IAU Near-Earth Object Working Group
Inter-Division A-F, Functional
Triennial Report 2021-2024

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The NEO Working Group is a functional inter-Division A-F WG. It continues its task of monitoring and participating to the international activities focused on planetary defense, of representing the IAU in international groups, such as the UN-endorsed International Asteroid Warning Network (IAWN; see: https://iawn.net). It also highly contributes to public outreach efforts, noting that NEOs and planetary defense are of high interest for the public. Below we summarise some of the main advances in this area during 2021–2024.

Space Missions
In 2021, the JAXA Hayabusa2 mission preliminary examination team performed the first analysis of samples (5.4 g in total) from the carbonaceous NEO Ryugu and found that its composition matches that of CI meteorites. Hydrated minerals, organic molecules, amino acids and uracile were also identified in the samples, in agreement with dynamical scenarios suggesting that asteroids may have brought to Earth the elements that contributed to the emergence of life on Earth. Analyses are still ongoing.

In November 2021, NASA launched the DART mission to the binary NEO Didymos. The successful impact of the NASA DART spacecraft on Dimorphos, the small moon of the binary asteroid Didymos, occurred on September 26, 2022 (see: https://dart.jhuapl.edu). DART successfully deployed the Italian Cubesat LICIACube two weeks before the impact. LICIACube observed the impact and the minutes following it, giving us precious data on the impact and its early ejecta. Telescopes around the world also observed the event, allowing the determination of the change of the orbital period of Dimorphos around Didymos, which was reduced by 33 minutes from its original 11 hours and 55 minutes. Moreover, the Hubble Space Telescope and the James Webb Space Telescopes for the first time pointed to the same object, showing us the asteroid system after impact, with a very long tail (even two) resulting from the production of ejecta, resembling a comet. Boulders remained identified in the system's vicinity a few months after impact on an escaping trajectory from the system. DART was thus extremely successful, demonstrating the possibility to hit a small target from which we knew initially only the size (and not the shape and other surface characteristics) and perform a deflection. The first results were published in 5 articles in the journal Nature in March 2023. In total, more than 80 papers were published so far after the impact. Results were presented at the AGU meeting in 2022, LPSC meeting in 2023 and 2024, and the Asteroids Comets, Meteors meeting in 2023. The images of the DRACO camera onboard DART revealed the shape and surface properties of Dimorphos, at least on one side, showing

a body with a surface extremely rich in boulders of various morphologies and an oblate spheroidal shape challenging binary formation models. Many questions remain, which include the actual value of the mass of Dimorphos that goes into the calculation of the momentum transfer efficiency of the DART impact, the internal structure of the asteroid, which plays a big role in its impact response, the possible reshaping of Dimorphos due to the impact, its rotational state etc. The answers to these questions will be provided by the ESA Hera mission, which is in development with a launch scheduled in October 2024 using a Falcon 9 of the company Space X. Hera spacecraft with its two Cubesats Juventas and Milani will get to Didymos by October 2026, providing us detailed measurements of DART impact outcome and full compositional and physical characterization of the asteroids, including for the first time subsurface and internal properties (see: https://www.heramission.space). Hera will then fully document the impact experiment and deflection test performed by DART at actual asteroid scale, offering an unbiased interpretation of the impact and its extrapolation to other scenarios.

On September 24, 2023, the NASA OSIRIS-REx mission successfully returned to Earth some samples of Bennu, a carbonaceous NEO. This is the first mission to return such a mass of samples, measured to be 121.6 grams. The analysis started in fall 2023 and shows that Bennu's composition matches the composition of CI meteorites, like Ryugu (the asteroid from which the JAXA Hayabusa2 mission returned some samples to Earth). While this kind of meteorites is rare on Earth, the fact that the two carbonaceous asteroids from which samples were returned match the composition of these meteorites tells us that CI material must be abundant in space and possibly filtered by Earth's atmosphere due to its low strength. In fact, the bulk densities of those samples, as well as those of Ryugu, are much lower than the bulk densities of CI meteorites, which has implications on mitigation methods.

Future Missions under development

The NEO Surveyor mission is in development at NASA. It will allow making the inventory of NEOs larger than 140 meters (including direct measurement of their diameter) within about 10 years for space and therefore assessing the threat of such objects on a short-middle timescale. The DART mission, although successful, showed the necessity to be able to anticipate the possible impact of an asteroid well in advance.

Other funded NEO missions include the extension of NASA OSIRIS-REx, called OSIRIS-APEX, which is on its way to visit the NEO Apophis several days after its closest approach to the Earth in 2029, JAXA Hayabusa2# (for Sharp or Small Hazardous Asteroid Reconnaissance Probe) that will perform a flyby of 2001 CC21 in 2026 and a rendezvous with the 30-meter-sized NEO 1998 KY26 with a 10 minute spin rate in 2031, which has high planetary defense relevance, the JAXA Destiny+ mission to the active NEO 3200 Phaethon, and the Chinese Tianwen-2 mission that is announced for a launch in 2025 to sample the very small NEO (469219) Kamoʻoalewa.

Although note devoted to NEOs, we want to mention the United Arab Emirates (UAE) Space Agency, which successfully performed the HOPE mission to Mars that included a flyby and new images of Deimos, and which is now developing the Emirates Mission to the Asteroid

belt (EMA). The mission will launch in 2028 to perform 7 asteroid fly-bys, ending with a rendezvous and landing on the asteroid Justitia, showing that new important actors contribute to the development of asteroid missions and related knowledge and discoveries.

Other missions are also under study at ESA, not yet funded at the moment of writing of this report, to visit Apophis before and during the encounter of the asteroid with Earth in 2029, in synergy with OSIRIS-APEX. In particular, RAMSES (Rapid Apophis Mission for SEcurity and Safety) is investigating a re-use of the Hera spacecraft design with two cubesats to be launched in April 2028 to perform a rendezvous with Apophis two months before its closest approach with Earth in 2029, and stay until at least August 2029. ESA delegations should meet in 2024 to approve the continuation of the study, while waiting for formal approval at ESA Council at Ministerial Level in 2025, so that it can be ready for launch in 2028. A mission concept called DROID (Distributed Radar Observations of Interior Distributions) is also studied in collaboration between CNES and JPL, focused on the internal structure of Apophis and its possible change, with measurements performed by a bistatic radar, using the same kind of architecture as RAMSES. Note that the possibility to launch fast reconnaissance missions follows the recommendation of the US Planetary Science Decadal Survey 2023-2032, which for the first time, includes planetary defense in this set of topics.

Other flyby concepts are under study in other countries, but we lack information to elaborate about them. Nevertheless, this shows that there is clearly a high international interest to visit Apophis and complement the measurements that APEX will perform after the closest approach. This is also why a working group is proposing to UN to define 2029 as the International Year of Planetary Defense (IYPD), so that public events can be organized worldwide along the year to educate the public on this topic and asteroid science, and set up observations during the approach of Apophis, while it will be visible by more than 2 billions people in Western Europe and North Africa with naked eyes. Images of the asteroid taken from a spacecraft and shared with the public on a screen while they observe its light with their eyes on the same time would enter in the collective memory.

At an early stage of development, the NEOMIR concept is being studied at ESA. This mission survey mission would complement NEO Surveyor by targeting smaller solar elongations. If approved, launch may take place in 2030 or after.

NEO surveys and risk assessment

Teams involved in discovering and tracking of NEOs continued to improve their capabilities. The leading teams are the Pan-STARRS NEO Survey and the Catalina Sky Survey, which now discover over 2,000 new NEOs each year between them. The majority of NEO searches still occur at Equatorial and Northern declinations, but in 2022/23 the ATLAS project began operating two survey units in South Africa and Chile. There is a strong dependence of discovery rate on the phase of Moon, because the bulk of new NEOs are discovered via ground based optical surveys. However, the pathfinding infrared space survey NEOWISE continues to operate and also finds NEOs. The current rate of discovery is 8 per day on average. In September 2022 the total number of NEOs surpassed 30,000, with the total now standing at over 34,000.

Newly reported NEOs are immediately assessed for impact risk at the NASA Centre for NEO Studies (CNEOS) at the Jet Propulsion Laboratory, USA; the ESA NEO Coordination Centre (NEOCC) at the European Space Research Institute, Italy; and the IAU Minor Planet Centre (MPC) at the Smithsonian Astrophysical Observatory, USA. Working on the real-time reporting of new NEOs, in 2021–2024 these led to the successful prediction of the impact of 4 small asteroids: 2022 EB5, 2022 WJ1, 2023 CX1 and 2024 BX1, bringing the total number to 8. The process that led to the prediction of the impact worked flawlessly: from the observations being sent to the Minor Planet Center to the impact predictions from the Scout system (JPL/CNEOS), especially in the case of the last three objects. All impactors were 1-3 m in diameter and led to spectacular but harmless fireballs. The last two impacts led to successful recovery of meteorites, allowing laboratory analysis of fresh NEO samples. These successful stories are just examples of how international collaborations lead to amazing results. While these impactors were small and could not create any harm, these cases demonstrate the importance of coordinated international efforts to discover and track potential hazardous asteroids.

Aside from enlarging the catalogue of known NEOs, these surveys allow modelling of the underlying NEO population. This leads to better knowledge of the overall impact risk, as well as providing the basis for studies of the origins and evolution of the NEO population. Modelling in 2023 of Catalina Sky Survey detections supported previous suspicions that the orbital distribution of NEOs is a function of size. The known population of NEOs with diameters larger than 140 meters is approaching 50% completeness. At smaller sizes the estimated number of NEOs still has significant uncertainties.

In the near future, the NEO discovery rate will see major increases. The Legacy Survey of Space and Time (LSST) is expected to start in 2025 at the Rubin Observatory, which will extend the sensitivity of ground based surveys by two magnitudes. Following this in 2027/28 will be the launch of the NEO Surveyor Mission (see above).

Community Organisation and Activities

The IAWN and Space Mission Planning Advisory Groups met two times per year in 2021-2024. They cover a wide range of activities, related to observations of NEOs, space missions, legal aspects and a planetary defense exercise. Reports of IAWN meetings can be found here: https://iawn.net/meetings.shtml, while reports of SMPAG meetings can be found here: https://www.cosmos.esa.int/web/smpag. In 2021 and 2022, IAWN conducted two different timing assessment campaigns. The goal of the campaigns was to provide an opportunity for the observers to check their timing accuracy by observing two near-Earth asteroids: 2019 XS in 2021 and 2005 LW3 in 2022. The campaigns have been proven to be extremely useful. Results have been published in two different papers, one for each campaign.

In Europe, the European Union and its Horizon 2020 program funded two projects in the time frame 2020-2023: NEO-MAPP (Near Earth Object Modelling and Payload for Protection) that supports activities related to the Hera mission and future NEO missions (see: https://neomapp.eu) and NEOROCKS that performed studies oriented on ground based observations and characterizations of NEOs and impact predictions (see:

https://neorocks.eu). These projects generated a lot of results and ended in May 2023 and April 2023, respectively.

Many international workshops and meetings have taken place in 2021-May 2024 that are relevant to NEO and planetary defense activities:

- The 6th IAA Planetary Defense Conference 2021 on April 26-30 in Vienna (Austria).

- The Apophis T-7 workshop took place on May 11-13, 2022 virtually and presented the activities related to this asteroid, as well as possible space mission projects (see: https://www.hou.usra.edu/meetings/apophis2022/).

- The Hera international workshop took place on May 30-June 3, 2022, in Nice (France) and gave an overview of the various activities and their advances regarding this mission (see: https://www.heramission.space/heraworkshop2022).

- The IAU Symposium S374 Astronomical Hazards for Life on Earth was held at the XXXI IAU General Assembly in Busan, Republic of Korea, in the week of August 8-11, 2022 (see: http://hazards.astronomia.edu.uy)

- The IAU Focus Meeting 8 Planetary Astronomy via Telescopic and Microscopic Approaches was also be held at the XXXI IAU General Assembly in Busan, Republic of Korea, on August 2-11, 2022 (see: https://iau2021fm8.kasi.re.kr).

- A Planetary Defense session was organized at the European Planetary Science Congress (EPSC) 2022 on September 18-23, in Grenada (see: https://meetingorganizer.copernicus.org/EPSC2022/session/44648).

- A Plenary Session on Planetary Defense took place at the IAC 2022 in Paris on September 18-23 (see: https://iac2022.org).

- A Planetary Defense Panel was organized at the SpaceOps Conference in Dubai on March 6-10, 2023 (see: https://spaceops2023.org/plenary-events/).

- The 8th IAA Planetary Defense Conference is took place on April 2-7 in Vienne (see: https://iaaspace.org/event/8th-iaa-planetary-defense-conference-2023/).

- The Apophis T-6 workshop took place on May 10-12, 2023 virtually and presented the activities related to this asteroid, as well as possible space mission projects (see: https://www.hou.usra.edu/meetings/apophis2023/).

- The Asteroids, Comets, Meteors 2023 took place in Flagstaff on June 18-23, 2023, and we can expect that NEO sessions will take place (see: https://www.hou.usra.edu/meetings/acm2023/).

- The Hera International Workshop is took place at ESA/ESTEC, on October 10th-13th, 2023.

- A planetary defense session was organized at the IAC 2023 in Bakou (see: https://www.iafastro.org/events/iac/iac-2023/).

- A DART/Hera Planetary Defense session was organized at the Lunar and Planetary Science Congress (LPSC) 2024 in the Woodlands, US in March 2024 (see: https://www.hou.usra.edu/meetings/lpsc2024/technical_program/?session_no=205)

- The Apophis T-5 workshop and Hera International workshop took place at ESTEC on April 22-26, 2024 (see: https://www.hou.usra.edu/meetings/apophis2024/ and https://www.cosmos.esa.int/web/hera-meetings/apophis_hera_04_2024)

- A planetary defense session is organized at the Assembly of the Japanese Geophysical Union (JpGU) in Chiba on May 29, 2024 (see: https://www.jpgu.org/meeting_e2024/)

Summary

NEOs and Planetary Defense remain very active areas of research, which always generate the high interest of the public and the medias, as demonstrated by the great amount of both scientific and popular articles that new results on NEO-related research generate. The media interest was at its maximum for the DART impact and is especially high when a new NEO is discovered. This is part of the reason why a committee is working on a proposal to the UN to define 2029, which is when Apophis will come close to Earth, as the International Year of Planetary Defense, which will trigger a big amount of public outreach activities along the year on this topic, noting that UN already endorsed June 30 as the Asteroid Day of each year.

We are looking forward to the next discoveries and space projects to be launched, starting with the ESA Hera mission this year!

Patrick Michel
On behalf of the NEO WG.

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