrial environment. [Short term: PDCO, OIIR]

1.4 Identify opportunities to leverage existing and planned cislunar space domain awareness capabilities to support detection, tracking, and characterization of NEOs, including through data sharing with planetary defense databases. Publicly shareable cislunar space domain awareness (SDA) information, space situational awareness (SSA) information, and space traffic coordination are key to promoting safety of access and use of space, supporting NASA, private industry, and international missions to the Moon, as well as providing additional data relevant to NEO detection and characterization. Identify synergies in systems developed to enable these missions, sharing associated data, in an accessible format, for planetary defense. Leverage architectures and data standards for SSA to support the interoperability of planetary. Leverage architectures and data standards for SSA and best practices from Department of Commerce's Traffic Coordination System for Space (TraCSS) to support the interoperability of planetary defense data, including a widely accessible database catalog. [Short term and Ongoing; PDCO, OIIR]

1.5 Support an interagency assessment to explore interest from key stakeholders in the coordinated development of current and future deep space radar facilities and identify where these facilities may be useful for planetary defense. Provide data to support the newly established interagency group on existing and planned deep space radar capabilities, informing key priorities, investment, and operational opportunities. [Short term; PDCO; OIIR, Space Technology Mission Directorate (STMD) in supporting roles]

1.6 Use the information developed in Actions 1.1, 1.2, 1.3, and 1.4 to inform investments in space domain awareness programs and technology improvements to enhance completeness and speed of NEO detection, tracking, and characterization. To the extent possible, develop methods to coordinate roadmap development across countries, independent commercial investment, and U.S. Government investment to prioritize cost, reduce redundancy, identify gaps, and leverage worldwide achievement. [Long term; PDCO]

1.7 Advance concepts for rapid characterization of a potentially hazardous NEO. Developing and exercising a plan for rapid characterization of a NEO will inform development of other capabilities and further aid in meeting Goals 2 and 3. Periodic exercises should serve to identify and correct any issues with the timeliness, quality, and quantity of information provided to the modeling group and decision makers. Such exercises could be in collaboration with the International Asteroid Warning Network which NASA/PDCO also coordinates. [Short term and Ongoing; PDCO]

1.8 Support analysis of emerging challenges in NEO survey and characterization in the upcoming decade, as well as solutions for mitigating and overcoming these challenges. New challenges have emerged in the detection and characterization of NEOs, including impacts to optical and infrared telescopes from the recent increases in the number of new and proposed large constellations of satellites in Low Earth Orbit (LEO). Many factors impact the observed brightness of these satellites, including their altitude, orientation, and design. Work is ongoing, including in collaboration internationally with the International Astronomical Union, to fully characterize the impact to NEO surveys and characterization, and to work cooperatively to identify mitigations between ground-based observers and satellite owner-operators. [Long term and Ongoing; PDCO, SMD]

1.9 NASA should seek to apply maturing commercial capabilities to the challenge of planetary defense survey, characterization, and mitigation efforts. [Medium term and ongoing; STMD, PDCO]

1.10 Consider strengthening planetary radar partnerships, beginning with a study of desired capabilities in collaboration with NSF and USSF. [Short term; PDCO]

1.11 Consider potential designs for a bolide detector tech demonstration, such as a hosted sensor on a mission, which could be developed in partnership with other U.S. organizations. [Medium term; PDCO, STMD]

Goal 2

Improve NASA Coordination on NEO Modeling, Predictions, and Information Integration

Why is this important?

Given the difficulty of accounting for the many uncertainties involved and the direct testing of large hypervelocity impacts of asteroids and comets, computational modeling is critical to better understanding potential NEO impact threats and mitigation scenarios. NEO modeling, prediction, and information integration capabilities support effective mitigation strategies by informing decision makers about: 1) predicted Earth impact probabilities, 2) impact timing and location, 3) impact effects and consequences, and 4) options for impact prevention.

What is NASA doing?

There are several existing efforts within NASA to support NEO modeling, prediction, and information integration. The Center for NEO Studies (CNEOS), hosted by NASA's Jet Propulsion Laboratory (JPL), is responsible for computing high-precision asteroid and comet orbits and their potential for impacting Earth. CNEOS developed and improved tools to compute high precision orbits, future motions, and assess NEO deflection techniques, including an NEO deflection simulation tool.

The Asteroid Threat Assessment Project (ATAP) team at NASA Ames Research Center leads efforts to model the potential damage and devastation that could occur from a NEO impact. By simulating the entry and passage of a natural object through Earth's atmosphere, given a range of initial conditions about its trajectory, size and composition, the ATAP Probabilistic Asteroid Impact Risk (PAIR) modeling can assess the potential for any given impact scenario object to survive the passage through the atmosphere and produce destructive effects at any selected location on Earth's surface, within a range of possible outcomes driven by the uncertainties in input parameters such as the object's physical properties. The interagency NEO Action Plan Modeling Working Group (MWG), led by the ATAP, was established in late 2019 and includes participation by Goddard Space Flight Center and the Department of Energy National Laboratories. The MWG developed initial computer simulations and held asteroid impact exercise meetings in 2019 and 2020.

What are the challenges?

The ability to assess the risks that NEOs may pose to Earth, and support any mitigation efforts, can be significantly improved by a sufficient set of ground and space-based observation, modeling, and predication capabilities. As a result, rapid assessments via modeling the variation of outcomes of potential NEO impact threats may be required while the specific properties of the NEO remain largely unknown.

In the event of an impending NEO impact, newly created foreign and domestic sources of information and analysis may become available. NASA needs to further improve the ability it has developed to coordinate, collect, assess, and then rapidly deliver verified and validated information to enable informed decision making and manage public awareness needs.

How will we solve challenges?

NASA will continue to coordinate with other relevant agencies on the development of validated modeling tools and simulation capabilities that aid in characterizing and mitigating NEO impact risks. NASA and its partners will also push to integrate hazard models into an operational risk assessment pipeline, so in the event of an impact threat we can be better prepared.

Action Plan

The following actions support goal 2:

Sustain and expand interagency NEO impact modeling group

2.1 Continue to support an interagency working group for coordination and enabling dissemination of the results of NEO threat modeling and analysis. This group will update plans for the management of modeling and analysis efforts, including a list of all contributing and affected organizations, and will help manage the tasking and flow of modeling and analysis results to relevant officials and organizations. [Ongoing; PDCO]

Advance development and integration of computational tools for modeling NEO impact risks and mitigation techniques

2.2 Ascertain what information each participating organization requires for threat analysis on what timeframe. Identify gaps and develop recommendations for modeling improvements. This includes an assessment of the adequacy of current modeling capabilities. [Short term; PDCO]

2.3 Continue development and validation of a suite of computer simulation tools for assessing the outcome of deflection or disruption techniques applied to a NEO. This analysis includes but is not limited to understanding how variations in NEO physical properties affect the effectiveness of a deflection or disruption technique and the largest deflection a NEO can tolerate (especially so-called "rubble pile" NEOs with little intrinsic strength) before beginning to disrupt. [Short term; PDCO]

2.4 Improve a suite of computer simulation tools for assessing the local, regional, and global risks associated with an impact scenario. Continue to assess the sensitivities of these models to uncertainties in NEO dynamical and physical properties. Probabilistic Earth impact consequence models should link to existing infrastructure mapping capabilities to achieve a suite of simulation tools that predicts potential impact damage and can provide, for a detected NEO on a potential impact trajectory, a list of at-risk infrastructure and associated probability of damage. This analysis includes but is not limited to understanding the level of damage that could be caused by an airburst over or impact on land and in ocean areas, particularly those effects on coastal areas. [Medium term; PDCO]

2.5 Develop an impact risk data pipeline to inform decision makers on results from integrated modeling of potential impact threats. The seamless integration of hazard models into an operational risk assessment pipeline is needed to fully understand (characterize) the wide range of possible consequences, especially cascading hazards, that could result from an asteroid impact event. This action should include the possibility for longer-term hazards that result from triggering events, such as high winds or extreme precipitation. The pipeline output should be in a format that is readily usable for emergency managers, resource managers and planners, and research scientists involved in mitigation and recovery efforts. [Medium term; PDCO]

Exercise, evaluate, and continually improve modeling and analysis capabilities

2.6 Continually assess the adequacy and validity of modeling and analysis of impact effects through annual exercises, test problems, comparison to experiments, and peer review activities. Structure exercises to identify gaps, formulate needed improvements, test connections within the national framework, and improve operational readiness. This action should include an annual lessons learned document and plan for increasing operational readiness to be shared among interested parties. [Ongoing; PDCO]

Goal 3

Develop Technologies for NEO Reconnaissance, Deflection and Disruption Missions

Why is this important?
Developing technologies for NEO reconnaissance, deflection, and disruption before an imminent threat arises will strengthen our ability to adequately respond and pursue efforts to prevent NEO impact disasters. An effective deflection or disruption mission will most likely require more detailed and accurate information about the incoming NEO than existing and currently planned remote observational capabilities can provide. A capability to responsively build and launch a spacecraft to rendezvous or fly by the NEO to perform reconnaissance may be needed.

What is NASA doing?
In 2022, NASA's DART mission successfully impacted an asteroid almost 7 million miles from Earth, altering its orbit and demonstrating our ability to respond to a potential asteroid threat for the first time via a kinetic impactor spacecraft. PDCO also funds modeling studies of additional deflection technologies, some in coordination with U.S. national laboratories.

What are the challenges?
Preparing to respond effectively to a NEO impact threat scenario includes developing and maturing capabilities for both deflection and disruption before the need arises to deploy them in an actual threat scenario. NASA's technological preparedness would be improved with further study of potential mitigation demonstration capabilities. In addition to the kinetic impactor approach, other NEO mitigation approaches may be more effective in different scenarios. For example, multiple technologies may be suitable for more benignly preventing NEO impacts that are predicted decades in advance, while deflection or disruption via a nuclear explosive device may be the only feasible option for NEOs that are very large or come with a short warning time.

How will we solve challenges?
NASA will advance technology development and programmatic processes that could support an effective mitigation campaign. Conceptual studies, early-stage technology development and engagement with international partners on such a mission can help fulfill this goal. NASA's Planetary Defense efforts should consider recommendations from the scientific community. The National Academies' *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*, released in April 2022, provides recommendations from the Planetary Science community on priorities for Planetary Science, including Planetary Defense. For example, the upcoming close approach of Apophis, an asteroid estimated to be approximately 330 meters in size, represents a significant opportunity for international collaboration to achieve major scientific benefits, at relatively low cost. Apophis is expected to pass within 31,600 kilometers of Earth's surface in April of 2029, offering a rare opportunity in this decade for advancing science in support of planetary defense. NASA is not planning any mission to Apophis before 2029, but is currently conducting conceptual studies and collaborating with international partners to identify opportunities for studying Apophis during its close encounter with Earth.

Action Plan

The following actions support goal 3:

Develop technologies and designs for rapid-response NEO reconnaissance missions

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. This collaboration should include evaluation of reconnaissance via spacecraft flyby or rendezvous, as well as mission concepts in which the reconnaissance spacecraft could also carry out deflection or disruption actions. This collaboration should consider both commercial-off-the-shelf parts and new hardware development. The launch vehicle infrastructure evaluation analysis should include consideration of both rapid-response reconnaissance and deflection/disruption missions, recommending processes for accomplishing rapid response planetary defense launch, accounting for integration and testing processes, launch vehicle procurement, authorization processes, and methods to prepare payloads for rapid launch, including technology development, contracting, and storage considerations. Begin to investigate how the U.S. government would authorize DoD/USSF to prepare and use responsive launch and/or other existing capabilities to support an emergent NEO threat situation. [Short term; PDCO, STMD]

3.2 Create plans for the development, testing, and implementation of NEO reconnaissance mission systems. These plans should lead to establishment of timely NEO reconnaissance capabilities, including rapid response. [Short term; PSD, PDCO, STMD]

Develop technologies and designs for NEO deflection and disruption missions

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. Technology assessments should include the most mature in-space concepts—kinetic impactors, gravity tractors, ion beam deflection—as well as less mature NEO impact prevention methods. This action includes preliminary designs for demonstration of a gravity tractor NEO deflection mission campaign, and/or an ion beams deflection campaign. Mission designs should include reconnaissance spacecraft and methods to measure the achieved deflection. Include an assessment of the value of alternative planetary defense approaches, to include pre-deployment of NEO deflection capabilities in space prior to an identification of an actual impact threat. They should consider contemporary work, including potential synergies with relevant private industry interests (e.g., asteroid mining), as well as NEO impact scenarios that may have received insufficient attention thus far (e.g., binary asteroids, high-speed comets). Ground-based facilities useful to support these missions should also be identified. Solicit for mission concept study proposals through the ROSES Yearly Opportunities for Research in Planetary Defense peer review cycle. Continue to encourage and incentivize creative and new ideas from diverse sources for NEO deflection and disruption technology through alternative methods, such as prizes, university grand challenges, STEM outreach, centers of excellence, gaming, etc. The risk analysis will address current deficiencies in understanding how rapidly the U.S. can deploy planetary defense missions while maintaining acceptable reliability and mission success probability, and with sufficient redundancy. [Medium term; PDCO, STMD]

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. Studies have shown that at this time in our understanding of the potential NEO impact hazard it is still possible that discovery of either even a relatively small object less than a few months to years before impact or a relatively large or fast-trajectory object would create a situation when only use of a nuclear explosive device (NED) would provide sufficient force to either deflect or disrupt the impactor in time to mitigate devastating effects on Earth. Therefore, it is still prudent to continue the research on the potential for NEDs to be used for PHO deflection and disruption missions. [Medium term; PDCO, STMD, Office of General Counsel (OGC), OIIR in supporting role]

3.5 Continue flight demonstrations to validate NEO deflection and disruption system concepts. Following the successful pathway demonstrated by the DART mission for the kinetic impact deflection technique, NASA will study whether future flight demonstrations should focus on test and validation of deflection/disruption system concepts on benign NEOs and identify design issues for correction. Results will inform decision-making processes during an actual NEO threat scenario. [Long term; PSD, PDCO]

Goal 4
Increase NASA Contributions to International Cooperation on NEO Preparation

Why is this important?
The potentially cataclysmic and existential consequences of a NEO impact coupled with the impact's indifference to borders and geopolitical dynamics presents a global challenge and a unique opportunity for engagement with the international community. Planetary defense is an intrinsically global endeavor, drawing upon telescopes and capabilities on every continent and in orbit.

What is NASA doing?
NASA and other programs share observations and research and explore how to coordinate our responses. For example, NASA's DART mission involved an Italian satellite, LICIACube, to flyby and provide observational analysis of the Didymos asteroid binary system after impact on Dimorphos. Additional ground-based observations of the orbital period change were contributed from every continent on Earth. NASA is also currently collaborating with the European Space Agency on its Hera mission, planned for 2024, which aims to further investigate the Didymos asteroid system.

NASA PDCO works with the IAWN and the SMPAG, international organizations dealing with NEOs whose establishment was recommended by the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) and endorsed by the UN General Assembly. These expert bodies promote coordination among astronomers, scientists, space agencies, lawyers, and policy makers seeking to detect, characterize, and respond to potential NEO impacts. NASA coordinates IAWN including observational campaigns to test worldwide capabilities in detection, tracking, and characterization. The most recent campaigns in 2021 and 2022 more fully characterized the asteroid Apophis and tested the accuracy of NEO position measurements by the world's observatories.

What are the challenges?
While the NASA and U.S. partners provide a significant majority of the world's NEO preparedness infrastructure, international capabilities for NEO observation and research are expanding, opening up the possibility of a truly global planetary defense effort. With the expansion of international capabilities related to NEO survey and mitigation, planetary defense is poised to become a global effort. To realize this vision, NASA needs to foster greater international collaboration and engagement.

How will we solve challenges?
NASA will continue to enhance its leadership role in fostering global collaboration and leveraging international capabilities to improve NEO preparedness and response. Increased outreach to other nations, both bilaterally and through relevant multilateral fora, is necessary to foster a better understanding of potential NEO impact risks and to muster the necessary resources, expertise, and capabilities to address those risks. Focusing resources on identifying and improving existing relevant international institutions can begin to improve our collective situational awareness, predictions, and overall preparedness for NEO events. Furthermore, by collaborating on and leveraging upcoming foreign planetary defense missions, NASA can advance its own goals and potentially avoid incurring some technology development costs.

Action Plan

The following actions support goal 4:

Build international awareness of potential NEO impacts as a global challenge

4.1 Continue to engage and inform foreign governments of the need for a collaborative and coordinated approach to preparing for a NEO event. Underscore U.S. positions in relevant international NEO impact initiatives and promote awareness in other international organizations and meetings. This action should include delivering an annual U.S. statement under the NEOs agenda item of the UNCOPUOS Scientific and Technical Subcommittee (STSC) ; special technical presentations on NEOs at UNCOPUOS and other relevant international fora (e.g., the International Astronautical Congress (IAC), workshops, symposiums, etc.); developing and implementing a plan for outreach and education to other countries to promote understanding of NEO impact effects by relevant international disaster management bodies to aid in decision-making; encouraging more countries to join SMPAG and the existing SMPAG members to increase their participation based upon coordination with their national governments; and adding NEOs as an agenda item in bilateral consultations, including existing space policy dialogues with spacefaring nations with relevant capabilities. These engagements can be informed by the talking points developed by Department of State and NASA within the Near-Earth Object Impact Threat Emergency Preparedness (NITEP) working group. In addition, the U.S. should continue to include NEO-related efforts in important national and international documents, such as the 2021 U.S. Space Priorities Framework and the 2021 UN General Assembly resolution "Space2030: Space as a driver of sustainable development," (A/RES/76/3), which calls for the world to "strengthen international cooperation and preparedness to respond to the threat posed by near-Earth objects." [Ongoing; OIIR, PDCO]

4.2 Continue to demonstrate U.S. leadership in technical international NEO organizations, and increase awareness among all countries, in particular space agency officials, of the need to address NEO issues in major international bodies. This action should include making NEO issues an agenda item at scientific and technical meetings as appropriate, as well as at major international conferences. In addition, the U.S. should continue participation within SMPAG, IAWN, and any other international organizations dealing with NEOs. [Ongoing; PDCO, OTPS, OIIR]

Increase international engagement and cooperation on observation infrastructure, numerical modeling, and scientific research

4.3 Continue to improve international collaboration on observation infrastructure and data sharing, as well as numerical modeling and scientific research. Since 2018, worldwide participation in the IAWN has increased from 13 to 50 signatories. The U.S. will continue working to encourage more countries to join IAWN so that it can serve as an effective body for international collaboration on observation infrastructure, scientific data sharing, numerical modeling, and scientific research. NASA will seek to expand bilateral or multilateral international cooperation on future NEO-related missions, such as the CubeSat provided by the Italian Space Agency for the Double Asteroid Redirection Test mission and cooperation with the European Space Agency's Hera mission, which will perform a detailed post-impact survey of the target asteroid, Dimorphos. It will be important to include strong identity, access control, accuracy, integrity and auditability capabilities for the reporting and information sharing and dissemination capabilities to mitigate risks associated not just with the malicious use of such reporting and alerting to spread panic, but to also with authorized but unintentional incorrect alerting or reporting. [Ongoing; PSD, PDCO, OIIR]

4.4 Support development of a plan for improving NEO monitoring through enhanced coordination (and potential expansion) of U.S. and key country ground-based telescopes. This plan should focus on existing telescopes but could look at coordinating new and planned hardware to optimize the range of capabilities. This action could include holding an international workshop on the use of ground-based telescopes to improve global NEO monitoring in conjunction with each International Astronautical Congress. [Short term; PDCO, OIIR]

4.5 Continue to encourage countries to initiate and continue programs to develop space- and ground-based telescopes to detect, track, and characterize NEOs and coordinate via the IAWN. This could include sponsoring sessions at international astronomical conferences on how to initiate and conduct programs for NEO observation, addressing both existing capabilities and needs. In addition to these conferences, the U.S. should work to initiate internationally coordinated global NEO exercises through its coordination of the IAWN. [Ongoing; PDCO, OIIR]

Foster consultation and coordination on NEO impact planning, mitigation, and response

4.6 Support strengthening of the IAWN and SMPAG as the primary international technical bodies for addressing hazardous NEO response planning and mitigation. Provide continued support and engagement to make both international bodies more effective. This action should include developing and implementing a plan to broaden and enhance U.S. interagency participation in these forums, and a list of actions to inform other nations about the activities, consistent with law. A template e-mail and briefing may be developed and used to demonstrate the value of joining IAWN and SMPAG to other countries. [Ongoing; PDCO, OIIR]

4.7 Support and encourage participation in tabletop and physical exercises with global partners regarding preparedness, prevention, response, and recovery efforts. Include realistic modeling data from the integrated suite of computational tools developed in Goal 2 and the scenarios developed in Action 5.1 to ensure high fidelity in the exercise. This action could include sponsoring a workshop for global and international disaster management organizations on NEO preparedness, response, and recovery. [Medium term; PDCO, OIIR]

4.8 Conduct exploratory discussions with international partners regarding U.S. participation and cooperation with upcoming foreign flight missions to NEOs such as a potential reconnaissance mission to Apophis. The upcoming close approach of the Apophis asteroid in 2029 represents an opportunity for international collaboration on technology demonstration missions for planetary defense with major scientific benefits, at relatively low cost. [Ongoing; PSD, PDCO, OIIR]

4.9. NASA will leverage existing and new research to develop long-term principles for NASA's planetary defense activities that maximize transparency, multilateral cooperation, and promote the benefits of applied planetary science for all humanity. NASA will share these principles in multilateral and scientific fora. [Short term and ongoing; OTPS, PDCO, OIIR]

Goal 5

Coordinate with FEMA and Other Agencies to Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols

Why is this important?

Following identification of any potential NEO impact, NASA, in coordination with other relevant Federal Agencies and Departments, will assess the nature of the threat and inform subsequent communications and mitigation decision making. Coordinated communications and notifications within the U.S. Government and with foreign governments, as needed, will improve impact emergency preparedness and reduce the physical and economic harm to the Nation. Developing and exercising thresholds, procedures, and action protocols to support decision-making and communications will aid agencies in preparing options and recommending courses of action, enabling timelier and more effective implementation of NEO impact response and mitigation measures.

What is NASA doing?

NASA serves as both the lead agency and a supporting agency in this national effort. For example, NASA is the lead for providing timely and accurate information of a potential impact threat and analysis to support a coordinated response. NASA Policy Directive 8740.1 describes the process of providing timely and accurate reporting of a very close approach or predicted NEO impact. Overseen by NASA's PCDO, it includes receipt and analysis of observations by the Minor Planet Center, transmission of potential impact analysis results by the JPL Center for NEO Studies, and formal notification to OSTP.

The NITEP interagency working group, established in 2019 and co-chaired by NASA, made significant progress towards strengthening and routinely exercising NEO impact emergency procedures and action protocols. These included the establishment of procedures and timelines for conducting NEO impact threat assessments and risk/benefit analyses for space-based mitigation options, as well as providing NEO threat notifications to government and nongovernment entities. NITEP also developed benchmarks for determining when to recommend NEO reconnaissance, deflection, and disruption missions.

Exercises and workshops have been successful means to articulate communication requirements. NASA, the Federal Emergency Management Administration (FEMA), and the asteroid-impact MWG have conducted various tabletop exercises to date to familiarize officials with the hazard and improve NASA's ability to communicate information.

What are the challenges?

Ensuring that information can be quickly exchanged and the public can be accurately informed of credible threats is a challenge. Current approaches provide a sound basis upon which to build, but agency awareness of NPD 8740.1 and NITEP recommendations is limited, and continued work is needed to further refine and strengthen these procedures and protocols. Periodic reviews are needed to ensure that notification protocols include all relevant agencies, including updated contacts, and account for the full range of potential circumstances. Additionally, there are opportunities for more extensive national-level exercises, potentially including media participants, non-governmental organizations, and international partners as observers.

How will we solve challenges?

Procedures for rapidly collecting, assessing and exchanging information about NEO threats within NASA and to the White House and Congress, state and local governments, the public, foreign governments, and other international organizations can be streamlined and improved. As noted in Goal 2, advancing our ability to provide rapid cost/benefit risk analysis of NEO threats would be of great benefit to the nation.

NASA will continue to strengthen and exercise procedures and protocols for assessing NEO threats, and for communication—from protocols within NASA to public and international community engagement. This includes periodic reviews and updates of procedures and protocols, as well as biannual interagency tabletop exercises, including a more extensive national level exercise in the next five years.

Action Plan

The following actions support goal 5:

Strengthen protocols for coordinated communications and notifications regarding NEO threats and incorporate NEO impacts into all-hazards response and recovery plans

5.1 Support maturation of a set of real-world scenarios based on credible impact threats with observable parameters to inform planning and procedure development. NASA should work with FEMA to lead biannual Interagency Tabletop Exercises (TTX), including a more extensive interagency TTX in the next five years, and include media participants, non-governmental organizations, and international partners as observers. [Medium term; PDCO, OIIR]

5.2 Continue to improve protocols for notifying the White House and Congress (including briefing appropriate subcommittees), Federal interagency, state and local governments, the public, foreign governments, and other international organizations, regarding NEO threats. Re-evaluate and validate the current notification protocol chain-of-command. Adjust accordingly the protocols for notifying and communicating from PDCO through NASA and within the Federal Government regarding NEO threats. Develop appropriate modifications to existing emergency alert protocols based on specific NEO impact factors, as creating a new system for just the NEO impact scenario is not warranted. This action should culminate in an action flowchart, specific notification checklists, and a specific joint annex to the NASA Policy Directive 8740.1 as a joint memo covering these procedures between NASA PDCO and FEMA. Enhance and exercise existing NASA PDCO and IAWN plans for exchange of information among national and international emergency response stakeholders. Participate in tabletop exercises that determine effectiveness with emergency managers at local, state, and national levels. [Ongoing; PDCO, OIIR, Office of Legislative and Intergovernmental Affairs (OLIA)]

5.3 Develop and share informational material for different audiences providing basic education, information on NEOs, impacts, uncertainties, and the scope of NASA's role. This action should include developing an integrated information and education package with social media, internet, and traditional press release formats for relevant information. [Short term; PDCO, Office of Communications (OCOMM)]

Establish protocols for recommending space-based reconnaissance and mitigation missions

5.4 Improve procedures and timeline for conducting a risk/benefit analysis for space-based mitigation mission options following a NEO threat assessment. [Short term; PDCO]

Goal 6

Improve NASA Contributions to Ongoing Interagency Coordination on Planetary Defense

Why is this important?

The National Planetary Defense Strategy sets out that planetary defense is an initiative that involves many elements of Federal, state, and local governments. With NASA in a key coordinating role, the stable, long-term development of U.S. planetary defense capabilities will require a collaborative and coordinated approach among various Federal Agencies and Departments with relevant expertise and capabilities in developing effective technologies, policies, practices, and procedures.

What is NASA doing?

NASA PDCO and OIIR play key coordinating roles in this effort. Activities include the use and support of astronomical observatories operated by NSF, data sharing and modeling efforts with USSF, collaborations with U.S. National Laboratories, emergency exercise planning with FEMA, and cooperation with other U.S. agencies.

What are the challenges?

Despite the best intentions of all involved, it is often difficult to coordinate and make effective progress on collaborative projects across agency boundaries for a mission whose level of endeavors fall short of requiring a joint program office. Substantial differences in processes and procedures, both real and perceived, often mire such endeavors in the respective bureaucracies. As a result, strategic, sustained, and enhanced coordination is needed to develop a stable, long-term planetary defense capability that can effectively decrease U.S. vulnerability to NEO impacts.

How will we solve challenges?

NASA will work to enhance ongoing interagency coordination and collaboration in planetary defense by seeking to improve communication channels, including new interagency groups, as needed, and exploring ways to leverage existing authorities that could facilitate implementation of collaborative efforts.

Action Plan

The following actions support goal 6:

6.1 Convene an ongoing interagency group on planetary defense to address more detailed implementation issues than is common for a White House-level interagency working group. This interagency group should begin with quarterly meetings to address issues and progress of ongoing work under this Action Plan. [Short term; PDCO, OIIR]

6.2 Work with agencies substantially involved with cooperation and collaborations outlined in the National Planetary Defense Strategy to identify offices and POCs (expected to be only part-time for most agencies) tasked with responsibility and authority to address and advance the activities supporting planetary defense called for within the Action Plan. This Action will clarify who has responsibility within these agencies for both contact on issues by the other agencies and for monitoring and assessing progress on actions and addressing any issues within the agency. These POCs would represent their respective agency on the interagency group established in Action 6.1. [Short term; OIIR, PDCO]

6.3 Establish a small study effort to explore existing authorities and legislation (e.g., Economy Act) that could be leveraged to improve and enhance implementation of interagency collaborations related to planetary defense. One objective would be to seek approaches to effectively partition actions required to achieve project objectives or streamline interagency funding transfers and assisted procurements when calling for work efforts across government agencies. Studies will also investigate gaps and authorities for agencies involved in planetary defense work. [Short term; Office of the Chief Financial Officer (OCFO), PDCO, OTPS]

Goal 7

Improve Organization of NASA's Planetary Defense Activities

Why is this important?

For NASA to effectively implement this Strategy and Action Plan, NASA needs to examine the budget, staffing and structure of NASA's planetary defense activities to ensure they are sufficient.

What is NASA doing?

NASA established the PDCO in 2016, and the roles and responsibilities of the office, and the Agency's responsibilities to provide timely notification of close approaches of near-Earth objects that may cause damage to the surface of the Earth to Executive Office of the President (EOP)/OSTP are featured in NPD 8740.1. In recent years, NASA increased funding for PDCO to enable the development of DART, NEOOP and the NEO Surveyor mission.

What are the challenges?

While the NASA PDCO benefits greatly from the close coordination with planetary science activities by being part of NASA Planetary Science Division, competing priorities in the Planetary Science portfolio, which currently includes development of several large missions, may limit opportunities for expanding planetary defense activities. However, competition for funding is likely to be an issue regardless of where the program is situated.

How will we solve challenges?

Based on the strategic goals and actions outlined in this strategy, NASA should formulate a stable program of record that features continued support for existing and planned survey and mitigation efforts that can also enable long-term development and maturation of technical capabilities. SMD should assess the scope of planetary defense activities and ensure there are appropriate staffing resources to meet the challenge. Planetary defense efforts at the agency may also benefit from greater engagement and support from other mission directorates, centers and offices. As noted previously, a worldwide trend is the rapid expansion of planetary defense capabilities and activities, and NASA can improve its capacity to lead and coordinate global efforts. Finally, NASA should seek to conduct an independent assessment of activities within SMD as part of its future budget formulation work.

Action Plan

The following actions support goal 7:

7.1 Conduct an independent assessment of the organization of planetary defense activities at NASA. Results of the study will be provided to leadership to guide organization, reporting structure or other modifications. [Short term; OTPS]

7.2 Formulate a budget and organizational plan to support the long-term sustainment, development and maturation of survey and mitigation capabilities. [Short term; PDCO]

Goal 8

Enhance Strategic Communications Related to Planetary Defense

Why is this important?

Raising public awareness about realistic concerns for potential impacts of NEOs to Earth can help improve emergency preparedness in the event of an incident and contribute generally to the Agency's goals of educating the public about science and technology.

What is NASA doing?

The DART mission was a milestone in the application of planetary science to a complex planetary defense technology demonstration. The success of the mission positively resulted in increased public awareness for planetary defense.

For mission-specific communications that do not rise to the level of a full-length web feature or press release, NASA uses its various blogs. Currently, the PDCO has a **NEO Surveyor blog**, a **DART blog**, and an overarching **Planetary Defense blog**. NASA also announces releases, features, and blogs posts and disseminates other information through its NASA Asteroid Watch Twitter account.

What are the challenges?

There is a challenge in getting information on activities and often time-sensitive updates about NEO observations, including potential threats, published externally. A more regular cadence of messaging could raise public awareness of the issue.

How will we solve challenges?

NASA informs and educates the public, Congress, and stakeholders in government about the NEO impact hazard and planetary defense. NASA will prepare a strategic communications plan to ensure timely and accurate information can be disseminated quickly in the event of potential NEO incident (e.g., NPD 8740.1). NASA should also consider bolstering its communications resources to ensure established communications procedures in place and ready should a NEO impact threat be discovered.

Action Plan

The following actions support goal 8:

8.1 Prepare a strategic communications plan related to planetary defense. Include procedures and protocols in event of a potential NEO impact threat. [Short term: PDCO, OCOMM]

8.2 Enhance leadership messaging of planetary defense to increase scientific knowledge, raise awareness and improve preparedness when addressing general public, Congress, media and partners. Highlight the 2023 National Planetary Defense Strategy, NASA's own planetary defense strategy, and unique NASA planetary defense programs and initiatives in public communications. [Ongoing; Office of the Administrator, SMD Associate Administrator, OTPS, OCOMM, OIIR, OLIA; PDCO in a supporting role]

Appendix A: Acronyms

Acronym	Definition
ATAP	Asteroid Threat Assessment Project
ATLAS	Asteroid Terrestrial-Impact Last Alert System
Caltech	California Institute of Technology
CNEOS	Center for Near-Earth Object Studies
CSS	Catalina Sky Survey
DART	Double Asteroid Redirection Test
DOD	Department of Defense
DOE	Department of Energy
EOP	Executive Office of the President
FEMA	Federal Emergency Management Agency
GSFC	Goddard Space Flight Center
IAC	International Astronautical Congress
IAU	International Astronomical Union
IAWN	International Asteroid Warning Network
IRTF	(NASA) Infrared Telescope Facility
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
LEO	Low Earth Orbit
LICIACube	Light Italian Cubesat for Imaging Asteroids
LINEAR	Lincoln (Labs) Near-Earth Asteroid Research
MANOS	Mission Accessible Near-Earth Objects Survey
MIT	Massachusetts Institute of Technology
MPC	Minor Planet Center
MWG	(NEO Action Plan) Modeling Working Group
NAC	NASA Advisory Council

Acronyms

Acronym	Definition
NAS	National Academy of Science
NEA	Near-Earth Asteroid
NEC	Near-Earth Comet
NED	Nuclear Explosive Device
NEO	Near-Earth Object
NEO Surveyor	Near-Earth Object Surveyor infrared telescope
NEOOP	Near-Earth Object Observations Program
NEOWISE	NEO Wide-field Infrared Survey Explorer
NITEP	NEO Impact Threat Emergency Protocols
NNSA	National Nuclear Security Administration of the Dept. of Energy
NPD	NASA Policy Directive
NSF	National Science Foundation
OCFO	(NASA) Office of the Chief Financial Officer
OCOMM	(NASA) Office of Communication
OGC	(NASA) Office of the General Counsel
OIG	(NASA) Office of Inspector General
OIIR	(NASA) Office of International and Interagency Relations
OLIA	(NASA) Office of Legislative and Intergovernmental Affairs
OMB	Office of Management and Budget
OODAA	Observe, orient, decide, act, and assess loop
OSTP	(White House) Office of Science and Technology Policy
OTPS	(NASA) Office of Technology, Policy, and Strategy
PAIR	Probabilistic Asteroid Impact Risk
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PBR	President’s Budget Request
PDCO	Planetary Defense Coordination Office
PDSSBN	Planetary Data System Small Bodies Node

Acronyms

Acronym	Definition
PDSWG	Planetary Defense Strategy Working Group
PHA	Potential Hazardous Asteroid
PHO	Potential Hazardous Object
POC	Point of Contact
PPBE	Planning, Programming, Budgeting, and Execution
PSD	Planetary Science Division
ROSES	Research Opportunities in Space and Earth Science
SAO	Smithsonian Astrophysical Observatory
SBDB	Small-Body Database
SDA	Space Domain Awareness
SMD	Science Mission Directorate
SMPAG	Space Mission Planning Advisory Group
SNL	Sandia National Laboratories
SSA	Space Situational Awareness
SST	Space Surveillance Telescope
STMD	(NASA) Space Technology Mission Directorate
STSC	Scientific and Technical Subcommittee of UNCOPUOS
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office of Outer Space Affairs
USGS	U.S. Geological Survey
USSF	U.S. Space Force
YORPD	Yearly Opportunities for Research in Planetary Defense
ZTF	Zwicky Transient Facility

Appendix B: NASA Contributions to Planetary Defense & NEO Surveys

Assets used for NEO surveys include both ground-based and space-based systems. The main capabilities and demonstrations to support planetary defense in the U.S. in the next decade are highlighted below.

See the National Planetary Defense Strategy, available online,[5] for a complete list of U.S. government-funded capabilities and systems.

Ground-Based NEO Observations Program Detection & Characterization

Minor Planet Center (MPC)

Under the auspices of Division F of the International Astronomical Union (IAU), the MPC designates all minor bodies discovered in the solar system (e.g., comets, asteroids, and natural satellites) and collects, computes, and disseminates astronomical data concerning the positions of these bodies to the world-wide planetary astronomy community. The MPC is fully funded by NASA as a sub-node of its Planetary Data System Small Bodies Node and is hosted by the Smithsonian Astrophysical Observatory (SAO) in Boston, MA.

Center for NEO Studies (CNEOS)

CNEOS is hosted by NASA's Jet Propulsion Laboratory and uses small body position data collected on NEOs at the MPC for its analyses. It is responsible for computing high-precision asteroid and comet orbits and their potential for impacting Earth to support NASA's PDCO. NEO parameters computed by CNEOS are archived in the JPL Small-Body Database (SBDB).

Catalina Sky Survey (CSS)

The CSS is a NASA-funded NEO discovery project based out of the University of Arizona's Lunar and Planetary Laboratory. Its primary assets consist of two wide-sky-field survey telescopes and one telescope for astrometric follow-up in the Catalina Mountains of Arizona.

Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)

Pan-STARRS is a two-telescope system for wide-field astronomical imaging developed and operated by the University of Hawai'i. Located on Haleakala, Maui, NASA provides funds to Pan-STARRS for NEO search and discovery operations.

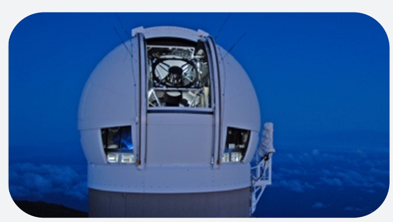

Figure 6: *Pan-STARRS. (Source: University of Hawaii and Ratkoski)*

5 https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

Asteroid Terrestrial-Impact Last Alert System (ATLAS)
Developed and run by the University of Hawaii, ATLAS is a relatively small telescope automated hazardous asteroid impact early warning system funded by NASA with telescopes in South Africa, Chile, and Hawai'i (Maui and Hawai'i Island).

Lincoln Near-Earth Asteroid Research (LINEAR)
MIT Lincoln Laboratory's LINEAR program has searched for and categorized Near-Earth Objects using data provided by U.S. Air Force R&D optical telescopes in partnership with NASA since 1998. Asteroid and comet data are now retrieved from the Space Surveillance Telescope (SST), which is now in operations on a site located in Western Australia.

Goldstone Solar System Radar
The Goldstone Solar System Radar originated in 1958. It features radar integration and a fully steerable 70-meter dish for high-resolution ranging and imaging of planetary and small-body targets, supporting both science objectives and planetary defense. Goldstone is located in Barstow, California and operated by JPL through NASA Deep Space Network funding.

Spacewatch
Spacewatch began independently as a NEO survey project, but currently operates as an NEO astrometric follow-up project funded by NASA. Spacewatch primarily uses two University of Arizona telescopes on the grounds of Kitt Peak National Observatory in Arizona.

Magdalena Ridge Observatory
The Magdalena Ridge Observatory is located at 10,600 feet in the Magdalena Mountains in New Mexico. It is built and operated by the New Mexico Institute of Mining and Technology. Continuing programs launched in 2008 include NASA- and NSF-funded research in astrometric follow up and spin rate determination of near-Earth asteroids and comets.

Astronomical Research Institute
The Astronomical Research Institute operates privately owned telescopes in Illinois and on the grounds of Cerro Tololo Inter-American Observatory in Chile. The project, funded via a NASA grant, performs astrometric follow-up of NEO discoveries in the northern and southern skies.

The Mission Accessible Near-Earth Objects Survey (MANOS)
The Mission Accessible Near-Earth Objects Survey first began in August 2013 with the task of physically characterizing the large population of sub-kilometer NEOs, which are more easily accessible by spacecraft mission but also pose the highest likelihood of impacting the Earth. Funded by NASA, the data from MANOS observations is used to understand the NEO population, provide planetary science data, and help develop impact risk assessments.

The Infrared Telescope Facility (IRTF)
The IRTF is a NASA telescope optimized for near-IR observations, located at an altitude of 13,600 feet on Hawai'i Island. It is operated and managed by the University of Hawai'i's Institute for Astronomy under NASA contract. Approximately 50 percent of the observing time is used for NASA planetary mission support and solar system science, including comets and asteroids.

Zwicky Transient Facility (ZTF)

ZTF is a wide-field survey camera based at Palomar Observatory performing a systematic study of the optical night sky, including near-Earth asteroids. It is funded by NSF and an international collaboration of partners, with grant support from NASA for data mining of NEOs, and funding from Caltech and the Heising-Simons Foundation.

Flight Programs

Double Asteroid Redirection Test (DART)

DART was the world's first mission to demonstrate asteroid deflection technology by altering the orbital period of a celestial body via a kinetic impactor spacecraft. It successfully impacted its target asteroid Dimorphos in 2022, changing the orbit period around its primary Didymos by 32 minutes (~5 percent), with post-impact analysis continuing.

NEOWISE

NASA's NEOWISE project has repurposed the Wide-field Infrared Survey Explorer space telescope since 2013 to continue to survey for NEOs and other small bodies using its remaining non-cryogenic infrared channels. It was launched in 2009 (as the Wide-Field Infrared Survey Explorer mission), with extended operations planned until at least June 2023.

Near-Earth Object (NEO) Surveyor

NEO Surveyor is a space-based, mid-infrared telescope in development for the purpose of rapidly accelerating the rate at which NASA can discover NEOs. From its vantage point at the L-1 gravitation stable point on the sunward side of Earth, it will be able to survey along Earth's orbit both ahead and behind the planet and closer to the direction of the sun than possible from the ground. By using two heat-sensitive infrared imaging channels, NEO Surveyor will be able to detect dark asteroids, which are the most difficult type to find, and it will be able to make significantly more accurate measurements of NEO sizes directly from these observations regardless of the amount of sunlight they reflect. NEO Surveyor is expected to launch no later than June 2028.

Asteroid Impact Threat Modeling and Simulation Resources

Asteroid Threat Assessment Project (ATAP)

The ATAP team at NASA Ames Research Center leads efforts to model the potential damage and devastation that could occur from an NEO impact. By simulating the entry and passage of a natural object through Earth's atmosphere, given a range of initial conditions about its trajectory, size and composition, the ATAP Probabilistic Asteroid Impact Risk (PAIR) modeling can assess the potential for any given impact scenario to survive the passage through the atmosphere and produce destructive effects at any selected points on Earth's surface, within a range of possible outcomes driven by the uncertainties in initial conditions. ATAP is assisted in this comprehensive modeling effort by the NASA High Performance Computing Center at Ames and expertise at the DOE NNSA Laboratories, USGS and other agencies.

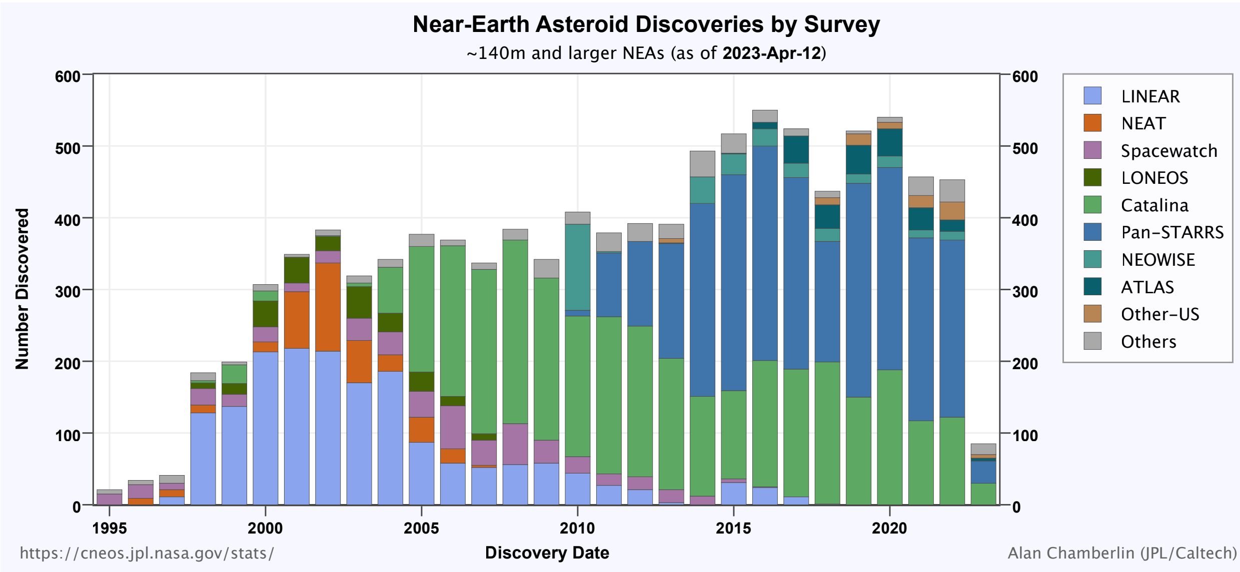

Figure 7: *Large NEO discoveries by survey. (Source: NASA)*

Appendix C: Examples of International Planetary Defense Programs

Double Asteroid Redirection Test (DART) Worldwide Observing Campaign
Global network of assets that participated in observing DART's post-impact effects, including documenting impact plume evolution and assessing the change in orbital period of Dimorphos about Didymos – critical to DART's mission success and to assessing the effectiveness of the world's first test of an asteroid deflection technique.

Figure 8: *Locations of observatories that supported the DART observation campaign. (Source: Johns Hopkins University Applied Physics Lab)*

International Asteroid Warning Network (IAWN)
The UN-endorsed IAWN collaboration currently consists of 50 signatories in 20 countries. IAWN is organized by NASA which supports the website at **http://www.iawn.net/**. U.S. signatories are NASA (contributed assets include all funded NEO survey, follow-up, characterization, and orbit determination and data center capabilities of NASA's NEO Observations Program), the Zwicky Transient Facility, and independent amateur astronomers at Squirrel Valley Observatory, Toole Observatory, and Farpoint Observatory.

In-Space NEO Encounters
Flight programs to conduct space-based observations have been conducted by space agencies since the launch of ISEE 3/ICE in 1978, which targeted the near-Earth object 21P/Giacobini-Zinner, passing through its plasma tail in September 1985. NEO encounters have also included multiple flyby missions as Halley's Comet passed through our solar system in the mid-1980's. Near-Earth Asteroid Rendezvous-Shoemaker made history by landing on an asteroid in 2001. Japan Aerospace Exploration Agency (JAXA's) Hayabusa, Hayabusa 2, ESA's Rosetta and NASA's EPOXI, OSIRIS-Rex and Double-Asteroid Redirection Test missions all encountered near-Earth objects.

There are additional flight missions under development for launch this decade: the European Space Agency's Hera mission may launch as early as 2024 to the asteroid Didymos and study the impact site of DART mission on the smaller nearby asteroid Dimorphos. The mission features two small satellites capable of sensing the interior of the asteroids to map their geological structure and chemical composition.

Appendix D: Support for Strengthening Planetary Defense Efforts at NASA

Biden-Harris Administration

In April 2023 the White House released the *National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense* (National Planetary Defense Strategy), which is available online.[6]

The Biden-Harris Administration also highlighted the importance of planetary defense in the 2021 U.S. Space Priorities Framework: "The United States will lead, in cooperation with commercial industry and international allies and partners, in efforts to enhance warning of and mitigation against potential near-Earth object impacts."

On August 9, 2022, the President signed the "CHIPS and Science Act" which affirmed a commitment to "... continue the development of a dedicated space based infrared survey telescope mission [NEO Surveyor] on a schedule to achieve a launch-readiness date not later than March 30, 2026, or the earliest practicable date..."

In 2022 the White House Office of Science and Technology Policy hosted the DART Mission team to brief senior leaders across the White House on the successful mission results.

Congress

The 2005 George E. Brown Near-Earth Object Survey Act directed NASA to find at least 90 percent of NEOs that are at least 140 meters by 2020. Since 2005, the number of NEOs catalogued in this range has almost tripled, while the total number of catalogued NEOs has increased by almost five times. In November 2022, the U.S. House Committee on Science, Space and Technology wrote to Administrator Nelson reiterating its strong support for planetary defense.

American Public

Support for planetary defense among the American public is extraordinary, with 62 percent ranking it among NASA's top priorities. Only climate change research was deemed a higher priority (Pew Research Center, 2019). A 2021 survey showed sustained support, with 62 percent of the public again placing it among the agency's most important priorities, above many of NASA's exploration goals (Morning Consult, 2021).

Further evidence of public interest in planetary defense was illustrated during the DART mission:

- DART's asteroid impact event was covered by 338 domestic newspapers and featured on 35 domestic front pages. Similarly, the news was covered by 153 international newspapers and featured on 5 international front pages.
- The DART impact broadcast, which was streamed on the agency's **YouTube** account, has accumulated over 5.5M views and was the agency's #1 trending video at the time of release. At peak viewership, the DART impact broadcast garnered nearly 1.1 million concurrent viewers and was NASA's largest live viewing audience since the Perseverance rover landing in February 2021.

6 https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

National Academies of Science and Planetary Science community

The National Academy of Sciences (NAS) highlighted planetary defense in the 2023-2032 Planetary Science and Astrobiology Decadal Survey. Notably, their recommendations included:

- NASA should fully support the development, timely launch and subsequent operation of NEO Surveyor.
- Subsequent to DART and NEO Surveyor, the highest priority mission should be a rapid-response flyby reconnaissance missions to a challenging near-Earth object.
- 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.

Appendix E: History and Evolution of Finding and Assessing the NEO Hazard

This is re-printed from the 2023 National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense.[7]

Observations of celestial bodies and comets have been recorded for thousands of years across civilizations, but the development of near-Earth object astronomical observation including asteroids is a comparatively recent development (and the understanding of the need to pursue capability to mitigate their impact risks even more recent!) The discovery of Ceres in 1801 by astronomer Giuseppe Piazzi was the first observation of an asteroid (later reclassified as a dwarf planet). The first near-Earth asteroid, 433 Eros, wasn't discovered until 1898 by Gustav Witt.

In 1973, Eleanor Helin and Gene Shoemaker at the California Institute of Technology started the first major systematic search for NEOs. Their Palomar Planet-Crossing Asteroid Survey mapped the orbits of 65 NEOs until the project finished in the mid-1990s.[8] Their legacy led to a new era of NEO searches: application of computers, digital imagers, and automated searches revolutionized NEO discovery efforts starting in the 1990s; hundreds of NEOs were being discovered per year by the 2000s.[9]

The importance of asteroids to Earth's geologic history and their current hazard became apparent in the 1980s as scientists began to hypothesize that an approximately 10 km-wide asteroid likely caused a mass extinction on Earth and killed off non-avian dinosaurs about 65 million years ago, and that this event corresponded to the age of Chicxulub impact crater.[10] The asteroid impact theory, attributed to the Alvarez *et al*. team, became widely (though not universally) accepted within the scientific community, signaling the need to establish "applied planetary science" as a discipline to guide effective planetary defense strategies.

After the very public near-Earth miss of the sub-kilometer asteroid FC 1989,[11] NASA issued a 1992 Spaceguard Survey Report recommending a goal to find 90 percent of NEOs one kilometer and larger. The impact of comet Shoemaker-Levy 9 with Jupiter in 1994 further raised public awareness to the asteroid and comet impact hazard and encouraged Congress to authorize the "Spaceguard Goal" of finding 90 percent of kilometer-size NEOs. In 1998, NASA initiated a Near-Earth Object Observations Program and formally adopted the original Spaceguard Goal (which was successfully completed by 2011).[12]

In 2003, as the original Spaceguard efforts were underway, a NASA-commissioned NEO Science Definition Team recommended expanding discovery efforts to include 140 meter and larger asteroids within five million miles of Earth's orbit.[13] The Science Definition Team identified 140 meters as the size that could cause severe

7 https://www.whitehouse.gov/wp-content/uploads/2023/04/2023-NSTC-National-Preparedness-Strategy-and-Action-Plan-for-Near-Earth-Object-Hazards-and-Planetary-Defense.pdf

8 Caltech. *Palomar history graphical timeline*. https://sites.astro.caltech.edu/palomar/about/timeline.html

9 Conway, Erik M, Rosenburg, Meg, Yeomans, Donald K. 2022. *A History of Near-Earth Object Research*, 10. https://www.nasa.gov/sites/default/files/atoms/files/a_history_of_near-earth_object_research_tagged.pdf

10 See for example: Alvarez et al, "Extraterrestrial cause for the Cretaceous-Tertiary extinction," Science, 1980; Hildebrand et al, "Chicxulub crater: a possible Cretaceous/Tertiary boundary impact crater on the Yucatán peninsula, Mexico," geology, 1991; and Schulte et al, "the Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary," Science, 2010.

11 House Hearing, 110th Congress. November 8, 2007. N*ear-Earth Objects (Neos)—Status of the Survey Program and Review of Nasa's 2007 Report to Congress*. https://www.govinfo.gov/content/pkg/CHRG-110hhrg38057/html/CHRG-110hhrg38057.htm

12 NASA Office of Inspector General. 2014. *NASA's Efforts to Identify Near-Earth Objects and Mitigate Hazards*, 24. https://oig.nasa.gov/docs/IG-14-030.pdf

13 Near-Earth Object Science Definition Team. *Study to Determine the Feasibility of Extending the Search for Near-Earth Objects to Smaller Limiting Diameters*. Prepared at the request of the NASA Office of Space Science Solar System Exploration Division, August 22, 2003. https://cneos.jpl.nasa.gov/doc/neoreport030825.pdf

regional devastation leading to national economic and societal upheaval. Two years later, the George E. Brown, Jr. Near-Earth Object Survey Act, directed NASA to find 90 percent of PHOs 140 meters and larger in 15 years. Additionally, the Act updated NASA's mission to make NEO detection, tracking, and research one of the Agency's seven explicit missions.[14]

By 2010, a memorandum by the White House Office of Science and Technology Policy (OSTP) began pivoting the Federal government towards a broad official planetary defense program, rather than one focused solely on NEO discovery.[15] The memo presented an interagency plan of action in the event of a PHO impact threat discovery, and recommended that NASA initiate a research program to assess mitigation and deflection technologies, continue to detect hazardous NEOs, and notify relevant Federal agencies in the case of a potential NEO impact threat. This would eventually lead to a broader NASA planetary defense program that includes planning for deflection and impact mitigation of PHOs in addition to just detection. A 2010 NASA Advisory Council (NAC) task force amplified these changes within NASA.

In February 2013, an undetected asteroid roughly the size of a house exploded over Chelyabinsk, Russia, injuring approximately 1,600 people. The incident dramatically raised global public awareness of the NEO threat.[16] In 2014, the United Nations Office of Outer Space Affairs (UNOOSA) endorsed the creation of the IAWN and the SMPAG, formally bringing to bear many of the world's space observatories and expanding planetary defense into a global effort.[17] By 2016, NASA established its Planetary Defense Coordination Office (PDCO) to organize and oversee planetary defense efforts.

In 2017, the NASA NEO Science Definition Team published an updated report, finding that a space-based NEO surveillance system would be needed to complete the George E. Brown Jr. Survey before 2033.[18] And in 2022, for the first time, the National Academies of Sciences, Engineering and Medicines (NASEM) Decadal Survey for Planetary Science prominently featured a section on planetary defense, recommending that NASA's PDCO should be "robustly supported as the critical organization to advance U.S. planetary defense capabilities" for at least the next decade.[19]

Today, a new era is starting: in 2022, NASA's DART mission successfully demonstrated the ability to alter the orbit of an asteroid. After thousands of years observing celestial bodies, this was the first demonstration of an ability to shift a potentially hazardous asteroid. Two revolutionary NEO search capabilities will come online soon, the NSF/DOE-supported Vera C. Rubin Observatory (beginning operations in 2024-2025), and the NEO Surveyor space telescope (anticipated for launch by 2028).[20] Planetary defense initiatives have also yielded unexpected scientific discoveries: NASA's NEO Observations Program-funded Pan-STARRS project discovered the first known interstellar object passing through our Solar System, *'Oumuamua*, opening a future field of scientific inquiry into interstellar objects. Looking ahead, the asteroid Apophis is predicted to pass within about 31,600 km of Earth's surface in 2029, presenting a serendipitous opportunity to further advance Earth's planetary defense through technology demonstrations and international collaboration.

14 S.1281 NASA Authorization Act of 2005, public law no.: 109-155. Sec. 321: George E. Brown, Jr. Near-Earth Object Survey. https://www.congress.gov/bill/109th-congress/senate-bill/1281/text

15 Issued in response to a Congressional tasking in the 2008 NASA Authorization Act. Holdren, John P. *OSTP Letter Report on NEOs*. 15 October 2010. https://www.nasa.gov/sites/default/files/atoms/files/ostp-letter-neo-senate.pdf

16 NASA. *Five Years after the Chelyabinsk Meteor: NASA Leads Efforts in Planetary Defense*. 15 February 2013. https://www.nasa.gov/feature/five-years-after-the-chelyabinsk-meteor-nasa-leads-efforts-in-planetary-defense

17 UNOOSA. *Near-Earth objects*, 2011-2012. 21 December 2012. https://www.unoosa.org/oosa/oosadoc/data/documents/2013/aac.105c.1l/aac.105c.1l.329_0.html

18 Near-Earth Object Science Definition Team. September 2017. *Update to Determine the Feasibility of Enhancing the Search and Characterization of NEOs*. https://cneos.jpl.nasa.gov/doc/2017_neo_sdt_final_e-version.pdf

19 National Academy of Sciences, Engineering, and Medicine. *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology. 2023-2032*, (Washington D.C.: National Academies Press) 2022.

20 In 2022, NASA approved the NEO Surveyor space telescope to begin mission development for launch by 2028. The NASA Authorization Act of 2022 passed by Congress also reaffirmed the George E. Brown, Jr. Survey goal and directed NASA to continue development and deployment of NEO Surveyor without further delay or diverted resource allocations to other missions. See: H.R. 4346 CHIPS and Science Act, public law no.: 117-167. Sec. 10825: Planetary Defense Coordination Office. https://www.congress.gov/bill/117th-congress/house-bill/4346/text?r=2&s=2.

NASA PLANETARY DEFENSE
STRATEGY AND ACTION PLAN

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NP-2023-04-3120-HQ