8th IAA Planetary Defense Conference – PDC 2023
3-7 April 2023, Vienna, Austria

IAA-PDC-23-0X-XX

Near Earth Objects in the recent Isolated Tracklet File

Robert Weryk(1), **Peter Vereš**(2), **and Richard Wainscoat**(3)
(1)*Physics and Astronomy, The University of Western Ontario*
1151 Richmond Street, London ON N6A 3K7, Canada
(2)*Minor Planet Center, Harvard-Smithsonian Center for Astrophysics*
60 Garden Street, Cambridge MA 02138, USA
(3)*Institute for Astronomy, University of Hawaii*
2680 Woodlawn Drive, Honolulu HI 96822, USA

Keywords: *NEOs, discovery, linking, tracklets, survey*

Introduction and Importance—

Numerous observational surveys are tasked with finding new Near Earth Objects (NEOs). Candidate detections are formed into "tracklets" and ranked based on a "digest" score, a quantitative estimate of how interesting an object is, and this score must be >65 to be considered for posting on the NEO Confirmation Page[1] (NEOCP) at the Minor Planet Center (MPC). Objects on the NEOCP which do not receive sufficient follow-up, or those that do not score high enough to post and can not be linked to an already known object, are relegated to the Isolated Tracklet File (ITF), a rich repository of orphan astrometry. As of March 2023, the ITF contains 3.1 million unique object names, mostly from the Pan-STARRS and Catalina Sky Surveys. We summarise those observatories/surveys having the largest tracklet counts in Table 1.

Table 1: Top ITF tracklet counts per observatory location code. The total count is 3.1 million, and those sites not listed each have less than 26000 tracklets in the ITF.

Tracklets	Code	Observatory / Location
1 271 900	F51	Pan-STARRS 1, Haleakala
540 916	G96	Mt. Lemmon Survey
351 164	F52	Pan-STARRS 2, Haleakala
350 650	W84	Cerro Tololo-DECam
125 596	691	Steward Observatory, KP-SW
59 414	703	Catalina Sky Survey
50 316	V00	Kitt Peak-Bok
36 574	695	Kitt Peak
36 027	807	Cerro Tololo, La Serena
34 828	644	Palomar Mountain/NEAT

Linking ITF tracklets allows for those objects to be identified/attributed in future data, and to be processed automatically without review, but even now with 1.27 million total known objects, linking what remains in the ITF is still challenging. While some objects eventually reach higher score and can post to the NEOCP after being observed by a survey telescope, linking them sooner allows valuable follow-up effort to be better spent elsewhere, but also allows for early targeted follow-up for objects of interest. Other objects which never exceed the minimum 65 score requirement, might not otherwise be designated.

Here we present a summary of our automated tool that links recent astrometry on a daily basis, and submits these linkages to the MPC's id-pipeline[2] which handles their attribution and designation automatically for non-NEOs. We have previously reported on our efforts[3] to develop this automated pipeline, and our current version mostly fulfills our linking requirements.

Method—

Our daily search begins shortly after the Daily Orbit Update (DOU) is issued by the MPC. The ITF data is retrieved, and the motion of each tracklet is fit and stored in an SQL database, indexed by epoch. The search method then runs in two steps, the first on those tracklets having their digest score 10+ and the second on score 0-9, each running with a similar strategy:

1. We consider all tracklet pairs having similar position angle that are within a small time window, fit a preliminary orbit.
2. If no residual trends are present, we propagate the orbit backwards in time, generate an ephemeris, and test tracklets having parallel motion within a certain distance by refitting the orbit. If the orbit fits well and passes some sanity/residual checks, then the tracklet is accepted, and the search continues for the remaining data in the ITF.
3. The final list of linkages are sorted, and single tracklet oppositions are pruned if necessary. We require 5+ tracklets to eliminate false-linkages, and those linkages not previously reported are submitted to the MPC via the id-pipeline.

[1] https://minorplanetcenter.net/iau/NEO/toconfirm_tabular.html
[2] https://minorplanetcenter.net/mpcops/submissions/identifications/

Our processing is split into two components to allow for lower latency reporting of objects which may be eligible for posting to the NEOCP if their score were to increase in the near future, and to allow for arc extensions of main belt asteroids which reduces the amount of data that must be reviewed in the future. The lowest scoring objects usually have slower motion and thus, the search for them can be tuned differently.

Potential NEO linkages only require 3+ tracklets, and are emailed to us for extra verification, and to allow a search for additional precovery data via image archives.

We also separately process the mid-month astrometry updates from the MPC, and search this dataset to find identifications and ITF tracklets for recent designations. Statistics from this mid-month search are beyond the scope of the current work.

Results—

Table 2 lists the linkage count submitted by us to the id-pipeline for the past eight months. There have been fewer linkages in recent months because Pan-STARRS has not been observing as often due to poor weather, but our method works on all available tracklets whether they were also observed by Pan-STARRS or not.

In terms of NEOs, we previously linked tracklets of (99942) Apophis during its Planetary Defense flyby campaign[4], when the community “pretended” that it was a new discovery. We have also found 58 previously unknown NEOs, including those from when our tool was in early development. The orbits of our “discovered” NEOs are illustrated in Figure 1, with their perihelia and absolute magnitudes shown in Figure 2. The majority are AMORs, which are Earth approaching but do not cross the Earth’s orbit, and therefore currently pose no hazard. The average size is ~300 metres.

Notable objects linked include 2019 GO$_{146}$, a 1.4 km NEO, and 2021 AF$_{8}$, a PHA. The search criteria have recently been tuned so that objects such as 2023 DZ2 would not be missed.

Table 2: Submitted linkages for the past eight months, for all orbital classes.

Year	Month	Submitted Linkages
2022	July	369
2022	August	1313
2022	September	2160
2022	October	2525
2022	November	1584
2022	December	721
2023	January	381
2023	February	143

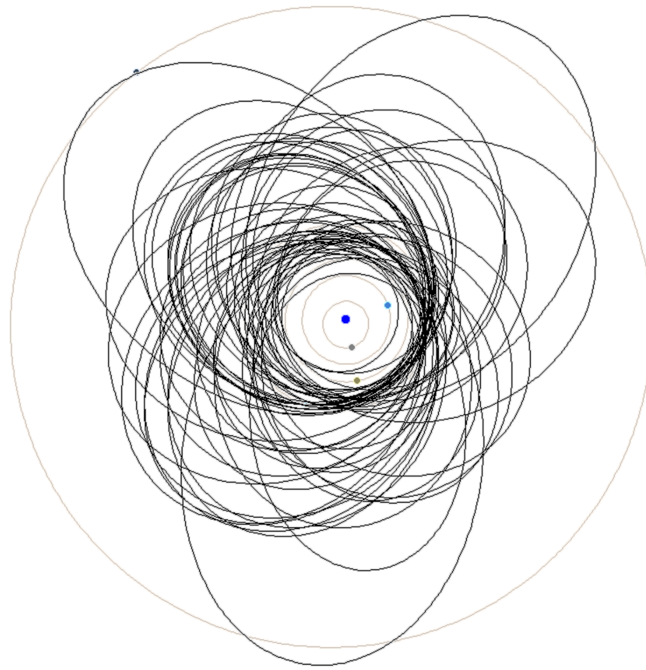

Figure 1: Near Earth Objects (NEO) found through our linking method on the Isolated Tracklet File (ITF).

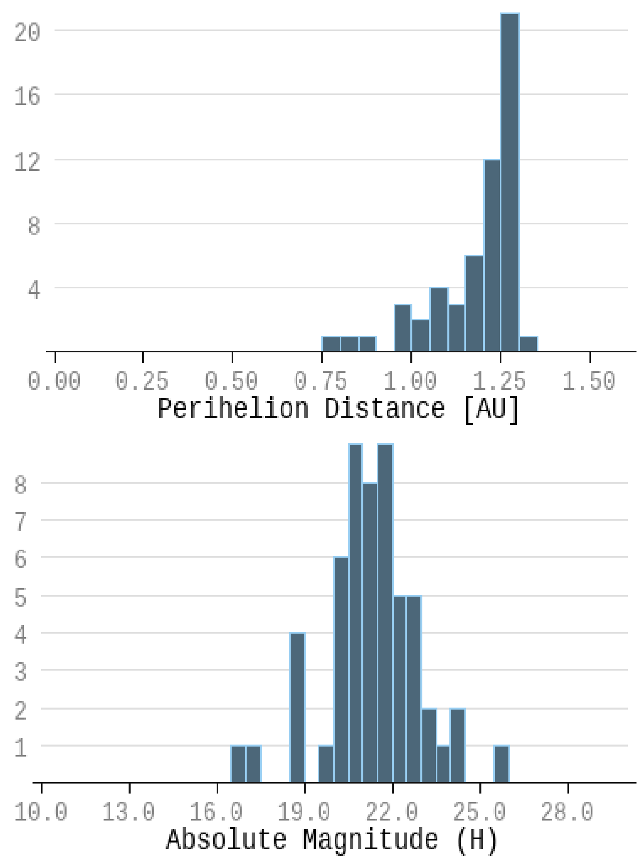

Figure 2: Distribution in perihelion distance and absolute magnitude for 55 of our linked Near Earth Objects.

Discussion—

An important question to ask for any linking algorithm is which types of orbits is our search sensitive to? We have begun some initial work to answer this question, by simulating random trajectories which arrive within ten lunar distances of the Earth. We picked random arrival directions and speeds, but required the Keplerian orbital elements to match[5] an existing designation from the catalogue of known NEOs to D' < 0.1. The ensures our simulated population is consistent with reality. We then generated synthetic astrometry, computed digest scores, and checked for any objects which would not have posted to the NEOCP. We did not find any potential "stealth" asteroids, which is probably not surprising given the q distribution in Figure 2, but there are a large number of cases where objects would first be visible at score <= 65.

A related question to ask is how many NEOs linked from the ITF might have been found anyway if they later reached higher score? Since weather and technical constraints may prevent survey telescopes from continuous operation, there is no way to be sure they would be found. Finding them early also helps to reduce future follow-up resources that could be better spent elsewhere. We thus think our linking tool provides a needed service.

Future Work—

We intend to continue searching the backlog of ITF data for additional NEOs, although as indicated by Figure 2, many of these are not expected to be near the Earth.

One limitation of our search method is that it requires 3+ tracklets for NEOs. However, there may be cases where NEOs are present in the ITF as only a single tracklet or pair of tracklets. Objects close to the Earth may "curve" sufficiently (in that their motion deviates from a great circle trajectory) and we intend to further explore this to identify low scoring tracklets likely near the Earth, which will allow for immediately follow-up. For more information, see the PDC 2023 talk "Updated Digest2 - the NEO classification code" by Veres et al.

References—

[3] Weryk, Wainscoat, Veres. PDC.2021, virtual.
[4] Reddy et al., 2022, PSJ, 3, 123.
[5] Drummond, 1981, Icarus, 3, 545-553.