

Detecting near-Earth objects using real-time synthetic tracking surveys

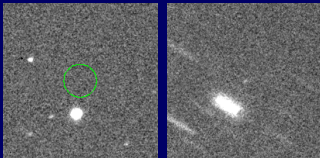
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Synthetic Tracking



- ▶ Synthetic Tracking: improve SNR by stacking across all possible motion vectors
- ▶ Trades off smaller telescopes for longer integration times and computational power
- ▶ Now possible thanks to "accelerator" hardware (GPUs)

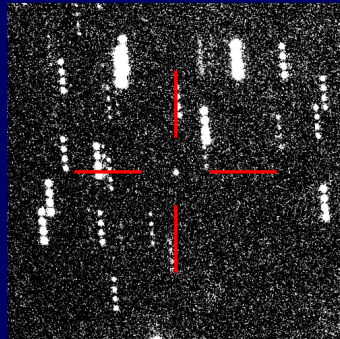


Figure: **2023 DZ2**, 27th of February 2023.
Detection as reported by STU, with reporting stage re-ran for press release, using a mean of 4 input images.

Who we are?

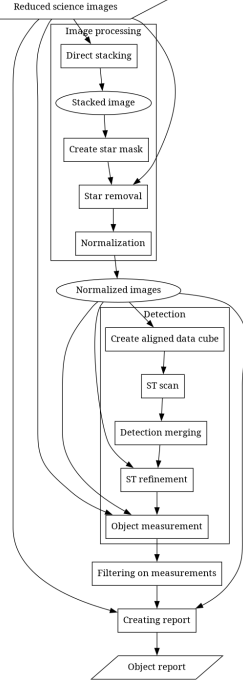
Former ParaSOL project (UEFISCDI funding) under EURONEAR



- ▶ Research network in NEA discovery
- ▶ Umbrella, a EURONEAR MOPS
 - Collaboration between professional and amateur astronomers
 - First version 10 years ago!
 - Stănescu and Văduvescu 2021
- ▶ ParaSOL: UEFISCDI-funded project to complete the suite
- ▶ **STU** (Synthetic Tracking on Umbrella), **IPP** (Image Pre-processing Pipeline), **Webrella**
- ▶ ParaSOL ended 2024
- ▶ Umbrella still continues

Synthetic Tracking with STU

- ▶ Hypothesis rejection design (very cheap initial scan, increasingly powerful filters following)
 - Level inputs & remove fixed sources
 - Fast shift-and-(add & median)
 - Combine & refine motion vectors
 - Measure detections
- ▶ Efficient GPU implementations
- ▶ Portable: .NET Framework (Linux, Windows and other OSes) + OpenCL – supported by many platforms



Runtime in practice

- ▶ **Real-time** synthetic tracking: faster than data acquisition even on large cameras and modest PCs
- ▶ Up to 2.8 Tpx s^{-1} co-addition rate on an AMD Radeon RX 6800 XT:
 - KASI: $4 \times 85 \text{ Mpx}$, $0.4'' \text{ px}^{-1}$, $12 \times \sim 2 \text{ min}$ cadence
 - **Acquisition time**: 21 min
 - Search cone: $10'' \text{ min}^{-1}$, total trajectories: 3×10^{13}
 - **Runtime** at full granularity: 8 min per CCD, with 2 min for actual ST scan
 - WFC on INT: $4 \times 9 \text{ Mpx}$, $0.33'' \text{ px}^{-1}$, $12 \times 6 \text{ min}$ cadence
 - **Acquisition time**: **4 fields** in 70 min
 - Search cone: $10'' \text{ min}^{-1}$, total 1.4×10^{13} trajectories.
 - **Runtime** at full granularity: 2 min per CCD, with 1.8 min for actual ST scan

Going even faster

- ▶ We define granularity in pixels – how many we skip on the farthest image
- ▶ KASI Near Earth Objects scan:
 $10'' \text{ min}^{-1}$ search cone, 2 px
granularity: 30 s scan
- ▶ INT Main Belt Asteroids & slow
NEOs: $2'' \text{ min}^{-1}$ search cone, 2 px
granularity: 1.6 s scan, 10 s full STU
- ▶ Practically instant for slow objects

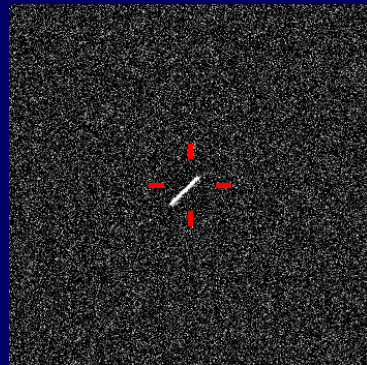


Figure: **Satellite trail** at $2000 \text{ arcseconds per minute}$ with a trail of 35 pixels.

Modern validation methods

Image size: 200px ▶ Parameters shown ▶ Sort by

Object n8a50019

Parameters

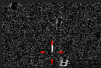
☐ Tracklet id 19

Velocity 1.221

Position angle 248.9

▼ MPC report line:

Ma51009	KC2024	02	11.10260	05	57	20.14	-08	57	15.8	19.7	R	W93
Ma51009	KC2024	02	11.10681	05	57	19.97	-08	57	22.8	19.5	R	W93



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Object n8a50020

Parameters

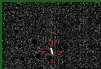
☒ Tracklet id 20

Velocity 9.548

Position angle 103.7

▼ MPC report line:

Ma52000	KC2024	02	11.10260	05	57	18.18	-09	28	27.9	19.6	R	W93
Ma52000	KC2024	02	11.10681	05	57	17.29	-09	27	31.8	19.9	R	W93
Ma52000	KC2024	02	11.11102	05	57	16.38	-09	26	35.3	20.1	R	W93



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Object n8a50021

Parameters

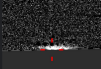
☐ Tracklet id 21

Velocity 4.58

Position angle 174.4

▼ MPC report line:

Ma52001	KC2024	02	11.10260	05	56	05.29	-08	57	18.4	18.6	R	W93
Ma52001	KC2024	02	11.10681	05	56	03.42	-08	57	15.6	21.0	R	W93



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Webrella interface with 2024 CW2 highlighted.

Output quality

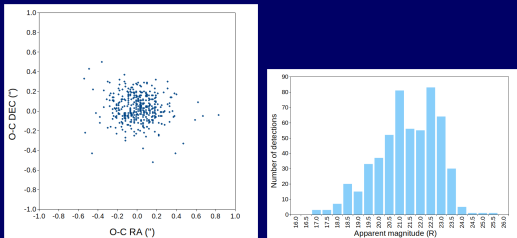


Figure: Position accuracy and magnitudes, EURONEAR 2.5m **INT** synthetic tracking archive. 142 objects detected out of 169.

► Stanescu et al 2025, A&A accepted

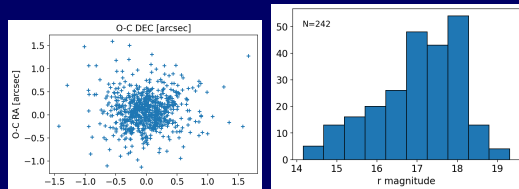


Figure: Position accuracy and magnitudes, 1.5m **TCS MuSCAT** *dichroic r-filter* dataset. All 242 objects detected.

► Vaduvescu et al 2025, New Astronomy

Results and conclusions

- ▶ O-C ~ 0.5 px (no subpixel models)
- ▶ Telescopes tested: TCS, INT, T025, SARA, KASI, T80S; $> 10^5$ images in total
- ▶ Operates successfully on datasets with uneven cadences
- ▶ Tested in survey conditions, primarily on INT and KASI
- ▶ Real-time synthetic tracking for the masses (cheap and fast)
- ▶ Proven survey capability for NEA detection
- ▶ Flexible to different survey regimes (space debris)
- ▶ False positives from image defects
- ▶ Low-SNR objects prone to noise hijacking

Next steps

Current activities

- ▶ Large refactor of the core umbrella library
- ▶ Further IPP development for very low-latency operation
- ▶ Improved usability: python bindings, local GUI interfaces
- ▶ Integrating 3rd-party tools
- ▶ Avoid detection hijacking

Planned activities

- ▶ Improved astrometric and photometric accuracy
- ▶ Characterizing the performance of newer STU versions
- ▶ General availability
- ▶ Improving job scheduling in Webrella
- ▶ Improving inter-pipeline communication