Finding Near Earth Objects

In the context of an Agency Grand Challenge

Lindley Johnson

Near Earth Object Program Executive

NASA HQ

September 4, 2014

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

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

NASA's NEO Search Program

(Current Systems)

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

http://minorplanetcenter.net/

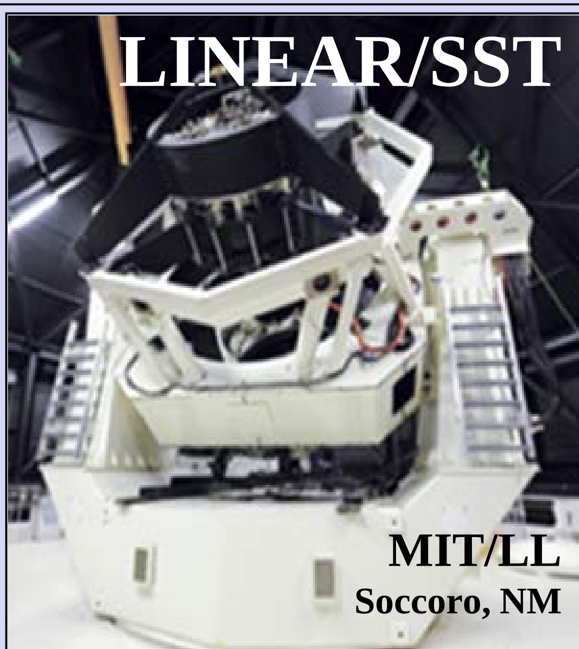
NEO Program Office @ JPL
- Program coordination
- Precision orbit determination
- Automated SENTRY

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

Operations
Jan 2010
Feb 2011,
135 NEAs found

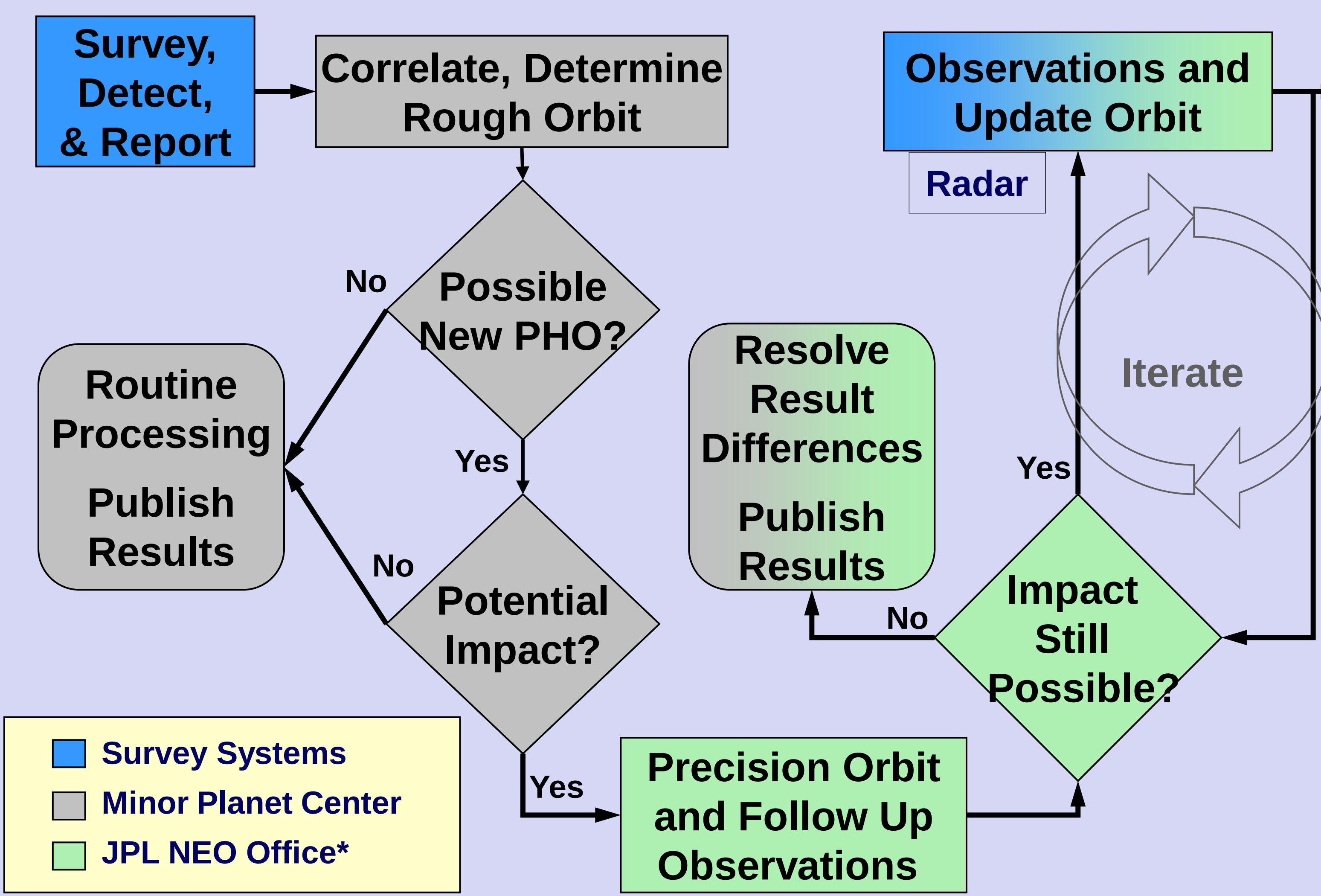
Reactivated
Sep 2013

Began ops in Dec
26 NEAs 3 comets



Spaceguard Survey Catalog Program

Current Spaceguard Survey Infrastructure and Process

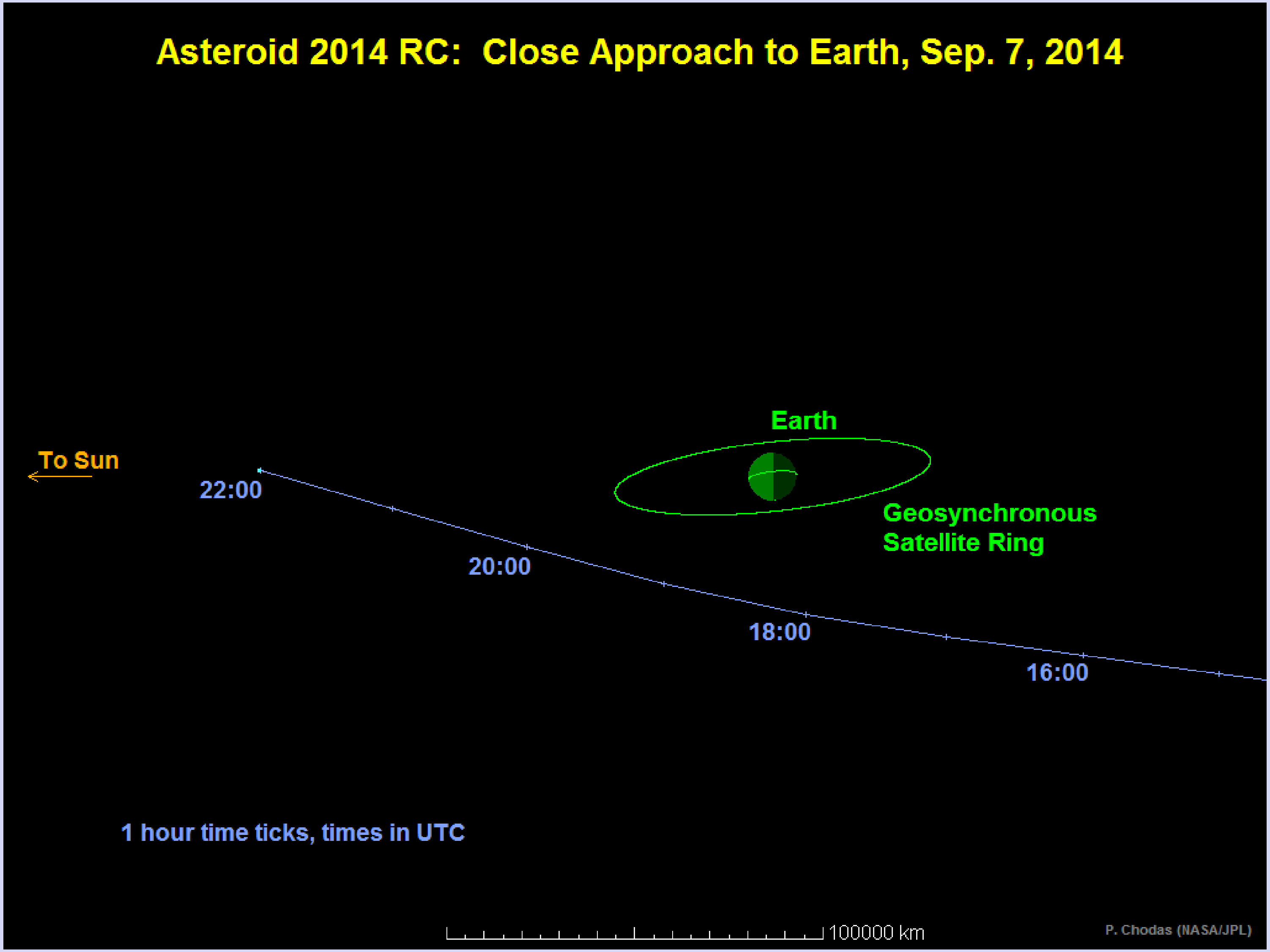


Alerts to NASA HQ

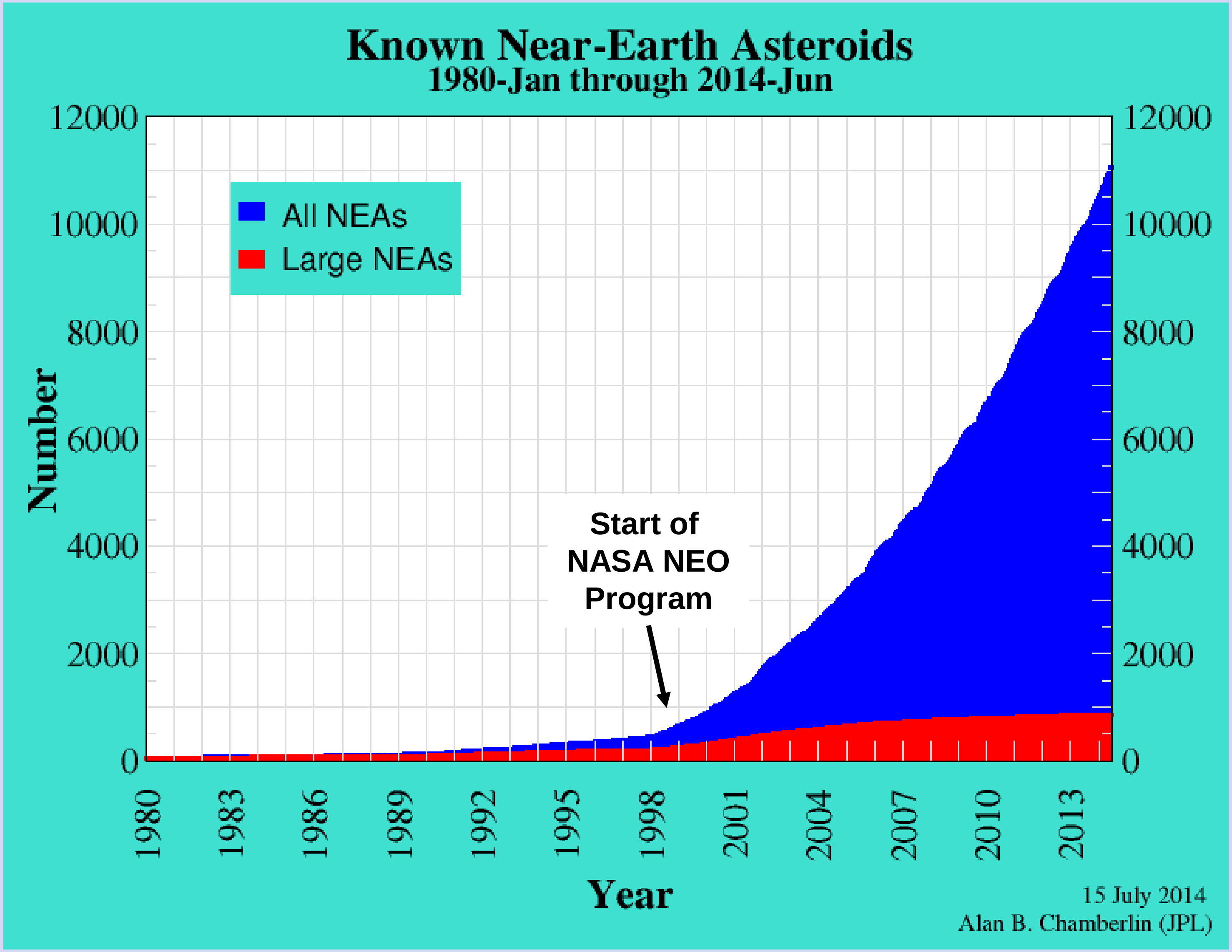
- **MPC** - PHO of interest
- **MPC** - possible close approach
- **JPL** - reports potential for impact
- **JPL** - publishes probability of impact

* In parallel with NEODyS

Near Earth Asteroid Close Approach



Known Near Earth Asteroid Population



11,405
9/01/14

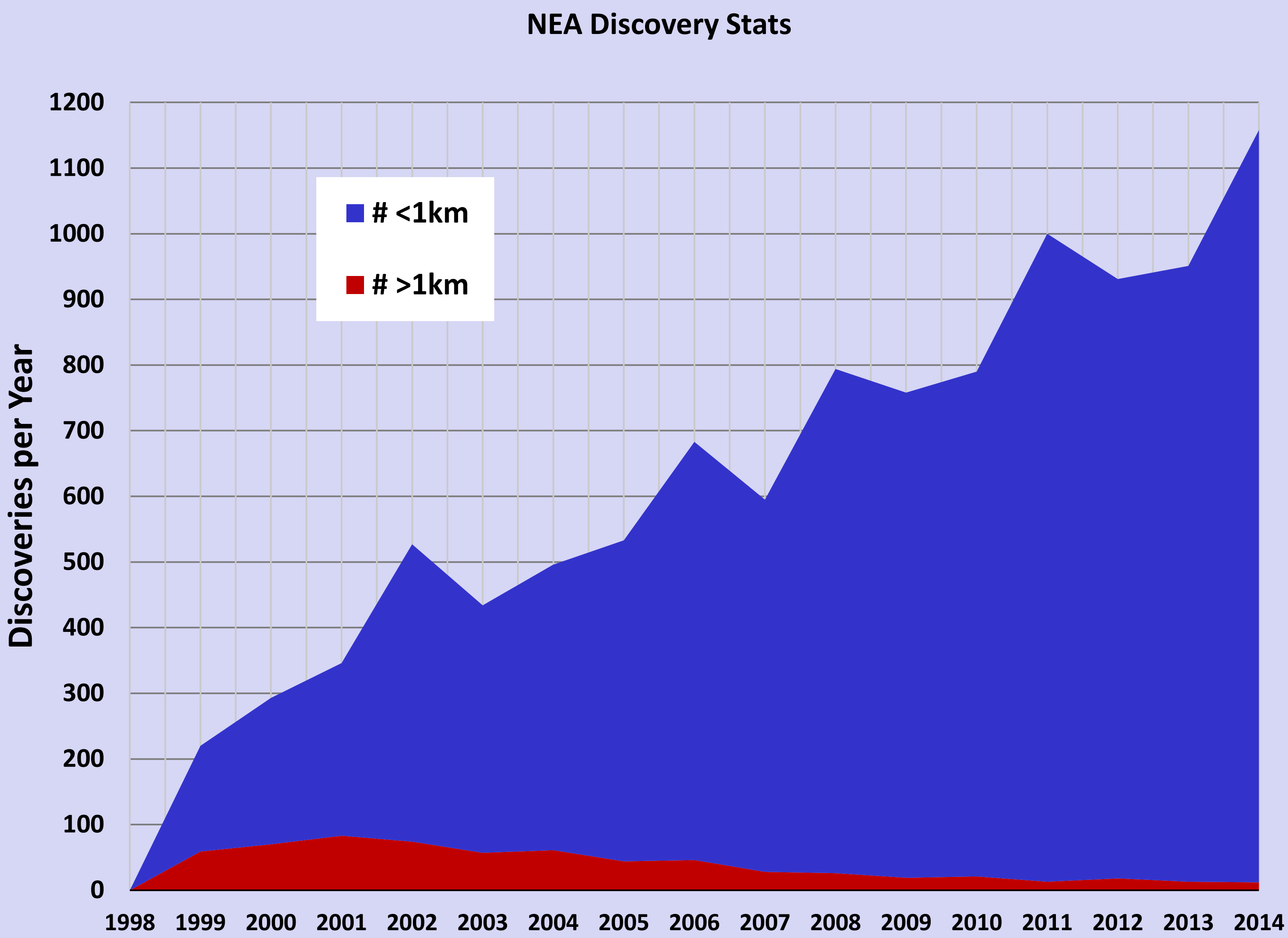
Includes 94 comets

1497 PHAs

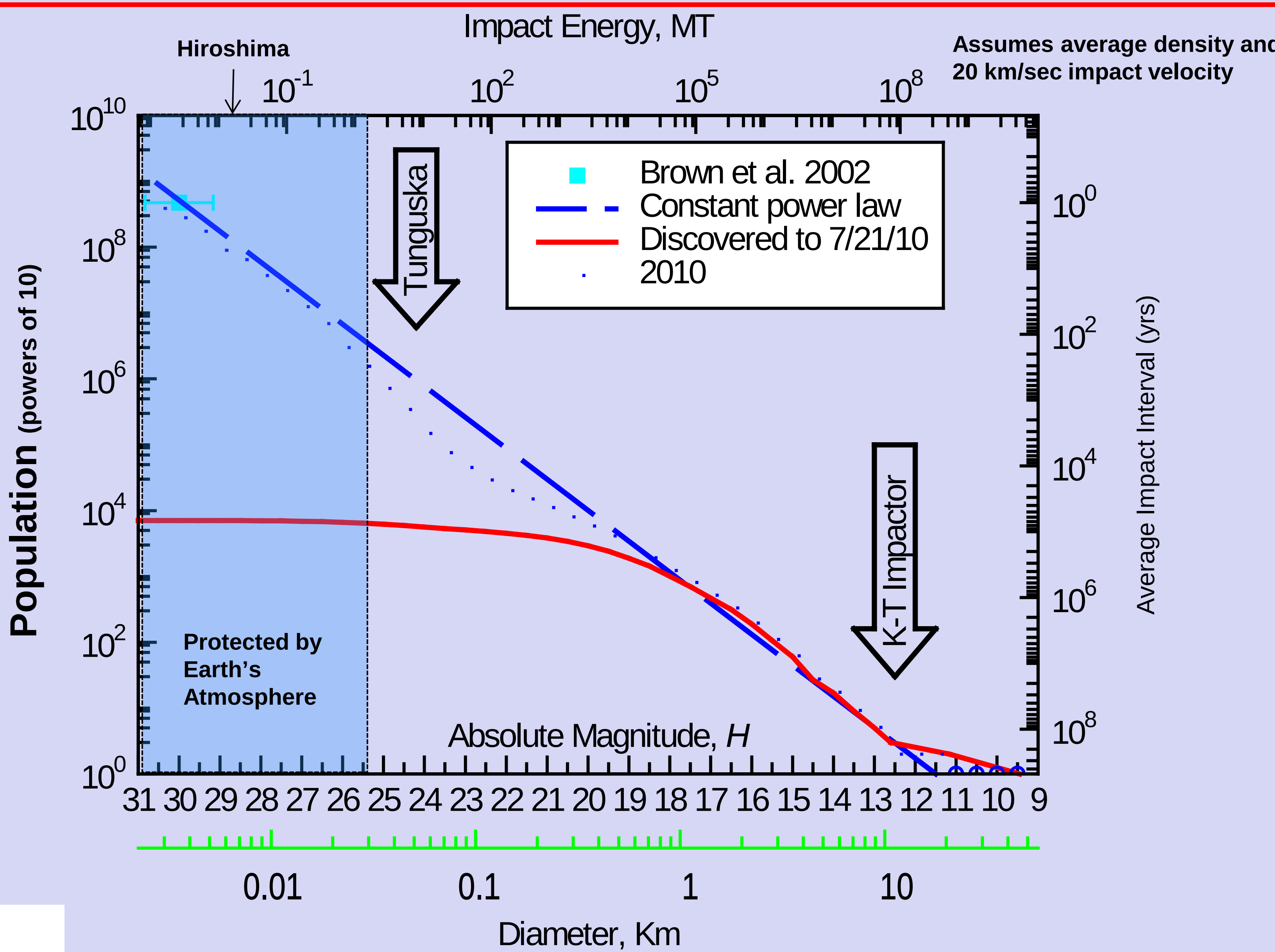
864
9/01/14

155 PHAs

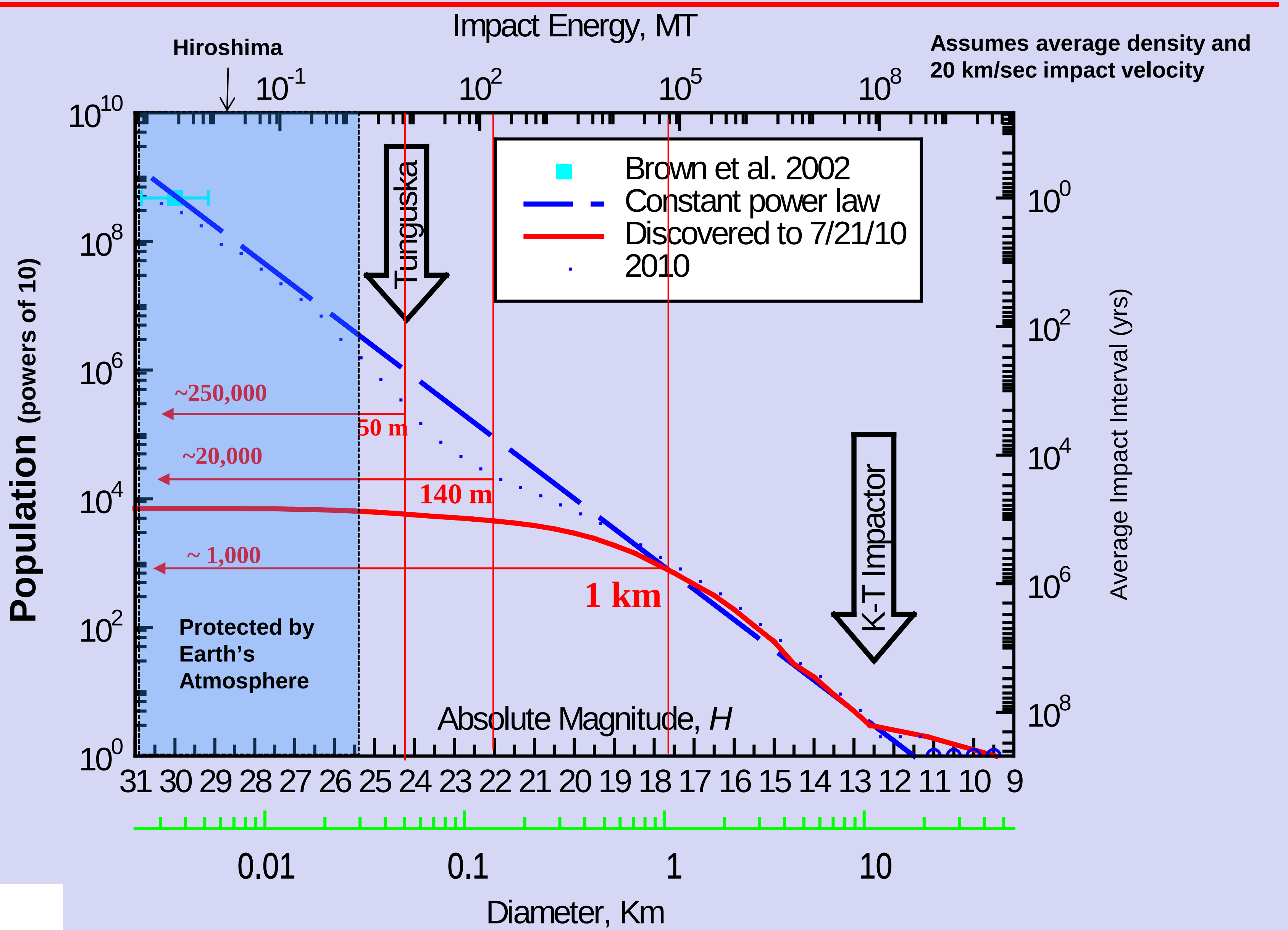
Near Earth Asteroid Discoveries



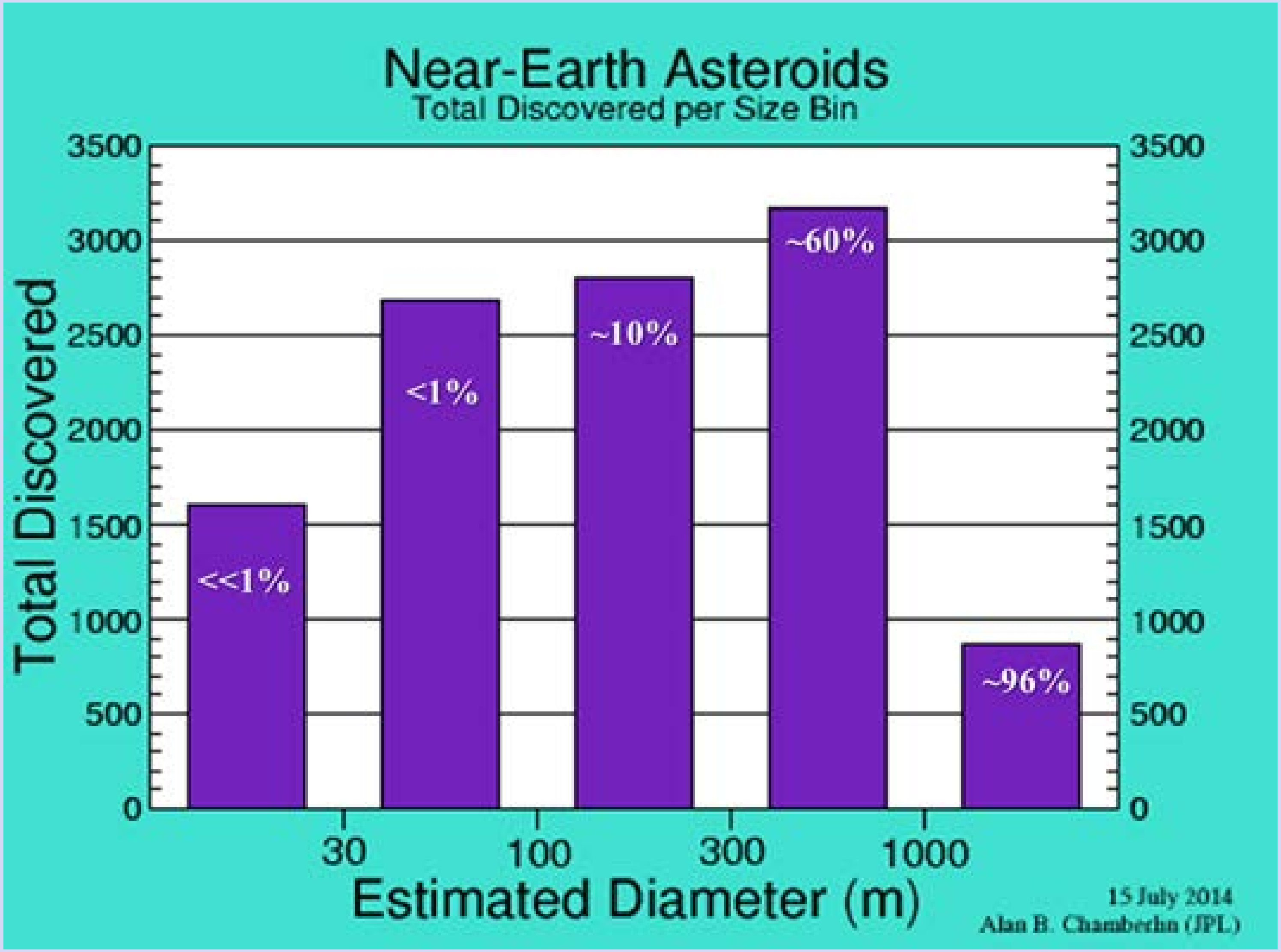
Population of NEAs by Size, Brightness, Impact Energy & Frequency (A. L. Harris 2010)



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



Known Near Earth Asteroid Population



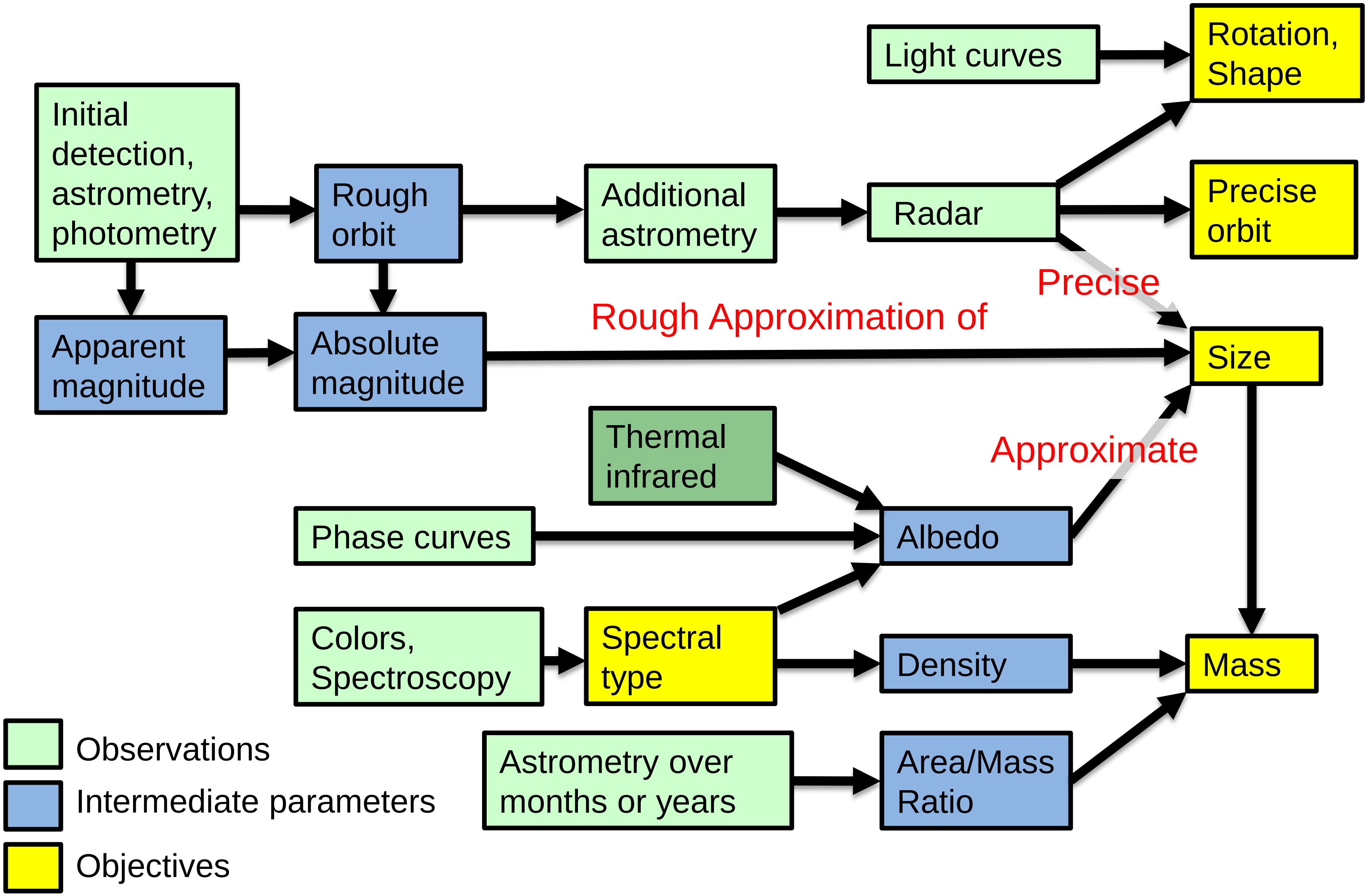
Physical Characterization of NEAs

- **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.

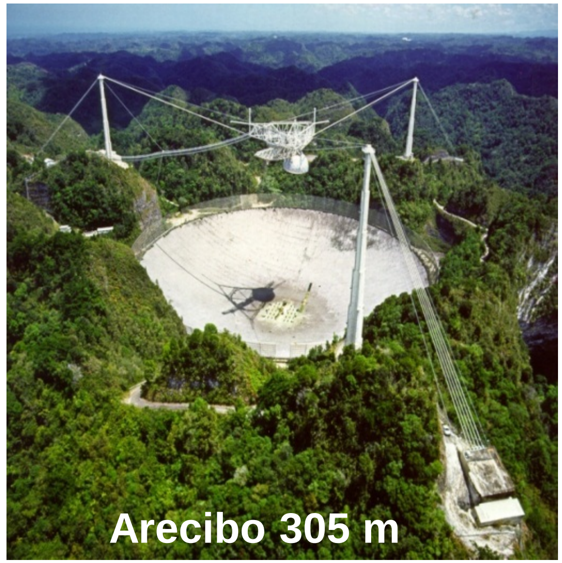
Assumed albedo
ρ = 0.04

Assumed albedo
ρ = 0.34

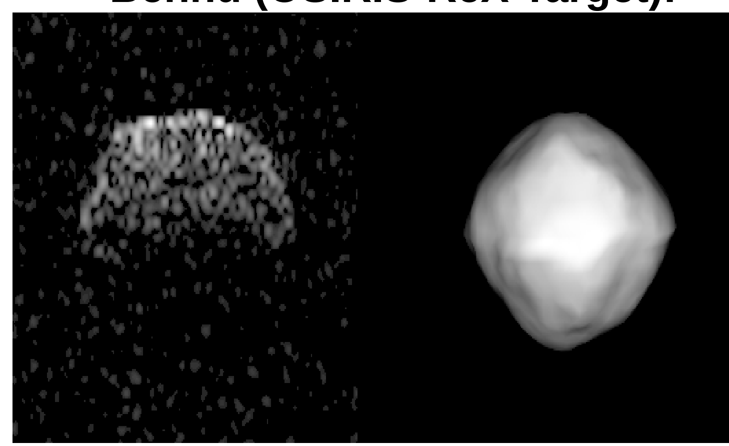
Characterization Process



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)

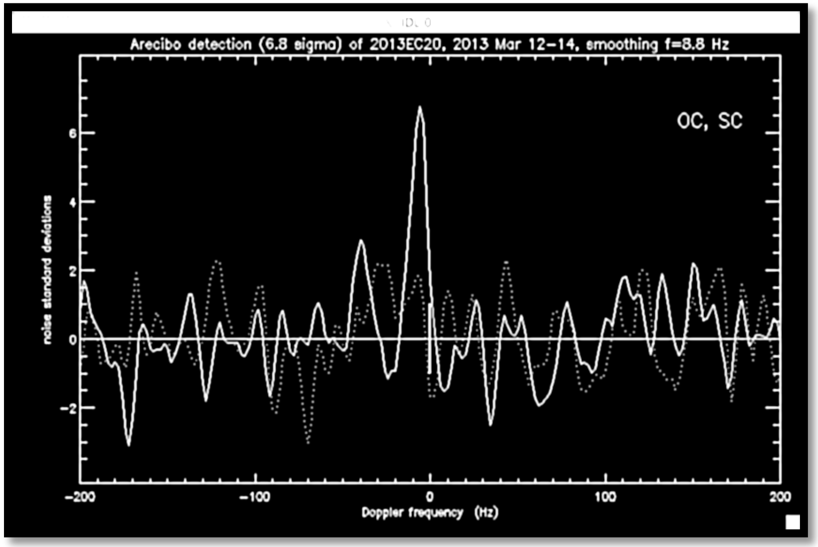
- Dedicated Planetary Science Observatory
- Characterization of Comets and Asteroids
- Spectroscopy and Thermal Signatures
- On-call for Rapid Response on Discoveries

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 Exercised for 2013 EC20

- Discovered 7 March 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

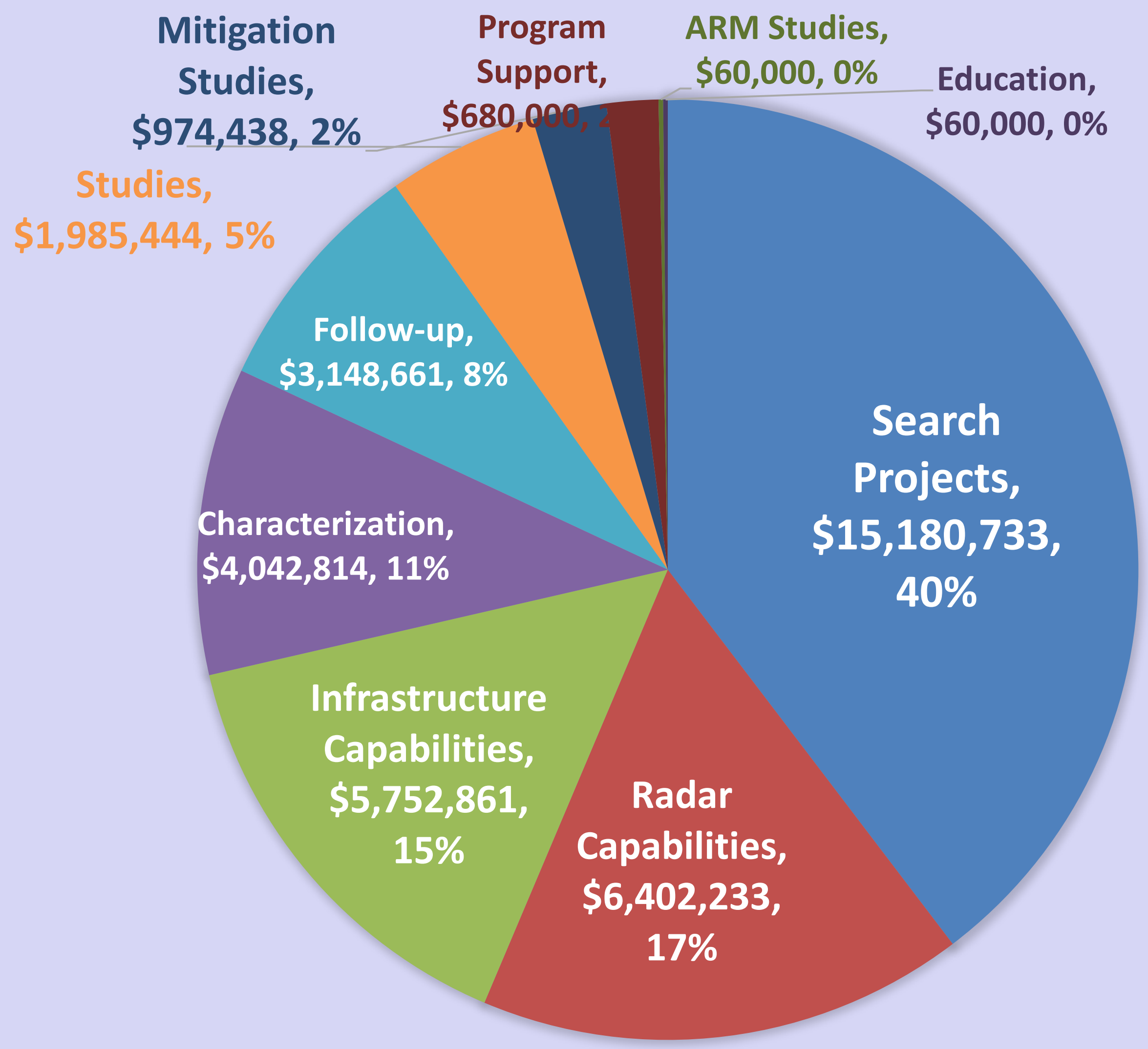


NEOO Project Stats 2014

Project Areas:

- Search
  - 8 Projects
- Radar
  - 8 Projects
- Infrastructure
  - 5 Projects
- Characterization
  - 13 Projects
- Follow-up
  - 13 Projects
- Concept Studies
  - 4 Projects
- Mitigation Studies
  - 5 Projects
- Program Support
  - <u> 3 Projects</u>

59 Projects

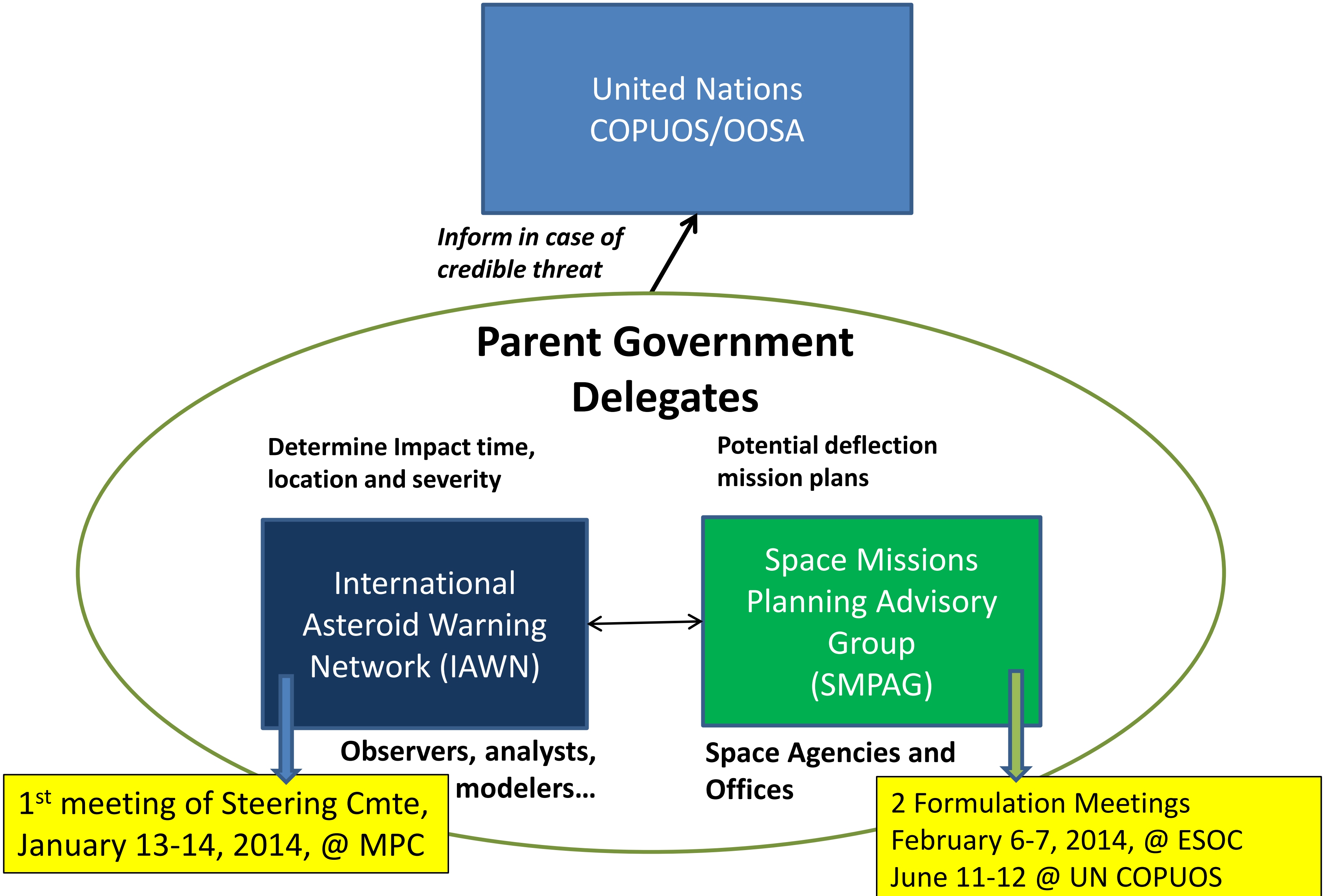


Mitigation Studies and Related Efforts

- Mitigation Studies
  - NEO Observations Program mitigation effects grants
  - NASA Innovative Advanced Concepts Program study awards
  - Kinetic Impactor demonstration mission studies
    - Impactor for Surface and Interior Science (ISIS) mission concept
    - Asteroid Impact and Deflection Assessment (AIDA) mission concept (with ESA)
- 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, May 2014 - FEMA HQ Impact Emergency Response Table Top Exercises (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

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

Overview for NEO Threat Response



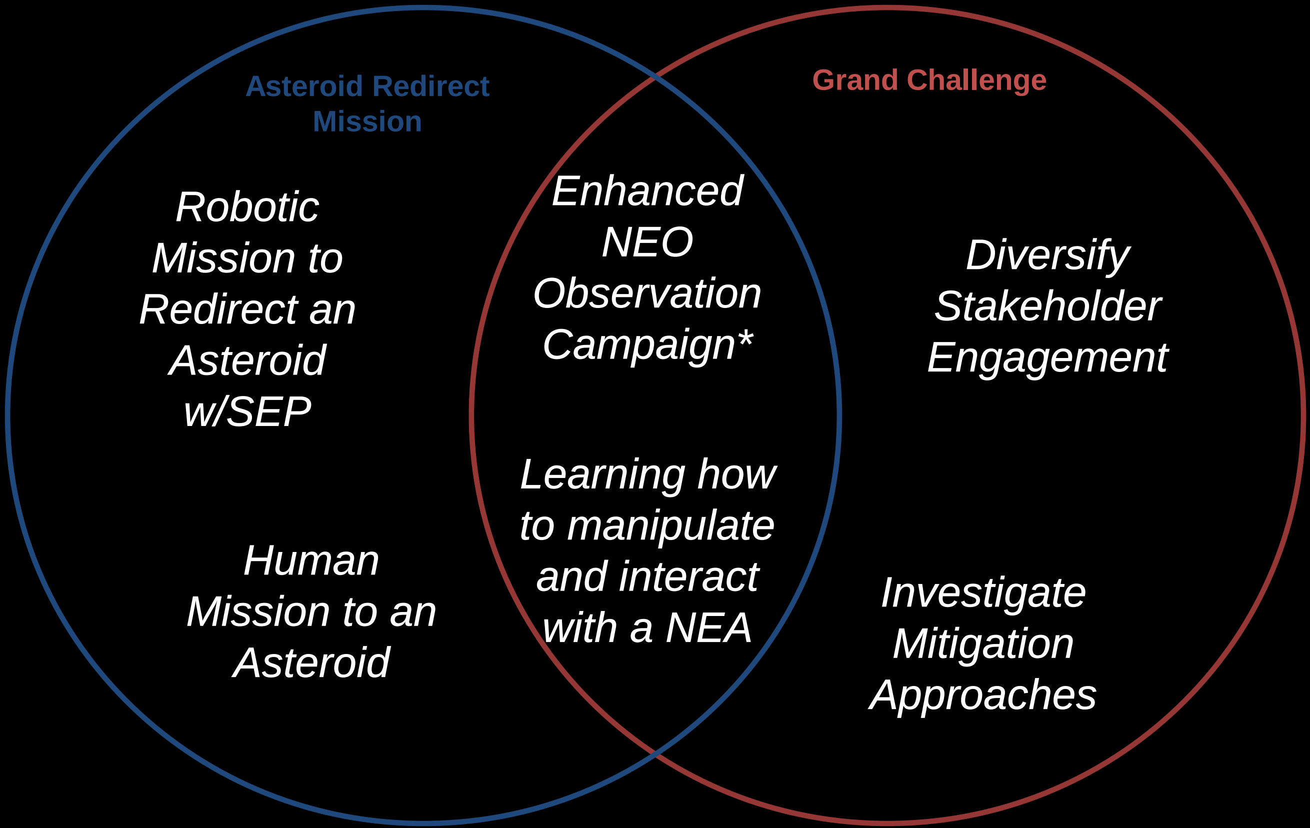
Grand Challenge Statement*

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

*Announced 18 June, 2013

FY14 Asteroid Initiative: What and How

Asteroid Initiative



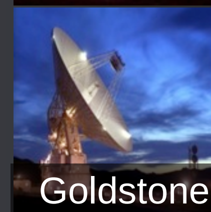
Both sets of activities leverage existing NASA work while amplifying participatory engagement to accomplish their individual objectives and synergize for a greater collective purpose.

* FY2014 PBR increases NEOO Program to $40M

Asteroid Redirect Mission: Three Main Segments

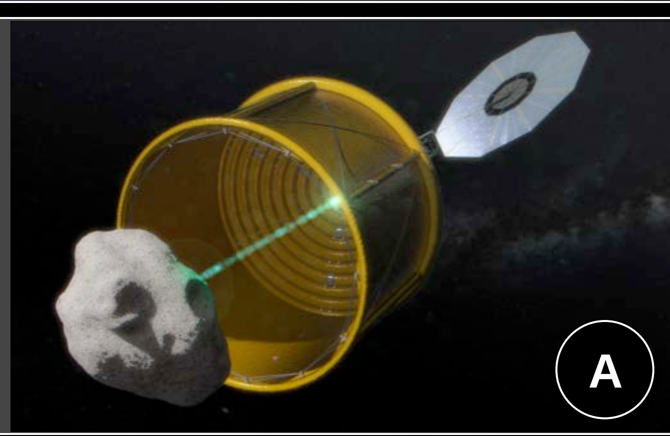
IDENTIFY

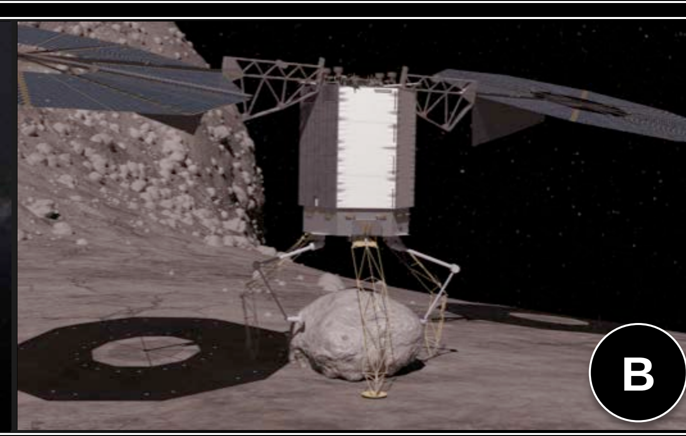
Ground and space based assets detect and characterize potential target asteroids



REDIRECT

Solar electric propulsion (SEP) based system redirects asteroid to cis-lunar space (two capture options)





EXPLORE

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

Observation Campaign Status

Since Asteroid Initiative was announced (April 2013)

- 1,010 more Near Earth Asteroids (NEAs) have been found by search teams
  - Catalina Sky Survey 59%
  - Pan-STARRS 34%
  - LINEAR 1% (converting to new Space Surveillance Telescope)
  - Spacewatch 2% (no longer a full time search asset)
  - NEO WISE 1% (reactivated December 2013)
  - Other 3%
- Only 11 greater than 1 kilometer in size. This population becoming well known
- 73 are in orbits potentially hazardous to the Earth (PHAs)
  - Only 1 is greater than 1 kilometer in size
- 36 are potentially spacecraft accessible (round trip delta V < 8 km/sec)
  - But only 20 in next 10 years (2015-2025)
- Of the 20, only 8 are estimated to perhaps be small enough for capture, but **none** have another opportunity to be adequately characterized using existing assets (largely ground-based)
- Of the 20, only 9 might make good candidates for boulder retrieval, but only **2** have another opportunity to be adequately characterized using existing assets (largely ground-based)

Observation Campaign Enhancements for Discovery

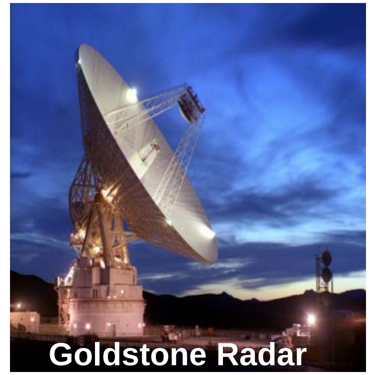
	Facility	V_{lim}	FOV (deg^2)	In Work or Potential Improvements	Ops Date
Current Surveys	Catalina Sky Survey:			Retune observation cadence	Late 2014
	Mt. Bigelow	19.5	8	Increase FOV to 19.4 deg^2	Late 2014
	Mt. Lemmon	21.5	1.2	Increase FOV to 5.0 deg^2	Late 2014
	Pan-STARRS 1	21.5	7	Increase NEO time to 50%	Mar 2014
				Increase NEO time to 100%	Late 2014
Future Surveys	DARPA SST	22+	6	Begin bulk data delivery - MPC	Jul 2014
	Palomar Transient Facility (PTF)	21	7	Improve software to detect streaked objects	Early 2014
	Pan-STARRS 2	22	7	Complete telescope system	Late 2014
	ATLAS	20	40	Entire night sky every night x2	Late 2015

V_{lim} = limiting magnitude , FOV = Field of View

Primary NEO Characterization Assets and Enhancements

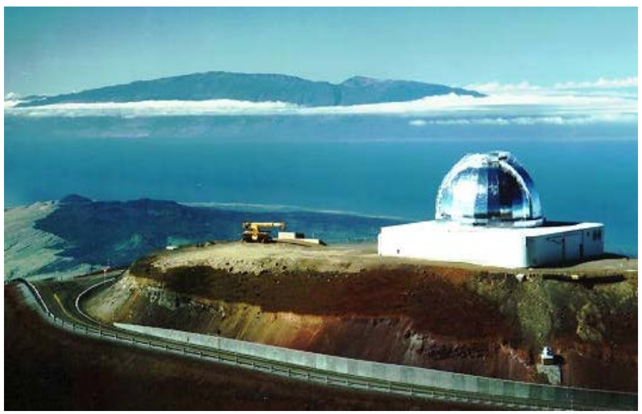
Radar (Goldstone and Arecibo)

- Increased time for NEO observations
- Streamlining Rapid Response capabilities
- Improve maintainability



Goldstone Radar

Arecibo Observatory

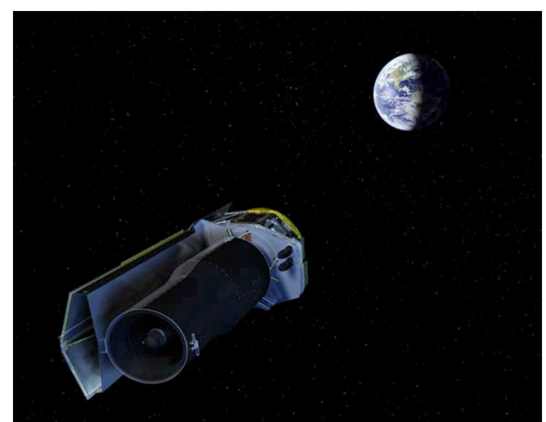


NASA InfraRed Telescope Facility (IRTF)

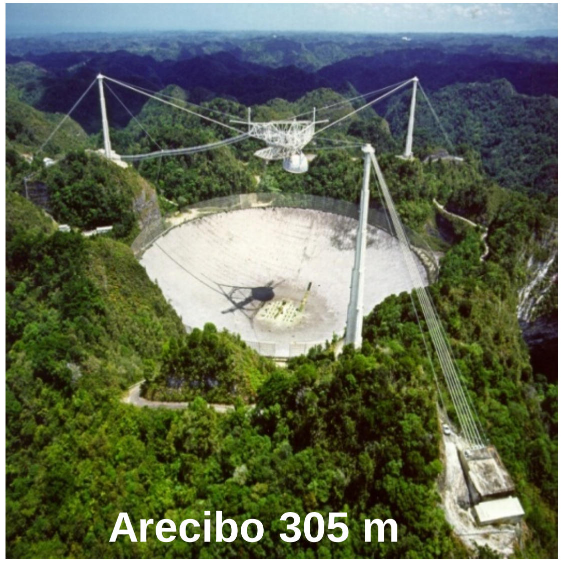
- Increased call-up for Rapid Response
- Improving operability/maintainability
- Improve Instrumentation for Spectroscopy and Thermal Signatures

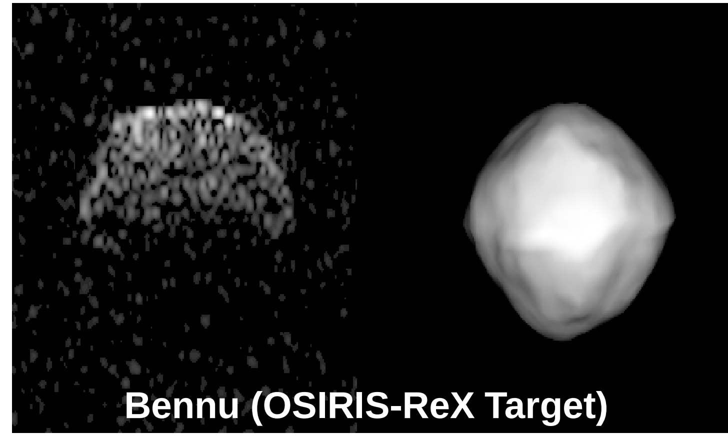
Spitzer Infrared Space Telescope

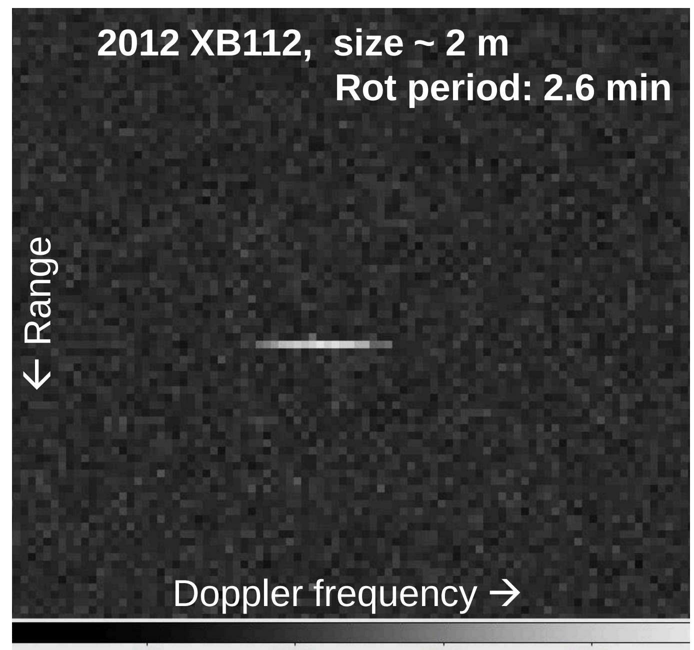
- Orbit about Sun, ~176 million km trailing Earth
- In extended Warm-phase mission
- Characterization of Comets and Asteroids
- Thermal Signatures, Albedo/Sizes of NEOs
- Longer time needed for scheduling



Radar Observations of ARRM Candidates

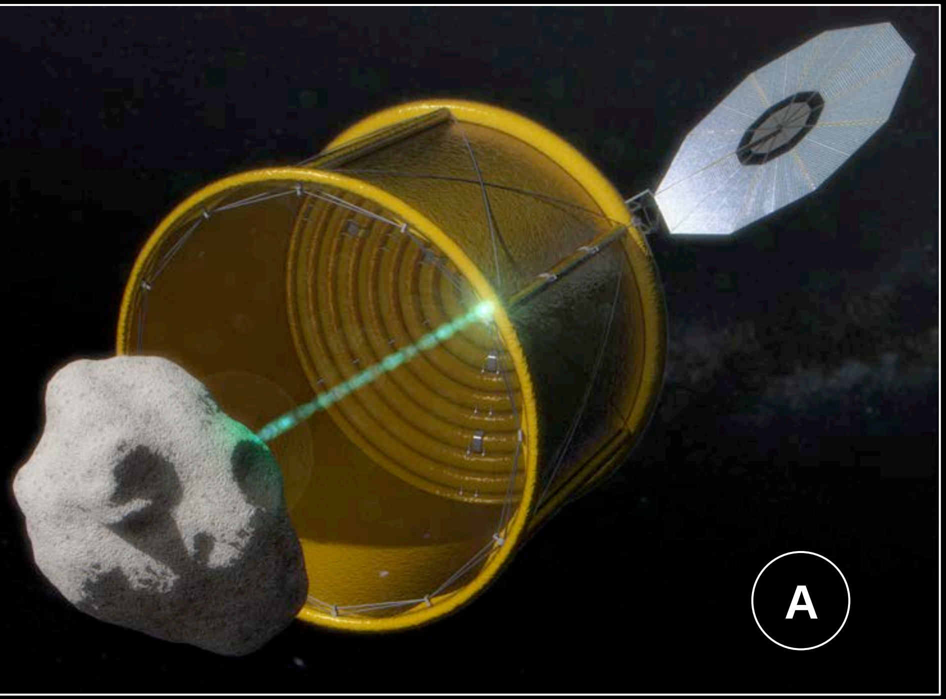






- For the Reference Concept, a candidate must pass < ~5 lunar distances to be detected; ~75% of current candidates could have been detected.
- For the Alternate Concept, a candidate must pass < ~8 lunar distances to have a high enough SNR to detect boulders.
- Radar observations can provide:
  - Size and shape to within ~2 meters.
  - High precision range/Doppler orbit data.
  - Spin rate, surface density and roughness.

Asteroid Redirect Robotic Mission: Two Capture Options



Current Candidates for Option A Concept

Mid-2019 Launch & 2021-26 Return

- Current list of Potential Candidates for the Reference Concept:

	Name	Was Radar Possible?	Estimated Size (m)	V_∞ (km/s)	Return Date	Maximum Returnable Mass (t)†	Comment
	2007 UN12	Y	3 – 18	1.2	12/2021	90	
	2008 EA9	?	5 – 25	1.9	5/2021	45	
KISS baseline	2008 HU4	Y	4 – 22	0.5	4/2026	800	Characterizable in 2016
Current baseline	2009 BD	Y	2.6 – 7	1.2	6/2023	430	Valid Candidate
	2010 UE51	Y	4 – 22	1.2	12/2022	90	
	2011 MD	Y	4 – 23	1.0	8/2024	620	Valid Candidate
	2013 EC20	Y	2 – 3	2.6	4/2025	90	Characterized, but small
	2013 GH66	Y	4 – 22	2.0	4/2025	100	
	2013 LE7	?	6 – 33	2.5	5/2023	100	
	2013 PZ6	N	5 – 23	n/a	8/2023	100	
	2013 XY20	N	11 – 60	1.8	12/2025	310	
	2014 BA3	Y	4 – 21	1.9	1/2024	500	

†Assumes Falcon Heavy and launch dates no earlier than June 2019.

- Potential Candidates:
  - Past discovery rate: **~1-2 per year**; in the last 12 months: **~5**.
  - Estimated discovery rate, with enhanced assets: **~5 per year**.
- Valid Candidates:
  - Currently two: **2009 BD, 2011 MD** characterized by Spitzer
  - Expected to increase at **~1-2 per year**.

Current Candidates for Option B Concept:
Mid-2019 Launch & 2023-24 Return

- Current list of Valid Candidates and possibly Valid Candidates for the Alternate Concept:

Target	Type	Asteroid V_∞ (km/s)	Earth Launch or Escape	Earth return	Max Return mass (t)	Boulder max diam (m)[c]	Characterization	
Itokawa[a]	S	5.7	3/2019	10/2023	6	1.6 - 1.8	Visited by Hayabusa in 2005	Valid
Bennu[b]	C	6.4	5/2019	11/2023	12	2.0 - 2.3	OSIRIS-REx, mid-2018	Expected
1999 JU3	C	5.1	6/2019	7/2023	13	2.0 - 2.3	Hayabusa 2, mid-2018	Expected
2008 EV5[a]	C	4.4	1/2020	6/2024	32	2.7 – 3.1	Radar in Dec. 2008, SNR= 240,000	Valid
2011 UW158	?	5.3	7/2018	7/2024	10	1.8 - 2.1	Radar in Jul. 2015, SNR = 280,000	Possible
2009 DL46[a]	?	5.7	11/2019	8/2024	11	1.9 - 2.2	Radar in May 2016, SNR= 48,000	Possible

[a]Earth gravity assist ~1yr prior to capture

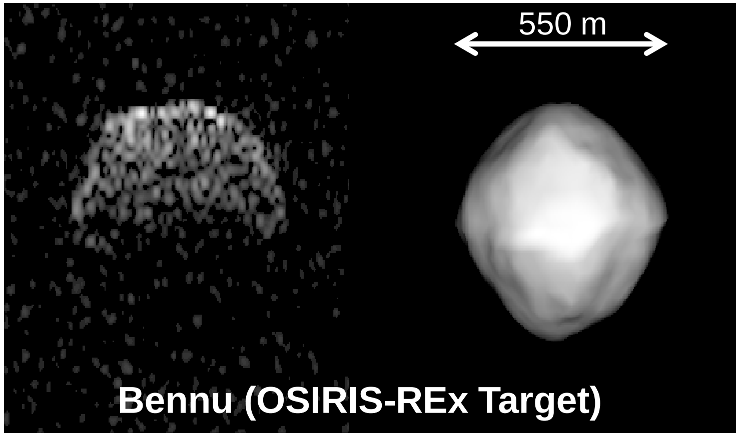
[c]Assuming densities in the range 2.0 to 3.0 g/cm^3

NB: Max Return masses and Boulder max diameters vary significantly with launch date and return date.

- Assumes a Falcon Heavy L/V, Earth departure in mid-2019, 400-day stay, and return in 2023, unless otherwise noted.
- Green rows: in situ characterization by imaging from a precursor mission.
  Grey rows: characterization by radar and inference of appropriate-sized boulders.
- Potential Candidates are characterized by radar at an average rate of ~1 per year.

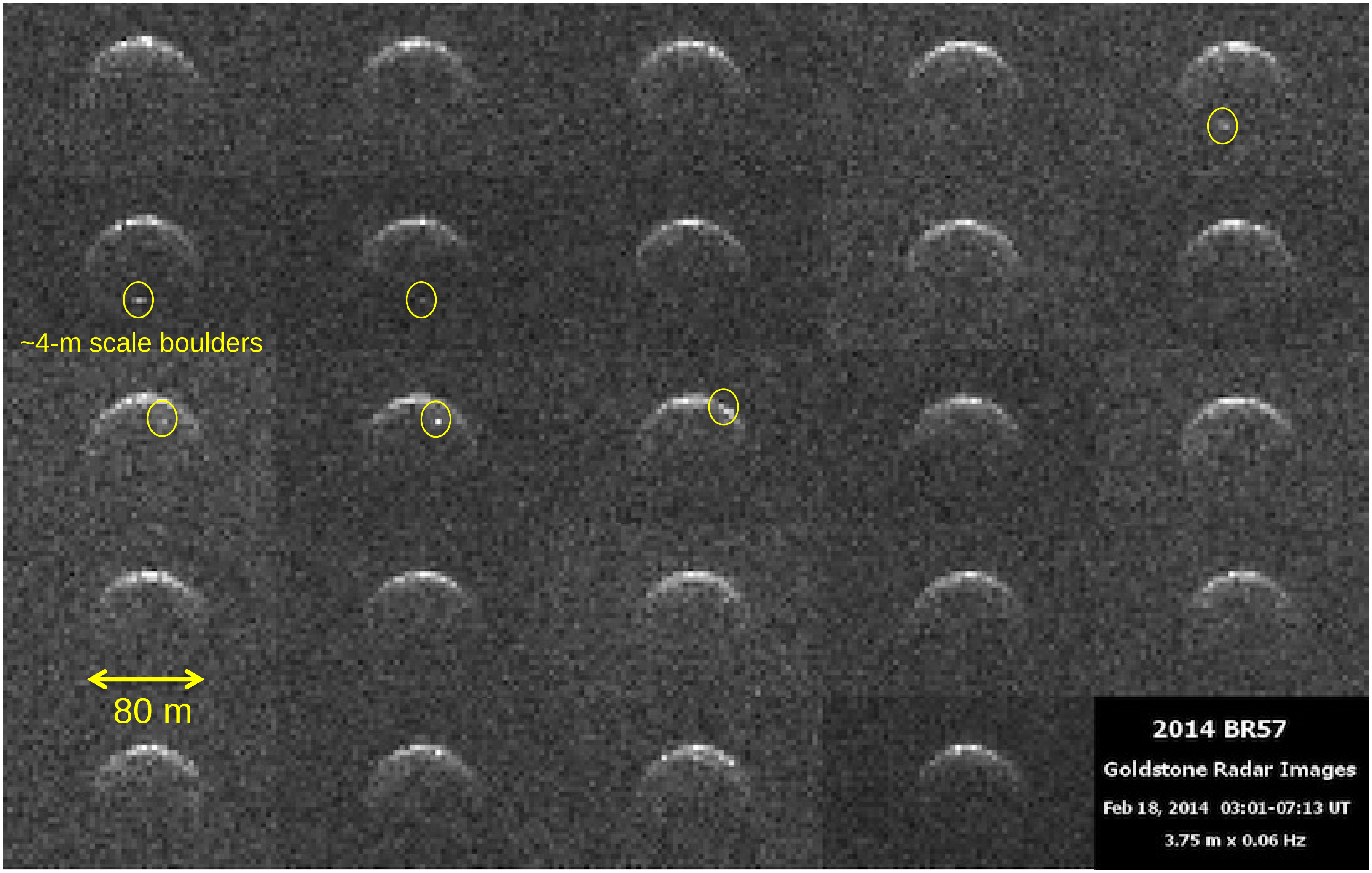
Radar Characterization of Boulders on Asteroids

- Current ground-based radar range resolution: ~4 m (Goldstone + Arecibo).
- Currently, radar cannot definitively detect boulders <4m, regardless of the SNR, but the presence of boulders might be inferred from radar observations.
- If the radar SNR exceeds ~5000, radar could detect ~4m-scale features that are probably boulders, and it can also determine *average surface roughness* at a scale of ~10 cm. Current radar observations can provide confidence in the presence or absence of <4m-scale boulders.
- The characterization challenge is verifying, or being able to infer with sufficient confidence, the presence of boulders of the appropriate size (<~3 m) available to be captured and removed from the surface.
- 11 potential candidates for the Option B Concept have been observed by radar with high enough SNR; evidence for 10m-scale boulders was seen on 2 of them: Bennu and 2008 EV5, both C-types.
- These two would be considered Valid Candidates by inference of the presence of ~3-m-scale boulders.



2014 BR57 observed by Goldstone Radar Feb 18th

- **Example of how ~4m-scale boulders can be seen at very high radar SNR.**



ARM Milestones to Mission Concept Review, February 2015

➢ FY14 Risk Reduction Plan for Boulder Capture Concept Option	Apr 3, 2014
➢ BAA Notice of Intent Due	Apr 4, 2014
➢ PPBE16 program submits due	Apr 28, 2014
➢ BAA Proposal Due Date	May 5, 2014
➢ STMD Solar Array Systems development Phase 1 complete	Jun 2014
➢ BAA Awards	NET Jul 14, 2014
➢ BAA Kickoff Meetings	Week of Jul 21
➢ **STMD Integrated Thruster performance Test with 120V PPU**	**Sep 2014**
➢ **HEOMD MACES EVA end-to-end mission sim complete**	**Sep 2014**
➢ **STMD SEP Solar Array RFP release**	**Oct, 2014**
➢ **BAA Interim Reports**	**Oct 31, 2014**
➢ **STMD Electric Propulsion RFP release**	**Nov 2014**
➢ **Robotic mission concept Option A/B downselect**	**mid Dec 2014**
➢ **BAA Period of Performance Ends**	**Dec 31, 2014**
➢ **Mission Concept Review**	**Feb 2015**

Summary of NEO 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 them.
- 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.