

# Spacewatch Astrometry and Photometry of Near-Earth Objects

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The Spacewatch Project is the longest-running of all present programs of astrometry of solar system objects and the first to use charge-coupled device (CCD) imaging detectors for such work (Gehrels *et al.* 1986, McMillan *et al.* 1986, 2007, 2010, 2012, 2014, Larsen *et al.* 2014, Scotti *et al.* 2014). Nowadays, to fill an underrepresented niche, Spacewatch specializes in followup observations of Near-Earth Objects (NEOs) of high priority while they are faint. Many asteroids and comets are being lost owing to insufficient followup astrometry, but only the most important ones can be followed with the limited resources available. We produce an annual average of  $\sim 8500$  lines of astrometry of  $\sim 1,000$  different NEOs. We contribute to the removal of half of the objects that were retired from impact risk lists. Our observations at elongations as small as 46 degrees support followup of hazardous NEOs and NEOs discovered by the NEOWISE spacecraft (Wright *et al.* 2010, Mainzer *et al.* 2011a,b), and we lead the community of NEO followup astrometrists in numbers of early observations of the latter type of objects (Nugent *et al.* 2015). Per year we observe about 35 radar targets, 50 NEOs that were measured by NEOWISE, and 100 potential rendezvous destinations. In the last 3 years we have observed half of all NEOs and PHAs observed by anyone in that time. We lead in followup of provisionally designated PHAs while faint ( $V \geq 22$ ); contributing 41% of all such observations.

With the **Steward Observatory 0.9-meter telescope** on Kitt Peak, site code 691, we survey with a  $1.85 \times 1.71$  deg mosaic of CCDs near opposition and at low elongation in the east. Three-pass coverage is 1400 square deg per lunation with an image scale of 1 arcsec per pixel and a R mag limit  $\sim 21$ . Astrometry of asteroids is good to  $\pm 0.3$  arcsec. Twelve years of such uniform surveying, amounting to 17 terabytes of data, will go live on the web in 2015 to support incidental astrometry & precoveries of NEOs (Larsen *et al.* 2015). Beyond the solar system, the cadence of the Spacewatch mosaic data will provide sampling of variable stars and galaxies on time scales from tens of minutes to 12 years, a range rarely available from databases of this type.

On the **Spacewatch 1.8-m telescope**, site code 291, the field of view =  $21 \times 21$  arcmin and the pixel scale = 0.6 arcsec/pixel. The V mag limit=23 and the astrometric

residuals on faint NEOs are  $\pm 0.3$  arcsec.

Our output with the **Bok 2.3-m telescope** of the Steward Observatory and the **Mayall 4-m telescope** of the Kitt Peak National Observatory from 2010-2015 was 1605 lines of astrometry on 249 different NEOs, including 94 different PHAs. 343 observations were made of PHAs with  $V \geq 22$ . Our average calendar span extension on large PHAs using the Bok and Mayall telescopes is 6 months, twice as long as that of the next most effective observing station. We extend the span of calendar time coverage on PHAs an average of 3.8 times. For 38 of 72 PHAs we added another observed opposition. With the Bok and Mayall we reduce uncertainties of orbital elements an average of a factor of 6 and the uncertainty of the time of perihelion passage an average of a factor of 19 (G. Williams 2014 private communication).

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