Z-Streak Analysis & Discovery of Near Earth Objects

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Introduction

Throughout this project, we utilized data captured through Caltech's Zwicky Transient Facility at Palomar Observatory to detect and analyze potential Near Earth Objects (NEO). Data captured in the form of "streaks" passes through multiple layers of filters to eliminate improbable candidates. This elimination process consists of machine learning and deep learning filters, finally leaving a data set of viable "streaks" for the final stage of human scanning. Through optimization of this final stage of human error detection, we were able to test the most viable candidates, leading to the discovery of a new Near Earth Object (NEO), Asteroid "2025 FD."

Background

Near Earth Objects (NEO) are comets or asteroids that come within 1.3 astronomical units (AUs) of the Sun.

NEOs can be classified into categories mainly by composition or orbit. They can be based on composition, C-type (chondrite), S-type (stony), or M-type (metallic), or orbit, the Main Asteroid Belt between Mars and Jupiter; asteroids that cross paths with Earth's orbit (Apollo, Amors, or Athens); and asteroids that orbit another body, known as Trojans.

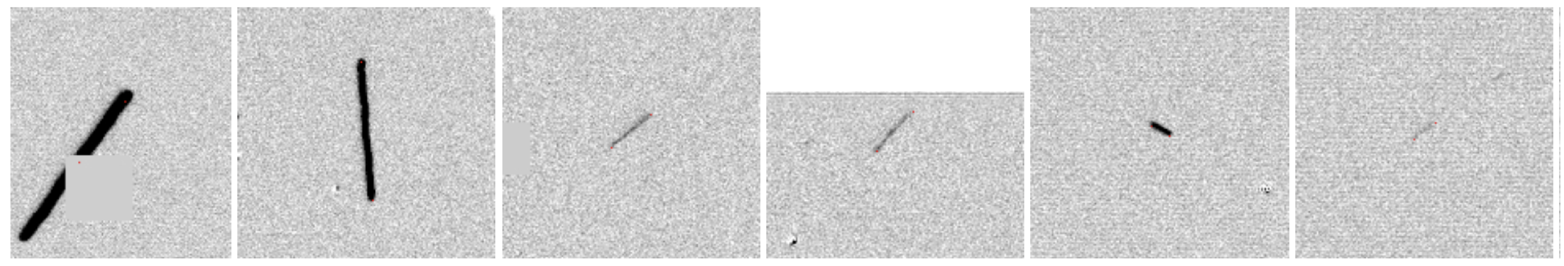


Figure 1: Submitted Scans for NEO Confirmation

Tools

To conduct our research, we used the following tools: Caltech's Palomar Observatory, Z-Streak imaging data, Project Pluto, and Find Orb.

Caltech's Palomar Observatory is located in San Diego County, California. Our project utilizes the Samuel Oschin Telescope, which operates robotically to scan large portions of the sky.

Z-Streaks are images of a fast-moving object's path across the night sky. These streaks—produced by Near Earth Objects, satellites, and space debris—vary in length, brightness, and direction depending on the object's speed, reflectivity, and trajectory.

Project Pluto and Find Orb calculate the orbit of Near Earth Objects, comets, asteroids, satellites, and space debris using observational data.

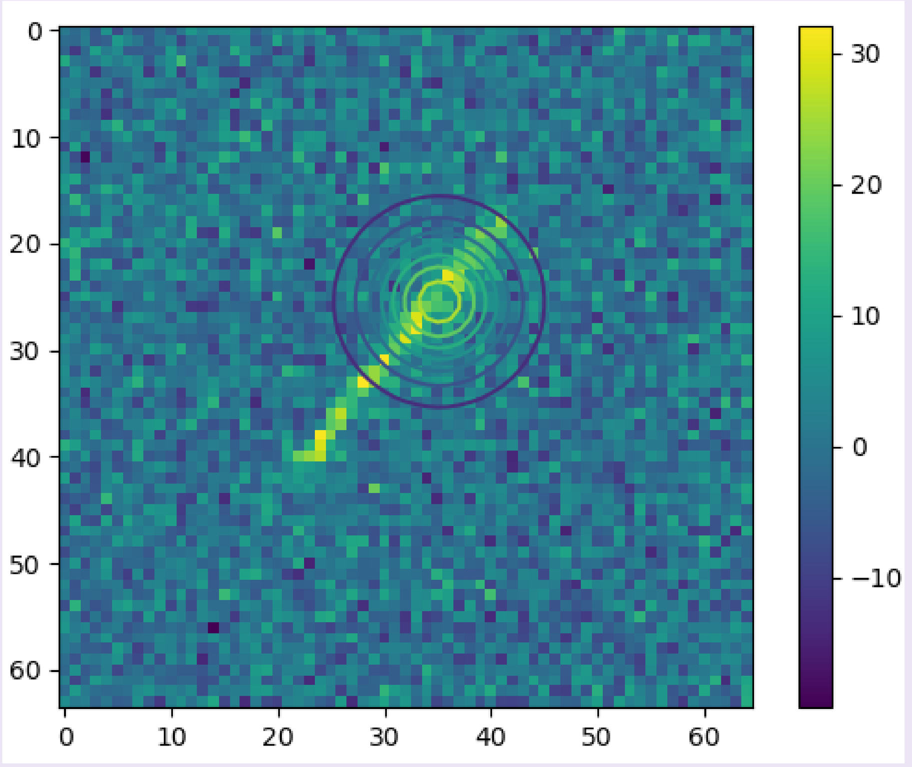
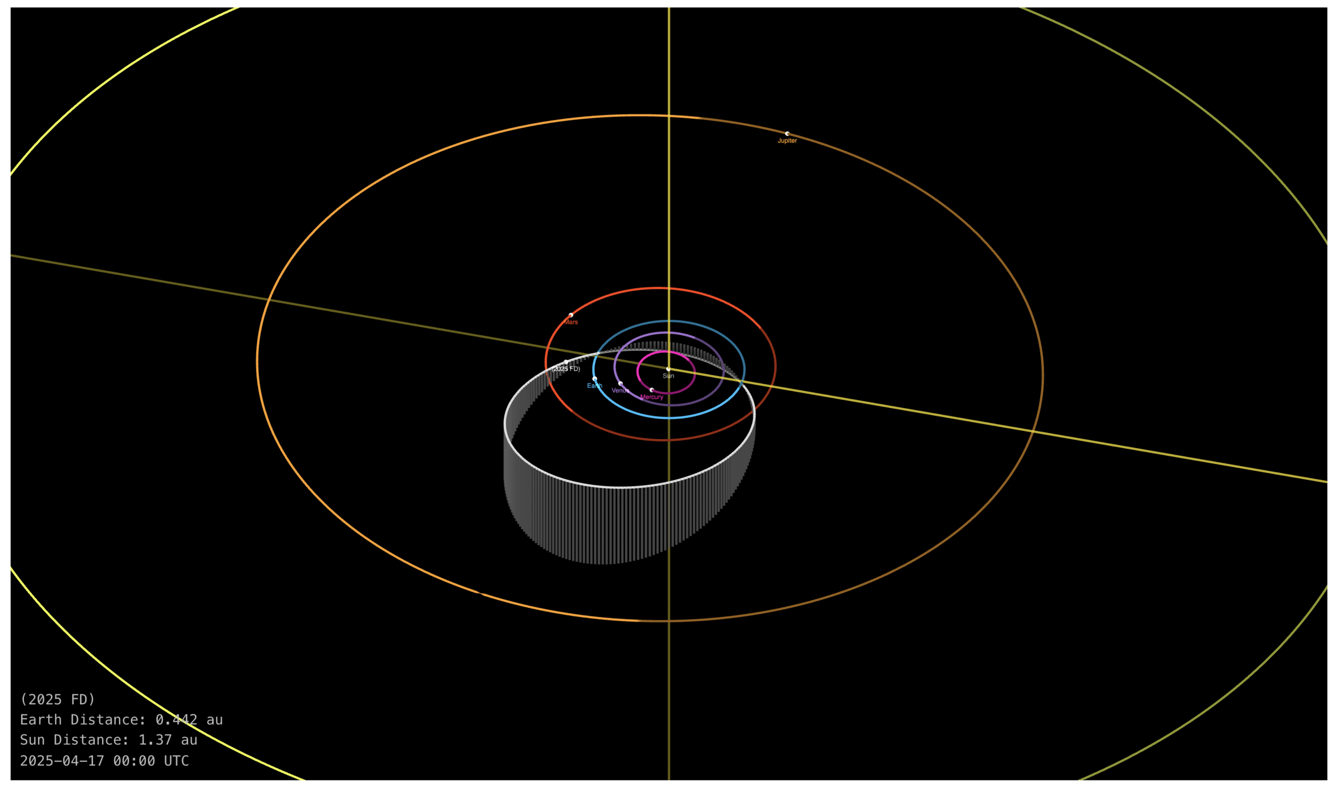


Figure 2: Images of IRSA Rendering

Methods, Analysis, and Data

We saw around 300,000 samples on any given day where scanning was possible due to proper weather conditions. On these days, we reduced our possible streaks down by a factor of 1/100 through ML/DL filtering. The program then checks if it recognizes the sat_id, otherwise, the next step is to fit the observations to possible orbits, using the find_orb function.

1. **Methods:** We processed telescope imaging data using a combination of Python scripts, AI models, and manual verification. Flagged objects were compared with known celestial bodies using ephemeris and simulation tools.
2. **Data:** We collected over numerous object detections during a single night of observation under clear skies. Each detection was time-stamped and filtered to remove noise, allowing us to isolate consistent streaks for further investigation.
3. **Scripts and Analysis:** On the backend of our Python script, we utilize a database provided by the Zwicky Transient Facility to categorize and observe fast-moving objects. This script (JS9) helps us from beginning to end, first, by employing a Least Squares Minimization to find the best length, position, width, and angle of the observed streak. The data is then converted to an ADES XML-formatted report to be submitted to the Minor Planets Center.



Simulation of Asteroid "2025 FD": semi-major axis of 2.4696761 AU, or close to 3.7 million km. It experienced its closest encounter with Earth on March 18, 2025. As of April 3, 2025, "2025 FD" is 0.228 AU from Earth and 1.193 AU from the sun. With an Earth MOID value of 0.0088 AU, "2025 FD" has little to no risk of collision with Earth.

Data and Images

We gathered a large volume of streak data from the Zwicky Transient Facility, which were filtered through machine learning models, then visually reviewed using tools like JS9 to identify clear, uninterrupted trails suitable for further analysis. This process led to the confirmation of Asteroid "2025 FD," distinguished by its consistent motion and orbital characteristics.

UT date	# of raw streaks	# ML-vetted	# DL-vetted	# scanned	# flagged	# flagged: artsat	# flagged: singleton	# flagged: submitted	# flagged: recovery	Scanner(s)	Last updated	Shepherd page
2025-03-19	130844	27083	2274	1617	32	0	0	0	0	Tanvi Batra (1617)	2025-03-19 06:55:07	link
2025-03-18	0	0	0	0	0	0	0	0	0		2025-03-18 00:00:01	link
2025-03-17	545809	85314	6516	5411	8	0	0	0	0	Samridh Tiwari (4035) Tanvi Batra (1376)	2025-03-17 19:26:07	link
2025-03-16	260063	62569	4068	3150	21	0	0	0	0	Yogesh Wagh (2073) Tanvi Batra (1077)	2025-03-16 16:52:08	link
2025-03-15	0	0	0	0	0	0	0	0	0		2025-03-15 00:00:02	link
2025-03-14	0	0	0	0	0	0	0	0	0		2025-03-14 00:00:01	link
2025-03-13	0	0	0	0	0	0	0	0	0		2025-03-13 00:00:01	link
2025-03-12	0	0	0	0	0	0	0	0	0		2025-03-12 00:00:01	link
2025-03-11	217132	3967	2180	2070	2	0	0	0	0	Samridh Tiwari (2070)	2025-03-11 08:47:40	link
2025-03-10	389577	72687	5156	4035	63	9	0	0	0	Yogesh Wagh (3805) Divya Kulkarni (230)	2025-03-10 13:42:52	link

Figure 3: Given Amounts of Streaks from March 10 - 19, 2025

Error

While ML algorithms streamlined our detection pipeline, observation capacity remained heavily constrained by external factors such as weather. In addition, labeling inconsistencies and overwriting bugs within our codebase occasionally resulted in the loss of valid detections. Manual verification was also limited by the availability of trained personnel, highlighting the need for broader international coordination and real-time validation to ensure robust candidate identification.

- **Automated Version Control for Designations** Implementing structured logging and version control for all candidate labels will prevent data overwrites and preserve detection lineage.
- **Augmented Global Collaboration Networks** Expanding observational partnerships across time zones will provide continuous coverage and faster follow-up verification for transient events.
- **Improved Training Sets for ML Models** Incorporating more diverse examples of false positives—such as satellite trails and imaging artifacts—will refine model accuracy and reduce misclassification.

Conclusion

Significance and Impact

Over the course of this project, we were able to show how important it is to track and identify Near Earth Objects, both for protecting Earth from potential impacts and for improving our understanding of the solar system. Using data from the Palomar Observatory, combined with AI ML/DL models, filters, and human scanning, we successfully narrowed down thousands of possible streaks to eventually identify Asteroid "2025 FD."

Some challenges that we faced along the way were unpredictable weather that limited observation nights, programming bugs that overwrote our findings, and human error.

Error Improvements and Future Work

While AI and ML filters helped reduce candidate streaks by a factor of 100, our detection capacity was still limited by external factors like weather, programming bugs, and human error. Labeling inconsistencies and overwriting bugs occasionally caused the loss of valid detections, while a shortage of trained personnel slowed manual verification. To address these challenges, future improvements should focus on expanding international collaboration networks, refining ML training sets with better examples of false positives, and developing scalable verification systems with confidence thresholds.

References

1. *About Irsa*, irsa.ipac.caltech.edu/about.html. Accessed 21 Apr. 2025.

2. Dunn, Tony. *GSIM* orbitsimulator.com/gravitySimulatorCloud/yr/gsim2023.html?sv%2C1%2CU-NIQTRCK%2C2460750.50%2C-148266713578.458862%2C11905290747.737581%2C1343940435.264809%2C-8015.447223%2C-26338.427329%2C-18626.202914%2C0%2C0%2C00FF00%2C90%2C65%2C%2C16000%2C0%2C12%2C1%2C0%2C25.053344%2C0.150000. Accessed 21 Apr. 2025.

3. "The International Astronomical Union Minor Planet Center." *MPEC 2025-F16 : 2025 FD*, minorplanetcenter.net/mpec/K25/K25F16.html. Accessed 21 Apr. 2025.

4. *Seeing and Weather*, sites.astro.caltech.edu/palomar/observer/seeing.html. Accessed 21 Apr. 2025.

5. "Small-Body Database Lookup." *NASA*, NASA, ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr= 2025%20FD&view=VOP. Accessed 21 Apr. 2025.

6. *The ZTF Science Data System (ZSDS) Explanatory Supplement*, irsa.ipac.caltech.edu/data/ZTF/docs/ztf_explanatory_supplement.pdf. Accessed 22 Apr. 2025.

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