Lessons Learned from Near-Earth Asteroid 2024 YR4 and the International Coordination that Retired the 2032 Earth Impact Risk

NASA Planetary Defense Coordination Office

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[1] The views and information in this document are solely based on research while at NASA and do not represent the views of the United States Air Force.

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Executive Summary

2024 YR4 provided the most apparent near-term risk of any asteroid the planetary defense community has discovered since the 2004 discovery of 99942 Apophis. The international effort related to the asteroid demonstrated decades of growth in technologies useful for Near-Earth Object (NEO) observation and a strategic maturation of the institutions and coordination mechanisms designed to defend the planet from potential impactors. Career-spanning efforts by individuals and organizations inside and outside of government brought about success in the 2024 YR4 event. These included NASA's Planetary Defense Coordination Office (PDCO), international partners at the European Space Agency (ESA), UN Office of Outer Space Affairs (UNOOSA), International Asteroid Warning Network (IAWN), Space Mission Planning Advisory Group (SMPAG), interagency partners, universities, private institutions, orbital calculation groups, key individuals, and observatories across the globe and in space. In decades past, an object such as 2024 YR4 would have been missed altogether or lost prior to having the orbit defined. However, the growth of sophisticated redundant technologies and advances in how to employ them enabled the modern planetary defense community to detect and confirm 2024 YR4, carry out extensive follow-on observations to refine its impact probabilities and physical characteristics, and coordinate and communicate sufficiently to resolve its risk level within the first apparition. Such growth has been the outcome of strategic decisions by leadership of the planetary defense community.

One of the newest survey technologies on Earth, the NASA/PDCO-funded Asteroid Terrestrial-impact Last Alert System (ATLAS) station of the University of Hawai'i in Chile, discovered 2024 YR4 on 27 Dec 2024. The asteroid reached a level 1 on the Torino Scale by 30 Dec 2024 – an impact risk level that currently occurs approximately two to three times a year. By 28 Jan 2025, the Center for Near-Earth Object Studies (CNEOS) at NASA's Jet Propulsion Laboratory (JPL), ESA NEO Coordination Centre (NEOCC), and NEO Dynamic Site (NEODyS) in Italy independently estimated 2024 YR4 met size and Earth Impact Probability (IP) minimums to be raised to level 3 on the Torino Scale. 2024 YR4 reached Torino level 3 when it reached at least a 1% chance of a 22 Dec 2032 Earth impact based also on its approximate size of over 50 meters (m) in diameter. This made it the most potentially hazardous object the planetary defense community had become aware of in twenty years. 2024 YR4 was estimated to be several times larger than the ~20 m meteor that exploded over Chelyabinsk, Russia in 2013, creating an approximate 0.5 Megaton airburst which damaged over 7,200 buildings and injured over 1,500 people. Because 2024 YR4 exceeded the 1% threshold

probability of a future impact, the PDCO carried out required agency and interagency notifications. IAWN, chartered in 2013 and coordinated by NASA's PDCO, also carried out required international notifications and coordinated further observation of 2024 YR4. While the IP for an asteroid may rise after discovery, it will usually fall as follow-on astrometric data further confine the probability ellipses for such objects and eliminate Earth from being within it. However, 2024 YR4's IP increased over the 52 days after its discovery and reached a high of 3.1% on 18 Feb 2025 before finally falling below the 1% threshold on 20 Feb 2025.

Over the course of the asteroid's apparition—its period of visibility from Earth during this orbit—progressively larger ground-based telescopes were needed to observe 2024 YR4. The ground-based assets included sub-2 m telescopes, in the first few days after discovery, and the large 8+ m telescopes. As the object's orbit took it farther from Earth, James Webb Space Telescope (JWST) also provided observations. From 27 Dec 2024 to the present, at least 63 assets and observatories across the globe published over 500 observations, from small personally owned telescopes to the largest professionally run telescopes on Earth, from venerable technologies to the newest available. Of the observatories involved, 24 provided the most useful data for astrometry, including observations and vetted detections in archival data known as "precoveries," to the Minor Planet Center (MPC) - the world's central processing organization for small body position measurements - at the Harvard and Smithsonian Astrophysical Observatory (SAO). Several provided useful data for physical characterization of the object which enables better understanding of the object size, mass, density, shape, spin, and colors. After seven weeks of additional observation, the worldwide coalition, coordinating through formal and informal networks, enabled the planetary defense community to successfully refine 2024 YR4's IP down to nearly zero and determine it posed no threat to Earth for the next century. It also more accurately refined the object's size at 60 +/-7 m through successful employment of the JWST. The community successfully carried out this mission through a period of wildfires that destroyed the homes of 150 personnel at NASA JPL and forced the shutdown of the JPL server, over the holidays (with the closest approach on Christmas Day and reaching Torino scale 1 near New Year's Eve), and while successfully and quickly adapting with personnel for a new Administration beginning 20 Jan 2025 unfamiliar with the notification policies and procedures, just as the object approached Torino level 3. This document provides a chronological record of this coordination effort and provides lessons learned to make future such efforts even more effective, in preparation for an anticipated increase in such events in the near future with new technologies. These lessons learned include further understanding of the notification process for a Torino 1-3 level event, how the astrometry and physical characterization communities coordinated, public messaging, and other areas of improvement for future detected significant asteroid impact hazards.

Introduction

On 3 Mar 2025, Dr. Kelly Fast, NASA's Acting Planetary Defense Officer and Lindley Johnson, NASA's Planetary Defense Officer Emeritus, directed this review of the broad NASA, interagency, and international effort associated with asteroid 2024 YR4. The review provides a narrative of actions associated with the asteroid and lessons learned. Its purpose is to inform and augment the full spectrum of planetary defense related to NEOs whose hazard rating on the Torino Scale rises above zero. Understanding and tracking the global response for asteroids similar to 2024 YR4 is vital to evolving the community for the next stages of planetary defense—defending Earth against both city-wide and regional devastators. In the past 25 years, two objects reached Torino Scale 3 or above. 2024 YR4, approximately 60 m in diameter, reached a peak IP of 3.1% in 2025, and 99942 Apophis, a 335 m diameter object, reached a peak IP of 2.7% in 2004. The ability for the community to more quickly estimate the risks of these objects was an outcome of the rapid increase in the global capacity to detect, characterize, track, and successfully refine the orbits of NEOs.

Discoveries of small but hazardous asteroids will increase in the next decade due to advances in planetary defense capabilities. This includes NASA's NEO Surveyor space telescope (launching no earlier than Sep 2027), the Vera C. Rubin Observatory's (National Science Foundation) Legacy Survey of Space and Time (LSST) Camera (Department of Energy, online in 2025), ESA's Flyeye telescope (completing in 2025) and NEO Mission in the Infra-Red (NEOMIR) (launch targeted in 2030s). NEO Surveyor and Vera Rubin Observatory alone are projected to discover about 10 times the number of NEOs found with current capabilities, which means the planetary defense community could be analyzing hundreds of thousands to millions of newly discovered objects in the coming decade. Analysis of actions taken for 2024 YR4 helps inform the community to ready itself for this mass influx of discoveries, to ensure their rapid orbital refinement, characterization, cataloging, and when necessary, alert notifications and mitigation strategies for objects that pose significant risk.

The PDCO assigned this project to Todd Borzych, a NASA SkillBridge Fellow from the U.S. Air Force (USAF) who worked for the PDCO in the Spring of 2025. Colonel Borzych, in his NASA capacity, interviewed 36 international subject matter experts involved in planetary defense, including astrometry and physical characterization astronomers from survey and follow-on observatories, asteroid mitigation specialists, interagency and international coordinators, and orbital specialists. He and colleagues spoke to leadership in NASA, ESA, and interagency partners and reviewed documentation on the 2024 YR4 effort, including 900 emails, associated briefings, web pages, news reports on the object, Slack channel data, and other data associated with 2024 YR4. The review also includes discussion of applicable guidance, including NASA Policy Directive 8740.1 and agreements on international notifications through IAWN.

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Chronological Narrative

Discovery (27 Dec 2024) to the First Full Moon (12 Jan 2025)

Detection. On 27 Dec 2024 at 05:42 UTC, the new ATLAS station of the University of Hawai'i located in Chile (MPC observatory code W68), while carrying out Near-Earth Asteroid (NEA) search operations for NASA, detected several unconfirmed asteroid candidates with its relatively new (2022) 50 cm survey telescope.[2] Astronomer Dr. Larry Denneau received the candidate list, which included the object at visual magnitude 16.2 that would be soon designated as 2024 YR4 and reported it to the MPC. The detection was two days after the object's closest approach of 2.2 Lunar distances from Earth (Christmas Day, 25 Dec 2024) as it passed from the daytime into the nighttime sky and occurred as the object was rapidly receding from its proximity to Earth.

Surveys such as ATLAS discover NEOs regularly, and at initial detection, risk levels for such objects are often not immediately apparent until confirmation and orbital refinement occurs. At the time, Dr. Denneau was not aware 2024 YR4 was an unusual NEA. In mid-January, the ATLAS staff would later learn of 2024 YR4's increased risk level when a search for further precoveries commenced.[3]

Confirmation. In accordance with processes long established by the PDCO and its predecessors[4], the initial alert by the ATLAS survey telescope was automatically listed on the MPC's NEO Confirmation Page (NEOCP), the site astrometry observers actively monitor to see what objects need confirmation. This triggered follow-on observations by other telescopes often referred to as "dedicated" telescopes. Unlike the survey telescopes which are designed to image broad swathes of the night sky rapidly to discover asteroids, dedicated telescopes are designed to follow-up on specific points of predicted orbits from previous observations. These rapid follow-up observations contributed to the initial confirmation process within hours of discovery and were carried out by the 1.0 m CSS Steward Observatory on Mount Lemmon, AZ (I52), the 0.3 m iTelescope Observatory at Siding Spring, Australia (Q62), and Y. Ikari, an independent astronomer in Moriyama, Japan employing a 0.26 m reflector (900) , as well as precovery observations (26 Dec 2024) from the 0.7 m wide field of view CSS Schmidt telescope (703) near Mount Bigelow, AZ. Such coordination of survey/discovery observatories with more precisely targeted, narrower field of view but larger aperture telescopes is a key example of the evolution of systematic coordinated observation efforts put in place by NASA, ESA, and the larger

[2] ATLAS is a wide-field survey which images the entire sky every night with 30-second exposures, down to a visual magnitude of 19.5, generally equivalent to a 50 m diameter NEOs.
[3] Dr. Larry Denneau learned later from Dr. Kelly Fast, PDCO/Acting Planetary Defense Officer, that JPL/CNEOS increased on the Torino scale. PDCO is exploring notifications to the survey observatories to facilitate earlier searches for precoveries.
[4] The PDCO was established in Jan 2016 at NASA HQ within the PSD. It coordinates U.S. interagency efforts to detect PHAs and plan responses to asteroid impact hazards. Internationally, the PDCO coordinates with international space agencies through the IAWN, which NASA chairs, and with the ESA-chaired SMPAG.

planetary defense community. It should be noted that this effort occurred as a matter of routine operations, without the observers yet knowing the object would soon reach Torino scale 1.

At 12:27 PM EST 27 Dec 2024, the MPC published a Minor Planet Electronic Circular (MPEC) on the object with these initial known survey and confirmation observations, which provided the designation of 2024 YR4 using its NEO Confirmation Page (NEOCP) Automatic Processing (NAP) system.[5] Dr. Matthew Payne, MPC Director, noted the process of designating 2024 YR4 occurred fully automatically, which occurs for around 50% of newly discovered objects now. ATLAS, he noted, is a very reliable observatory, and reliable observations make it easier for the MPC to designate an object.

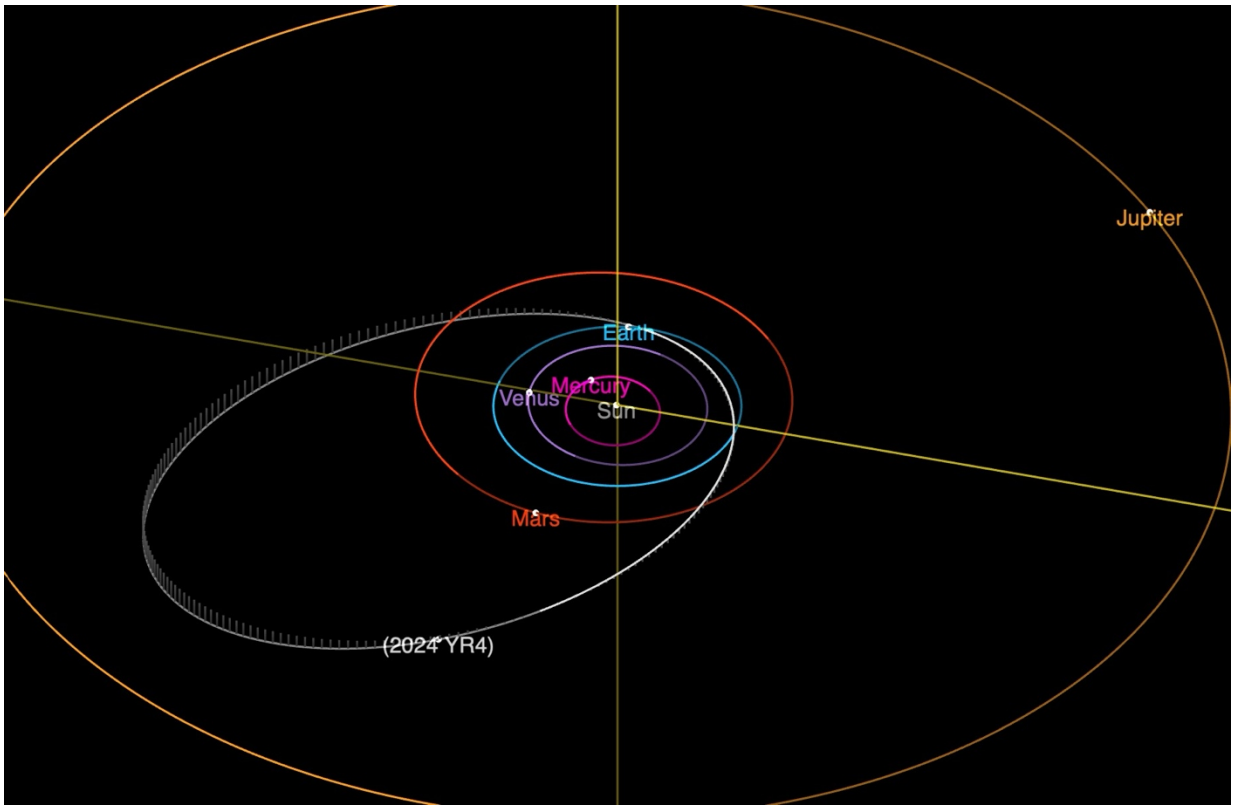

Figure 1: 2024 YR4 Orbit (NASA/JPL/CNEOS)

Figure 1 shows the CNEOS depiction of 2024 YR4's orbit relative to the inner planets and Jupiter. The object's eccentricity is 0.66, its semimajor axis 2.5 Astronomical Units (AU), its orbital period 4 years, its inclination 3.5 degrees, Minimum Orbital Intersection Distance with Earth (MOID) 0.003 AU, and upcoming close approaches will occur in 2028 and 2032. (D. Farnocchia)

[5] The designation signified the late December discovery; the designation 2024 YR4 means this is the 117th object found in the last half of December 2024.

Initial impact hazard assessment. Soon after the discovery MPEC, the three impact monitoring systems – NASA/CNEOS' Sentry, ESA/NEOCC's Aegis, and NEODyS in Italy – found a small (~0.05%) probability of impact in 2032. The corresponding Palermo Scale was > -2, which led to internal notifications across the three teams and technical verification before posting the results. Despite differences in the way astrometric data is evaluated by the different teams, the initial impact probabilities from Sentry, Aegis, and NEODyS were very similar, within <20% of each other. Nonetheless, the slightly larger impact probability computed by Aegis and NEODyS resulted in a Torino Scale of 1, while CNEOS initially assigned 2024 YR4 to level 0.

Asteroids reach (but don't typically remain on) level 1 on the Torino Scale two to three times per year with the current global observational regime,[6] so while a little unusual, it was not surprising to see an asteroid at Torino Scale 1. With most newly discovered asteroids, additional observations generally result in a quick re-assignment to Torino Scale level 0 because of declining estimated impact probabilities. These automated internal notificaitons are based on factors such as early estimates for IP and size but generally require further human examination prior to launching observation campaigns. In Europe, Dr. Marco Micheli, a member of the ESA astrometry community, noticed the 27 Dec alerts and determined there was sufficient time to observe the object over time for astrometric purposes.

Additional observations led to Torino Scale 1. On 29 Dec 2024, Dr. Davide Farnocchia at CNEOS analyzed an additional MPEC from the MPC containing further observations from 28 and 29 Dec that enabled him to confirm 2024 YR4 reached an impact probability that would justify raising its Torino Scale level to 1, given its size. CNEOS updated its Torino Scale status, with corresponding green highlighting, on its Sentry alert system website, which it describes as a "highly automated collision monitoring system that continually scans the most current asteroid catalog for possibilities of future impact with Earth." Dr. Farnocchia used a novel approach to Asteroid impact monitoring that he and Dr. Javier Roa developed with Dr. Steve Chesley (published in 2021), which allows accurate predictions of IPs with less computational expense than what Monte Carlo modleing enables. Early estimates indicated 2024 YR4 was in the size-range with the capacity to cause local to regional destruction should it impact Earth. CNEOS found the object had an almost exact four-year orbital period about the Sun and would come close to Earth again in 2028 and 2032. On its 2032 visit, it would come uncomfortably close to Earth moving at 13 kilometers per second (km/s) (Vinf) or strike Earth at 17 km/s impact velocity. On the morning of 31 Dec 2024, since the Torino Scale level of 2024 YR4 had remained at 1, CNEOS alerted NASA's PDCO. The PDCO's internal dashboard's "Sentry Status," a triangle that graphically displays the Torino Scale level based on CNEOS API feeds from the Sentry Earth Impact alert system, also changed colors to the corresponding green to indicate the Torino level 1. Dr. Farnocchia noted 2024 YR4 would be well-observable, even as late as April 2025, which meant further orbital refinement through astrometry would be possible

[6] As technology to find asteroids has increased, this rate has increased, and most planetary defense specialists predict it will increase again in the near future. A non-comprehensive listing of non-zero Torino Scale asteroids can be found here.

for some time, although it was not yet known whether the community would be able to rule out the risk of a future impact during that period of observability.

As the 2024 YR4 apparition progressed, larger aperture (diameter) telescopes progressively looked deeper into the sky. Between 24 Dec 2024 and the 12 Jan 2025 full Moon, 226 observations were provided to the MPC, with varying quality. Of these, in addition to the initial discovery and confirmation observations, high quality follow-on observations for astrometry in the first lunation came from the 1.54 m Danish Telescope at La Silla, Chile (W74), the University of Hawaii 88-inch (2.2 m) telescope on Mauna Kea (UH-88; T12), the 4.3 m Lowell Discovery Telescope (LDT; G37), and the 3.58 m La Palma TNG, Canary Islands, Spain (Galileo; Z19).

Physical characterization. Members of the global physical characterization community, not accustomed to monitoring the Sentry warnings, did not notice 2024 YR4's Torino level 1 in time to employ physical characterization assets in the earliest part of the apparition. An increasing number of astronomers began to notice the 2024 YR4's increasing significance in early January, but most of these were members of the astrometric community and not the physical characterization community since the astrometric community tracks objects on the risk lists and often rule out risk altogether before any physical characterization priorities arise. The window of opportunity for many physical characterization observations, which require the target to be brighter, when it is closer to Earth, is much smaller than for astrometry, which only essentially requires points of light to be bright enough to detect. Also, the particularly exquisite astrometry offered by radar ranging has a very limited time window because radar must also occur when such objects are relatively near Earth. Objects like 2024 YR4 which approach near Earth normally do so at high relative velocities to Earth. This means they are only close to Earth—and observable using radar—for a short time window. Opportunities for this early exquisite astrometry by radar and some aspects of physical characterization rapidly disappeared as 2024 YR4 became too distant and faded from its peak brightness. The astronomers using the only currently viable option for radar—the Goldstone radar—had a very narrow window of opportunity. This was until 29 Dec 2024 (and that was not certain)—prior to the object rising to Torino Scale 1, which was occurring from 29-30 Dec 2024 as CNEOS analyzed new data from MPC. Only the Arecibo Observatory, had it not suffered catastrophic damage and closed its large radar, would have had the capacity to image 2024 YR4 after 30 Dec 2024. Had Arecibo been in working condition and done so, such radar imaging would likely have removed 2024 YR4 from the risk list and reduced its Torino level to 0 early on, according to Dr. Lance Benner.

NASA's InfraRed Telescope Facility (IRTF) on Mauna Kea, HI uses infrared (IR) spectroscopy and imaging and fast non-sidereal tracking capability to determine asteroid spectral and thermal characteristics, helping to constrain asteroid mineralogical composition, spin, and possibly albedo and size. The IRTF had a slightly larger window for observations than the Goldstone radar; IRTF astronomers could have imaged 2024 YR4 until 2 Jan 2025 but IRTF observers had not yet learned of the object's Torino 1 status.

No automated system currently alerts physical characterization sites, but the PDCO and IAWN are in discussions on the appropriate balance for such a system. For example, in April

2025, based on the 2024 YR4 experience, PDCO immediately evaluated an object that briefly reached Torino 1 during April 2025. For the object, 2025 FA22, NASA's IAWN administration team experimented with an automated alert system which prompted it and the PDCO of 2025 FA22's Torino 1 status on 25 Apr 2025 in addition to manual notifications from CNEOS.

Polarimetry, another physical characterization technology which may have been able to provide albedo for the object, was only available generally in the first 24 hours after discovery of 2024 YR4 because polarimetry is mainly carried out by small telescopes.[7] These have limited opportunity to observe small, faint objects. Among larger telescopes, the VLT is capable of polarimetric observations, but 2024 YR4 was at the wrong phase angle for the VLT to obtain these measurements.

While opportunities were limited, over the next lunations a redundancy in assets enabled adequate physical characterization of 2024 YR4. Some physical characterization did occur during the first lunation. Dr. Petr Pravec, a Czech astronomer, employed the Danish Telescope on 3 and 4 Jan 2025 to find light curve and a rotation period for 2024 YR4 and determined it was not tumbling; Dr Pravec and Dr. Devogele, later using VLT data, found it rotated rapidly about the principal axis only.

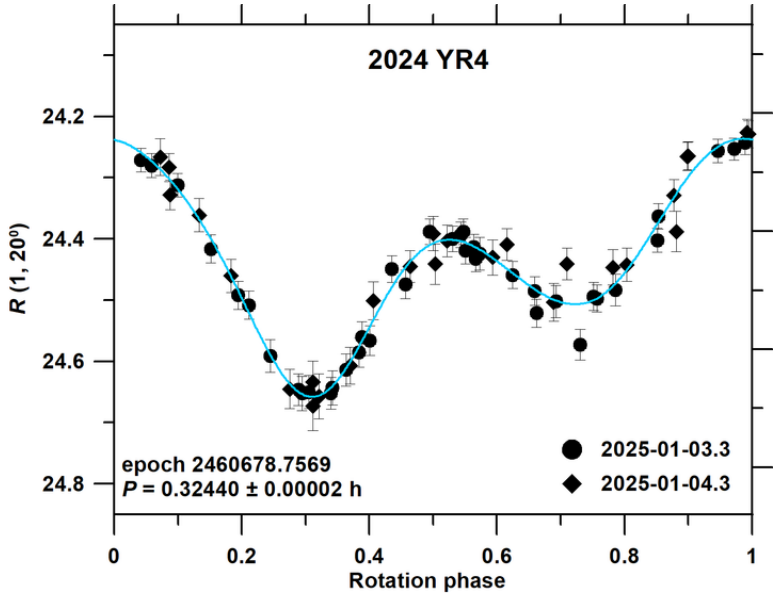

Figure 2: Early light curve (4 Jan 2025) (Dr. Petr Pravec and Dr. Maxime Devogele)

They also estimated the absolute magnitude for the object of 23.8. Further, Dr. Pravec worked with Dr. Marco Micheli and others to use additional Danish Telescope time for additional astrometric measurements as the object became too faint for characterization. On 7 Jan 2025, MANOS used the relatively new (13 years old) LDT (Dr. Nicholas Moskovitz) to obtain the spectrophotometry also known as "colors" of the object. Dr. Moskovitz, the MANOS PI, commented this "provided an initial S-type taxonomic classification (and inferred albedo) and

[7] These include the 2 m Bulgarian National Astronomical Observatory in Rozhen, the 2.15 m telescope of the Complejo Astronomico, Large Millimeter Telescopes in Mexico, and the 2.56 m Nordic Optical Telescope (NOT).

confirmed early reports of the ~20-minute rotation period." On 7 Jan 2025, Dr. Pravec emailed Dr. Julia de Leon and asked if she could take the visible spectrum of 2024 YR4 using 10.4 m Gran Telescopio Canarias (GTC-Z18), which she did on 13 Jan 2025. The asteroid's spectra were consistent with an S or L spectral type, although during this lunation period K type (low albedo) was also a possibility.

California wildfires. On 8 Jan 2025, a windstorm and wildfires in California prompted the closure of the JPL buildings and forced the evacuation of CNEOS personnel. JPL servers closed down for the first time in decades. CNEOS Director Dr. Ryan Park commented that CNEOS was able to operate despite this challenging situation because Dr. Farnocchia was able to continue remotely working on 2024 YR4 from his home in Idaho. Dr. Farnocchia mentioned that Alan Chamberlin, working from New Mexico, was instrumental in bringing the systems back up, and Jon Giorgini, working from South Dakota, was available to help with JPL's Horizon's system used by observatories to point their telescopes accurately. Also, the international collaboration with NEOCC and NEODyS remained especially vital during this period. The wildfires reached close to the Mount Wilson Observatory the next day but did not physically damage JPL facilities. JPL remained closed until reopening in phases from 21-27 Jan 2025. While JPL was saved, 150 staff members lost their homes.

Precoveries discovered during this and the next lunation period. In addition to new observations, astronomers worldwide searched for "Precovery" observations. A precovery is a position measurement from an image that predates an object's discovery. Good (well-vetted) precoveries can provide additional astrometric data to refine the orbits of hazardous asteroids. Prerecovery efforts for 2024 YR4, according to Dr. Marco Micheli, included inspections by several astronomers of past images taken by CSS, the NASA-funded Panoramic Survey and Rapid Response System (PAN-STARRS, the Gaia Space Observatory, NASA's NEO Wide-Field IR Survey Explorer (NEOWISE), the US Space Force's (USSF) Space Surveillance Telescope (SST), the Transiting Exoplanet Survey Satellite (TESS) (and other exoplanetary surveys), and datasets indexed by the Canadian Astronomy Data Centre (CADC) Solar System Object Image Search (SSOIS) service – in particular, images from the Blanco Dark Energy Camera (DECam) imager in Aug 2016 and B612's Asteroid Discovery Analysis and Mapping (ADAM) platform. Dr. James Bauer, who conducted part of this search, noted he found "nothing believable." Dr. Timothy Spahr, former director of the MPC, noted precoveries that are not solidly understood to be the same object (speculative observations) could skew the predictions for the object – something that "would not have been appropriate for an object with this much significance." For this reason, no credible precoveries from previous intersections of the object with Earth's orbit in 2020 and 2016 were found. One suggested precovery in 2018 had low credibility due to the magnitude being 29 and thus too faint to have been detected by the telescope in question; therefore, that claimed precovery was not used. On 17 Jan 2025, however, Dr. Larry Denneau and Dr. John Tonry found a weak, trailed precovery from an ATLAS Chile image taken on 25 Dec 2024, two days before discovery. To find the image, they computed where prior exposures should be found and then hand-searched for what they found was a faint streak. The trail was a single image, but after verification by Dr. Marco Michelli, the image helped with orbital refinement.

End of first lunation period. As 2024 YR4 became less visible due to the first full Moon after its discovery, Dr. Farnocchia informed Dr. Fast he believed it likely the asteroid's IP would rise to 1% towards the last half of February or the first half of March, based on "Monte Carlo samples drawn from the current covariance." He also created the following graphic that demonstrated there was a 70% chance the IP would increase to above 1% as additional observations were reported:

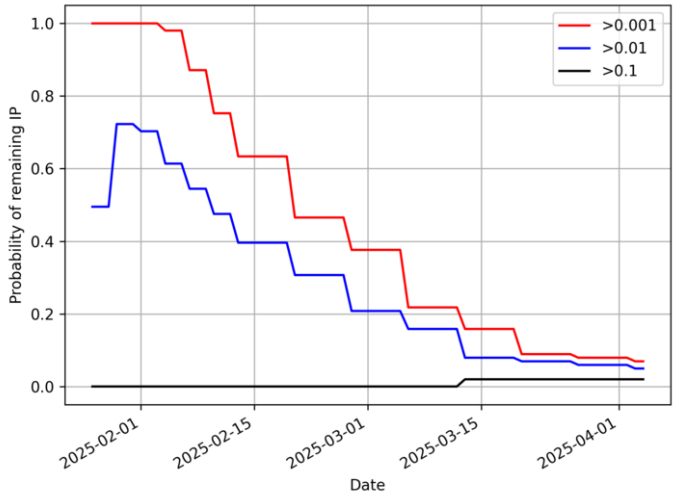

Figure 3: Probability of future IPs for 2024 YR4 (Dr. D. Farnocchia)

Email communications between Dr. Farnocchia and Dr. Fast noted that if insufficient data was obtained before 2024 YR4 became too faint in April or May of 2025 for any observations, the world would have to wait until 2028 to better determine its 2032 IP, leaving uncertain the need for mitigation measures.

Other institutions and individuals also computed IPs for 2024 YR4, including the Japanese Space Agency (JAXA), which used its Deep Space Multi-Object Orbit Determination System (DMOODS) software and reported at the May 2025 Planetary Defense Conference that they find similar (though slightly lower) results throughout the apparition with DMOODS.[8]

Climbing Impact Probability

Second Lunation. From 13 Jan -12 Feb 2025 (the period before the next Full Moon), global awareness of 2024 YR4's climbing IP grew rapidly, and the MPC received 184 more observations from ~23 different observatories worldwide. While having multiple observations was very helpful, some improvements to such collaborative efforts came to light during the event. Some of the observations "crowded" the data, requiring careful analysis at CNEOS, NEOCC, and NEODyS to ensure observations with significant errors did not corrupt orbit

[8] JAXA uses DMOODS to measure deep space probes and celestial bodies and added a function to enable direct import of ground-based data from ground-based telescopes using MPC.

solutions based on better observations. Some observatories reported data without providing error estimates, resulting in their data being down weighted despite in some cases being good observations otherwise. Others used outdated star catalogues, so their data was excluded.

The highest quality observations during the second Lunation came from the following observatories:

- 1.54 m Danish Telescope
- European Southern Observatory's 8.2 m Very Large Telescope at Paranal Observatory (VLT; 309)
- 8.1 m Gemini South on Mauna Kea, HI (I11)
- 2.4 m MRO (702)
- 2.56 m NOT
- La Palma, Canary Islands (Z23)
- 2.2 m UH-88
- 4.3 m LDT
- 1 m at Cerro Tololo Inter-American Las Cumbres Observatory, Chile, (LCO; W87).

According to Dr. Farnocchia, among the most productive of the follow-on observers was the Danish Telescope, which reported 53 high-quality observations from 17 nights from 7 Jan- 6 Feb 2025. Dr. Marco Micheli agreed that the Danish Telescope and the MRO on the US side became the reference telescopes until early February. MANOS also continued to collect astrometry with LDT during this period and through the end of February, and the VLT contributed highly significant astrometry.

Inauguration. The 20 Jan 2025 Presidential Inauguration and the federal hiring freeze that followed, along with the return-to-work, reduction in government employees and other executive orders, created some temporary changes in day-to-day life for all government employees during this period. This had little effect on the planetary defense community's worldwide effort to obtain critical observations of 2024 YR4 and provided only a small challenge in determining the latest points of contact at U.S. government for NASA to notify and for a meeting NASA leadership held with interagency partners.

Further physical characterization and astrometry. Dr. Maxime Devogele, a physical characterization scientist at the NEOCC, found out about 2024 YR4's significance on 7 Jan 2025 and involved himself in the physical characterization effort from that point forward. Dr. Devogele used the 3.58 m La Palma TNG to obtain colors. He also noted the VLT produced both characterization data (M. Devogele and O. Hainaut) as well as enough high-quality astrometric data to push 2024 YR4's IP to 1%. He noted the VLT was extremely accommodating throughout the 2024 YR4 apparition. He also submitted a proposal for NIR observations on the evening of 19 Jan 2025; on Monday his proposal was accepted and that next morning (21 Jan), VLT provided NIR data for further physical characterization. Further physical characterization data came around 27 Jan 2025, when Dr. Devogele spliced data from Mount Lemmon (I52) observations on 27 and 28 Dec 2024 (T. Beuden), LDT data from 7 Jan 2025 (N. Moskovitz), and the VLT data from 21 Jan 2025 (P. Pravec) to phase the rotation period from discovery until

that date and extended the light curve. The data from VLT and the La Silla Danish telescope indicated a rotational period near 19.5 minutes.

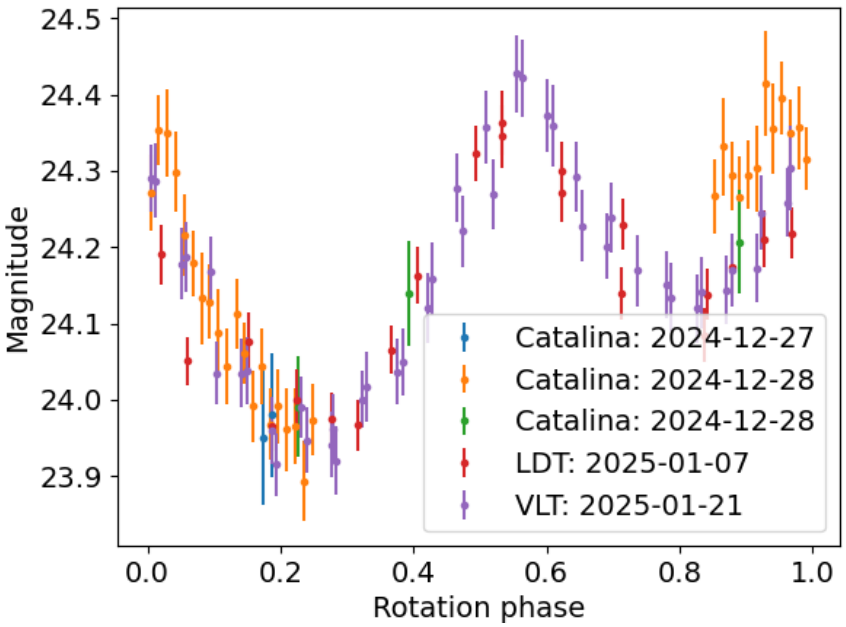

Figure 4: Later light curve (7 Feb 2025)- spliced data from multiple observers by Dr. M. Devogele

Further characterization from Director's Discretionary Time (DDT) using the 8.1 m Gemini South's Gemini Multi-Object Spectrograph (GMOS) on 7 Feb 2025 and from the Keck I Keck/Multi-Object Spectrometer For Infra-Red Exploration on 12 Feb 2025 helped T. Bolin, et al to also determine a spectrum. They estimated a size of 30-65 m using their measured absolute magnitude (mag) of 23.9 +/- .3 mag, and assuming an albedo of 0.15-0.4, confirmed the rotation period and provided color photometry, some spin vector and shape data, determining the object to be oblate.

Informal collaborative efforts. As awareness of 2024 YR4's rising IP grew, formal governmental and informal non-governmental networks developed. On 17 Jan 2025, an informal Slack channel was established to help coordinate orbital specialists, astrometric specialists, physical characterization specialists, and mitigation experts. This Slack channel, born out of a desire to collaborate internationally with more efficiency than email allowed, proved helpful in coordination of what initially became an informal observation campaign. It did not supplant official communications, which continued to handle and govern communications regarding 2024 YR4 in accordance with NASA directives and IAWN[9] agreements, but it augmented those communications. Members of the Slack channel also heavily communicated with the PDCO, IAWN, and ESA and maintained discipline with information they communicated to one another. IAWN is examining the merits of creating a more formal channel for future Torino scale events

[9] Both IAWN and SMPAG are endorsed by the United Nations and its Committee on the Peaceful Uses of Outer Space (UNCOPUOS)

and has implemented such a channel as a test for the recent 2025 FA22 Torino 1 object. ESA is implementing its own plans for additional collaboration.

In addition to the Slack channel, non-governmental organizations and individuals participated in multiple aspects of the 2024 YR4 event. Dr. Marco Micheli emphasized in an interview with the PDCO that early observations by amateur astronomers should not be discounted for such objects. Y. Ikari observations in the initial confirmation stage eventually proved reliable. Civilians such as those in the B612 Foundation, also played a role in these informal communications networks. B612 members provided early awareness to several individuals about the significance of 2024 YR4. For example, B612's Rusty Schweickart reached out to Dr. Andy Rivkin (among others) on 14 Jan 2025 about the object, which is how he initially learned about the object. Dr. Rivkin in turn contacted the PDCO's Dr. Fast to discuss the possibility of requesting time on the JWST, which Dr. Rivkin was encouraged to do.

Other informal networks included phone calls and emails between individuals who commonly communicate with one another about interesting objects. For example, Czech Astronomer Dr. Petr Pravec and the Goldstone radar specialist Dr. Lance Benner commonly communicate about interesting objects for mutually beneficial observations and had an email conversation about 2024 YR4 in early Jan 2025. While too late for obtaining effective radar, this is further example of effective informal and formal networks that form the bonds within the growing planetary defense community. Dr. Rivkin described these bonds as part of a "virtuous cycle," which occurred throughout the 2024 YR4 event. Collaboration between key US and European colleagues, he noted, also provided important information for designing what became a successful JWST proposal and carrying out later analysis on the data JWST would provide. Email communications were the main stay for both formal and informal communication as well as the informal Slack channel.

Approaching 1% IP. Observations continued to be reported to the MPC, and the three orbit computation centers (CNEOS, NEOCC, and NEODyS) continued to compute the IP. The three institutions, while maintaining independent methods and computations, checked rationale and data used. In addition to new observations, some previous observations were resubmitted to the MPC with more precisely measured data, including uncertainty estimates, and some requests for deletions occurred. The MPC, normally accustomed to replacing observations on an orderly monthly basis, had its system in prep mode, where they do not do deletions typically. Also, the MPC, which does not compute impact probabilities out as far as 100 years as CNEOS does, was not aware of the significance of 2024 YR4 when the first requests for replacements started coming in. However, the MPC staff rose to the challenge quickly and made manual replacements. Staff at the MPC are currently exploring system improvements to allow such deletions and replacements to be undertaken on an immediate basis.[10] Replacement observations also are a challenge for the NEOfixer system, which lists observations in order of submission and aids observers globally to coordinate and prioritize observations. Efforts are underway to address

[10] Initially, personnel at the MPC did not know why replacement observations were being sent in, but soon realized 2024 YR4 had become a Torino Scale level 1 event. This is also addressed in the lessons learned.

how to handle special cases requiring replacement observations. NEOfixer initially did not treat 2024 YR4 much differently from any other small object.

The orbital predictions were placed on the websites of the three centers and in CNEOS' Sentry system. Orbital computation specialists navigated the challenge of determining which observational data were the most reliable, down weighting those which did not provide uncertainty estimates and excluding those which used old star charts. On 21 Jan 2025, CNEOS found 2024 YR4 had a 0.55% IP and an estimated size of 40-90 m. The IP still did not decline as is typical with more observations. CNEOS subsequently estimated the IP at 0.5%, NEOCC at 0.99%, and NEODyS at 0.89%. Dr. Farnocchia emailed the PDCO, including Dr. Fast and Lindley Johnson, and described these estimates. He said he predicted the IP would climb with further refinement based on existing observations.

Informing NASA internally. On 22 Jan 2025, Dr Fast emailed Dr. Charles Webb, NASA's PSD Acting Director, to inform him 2024 YR4 – then estimated at ~56 m in diameter – had a "low but non-zero probability of impacting Earth on 22 Dec 2032 and causing localized damage. In the coming weeks it could reach a 1% IP reporting threshold in accordance with NPD 8740.1 and with data being public, it could receive public attention sooner." After further discussions on that day between CNEOS, NEOCC, and NEODyS, Dr. Paul Chodas noted the IP could reach as high as 4-5 percent "before (hopefully) dropping to zero." Lindley Johnson noted this would be the second most significant close approach event after Apophis' 2029 approach, and noted he wished there was a way to get radar on it. Unfortunately, as noted, Arecibo, the largest radar system previously available in the world for imaging such objects, was catastrophically damaged 1 Dec 2020, and was unavailable to assist in refining the size and shape of the object.

Mitigation analyses. Some individuals and groups began informal mitigation and impact damage analysis during this period; however, the PDCO noted the IP and Torino levels were still low and subject to change as additional data were reported, and provided guidance that NASA would not yet publicize any mitigation analysis work.

Torino Scale 3 Notifications

IP moves toward 1%- informal advanced discussions. In the coming days, still during the second lunation, the IP continued to climb. According to Dr. Devogele, the 8m VLT provided highly accurate observations on 21 Jan 2025; when this data was added to the orbital calculations, it pushed the IP further toward 1%. On 23 Jan 2025, the day before NASA personnel were scheduled to fly to the Sundance Film Festival to be featured speakers on a Planetary Defense panel, the IP rose to close to 1%. Dr. Fast remained prepared to speak to Richard Moissl at ESA if asked for comment during the panel to ensure the US coordinated press communications with its ESA partners. CNEOS, NEOCC, and NEODys agreed to verify one another's data while not changing the methods they each used to compute refined orbits to ensure each was using or aware of choices made regarding the reliability of data.

On 27 Jan 2025, Dr Farnocchia notified Dr. Fast and Lindley Johnson that CNEOS, NEOCC, and NEODyS all agreed the IP had crossed 1%, moving YR4 from 1 to 3 on the Torino scale,[11] the highest rating for an object since Apophis. Because estimates at the time suggested the object to be roughly 60 m in diameter (40-90 m range), it reached Torino scale of 3 (objects over 1% IP and over 50 m in diameter), making the 1908 Tunguska meteor a good point of comparison. This signified that "attention by public and by public officials is merited if the encounter is less than 10 years away." The PDCO staff monitored the CNEOS and MPC websites, which for the first time in several years changed to have banners and colors signifying a Torino Scale 3 event. The PDCO determined 2024 YR4 merited carrying out the full notification process within the U.S. government in accordance with NPD 8740.1[12] as well as the IAWN notification process.

That same day (27 Jan 2025) Dr. Fast, acting as the IAWN Coordinating Officer, provided advanced warning to the IAWN Steering Committee and Permanent Observers that she would call an IAWN Steering Committee meeting regarding "risk list object 2024 YR4." Individuals in this invitation included Mr. Michael Zolnowski, Dr. Alan Harris, Dr. Boris Shustov, Dr. Richard Moissl, Dr. Detlef Koschny, Dr. Gonzalo Tancredi, and Ms. Romana Kofler. On the morning of 28 Jan 2025, Dr. Fast, acting as the IAWN Coordinating Officer, emailed IAWN signatory points of contact (POCs) to provide an informal advanced notice that the IP surpassed the 1% future IP threshold, reaching Torino level 3. She told them that once the IP was verified, IAWN would formally notify the SMPAG and UNOOSA.[13]

IP rises to 1%- Internal NASA and FEMA notifications begin (28 Jan 2025). In the evening of 28 Jan 2025, Dr Fast informed Dr. Nicola Fox, Associate Administrator of the NASA/SMD, that the notification threshold had been crossed. Dr. Fox directed Dr. Fast to proceed with formal NPD 8740.1 notifications. At 8:56 PM EST on 28 Jan 2025, Dr. Fast initiated required notifications to the NASA Acting Administrator (Dr. Janet Petro), SMD Associate Administrator (Dr. Fox), PSD/Acting Director (Dr. Charles Webb), NASA's OIIR Director (Dr. Margaret Kieffer), other NASA/HQ personnel (Elaine Denning, Kevin Conole, Andrew Rowe, Karen Fox, Molly Wasser, and Josh Handal), JPL/CNEOS (Dr. Ryan Park), and FEMA (Michael Manchester). The notification email stated:

[11] Torino Scale 3 meant 2024 YR4 was classified as "a close encounter, meriting attention by astronomers. Current calculations give a 1% or greater chance of collision capable of localized destruction."

[12] The PDCO has notification responsibilities for NEOs once they reach notification thresholds established in NASA NPD 8740.1 (27 Jan 2017) Notification and Communications Regarding Potential NEO Threats. NPD 8740.1 provides broad discretion to the PDCO to determine when implementation of required notifications should take place.

[13] PDCO, as the coordinator of IAWN, with concurrence by the IAWN Steering Committee, sends notification to the program officer for planetary defense at UNOOSA for dissemination to member states, as noted by the UNCOPUOS in its annual reports (*e.g.,* A/78/20, para. 119). PDCO, on behalf of IAWN, also notifies the chair (ESA) of the SMPAG, which is the forum for national space agencies and space offices to develop and make recommendations for any in-space response to an asteroid impact threat.

> Please see the attached notification[14] sent by the Planetary Defense Coordination Office (PDCO) in compliance with the attached NASA Policy Directive 8740.1[15] Notification and Communications Regarding Potential Near-Earth Object Threats that assigns responsibilities to ensure timely notification. The attached notification contains the latest details of a potential asteroid impact threat as vetted by the JPL Center for Near-Earth Object Studies (CNEOS) and PDCO. This is not an exercise. The notification is also being sent to the interagency distribution confirmed with OIIR for 8740.1 compliance.

Interagency Notifications. At 8:57 PM EST on 28 Jan 2025, Dr. Fast sent an email notification to the Office of Science and Technology (Lisa Friedersdorf), NCC/EOP (Augusta Binns-Berkey), FEMA (Michael Manchester and Jeremy Greenberg), USSF (Mr. Merric Garb and Brig Gen Jesse Morehouse), and State Department (Ryan Guglietta) to inform them of the details of the potential asteroid impact threat (1.2% IP) in compliance with NASA PD 8740.1, copying NASA/OIIR and Public Affairs on the email.

In the morning of 29 Jan 2025, NASA senior leadership, including Acting Administrator Janet Petro and Associate Administrator Nicola Fox, conducted a Microsoft Teams call with representatives from other US federal agencies with stakes in planetary defense, including FEMA, DoD, and OSTP, to inform them of the asteroid's Torino 3 status and that NASA's PDCO would contact their staffs with further information.

Media and Public Messaging. Also on 29 Jan 2025, Lindley Johnson made requests directly to some non-NASA organizations that they align their messaging with what NASA was providing on its websites. He stated that putting projected threat corridors online was premature, given such estimates would have high errors, and the asteroid's IP would likely soon diminish. Over the course of the next four weeks, NASA, ESA, and the broader planetary defense community fielded interviews and questions resulting in over 75 different news reports in mainstream and space-specific media, many linked to in the Appendix for this report. Several US entities and individuals who received such media requests contacted NASA for assistance to ensure they provided information that was accurate and aligned with NASA's public messaging.

That same day, NASA also alerted members of NASA's Asteroid Watch on the social media platform X, another mechanism to alert the distributed global planetary defense community and inform the public and media channels. As Josh Handal explained, @AsteroidWatch serves as a functional information system aligned with national and NASA strategy, providing timely updates of NEOs that are expected to impact or approach within a distance warranting public notifications. This use of the X platform continued to help communicate updates for 2024 YR4 as its IP changed, with posts each receiving hundreds of thousands of views.

Formal IAWN and Interagency Notifications (29 Jan 2025). Concurrent with the Acting Administrator's morning meeting, on 29 Jan 2025, Dr. Fox directed Dr. Fast to move

[14] Appendix B – NASA Potential Asteroid Impact Notifications for 2024 YR4
[15] https://nodis3.gsfc.nasa.gov/displayDir.cfm?Internal_ID=N_PD_8740_0001_&page_name=main

forward coordinating notifications by IAWN. Throughout 29 Jan 2025, Dr. Fast and Lindley Johnson worked internally and with the IAWN Steering Committee to revise and synchronize text for a formal IAWN notification. At 9:23 PM EST on 29 Jan 2025, Dr. Fast emailed UNOOSA (Msr. Romana Koffler) and SMPAG (Dr. Detlef Koschny) to formally inform them of the IP estimated by CNEOS, NEOCC, and NEODyS.[16] She also informed the IAWN signatory POCs that IAWN formally notified UNOOSA and SMPAG about 2024 YR4, the first such notification outside of an exercise. The notification stated the object was 40-90 m (130-300 ft) in diameter and (at the time) had a 1.3% IP as calculated by CNEOS and NEOCC with NEODyS. The notification was in accordance with criteria and thresholds for impact response actions in report A/AC.105/C.1/2017/CRP.25 to the Scientific and Technical Subcommittee of the UNCOPUOS, which states, "(1) IAWN shall warn of predicted impacts exceeding a probability of 1 percent for all objects characterized to be greater than 10 meters in size, or roughly equivalent to absolute magnitude of 28 if only brightness data can be collected." Dr. Fast also made sure the observers for the upcoming 4 Feb 2025 IAWN meeting were all notified of 2024 YR4, ensuring wide knowledge of the object's Torino level 3 status.

At 4:09 PM EST on 29 Jan 2025, Dr. Fast also sent an interagency notification in accordance with the 2023 National Strategy and Action Plan for NEO Hazards and Planetary Defense. This notification, with the same attachment previously sent out, went to addressees at USSF, US Space Command, the National Reconnaissance Office, the National Oceanic and Atmospheric Administrations (NOAA), the National Nuclear Security Administration (NNSA), the Executive Office of the President's Office of Management and Budget (EOP/OMB), the U.S. Geological Survey (USGS), FEMA, the State Department, the U.S. Agency for International Development (US AID), the Institute for Defense Analyses (IDA), and several more NASA personnel, stating:

> Please see the attached notification sent by the Planetary Defense Coordination Office (PDCO) at NASA and shared here per the National Strategy and Action Plan for Near-Earth Object Hazards and Planetary Defense. I am sending to the contacts used for the last Planetary Defense Interagency Working Group meeting. The attached notification contains the latest details of a potential asteroid impact threat as vetted by the JPL Center for Near-Earth Object Studies (CNEOS) and PDCO. This is not an exercise.

Public Messaging. NASA refrained from making many public statements early on to avoid overdramatizing an event that in all likelihood would move down in IP in the near future. Press agencies began publishing information about 2024 YR4, and Dr. Richard Moissl noted to Dr. Fast that ESA was being "showered with media inquiries." He worked with the PDCO to synchronize public messaging. He emailed other European stakeholders to provide ESA guidance on how to respond to public requests for comment; he pointed them to the ESA FAQ webpage, which included the following recommended messaging:

- Be forthcoming with the facts that are known at the moment, but do not pre-empt future statements and avoid speculation.
- Point out the fact that ~1% IP also means ~99% non-impact.

[16] Appendix C – IAWN Potential Asteroid Impact Notifications for 2024 YR4

- Point out that the data is relatively sparse, but more data is taken with the appropriate resources to get a picture in a minimum of time.
- IAWN is currently consolidating the information and will communicate shortly, being supplemented by its members.
- We are working tirelessly to get more data, assess the situation constantly and provide further updates as soon as possible.

NASA also received media requests, something that increased significantly over the next weeks as the IP continued to climb. NASA's Senior Science Communications Officer drafted a blog post with key information about 2024 YR4, which went for review and was posted on 29 Jan 2025.

UNOOSA notification to member states. On 30 Jan 2025, UNOOSA, in its capacity as the permanent secretariat of SMPAG[17], notified members of the UN with the IAWN information notification concerning a potential impact of asteroid 2024 YR4 that exceeded 1% IP threshold for 22 Dec 2032. This UNOOSA circular reached the attention of the UN Director General, who acknowledged it – a rare occurrence.

Mitigation analysis and Impact Risk assessments. Thresholds for SMPAG to start mitigation mission option(s) planning are met when an object's Earth impact is predicted to be within 50 years, with an IP greater than 1% and size estimate greater than 50 m. However, these thresholds are recommended guidance and not prescriptive directives. The PDCO realized in this specific situation that it was not reasonable or responsible for a real world 1% situation to do specific risk assessments for geographic areas because it leaves out the context of the broad swath out into space where the asteroid could also pass by safely. For this reason, only general risk assessment and affected locations were listed in the notifications, but not a specific risk corridor. NASA did not want to put its weight behind any statement pinpointing the location of a potential impact unless the IP rose further before 2024 YR4 became less observable.

NASA reasoned a concerted effort at mission planning could wait until the end of April or May, when the object would fade from view and after the most data could be obtained. SMPAG members came to that conclusion and also did not trigger formal mitigation mission planning, choosing to wait to see if data coming back until the end of the object's apparition would bring the IP higher, and in such case mission planning could begin, with little lost time. At its 24th meeting on 5 Feb 2025, the SMPAG stated:

> At this meeting, it was concluded that SMPAG will continue to actively monitor the evolution of the impact probability and possible knowledge about the object size. The Group has started to discuss activities but considers it is premature to develop specific recommendations for space missions. This will be reassessed at a future meeting, which will be held towards the end of this visibility period (roughly the end of April/early May 2025) or earlier, if the evolution of the threat merits.

[17] In accordance with United Nations General Assembly resolution 71/90, para. 9.

Should insufficient information be obtained before the apparition ended in April 2025 (or May if space telescopes are used) to constrain the orbit sufficiently, mission planning could still have been considered.

Although a formalized mission planning effort did not materialize for 2024 YR4, individuals and institutions began impact risk assessments and mitigation analysis in preparation for an increased IP. These included Dr. Lorien Wheeler and Dr. Jessie Dotson at NASA's Asteroid Threat Assessment Project (ATAP), and Dr. Brent Barbee, GSFC's lead Planetary Defense Applications Scientist and Community Liaison, who examined mission options for reconnaissance and mitigation.

Internationally, JAXA also examined a theoretical use of Hayabusa 2 to investigate whether it could be used to deflect 2024 YR4 with potential orbital scenarios. At the 2025 Planetary Defense Conference, JAXA presented this information and a case for staging a constellation of 12 spacecraft in an "asteroid flyby cycler orbit" to perform one NEO flyby per month for asteroid reconnaissance and potentially for redirection.

On 30 Jan 2025, Dr. Farnocchia informed the PDCO that a preview of new astrometry from Marco Micheli indicated the IP might move up to 1.5%, based on additional images CSS found. Also, Dr. Rivkin examined the potential to observe the object farther along its arc into May using NASA's Hubble Space Telescope.

4 Feb 2025—20th Meeting of the IAWN Steering Committee. On 4 Feb 2025, the IAWN Steering Committee met in Vienna, Austria (as it does annually on the margins of the UNCOPUOS Scientific and Technical Subcommittee Meeting) with an open session for IAWN signatories to join virtually or in person. The meeting proved helpful for 2024 YR4 observations and coordination. Had it not already been scheduled, Dr. Fast noted that a dedicated meeting would have been called. The meeting included briefings on 2024 YR4 from Dr. Fast (update and communications), Dr. Farnocchia (orbital computation), Dr. Marco Micheli (discovery, prediscovery, and early follow-up), Dr. Maxime Devogele (physical characterization), Dr. Frederica Spoto (MPC involvement), Dr. Alex Gibbs (CSS NEOFixer), and Dr. Detlef Koschny (SMPAG). Dr. Fast advised members to work through their public affairs and/or communications offices if they had such an office, or through NASA or ESA for messaging. She encouraged IAWN signatories to highlight their activities and the significance of 2024 YR4 but to avoid speaking on behalf of other signatories or to speculate outside of IAWN responsibilities. She noted this was the first time the UN received notification from IAWN to provide information to member states and that such a notification had been accomplished via the UNOOSA circular noted above. Dr. Farnocchia, Dr. Micheli, Dr. Devogele, and the other presenters provided lessons learned in the process so far and advice for how to proceed. Some astronomers later noted the lessons learned provided at this meeting helped guide their efforts. For example, it was helpful to understand the need for further coordination between observatories. Two or three observatories were ideal for an observation period; having only one could create bias, and more than three could complicate the orbital refinement process and waste resources.

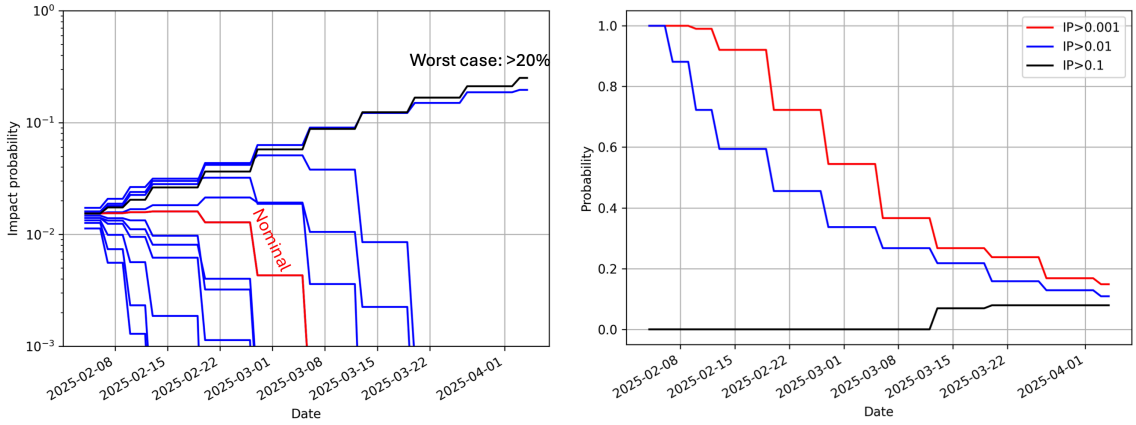

Figure 5: Statistical analysis of possible impact probability evolution, assuming 50 milliarcsecond astrometry (left) and probability of future IPs (right) for 2024 YR4 as presented on 4 Feb 2025 at the 20th Meeting of the IAWN Steering Committee (Dr. D. Farnocchia)

As the IP continued to increase to 1.9%, the community continued to consider alternative possibilities for refining the orbit. On 6 Feb 2025, Dr. Moissl sent a question on behalf of ESA to Dr. Fast regarding the capacity for NASA's Lucy spacecraft, whose mission is to explore a number of Jupiter Trojan asteroids, including flying by multiple asteroids, to image 2024 YR4. The Lucy team conducted preliminary analysis of the potential for such observation and concluded such assistance might be feasible but would involve significant risks and costs to study further, and it was assessed through CNEOS that the potential factor of ten improvement in the orbit Lucy might achieve would also be achievable through ground-based observations over the next month, as well as the potential of JWST observations. For these reasons, no formal request for assistance from the Lucy spacecraft occurred.

Impact Probability Peaks at 3.1% and then Drops to Negligible Level

Third lunation period (12 Feb-14 Mar 2025) astrometry. As YR4 became fainter, large telescopes provided the highest quality observations between the second and third full moons. These included the 8.1 m Gemini North (T15), the 10 m W. M. Keck Observatory (T16), the 8.2 m Subaru Telescope (T09), and the 3.58 m Canada France Hawaii Telescope (CFHT; T14)), all on Mauna Kea, HI (T14); also the 8.1 m Gemini South (I11) on Cerro Pachon, Chile, the 5.08 m Hale Telescope on Palomar Mountain Observatory, CA(675), the Two Meter Twin Telescope, Canary Islands (Y68-two 2m telescopes equivalent to a larger virtual single telescope), and the Mt. Graham Large Binocular Telescope Observatory (LBT), AZ (G83) (two 8.4 m diameter mirrors equivalent to a larger virtual single telescope). LDT (4.3 m), NOT (2.54 m), MRO (2.4 m), and UH 88 (2.2 m) also continued to provide images.[18] The following graphic

[18] MRO managed to image the object to 25.5 magnitude, beyond the 24.5 faintness limit they previously believed they had. This 25.5 imaging was also accomplished with low uncertainty as late as 28 Feb 2025.

produced by Dr. Micheli and Dr. Farnocchia illustrates much of the progression of observations throughout the apparition.

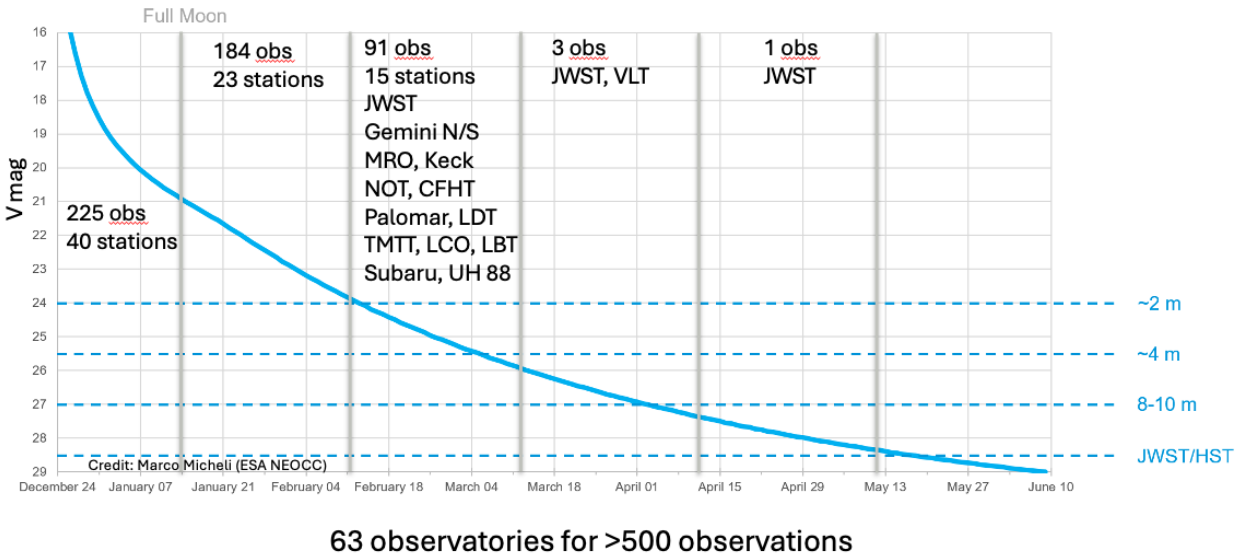

Figure 6: Progression of Observatories as 2024 YR4's current apparition fades (D. Farnocchia and M. Micheli)

IP peaks at 3.07% and begins to drop. On 18 Feb 2025, CNEOS updated the IP using a single 15 Feb 2025 measurement from the NOT and another single position from the MRO and found the IP peaked at 3.1%, with NEOCC at 2.8%, and NEODyS at 2.3%. That same evening, Dr. Farnocchia informed the PDCO that new astrometry from the LDT indicated the IP would drop to 2.5%. The following day, the IP dropped further with additional new observations, and by 20 Feb 2025, it was well below 1%. CNEOS informed the PDCO that, based on their simulations, it was unlikely that the probability would rise again. Further high-quality follow-on observations continued from MRO, NOT, CFHT, and the LBT. Dr. Farnocchia produced an animation to show the decreased uncertainty showing the distribution of orbits shifting away from Earth (the first and last frames are shown in the figure below).

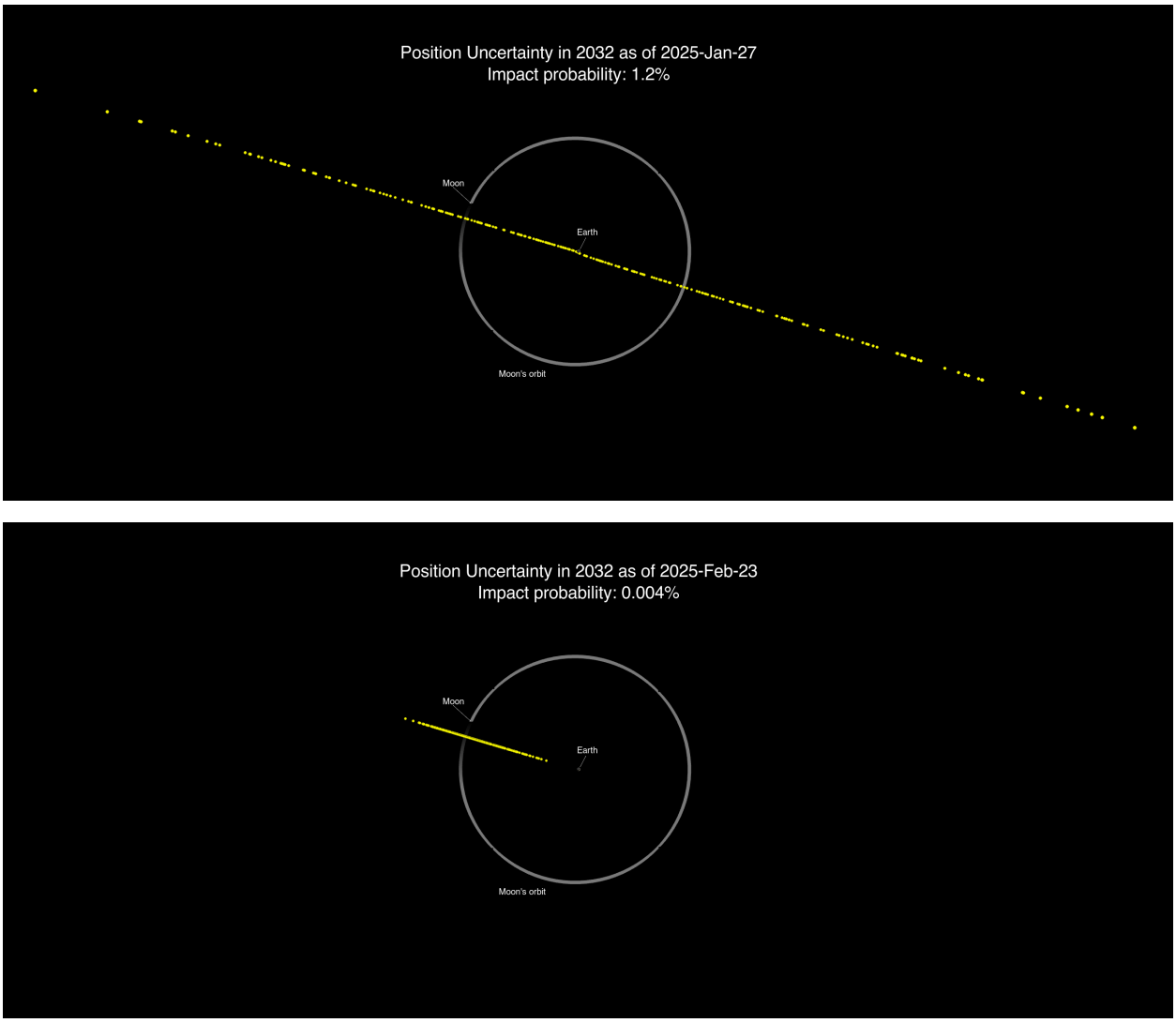

Figure 7: Evolution of Position Uncertainty 2024 YR4 (Dr. Davide Farnocchia). Animation available at: https://science.nasa.gov/wp-content/uploads/2025/02/2024-YR4-Monte-Carlo-Animation.gif

Closure notifications due to IP drop. IAWN, NASA, and ESA then made follow-on notifications, informing the international community that sufficient observational data conclusively showed 2024 YR4 was not a threat to Earth. On 24 Feb 2025, Dr. Fast provided the required notifications[19] to NASA members and interagency members about 2024 YR4, this time telling them of the IP dropping to 0.004% and providing no significant potential for future impact. Dr. Fast also emailed the same information[20], as the IAWN Coordinating Officer, to UNOOSA and SMPAG, and also to the IAWN signatory POCs and February meeting observers she previously had informed.

Success in IP estimations. Gaining enough quality observations to decrease 2024 YR4's orbital uncertainties was a remarkable success, and it ultimately led to ruling out the possibility

[19] Appendix B – NASA Potential Impact Notifications for 2024 YR4
[20] Appendix C – IAWN Potential Impact Notifications for 2024 YR4

of Earth impact on 22 Dec 2032. Several scientists and astronomers had previously mentioned the possibility that the IP could remain above 1% as the asteroid faded from observability, lending to a complex decision-making environment. That still could have happened had the asteroid been on a trajectory that was closer to or on an impacting trajectory. However, with the number of quality observations that continued to be sent into the MPC which helped to reveal the non-impacting trajectory past Earth, this would not be born out. On 25 Feb 2025, news articles went out globally stating NASA and ESA had given the all-clear on 2024 YR4.

JWST observations. Although aware the 2024 YR4 IP had dropped well below 1%, the DDT for JWST, already approved, was retained for the asteroid in order to demonstrate the capability. On 8 Mar 2025, the JWST obtained near-IR imagery using its NIRCAM, although it experienced a common malfunction which prevented it from obtaining mid-IR (MIRI), so while it provided valuable astrometry, it did not constrain the object's size further. JWST provided an additional opportunity for MIRI data in the fourth lunation period.

Characterization. For characterization data during this period, the NOT provided a bridge from the smaller La Silla Danish telescope; the second half of February was NOT's opportunity to provide images used for physical characterization (for the light curve), and as the object faded, NOT also continued to provide valuable astrometry, along with the larger telescopes previously mentioned. During this third Lunation, the VLT (O. Hainaut) and LBT (A. Giunta) provided photometry, and at the end of the period, the 8.1 m Gemini North provided further light curve data (A. Burdanov).

Aftermath

Fourth lunation period (14 Mar – 12 Apr 2025). During the next period between full moons, only the VLT (22 and 23 Mar 2025) and JWST (26 Mar, Rivkin *et al.*) were able to obtain observations of quality to help with astrometry, with the VLT observing 2024 YR4 at 26.5 magnitude, the faintest it was observed at (as of 12 May 2025) by ground-based observers. On 26 Mar 2025, the JWST also provided further characterization data; this time, its MIRI observations worked, and this data enabled further constraining of the size of 2024 YR4 to 60 +/- 7 m from the original estimate of 40-90 m, confirming it was a size range sufficient to cause regional or local devastation if it struck Earth. Because of this size-constraint and the estimated albedo of the object, Dr. Devogele stated the most likely type for 2024 YR4 is an L-type; it is a darker object than most S-types, although S-type is not eliminated. Dr. Peter Jenniskens, who studies meteorite falls and their association with planetary defense, proposed that 2024 YR4 is an H-chondrite, though he stated it had a small chance of being an L-chondrite.

By this time, the asteroid's Earth IP was already negligible, but its lunar IP climbed to 3.8%. IAWN and the PDCO have no direction to monitor lunar impacts, but further observations for science and for understanding of such an impact on technologies in cislunar space and in the geo belt may occur.

Subsequent lunation periods. After the 12 Apr 2025 Full Moon, no further ground-based observation was possible because the object became too faint, leaving only the JWST as an option to find more astrometry on the asteroid. Imaging occurred near mid-May 2025. According to Dr. Rivkin, the NIRCam took images, but the MIRI camera was again aborted due to guide-star acquisition issues. Although a revised size estimate was not possible, an additional position measurement on May 11 was ultimately retrieved from the data and submitted to the Minor Planet Center. On June 3, CNEOS informed PDCO that the lunar impact probability had risen slightly to 4.3% from the orbital arc extension from that position measurement – the last one possible during that apparition. Also, for future apparitions, the object could be observable by NASA's Hubble Space Telescope, which Dr. Tony Roman and Rob Landis have explored.

Case studies and exercises. Although no formal mission planning was directed, informal mission planning teams still examined potential missions, and now 2024 YR4 is also being included as a case study for future exercises, including with the interagency Modeling Working Group (MWG) that includes NASA, NNSA, and USGS. The PD Mission Analysis and Research Group at GDSC examined mission possibilities if 2024 YR4 had continued to increase in IP to determine gaps in US and international capabilities. They found a mission could theoretically be launched for reconnaissance in Dec 2025, which would reach 2024 YR4 in Feb 2027, well before it's Dec 2028 near approach to Earth. This mission could ideally be designed as both a reconnaissance and a mitigation mission, per the National Preparedness Strategy and Action Plan for NEO Hazards and Planetary Defense. The plan states in section 3.1 that for reconnaissance missions to PHAs, "the launch vehicle infrastructure evaluation analysis will include consideration of both rapid-response reconnaissance and deflection/disruption missions..." Dr. Barbee, who led this analysis, stated such a rapid response mission is not currently possible in that limited time given our current technologies.

Lessons Learned

The discovery, follow-on observation, orbital refinement, notifications, and characterization of 2024 YR4 provided many lessons learned, some as a note of success and some for improvement of the planetary defense network:

1. **Alerts and coordination.** Striking a balance between alerting observers early enough and having too many false alarms is a challenging part of planetary defense. In the case of 2024 YR4, Torino 1 was not confirmable by NASA until observations from 28 and 29 Dec 2024 were processed through the MPC to CNEOS, and further orbital analysis was carried out.
    a. **Astrometric Community.** The PDCO became aware 2024 YR4 reached Torino 1 the morning of 31 Dec 2024, soon after sufficient observations were obtained from 28 and 29 Dec 2024 for reliable verification that the object's IP was rising to a sufficient level to merit an increased Torino level. The astrometric community, which monitors Sentry, estimated it had sufficient time to observe the asteroid from then until the end of the apparition in April or May 2025, and by 23 Feb, after peaking at 3.1% on 18 Feb 2025, it successfully reduced the IP to a negligible level.
    b. **Physical Characterization Community.** As discussed, the physical characterization community, which generally does not systematically monitor Sentry, may have had some opportunities to obtain more data earlier if they had become aware of 2024 YR4 sooner. Physical characterization can improve the knowledge later needed for risk assessment and mission planning, if needed. However, redundancy again helped in this area; important physical characterization, though missed by radar, polarimetry, and the IRTF, was still carried out by other assets. Nevertheless, the PDCO is exploring the potential for IAWN alerts to improve future physical characterization opportunities. Further comments on physical characterization can be found in section 3. If faster notifications to the physical characterization community (and the radar community) become possible, more opportunity for characterization and exquisite astrometry when the asteroids are nearest Earth could become the norm. **Recommended possibilities for addressing this include developing an API for automatic alerts from the Sentry system for Torino Scale 1 events, development of a standing IAWN Slack channel for such events, an earlier notification internally of Torino 1 events to key IAWN stakeholders, and other possibilities.** Currently, the PDCO (through the IAWN administration team at the University of Maryland) and the NEOCC are exploring these and other options and in fact have already employed such an alert experimentally with asteroid 2025 FA22, which reached Torino level 1 on 25 Apr 2025 and fell back to Torino level 0 a few days later. IAWN also initiated an experimental Slack channel for 2025 FA22, which represents an opportunity to exercise with another real-world object. Once additional alert procedures are created, the PDCO through

its coordination of IAWN will endeavor to ensure the planetary defense community is notified widely of any changes made.

c. **Survey Community.** Observatories which accomplish follow-on observations of NEOs were better informed about 2024 YR4 being an object of interest than the survey observatories, whose mission is to initially identify these objects but not track them after. Like the physical characterization community, the survey community does not closely monitor Sentry, which is largely designed to help spur follow-on observations. However, survey observatories can still play pivotal roles in the early stages of NEO characterization and orbital refinement if they become aware early of the significance of an object, and that pivotal role lies in their ability to provide precovery data. ATLAS astronomer Larry Denneau noted he sent the initial 2024 YR4 discovery data into the MPC but did not understand its significance at the time. He also did not see the alert on the Sentry system. He opined that an early email to key stakeholders, for example the IAWN email list, of asteroids that need additional scrutiny, could speed up the process of finding precoveries, which may help determine more rapidly if an object will exceed IP thresholds to warrant the use of large follow-on observatories and space telescopes. NASA is exploring options to alert the survey community of Torino Scale 1 objects via IAWN and has implemented one experimentally for 2025 FA22. This includes examining ways to alert key sites that may have precovery data.

d. **Orbit Analysts.** Dr. Park observed that the communication between the orbit analysist and observer community was particularly good. Observers shared what they acquired quickly and openly, allowing others to independently reduce the data. He also noted over the past decade, the observational data used to produce orbits has been improving, and the orbital models worked very well for 2024 YR4. Training specialists capable of conducting the specific advanced analyses and mathematics required to precisely determine NEO orbits is challenging, and the population of such specialists is small. The temporary shutdown of JPL during the January wildfires forced most of the CNEOS orbital analysts to evacuate. The consistent work of Dr. Farnocchia from Idaho through the wildfires (and prior to that through the holidays) enabled critical but singular support to the planetary defense community.

e. **MPC.** While the MPC is the center for reporting NEO position data, its astronomers do not monitor Torino levels and do not perform the 100-year projection for Earth IPs; that is the work of CNEOS, NEOCC, and NEODys. **Therefore, MPC could also benefit from notification in some cases when an object is found to be at Torino level 1, to understand if a need for manual replacement of observations could be forthcoming, and for other efficiencies. The MPC also noted for objects of significance, they receive many repeat questions that could be addressed through some sort of chat or channel function for "reasonably urgent, focused activity."** Finally, the MPC does not have sufficient personnel to conduct 24/7 operations and is exploring more

automation to prepare for the increase in observations predicted from new technologies on the horizon.

f. **DoD.** The Department of Defense has assets that may in some circumstances be able to provide additional data for objects like 2024 YR4. Early alert of key liaisons to the DoD who can, as needed, seek assistance for additional astrometric and characterization data is also part of NASA PDCO's ongoing exploration of beneficial interagency partnerships.

g. **IAWN.** IAWN notifications to SMPAG and UNOOSA occurred in accordance with agreements when the object's IP exceeded 1% and again when it dropped down. UNOOSA in turn notified member states as planned. Weekly meetings between US and European collaborators on Mondays was very helpful, as well as the 4 Feb 2025 IAWN meeting. IAWN also played a role in coordinating observers through an observer coordination webpage. Dr. Melissa Bruker noted this coordination page was particularly useful for deconflicting and improving the efficiency of the use of observatory time.

h. **Internal NASA and interagency notifications.** These occurred in accordance with NASA Policy Directive 8740.1. Some refinement of addressees has occurred recently, as a result of this real-world event.

2. **Public Relations.** 2024 YR4 was generally a public relations success, based on the openness of information flow to the public and the accuracy of information provided by NASA and ESA. The effort to ensure a unified narrative was provided for public consumption helped minimize confusion and did not delay information flow more than a few days at most. NASA and ESA strove to find the balance between too much unverified data that could cause alarmism and having insufficient data, which can cause public mistrust. Some internal concerns were raised that some organizations were not well-credited with the work they did early on because of the need to control the narrative regarding 2024 YR4. An examination of 70 major articles shows that substantial credit was provided to NASA, ESA, JPL, and CNEOS.

   A common question from media outlets was why the IP kept changing. However, consistent messaging helped educate media outlets on the reasons for this and other repeat matters. As the PD community answered media inquiries, there was a concern over the potential for sensationalist articles or manipulative disinformation, and for a small fraction of articles, some of this occurred. For example, one amateur scientist put an estimated impact corridor online which was based on correct data, and which was fairly accurate at that time. However, according to Dr. Micheli, a newspaper redrew the same impact corridor on another map, modifying it to go over several countries not on the original impact corridor map. Once this happened, some minor newspapers propagated this incorrectly portrayed impact corridor. Despite a few errors like this, most reporting from major and even minor media outlets was not sensationalist and provided the facts of the asteroid's small but non-zero impact probability. ESA released more information somewhat earlier than NASA did, which may have given an early (mistaken) perception in a small minority of media outlets of a lack of NASA engagement. However, most

major and minor media outlets portrayed both NASA and ESA accurately as being engaged in determining the future hazard potential of 2024 YR4. Multiple members of the PD community contacted the PDCO for guidance on how to respond to media, and as a review of over 900 PDCO emails pertaining to 2024 YR4 shows, guidance was provided quickly in almost every case. Media outlets worked with NASA personnel or NASA-derived information to produce well over 100 reports on 2024 YR4. Internally, release of information online required approval in the NASA chain of command.

One area of exploration NASA is engaged in is determining what information for Torino scale events is releasable without explicit approval of the NASA chain above the PDCO, given that all related information is posted but not summarized on the MPC and CNEOS websites already. **Currently no prohibition on sharing the raw data exists; summary statements and web postings from NASA are the area that may merit some new efficiencies to ensure NASA guides the information flow in the U.S. One suggestion from CNEOS is that basic information could be preapproved for release on a webpage such as current orbit IP, discovery date, the telescope that discovered the object, basic orbit information, rough magnitude and size estimates, close approach information, Torino scale level, and when the object would be observable.**

3. **Astrometry, Data transfer, and Orbital Estimates.** Multiple recommendations for future 2024 YR4-like events were provided by observers and orbital specialists:
    a. **Established practice of reporting uncertainties was helpful.** Many observatories have transitioned to habitually reporting uncertainties, which was very helpful to CNEOS, NEOCC, and NEODys in developing stable orbital solutions. Some observers could update their reporting practices; some lacked the uncertainty figures, had errors, or bias in their astrometric data. About 20% of the data were reported using the old observation formats from the MPC, which did not allow the reporting of uncertainties. Some observations were excluded in the orbit analysis because they did not provide such uncertainties, or their observations appeared to contain bias. Also, some observations had larger errors than is typical for those sites and were either not used or were down weighted. **Training and education should continue in this matter, to ensure the adoption of the new Astrometry Data Exchange Standard (ADES) standard, which has fields for uncertainty reporting.**
    b. **Best practice- more than one telescope during an observational period.** More than one telescope usage during each observation period helped identify biases from individual observatories. Once this was mentioned at the 4 Feb 2025 IAWN Steering Committee meeting, more observatories sought to coordinate with one another through direct contact and also through the system NEOFixer. Understanding of this best practice should continue to be shared throughout the observation community.
    c. **Inaccurate/old star catalogs.** A few locations used old star catalogs, rather than the Gaia catalog, which is the standard our interviewees stated everyone should be using for observations they are sending to MPC. In some cases, this necessitated

not using their observations. **Continued reminders of using current star catalogs would be helpful.**

d. **Having pre-awarded time helps**. Several astronomers reported using pre-awarded time for 2024 YR4. Dr. de Leon, for example, was able to observe for characterization in early January 2025 because she already had been awarded time on 10.8 m GTC telescope in the form of general observational proposal to observe NEAs, Virtual Impactors, and PHAs. IRTF astronomers had already been awarded time, which they could have used had they been aware of the object's significance. Dr. Brucker was able to trigger her one hour of Target of Opportunity (ToO) time on 26 Feb 2025 with one of the 10 m W. M. Keck Observatory telescopes, adding in valuable astrometry data through NASA's parternship in Keck. JWST was awarded DDT for 2024 YR4, but a near concurrent request for standing Target of Opportunity time on JWST was denied. **Such standing time, particularly specific to planetary defense purposes, may be very helpful for observation of future objects like 2024 YR4.**

e. Language barriers. Reporting from observatories from some nations in Asia has faced a long-lasting difficulty due in part to language barriers. **Further communication to improve collaboration with observers in Asia could substantially increase the potential for ground-based observations, given only 12 time zones are covered from Hawaii to Eastern Europe.**

f. **Precoveries and negative precoveries.** Precoveries for these significant events should be vetted by a peer review process to ensure incorrect data is not entered into the MPC. Also, Dr. Denneau commented that his team would like to develop software that can help with automating the process of finding precoveries to more rapidly extend the arc for newly discovered asteroids. Negative observations in archival images to rule out an impact coule be used as a last resort when the object is no longer observable. However, negative observations are challenging and should follow the corresponding MPC protocol (https://minorplanetcenter.net/mpcops/documentation/negative-observations/)

g. Potential for independent and amateur astronomy community contribution for similar objects. Amateur astronomers played a minor role with 2024 YR4, but Dr. Micheli emphasized amateur astronomers are contributing a lot of good work in the planetary defense arena, particularly in immediately following up on objects. He noted the early Japanese amateur observation was good data, though the observer was not well known. The independent Schiaparelli observatory spent 4-5 hours observing for astrometry as late as 2 Feb 2025, pushing their telescope to the limit. Dr. Micheli was able to use that data as well. He emphasized that the role in first reaction to objects such as these is still significant among amateur astronomers, and on the holidays, a lot of people are home observing. In August 2016, 2024 YR4 was at magnitude 20.5, which means amateur observers could have seen it then as it crossed the northern sky. Amateur observers may, therefore, have pictures of galaxies that, unbeknownst to them, may have images of 2024 YR4 in them. He noted someone at their home may have a hard drive sitting with

images of the object on it. **If 2024 YR4 had reached a higher IP, one possible avenue for additional astrometry could have been reaching out to such amateur astronomers for potential precoveries. One good precovery from years prior, Dr. Micheli emphasized, could yield data that could collapse the orbital uncertainties. While this might be very difficult, it is a potential resource.**

h. **Simulating possible future IPs helped.** Throughout the apparition, Dr. Farnocchia provided updated estimates not only for the IP but predictions about the likelihood of the IP to rise or decline to various levels in the future. He did this by running simulations on each predicted orbit compatible with previously reported astrometry. **These predictions helped the PDCO make better informed recommendations to NASA leadership.**

4. **Spacecraft.** NASA's Lucy spacecraft had some potential for observing 2024 YR4 if such an operation had proven feasible and essential. Lucy's capacity for accurate observations of 2024 YR4 was not certain, and it would have had to consider its approaching 20 Apr 2025 encounter with asteroid Donaldjohansen. Some analysis external to the Lucy team suggested that if it could observe 2024 YR4, Lucy could with a single point observation have reduced the B-plane uncertainty from 270,000 km to 25,000 km or less; however, the Lucy team's preliminary analysis indicated this was not certain, and ground-based observatories would likely achieve this without Lucy by the end of the apparition, so no formal request was made to the Planetary Science Division by PDCO.

5. **Physical Characterization.** The physical characterization community does not have the same developed mechanisms for coordination that the astrometric community currently has through the MPC, NEOFixer, and other automation. During talks at the 2025 Planetary Defense Conference, Dr. Devogele suggested the possibility of forming an "MPC for physical characterization" to coordinate efforts in this community, though IAWN is already exploring better coordination in this area. Nevertheless, the community had sufficient redundancy for this object. Further opportunities for future such objects using polarimetry, radar, IRTF, and other observers such as MRO, but most essential physical characterization for planetary defense-related goals was achieved through the combined work of CSS, the Danish Telescope, the GTC, LDT, VLT, LBT, Gemini South, Keck, and JWST. The physical characterization community tends to communicate in clusters, so further coordination may enhance future data acquisition for a robust increase in asteroids. The following are areas of physical characterization that could have potentially been used for 2024 YR4 but had very short opportunities for use.

   a. **Polarimetry.** Dr. Devogele commented that polarimetry from small telescopes would only have been obtainable in the first 24 hours after discovery of 2024 YR4. Some bigger telescopes that have polarimetric lenses such as VLT (or NOT) could have gotten polarimetry if the phase angle was right, but it was not.

b. **Radar.**

i. **Goldstone radar.** Had the Goldstone radar imaged the object, the IP could have dropped early on, although the opportunity to do so for 2024 YR4 was extremely limited. Goldstone personnel were not aware of the object's significance early enough to provide radar coverage. If personnel at Goldstone had some sort of text notification (not a current practice) right after discovery, for example by 28 Dec 2024 according to Dr. Benner, then they would have tried it and probably gotten a detection. He stated this could have produced Doppler astrometry and a range detection with 1.5 km precision if they focused radar on it for most of the track. That could have reduced the Torino level or prevented it from moving to 1 in the first place. However, the importance of the object was not yet certain by 28 Dec 2024. Also, the three observers who operate Goldstone would have had to have been called or texted to have a reliable chance of them being able to react in time due being away for the holidays. Together with the other optical data recorded through the end of the year, Goldstone had the capacity to reduce 2024 YR4's IP to negligible and prevent it from reaching Torino 1, but with so little time, it would have been an unlikely outcome.

ii. **Arecibo's destruction.** Had Arecibo not catastrophically collapsed in 2020, it would have had the capacity to image 2024 YR4, possibly until 2 Jan 2025, and would have had a reasonable chance of preventing the asteroid from reaching Torino 3. Dr. Benner explained that reductions of 3-4 magnitudes in the time delay (i.e., range) uncertainties are common for asteroids like this. Dr. Petrov, who previously worked at Arecibo, also opined Arecibo could have dramatically improved the predictions for 2032 early on. Dr. Farnocchia explained the data set on 2024 YR4 has a 70,000 km uncertainty by June 2025 using the last position measurement of the apparition by JWST taken in May 2025; Arecibo alone could have reached that uncertainty on Jan 2, 2025 and a 15,000 km (3-sigma) uncertainty in combination with Goldstone radar. So, the current level of knowledge (or better) could have been achieved within a week of discovery, while optical tracking alone required months. It also would have increased our understanding of the object's IP for the Moon.

c. **IRTF.** IRTF users became aware of the asteroid's significance only after an opportunity for observation was over. Dr. Vishnu Reddy emphasized the IRTF could have imaged 2024 YR4 if the notification system provided faster notification to physical characterization astronomers. Dr. Cristina Thomas was using the IRTF on 2, 3, and 4 Jan 2025, but due to an issue with the VPN, manually instructed the person working at the facility to observe only the brightest objects. Had she been controlling the telescope, with her high level of skill, she would have observed fainter objects such as 2024 YR4 on 2 Jan 2025; she stated it would likely have been too faint on 3

Jan 2025. If she had known of its Torino 1 status, she would have pressed her observer on 2 Jan 2025 to try to image the fainter objects that night. MANOS PI Dr. Moskovitz echoed this, stating MANOS missed an opportunity with 2024 YR4 to trigger observations for characterization, for example at IRTF, when it was bright in the week after discovery. By the time 2024 YR4 started getting attention in the physical characterization community, it was too faint to access from IRTF. MANOS has "made changes to the types of alerts they use to trigger observations and now include virtual impactors like 2024 YR4 (Torino scale ≥ 1) and imminent impactors on the NEOCP (Scout impact rating ≥ 2) in their alert stream." These alerts are "handled through a dedicated MANOS Slack channel viewable to all MANOS team members," which they believe will help their response time for such objects. In addition, they "now have the ability to target NEOCP objects at the LDT and IRTF (as of 2022), which will enable more efficient operations during these high priority events."

The PDCO, which funds IRTF, is examining the process for planetary defense related proposals as considered by the Time Allocation Committee's (TAC).

d. **MRO.** MRO personnel became aware of 2024 YR4's significance around 16 Jan 2025 and began imaging it on 24 Jan 2025. They noted that for future similar circumstances, if they and other observers know earlier, they may be able to obtain more information to help with light curves, the spin rate, spectroscopic measurements for mineral composition, and other physical characterization aspects.

6. **Mitigation.** Exercise practice has traditionally been to begin mitigation planning with Torino 1 level events. However, in practice, this proved premature. **Modification of exercises and guidance which has fed into the exercises to match the reality should be a long-term goal.** Also, as Dr. Barbee stated, if we see another 2024 YR4-like object that is in the "upper end of the 40-90 m range and faded from observation with a 10% or higher IP," speed would have been helpful for mitigation. He advised continued exploration of rapid response dual reconnaissance/mitigation missions. **Other recommendations from the risk assessment and mitigation communities include having further conversation on when to use different standard deviation levels in damage estimates.**

7. **Future technology.**
   a. **NEO Surveyor space telescope.** NEO Surveyor is planned for launch no earlier than Sep 2027 and is a dedicated space-based infrared surveyor of NEOs. Dr. Park, CNEOS Manager, stated that if NEO Surveyor had been flying in 2024, "it would likely have detected 2024 YR4 in the Oct-Nov 2024 timeframe, a month or two earlier than found on the ground, and also could have extended the observation arc by a few weeks. If on station in 2028, it might [be] able to help with the

diameter." NEO Surveyor is projected to discover five times as many asteroids as current technologies can.

b. **Vera Rubin Observatory.** The NSF and DOE's nearly complete Vera C. Rubin Observatory houses the LSST, which at 8.4 m is the largest digital camera ever built "will repeatedly scan the sky for 10 years and create an ultra-wide, ultra-high-definition time-lapse record of our Universe." LSST will combine the wide-field scanning capabilities of traditional surveys such as ATLAS but will also have the deeper observational capabilities of the larger optical telescopes. While Vera Rubin is designed for astrophysics and not specifically for planetary defense, it is anticipated to provide another five times as many asteroids as current technologies can, bringing the population of known asteroids into the tens of millions. Experts consulted for this lessons learned document had varying estimates for how many additional Torino 1 events may occur once data from Vera Rubin and NEO Surveyor become available, from one per month to several per year, but most believe the population will increase. It is difficult to carry out such an estimate because both technologies may find many more objects, but they may also be able to quickly eliminate many of these from having IPs of any concern.

c. **ESA technologies.** Flyeye and NEOMIR could also, if they come to fruition, add substantial value for finding NEOs. NEOMIR, as planned, will have a large field of view at 1.7 degrees by 7 degrees and will survey close to the Sun from the Sun-Earth Lagrange 1 point. Theoretically, according to ESA, NEOMIR would have been able to detect 2024 YR4 about one month prior to the discovery if it had already been in place, and it could also have detected Chelyabinsk in the days prior to impact. As ESA presented at the 2025 Planetary Defense Conference, this would have allowed for a combination of space-based and ground-based astrometry, which would have provided a precise orbit and given advanced warning for physical characterization.

d. **Current technology enhancements.** Existing surveys and telescopes such as ATLAS, PAN-STARRS, and others are exploring ways to enhance their capacity to detect asteroids as small as 2024 YR4. This includes, in the case of ATLAS, exploration of using fewer exposures (3 instead of 4) enhanced by linking them on multiple nights. This also includes exploring new software for optimizing observers and ways to synchronize surveys with LSST and NEO Surveyor.

8. **Augmented staffing in the PDCO.** The PDCO has a very limited group of personnel to monitor and coordinate for Torino level events. While automation can potentially increase to help with alerts and coordination, an increase in personnel in the PDCO could help increase the ability of the organization to respond to the anticipated 10X increase in discoveries with the NEO Surveyor space telescope and the LSST.

Summary

The review found the planetary defense community carried out an observation campaign that resulted in the successful discovery, confirmation, follow-on observation, and resolution of 2024 YR4's risk level from Torino 3 to Torino 0 within its first apparition. This success was largely due to the strategic approach to planetary defense over the past several decades, involving the funding of increasingly better survey and follow-up technologies, evolved methods for orbital computations, and improved coordination mechanisms. Operationally, the PDCO and IAWN carried out all actions and notifications in accordance with applicable directives and agreements. The international community successfully managed the process of the 2024 YR4 detection, characterization, orbital refinement, notifications, and planning for future actions. The community also navigated well the need for an early effort to characterize the NEO and to find and vet "precoveries" as IPs grew, prior to 2024 YR4's rapid fading from observability. Lessons learned in the second half of this document capture ways for enhancing an already robust process of coordinating follow-on observations and communicating between stakeholders to allow earlier opportunity for physical characterization and orbital refinement for future Torino scale events. Such process augmentation will enable the planetary defense community to better prepare for the increase in the discovery of such objects in the near future due to the near-term advent of advanced new planetary defense technologies.

Appendix A – Chronological Sampling of Communications/Media/Online Reports

Wikipedia: https://en.wikipedia.org/wiki/2024_YR4#/media/File:Mmexport1738033309783.jpg

https://en.wikipedia.org/wiki/2024_YR4#/media/File:Mmexport1738033309783.jpg

NASA: https://blogs.nasa.gov/planetarydefense/2025/01/29/nasa-shares-observations-of-recently-identified-near-earth-asteroid/

ESA: https://www.esa.int/Space_Safety/Planetary_Defence/ESA_actively_monitoring_near-Earth_asteroid_2024_YR4

Washington Times: Astronomers are Keeping an Eye on This Asteroid's Odds of Hitting Earth (Robin George Andrews)

Business Insider: https://www.businessinsider.com/asteroid-yr4-possible-earth-impact-2032-odds-nasa-esa-2025-1

The Planetary Society: "Should you be worried about Asteroid 2025 YR4"

CNEOS: https://cneos.JPL-CNEOS.nasa.gov/news/news210.html

University of Hawaii: http://manoa.hawaii.edu/news/article.php?aId=13693

Maui Now: Maui Now online story

Scientific American: https://www.scientificamerican.com/article/will-asteroid-2024-yr24-strike-earth-in-2032/)

Mashable: Mashable (1/31), "NASA Spotted a Big Asteroid That May Hit Earth."

Arstechnica: https://arstechnica.com/space/2025/02/thanks-to-nasa-you-probably-wont-have-to-worry-about-this-asteroid-killing-you/

The Hill: https://thehill.com/homenews/5129996-nasa-imagery-large-asteroid-earth-2032/

Express: https://www.express.co.uk/news/uk/2011108/chance-asteroid-hitting-earth

Tech Times: https://www.techtimes.com/articles/309305/20250207/nasa-warns-world-breaker-asteroid-could-hit-earth-2023-it-only-one-43-chance.htm

CBS News: https://www.cbsnews.com/news/city-killer-asteroid-odds-hitting-earth-increase-webb-telescope/

ABC News: https://abcnews.go.com/US/chances-asteroid-striking-earth-decade-doubled-nasa/story?id=118653026

YouTube: https://youtu.be/LFj0D6qp1HQ?si=Iol8WDhT49SFD7r0

B612 Foundation: https://b612foundation.org/a-stark-reminder-the-chelyabinsk-anniversary-and-asteroid-2024-yr4/

Axios: https://www.axios.com/2025/02/12/asteroid-earth-impact-risk

The Atlantic: https://www.theatlantic.com/science/archive/2025/02/earth-killer-asteroids-2024-yr4/681660/

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The Space Show: https://thespaceshow.com/show/14-feb-2025/broadcast-4335-dr.-edward-lu-b612-foundation)

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USA Today: https://www.usatoday.com/story/news/nation/2025/02/12/asteroid-2024-yr4-odds-impact-earth-nasa/78456125007/

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The following is titled, “Is Asteroid 2024 YR4 going to kill us all?” https://youtu.be/-xxmzO76Kas?si=aiN3MqMmgH92dMaP

Apple News: https://apple.news/AqEalNglgQdGwat-hMzTTbw 'City-killer' asteroid 2024 YR4 could hit the moon instead of us, scientists say.

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Washington Times: https://www.washingtontimes.com/news/2025/feb/19/chance-rises-asteroid-2024-yr4-hitting-earth-2032/

CNN: https://www.cnn.com/2025/02/19/science/asteroid-2024-yr4-earth-collision-risk/index.html

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Live Science: https://www.livescience.com/space/asteroids/nasa-changes-odds-of-the-asteroid-hitting-earth-in-2032-yet-again-but-this-time-its-good-news

UPI: https://www.upi.com/Science_News/2025/02/20/NASA-asteroid-impact-probability-lowered/2801740063167/

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Fox: https://fox2now.com/news/national/youre-going-to-see-more-city-killer-asteroids-but-fret-not-mit-astronomer/

CBS: https://www.cbsnews.com/boston/news/asteroid-hitting-earth-odds-go-up-again/

USA Today: https://www.usatoday.com/story/news/nation/2025/02/21/nasa-odds-2024-yr4-asteroid-city-killer/79333551007/

Live Science: https://www.livescience.com/space/asteroids/asteroid-yr4-impact-odds-plummet-as-nasa-changes-threat-level-of-city-killer

Chron: https://www.chron.com/news/space/article/asteroid-nasa-odds-20179438.php

Boston: https://www.boston.com/news/world-news/2025/02/25/nasa-gives-all-clear-asteroid-threaten-earth/

NASA: https://blogs.nasa.gov/planetarydefense/

Appendix B – NASA Potential Asteroid Impact Notifications for 2024 YR4

POTENTIAL ASTEROID IMPACT NOTIFICATION

Date: January 28, 2025
From: NASA Planetary Defense Coordination Office
Title: Potential for Impact of Near-Earth Asteroid 2024 YR4 on December 22, 2032

Impact Probability	1.2% as calculated by NASA JPL Center for NEO Studies
Date of Potential Impact	December 22, 2032
Impact Risk Corridor	Across the eastern Pacific Ocean, northern South America, the Atlantic Ocean, Africa, the Arabian Sea, and South Asia
Asteroid Size	Most likely in the range 40–90 meters (130–300 feet) in size
Expected Damage Level if Impact Occurs	Severe blast damage in the unlikely event of an impact
When will there be new information?	The asteroid will be observable, and information will be updated, through early April 2025 and then again starting in June 2028 when the asteroid will return to the vicinity of Earth

ADDITIONAL DETAILS:

- **Notification Threshold:** 1% is the notification threshold for IAWN[1]
- **Impact Probability:** There is a 1.2% probability that near-Earth asteroid (NEA) 2025 YR4 could impact Earth on 22 December 2032. While there is large uncertainty in whether the asteroid will impact Earth, if an impact occurs it will be on this date. There is almost a 99% probability that 2024 YR4 will safely pass by Earth on this date.
- **Impact Probability Confirmation:** The impact probability was calculated by the NASA JPL Center for Near-Earth Object Studies (CNEOS). It was cross-checked with ESA Near-Earth Objects Coordination Centre (NEOCC) with the NEO Dynamic Site (NEODyS), in coordination with the worldwide network of observatories in the International Asteroid Warning Network (IAWN) submitting observations to the Minor Planet Center (MPC).
- **Future Observability and Update to Impact Probability:** Future observations will reduce the uncertainty in the 2024 YR4's trajectory and impact probability. The NEA will be observable through early 2025 April, after which point it will become too faint to be observable from Earth until June 2028 when the asteroid's approximately 4 year orbit returns it to the vicinity of Earth. The NEA will be quite faint and will likely require large (2-meter and larger) telescopes. By the end of the 2025 observability window, the impact probability could increase to a couple tens of percent or it could more likely drop back below the notification threshold (1% impact probability). Detections of 2024 YR4 in archival images have not been found but searches will continue as the orbit is better constrained.
- **Impact Risk Corridor:** The impact risk corridor for 2025 YR4, which is the region of Earth along which a potential impact could occur, extends across the eastern Pacific Ocean, northern South America, the Atlantic Ocean, Africa, the Arabian Sea, and South Asia
- **Asteroid size:** 2024 YR4 is likely in the range 40–90 meters (130–300 feet). The size cannot be further constrained without deep space radar observations, thermal infrared observations, or imagery from a spacecraft that could closely approach the asteroid. Additionally, the asteroid is now too distant for radar observations and will not come within radar range until 2032.
- **Expected Damage Level if Impact Occurs:** Blast damage could occur as far as 50 km from the impact site, based on the larger end of the size range.
- **Discovery:** 2024 YR4 was first reported on 27 December 2024 by the Asteroid Terrestrial Last Alert System (ATLAS) station of the University of Hawai'i in Chile during NEA search operations for NASA. NASA-funded astronomers and the worldwide network of observatories of the IAWN continued to perform follow-up observations. Detections were also found in archival images taken on 25 and 26 December 2024.

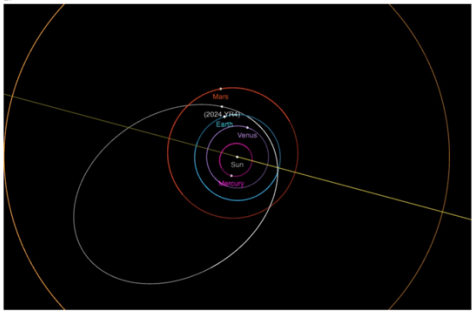
This notification is issued by the Planetary Defense Coordination Office (PDCO) in compliance with NASA Policy Directive 8740.1. NASA established the PDCO to manage its ongoing mission of planetary defense. The PDCO is responsible for detection, tracking, and characterization of potentially hazardous objects (PHO's) and for issuing warnings of possible impact effects when the probability of impact is greater than 1%.

[1]*The International Asteroid Warning Network (IAWN) established criteria and thresholds for impact response actions. The threshold for issuing warnings of possible impact effects is a probability of impact greater than 1% and a rough size estimated to be greater than 10 meters (33 feet). IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations that is currently coordinated by NASA.*

Graphics

1. Helio-centric orbit diagram of 2024 YR4 relative to Earth orbit
2. Position relative to Earth orbit of 2024 YR4 at discovery in December 2024 and after two orbits of the asteroid around the Sun on 2032 Dec. 22
3. Possible locations of 2024 YR4 relative to Earth on 2032 Dec. 22 from Monte Carlo modeling

1.



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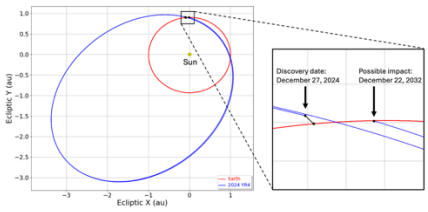

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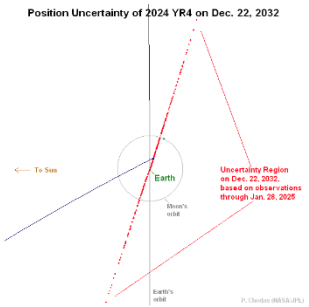


FINAL NOTIFICATION: NO SIGNFICANT POTENTIAL FOR FUTURE IMPACT WITH EARTH BY NEAR-EARTH ASTEROID 2024 YR4

Date: February 24, 2025
From: NASA Planetary Defense Coordination Office, NASA Headquarters
Title: Final Notification: Probability of Impact of Near-Earth Asteroid 2024 YR4 on 22 December 2032 Drops to 0.004% - No Significant Potential for Future Impact with Earth

Impact Probability	0.004% on 22 December 2032 as calculated by NASA JPL Center for Near-Earth Object Studies
Date of Potential Impact	There is no significant potential for an impact with Earth for the next century

ADDITIONAL DETAILS:

- **Notification Threshold:** 1% is the notification threshold for IAWN[1]; reissuance of notification if impact probability drops below 1%.
- **Impact Probability:** Continued observations of 2024 YR4 during January and through 23 February 2025 have dropped the probability of Earth impact on 22 December 2032 to 0.004% (1 chance in 26,000) after the asteroid had reached a peak impact probability of 3.1%. There is now no significant potential for an impact with Earth for the next century.
- **Impact Probability Confirmation:** The impact probability was calculated by the NASA JPL Center for Near-Earth Object Studies (CNEOS). It was cross-checked with ESA Near-Earth Objects Coordination Centre (NEOCC) and the NEO Dynamic Site (NEODyS, Italy) in coordination with the worldwide network of observatories in the International Asteroid Warning Network (IAWN) submitting observations to the Minor Planet Center (MPC). The impact probability with Earth dropped below 1% as of 21 February 2025; NASA and IAWN continued to monitor the impact probability to confirm the drop below the notification threshold.
- **Close Approach to Earth on 22 December 2032:** The asteroid will pass at a distance beyond the geosynchronous satellites and possibly beyond the Moon. IAWN will continue to track 2024 YR4 to more precisely predict the distance.
- **Future Observability:** 2024 YR4 will be observable through early 2025 April, after which point it will become too faint to be observable from Earth until 2028.
- **Asteroid size:** 2024 YR4 is likely in the range 40–90 meters (130–300 feet). The James Webb Space Telescope is scheduled to observe the asteroid in March to better determine its size. The asteroid will not come within deep space radar range until 2032.

This notification is issued by the Planetary Defense Coordination Office (PDCO) in compliance with NASA Policy Directive 8740.1. NASA established the PDCO to manage its ongoing mission of planetary defense. The PDCO is responsible for detection, tracking, and characterization of potentially hazardous objects (PHO's) and for issuing warnings of possible impact effects when the probability of impact is greater than 1%.

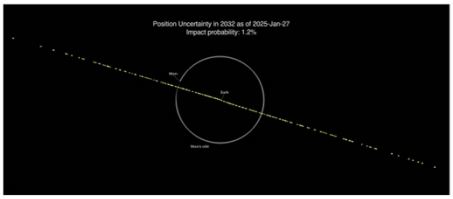
[1]The International Asteroid Warning Network (IAWN) established criteria and thresholds for impact response actions. The threshold for issuing warnings of possible impact effects is a probability of impact greater than 1% and a rough size estimated to be greater than 10 meters (33 feet). IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations that is currently coordinated by NASA.

Graphics

Monte Carlo modeling of 2024 YR4's swath of possible locations on 22 December 2032

- as of 27 January 2025 – 1.2% probability of impact
- as of 18 February 2025 – 3.1% probability of impact (maximum impact probability)
- as of 23 February 2025 – 0.004% probability of impact

1.



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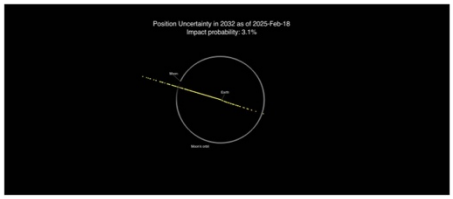

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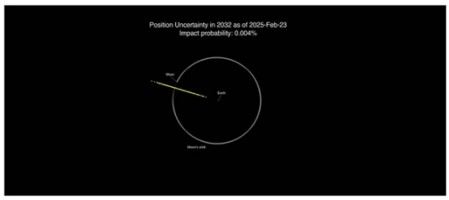


Appendix C – IAWN Potential Asteroid Impact Notifications for 2024 YR4

INTERNATIONAL ASTEROID WARNING NETWORK (IAWN)

POTENTIAL ASTEROID IMPACT NOTIFICATION

Date: 29 January 2025
From: International Asteroid Warning Network (IAWN)
IAWN Coordinating Officer (NASA) for the IAWN Steering Committee
To: Chair (ESA), Space Mission Planning Advisory Group (SMPAG);
Planetary Defence Programme Officer, United Nations Office of Outer Space Affairs (UNOOSA)
Title: Potential for Impact of Near-Earth Asteroid 2024 YR4 on 22 December 2032

Impact Probability	1.3% as calculated by NASA JPL Center for NEO Studies and ESA Near-Earth Objects Coordination Centre (NEOCC) with the NEO Dynamic Site (NEODyS)
Date of Potential Impact	22 December 2032
Impact Risk Corridor	Across the eastern Pacific Ocean, northern South America, the Atlantic Ocean, Africa, the Arabian Sea, and South Asia
Asteroid Size	Most likely in the range 40–90 meters (130–300 feet) in size
Expected Damage Level if Impact Occurs	Severe blast damage in the unlikely event of an impact
When will there be new information?	The asteroid will be observable, and information will be updated, through early April 2025 and then again starting in June 2028 when the asteroid will return to the vicinity of Earth

ADDITIONAL DETAILS:

- **Notification Threshold:** 1% is the notification threshold for IAWN[1]
- **Impact Probability:** There is a 1.3% probability that near-Earth asteroid (NEA) 2025 YR4 could impact Earth on 22 December 2032. While there is large uncertainty in whether the asteroid will impact Earth, if an impact occurs it will be on this date. There is almost a 99% probability that 2024 YR4 will safely pass by Earth on this date.
- **Impact Probability Confirmation:** The impact probability was calculated by the NASA JPL Center for Near-Earth Object Studies (CNEOS) and ESA Near-Earth Objects Coordination Centre (NEOCC) with the NEO Dynamic Site (NEODyS), in coordination with the worldwide network of observatories in the International Asteroid Warning Network (IAWN) submitting observations to the Minor Planet Center (MPC).
- **Future Observability and Update to Impact Probability:** Future observations will reduce the uncertainty in the 2024 YR4's trajectory and impact probability. The NEA will be observable through early 2025 April, after which point it will become too faint to be observable from Earth until 2028 June when the asteroid's approximately 4 year orbit returns it to the vicinity of Earth. The NEA will be quite faint and will likely require large (2-meter and larger) telescopes. By the end of the 2025 observability window, the impact probability could increase to a couple tens of percent or it could more likely drop back below the notification threshold (1% impact probability). Detections of 2024 YR4 in archival images have not been found but searches will continue as the orbit is better constrained.
- **Impact Risk Corridor:** The impact risk corridor for 2025 YR4, which is the region of Earth along which a potential impact could occur, extends across the eastern Pacific Ocean, northern South America, the Atlantic Ocean, Africa, the Arabian Sea, and South Asia
- **Asteroid size:** 2024 YR4 is likely in the range 40–90 meters (130–300 feet). The size cannot be further constrained without deep space radar observations, thermal infrared observations, or imagery from a spacecraft that could closely approach the asteroid. Additionally, the asteroid is now too distant for radar observations and will not come within radar range until 2032.
- **Expected Damage Level if Impact Occurs:** Blast damage could occur as far as 50 km from the impact site, based on the larger end of the size range.
- **Discovery:** 2024 YR4 was first reported on 27 December 2024 by the Asteroid Terrestrial Last Alert System (ATLAS) station of the University of Hawai'i in Chile during NEA search operations for NASA. NASA-funded astronomers and the worldwide network of observatories of the IAWN continued to perform follow-up observations. Detections were also found in archival images taken on 25 and 26 December 2024.

[1]*This notification is issued by the International Asteroid Warning Network (IAWN)* in accordance with criteria and thresholds for impact response actions in report A/AC.105/C.1/2017/CRP.25 to the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space. The threshold for issuing warnings of possible impact effects is a probability of impact greater than 1% and a rough size estimated to be greater than 10 meters (33 feet). IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations. https://iawn.net*

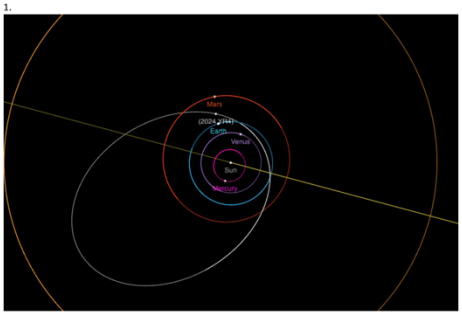
The Committee in its annual reports (e.g. A/78/20, para. 119) notes that should a credible threat of impact be discovered by the IAWN, available information would be provided by IAWN and disseminated to all Member States through the Office for Outer Space Affairs. The Office for Outer Space Affairs disseminates information pursuant to General Assembly resolution 78/72, paragraph 14, concerning the work carried out by the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) and in its capacity as the permanent secretariat of SMPAG. IAWN also provides information to SMPAG.

**The United Nations General Assembly in its resolution 70/82 of 9 December 2015 noted with satifaction the establishment of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) to implement recommendations for an international response to the near-Earth object impact that were endorsed by the Committee on the Peaceful Uses of Outer Space in 2013 (A/68/20, para. 144).*

Graphics and Websites

1. Helio-centric orbit diagram of 2024 YR4 relative to Earth orbit
2. Position relative to Earth orbit of 2024 YR4 at discovery in December 2024 and after two orbits of the asteroid around the Sun on 22 December 2032
3. Possible locations of 2024 YR4 relative to Earth on 22 December 2032 from Monte Carlo modeling

1.



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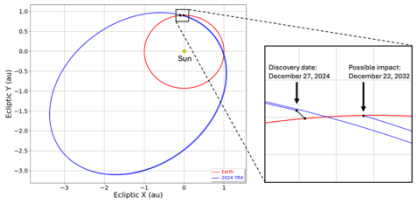

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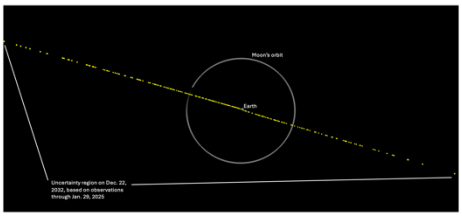


INTERNATIONAL ASTEROID WARNING NETWORK (IAWN)[1]

FINAL NOTIFICATION: NO SIGNFICANT POTENTIAL FOR FUTURE IMPACT WITH EARTH BY NEAR-EARTH ASTEROID 2024 YR4

Date: 24 February 2025
From: International Asteroid Warning Network (IAWN)
IAWN Coordinating Officer (NASA) for the IAWN Steering Committee
To: Chair (ESA), Space Mission Planning Advisory Group (SMPAG);
Planetary Defence Programme Officer, United Nations Office of Outer Space Affairs (UNOOSA)
Title: Final Notification: Probability of Impact of Near-Earth Asteroid 2024 YR4 on 22 December 2032 Drops to 0.004% - No Significant Potential for Future Impact with Earth

Impact Probability	0.004% on 22 December 2032 as calculated by NASA JPL Center for NEO Studies, ESA Near-Earth Objects Coordination Centre (NEOCC), and NEO Dynamic Site (NEODyS)
Date of Potential Impact	There is no significant potential for an impact with Earth for the next century

ADDITIONAL DETAILS:

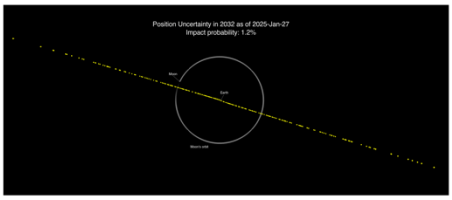
- **Notification Threshold:** 1% is the notification threshold for IAWN[2]; reissuance of notification if impact probability drops below 1%.
- **Impact Probability:** Continued observations of 2024 YR4 during January and through 23 February 2025 have dropped the probability of Earth impact on 22 December 2032 to 0.004% (1 chance in 26,000) after the asteroid had reached a peak impact probability of 3.1%. There is now no significant potential for an impact with Earth for the next century.
- **Impact Probability Confirmation:** The impact probability was calculated by the NASA JPL Center for Near-Earth Object Studies (CNEOS), ESA Near-Earth Objects Coordination Centre (NEOCC), and NEO Dynamic Site (NEODyS), in coordination with the worldwide network of observatories in the International Asteroid Warning Network (IAWN) submitting observations to the Minor Planet Center (MPC). The impact probability with Earth dropped below 1% as of 21 February 2025 and IAWN continued to monitor the impact probability to confirm the drop below the notification threshold.
- **Close Approach to Earth on 22 December 2032:** The asteroid will pass at a distance beyond the geosynchronous satellites and possibly beyond the Moon. IAWN will continue to track 2024 YR4 to more precisely predict the distance.
- **Future Observability:** 2024 YR4 will be observable through early 2025 April, after which point it will become too faint to be observable from Earth until 2028.
- **Asteroid size:** 2024 YR4 is likely in the range 40–90 meters (130–300 feet). The James Webb Space Telescope is scheduled to observe the asteroid in March to better determine its size. The asteroid will not come within deep space radar range until 2032.
- **IAWN website:** https://iawn.net

Graphics

Monte Carlo modeling of 2024 YR4's swath of possible locations on 22 December 2032

1. as of 27 January 2025 – 1.2% probability of impact
2. as of 18 February 2025 – 3.1% probability of impact (maximum impact probability)
3. as of 23 February 2025 – 0.004% probability of impact

1.



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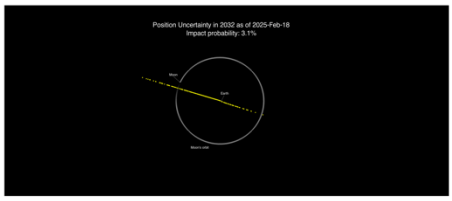

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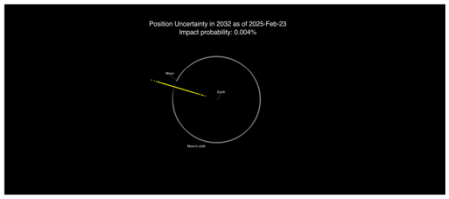

[1] *IAWN is a worldwide collaboration of asteroid observers and modelers that was recommended by the United Nations, pursuant to the General Assembly resolution 70/82 of 9 December 2015 notes with satifaction the establishment and the work of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) to implement recommendations for an international response to the near-Earth object impact that were endorsed by the Committee on the Peaceful Uses of Outer Space in 2013 (A/68/20, para. 144). See https://iawn.net.*

[2] *Agreed criteria and thresholds by the International Asteroid Warning Network (IAWN) and the Space Mission Planing Advisory Group (SMPAG), (see Status report by the IAWN and SMPAG to the 62nd session of the Scientific and Technical Subcommittee of the United Nations Committee on the Peaceful Uses of Outer Space, A/AC.105/C.1/2025/CRP.6. The Committee in its annual reports (A/79/20, para. 135) notes that should a credible threat of impact be discovered by the IAWN, available information would be provided by IAWN and disseminated to all Member States through the Office for Outer Space Affairs. The threshold for issuing warnings of possible impact effects is a probability of impact greater than 1% and a rough size estimated to be greater than 10 meters (33 feet).*