Rapid Pre-Discovery of Near-Earth Objects

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BACKGROUND & MOTIVATION

The Rubin Observatory Legacy Survey of Space and Time (LSST) will provide an unprecedented number of potential Near-Earth Object (NEO) discoveries [1]. Additional follow-up observations are typically needed for confirmation and orbit refinement but may require significant time and resources [2].

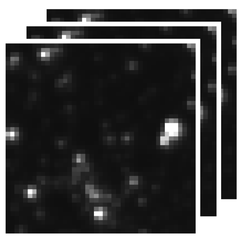
Pre-discovery offers a complementary solution to rapidly confirm new NEO objects and reduce their orbit uncertainty by searching archival image data. Several challenges with pre-discovery :

1. **Large search volume due to high initial orbit uncertainty**
2. **NEO candidates may be fainter than sensitivity limits of existing sensors**

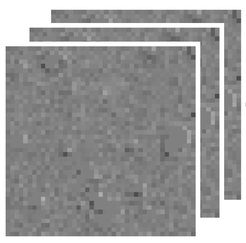
This project demonstrates a **novel pre-discovery approach** using a **synthetic tracking** technique called the **Fast X-ray Transform (FaXT)**[3]. FaXT leverages divide-and-conquer strategy and dynamic-programming techniques to efficiently compute a large number of trajectory hypotheses, enabling the **detections of very faint objects over large search volumes**. This methodology enables robust NEO pre-discovery capabilities using existing sensor data, facilitating faster confirmation and improved orbit for newly identified NEOs.

PRE-DISCOVERY PIPELINE FOR FAINT NEOS

Archival Images

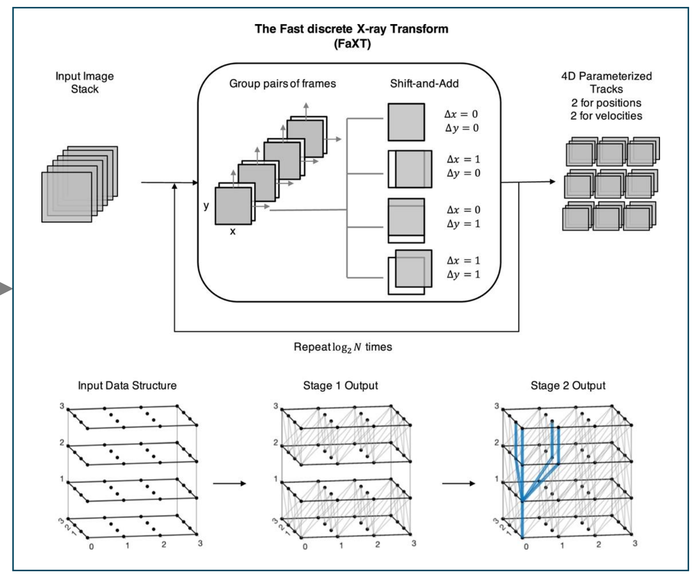


Background & Star Subtraction



- Static-source subtraction
- Spatial background subtraction
- Bright star masking

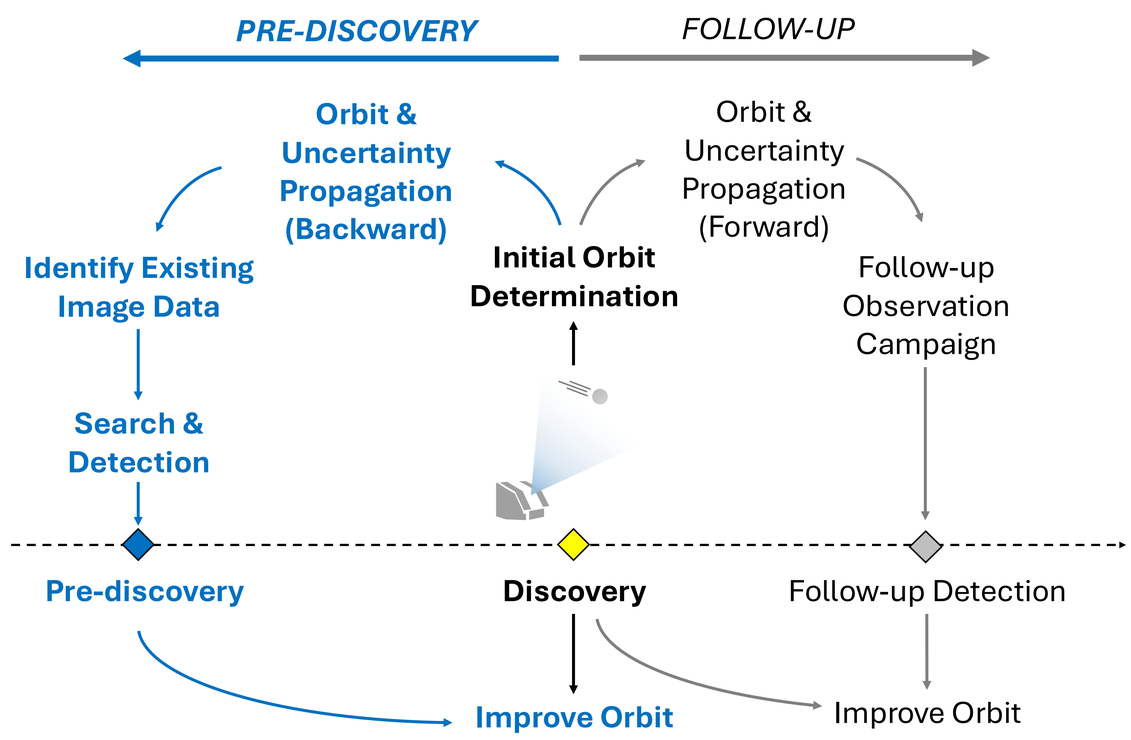
Synthetic Tracking
Fast X-ray Transform (FaXT)



- Linear track hypotheses generation through efficient combination of shorter segments
- Source detection in 4D position-velocity space

PRE-DISCOVERY

PRE-DISCOVERY OVERVIEW

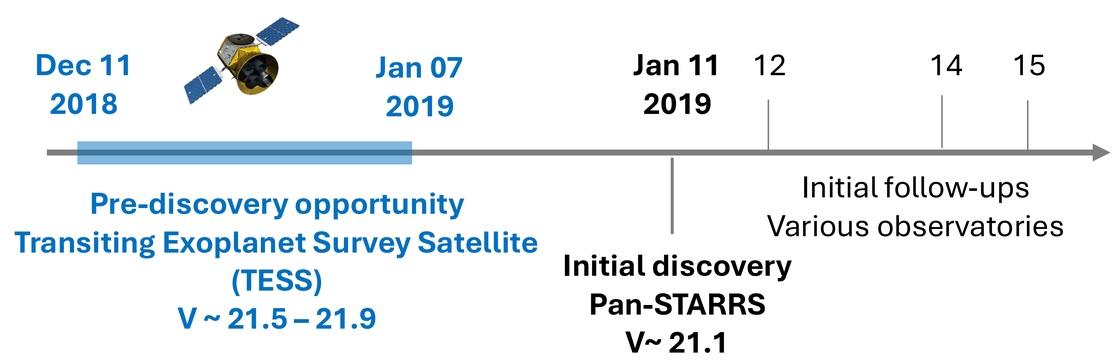


PROS
Rapid orbit improvement upon first discovery / No additional observation resources needed

CONS
Limited by sensitivity of existing image data / Potential large search space due to gap time

PROOF-OF-CONCEPT: 2019 AH11 PRE-DISCOVERY

2019 AH 11 Observation Timeline

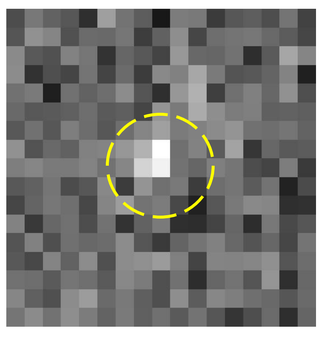


2019 AH11 was first discovered on January 2019 by Pan-STARRS. We found that this NEO was in the field-of-view of the Transiting Exoplanet Survey Satellite (TESS) instrument in the month leading up to initial discovery. The apparent visual magnitude of 2019 AH11 during this time was approximately V ~ 21.5 – 21.9, much fainter than TESS single-frame sensitivity limit at V ~ 19 [4]. **The goal of this work is to demonstrate pre-discovery of 2019 AH11 without precise orbit assumption and beyond single-frame detection limit.**

PRE-DISCOVERY RESULTS

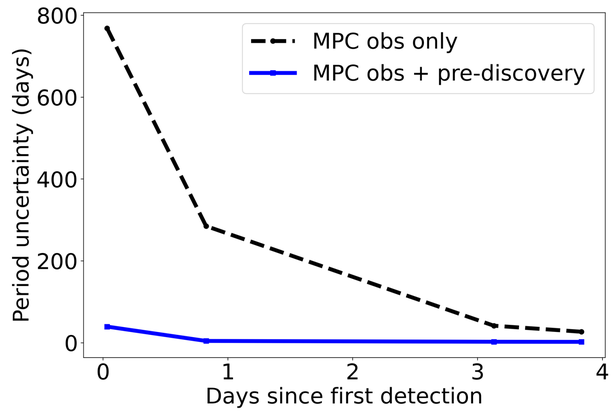
We present the **successful pre-discovery of 2019 AH11 in TESS** data through **dynamic-programming synthetic tracking**. The detection was made by searching a 512-frame stack (30-min/frame) spanning Dec 11 – 27, 2018. The search volume for this proof-of-concept is 35 arcminutes in initial position and 0.14”/min in velocity with a total of **100 million track hypotheses**. The detection was made with high-confidence, with an SNR of 14.0. It is worth noting that the astrometric precision of this detection is limited by TESS's relatively large pixels.

To assess the impact of pre-discovery on orbit determination, the *Find_Orb* software was used to compute orbit estimates and associated uncertainties based on available observational data [5]. The results indicate a **substantial reduction in orbit uncertainty**; the uncertainty in orbital period drops from nearly 800 days to 40 days after discovery and subsequently to about 2 days with early follow-up observations. Importantly, we found that the relatively low astrometric precision of the TESS detection had minimal impact on the overall orbit refinement performance.



Detection of 2019 AH11 in TESS data
Dec 11– 27, 2018
V ~ 21.8

First discovered Jan 11, 2019



Orbital period uncertainty with and without pre-discovery

KEY POINTS

- **Pre-discovery offers a rapid and resource-efficient method to improve NEO orbits following initial detections**
- **Dynamic-programming synthetic tracking can affectively address pre-discovery challenges in sensitivity and search space**
- **Successful pre-discovery of NEO 2019 AH11 was demonstrated with TESS at V ~ 21.8, showing substantial orbit improvement despite modest astrometric precision**

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References

1. Grav, Tommy, A. K. Mainzer, and Tim Spahr. "Modeling the performance of the LSST in surveying the near-Earth object population." *The Astronomical Journal* 151.6 (2016): 172.
2. Wagg, Tom, et al. "Expected Impact of Rubin Observatory LSST on NEO Follow-up." *arXiv preprint arXiv:2408.12517* (2024).
3. Nguyen, Tam, et al. "Efficient Search and Detection of Faint Moving Objects in Image Data." *The Astronomical Journal* 167.3 (2024): 113.
4. Woods, Deborah F., et al. "Asteroid Observations from the Transiting Exoplanet Survey Satellite: Detection Processing Pipeline and Results from Primary Mission Data." Publications of the Astronomical Society of the Pacific 133.1019 (2021): 014503.
5. Gray, Bill. "Find_Orb: Orbit determination from observations." Astrophysics Source Code Library (2022): ascl-2202.