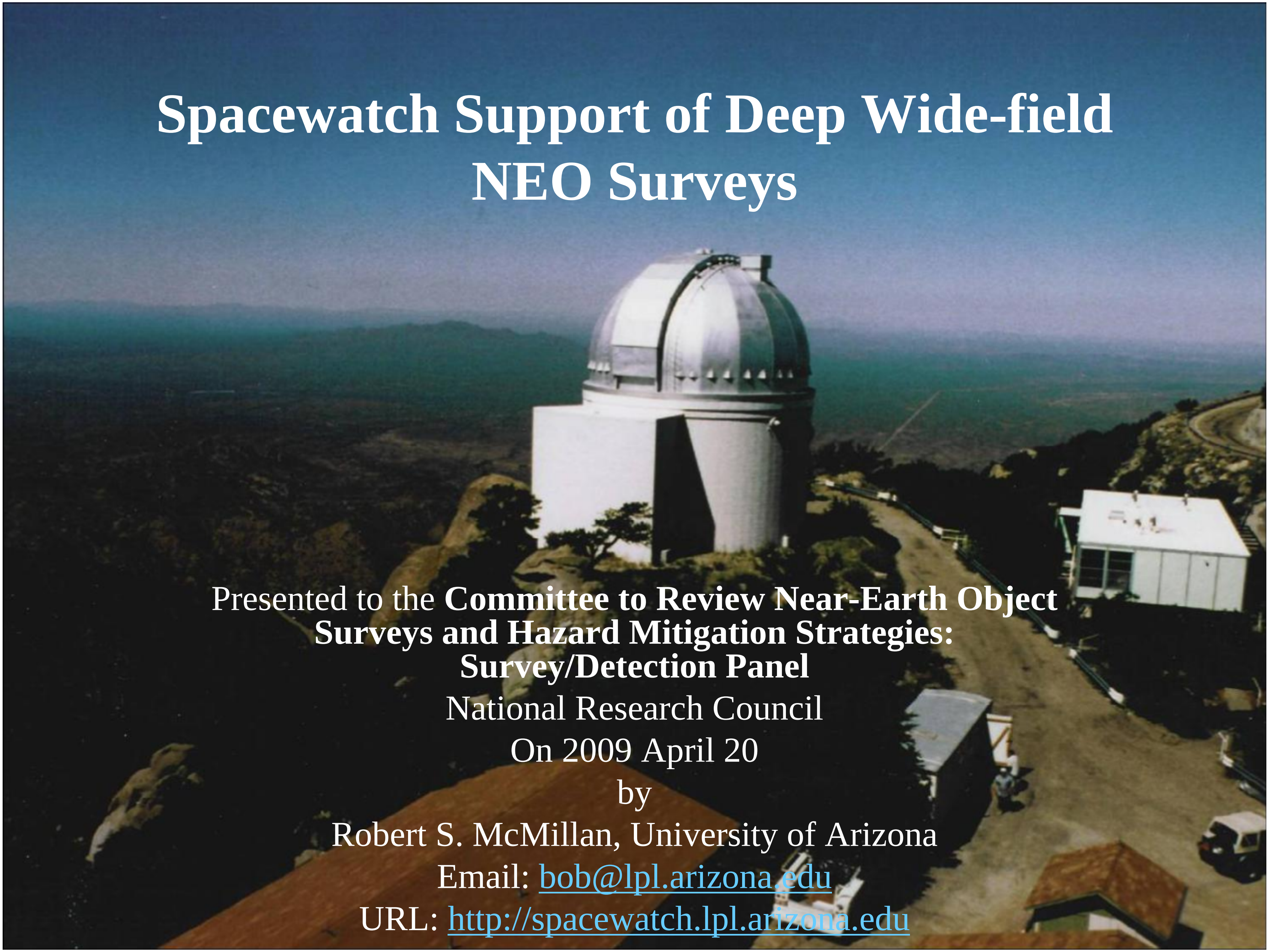

Spacewatch Support of Deep Wide-field NEO Surveys

Presented to the **Committee to Review Near-Earth Object Surveys and Hazard Mitigation Strategies: Survey/Detection Panel**

National Research Council

On 2009 April 20

by

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Abstract

- More observations of positions and magnitudes (followup) of NEOs needed.
- Demand for followup will increase with new deep, wide-area surveys.
- Spacewatch an established observatory:
  - Equipment suited to followup.
  - Room for improvement.
  - Expansion to larger telescopes.

Types of Detections of Asteroids

- Discovery: Previously unknown object.
- Followup:
  - Targeted on specific object.
  - Incidental Astrometry (IA) while surveying or following up some other object.
  - Recovery or rediscovery: targeted or incidental observation of a lost or uncertain object.
  - Prediscovery observation (“precovery”):
    - Old IA linked by MPC.
    - Old images re-inspected on request)

Why Targeted Followup is Needed

- Discovery arcs too short to define orbits.
- Objects can escape redetection by surveys:
  - Surveys busy covering other sky (revisits too infrequent).
  - Objects tend to get fainter after discovery.
- Followup observations need to outnumber discoveries ×10-100.
- Sky density of detectable NEOs too sparse for IA alone.

Definitions

- PHA = "Potentially Hazardous Asteroid" but not really…
- PHA *orbit* gets close to Earth's *orbit*, but not necessarily to the asteroid itself.
- Close approach lists by MPC, JPL, NEODyS.
- "Virtual Impactor" (VI) = colloquial usage for an object with some virtual impact solutions.

Completeness of Followup

- 40% of PHAs observed on only 1 opposition.
- 18% of PHAs' arcs $<30^d$; 7 PHAs obs. $< 3^d$.
- 20% of potential close approaches will be by objects observed on only 1 opposition.
- 1/3rd of H≤22 VI's on JPL risk page *are lost.*
  - ½ of those were discovered within last 3 years.

How “lost” can they get?

- (719) Albert discovered visually in 1911.
- “Big” Amor asteroid, diameter ~2 km.
- Favorable apparitions only every 30 yrs.
- Missed in 1941 & 1971.
- 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.

How lost they can get (cont'd.)

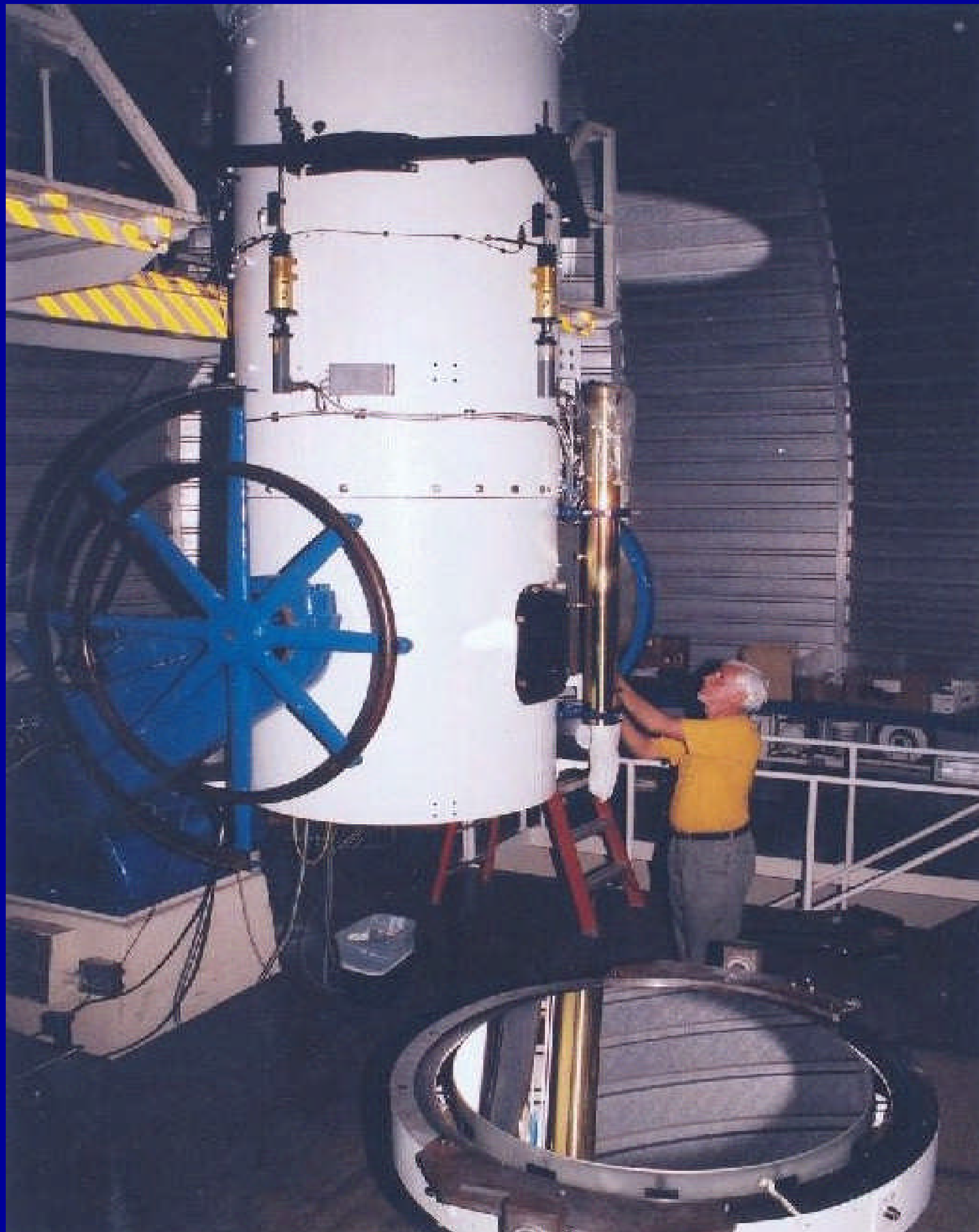
- 2003 BK47 discovered 2003 Jan 30.
- V=21.8, 0.4 deg/day, Δ=1.6 AU.
- Followed for a month until too faint.
- PHA w/ a=2.74, e=0.71, P_s=1.28 yr.
- Diameter ~ 0.4-1.2 km.
- Next favorable apparition in mid-2011.
- Uncertainty in 2011 ~2-3 degrees.

Spacewatch Project

- 1st use of CCDs for solar system astrometry (1984), led by T. Gehrels.
- Got MPC to save Incidental Astrometry (IA).
- Studies of NEOs, main belt asteroids, TNOs.
- ~$20M assets, doing followup to complement wide-area surveys.

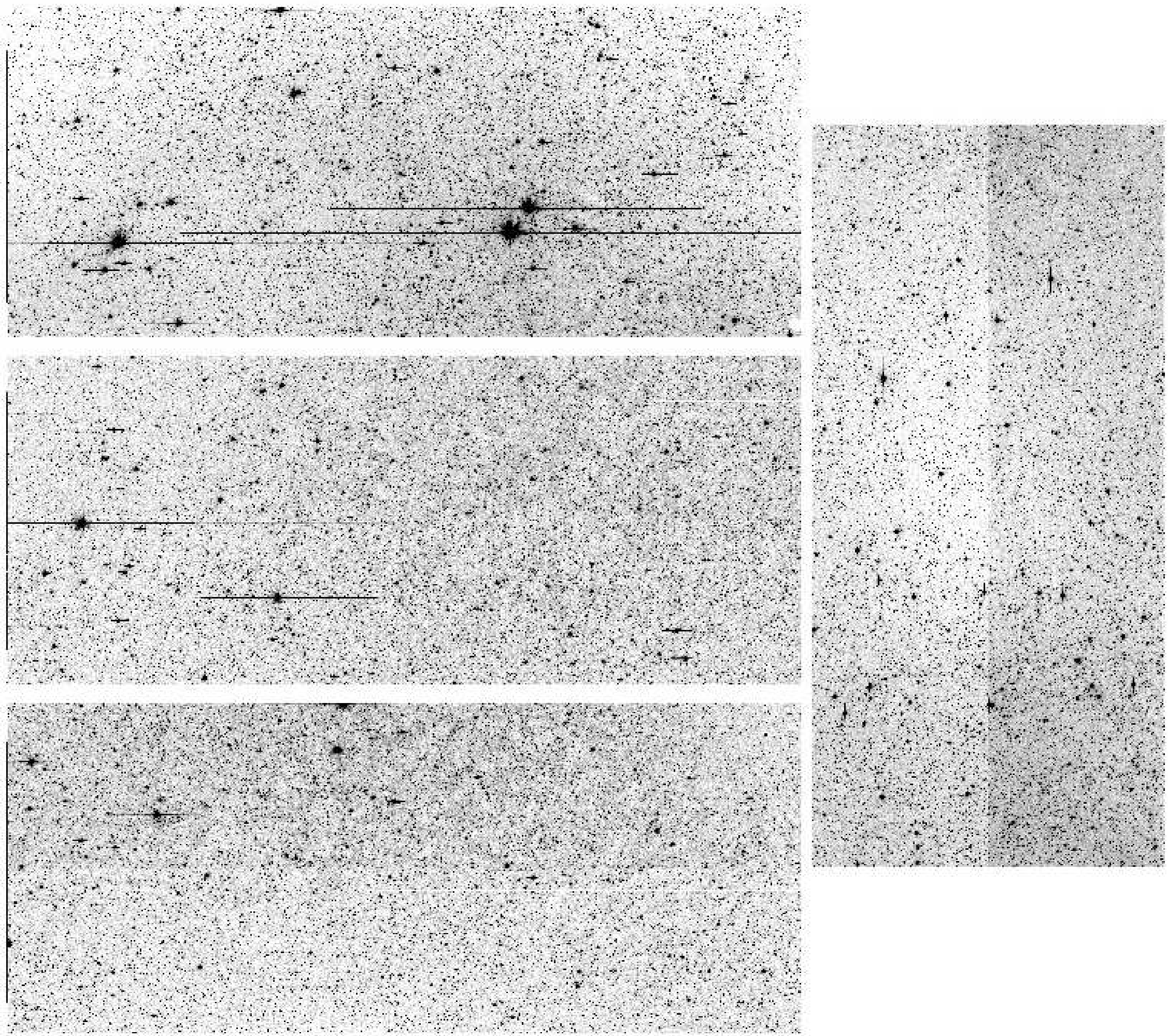
Current Spacewatch Systems

- 0.9-meter telescope refurbished in 2002:
  - New drive motors, electronics, optics, CCDs.
  - Original (1921) mount, fork, gears & tube.
- 1.8-meter telescope designed in 1992, commissioned in 2001.
- Emphasis on followup of NEOs when faint.
- Relevance to the future of NEO surveys.

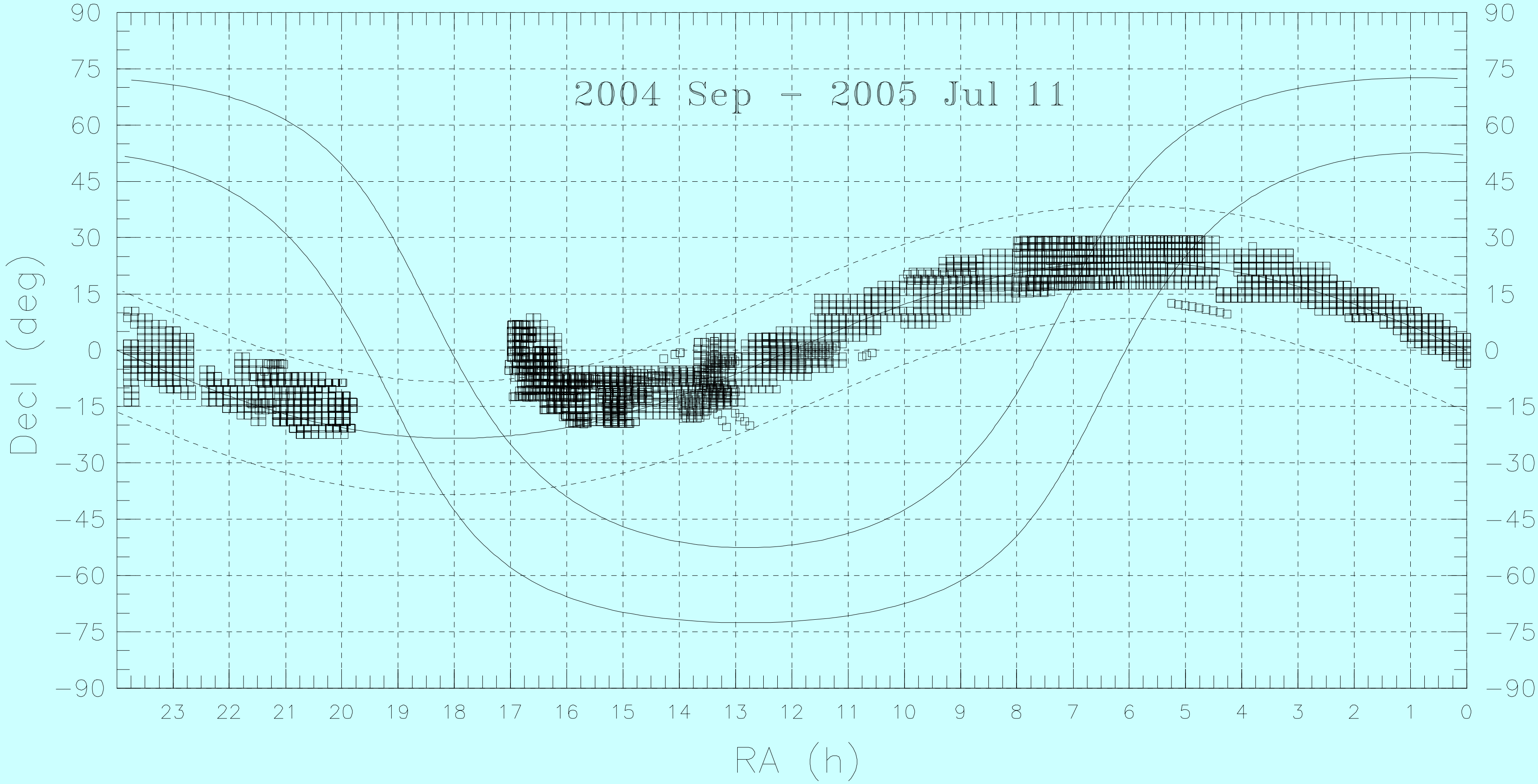


0.9-meter Spacewatch Telescope

- 4-CCD Mosaic with 37 million pixels, 2.9 deg^2.
- 1 arcsec pixels for good astrometry.
- Bandpass ≈ 0.5-0.9 microns; λ_{eff} ≈ 0.7 microns.
- Began 2003 Apr; 23 nights scheduled per lunation.
- Fully automated in 2005 May.
- Patterns near opposition & East in morning.
  - 1400 deg^2 per lunation.
  - 2 min exposure & 2 min read & slew.
  - V mag limit ≈ 20.5-21.7 depending on conditions.
  - .

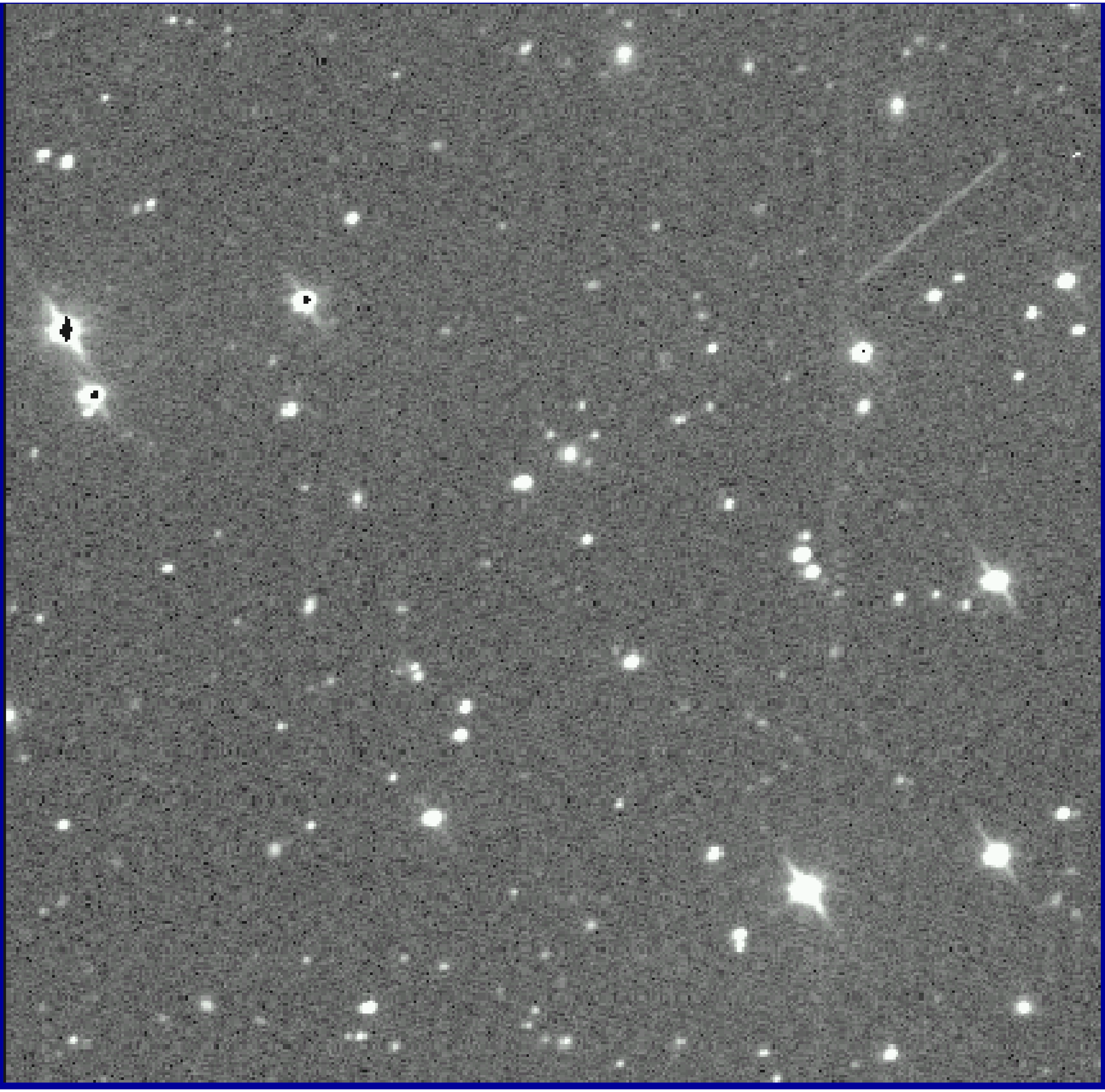


Typical Annual Coverage by 0.9-m

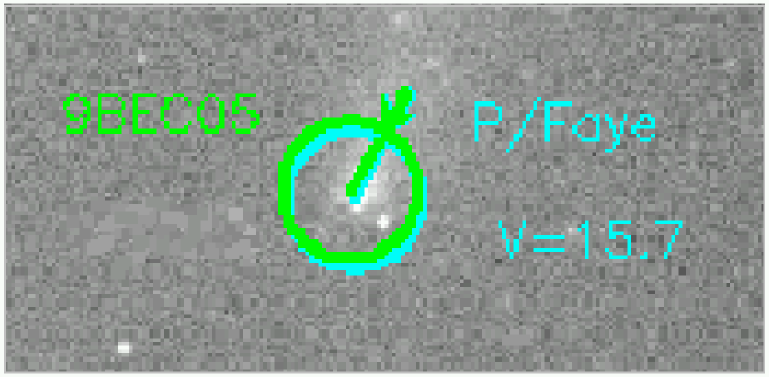


Example of Discovery

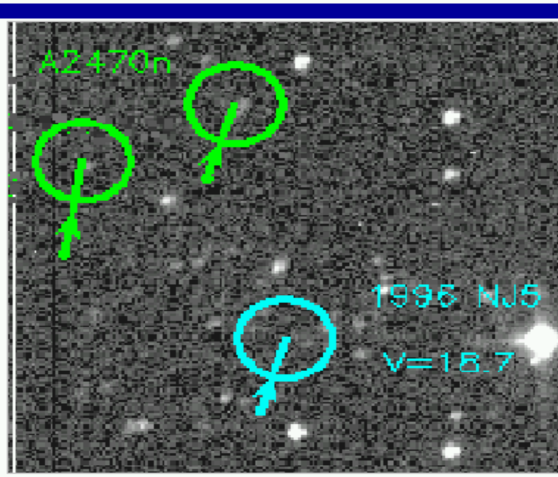
- Fast-Moving Object (FMO) 2003 SW130.
- Discovered 2003 Sept 20 by A. Gleason.
- V ~19; rate ~12.5 deg/day, Δ~0.004 AU
- Aten asteroid; closest approach 0.001 AU
- H=29, diam. ~3-9 meters.
- a=0.88 AU, e=0.30, MOID=0.0008 AU.



Pass 1: Known Comet



Pass 3: Known Comet Found by Software



Pass 3: Known object identified, but displaced from expected position

1.8-meter Telescope

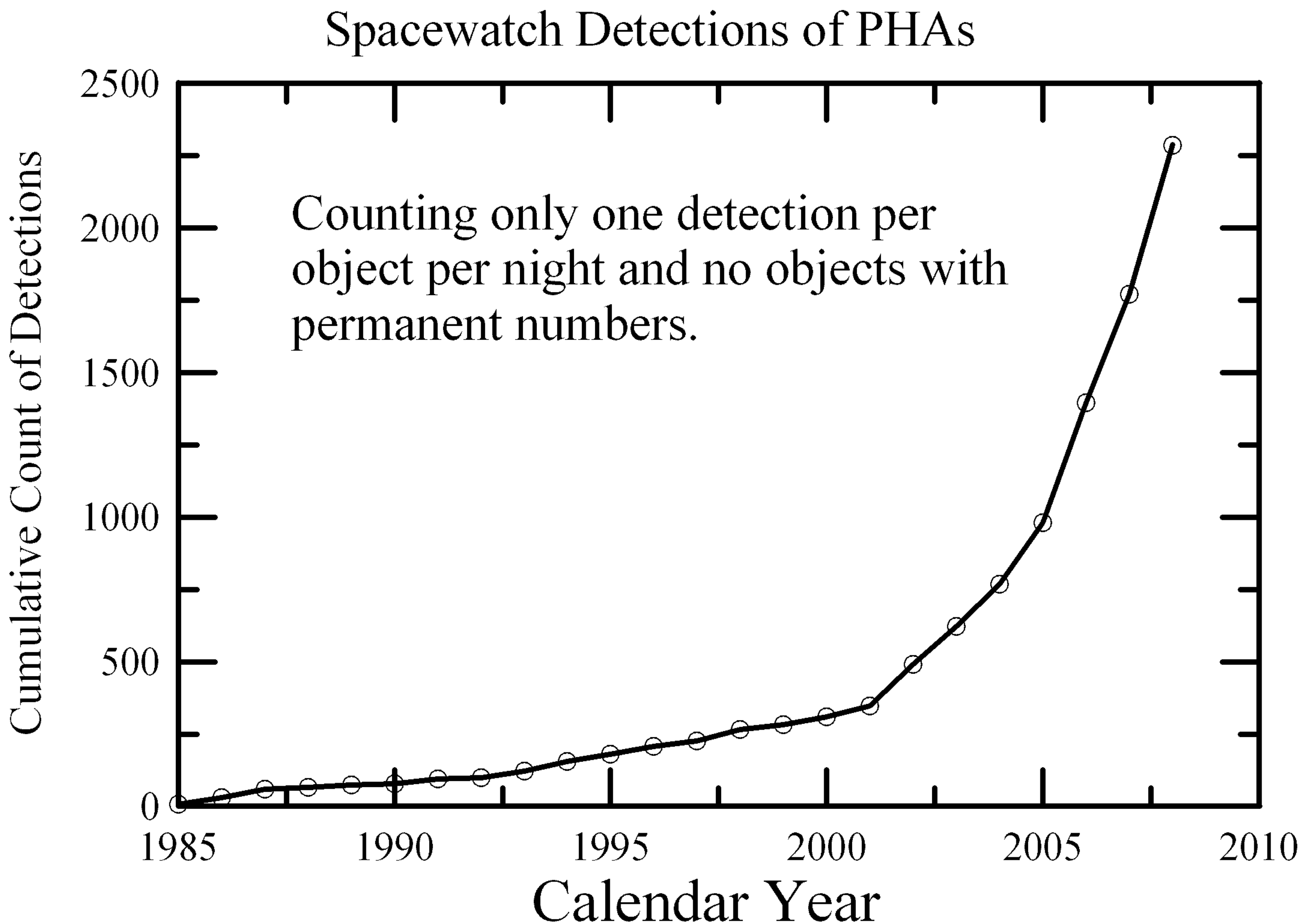
- FOV= 0.6 x 0.6 deg on 2048 × 2048 CCD.
- Same bandpass & scale as 0.9-meter.
- Has reached V=23.3 by shift & stacking.
- Typical $V_{lim} \approx 22.3$.
- Mostly drift scanning for smoother background & responsivity.

Stacking @ asteroid rate.

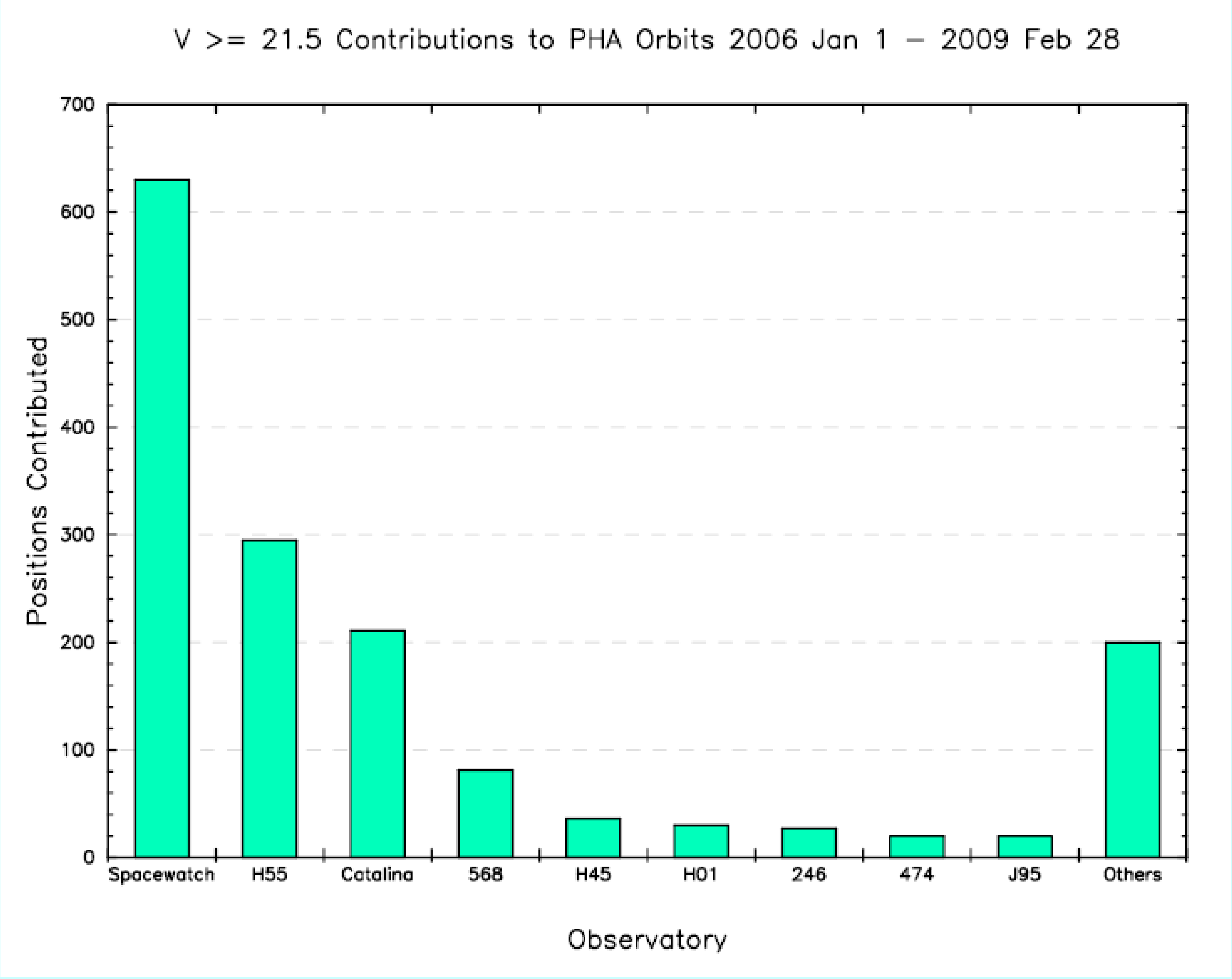
Spacewatch 1.8-meter telescope scans.

Followup of NEOs by Spacewatch

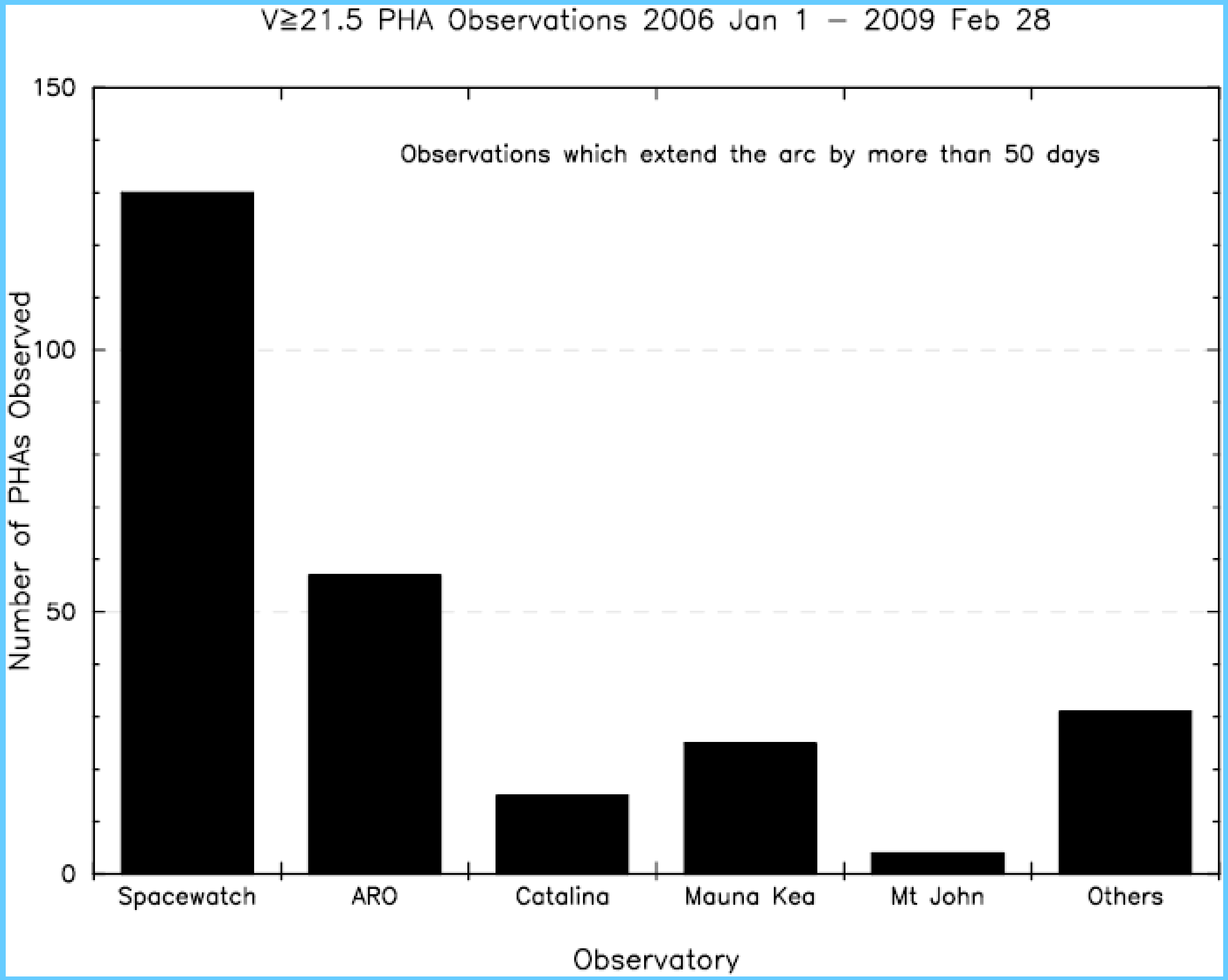
- ⅔rds by 1.8-meter scope; ⅓ by 0.9-meter.
- Concentrating on PHAs, MPC's NEO CP objects, JPL & NEODyS impact risk listings.
- Niche is V≥20 mag → distant priority obj's.
- Look @ detections *vs*. time.
- Look @ detections *vs*. community.
- Examples of recoveries.


Spacewatch Detections of PHAs
Counting only one detection per object per night and no objects with permanent numbers.
Cumulative Count of Detections
0
500
1000
1500
2000
2500
1985
1990
1995
2000
2005
2010
Calendar Year

Observations of PHAs, by Observatory



>50^{d} arc-lengthening PHA Followup



Examples of Spacewatch Recoveries of Uncertain PHAs.

Object	Unc. (deg)	H mag	V mag	MPEC	Arc Before	Arc After	Net O-C (arcsec)
2000 UL11	2	20.1	21.9	2003-S71	28d	1039d	3320
1998 VS**	4	22.3	21.3	2003-Y18	32d	1831d	1581
2001 US16	2	20.2	20.7	2004-B68	31d	802d	485
2000 EV70*	3	20.5	20.9	2004-E11	46d	1193d	214
1999 VT25	3	21.4	21.5	2004-U47	26d	1786d	7556
1990 SM	80	16.2	21.2	2005-C26	24d	5225d	23022
2002 TW55	1	18.0	21.7	2005-E54	52d	831d	237
2003 BH	?	20.7	22.7	2005-J56	51d	844d	45
1998 VF32	2	21.2	21.2	2005-W43	14d	2555d	5581
2001 YP32	2	22.0	21.4	2005-X55	109d	1453d	21
2004 JQ1	1	20.1	21.8	2006-C02	31d	600d	210
2004 RY109	0	19.1	22.6	2006-C19	94d	510d	22
2005 TR50**	1	20.2	21.5	2006-F24	2d	164d	3660
2000 PP9	1	19.3	21.4	2007-H51	144d	2513d	402
2003 WG	1	19.1	20.9	2007-K24	32d	1246d	2067
2005 GO22	1	18.7	21.8	2007-L56	35d	764d	1366

- Notes: ** Asteroids 1998 VS and 2005 TR50 lost their PHA status due to the recoveries' updates of their orbits. Station G96 recovered 2005 TR50 on the same night as Spacewatch.
- * Spotted by on-line volunteer Peter B. Lake.

Additional Recoveries of PHAs with more than 2000 days between measurements.

Object	Veph	MPEC	Date	Arc ext.(d)
J96S00K	22.4	2003-R29	2003 09 04	2245
J95S00A	22.4	2003-R29	2003 09 04	2877
J98S15C	22.8	2005-J65	2005 05 14	2182
J90H00A	21.4	2005-R01	2005 08 28	5574
J99A10Q	21.6	2006-X52	2006 12 12	2847
(175706)	21.3	2006-Y44	2006 12 24	2080
J96E00O	21.6	2006-Y72	2006 12 26	2851
J91J00W	22.0	2007-B05	2007 01 15	3519
J96R03G	22.1	2007-P25	2007 08 09	3738
K00E70W	20.5	2007-Y51	2007 12 28	2834
K00W10K	20.3	2007-Y51	2007 12 28	2148

- Note: “Veph” = ephemeris magnitude at the time of the recovery.)

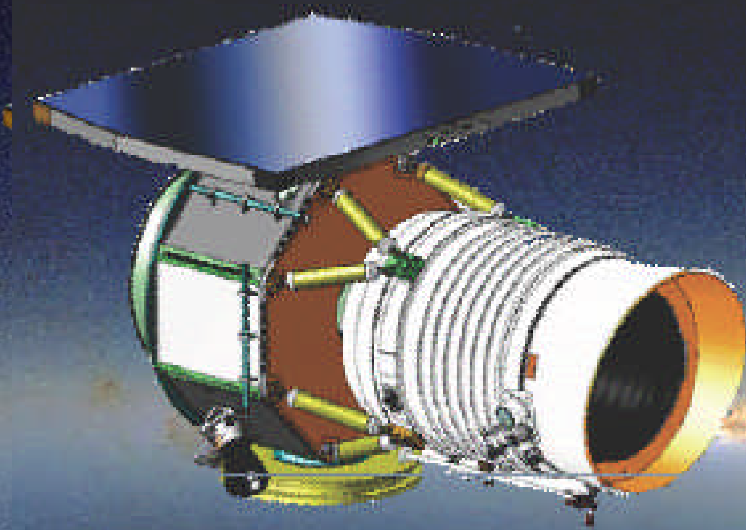
Future Roles of Spacewatch:

- Wide-field Infrared Survey Explorer (WISE):
  - UCLA/JPL MIDEX spacecraft mission in 2010.
  - Thermal IR detection allows diameter measures.
  - Searches 90 deg from Sun.
- Panoramic Survey Telescope and Rapid Response System (Pan-STARRS):
  - IfA/U. Hawaii.
  - PS-1 single-scope prototype soon.

WISE Wide-field Infrared Survey Explorer

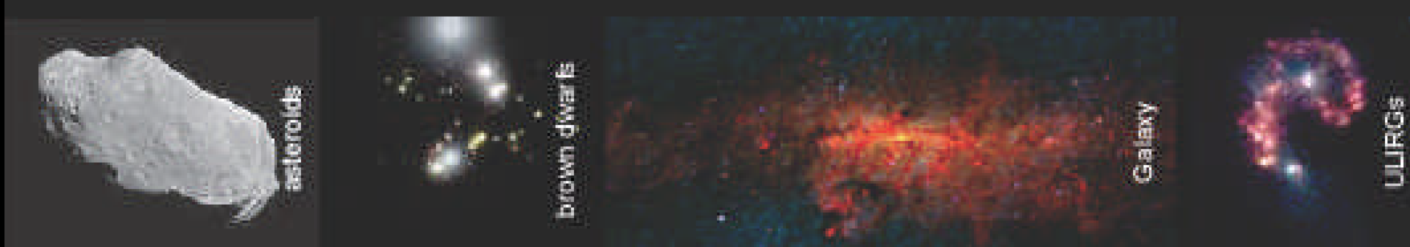
NASA

WISE will map the sky in infrared light, searching for the nearest and coolest stars, the origins of stellar and planetary systems, and the most luminous galaxies in the Universe.



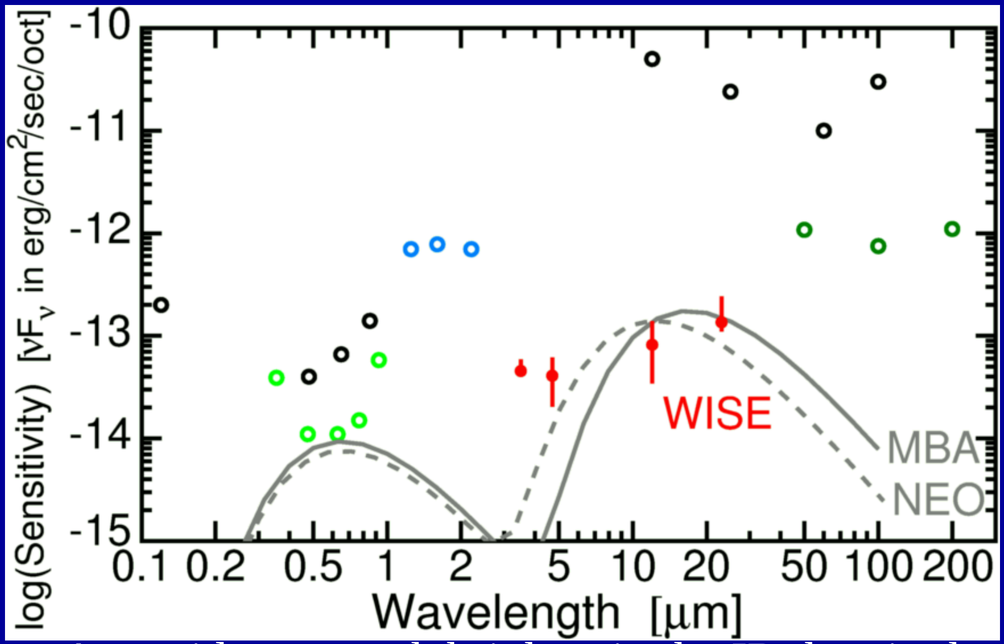
WISE will deliver to the scientific community:

- Over 1 million images covering the whole sky in 4 infrared wavelengths
- Catalogs of ≈ 500 million objects seen in these 4 wavelengths



wise.astro.ucla.edu

WISE and Asteroids

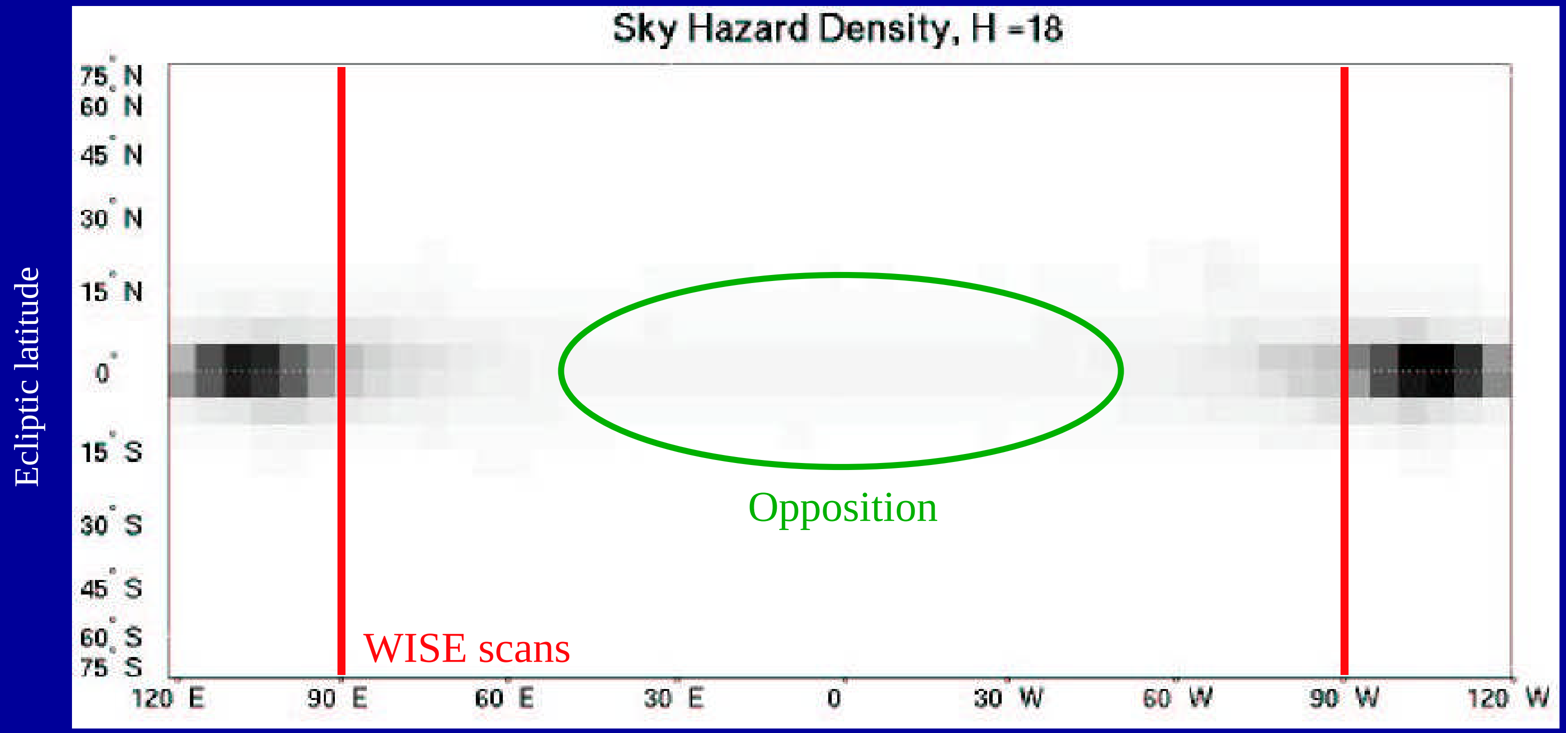


Gaspra

Asteroids move

- Asteroids are much brighter in the IR than in the optical.
- They move in the hours between WISE frames.
- For asteroids with known orbits, WISE sensitivity will be slightly better than for fixed celestial objects:
  - –Asteroids generally move in the same direction that WISE scans and thus get more repeated observations than stars.
  - –Asteroids' movement across the sky greatly reduces the confusion noise from unresolved celestial sources.

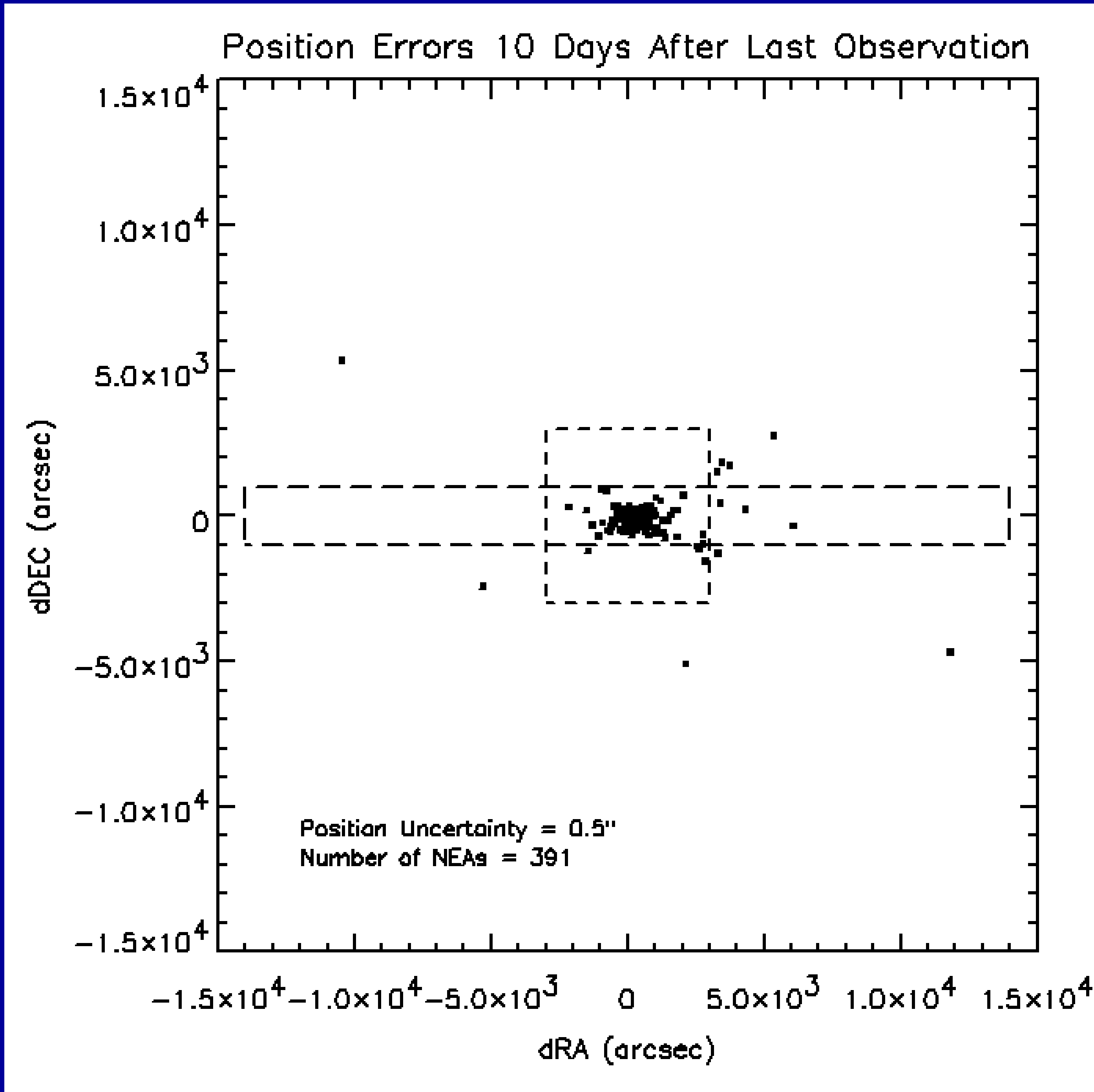
WISE will find PHAs

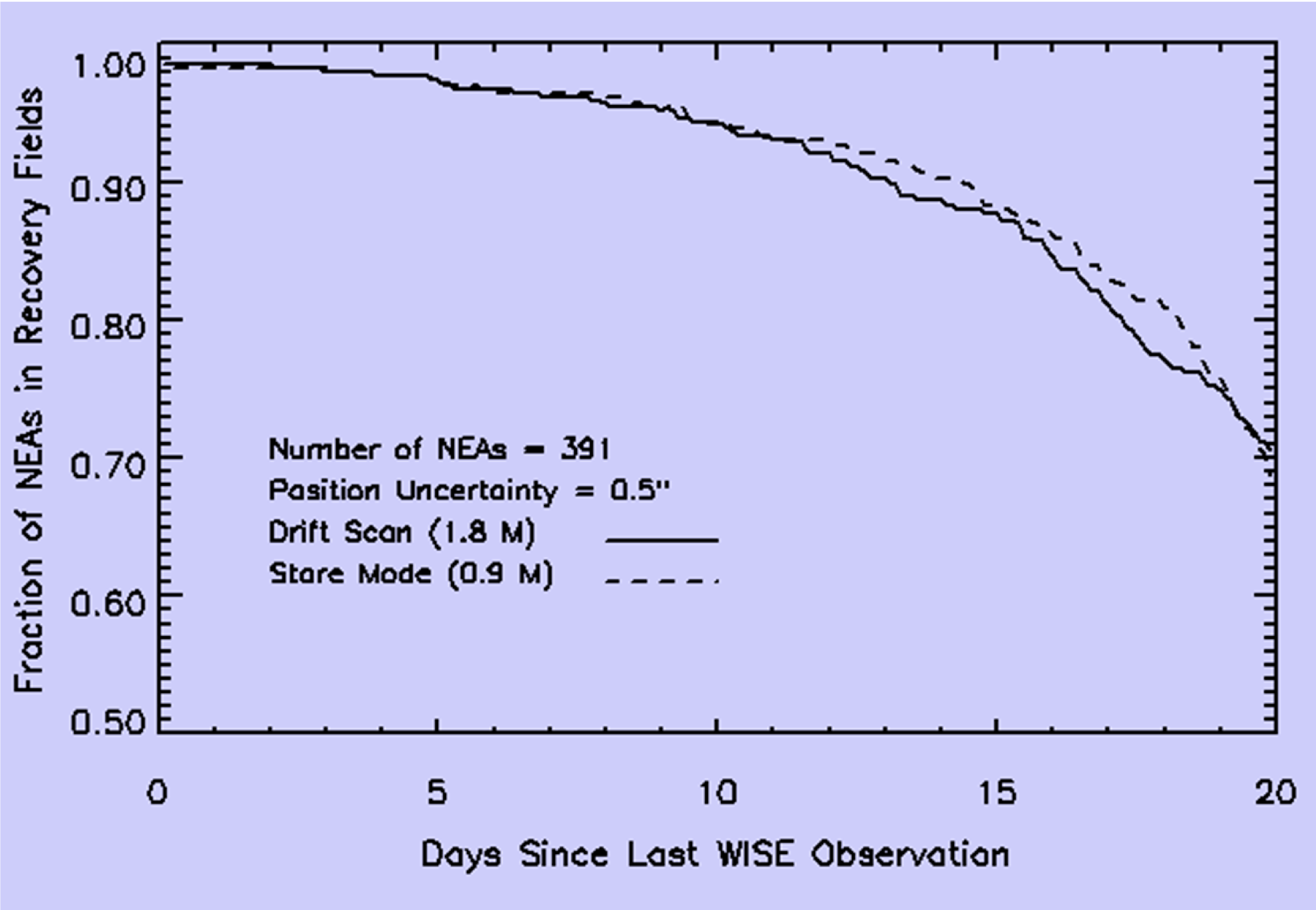


- Chesley and Spahr (2003) found that the asteroids most likely to impact the Earth tend to be close to the Sun. WISE observes at ~90º from the Sun, while current surveys work mostly around opposition, 180º from the Sun.

Incidental Detections of Asteroids in WISE All-sky IR Survey

- Several $\times 10^5$ detections @ 12 & 23 μm.
- Main belt asteroids ≥ 3 km in diameter.
- 100's of NEOs ≥ few× 100 m in diameter.
- Detection tracklets long & dense compared to typical ground-based ones.
- "NEOWISE" to turn around detections for posting by MPC in ≤ 10 days.


Position Errors 10 Days After Last Observation
1.5x10^4
1.0x10^4
5.0x10^3
0
−5.0x10^3
−1.0x10^4
−1.5x10^4
dDEC (arcsec)
−1.5x10^4
−1.0x10^4
−5.0x10^3
0
5.0x10^3
1.0x10^4
1.5x10^4
dRA (arcsec)
Position Uncertainty = 0.5"
Number of NEAs = 391



Fraction of NEAs in Recovery Fields
1.00
0.90
0.80
0.70
0.60
0.50
0
5
10
15
20
Days Since Last WISE Observation
Number of NEAs = 391
Position Uncertainty = 0.5"
Drift Scan (1.8 M)
Stare Mode (0.9 M)

Pan-STARRS-1's Followup Needs (Jedicke 2006 private comm.)

- Detect ~5,000 H≤22 NEOs during PS1 ops.
- ~10% might lack 3rd night due to weather, picket fence, camera fill factor, guiding OTA cells, etc.
- Another ~10% with poorly determined orbits.
- → ~200-300 PS1-discovered NEOs/yr.
- → ~200 V≤23 targets/yr for Spacewatch.

Proposed Enhancements

- Software
  - Automate search patterns (both ‘scopes).
  - Automate target selection, pointing, focusing, rotation (1.8-meter ‘scope).
- Hardware (1.8-meter ‘scope):
  - Faster, flatter, higher resolution CCD(s).
- Gains:
  - ↑50% in time efficiency
  - ↑0.5 – 1.0 mag in sensitivity
  - “Staring” exposures @ any declination.

Use Bigger Telescopes

- Target-of-Opportunity Mode → V=23.
  - KPNO 4-meter MOSAIC camera, FOV 35´×35´.
  - WIYN 3.5-meter MiniMo camera, FOV 10´×10´.
- Steward 2.3-m 90Prime camera, FOV ~1 deg^2.
- New Staff Member
  - Learn, propose, coordinate, observe, analyze, report.
- ~100 hours (~100-300 NEOs) per yr possible.

Preliminary Cost Estimates

- Continue @ subsistence level: $587K/year.
- Continue w/ upgrades & larger ‘scopes: $730K/year.
- All of the above plus new detector(s) :
  - Annual cost $730K.
  - Plus one-time cost of $190K.

Advantages

- Better orbits for many NEOs, especially PHAs.
- Avoid loss of some objects after discovery.
- Prompt response to urgent requests.
- Personnel, assets, infrastructure, & site.
- Predictable costs.

Disadvantages: Compared to What?

- No comparable followup telescope.
- ???

Summary

- Followup needs will increase.
- Biggest ‘scope dedicated to followup.
- Flexible in time allocation.
- Expansion to 2.3-m, WIYN, 4-meter.

Acknowledgements

- The Spacewatch Team & the WISE Team.
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- NASA's NEOO & PAST Programs.
- The Brinson Foundation, the estates of R. L. Waland and R. S. Vail, & other private donors.