Automated Follow-Up Characterization of Hazardous and Resourceful Near-Earth Asteroids Using SAAO Telescopes

Near-Earth asteroids (NEAs) originate from the main asteroid belt but have since shifted into orbits that bring them close to Earth's orbital path. Currently, around 35,000 NEAs have been discovered and catalogued,[1] with approximately 3,000 new discoveries each year.[2] Many of these newly discovered asteroids rapidly fade in brightness as they move away from Earth, often leaving only a small window of a day or two for additional follow-up characterization with 1-meter class telescopes. Rapid reaction to conduct follow-up observations is therefore critical.

As part of the South African Astronomical Observatory's (SAAO's) Intelligent Observatory project (Potter et al. 2021, Erasmus et al., submitted), several SAAO-owned facilities have been fully automated and integrated into an API-driven observatory control system. This setup allows for fully automated and machine-triggered same-night follow-up observations of any discovered transient object, whether an asteroid or otherwise. Leveraging this capability, a program for fully automated multi-filter photometric observations has been established and successfully observed over 200 NEAs already.

The first aim of this PhD project would be to:

- Continue with this program and analyse the collected data.
- Use the already collected data to investigate the taxonomic distribution of the understudied small-NEA population.
- Enhance the efficiency of follow-up observations by refining the triggering criteria and automating the data reduction (e.g submitting astrometry to the MPC without human interaction).
- Investigate the expansion to other robotic characterisation techniques available with SAAO telescopes, such as spectroscopy and polarimetry.
- Extend the program to utilise larger telescopes (e.g., SAAO's 74-inch telescope and SALT) to target fainter discoveries.

While the presence of NEAs poses a risk via potential impacts with Earth, they also hold promise for extracting valuable resources in space (e.g. water, precious metals and volatiles). Currently new discoveries are primarily (~85%) of smaller (<300m) asteroids[3], as asteroids have a power law size distribution and most of the larger (>1km) ones have already been detected. Many of these smaller asteroids make singular Earth flybys, fading rapidly in brightness as they recede from view, unlikely to ever be seen again with Earth-based telescopes for thousands of years. However, a subset of these small NEAs shares orbits and orbital periods very similar to Earth's, resulting in multiple close flybys in the forthcoming decades providing multiple chances for characterisation and/or exploitation via orbital capture.

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[1] https://www.minorplanetcenter.net/
[2] https://cneos.jpl.nasa.gov/stats/site_all.html
[3] https://cneos.jpl.nasa.gov/stats/size.html

Although the mechanics of capturing such asteroids in orbit around the Earth can be intricate and contingent upon many factors like asteroid mass and relative velocity, several studies (e.g., J.P. Sanchez et al. 2011, J. R. Brophy et al. 2012, S. Gong et al. 2015, Y. Wang et al. 2021, L. Ionescu et al. 2022, Y. Zhang et al. 2022, M. Tan et al. 2023) have theoretically proposed some approaches for feasibly capturing relatively small asteroids using existing spacecraft technology and in some cases with gravity assists. It is reasonable to anticipate that technological advancements will only further enhance the feasibility of capturing sub-100m objects in the next few decades. Once captured in an orbit within the proximity of Earth, subsequent technological advancements may facilitate the deployment of increasingly sophisticated and capable spacecraft for the purpose of extracting or mining valuable materials.

The additional objectives of this project is to identify and thoroughly characterise all sub-300m NEAs observable with telescope from Sutherland within the duration of the PhD, that are also predicted to undergo multiple close flybys of Earth in the next century. These small multi-flyby asteroids could potentially serve as candidates for future capture missions, making it crucial to ascertain as many of their physical properties (such as rotation period, taxonomic type, and shape) as possible to identify the most suitable candidates for space-mining attempts.

Observations will be conducted utilising the robotic Mookodi instrument on the 1-meter Lesedi telescope where possible and supplemented by manual observations the 74-inch telescope, and potentially the Southern African Large Telescope (SALT) for fainter objects.

The second aim of this Phd project will therefore have several key activities, including:

- Conducting a comprehensive literature review of proposed approaches for capturing asteroids.
- Utilising the various APIs provided by JPL Horizons and/or CNEOS[4] to determine potential observing candidates for the upcoming observing seasons.
- Employing both robotic and manual telescopes to gather detailed and in depth observational data on selected multiple flyby NEAs.
- Using existing photometric and spectroscopic pipelines to extract crucial data such as photometric colours and spectral signatures from observed NEAs, providing valuable insights into their physical characteristics.
- Augmenting observational data with publicly available datasets, such as those from ATLAS[5] (Tonry et al., 2018), to enrich the analysis and facilitate the extraction of additional physical properties of the observed NEAs.

The project is open to students registered at any R.S.A university but requires some presence during work hours at the SAAO campus in Cape Town. Co-supervision at the relevant university will be arranged after discussion with the student. During the project several trips to Sutherland may be required. All expenses, including travel from Cape Town, accommodation and food will

[4] https://ssd-api.jpl.nasa.gov/
[5] https://fallingstar-data.com/forcedphot/

be provided during the Sutherland trips. The student will be expected to work in a team environment with other astronomers (and software developers, and electronic/mechanical engineers if needed). Programming experience in Python is essential, experience with photometric, astrometric and/or spectroscopic pipelines and previous observing experience will be advantageous.

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