

THE RAPID-RESPONSE FULLY-AUTOMATED NEA FOLLOW-UP PROGRAM WITH THE SAAO'S 1-M LESEDI TELESCOPE Thobekile Ngwane^{1,2}; thobekilesn@gmail.com; Nicolas Erasmus^{2,3}, Paul Groot^{1,2,4},
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Introduction: Near-Earth Asteroids (NEAs) are a class of minor planets in our Solar System that have escaped from the main asteroid belt due to resonance interactions with major planets like Jupiter [1, 2]. NEAs represent both a scientific opportunity to understand the building blocks used in our Solar system and a potential hazard to our planet. Although significant resources have been devoted to the discovery of these objects, resulting in more than 38,000 known NEAs as of March 2025, characterisation efforts still lag behind. This characterisation gap is particularly significant for small NEAs (<100 m in diameter), which remain poorly understood despite their potential to cause significant regional damage upon impact, as demonstrated by the 2013 Chelyabinsk event [3].

Characterising newly discovered small NEAs is difficult due to their extremely short observational window, as they typically brighten dramatically during close Earth approaches but quickly fade beyond the reach of moderate-sized telescopes within days or even hours. This creates the need for a rapid-response follow-up systems that can obtain observational data while these objects remain observable.

To address this, a fully-automated NEA follow-up program was developed using the robotic capabilities of the South African Astronomical Observatory's (SAAO's) 1-meter Lesedi telescope. This facility's location in the southern hemisphere provides crucial coverage for objects often missed by northern observatories, while its automated operation enables immediate response to discoveries without human intervention. This paper describes our methodology, presents results from approximately 230 NEA observations conducted since February 2023, and analyses the taxonomic distribution of small NEAs based on multi-filter photometric data. By focusing specifically on rapid-response observations of newly discovered objects, this work provides insights into a population size that has been under-represented in NEA characterization studies.

Methods and Instrumentation: The rapid-response capabilities used in this study are

enabled by the 1-meter Lesedi telescope at the SAAO, equipped with the Mookodi instrument [4]. This instrument provides both multi-filter photometry and low-resolution spectroscopy capabilities, though this study focuses exclusively on photometric data. The telescope's fully robotic operation presents significant advantages over conventional follow-up strategies that often require human intervention, resulting in crucial time delays.

The automated monitoring system employs custom Python scripts that continuously parse NASA JPL's Scout¹ service for new NEA candidates. When candidates meeting the observation criteria are identified (V-magnitude <19, altitude >30°), the system autonomously generates and submits observation requests to the telescope's queue system. The V-magnitude limit is adjusted depending on lunar illumination. This approach addresses a significant gap in rapid response capabilities, enabling observations often within hours of discovery which is critical for small NEAs that quickly become too faint for characterisation.

Observations typically consist of multiple g , r , and i filter exposures interspaced with unfiltered images. Data reduction follows standard procedures using the Lesedi reduction pipeline, which performs bias subtraction and flat-fielding. Calibrated magnitudes for the NEAs are extracted from the frames using the PHOTOMETRYPIPELINE (PP): An Automated Pipeline for Calibrated Photometry [5].

To classify these asteroids, photometric measurements were obtained using g , r , and i filters and processed through the PHOTOMETRYPIPELINE, creating a dataset for generating colour-colour plots ($r - i$ vs. $g - r$). These plots were then used to infer taxonomic types. These are then superimposed on a decision boundary generated by a machine learning algorithm [6], which uses the Bus-DeMeo Classification Scheme [7], to separate asteroids into their different types. For this project we considered the S, C, X, V, D, and Q type asteroids. Taxonomic classifications are valuable not only for understanding the origins of NEAs within the Solar System but also for providing critical information relevant to planetary defense strategies,

¹<https://cneos.jpl.nasa.gov/scout/#/>

particularly when assessing potential asteroid impact scenarios.

Results: Since the project's initiation in February 2023, we have successfully observed a total of 230 NEAs, including 15 Potentially Hazardous Asteroids (PHAs). Analysis of this dataset reveals several patterns in the taxonomic distribution of small NEAs. The median absolute magnitude (H) of our observed sample was 24.9, corresponding to a diameter of 35 m - 86 m (depending on an assumed albedo of between 0.05 to 0.30). The absolute magnitude values for all observed NEAs were obtained from NASA's JPL Horizons System². Astrometry for these observations was submitted to the Minor Planet Centre (MPC)³, which assisted in orbit refinement. Figure 1 shows the number of asteroids followed up on versus the time in days, and it shows that 61% of these observations occurred within one day of discovery. This time was calculated as the interval between the discoverer's last observation and the first follow-up conducted by the Lesedi telescope. A faster response time is possible; however, it is limited by the timing of submissions by the discoverer to the MPC. Even with this limitation, some targets were observed in significantly less time; approximately 10% were observed within three hours of discovery, with asteroid 2023 QN7 being the fastest at 57.4 minutes.

These rapid observations were possible primarily because the NEAs were discovered by observatories geographically close to the Lesedi telescope, such as ATLAS-STH (M22), which shares the South African Astronomical Observatory (SAAO) site, and the Moonbase South Observatory (L87) at Hakos, Namibia, which is located at a relatively similar longitude and latitude to Lesedi. Another contributing factor is that humans overseeing these discoveries often monitor them in semi-real time and promptly submit observation data to the MPC. For example, ATLAS benefits from its global network and time zone advantages: when ATLAS-STH observes at night, it is daytime in Hawaii, allowing operators to monitor and respond to ATLAS-STH discoveries during their Hawaii office hours. The small NEA population was identified as the primary focus for observation to determine whether its taxonomic distribution aligns with previously published findings for larger NEAs. As shown in Figure 2, the majority of the asteroids followed up (75%) had diameters of less than 100 m,

²[https://ssd.jpl.nasa.gov/horizons/app.html#/
/](https://ssd.jpl.nasa.gov/horizons/app.html#/)

³<http://www.minorplanetcenter.net/iau/mpc.html>

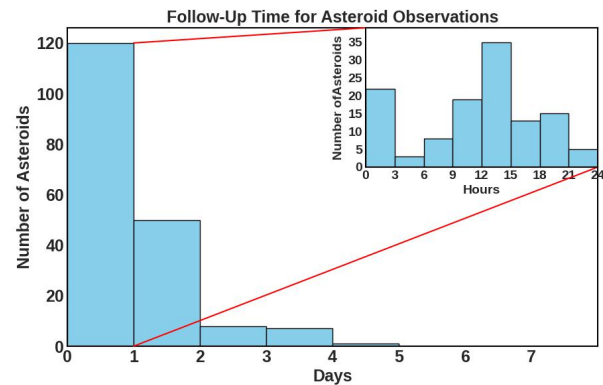


Figure 1: Shows histogram of the distribution of follow-up observation times for asteroids, measured in days after their initial discovery. The x-axis represents the time to follow up, which is the difference between the last observation of the discoverer and the first follow-up observation of the Lesedi telescope versus the number of asteroids observed. Approximately 10% of the observations were done within the first 3 hours, with the most being done between 12 and 15 hours at 20%.

which demonstrates that the project successfully achieved its goal of probing the small NEA population. The absolute magnitude (H -mag) values were used to estimate the possible diameters of these objects using the Asteroid Size Estimator⁴. This tool calculates an asteroid's size based on its absolute magnitude (H) and an assumed geometric albedo (a). For this project, diameters were estimated by averaging size values generated using albedos of 0.05 and 0.30. This approach was selected because these values represent the lower and higher limit albedos of a typical very dark C-type and very bright S-type asteroid, which are the most abundant asteroid classes. The assumed albedo is typically assumed based on the spectral class of the asteroid, which corresponds to its composition—e.g., S-type asteroid albedos can range between approximately 0.17 and 0.22 ([8]).

Discussion: One of the primary aims of this study was to conduct rapid follow-up observations of Near-Earth Asteroids (NEAs) and investigate the small NEA population. Figure 1 illustrates the number of successful follow-up observations conducted over different time intervals. The data reveal that approximately 61% of follow-up observations were completed within one day, with 10% achieved in less than three hours. The majority

⁴https://cneos.jpl.nasa.gov/tools/ast_size_est.html

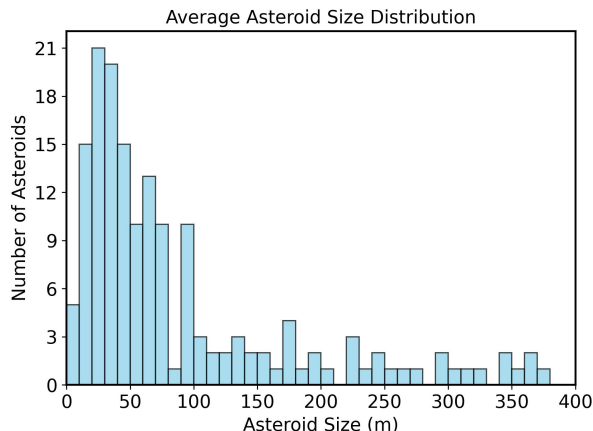


Figure 2: Histogram showing the distribution of estimated average diameters (in meters) for Near-Earth Asteroids (NEAs) observed in this study with assumed albedo values of 0.05 and 0.30 to get an average size. A majority of the observed NEAs are small, with sizes concentrated below 100 metres. This distribution shows the prevalence of smaller NEAs in the sample and supports the project’s aim of probing the small NEA population (<300 m).

of these observations occurred within a day of discovery. Although a faster response time is theoretically possible, it is constrained by the time required to report discoveries to the Minor Planet Centre (MPC).

In summary, these results demonstrate the capability of the Lesedi telescope to perform rapid follow-up observations, including same-night observations in some cases. The telescope’s ability to observe smaller NEAs is evident, with the smallest asteroid followed up being 2023 SL5, which has an estimated absolute magnitude of 28.7 and a diameter between 4 m and 11 m, depending on its assumed albedo of 0.05 and 0.30. This shows Lesedi’s capability and the observing strategy used for this project in targeting and successfully observing very small asteroids. While our results regarding the taxonomic distribution of small NEAs reveal important patterns, several limitations should be acknowledged. The bias toward higher albedo objects in discovery surveys likely influences our sample composition, potentially leading to an overrepresentation of S-type and C-type asteroids.

The evidence presented here raises important questions about the validity of current models describing the delivery mechanisms of small NEAs from their source regions. The high proportion of S-types in our sample supports the hypothe-

sis that many small NEAs originate from the inner main belt through Yarkovsky-driven orbital evolution rather than representing fragments of large MBAs across all belt regions as suggested by some dynamic models. A critical analysis of our colour data suggests that the $g-r$ vs $r-i$ color space provides effective discriminatory power between major taxonomic complexes but shows limitations in distinguishing between specific subtypes. This finding aligns with [9], though our machine learning approach to classification boundaries shows improved accuracy for objects with intermediate spectral properties. The automated nature of our follow-up system demonstrates significant benefits over traditional approaches.

Conclusion: This study has shown that automated rapid-response systems significantly enhance our ability to characterize the small NEA population, addressing a critical gap in NEA research where characterization has lagged substantially behind discovery. The preliminary taxonomic distribution revealed through our multi-filter photometry suggests a more similar compositional structure to the larger population size however this work found more X-type asteroids.

The implications of these findings extend beyond compositional studies to impact hazard assessment. Our observation that X-type asteroids may be overrepresented among NEAs and potentially among PHAs, warrants further investigation, particularly considering the varying physical properties associated with these objects that could affect potential impact mitigation strategies. We are refining the taxonomic classification of our observed sample of small NEAs and plan to publish the results in the near future (Ngwane et al., in prep). Preliminary results indicate that the taxonomic distribution is broadly similar to that of the larger-sized population reported in the literature, with notable differences in the X-type frequency.

This project contributes to the broader understanding of NEA taxonomy, particularly in highlighting the significant presence of X-types and a substantial fraction of stony-type asteroids. Our future plans include expanding the program to use larger telescopes, such as the SAAO’s 74-inch telescope and the South African Large Telescope (SALT), to observe fainter discoveries. Additionally, we aim to improve the efficiency of follow-up observations by refining the triggering criteria and automating the data reduction process. This automation would include submitting astrometry to the MPC without human interaction, potentially using tools such as Automated Streak Detection for Astronomical Im-

ages (ASTRiDE; [10]) to detect asteroid streaks in our observations.

References: [1] A. Morbidelli, et al. (2002) *Asteroids III* 3. [2] J. Smith (2020) *Introduction to Planetary Science* Academic Press, New York. [3] P. G. Brown, et al. (2013) *Nature* 503(7475):238. [4] N. Erasmus, et al. (2024) *Journal of Astronomical Telescopes, Instruments, and Systems* 10:025005 . [5] M. Mommert (2017) *Astronomy and Computing* 18:47 ISSN 2213-1337 doi. [6] P. Janse vanRensburg (2021) *Characterisation of small, close-approaching near-earth asteroids* Master's thesis Faculty of Science. [7] F. E. DeMeo, et al. (2009) *Icarus* 202(1):160 ISSN 0019-1035 doi. [8] R. P. Binzel, et al. (2004) *Icarus* 170(2):259 ISSN 0019-1035 doi. [9] M. Popescu, et al. (2021) in *European Planetary Science Congress EPSC2021–820* doi. [10] D.-W. Kim (2016) ASTRiDE: Automated Streak Detection for Astronomical Images Astrophysics Source Code Library, record ascl:1605.009.