Status of Arecibo Observatory and the Planetary Radar Program

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Arecibo Observatory, USRA

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Management

- Arecibo Observatory is a facility of the NSF
- Operated via cooperative agreement with SRI International partnered with USRA and UMET since 2011:
  - SRI specializes in atmospheric research
  - USRA specializes in astronomy and planetary radar
  - UMET specializes in facilities and public outreach
- NSF AST supports Radio Astronomy (galactic, extragalactic, pulsars); NSF AGS supports Aeronomy (*e.g.*, newly commissioned heating facility)
- NSF provides ~2/3 of the operational budget of the observatory; supporting the planetary radar requires an outside funding source
- NASA NEOO currently supports the planetary radar observing program and planetary radar infrastructure through two grants (~$3.5M/yr) to USRA through FY16

Radar Personnel

- Fully supported by NASA since **October 2010**:
  - **Science**: Mike Nolan (PI), Ellen Howell, John Harmon, and Patrick Taylor
  - **Transmitter**: Victor Negron
- **Current**:
  - **Science**: Joan Schmelz (PI), Patrick Taylor (group lead), James Richardson, Edgard Rivera-Valentin, Linda Rodriguez-Ford, and Luisa Zambrano-Marin
  - **Transmitter**: Victor Negron, Juan Marrero, Johbany Lebron, and Adrian Bague
- **Future**:
  - Anne Virkki (University of Helsinki)
  - Software developer

The Arecibo Radar System

- Planetary radar at Arecibo has existed for its 52-year history
- The largest and most sensitive single-dish 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** (or finer in collaboration with Goldstone)
- **Scattering properties**: albedo, radar albedo, and polarization
- 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, Marco Polo-R, and Psyche

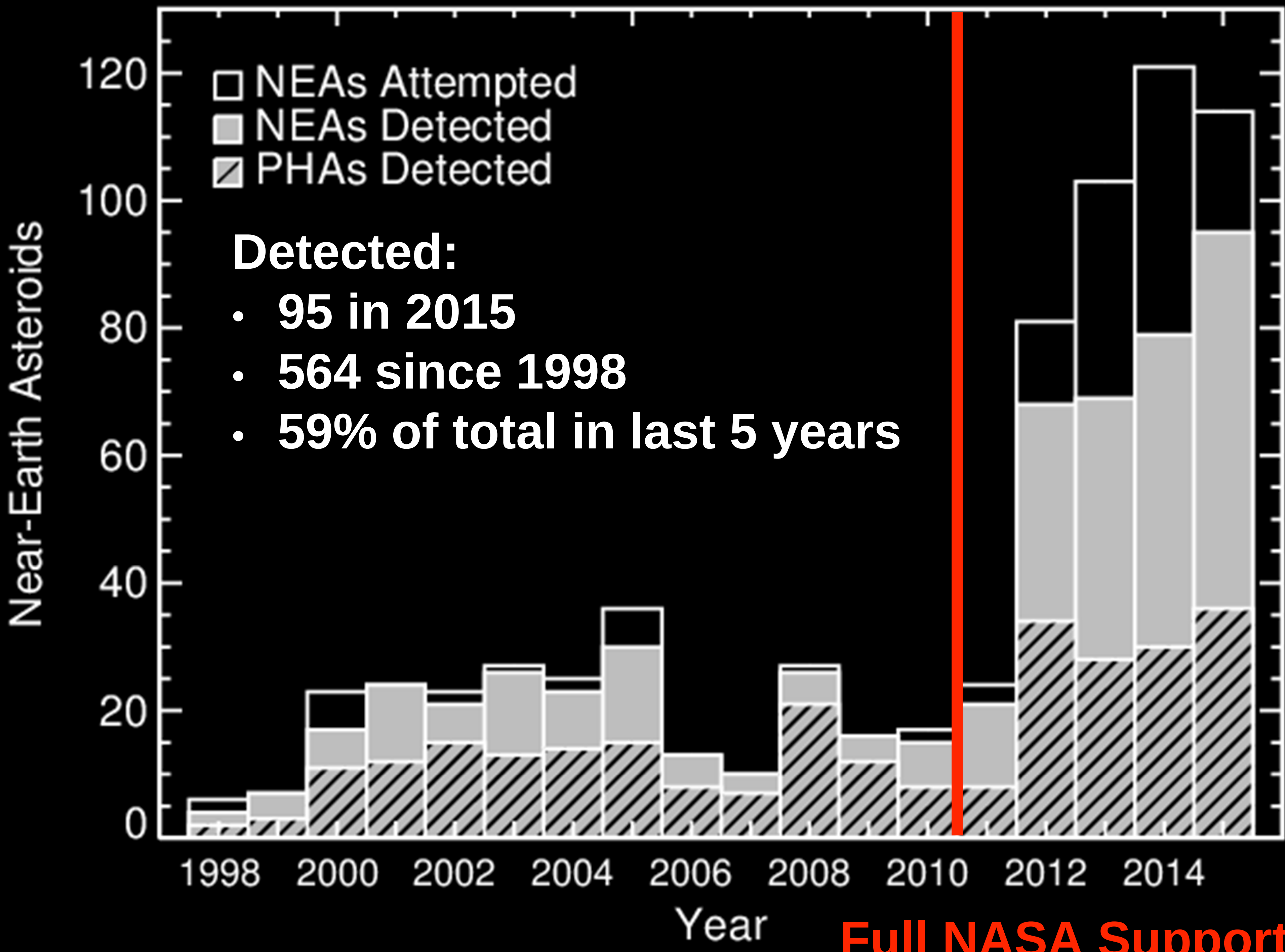
Objectives

- Provide research and operational support of the Arecibo planetary radar program to **obtain a broad sample of near-Earth objects** and other Solar System bodies
- **Goal**: 700-900 h of operation, 600 h for NEOs (up to ~15% of available telescope time)
  - **Status**: ~600 h of operation, ~500 h for NEOs
- **Goal**: Attempt observations of 125 NEOs annually
  - **Status**: 100+ attempts for the past three years
- **Goal**: Rapid response to targets of opportunity
  - **Status**: can schedule within 24 h if necessary; can setup and start tracking in < 10 min

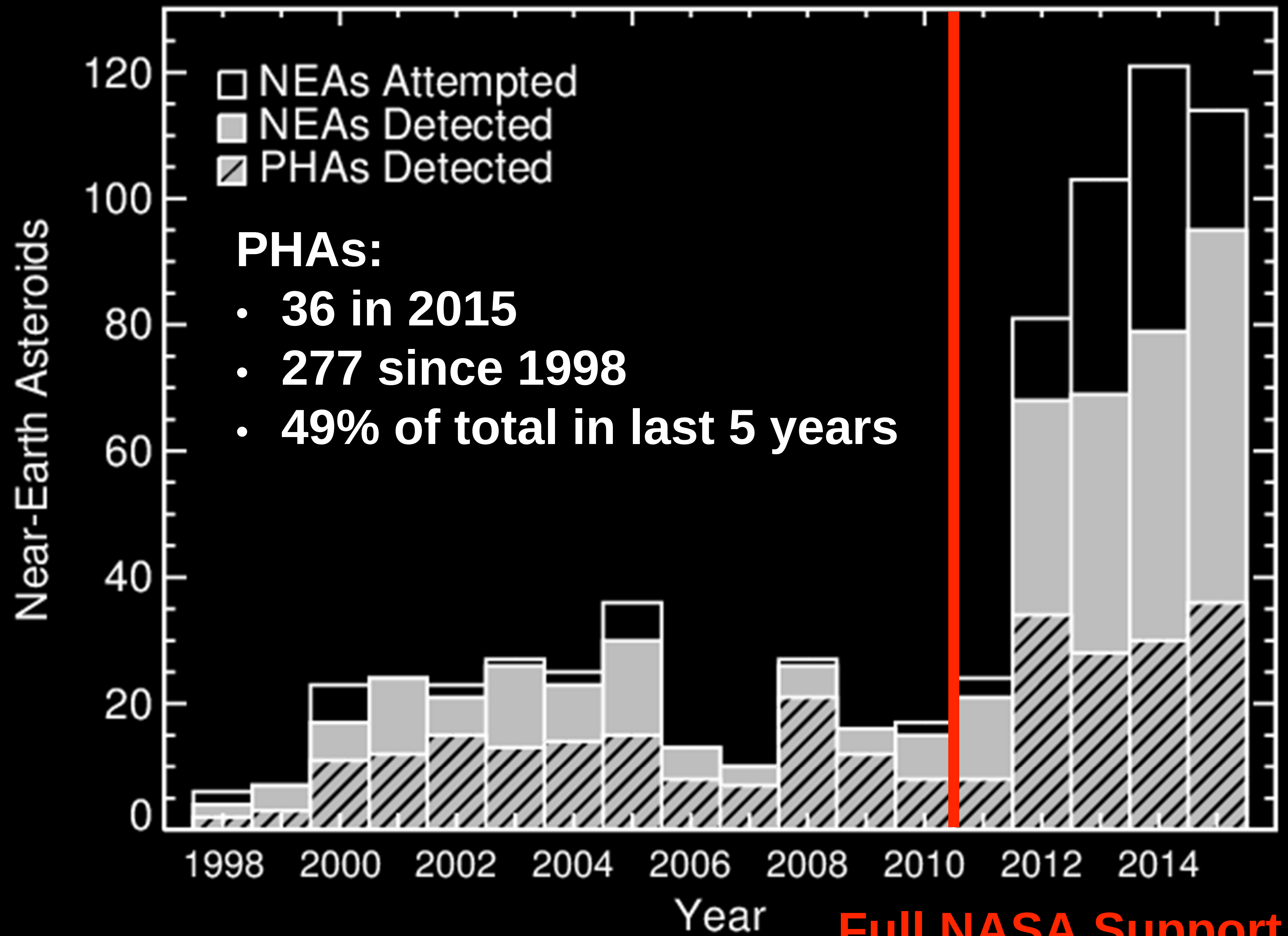
Modes of Observing

- **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

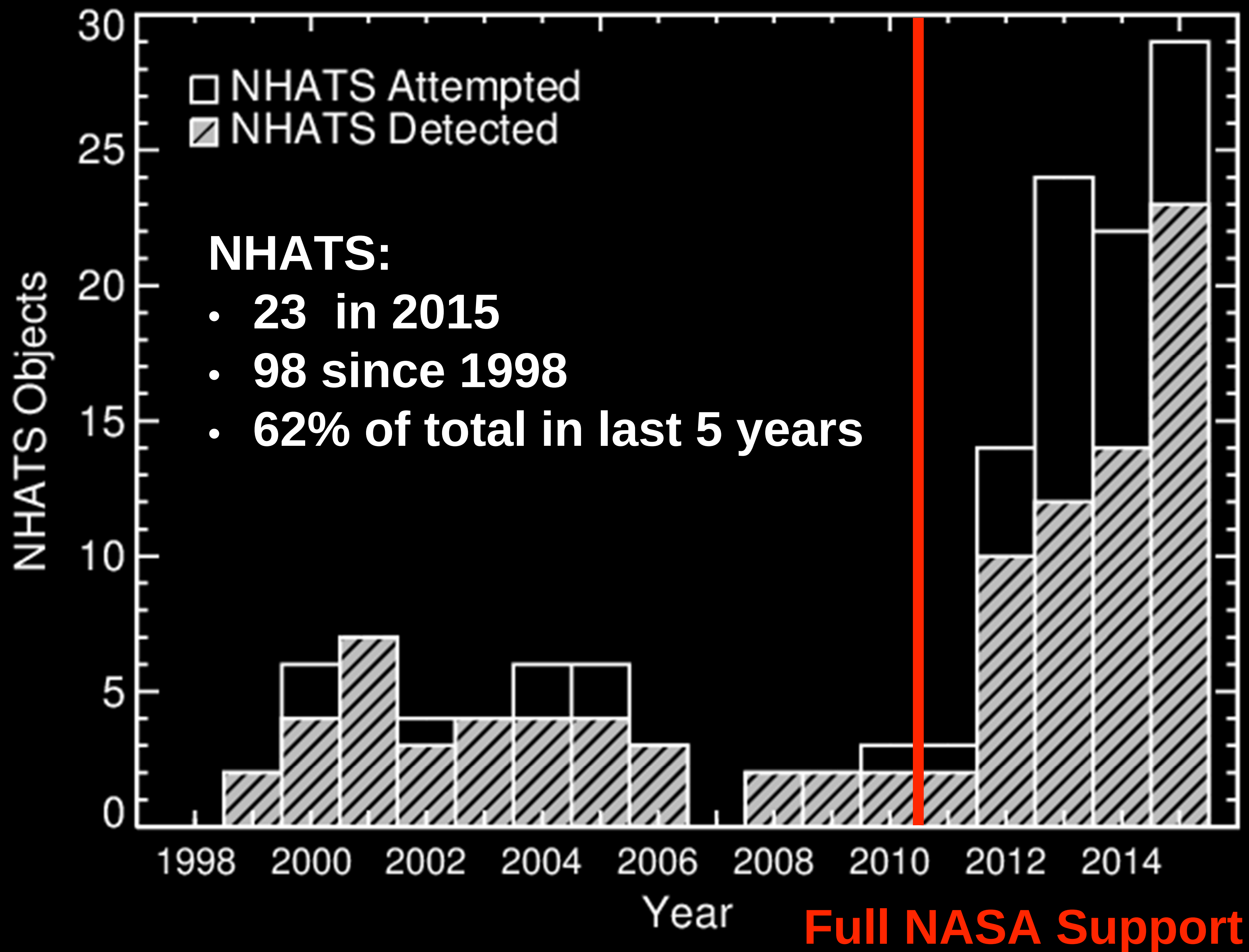
www.naic.edu/~pradar



NEAs Attempted
NEAs Detected
PHAs Detected
Detected:
• 95 in 2015
• 564 since 1998
• 59% of total in last 5 years
Near-Earth Asteroids
0
20
40
60
80
100
120
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year
Full NASA Support



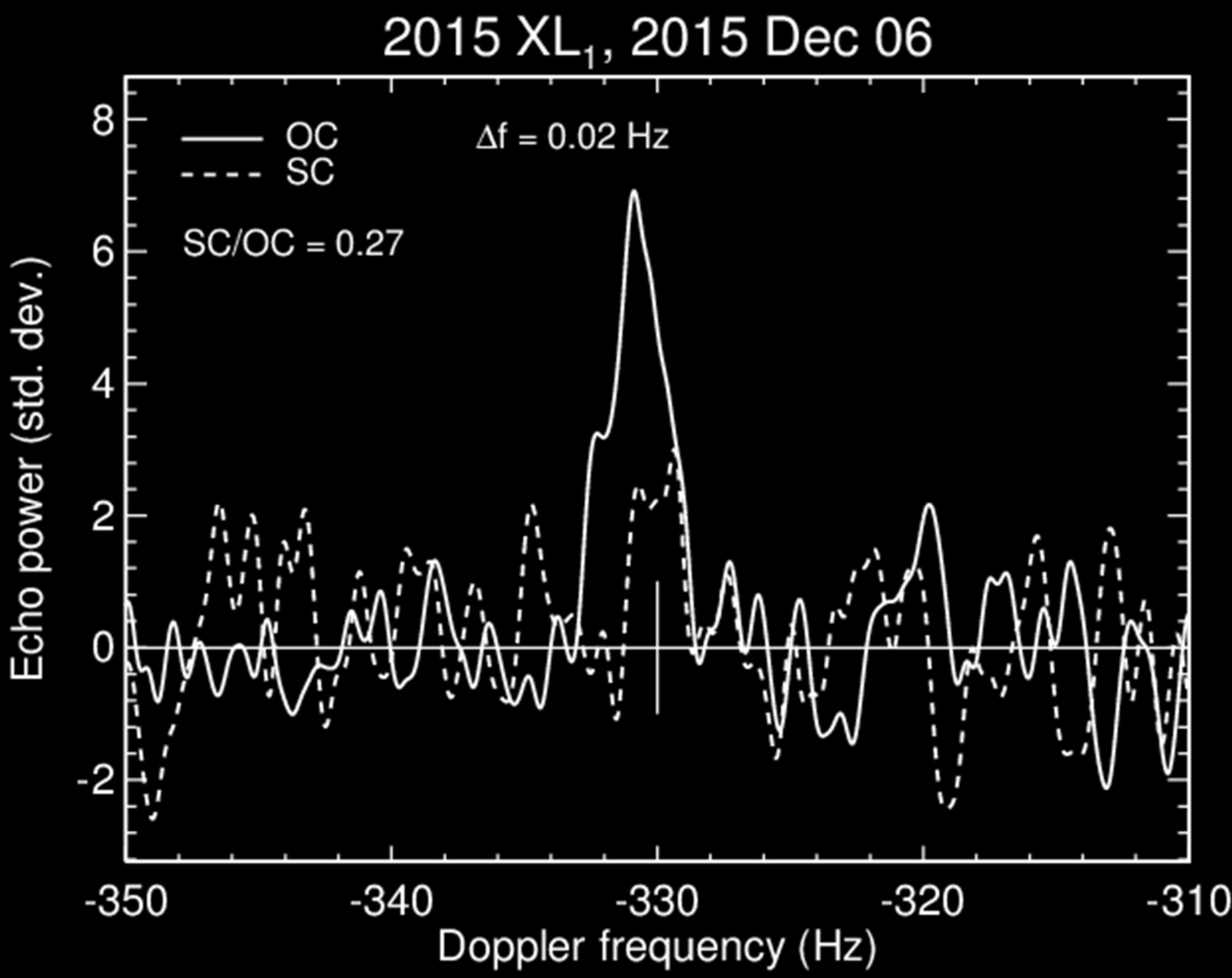
NEAs Attempted
NEAs Detected
PHAs Detected
PHAs:
• 36 in 2015
• 277 since 1998
• 49% of total in last 5 years
Near-Earth Asteroids
0
20
40
60
80
100
120
1998
2000
2002
2004
2006
2008
2010
2012
2014
Year
Full NASA Support



NHATS Attempted
NHATS Detected
NHATS:
• 23 in 2015
• 98 since 1998
• 62% of total in last 5 years
NHATS Objects
Year
Full NASA Support

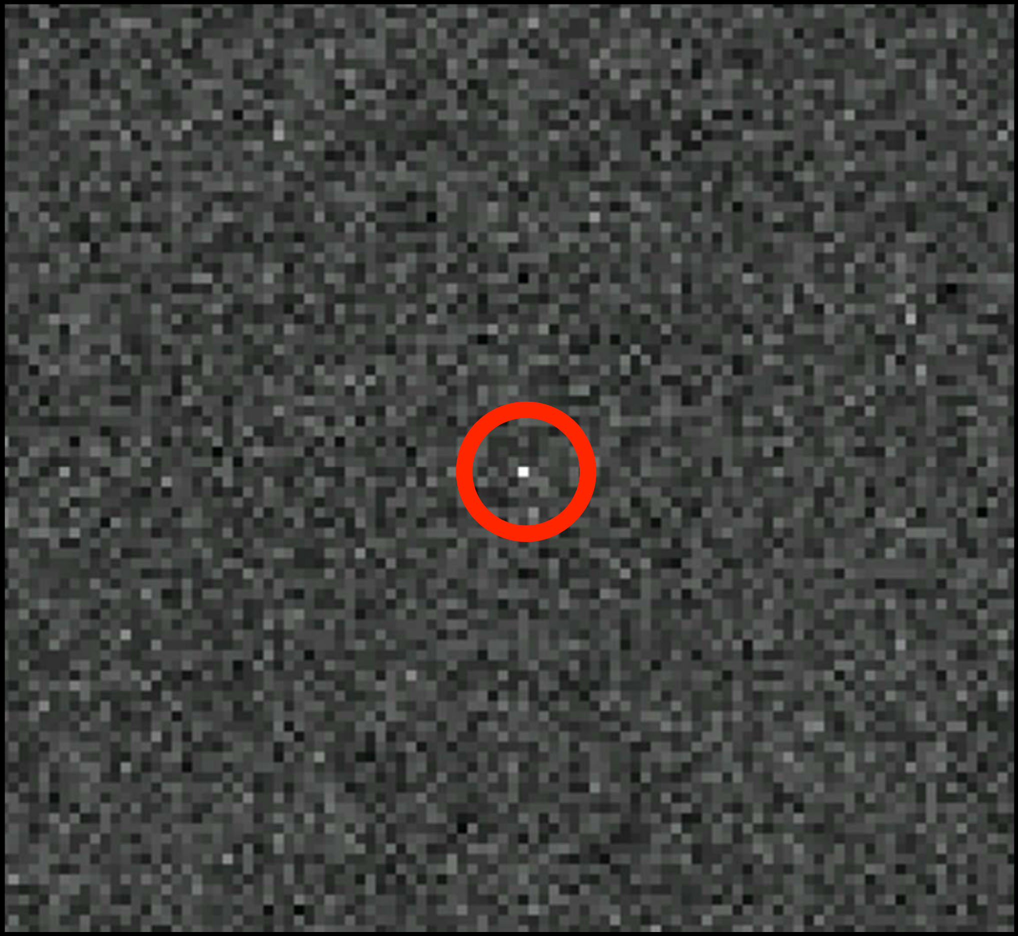
What is Learned from Every Detection?

- 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



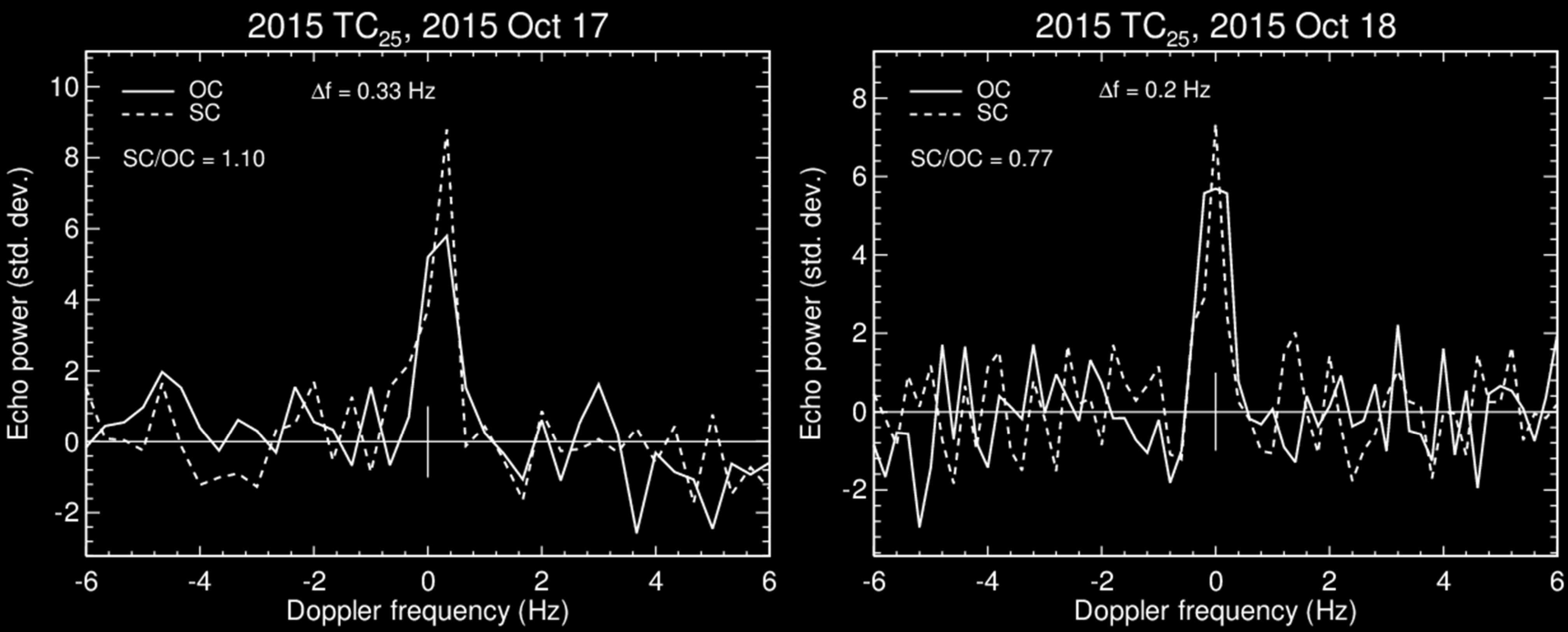
What is Learned from Radar Ranging?

- 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

(385186) 1994 AW1

- First serious candidate binary NEA from lightcurves

D_p ~ 800 m

D_s ~ 300 m

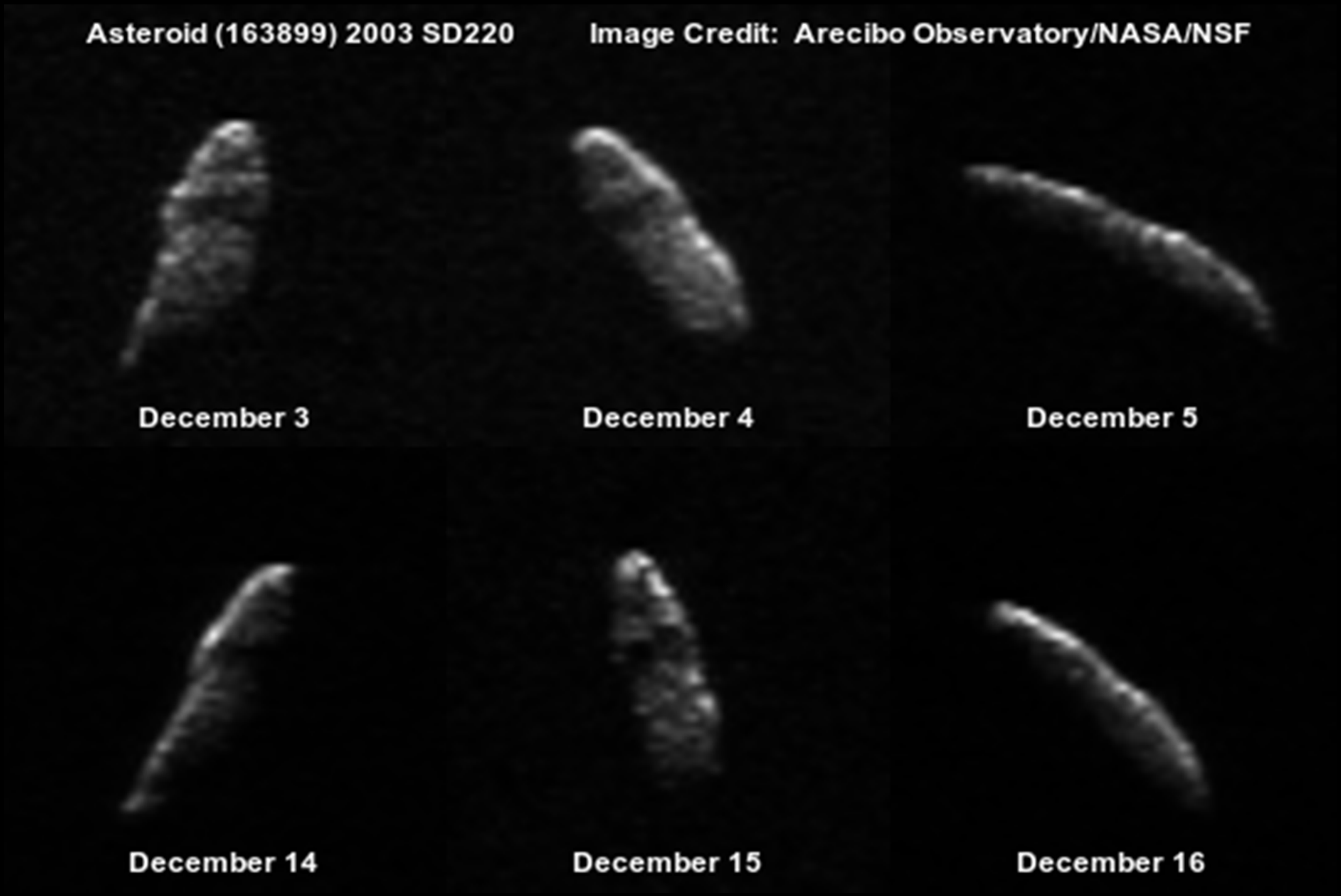
Tidally locked

a ~ 2 km

P_{orb} ~ 1 day

- Radar has detected ~50 binary asteroids

(163899) 2003 SD220: PHA, NHATS



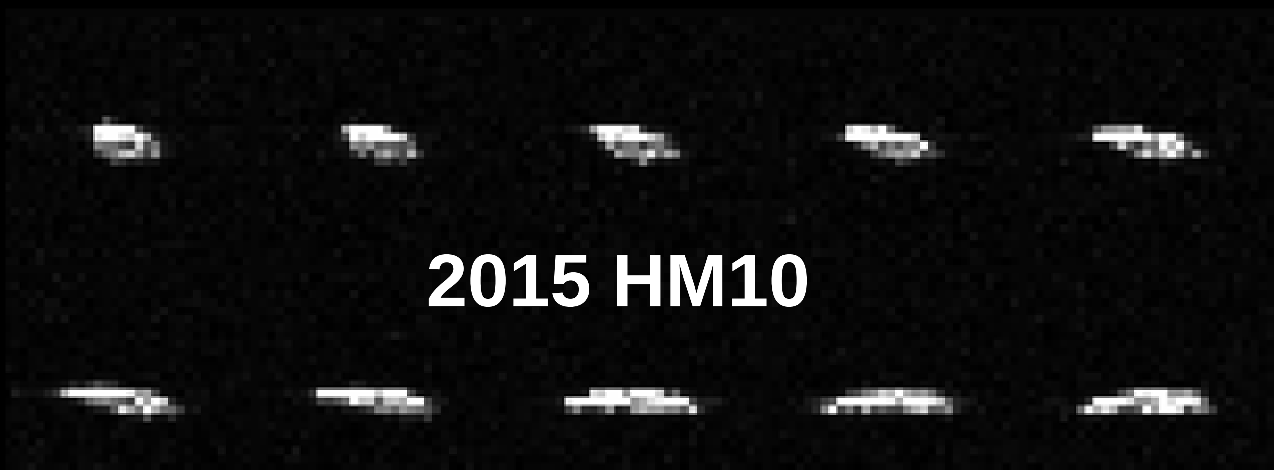
- The polar opposite of 2015 TC25: very elongated at 2.6+ km long and very slowly rotating at ~12 days

(436724) 2011 UW158: PHA, NHATS

- Oblong shape 600 m x 300 m with three parallel ridges
- Rotates extremely rapidly for its size in ~37 minutes!
- Rotation and size imply it is cohesive or monolithic
- Shape modeling in progress by Shantanu Naidu (JPL)

Synergistic Observations

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



2015 HM10

2014 HQ124

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

Summary and Future

- Radar is arguably the best ground-based method for detailed physical characterization of NEAs
- Provide astrometry, rotation rate, and scattering properties for all; basic shapes for many; shape models possible for several
- 2015 was a record year despite major changes in personnel
- Detection of 80-100 NEOs per year is sustainable; must improve publication and public dissemination of results
- Planetary radar program is strong, but requires a healthy observatory to operate and cannot support the observatory on its own