Near Earth Object Program
Single Dish Telescope Workshop

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Near Earth Object
Program Executive
NASA HQ

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Terminology

- "Near Earth Objects (NEOs)"- any small body (comet or asteroid) passing within 1.3 astronomical unit (au) of the Sun
  - 1 au is the distance from Earth to Sun = ~ 150 million kilometers (km)
  - NEOs are predicted to pass within ~ 48 million km of Earth's orbit
  - e.g. any small body passing between orbits of Venus to Mars
  - Population of:
    - Near Earth Asteroids (NEAs)
    - Near Earth Comets (NECs) – also called Earth Approaching Comets (EACs)
      - 101 currently known
- "Potentially Hazardous Objects (PHOs)" – small body that has potential risk of impacting the Earth at some point in the future
  - NEOs whose orbits pass within 0.05 au of Earth's orbit
    - ~ 8 million km = 20 times the distance to the Moon
  - Appears to be about 15% of all NEOs discovered

US Policy Source

US Office of Science and Technology Policy (OSTP)
Letter to Congress dated 15 October, 2010*

Response to Section 804 of NASA Authorization Act of 2008

The Director of OSTP will:

(1) develop a policy for notifying Federal agencies and relevant emergency response institutions of an impending near-Earth object threat, if near-term public safety is at risk; and

(2) recommend a Federal agency or agencies to be responsible for –

(A) protecting the United States from a near-Earth object that is expected to collide with Earth; and

(B) implementing a deflection campaign, in consultation with international bodies, should one be necessary

* http://www.whitehouse.gov/sites/default/files/microsites/ostp/ostp-letter-neo-senate.pdf

1: NEO Threat Detection

Within US Government:

- NASA will coordinate NEO detection and threat information from all organizations within the NEO observation community
- NASA has instituted communications procedures, including direction with regard to public release of information
- NASA notification procedures are set into motion only after the necessary observations, analyses, and characterization efforts have taken place to determine that a space object indeed represents a credible threat
  - Depends on level of risk and urgency, may unfold for years after detection
  - Will entail various combinations of:
    - Increased monitoring
    - Cross-checks of potentially hazardous trajectories as needed
    - Accelerated observations and orbit determination if potential hazard is near term

2: NEO Threat Notification

Upon notification from NASA:

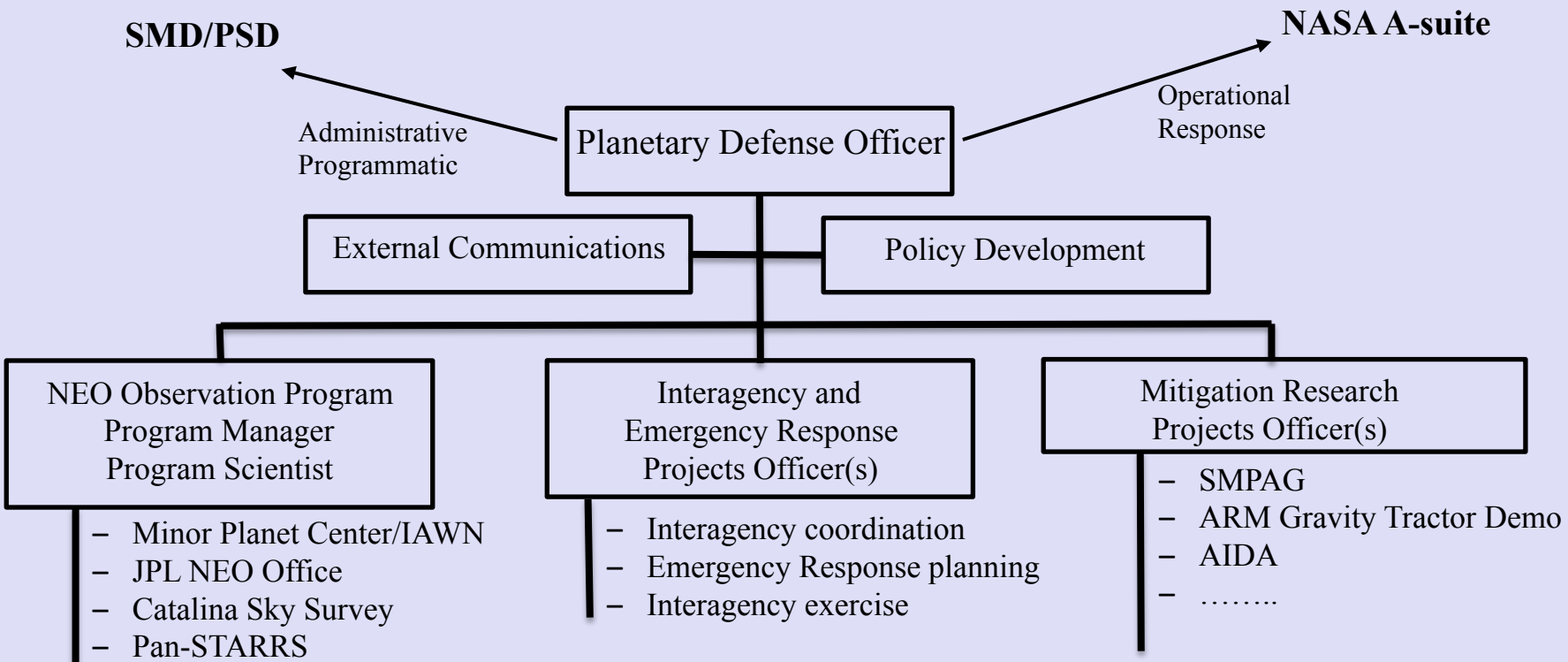
Of impending NEO Threat to United States territory:

- The Federal Emergency Management Agency (FEMA) takes lead to notify appropriate Federal, state and local authorities and emergency response institutions utilizing existing resources and mechanisms
  - When time/location of affected areas known, activate National Warning System
  - Analogous to large re-entering space debris and/or hurricane warning procedures
  - Post-impact event, analogous to other disaster emergency and relief efforts

Of NEO Threat beyond United States territory:

- Recognizing vital role US efforts lead in NEO detection activities, US Department of State facilitates international notifications in effort to minimize loss of human life and property
  - Bilaterally through diplomatic channels to potentially affected countries
  - To member nations of multilateral forums – UN entities (OOSA, COPUOS), NATO, etc
  - Post-impact event, convey offers of disaster relief and technical assistance

Planetary Defense Coordination Office



NEO Observation Program

- ❑ Established as a research program
- ❑ Formalizing program documentation
- ❑ Staffing approved for 5.4 FTE

Near Earth Object Program

US component to International Spaceguard Survey effort
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

- Averaged ~$4M/year Research funding 2002-2010
- That goal reached by end of 2010

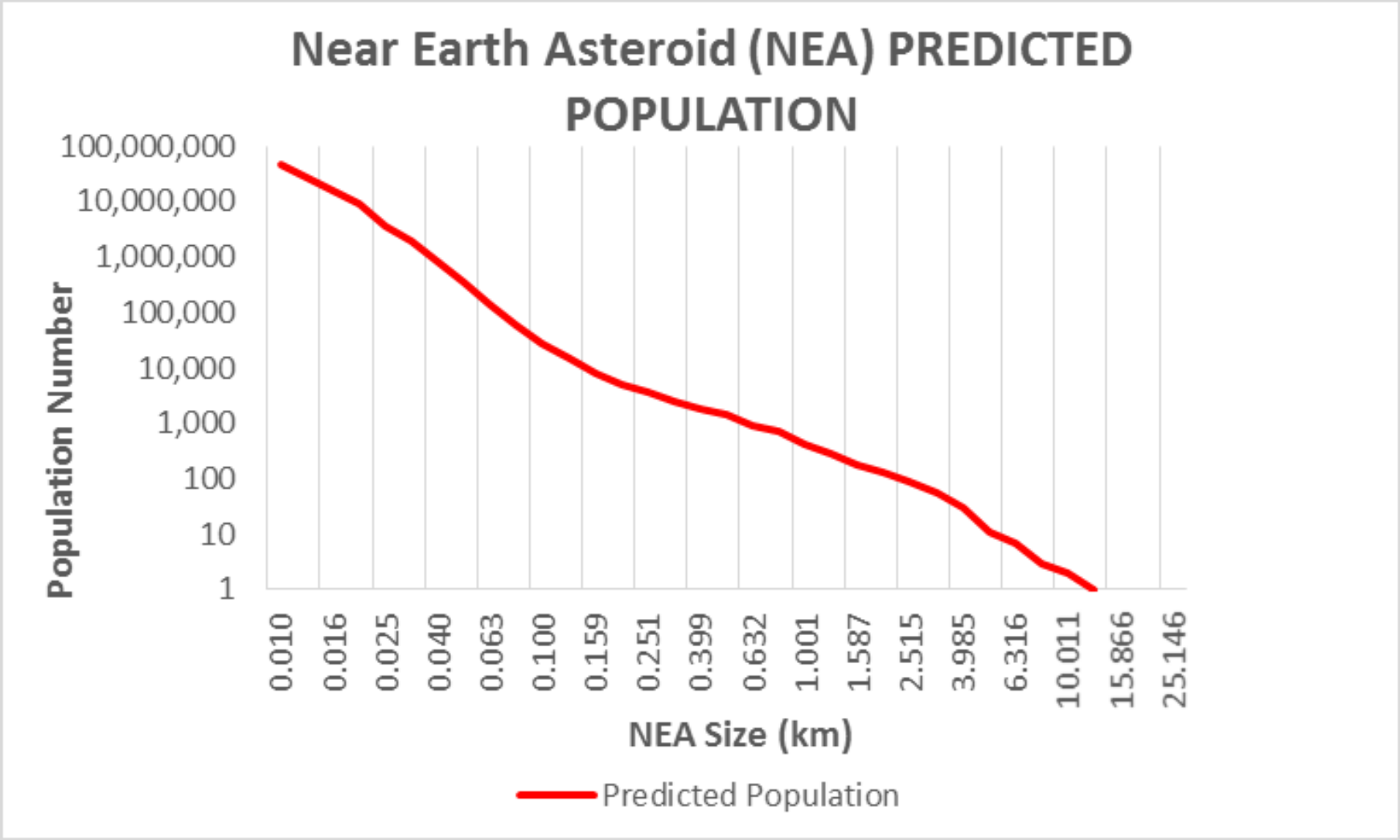
NASA Authorization Act of 2005 provided additional direction:

"…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].

Updated Program Objective: Discover $\geq$ 90% of NEOs larger than 140 meters in size as soon as possible

- In FY2012 budget increased to $20.5 M/year
- With FY2014, FY2015 budgets now at $40 M/year

Near Earth Asteroid Survey Status



NASA's NEO Search Program

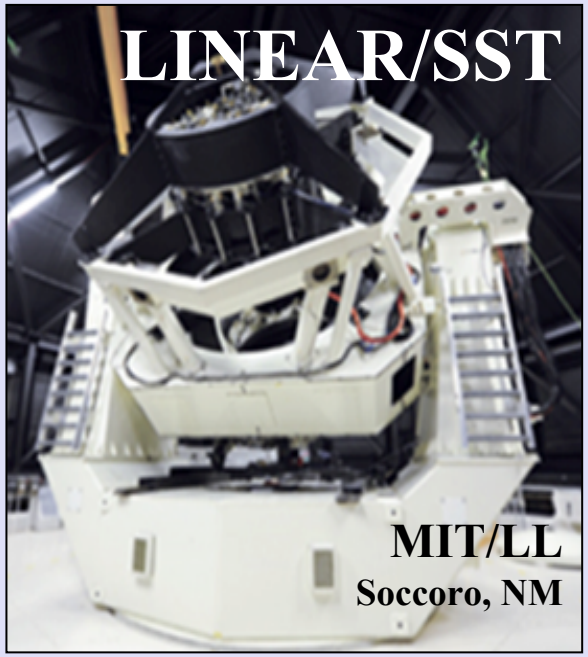
(Current Survey Systems)

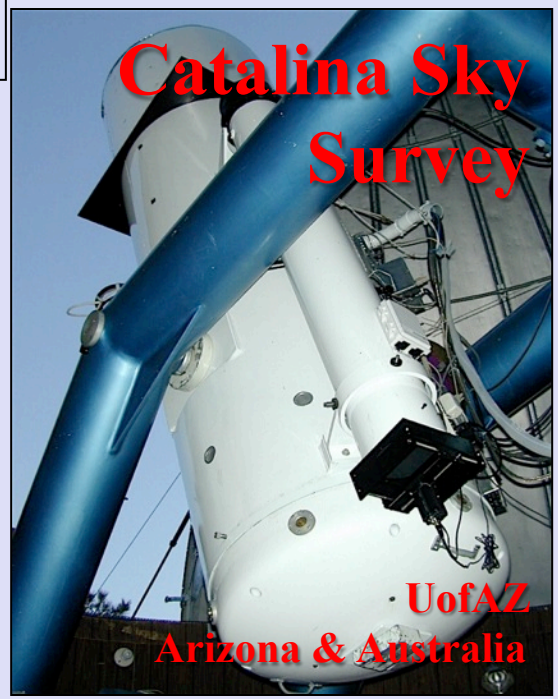
Minor Planet Center (MPC)
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

http://minorplanetcenter.net/

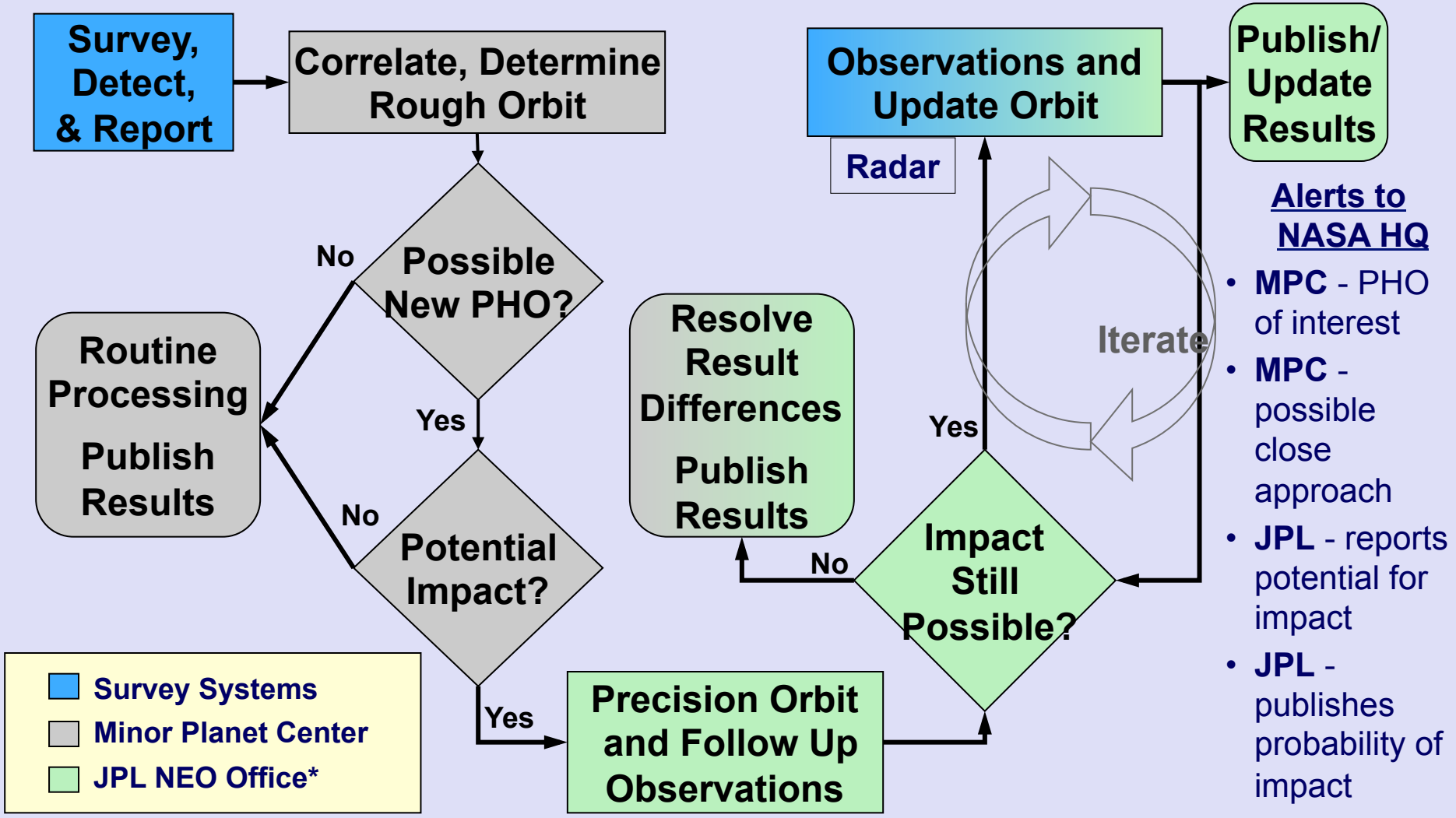
NEO Dynamics Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

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





Spaceguard Survey Catalog Program
Current Spaceguard Survey Infrastructure and Process



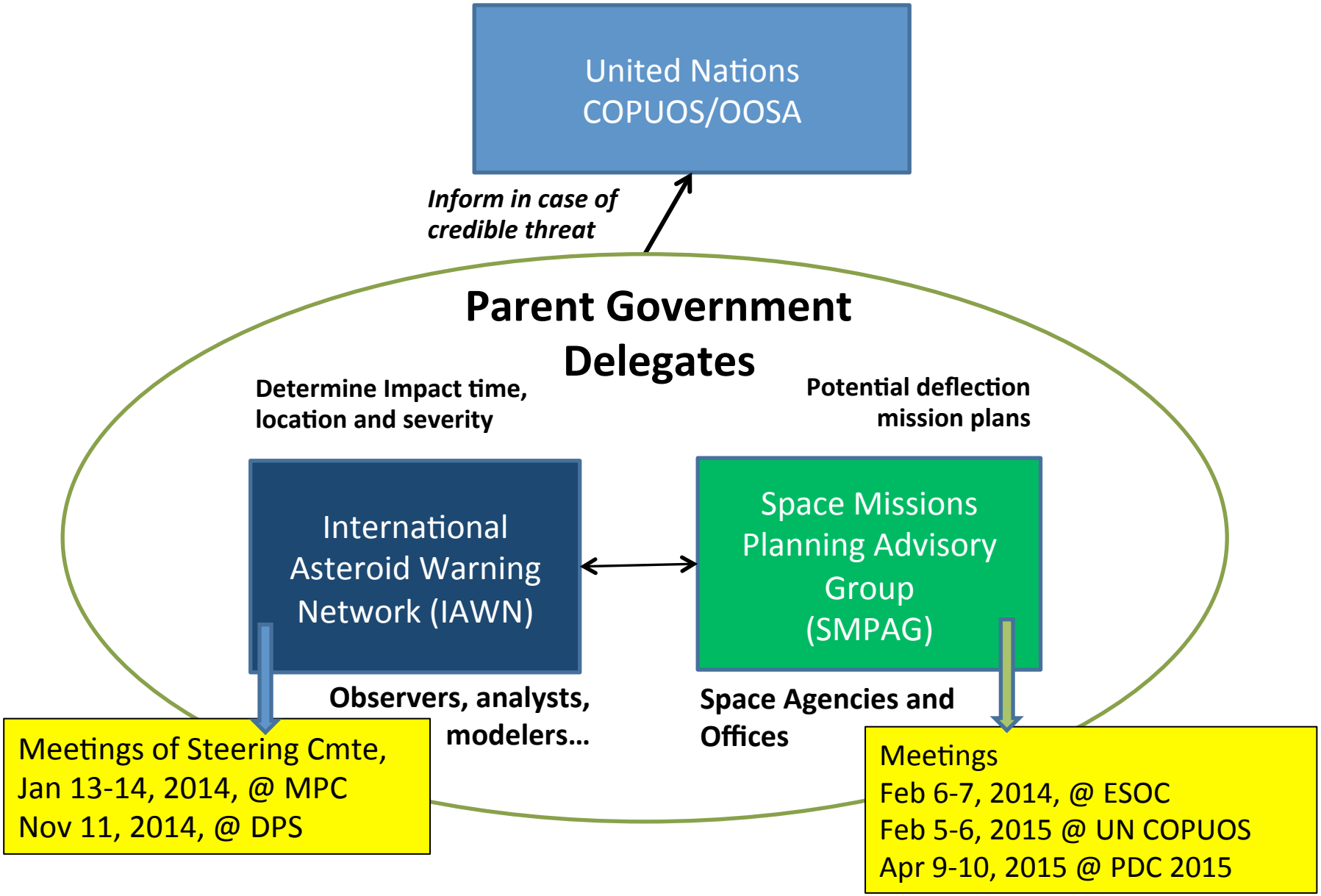
* In parallel with NEODyS

Worldwide Observing Network

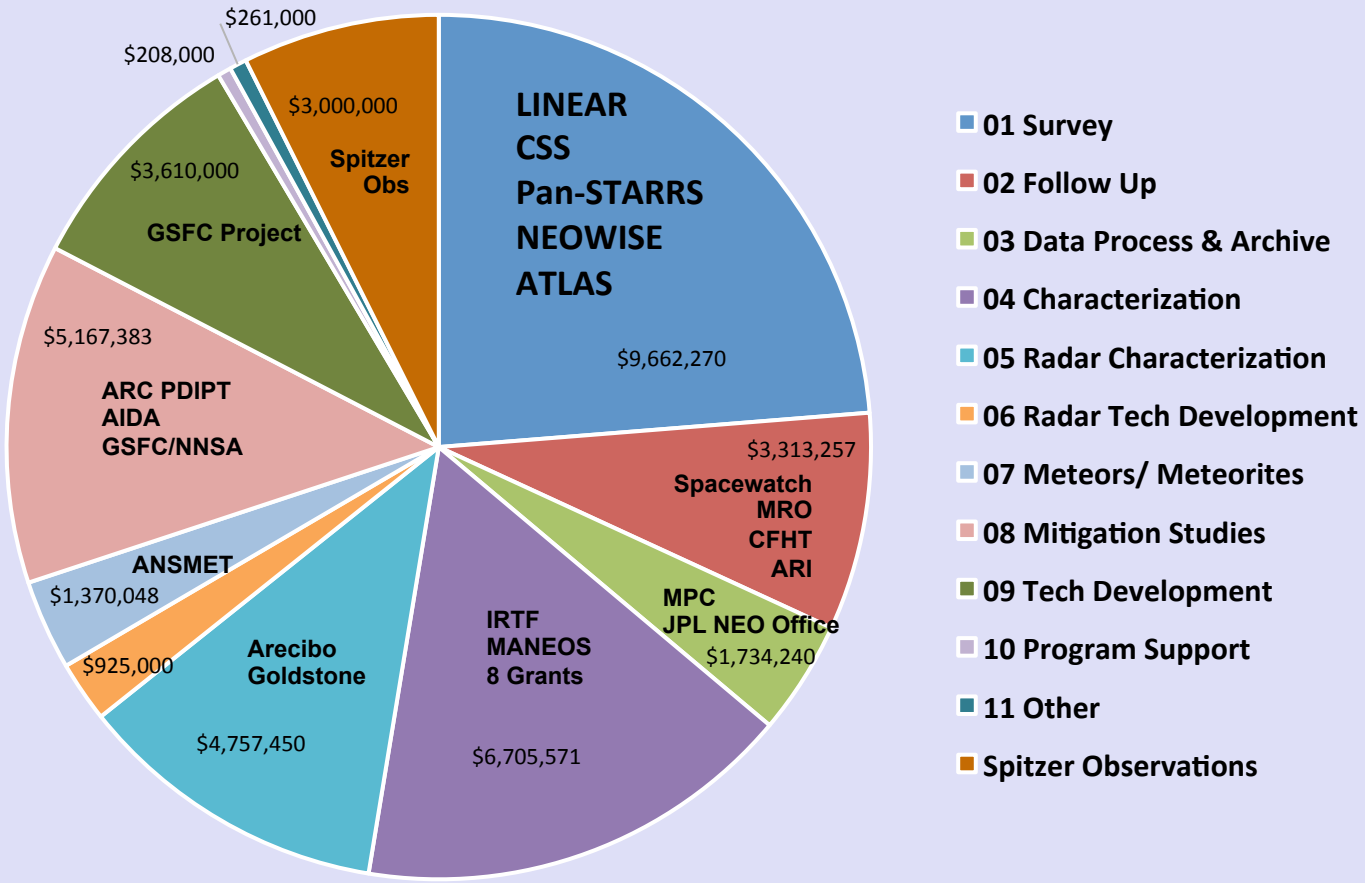
Received ~15 Million Follow-up Observations from 31 countries in 2014

UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

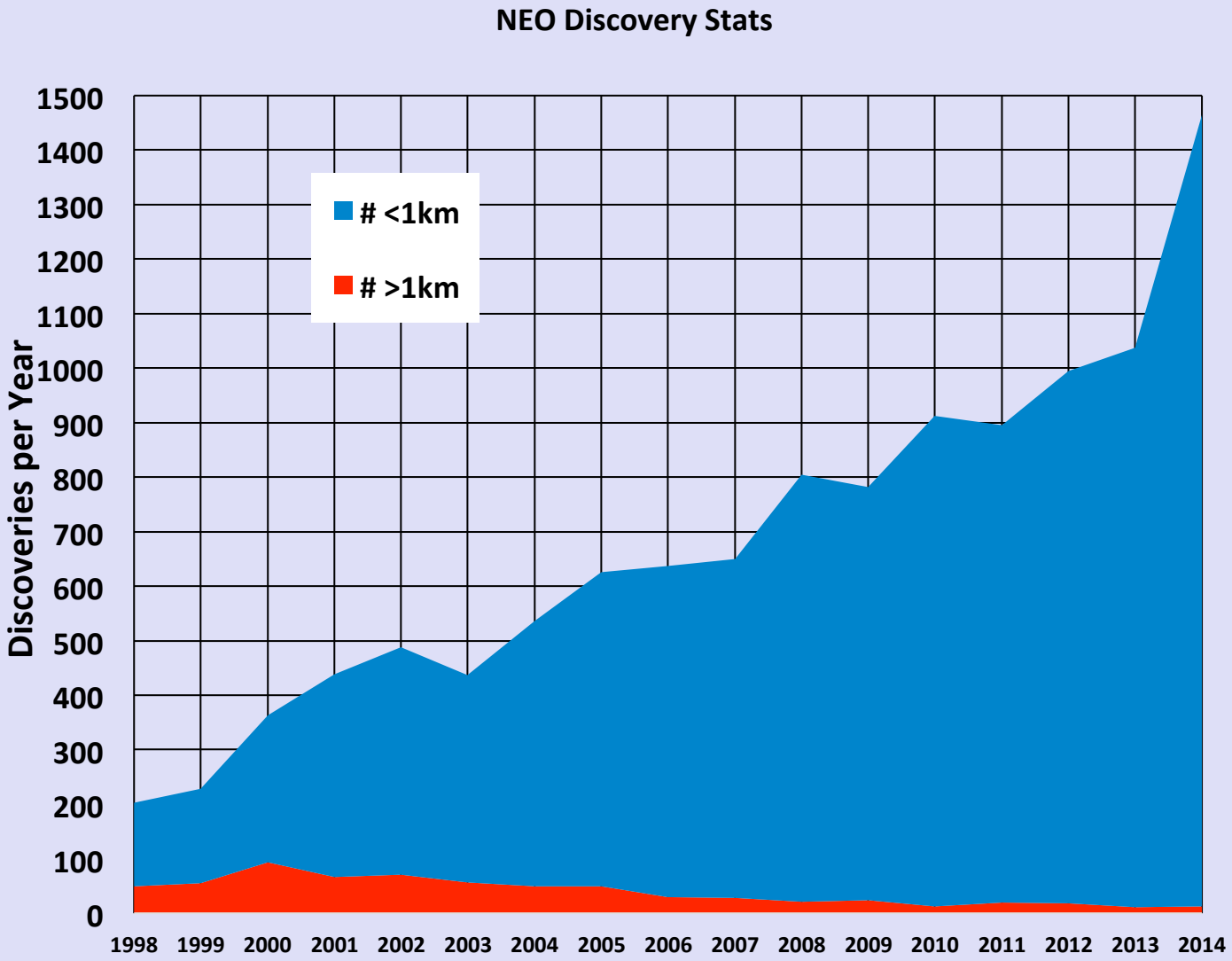
Overview for NEO Threat Response



NEO Program FY2015 ($40M)

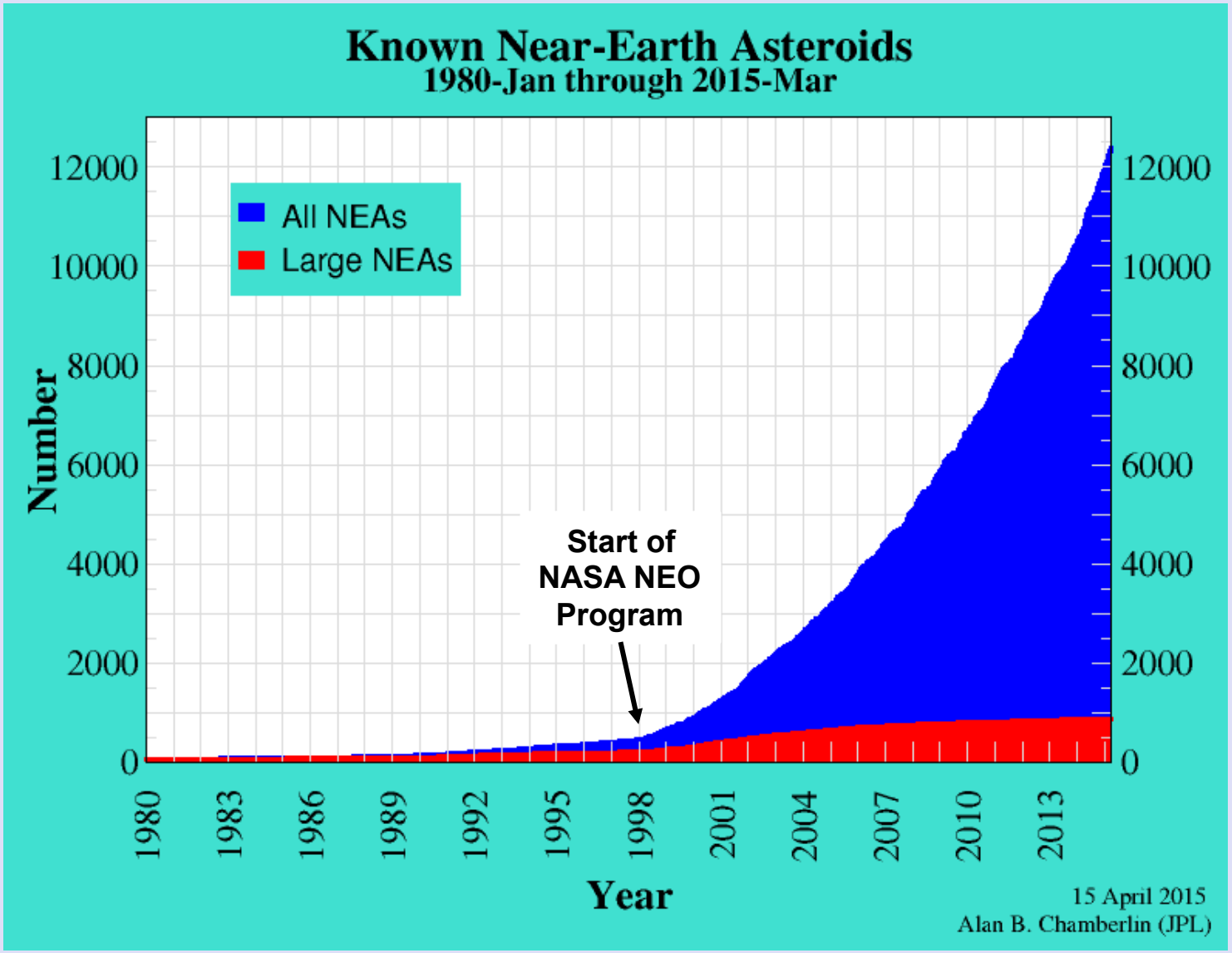


Annual Near Earth Asteroid Discoveries



1478 in 2014

Known Near Earth Asteroid Population



As of 06/01/15 12,691

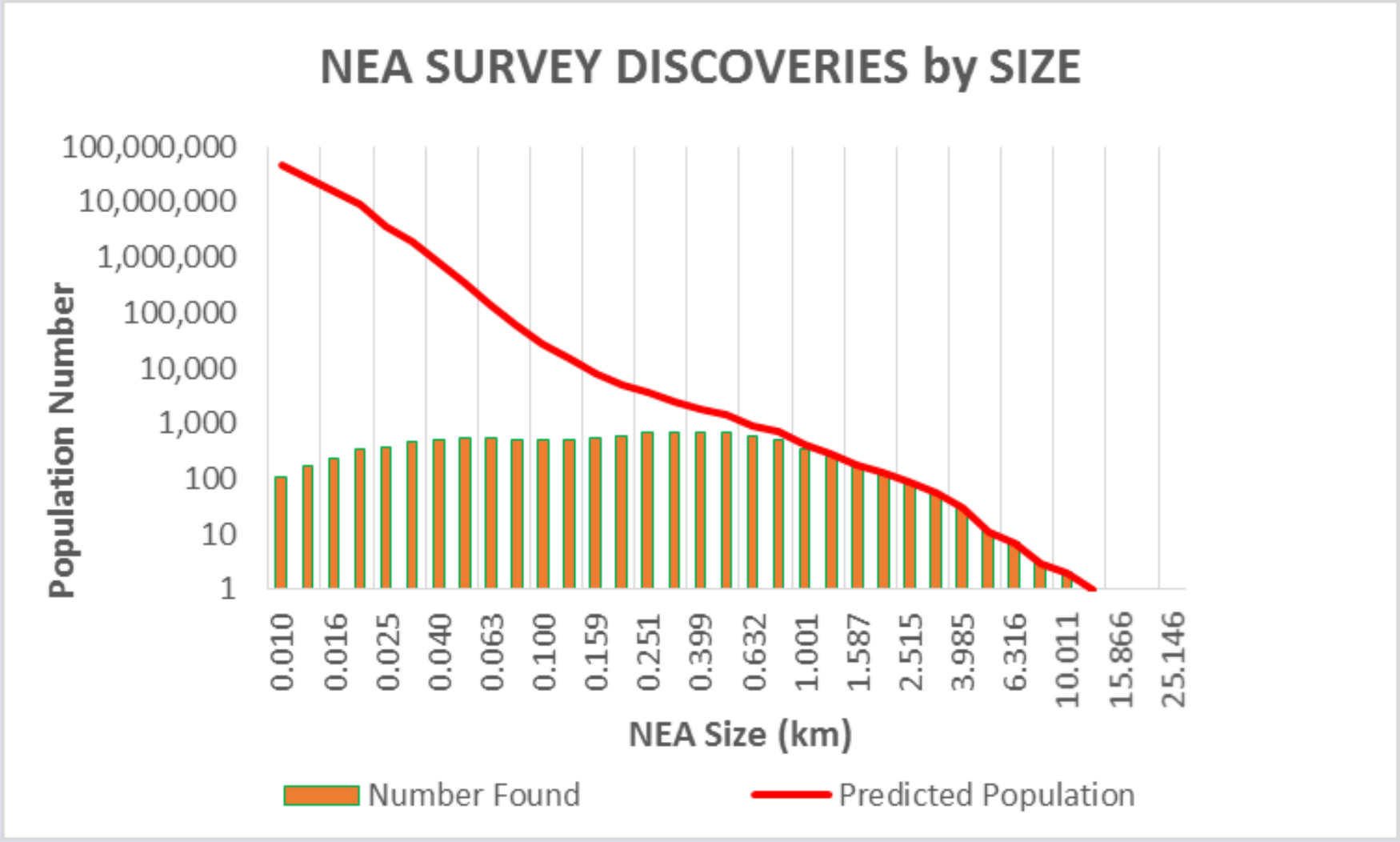
Also 101 comets

1592 Potentially Hazardous Asteroids

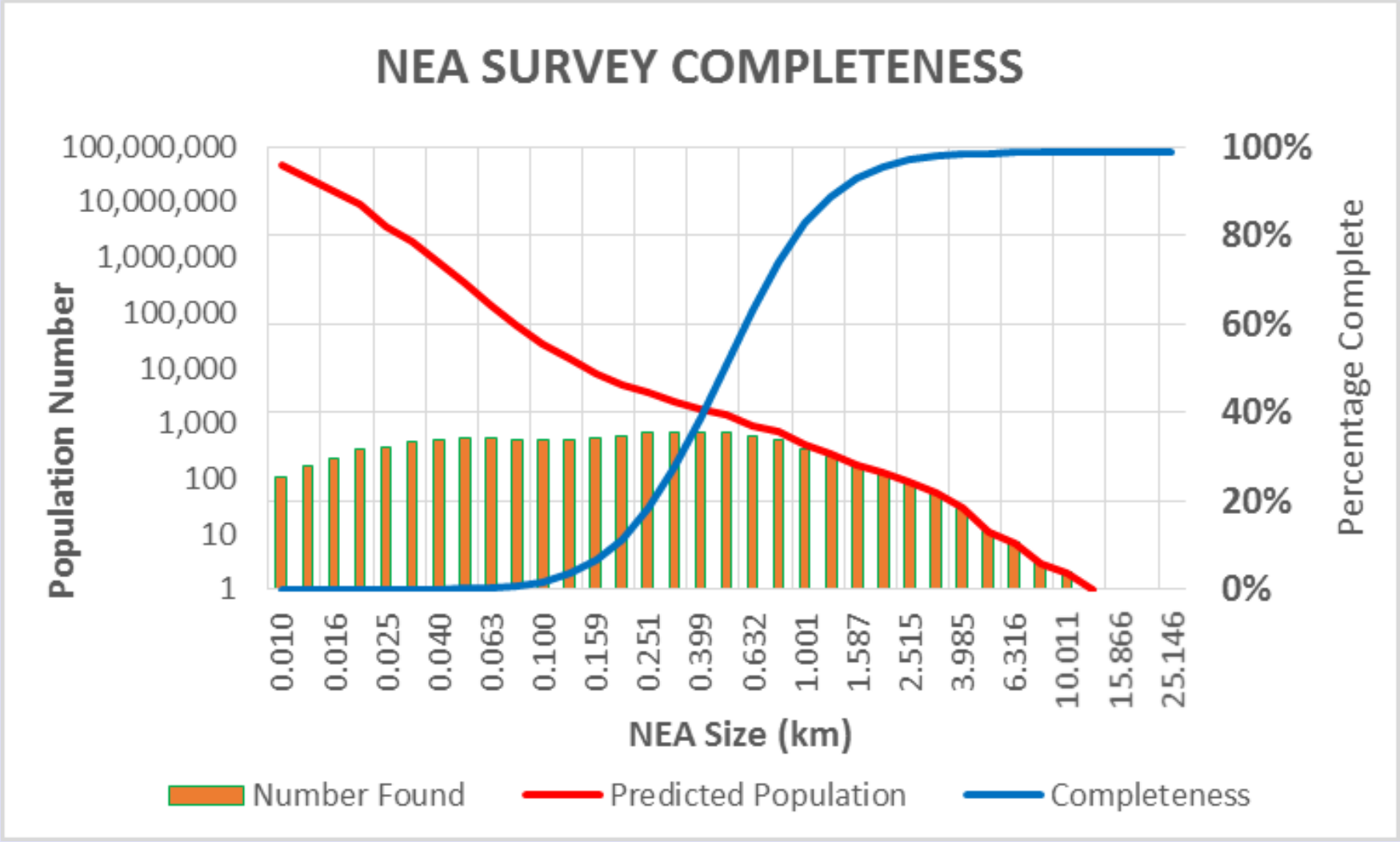
871

153 PHAs

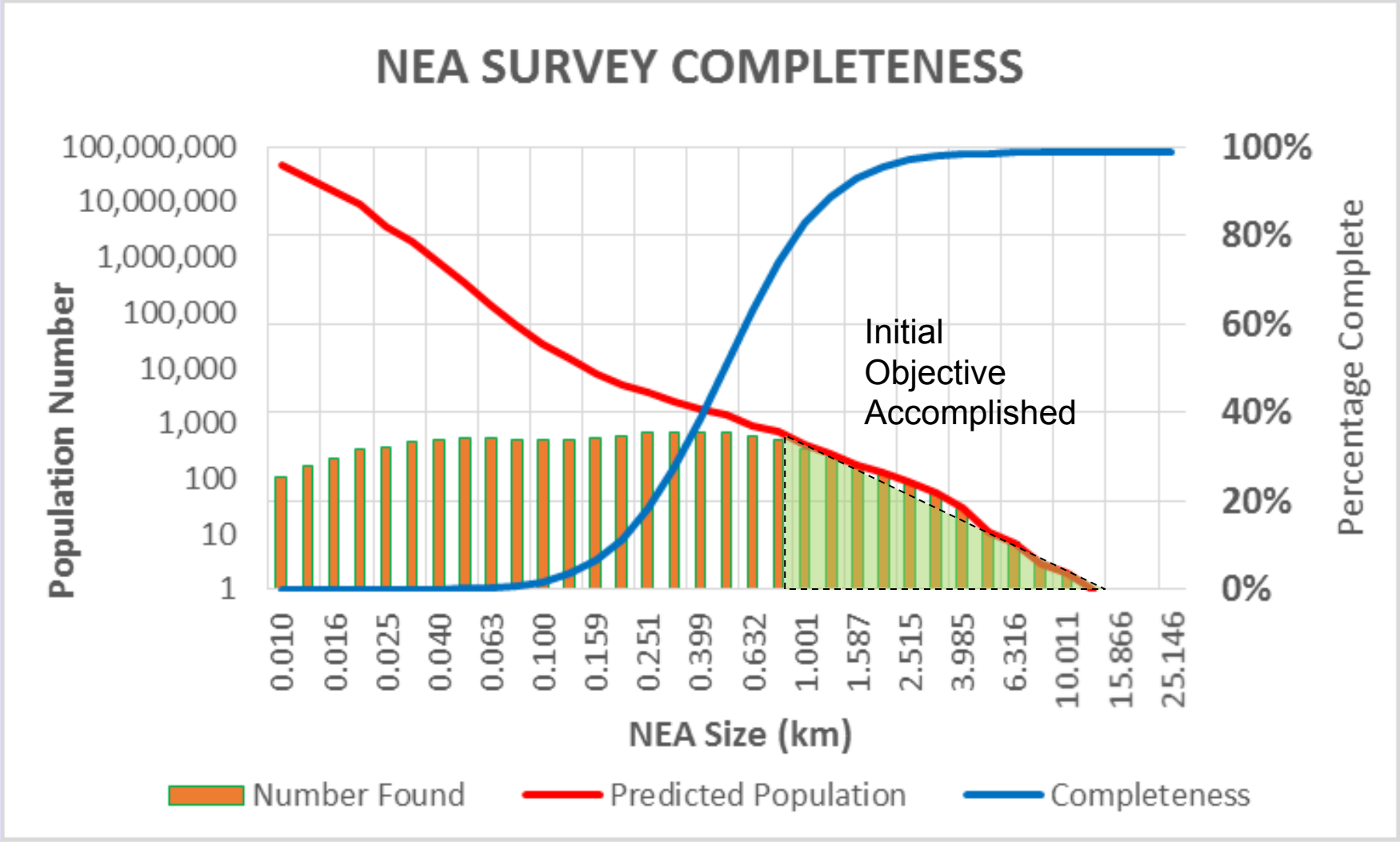
Near Earth Asteroid Survey Status



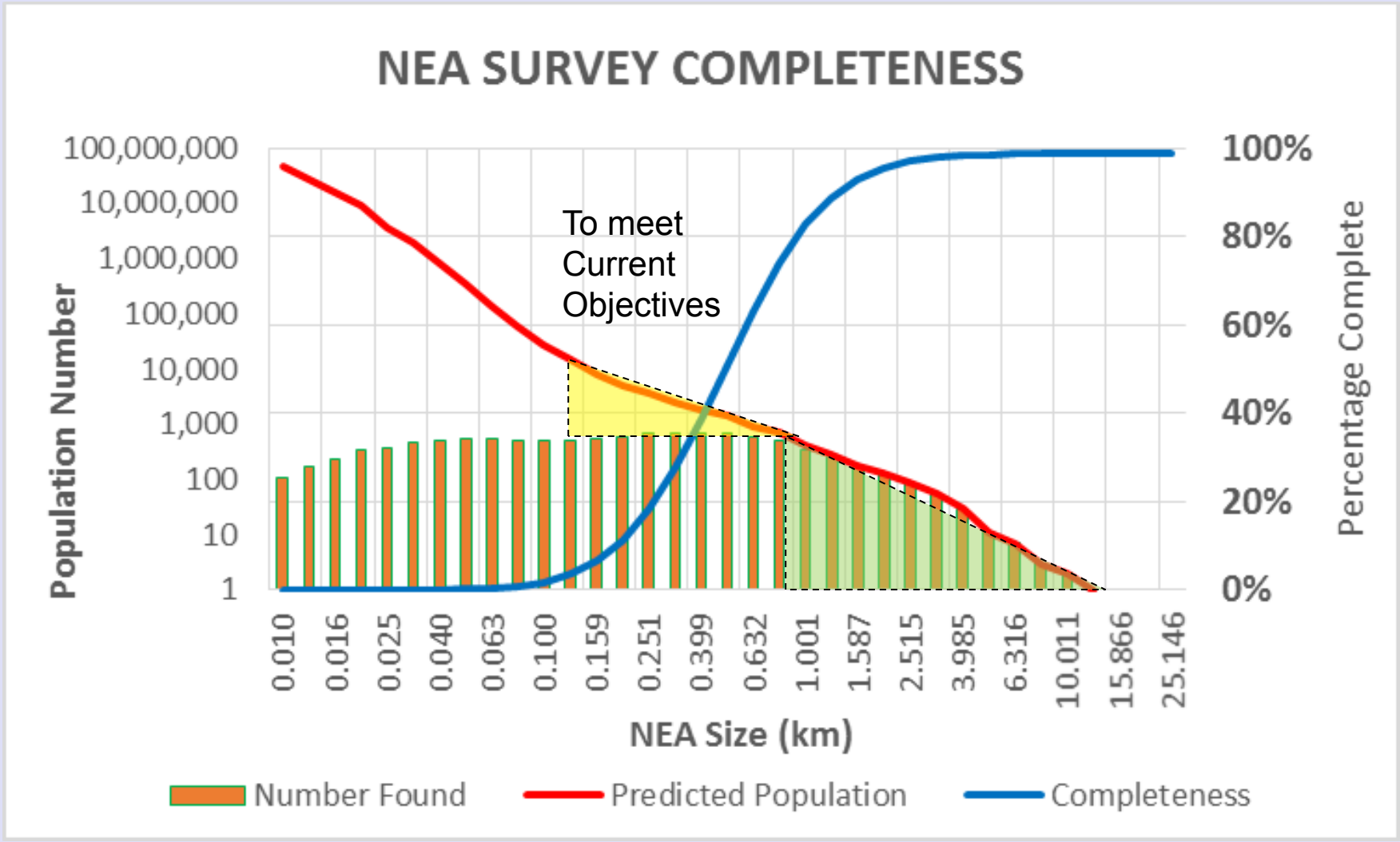
Near Earth Asteroid Survey Status

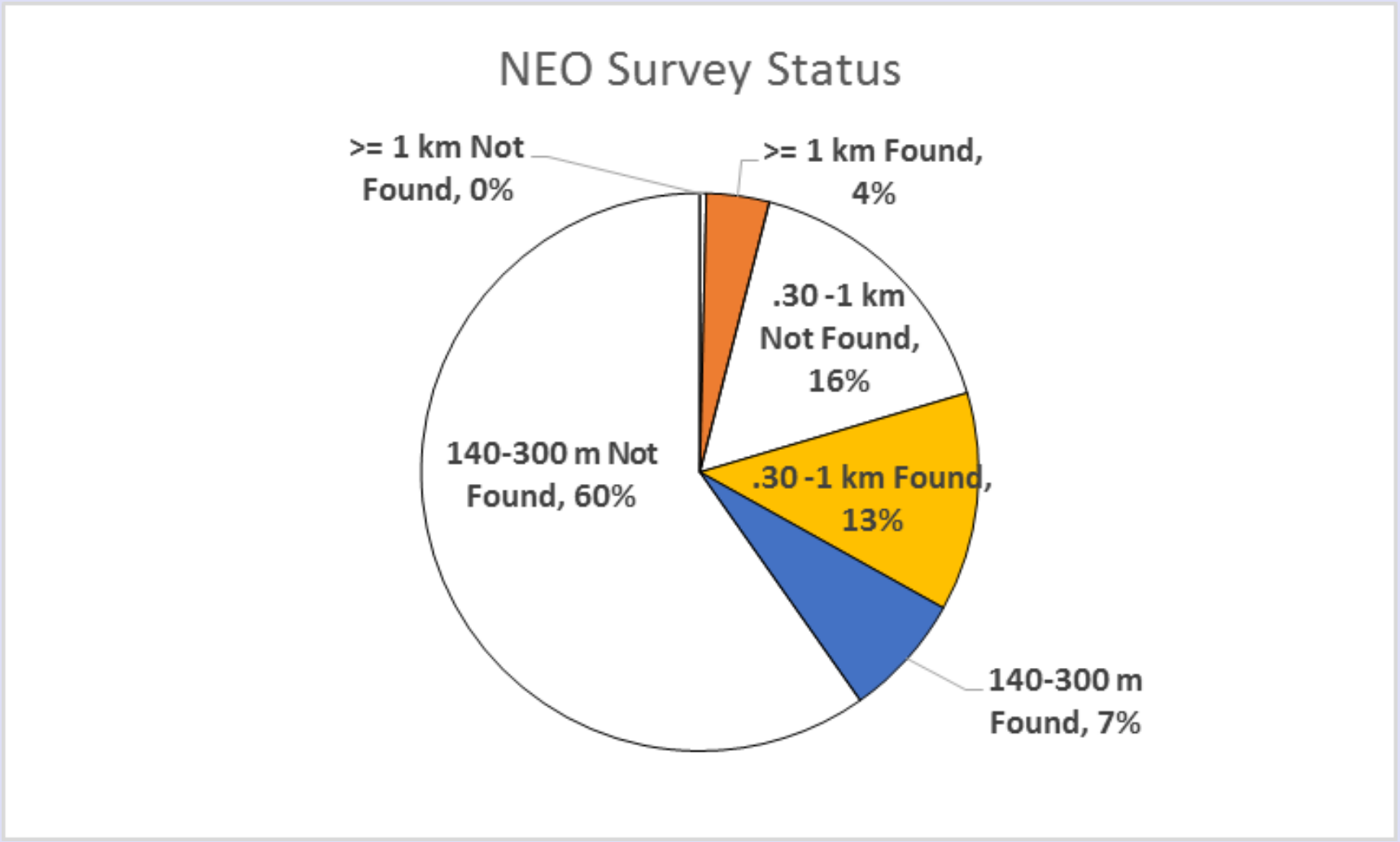


Near Earth Asteroid Survey Status



Near Earth Asteroid Survey Status



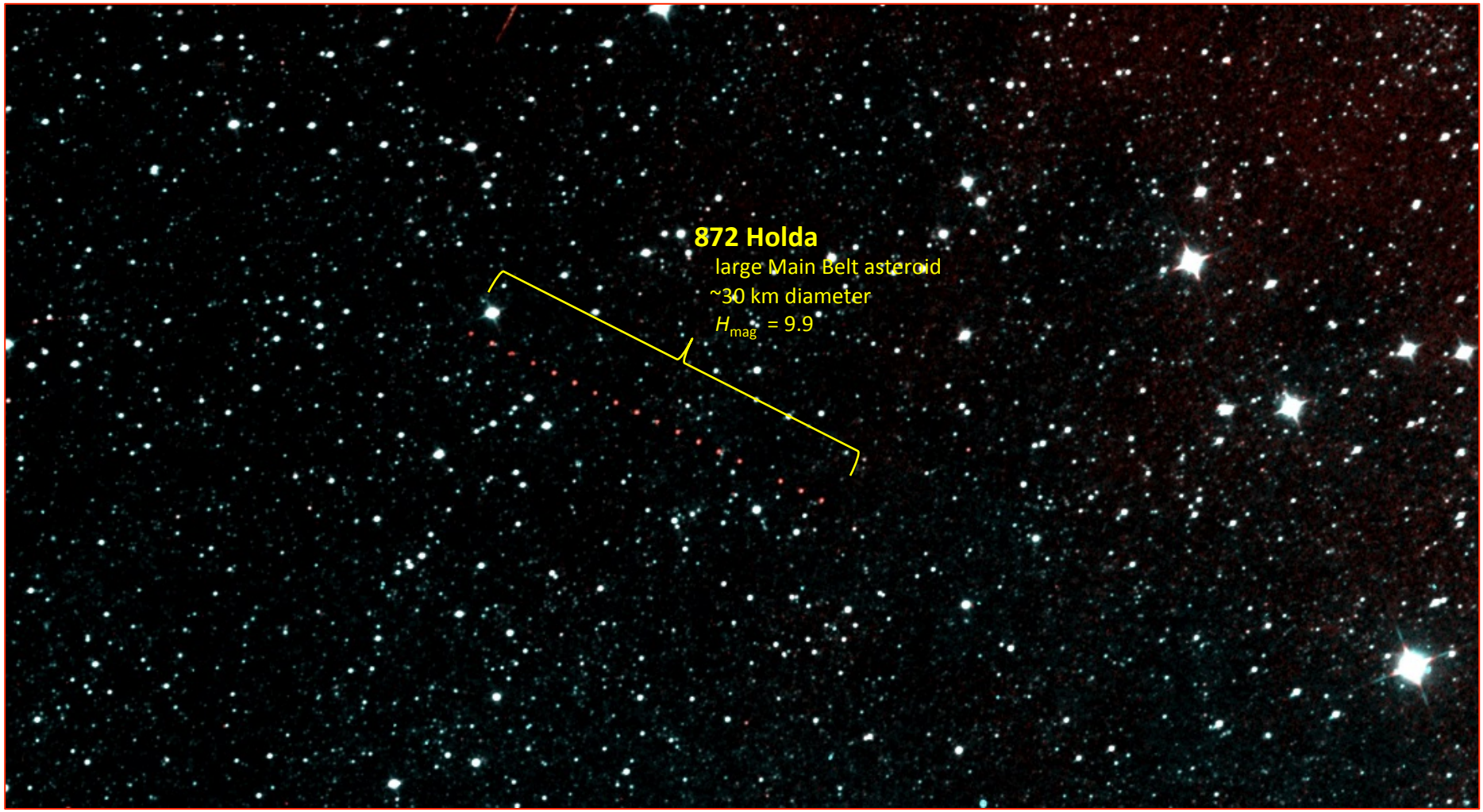

NEO Survey Status
>= 1 km Not Found, 0%
>= 1 km Found, 4%
.30 -1 km Not Found, 16%
.30 -1 km Found, 13%
140-300 m Found, 7%
140-300 m Not Found, 60%

Options for the NEO Survey

Compelling options (beyond what is assumed in the current NEO program and budget) for accelerating progress towards the goal of detecting 90 percent of NEO's 140 meters in diameter or greater

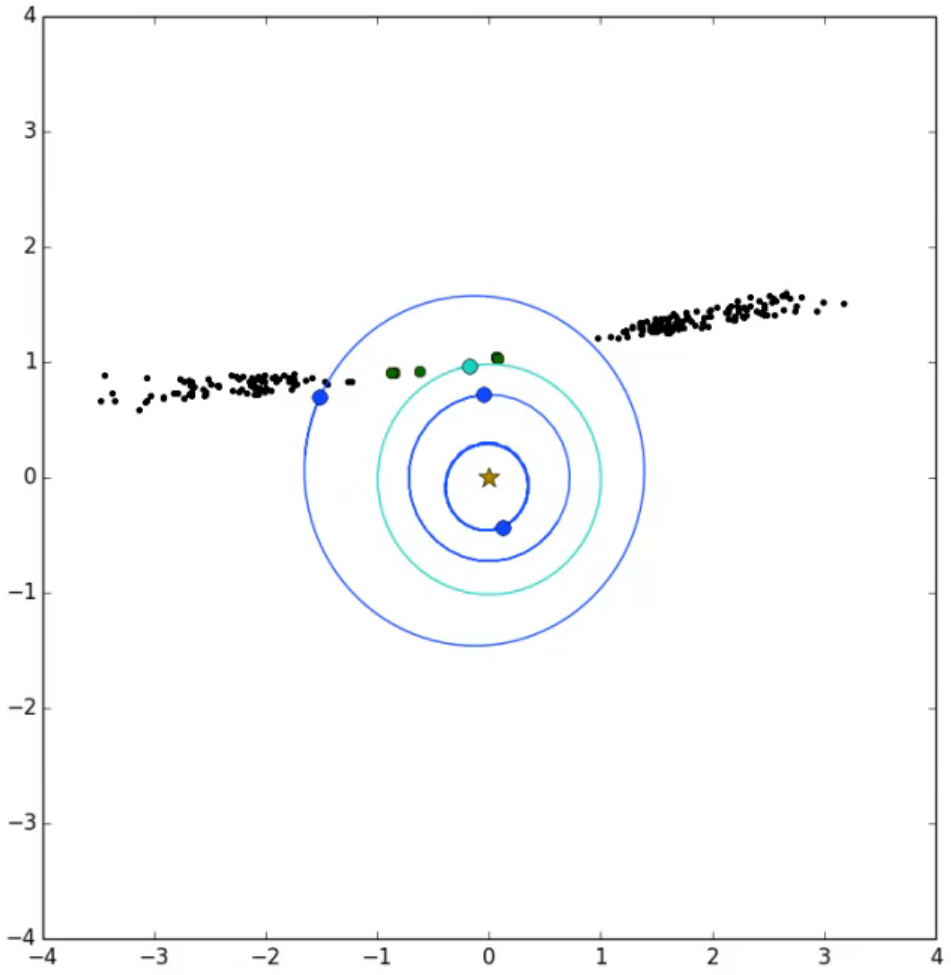
- Options for accelerating the detection and tracking of 90% of $\geq$ 140 meter PHAs
  - Ground-based – Build larger telescopes dedicated to PHA search and track
  - Space-based – Enables the build of Infra-Red (IR) detection and tracking
    - Asteroid signature more prominent in IR bands
    - Also allows better estimates of size
  - Mix of Space and Ground-based capabilities

IR Detection of NEOs



Composite image showing multiple detections of the large Main Belt asteroid 872 Holda on the first day of survey operations in December 2013.

Observations from NEOWISE - 2014



WISE Operations
Jan 2010
Feb 2011,
135 NEAs found

Reactivated
Sep 2013

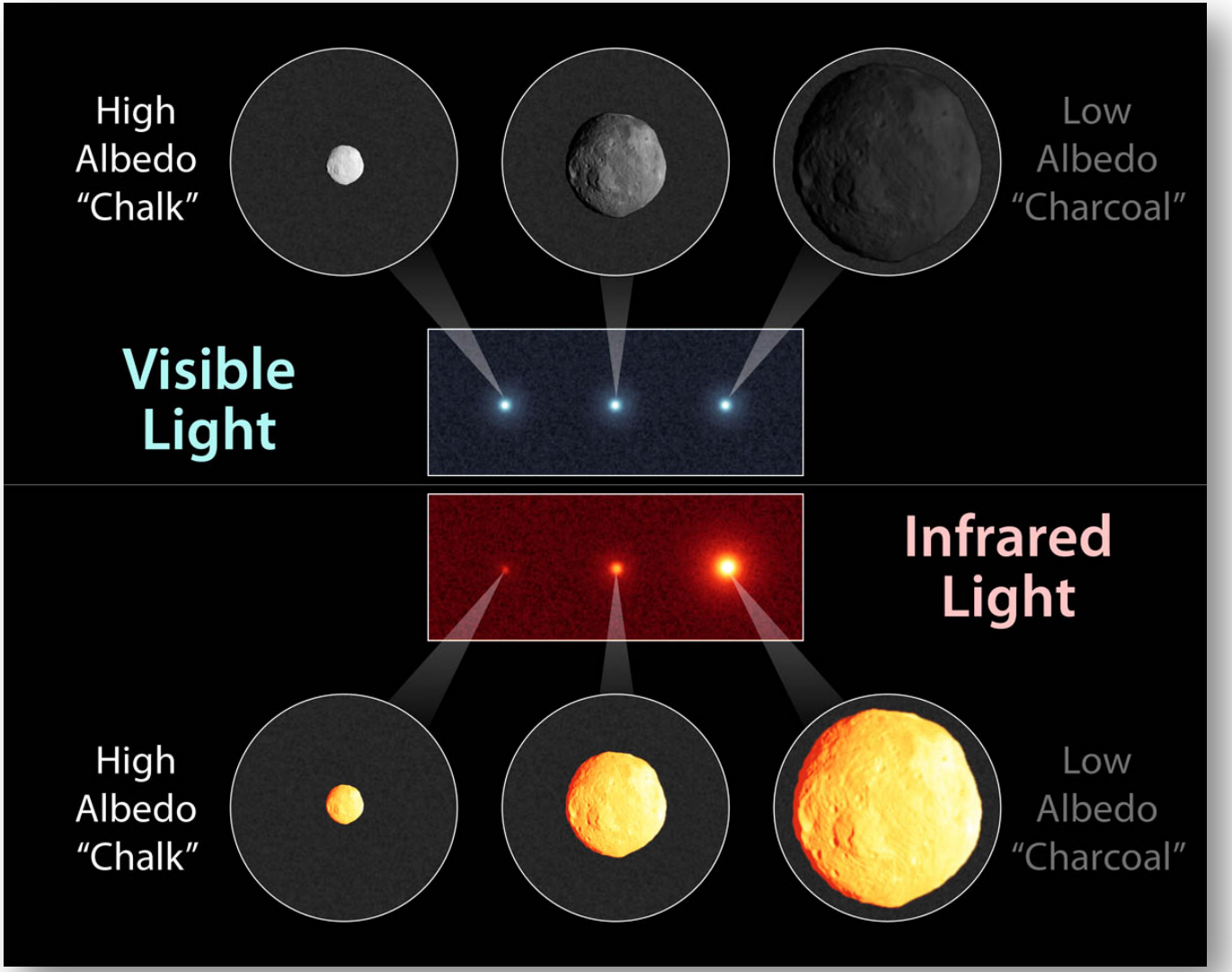
NEOWISE began Ops
Dec 2013
Has found
40 NEAs
3 comets

IR Characterization

Allows more accurate size estimates:

Visible Light:
± 200% uncertainty

Infra-Red Light:
± 20% uncertainty



CHELYABINSK EVENT

February 15, 2013
17-20 meter object
~500-550 kilotons TNT

Chelyabinsk Airburst, Feb. 15, 2013

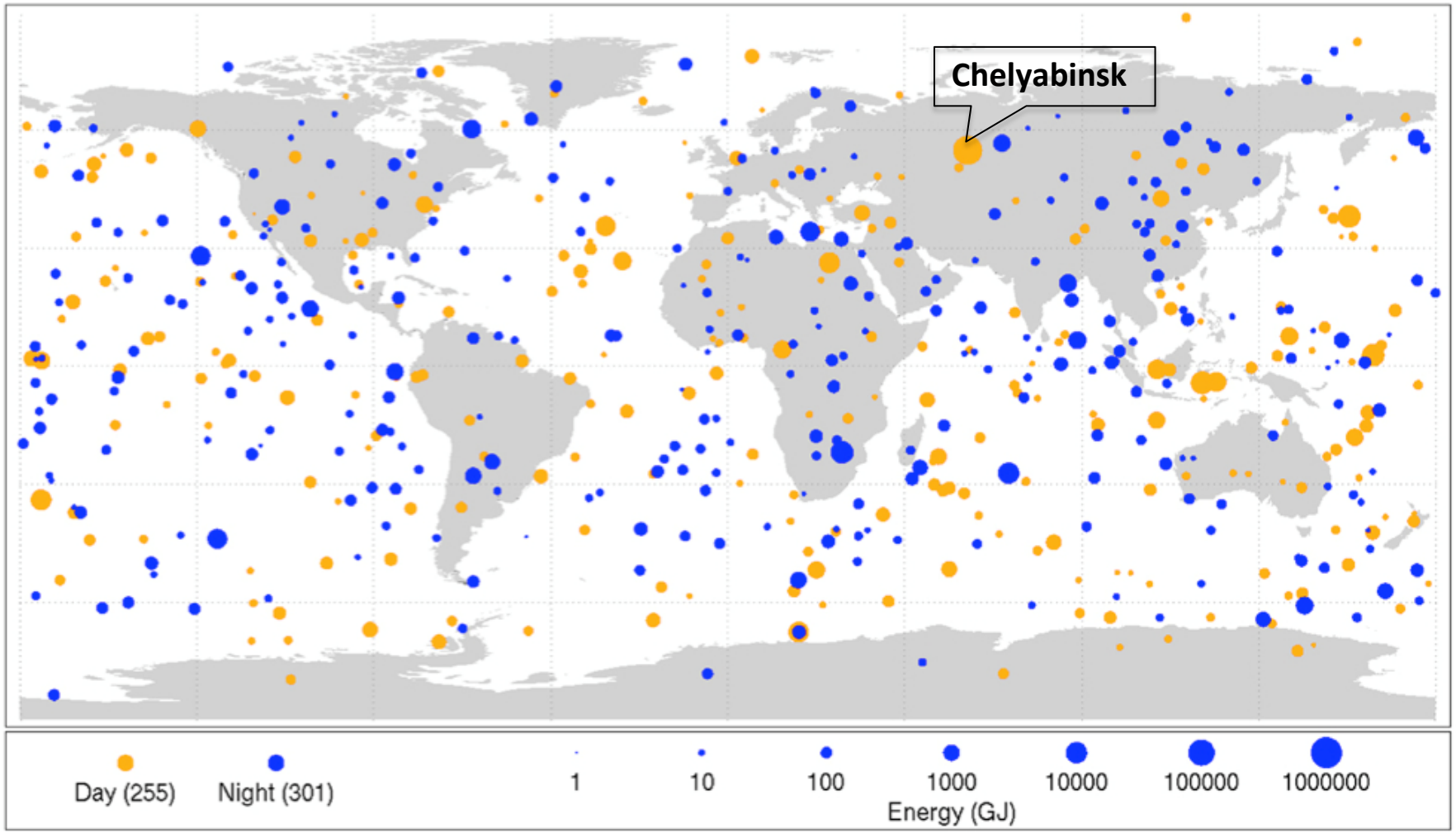
- **A 20-meter (60-foot) asteroid entered the atmosphere at about 19 km/s (12 mi/s)**
- **The event released about 500 kt of energy, producing a large shock wave**

CHELYABINSK EVENT

February 15, 2013
1613 citizens injured
~$30 million damages

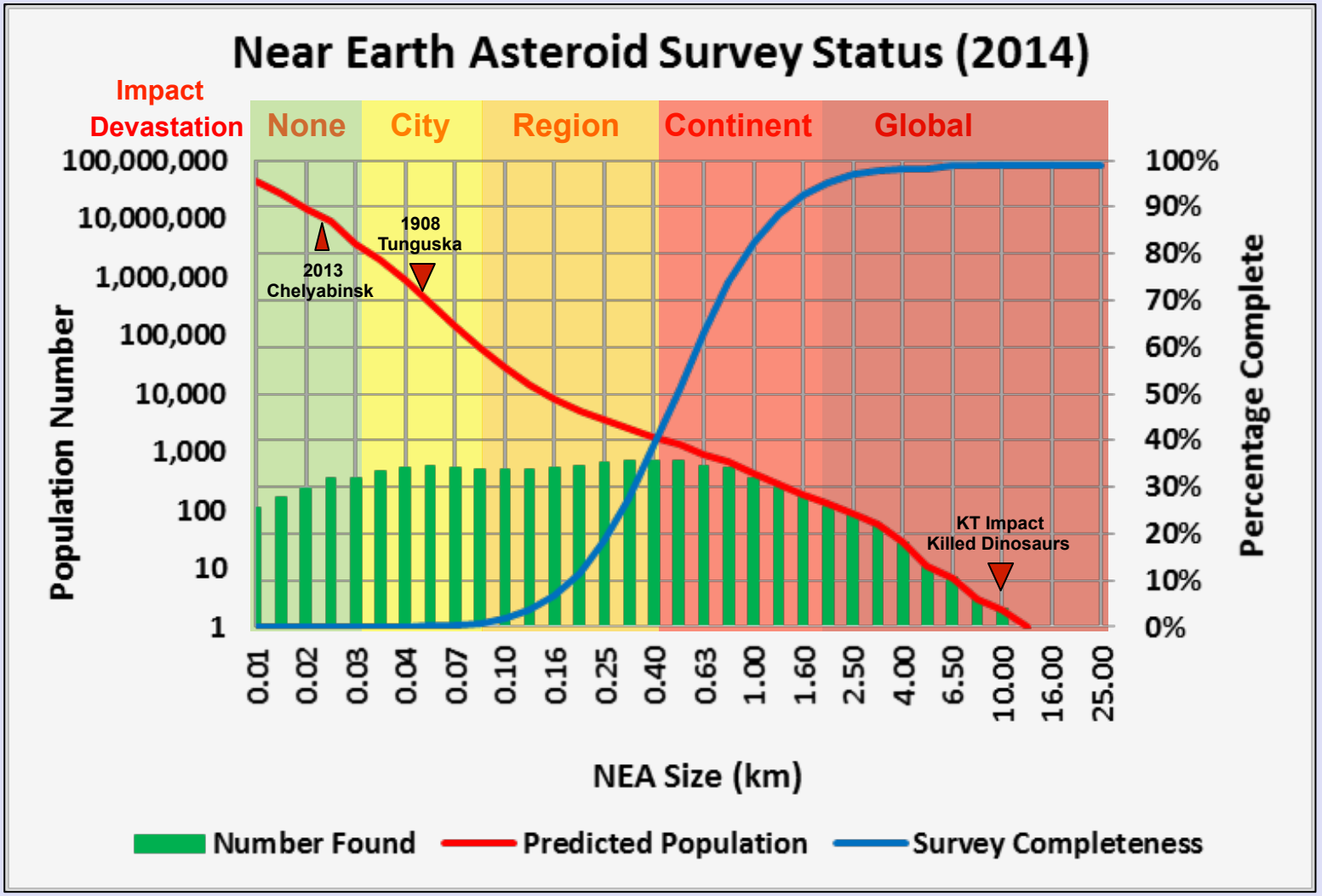
Bolide Events 1994 – 2013

Small Asteroids that Disintegrated in Earth's Atmosphere

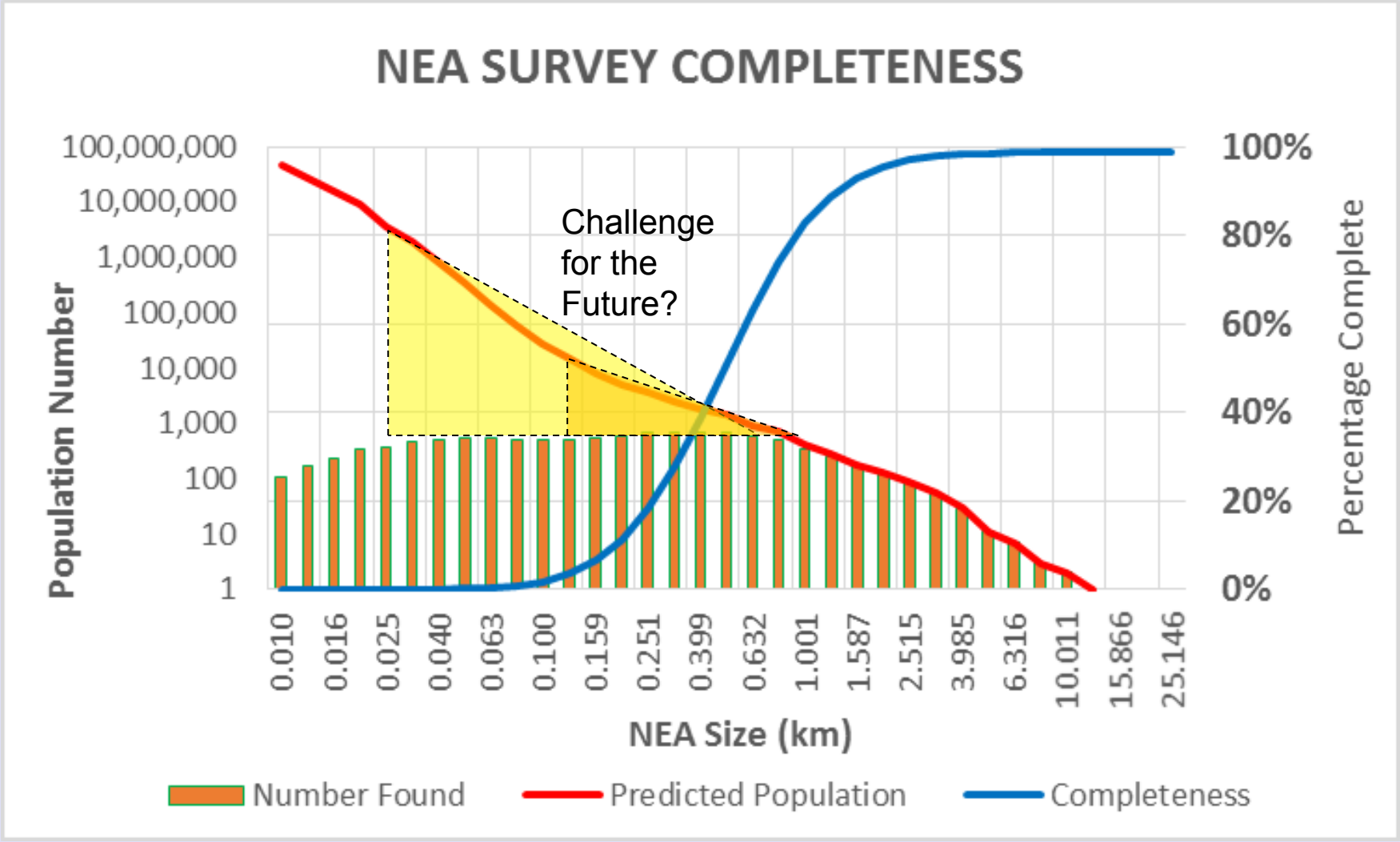


This diagram maps the data gathered from 1994-2013 on small asteroids impacting Earth's atmosphere and disintegrating to create very bright meteors, technically called "bolides" and commonly referred to as "fireballs". Sizes of orange dots (daytime impacts) and blue dots (nighttime impacts) are proportional to the optical radiated energy of impacts measured in billions of Joules (GJ) of energy, and show the location of impacts from objects about 1 meter (3 feet) to almost 20 meters (60 feet) in size.

Near Earth Asteroid Survey Status



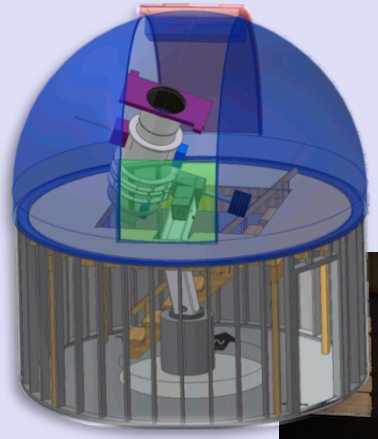
Near Earth Asteroid Survey Status



Near Term Impact Warning

Asteroid Terrestrial-impact Last Alert System –ATLAS*:

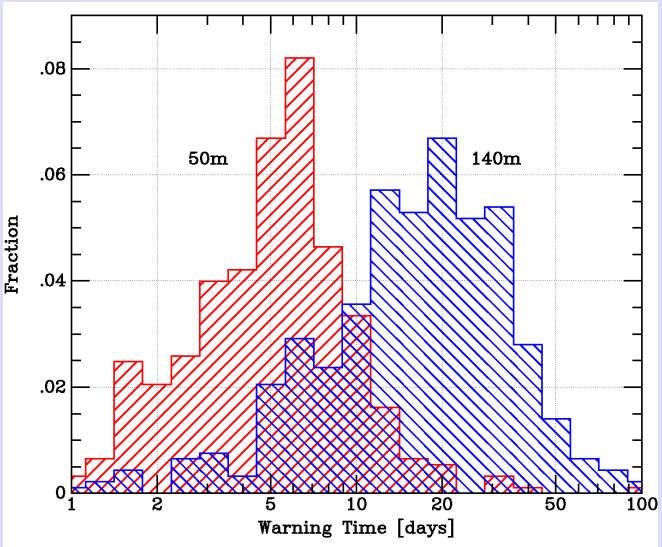
A project to patrol **the entire night sky every night** in search of incoming asteroids



A geographically dispersed network (~ 6 sites) of small coupled telescopes observing "shallow but wide" to provide more complete sky coverage for warning of near-term impact threats

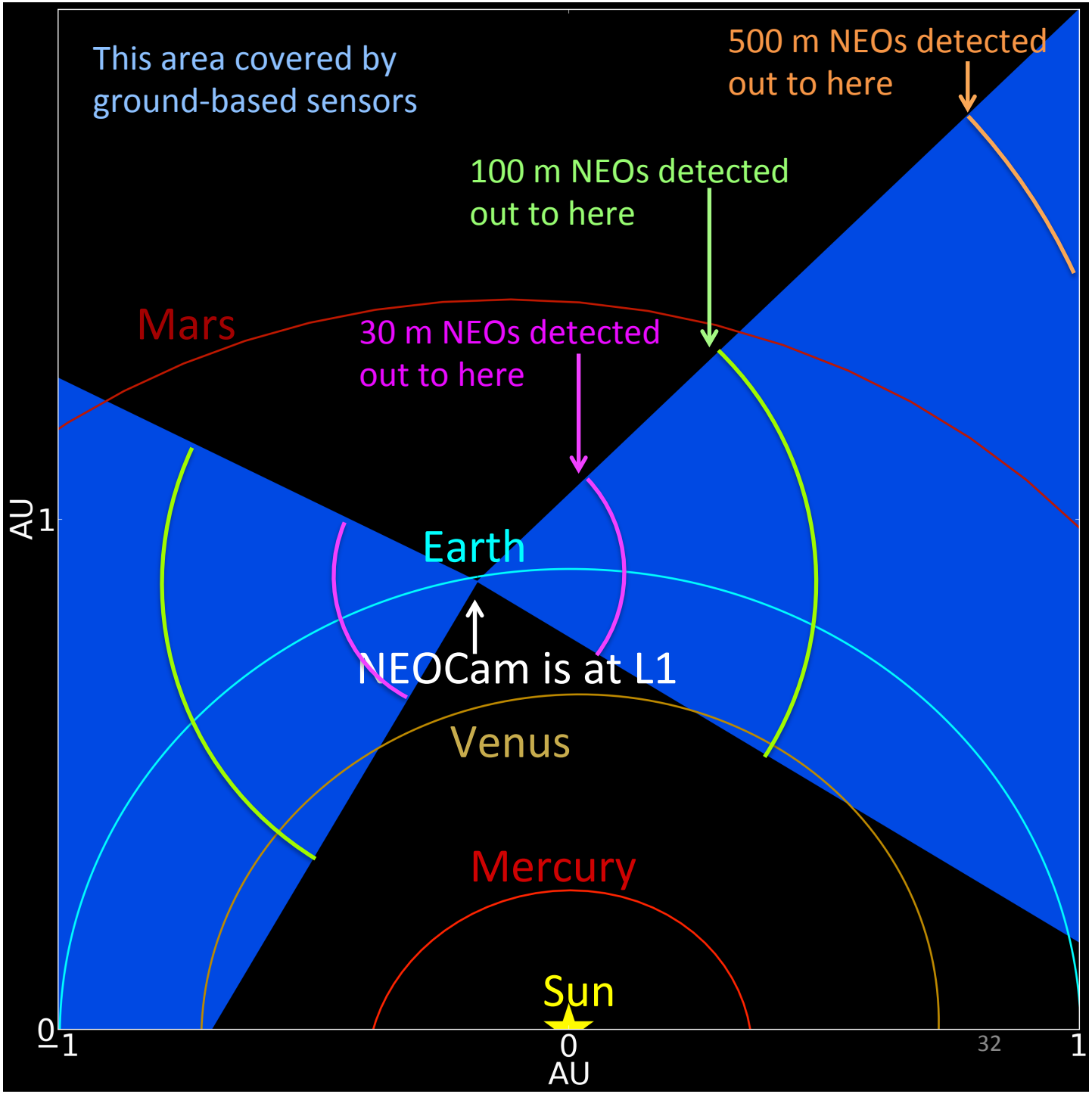
ATLAS telescope design

***Courtesy University of Hawaii Institute for Astronomy**



Blue = NEOCam viewing zones

- NEOCam detects 100m NEOs out to 0.6 AU from Earth when they are 1 AU from the Sun
- 30 m NEOs are detected 0.2 AU from Earth when they are 1 AU from the Sun
  - This may allow up to ~23 days of warning time



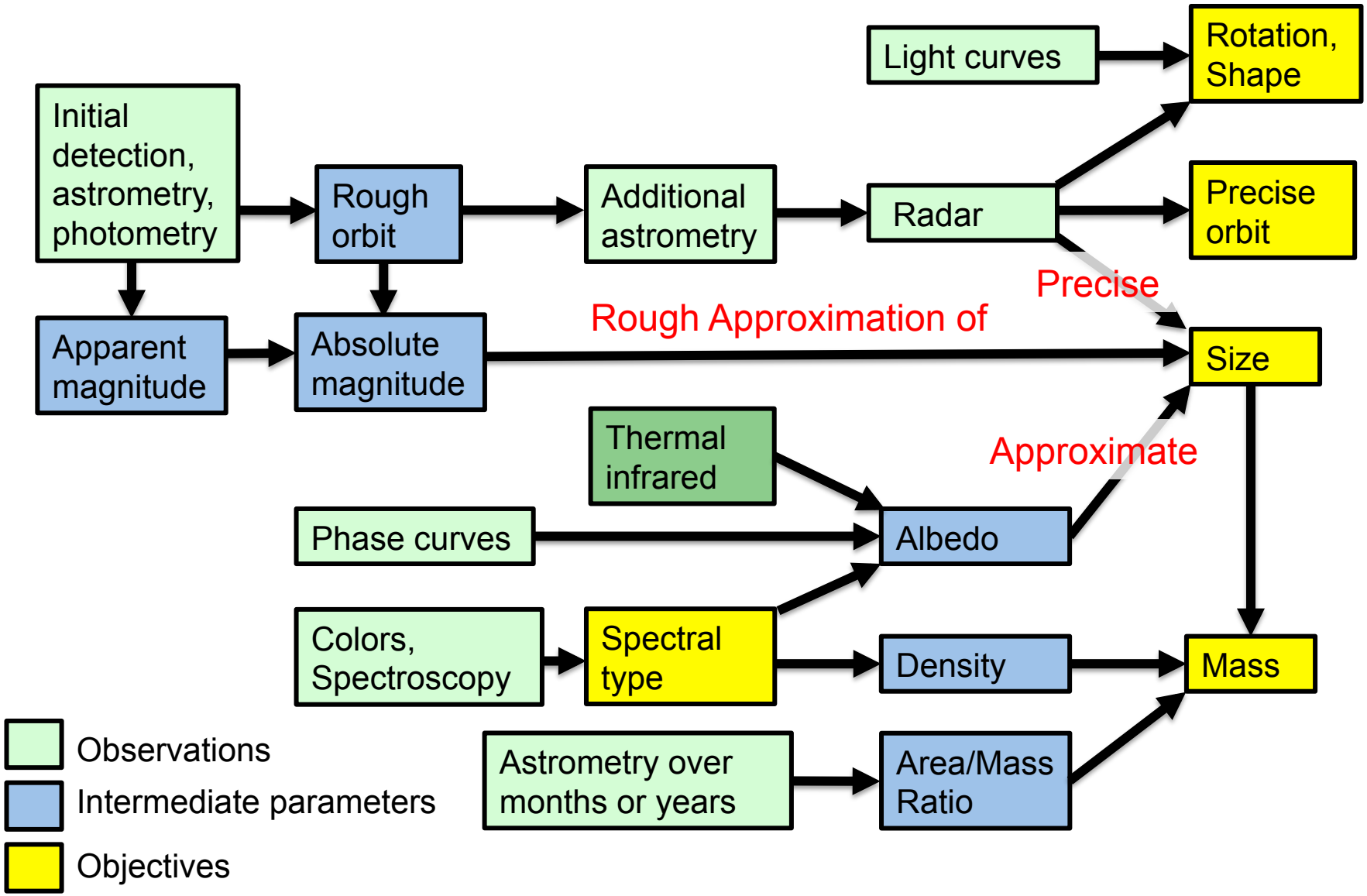
Physical Characterization of NEAs

- **Radar** is essential for obtaining an accurate estimate of size and shape to within ~2 m, as well as rotation state.
- Ground-based and space-based **IR** measurements are important for estimating albedo and spectral class, and from these an approximate density can be inferred.
- **Light curves** are important to estimate shape and rotation state.
- **Long-arc high-precision astrometry** is important for determining the area-to-mass ratio.
- Mass is estimated from size and shape using an inferred or assumed density, and it should be constrained by the estimate of the area-to-mass ratio. Even so, mass may only be known to within a factor of 3 or 4.
- Composition can only be roughly assessed via analogy to spectral class.

Assumed albedo
ρ = 0.04

Assumed albedo
ρ = 0.34

Characterization Process



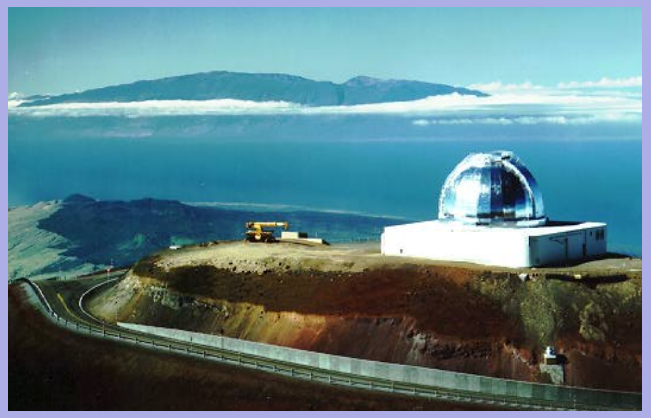
Primary NEO Characterization Assets and Enhancements

Radar (Goldstone and Arecibo)

- Increased time for NEO observations
- Streamlining Rapid Response capabilities
- Increased resolution (~4 meters)
- Improve maintainability


Goldstone Radar


Arecibo Observatory



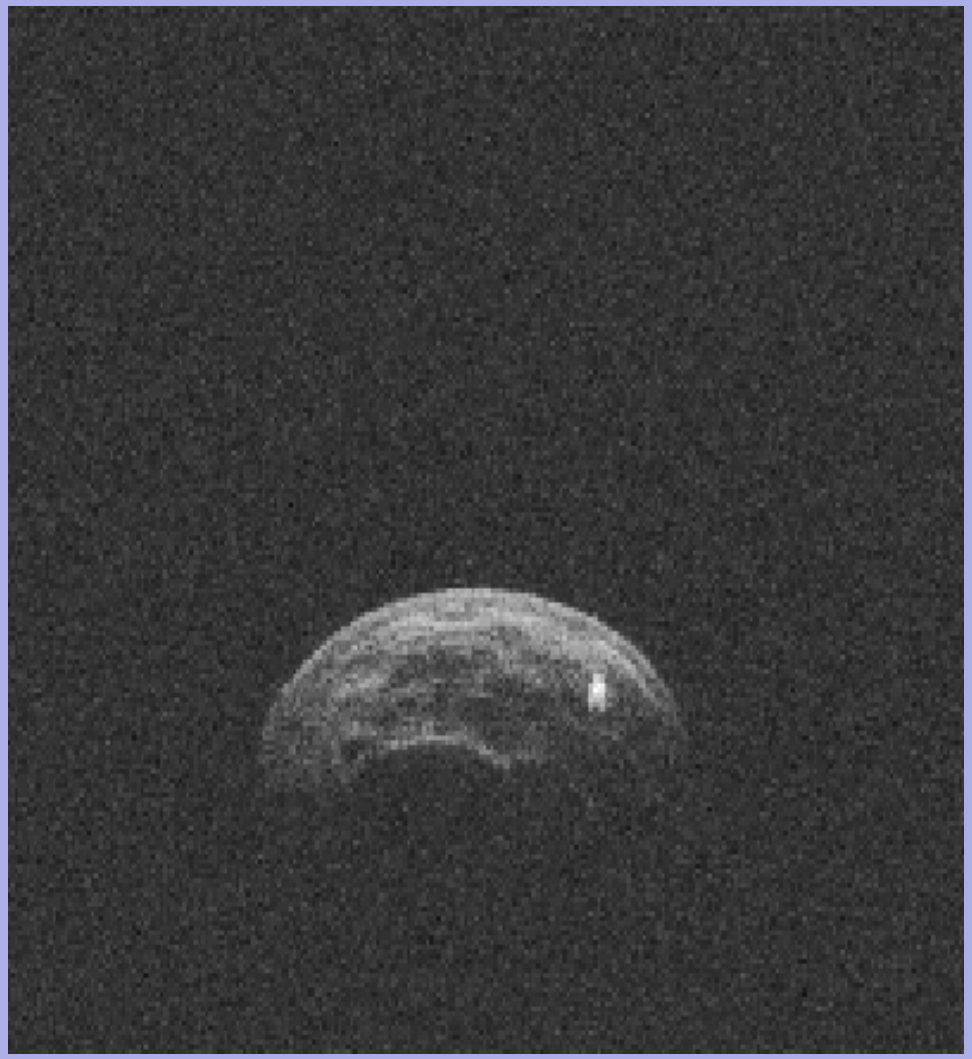
NASA InfraRed Telescope Facility (IRTF)

- Increased call-up for Rapid Response
- Improving operability/maintainability
- Improve Instrumentation for Spectroscopy and Thermal Signatures

Spitzer Infrared Space Telescope

- Orbit about Sun, ~176 million km trailing Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling

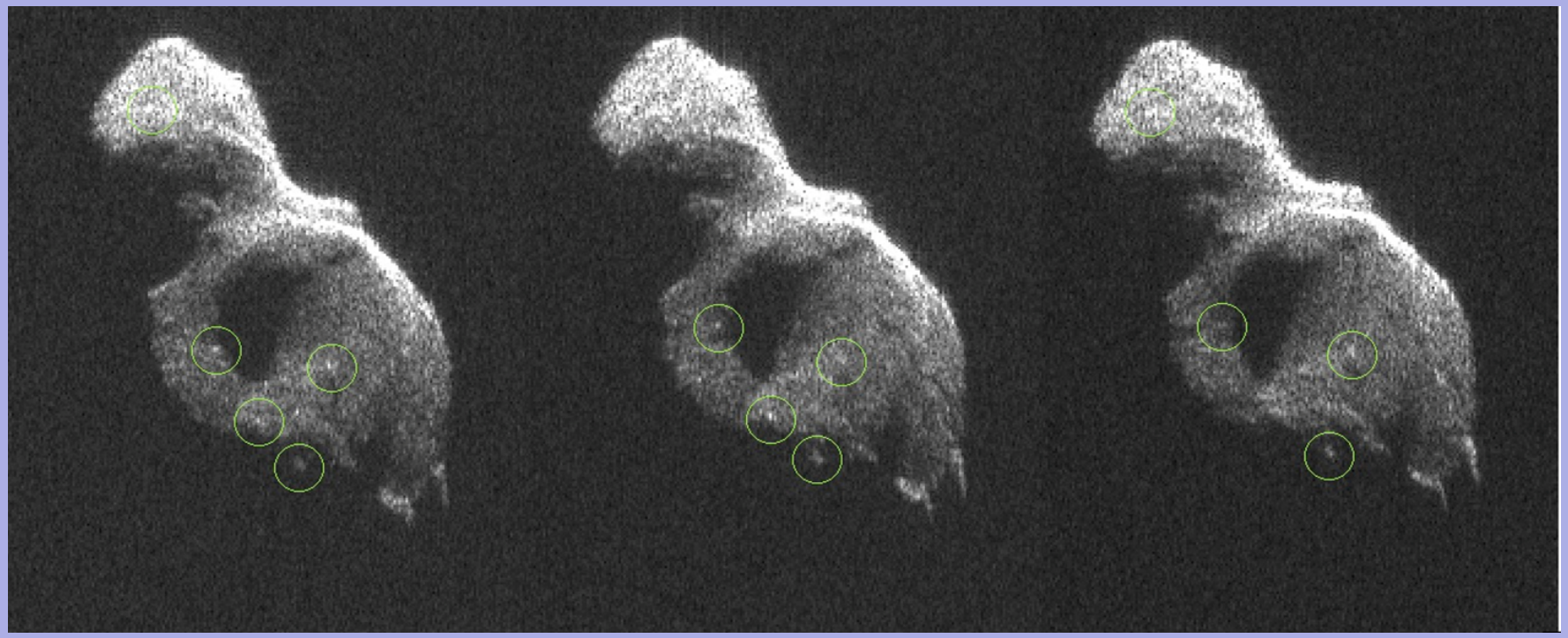
Radar Images of Asteroid 2004 BL86, Jan. 26, 2015



- Earth close approach of about 3.1 lunar distances
- The asteroid has a moon!
- Main Asteroid is about 330 meters across; satellite is about 70 meters across (it's small and blurry size in the image is an artifact of the processing)
- Radar pulses were transmitted from Goldstone, received at Greenbank
- Resolution is ~4 meters

Radar Imaging of 100 meter class NEAs

For observing this asteroid found by NEOWISE, radar scientists had the 70-meter (230-foot) Goldstone deep space radio antenna transmit signals to the asteroid, then the 305-meter (1000-foot) Arecibo Observatory collected the reflected radio waves. Images were produced with resolutions as fine as 3.75 meters that reveal an elongated asteroid at least 370 meters (1200 feet) in size with irregular surface features and a rotation period of about 20 hours.



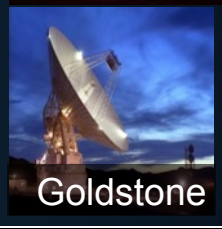
Asteroid Redirect Mission: Three Main Segments

IDENTIFY

Ground and space based assets detect and characterize potential target asteroids


Pan-STARRS


NEOWISE

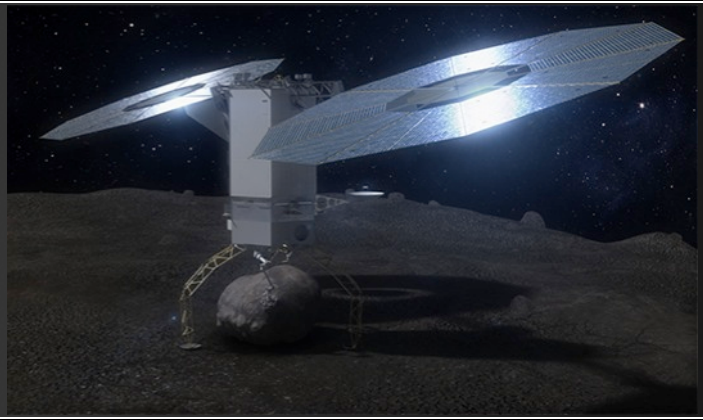

Goldstone

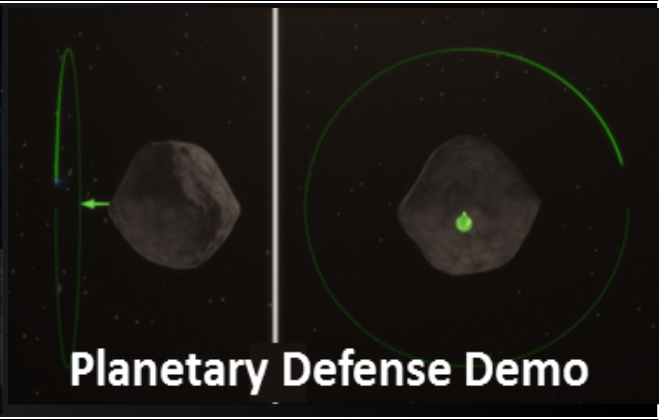

Arecibo


Infrared Telescope Facility

REDIRECT

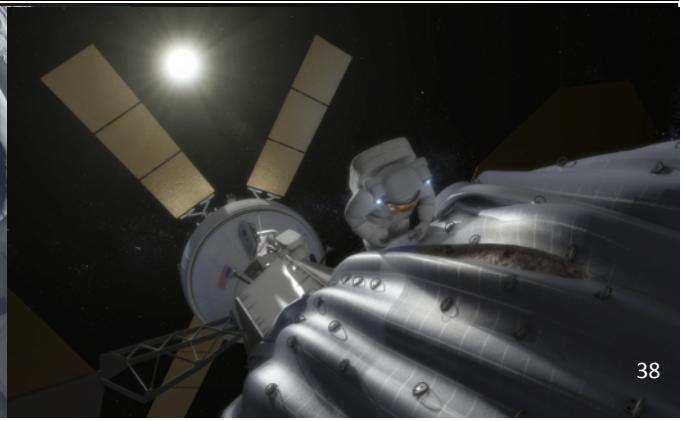
Solar electric propulsion (SEP) based system collects boulder, redirects asteroid, and returns mass to cis-lunar space




Planetary Defense Demo

EXPLORE

Crew launches aboard SLS rocket, travels to redirected asteroid in Orion spacecraft to rendezvous with redirected asteroid, studies and returns samples to Earth



ARM: Continued Search for NEO Candidates

Potential Candidates as extracted from NHATS Accessible NEOs
(As an example of need for enhanced characterization capabilities)

Object Designation	Orbit ID	H (mag)	Estimated Diameter (m)	OCC	Min. delta-V [delta-V, dur.] (km/s), (d)	Viable Trajectories	Next Optical Opportunity (yyyy-mm [Vp])	Next Arecibo Radar Opportunity (yyyy-mm [SNR])	Next Goldstone Radar Opportunity (yyyy-mm [SNR])
(2007 UY1)	31	22.9	46 - 205	2	**5.543**, 354	537652	2019-09 [23.4]	2020-10 [32]	2022-02 [18]
(2001 CQ36)	31	22.5	55 - 246	0	**5.824**, 354	473271	2021-01 [20.5]	2021-02 [18]	2031-02 [150]
(2013 WA44)	17	23.7	32 - 142	3	**5.936**, 354	603331	2020-12 [19.9]	*none*	*none*
(2006 FH36)	16	22.9	46 - 205	2	**6.077**, 346	630059	2019-03 [23.7]	2021-08 [17]	*none*
(2014 YD)	20	24.3	24 - 107	3	**6.115**, 258	780622	2015-06 [20.1]	*none*	*none*
(2001 QJ142)	21	23.7	32 - 142	0	**6.299**, 354	638369	2023-11 [19.6]	2024-04 [74]	*none*
(2012 BA35)	9	23.8	30 - 135	4	**6.377**, 354	242768	2021-04 [23.2]	2021-07 [28]	2021-08 [170]
(2014 QH33)	15	24.4	23 - 101	0	**6.514**, 354	214335	2022-01 [21.0]	*none*	*none*
(1999 AO10)	15	23.9	29 - 129	5	**6.550**, 194	462473	2018-12 [22.4]	2026-02 [780]	2026-02 [29]
341843 (2008 EV5)	102	20	174 - 778	0	**6.654**, 354	320650	2021-12 [21.8]	2023-12 [9600]	2023-12 [320]

ARM Design Reference Candidate

INTERAGENCY WORKING GROUP FOR DEFLECTING AND MITIGATING THE IMPACT OF EARTH-BOUND NEAR-EARTH OBJECTS COMMITTEE ON HOMELAND AND NATIONAL SECURITY NATIONAL SCIENCE AND TECHNOLOGY COUNCIL

D. Membership

The members from each of the departments and agencies listed below should be able to provide technical recommendations and facilitate communications within their respective organizations. The following NSTC departments and agencies are represented in the DAMIEN-IWG:

- Department of Commerce
- Department of Defense
- Department of Energy
- Department of Homeland Security
- Department of the Interior
- Department of State
- National Aeronautics and Space Administration (Co-Chair)
- National Science Foundation
- Office of the Director of National Intelligence

The following organizations in the Executive Office of the President shall also be represented on the DAMIEN-IWG:

- National Security Council
- Office of Management and Budget
- Office of Science and Technology Policy (Co-chair)

Each department, agency, and organization is expected to provide a senior level (describe level desired) participant for executive level meetings, as well as a working level member to participate in interagency working group activities.