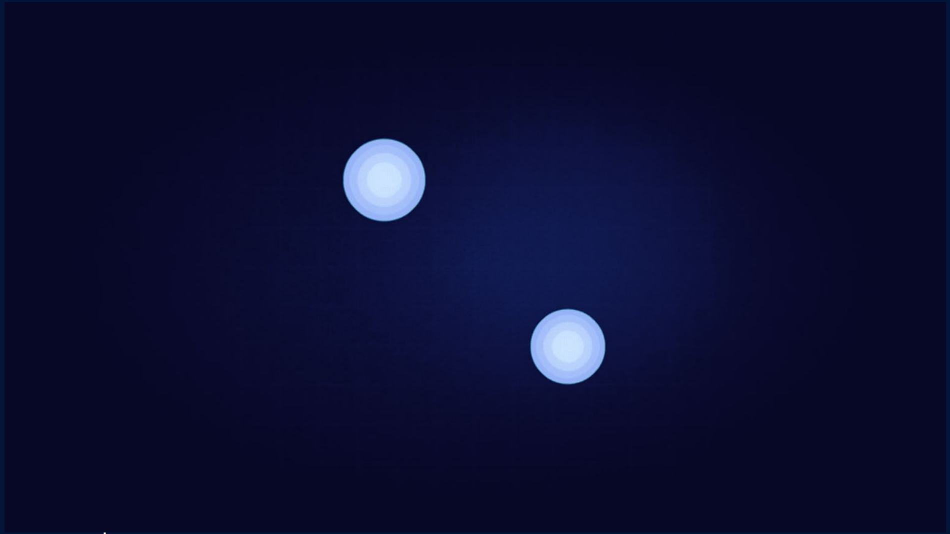
Validating the **Wayfinder System** for the InterPlanetary Network

Gamma-ray Bursts

A short, intense flash of very high -energy radiation produced during the following extreme events

Neutron Star Merger



Massive Star Core-collapse

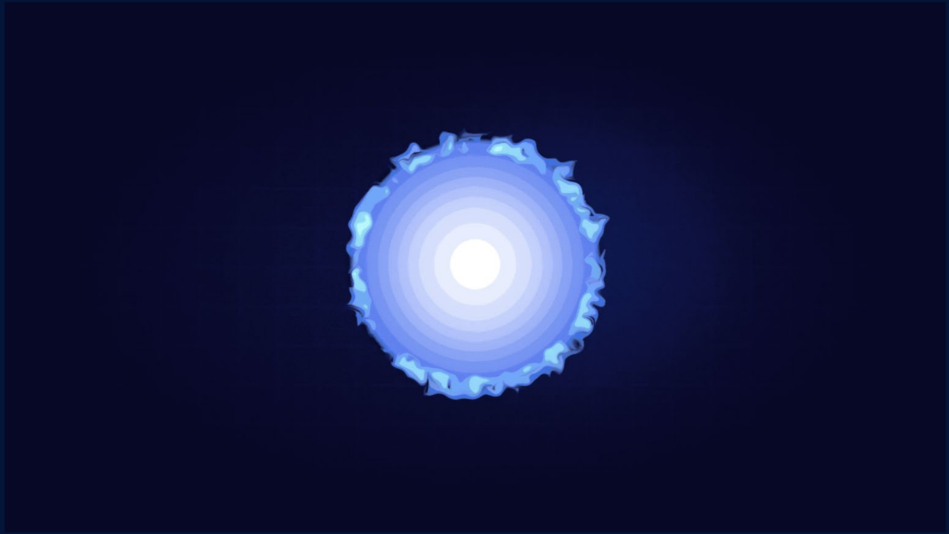


Fig. 1 and 2, Credit: NASA

Why are **GRBs** important to study?

- The most powerful explosions since the Big Bang

- Examine how matter behaves under extreme conditions not reproducible on Earth

- GRB research has contributed to groundbreaking discoveries
    - First multi-messenger astronomical event (Abbott et al., 2017)
    - Precise measurement of the speed of gravity (Abbott et al., 2017)
    - Identifying the origins of heavy elements (Patel et al., 2025)

InterPlanetary Network

- The IPN is collection of spacecraft equipped with gamma-ray burst detectors
- Together, they work to:
  - Detect bursts
  - Localize bursts
  - Alert community
- Led by Dr. Eric Burns

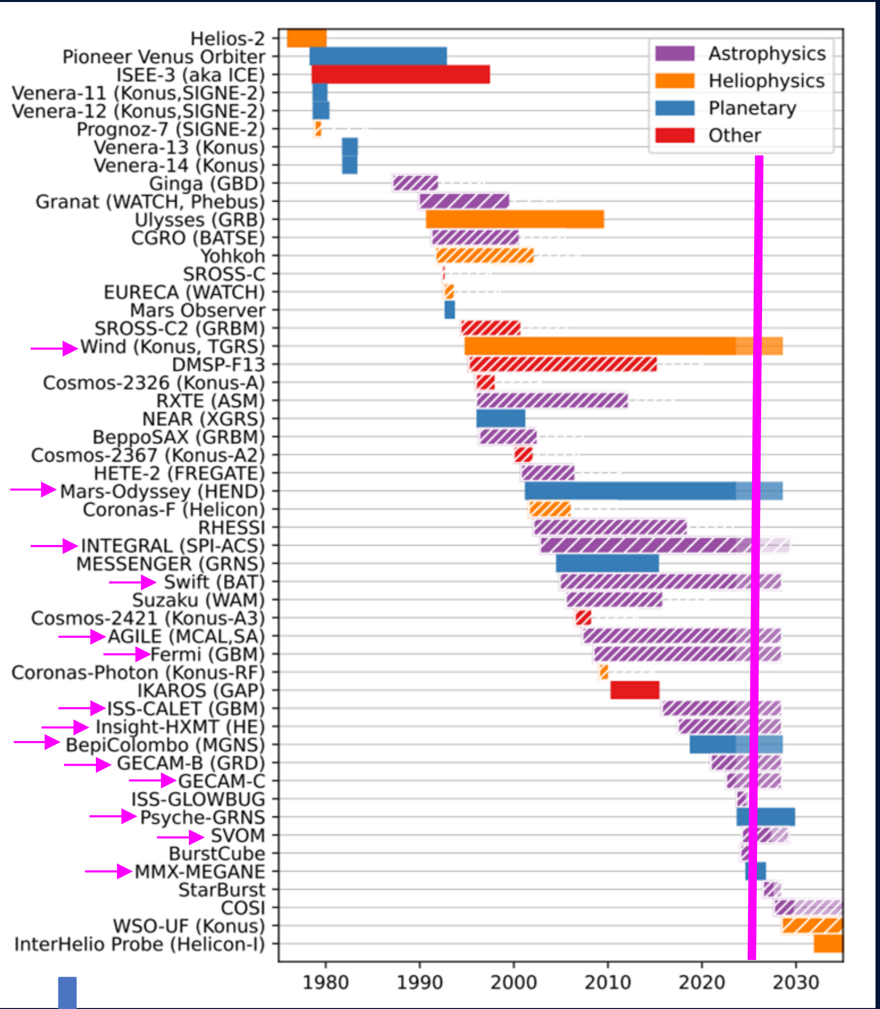


Fig. 3, Credit: Burns, et al.

Past, present, and future IPN Missions

IPN Localization

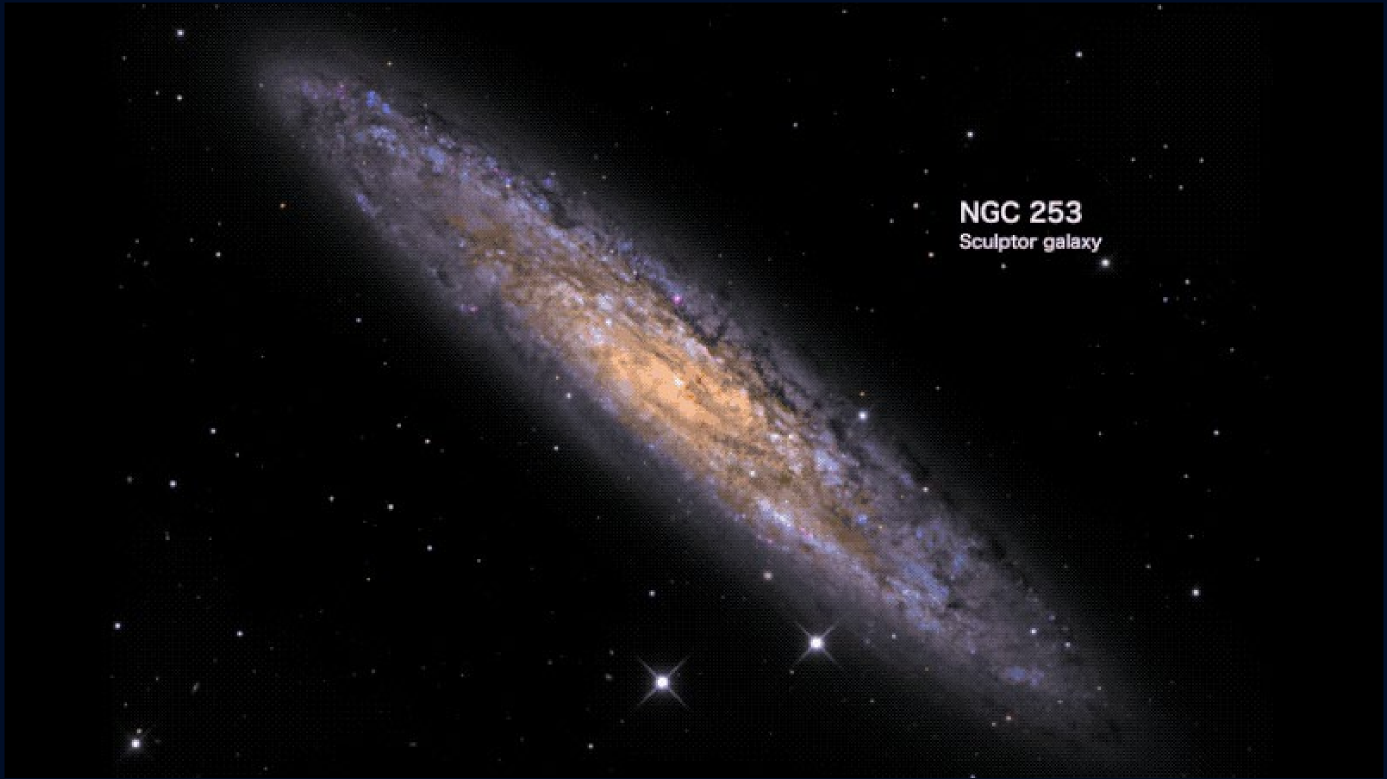


Fig. 4, Credit: NASA

Localizations are made by triangulation using differences in detection arrival times and spacecraft distances

IPN Automation

- Accurate localization requires knowing the precise positions of the detectors
- Currently, the IPN must retrieve these positions manually for each event
- The time this takes can result in valuable science being lost (Burns et al., 2023)
- Automating this process will reduce localization time from hours to minutes (Burns et al., 2023)

Wayfinder System

- Predicts spacecraft positions in real-time
- Necessary component of automating IPN localizations
- Built by the IPN software engineer, Courey Elliott
- My project is to determine the accuracy of these predictions

How Wayfinder Works

Two-line Element (TLE) Data

- Path information on satellites in low Earth orbit in a special format
- Provided by U.S. Space Force

Ephemeris Data

- Path information for interplanetary spacecraft
- Provided by NASA's JPL Horizons

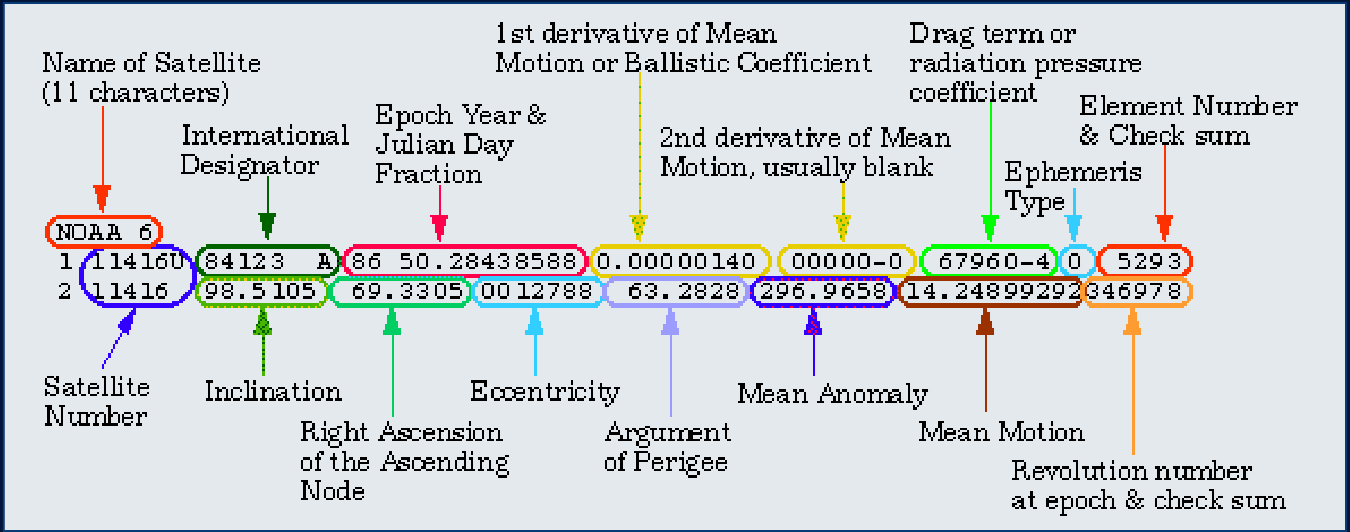
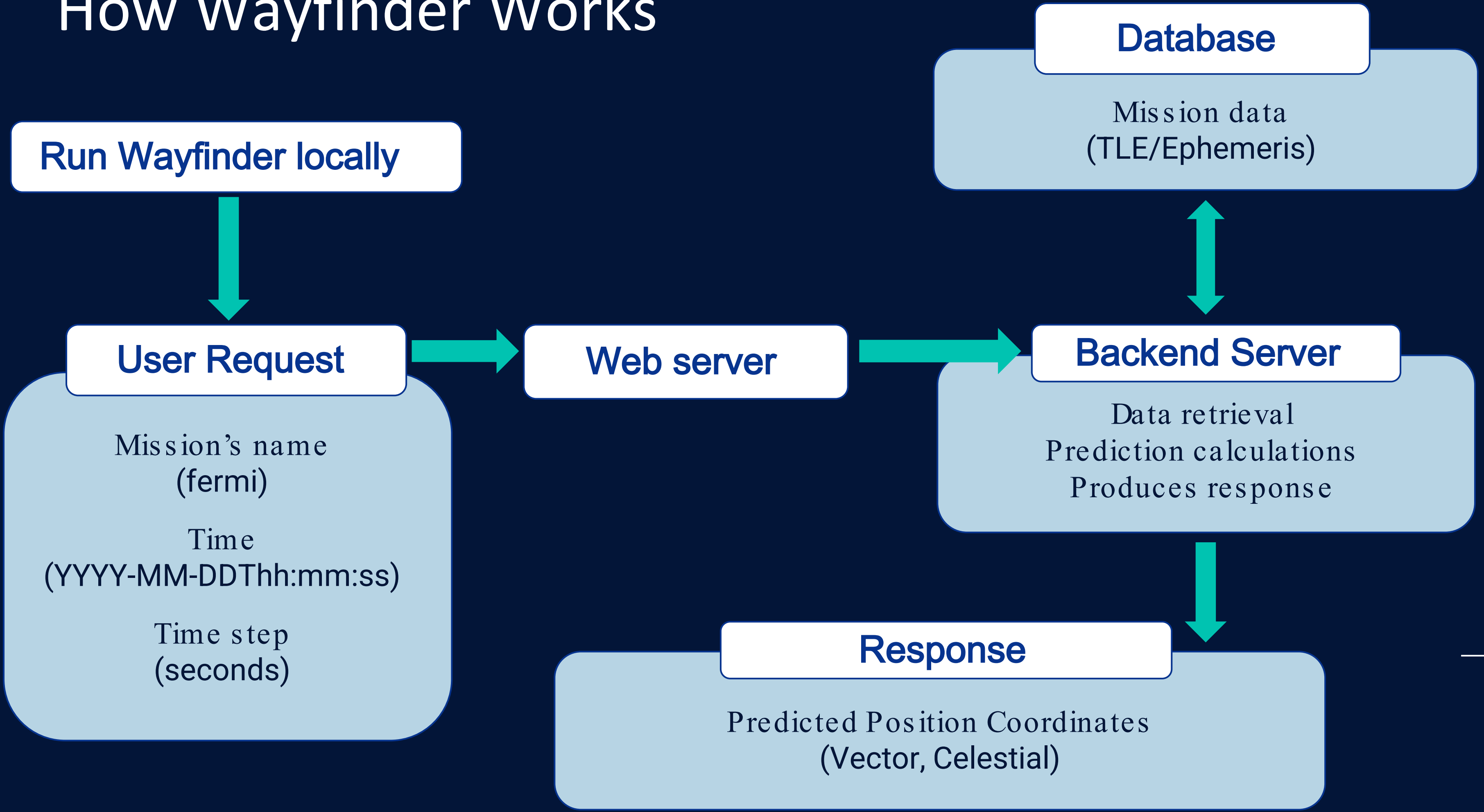


Fig. 5 Credit: Kaitlyn's Tech Log

How Wayfinder Works



Testing Wayfinder

Missions

Earth-Orbiting	Interplanetary
Fermi*	Psyche
Swift*	Mars-Odyssey
INTEGRAL	

How

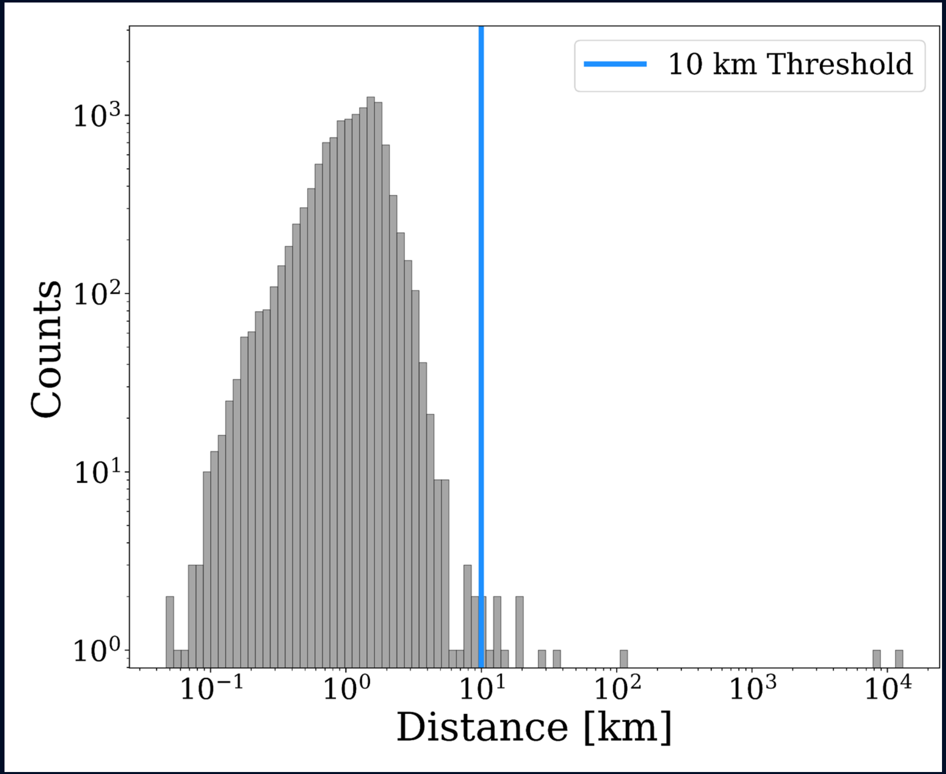
1. Generate 2 random timestamps since the mission's launch date
2. Retrieve mission's documented position at each time
3. Get Wayfinder predictions for each time
4. Calculate the distance between the two sets of vector coordinates

Testing Wayfinder

CURRENT GOAL

Find Wayfinder predictions to be within 10 km of the recorded positions for spacecraft in low Earth orbit

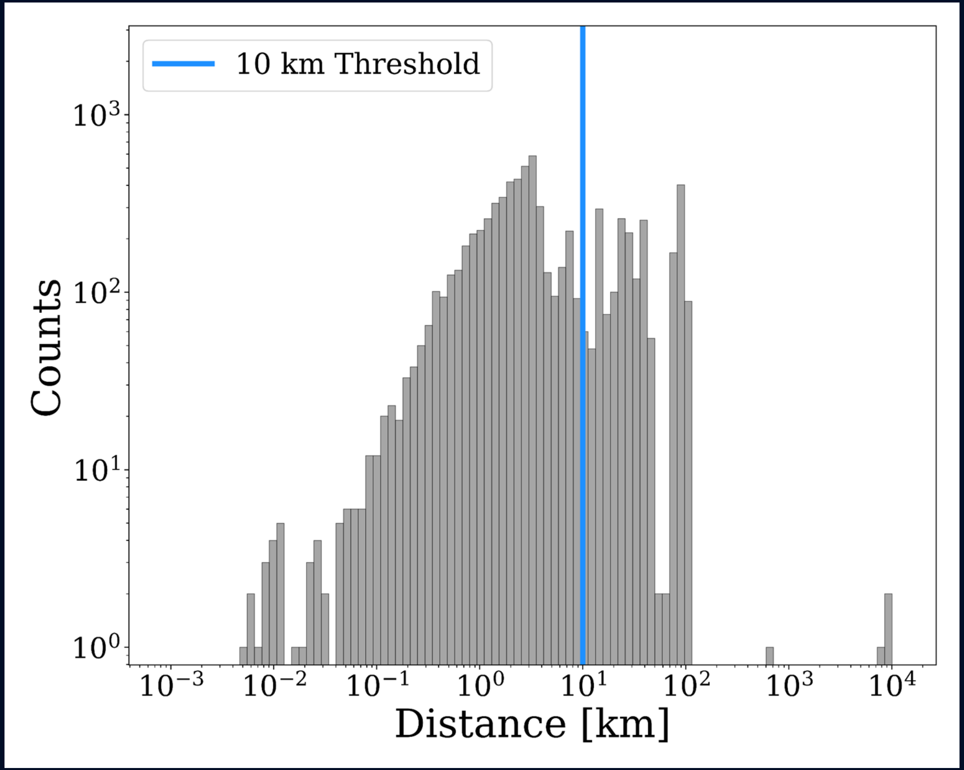
Testing Wayfinder



Fermi

- Fermi has an onboard GPS, so its positions in orbit are well-known
- ~99.9% of distances were < 10 km
- Investigating extreme values, find that occasionally TLEs report bad data
- Suggested a need in Wayfinder system for a TLE validation check

Testing Wayfinder

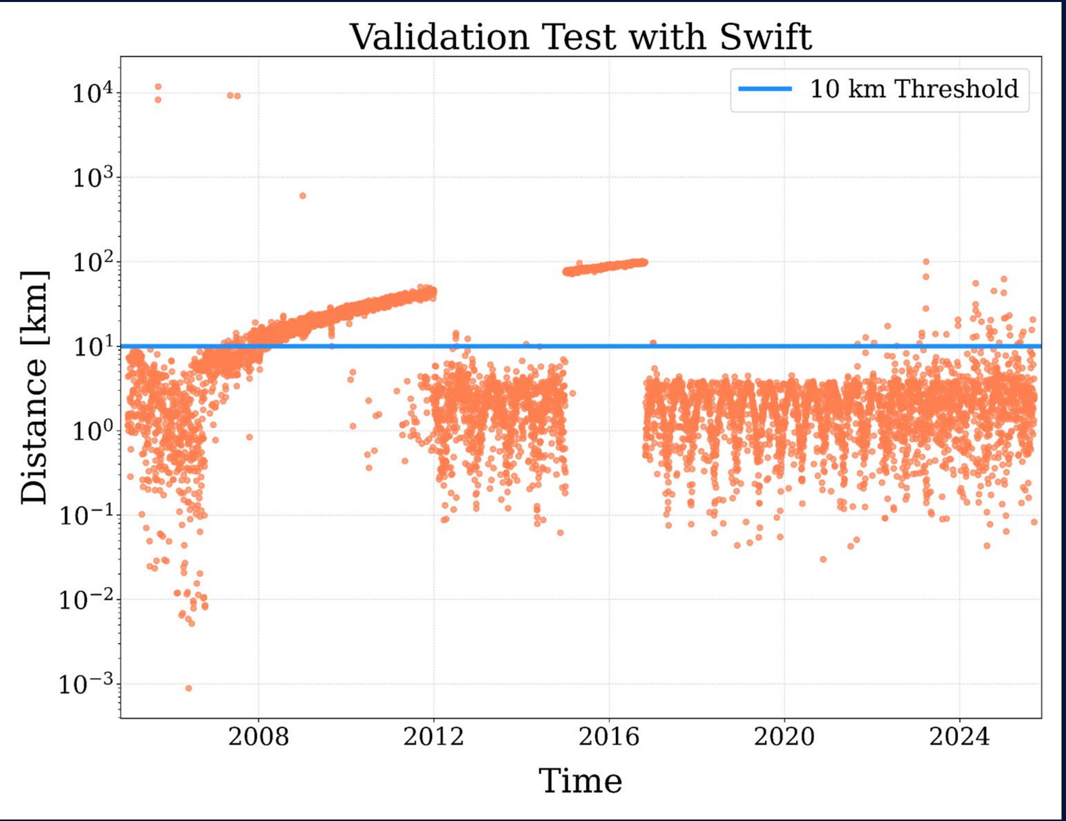


Swift

- Thousands of values > 10 km
- Ran test several times and found the same results

Testing Wayfinder - Swift

- Found unexpected behavior when plotting the distances over time
- Swift does not have onboard GPS and has to correct the internal clock drift over time
- The Swift position data used did not have these corrections



Results & Future Work

- After understanding Swift's behavior, we find ~98.5% of distance values were < 10 km
- We have determined Wayfinder predictions are reliable for satellites in low Earth orbit
- Future tests:
  - INTEGRAL → highly elliptical orbit
  - Psyche → interplanetary
  - Mars-Odyssey → interplanetary

References / Image Credit

Abbott, B. P. et al. (2017). *Gravitational Waves and Gamma -Rays from a Binary Neutron Star Merger: GW170817and GRB170817A* The Astrophysical Journal Letters, 848(2), L13. https://arxiv.org/abs/1710.05834

Burns, E., et al. (2023). Gamma -Ray Transient Network Science Analysis Group Report. https://arxiv.org/abs/2308.04485

Patel, A., Metzger, B. D., Cehula, J., Burns, E., Goldberg, J. A., … (2025). Direct Evidence for r -process Nucleosynthesis in Delayed MeV Emission from the SGR 1806-20 Magnetar Giant Flare. The Astrophysical Journal Letters, 984(1), L29. https://arxiv.org/abs/2501.09181

Figure 1 Image Credit: NASA's Goddard Space Flight Center. "Neutron Star Merger." https://science.nasa.gov/universe/gamma-ray-bursts-black-hole-birth-announcements/

Figure 2 Image Credit: NASA's Goddard Space Flight Center. "Core-collapse." https://science.nasa.gov/universe/gamma-ray-bursts-black-hole-birth-announcements/

Figure 3 Image Credit: Burns, E., et al. (2023). *Gamma-Ray Transient Network Science Analysis Group Report* (Fig. 3). https://arxiv.org/abs/2308.04485

Figure 4 Image Credit: NASA's Goddard Space Flight Center; DSS; SDSS; Adam Block, Mount Lemmon SkyCenter, University of Arizona. https://svs.gsfc.nasa.gov/13792

Figure 5 Image Credit: Kaitlyn's Tech Logs. "Two-Line Elements". https://kaitlyn.guru/projects/two-line-elements-tle/