

If Asteroid 2024YR4 hits the Moon, Will it be Visible from the Earth?

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Abstract

2024YR4 is an asteroid with an estimated diameter of 53 to 67 meters that is classified as an Apollo-type (Earth-crossing) near-Earth object. As of April 2025, it is estimated to have a 4% chance of impacting the Moon on 22 December 2032 at 15:19 UTC (Universal Coordinated Time). [1, 2, 3, 4]

While it is likely that the impact point will be visible to an observer on the night side of the Earth, it is not clear whether the event will be visible to the naked eye. This paper describes what is currently known about Asteroid 2024YR4, and estimates the size of the impact fireball. [5, 6, 7, 8, 9]

The estimated energy of impact is 6.8 Megatons. The conclusion is that the impact will produce a luminous cloud for a few seconds, and that this should be visible to the naked eye.

Introduction

The Asteroid 2024YR4 is a medium-sized object which was discovered in 2024. Because of its recent discovery, the orbital parameters have not been completely measured. At one point, it seemed possible that this object would hit the Earth in the next decade, but improved observations now rule that out. Using currently available data, observers estimate that there is a small chance of impacting the moon.

If the impact happens on 22 December, 2032, the moon will be in a waning Gibbous phase (nearly full), which means that most people on the Earth who have a line of sight to the moon will be in darkness. Because of the relatively small size of the object, and because of the moon being bright, it is not clear if the explosion will be visible without optical devices.

The actual explosion will be in the Megaton⁽¹⁾ range, and will produce an incandescent cloud (called “the fireball” for historical reasons), which will persist for a few milliseconds. The explosion will also produce a dust cloud, which will initially be red-hot, and which may be visible for a few minutes.

Brightness of the Full Moon; Brightness of the Fireball

The brightness of the Gibbous phase of the moon is slightly less than the brightness of a full moon. The area of a full moon is $9.4 * 10^{12}$ meters squared. The solar radiation flux is approximately 1361 W/meter squared, and the albedo is approximately 12%.

When you put these numbers together, you get a brightness of approximately $1.5 * 10^{15}$ Watts. This is equivalent to 0.36 Megatons/second. By contrast, the estimated energy of impact is 6.8 Megatons.

Preliminary estimates suggest that the impact fireball will be too small to be seen with the naked eye, but that its associated hot dust cloud will produce a power output of 0.2 Megaton/second for 1-5 seconds, which is roughly the brightness of the entire moon. Since the dust cloud is much smaller than the moon itself, this should be easily visible to an observer on the Earth.

Formation of the Fireball

The term “fireball” dates back to the period when most explosions studied were in air. Typical fuel/air explosions observed in the 19th or 20th century produced spherical, low-density objects, if they were a moderate distance from the ground or water. Gunpowder, dynamite, or TNT explosions were similar. If the explosive was on the ground, then a hemisphere would be observed.

In vacuum, things are different. Hot gas moving in vacuum tends to go in a straight line, which produces objects which are fan-shaped, irregular, or splatter-form. For our purposes, this is a detail. At the Earth-Moon distance, the exact shape of the fireball does not matter very much, because the human eye cannot resolve shapes much smaller than 100 km. To the naked eye, the explosion would be an unresolved shape.

A supersonic object gains mass by accretion as it moves through the material it is impacting. Because of conservation of momentum, this slows down the impactor. When the impactor and its accreted material slows down to a sub-sonic speed, there is a phase change, and the impactor is now described as a “Fireball”, which expands at a subsonic rate.

The impact rule of thumb is that an impactor will gain mass proportional to the local speed of sound by the time it becomes subsonic. Therefore, if an impactor arrives at Mach 5, it will have a mass of 5 times its initial mass by the time it goes subsonic.

In this case, the speed of sound in moon rock is 4000 m/sec. The estimated impact speed is 14000 m/sec, or Mach 3.5. Assuming that the initial mass of the impactor was $2.9 * 10^8$ kg, we get an initial mass of the fireball of $1.0 * 10^9$ kg, or 1 Megaton. In other words, this event is going to produce a Megaton of vaporized rock.

Initial Temperature of the Fireball

The boiling point of moon rocks is approximately 3300 °K. This value is based on the boiling points of the two most common compounds in moon rocks, silicon dioxide and aluminum oxide, rounded up to the nearest 100 degrees.

Silicon dioxide boiling point = 2230 °C. = 2502 °K.

Aluminum oxide Boiling point = 2977 °C = 3249 °K.

Nominal boiling point of Moon Rock = 3000 °C = 3300 °K.

Using the vaporization rule of thumb tells us that some of the impact energy will raise the material temperature to 3300 °K. That is to say, 1 Megaton of energy was used to vaporize the impactor plus its accreted moon rock.

The additional energy of the impact raises the temperature of the fireball in a linear fashion. This is a factor of 6.8 (6.8/1.0), which is 22000 °K.

Fireball Appearance and Evolution

The initial fireball will have an estimated diameter of 60 meters. The equivalent disk has a surface area of 2800 square meters.

The radiation emitted over the first few milliseconds will be black-body radiation, or more accurately, dark-gray-body radiation⁽²⁾. The radiation emission of a black body at 22000 °K is $4.0 * 10^{10}$ Watts per Square Meter, which is $3.7 * 10^{13}$ Watts (8.9 kilotons/second).

Because of the small size of the initial fireball, it will be emitting a relatively small amount of power. Over the next few milliseconds, fireball will expand. As it expands, the temperature will drop and the surface area will increase.

The reduction in radiation because of the temperature drop is proportional to the fourth power of the temperature, which is proportional to the 2/3 power of the diameter. This means that the radiated power will drop off rapidly. Most of the energy of the initial impact will not be converted into visible light: It will mostly be converted into mechanical energy.

Formation of the Dust Cloud

Given that the fireball increases in radius by 4 m/msec (4,000 m/sec), we can expect that the temperature will fall rapidly as long as it obeys the ideal gas law. After the temperature goes below 3300 °K, the rock vapor will turn into dust particles, and the details of the temperature curve become complicated. This will occur at approximately 50 milliseconds.

Evolution of the Dust Cloud

The dust cloud will form as the fireball cools down. It will initially be at a temperature of 3300 °K, and optically dense. As such, it will be glowing red-hot for at least a few seconds.

The average dust particle will initially have a speed of 4000 m/sec. At least some of the dust particles will have lunar escape velocity.

After the dust particles form, the dust cloud will expand until it is so diffuse that it becomes transparent. If we assume that the dust particles are 1 micro-gram each, then there are $2.9 * 10^{17}$ particles, with a total surface area of $1.1 * 10^9$ square meters. The estimate is that the dust cloud will become optically semi-transparent when it has reached a diameter of 80 km, approximately 10 seconds after impact.

Radiation Evolution of the Dust Cloud

The initial temperature of the dust particles is 3300 °K, which means that the corresponding power density is $6.7 * 10^6$ W/meter², assuming Black-Body radiation⁽²⁾. Given that the total surface area is $1.1 * 10^9$ square meters, we get a nominal power output of $7.4 * 10^{15}$ Watts, or 1.8 MT/second.

Since this radiation power level is comparable with the total energy of the event, it is obvious that the temperature will fall off rapidly, and that the radiated power will be reduced by a factor of 2 every few hundred milliseconds. The dust cloud will therefore fade from view, for a naked-eye observer, in a few seconds.

Numbers

The mass and density of 2024YR4 have not been measured accurately. We use a radius of 30 meters for modeling purposes. The mass can be estimated by using an assumed density and the estimated diameter. Assuming a density of 2.6 g/cm³, which is within the density range for stony asteroids, with an assumed radius of 30 m, the estimated mass is $2.9 * 10^8$ kg. The mass uncertainty is likely to be approximately 50%. [1, 2, 3]

The orbital velocity is well understood, and if this object impacts the Moon, it will have a velocity of 14 km/s. The event would create a crater with a radius of roughly 100 meters on the lunar surface.

The speed of sound in moon rocks is variable, but generally ranges from 3,600 to 4,200 meters per second. This is roughly equivalent to the speed of sound in solid rocks on Earth, such as basalt.

The brightness of the Gibbous phase of the moon is slightly less than the brightness of a full moon. The area of a full moon is $9.5 * 10^{12}$ meters squared. The solar radiation flux is approximately 1361 W/meter squared, and the albedo is approximately 12%.

Impactor Radius	Rivkin et al. ⁽²⁾	= 30 meters	
Impactor Density	Bolin et al. ⁽¹⁾	= 2.6 gram/cc	= 2600 kg/cubic meter
Impactor Mass	$d*(4/3)*\pi*(r^3)$	= $2.9 * 10^8$ kg	= $2.9 * 10^{17}$ microgram
Impact Speed	Bolin et al. ⁽¹⁾	= 14 km/s	= 14000 meter/sec
Estimated Energy	$(1/2)*m*v^2$	= 6.8 MT	= $2.8 * 10^{16}$ J
Speed of Sound in Moon Rock		= 4000 m/sec	
Impact Speed		= 14000 m/s	= Mach 3.5
Vaporization Temperature of Moon Rock		= 3000 °C	= 3300 °K.
Initial Temperature	$v_{Mach} * T_{Vapor}$	= 22000 °K	
Initial Power Density	σT^4	= $1.3 * 10^{10}$ Watts/meter ²	
Initial Radiated Power	Area*PD	= $3.7 * 10^{13}$ Watts	= 8.9 kilotons/second
Initial Fireball Mass	$v_{Mach} * m$	= $1.0 * 10^9$ kg	
Radius of the moon		= 1740 km	= $1.7 * 10^6$ meter
Area of a full moon	$\pi*(r^2)$	= $9.5 * 10^{12}$ meters ²	
Solar Radiation		= 1361 W/meter ²	
Lunar Albedo		= 12%.	
Brightness of full moon	Area*R*A	= $1.5 * 10^{15}$ W	= 0.36 Megatons/second.
Total Dust Cloud Mass		= $1.0 * 10^9$ kg	= $1.0 * 10^{18}$ microgram
Number of Dust Particles		= $1.0 * 10^{18}$	
Total surface area of the dust cloud		= $1.1 * 10^9$ meters ²	= $1.1 * 10^{21}$ micrometer ²

Notes

(1) The terms “Megaton” and “Kiloton” have two distinct meanings, depending on the context. When used as a unit of mass, Megaton means “1 million metric tons”, or $1 * 10^9$ kilograms. Kiloton means “1 thousand metric tons”, or $1 * 10^6$ kilograms.

When used as a unit of energy, Megaton means “the energy released by a Megaton of TNT”, or $4.2 * 10^{15}$ Joules. Megaton is often abbreviated as “MT”. Kiloton means “the energy released by a Kiloton of TNT”, or $4.2 * 10^{12}$ Joules. Kiloton is often abbreviated as “kT”.

(2) The thermal radiation power density of a Black Body is:

$$\begin{aligned} \text{Power Density} &= \sigma T^4 \text{ Watts/meter}^2 \\ \sigma &\text{ is the Stefan–Boltzmann constant. It has the value} \\ \sigma &= 5.7 * 10^{-8} \text{ W}/(\text{meter}^2 * \text{K}^4). \end{aligned}$$

References

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[2] Rivkin, A. S.; Mueller, T.; MacLennan, E.; Holler, B.; Burdanov, A.; de Wit, J.; et al. (27 March 2025): "[JWST Observations of Potential Impactor 2024 YR4 \(March 27, 2025\)](#)" (PDF). International Asteroid Warning Network.

[3] Elango, Sriram S.; Loeb, Abraham (April 15, 2025) “Astrometric Parallax Measurements with JWST for Localization of Near-Earth Objects”: <https://arxiv.org/pdf/2504.04003>

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[5] ESA News Blog: <https://blogs.esa.int/rocketscience/> Note that this web site is dynamic.

[6] NASA Planetary Defense News: <https://science.nasa.gov/blogs/planetary-defense/> Note that this web site is dynamic.

[7] NASA. Center for Near-Earth Object Studies: <https://cneos.jpl.nasa.gov/news/> Note that this web site is dynamic.

[8] NASA. JPL Horizons: "[2024 YR4 uncertainty in mid-2034](#)". Note that this web site is dynamic.

[9] NASA. Jet Propulsion Laboratory, Center for Near Earth Object Study: Sentry. <https://cneos.jpl.nasa.gov/sentry/details.html#?des=2024%20YR4> Note that this web site is dynamic.