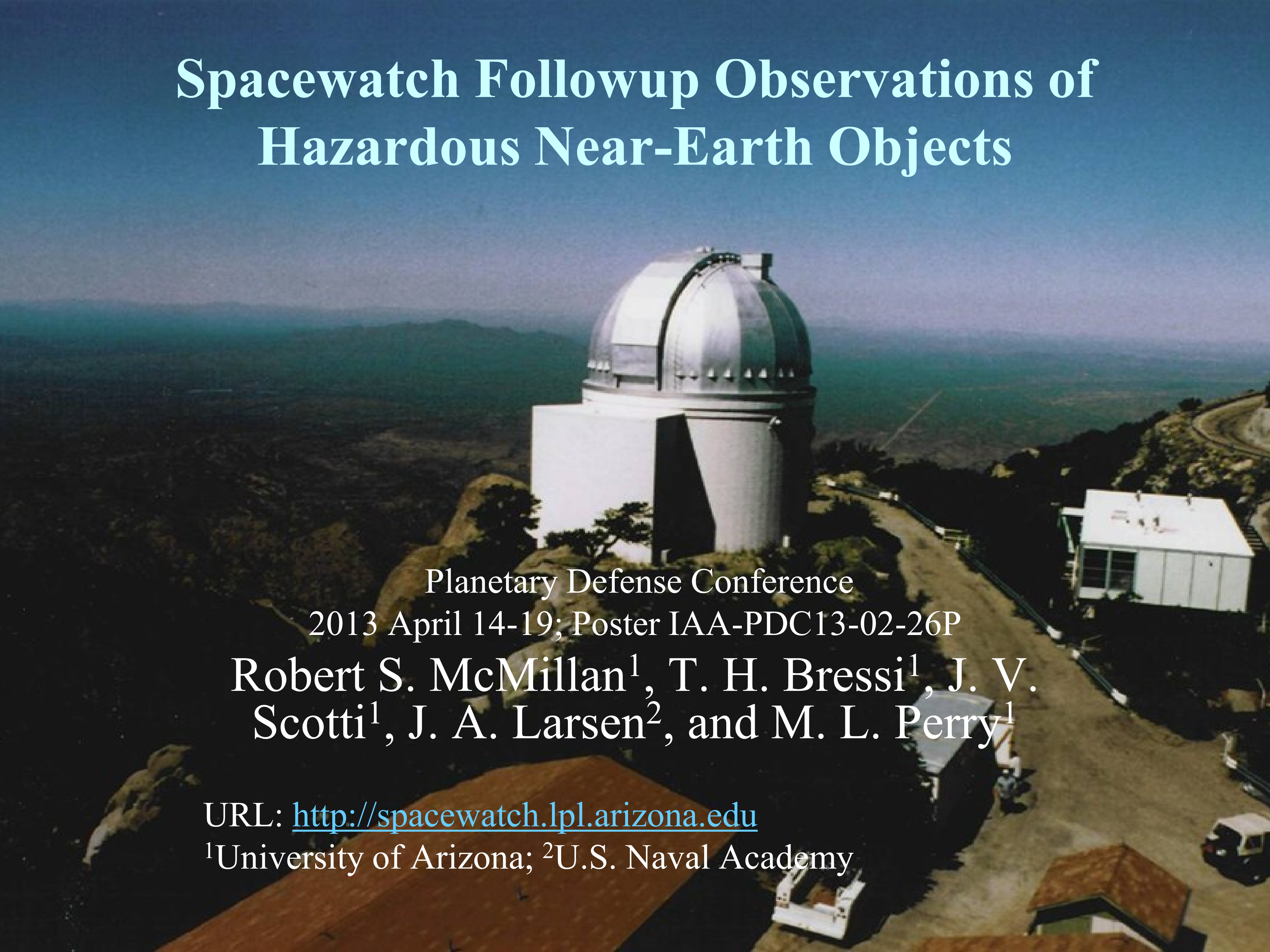

Spacewatch Followup Observations of Hazardous Near-Earth Objects

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Abstract

- Follow-up of "large" NEOs ($H \leq 22$) as they recede from Earth after discovery and become fainter, as well as VIs, PHAs, & NEOs observed by WISE.
- New, fast-reading CCD on 1.8-meter telescope.
- Observed at elongations as small as 46°.
- ~2800 tracklets of NEOs accepted by MPC from Spacewatch each year.
- Big, long archive from mosaic on 0.9-m telescope supports precoveries.

Why Targeted Followup is Needed

- Discovery arcs too short to define orbits:
  - Followup observation intervals need to be thousands of times longer than discoveries.
- Objects can escape redetection by surveys:
  - Surveys too busy covering other sky.
  - Objects tend to get fainter after discovery.
- Sky density of detectable NEOs is too sparse to rely on incidental redetections alone.

Why More Followup is Needed

- 1/3rd of PHAs observed on only 1 opposition.
- 1/6th of PHAs' arcs <30^{d}.
- ~Half of potential close approaches in the next 30 years will be by objects observed on only one opposition.
- 2/3^{rds} of H≤22 VI's on JPL risk page *are lost* and > half of those were discovered within the last 6 years by modern surveys.

How “lost” can they get?

- (719) Albert discovered visually in 1911.
- “Big” Amor asteroid, diameter ~2 km.
- Favorable (perihelic) apparitions 30 yrs apart.
- Missed in 1941 due to inattention.
- Missed in 1971 due to large uncertainty.
- MPC recognized (719) as a rediscovery by Spacewatch in 2000.

1979 XB: A “Big” Lost “VI”!

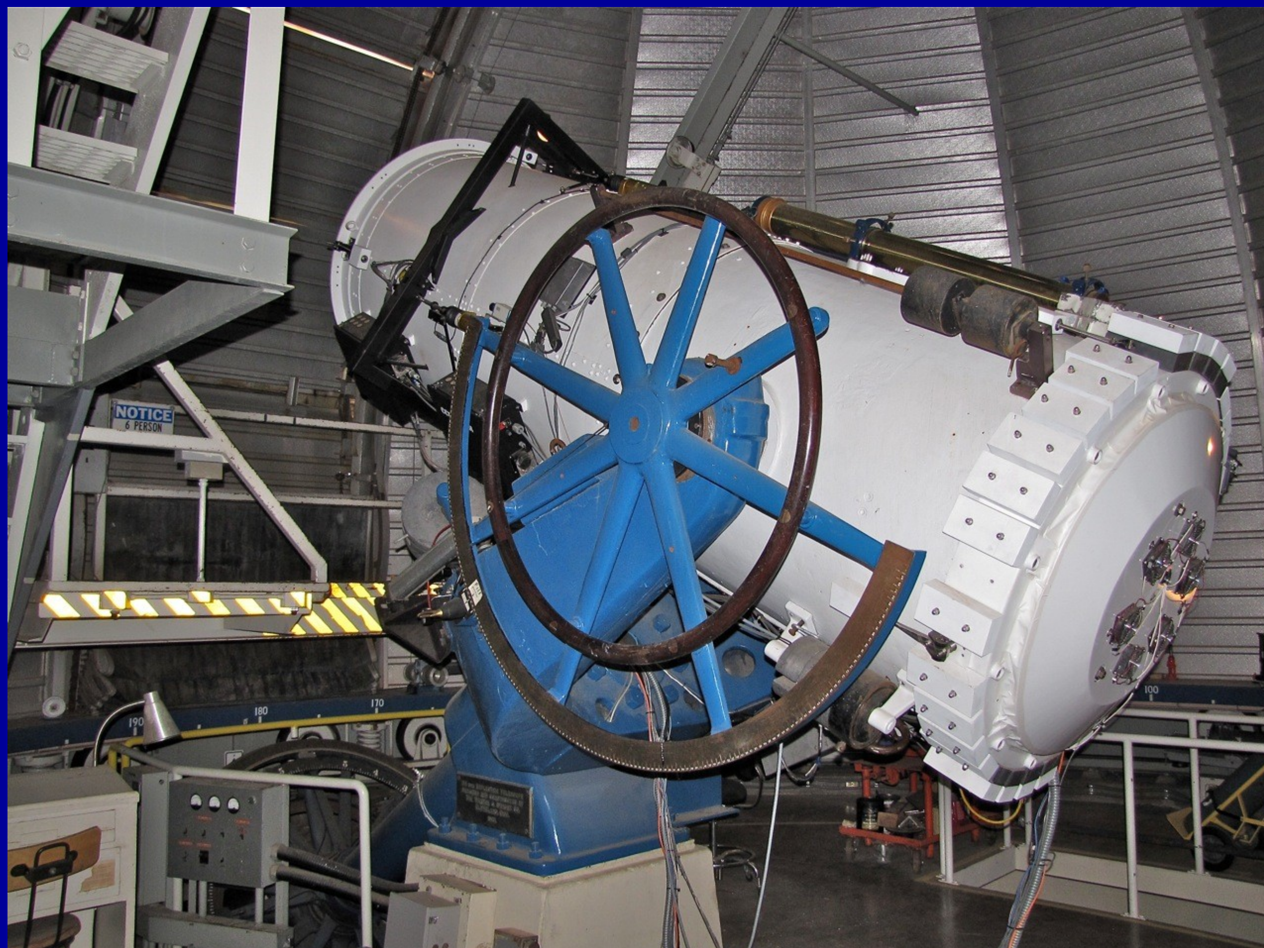
- 4-day observed arc in 1979 December.
- H ≈ 18.5 ↔ Diameter 370-1200 m.
- Synodic period ≈ 1.4^{y}.
- Possible close encounters in 2056 & 2086.
- Not rediscovered in >3 decades of modern surveying.

0.9-m Telescope Modernized by Spacewatch in 2002

- Hyperboloidal primary & refractive field corrector.
- Mosaic of 4 CCDs.
- Bandpass ≈ 0.5-0.9 μm; λeff ≈ 0.7 μm.
- Began 2003 April; 22 nights per lunation.
- Automated in 2005 May.
- Patterns near opp'n, & low elongation in east.
- 1400 deg^2 per lunation; V mag ≈ 20.5-21.7.

0.9-m Telescope in 2012

Photo by Roger Carpenter, 2012 Feb



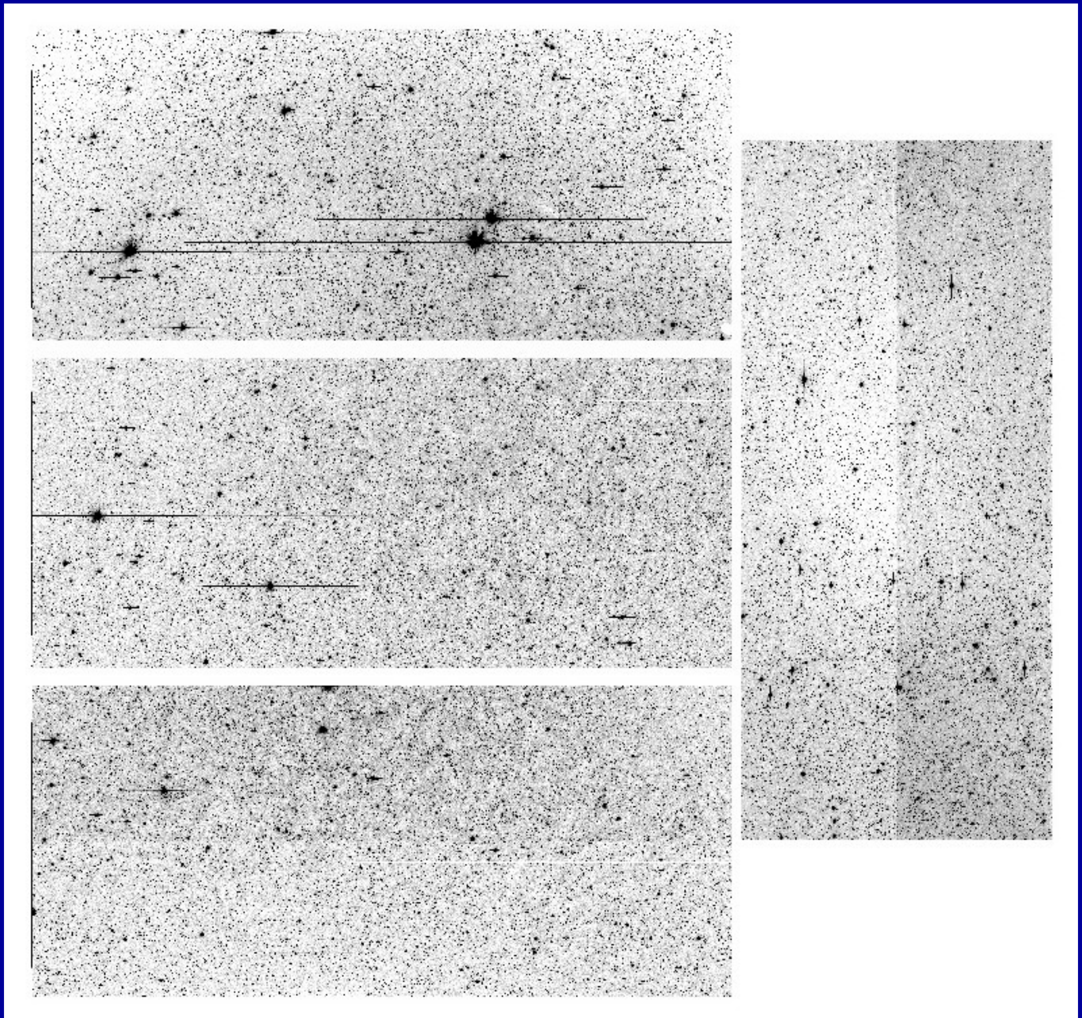
Spacewatch CCD Mosaic on 0.9-m telescope.

Four EEV Grade-1, back-illuminated, antireflection-coated CCDs of 4608x2048 pixels each.

37 million pixels.

1 arcsec per pixel.

2.9 deg^2 covered.



Archive from Mosaic on 0.9-m:

- Revisits @ 4^d intervals aid MBA linkages.
- ~15 TB in size.
- 10 yrs of uniformly conducted surveying.
- Incidental astrometry & precoveries of NEOs.
- V mag limit ~20-21.
- Coverage ~1400 deg^2 per lunation (3 passes per pointing) mostly along ecliptic and low-elongation in the east.

Spacewatch 1.8-meter Telescope on Kitt Peak

New CCD w/ fast read.

FOV = 20′×20′.

Scale = 0.6 arcsec/pixel.

Bandpass = “V+R+I”.

Limit V=23.3 by shift & stacking.

50% more obs of PHAs per year.

Astrometric residuals of **0.3 arcsec,** *vs.* 0.6 arcsec on NEOs with the old CCD.

Photo by Roger Carpenter, 2012 Feb.

2.3-meter Bok Telescope of Steward Observatory on Kitt Peak

90Prime mosaic camera:

FOV ~1 deg^2 ; 0.45"/pixel.

V mag limit ≈ 24.

~ 24 nights per year.

~3-4 objects per hour.

56 nights 2010-2013A with 495 object-visits for astrometric and BVRIz followup.

Photo 2007 by Marc Murison, USNOFS.

4-meter Mayall Telescope of Kitt Peak National Observatory

Prime focus mosaic of CCDs covers 37 x37 arcmin field.

Time awarded to Spacewatch for faint (V≥23) Virtual Impactors & PHAs .

20 nights awarded 2010-2013A; ~150 object-visits accomplished.

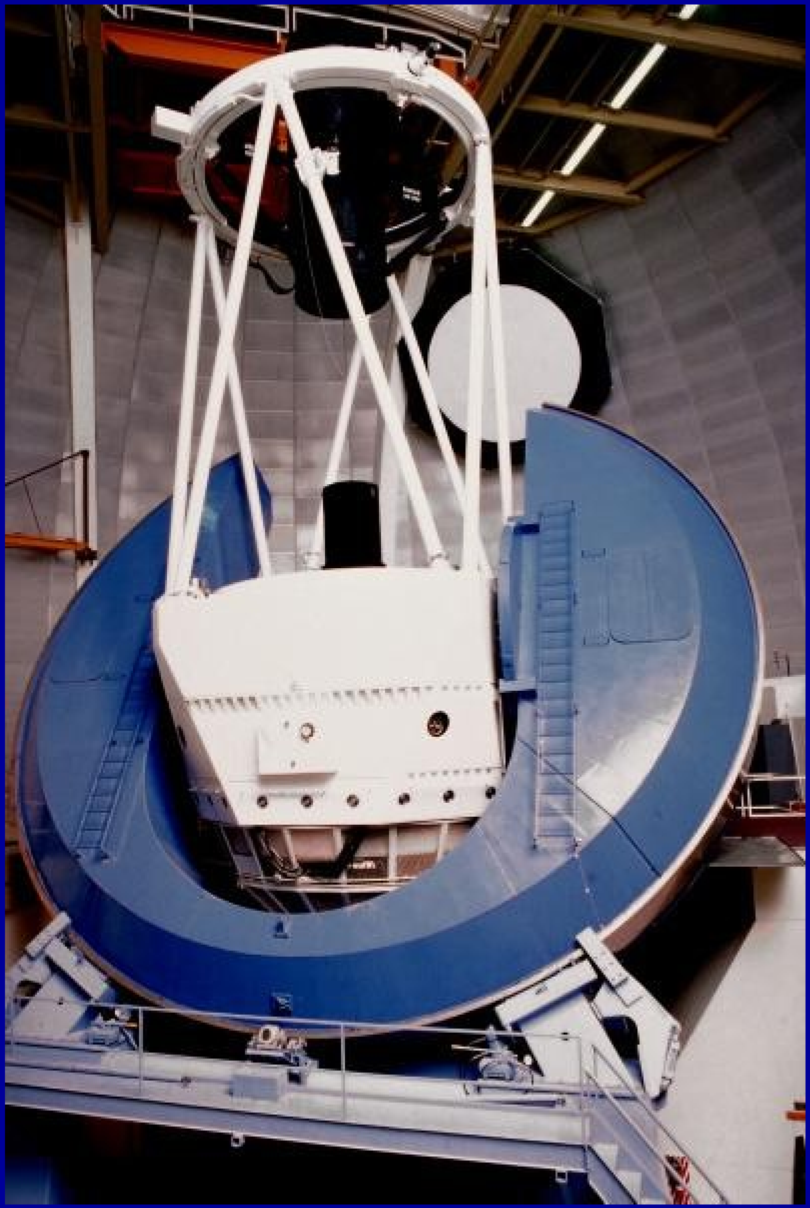
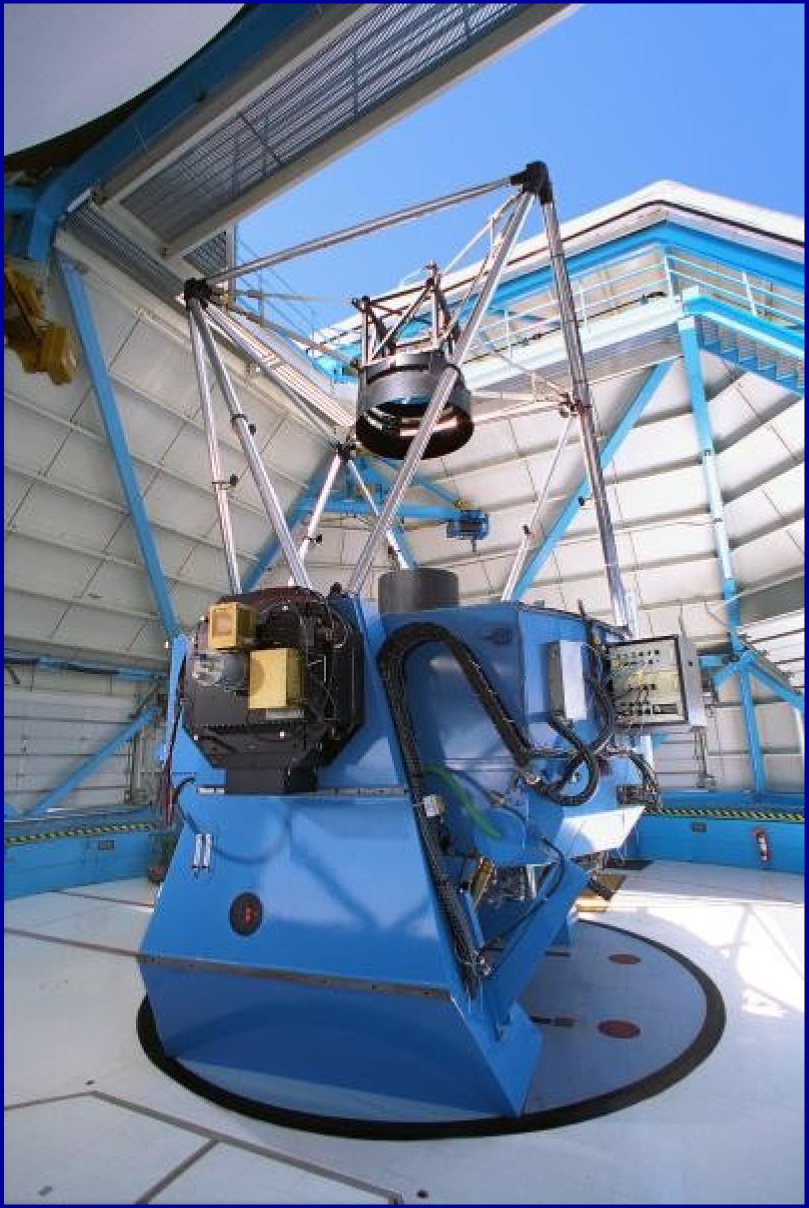


Photo: NOAO/AURA/NSF

3.5-m telescope of Wisconsin-Indiana-NOAO (WIYN) on Kitt Peak, Az.

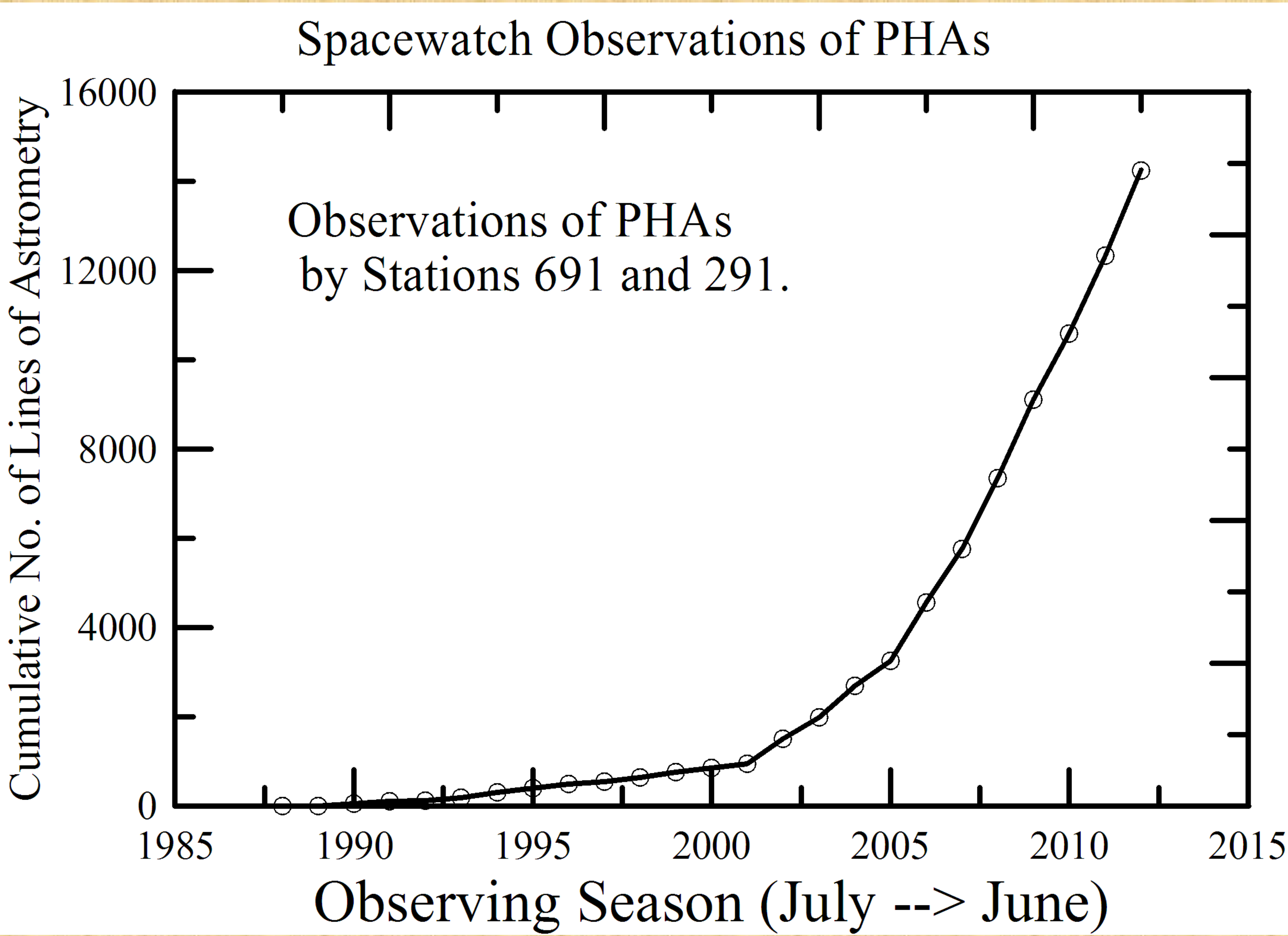
Used by Spacewatch in 2010 in Target-of_Opportunity (ToO) mode to recover selected faint NEOs discovered by the Near-Earth Object Wide-field Infrared Survey (NEOWISE) spacecraft mission.

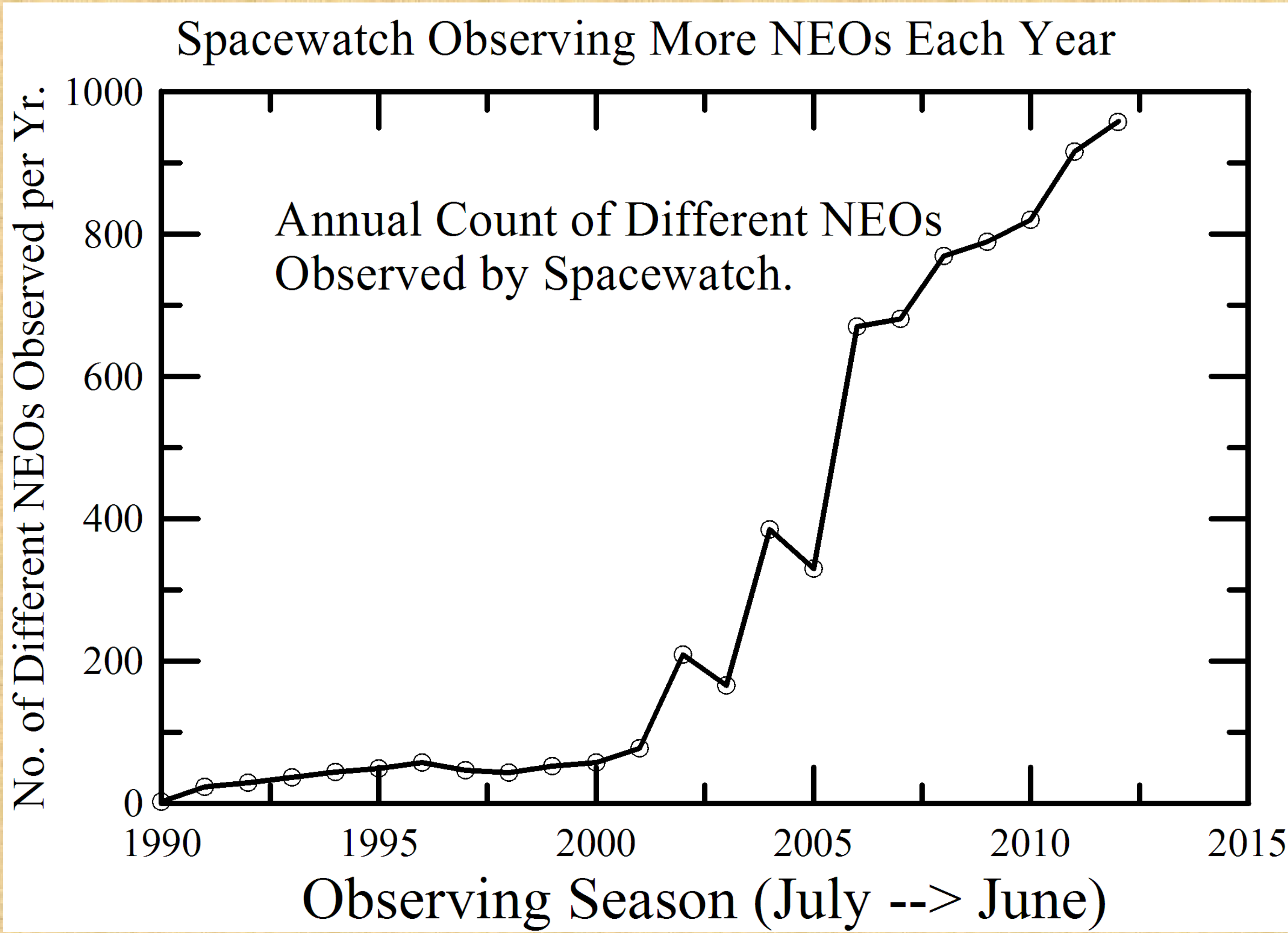
Photo: NOAO/AURA/NSF;



Spacewatch Contributions

- Between 2007 July 1 and 2012 June 30 Spacewatch observed:
  - 57% of all NEOs observed in that time.
  - 67% of all PHAs observed in that time.
- Leading station in followup of provisionally designated PHAs while faint ($V \geq 21.5$); contributing 31% of all such observations.


Spacewatch Observations of PHAs
Observations of PHAs
by Stations 691 and 291.
Cumulative No. of Lines of Astrometry
16000
12000
8000
4000
0
1985
1990
1995
2000
2005
2010
2015
Observing Season (July --> June)



Spacewatch Observing More NEOs Each Year
Annual Count of Different NEOs
Observed by Spacewatch.
No. of Different NEOs Observed per Yr.
0
200
400
600
800
1000
1990
1995
2000
2005
2010
2015
Observing Season (July --> June)

Spacewatch Observations of WISE-detected Asteroids

- Recoveries & astrometry improve orbits.
- Photometry supports albedo determination.
- Lightcurves reveal rotation period, amplitude, & and rotational phase.
- *BVRIz* taxonomic photometry to compare with albedos & orbital classes.

Acknowledgements

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