SIMULATING CURRENT AND FUTURE OPTICAL GROUND BASED NEO SURVEYS Tommy Grav[1], T. Spahr[2], A.M. Mainzer[3], J.M. Bauer[3], [1]Planetary Science Institute, Tucson, AZ 85719, USA; tgrav@psi.edu; [2]Independent, USA; [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA

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Introduction:

Surveys for near-Earth objects (NEOs) have undergone rapid development over the last decade. The current surveys have discovered more than 12,000 NEOs to date, and more than 1,400 new NEOs were discovered in the last year. More than 90% of the NEOs larger than 1km in diameter have been discovered to date, representing considerable progress by the astronomical community [1]. In 2005, the U.S. Congress mandated that NASA should discover and track 90% of objects larger than 140m in diameter in 15 years, i.e. before 2020. We have undertaken a project to perform high-fidelity simulations of a variety of ground-based optical surveys, including present and proposed future facilities, to evaluate the potential of these projects to reach this congressionally mandated goal. Our survey simulations include NEO populations models based on the orbital element models of [2], [3], and [4], together with physical properties derived from recent measurements of diameters and albedos from [1, 5]. The simulations replicate the historical performances of the existing suite of ground-based projects such as the Catalina Sky Survey and the Pan-STARRS project and predict their future performance. The work, also explores the performance of the future ground-based optical surveys, like LSST.

Current Status of NEO Surveys:

The known NEO population now consists of more than 12,300 objects, $\sim 1,400$ of which were discovered last year. The two current major surveys for NEOs are the Catalina Sky Survey (CSS) and the Pan-STARRS project. The CSS has been the leading NEO survey project during most of the last decade, but when Pan-STARRS went from a general science survey telescope to a dedicated NEO survey telescope in early 2014, it increased its discovery rate by 60%. This has cemented Pan-STARRS as the leading discovery telescope, responsible for more than 40% of the discoveries in 2014 (see Figure 1). Early numbers for 2015 indicate that this trend is persisting.

However, caution must be exercised when considering how the increase in detection took place. While the overall increase in discoveries was 42% between 2014 and 2015, the increase in discoveries for objects larger than $\sim$ 140m was only 26%. For objects smaller than $\sim$ 140m the increase in discoveries between the two years was 53%. In fact, the fraction of discovered objects per year that are smaller than $\sim$ 140m has steadily increased from 56% in 2011 to 65% in 2014.

Current Surveys into the Future:

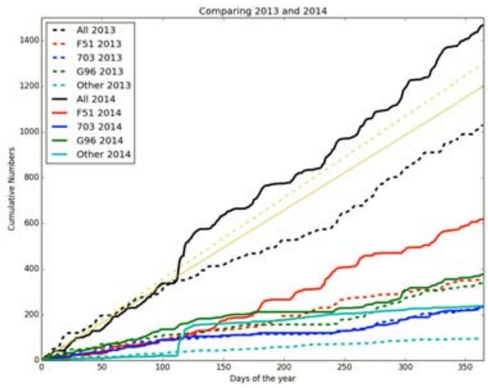

Figure 1: Comparing the discovery rate of the major surveys during 2013 and 2014. Pan-STARRS (F51) saw a significant increase in discoveries in 2014 as the focus of the survey changed to focus on NEO discovery. Both CSS telescopes (G96 and 703) performed near identically between the two years.

Our simulations of the current surveys are capable of reproducing the discovery and re-detection statistics seen over the last two decades by assuming that the sky is covered every 5-6 days to a limiting magnitude that has increased from about $V \sim 19$ to $V \sim 21$ in the last 10 years. The synthetic NEO populations derived for our simulation of space-based infrared surveys in [1], [5] and [6] were used for all our simulations of future performance. The predicted performance of the combination of CSS and Pan-STARRS for the objects larger than $\sim$ 140m is shown in Figure 2. Our simulations show that the efficiency of the current survey to discover new objects larger than $\sim$ 140m becomes diminished, leading to a survey completeness of $\sim 40\%$ in the mid-2020s, unless more capable systems or significant improvements are implemented.

LSST:

LSST is an 8.4m telescope with a 9.6 square degree imager that is being built in Chile with funding from the National Science Foundation and the Department of Energy. The project will produce a 6-band wide-field deep astronomical survey covering over 20,000 square degrees of southern sky, visiting each pointing on the sky over 1000 times in 10 years. While it is an impressive project, it faces some fundamental issues that will limit its effectiveness as a NEO survey telescope. As currently envisioned each pointing will only be visited two times per night. This approach was tested by

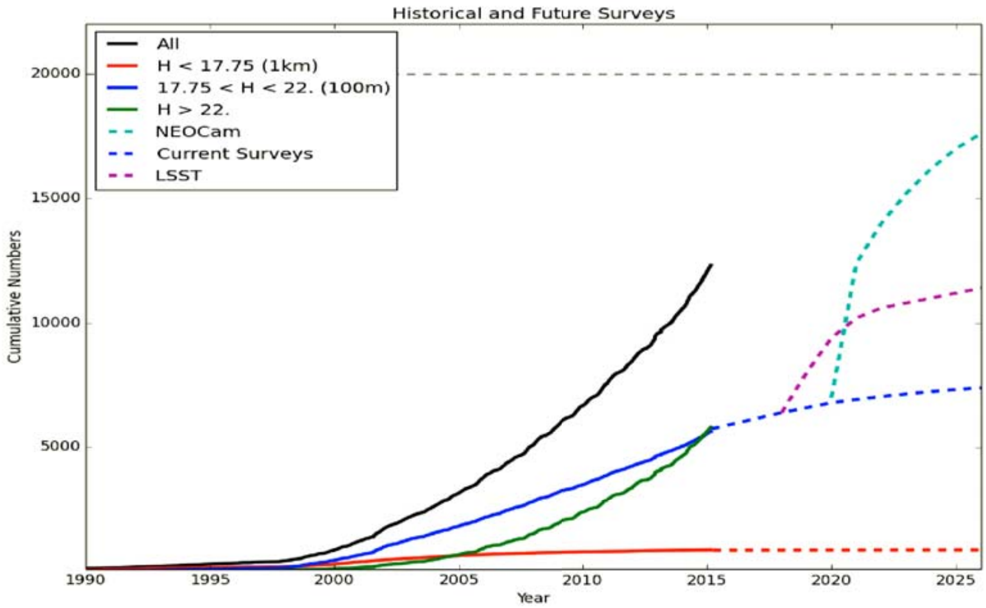

Figure 2: The historical cumulative discovery numbers for the NEOs. While the number of discoveries per year is increasing, most of the recent increase is for objects smaller than ~ 140m. Shown is also the future projections of the current surveys, LSST and the space-based infrared survey concept NEOCam.

Pan-STARRS and has proven to be highly problematic, leading the Pan-STARRS project to return to a 4-5 detections per night cadence that has proven to be highly successful in CSS, NEOWISE and now Pan-STARRS. The significant increase in discovery numbers in 2014 also shows that the broad sky survey goals and methods of LSST, which were very similar to the goals and methods of the Pan-STARRS project up until the dedicated NEO survey started in early 2014, is less than optimal for discovery of NEOs.

In [7] it was claimed that LSST would be able to satisfy the congressional mandate by reaching 90% completeness in 10 years. However, as the design has matured, it is necessary to revisit the simulations. To better understand the performance of the more mature LSST, we performed our own simulation. The survey cadences were taken from 10 year simulations of optimized pointing history available at the LSST website (www.lsst.org/lsst/), noting that only two detections per night cadences are available from the LSST project. The limiting magnitudes in the 6 filters were derived for different airmasses using the official LSST exposure time calculator (link is available on the LSST website). An object was considered to be discovered if it was detected twice on two individual nights within 10 days of each other. The resulting survey completeness is shown in Figure 2, reaching a completeness of less than 60% in 10 years. **We emphasize that this is using a two detection per night cadence that remains unproven**. If the LSST project adopted the standard NEO cadence of 4 detections per night cadence, something that might not be compatible with the projects's other science goals, our simulations show that the completeness would be $\sim 10\%$ lower after 10 years due to the significantly diminished sky coverage.

Conclusion:

By using the same framework for all our simulations we have been able to reproduce the performance of the optical surveys, as well as that of the NEOWISE infrared survey [1] and [5]. We have extended the simulations to predict the future performance of the current surveys (CSS and Pan-STARRS), LSST and the space-based infrared survey telescope NEOCam (see Figure 2). Our simulations show that neither the current surveys nor a future LSST, are capable of achieving the congressional mandate of discovering 90% of the NEOs larger than 140m in the next 15 years. However, with a space-based infrared system, such as NEOCam [6], the goal can be more rapidly achieved for the PHA population.

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