NATIONAL PREPAREDNESS STRATEGY & ACTION PLAN FOR NEAR-EARTH OBJECT HAZARDS AND PLANETARY DEFENSE

A PRODUCT OF THE
PLANETARY DEFENSE INTERAGENCY WORKING GROUP
OF THE
NATIONAL SCIENCE & TECHNOLOGY COUNCIL

APRIL 2023

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About the Planetary Defense Interagency Working Group

The Planetary Defense Interagency Working Group, the current name for what has been previously titled the Detecting and Mitigating the Impact of Earth-bound Near-Earth Objects (DAMIEN) Interagency Working Group (IWG), is under the Committee on Homeland and National Security, NSTC. The DAMIEN IWG was first convened in January 2016 to define, coordinate, and oversee goals and programmatic priorities of Federal science and technology activities related to potentially hazardous near-Earth objects (NEOs).

About this Document

This document was developed through the extensive discussions and interchange of representatives from the U.S. government agencies involved in the Planetary Defense IWG. This 2023 Planetary Defense Strategy and Action Plan will improve our Nation's preparedness to address the hazard of NEO impacts by leveraging and enhancing existing national and international assets and adding important capabilities across government.

About the Cover

Courtesy of the National Aeronautics and Space Administration (NASA) Planetary Defense Coordination Office, this cover depicts orbit traces from near-Earth asteroids based on analysis by NASA's Center for Near-Earth Object Studies at the Jet Propulsion Laboratory. These orbit traces are based on the population model published in the 2017 Report of the NEO Science Definition Team.

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Executive Summary

Near-Earth Objects (NEOs) are asteroids and comets that orbit the Sun but have orbits that can bring them into Earth's neighborhood—within 30 million miles of Earth's orbit. Planetary defense encompasses all the capabilities needed to detect and warn of potential 10-meter and larger NEO impacts with Earth, and to either prevent such an event or mitigate the possible effects of an impact.

This *National Preparedness Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense* (2023 Planetary Defense Strategy) updates the United States' first comprehensive Near-Earth Object Preparedness Strategy and Action Plan, released in 2018. The 2023 Planetary Defense Strategy 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 2023 Planetary Defense Strategy focuses on six goals in total across Federal Departments and Agencies for the decade ahead:

- **Goal 1: Enhance NEO detection, tracking, and characterization capabilities**. Early detection and tracking of a potential NEO impact threat provides the greatest leverage to adequately respond in time to prevent loss of life and damage to critical infrastructure.
- **Goal 2: Improve NEO modeling, prediction, and information integration.** Departments and Agencies will coordinate the development of validated modeling tools and simulation capabilities that aid in characterizing and mitigating NEO impact risks while integrating and streamlining data flows to support effective decision-making.
- **Goal 3: Develop technologies for NEO reconnaissance, deflection, and disruption missions.** NASA will continue to lead development of technologies that could potentially be used in fast-response NEO reconnaissance missions and timely missions to deflect or disrupt hazardous NEOs.
- **Goal 4: Increase international cooperation on NEO preparedness.** The potentially cataclysmic consequences of a NEO impact, independent of national borders and geopolitical dynamics, presents special opportunity for engagement with the international community to foster cooperation in joint research and response efforts.
- **Goal 5: Strengthen and routinely exercise NEO impact emergency procedures and action protocols.** The United States will strengthen and exercise procedures and protocols for assessment of NEO threats, communication—including to the public and international community—regarding threats, and response and recovery activities.
- **Goal 6: Improve U.S. management of planetary defense through enhanced interagency collaboration.** Actions under this goal will improve ongoing coordination and implementation on projects across Federal agency boundaries.

Overview and Rationale

Managing the NEO Impact Hazard

Near-Earth Objects (NEOs) are asteroids and comets that come close to or pass across Earth's orbit around the Sun.[1] They range in size from small "meteoroids" only a few meters across, to much larger bodies several kilometers wide. When NEOs periodically impact Earth, smaller objects harmlessly fragment and disintegrate in the atmosphere, while larger objects can cause local damage at the surface or even global devastation.

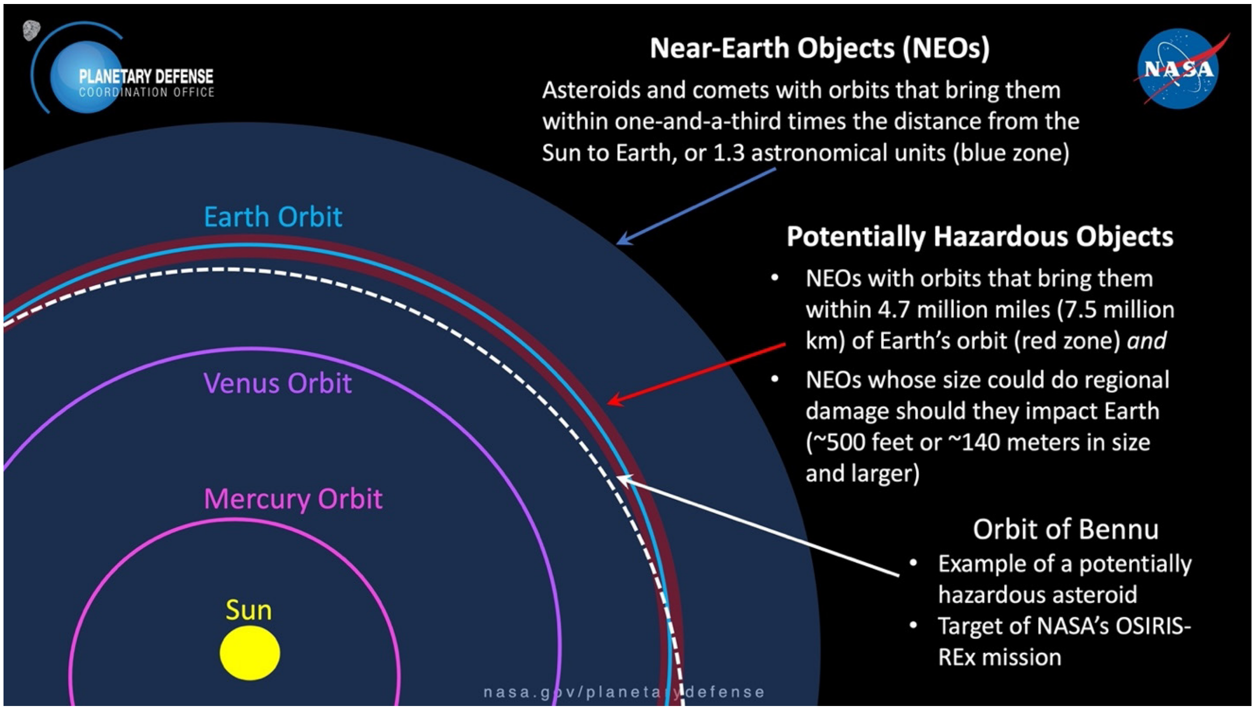


Figure 1: Near-Earth Objects in the Solar System (Source: NASA)

This hazard exists because our planet orbits the Sun amidst millions of smaller objects that cross Earth's orbit, including 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:

- Up to 1,000 NEOs greater than 1 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 for impact.
- As many as 25,000 objects larger than 140 meters in size, capable of causing regional devastation, are believed to exist. Only about 42 percent have been detected and tracked to date.

[1] NEOs include both Near-Earth Asteroids (NEAs) and Near-Earth Comets (NECs). Most NECs are short-period comets. The NEO population includes far more NEAs than NECs: as of February 2023, there are 31,357 identified NEAs and 199 identified NECs. For details see: https://cneos.jpl.nasa.gov/stats/totals.html.

- Over 230,000 objects likely exist that are 50 meters or larger 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. It is estimated that less than one percent of these small bodies have been discovered.[2]

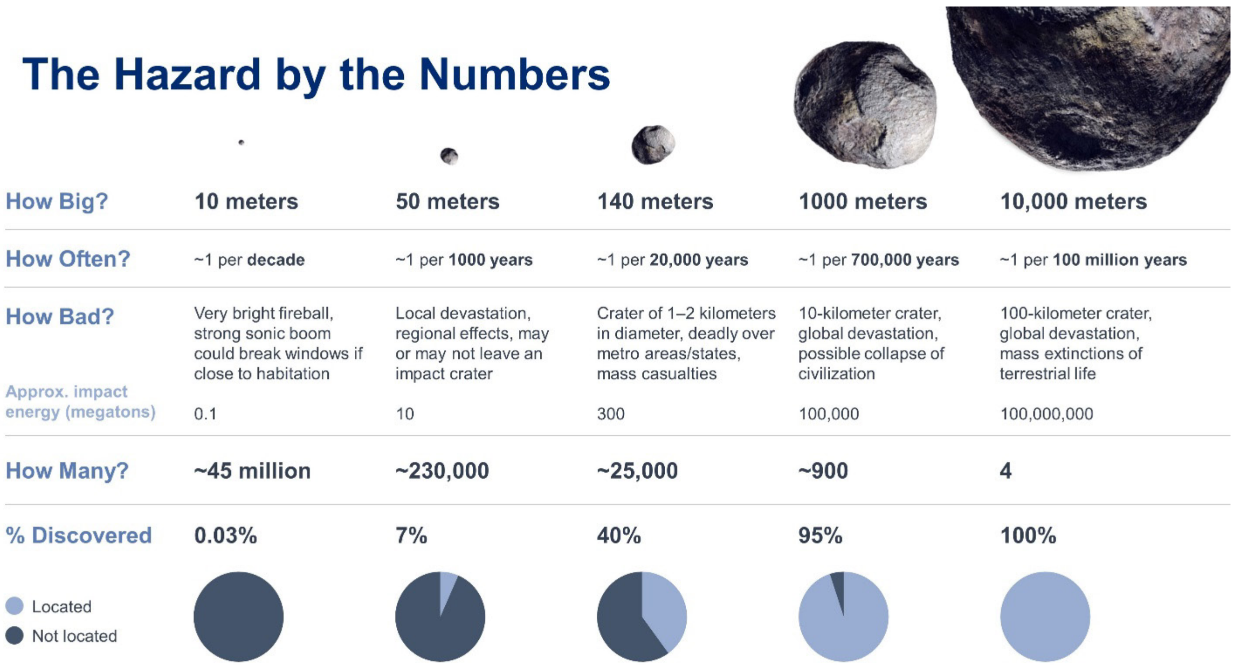


Figure 2: NEO size, frequency of Earth-impact, and hazard. (Credit: Johns Hopkins University/Applied Physics Laboratory)

Planetary defense encompasses all the capabilities needed to detect and warn of potential 10-meter and larger NEO impacts with Earth, and to either prevent such an event or mitigate the possible effects of an impact. Planetary defense involves:

1. Finding and tracking NEOs that pose an impact hazard for Earth;
2. Characterizing each NEO to determine its precise trajectory, as well as its size, shape, mass, composition, rotational dynamics, and other parameters needed to assess the likelihood and severity of devastation if it has a potential Earth impact;
3. For a NEO with potential Earth impact, warning of the impact timing and potential effects, and advising on possible means to mitigate the impact; and
4. Planning and implementing measures to deflect or disrupt (break up) an object on an impact course with Earth, or to mitigate the effects of an impact. Mitigation measures that can be taken

[2] Analysis by NASA's Planetary Defense Coordination Office and NASA's Center for NEO Studies, based on the NEO population model published in *Report of the Near-Earth Object Science Definition Team: Update to Determine the Feasibility of Enhancing the Search and Characterization of NEOs*, September 2017.

on Earth to protect lives and property include evacuation of the impact area and movement of critical infrastructure.

Figure 3: ***Planetary Defense as a Decision Cycle.*** *Planetary defense can be described as a cycle akin to the observe, orient, decide, act, and assess 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 U.S. government can make advancements. (Source: NASA)*

The hazard of NEO impacts is challenging to assess when we do not have a complete NEO survey catalog. Future survey projects, such as the space-based mid-infrared NEO Surveyor mission, will dramatically improve our risk assessments. When paired with new characterization and 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.

Short History of Finding NEOs and Assessing the NEO Impact Hazard

A more comprehensive history can be found in Appendix D.

Observations of celestial bodies and comets have been recorded for thousands of years across civilizations, but the development of NEO astronomical observation including asteroids is a comparatively recent development. Even more recent is research to understand and pursue developing the capability to mitigate their impact risks.

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 kilometer-wide asteroid likely caused a mass extinction on Earth and killed off non-avian dinosaurs about 66 million years ago, and that this event corresponded to the age of Chicxulub impact crater.[3] The asteroid impact theory,

[3] 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.

attributed to the Alvarez *et al.* team, became widely accepted within the scientific community, signaling the need to establish "applied planetary science" as a discipline to guide effective planetary defense strategies.

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.[4] In 2014, the United Nations Office of Outer Space Affairs (UNOOSA) endorsed the creation of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG), formally bringing to bear many of the world's space observatories and expanding planetary defense into a global effort.[5] By 2016, NASA established its Planetary Defense Coordination Office (PDCO) to organize and oversee its NEO Observations Program, established in 1998, and other ongoing planetary defense efforts.

Today, a new era is starting: in 2022, NASA's Double Asteroid Redirection Test (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 National Science Foundation (NSF)/Department of Energy (DOE)-supported Vera C. Rubin Observatory (beginning operations in 2024-2025), and the NEO Surveyor space telescope (anticipated for launch by 2028).[6] Looking ahead, the asteroid Apophis is predicted to pass within about 31,600 kilometers of Earth's surface in 2029, presenting a serendipitous opportunity to further advance Earth's planetary defense through technology demonstrations and international collaboration.

peninsula, Mexico," Geology, 1991; and Schulte et al, "the Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary," Science, 2010.

[4] 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.

[5] 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.

[6] In 2022, NASA approved the NEO Surveyor space telescope to begin mission development for launch by 2028. Title VII of the CHIPS and Science Act, the National Aeronautics and Space Administration Authorization Act of 2022 (P. L. 117- 167 § 10825), 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.

Major U.S. Contributions to Planetary Defense & NEO Surveys

Assets used for NEO surveys include both ground- and space-based systems. Some of the main current capabilities, and demonstrations to support planetary defense by the United States in the next decade, are highlighted below. A more comprehensive list of current and planned planetary defense projects and missions can be found in Appendix B.

CURRENT MAJOR CAPABILITIES IN OPERATION OR IN DEVELOPMENT

The **Catalina Sky Survey (CSS)** and the **Panoramic Survey Telescope and Rapid Response System (Pan-STARRS)** are the current major NEO detection and tracking survey projects funded by NASA PDCO's Near-Earth Object Observation Program. CSS is based out of the University of Arizona's Lunar and Planetary Laboratory. Pan-STARRS has two systems for wide-field astronomical imaging developed and operated by the University of Hawaii. They both report NEO discovery and tracking data to the Minor Planet Center.

Pan-STARRS1 Telescope, Credit: University of Hawaii & Ratkoski

The **Minor Planet Center (MPC)** and the **Center for NEO Studies (CNEOS)** support NEO discovery and orbit determination, prediction, and archive activities. The MPC is funded by NASA as a sub-node of its Planetary Data System Small Bodies Node and operates at the Smithsonian Astrophysical Observatory. It has the International Astronomical Union sanction to designate all minor bodies 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 worldwide community. CNEOS is hosted by NASA's Jet Propulsion Laboratory and uses data on NEOs collected 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 provided by CNEOS are archived in the JPL Small-Body Database (SBDB).

The **Vera C. Rubin Observatory (Rubin)** is a joint National Science Foundation (NSF) and Department of Energy (DOE) multi-disciplinary facility that is currently under construction in north-central Chile. It will comprise an 8.4-meter wide-field optical telescope, a 3.2-gigapixel camera, and an advanced data management system. Taken together, these components are designed to carry out a deep survey of nearly half the sky and enable a broad range of fundamental astrophysical research. Rubin Observatory will collect about 20 terabytes of imaging data every night. It will produce the widest-field sky image to

Credit: Y. AlSayyad/Rubin Obs./NSF/AURA date and issue alerts for changing and transient objects within 60 seconds of their discovery. The Rubin Observatory will significantly increase NEO detection and characterization rates.

The **Near-Earth Object (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 on the sunward side of Earth, it will be able to survey along Earth's orbit 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 2028.

OPPORTUNITY FOR A RAPID-RESPONSE, FLYBY OR RENDEZVOUS RECONNAISSANCE MISSION

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.

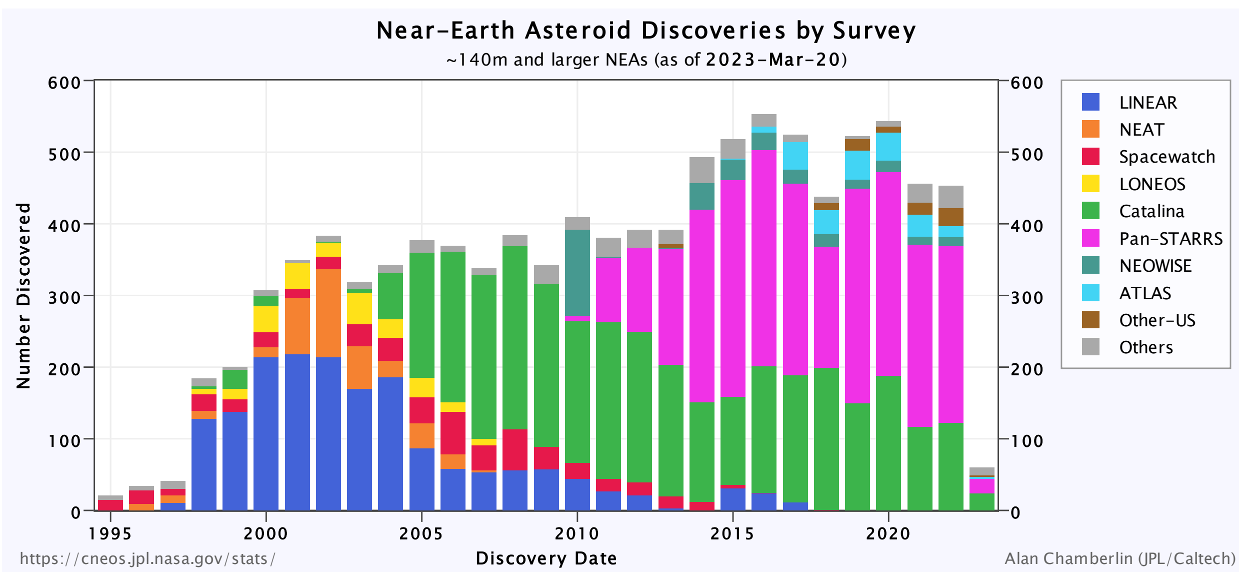


Figure 4: Large NEO Discoveries by Survey (Credit: NASA)

Key Developments Since Publication of the 2018 National Near-Earth Object Preparedness Strategy and Action Plan & Rationale for an Updated Strategy

Since the first Strategy and Action Plan was released in 2018, there has been significant progress toward accomplishing its goals. Key milestones during this period are described below. A more comprehensive list of developments since 2018 can be found in Appendix C.

GOAL 1: ENHANCE NEO DETECTION, TRACKING, AND CHARACTERIZATION CAPABILITIES	The NEO Surveyor space telescope was announced by NASA as a directed mission in 2019. It passed Key Decision Point (KDP) B in mid-2021, beginning key instrument development, KDP C in late 2022. NSF and DOE have continued to support construction of Vera C. Rubin Observatory. Integration and testing of the telescope mount assembly (TMA) will be complete by Spring 2023, and the Commissioning Camera was successfully installed and tested on the TMA in 2022. The Observatory is nearing completion, with the first light expected in 2024. NASA coordinates the UN-recommended International Asteroid Warning Network (IAWN) and has led observational campaigns to test the 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.
GOAL 2: IMPROVE NEO MODELING, PREDICTION, AND INFORMATION INTEGRATION	The NEO Action Plan Modeling Working Group (MWG), chaired by the NASA Ames Research Center Asteroid Threat Assessment Project (ATAP), was established in 2019. The MWG developed initial computer simulations and held asteroid impact exercise meetings in 2019 and 2020. CNEOS developed and improved tools to compute high-precision orbits, future motions, and assess NEO deflection techniques, including a NEO deflection simulation tool.
GOAL 3: DEVELOP TECHNOLOGIES FOR NEO DEFLECTION AND DISRUPTION MISSIONS	NASA successfully demonstrated the Double Asteroid Redirection Test (DART), humanity's first-ever planetary defense technology test mission. DART used a kinetic impactor to alter the orbital period of a small asteroid for the first time. DART was launched in 2021 and impacted its target, Dimorphos, the small moonlet of asteroid Didymos, in 2022. Rapid response reconnaissance missions were assessed by the UN-endorsed Space Mission Planning Advisory Group (SMPAG) and the 2023-2032 Planetary Science and Astrobiology Decadal Survey.
GOAL 4: INCREASE INTERNATIONAL COOPERATION ON NEO PREPAREDNESS	NASA's DART mission included an Italian satellite, LICIACube, which carried out flyby 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 personnel are collaborating with the European Space Agency on its mission Hera, planned for launch in 2024, to more fully investigate the DART-impacted Didymos binary asteroid system.

	The United States supported increased participation in core international bodies dealing with NEOs, including the SMPAG, from 12 to 18 members, and IAWN, from 13 to 50 signatories.
GOAL 5: STRENGTHEN AND ROUTINELY EXERCISE NEO IMPACT EMERGENCY PROCEDURES AND ACTION PROTOCOLS	The NEO Impact Threat Emergency Protocols (NITEP) IWG, established in 2019, made significant progress toward implementation of objectives under Goal 5, including completion of two actions. Advances included: Establishment of procedures and timelines for (1) threat assessment upon detection of potential NEO impacts and (2) risk/benefit analysis of mitigation options following a threat assessment; Development of benchmarks for determining when to recommend NEO reconnaissance, deflection, and disruption missions; and Review of protocols for notifications and communications regarding NEO threats within the Federal Government, as well as guidance on content for notifications and communications to the public, Congress, and international stakeholders.

The need to update the 2018 National Near-Earth Object Preparedness Strategy and Action Plan is based on:

- Recognition that global efforts to identify potentially hazardous NEOs need to be supported with new capabilities, requiring an updated strategy. With less than 50 percent of NEOs capable of regional devastation catalogued, our assessment of the risks to Earth is incomplete.
- Opportunity for new international, including bilateral and multilateral, cooperation with the emergence of new international capabilities. As new observatories are commissioned and new mitigation demonstration missions are developed globally, the U.S. has an opportunity to advance and lead in coordination of worldwide efforts for humanity's defense of the planet.
- Increasing prioritization of planetary defense by the scientific community, most recently in the 2023-2032 Planetary Science Decadal Survey, shows an acknowledgement that "applied planetary science" should be a focus area for more robust research and development.
- Recognition that, after NASA's DART mission in 2022, the U.S. has the opportunity to consider development of follow-on NEO reconnaissance and mitigation demonstration missions that could further improve our technological preparedness.
- Recognition that the U.S. can improve its long-term strategic outlook and interagency coordination for maturing planetary defense capabilities and impact threat response efforts.

Figure 5: Didymos and Dimorphos after DART impact, (Credit: ASI/NASA)

Objectives

The 2023 Planetary Defense Strategy builds on existing efforts by Federal Departments and Agencies to detect and characterize the NEO population and to respond to prevent NEO impacts on Earth. It updates the core five goals of the 2018 Strategy and Action Plan, including updated action planning for each goal for the next 10 years, and adds a sixth goal to improve interagency coordination and collaboration.

- **Goal 1: Enhance NEO detection, tracking, and characterization capabilities.**
- **Goal 2: Improve NEO modeling, prediction, and information integration.**
- **Goal 3: Develop technologies for NEO deflection and disruption missions.**
- **Goal 4: Increase international cooperation on NEO preparedness.**
- **Goal 5: Strengthen and routinely exercise NEO impact emergency procedures and action protocols.**
- **Goal 6: Improve U.S. management of planetary defense through enhanced interagency collaboration.**

Advances in two key areas are of critical focus for this document's 10-year horizon—one involving technical NEO observation capabilities and the other concerning international cooperation:

- The need to improve technical capabilities involves first enhancing NEO detection, tracking, and general population characterization capabilities (Goal 1). Earlier detection of any potential impact threat provides the most leverage and cost-effective basis for managing risks from potentially hazardous NEOs. Completion of planned ground and space-based wide-field sky survey assets will accelerate achievement of this goal within the next 10 years. Also important is the rapid characterization of any potential impact threat once detected (contained in Goal 3). Development of technologies for rapid response reconnaissance by either a spacecraft flyby or rendezvous with a potential impact threat object is key to reducing uncertainties and providing critical information for decision making. One other important characterization asset is acquisition of improved deep space radars with planetary range for PHO observation and imaging, which would address needs in both Goals 1 and 3. Prioritization of these capabilities is consistent with Decadal Survey recommendations.
- The second objective concerns prioritizing opportunities to increase international cooperation for planetary defense (Goal 4). The United States has the opportunity to lead in creating new multilateral initiatives and cooperating with new partners worldwide on planetary defense. In addition to including planetary defense topics in bilateral discussions, avenues for diplomacy created under the auspices of the UN Committee on Peaceful Uses of Outer Space (UNCOPUOS) are conducive to advancing these initiatives.

A set of strategic actions supports each goal. Each action includes a desired timeline for completion. 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 Action Plan.

Each action includes a list of relevant agencies, with the recommended lead agency listed first and underlined. These lists of relevant agencies are not meant to be exhaustive or limiting. The U.S. Government views planetary defense as a mission that will involve many elements of Federal, State, local government, industry, academia, and society as a whole. This Strategy and Action Plan assigns civil agencies lead roles addressing the identified goals as the U.S. Government views planetary defense as a civil-led mission. The Department of Defense (DOD) has relevant expertise and capabilities and plays a supporting role to civil authorities. The updated 2023 Planetary Defense Strategy describes ongoing implementation efforts across the Federal Government, evaluating where progress has been made since 2018 and addressing early implementation issues. In addition, it provides a more detailed assessment of interagency roles and responsibilities. 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.

Ultimately, the update allows for opportunities to refresh the ongoing work in NEO preparedness in light of recent trends, developments, and priorities. It aims to mature and stabilize planetary defense programs and coordination across the U.S. Government and its partners. Such advances are key to ensuring long-term maintenance of survey, mitigation, and preparedness goals.

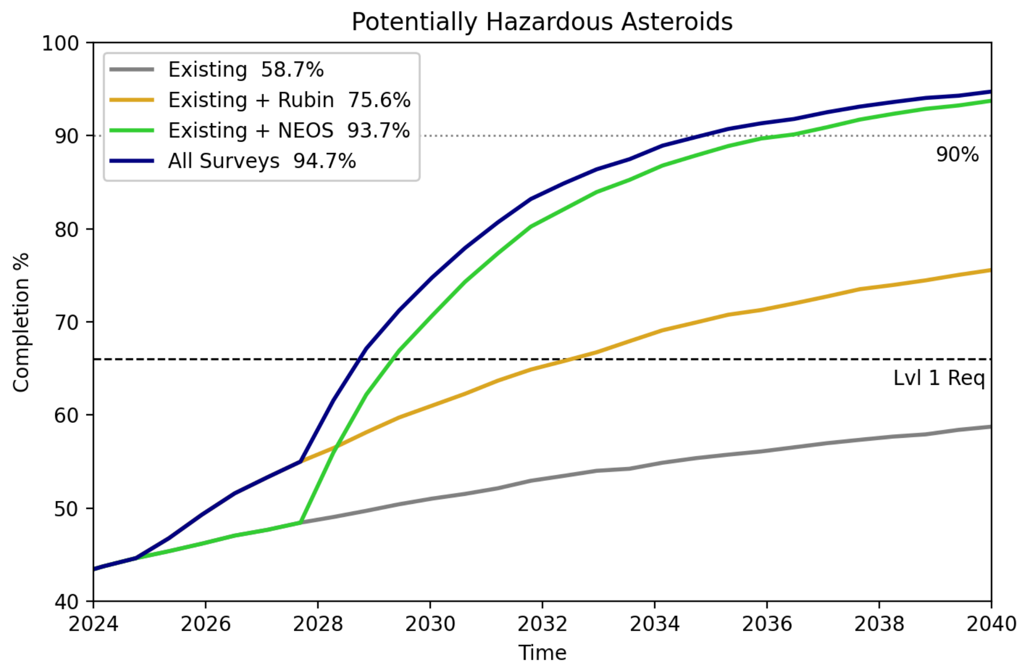


Figure 6: Predicted NEO survey completeness, combining current capabilities with projected contribution by Rubin Observatory and then NEO Surveyor after five years of operations. (Credit: NASA PDCO)

Goal 1: Enhance NEO Detection, Tracking, and Characterization Capabilities

Early detection and tracking of a potential NEO impact threat provides the greatest leverage to adequately respond in time to prevent loss of life and damage to critical infrastructure. Providing years to decades of warning, entirely possible by appropriately applying known technology, will enable use of more options to prevent the impact. NASA will lead the development of a roadmap for improving national capabilities for NEO detection, tracking, and characterization. Supporting actions will reduce current levels of uncertainty and aid in more accurate modeling and more effective decision-making.

The following actions support this goal:

Improve national 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 (potentially such as the Department of Commerce's (DOC) Traffic Coordination System for Space (TraCSS)), 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. [Short term; <u>NASA</u>, National Science Foundation (NSF), DOD, DOC/NOAA]

1.2 Identify technology and data processing capabilities and opportunities in existing and new telescope programs to enhance characterization of NEO composition, dynamics, 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, in a database that is accessible to science, academic, government, and commercial entities, as applicable, allowing for development and use of evolving data analytics or emergent behaviors. [Short term; <u>NASA</u>, NSF, United States Geological Survey (USGS), DOE, DOD/USSF (to leverage existing and planned DOD capabilities)]

1.3 Continue and enhance multi-agency efforts to detect large meteoroids and small asteroids entering Earth's atmosphere and provide rapid public notification. Worldwide these events occur 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 worldwide science community enables further data collection, provides information to calm the general public, and allows for timely collection of meteoritic samples of the object before contaminated by the terrestrial environment. [Short term: <u>NASA and DOD/USSF,</u> other relevant agencies]

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 and best practices, including from DOC's TraCSS, to support the interoperability of planetary defense data, including a widely accessible database catalog. [Short term; NASA, DOD, DOC]

1.5 Conduct an interagency assessment to explore interest from key government stakeholders in the coordinated development of current and future deep space radar facilities and identify where these facilities may be useful for planetary defense. Given the loss of the Arecibo Observatory's 305-meter antenna, 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; NSF, NASA, DOD]

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; NSF, NASA, DOC]

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 will 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. [Short term and Ongoing; NASA, NSF, USGS, DOD]

1.8 Analyze emerging challenges for survey and characterization of NEOs 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; NSF, DOS, NASA, DOC, FCC]

Goal 2: Improve NEO Modeling, Prediction, and Information Integration

Agencies will coordinate the development of validated modeling tools and simulation capabilities that aid in characterizing and mitigating NEO impact risks while integrating and streamlining data flows to support effective decision-making.

The following actions support this goal:

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; NASA, DHS Science and Technology Directorate, DHS Cybersecurity and Infrastructure Security Agency (DHS/CISA), DOE National Nuclear Security Administration (DOE/NNSA), in collaboration with other providers of threat risk effects modeling and analysis results]

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; NASA, DHS Federal Emergency Management Agency (DHS/FEMA), DOD, DOE/NNSA Labs]

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 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. [Medium term; DOE/NNSA Labs, NASA]

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 populations and 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; NASA, DOE/NNSA Labs, DOD, DOC/NOAA, DHS/FEMA, USGS]

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 will include the possibility for longer-term hazards that result from triggering events, such as high winds or extreme precipitation. The pipeline output will 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; DHS/FEMA, NASA, DOE/NNSA Labs, USGS, DOD, DOC/NOAA, NSF, DOS]

Exercise, evaluate, and continually improve modeling and analysis capabilities

2.6 Continually assess the adequacy and validity of modeling and analysis of impact effects and mitigation techniques through bi-annual tabletop type exercises, and seminars or regular briefings to interested parties. This modeling effort will include analysis of impacts effects to both populations and national critical infrastructure. This action will structure exercises to identify gaps, formulate needed improvements, test connections within the national framework, and improve operational readiness. This action will also include a lessons-learned document when applicable and plan for increasing operational readiness to be shared among interested parties. [Ongoing; NASA,

DHS/FEMA, DHS/CISA, DOE/NNSA, USGS, DOC/NOAA, in collaboration with providers of modeling and analysis results]

Goal 3: Develop Technologies for NEO Reconnaissance, Deflection, and Disruption Missions

NASA will continue to lead development of technologies for fast-response NEO reconnaissance missions and timely missions to deflect or disrupt hazardous NEOs. Developing these technologies before an imminent threat arises will strengthen our ability to adequately respond and **pursue efforts to prevent NEO impact disasters.**

The following actions support this goal:

Develop technologies and designs for rapid-response NEO reconnaissance missions

3.1 Collaborate 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 dedicated 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 will consider both commercial-off-the-shelf parts and new hardware development. The launch vehicle infrastructure evaluation analysis will include consideration of both rapid-response reconnaissance and deflection/disruption missions, recommending processes for accomplishing rapid response planetary defense space-lift, 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. The collaboration should begin to define 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; NASA, DOD/USSF]

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 capability. [Short term; NASA, DOD/USSF]

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 will include the most mature in-space concepts—kinetic deflectors, 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 will include reconnaissance spacecraft and methods to measure the achieved deflection. Analyses will include an assessment of optimal planetary defense resource allocations between surveys and NEO deflection systems. They should consider contemporary work, including potential synergies with relevant private industry interests (e.g., asteroid resource surveys), 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. 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, and game-based approaches to solving challenges. The risk analysis will address current deficiencies in understanding how rapidly the United States can deploy planetary defense missions while maintaining acceptable reliability and mission success probability, and with sufficient redundancy. [Medium term; NASA, DOE/NNSA, DOC, other relevant agencies]

3.4 Continue the study of circumstances when only use of a nuclear explosive device would provide the necessary capability to mitigate an impending NEO impact threat, and the technologies, capabilities, international coordination, and other considerations required for such contingencies. Assess the legal and national policy implications of such an option. Studies have shown that at our current understanding of the potential NEO impact hazard it is still possible that discovery of either 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 remains prudent to continue research on the potential for NEDs to be used for PHO deflection and disruption missions. [Medium term; DOE/NNSA, NASA, DOS, other relevant agencies]

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 future deflection technique 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. Thorough flight testing of a deflection/disruption system prior to an actual planetary defense mission would substantially increase the chance of mission success. [Long term; NASA, DOE/NNSA Labs]

Goal 4: Increase International Cooperation on NEO preparedness

An "all-of-government" approach will be taken to inform and develop international support for addressing global NEO impact risks. The potentially cataclysmic and existential consequences of a NEO impact coupled with the impact's indifference to national borders and geopolitical dynamics presents a unique opportunity for engagement with the international community to foster cooperation in joint research and response efforts. International engagement and cooperation will help the United States better prepare for and more effectively address a potential NEO impact threat. While the scientific community has made great strides in identifying a significant portion of the NEO population, a large number of NEOs remain unidentified so the United States will work closely with international partners to hasten these survey and preparedness efforts. Increased outreach to other nations, both bilaterally and through relevant multilateral fora, is necessary to foster a better understanding of the threats NEOs pose, as well as muster the necessary resources, expertise, and capabilities to address those risks. The following actions support this goal:

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 comprehensive 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 bodies and meetings. This action could include delivering an annual U.S. statement under the NEOs agenda item of the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS) Scientific and Technical Subcommittee (STSC); technical presentations on NEOs at UNCOPUOS and other relevant international fora (e.g., the International Astronautical Congress, workshops, symposiums, etc.); developing and implementing a plan for outreach and awareness raising 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 State and NASA within the Near-Earth Object Impact Threat Emergency Preparedness (NITEP) working group. In addition, the United States could 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." The United States could also highlight the importance of international cooperation on NEO research and preparedness efforts during the UN Secretary General's 2024 "Summit of the Future," which will have a space-track event focused on international cooperation in outer space. [Ongoing; DOS, NASA Office of International and Interagency Relations]

4.2 Continue to demonstrate U.S. leadership in technical international NEO fora, and increase awareness among all countries, in particular space agency officials, of the need to address NEO issues in major international bodies. This action will include making NEO issues an agenda item at meetings with relevant international scientific and technical bodies, other national space agencies, and at relevant international conferences, when appropriate. In addition, the United States should continue active participation within SMPAG, IAWN, UNCOPUOS, and any other international entities that address issues related to NEOs. [Ongoing; NASA, DOS]

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 United States 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 Light Italian CubeSat for Imaging of Asteroids (LICIACube) 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. For reporting, information sharing, and dissemination capabilities, it will be important to mitigate risks associated not just with the malicious use of such capabilities to spread panic, but also with authorized but unintentional incorrect alerting or reporting. Methods toward this end, among others, include strong identity, access control, accuracy, integrity and auditability capabilities. [Ongoing; NASA, NSF, DOS, DOC]

4.4 Lead development of a plan for improving NEO monitoring through enhanced cooperation (and potential expansion) among U.S. and key country ground-based observatories. This plan will 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; NSF, NASA, DOS]

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. Activities could include hosting technical or informational sessions at international astronomical conferences on how to initiate and conduct programs for NEO observation, addressing both existing capabilities and needs, including the biannual Planetary Defense Conferences organized by the International Academy of Astronautics (IAA). In addition to these conferences, the United States will work to expand internationally coordinated global NEO exercises. The United States will also continue advocating for greater international cooperation on addressing the challenge large satellite constellations pose for astronomical observations, including in the detection of NEOs, within appropriate fora like the UNCOPUOS STSC. [Ongoing; NASA, NSF, DOS]

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

4.6 Continue to strengthen 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 and to increase the number of actively participating nations. This action should include developing and implementing a plan to broaden and enhance U.S. interagency participation in these forums, and actions to encourage other nations to join the activities, consistent with applicable law. The United States will continue to advocate for upholding the status and responsibilities of IAWN and SMPAG within UNCOPUOS, and specifically their reports to the Committee. [Ongoing; DOS, NASA]

4.7 Expand 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; DOS, DHS/FEMA, NASA, USGS]

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 a rare opportunity for international collaboration on technology demonstration missions for planetary defense with major scientific benefits, at relatively low cost. [Ongoing; NASA, DOS]

Goal 5: Strengthen and Routinely Exercise NEO Impact Emergency Procedures and Action Protocols

The United States will strengthen and exercise procedures and protocols for assessing NEO threats, communication—including to the public and international community—regarding threats, and response and recovery activities. Coordinated communications and notifications within the U.S.

Government and with foreign governments will improve impact emergency preparedness and reduce the physical and economic harm to the Nation.

The following actions support this goal:

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

5.1 Mature development of a set of real-world scenarios based on credible impact threats with observable parameters to inform planning and procedure development. NASA and FEMA in its consequence management role should 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. NEO Impacts should be considered and included in any future editions of Federal Interagency Operational Plans (FIOPs) and any proposed Domestic Incident Response Playbooks to prepare for response and recovery in advance of potential impacts. This action should lead to materials made widely available, such as on NASA websites and ready.gov, and that can provide the basis for advance planning and exercises at the Federal, State, and local levels. It should also include providing after-action reports from previous exercises to DHS/CISA and the FEMA National Exercise Division, which manages the overall National Exercise Program, along with names of subject matter experts who can answer questions from government officials. [Medium term; <u>NASA</u>, DHS/FEMA, DHS/CISA, USGS, OSTP, NSC]

5.2 Continue to improve protocols for notifying The White House and Congress (including briefing subcommittees of jurisdiction), 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 within the Federal Government regarding NEO threats. This action will comply as much as possible with current alert and warning protocols as creating a new system for just this scenario is not warranted. Develop appropriate modifications from existing emergency alerts based on specific NEO impact factors. 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 existing NASA PDCO and IAWN plans for exchange of information among national and international emergency response stakeholders. Use TTXs to determine effectiveness with emergency managers at local, state, and national levels. Exercise and improve the action flowchart for NASA PDCO. Enhance warning protocols and text for emergency alerts. [Ongoing; <u>NASA,</u> OSTP, FEMA, DOS]

5.3 Develop and share informational material for different audiences providing basic education, information on uncertainties, and emergency response plans. This action will include developing an integrated information package for use with social media, internet, and traditional press release formats for relevant information. [Short term; <u>NASA</u>, DHS/FEMA, OSTP]

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; <u>NASA</u>, OSTP, DOE NNSA, DOD]

Goal 6: Improve U.S. Management of Planetary Defense through Enhanced Interagency Collaboration

The U.S. government Departments and Agencies involved in improving the Nation's preparedness for Planetary Defense will improve ongoing interagency coordination/collaboration in three ways:

6.1 Convene an interagency group on planetary defense to address more detailed implementation issues than is practiced in White House-level interagency working groups. This interagency group will begin with quarterly meetings to address issues and progress of implementation work under this Action Plan. [Short term: NASA, DOD, DOE, DOC, DOC/NOAA, DHS/FEMA, DOS, NSF]

6.2 Agencies substantially involved with cooperation and collaborations outlined in this 2023 Planetary Defense Strategy will 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 Strategy. 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 will represent their respective agency on the interagency group established in Action 6.1. [Short term: NASA, DOD/USSF, USSPACECOM, DOE, NSF, DHS/FEMA, USGS, DOS, DOC]

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: NASA, DHS/FEMA, and other relevant agencies]

Conclusion

Hazardous NEO impacts pose a complex risk to both human life and critical infrastructure, and have the potential to cause substantial and possibly even unparalleled economic and environmental harm. This Strategy and Action Plan 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 activities outlined herein will improve detection, research, mission planning, emergency preparedness and response, international engagement, and internal U.S. government coordination on planetary defense. Implementing the NEO and Planetary Defense Strategy will increase the United States' ability and readiness, together with domestic and international partners, to mitigate the impact hazard posed by NEOs.

Appendix A: Acronyms

ACRONYM	DEFINITION
ASC	Advanced Simulation and Computing
ATAP	Asteroid Threat Assessment Project
ATLAS	Asteroid Terrestrial-Impact Last Alert System
CalTech	California Institute of Technology
CISA	Cybersecurity and Infrastructure Security Agency
CNEOS	Center for Near-Earth Object Studies
CSS	Catalina Sky Survey
DART	Double Asteroid Redirection Test
DHS	Department of Homeland Security
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOS	Department of State
FCC	Federal Communicational Commission
FEMA	Federal Emergency Management Agency
FIOP	Federal Interagency Operational Plan
IAWN	International Asteroid Warning Network
IRTF	Infrared Telescope Facility
JAXA	Japan Aerospace Exploration Agency
JPL	Jet Propulsion Laboratory
KDP	Key Decision Point
LCO	Las Cumbres Observatory
LEO	Low Earth Orbit
LICIACube	Light Italian Cubesat for Imaging of Asteroids
LINEAR	Lincoln Near-Earth Asteroid Research
MANOS	Mission Accessible Near-Earth Objects Survey
MIT	Massachusetts Institute of Technology
MPC	Minor Planet Center
MWG	Modeling Working Group
NASEM	National Academies of Sciences, Engineering, and Medicine
NEA	Near-Earth Asteroid
NEO	Near-Earth Object
NEO Surveyor	Near-Earth Object Surveyor infrared telescope

ACRONYM	DEFINITION
NEOWISE	NEO Wide-field Infrared Survey Explorer
NITEP	NEO Impact Threat Emergency Protocols
NNSA	National Nuclear Security Administration of the Dept. of Energy
NOAA	National Oceanic and Atmospheric Administration
NPD	NASA Policy Directive
NRAO	National Radio Astronomy Observatory
NSF	National Science Foundation
OSTP	Office of Science and Technology Policy
Pan-STARRS	Panoramic Survey Telescope and Rapid Response System
PDC	Planetary Defense Conference
PDCO	Planetary Defense Coordination Office
PHO	Potentially Hazardous Object
POC	Point of Contact
SAO	Smithsonian Astrophysical Observatory
SBDB	Small-Body Database
SDA	Space Domain Awareness
SMPAG	Space Mission Planning Advisory Group
SSA	Space Situational Awareness
SST	Space Surveillance Telescope
STSC	Scientific and Technical Subcommittee (of UNCOPUOS)
TIM	Technical Interchange Meeting
TMA	Telescope Mount Assembly
TraCSS	Traffic Coordination System for Space
TTX	Tabletop Exercises
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNOOSA	United Nations Office of Outer Space Affairs
USGS	United States Geological Survey
USSF	United States Space Force
USSPACECOM	United States Space Command
ZTF	Zwicky Transient Facility

Appendix B: Additional Planetary Defense Programs and Missions (Current and Proposed)

United States Government Programs

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 worldwide 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 Haleakalā, Maui, NASA provides funds to Pan-STARRS for NEO search and discovery operations.

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's Lincoln Laboratory LINEAR program has searched for and categorized Near-Earth Objects using data provided by US 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 is radar integrated with 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 near 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 a NEO astrometric follow-up project funded by NASA. Spacewatch primarily utilizes 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.

Las Cumbres Observatory

The Las Cumbres Observatory (LCO) is a global telescope network founded in 2005 and run by a non-profit science institute with partial support from NSF. It includes a homogeneous telescope network deployed in different locations in the northern and southern hemispheres. LCO's global coverage and the apertures of telescope available make it ideal for follow-up and characterization of objects in the Solar System, including comets and asteroids.

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.

Vera C. Rubin Observatory (Rubin)

The Vera C. Rubin Observatory is a joint National Science Foundation (NSF) and Department of Energy (DOE) multi-disciplinary facility that is currently under construction in north-central Chile. It will comprise of an 8.4-meter wide-field optical telescope, a 3.2-gigapixel camera, and an advanced data management system. Taken together, these components are designed to carry out a deep survey of nearly half of the sky for 10 years and enable a broad range of fundamental astrophysical research. Rubin Observatory will collect about 20 terabytes of imaging data every night. It will produce the widest-field sky images ever and issue alerts for changing and transient objects within 60 seconds of their discovery. The Rubin Observatory will significantly increase NEO detection rates.

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 33 minutes (~5%), 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 RESOURCE

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 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 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.

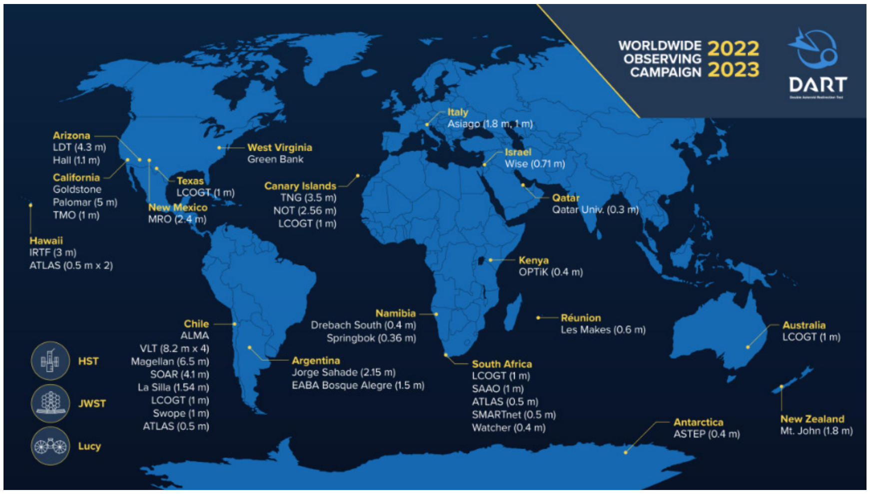
NNSA High-Performance Computing

The NNSA laboratories are world leaders in multi-physics simulations and high-performance computing. They currently host six of the world's fastest supercomputers and will bring its first exascale (10^{18} floating point operations per second) class computing platforms, Crossroads and El Capitan, online during the time covered by this action plan. The NNSA Advanced Simulation and Computing (ASC) program has developed, vetted, and maintained multi-dimensional, high-fidelity multi-physics codes on these platforms over the past quarter century. These high-performance computing platforms and multi-physics codes are used to conduct high-fidelity simulations in support of many missions, including stockpile stewardship, nuclear non-proliferation, and planetary defense.

Examples of International Planetary Defense Collaborations

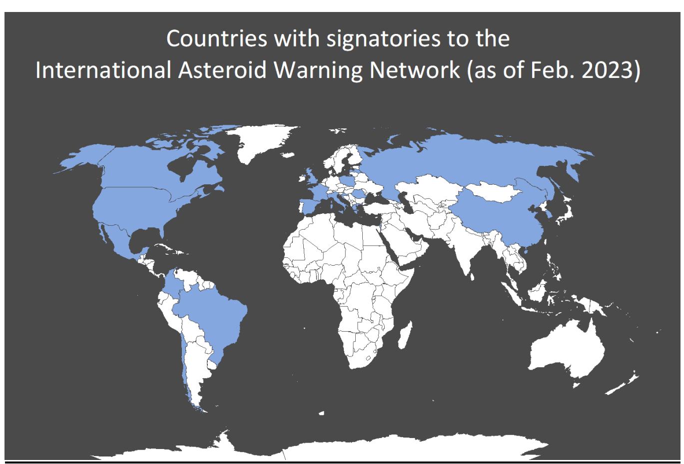
DOUBLE ASTEROID REDIRECTION TEST (DART) WORLDWIDE OBSERVING CAMPAIGN

The world diagram below depicts the worldwide network of astronomical 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.



INTERNATIONAL ASTEROID WARNING NETWORK (IAWN)

The UN-endorsed IAWN collaboration is established to coordinate and consolidate the information from observatories and orbit determination analysts worldwide to provide the best information available on any potential NEO impact threat to all member states so that all countries have a common understanding of any potential impact threat. IAWN currently consists of 50 signatories in 20 countries. Many participated in the DART mission observing campaign (See above). IAWN is coordinated by NASA, which supports the website at https://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.



SPACE MISSION PLANNING ADVISORY GROUP (SMPAG)

A second entity endorsed by the United Nation for international collaborations in Planetary Defense is the SMPAG, a forum for national space agencies to discuss and initiate collaborations on technologies and techniques that might be used to deflect or disrupt a NEO impact threat while it is still in space. See https://www.smpag.net. The SMPAG (acronym pronounced "same-page") currently has the space agencies or offices of 18 UN member states participating, and expects the application of three more space agencies in the near future. Participating agencies in SMPAG would consolidate plans and capabilities from the member states to recommend collaborative courses of action to their national leadership if an impact threat is discovered and verified by IAWN.

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 Comet 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 the inner Solar System in the mid-1980's. Near-Earth Asteroid Rendezvous-Shoemaker made history by landing on the asteroid Eros in 2001. JAXA's Hayabusa, Hayabusa 2, ESA's Rosetta and NASA's EPOXI, OSIRIS-REx and DART missions all encountered near-Earth objects.

There are additional flight missions under development for launch this decade:

The European Space Agency's Hera mission will launch in 2024 to the asteroid Didymos and study the impact site of the DART mission on the smaller nearby asteroid Dimorphos. The mission also features two small satellites capable of sensing the interior of the asteroids to map their geological structure and chemical composition.

Appendix C: Additional Developments Since the 2018 National Near-Earth Object Preparedness Strategy and Action Plan

GOAL 1: ENHANCE NEO DETECTION, TRACKING, AND CHARACTERIZATION CAPABILITIES.

- The NEO Surveyor space telescope was announced by NASA as a directed mission in 2019. It passed Key Decision Point (KDP) B in mid-2021 and KDP C in late 2022, beginning full project development.
- NSF and DOE have continued to support construction of the Vera C. Rubin Observatory. Integration and testing of the telescope mount assembly will be complete by Spring 2023, following the successful installation of the Commissioning Camera in 2022. The Observatory is nearing completion, with the first light expected in 2024. It will conduct its survey in six optical bands to assist with NEO characterization.
- The NASA-funded Asteroid Terrestrial-impact Last Alert System (ATLAS) became the first survey capable of searching the entire night sky every 24 hours for NEOs. This was made possible by the establishment of two new ATLAS telescope in the southern hemisphere—one at the El Sauce Observatory in Chile and the other at the Sutherland Observing Station in South Africa – in addition to the first two ATLAS telescopes in Hawaii.
- Pan-STARRS 2 became fully operational under NASA funding with the completion of its Gigapixel-2 camera. Operations and data processing for the two Pan-STARRS telescopes were optimized to improve performance as a system. NSF supported algorithm development and data archiving.
- Continued NASA funding enabled the Catalina Sky Survey (CSS) to upgrade its follow-up telescope camera for wider-field and improved faint object capability and to add a brokering system for optimizing NEO follow-up target selection that it has made available to the worldwide observing community.
- The Zwicky Transient Facility (ZTF) began operations at the Palomar Observatory in March 2018 as an astrophysics science sky survey. NASA awarded a grant to support the processing the ZTF data to extract NEO positions for submission to the Minor Planet Center. Continued operations of ZTF are partially supported by NSF.
- The Space Surveillance Telescope (SST) was relocated to Australia, where it will be operated jointly by the U.S. Space Force and the Royal Australian Air Force as part of the Space Surveillance Network. NASA continues to fund the LINEAR project at MIT Lincoln Laboratory to process SST survey images for natural object (i.e., NEO) detections.
- Initiation of an interagency study to examine needs and technologies for deep space planetary radar capability following the loss of the Arecibo Observatory's 305-meter radio telescope on December 1, 2020. Prior to the loss, the facility has had the most productive few years of radar observations of NEOs. Planetary radar has continued since with the Goldstone Solar System Radar near Barstow, CA.
- Preliminary testing on NSF's Green Bank Telescope of a prototype low-power radar, developed by Raytheon in conjunction with NSF's Very Long Baseline Array which is operated by the National Radio Astronomy Observatory, resulted in highest resolution images of the Moon collected from ground. NSF is funding conceptual designs of next-generation medium- and high-power radars for potential deployment on current and future radar-capable facilities.
- Enhanced data collection on bolide (bright meteors) events through collaboration between NASA and DOD/USSF for more detailed analysis of bolide event light curves to discern object strengths and composition.
- Modest increase in number of projects supported by NASA that research Near-Earth Asteroid (NEA) physical properties. Understanding NEA physical properties is critical for modeling potential impact effects

and determining if and what mitigation actions might be necessary to deflect a Potentially Hazardous Object (PHO).

- CNEOS and ATAP led the development of the hypothetical impact scenarios used for simulated impact threat exercises in two Planetary Defense Conferences (PDCs).
- Conducted National Interagency Table-Top Exercise (TTX) #4 to inform and assess the ability of the United States to respond effectively to a (simulated) asteroid impact threat.[7]
- Led International Asteroid Warning Network (IAWN) exercise of worldwide observation capabilities of asteroids, including Apophis. The exercises brought together more than 100 astronomers around the world to test the international discovery and tracking systems for PHOs. The exercises confirmed that, between initial-detection and follow-up characterization, the international planetary defense community can act swiftly to identify and assess the hazards of newly discovered near-Earth Objects.
- The Planetary Science and Astrobiology Decadal Survey 2023-2032 recommended that NASA should support the development, timely launch, and subsequent operation of the NEO Surveyor mission.

GOAL 2: IMPROVE NEO MODELING, PREDICTION, AND INFORMATION INTEGRATION.

- The NEO Action Plan Modeling Working Group (MWG), chaired by NASA Ames Asteroid Threat Assessment Project and with participation from U.S. national laboratories, was established in late 2019. The MWG developed initial computer simulations and held asteroid impact exercise meetings in 2019 and 2020.
- CNEOS developed NEO deflection simulation tools and enhanced their software capabilities that compute high precision orbits, future motions, and assess impact hazards of NEOs.
- NASA Ames Research Center, USGS, and Los Alamos National Laboratory conducted a Global Effects Technical Interchange Meeting (TIM) in 2022.
- Used existing tools of the USGS traditionally used for modeling the effects of other natural disasters, for modeling an asteroid impact event.

GOAL 3: DEVELOP TECHNOLOGIES FOR NEO DEFLECTION AND DISRUPTION MISSIONS.

- NASA successfully demonstrated the Double Asteroid Redirection Test (DART), the first planetary defense test mission, by using a kinetic impactor to alter the orbital period of a celestial body for the first time. DART was launched in 2021 and impacted Dimorphos in 2022.
- Rapid response reconnaissance missions were assessed by the UN-endorsed Space Mission Planning Advisory Group (SMPAG) and the 2023-2032 Planetary Science and Astrobiology Decadal Survey recommended a rapid-response, flyby reconnaissance mission to a NEO to follow DART.
- NASA has begun preliminary concept studies related to a rapid-response flyby reconnaissance mission. More work on rapid response reconnaissance missions on-going in 2023 workshops.

[7] NASA. *2022 Interagency Tabletop Exercise (PD TTX4)*. https://cneos.jpl.nasa.gov/pd/cs/ttx22.

GOAL 4: INCREASE INTERNATIONAL COOPERATION ON NEO PREPAREDNESS.

- The DART mission involved an Italian satellite, LICIACube, which carried out observational analysis of the Didymos asteroid binary system after impact on Dimorphos. Additionally, ground-based observations of the orbital period change were contributed from other areas of the world.
- Provided scientific support and collaborated on the European Space Agency's planetary defense mission Hera, planned for 2024, which aims to investigate the DART-impacted Didymos binary asteroid system.
- Increased participation in core international bodies dealing with NEOs, including the SMPAG, from 12 to 19 member states, and the International Asteroid Warning Network (IAWN), from 13 to 50 signatories.
- Conducted Planetary Defense Conference exercises which practiced a scenario in which a fictional asteroid was discovered on a collision course with Earth. The purpose of the exercises was to work out the questions and concerns that may arise from time of discovery of a PHO through its predicted impact with Earth.[8]
- Maintained "NEOs" as an agenda item and delivered an annual statements and presentations at the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS), which now has 102 Member States.
- Included 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 "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."
- DOS hosted an International Asteroid Day event in 2022 with a panel consisting of space agency representatives and planetary scientists from the U.S. and the international community.
- Developed talking points to deliver to other nations concerning the importance of NEO research, tracking, funding, and mitigation.

GOAL 5: STRENGTHEN AND ROUTINELY EXERCISE NEO IMPACT EMERGENCY PROCEDURES AND ACTION PROTOCOLS.

- The NEO Impact Threat Emergency Protocols (NITEP) IWG, established in 2019, made significant progress toward implementation of Goal 5, including completion of two actions. Advances included:
  - Establishment of procedures and timelines for (1) threat assessment upon detection of potential NEO impacts and (2) risk/benefit analysis of mitigation options following a threat assessment;
  - Development of benchmarks for determining when to recommend NEO reconnaissance, deflection, and disruption missions; and
  - Review of protocols for notifications and communications regarding NEO threats within the Federal Government, as well as guidance on content for notifications and communications to the public, Congress, and international stakeholders.
- Updated NASA Policy Directive (NPD) in 2021, which details how NASA will provide timely and accurate reporting of a very close approach or predicted impact of a NEO. Another update underway will include administrative changes and an annex detailing agency points of contact.
- Initiated preliminary plan for Interagency Tabletop exercises to be conducted every two years.

[8] NASA. *Hypothetical Impact Scenarios*. https://cneos.jpl.nasa.gov/pd/cs.

- Demonstrated to most participants at the FEMA/NASA Planetary Defense tabletop exercise (TTX) that current protocols by NASA are effective for notifications to inter-governmental partners and leadership.

Appendix D: History and Evolution of Finding NEOs and Assessing the NEO Impact Hazard

Observations of celestial bodies and comets have been recorded for thousands of years across civilizations, but the development of NEO astronomical observation including asteroids is a comparatively recent development. Even more recent is research to understand and pursue developing the capability to mitigate their impact risks. 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, was not 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.[9] 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.[10]

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 kilometer-wide asteroid likely caused a mass extinction on Earth and killed off non-avian dinosaurs about 66 million years ago, and that this event corresponded to the age of Chicxulub impact crater.[11] The asteroid impact theory, attributed to the Alvarez *et al.* team, became widely 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 1989 FC,[12] 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).[13]

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

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

[10] 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.

[11] 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.

[12] House Committee on Science and Technology, Subcommittee on Space and Aeronautics, 110th Congress. November 8, 2007. Hearing on "*Near-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.

[13] 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.

within five million miles of Earth's orbit.[14] The Science Definition Team identified 140 meters as the size that could cause severe 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 potentially hazardous objects (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. [15]

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.[16] 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 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.[17] In 2014, the United Nations Office of Outer Space Affairs (UNOOSA) endorsed the creation of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG), formally bringing to bear many of the world's space observatories and expanding planetary defense into a global effort.[18] 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.[19] In 2022, for the first time, the Planetary Science and Astrobiology Decadal Survey prominently featured a section on planetary defense, and recommended that NASA's PDCO should be "robustly supported and sustained as the critical organization to advance U.S. planetary defense capabilities" for at least the next decade.[20]

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[14] 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.

[15] National Aeronautics and Space Administration Authorization Act of 2005 (P. L109-155. §. 321)

[16] Issued in response to the National Aeronautics and Space Administration Authorization Act of 2005. 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.

[17] 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.

[18] 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.

[19] 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.

[20] National Academies 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.

Today, a new era is starting: in 2022, NASA's Double Asteroid Redirection Test (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 National Science Foundation (NSF)/Department of Energy (DOE)-supported Vera C. Rubin Observatory (beginning operations in 2024-2025), and the NEO Surveyor space telescope (anticipated for launch by 2028).[21] 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 kilometers of Earth's surface in 2029, presenting a serendipitous opportunity to further advance Earth's planetary defense through technology demonstrations and international collaboration.

[21] In 2022, NASA approved the NEO Surveyor space telescope to begin mission development for launch by 2028. Title VII of the CHIPS and Science Act, the National Aeronautics and Space Administration Authorization Act of 2022 (P. L. 117- 167 § 10825), 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.