The Need for Speed in Near-Earth Asteroid Characterization

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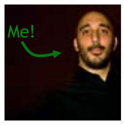


Abstract

The current discovery rate of Near Earth Asteroids (NEAs) is set to increase in the next few years from ~900/year to ~2,000/year thanks to new surveys coming online and equipment upgrades to current ones. Despite this, the rate of characterization is expected to remain the same: ~100 spectra and a few dozen light curves per year. At this rate it will take up to a century to characterize just the NEA population with sizes above 100m. Characterization is crucial to science, space missions and planetary defense and cannot be left by the wayside. Herein we discuss the challenges of, and opportunities for, optimal NEA characterization. In particular we find that immediate follow-up (within days) of discovery is essential, especially for NEAs smaller than 100m, which will remain too dim for spectroscopy for many years, even decades, following their discovery. A dedicated telescope (2-4m) could perform optical spectroscopy while a number of smaller telescopes would take light curves. Coordination could be performed by the Minor Planet Center as an extension of the services they provide through the NEO Confirmation Page.

Motivation

NEAs have attracted public interest in recent times in part due to the unexpected Feb. 15, 2013 event when a 17m meteor exploded with 500kt TNT of energy over the city of Chelyabinsk, Russia and injured over 1,000 people. The start-up of two private companies aiming to mine valuable resources from NEAs in the near future has also rekindled interest in the scientific and for-profit exploration of asteroids. In addition, NASA has made NEAs the prime targets for human space exploration.

In 2005 the U.S. Congress issued a mandate to NASA to find at least 90% of the (13,200±1,900[1]) NEAs larger than 140m ($H \leq 22$) by 2020. There is no mandate to characterize these NEAs, even though their potential threat depends in no small part on their composition and physical structure. Spectral classification yields the highest scientific return as it provides composition, which also yields an albedo estimate, and thus a more stringent constraint on an object's size. Over 1,000 NEAs are discovered each year but spectra are taken of only ~100, and light curves of a few dozen. **At this rate it will take over a century to characterize the population of >140m NEAs.** Smaller than 140m asteroids may never be characterized.

There are compelling scientific reasons to characterize NEAs, which also have implications for planetary defense: Understanding the composition and structural make up of the smaller ($H > 22$) NEAs will provide knowledge of the size group of asteroids most likely to impact Earth in the near future, while testing current theories of how the NEA population is fed by the Main Belt.

Method

The IAU Minor Planet Center (MPC[2]) serves as the world's clearinghouse for NEA observations and orbital data. In addition it provides web-based tools for generating lists of objects that are currently observable from any site, along with ephemerides. The European NEODyS-2[3] site provides convenient text tables of observations for each NEA taken from the MPC's database.

To quantify various observational follow-up challenges we use these resources, via our own Python programs, to look at the properties of the >10,000 known NEAs (as of end 2013). We also make use of a subsample consisting of the 6,763 NEAs discovered during the 10 years spanning January 1, 2002 to December 31, 2011. For these we generated daily ephemerides, including calculated apparent V magnitudes, to determine how each NEA's brightness changed during its discovery apparition.

Based on the results of our analysis, we project forward to the coming several years and define a set of fiducial magnitudes and timescales to lay out constraints for follow-up observations. Finally, we use our own Python-based exposure time calculators to outline the telescope resources that would be needed to keep characterization (spectra, light curves, astrometry…) keep better pace with discovery.

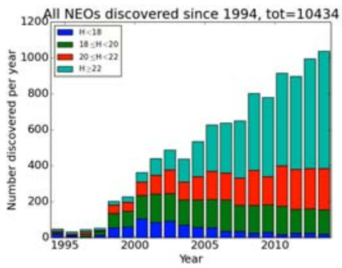
[1] Mainzer et al. 2011: ApJ 743, 156

[2] http://www.minorplanetcenter.net

[3] http://newton.dm.unipi.it/neodys

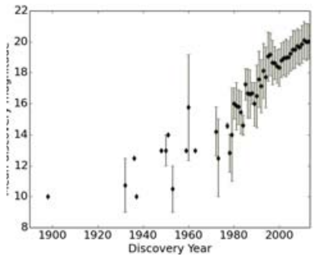
NEA Discovery History:

more



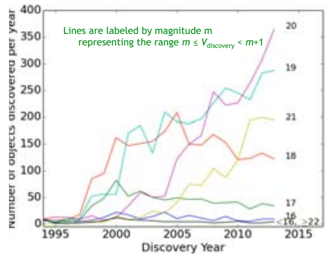
NEA discovery since 1994. Discovery rate of large ($H < 22$) NEAs has been steady for more than a decade. At this rate, the 2005 Congressional mandate will be met more than a decade late. Meanwhile the rate for small ones continues to rise.

fainter



Mean discovery magnitude (first recorded magnitude, approximately V-band). For the past few decades, surveys have been going 1 mag deeper every ~7.5 years. The current mean is $V = 20$.

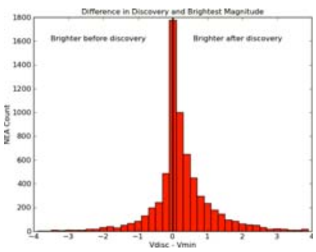
smaller



Number of NEAs discovered discovered/yr at each magnitude since 1994. Rates at $V < 19$ saturated c. 2000 as surveys become more complete for bigger objects. Plot is very useful for planning follow-up programs. Note that there are still ~100/yr found within range of large amateur telescopes.

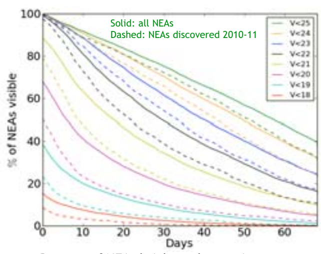
NEAs After Discovery:

found at peak



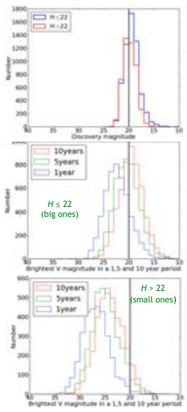
Discovery magnitude compared to brightest magnitude in the discovery apparition. Most (60%) of NEAs are discovered within 0.5 mag of their peak. But many are found just *before* peak brightness.

fade fast



Percent of NEAs brighter than a given magnitude v. time after peak during discovery apparition. The typical NEO will dim by **0.5 mag after 1 week, 3.5 mag by 1 month,** and by **more than 5 mag by 6 weeks**. Follow-up observations must be done soon after discovery!

return faint



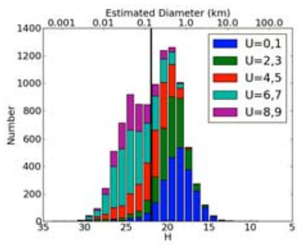
Discovery magnitude for large ($H \leq 22$) and small NEAs discovered as of 2013 March. As >80% have synodic period <3yrs, most will have several return apparitions within a decade.

While large objects tend to return within a decade to similar brightness as at discovery…

…Small ones tend to return ~5 magnitudes (100x) fainter. So it's critical to conduct follow-up observations for characterization on the discovery apparition!

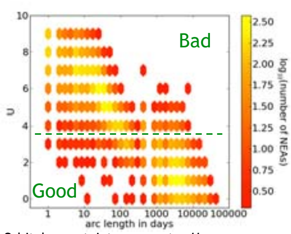
NEA Orbits:

poorly known



Orbital uncertainty parameter U. If $U > 3$ there is small chance that the NEA can be recovered during return apparitions. Most (60%) of $H \leq 22$ NEAs have $U \leq 3$, but less than 10% of $H > 22$ NEAs do.

follow longer



Orbital uncertainty parameter U v. arc length. Reducing orbital uncertainty parameter on the discovery apparition to levels practical for recovery on subsequent levels will require astrometry over several months.

Requirements for Follow-Up:

Using these results, we can project magnitudes for NEAs that will be discovered in the next few years. Follow-up observations will have to be tracked on the NEA (typical motion of a few arcsec/min) or taken with $t < 1$min exposures to prevent trailing.

R mag	Circumstance
20.5	Mean for new discoveries on same night; or, most $H \leq 22$ reapparitions
22.0	Most new discoveries at ~1 week
24.0	Mean new discoveries at ~1 month
25.0	Most new discoveries at ~1month or $H > 22$ reapparitions

Can Characterization Catch Up with Discovery?

Given the requirements, we can determine strategies for closing the wide, and increasing, gap between discovery and characterization within a decade (rather than centuries) timescale. We find that:

Rapid follow-up of new discoveries will be essential given fast fading, particularly as an increasing number will be smaller ($H > 22$) NEAs, projected to be ~100 times (~5 mag) fainter on subsequent apparitions.

- Spectral follow-up that keeps pace with discoveries could be accomplished with a dedicated 2m telescope observing NEAs within days of discovery.
- Long-arc (months) astrometry would require a 4m+ telescope, and the same observations could be used to measure phase curves and colors that would help to constrain albedos.
- Light curves for the bigger new NEAs (large ones rotate slowly) could be collected shortly after discovery with a 2m telescope, but the cadences required to measure fast rotations likely for smaller new NEAs would require rapid follow-up with a 4m.

Already-known large ($H \leq 22$) NEAs making return apparitions are predicted to reach brightness similar to their discovery magnitude. For these, targeted follow-up spectroscopy and photometry can be done with 2m telescopes. For the brightest of these, 0.5-1m amateur telescopes can contribute light curves (for slow rotators) and astrometry, as they already do.