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# Finding Near Earth Objects

## *Before They Find Us!*

### *(and knowing what to do about it)*

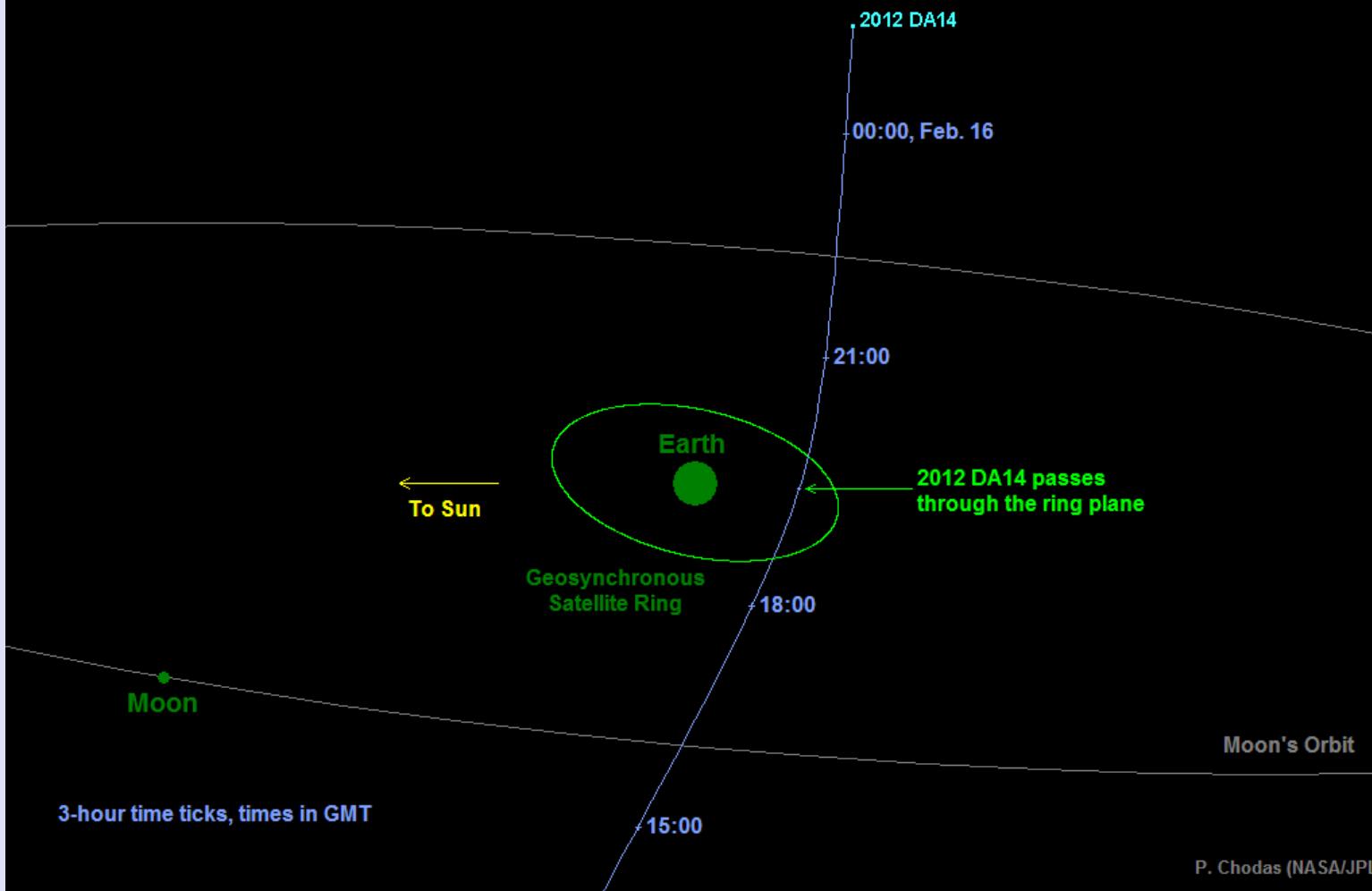
## International Asteroid Warning Network Steering Committee Meeting #1

Lindley Johnson  
Near Earth Object  
Programs Executive  
NASA HQ  
January 13, 2014



# Close Approach of 2012 DA14

Asteroid 2012 DA14: Close Approach to Earth, Feb. 15, 2013





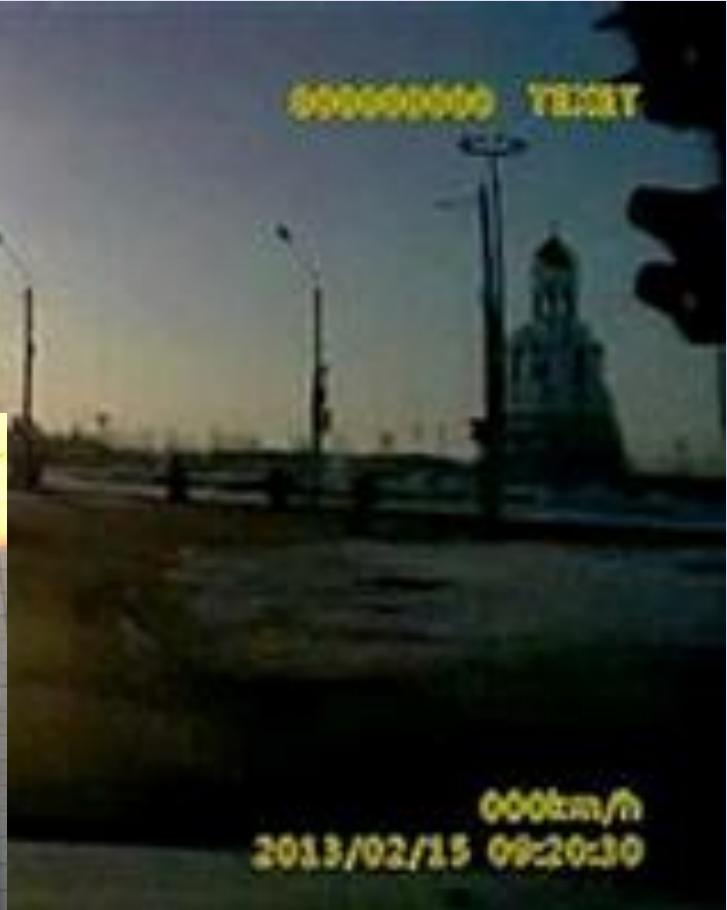
# CHELYABINSK EVENT



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



# CHELYABINSK EVENT



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



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# United States Government Policy and Approach Regarding Planetary Defense



# Source

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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](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



# 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



# 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  $\geq$  90% of NEOs larger than 140 meters in size as soon as possible

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



# NASA's NEO Search Program

## (Current Systems)



### Minor Planet Center (MPC)

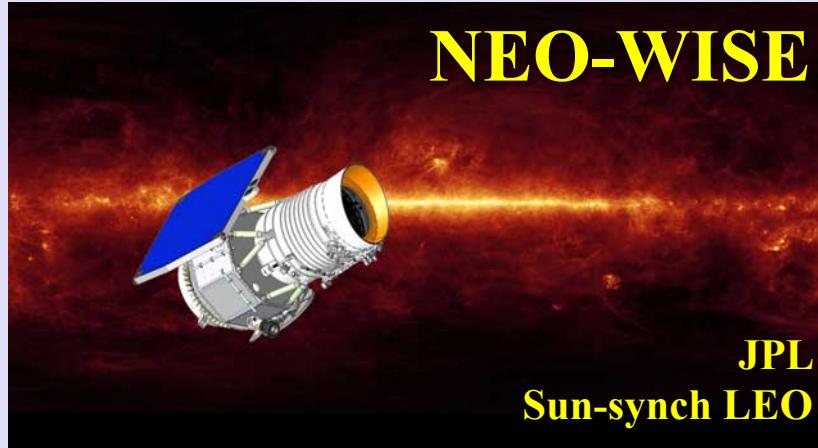
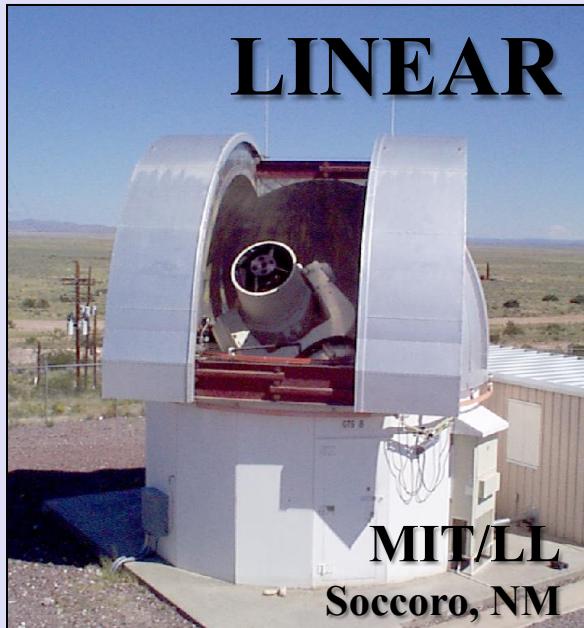
- IAU sanctioned
- Int'l observation database
- Initial orbit determination

[www.cfa.harvard.edu/iau/mpc.html](http://www.cfa.harvard.edu/iau/mpc.html)

### NEO Program Office @ JPL

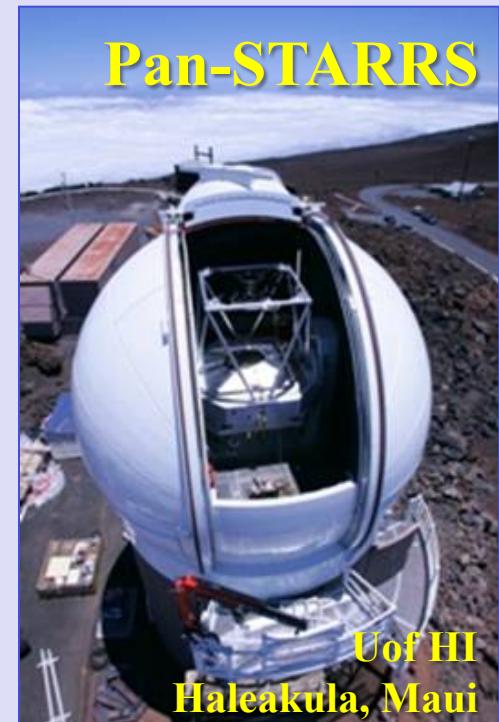
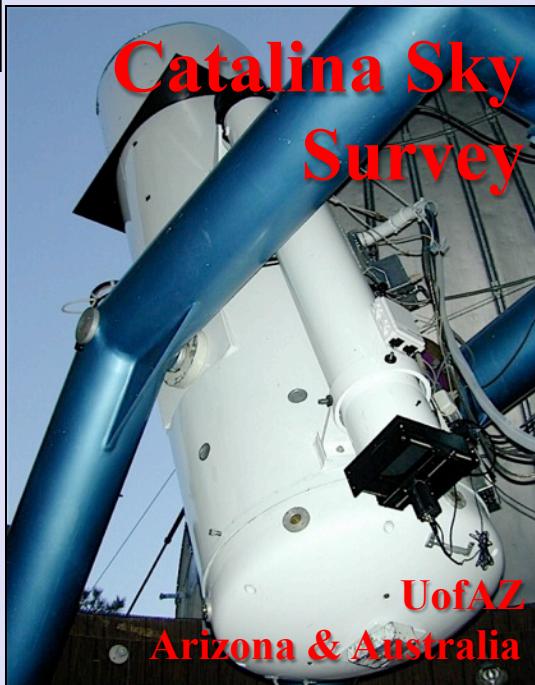
- Program coordination
- Precision orbit determination
- Automated SENTRY

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



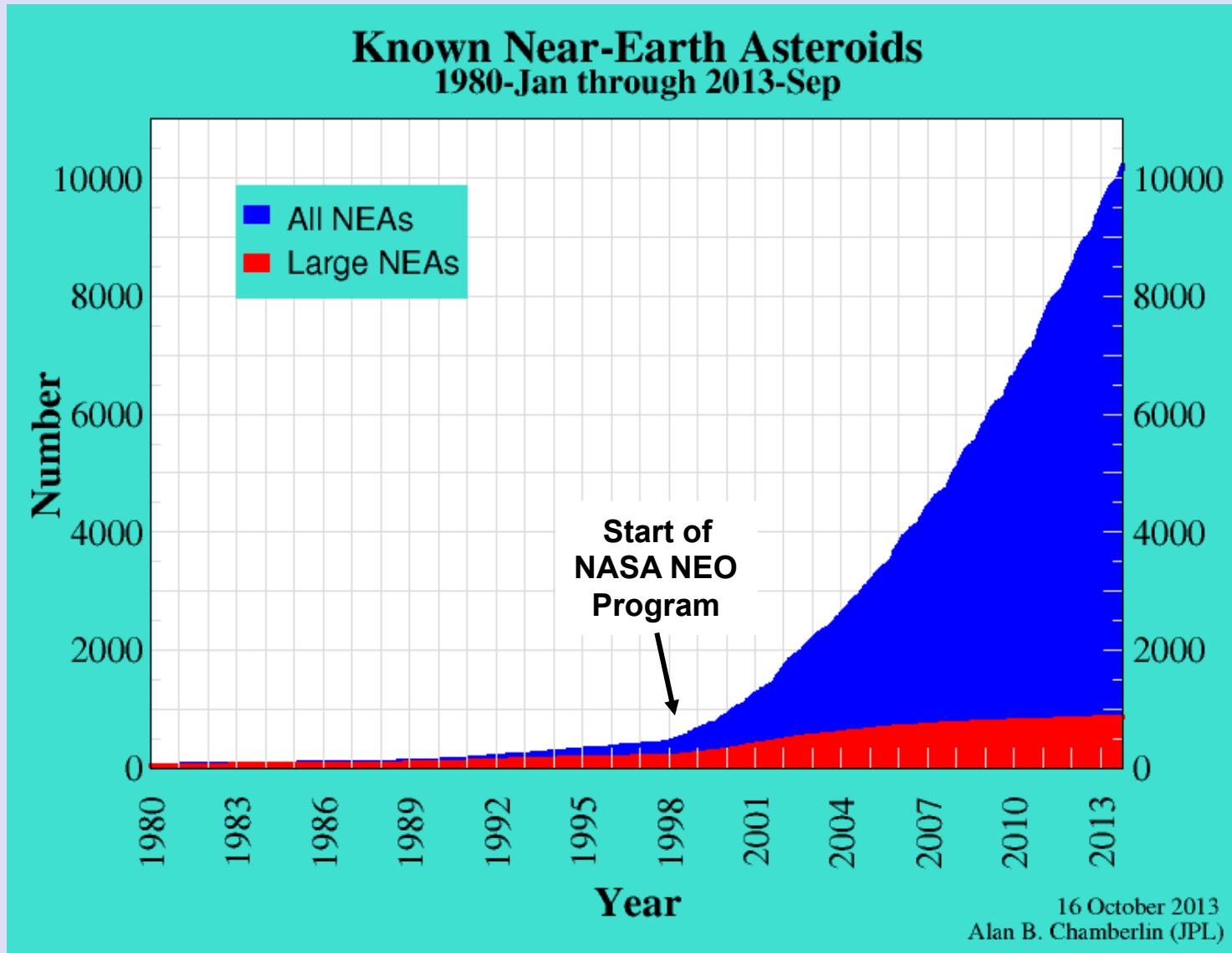
Operations  
Jan 2010  
Feb 2011,  
129 NEAs found

Reactivated  
Sep 2013





# Known Near Earth Asteroid Population



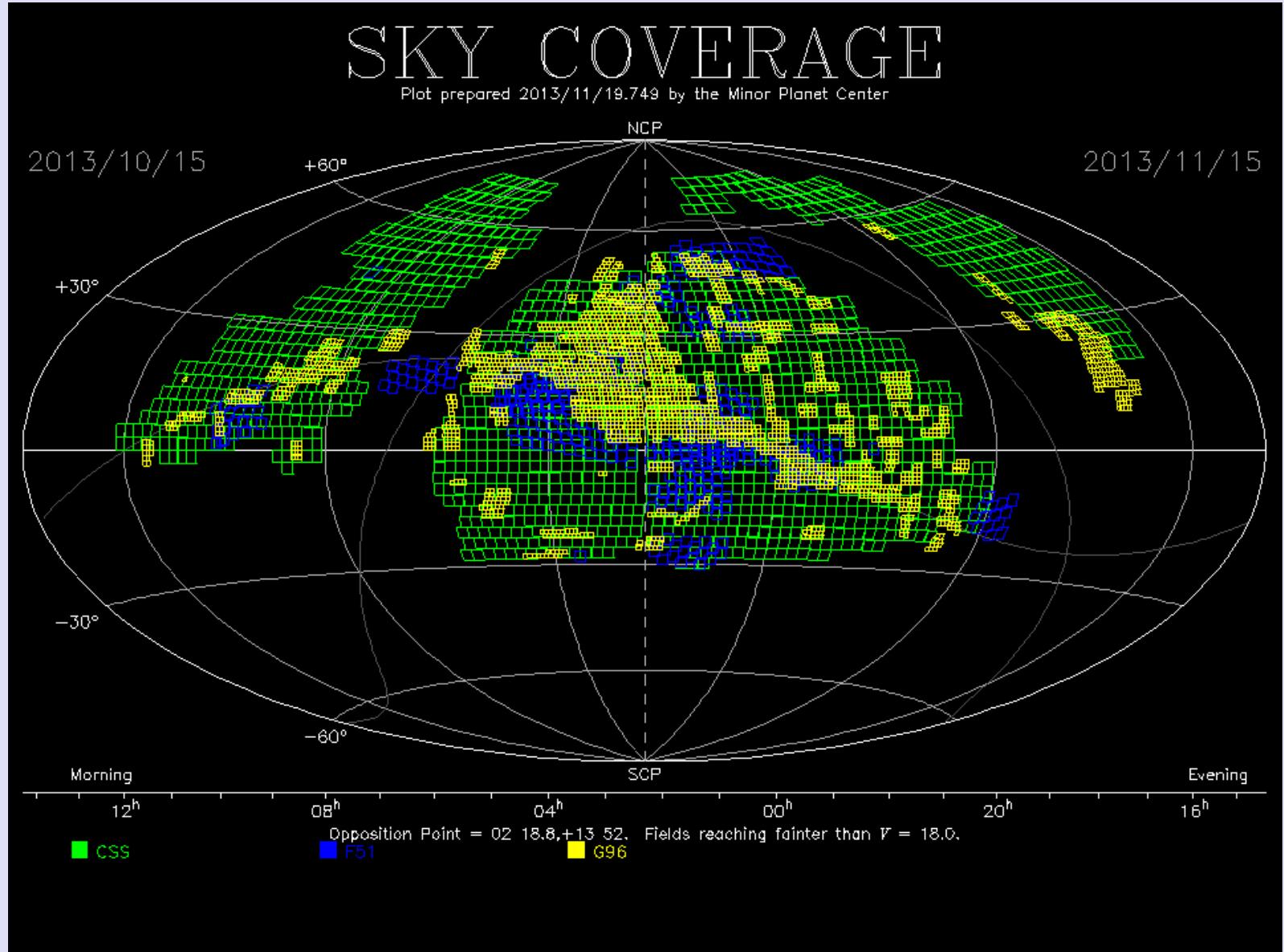
10,573  
12/31/13

Includes 94  
comets

864  
12/31/13

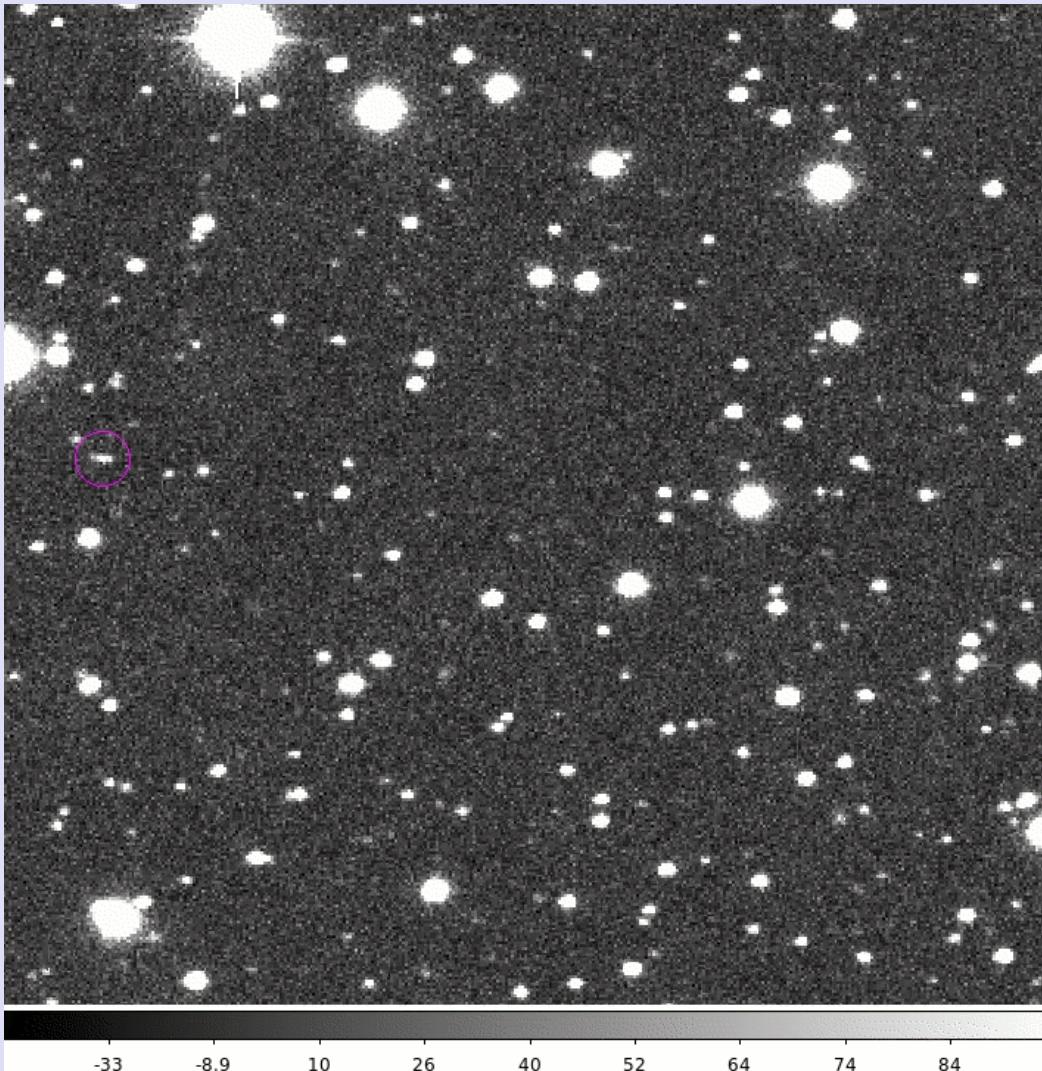


# Searching the Sky for Asteroids





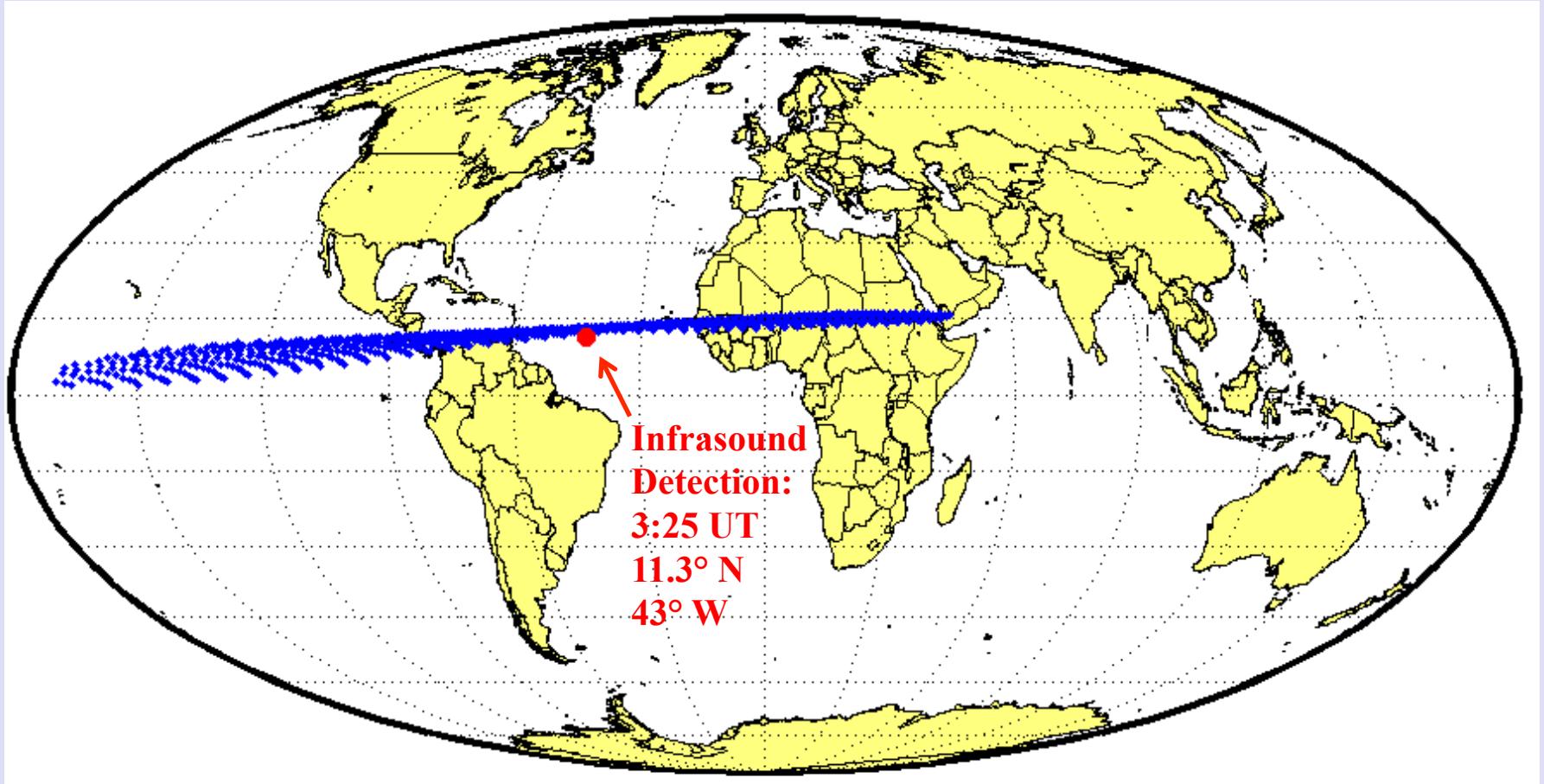
# Discovery Images of Asteroid 2014 AA



Courtesy of Catalina Sky Survey



# 2014 AA Predicted Impact Location

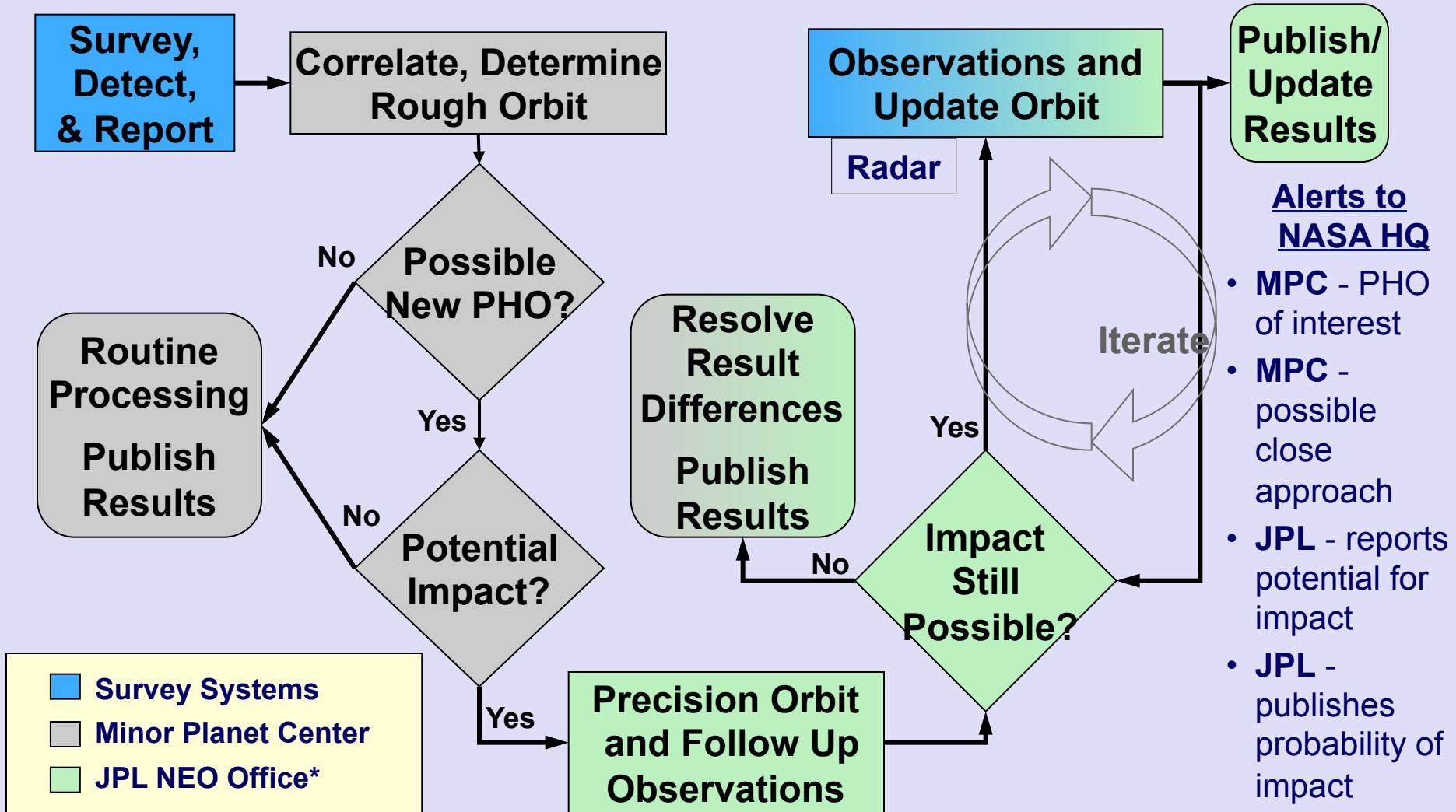


Credit Steve Chesley, NEO PO, JPL



# Spaceguard Survey Catalog Program

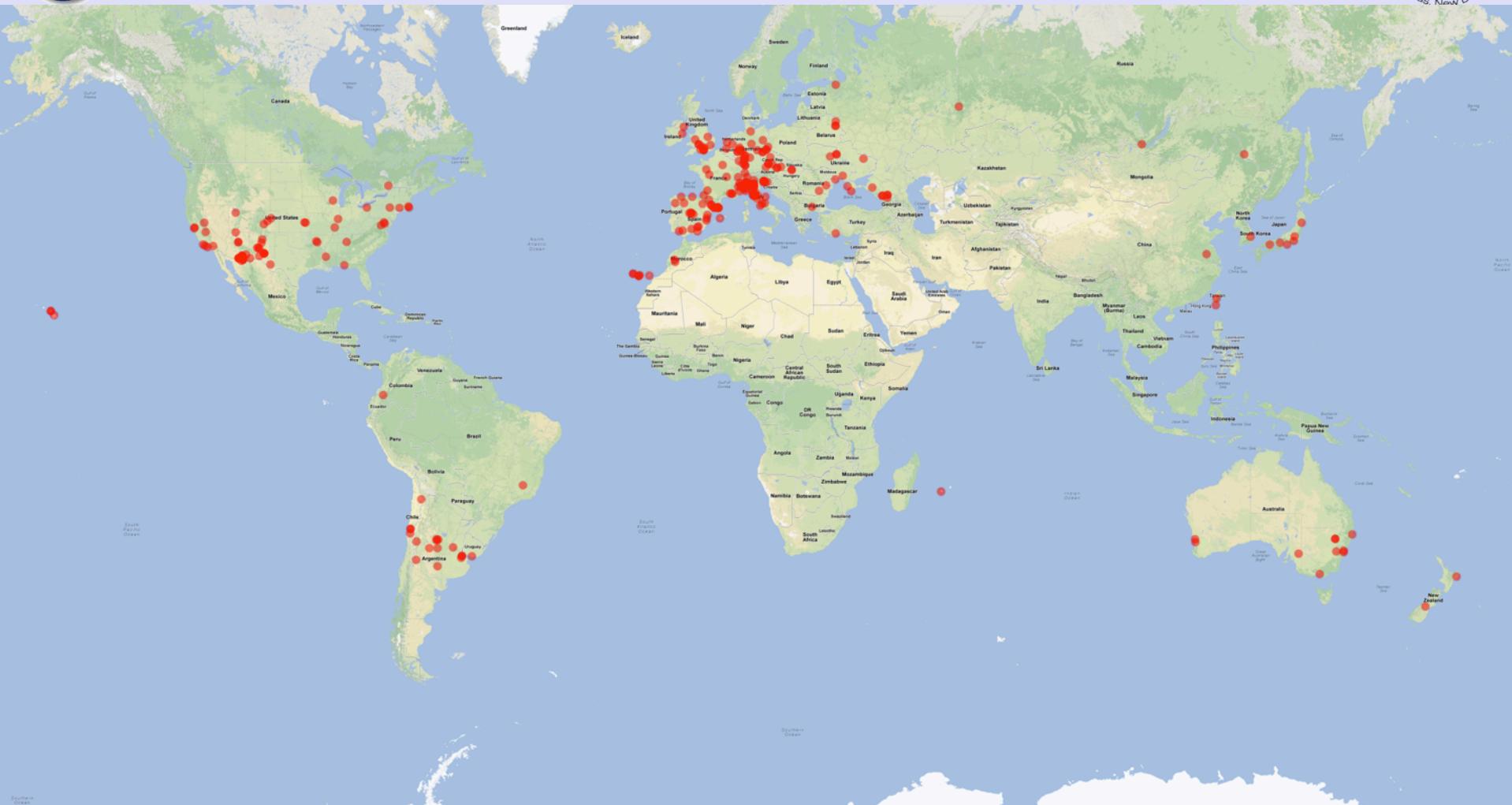
## Current Spaceguard Survey Infrastructure and Process



\* In parallel with NEODyS



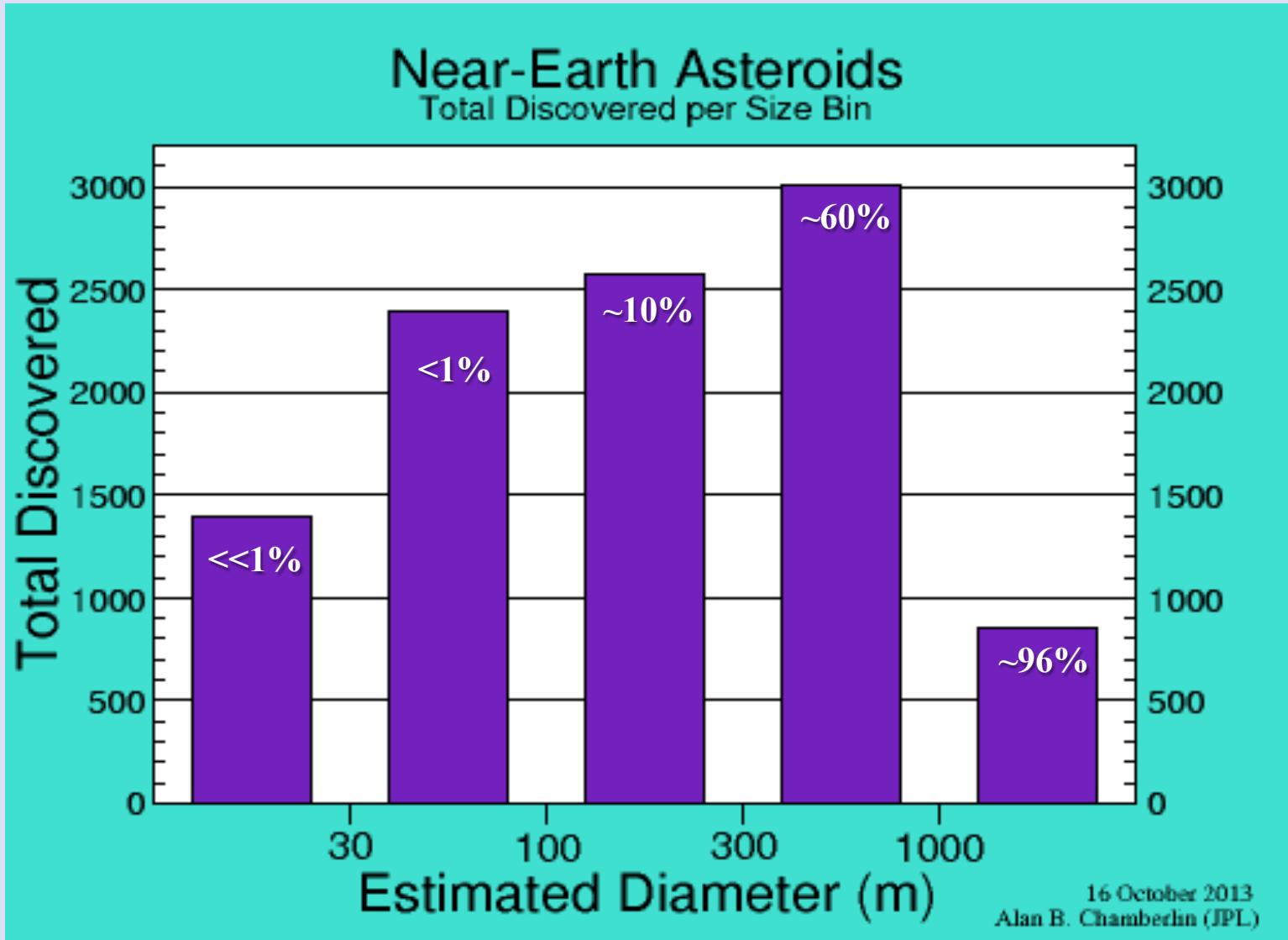
# Existing Worldwide Observing Network



Data from 46 countries in 2012

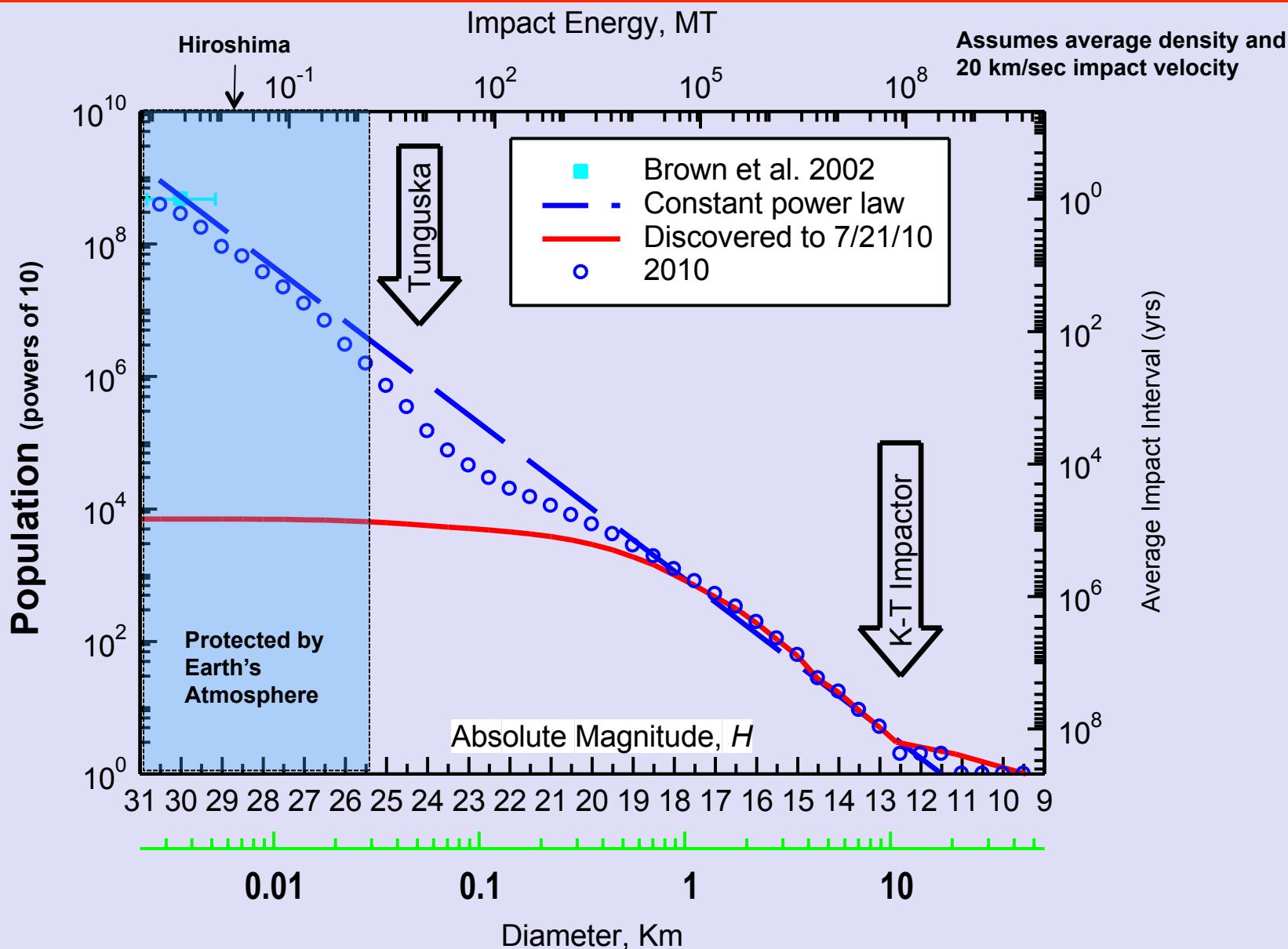


# Known Near Earth Asteroid Population



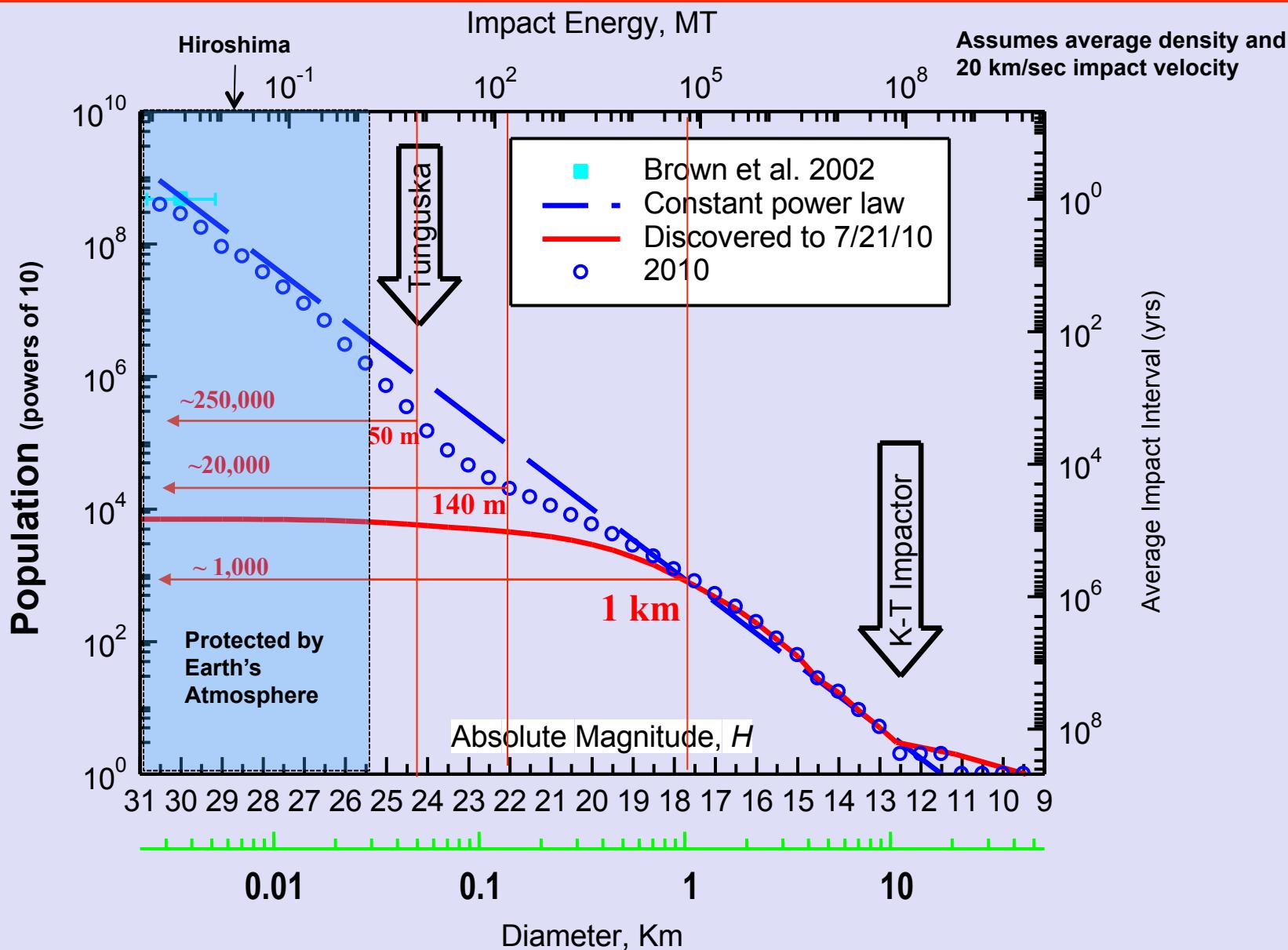


# Population of NEAs by Size, Brightness, Impact Energy & Frequency (A. L. Harris 2010)





# 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.

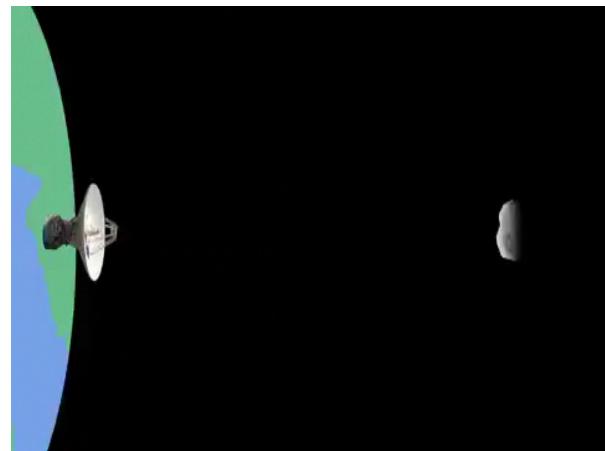
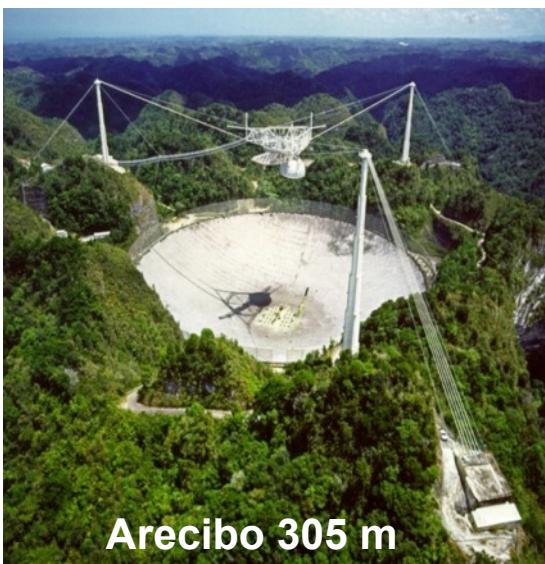


Assumed albedo  
 $\rho = 0.04$

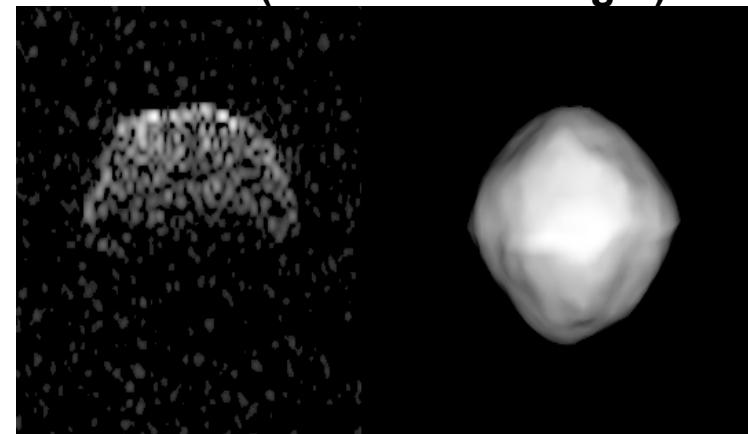


Assumed albedo  
 $\rho = 0.34$

# Radar Observations of NEOs



**Bennu (OSIRIS-ReX Target):**



**Observations**

**Shape Model**

- These are complementary capabilities.
- 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.

# NEO Infrared Characterization



## NASA InfraRed Telescope Facility (IRTF)

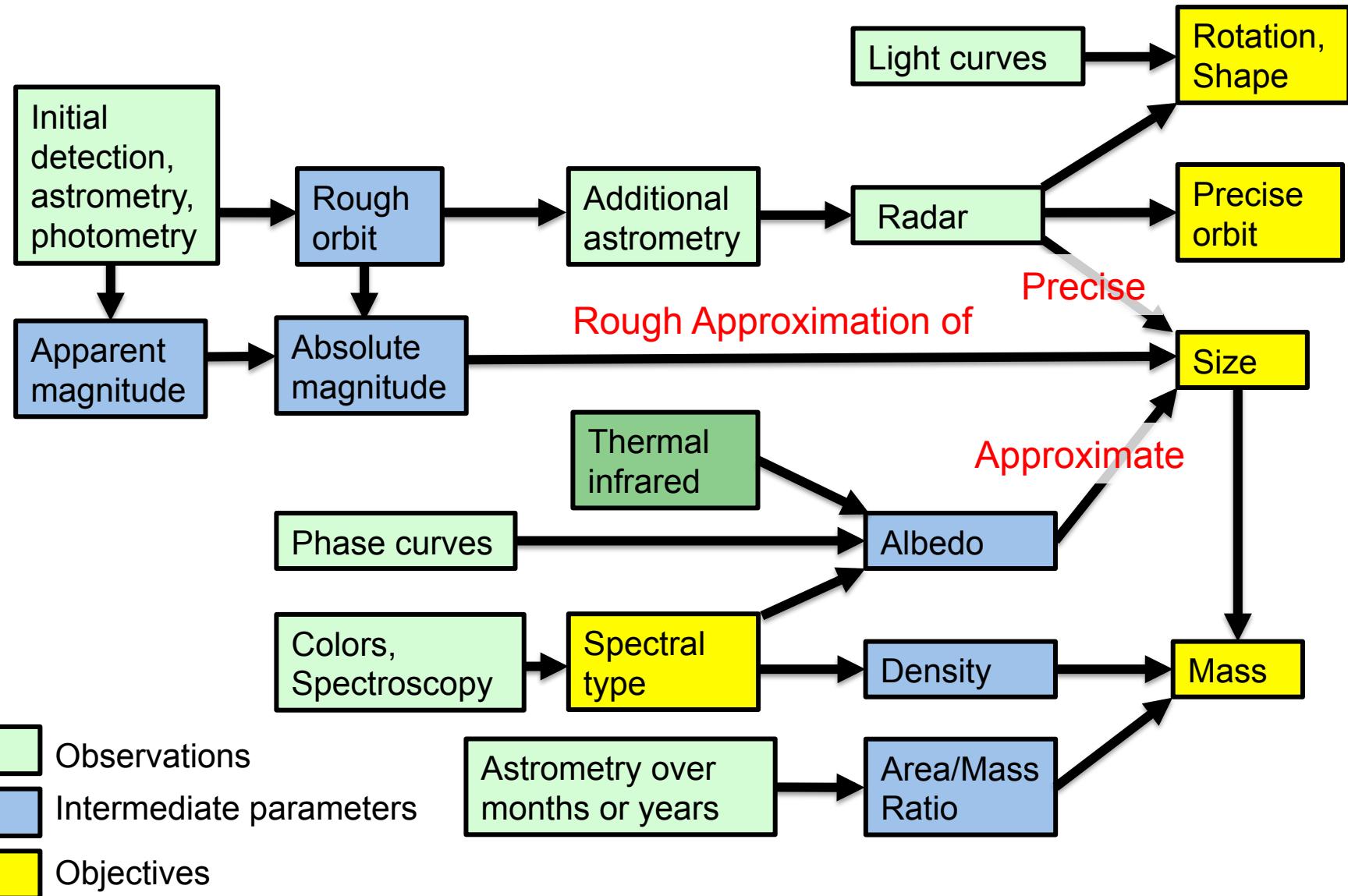
- Dedicated Planetary Science Observatory
- Characterization of Comets and Asteroids
- Spectroscopy and Thermal Signatures
- On-call for Rapid Response on Discoveries

## 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



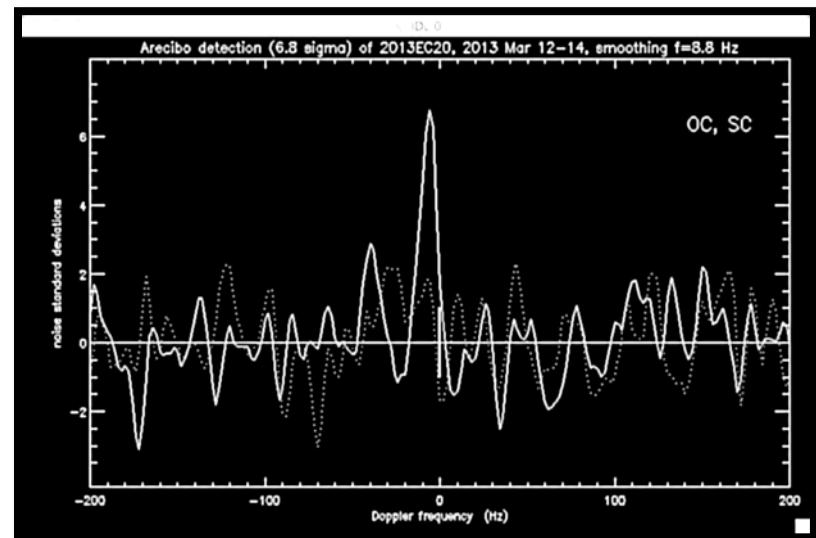
# Characterization Process



# 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  $\Rightarrow$  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  $\Rightarrow$  albedo  $>$  ~0.4
  - Constrains mass to  $<$  50 t
  - Spin rate: 0.5 – 2 rpm





# Mitigation Studies and Related Efforts

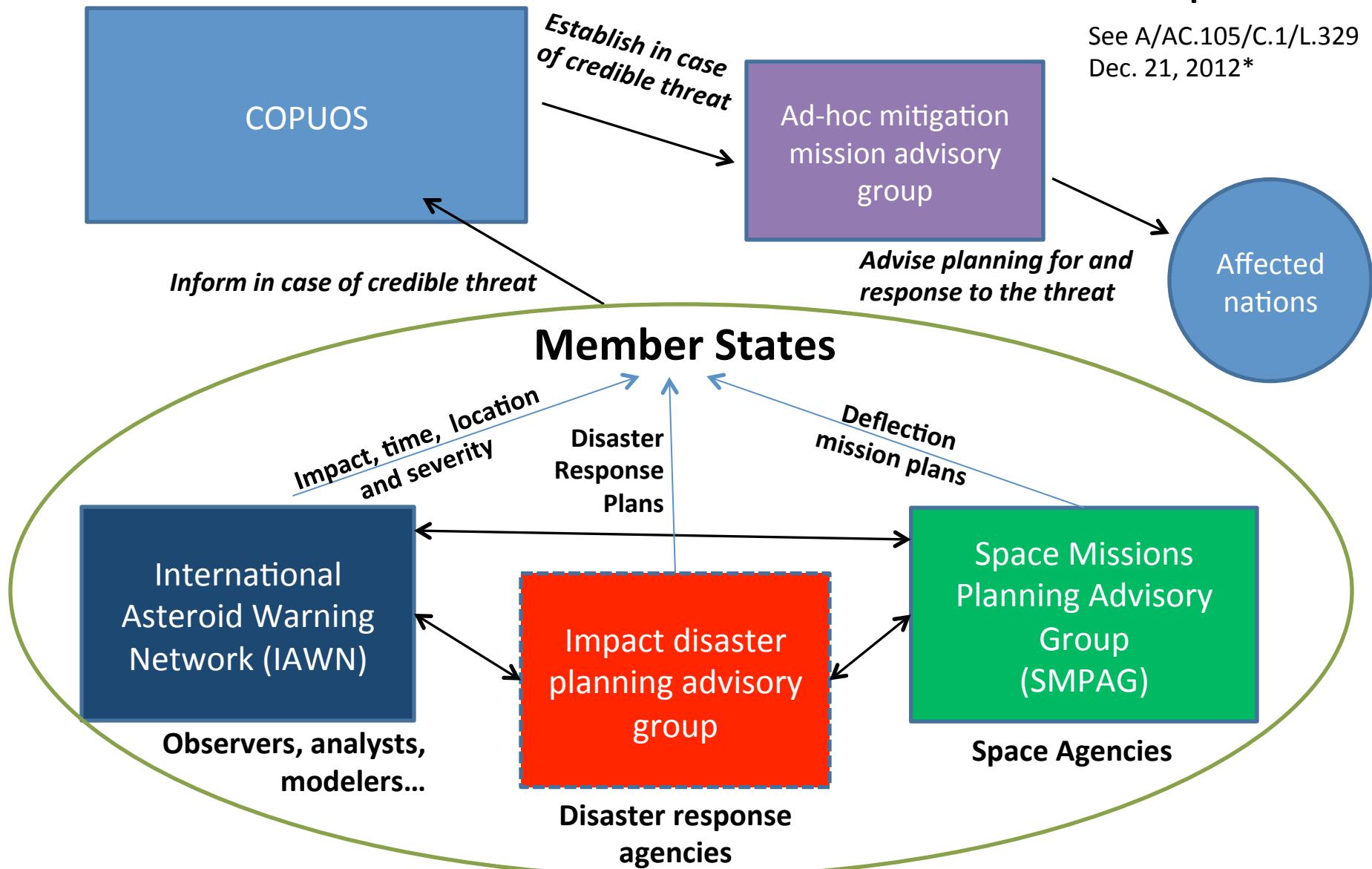


- NASA Mitigation Studies
  - NEO Observations Program mitigation effects grants
  - NASA Innovative Advanced Concepts Program study awards
  - Kinetic Impactor demonstration mission studies
- Interagency Efforts
  - Impact Effects Studies
    - DOE National Laboratories – Sandia and Lawrence Livermore
  - 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

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

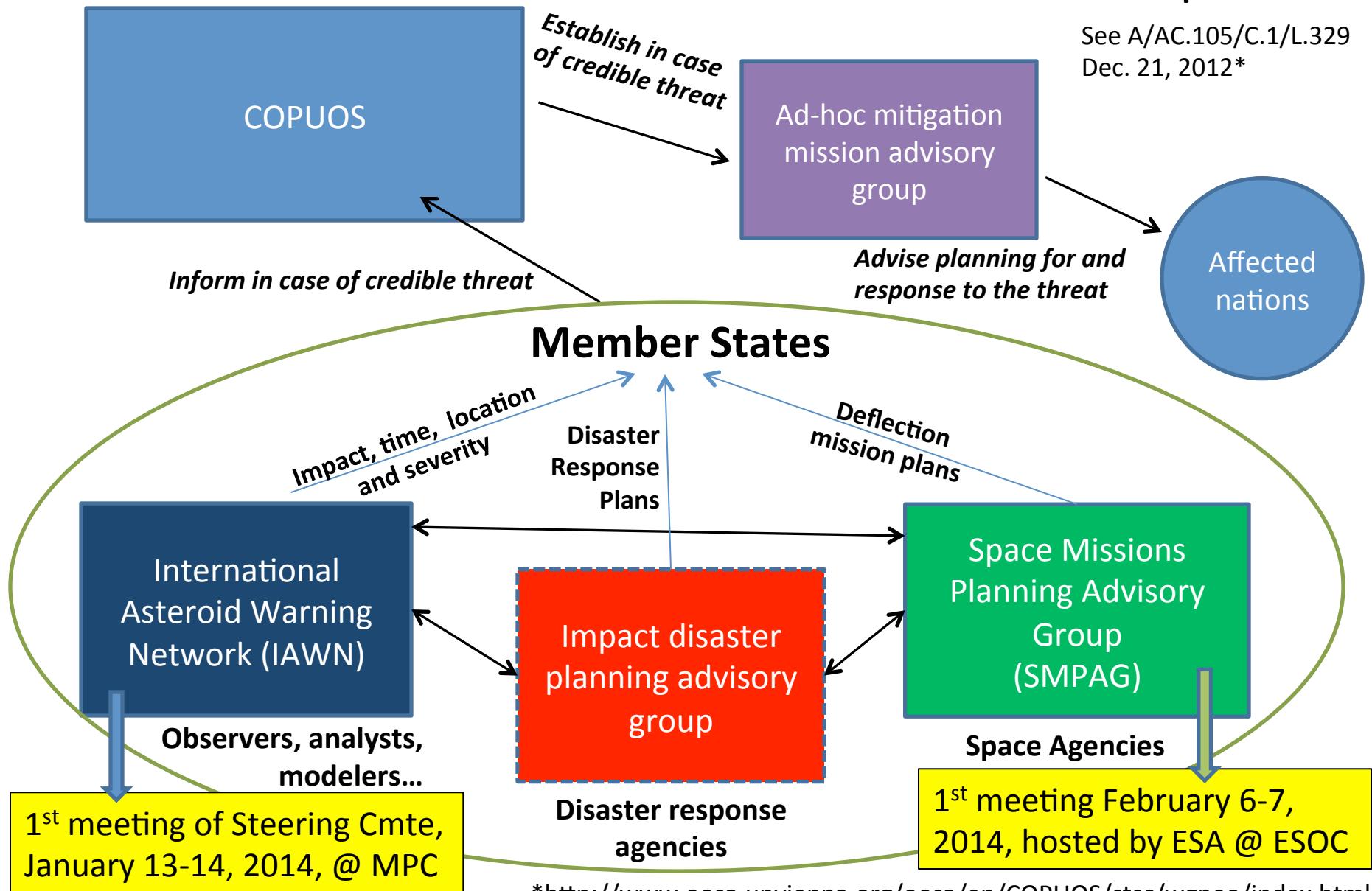
**Overview for NEO  
Threat Response**

See A/AC.105/C.1/L.329  
Dec. 21, 2012\*



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

# Overview for NEO Threat Response





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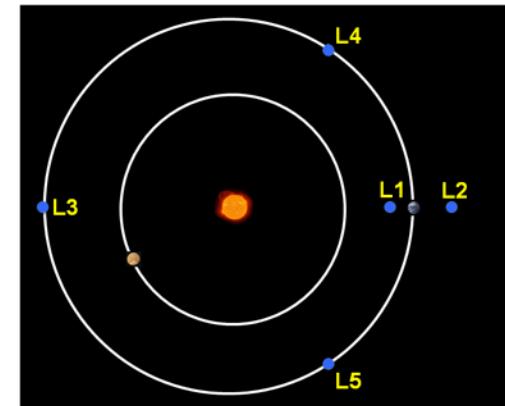
# Future Capability for Planetary Defense

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](http://www.nasa.gov/pdf/171331main_NEO_report_march07.pdf)

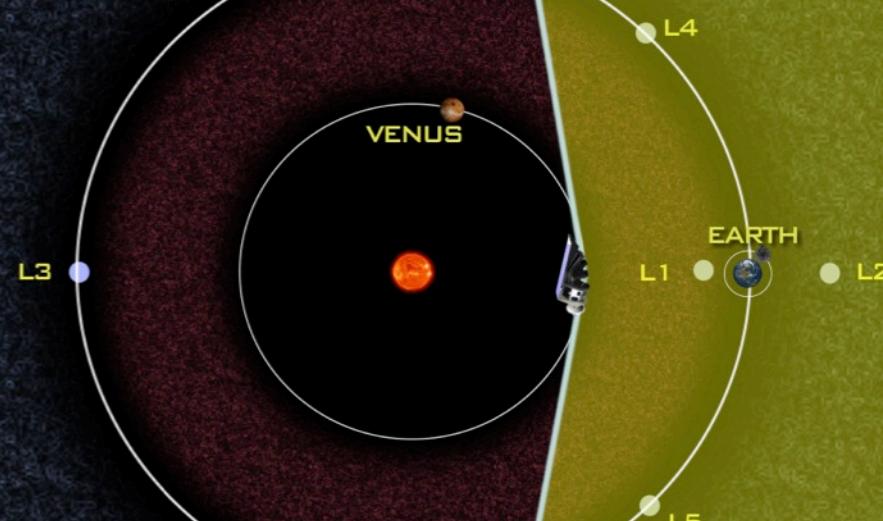
NRC Report – “Defending Planet Earth: Near-Earth-Object Surveys and Hazard Mitigation Strategies”, January 2010 [http://www.nap.edu/openbook.php?record\\_id=12842](http://www.nap.edu/openbook.php?record_id=12842)

# Various Space-based NEO Survey Telescope Concepts

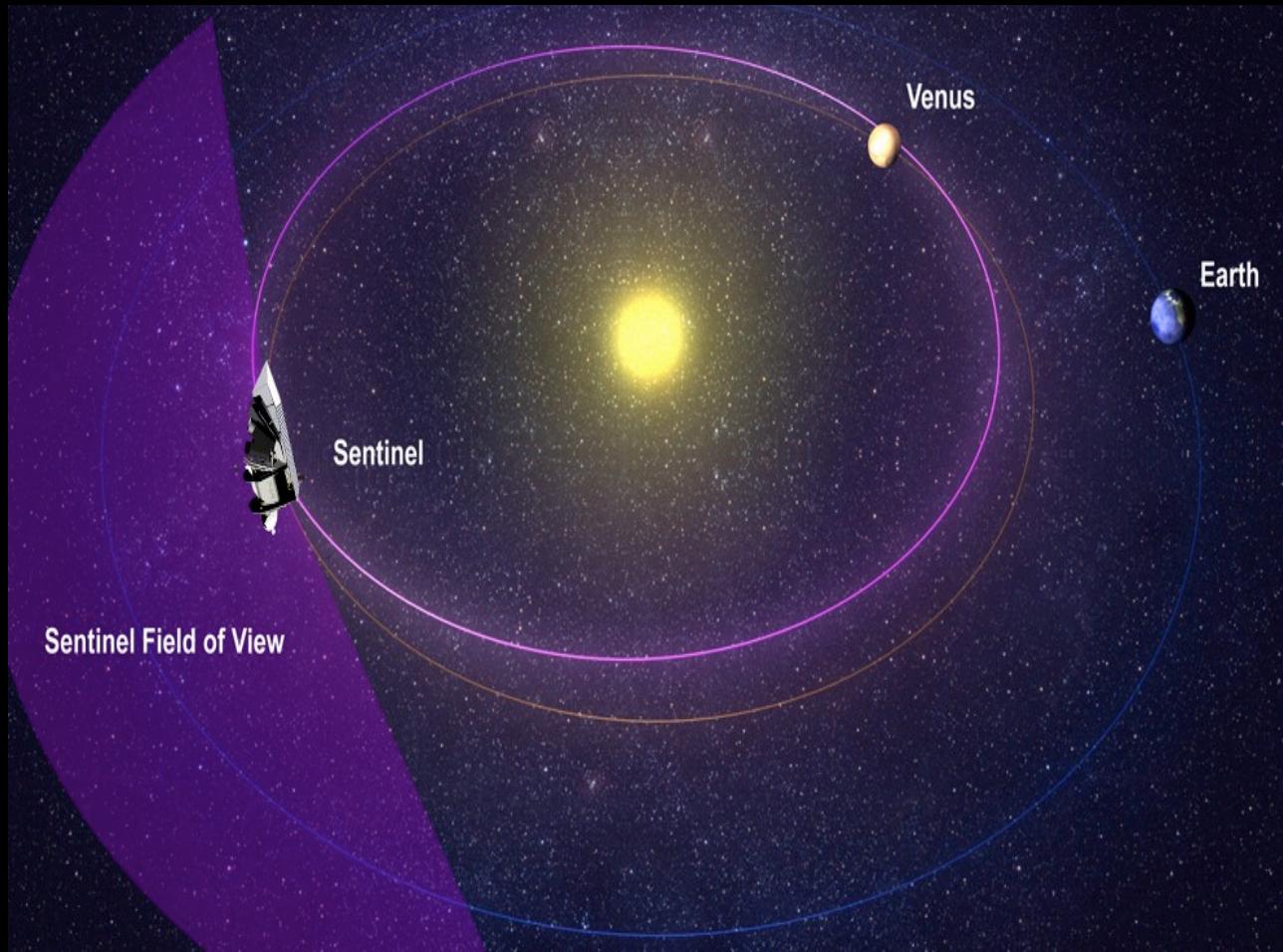
- A Space based NEO survey telescope will discover hazardous and highly accessible NEO targets suitable for human exploration in a timely manner.
  - Optimized for detection of objects in Earth-like orbits within two years of launch
  - Launch ready in 4 to 5 years with low risk
- The survey will include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



Study	Description	Survey Type	Picture	Cost
NEOCam/JPL	<ul style="list-style-type: none"><li>• Sun-Earth L1 orbit</li><li>• Mid-IR</li><li>• 50cm aperture</li></ul>	Sweet Spot		< \$500 M (excluding launch)
NEOStar/BATC	<ul style="list-style-type: none"><li>• Trailing Venus orbit</li><li>• Mid-IR</li><li>• 50cm aperture</li></ul>	Opposition		~ \$500 M (excluding launch)
NEST – L2/APL	<ul style="list-style-type: none"><li>• Sun-Earth L2 orbit</li><li>• Visible</li><li>• 90cm aperture</li></ul>	Sweet Spot		< \$500 M (excluding launch)
NEST - Venus/APL	<ul style="list-style-type: none"><li>• Trailing Venus orbit</li><li>• Mid-IR</li><li>• 90cm aperture</li></ul>	Opposition		~ \$500 M (excluding launch)



# Public Private Partnership- Space Act Agreement with B612 Foundation





# Grand Challenge Statement\*

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



\*Announced June 18, 2013 34

# FY14 Asteroid Initiative: What and How

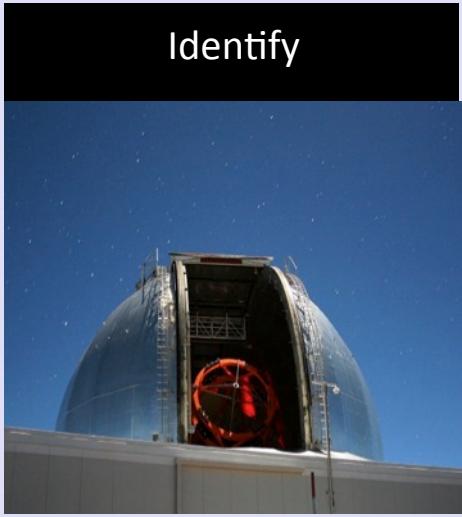


Both sets of activities leverage existing NASA work while amplifying participatory engagement to accomplish their individual objectives and synergize for a greater collective purpose.

\* FY2014 PBR increases NEOO Program to \$40.5M



# Asteroid Redirect Mission Consists of Three Main Segments



## Identify

### Asteroid Identification Segment:

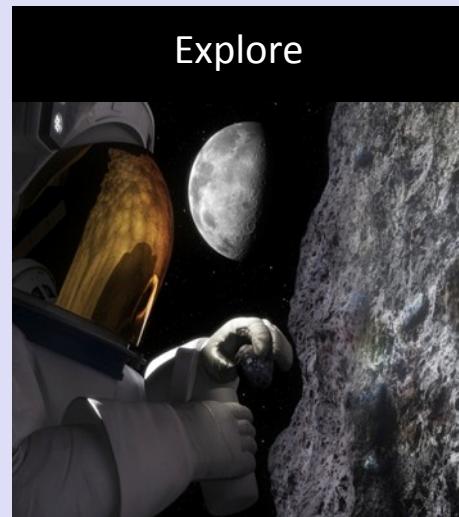
Ground and space based NEA target detection, characterization and selection



## Redirect

### Asteroid Robotic Redirection Segment:

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



## Explore

### Asteroid Crewed Exploration Segment:

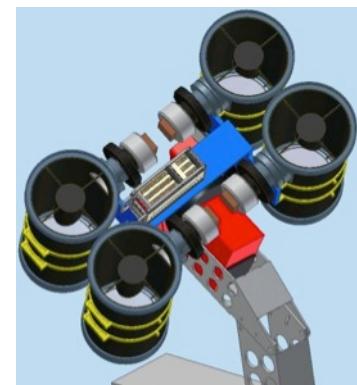
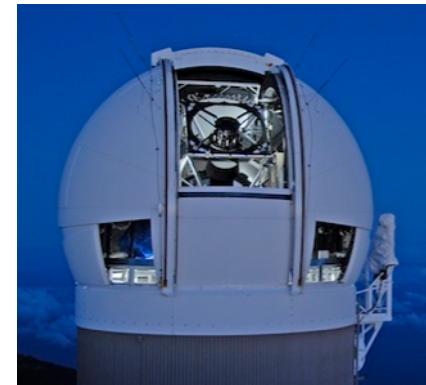
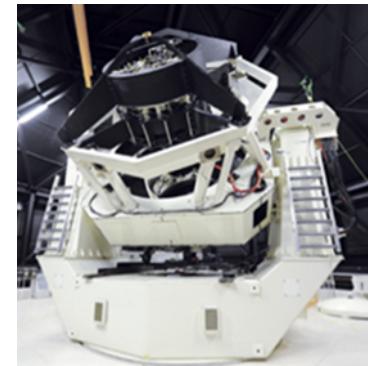
Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid

Tasked to NEOO with additional funding

# 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.

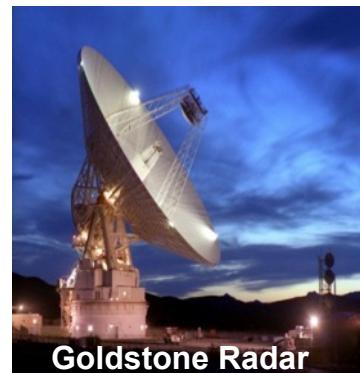


# NEO Characterization Enhancements

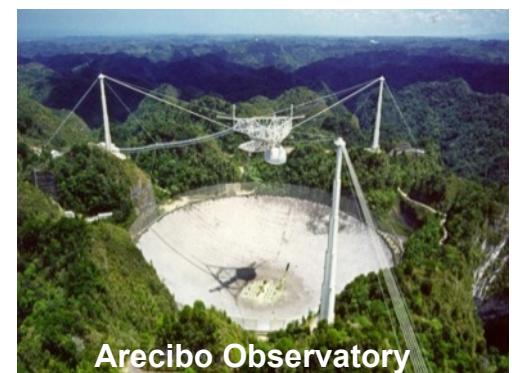


## Radar (Goldstone and Arecibo)

- Increase time for NEO observations.
- Streamline Rapid Response capabilities.



Goldstone Radar



Arecibo Observatory



## 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.



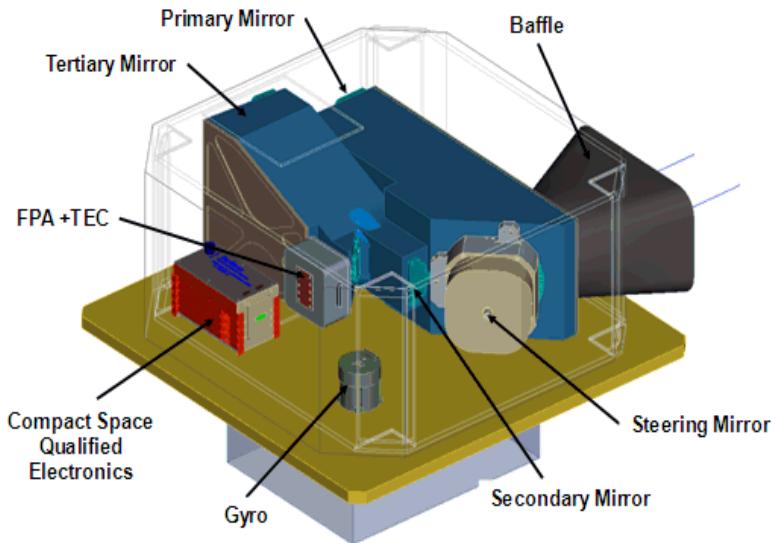
# Detecting NEOs from GEO



## Objective:

Improve the rate of detection of smaller, long synodic period NEAs. Request for Information released in October 2012 showed that several short term, affordable options may exist.

Needs Addressed: Smaller hazardous NEAs, Human spaceflight target detection, orbit determination, size



NEA Detector Concept  
(Source: Raytheon)

## IR Instrument Phase A Studies:

- AO in work to request proposals for Phase A studies for a suite of 3 IR instruments to be hosted on commercial geosynchronous spacecraft
- Goal is to fund 3 Phase A studies, with possible down-select to one proposal by 2015.



# 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.



# IAWN SC Meeting #1

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## Items for Discussion

- How do we organize Steering Committee?
  - What is its role?
  - What is the representation?
  - Are Terms of Reference needed?