National Aeronautics and Space Administration

Near-Earth-Object Orbit Determination using High Precision Astrometry and Parallax

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Program: Topic

Project Objective:

Surveying Near-Earth-Objects (NEOs) are important for planet defense, solar system formation study, potential mining, and providing mission targets. Once detected, NEOs need to be cataloged, i.e. their orbits should be determined accurate enough to ensure their next apparitions can be unambiguously predicted.

Traditional wisdom requires a dozen measurements of accuracy ~0.5 arcsec spanning over 3 weeks to catalog a NEO. Using the synthetic tracking technique and Gaia Data Release 2 Catalog, we are able to achieve 10 mas level NEO astrometry (Fig. 1). This project explores how accurate astrometry can help NEO orbit determination. Our objects are:

- Perform a simulation study to quantify the uncertainties of the estimated NEO orbits based on astrometric follow-up observations as function of the astrometric accuracy, distance of the NEO from the Earth, temporal range of the observations (arc length of orbit), and number of observations. Find out what is needed to catalog a NEO.
- Study how parallax derived from observations of two observatories at different geographical location help orbit determination.
- Perform NEO follow-up observations to help cataloging NEOs and verify the efficacy of accurate astrometry.

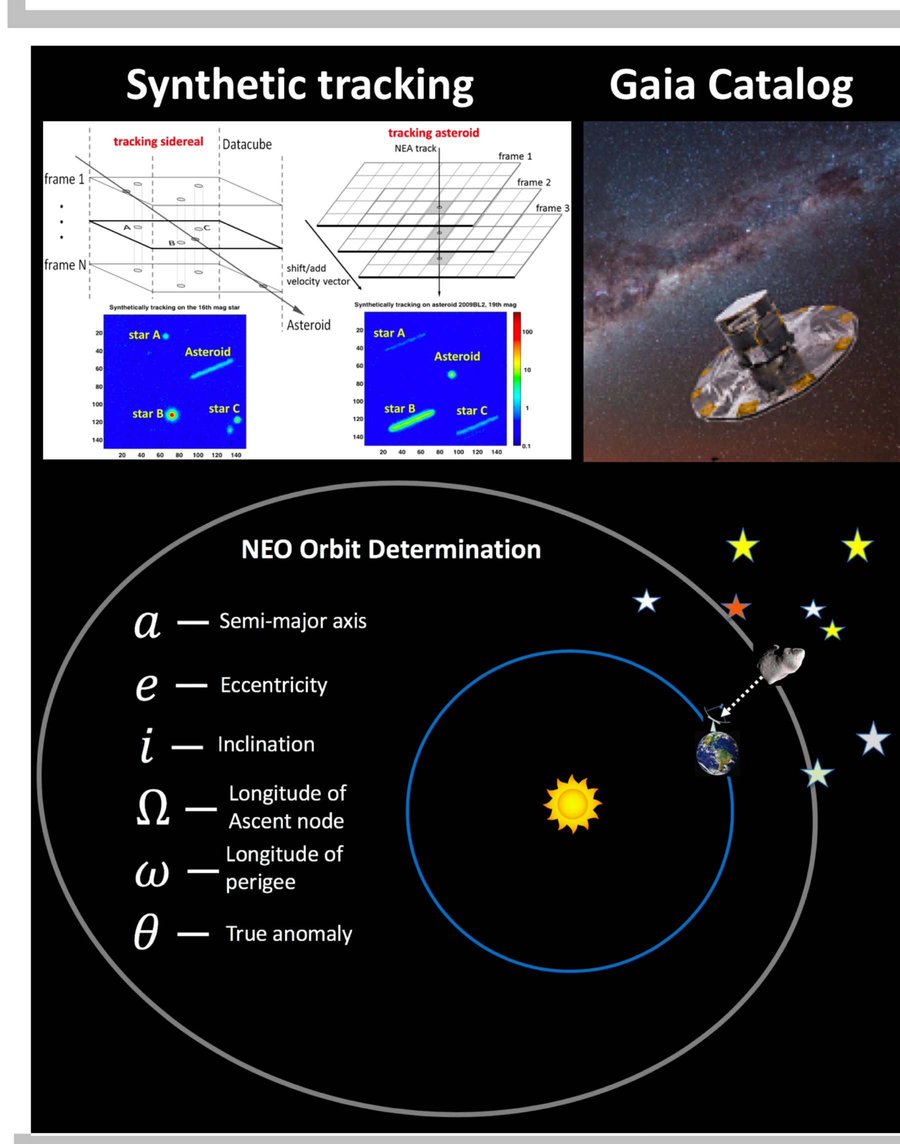

Figure 1: Using synthetic tracking is essential for achieving accurate NEO astrometry from both improving signal to noise ratio and making atmospheric or telescope jitter effects common between target and reference objects. Gaia Catalog provides the foundation of accurate absolute astrometry. Orbit determination performance depends on accuracy and number of measurements and coverage of temporal range (arclength of orbit).

To the first order Orbit accuracy ~

$$\frac{\text{astrometry accuracy}}{\sqrt{N_{obs}}\ \text{arclength}^2}$$

Benefits to NASA and JPL (or significance of results):

NASA's NEO search program has achieved greater than 90% completeness in surveying objects of 1 km and greater in size, effort has shifted to smaller objects around 100 m to fulfill the congressional mandate to also achieve 90% completeness. Most of NEOs are Near Earth Asteroids (NEAs). It has been estimated to have ~50,000 NEAs down to size of ~100 m. To help catalog all the new objects, it is crucial to have efficient follow-up observations.

Our work will advance the start-of-the-art of using a dozen NEO measurements of ~0.5 arcsec level accuracy spanning over 3 weeks time to catalog a NEO to using only 3-4 measurements of 10 mas level accuracy over a week. Not only this would be efficient, but also it enables to catalog the fast moving NEOs, whose time window for convenient observations are less than 3 weeks.

Another benefit is to better determine whether a newly discovered object is a Potentially Hazardous Asteroid (PHA) and the probably of impacting earth and providing accurate orbit for NEO mission targets.

Future spacecraft will likely carry laser communication devices for higher data rate. It would be operationally efficient to measure the spacecraft position in the sky while it is communicating with a ground terminal. Exploring accurate astrometry in orbit determination help understand the potential and sensitivity of using ground-based astrometry in determining the ephemeris of spacecraft for optical navigation.

FY19 Results:

Performed a simulation study using the Granvik's NEO orbit database (Fig.2) to generate about 2000 NEO observation scenarios and quantify uncertainties of the estimated orbits from using N=3,4,5 observations of accuracies of 10, 20, 30, 50 mas.

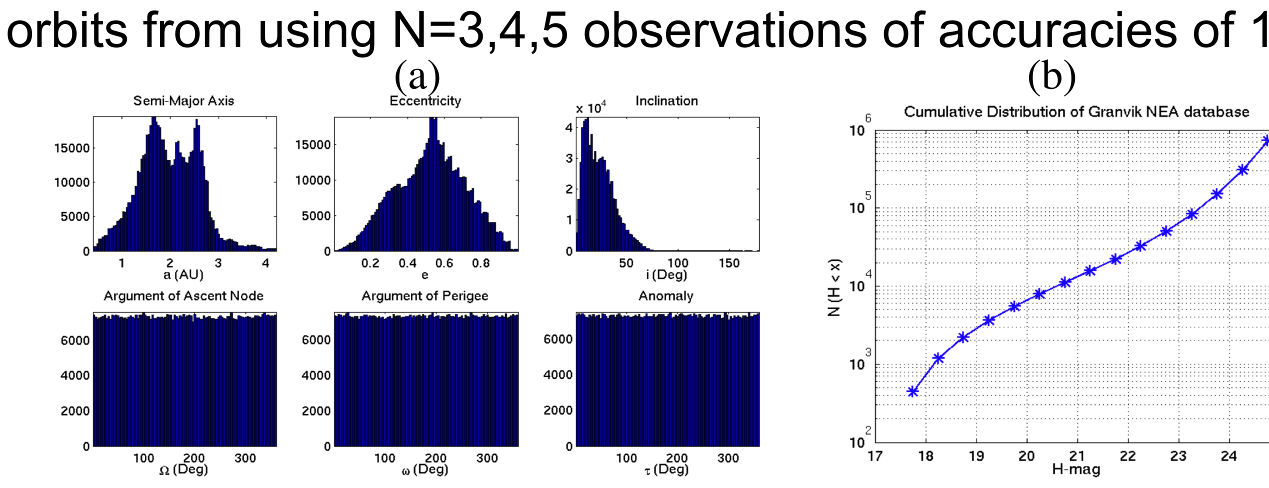

Figure 2: Granvik NEO orbit database, (a) distributions of orbital parameters; (b) 731683 NEOs with H-mag < 25 (~35m @ albedo = 0.15)

- Monte Carlo method is used to quantify uncertainties of estimated orbit parameters. The distribution of uncertainties of orbit parameters (a, e, i, Ω, ω) are in Fig. 3 (first 5 plots) for the case of using 3x20 mas measurements. Errors in orbital elements are highly correlated. Volume of uncertainty at 6σ has only effectively one or two dimensions in 5-d space. An example is shown in Table 1.

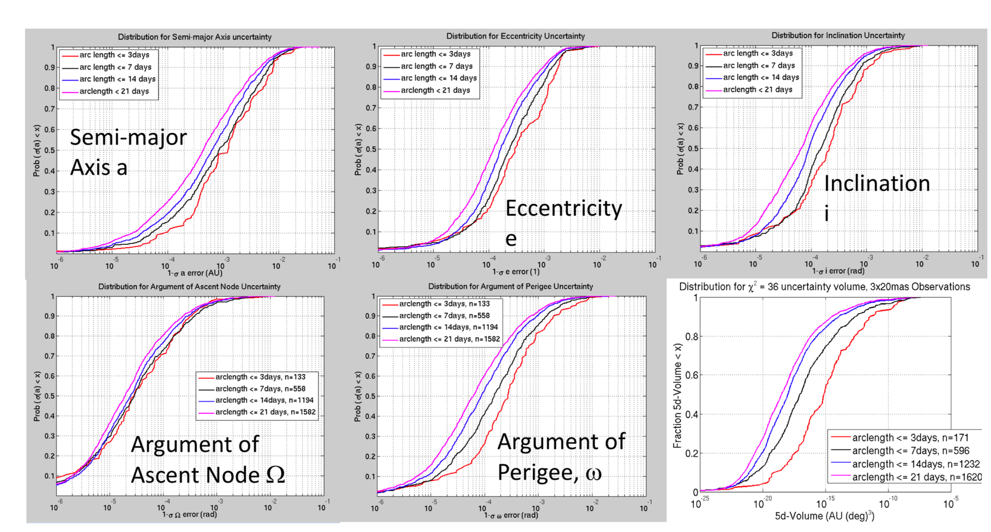

Table 1: correlation matrix between 5 orbital parameters

	a	e	i	Ω	ω
a	1.0000	-0.8821	0.9991	0.9991	-1.0000
e	-0.8821	1.0000	-0.9010	-0.9004	0.8807
i	0.9991	-0.9010	1.0000	1.0000	-0.9989
Ω	0.9991	-0.9004	1.0000	1.0000	-0.9990
ω	-1.0000	0.8807	-0.9989	-0.9990	1.0000

Figure 3: Distribution of uncertainties of 5 orbit parameters and volume in 5-d space of 6σ uncertainty (χ^2 = 36). Different colors are for different coverages of arclengths of orbits.

- Distribution of the volume of 6σ ellipspoid (χ^2=36) in 5d (a, e, i, Ω, ω) space is shown in the last plot (right bottom) in Fig 3. the volume is much smaller than 1e-7 (AU deg^3) if we use 3x20 mas astrometric measurements to determine orbit with even an arc shorter than 3 days. Given the average density of NEA in 5d space is ~16 /(AU deg^3), the asteroid orbit is determined without confusion.
- Note that this volume decreases with 5th power of astrometric precision. The error in predicted (RA,DEC) for future observation is linearly proportion to astrometric precision.

Solved two issues in instrumentation

- Diagnosed the unstable high dark count and replaced the detector
- Found extra background light from the baffle tube and significantly reduced the background light by covering the tube using dark materials. (See Fig 4).

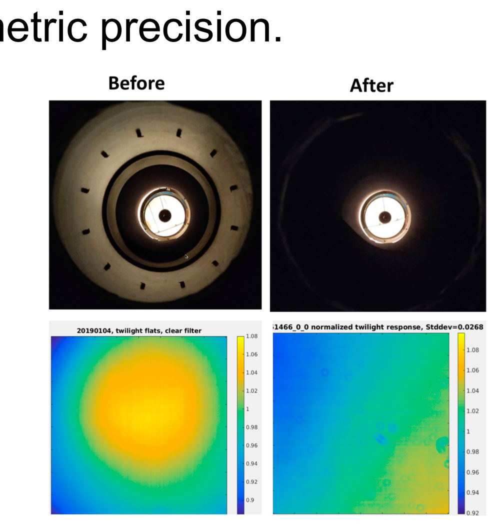

Figure 4: Instrument improvement from reducing reflection of the baffle tube.

Supported an awarded NEO observation using Palomar 5 m telescope, acquired data for future analysis

Started to regularly perform NEO follow-up observations and report to the Minor Planet Center.

Implemented correction of chromatic air refraction effects to allow using clear filter (broadband) and still achieve 10 mas level accuracy in systematic errors.

Acknowledgements

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Publications:

1. Zhai, C., Shao, M., Saini, N., Trahan, R, et al, *Near-Earth-Object Orbit Determination using Accurate Astrometry and Parallax,* 50th DPS Meeting, Knoxville, TN, Oct 21-26, 2018.
2. Zhai, C., Shao, M., Saini, N., Trahan, R, et al, *Accurate Near-Earth-Asteroid Astrometry using Synthetic Tracking and Applications,* EPSC-DPS Joint Meeting 2019, Sept 15-20, Geneva, Switzerland, 2019.

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