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Expanding our Planetary Defense Umbrella to Cislunar Space

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Abstract

Most efforts to look at Planetary Defense have only considered protecting the Earth. But there are now concrete plans to establish human settlements and other significant infrastructure on the surface of the Moon over the course of the next several decades. This puts the people – and strategic assets – there at risk from asteroid and comet impacts. While major impacts both on Earth and on the Moon are rare, Earth’s atmosphere protects it from the impact of the much more frequent smaller objects. The Moon lacks this natural shield, and thus potentially damaging impacts can be expected to happen much more frequently. This paper therefore explores whether or not our planetary defense umbrella should be expanded to include cislunar space, and how this could be achieved.

Keywords: Planetary Defense, space strategy, cislunar strategy

Introduction

The past several decades have seen our species make great strides in our ability to protect our home planet from impacts of asteroids and comets.¹ At the same time, mankind has also started to expand its sphere of influence into space, especially to the Moon,² and it is appropriate now to consider widening the sphere of vigilance and protection. The upcoming conjunction between Earth and the asteroid Apophis in April 2029 illustrates this threat, since simulations show that Apophis will not just pass closely by Earth, but also closely by the Moon³. Similarly, at the time of this writing, observational data cannot exclude a collision of the newly-discovered Near-Earth Object (NEO) 2024 YR4 with the Moon.⁴ We therefore explore if and how the Planetary Defense system-of-systems protecting Earth from asteroids and comets can be expanded to also cover the Moon.

¹ See, for example, Conway et al., 2022

² NASA, 2025a

³ JPL Small-Body Database, 2025b

⁴ JPL Small-Body Database, 2025a

Motivation

While major impacts of asteroids and comets both on Earth and on the Moon are rare, Earth's atmosphere protects it from the impact of the much more frequent smaller objects of a few meters or less in size. The Moon lacks this natural shield, and thus potentially damaging impacts can be expected to happen much more frequently.

Furthermore, due to the Moon's lower gravity field and again due to its lack of atmosphere, even smaller impacts can generate ejecta that can make it into cislunar space and threaten people and infrastructure there. At the same time, habitats and other structures on and around the Moon will likely be less physically resilient than terrestrial structures, and thus more vulnerable to impacts and related second-order effects such as Moonquakes. Evacuating a predicted impact area on the Moon will be more challenging as well compared to Earth.

Finally, combining Lunar exploration with Planetary Defense efforts could create another fruitful area of international collaboration, with geostrategic benefits.

This paper therefore explores whether or not our planetary defense umbrella should be expanded to include cislunar space, and how this could be achieved. It provides a brief overview of the status quo, then discusses the consequences of a NEO impact on the Moon, identifies the object sizes of most concern and the likelihood of their impact, and then surveys potential ways forward.

Status Quo

The authors' survey of Planetary Defense capabilities and activities, while not comprehensive, did not yield many tie-ins to the Moon. Planetary Defense, as currently defined, involves protecting only Earth from asteroid and comet impacts.

While the authoritative history of NEO research mentions the Moon, it is in the context of Lunar cratering providing visible evidence for NEO impacts that started interest in NEO impacts on Earth.⁵ Furthermore, the topic of Planetary Defense for the Moon (PD-M) is not mentioned in existing U.S. policy documents:

- The U.S. "National Cislunar Science & Technology Action Plan" mentions "aiding planetary defense" through extending U.S. Space Situational Awareness capabilities into Cislunar space, but does not discuss PD-M.⁶
- The U.S. "National Preparedness Strategy for Near-Earth Object Hazards and Planetary Defense" similarly only mentions leveraging Cislunar domain awareness data.⁷
- NASA's "Planetary Defense Strategy and Action Plan" does not mention PD-M, either.⁸

However, there are some links, albeit limited. NASA's Small-Body Database calculates "close approaches to planets, the [M]oon, and the largest few main-belt asteroids."⁹

⁵ Conway et al., 2022.

⁶ Millard, 2024.

⁷ Daniels, 2023.

⁸ NASA, 2023a.

⁹ JPL, 2025a/b.

Finally, some existing Planetary Defense capabilities involve looking for impacts on the Moon. For example, NASA has a “Lunar Impact Monitoring Program,”¹⁰ and will deploy a Lunar seismometer package as part of its Artemis Program.¹¹

Consequences of a NEO Impact on the Moon

Even very small NEOs that would burn up harmlessly in Earth’s atmosphere and might not even be detected by our Planetary Defense sensors are cause for concern on the Moon. According to NASA’s Lunar Impact Monitoring Program, due to the high speeds at which NEOs travel (20 km/s or more) and their resulting high kinetic energies, such objects can still cause significant damage. For example, a “space rock” with a mass of only 5kg can create a crater of over 9m diameter on impact, and eject 75t of regolith.¹² In 2013, a NEO with an estimated mass of 16kg caused an impact crater of approximately 15m diameter.¹³ Even smaller objects that do not cause significant cratering can still pierce the hull of a pressurized module, or damage other infrastructure, similar to Micrometeoroid and Orbital Debris impacts on the International Space Station and other space vehicles.

However, since the number of potential impactors is inversely related to their size (see discussion in the next section), many more smaller objects exist, posing a scalability challenge. To make the problem more tractable, it is therefore important to define a size threshold for objects that Planetary Defense for the Moon (PD-M) should, at least initially, focus on.

Size Threshold for Planetary Defense for the Moon

In the context of protecting Earth from potentially-hazardous objects, those with diameters of less than approximately 15m are of little concern, since they are unlikely to cause damage on the ground. However, in the case of the Moon, as mentioned above, much smaller objects will reach the Lunar surface and can cause damage.

At the same time, just like other in-space systems, Lunar infrastructure will have to be protected against micrometeoroid impacts anyways. In particular, pressurized vessels such as habitats will have to mitigate the risk of being punctured by a micrometeoroid. However, the direct damage caused by micrometeoroids is generally localized, with the area of structural damage along the path of an impactor not much larger than its diameter.

It thus seems reasonable for PD-M to focus on objects that cause more widespread damage, such as cratering. Additional analysis will be required to determine a specific threshold by mass, diameter, and/or speed. However, as discussed at the beginning of this section, objects with a mass as low as a few kilograms can cause cratering and may therefore have to be included.

¹⁰ NASA, 2023b

¹¹ NASA, 2024.

¹² NASA, 2023b.

¹³ Suggs et al., 2014.

Effects of Larger Impactors

In contrast to a damaging NEO impact on Earth, a Lunar impact will not cause a blast wave or thermal pulse due to the lack of atmosphere, nor, obviously, can it cause a tsunami. However, other effects extending beyond the immediate footprint of the impactor still are a concern: cratering, causing a “Moonquake,” and generation of ejecta.

Due to the lower gravity of the Moon and, again, its lack of atmosphere, ejecta generation could cause secondary impacts at large distances from Ground Zero, and could inject debris into Lunar orbit, creating a risk to assets near the Moon. Very large impacts could lead to ejecta getting close to Earth, increasing the risk to vehicles and platforms in Earth orbit, or could even lead to ejecta impacting on Earth itself.

Lunar and Cislunar Infrastructure at Risk

Over the course of the next decade, multiple countries plan to establish permanent infrastructure in and around the Moon. For example, NASA’s Artemis Program involves habitats, rovers, and other components near the Lunar south pole, as well as a small space station in a near-rectilinear halo orbit.¹⁴ Canada, Japan, the United Arab Emirates, and the member nations of the European Space Agency are involved directly,¹⁵ while, at the time of this writing, over 50 nations have joined the related Artemis Accords.¹⁶

The People’s Republic of China is working on setting up a permanent Lunar presence as well, under its “International Lunar Research Station” (ILRS) program.¹⁷ This, too, involves multiple additional nations which will thus have a stake in PD-M.

Beyond these currently-funded efforts, there are additional plans to place large-scale infrastructure on the Moon, for example to enable water ice mining and processing. The architecture proposed by Lockheed Martin can serve as an illustrative example for this.¹⁸

Likelihood of NEO Impacts on the Moon

While Earth and Moon are over 380,000 km apart, that is still small compared to typical NEO miss distances,¹⁹ and thus the NEO flux affecting Earth and Moon is roughly the same. However, both due to its larger cross-section and due to its larger area of gravitational influence, Earth is more likely to collide with a NEO than the Moon (see Table 1).

At the same time, the number of NEOs of a certain size is inversely related to their size: there are many more smaller objects than larger objects (see Figure 1). In case

¹⁴ NASA, 2025a.

¹⁵ NASA, 2025c.

¹⁶ NASA, 2025d.

¹⁷ CNSA, 2021.

¹⁸ Lockheed-Martin, 2025.

¹⁹ For example, of the 3,228 objects of magnitude 26 or brighter listed in the CNEOS Close Approach database at the time of this writing, only 136 (4.2%) are expected to pass by Earth closer than two Lunar Distances (CNEOS, 2025b).

of Earth, as mentioned above, objects smaller than approximately 15m in diameter generally burn up in the upper atmosphere without causing any damage. However, since the Moon lacks an atmosphere, objects of any size will impact the surface of the Moon and can thus cause damage. Again as discussed above, this section will focus on larger objects, but will also briefly cover micrometeoroids for context.

To illustrate the relative random spatial distribution of the flux of objects hitting Earth, Figure 2 shows the location and approximate energy of all larger bolides reported by US Government sensors that have impacted Earth since 1985, with only the Chelyabinsk object, with an estimated diameter of 19m, known to cause damage on the ground.²⁰ Figure 3 provides a more detailed look at bolides detected by the NOAA/NASA “Geostationary Operational Environmental Satellites” over the Americas and adjacent oceans, showing peaks in the temporal distribution that are connected to periodic meteor showers.

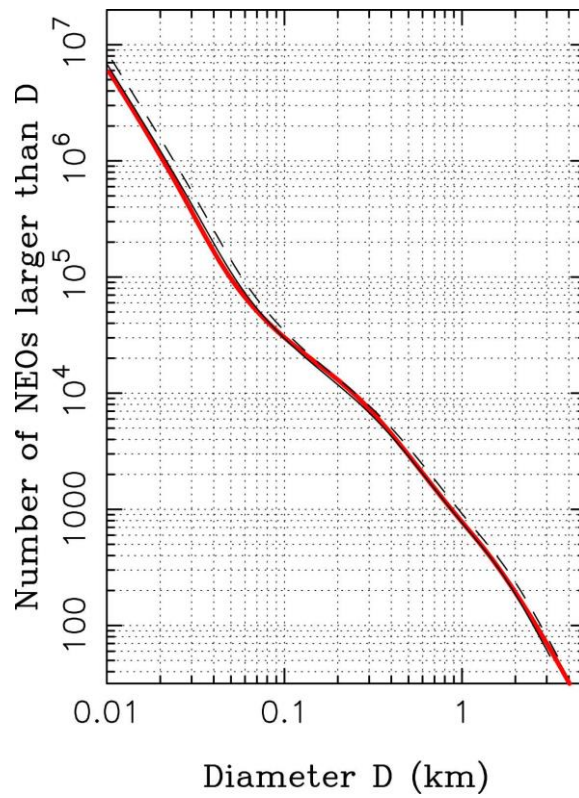
Table 1: Comparison of Some Parameters Affecting NEO Collision Likelihood

Body	Radius [km]	Approx. Cross-Sectional Area [km²]	Area Ratio	Approx. Hill Sphere Radius [km]	Volume Ratio
Earth	6,371	127,516,000	13.4	1,500,000	15,625
Moon	1,738	9,490,000		60,000	

Data Source: JPL Horizons System, 2025

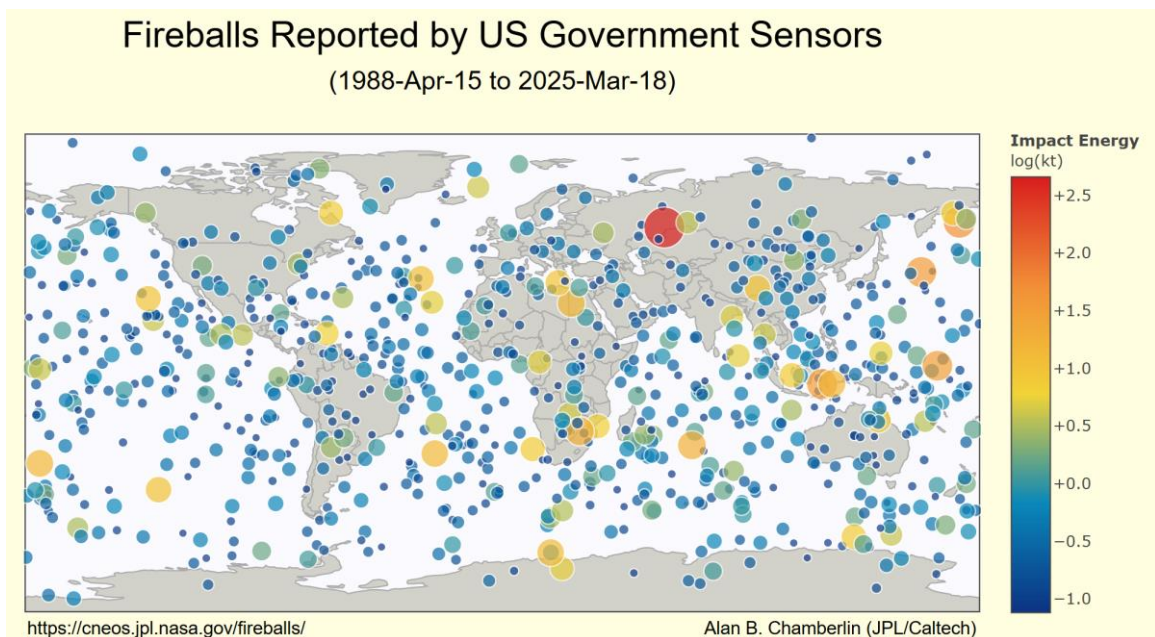
²⁰ Popova et al., 2013; Borovička et al., 2013.

Figure 1: NEO Distribution by Size



Source: Nesvorny et al. (2024)

Figure 2: Bolide Events in Earth's Atmosphere by U.S. Government Sensors From April 1985 to March 2025



Source: CNEOS, 2025a

Figure 3: Map (left) and Monthly Count (right) of Bolide Events Over the Americas Detected by the GOES Satellites in 2024



*Note: Medium and high confidence detections by either GOES-E or GOES-W only.
Source: NASA, 2025b*

Impact Risk for Larger NEOs

NEOs of 10m diameter are expected to hit Earth approximately once every decade,²¹ and thus a rough estimate for their impact frequency on the Moon, based solely on the area ratio given in Table 1, would be approximately every 130 years. However, as mentioned previously, smaller NEOs, which are much more frequent, put Lunar infrastructure at risk as well. A recent estimate by the head of NASA’s Meteoroid Environment Office states that objects 2.5m across, which have a kinetic energy of approximately one kiloton of TNT, impact the Moon “about every four years.”²²

Two examples illustrate the potential for (relatively near-)misses of large NEOs:

- In mid-April of 2025, based on observations available then, NASA assessed the ~50m object 2024 YR4 to have a 3.8% chance of colliding with the Moon on 22 December 2032, with a three-sigma minimum distance as per CNEOS database of 1016km.²³ Figure 3 shows the extent of the position uncertainty.
- On the other hand, while the asteroid Apophis, several hundred meters in size, will pass very close to Earth on 13 April 2029 at slightly more than 38,000km, it will miss the Moon by more than 95,900km.²⁴

Impact Risk for Micrometeoroids

Although, as mentioned above, micrometeoroids are not included in PD-M, they are briefly discussed here to provide context at the low end of the size spectrum.

Observations of the Moon between 2006 and 2014 detected 126 impacts visible from Earth during a total of 267h of observation time, resulting in an average of

²¹ CNEOS, 2024.

²² Wendel, 2022.

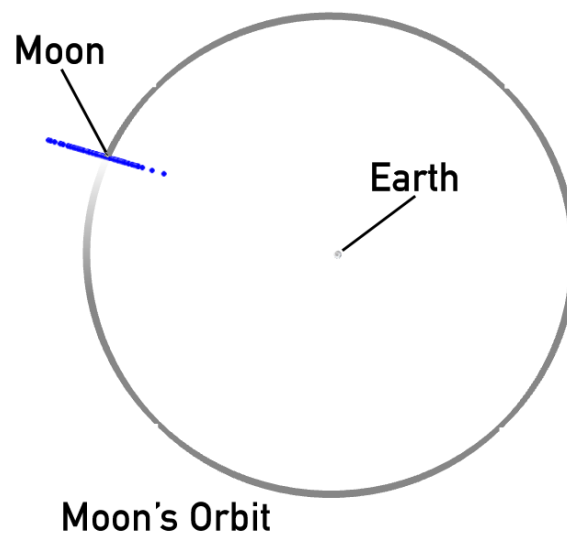
²³ JPL Small-Body Database, 2025a; NASA, 2025e.

²⁴ JPL Small-Body Database, 2025b.

approximately 11 impacts per day, which translates to a flux of $6 * 10^{-4}$ impacts per year and square kilometer for objects with a mass of 30g or more.²⁵

However, the impact frequency is not uniform; it peaks during certain times of the year when “meteor showers” occur.²⁶ Cooke et al. (2007) estimate that the impact rate of 1kg-class meteoroids on the Moon increases from one every 11 hours to one every hour during a meteoroid shower. More recently, Cooke stated:²⁷ *“There are about 100 pingpong-ball-sized meteoroids hitting the moon per day.”*

Figure 3: Position Uncertainty of Asteroid 2024 YR4 During Close Approach to Earth-Moon System in 2032, as of 2 April 2025



Source: adapted from NASA, 2025e.

Note: blue dots represent potential positions of 2024 YR4.

What Can be Done?

While additional analysis regarding the need for PD-M is still required, it is already clear that an expansion of Earth's Planetary Defense shield to the Moon could be accomplished by expanding or creating capabilities that cover the same categories as current Planetary Defense efforts:²⁸

- **Finding and tracking:** Due to the relatively close proximity of Earth and Moon, current NEO search efforts should be sufficient for this.
- **Characterizing:** This step of the Planetary Defense process would have to also prioritize objects that have a collision risk with the Moon.

²⁵ Suggs et al., 2014, estimates a flux of $7 * 10^{-8}$ meteoroids per hour and square kilometer for objects greater or equal to 30g (which can be reliably detected from Earth).

²⁶ Suggs et al., 2014; see also Figure 2b.

²⁷ Wendel, 2022.

²⁸ NASA, 2023a.

- **Assessing impact risk:** Existing high-precision trajectory calculation and impact likelihood prediction tools would have to also consider impacts with the Moon. While, as mentioned above, JPL’s “Small Body Database” already shows impact likelihood and miss distances for the Moon,²⁹ a column for “Close Approach Distance to Moon” could be added to the CNEOS Close Approach tables,³⁰ and Lunar impact prediction could be added to the ATLAS, SENTRY, SCOUT, and NEODyS systems.
- **Warning:** The limited number of organizations active on the Moon facilitates warning. However, PD-M warning should be designed into Lunar communication systems and procedures from the beginning, as part of overall mission risk mitigation efforts.
- **In-space mitigation:** Deep-space mitigation would leverage the same capabilities as terrestrial Planetary Defense. However, due to the lack of an atmosphere of the Moon, last-minute mitigation relatively close to the Lunar surface may have to be considered as well, especially for the more frequent smaller objects.
- **Mitigation on the ground:** Protecting Lunar infrastructure from impactors will require special measures that are not part of terrestrial Planetary Defense. Evacuation, sheltering, and safing procedures and capabilities will be different as well. However, Lunar and Cislunar infrastructure already has to be designed with micrometeoroid protection in mind. Thus, close collaboration between PD-M and micrometeoroid protection experts will help ensure that Lunar infrastructure is not just resilient to micrometeoroids, but also to ejecta and Moonquakes resulting from larger impacts.
- **Planning and coordination:** The organizations that are leading, or providing capabilities for, terrestrial Planetary Defense efforts can do the same for the Moon. However, since the number of organizations with infrastructure on the Moon will be relatively limited, these organizations should be expected to contribute to PD-M as well. Furthermore, since novel mitigation methods may be used for PD-M, additional related coordination will be needed.

The above discussion shows that many existing Planetary Defense systems and capabilities can be used, in some cases with only slight modifications required, but that additional capabilities may be needed for full-scale PD-M.

Further research on Lunar impact risk, including on the direct and indirect consequences, is needed as well. NASA’s “Lunar Environment Monitoring Station” (LEMS) Moon seismometer can provide valuable data for this.³¹ This kind of research can also help determine the appropriate size threshold for PD-M.

It would also be helpful to define Lunar impact risk categories for NEOs, similar to the Palermo or Torino Scales used in terrestrial Planetary Defense. For example, a “PD-M Scale” could capture the Lunar impact risk posed by a given object. Following the Palermo Scale approach,³² the PD-M Scale value could be computed as the base-10 logarithm of the relative risk $R = P_I / (f_B \times DT)$, with P_I as the impact probability of the object with the Moon, f_B as the annual background impact frequency for same- or

²⁹ JPL, 2025a/b.

³⁰ CNEOS, 2025b.

³¹ NASA, 2024.

³² CNEOS, 2025e.

higher-energy objects, and DT the time remaining before impact, in years. Furthermore, $f_B = a \times E^b$, with E the impact energy (in megatons of TNT) of the object. In the case of Earth, the Palermo scale uses values of $a = 0.03$ and $b = -4/5$.³³ For the PD-M Scale, these parameters may have to be adjusted.

Like with the Palermo Scale, PD-M Scale values would be higher for higher impact likelihoods, higher impact energies, and shorter warning times. A more sophisticated version of the PD-M Scale would only consider the impact risk of objects with those areas of the Moon that have significant infrastructure, or could even make the impact risk zone of concern dependent on the size of the impactor, based on more detailed simulations of impact effects.

International Collaboration Aspects

Just as establishing a foothold of our species on the Moon is an international endeavor, protecting that beachhead from cosmic threats such as asteroid impacts can be a joint effort of humanity as well. Nations contributing to terrestrial Planetary Defense should thus consider working together on PD-M as well.

However, as with Planetary Defense efforts in general, dual-use aspects have to be considered, and any PD-M collaboration is inevitably going to play out in the context of Cislunar and overall geostrategic competition.

Conclusions

As the discussions above have shown, Planetary Defense of the Moon is a topic worthy of further exploration. In the meantime, low-cost measures to include the Moon in our civilization's Planetary Defense shield are possible and can be taken today. This would provide protection to humans and infrastructure on the Moon, and would also signal the expansion of humanity's sphere of influence beyond our home planet.

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Abbreviations

ATLAS: Asteroid Terrestrial-impact Last Alert System

CNEOS: Center for Near-Earth Object Studies

GOES: Geostationary Operational Environmental Satellite

GSFC: Goddard Space Flight Center

ILRS: International Lunar Research Station

³³ CNEOS, 2025e.

ISS: International Space Station
JHU-APL: Johns Hopkins University Applied Physics Laboratory
JPL: Jet Propulsion Laboratory
MMOD: Micrometeoroid and Orbital Debris
NASA: National Aeronautics and Space Administration
NEO: Near-Earth Object
NOAA: National Oceanic and Atmospheric Administration
PD: Planetary Defense
PD-M: Planetary Defense for the Moon
TNT: Trinitrotoluol

References

Borovička, Jiri; Pavel Spurný, Peter Brown, Paul Wiegert, Pavel Kalenda, David Clark, and Lukáš Šrbený: “The trajectory, structure and origin of the Chelyabinsk asteroidal impactor.” *Nature* 503, 235–237, November 2013.
<https://doi.org/10.1038/nature12671>

Center for Near Earth Object Studies: “2024 Interagency Tabletop Exercise (PD TTX5) Read-ahead materials.” Report, 2024.
https://cneos.jpl.nasa.gov/pd/cs/ttx24/TTX5_longReadAhead.pdf

Center for Near Earth Object Studies: “Fireball and Bolide Data” web page, 2025a.
<https://cneos.jpl.nasa.gov/fireballs>

Center for Near Earth Object Studies: “NEO Earth Close Approaches” web page, 2025b. <https://cneos.jpl.nasa.gov/ca>

Center for Near Earth Object Studies: “Scout: NEOCP Hazard Assessment” web page, 2025c. <https://cneos.jpl.nasa.gov/scout/#/>

Center for Near Earth Object Studies: “Sentry: Earth Impact Monitoring” web page, 2025d. <https://cneos.jpl.nasa.gov/sentry>

Center for Near Earth Object Studies: “Palermo Technical Impact Hazard Scale” web page, 2025e. https://cneos.jpl.nasa.gov/sentry/palermo_scale.html

China National Space Administration: “International Lunar Research Station (ILRS) Guide for Partnership.” 16 June 2021.
<https://www.cnsa.gov.cn/english/n6465652/n6465653/c6812150/content.html>

CNEOS - see “Center for Near Earth Object Studies”

CNSA - see “China National Space Administration”

Conway, Erik M.; Yeomans, Donald K.; Rosenburg, Meg: “A History of Near-Earth Objects Research.” NASA SP-2022-4235, 2022. <https://www.nasa.gov/history/history-publications-and-resources/nasa-history-series/a-history-of-near-earth-objects-research>

Cooke, W.J.; R.M Suggs, J.R. Suggs, W.R. Swift, N.P. Hollon: “Rate and Distribution of Kilogram Lunar Impactors.” Lunar and Planetary Science XXXVIII paper 1986, 2007. <https://www.lpi.usra.edu/meetings/lpsc2007/pdf/1986.pdf>

Daniels, Matthew: “New Planetary Defense Strategy Outlines Key US Government Goals”. 3 April 2023. <https://bidenwhitehouse.archives.gov/ostp/news-updates/2023/04/03/new-planetary-defense-strategy-outlines-key-us-government-goals>

JPL Horizons System, version 4.94 (September 2022). Queried on 22 March 2025a. <https://ssd.jpl.nasa.gov/horizons>

JPL Small-Body Database: “2024 YR4.” Queried on 22 April 2025a. https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=2024%20YR4&view=OPC

JPL Small-Body Database: “99942 Apophis.” Queried on 23 March 2025b. https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=apophis&view=OPC

Lockheed-Martin Corporation: “A Water-Based Lunar Architecture.” Web site, 2025. <https://www.lockheedmartin.com/en-us/capabilities/space/human-space-exploration/water-based-lunar-architecture.html>

Millard, Lindsay, et al.: “National Cislunar Science & Technology Action Plan.” National Science and Technology Council, December 2024. <https://bidenwhitehouse.archives.gov/wp-content/uploads/2024/12/Cislunar-Implementation-Plan-Final.pdf>

NASA - see “National Aeronautics and Space Administration”

National Aeronautics and Space Administration: “Artemis Partners.” Web page, 19 March 2025c. <https://www.nasa.gov/artemis-partners>

National Aeronautics and Space Administration: “Artemis.” Web page, 2025a. <https://www.nasa.gov/humans-in-space/artemis>

National Aeronautics and Space Administration: “Bolide Detections from Geostationary Lightning Mapper.” Web page, accessed on 23 March 2025b. <https://neo-bolide.ndc.nasa.gov>

National Aeronautics and Space Administration: “Lunar Environment Monitoring Station (LEMS).” Web page, 22 October 2024. <https://science.nasa.gov/lems>

National Aeronautics and Space Administration: “Lunar Impact Monitoring Program.” Web page, October 2023b. <https://www.nasa.gov/meteoroid-environment-office/about-lunar-impact-monitoring>

National Aeronautics and Space Administration: “NASA Planetary Defense Strategy and Action Plan.” Report, April 2023a. <https://go.nasa.gov/3UO2mmt>

National Aeronautics and Space Administration: "NASA Update on the Size Estimate and Lunar Impact Probability of Asteroid 2024 YR4." Web page, 2 April 2025e. <https://science.nasa.gov/blogs/planetary-defense/2025/04/02/nasa-update-on-the-size-estimate-and-lunar-impact-probability-of-asteroid-2024-yr4>

National Aeronautics and Space Administration: "The Artemis Accords." Web page, 8 April 2025d. <https://www.nasa.gov/artemis-accords>

Nesvorný, David; David Vokrouhlický, Frank Shelly, Rogerio Deienno, William F. Bottke, Carson Fuls, Robert Jedicke, Shantanu Naidu, Steven R. Chesley, Paul W. Chodas, Davide Farnocchia, Marco Delbo: "NEOMOD 3: The debiased size distribution of Near Earth Objects." *Icarus*, Volume 417, 2024. ISSN 0019-1035. <https://doi.org/10.1016/j.icarus.2024.116110>

Popova, Olga P., et al.: "Chelyabinsk Airburst, Damage Assessment, Meteorite Recovery, and Characterization." *Science* 342, 1069-1073, November 2013. <https://doi.org/10.1126/science.1242642>

SpaceDyS: "NEODyS-2." Web page, 2025. <https://newton.spacedys.com/neodys>

Suggs, R.M.; D.E. Moser, W.J. Cooke, R.J. Suggs: "The flux of kilogram-sized meteoroids from lunar impact monitoring." *Icarus*, Volume 238, 2014, Pages 23-36. ISSN 0019-1035. <https://doi.org/10.1016/j.icarus.2014.04.032>

Tonry, J.L.; L. Denneau, A. N. Heinze, B. Stalder, K. W. Smith, S. J. Smartt, C. W. Stubbs, H. J. Weiland, and A. Rest: "ATLAS: A High-cadence All-sky Survey System." *Publications of the Astronomical Society of the Pacific*, Volume 130, Number 988, May 2018. <https://iopscience.iop.org/article/10.1088/1538-3873/aabadf>

Wendel, JoAnna: "How many space rocks hit the moon every year?" News article, LiveScience website, 11 April 2022. <https://www.livescience.com/how-many-moon-meteorites>