Aspect Ratio and Rotation Statistics of Near-Earth Asteroids

Abstract We propose to search for Near Earth Asteroids (NEAs) in datasets collected by the Mission Accessible Near-Earth Object Survey (MANOS) led by Dr. Nicholas Moskovitz of Lowell Observatory over the past 3.5 years (Moskovitz *et al.* 2014). We will identify NEAs in the fields and determine both their aspect ratio and rotation rate to generate unbiased statistics of the rotation rate and shape of NEAs.

Science The demand for NEA research by NASA has increased in the last few years after the Chelyabinsk meteor event in 2013. The asteroid community is working to meet that demand with the creation of several new surveys and the improvement of existing surveys to further our understanding of the population properties of NEAs. However, with a discovery rate of over 1000 NEAs per year, the current characterization rate of 75 NEAs per year is far too low, and we are reaching a bottleneck in the science output (Elvis *et al.* 2013). Understanding the population of NEAs is important for furthering our understanding of the formation of the Solar System, for selecting mission targets, and for protecting ourselves against hazardous objects like the Chelyabinsk meteor. As a result, it is important we come up with a system to streamline the characterization of NEAs to increase annual yields.

Our knowledge of NEAs is currently dominated by the 100-km and larger diameter regime due to observational bias. The MANOS survey is designed specifically to help break that bias by characterizing objects in the size range of 10s of meters in diameter to give a complete picture of the true NEA population features. Figure 1 below shows the distribution of characterized small near-earth asteroids through the MANOS survey compared to other surveys (Thirouin *et al.* 2016). The goal of my research is to provide an unbiased survey to draw conclusions on the generalized traits of the population of NEAs with no preference in size. We will use the target NEAs MANOS has observed as well as the field asteroids in the images to form our unbiased population of NEAs. The characteristics of the targets are unknown, making the sample representative of all NEAs. The characteristics of interest are the rotation period of the object and its shape (axial ratio). Both of these parameters are found by studying the light curve of the object, obtained through photometric studies. While the period of the light curve reveals the rotation rate, the amplitude gives an initial measurement of the aspect ratio, or shape of the object. Phase angle may play a role in the amplitude, but this depends on the geometry of the observation (Harris *et al.* 1984). It is also possible that the object is tumbling, which is critical information to have prior to a spacecraft encounter. We can also learn something about the composition of the object from the rotation rate. Asteroids with a period faster than 2 hours will disrupt if they have a rubble pile, or fractured, structure. Unfractured asteroids have the ability to rotate much faster without experiencing rotational breakup (Statler *et al.* 2013). All of these traits play a role in our understanding of the general population of NEAs.

The MANOS team has been collecting data every month for the last 3.5 years to study meter sized NEAs. We will characterize all asteroids in the field at the different telescope pointings to collect a size-independent sample of NEAs. There are other programs aiming to do similar work to reduce the science bottleneck in NEA characterization after discovery, but no large individual survey characterizes more than 20 NEAs per year (Elvis *et al.* 2013). LINNAEUS is a survey similar to what we are proposing using the Spitzer Space Telescope, but appears to have been unfunded (Elvis *et al.* 2014).

Even if our own sample of objects reveal no correlation in rotation rate, shape, and size, we will still be contributing to the larger sample of characterized NEAs. Increasing the number of characterized objects helps address outstanding questions regarding the prospect of exploration, impact hazard, composition statistics, and Solar System origins.

Technical To execute the proposed research, we will use datasets collected by the MANOS program. MANOS began collecting data in August of 2013. The MANOS program uses three telescopes: the 8-m Gemini North and South telescopes, the SOAR 4-m, the Kitt Peak Mayall 4-m, Lowell Observatorys DCT 4-m, and the CTIO 1.3-m. They receive an average of three nights per month of observation time from the various telescopes. Over the lifetime of the program, MANOS has over 125 full nights of observations. This is anywhere from 800 MB to 1 TB worth of data.

The data are in the hands of the MANOS team, led by Nicholas Moskovtiz of Lowell Observatory, who has given permission for us to use the MANOS data for this research. As a result, the data acquisition is straightforward. The fields observed by MANOS are of NEAs and provide the cadence that is necessary for obtaining lightcurves of all NEAs in the field. We are interested in short exposures of 30-60 seconds with anywhere from 10-30 minutes on a field. The MANOS datasets are just this, making them ideal for our science goals. There are many databases containing NEAs and Main Belt Asteroids as background objects which we could use, but the exposure times and time at each pointing will not be compatible with our science goals because we need consistency to get full lightcurves.

Using MANOS data is also ideal because most of the pipelines required for the work have already been set up by Michael Mommert, a MANOS team member and postdoctoral researcher at Northern Arizona University (NAU). There are six essential steps required to execute the proposed research outlined in Table 1 below. Computations will be run outside of class on Monsoon, but class time will be used for the three week duration of the project to write and test code before submitting jobs to Monsoon. Because the MANOS data comes from multiple telescopes, the class will be split into groups of 1-2, each responsible for the data from their assigned telescope(s). Everyone will have the same tasks, but work on individual datasets, specific to their telescope(s). We will primarily use pre-written code to assist us in the data reduction process. The first step will be to reduce the datasets by bias subtracting and flat-fielding the images. We will use python code that is already written to create master biases, master flats, and reduce the data images. There are telescope parameter files that the code uses, so each group will be responsible for making sure these are set up to their needs. The next step is to locate all of the serendipitous asteroids in each of the fields. For this, we will use a script that Michael has written. The script may need to be adjusted to accommodate each of the telescopes. We will also use Michael's Photometry Pipeline (Mommert 2017) to perform aperture photometry on each of our targets. Code will need to be written to automate the processes required for determining the rotation rate and axial ratio for each of the objects. Finally, we will visualize our results with plots and statistical analysis to search for trends in the population of targets. Specifically, we want to determine if there is a relationship between the size, shape, and rotation rate of the objects. Trends could lead to connections between the population of potentially hazardous objects with NEAs and Main Belt Asteroids with NEAs.

We will need at least 3 TB of storage space for the raw data, the reduced images, and the photometry results. The NAU Monsoon High Performance Computing Cluster allows for up to 5 TB of storage free, so this is where I recommend we store our data. Running the photometry pipeline on the images will be the most computationally time intensive individual task required for the project. From my experience using the photometry pipeline, I estimate it would take on the order of 10 minutes to run SExtractor and SCAMP on one object. Thirouin *et al.* (2016) published results on 68 objects with photometric results since the beginning of MANOS. This is only a subset of the objects observed during the lifetime of the project. If we assume this subset was 66% of the entire dataset, then we can assume at least 100 fields have been observed with MANOS. If we also assume that there are on average, two field asteroids per pointing, then we have 200 objects to run through the pipeline. This requires, at most, 33 hours on a single CPU. This time can be decreased using multiple cores of Monsoon. I predict the other tasks in total will require an equivolent amount of computation time.

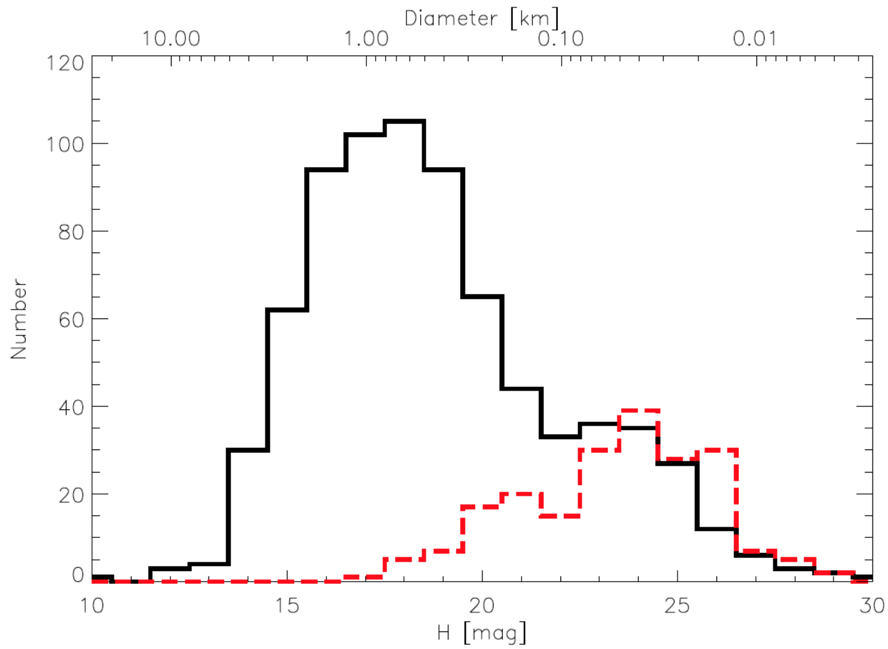

Fig. 1.— The histogram shows the distribution of NEAs that have been characterized by their light curves. Warner et al. (2009) data is shown in as a solid line and the MANOS targets are displayed as a dashed line (Thirouin *et al.* 2016).

Table 1: Plan of Action

Task	Necessary Code	Code Modification
Bias Subtract & Flat Field the Data	Python code exists for each telescope: makedark.py, makeflat.py, reduce.py	1 day
Extract field asteroids	Mommert Extraction Code - will need some revisions	1 day
Perform aperture photometry on the field asteroids	Mommert Photometry Pipeline	3 days
Determine Rotation Rate	Write code to determine period of lightcurves	2 days
Determine Axial Ratio of Projected Ellipse	Write code to determine the axial ratio of the projected ellipse (ignore phase angles less than 25°	2 days
Draw conclusions	Use statistics and visual analysis techniques	2 days

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