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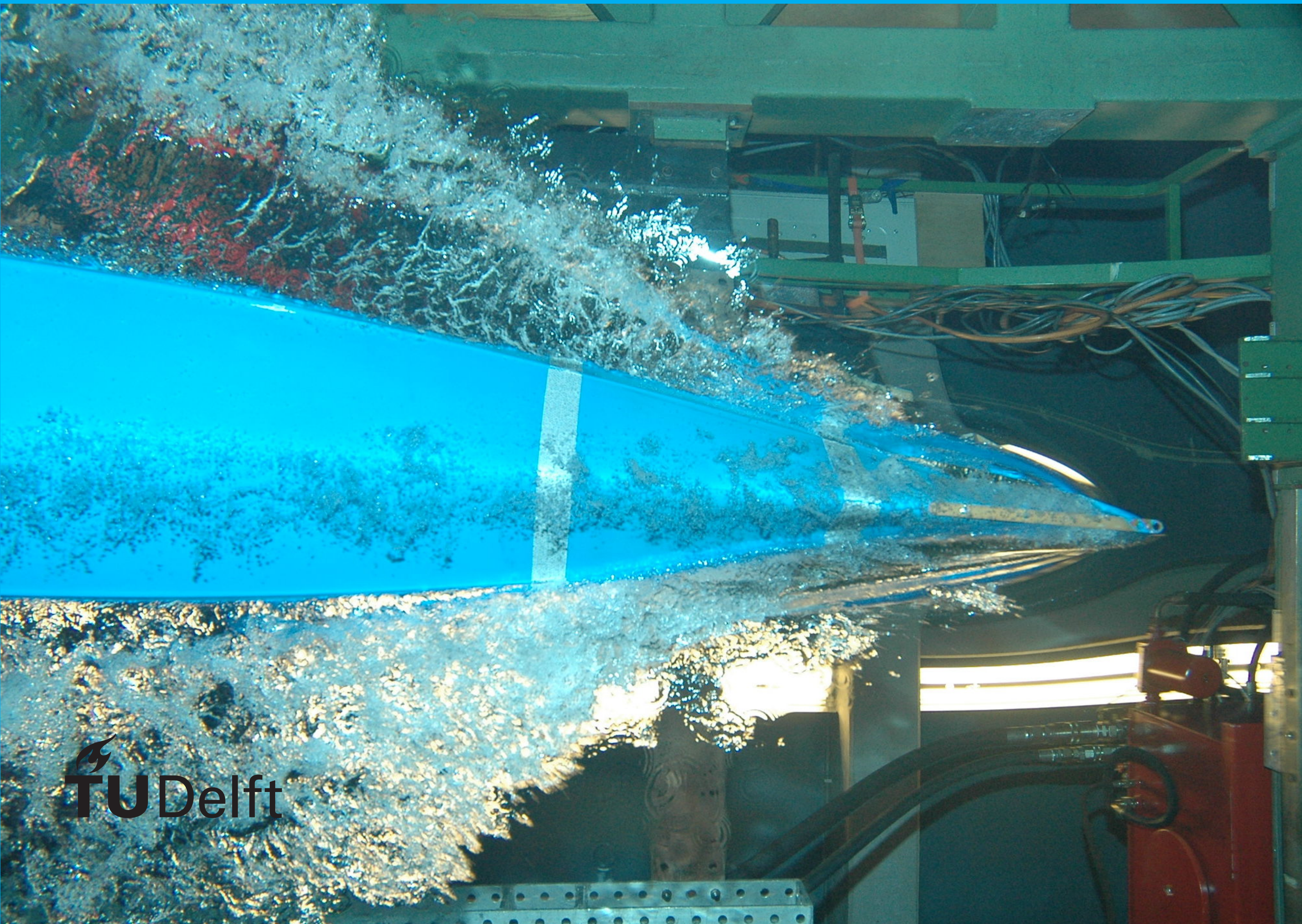

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by

J. Random Author

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Preface

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J. Random Author
Delft, January 2013

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1 Introduction

66 Million years ago, an asteroid the size of Rotterdam initiated what is perhaps the most well known cataclysmic event in the history of life on Earth. With an impact releasing the energy of a billion nuclear bombs, the asteroid left a 180 km crater in the Gulf of Mexico. Launching enough debris into the atmosphere to block out the light of the Sun, eventually leading to the extinction of three quarters of spiecies on Earth, most famously the non-avian dinosaurs (Chiarenza et al., 2020). In recorded human history, a multitude of noteworthy asteroids have impacted Earth, such as the Tunguska impactor in 1908 in Siberia. Flattening over 2000 km^2 of forest, events such as this serve as a staunch reminder of the massive kinetic energy that can be released by an object descending to Earth from space, and the danger this poses to human civilization.

Cognizant of such hazard, the United States launched the Spaceguard Survey in 1992, aiming to “identify 90% of near-Earth Asteroids (NEA’s) larger than 1 km within 10 years.” (Morrison, 1992). With improvements in observation technology, more meteors were witnessed and recorded, leading to greater awareness into the frequency and unpredictability of such events. Of course, impacts from space are not a problem exclusive to Earth; as the 1994 impact of comet Shoemaker-Levy 9 into Jupiter proved. This impact showed that impacts of objects large enough to cause global catastrophy were not as highly improbably as once considered, and asteroid identification efforts took off with it.

The initial spaceguard survey goal was completed succesfully, and it is known that there are - within reasonable probability - no civilization-ending asteroids destined for Earth impact in the coming millenium. Nevertheless, smaller asteroids can still pose a local threat to human life or property. In addition, much is still unknown about the exact population of near-Earth asteroids, and such knowledge might provide valuable insights into the origin and evolution of the Solar system. Therefore, NASA extended the spaceguard mandate to detect 90% of all NEA’s larger than 140m (A. Harris, 2008).

Since then, a lot of progress has been made in cataloguing and identifying smaller NEA’s. Additionally, consideration has been given to survey for smaller limiting diameters (e.g. Stokes et al., 2003). However, such efforts have to date still been very unsuccesful: For example, in 2013, a meteoric airburst over the city of Chelyabinsk, Russia, seriously injured almost 1500 people and damaged several thousands of buildings. Although damage was limited due to the high altitude of the explosion, no precautionary measures were taken, as the asteroid was completely unknown until the moment of atmospheric entry. Luckily, such events are not a common occurence. However, the large majority of NEA’s of this size is completely unknown, and as such they can strike anywhere at any time.

1.1. Near-Earth Asteroids

Asteroids are perhaps the most diverse object in the Solar system: ranging in size from tiny chips to dwarf planets such as Vesta and Ceres; from rocky compositions, to fully metallic monoliths, and composites in various elements and mineral shapes; from close to the Sun on short orbits, to distant eccentric long period trajectories. All of this greatly increases the complexity of surveying for near-Earth asteroid. Before continuing, the definition of a near-Earth asteroid will be given as follows: *a near-Earth asteroid is any asteroid with a perihelion* $q \leq 1.3\text{AU}$ *and semi-major axis* $a \leq 4.2\text{AU}$.

Current knowledge of the asteroid population is based on past and current NEA surveys. The most important parameter to consider is the size-frequency distribution of the objects. After all, larger objects exhibit a larger impact energy and hence threat, but small objects are more common and harder to detect. A good representation for this size-frequency distribution is a power law as follows:

$$\frac{dN}{dD_p} \propto D_p^{-k} \tag{1.1}$$

With exponent k in the range of 2.95 - 3.5 (Ivanov, 2008). Commonly, the size of the asteroid can not be directly ascertained; the target is too small to accurately determine the size. However, estimates can be made based on the absolute magnitude H of the object by relation with an assumed albedo p_v ($p_v = 0.14$ is often used as an approximation) using the relationship first derived by Bowell et al., 1989:

$$D = \frac{1329\text{km}}{\sqrt{p_v}} \cdot 10^{-H/5} \tag{1.2}$$

As a result of the success of the spaceguard survey efforts, past efforts have more than likely identified all NEA's with $H \leq 15$, corresponsing to the *flying mountains* several kilometers in diameter. Also, at smaller limiting diameters, a lot of NEA's have been - and continue to be - found. The surveys through which this is achieved will be discussed in further detail in **??**. Through a process of modelling the asteroid population, and simulating the performance of past surveys on it, followed by fitting the results, Granvik et al., 2018 have produced a parametric model of the NEA population. The distribution of orbital elements in this model can be seen in Figure 1.1.

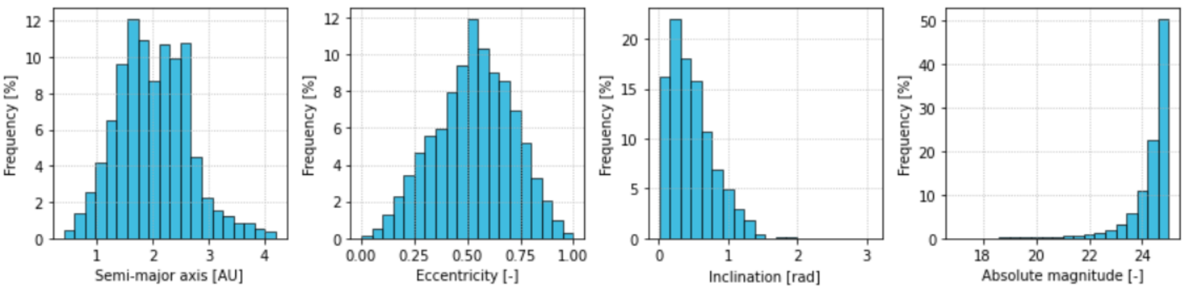

Figure 1.1: Frequency of orbital elements for modelled NEA population according to Granvik et al., 2018

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Several things are of note: First and foremost, the population is very diverse; there is no particular concentration of NEA's anywhere that allows for simple exploitation in survey design. Secondly, the bulk of NEA's has a semi-major axis of $1.0\text{AU} < a < 3.0\text{AU}$. The dips at $a = 2.0\text{AU}$ and $a = 2.5\text{AU}$ correspond to the 4:1 and 3:1 orbital resonance with Jupiter, respectively. The inclination of asteroids is concetrated among the ecliptic, but very low inclinations are rare due to gravitational interactions with the planets. Lastly, the effect of Equation 1.1 can be seen: 50% of the asteroids in the population generated by Granvik et al., 2018 has $24.6 \leq H < 25$, corresponding to a diameter of $D \leq 40\text{m}$.

Among these small NEA's was the asteroid which entered Earth's atmosphere over Chelyabinsk in 2013. It is currently estimated that this asteroid had a diameter of 17 to 20 meters (Yeomans and Chodas, n.d.). Assuming an albedo of $p_v = 0.14$, this would give it an absolute magnitude of $H \approx 26.5$. As previously discussed, completeness at these limiting diameters is very low. Figure 1.2 shows the completeness as a function of size according to A. W. Harris and D'Abramo, 2015. They estimate that, at their time of writing, less than 0.005% of all asteroids of this size have been identified. Through new and continued survey efforts, Stokes et al., 2017 project that the completeness at this size will increase to approximately 1.5% by 2023.

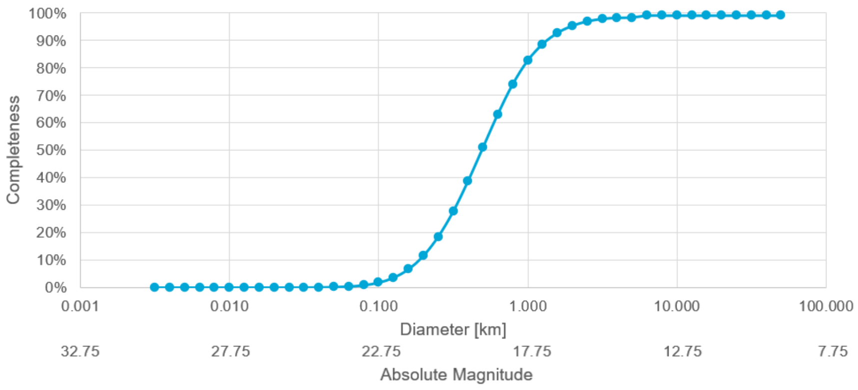


Figure 1.2: Expected survey completeness as a function of near-Earth asteroid diameter. A. W. Harris and D'Abramo, 2015

The problem can be seen in more detail in Figure 1.3. Here, A. W. Harris and D'Abramo, 2015 show the expected and identified population of NEA's as a function of their size. The effect of the continued spaceguard efforts can be seen clearly here: the asteroid population with $D > 1\mathrm{km}$ is completely known, and the population of asteroids $D > 140\mathrm{m}$ is nearing the targeted 90% completion. However, as the search efforts have been designed specifically to identify targets at this limiting size, the population with $D < 100\mathrm{m}$ is still by far and large undiscovered.

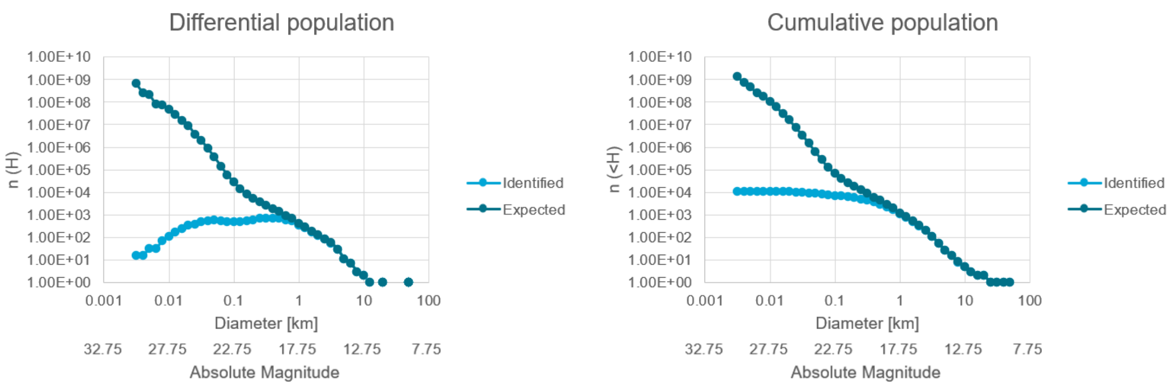
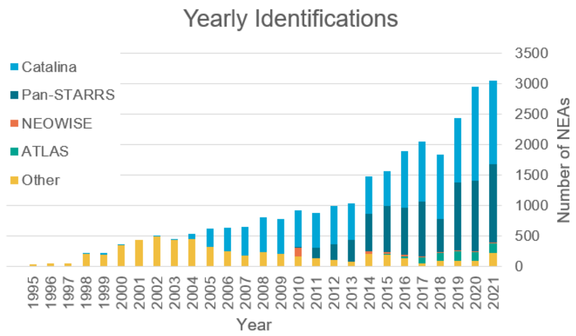
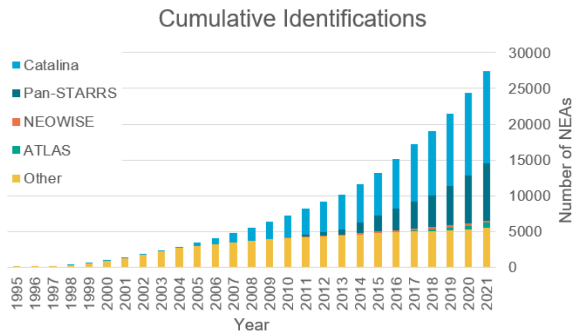


Figure 1.3: State of asteroid identification progress as of August 2014, compared to the expected number of asteroids per diameter. Note that the y-axis is logarithmic. A. W. Harris and D'Abramo, 2015

1.2. Past and Current Identification Efforts

Before continuing to the topic of the presented research, first some discourse shall be given to the missions that have resulted in the current knowledge of the NEA population. For brevity, not all missions will be listed; just a representative sample judged by the author to give a good overview of the state of the art. The missions are separated into two categories: space-based, and Earth-based. The latter comprises telescopes on Earth, with the advantage of having access to Earth infrastructure, providing larger telescopes and practically unlimited power, communication bandwidth, storage and computational resources. However, Earth-based systems are hindered by atmospheric distortion, extinction of light as it passes through the air, weather, limited search area depending on geographic position, and day-night cycles. Space-based systems contrast this: they are limited mostly by the maximum aperture of the telescopes they can support, the on-board processing capabilities and the computational power. Atmospheric and weather effects are mostly non-existant in space, however interference from the Sun, Earth and Moon should not be underestimated. To date, all NEA surveys from space have been carried out from orbits around Earth. Some proposals for deep space missions will be discussed in section 1.3.





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The University of Arizona

1.2.2. Space-based Surveys

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7.2. Recommendations for Further Research

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Verification and Validation

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