Study on Use of LSST for NEO Detection and Tracking

Brief to AAAC

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National Interest in Asteroid Hazard

Congressman Lamar Smith (R-Texas) — Chairman of U.S. House of Representatives Committee on Science, Space, and Technology

"Threats from Space: A Review of U.S. Government Efforts to Track and Mitigate Asteroids and Meteors, Part 1"

Congressional Hearing by the U.S. House of Representatives Committee on Science, Space, and Technology (19 March 2013), post-Chelyabinsk event

General William Shelton — then-Chief of the U.S. Air Force Space Command

"The Administration places a high priority on tracking asteroids and protecting our planet from them, as evidenced by the five-fold increase in the budget for NASA's NEOO program since 2009. The United States has an effective program for discovering larger NEOs, but we need to improve our capabilities for the identification and characterization of smaller NEOs."

John Holdren, Director, Office of Science and Technology Policy, Science advisor to President Barack Obama

National Space Policy, June 28 2010 – "Pursue capabilities, in cooperation with other departments, agencies, and commercial partners, to detect, track, catalog, and characterize near-Earth objects to reduce the risk of harm to humans from an unexpected impact on our planet and to identify potentially resource-rich planetary objects." https://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

Administration guidance was provided in OSTP Letter to Congress dated 15 October, 2010, as Response to Section 804 of NASA Authorization Act of 2008
https://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp-letter-neo-senate.pdf

Planetary Defense Coordination Office

This new office was recently established at NASA HQ to coordinate planetary defense related activities across NASA, and coordinate both US interagency and international efforts and projects to address and plan response to the asteroid impact hazard.

Planetary Defense Coordination Office Mission Statement:

Lead national and international efforts to:

- Detect any potential for significant impact of planet Earth by natural objects
- Appraise the range of potential effects by any possible impact
- Develop strategies to mitigate impact effects on human welfare

Planetary Defense Coordination Office

Administrator
Associate Administrator

Associate Administrator,
Science Mission Directorate

Planetary Science Division
Program Director

Public Communications — Lead Program Executive
Planetary Defense Officer — Policy Development

NEO Observation Program
Program Manager
Program Scientist

- Minor Planet Center/IAWN
- Center for NEO Studies @ JPL
- Catalina Sky Survey
- Pan-STARRS
- LINEAR/SST
- IRTF
- GSSR
- NEOWISE
- ……..

Interagency and
Emergency Response
Program Officer(s)

- Interagency coordination
- Emergency Response planning
- Interagency exercise

Mitigation Research
Program Officer(s)

- SMPAG
- ARM Gravity Tractor Demo
- AIDA
- Short Warning Mitigation
- ……..

NEO Observation Program

- ❑ Officially established as a research program
- ❑ Formalized program documentation
- ❑ PDCO also includes emergency response and mitigation elements
- ❑ PDCO Staffing at ~5.0 FTE

NEO Observations Program

Detection and tracking of natural objects – asteroids and comets – that approach within 28 million miles of Earth's orbit

US component to International Asteroid Warning Network

Has provided 98% of new detections of NEOs since 1998

Began with NASA commitment to House Committee on Science in May 1998 to find at least 90% of 1 km and larger NEOs

- That goal reached by end of 2010

NASA Authorization Act of 2005 increased scope of objectives:

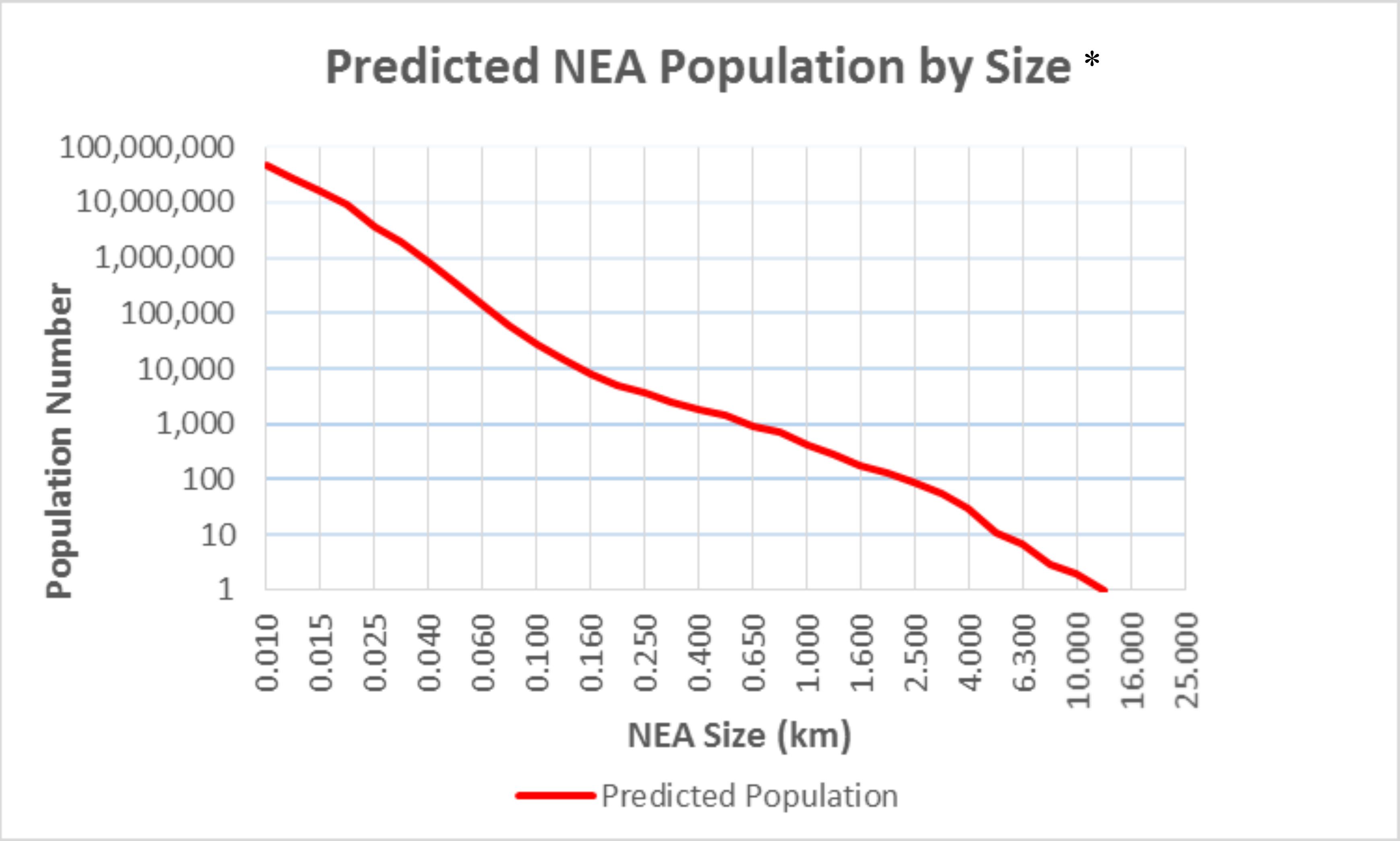
- Amended National Aeronautics and Space Act of 1958 ("NASA Charter") to add:

  ''The Congress declares that the general welfare and security of the United States require that the unique competence of the National Aeronautics and Space Administration be directed to detecting, tracking, cataloguing, and characterizing near-Earth asteroids and comets in order to provide warning and mitigation of the potential hazard of such near-Earth objects to the Earth.''

- Made NEO detection, tracking and research 1 of 7 explicitly stated purposes of NASA!
- Provided additional direction:

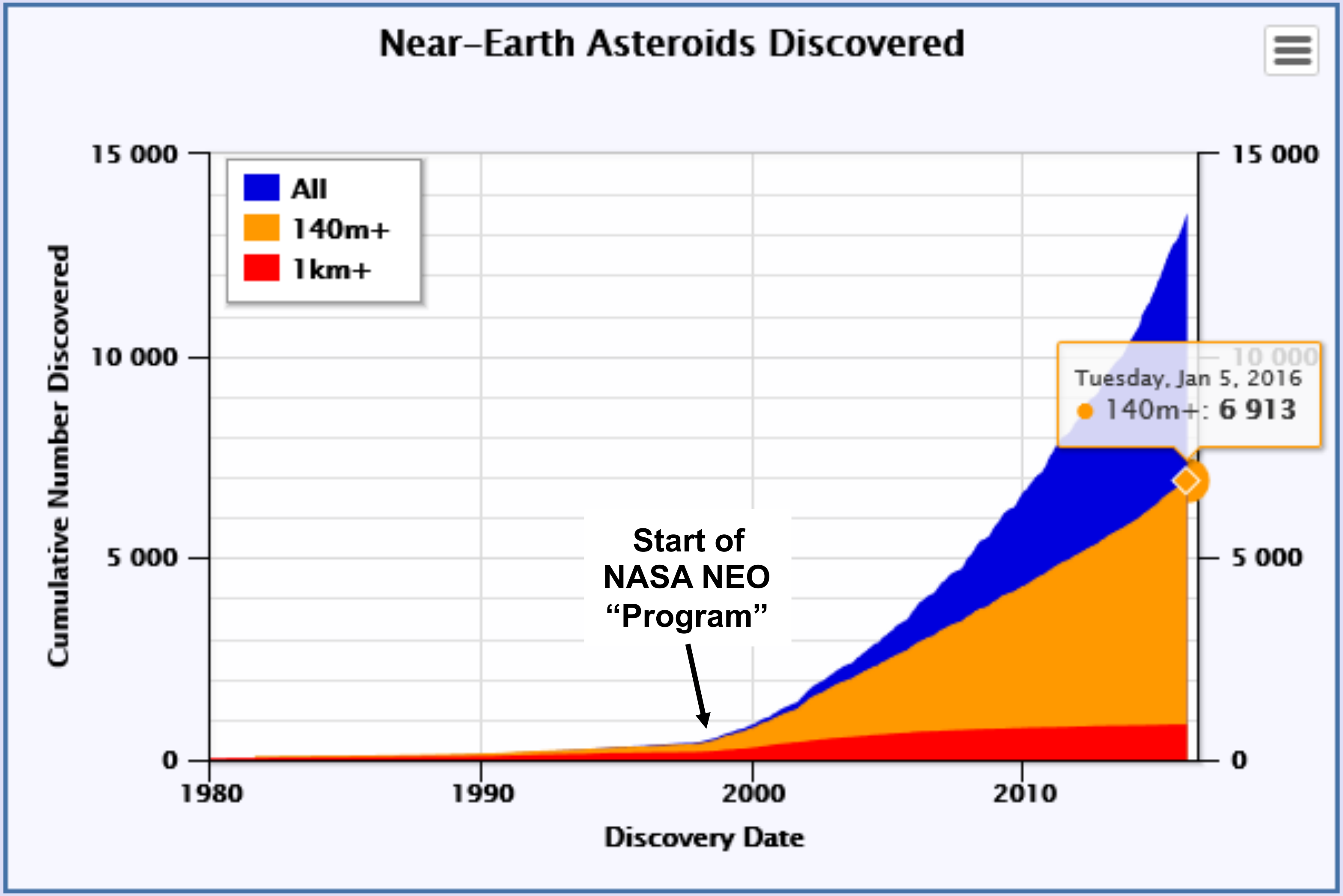
  "…plan, develop, and implement a Near-Earth Object Survey program to detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter in order to assess the threat of such near-Earth objects to the Earth. It shall be the goal of the Survey program to achieve 90 percent completion of its near-Earth object catalogue within 15 years [by 2020]"

Near Earth Asteroid Survey Status



*Harris & D'Abramo, "The population of near-Earth asteroids", Icarus 257 (2015) 302–312, http://dx.doi.org/10.1016/j.icarus.2015.05.004

Known Near Earth Asteroid Population



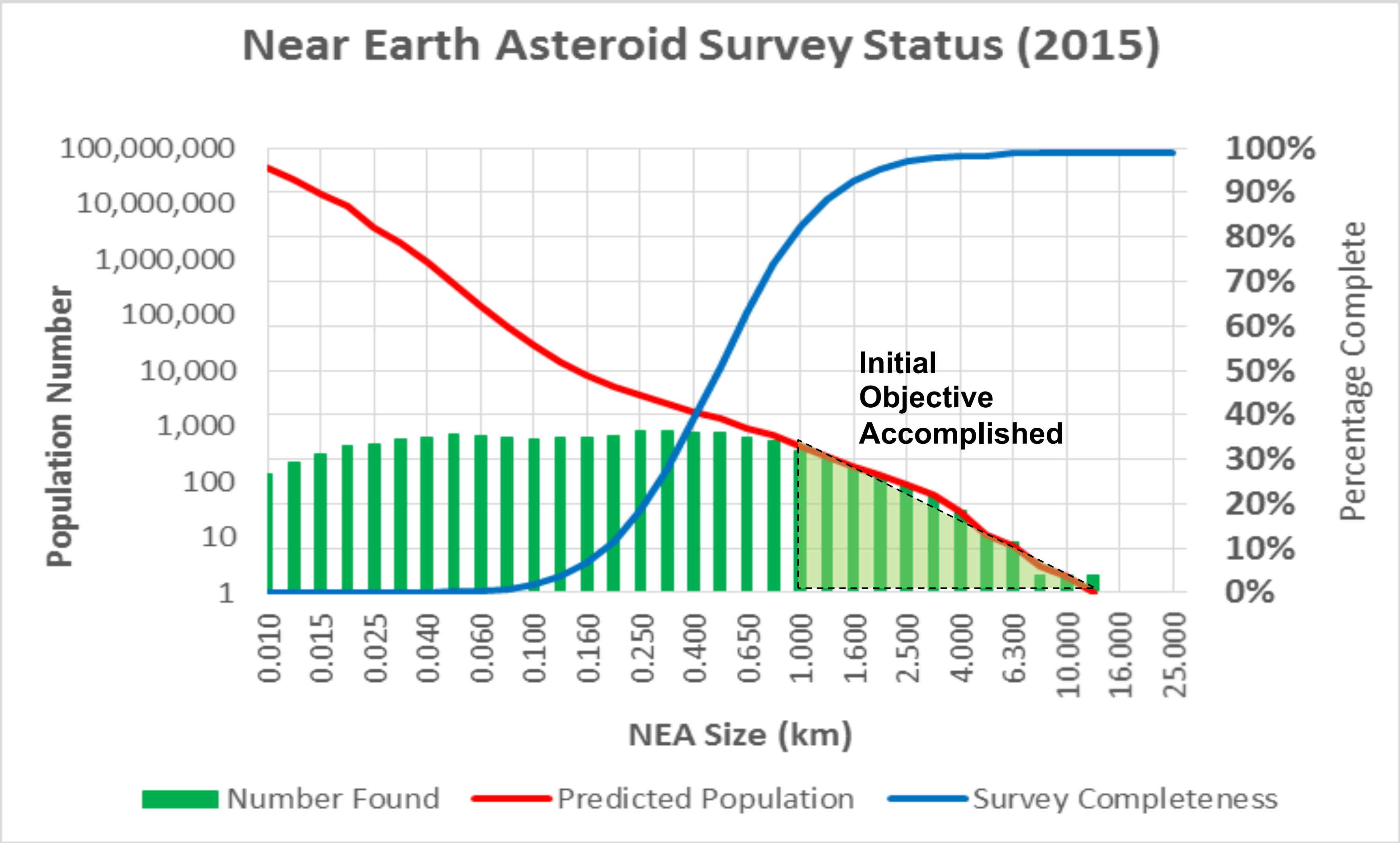
As of 12/31/15
13,514

Also 105 comets

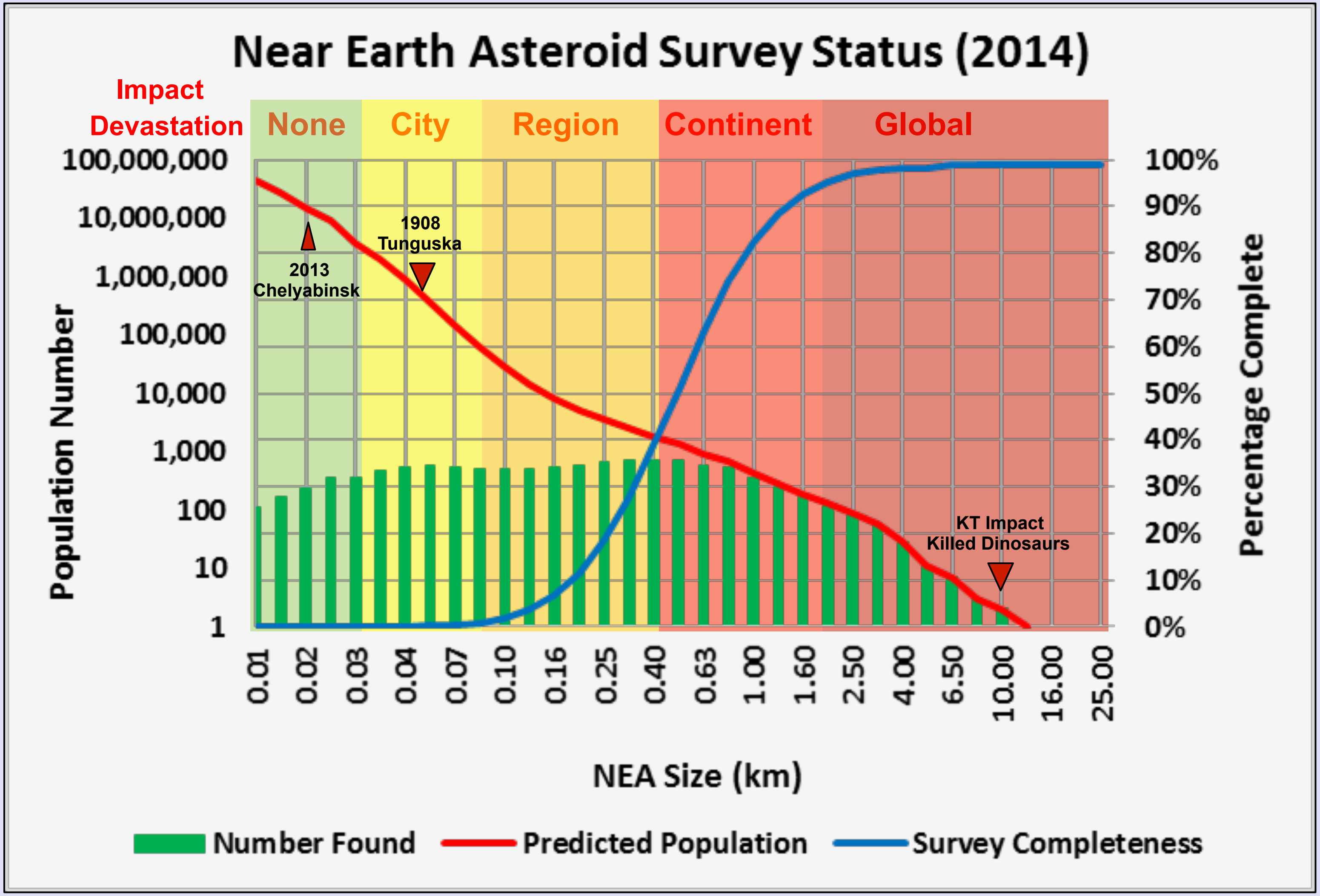
1649 Potentially Hazardous Asteroids
Come within 5 million miles of Earth orbit

879
153 PHAs

Near Earth Asteroid Survey Status

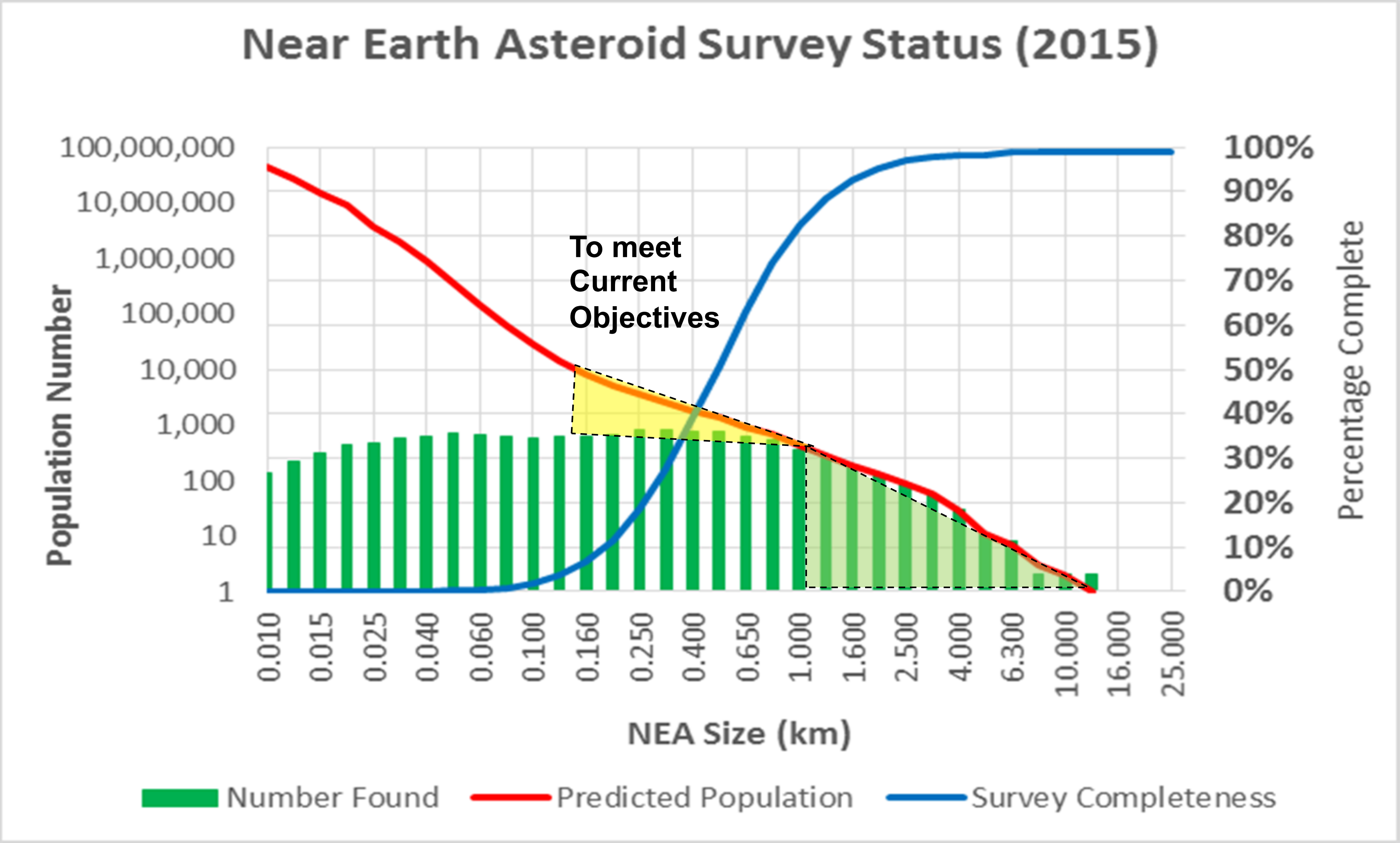


Near Earth Asteroid Survey Status



Study to Determine the Feasibility of Extending the Search for Near-Earth Objects to Smaller Limiting Diameters
Report of the Near-Earth Object Science Definition Team, August 22, 2003, http://neo.jpl.nasa.gov/neo/neoreport030825.pdf

Near Earth Asteroid Survey Status



NASA's NEO Search Program

(Current Survey Systems)

Minor Planet Center (MPC)

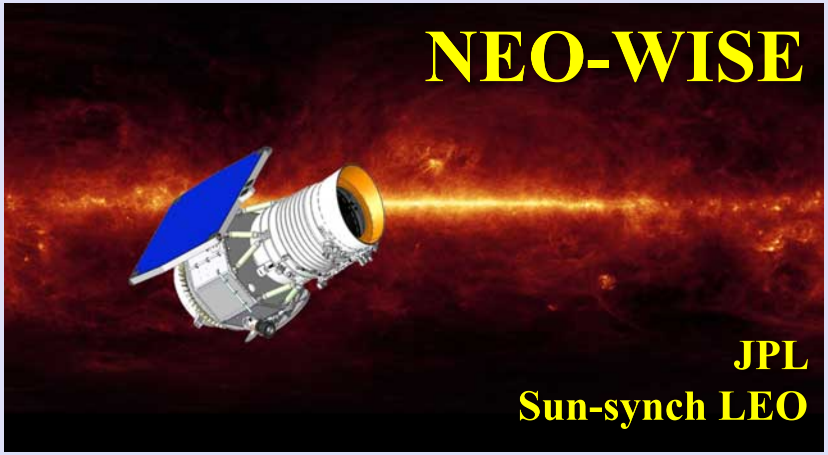
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

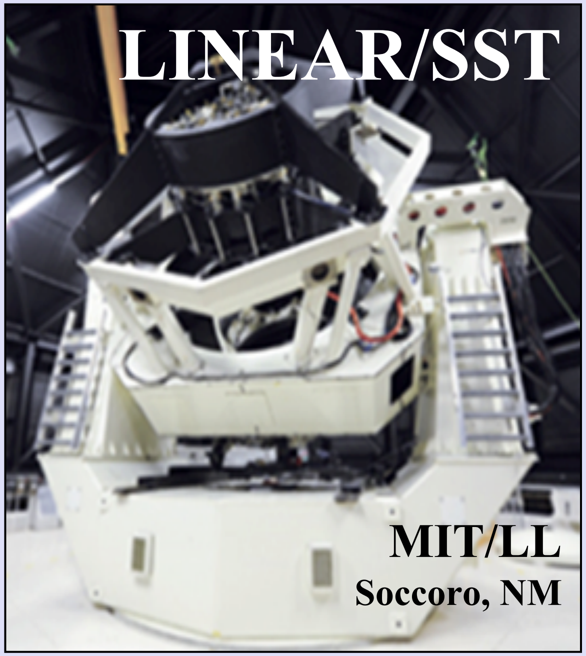
http://minorplanetcenter.net/

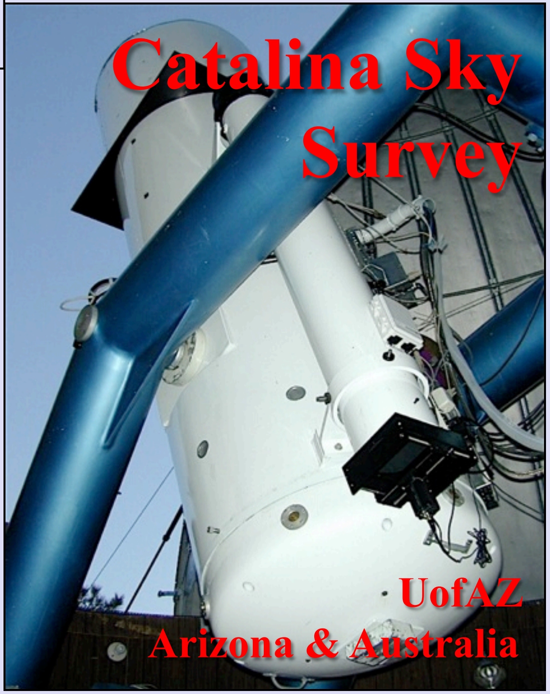
Center for NEO Studies @ JPL

- Program coordination
- Precision orbit determination
- Automated SENTRY

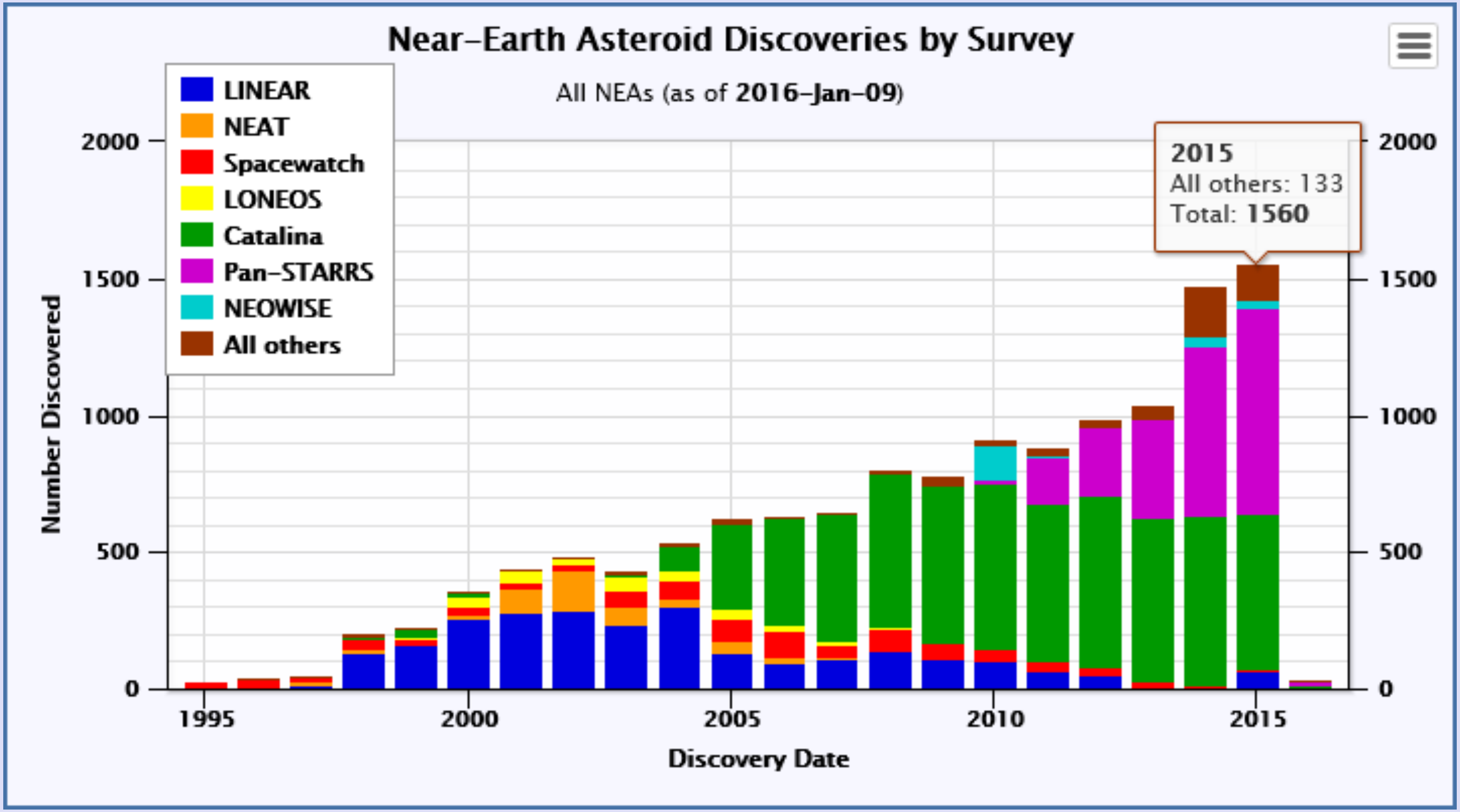
http://neo.jpl.nasa.gov/





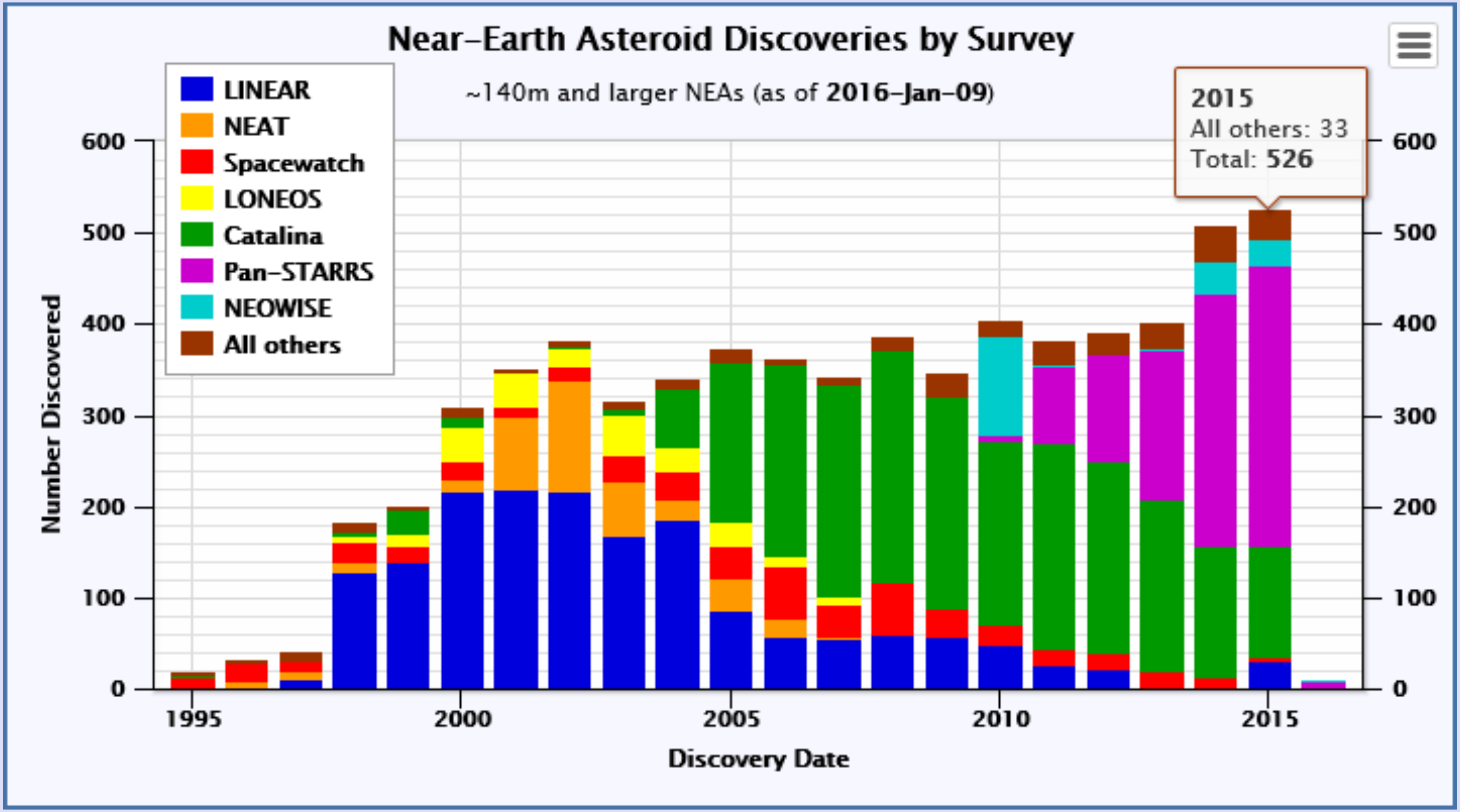


Growth in Capability



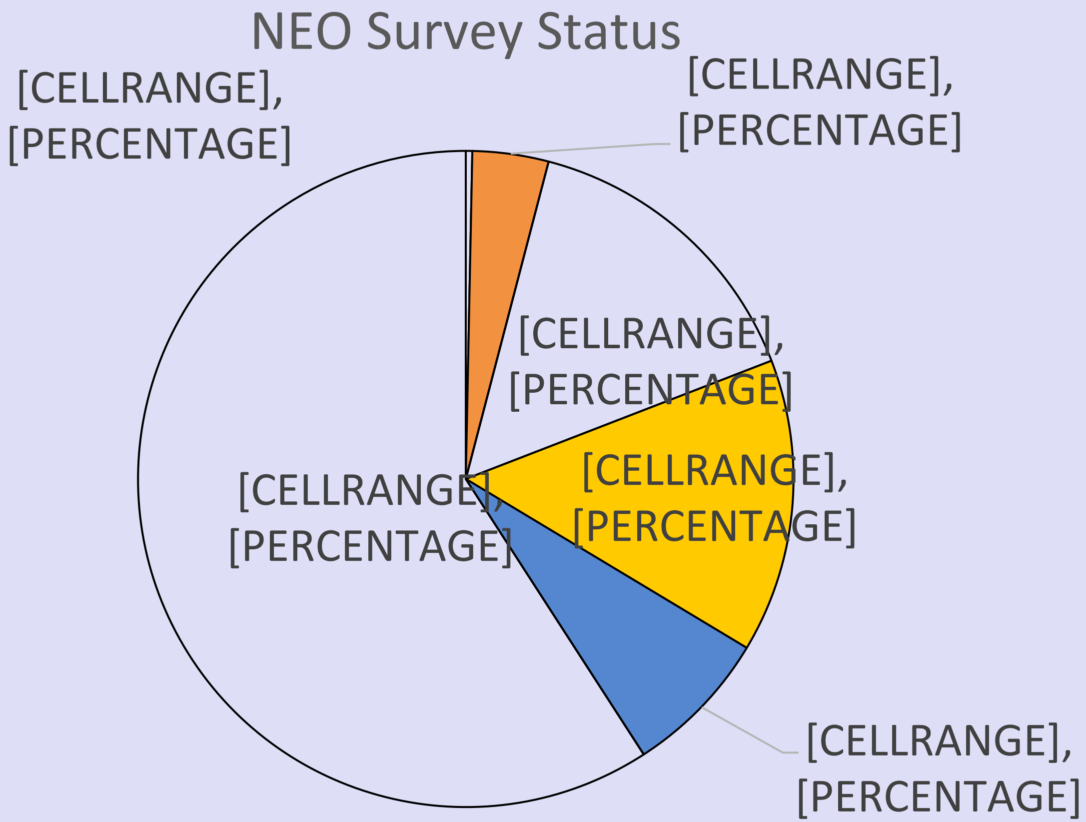
As more capable telescopes are added, discoveries include more <140m NEOs

Discoveries for Current Objective



Near Earth Asteroid Survey Status
Alternative Graphic

Population >= 140 meters in estimated size ~ 25,500 = 100%



Requirements for NEO Surveys

- NEOs at discovery threshold not like other planetary astronomy targets:
  - Faint (V ~ 22)
  - Rapidly moving (up to several degrees/day ~ arcsec/min)
  - Not necessarily close to the ecliptic (especially when close to Earth at discovery)
- Traditional-design optical telescopes not the instruments of choice
  - Typical FoVs are less than 0.1 square degree
  - Examples: Keck, Gemini, Subaru, VLT (ground); Hubble, Spitzer, JWST (space)
- NEO surveys must be "deep & wide" – large areas at limits of detectability
  - Previously meter-class telescopes with "large-format" cameras – now CCDs
  - Larger apertures with larger fields of view now in use and being developed:
    Pan-STARRS, SST, LSST
  - Typical FoVs several sq. degrees. Pan-STARRS 7 sq. degrees in single image. LSST plans 9 sq. degrees
- Multiple detections necessary to complete discovery and determine orbit
- Orbit must be accurate enough to enable later recovery – otherwise detection is pointless
  - Current state-of-the-art for discovery & orbit determination: 4 detections in 1 night

Essential Steps in NEO Discovery

- Detect and recognize objects in single images that are not already-known sources.

- Link detections in multiple images and establish that they constitute a single moving object, rather than unrelated events.
- Obtain enough positional measurements to determine an orbit; orbit must be accurate enough to guarantee later re-observation.

LSST Technology Issues for NEO Discovery

- Detect and recognize objects in single images that are not already-known sources.

LSST detects new sources by "differencing" an average of past images from each new image. This also produces "false positive" sources in quantities that will *far outnumber* – maybe by *orders of magnitude* – real objects. Machine-learning methods to filter false positives may mitigate the problem, but exactly how well they will perform is not yet known.

- Link detections in multiple images and establish that they constitute a single moving object, rather than unrelated events.

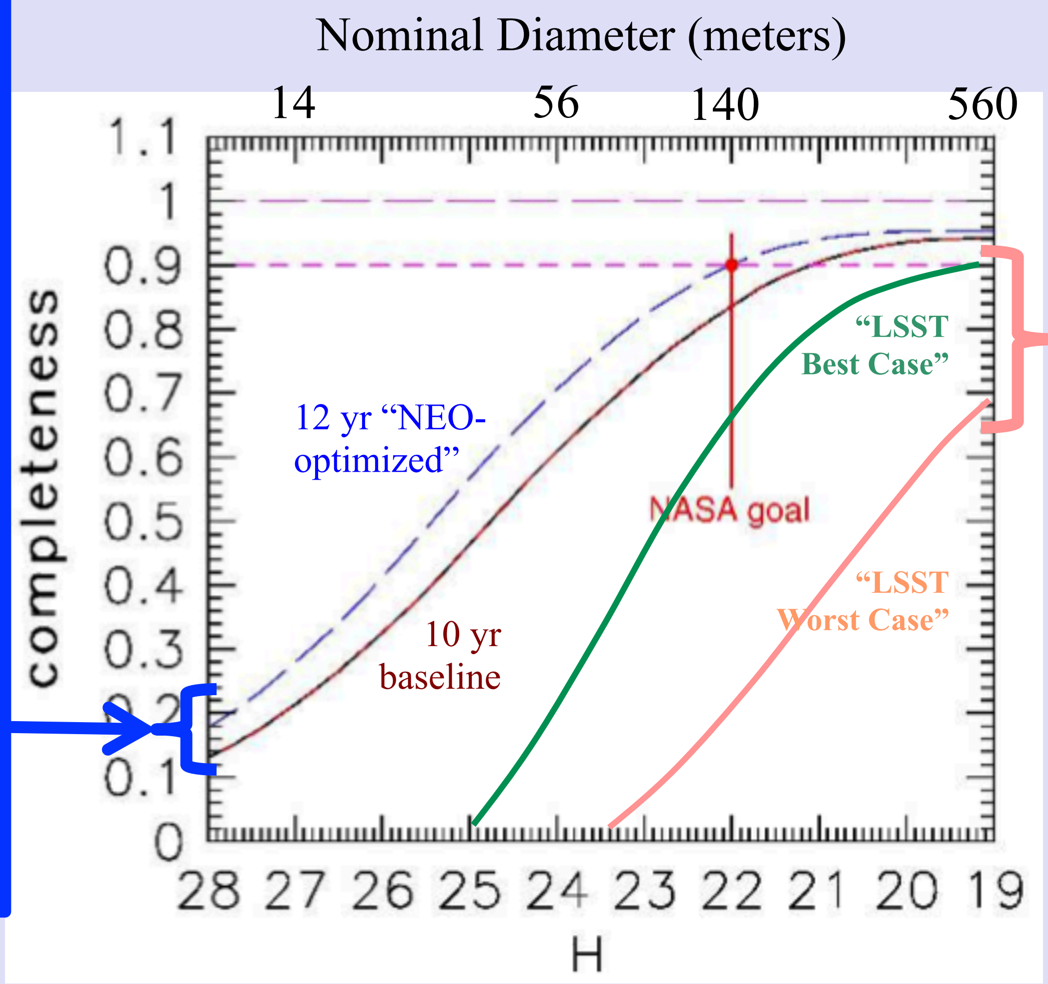
The moving object pipeline system (MOPS) could be computationally overwhelmed by the need to check and exclude links involving false positives; where that computational threshold lies is not yet determined.

- Obtain enough positional measurements to determine an orbit; orbit must be accurate enough to guarantee later re-observation.

Operating surveys typically get 4 positions per night, enough to determine and project an orbit after 1 night. LSST baseline survey will get typically 2 closely spaced positions per night, delaying new-object orbit determinations by days to weeks at best, and at worst providing only "one night stands". The exact consequences are not yet determined.

LSST and NEO Discovery Completeness– Estimates

LSST project estimates are promising, assuming everything works as estimated. However, performance rests on technology & methods that have never been attempted for NEO discovery; at this point they "work on paper". (Ivezic et al., arXiv:0805:2366v4)



Some independent estimates are far less optimistic. However, these estimates are dependent on assumptions on how system performs and do not attempt to explicitly model LSST's new "technology". (Christensen et al., Plan. Def. Conf. 2015)

NASA Study of LSST NEO Capabilities

- Once built and commissioned, LSST may prove to be
  - a highly effective NEO discovery engine
  - an excellent instrument for NEO follow-up and tracking
  - a valuable source of scientific data aiding in NEO characterization
- NASA needs a better assessment of LSST's capabilities vis-à-vis NEOs than is currently available.
  - LSST could potentially become an important contributor to NASA's NEO discovery & tracking system.
  - But there is, as yet, no end-to-end simulation of NEO discovery with LSST that fully accounts for all effects that could seriously affect performance.
- NASA PDCO has commissioned a quasi-independent study of LSST NEO capabilities.
  - Purpose: "to produce the most reliable projection possible, given the resources made available and the specified timeline, of the expected performance of LSST for NEO discovery and orbit determination."

NASA Study of LSST NEO Capabilities

OVERVIEW

- Single, coordinated effort involving the LSST project with a team knowledgeable on NEO surveys (JPL [study lead] & IPAC), with independent review
- Use independent implementations of the moving object pipeline, run by independent investigators, run on the same input data.
- Evaluate effects of false positives, detection thresholds, alternative cadences.
- Study plan and final report to be vetted by independent reviewers.

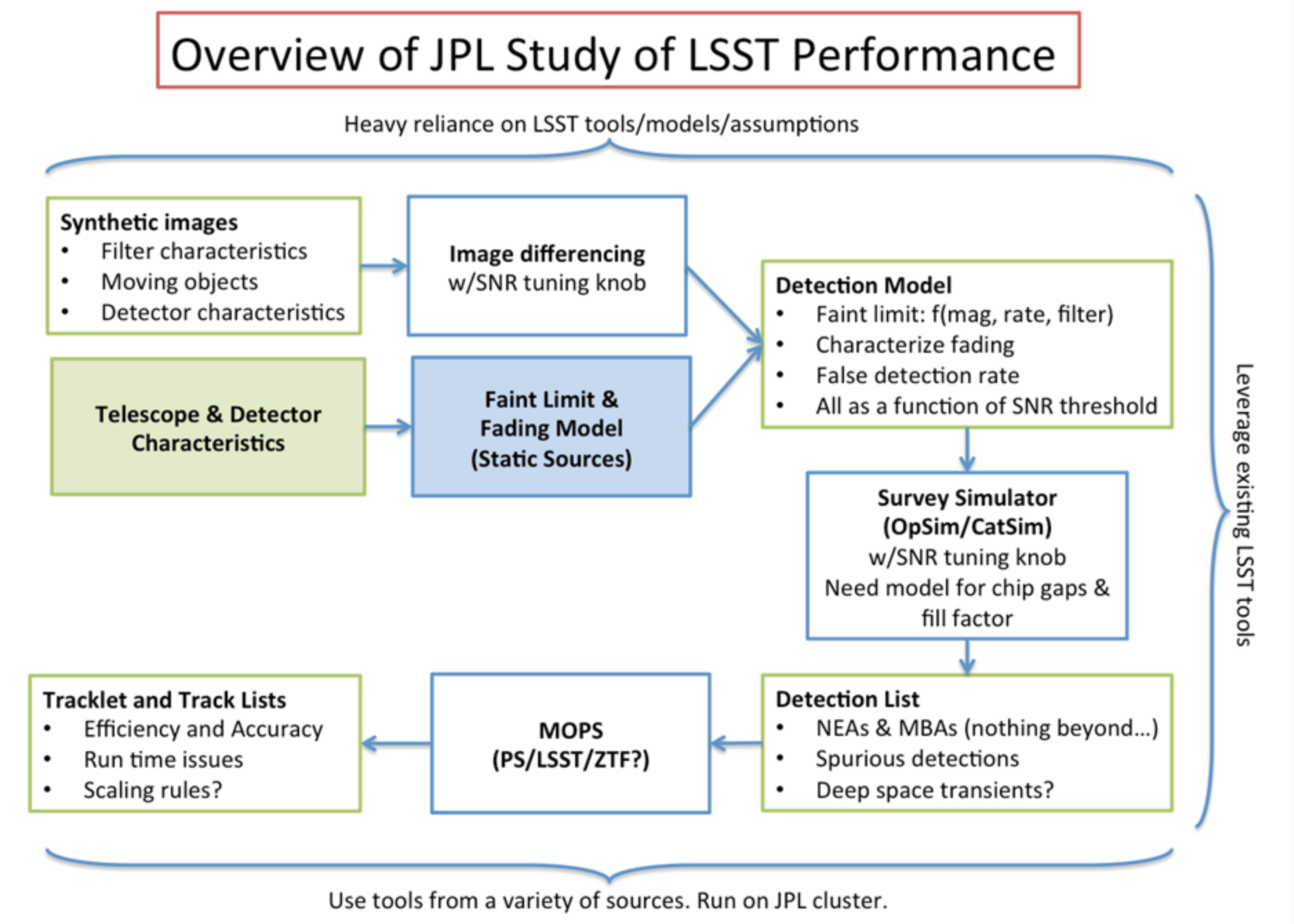
CURRENT STATUS

- Study plan drafted (Steve Chesley, JPL), signed on to by IPAC & LSST.
- Plan reviewed by 5-person team; written review returned to JPL, IPAC, LSST leads.
- Technical telecon with Chesley, Zeljko Ivezic, Mario Juric, George Helou.

TIMELINE

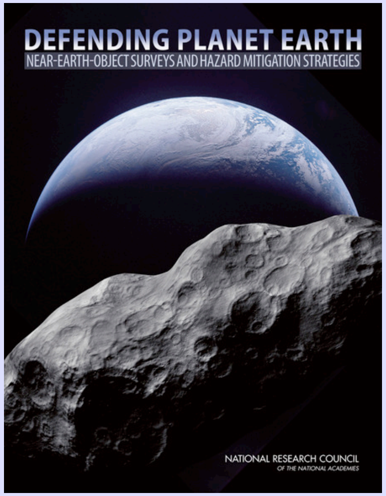
- Work in progress.
- Report to be reviewed & delivered to NSF & NASA not later than Sept 2016.

Study Plan (Rough Sketch)



NEO Discovery Will Continue to Require a System Approach

From NRC/SSB Study, “Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies” (**2010**)



Combined ground- and space-based surveys have a number of advantages. Such surveys discover more NEOs of all sizes, including a substantial number smaller than 140 meters in diameter. These combined surveys also provide more characterization data about the entire NEO population. With both infrared and visible data for most targets, it would be possible to obtain accurate diameter estimates for all objects, as well as measurements of their albedos and their surface and thermal properties. These high-value characterization data could help to guide mitigation campaign studies. Additionally, a dual survey provides much information on the population of objects smaller than 140 meters in diameter.

- **If the completion of the survey as close as possible to the original 2020 deadline is considered more important, a space mission conducted in concert with observations using a suitable ground-based telescope and selected by peer-reviewed competition is the better approach. This combination could complete the survey well before 2030, perhaps as early as 2022 if funding were appropriated quickly.**

Backup

NRC NEO Study

Ground-based Options

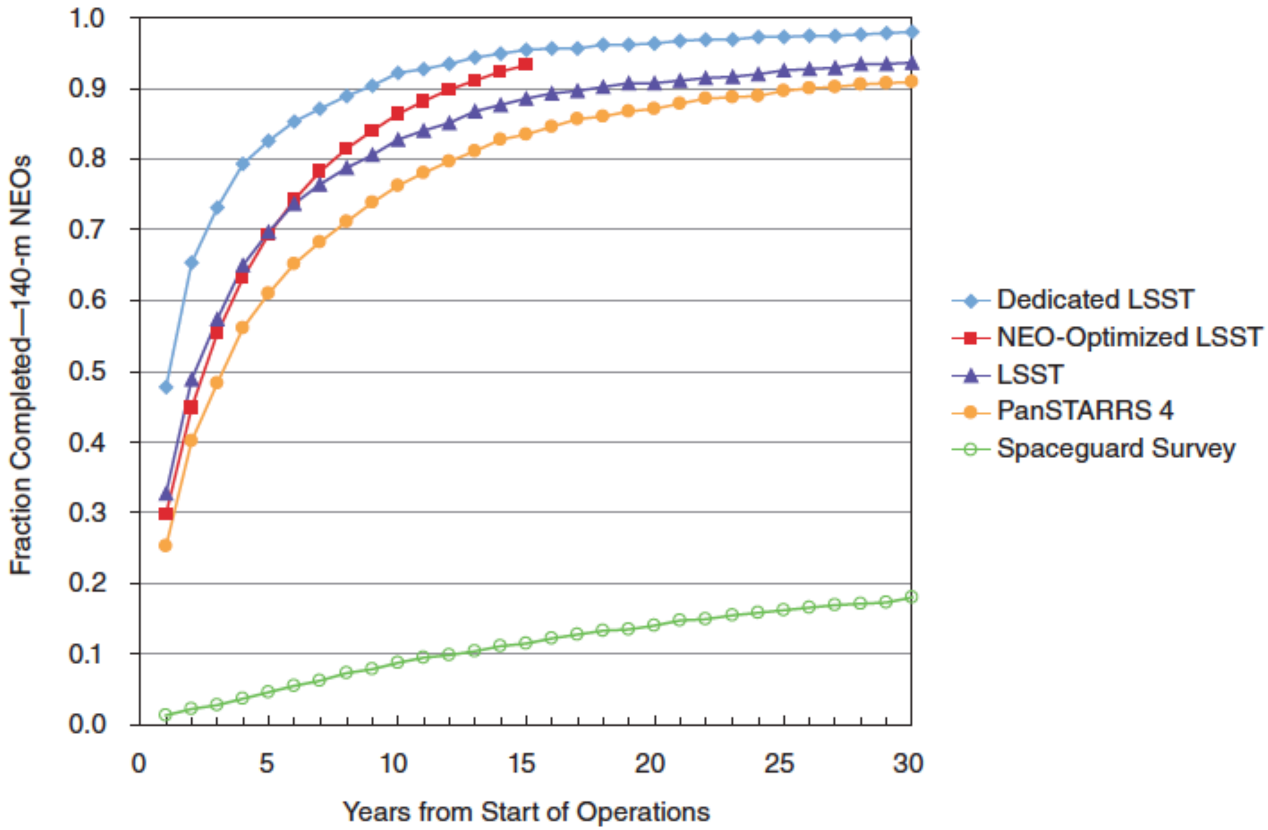


FIGURE 3.6 Years to 90 percent completion for the detection of potentially hazardous near-Earth objects (NEOs) 140 meters in diameter or larger with various ground-based telescopes. NOTE: LSST, Large Synoptic Survey Telescope; PanSTARRS, Panoramic Survey Telescope and Rapid Response System. SOURCE: Courtesy of Steve Chesley, Jet Propulsion Laboratory. NEO-optimized LSST numbers courtesy of LSST project.

NRC NEO Study

Space-based Options*

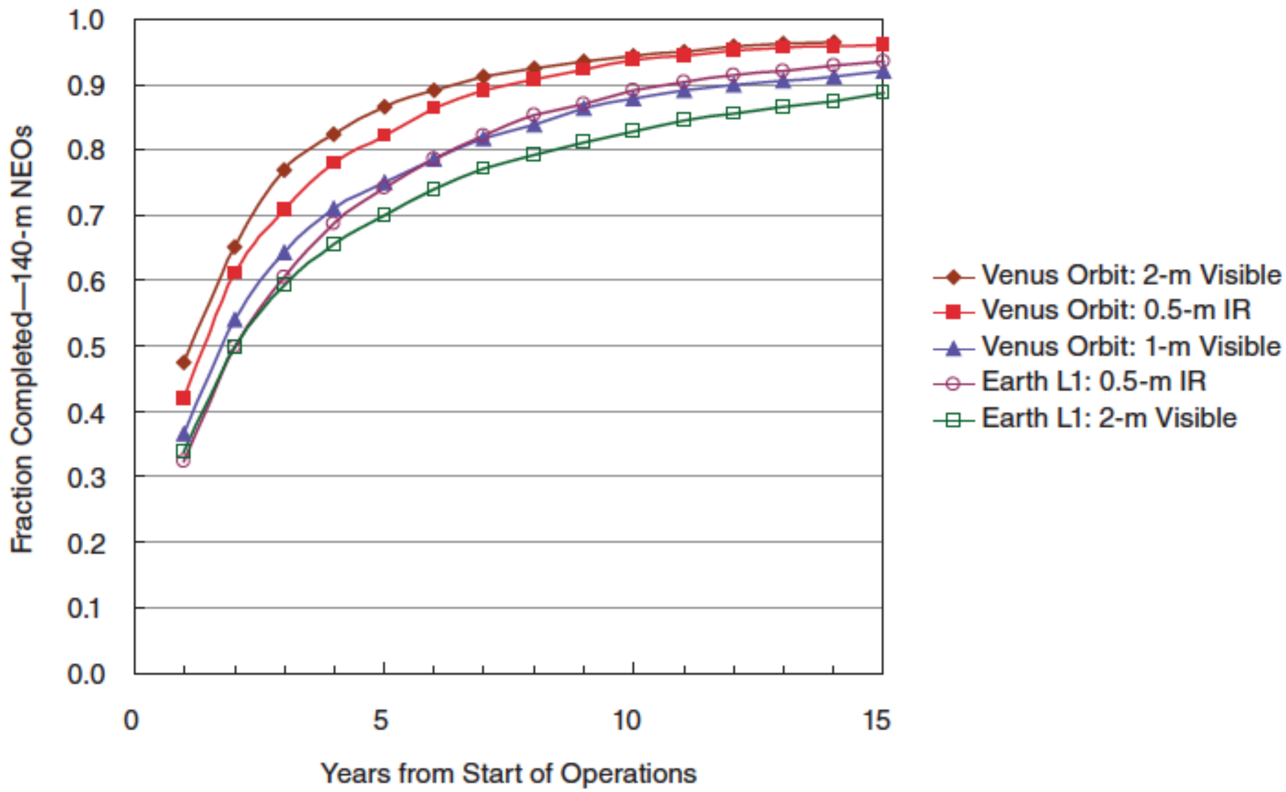


FIGURE 3.7 Years to 90 percent completion for the detection of potentially hazardous near-Earth objects (NEOs) 140 meters in diameter or larger with various space-based telescopes. NOTE: IR, infrared; L1, Lagrangian point 1. SOURCE: Courtesy of Steve Chesley, Jet Propulsion Laboratory.

*Studied accessibility only. Does not include losses due to on-board processing or telecommunication

NRC NEO Study

Mixed Architecture Options

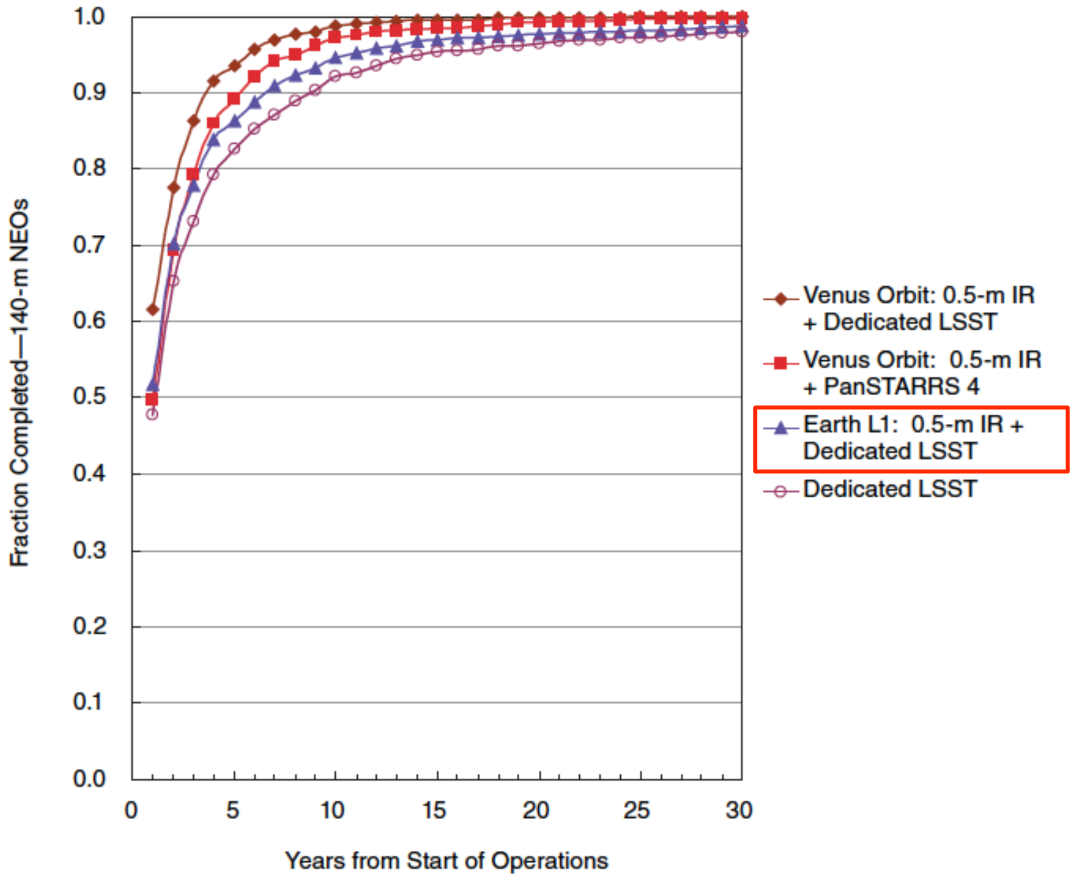


FIGURE 3.8 Years to 90 percent completion of the congressionally mandated survey for the detection of potentially hazardous near-Earth objects (NEOs) 140 meters in diameter or larger for combinations of space-based 0.5-meter infrared (IR) telescopes and ground-based telescopes. NOTE: LSST, Large Synoptic Survey Telescope; PanSTARRS, Panoramic Survey Telescope and Rapid Response System; L1, Lagrangian point 1. SOURCE: Courtesy of Steve Chesley, Jet Propulsion Laboratory.

NRC NEO Study

Mixed Architecture for Smaller Sizes

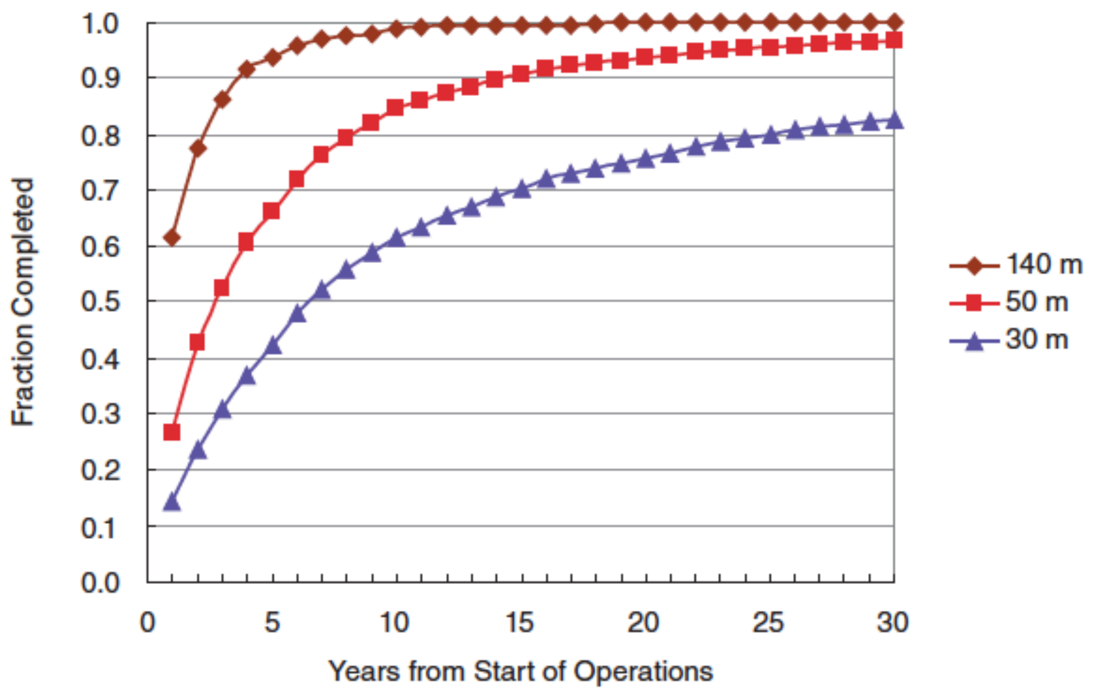


FIGURE 3.10 Years to completion for a 0.5-meter infrared telescope in a Venus-like orbit plus a dedicated Large Synoptic Survey Telescope (LSST) for near-Earth objects (NEOs) with diameters greater than or equal to 30, 50, and 140 meters. Note that 90 percent completion is never achieved within 30 years for NEOs with diameters down to 30 meters in diameter. SOURCE: Courtesy of Steve Chesley, Jet Propulsion Laboratory.