Observing near-Earth objects with the H-SC observatory

Landon M. Ostermann ’28, Spencer J. Schneider ’26 and Jonathan W. Keohane

Department of Physics and Astronomy, Hampden-Sydney College, Hampden-Sydney, VA 23943

Abstract

The identification of undiscovered NEOs, or near-Earth objects, is an ongoing endeavor that sees worldwide contribution. Once a potential NEOs is confirmed, observations from multiple sources are required to constrain its orbit. The goal of this project was to establish a workflow for taking these observations using the Hampden-Sydney Observatory. Measuring NEOs is done by taking short exposures, identifying the target moving between them, and taking measurements of the target's astrometry. Advancements in recent years, such as synthetic tracking, have greatly improved the signal to noise ratio (SNR) of observations and made using small telescopes for detection more feasible. Using these methods, astrometric measurements were successfully taken of multiple different NEOs and submitted in a report to the Minor Planet Center. The Hampden-Sydney Observatory was assigned observatory code W40 and is now designated a permanent observing site for submitting future reports.

Introduction

NEOs are asteroids or comets that come within 1.3 AU of Earth (Du, 2024) . As of late 2024, only approximately 44% of NEOs larger than 140m are estimated to have been detected (*Space and Aeronautics Subcommittee,* 2025*)*. The Minor Planet Center, or MPC, is the organization responsible for aggregating and publishing the astrometry and photometry of NEOs. The database they maintain consists of observations submitted by independent observatories. Submitting data requires an observatory code being issued by the MPC, which designate permanent observing sites and are granted upon successfully submitting qualifying measurements (Minor Planet Center, 2022). As such, our research focused on developing a pipeline for observing asteroids and generating reports for the purpose of submitting to the MPC.

The Hampden-Sydney Observatory belongs to the Skynet Robotic Telescope Network operated by the University of North Carolina at Chapel Hill. Skynet connects ≈20 telescopes across four continents, of which the Hampden-Sydney Observatory has the largest field of view. The Skynet API allows the automation of certain tasks, such as submitting observations to the observatory queue. The University of Arizona's NEOfixer provides information on potential targets based on what is visible from H-SC, then lists orbital elements of potential targets. The NEOfixer API can be used to automatically identify new targets and submit observations with the Skynet API. These targets are known or potential NEOs that require more data to reduce uncertainties in their orbits.

Commercial software, namely Tycho Tracker, has made NEO detection accessible to amateur astronomers interested in contributing observations. Released in 2020, Tycho Tracker features graphics processing unit (GPU) powered synthetic tracking, allowing for the creation of observations from groups of exposures that don’t each individually show the target clearly (Parrott, 2020). This addresses one of the main limitations of observing NEOs: that exposure time is limited by the rate the target moves, meaning the faster and dimmer a target is the harder it is to observe.

Materials and Methods

The Hampden-Sydney Observatory [1] has a 17" PlaneWave Telescope with an effective diameter of 17” and a 1949 mm effective focal length. The mount is the PlaneWave Ascension 200HR, a German equatorial mount with a slew rate of 5 degrees/second and slew range of 22.5 degrees past the East/West meridian. The camera is a ZWO ASI6200MM Pro with a 61.2 MP CMOS sensor array, creating a pixel size of 0.4 arcseconds/pixel and a field of view of 64 arcminutes by 42 arcminutes. Observations are queued via Skynet, where targets, exposure times, and filters are specified. All

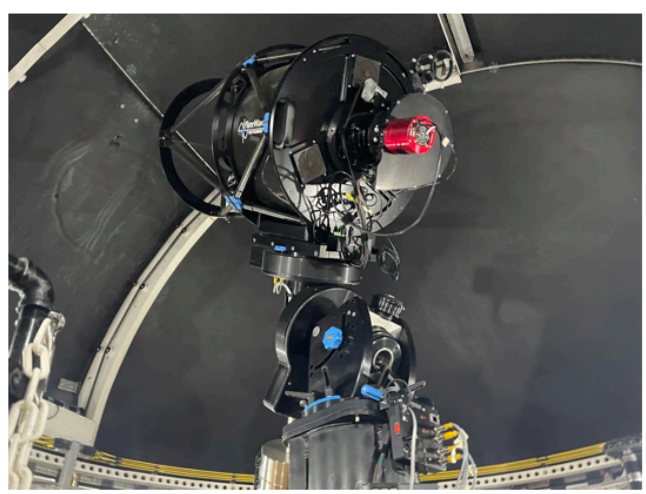

Figure 1: The telescope of the Hampden-Sydney Observatory with the dome shutter closed. The ZWO ASI6200MM Pro Camera is the red object attached to the visible end of the optical tube. Both sit atop the PlaneWave Ascension 200HR German Equatorial Mount.

observations were taken using the SLOAN/SDSS r' filter, which captured the most light of the available filters to select from.

The ability of the H-SC observatory to observe a given object is dependent on its magnitude and rate. To ensure the target appears as a point and not a line, the exposure time must not be long enough for the target to move more than one pixel, or about half an arcsecond. However, if the object is faint and has a fast rate, it may be impossible to observe. The H-SC observatory can see up to magnitudes of 18-19 with the longest exposures. While it is best for targets to be visible in individual exposures, synthetic tracking also allows for SNR improvements when this is not the case. Observations will be taken multiple times per night, usually for 30 minutes of total observing time, over multiple nights. After exposure times are calculated, observations are submitted via Skynet.

These exposures are taken into Tycho Tracker to create observations. Groups of exposures are then plate solved using visible stars to match to known catalogues and determine the location of the exposures. Once finished, these exposures are aligned and stacked to the target, with the image in the middle of the set serving as the base for the stack. As such, the astrometry of a given observation will be the location of the target in the middle of the stack of exposures, with the additional exposures being used to increase the SNR [2]. Synthetic tracking determines how to stack to the target by applying different motion vectors between individual exposures and identifying moving objects (Shao, 2014). While typically used for discovering unknown NEOs, synthetic tracking can be used in addition to known orbital elements, thereby closing the parameter space some and making computation less intensive. Once this is done, a final observation with a higher SNR and lower uncertainty is produced, making the target appear as a point across a field of smeared stars [3]. Three of these observations per night are required to constrain orbit.

Figure 3. Example of completed observations taken from Tycho Tracker. Seen are three stacked images of 2008 DG5 with corresponding astrometric measurements. The target, 2008 DG5, appears as a bright point while background stars appear as faint smears.

Afterwards, a report is generated in the Astrometry Data Exchange Standard (ADES) format containing astrometric positions and photometric measurements of every given observation along with uncertainties. Residuals under 1.5 are accepted, but residuals less than 1 are considered to be good quality. ADES reports also include information like the submitter's name, camera type, location coordinates, and software used. Once submitted, the MPC compares the submitted observations to known values and determines if the observations are within acceptable margins of error.

Results

Different exposures were collected between November 2024 and June 2025, not all of which were near-Earth. Data from December 2024 to February 2025 turned out to be unusable due to the telescope

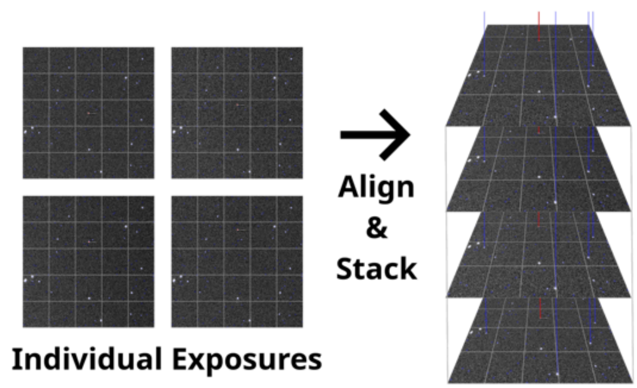

Figure 2. Visualization of synthetic tracking with plate solved reference stars in blue used for alignment, and with motion vector marked in red being used to shift individual exposures and stack to target.

being out of focus during that time. The exposures taken were initially processed and sent to the MPC, where they were rejected. When unfocused, targets appear as rings rather than points, potentially impacting astrometric measurements. As a result, many exposures were not used in any reports. While there were a handful of observations taken before and after the telescope was out of focus, additional targets were selected throughout the remainder of the summer.

MPC Provisional ID	Time (UTC)	RA (degrees)	Dec (degrees)	RA Uncertainty (arcsec)	Dec Uncertainty (arcsec)	Track Uncertainty (arcsec)	Apparent Magnitude	Magnitude Uncertainty	Exposure Time (sec)
1993 VW	2025-06-25T04:51:58Z	277.11911	-9.01293	0.50	0.44	0.32	17.7	0.52	135

1993 VW	2025-06-25T04:56:19Z	277.11777	-9.01287	0.71	0.67	0.32	18.0	0.61	90
1993 VW	2025-07-01T06:10:29Z	274.43596	-8.99666	0.32	0.30	0.21	16.8	0.24	45
1993 VW	2025-07-01T06:11:16Z	274.43556	-8.99614	0.39	0.38	0.21	17.9	0.40	45
1993 VW	2025-07-01T06:12:04Z	274.43529	-8.99659	0.84	0.83	0.21	17.7	0.68	45
1993 VW	2025-07-01T06:13:39Z	274.43482	-8.99669	0.43	0.41	0.21	17.1	0.34	45
1993 VW	2025-07-01T06:14:26Z	274.43428	-8.99644	0.57	0.56	0.21	17.6	0.54	45
1993 VW	2025-07-06T03:29:58Z	272.50384	-9.07813	0.27	0.26	0.29	16.7	0.65	180
1993 VW	2025-07-06T03:52:27Z	272.49721	-9.07781	0.57	0.57	0.30	17.9	0.49	135
1993 VW	2025-07-06T03:56:14Z	272.49610	-9.07808	0.30	0.27	0.32	16.7	0.14	135
1994 LX	2025-07-01T06:39:25Z	262.12165	+9.00579	0.16	0.22	0.24	16.6	0.09	180
1994 LX	2025-07-01T06:42:42Z	262.12033	+9.00445	0.16	0.24	0.24	17.0	0.12	180
1994 LX	2025-07-01T06:45:59Z	262.11901	+9.00313	0.16	0.23	0.25	16.6	0.19	180
1994 LX	2025-07-01T06:49:14Z	262.11771	+9.00179	0.15	0.20	0.22	16.4	0.05	180
1994 LX	2025-07-01T06:52:30Z	262.11642	+9.00042	0.16	0.20	0.23	16.2	0.16	180
1994 LX	2025-07-04T06:29:22Z	260.47434	+7.22806	0.44	0.29	0.37	18.3	0.52	180
1994 LX	2025-07-04T06:34:40Z	260.47216	+7.22614	0.42	0.39	0.44	18.4	1.66	180
1994 LX	2025-07-04T06:40:45Z	260.46846	+7.22298	0.27	0.49	0.41	18.1	1.32	150
1994 LX	2025-07-05T02:55:36Z	260.02593	+6.71509	0.22	0.35	0.39	16.4	0.11	180
1994 LX	2025-07-05T02:59:15Z	260.02468	+6.71351	0.19	0.35	0.38	16.3	0.10	180
1994 LX	2025-07-05T03:02:29Z	260.02339	+6.71223	0.20	0.36	0.38	16.5	0.09	180
1994 LX	2025-07-05T03:05:44Z	260.02217	+6.71083	0.18	0.35	0.37	16.2	0.08	180
1994 LX	2025-07-05T03:08:59Z	260.02097	+6.70949	0.20	0.36	0.38	16.4	0.09	180
2002 LJ3	2025-06-25T03:05:59Z	255.66272	-9.07398	0.30	0.30	0.39	16.6	0.13	90
2002 LJ3	2025-06-25T03:07:34Z	255.66215	-9.07423	0.35	0.35	0.39	17.6	0.26	90
2002 LJ3	2025-06-25T03:31:10Z	255.65402	-9.07627	0.37	0.42	0.46	18.1	0.34	90
2002 LJ3	2025-07-05T02:51:22Z	251.26898	-10.64130	0.54	0.62	0.46	18.0	0.44	45
2002 LJ3	2025-07-05T02:52:10Z	251.26869	-10.64213	0.70	0.77	0.41	18.4	0.79	45
2002 LJ3	2025-07-05T02:52:57Z	251.26870	-10.64180	0.81	0.87	0.41	17.5	0.61	45
2003 AY2	2025-07-06T03:18:08Z	265.92934	-12.56267	0.22	0.38	0.37	17.0	0.19	700
2003 AY2	2025-07-06T03:33:55Z	265.93858	-12.55627	0.23	0.22	0.25	17.1	0.46	700
2003 AY2	2025-07-06T04:23:39Z	265.96756	-12.53614	0.23	0.18	0.21	16.7	0.18	700
2003 AY2	2025-07-06T05:13:46Z	265.99670	-12.51575	0.26	0.25	0.32	17.0	0.17	680

2003 AY2	2025-07-06T05:41:18Z	266.01265	-12.50460	0.21	0.25	0.28	16.6	0.33	680
2003 MH4	2025-06-24T06:25:02Z	320.59479	-5.40416	0.35	0.42	0.42	18.1	0.72	180
2003 MH4	2025-06-24T06:28:17Z	320.59284	-5.40408	0.31	0.39	0.43	17.6	0.28	180
2003 MH4	2025-06-24T06:31:32Z	320.59109	-5.40407	0.31	0.39	0.43	17.5	0.17	180
2003 MH4	2025-06-24T06:34:48Z	320.58936	-5.40398	0.34	0.40	0.41	17.6	0.27	180
2003 MH4	2025-06-24T06:38:03Z	320.58763	-5.40395	0.30	0.38	0.42	17.6	0.41	180
2003 MH4	2025-07-01T05:41:05Z	316.07826	-5.52073	0.40	0.40	0.27	X	X	180
2003 MH4	2025-07-01T05:44:19Z	316.07700	-5.52063	0.30	0.30	0.27	18.1	0.37	180
2003 MH4	2025-07-01T06:21:14Z	316.06020	-5.52182	0.43	0.43	0.27	18.5	0.33	180
2003 MH4	2025-07-01T06:58:09Z	316.04366	-5.52305	0.37	0.30	0.33	18.8	0.70	180
2003 MH4	2025-07-01T07:01:26Z	316.04209	-5.52294	0.34	0.27	0.33	17.9	0.28	180
2005 JF21	2025-07-01T07:04:17Z	334.76559	+8.33512	0.27	0.31	0.34	16.1	0.13	80
2005 JF21	2025-07-01T07:05:36Z	334.76709	+8.33520	0.30	0.42	0.41	17.4	0.45	60
2005 JF21	2025-07-01T07:06:43Z	334.76828	+8.33541	0.24	0.38	0.41	16.1	0.13	60
2005 JF21	2025-07-01T07:07:50Z	334.76951	+8.33553	0.37	0.48	0.41	X	X	60
2005 JF21	2025-07-01T07:08:58Z	334.77085	+8.33572	0.26	0.41	0.42	16.7	0.34	60
2005 JF21	2025-07-06T05:32:08Z	343.47040	+9.06223	0.31	0.29	0.40	16.2	0.09	120
2005 JF21	2025-07-06T05:36:06Z	343.47546	+9.06254	0.32	0.30	0.40	16.3	0.09	100
2005 JF21	2025-07-06T05:39:46Z	343.48018	+9.06286	0.31	0.31	0.41	16.3	0.11	100
2005 JF21	2025-07-06T05:43:38Z	343.48556	+9.06326	0.31	0.24	0.37	15.6	0.05	100
2005 JF21	2025-07-06T05:46:37Z	343.48895	+9.06345	0.31	0.24	0.37	16.2	0.12	100
2005 VO5	2025-07-01T05:55:18Z	271.57510	-16.58185	0.11	0.15	0.16	15.6	0.37	180
2005 VO5	2025-07-01T05:58:28Z	271.57458	-16.58683	0.11	0.13	0.16	15.4	0.08	180
2005 VO5	2025-07-01T06:01:39Z	271.57413	-16.59176	0.11	0.13	0.15	15.5	0.54	180
2005 VO5	2025-07-01T06:04:49Z	271.57369	-16.59667	0.10	0.13	0.15	14.9	0.64	180
2005 VO5	2025-07-01T06:07:59Z	271.57322	-16.60161	0.07	0.11	0.11	15.5	0.23	180
2005 VO5	2025-06-25T04:14:10Z	271.95870	-7.69919	0.30	0.20	0.32	16.4	0.23	180
2005 VO5	2025-06-25T04:17:23Z	271.95853	-7.70116	0.30	0.20	0.32	16.7	0.20	180
2005 VO5	2025-06-25T04:31:31Z	271.95718	-7.71038	0.24	0.13	0.23	16.5	0.14	180
2005 VO5	2025-06-25T04:45:40Z	271.95583	-7.71943	0.23	0.14	0.21	16.8	0.10	180
2005 VO5	2025-06-25	271.95558	-7.72157	0.21	0.12	0.20	16.5	0.32	180

	T04:48:51Z								
2008 DG5	2025-06-02T02:23:14Z	212.97915	+13.61102	0.36	0.24	0.44	13.4	0.01	200
2008 DG5	2025-06-02T02:29:21Z	212.97545	+13.63879	0.23	0.21	0.31	13.4	0.03	200
2008 DG5	2025-06-02T02:41:54Z	212.96786	+13.69580	0.16	0.29	0.33	13.4	0.02	200
2008 DG5	2025-06-02T02:54:26Z	212.96012	+13.75280	0.15	0.33	0.36	13.4	0.01	200
2008 DG5	2025-06-02T03:01:08Z	212.95603	+13.78318	0.12	0.25	0.27	13.4	0.01	200
2008 DG5	2025-06-03T02:54:14Z	212.51325	+20.73165	0.28	0.29	0.40	13.6	0.01	40
2008 DG5	2025-06-03T02:55:56Z	212.51208	+20.74039	0.24	0.26	0.36	13.6	0.01	40
2008 DG5	2025-06-03T02:57:18Z	212.51115	+20.74736	0.25	0.25	0.35	13.5	0.01	40
2008 DG5	2025-06-03T02:58:44Z	212.51014	+20.75472	0.25	0.26	0.36	13.5	0.01	40
2008 DG5	2025-06-03T03:00:16Z	212.50906	+20.76256	0.28	0.35	0.45	13.6	0.03	40
2025 FU5	2025-06-02T05:53:50Z	267.85701	-22.21471	0.26	0.33	0.35	15.7	1.01	280
2025 FU5	2025-06-02T06:03:27Z	267.89310	-22.21751	0.35	0.30	0.29	16.5	0.15	280
2025 FU5	2025-06-02T06:19:45Z	267.95431	-22.22091	0.35	0.29	0.39	16.0	0.42	280
2025 FU5	2025-06-02T06:36:22Z	268.01661	-22.22481	0.19	0.18	0.23	16.1	0.60	280
2025 FU5	2025-06-02T06:46:33Z	268.05476	-22.22716	0.69	0.73	0.33	17.0	0.92	280
2025 FU5	2025-06-03T06:18:44Z	273.38440	-22.45329	0.33	0.31	0.21	16.1	0.38	91
2025 FU5	2025-06-03T06:22:15Z	273.39599	-22.45384	0.42	0.41	0.20	16.4	0.34	91
2025 FU5	2025-06-03T06:25:57Z	273.40852	-22.45425	0.17	0.17	0.10	16.0	0.32	91
2025 FU5	2025-06-03T06:29:27Z	273.42016	-22.45459	0.23	0.22	0.10	16.3	0.37	84
2025 FU5	2025-06-03T06:32:38Z	273.43079	-22.45488	0.38	0.37	0.12	16.6	0.34	84

Table 1. The report sent to the MPC, containing nine different targets. Adapted from ADES format. Not all observations have photometric data.

During this period, ≈35 different targets were observed to varying degrees of success. Some observations were unusable due to observing conditions, while others had exposure times that either didn't capture the target or resulted in a streak instead of a point. As more exposures were taken, these variables were better refined and saw less uncertainty. By early July, there were enough reliable observations to report to the MPC. The new report had no track uncertainties above 0.5 arcseconds, well within the 1.5 arcsecond limit. Photometric measurements appeared more inaccurate, with magnitude uncertainties going as high as magnitudes of 1.66 with 1994 LX. The lowest magnitude uncertainty, however, was a magnitude of 0.01 with 2008 DG5, suggesting a wide range of variability. Larger uncertainties may be due to observing conditions on the given night the exposures were taken; however, astrometric measurements are not as impacted by unfavorable conditions. Observations were collected as dim as magnitudes of 18.8 with a magnitude uncertainty of 0.7 for 2003 MH4, meaning the dimmest observation visible in each individual exposure had a magnitude of at least 18.1 with 180 second exposure stacks. Given the improvements provided to SNR by synthetic tracking, dimmer targets are likely possible. Upon review, the MPC found the observations to be within acceptable margins of error, and the Hampden-Sydney Observatory was assigned the observatory code W40.

Conclusion

The Hampden-Sydney Observatory proved capable of observing targets with magnitudes up to 18, showing promising ability with faint targets. The observatory's filter wheel now has an open filter, which could potentially allow for more light than the

SLOAN/SDSS r’ filter. This change could allow for the observation of dimmer targets than those already observed. With the Hampden-Sydney Observatory successfully being issued an observatory code, future reports are now capable of being submitted directly to the MPC. Obtaining the designation as a permanent observing site allows for fuller utilization of the NEOfixer API, which requires an observatory code for queries. With working practices established, further work could be done to create an automation pipeline capable of identifying targets and submitting observations to Skynet. Some parts of this pipeline are already completed, such as working Python and Bash scripts capable of listing potential targets. An exposure time calculator could also be developed and added to existing scripts. Overall, the work done so far has mapped the capabilities of the Hampden-Sydney Observatory and provided a foundation for future expansion of its utilization.

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