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Research paper

Asteroid 2024 Yr4: A Comprehensive Review

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Abstract

Asteroid 2024 YR4, a recently discovered near-Earth object (NEO), has captured considerable attention due to its unique orbital characteristics and potential implications for planetary defense strategies. This review paper aims to provide a comprehensive analysis of Asteroid 2024 YR4, focusing on its discovery, orbital properties, physical attributes, and the implications for future research and impact risk assessment. This study highlights the importance and the critical role of coordinated global efforts in monitoring the asteroid. Our study underscores the need for sustained funding in asteroid tracking systems to address future risks and enhance our understanding of NEO dynamics.

Keywords: *Asteroid 2024 YR4; Near-Earth objects (NEOs); planetary defense.*

1. Introduction

Asteroids are rocky objects that orbit the Sun and are mostly located in the asteroid belt between Mars and Jupiter. They range in size from little stones to those that are hundreds of kilometers diameter. Asteroids are pieces of planetary material that never came together to become planets and were formed in the early solar system. This essay examines the physical traits, orbital dynamics, and scientific relevance of [asteroid]. One such asteroid is Asteroid 2024 YR4, a recently discovered near-Earth object (NEO) that has attracted scientific interest due to its unique trajectory and physical features. It was first discovered on December 27, 2024, by the ATLAS (Asteroid Terrestrial-impact Last Alert System) survey at Mauna Loa, Hawaii. Asteroid 2024 YR4 was classified as a hazardous NEO due to its size and its trajectory, which initially raised concerns about a potential impact with Earth in 2032. Upon its discovery, the asteroid was quickly placed under close surveillance by NASA's Jet Propulsion Laboratory (JPL), the European Space Agency (ESA), the Russian space agency, Roscosmos, and China's National Space Administration (CNSA) [1].

2. Some Physical Features of Asteroid 2024 YR4

Asteroid 2024 YR4 has a spectrum that best matches R-type and Sa-type asteroids and a diameter of ~ 40-90 m. During its close approach, the asteroid traveled at a velocity of approximately 17.20 km/s (approximately 61,000 km/h). On December 25, 2024, 2024 YR4 passed Earth at approximately 828,800 kilometers. The next anticipated close approach is on December 22, 2032, with a projected distance of about 264,472 kilometers [1,2].

3. Impact Probability and Estimated Risks

NASA's Sentry, an automated system for monitoring asteroid risks, quickly added 2024 YR4 to its list of potential impact hazards. The system is used to predict long-term impacts of NEOs, and its predictions are updated regularly based on new observational data. Initially, the risk was classified as "high" due to uncertainties in the asteroid's trajectory, particularly concerning the lack of complete observational arcs and the asteroid's high velocity relative to Earth. These initial uncertainties contributed to the relatively high probability of a collision in 2032, making it an object of primary interest for planetary defense studies [1]. Additionally, international space agencies, including ESA and Roscosmos, echoed NASA's early concerns. The ESA initially calculated a 2.8% chance of impact, corroborating NASA's initial estimates. The asteroid's orbit brought it into proximity to Earth, raising alarms regarding the potential consequences of an impact. While there was no immediate cause for panic, the situation was treated with urgency, and observations were ramped up in early 2025 [2]. China's CNSA also participated in the global monitoring efforts and, alongside ESA and NASA, confirmed the asteroid's new trajectory. Chinese scientists contributed additional observational data using both ground-based telescopes and their own space-based monitoring systems. While their early reports aligned with those from ESA and NASA, Chinese researchers underscored the importance of continued monitoring as a part of their planetary defence initiative [3].

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4. Revised Risk Assessment and Current Status

By February 2025, continuous monitoring led to a significant improvement in the accuracy of the asteroid's orbital calculations. Additional observations allowed astronomers to refine their models and reduce the uncertainties that had initially plagued the risk assessments. The revised analysis by NASA and ESA indicated that the asteroid's impact probability had dramatically decreased to 0.004%, a near-negligible value. Consequently, the Torino Scale rating for 2024 YR4 was revised down to 0, indicating that the asteroid no longer posed a significant threat to Earth [1, 2]. This decline in risk was due to refined observational data, which helped to more precisely determine the asteroid's orbit. China's CNSA also participated in the global monitoring efforts and, alongside ESA and NASA, confirmed the asteroid's new trajectory. Chinese scientists contributed additional observational data using both ground-based telescopes and their own space-based monitoring systems. While their early reports aligned with those from ESA and NASA, Chinese researchers underscored the importance of continued monitoring as a part of their planetary defense initiative [3]. The initial discovery of asteroid 2024 YR4 raised significant concerns regarding its potential to impact Earth in 2032. However, through continuous monitoring and collaboration between international space agencies, the risk has been greatly reduced. The asteroid, once rated at a 2.8% chance of impact, now poses a negligible risk, with an impact probability of 0.004%. This significant decrease in risk highlights the critical role of continuous observation and data refinement in accurately assessing the threat posed by near-Earth objects. Impact Probability and Estimated Risks and a Comparison with Other Asteroids' Risk Estimations and Probability Fluctuations. The impact probability of a near-Earth object (NEO) such as asteroid 2024 YR4 is typically calculated using orbital modeling, a technique used to predict the trajectory of an object in space based on gravitational influences and observational data. Orbital modeling incorporates data points gathered from telescopes and spacecraft to generate a mathematical model of the object's motion over time [4]. These models are continuously updated as more observations are made, which is why the risk probability can change significantly as the asteroid's trajectory becomes more accurately defined [6]. The precision of orbital modeling is critical in determining the long-term threat posed by an asteroid, yet, because of the complexities of gravitational forces and observational limitations, these models can undergo significant changes, particularly early in the observation process [7]. Asteroid 2024 YR4 is not unique in its fluctuating risk estimations; a key example is Asteroid Apophis, which has experienced similar changes in its calculated impact probability over time [5]

5. The Role of Orbital Modeling and Initial Risk Assessment

When asteroid 2024 YR4 was first discovered, the initial impact probability was estimated to be 2.8%, as mentioned earlier. This assessment was primarily based on sparse initial observations, which led to large uncertainties in the asteroid's orbit. For an asteroid of its size (40 to 90 meters), the potential impact would be catastrophic, releasing energy equivalent to a significant explosion. The Torino Scale rating of 3 reflected the substantial concerns, placing the asteroid in the category of potentially hazardous objects that required immediate and ongoing monitoring [1,2]. Similarly, Asteroid Apophis provides a valuable comparative case study of fluctuating risk estimations. When Apophis was first discovered in 2004, it was initially classified as a potentially hazardous asteroid (PHA), with an estimated 2.7% chance of impact in 2029. This estimate, like that of 2024 YR4, led to a Torino Scale rating of 4, indicating a moderate risk. However, as observational data increased and its orbital model became more refined, the impact probability for 2029 dropped significantly. By 2010, the probability was revised to 0% for the 2029 impact, demonstrating how orbital uncertainties can lead to significant fluctuations in risk assessments [4, 5]. This case of Apophis illustrates the complexities and challenges associated with assessing asteroid impact risks over long-time spans.

6. Comparative Analysis of Other NEO Risk Assessments

Another well-known case is Asteroid 2004 MN4, which was later renamed Apophis. Apophis's impact risk initially fluctuated between a 1 in 37 chance of impact to nearly 2.7% during the early years after its discovery, creating global media attention and concern. However, its risk was dramatically revised downwards with more observations, like how 2024 YR4's risk dropped from 2.8% to a 0.004% [1] chance, and more recently, to 0.001%. [2] These fluctuations underline the important role that ongoing surveillance and orbital recalculations play in refining our understanding of NEO trajectories [4]. NASA, ESA, Roscosmos, and CNSA all stress the importance of international collaboration in planetary defense. These agencies have developed robust systems to track and monitor potential impact hazards, such as NASA's Sentry and ESA's NEO Coordination Centre, which are used to continually update impact probability estimates based on new data [1; 2].

7. The Importance of Long-term Monitoring and Reassessments

As demonstrated by asteroid 2024 YR4, initial observations may present a high probability of impact due to limited observational data. However, with ongoing monitoring, the uncertainty in the asteroid's orbit decreases, and more accurate predictions can be made. The gradual revision of the risk from 2.8% to 0.004% emphasizes the need for long-term observation and reassessment of risk levels [1; 2]. By contrast, the fluctuating risks of Apophis further stress how initial risk percentages can change dramatically as more data is incorporated into the modeling. The changes in Apophis's risk, particularly from an estimated 2.7% chance of impact in 2029 to a 0% impact probability with more observations, highlight the challenges and complexities in early risk assessments of NEOs [4; 5]. The risk assessments for asteroid 2024 YR4, like those for other NEOs such as Apophis, highlight the inherent uncertainties in predicting asteroid impact probabilities. The initial high risk was reduced substantially as more observational data were obtained, demonstrating the importance of continuous monitoring and data refinement. As seen with both 2024 YR4 and Apophis, the fluctuating nature of impact risks underscores the importance of international collaboration and the evolving nature of planetary defense strategies.

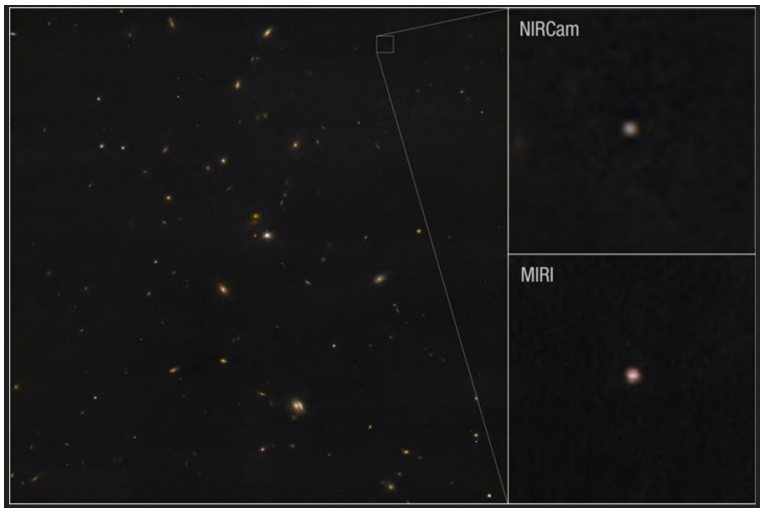

Fig.1: NASA's James Webb Space Telescope images of the asteroid 2024 YR4 using both its NIRCam (Near-Infrared Camera) and MIRI (Mid-Infrared Instrument). Credit: NASA, ESA, CSA, STScI, A. Rivkin (JHU APL).

8. What Would Happen if the Asteroid 2024 YR4 Hit Earth

Asteroid 2024 YR4 is on a path toward Earth. While the chances of impact remain uncertain, if it were to strike, the energy released would be about equal to 8 million tons of TNT, or 500 times the power of the atomic bomb detonated on Hiroshima, even if the likelihood of collision is still unknown [8]. If 2024 YR4 were to enter the atmosphere over the ocean, models indicate that airbursting objects of this size would be unlikely to cause significant tsunamis, either from the middle of the ocean or even nearer shore. If the asteroid entered the atmosphere over a populated region, an airburst of an object on the smaller side of the size range, about 40 to 60 meters (130 to 200 feet), could shatter windows or cause minor structural damage across a city. On the other hand, according to computer models, massive tsunamis could be caused if 2024 YR4 were to enter the atmosphere over the ocean. An airburst may break windows or inflict moderate structural damage throughout a city if the asteroid enters the atmosphere over a populated area [9].

9. Is it possible to deflect asteroid 2024 YR4? Could we use a spacecraft like DART

Important considerations regarding planetary defense tactics are brought up by the possible deflection of asteroid 2024 YR4. Similar spacecraft technology might be taken into consideration for 2024 YR4, taking inspiration from NASA's successful DART (Double Asteroid Redirection Test) mission, which showed that it was possible to change an asteroid's trajectory via kinetic collision. To determine whether such a mission is feasible, important variables such the asteroid's size, composition, orbit, and amount of time before a possible Earth approach must be examined. According to preliminary evaluations, a spacecraft based on DART would be a practical way to change 2024 YR4, supporting international efforts to reduce the threat posed by asteroids, provided it has enough lead time and is precisely targeted [9-12].

10. Conclusion and Recommendations

Asteroid 2024 YR4 offers a valuable case study in the broader context of planetary defense and near-Earth objects (NEO) monitoring. This work has examined the current understanding of the asteroid's characteristics. In addition, it also explores the potential deflection methods inspired by the DART mission. As the modern tools to detect and track NEOs continue to improve, we also need to improve our ability to respond to them effectively. Continued investment in research, international collaboration, and the development of reliable deflection technologies will be a crucial global aspect in ensuring an effective planetary defense strategy for objects like 2024 YR4 and beyond.

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