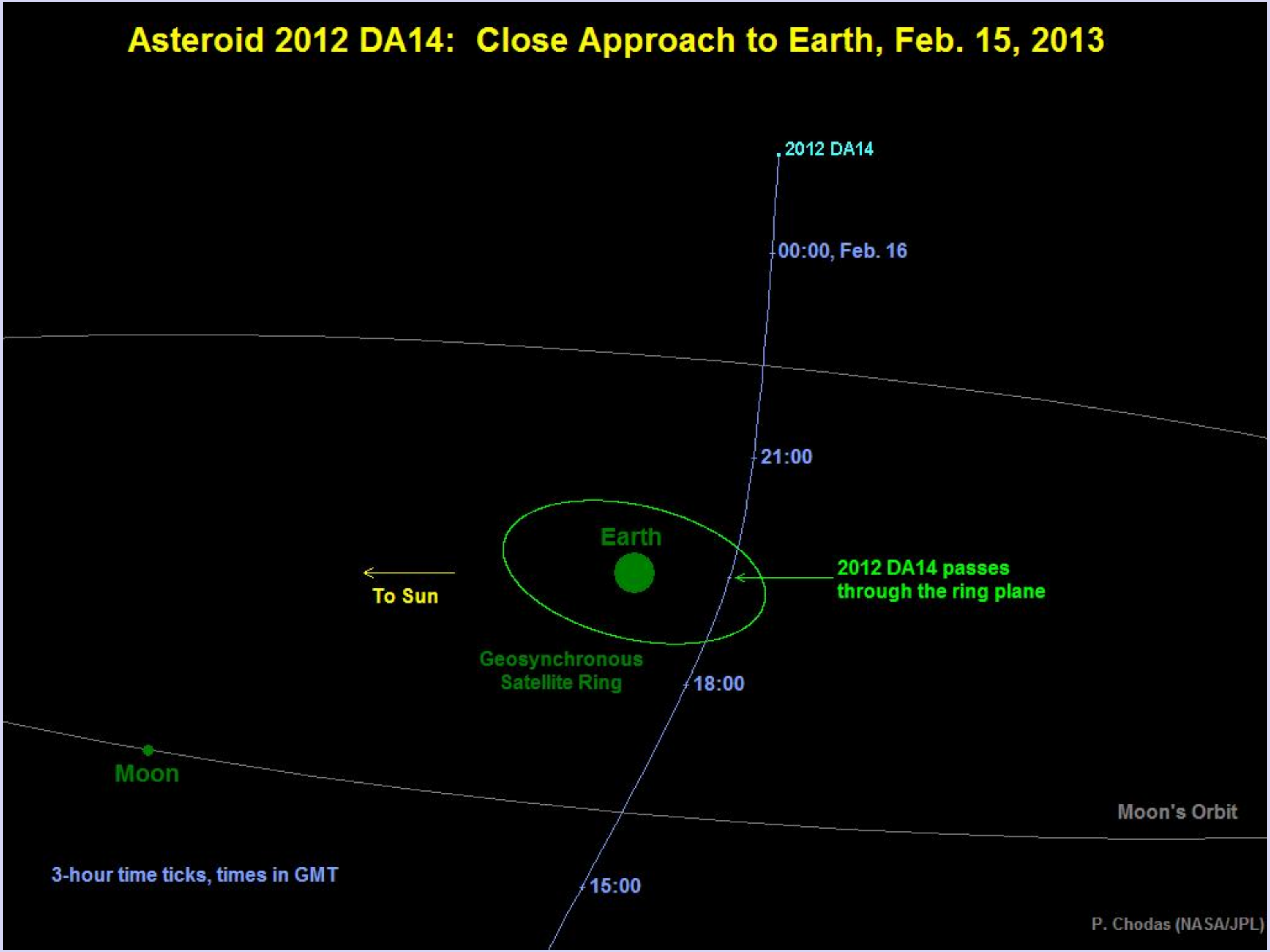
Finding Near Earth Objects
Before They Find Us!
(and knowing what to do about it)

Agency Grand Challenge
Seminar Series

Lindley Johnson
Near Earth Object
Programs Executive
NASA HQ

February 28, 2014

Close Approach of 2012 DA14



CHELYABINSK EVENT

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

CHELYABINSK EVENT

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

United States Government Policy and Approach Regarding Planetary Defense

Source

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

Background

- US President's new plan for human space flight, announced April 15, 2010*, establishes the goal of conducting a human mission to an NEO by 2025

  * http://www.whitehouse.gov/the-press-office/remarks-president-space-exploration-21st-century

- US National Space Policy, June 28, 2010*

  NASA shall: "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."

  * http://www.whitehouse.gov/sites/default/files/national_space_policy_6-28-10.pdf

- US President's FY2014 NASA Budget Request:

  "The budget request includes a doubling of NASA's efforts to identify and characterize potentially hazardous near-Earth objects (NEOs). This increase in the budget reflects the serious approach NASA is taking to understand the risks of asteroid impacts to our home planet. It will also help identify potential targets for the future human mission to an asteroid."

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

NEO Threat Notification

Upon notification from NASA:

Of impending NEO Threat to United States territory:

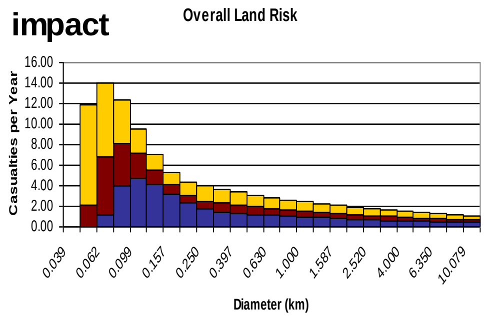
- The Federal Emergency Management Agency (FEMA) takes lead to notify appropriate Federal, state and local authorities and emergency response institutions utilizing existing resources and mechanisms
  - When time/location of affected areas known, activate National Warning System
  - Analogous to large 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:

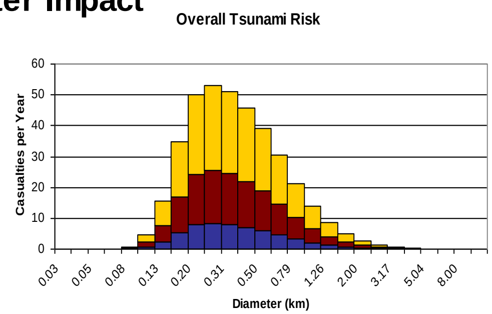
- US Department of State facilitates international notifications in effort to minimize loss of human life and property
  - Bilaterally through diplomatic channels to potentially affected countries
  - To member nations of multilateral forums – UN entities (OOSA, COPUOS), NATO, etc
  - Post-impact event,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

Integrated Unknown Impact Risk*

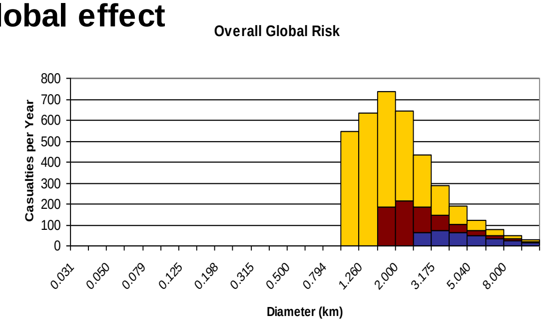
Land impact



Water Impact

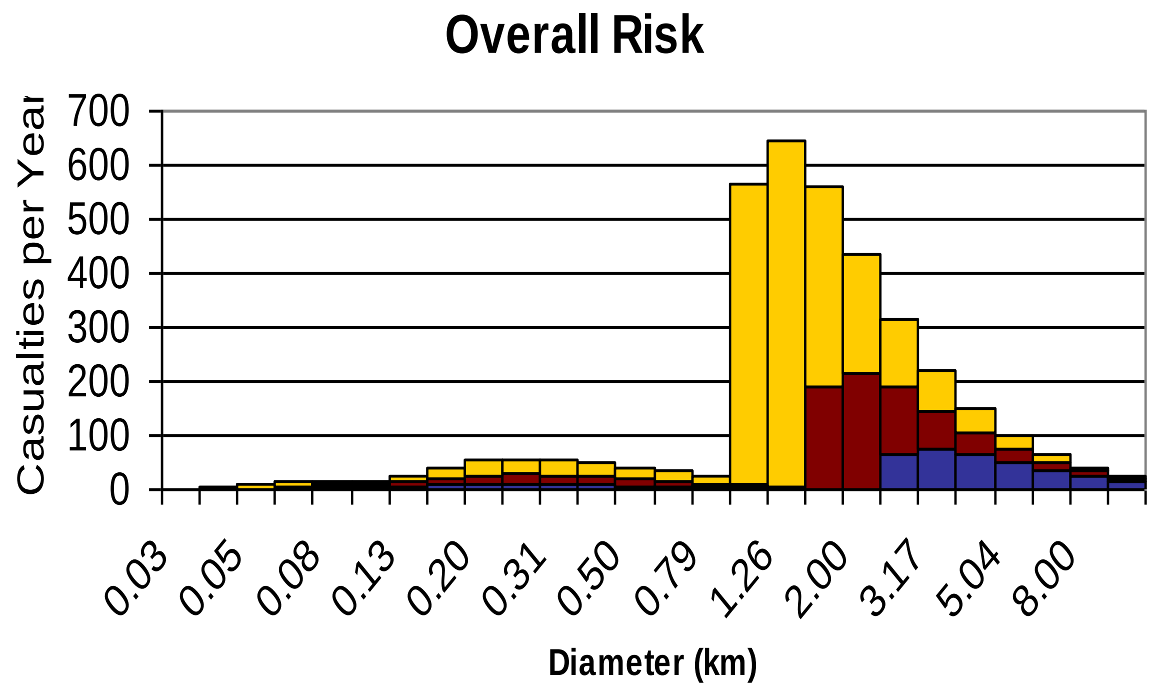


Global effect



Min Nom Max

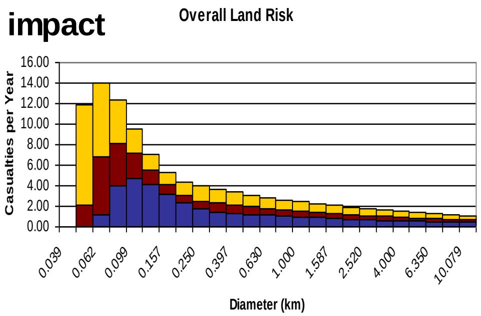
~1250 casualties/year



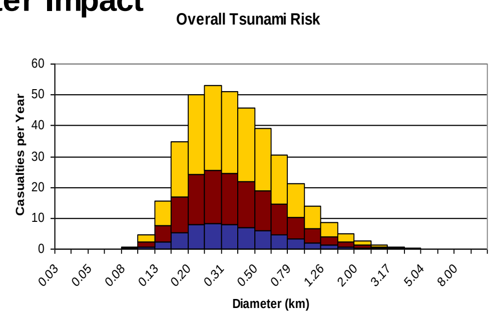
* Near Earth Object Science Definition Team Report, Aug 22, 2003

Residual Unknown Impact Risk*

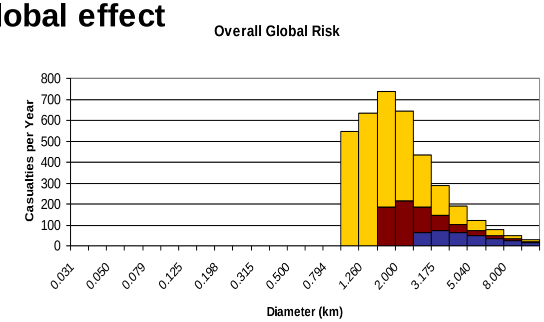
Land impact



Water Impact

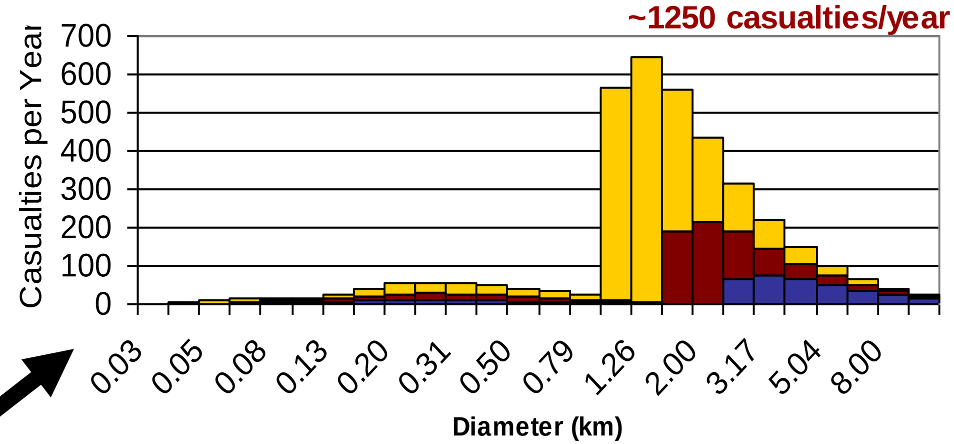


Global effect



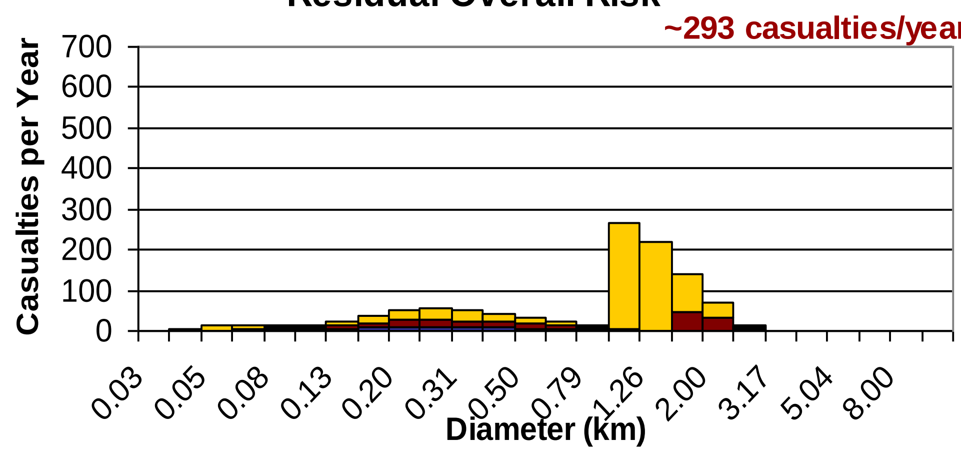
Min Nom Max

Overall Risk



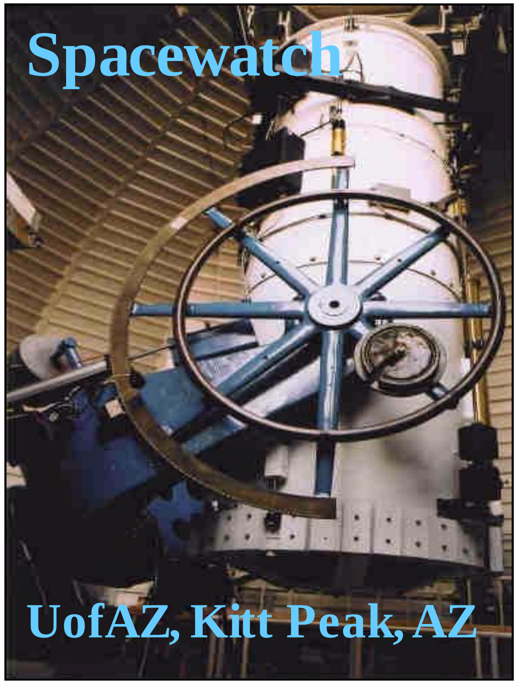
Search Until 2008

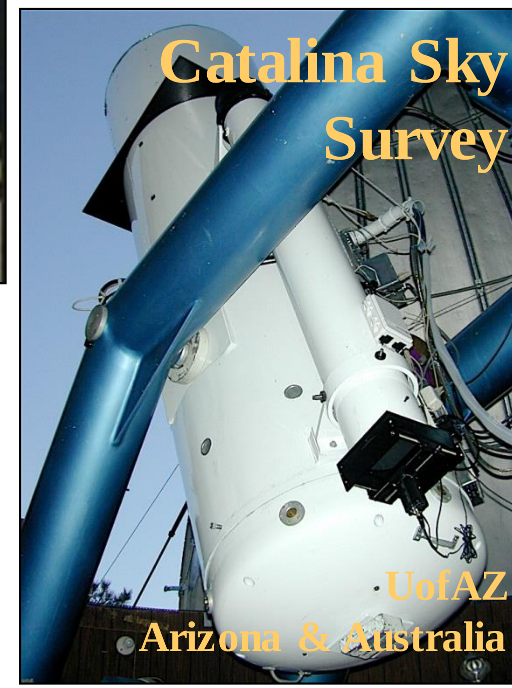
Residual Overall Risk



* Near Earth Object Science Definition Team Report, Aug 22, 2003

NASA's NEO Search Projects (circa 2004)





NASA's NEO Search Program

(Current Systems)

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

http://minorplanetcenter.net/

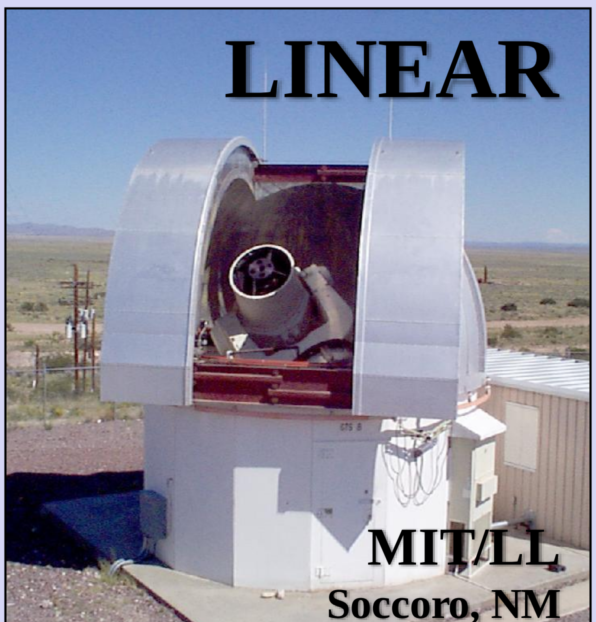
NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

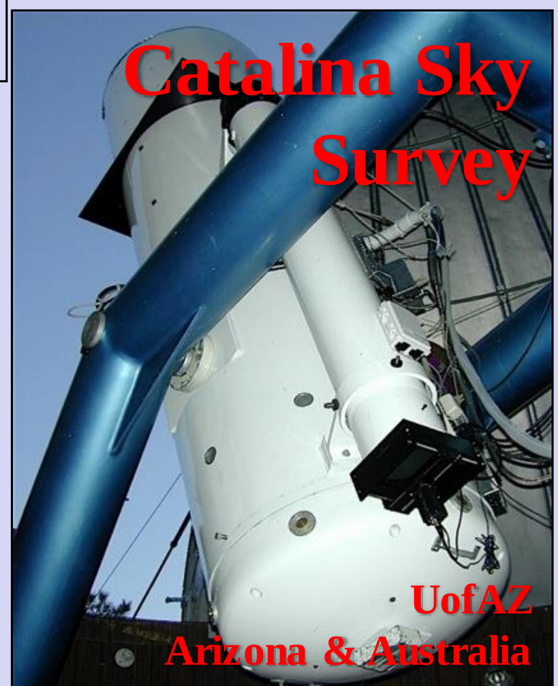
http://neo.jpl.nasa.gov/

Operations
Jan 2010
Feb 2011,
129 NEAs found

Reactivated
Sep 2013

Ops in Dec
6 NEAs 1 comet





Data Analysis/Management

- Minor Planet Center (MPC)
  - Smithsonian Astrophysical Observatory, Cambridge, MA
    - Dr Tim Spahr, Director
  - Widewide observation coordination and correlation, initial orbit determination

  http://minorplanetcenter.net/

- Near Earth Object Program Office
  - Jet Propulsion Laboratory, Pasadena, CA
    - Dr Donald Yeomans, Program Manager
  - Precision orbit determination and hazard prediction
    - Compares results with NEODynamics System, Univ of Pisa, Italy

  http://neo.jpl.nasa.gov

NEO Observations 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

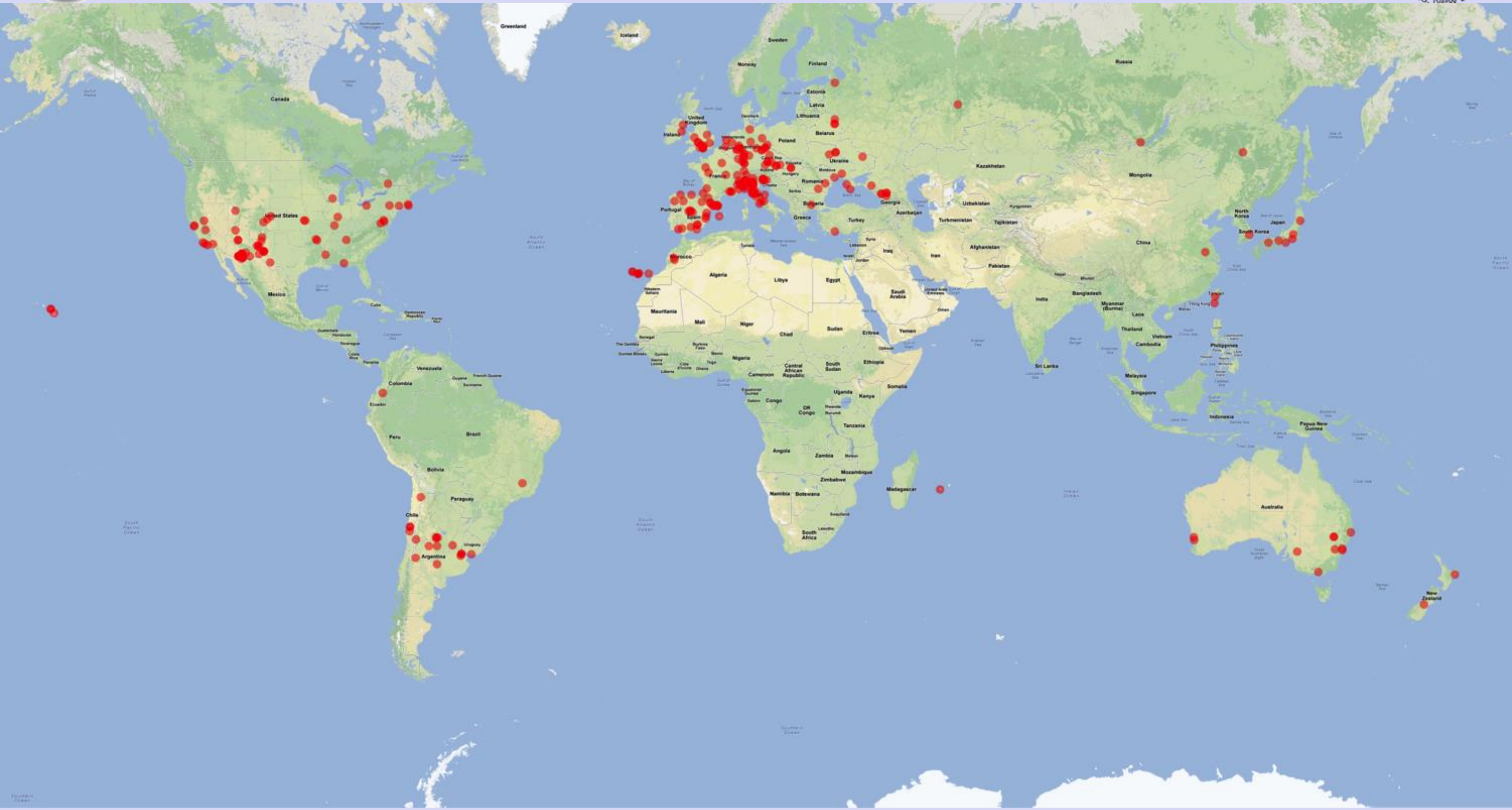
NASA Authorization Act of 2005 provided additional direction:

"…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 ≥ 90% of NEOs larger than 140 meters in size as soon as possible

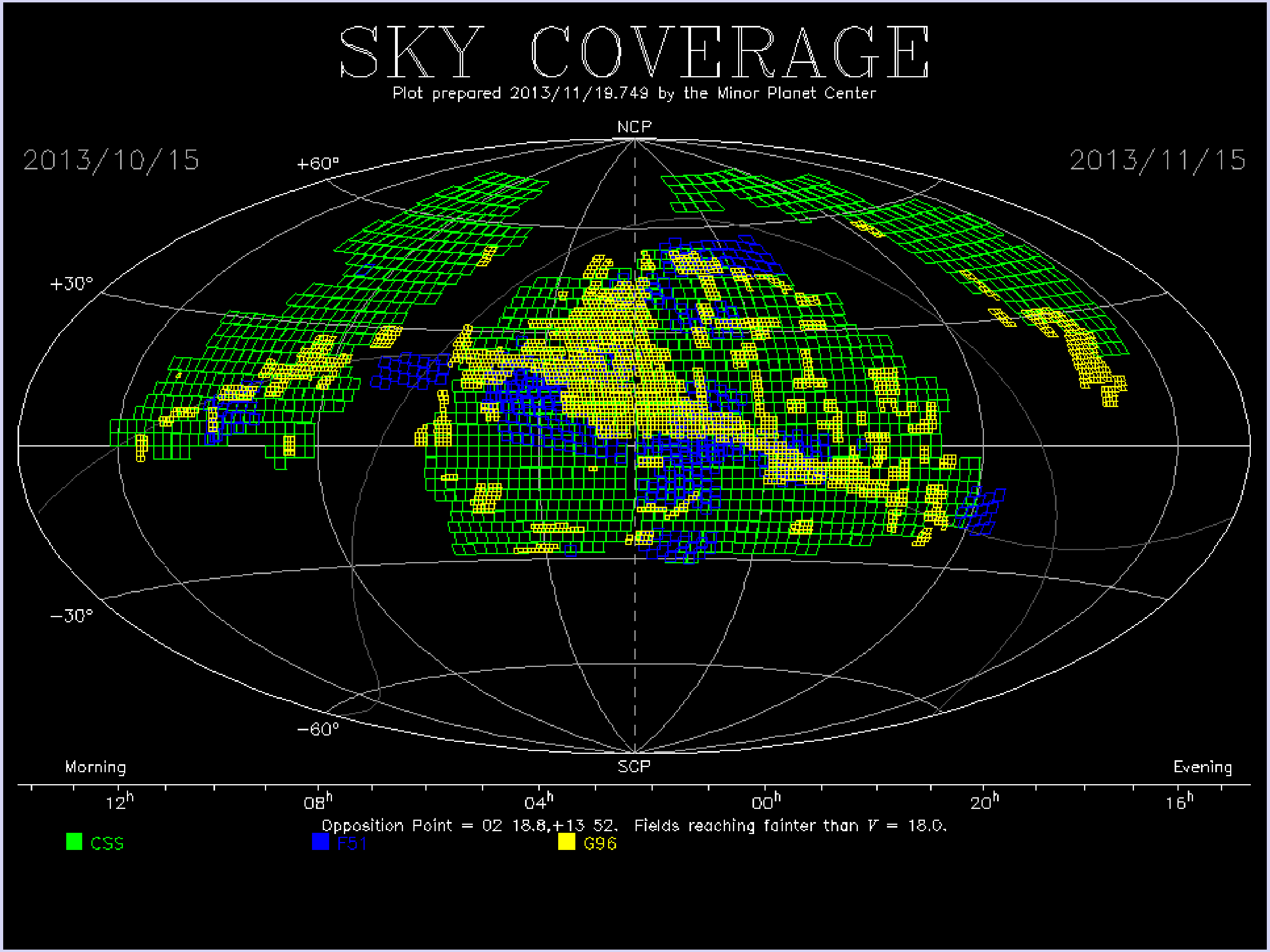
- Starting with FY2012, now has $20.5 M/year
- FY2014 budget increases to $40.5 M/year

Existing Worldwide Observing Network



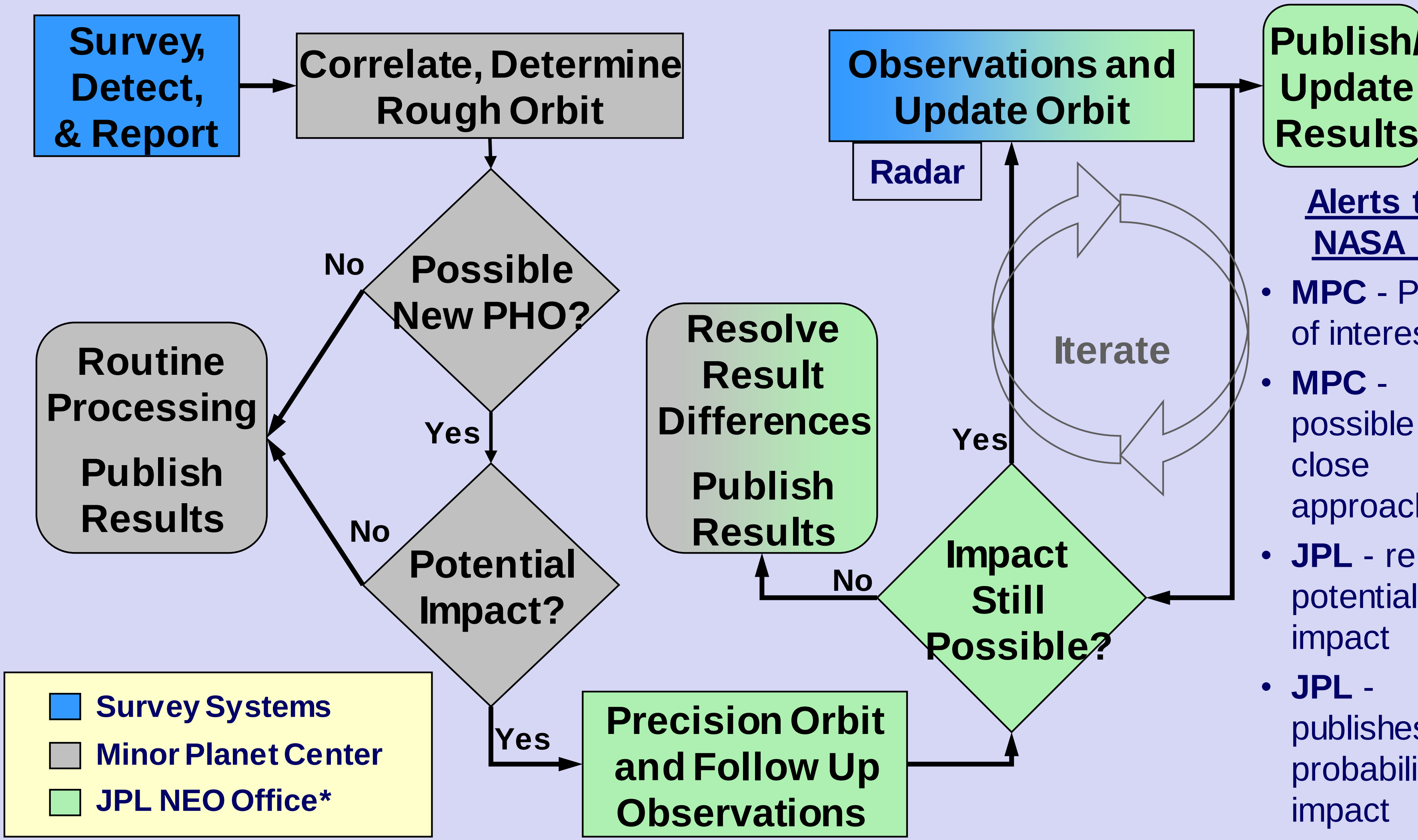
Data from 46 countries in 2012

Searching the Sky for Asteroids



Spaceguard Survey Catalog Program

Current Spaceguard Survey Infrastructure and Process

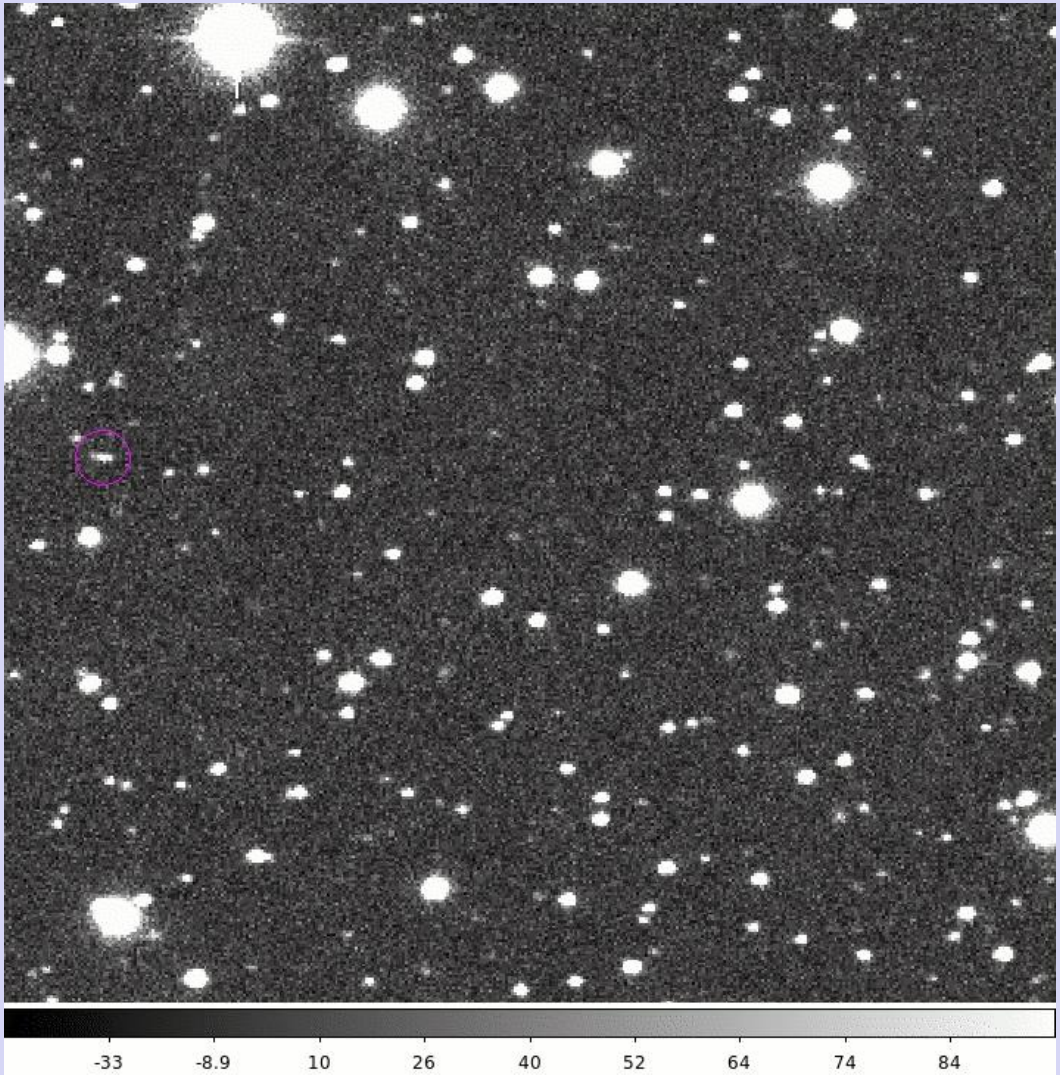


<u>Alerts to NASA HQ</u>

- **MPC** - PHO of interest
- **MPC** - possible close approach
- **JPL** - reports potential for impact
- **JPL** - publishes probability of impact

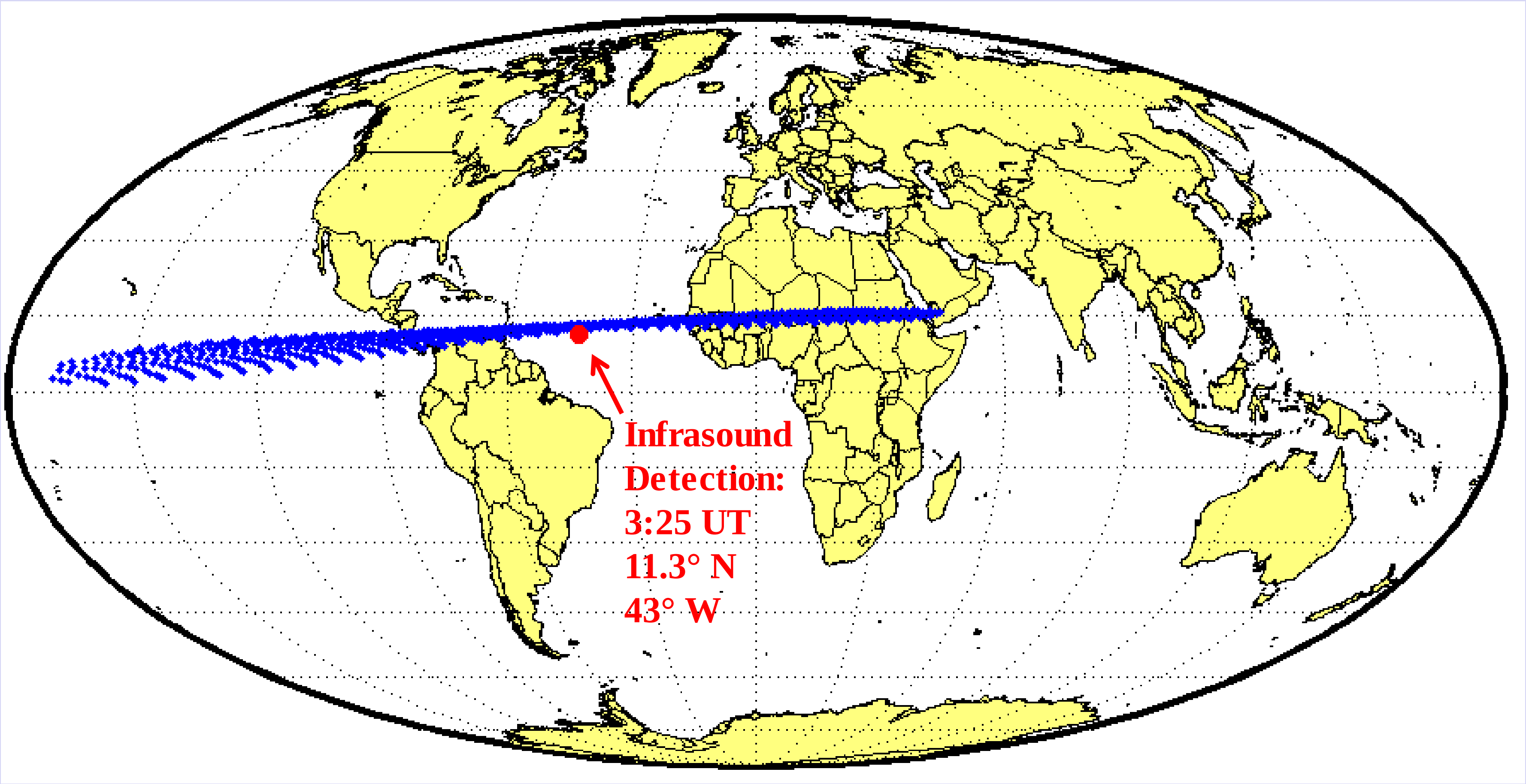
* In parallel with NEODyS

Discovery Images of Asteroid 2014 AA



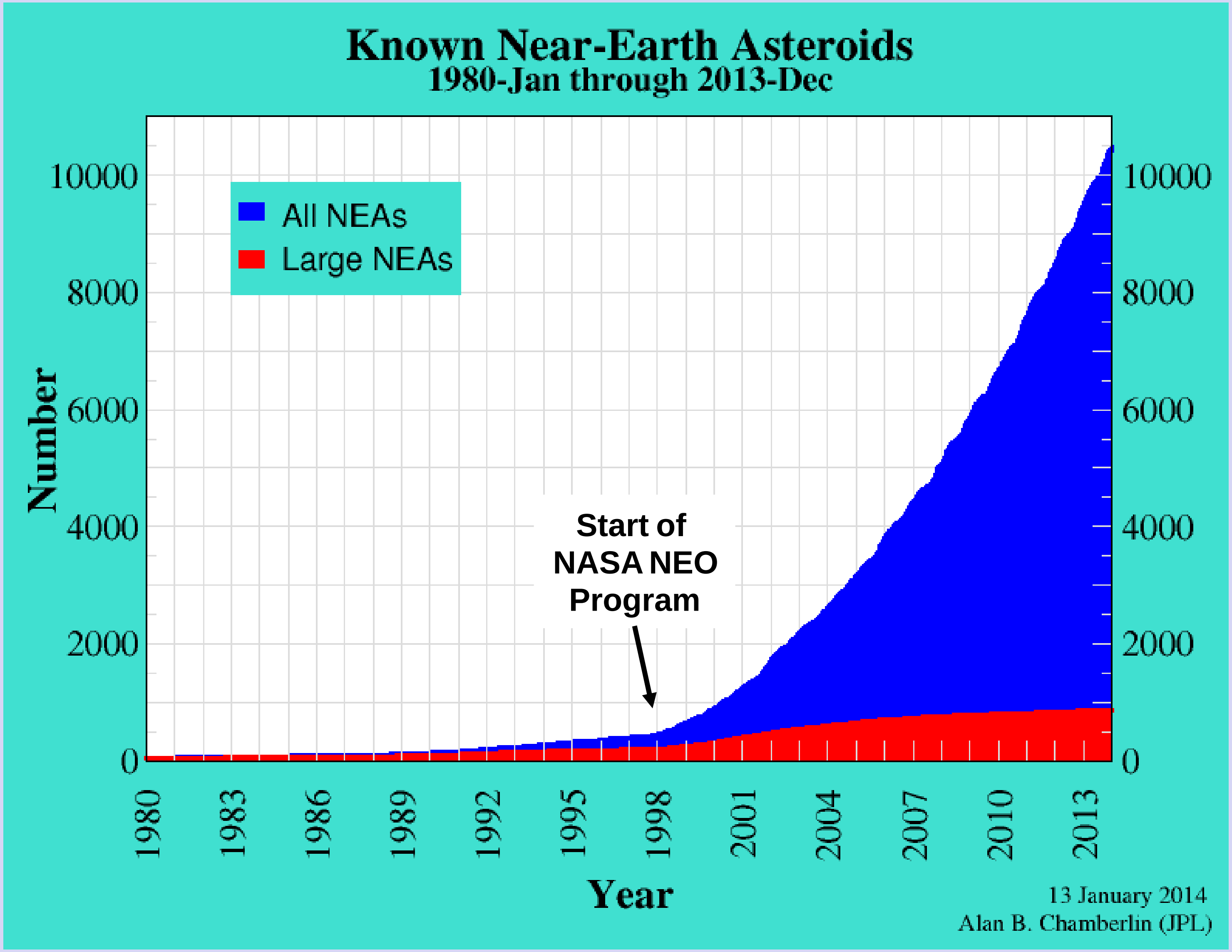
Courtesy of Catalina Sky Survey

2014 AA Predicted Impact Location



Credit Steve Chesley, NEO PO, JPL

Known Near Earth Asteroid Population



10,675
2/1/14

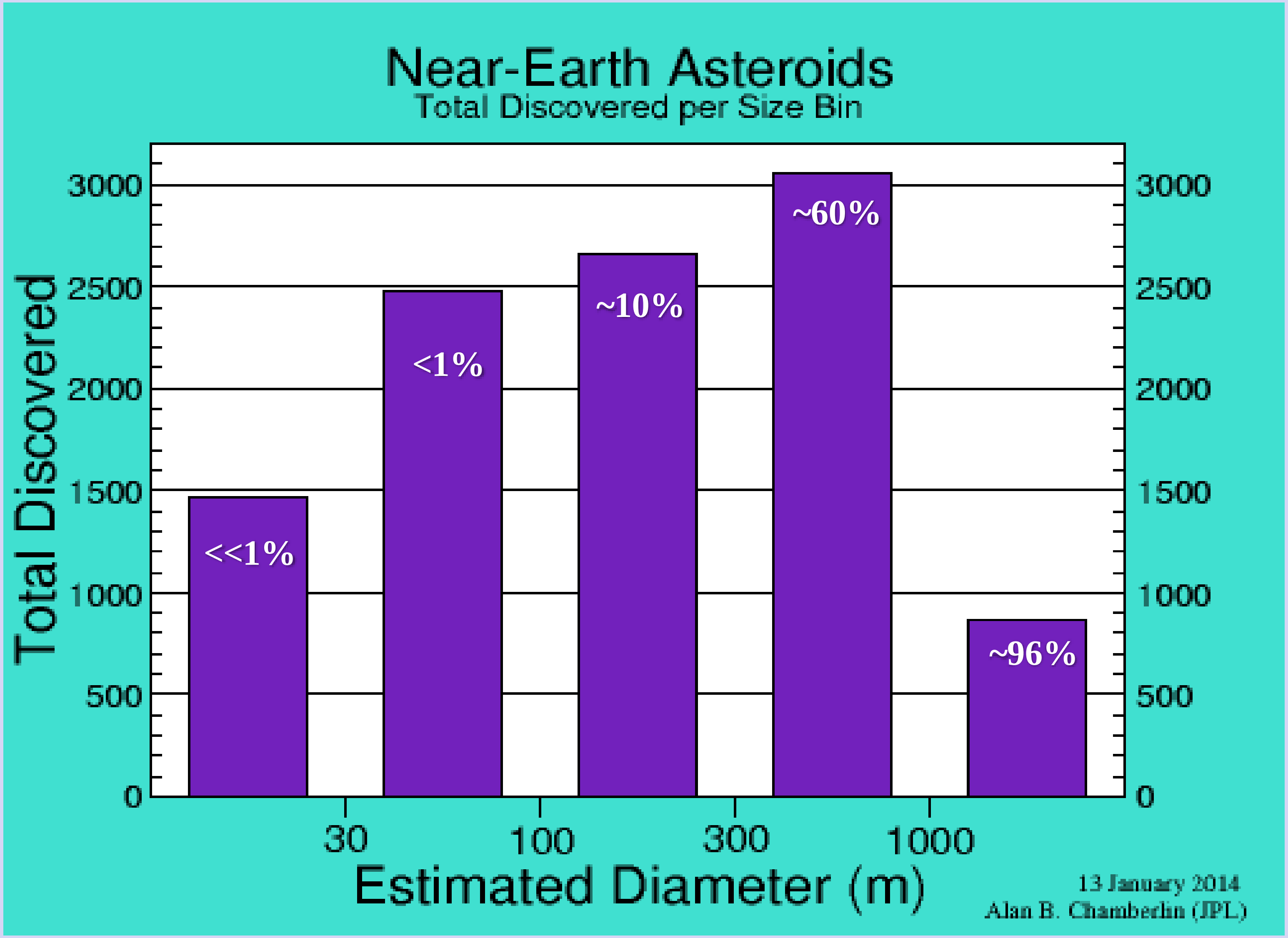
Includes 94 comets

1449 PHAs

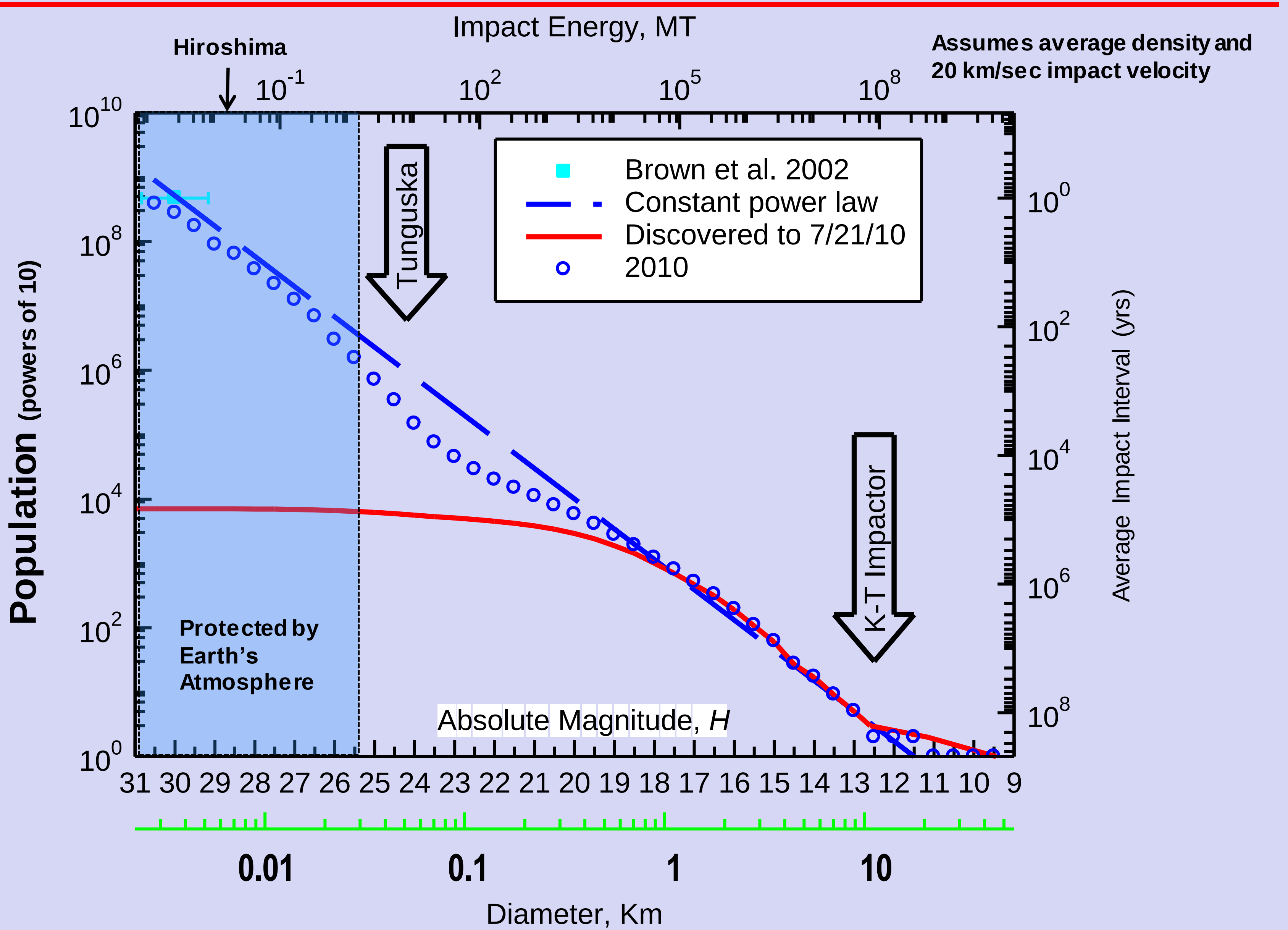
866
2/1/14

154 PHAs

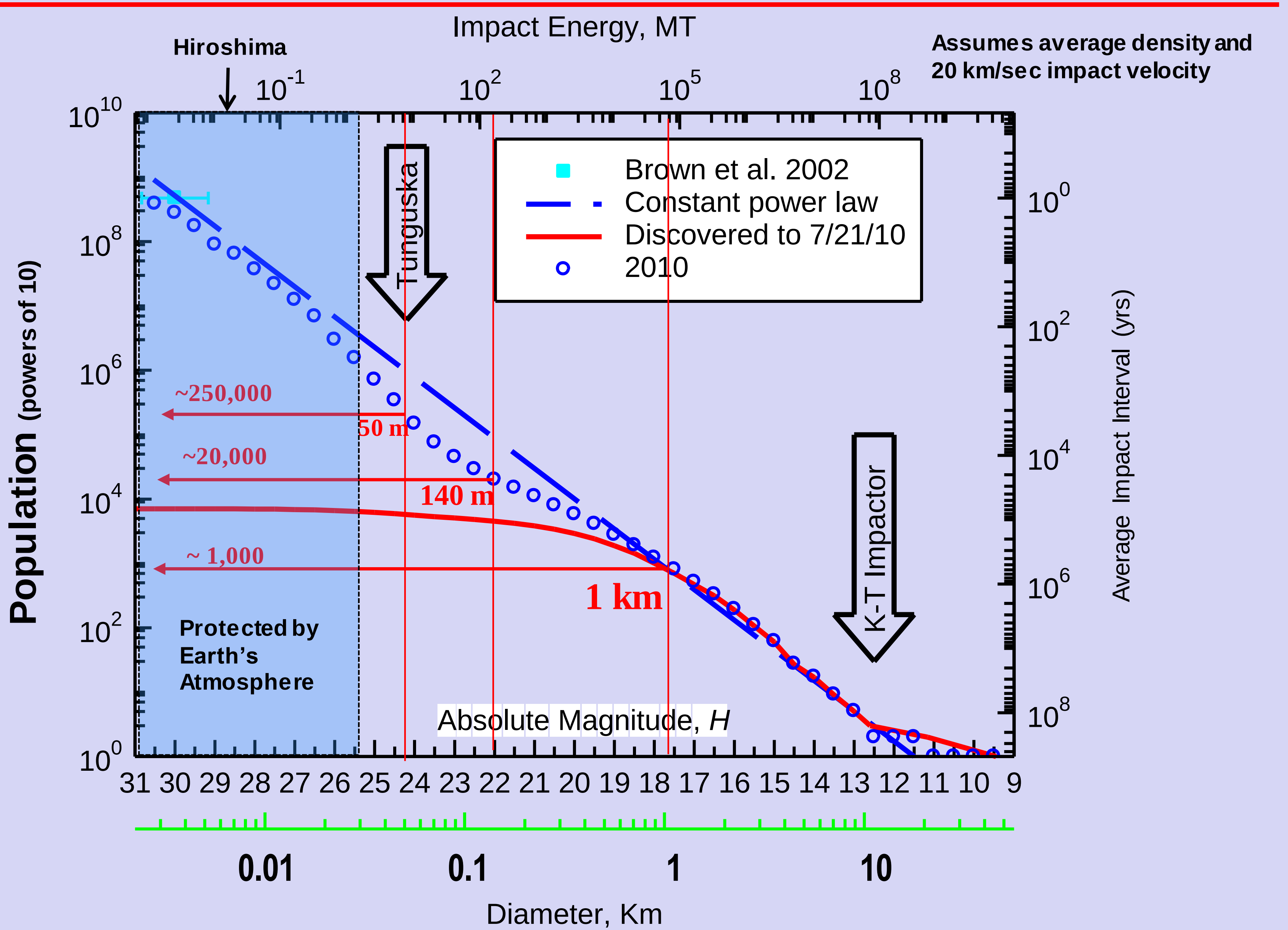
Known Near Earth Asteroid Population



Population of NEAs by Size, Brightness, Impact Energy & Frequency (A. L. Harris 2010)



Population of NEAs by Size, Brightness, Impact Energy & Frequency (A. L. Harris 2010)



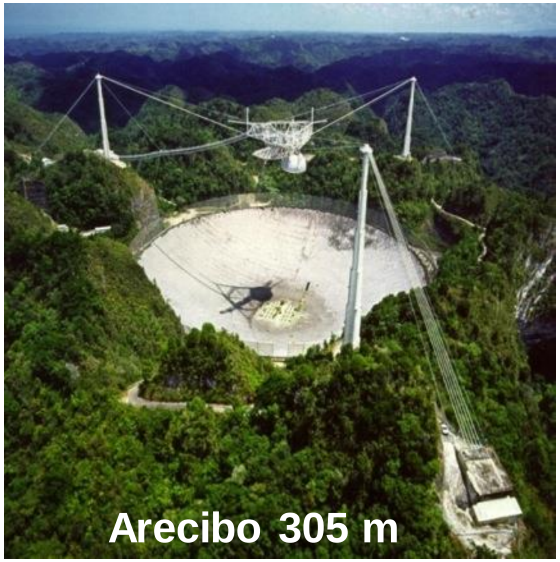
Physical Characterization of NEAs

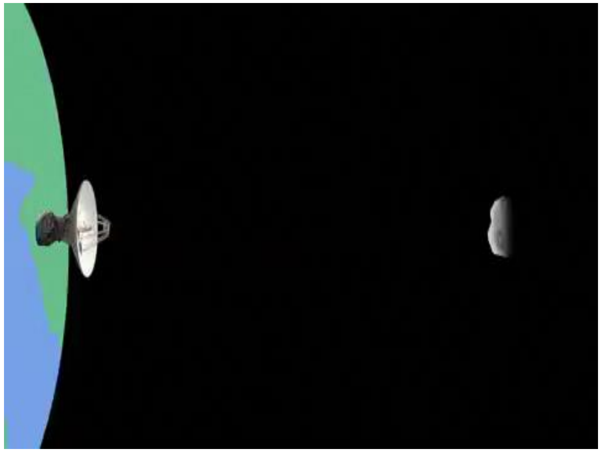
- **Radar** is essential for obtaining an accurate estimate of size and shape to within ~2 m, as well as rotation state.
- Ground-based and space-based **IR** measurements are important for estimating albedo and spectral class, and from these an approximate density can be inferred.
- **Light curves** 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

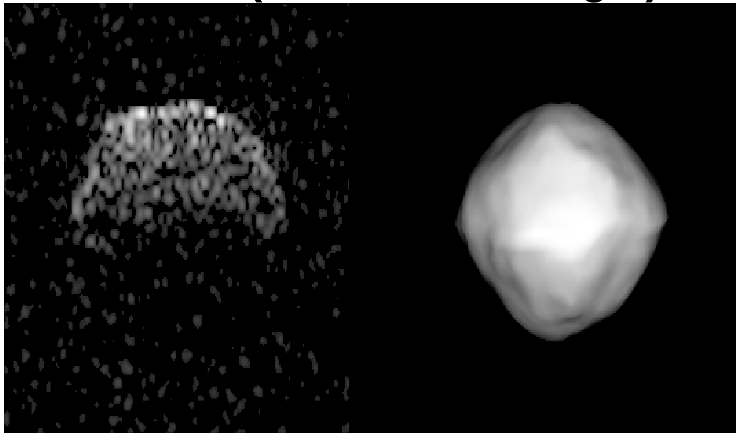
Radar Observations of NEOs





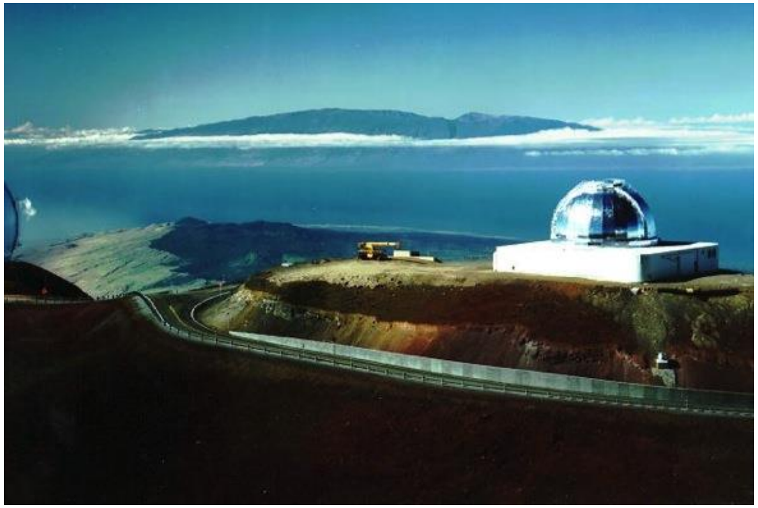
- These are complementary capabilities.
  - Arecibo has more power and range
  - Goldstone has more resolution and field of regard
- Currently, 70-80 NEOs are observed every year.
- Radar observations can provide:
  - Size and shape to within ~2 meters.
  - High precision range/Doppler orbit data.
  - Spin rate, surface density and roughness.

Bennu (OSIRIS-ReX Target):



Observations **Shape Model**

NEO Infrared Characterization



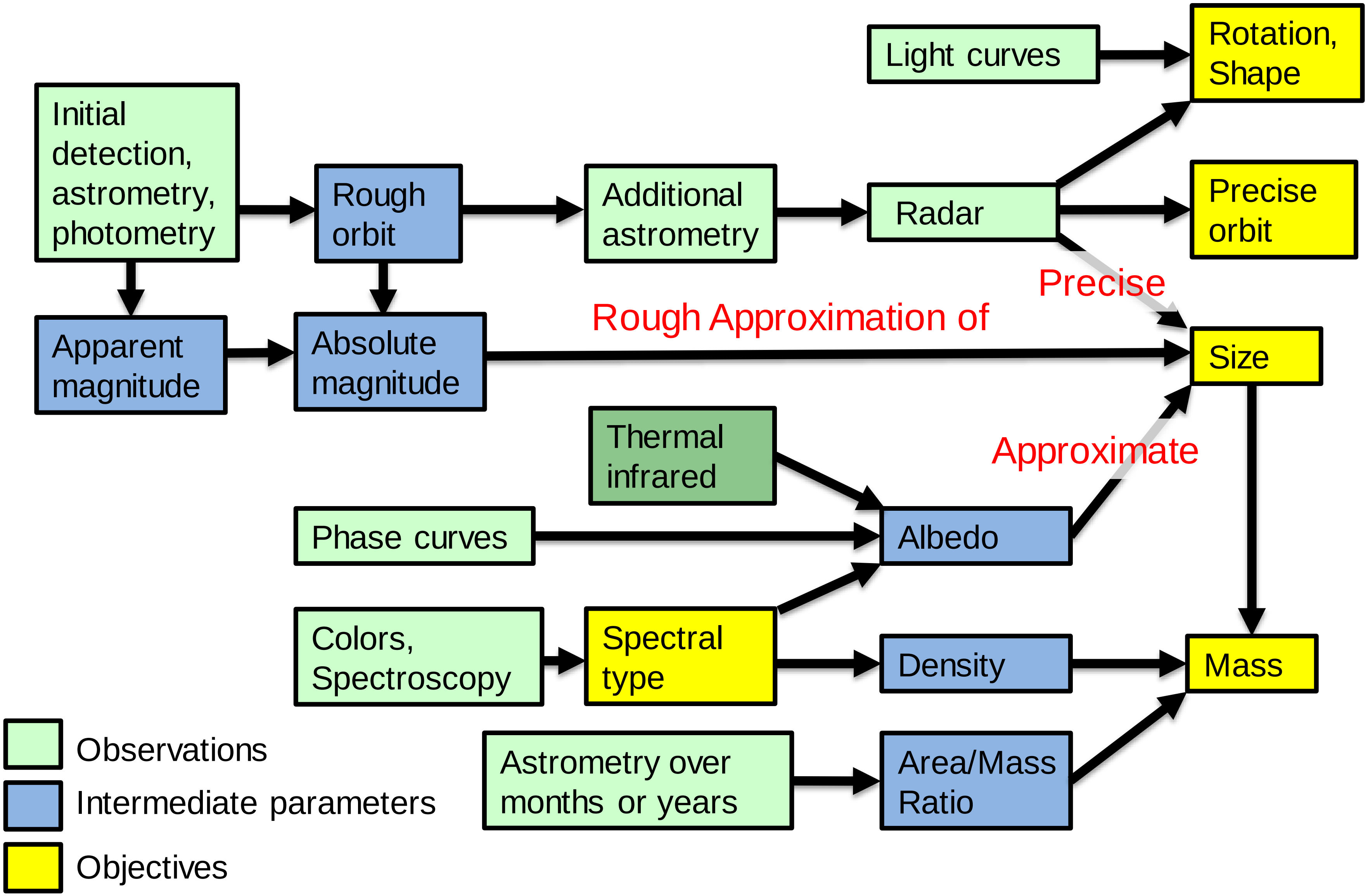
NASA InfraRed Telescope Facility (IRTF)

- Dedicated Planetary Science Observatory
- Characterization of Comets and Asteroids
- Spectroscopy and Thermal Signatures
- On-call for Rapid Response on Discoveries

Spitzer Infrared Space Telescope

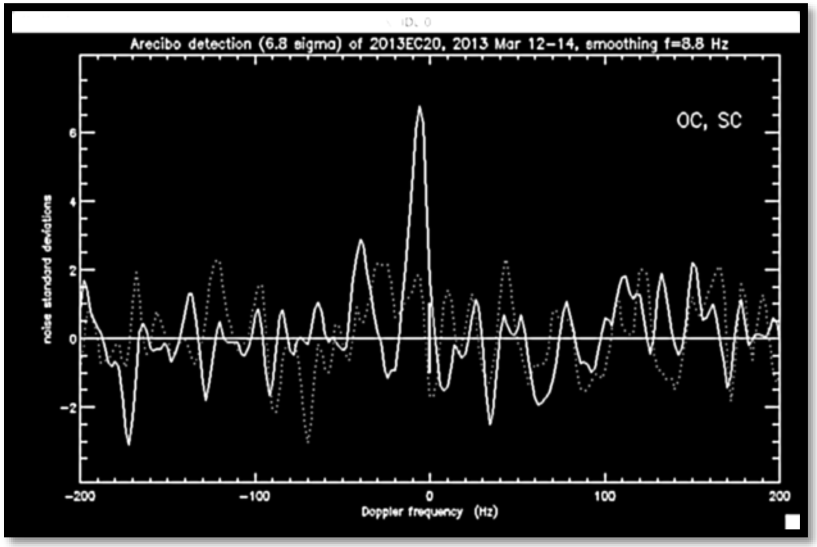
- Orbit about Sun, ~176 million km from Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling

Characterization Process



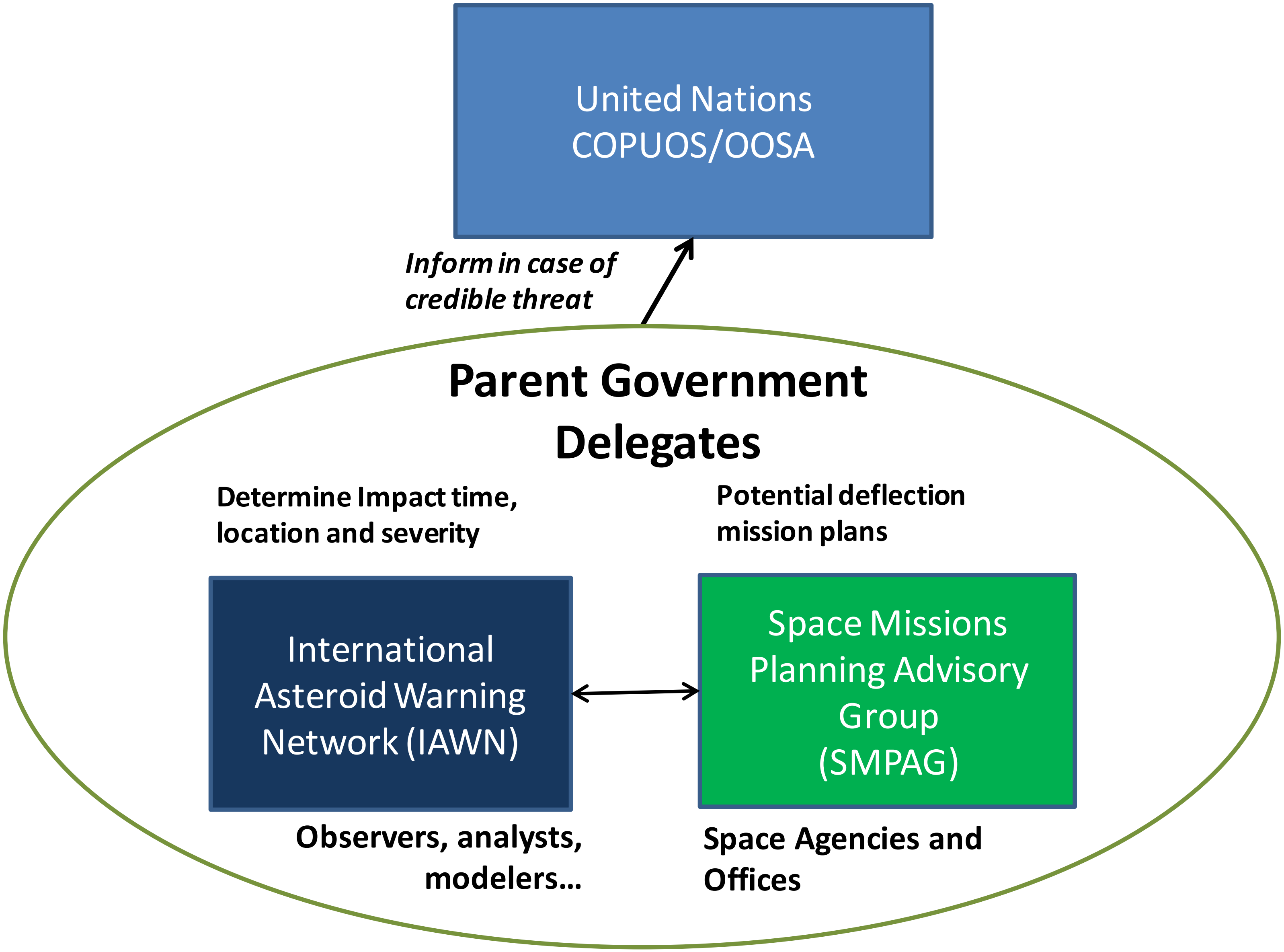
Characterization Process Exercised for 2013 EC20

- Discovered March 7, 2013 by Catalina Sky Survey.
  - Initial size estimate: ~6m, Close approach 8 March at 0.5 lunar distance.
- Request follow-up astrometry ⇨ orbit update to enable IRTF observation.
- IRTF Interrupt: Spectra and thermal IR [Moskovitz & Binzel]:
  - L- or Xe-type, inferred albedo range of 0.1-0.4, density range of 2.0-3.0 g/cc
  - Diameter = 2.6 - 8.4 m, mass = 20 - 930 t
  - Spin rate ~0.5 rpm
- Arecibo radar @~3 lunar dist. [Borozovic]:
  - Diameter = 1.5 - 3 m ⇨ albedo > ~0.4
  - Constrains mass to < 50 t
  - Spin rate: 0.5 – 2 rpm

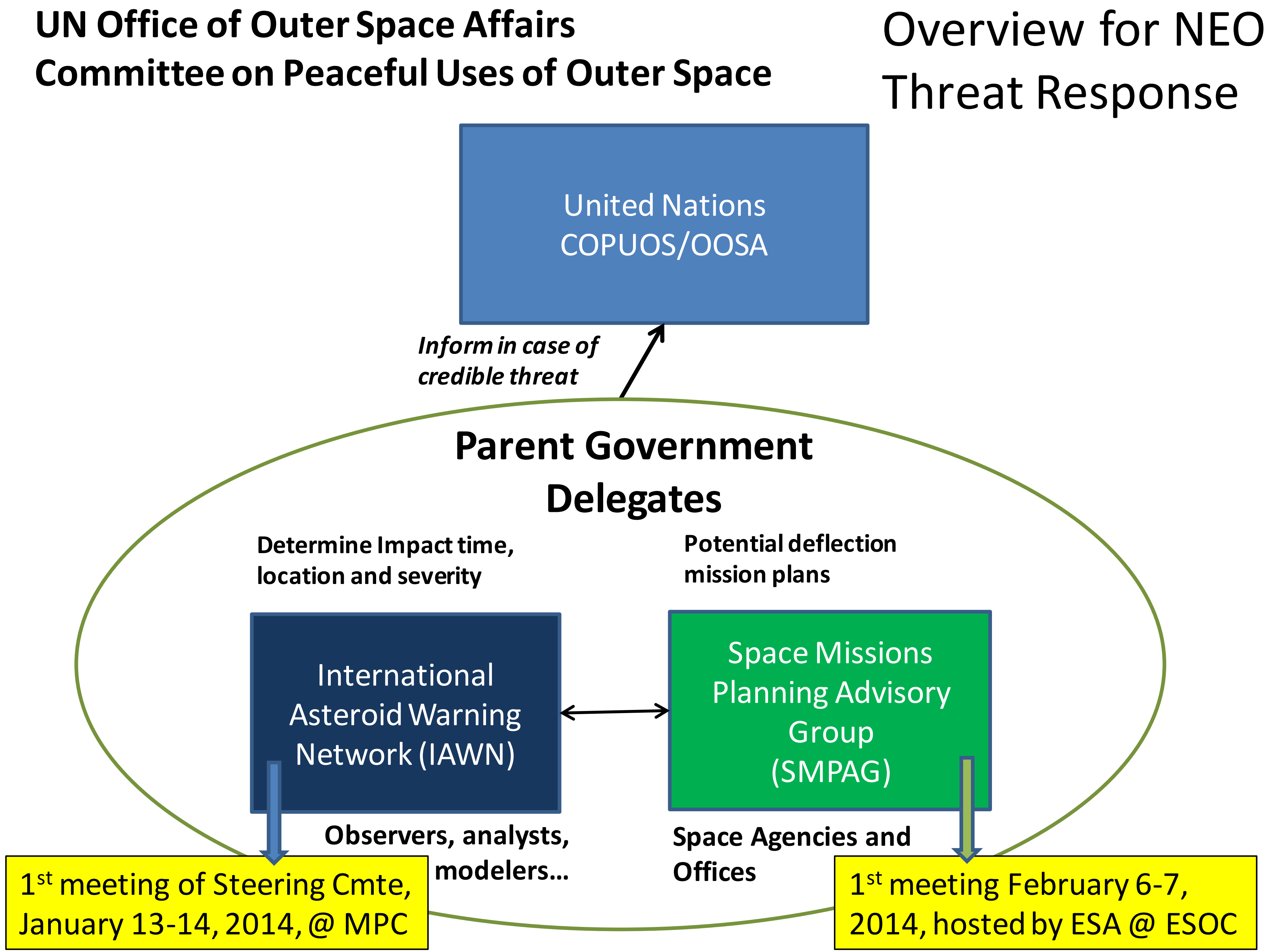


UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space

Overview for NEO Threat Response*



*http://www.oosa.unvienna.org/oosa/en/COPUOS/stsc/wgneo/index.html


UN Office of Outer Space Affairs
Committee on Peaceful Uses of Outer Space
Overview for NEO Threat Response
United Nations COPUOS/OOSA
Inform in case of credible threat
Parent Government Delegates
Determine Impact time, location and severity
Potential deflection mission plans
International Asteroid Warning Network (IAWN)
Space Missions Planning Advisory Group (SMPAG)
Observers, analysts, modelers…
Space Agencies and Offices
1st meeting of Steering Cmte, January 13-14, 2014, @ MPC
1st meeting February 6-7, 2014, hosted by ESA @ ESOC

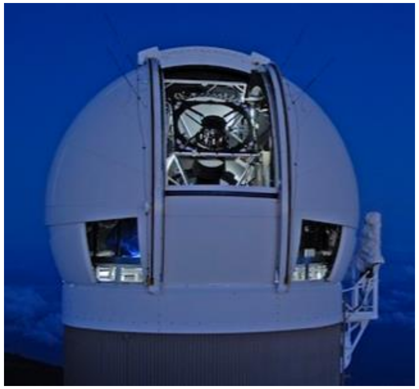
Future Capability for Planetary Defense

NASA Near-Earth Object Survey and Deflection - Analysis of Alternatives Report to Congress, March 2007 http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf

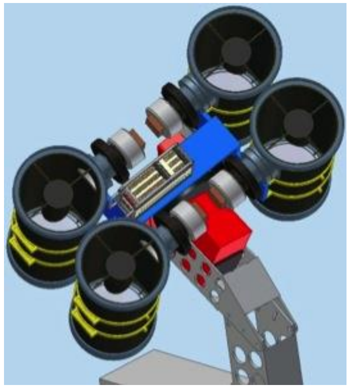
NRC Report – “Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies”, January 2010 http://www.nap.edu/openbook.php?record_id=12842

Primary Enhancements for NEO Search

- **NEO Time on DARPA Space Surveillance Telescope**
  - Large 3.6m telescope, first light: Feb 2011, now in testing.
  - Eventual operations by AFSPC for DoD Space Situational Awareness.
  - Testing of NEO detection capability: Late 2013, early 2014.



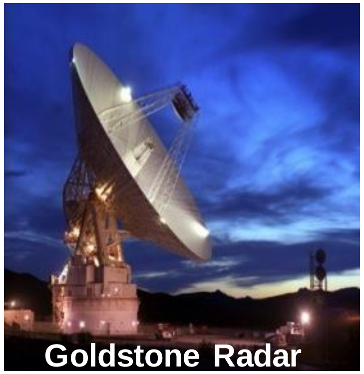
- **Enhancing Pan-STARRS 1, Completing Pan-STARRS 2**
  - Increase NEO search time to 100% on PS1: Early 2014.
  - Complete PS2 (improved copy of PS1): Late 2014.

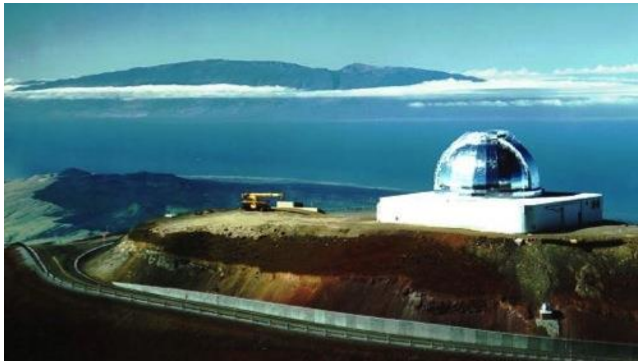


- **Accelerated Completion of ATLAS**
  - Set of small telescopes with extremely wide fields of view covering the entire night sky every night, but not as deeply.
  - Final design selection soon. Completion: Early 2015.

NEO Characterization Enhancements

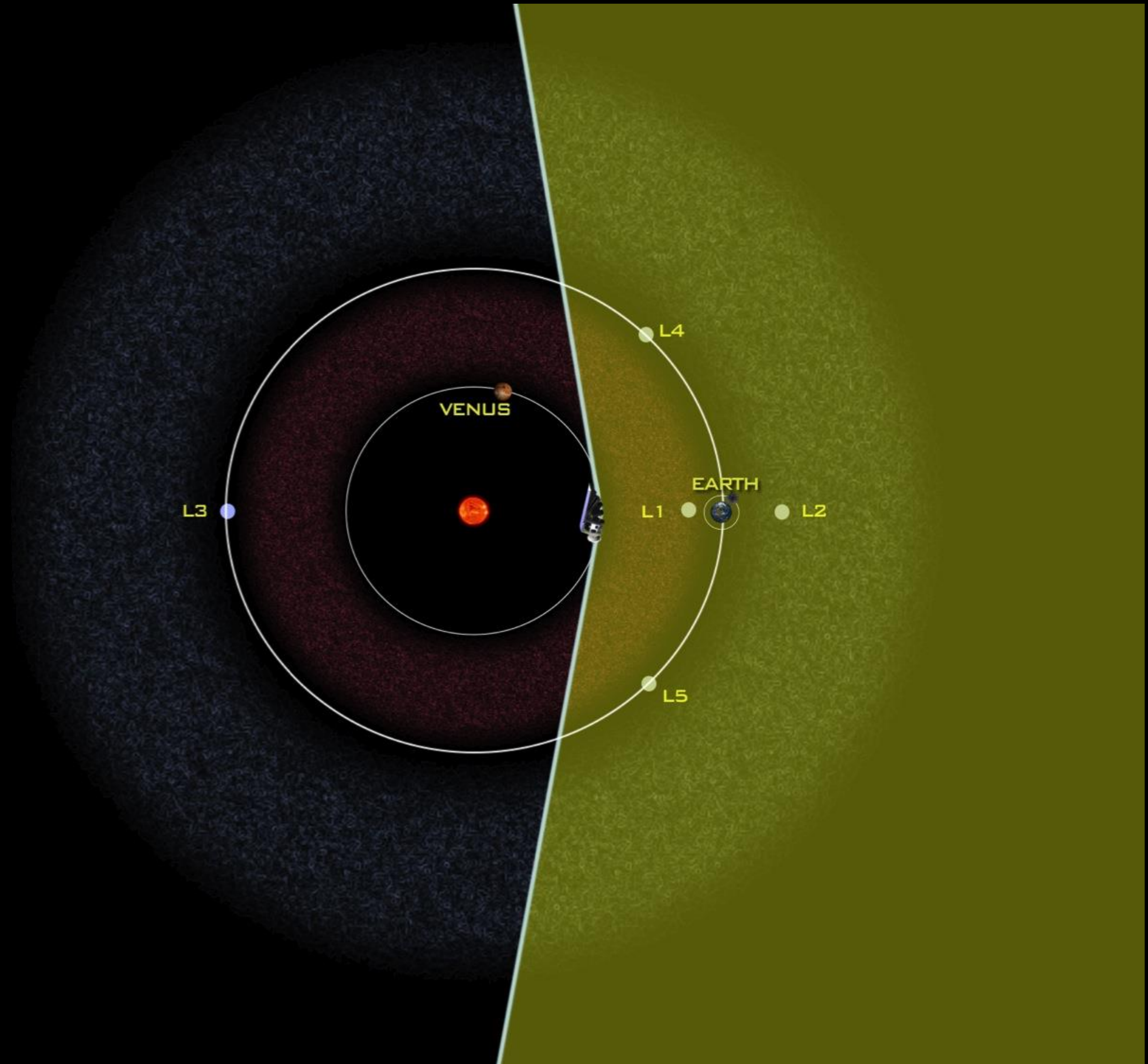
Radar (Goldstone and Arecibo)
- Increase time for NEO observations.
- Streamline Rapid Response capabilities.





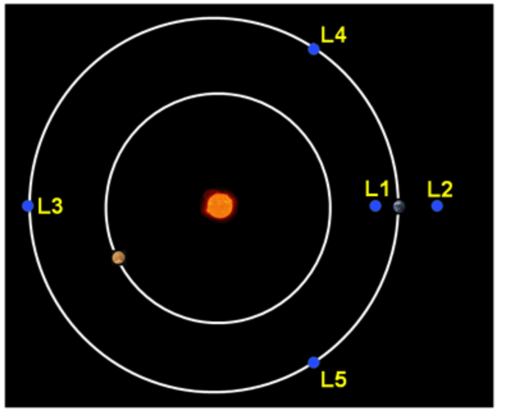
NASA InfraRed Telescope Facility (IRTF)
- Increase On-call for Rapid Response.
- Improve Instrumentation for Spectroscopy and Thermal Signatures.

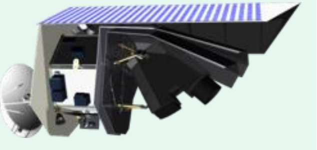
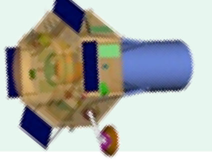
Reactivate NEOWISE
- ~3 year warm phase dedicated to NEO Search/Characterization data collection.


VENUS
EARTH
L1
L2
L3
L4
L5

Various Space-based NEO Survey Telescope Concepts

- A Space based NEO survey telescope will discover hazardous and highly accessible NEO targets suitable for human exploration in a timely manner.
  - Optimized for detection of objects in Earth-like orbits within two years of launch
  - Launch ready in 4 to 5 years with low risk
- The survey will include follow-up of all detected objects, *plus characterization (size, rotation rate) of selected objects*.



Study	Description	Survey Type	Picture	Cost
NEOCam/JPL	•Sun-Earth L1 orbit •Mid-IR •50cm aperture	Sweet Spot		< $500 M (excluding launch)
NEOStar/BATC	•Trailing Venus orbit •Mid-IR •50cm aperture	Opposition		~ $500 M (excluding launch)
NEST – L2/APL	•Sun-Earth L2 orbit •Visible •90cm aperture	Sweet Spot		< $500 M (excluding launch)
NEST - Venus/APL	•Trailing Venus orbit •Mid-IR •90cm aperture	Opposition		~ $500 M (excluding launch)

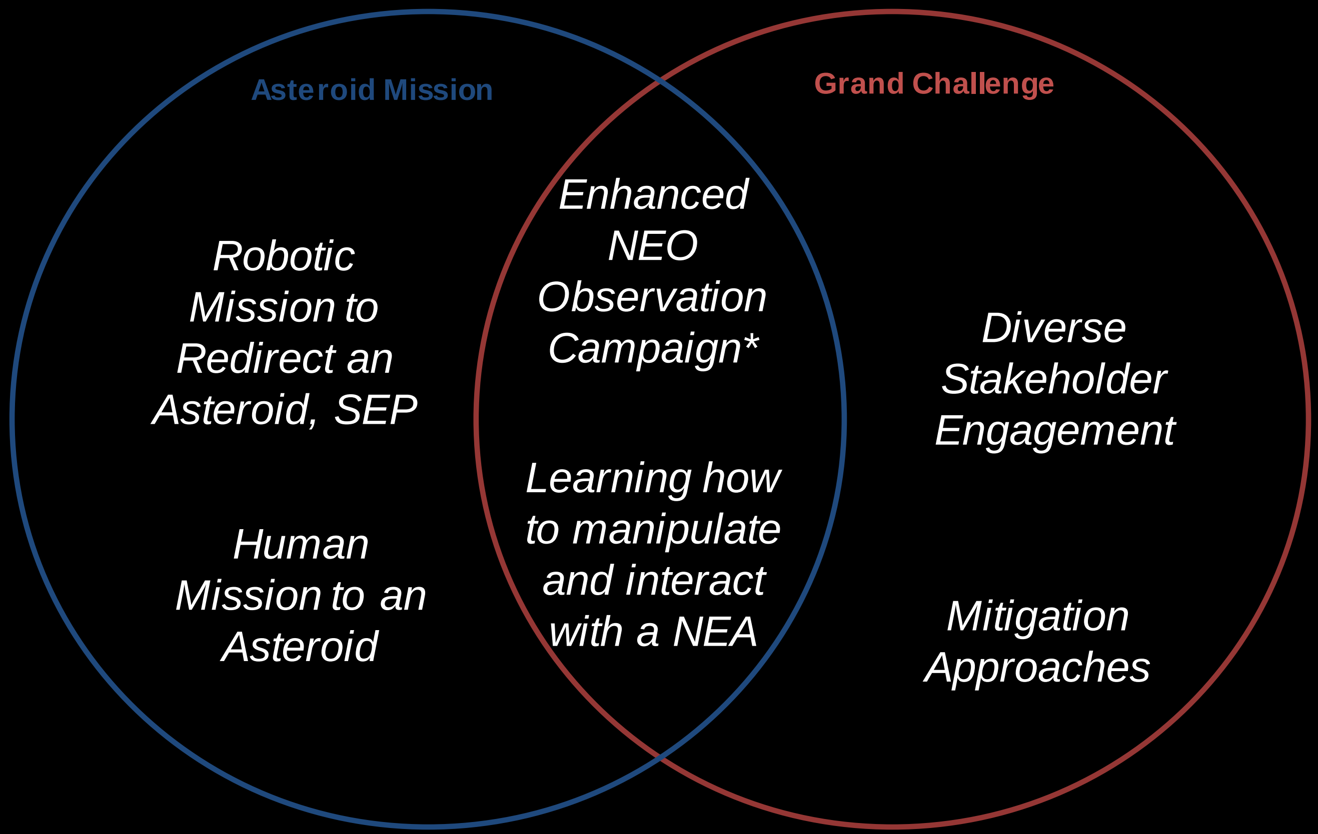
Grand Challenge Statement*

Find all asteroid threats to human populations and know what to do about them

*Announced June 18, 2013

FY14 Asteroid Initiative: What and How

Asteroid Initiative



Both sets of activities leverage existing NASA work while amplifying participatory engagement to accomplish their individual objectives and synergize for a greater collective purpose.

* FY2014 PBR increases NEOO Program to $40.5M

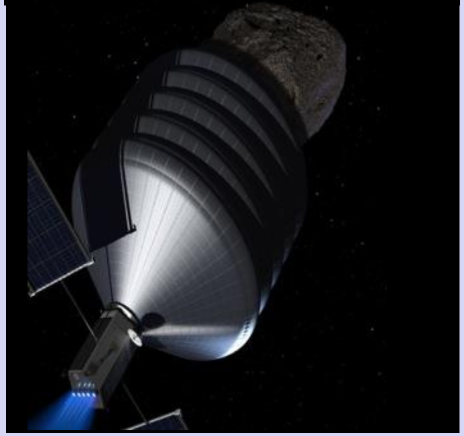
Asteroid Redirect Mission Consists of Three Main Segments

Identify

Asteroid Identification Segment:

Ground and space based NEA target detection, characterization and selection

Redirect



Asteroid Robotic Redirection Segment:

Solar electric propulsion (SEP) based robotic asteroid redirect to trans-lunar space

Explore

Asteroid Crewed Exploration Segment:

Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid

Tasked to NEOO with additional funding

Potential NEO Mitigation/Deflection

- Essential first step is continued enhancement of efforts to detect NEOs
  - Identify potential impact hazards early
  - Provide as much advanced warning of impact threat to enable more mitigation options
- Potential roles and responsibilities for mitigation options is in early stage of development and not yet ready for implementation
  - Wide range of possible scenarios and challenges involved
  - Significantly more analysis and simulation needed to understand feasibility and effectiveness of several approaches, and technical assessment of current technologies
- NASA to take lead to conduct foundational analysis and simulation, assessment of applicable technologies
  - Close coordination with DOD, FEMA, and other relevant departments and agencies
  - Possible emergency response exercises to be led by FEMA
  - Outreach to relevant private-sector stakeholders to leverage related work
  - Important to engage other nations and multilateral forums to explore opportunities for international cooperation, e.g. UNCOPUOS, European Union, ISECG

Mitigation Studies and Related Efforts

- NASA Mitigation Studies
  - NEO Observations Program mitigation effects grants
  - NASA Innovative Advanced Concepts Program study awards
  - Kinetic Impactor demonstration mission studies
- Interagency Efforts
  - Impact Effects Studies
    - DOE National Laboratories – Sandia and Lawrence Livermore
  - Impact Emergency Response Exercises
    - December 2008 US Air Force Interagency Deliberate Planning Exercise – Natural Impact Hazard
    - April 2013 - FEMA HQ Impact Emergency Response Table Top Exercise (TTX)
  - Newly initiated capabilities studies with DARPA and DOE National Nuclear Security Administration (NNSA)
- International Efforts
  - UN Committee on Peaceful Uses of Outer Space Scientific and Technical Subcommittee
    - NEO Working Group and Action Team–14
  - Supporting FEMA with impact response discussions with Russian EMERCOM

Summary of NASA PD Efforts

- NEOO project enhancements will add capability to find hazardous asteroids as well as ARRM candidate targets.
- Simulations suggest there are thousands of suitable ARRM candidate targets; the challenge is to find several that will meet the mission envelope.
- With several survey enhancements in process, and new surveys coming online within the next 2 years, both the NEO and the ARRM candidate discovery rates should at least double.
- Rapid response after discovery is critical for physical characterization of both hazardous and ARRM candidates. The process has already been successfully exercised for difficult-to-characterize candidates.
- Goldstone and Arecibo radars are key characterization assets for NEAs of interest because they provide accurate estimates of size and rotation state.
- Other major assets for characterization are available. Interagency agreements for target-of-opportunity observing time from important non-NASA facilities (eg. Subaru) can be negotiated.
- There are several ongoing efforts with interagency and international entities
- The recent increased interest in NEOs, the hazard and opportunity they pose, has made this a rapidly expanding mission area for Planetary Science.