Status of Arecibo Observatory and the Planetary Radar Program

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Small Bodies Assessment Group (SBAG) Meeting

January 11, 2017 @ Tucson, AZ

Management

- **Arecibo Observatory** is a facility of the **NSF** specializing in radio astronomy, atmospheric sciences, and planetary radar
- **NSF AST** supports Radio Astronomy
- **NSF AGS** supports Atmospheric Sciences
- **NSF** provides **~2/3** of the operational budget of the observatory; supporting the planetary radar requires an outside funding source
- **NASA NEOO supports Planetary Radar** via two grants through September 2017; proposal submitted to SSO/NEOO in 2016
- **NSF support** continues at the current level until **March 2018**
  - **AGS Portfolio Review** in 2016 recommended reducing Arecibo support to **$1.1 M by 2020**, under assessment by Nat. Acad.

Recent Arecibo Timeline

- **October 2015:** Dear Colleague Letter requests community responses on viable concepts of future continued operation of Arecibo (due January 2016)
- **May 2016:** Scoping of environmental impact statement
  - 30-day public comment period (ended in June)
- **Ongoing:**
  - National Historic Preservation Act Consultation
  - Endangered Species Act Consultation
  - Collaboration Solicitation
- **September 2016:** Dear Colleague Letter announcing intent to release a solicitation for continued operations of Arecibo in FY17 Q1

Recent Arecibo Timeline

- **October 2016:** Draft Environmental Impact Statement published

  https://www.nsf.gov/mps/ast/env_impact_reviews/arecibo/arecibo_drafteis.jsp

  - 45-day public comment period (ended in mid-December)

- **January 2017(?):** Solicitation for continued operations, should include a budget guideline, may have a short response time

- **May 2017:** Final Environmental Impact Statement published

  - >30-day “cooling off” period

- **Summer 2017:** Record of Decision

  - Based on science priority, budget, and programmatic considerations (collaborators, risk, viability)

Draft Environmental Impact Statement

- **Discusses impacts of five possible scenarios:**
  - Continued science operations with interested collaborators: ***agency-preferred alternative***
  - Continued education operations with interested collaborators
  - Mothballing of facilities
  - Partial deconstruction of the site
  - Complete deconstruction of the site

Draft Environmental Impact Statement

- **Radar notes from agency-preferred alternative** (as written)**:**
  - Notes Arecibo's role in tracking and characterization of PHOs is "a task that is the responsibility of the NASA PDCO;" NASA is studying the effect of losing Arecibo
  - States that "to conform to the requirements of future collaborators," ~half of on-site structures will be demolished including those essential to the planetary radar program
  - Suggests the limited field of view of Arecibo limits the ability to track and characterize possible impactors
  - Concentrates on imminent, inevitable impacts; compares frequency of catastrophic impacts to the lifetime of the observatory
  - Combines Arecibo field of view, frequency of impacts, and the lack of mature deflection technology to reach conclusion
  - Concludes that eliminating the planetary defense capabilities of Arecibo presents "an overall, negligible, adverse, long-term impact on public safety"
- Concludes alternatives would "not result in disproportionately high and adverse [effects] to minority and low-income populations"

Draft Environmental Impact Statement

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  - Notes Arecibo's role in tracking and characterization of PHOs is "a task that is the responsibility of the NASA PDCO;" NASA is studying the effect of losing Arecibo
  - Describes deconstruction of ~half of on-site structures "to conform to the requirements of future collaborators," including those essential to the planetary radar program
  - Suggests the limited field of view of Arecibo limits the ability to track and characterize possible impactors
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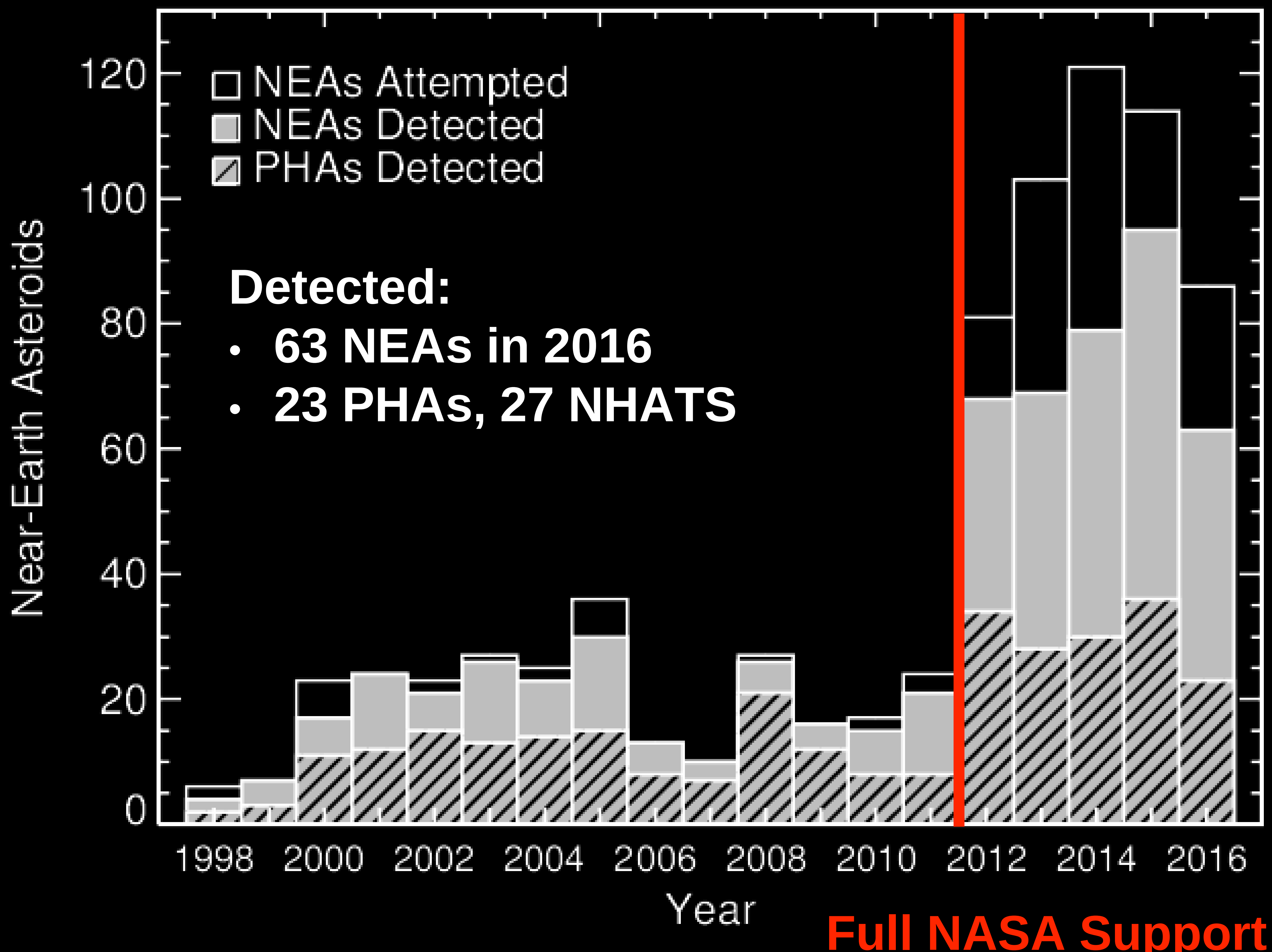
Science Requiring Arecibo (and GBT)

- 100+ asteroids/year accessible only to Arecibo or Goldstone+GBT
- Long-term observations: Yarkovsky drift, solar J2/GR effects
- Characterization of asteroid Apophis in 2021
- Validation of DART kinetic impactor demonstration in 2022
- Observations of the Galilean satellites in 2023:
  - Tidal dissipation of Jupiter and satellites
  - Possible radar detection of volcanism on Io
- Validation of ARM enhanced gravity tractor demonstration
- Recovery and tracking of defunct lunar spacecraft (space situational awareness in general) requiring bistatic setups



NEAs Attempted
NEAs Detected
PHAs Detected
Detected:
• 63 NEAs in 2016
• 23 PHAs, 27 NHATS
Near-Earth Asteroids
0
20
40
60
80
100
120
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Full NASA Support

Summary and Future

- Radar is a unique and powerful method for post-discovery dynamical and physical physical characterization of NEAs
- Detection of 80-100 NEOs per year is sustainable and could possibly increase
- Planetary radar program is strong, but requires a healthy observatory to operate and cannot support the observatory on its own
- Official NSF solicitation expected this month
- Final Environmental Impact Statement in May 2017;
  NSF Record of Decision in Summer 2017

Back-up Slides

Radar Personnel

- **Current**:
  - **Science**: Joan Schmelz (PI), Patrick Taylor (group lead), Edgard Rivera-Valentin, Anne Virkki, Linda Rodriguez-Ford, Luisa Zambrano-Marin, and Betzaida Aponte-Hernandez
  - **Transmitter**: Victor Negron, Juan Marrero, Johbany Lebron, and Adrian Bague
- **Future**:
  - **Postdocs**: Flaviane Venditti and Sriram Bhiravarasu

The Arecibo Radar System

- Planetary radar at Arecibo has existed for its 50+ year history
- The largest and most sensitive single-dish (fully operational) telescope in the world
- The most powerful and most active planetary radar in the world
- D = 305 m, ~20 acre collecting area, antenna gain of 20 million
- 1 MW transmitter at S band (12.6 cm, 2380 MHz)
- Capable of detecting:
  - any PHA within 0.05 AU (~20 lunar distances)
  - any asteroid > 10 m within ~0.015 AU (~6 lunar distances)

Critical Capabilities

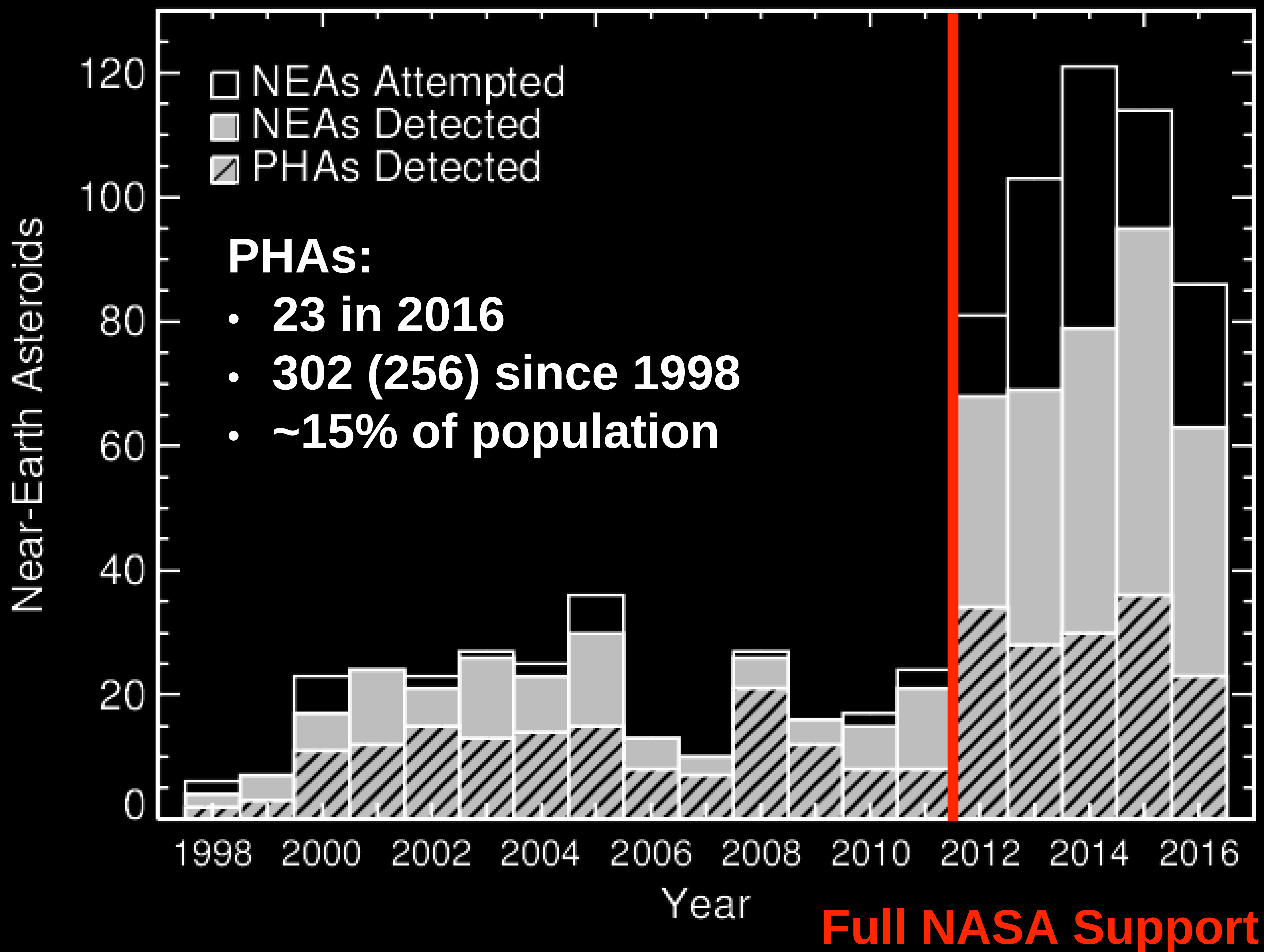
We control the transmitted signal, so any change is due to **target properties**:

- Line-of-sight distance and velocity **astrometry** with fractional precision of 10^7
- All detections provide an estimate of the **rotation rate**
- Size, shape, surface features: **spatial resolution as fine as 7.5 m (3.75 m with Goldstone)**
- **Scattering properties**: albedo, radar albedo, (de)polarization, near-surface bulk density and porosity
- **Bulk density and internal structure:** unambiguous detection of multiple-asteroid systems provides volumetric bulk density and porosity estimates; spin barrier and more rapid rotators
- At its highest fidelity a radar campaign is **roughly equivalent to a spacecraft flyby** at a tiny fraction of the cost
- Navigational support and characterization of gravitational and surface environments for **spacecraft missions**: Hayabusa, EPOXI, OSIRIS-REx, AIDA, ARM, Psyche

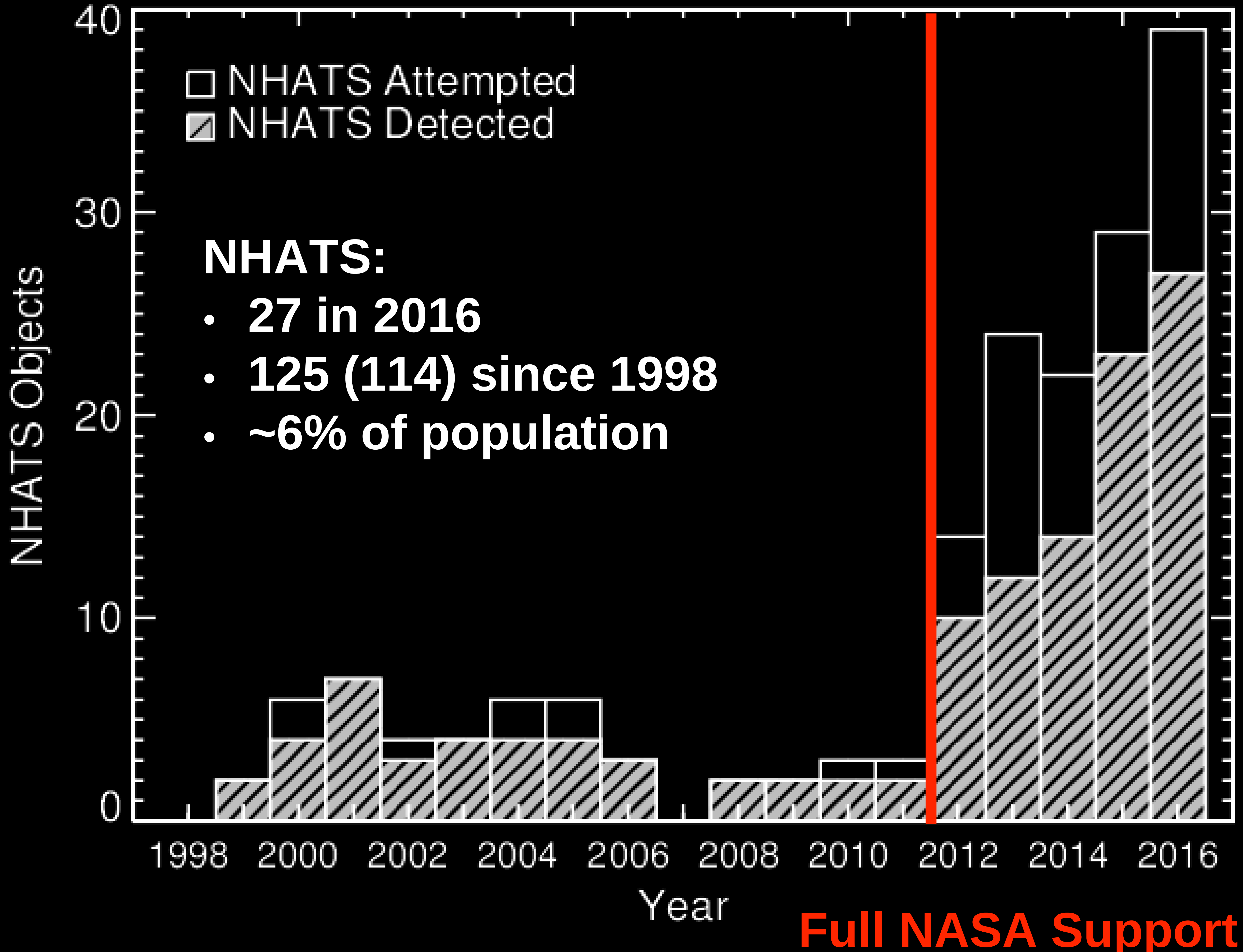
Modes of Observing

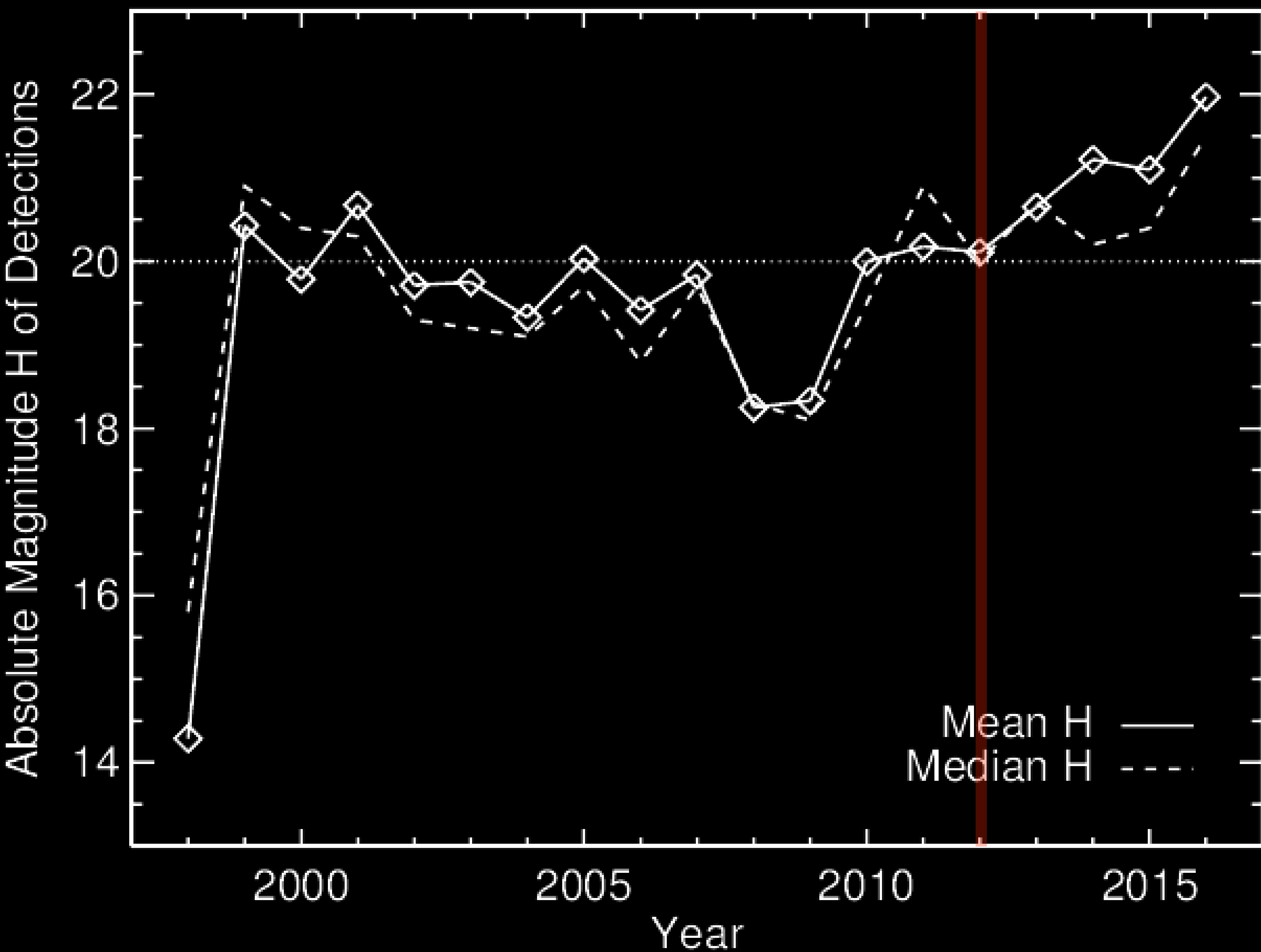
- **High-priority proposal**: imaging targets, often with high enough fidelity for shape modeling
- **Medium-priority proposal**: coarse imaging and astrometry targets
- **Survey nights**: whatever is up near new moon
- **Targets of opportunity**: during scheduled observations
- **Urgent proposals**: rapid response to new discoveries of interest such as PHAs, NHATS objects, or high-res imaging targets

www.naic.edu/~pradar

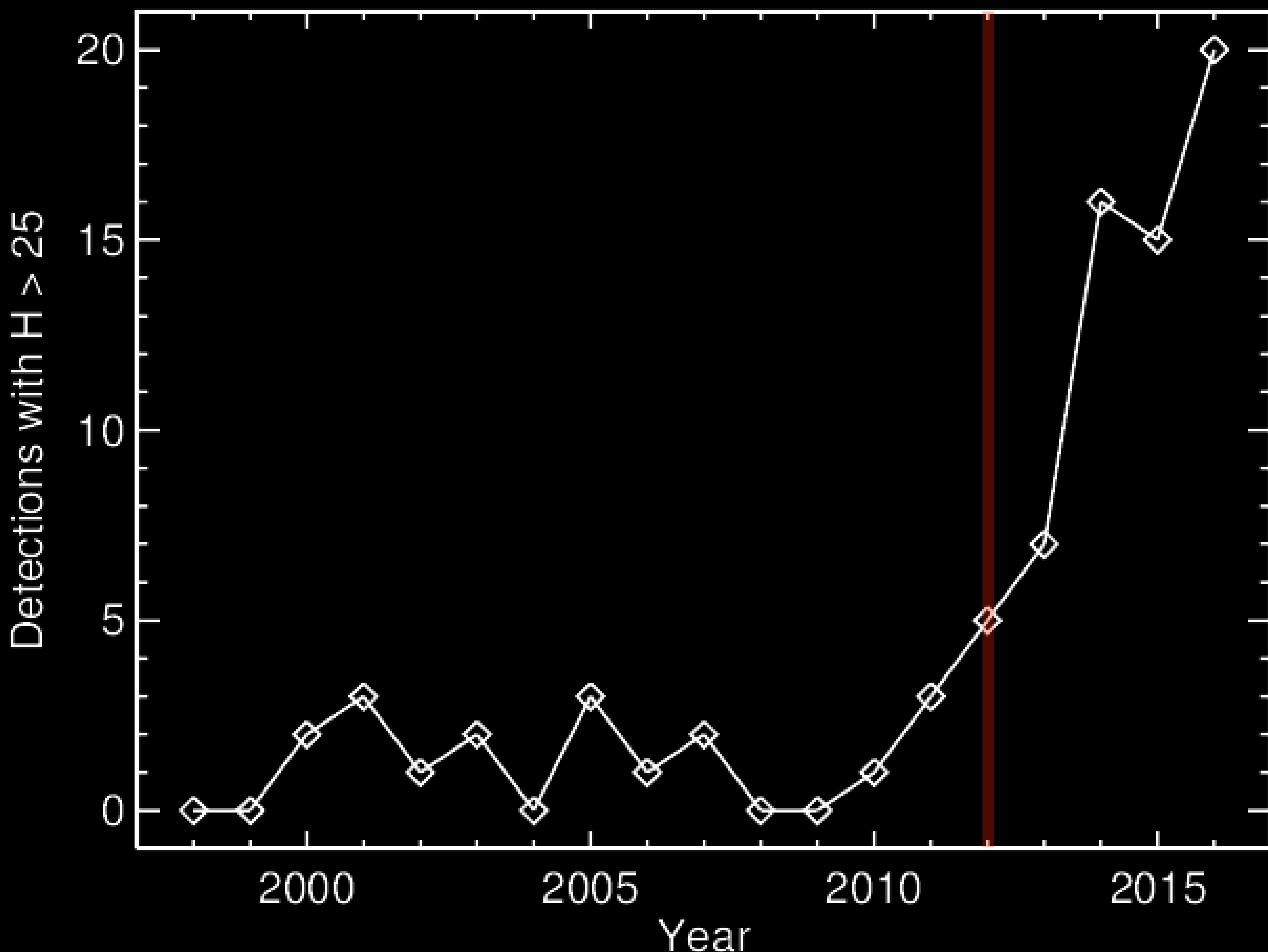


NEAs Attempted
NEAs Detected
PHAs Detected
PHAs:
• 23 in 2016
• 302 (256) since 1998
• ~15% of population
120
100
80
60
40
20
0
Near-Earth Asteroids
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Full NASA Support

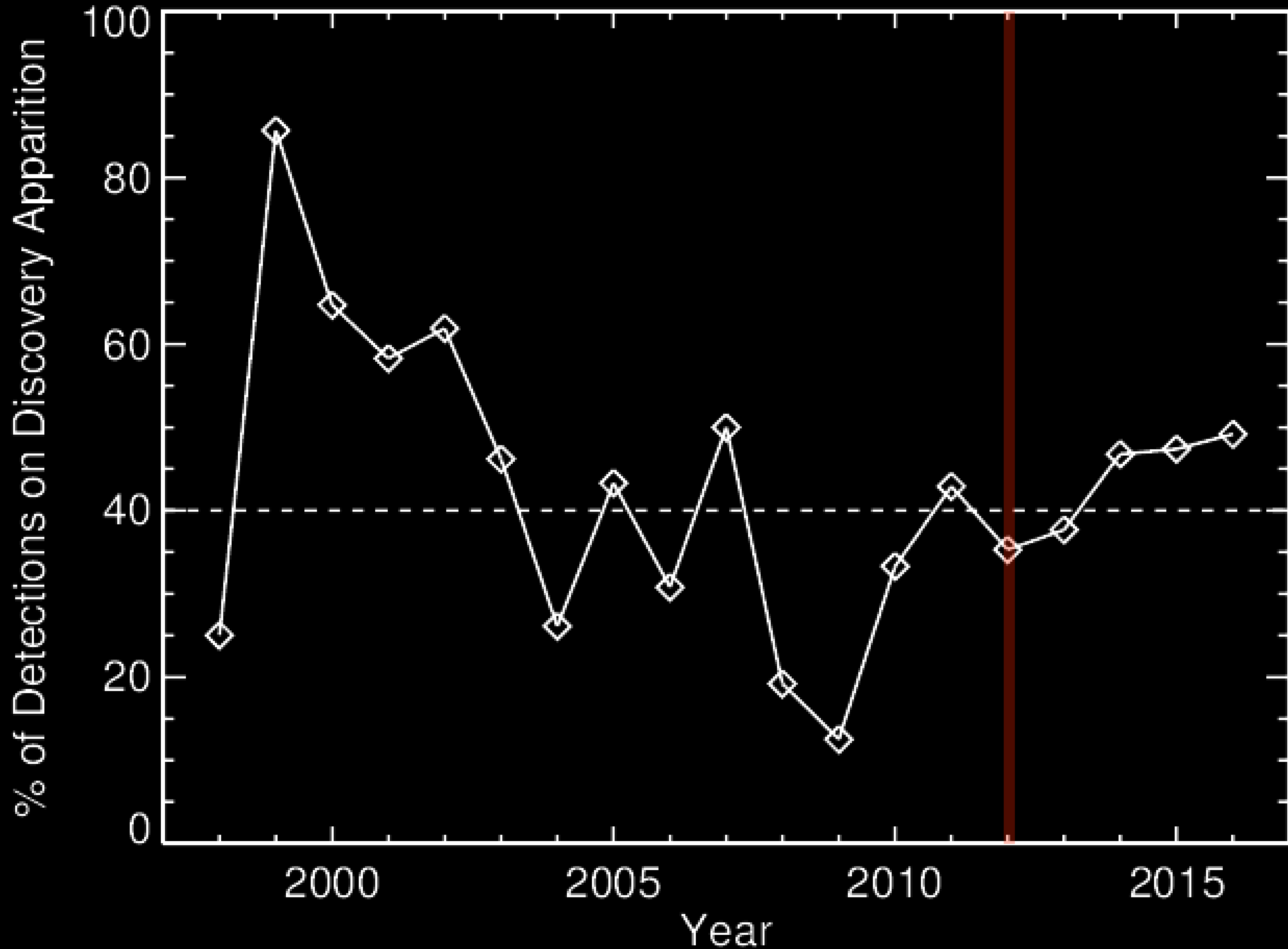

NHATS Attempted
NHATS Detected
NHATS:
• 27 in 2016
• 125 (114) since 1998
• ~6% of population
NHATS Objects
0
10
20
30
40
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Year
Full NASA Support



Absolute Magnitude H of Detections
22
20
18
16
14
2000
2005
2010
2015
Year
Mean H
Median H



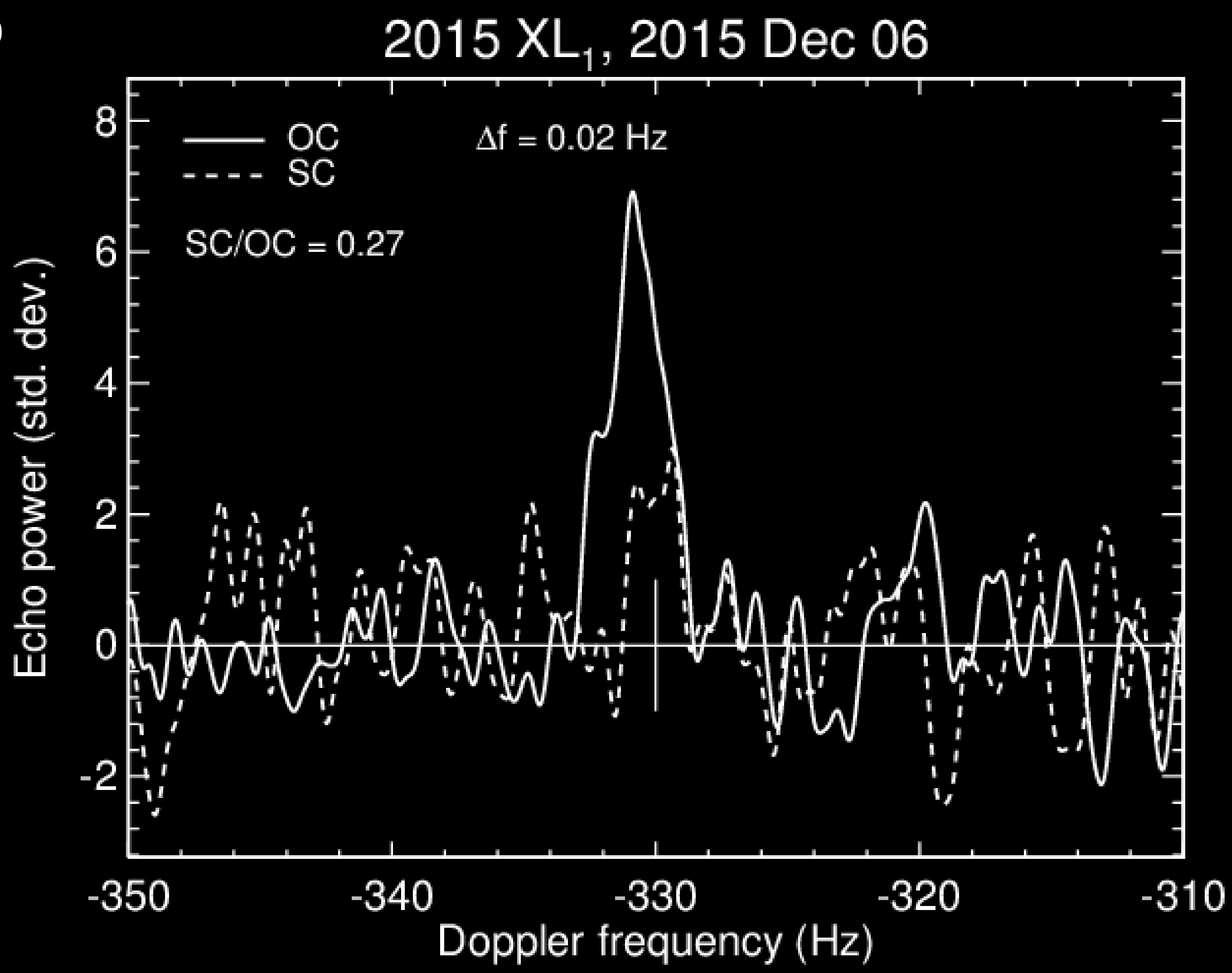
Detections with H > 25
20
15
10
5
0
2000
2005
2010
2015
Year



% of Detections on Discovery Apparition
0
20
40
60
80
100
2000
2005
2010
2015
Year

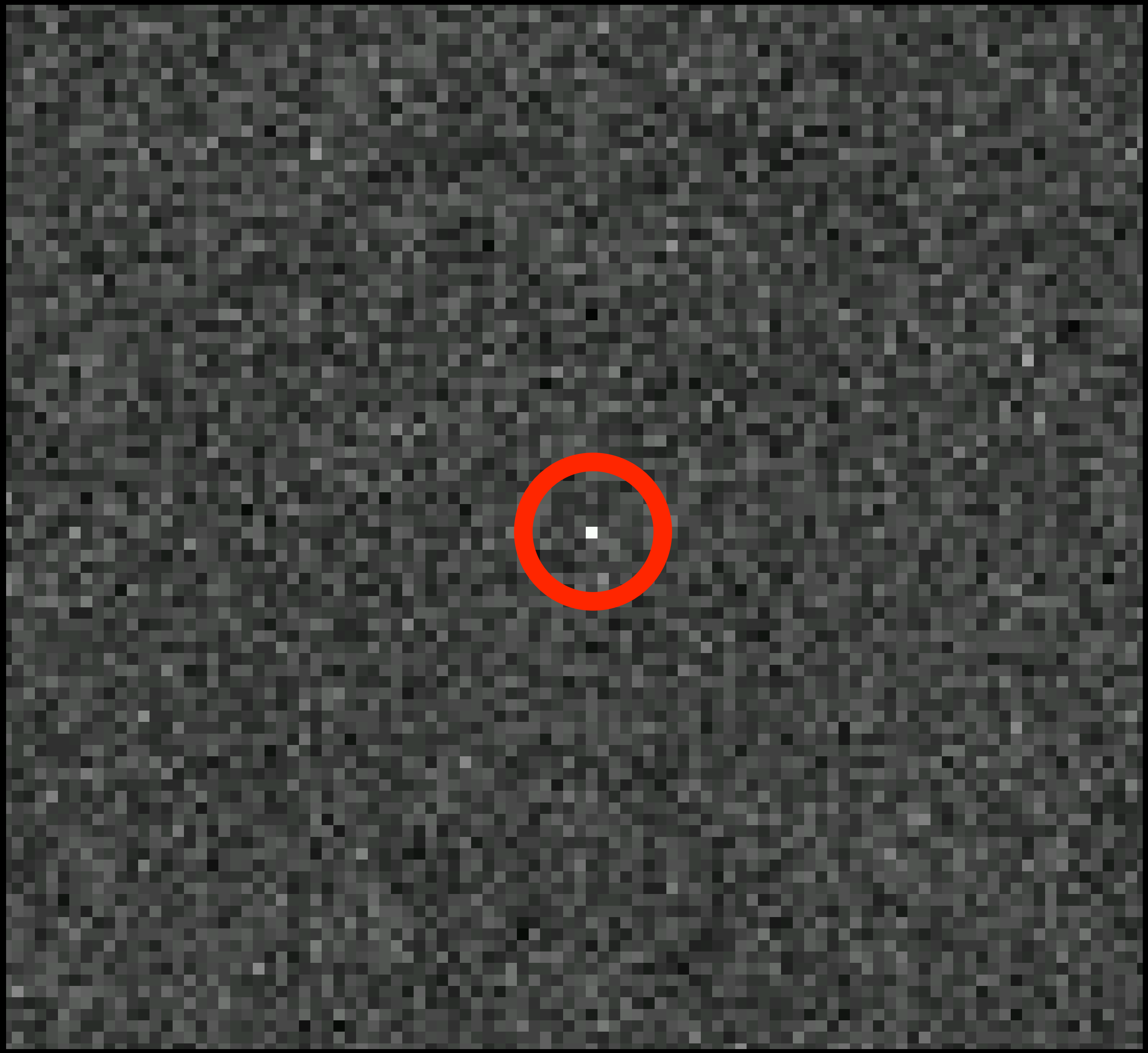
What is Learned from Every Detection?

- Frequency only: no spatial resolution
- Astrometry:
  330 Hz ~ 20 m/s line-of-sight velocity correction
- Rotation rate:
  estimated from echo bandwidth and assumed size
- Polarization ratio:
  ~0.2 is common; higher SC/OC correlates with some compositions, *i.e.*, E and V types



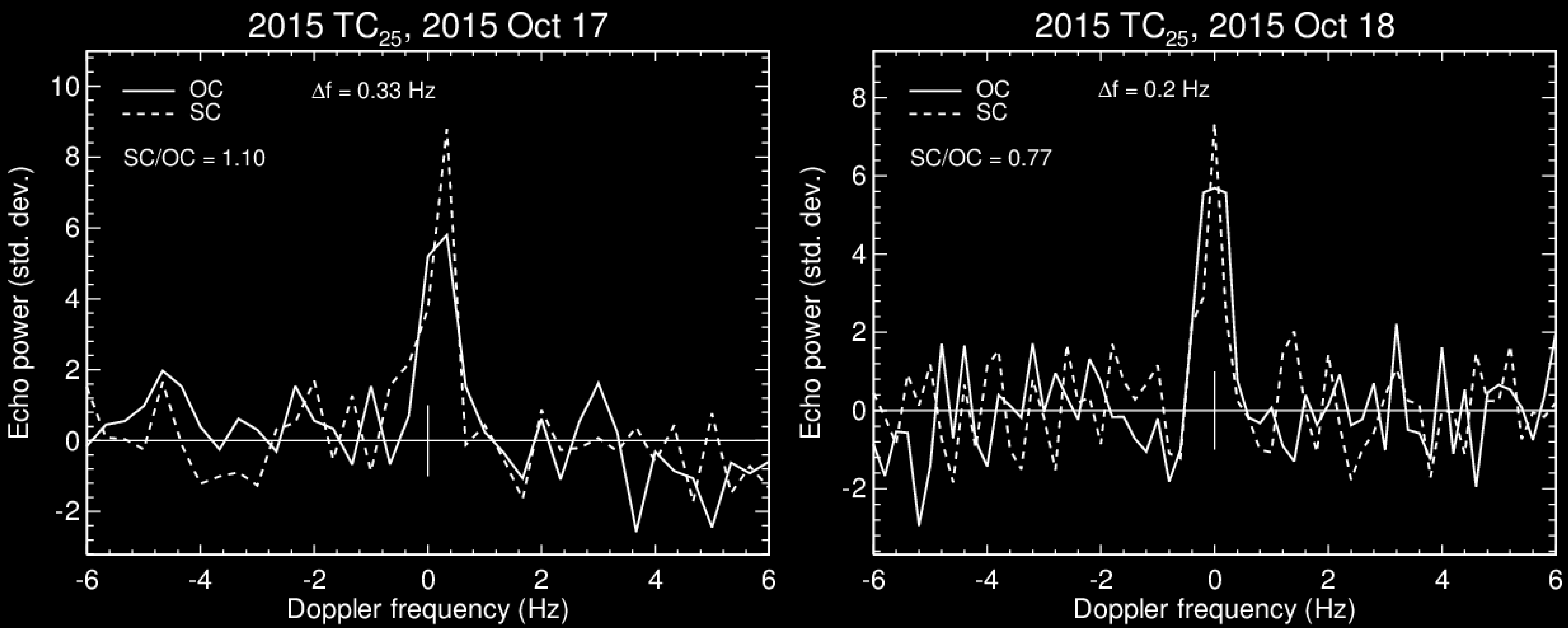
What is Learned from Radar Ranging?

- While only 1 pixel, we know where that pixel is in space very precisely
- Range typically known to <1 km while millions of kilometers away
- Right: distance to 2013 LB2 was corrected by ~1 Earth diameter
- Further spatial resolution reveals size, shape, and surface structure as signal allows



2013 LB2

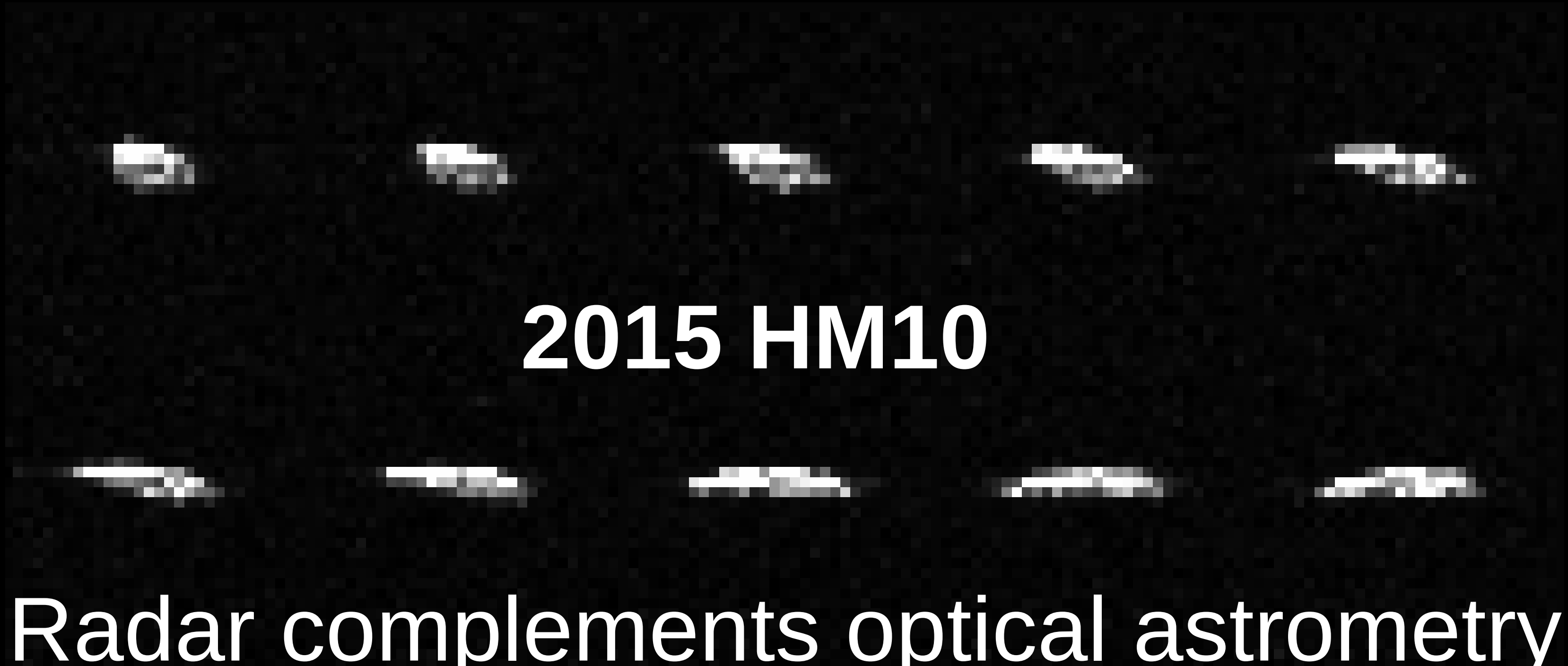
2015 TC25: NHATS



- The smallest asteroid detected with Arecibo at ~2 meters in diameter
- SC/OC ~ 1 suggests relatively rare E-type composition
- Coordinated rapidly after discovery to observe with optical, infrared, and radar assets also revealing ~2 minute rotation and high albedo

Synergistic Observations

- Goldstone to Arecibo
- Arecibo to Green Bank
- Arecibo to VLBA
- Arecibo to LRO



- Radar complements optical astrometry and lightcurves, calibrates infrared observations, aids in albedo estimates