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

Mălin Stănescu [1], Marcel M. Popescu[2,1], Ovidiu Văduvescu[2], Lucian Curelaru, Daniel Nicolae Bertești eanu[1], Marian Predatu[2]

[1]Astroclubul București, 21 Lascăr Catargiu, Bucharest, Romania

[2]University of Craiova, Craiova, Str. A. I. Cuza nr. 13, 200585 Romania

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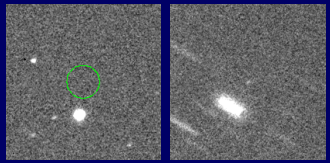
Synthetic Tracking



- 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)

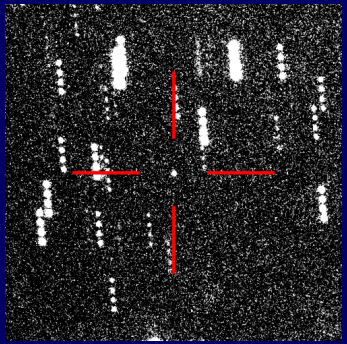


Figure: **2023 DZ2**, 27th of February 2023. Detection as reported by STU, with reporting stage re-ran for press release, using a mean of 4 input images.

Who we are?

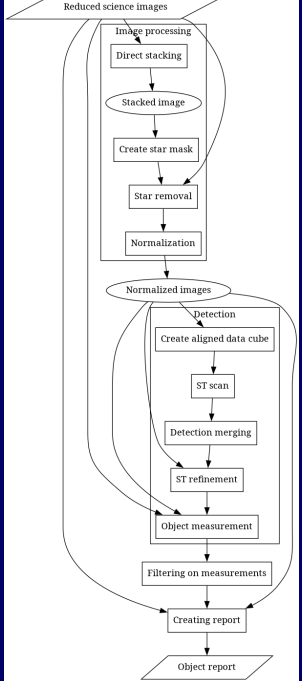
Former ParaSOL project (UEFISCDI funding) under EURONEAR

- 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 $2.8\,\mathrm{Tpx\,s^{-1}}$ co-addition rate on an AMD Radeon RX 6800 XT:
  - KASI: $4 \times 85\,\mathrm{Mpx}$, $0.4''\,\mathrm{px^{-1}}$, $12\times \sim 2\,\mathrm{min}$ cadence
  - **Acquisition time**: 21 min
  - Search cone: $10''\,\mathrm{min^{-1}}$, total trajectories: 3×10^{13}
  - **Runtime** at full granularity: 8 min per CCD, with 2 min for actual ST scan
  - WFC on INT: $4 \times 9\,\mathrm{Mpx}$, $0.33''\,\mathrm{px^{-1}}$, $12 \times 6\,\mathrm{min}$ cadence
  - **Acquisition time**: **4 fields** in 70 min
  - Search cone: $10''\,\mathrm{min^{-1}}$, 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: $10''\,\mathrm{min}^{-1}$ search cone, 2 px granularity: 30 s scan
- INT Main Belt Asteroids & slow NEOs: $2''\,\mathrm{min}^{-1}$ search cone, 2 px granularity: 1.6 s scan, 10 s full STU
- Practically instant for slow objects

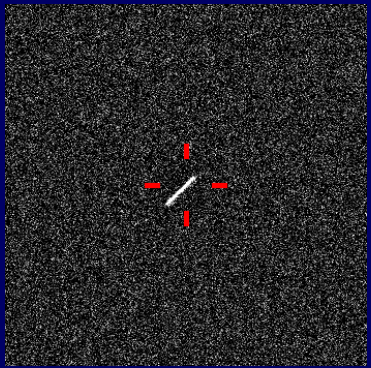
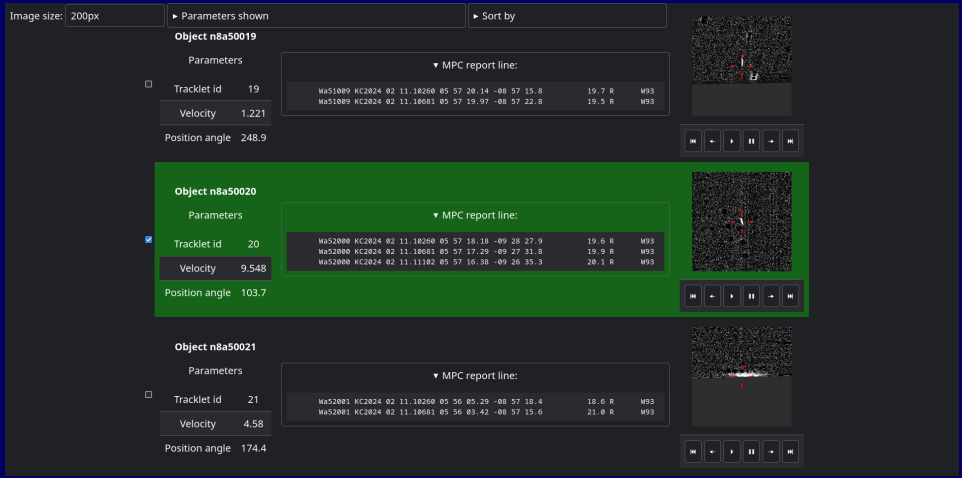


Figure: **Satellite trail** at 2000 arcseconds per minute with a trail of 35 pixels.

Modern validation methods



Webrella interface with 2024 CW2 highlighted.

Output quality

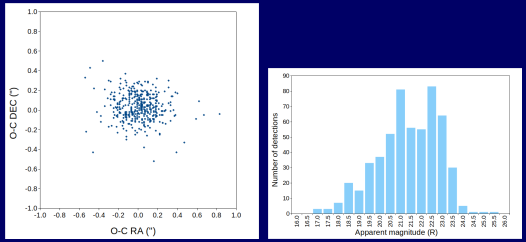


Figure: Position accuracy and magnitudes, EURONEAR 2.5m **INT** synthetic tracking archive. 142 objects detected out of 169.

- Stanescu et al 2025, A&A accepted

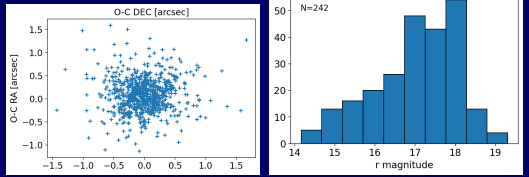


Figure: Position accuracy and magnitudes, 1.5m **TCS MuSCAT** *dichroic r-filter* dataset. All 242 objects detected.

- 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