SPACEWATCH® Near-Earth Astrometric Follow-up

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The Brinson Foundation

SPACEWATCH® was founded at the University of Arizona's Lunar and Planetary Laboratory (LPL) by Prof. Tom Gehrels and Dr. Robert S. McMillan in 1980. The original mission was to explore populations of minor planets in the solar system with the Steward Observatory 0.9-m telescope on Kitt Peak. This discovery survey included studies of Main Belt asteroids, Trojan asteroids, Centaurs, Trans-Neptunian objects, comets, and near-Earth asteroids (NEAs).

Today, Spacewatch is led by Dr. Melissa Brucker with the mission to perform follow-up astrometry of near-Earth objects (NEOs) of planetary defense or scientific interest especially Potential Hazardous Asteroids (PHAs) and virtual impactors (VIs).

- We lead in follow-up astrometry of PHAs while they are faint ($V \geq 22.5$)
- More than 80% of our NEO observations are unique for that date
- More than 25% of Minor Planet Electronic Circulars in which our observations appear contain one of our tracklets as the final tracklet before designation.

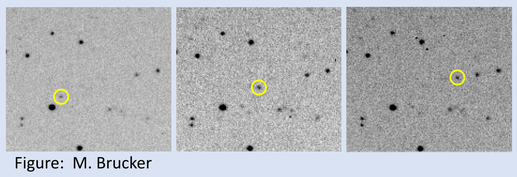
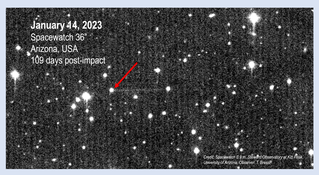


Figure: M. Brucker

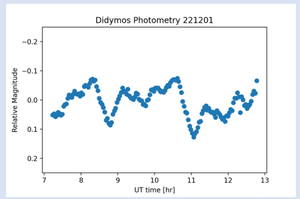
One of our notable discoveries is 65803 Didymos (1996 GT) [discovery images above], whose moon Dimorphos was the target of the Double Asteroid Redirection Test (DART) mission - NASA's first planetary defense exercise.

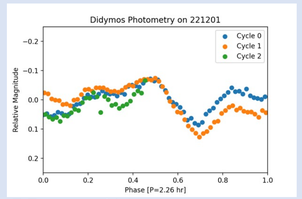
Between October 17, 2022 and January 22, 2023, we observed the Didymos system on 25 different nights with the 0.9-m telescope. All current Spacewatch observers (Bressi, Brucker, Lejoly, Mastaler, Read, Scotti, and Tubbiolo) and Prof. Larsen and Midshipman Taiya Tataro (USNA) collected lightcurve data.

Below: the Didymos system and its debris tail on Jan. 14, 2023 with the 0.9-m telescope.



Thomas *et al.* (2023 *Nature* **616**, 448) determined that the impact reduced Dimorphos' orbital period by 33 minutes from 11 hours 55.29 minutes to 11 hours 32 minutes. Prof. Larsen and Prof. Matthew Knight (USNA) independently analyzed our 25 nights of the Didymos binary system's lightcurve data and submitted the results to the DART Science Investigation Team.





Figures: M. Knight using data collected by . Mastaler, T. Tataro, and J. Larsen.

The figures above are Spacewatch examples of a time series and lightcurve of the Didymos system from December 1, 2022. Dimorphos is orbiting Didymos and passing in front of and behind it and the two bodies are each rotating.

Spacewatch is supported by NASA/YORPD grant 80NSSC21K0657, the Lunar and Planetary Laboratory, Steward Observatory, Kitt Peak National Observatory, the Brinson Foundation of Chicago, IL, the estates of R. S. Vail and R. L. Waland, and other private donors. We rely on JPL and MPC for their web services.

The astronomical community is honored to have the opportunity to conduct astronomical research on Iolkam Du'ag (Kitt Peak) in Arizona. We recognize and acknowledge the very significant cultural role and reverence that this site has to the Tohono O'odham Nation.

University of Arizona Land Acknowledgement: We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and Indigenous communities through education offerings, partnerships, and community service.

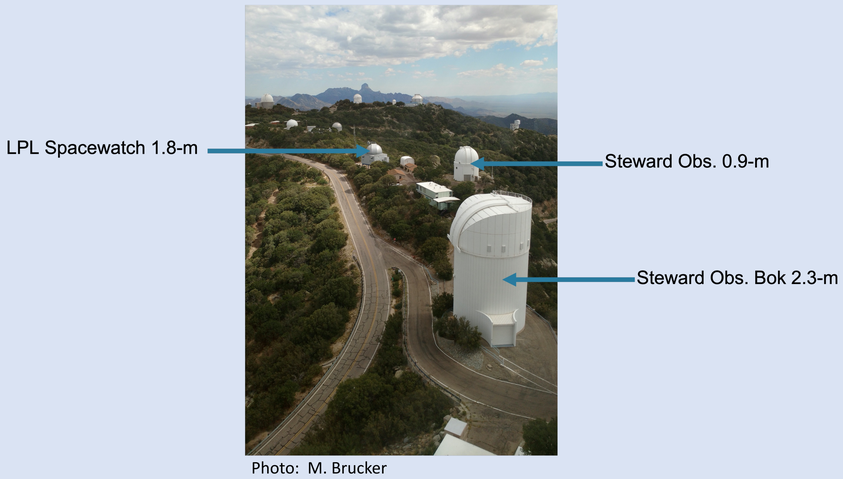


Photo: M. Brucker

In 2019, Spacewatch, the Catalina Sky Survey, and the University of Minnesota began a collaboration using the 90Prime camera on the Bok 2.3-m to discover faint asteroids, especially larger NEOs and Earth Trojan candidates. More than 450 NEOs have been discovered so far. According to the PDS Small Bodies Node, the Bok NEO Survey is the fourth site in discovery MPECs over the last 12 months, fifth over the past 5 years, and tenth since Sept. 19, 1993.

Because VIs are our highest priority targets, we have a program specifically to recover faint VIs with larger telescopes. We apply for time on Keck I, Gemini North, Gemini South, the MMT, and the Blanco telescope. We measure the VI astrometry to reduce the uncertainty in knowledge of the VIs' heliocentric orbital elements during their discovery apparitions (and beyond) to rule in or out possible impact(s).

Because many of the VIs have observations that span only a very short time, they could become lost or difficult to find after long intervals between visits near Earth.

Time Span of Observations vs. (Time until First Possible Impact) – 1 Year

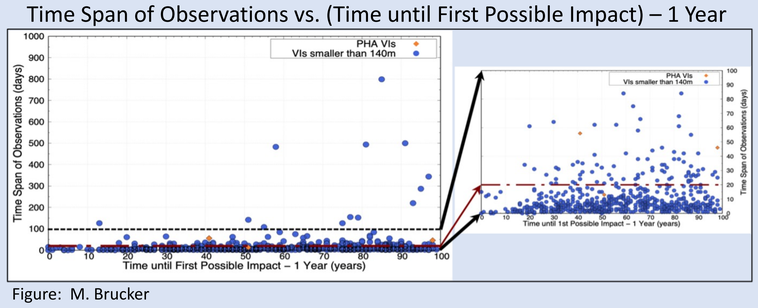


Figure: M. Brucker

Of VIs newly designated after Nov. 15, 2019, 605 still were listed on JPL Sentry as of February 16, 2023. 510 had observations that spanned ≤ 20 days. In both plots, the maroon horizontal dash-dotted line marks 20 days. Left: all 605 VIs. Right: VIs with observations spanning ≤ 100 days.

The VI 2022 LX that we observed with LRIS on Keck I is an example result from the 2022A observing semester. We created 3 stacks of 12 30s exposures using JPL Horizons ephemeris rate. 2022 LX is circled in yellow. The thin black squiggles and lines are cosmic rays.

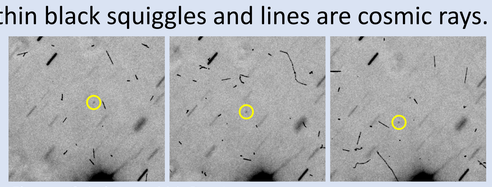


Figure: C. Lejoly and M. Brucker

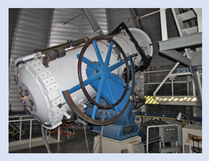
2022 LX's orbit was updated with our measurements. This improved the orbital elements' uncertainties by about 30%.

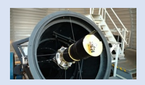
Orbital Element	Value Before	1-σ Uncert.	Value After	1-σ Uncert.	Units	% Diff. in Uncert.
e	0.59164865	1.3219E-04	0.59174542	9.2783E-05		29.81
a	2.41228112	7.7065E-04	2.41284546	5.4110E-04	au	29.79
i	0.86824794	1.2330E-04	0.86833774	8.7021E-05	deg	29.42
Ω	310.011834	2.1130E-03	310.013409	1.4534E-03	deg	31.22
ω	351.017501	1.7744E-03	351.01617	1.2108E-03	deg	31.76

where Ω is the longitude of the ascending node and ω is the argument of perihelion. The 'after' values are from JPL's Small-Body Database Lookup webpage in February 2023.

SPACEWATCH® operates the Steward Observatory 0.9-m telescope (691) and the LPL Spacewatch II 1.8-m telescope (291) at the Kitt Peak station of Steward Observatory. We use these telescopes 24 nights per lunation for astrometric follow-up of near-Earth asteroids (NEAs). We also receive considerable time on the Steward Observatory Bok 2.3-m telescope for follow-up of fainter targets during bright time.

Telescope	MPC Observatory Code	Maximum TEM[a]	FOV	Image Scale ("/pixel)	Pixel Size (mm)	Pixels	f ratio	Filter[b]
0.9m	691	V ~ 22.2	1.7°x1.7°	1.00	13.5	4x4608x2048	f/3	Schott OG 515
1.8m	291	V ~ 23.0	20′ x20′	0.62	15	2048x2048	f/2.7	Schott OG 515
Bok 2.3m/SCC	^695	V ~ 24.2	5′ x5′	0.26	15	2048x2048	f/9	open/Schott OG 515



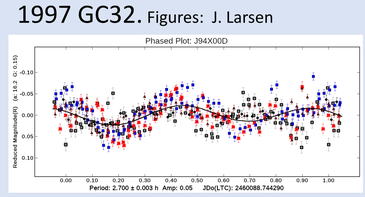


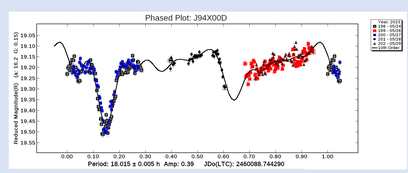
Left: 0.9-m telescope. Middle: Spacewatch Mosaic Camera. Right: 1.8-m telescope
Photos: Roger E. Carpenter, MD and M. Brucker

Our astrometric target selection is prioritized with VIs and NEO Confirmation Page objects as our highest priority, then candidates for detection of the Yarkovsky Effect, PHAs that will be within 0.03 AU of Earth within the next 40 years, NEAs listed on NEODyS's Priority and Faint Priority lists, potential targets of planetary radar, NEAs observed by the NEOWISE mission, small NEAs that will be within 0.03 AU of Earth within the next 40 years, and objects listed on the JPL Near-Earth Object Human Space Flight Accessible Targets Study (NHATS) webpage.

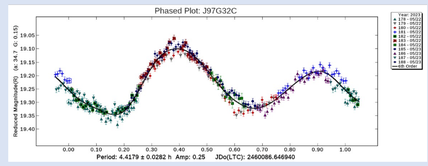
We prioritize observing fainter objects, each of which require longer exposure times to observe than bright targets. When observatories on Kitt Peak were operational between Nov. 16, 2019 and Feb. 15, 2023, for the 1.8-m, 0.9-m, and Spacewatch Cassegrain Camera on the 2.3-m, we submitted a monthly average of 12,143 lines of astrometry. According to the PDS Small Bodies Node, Spacewatch is sixth in discovery MPECs and seventh in Precovery MPECs with the 0.9-m and fifth in contributing to MPECs with the 1.8-m since Sept. 19, 1993.

The Brinson Foundation of Chicago supports Spacewatch to observe NEAs for rotational lightcurves and period determination. Our targets may be potential targets of planetary radar, VIs, candidates for detection of the Yarkovsky Effect, NEAs with characterization data, and specific requests of scientific or planetary defense interest. We use the Asteroid Lightcurve Database (Warner *et al*. 2009, *Icarus* **202**, 134) and the Minor Planet Bulletin as resources when choosing targets. This spring, we observed (488453) 1994 XD and (513125) 1997 GC32. Figures: J. Larsen





Binary PHA (488453) 1994 XD was discovered by Spacewatch founder Tom Gehrels on December 1, 1994. We observed it on May 24 through 29, 2023 to complement upcoming (at the time) planetary radar observations. The left plot shows its short primary rotation period and the right plot shows the longer secondary period determined from our observations. We captured the full trough of the secondary lightcurve in its entirety twice, so J. Larsen was able to compute the orbital period directly. He performed a dual period analysis in MPO Canopus and found rotation periods of 2.700 ± 0.003 hours and 18.015 ± 0.005 hours.



NEA (513125) 1997 GC32 was discovered by the LINEAR survey. It did not have a known period or amplitude posted in the Asteroids Lighturve Database as of July 30, 2023. We observed it on May 22 and 23, 2023 to complement existing NEOWISE size and reflectivity data. We determined a rotation period of 4.4179 ± 0.0282 hours.