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An improved classification scheme for distinguishing NEOs from MBAs

ASTR 597A Final Project

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1. INTRODUCTION

Near-Earth Objects (NEOs) are asteroids and comets that have a perihelion distance less than 1.3 au. It is estimated that approximately one fifth of this population passes close enough to Earth that small perturbations in their orbit may lead to intersections with the Earth's orbit and potential collisions (e.g. Jones et al. 2018). A subset of these objects are known as Potentially Hazardous Asteroids (PHAs), these objects are defined as being at least 140m in diameter that pass within 0.05au of the Earth[1]. PHAs are large enough to make it through the Earth's atmosphere and still cause continent scale damage through impact. Given the threat posed by these objects, a world-wide effort[2] has been ongoing to catalogue and determine the orbits and sizes of NEOs including identifying any posing a hazard to the Earth.

The Minor Planet Center maintains a catalogue of known NEOs and their orbits[3], as well as the NEO confirmation page (NEOCP[4]). The NEOCP is a continously updated web page listing newly discovered NEO candidates that should be prioritised for additional observations by the NEO follow-up community. These follow-up observations contribute additional astrometric observations necessary to more accurately determine the orbit of the candidate, as well as photometry to constrain its size. An object is only listed on the NEOCP when it has a high probability of being an NEO. This probability is quantified using the `digest2` code (Keys et al. 2019). `digest2` assigns a score between 0 and 100 based on potential orbits that fit the observations and only objects with a score of 65 or more are listed on the page. Currently, on average around two dozen objects are added to the NEOCP on each night.

The Rubin Observatory Legacy Survey of Space and Time (LSST, Ivezić et al. 2019) will rapidly increase the rate at which NEO candidates are identified and reported to the NEOCP. Jones et al. (2018) showed that at the end of the 10-year LSST baseline survey the completeness of NEOs with an absolute magnitude of $H \leq 22$ would be 73%. Most of these objects will be discovered using "tracklet linking": a computational technique where at least three pairs of observations ("tracklets") observed over a 15-night period are identified as belonging to the same object (Jurić et al. 2017; Heinze et al., in prep). The orbits of objects discovered with

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[1] https://cneos.jpl.nasa.gov/about/neo_groups.html
[2] E.g. https://www.unoosa.org/oosa/en/ourwork/topics/neos/index.html
[3] https://www.minorplanetcenter.net/iau/MPCORB/NEA.txt
[4] https://www.minorplanetcenter.net/iau/NEO/toconfirm_tabular.html

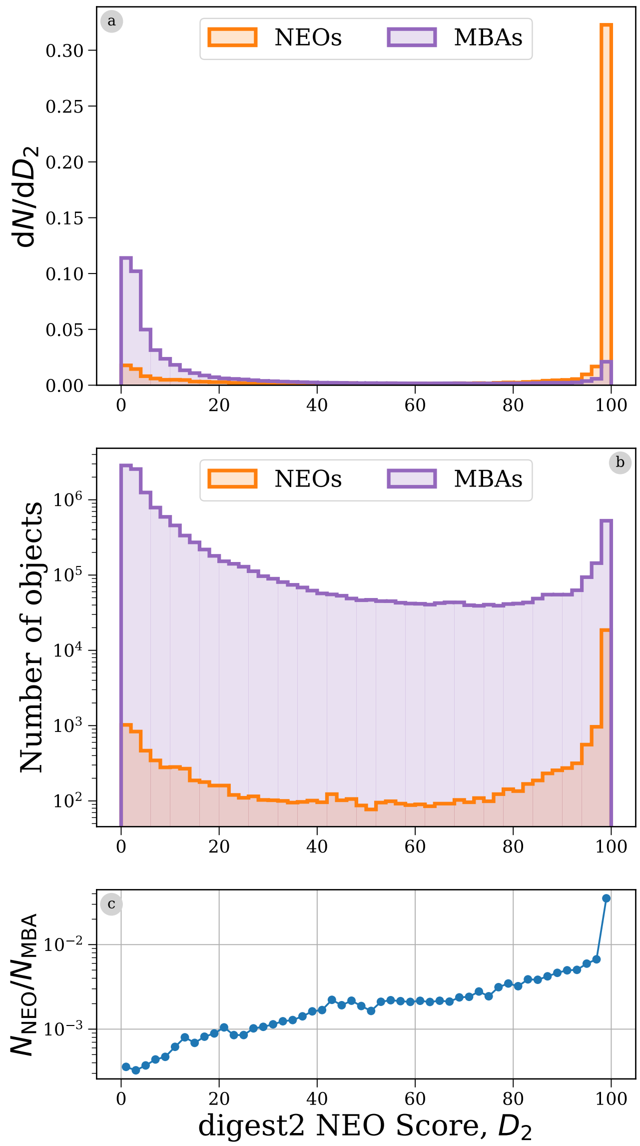

Figure 1. `digest2` scores for all NEOs and MBAs observed in the first year of our simulated LSST observations. **(a)** normalised histograms of `digest2` scores, **(b)** the same histograms un-normalised **(c)** ratio of the histograms in (b). Note that the latter two panels are on a logarithmic scale.

this technique will typically be reasonably well known, and in need of no immediate follow-up. However, this tracklet linking comes at a cost: the object is not identified as interesting until the third tracklet is imaged – at best, two nights after the first observation or, at worst, nearly two weeks later. This means that potentially interesting (or hazardous) objects may be missed until it's too late to observe (or react to) them.

The number of objects submitted to the NEOCP will increase by several orders of magnitude, and a large fraction of these submissions will be main belt asteriods (MBAs) (Wagg et al. in prep). This would present difficulties for community follow-up, with too many available candidates (and of low purity) passing the current submission criteria.

Due to the vast MBA background, `digest2` performs poorly in identifying NEO candidates, as is demonstrated in Figure 1. We show due to the extreme number of MBA submissions, only 1.5% of submissions meeting the current criteria (a score of least 65) are NEOs, and only 10% of objects with a perfect score of 100 are actually NEOs. It is clear that this classification scheme requires improvement.

The aim of this paper is to augment `digest2` in classifying NEOs in the presence of a significant MBA background. We simulate one year of LSST observations on a synthetic solar system catalogue and calculate `digest2` scores for each tracklet. We investigate three additional parameters - ecliptic latitude, direction of motion relative to the ecliptic and apparent magnitude - as potential further discriminators between NEOs and MBAs in addition to the `digest2` score. We consider various combinations of these parameters to further refine submissions to the NEOCP and highlight how sorting submissions by these parameters can better identify high probability NEO candidates.

2. METHODS

2.1. *Simulated tracklet population*

We create a population of simulated tracklets by performing mock LSST observations on the Synthetic Solar System Model (Grav et al.

2011). We use a modified "Baseline v2.1"[5] 10 year scheduler simulation strategy (Naghib et al. 2019; Cornwall et al. 2020). These observations account for both scheduled and unscheduled downtime and simulate the current baseline observing strategy that will be followed by LSST. The resulting simulations span 3653 days, and have over 50 million observations. The modification consists of shifting the start of LSST to March 2022, around the epoch of the MPCORB catalog used to generate the input hybrid catalogue dataset.

We select observations from the simulated LSST dataset that correspond to tracklets. For a tracklet to be built, we require it to satisfy the following criteria:

1. **Number of observations:** We consider only objects which have at least 3 observations on a given night.
2. **Maximum time separation:** We set the maximum time between observations to 90 minutes.
3. **Minimum arc length:** We ensure that each tracklet is at least 1 arcsecond in length.

The motivation behind these cuts is to ensure that the tracklet constrains the on-sky motion of the object sufficiently well, so that its position at a later time can be easily extrapolated. With fewer observations or shorter tracklets, many different orbits could reproduce the same motion on the sky. Moreover, observations that are separated too significantly in time may be spurious linkages, where observations of multiple objects are incorrectly assumed to be of the same source.

2.2. *New parameters to consider in scoring*

- MBAs are constrained to lie in the ecliptic plane - we can leverage this
- Ecliptic latitude split the population well directly because of this
- Direction of motion relative to the ecliptic plane works too since closer things aren't constrained as strongly
- Apparent magnitude is correlated with distance
- Show plots of all of them

3. RESULTS

- Combine all 3 into 1 score, plot that up, compare to earlier one
- Decide on threshold and analyse performance with contingency matrix
- (Consider whether we could weight the different parameters differently to improve matters)

4. DISCUSSION

- Recommend sorting rather than just a threshold
- Coordination between groups will be important NEOFixer

5. CONCLUSION

- Point out whether we did better :shrug:

[5] https://community.lsst.org/t/survey-simulations-v2-1-april-2022/6538

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Cornwall, S., Eggl, S., Juric, M., & Jones, L. 2020, in AAS/Division for Planetary Sciences Meeting Abstracts, Vol. 52, AAS/Division for Planetary Sciences Meeting Abstracts, 110.04

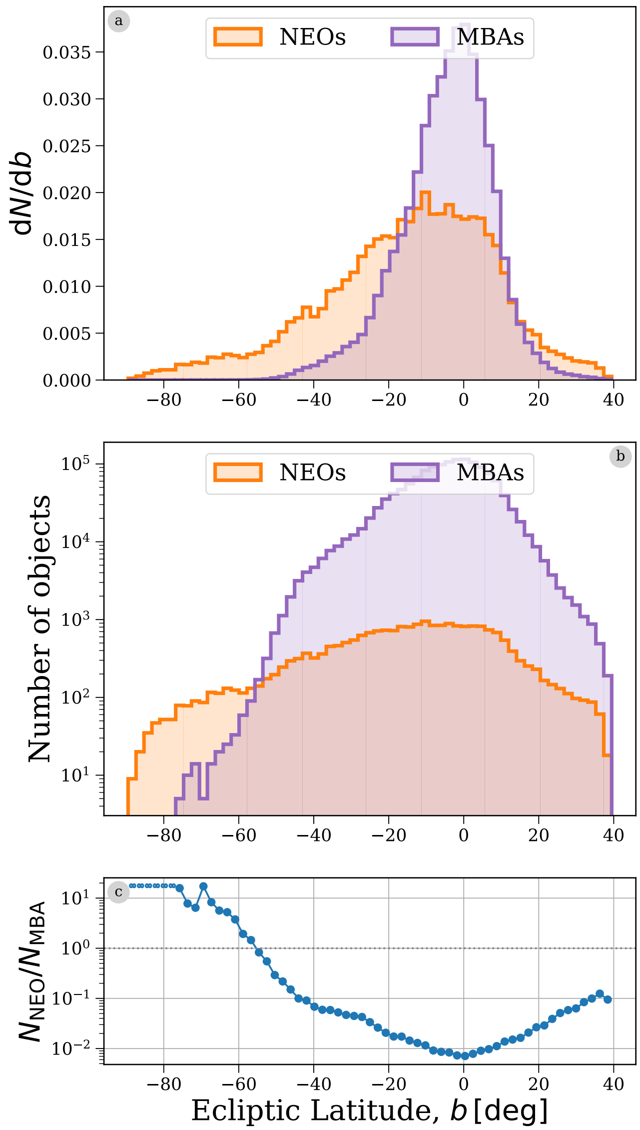

Figure 2. As Figure 1, but for ecliptic latitude and only for observations with a `digest2` score of at least 65.

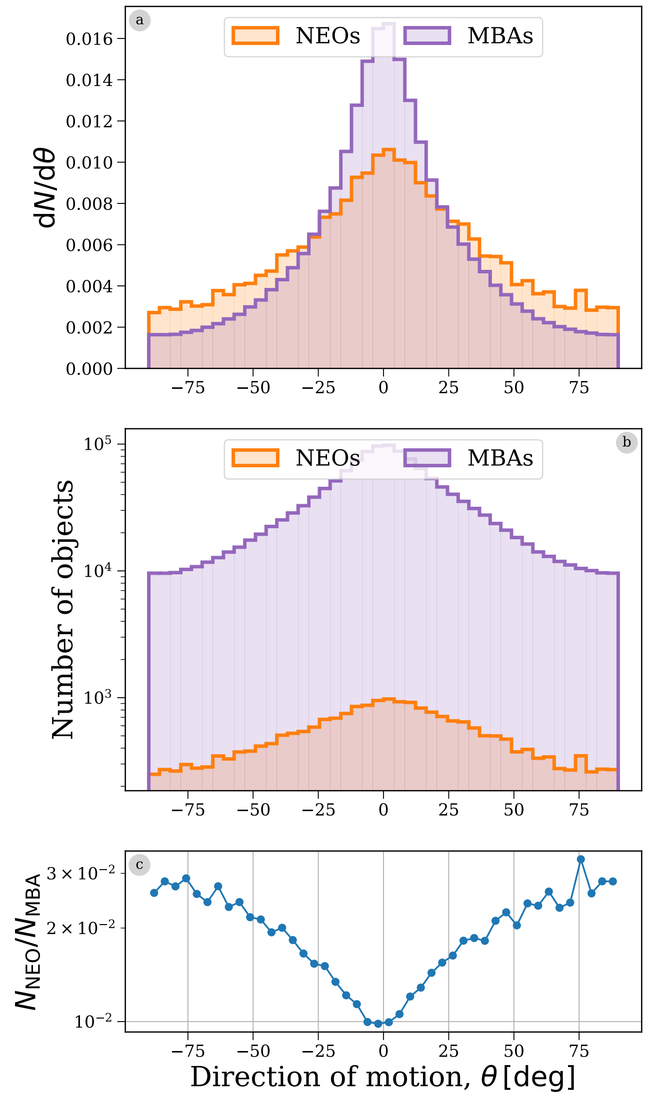

Figure 3. As Figure 1, but for direction of motion relative to the ecliptic plane and only for observations with a `digest2` score of at least 65.

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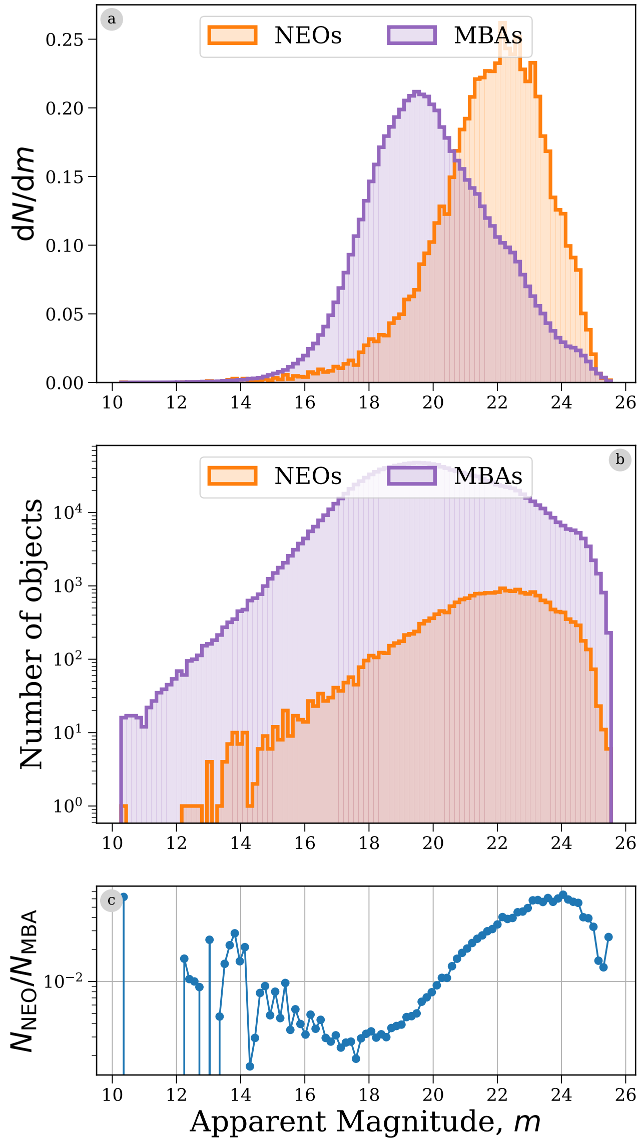

Figure 4. As Figure 1, but for apparent V-band magnitude and only for observations with a `digest2` score of at least 65.

Wagg, T., Juric, M., Yoachim, P., et al. in prep.

https://www.tomwagg.com/html/paper_posts/lsst_neocp.html

APPENDIX

A. DISTRIBUTIONS OF PARAMETERS FOR ALL OBSERVATIONS

The following plots show the distribution for the three parameters that we consider for the entire population of observations - in contrast to the earlier plots that only consider observations with a `digest2` score of at least 65. In general one can see that the distributions are less clear cut, in particular for the apparent magnitude distribution.

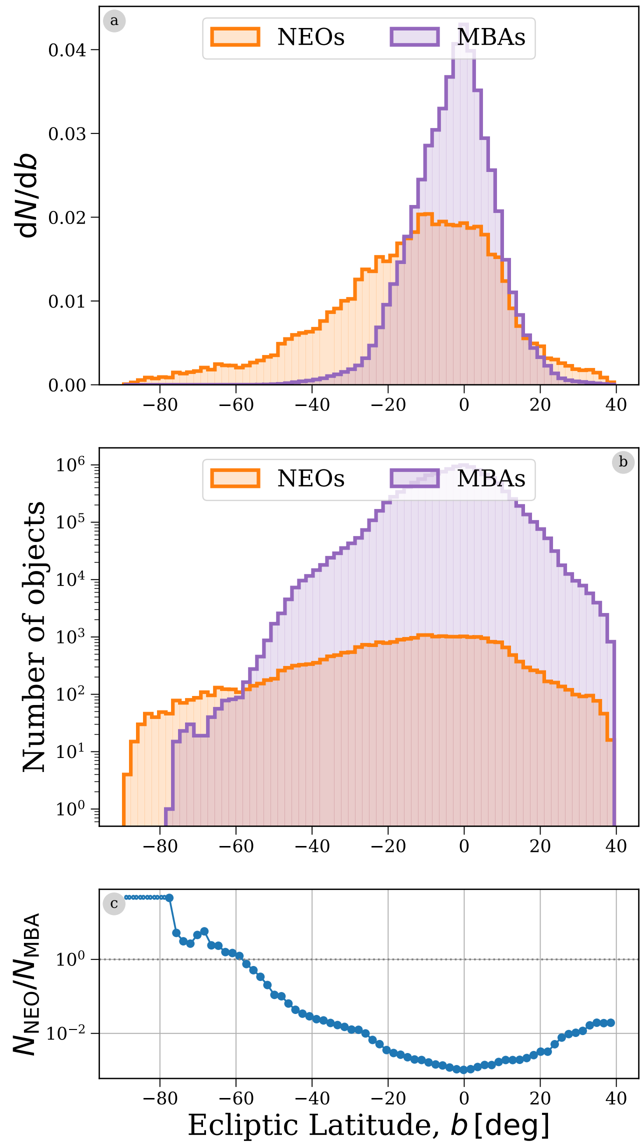

Figure 5. As Figure 1, but for ecliptic latitude.

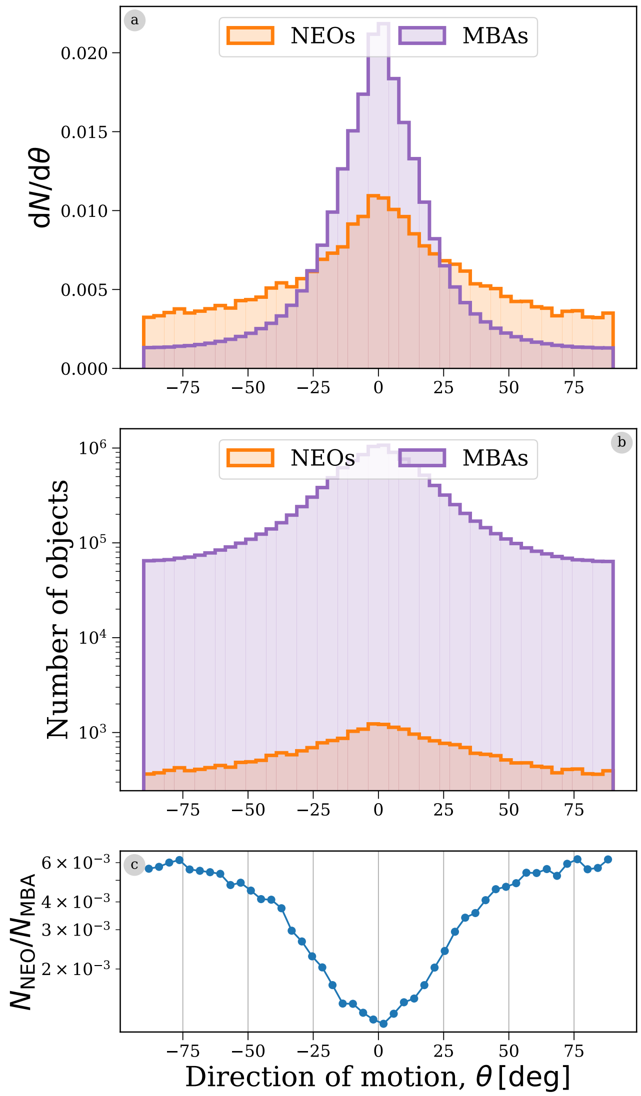

Figure 6. As Figure 1, but for direction of motion relative to the ecliptic plane.

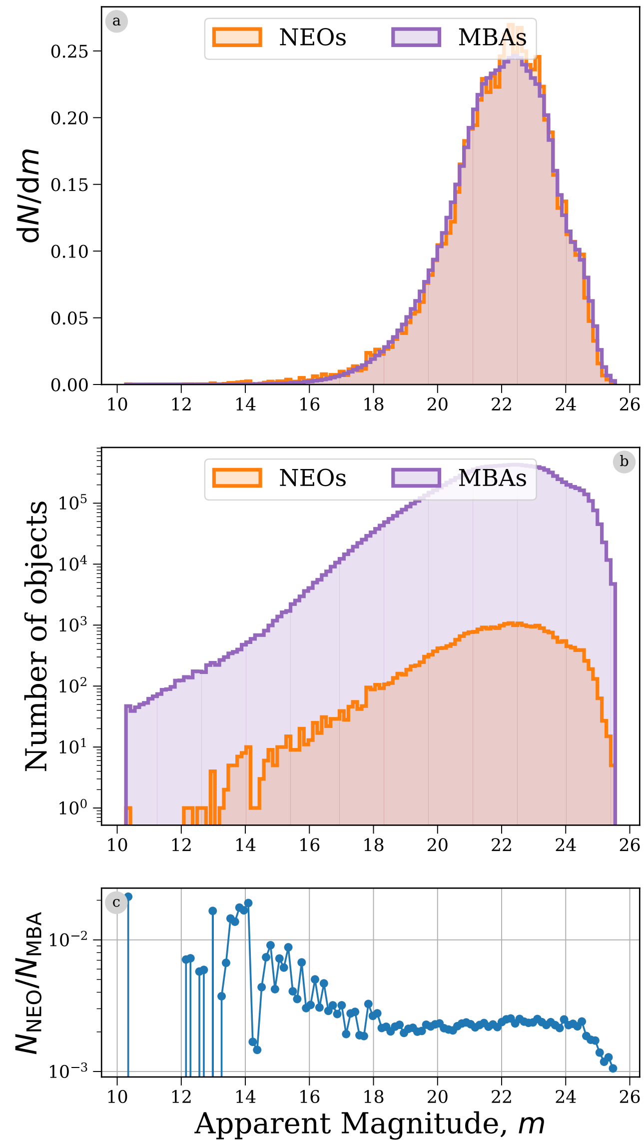

Figure 7. As Figure 1, but for apparent V-band magnitude.