**PDC 2025**
**Stellenbosch, Cape Town, South Africa**

*Please submit your abstract at* `https://iaaspace.org/pdc.`

*(please select the topic that best fits your abstract from the list below)*
*(you may also add a general comment - see end of this document)*

☒ **Near-Earth Object (NEO) Discovery**

# Modern computational techniques for improving moving object detection pipelines with the Catalina Sky Survey

Carson Fuls[a], David Rankin[a], Alex Gibbs[a], Frank Shelly[a], Robert Seaman[a], Tracie Beuden[a], Vivian Carvajal[a], Don Fay[a], Jacqueline Fazekas[a], Al Grauer[a], Hannes Gröller[a], Joshua Hogan[a], Richard Kowalski[a], Steve Larson[a], Greg Leonard[a], Kacper Wierzchos[a]

[a] *University of Arizona Lunar and Planetary Laboratory, 1629 E. University Blvd., Tucson, AZ, 85721-0092, USA, 1-520-621-6963*

---

*Keywords:* Survey, Follow-Up, Algorithms

---

The Catalina Sky Survey is a world leader in the discovery and astrometric follow-up of near-Earth objects (NEOs) As such, we continuously update and refine our algorithms to improve our operations. Here, we present three recent enhancements to the Catalina Sky Survey operations model in both discovery survey and targeted follow-up.

First, we have recently, in collaboration with the ATLAS group [1], developed a machine learning routine that classifies transient detections. Currently, three classes have been developed: stellar, streak, and diffraction spike. We have trained a convolutional neural network using data sets containing thousands of examples of each class from our 703 Schmidt survey telescope. Examples from the training sets are shown in Figure 1. Transient sources are classified using the 30x30 matrix of pixels surrounding them. These classifications are then used to weigh potential discovery tracklets made up of four transients. Tracklets consisting of probable diffraction spikes are demoted while those consisting of probable streaks or stellar objects are promoted. Preliminary results show a 5% increase in known NEO tracklets scoring above our review threshold. We plan on expanding this functionality to our G96 survey telescope once our training data set for it is complete.

Second, we have developed a “second chance” reprocessing routine for failed follow-up attempts. Working with the developer of Tycho Tracker synthetic tracking software, we have incorporated their software into our normal operations. When a follow-up target is not found by our normal moving object detection pipeline, we can now re-stack the images using a range of motion vectors. This technique can recover objects that had significant star interference or were tracked at different rates than the true sky motion of the target. An example of the routine’s effectiveness can be seen in Figure 2, where our normal stacking on the object’s rate of motion is seen in Figure 2a, and the power of synthetic tracking to reduce the interference from background stars is seen in Figure 2b. It can be triggered as soon as a follow-up attempt has been found unsuccessful and completed within minutes. This has directly reduced the amount of telescope time used to re-observe targets and has saved over 70 follow-up targets since becoming operational in early 2024.

Finally, to probe deeper into our nightly candidate tracklets, we have developed a citizen science project on the Zooniverse platform called ”The Daily Minor Planet”. This project takes 22 additional candidate tracklets from our nightly G96 survey and presents them to volunteers for review. If a candidate

*Email addresses:* fulsdavid@arizona.edu (Carson Fuls), davidrankin@arizona.edu (David Rankin), gibbs@arizona.edu (Alex Gibbs), shellyf@arizona.edu (Frank Shelly), rseaman@arizona.edu (Robert Seaman), tbeuden@arizona.edu (Tracie Beuden), vcarvajal@arizona.edu (Vivian Carvajal), dfay@arizona.edu (Don Fay), jacqui@arizona.edu (Jacqueline Fazekas), algrauer@me.com (Al Grauer), hgr@arizona.edu (Hannes Gröller), joshuahogan@arizona.edu (Joshua Hogan), kowalski1@arizona.edu (Richard Kowalski), slarson@arizona.edu (Steve Larson), gleonard@arizona.edu (Greg Leonard), kwierzchos@arizona.edu (Kacper Wierzchos)

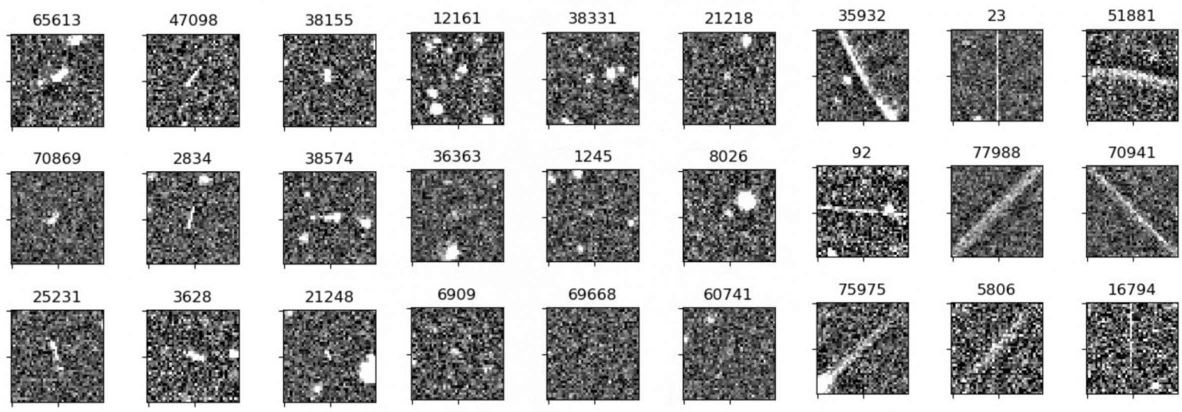
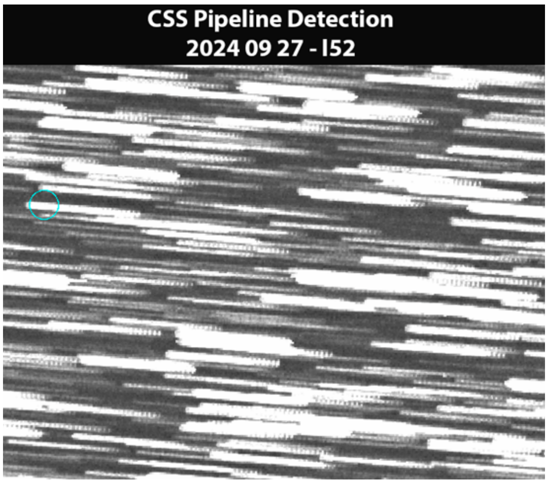
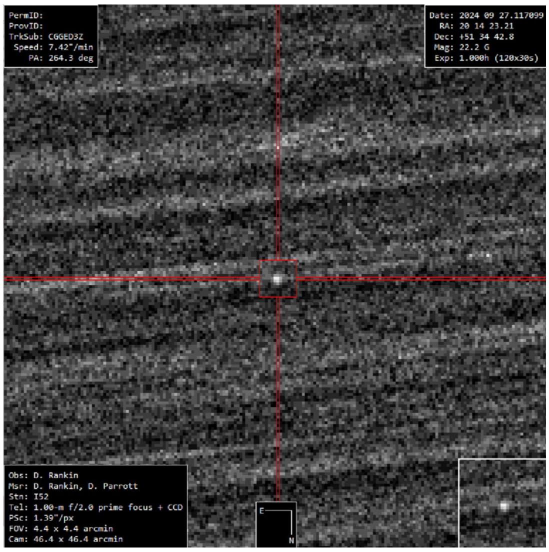



**Figure 1: Example machine learning training data from a CSS survey telescope (MPC code 703). The left three columns were manually classified as "Streak", the middle three columns as "Stellar", and the right three as "Spike". These images, and thousands more like them, were then used to train our model.**




**(a) Follow-up attempt with many stacked images in a crowded star field. The initial predicted position is indicated with the blue circle, directly over a streaked stack of background stars.**



**(b) Synthetic tracking stack of all follow-up images easily reveals the target.**

**Figure 2: Example of a NEO that was not initially detected with normal stacking that was recovered using synthetic tracking.**

receives sufficient votes by the volunteers as being real, it is reviewed by our follow-up observers and can be reported to the Minor Planet Center. This has doubled the number of candidates reviewed from our survey data, resulting in three confirmed NEO discoveries, and has enabled thousands of volunteers from around the world to participate directly in planetary defense.

**Comments:**

*(Oral presentation preferred.)*

## References

[1] A. C. Rabeendran, L. Denneau, A Two-stage Deep Learning Detection Classifier for the ATLAS Asteroid Survey, Publications of the Astronomical Society of the Pacific 133 (2021).