The NEO Surveys

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Introduction

Over the last 15 years, Near-Earth Object (NEO) surveys have been extremely successful finding more than 90% of the Near-Earth Asteroids (NEAs) larger than one kilometer and about 40% of the NEAs larger than 140 meters. The vast majority of NEO discoveries have been due to NASA-supported ground-based telescopic surveys including the Catalina Sky Survey (CSS) and Spacewatch near Tucson Arizona, the LINEAR project near Socorro New Mexico, Pans-STARRS1 on Haleakala, Maui, Hawaii, LONEOS near Flagstaff Arizona and the NEAT project run by NASA/JPL. Using a near-infrared space telescope in an Earth polar orbit, the NEOWISE project was actively discovering and characterizing NEOs for ten months in 2010 before its cryogens were exhausted. It continued another four months into early 2011 as a post-cryogenic mission. The LONEOS and NEAT surveys have been terminated and Spacewatch is now primarily a follow-up facility.

The Discovery Surveys

The Catalina Sky Survey (CSS), based at the University of Arizona, is the current frontrunner in terms of NEO discoveries, an achievement that is due, in large part, to their comprehensive sky coverage, human attention to potential discovery images and on site follow-up observation capabilities. In 2012 alone, CSS discovered more than 625 NEOs. Some 20% of CSS observing time is devoted to the post-discovery, follow-up observations that allow the object's orbit to become secure.

CSS discovery telescope assets (Aperture, f number, MPC Observatory Code, field of view, pixel size):
Schmidt: 0.68-m, f/1.8, Obs. code = 703, 8.2 sq. deg., 2.5 arcsec/px
Mt. Lemmon: 1.50-m, f/2.0, Obs. code = G96, 1.2 sq. deg., 1.0 arcsec/px
Uppsala Schmidt, Australia: 0.50-m, f/3.5, Obs. code = E12, 4.2 sq. deg., 1.8 arcsec/px (Part time use)

CSS follow-up telescope
Mt. Lemmon: 1.00-m, f/2.6, Obs. code = I52, 0.25 sq. deg., 1.0 arcsec/px

CSS future plans: Through a continuous improvement program, CSS will begin use of the 1-m follow-up telescope in 2013, the Catalina Schmidt will be upgraded to a larger CCD array that will increase its field of view from 8.2 to 19.6 square degrees and the Mt. Lemmon 1.5-m will be upgraded to a larger CCD array that will increase its field of view from 1.2 to 5 square degrees.

CSS personnel: The following personnel are responsible for the CSS survey operations: Stephen Larson (PI), Eric Christensen (Co-I and Survey Operations Manager), Andrea Boattini (observer, data analyst), Alex Gibbs (Senior software engineer, observer), Al Grauer (observer), Richard Hill (observer, archivist), Jess Johnson (observer), Richard Kowalski (observer), Rob McNaught (Observer, Siding Spring Observatory) and Frank Shelly (Senior software engineer).

The **Pan-STARRS** survey is currently second in terms of discovery numbers and with an increasing percentage of time being devoted to NEO search, their discovery rates will soon increase.

The Pan-STARRS discovery telescope, run by the University of Hawaii's Institute for Astronomy, is a 1.8-meter telescope on Haleakala in Maui Hawaii. It has a very large camera with a 7 square degree field of view. Until recently, 5% and then 6.5% of the observing time was dedicated to NEO discovery observations. Beginning in November 2012, the time dedicated to NEO discovery was increased to 11%. In addition, 56% of the observing time is used for a 3-pi survey using three color filters that is also executed in a manner that leads to the discovery of NEOs.

Much of the critical follow observations are carried out by the University of Hawaii 2.2 meter telescope (Dave Tholen), Las Cumbres Observatory, Faulkes Telescope North (T. Lister, J.D. Armstrong), Cerro Tololo (R. Holmes), Spacewatch (R. McMillan), Magdalena Ridge (E. Ryan) and Tenagra II (S. Abe).

Pan-STARRS discovery Telescope
1.8-m, f/4, Obs. code = F51, 7 sq. deg., 0.26 arcsec/px

Future plans: The main short-term change is the increase from 6.5% to 11% observing time. In 2012, PS1 discovered more than 240 NEOs, a tally that will likely increase significantly in 2013 when more time will be devoted to NEO discovery.

Pans-STARRS personnel: The following personnel are responsible for the operations of the Pans-STARRS survey: Richard Wainscoat (PI), Larry Denneau (part time) and Denver Green (software engineers), Peter Veres (postdoctoral fellow), Marco Micheli (part time observer).

The **LINEAR** (Lincoln Near-Earth Asteroid Research) program leads in the discovery of the NEOs larger than one kilometer so LINEAR is largely responsible for successfully meeting the so-called Spaceguard goal of finding 90% of the NEOs with a diameter of one kilometer or larger. The LINEAR program, run by MIT's Lincoln Lab, has applied electro-optical sensor technology developed for US Air Force Space Surveillance applications to the problem of discovering near-Earth asteroids and comets. LINEAR has been a significant contributor to NEO discoveries since the program inception in March 1998. The program will continue this consistent and reliable NEO search program while seeking ways to further expand the survey capacity through continually fielding improved algorithms and shared use of new space surveillance assets. To accomplish this, Lincoln Laboratory will continue to conduct wide-area searches for asteroids, operating the legacy 1.0-meter LINEAR telescope system located at Lincoln Laboratory's Experimental Test Site (ETS) near Stallion Range Center on the US Army's White Sand Missile Range (WSMR) in central New Mexico. The Laboratory will supplement the 1.0-meter system when possible with the recently fielded 3.5 meter Space Surveillance Telescope (SST). This new, novel telescope system was developed with DARPA funding and is advantageously located within WSMR on Atom Peak at 2400m elevation.

Asteroid searches will be scheduled for a minimum of 20 nights/lunar month, for a total of about 250 nights/year. All validated asteroid observations made by the LINEAR program will be submitted to the International Astronomical Union's Minor Planet Center (MPC) to be combined with observations by other programs and disseminated to the wider astronomical community.

LINEAR discovery telescopes
Legacy: 1.0-m, f/2.2, Obs. code = 704, 2 sq. deg., 2.25 arcsec/px
SST: 3.5-m, f/1.0, Obs. Code = N/A, 6 sq. deg., 0.89 arcsec/px

LINEAR future plans: To enhance the current survey system, algorithms that maximize the productivity of the LINEAR and SST telescopes will be explored and implemented as the new search system becomes operational. Contributions from SST are anticipated in early 2013. Current SST efforts center around validation of test data and detections rates of cataloged asteroids.

LINEAR personnel: Dr. Grant Stokes is the principal investigator for the LINEAR program. Co-investigators are Drs. Deborah Woods and Ronak Shah. The LINEAR program maintains a core team of systems maintainers and software developers at ETS. These include: Mr. Peter Trujillo (Site Manager), Mr. Gregory Spitz, Mr. Matthew Blythe (principal observers), and Ms. Julie Johnson and Mr. Alex Szabo (software support).

NEOWISE: The Wide-field Infrared Survey Explorer (WISE) is a NASA infrared-wavelength astronomical space telescope active from December 2009 to February 2011. It was launched on December 14, 2009, and decommissioned/hibernated on February 17, 2011 when its transmitter was turned off. It performed an all-sky astronomical survey with images in 3.4, 4.6, 12 and 22 μm wavelength range bands, over 10 months using a 40 cm (16 in) diameter infrared telescope in Earth-orbit. The initial mission length was limited by its hydrogen coolant, but a secondary post-cryogenic mission continued four more months with two of the four detectors remaining operational.

The NEOWISE project has delivered the most physical data on the largest number of minor planets yet, and efforts are underway to mine even more out of the dataset. To date, the project has resulted in the detection of ~158,000 asteroids at thermal infrared wavelengths, including ~700 NEOs, and has discovered ~34,000 new asteroids, 135 of which are NEOs. The project has detected more than 155 comets, including 21 discoveries. Preliminary physical properties such as diameter and visible albedo have been computed and published for nearly all of these objects to date, enabling a range of studies of the origins and evolution of the small bodies in our solar system. So far, NEOWISE data have been used to constrain the numbers, sizes, and orbital elements of NEOs, including potentially hazardous asteroids, as well as the Jovian Trojans, Hilda-group asteroids, and the physical properties and collisional history of Main Belt asteroid families. Efforts are underway to perform detailed analysis of the small body thermophysical properties, as well as the dust and gas properties of active bodies. Nucleus sizes have been computed for nearly the entire NEOWISE cometary sample to date in order to apply debiasing techniques to extrapolate the sample to the population writ large.

NEOWISE future plans: The project is funded to complete five tasks by the end of FY2014: 1) Reprocess the Post-Cryogenic Survey data collected after the depletion of the mission's solid hydrogen to bring these data to the same level of calibration as the fully cryogenic dataset; 2) Optimize the WISE Moving Object Processing System (WMOPS) to enable extraction of moving objects at lower signal-to-noise levels and with fewer detections; 3) Deploy WMOPS on the entire NEOWISE dataset; 4) Perform stacking on the entire catalog of ~600,000 known minor planets to obtain detections of objects either too faint or with too few detections to have been found by WMOPS; 5) Compute physical properties for all objects detected in the NEOWISE data, either by stacking or with WMOPS, and deliver them to NASA's Planetary Data System.

NEOWISE personnel: Current key personnel include Amy Mainzer, James Bauer, Tim Conrow, Roc Cutri, John Dailey, Tommy Grav, Joe Masiero, Carrie Nugent, Rachel Stevenson, and Ned Wright.

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