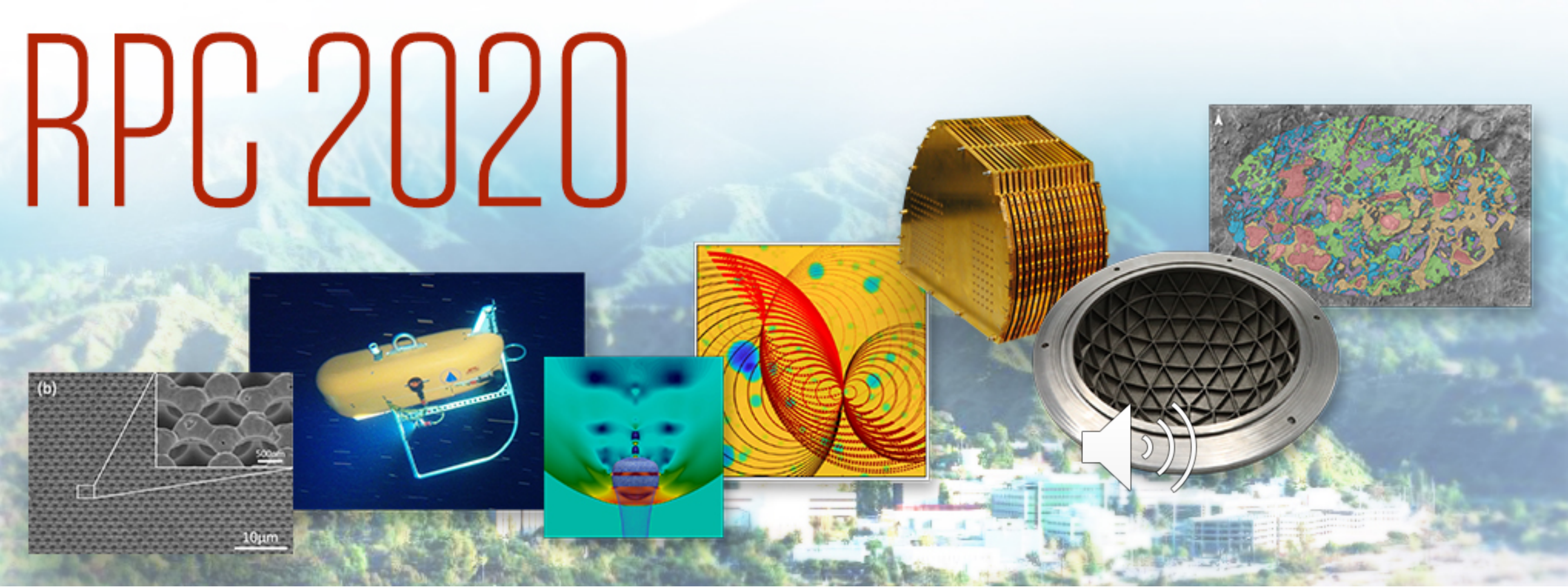

Virtual Research Presentation Conference

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

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Program: Topic

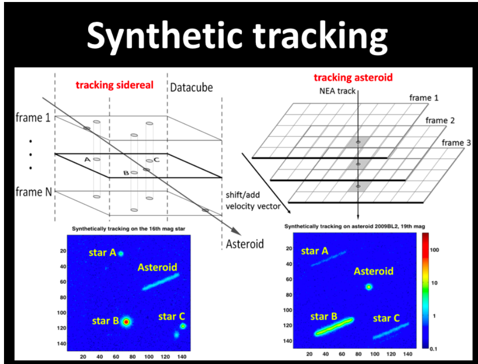
Assigned Presentation # RPC-183

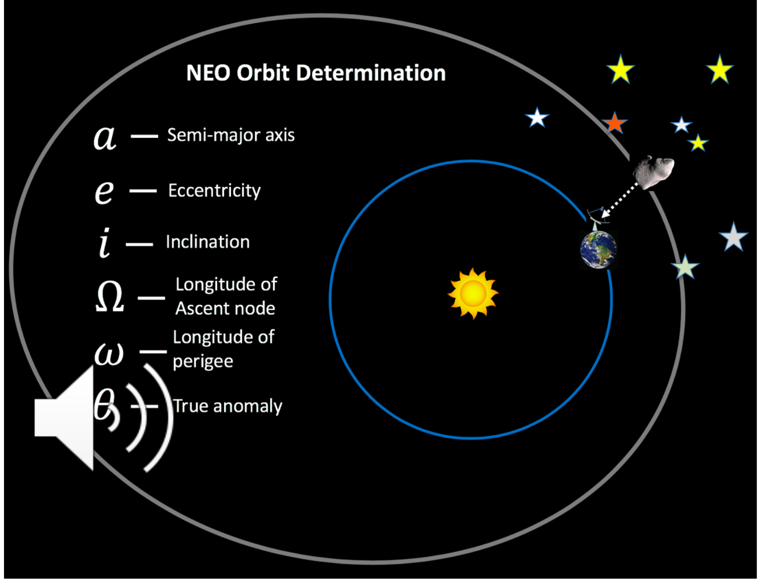
Jet Propulsion Laboratory
California Institute of Technology

Tutorial Introduction

Abstract

Near-Earth-Objects (NEOs) are asteroids or comets nudged by the gravitational force of planets to an orbit that can come to the Earth within 0.3 AU. NEOs are interesting for planetary defense, solar system formation study, exploration targets, and mining. NASA's NEO program has found more than 90% of NEOs larger than 1 km and shifted to surveying NEOs down to 100 m or smaller. NEOs are usually discovered when they come close to the Earth and become bright. Upon discovery, we need to determine a NEO's orbit with sufficient accuracy so that it is cataloged, *i.e.* it can be recovered at the next apparition a few years to more than 10 years later, without being confused with another NEO. Typically, it requires about a dozen measurements with arcsecond level accuracy for at least 3-4 weeks. Small asteroids, however, cannot be observed conveniently for several weeks. Consequently, many newly discovered small NEOs get lost. We study the possibility of using highly accurate astrometric measurements at 10 mas level, achieved by using synthetic tracking, to compensate the shortcoming of the short time of observation. Together with parallax, we found we can catalog a NEO with 4 observations over only 3 days.





Problem Description

a) NASA is surveying NEOs down to 100 m or smaller for planetary defense and future exploration. One challenge is to catalog NEOs timely upon discovery, i.e. determine their orbit well enough with no confusion at next apparition. Typically, it requires a dozen of measurements with arcsecond level accuracy over 3-4 weeks (arc length).

b) Small NEOs are observed when they are close to the Earth, tend to move fast, and can only be conveniently observed for ~ 1 week, covering a shorter arc. Many newly discovered NEOs get lost.

c) Current state-of-the-art (SOA) NEO survey astrometry is ~ 120 mas for slowly moving NEOs and degrades to ~200 mas for fast moving NEOs. We advance the SOA to 10-50 mas accuracy achieved by using the synthetic tracking technique. This study address whether more accurate astrometry can compensate the loss of orbit determination sensitivity due to short arc for cataloging NEOs.

d) Benefit to NASA and JPL
   a) Find all the threats from NEOs for planetary defense
   b) Fulfill the congressional mandate to survey NEOs down to 140 m with 90% completeness as soon as possible.
   c) Help NASA track priority targets for future exploration.
   d) Put JPL in a leading position in using accurate astrometry to perform efficient NEO follow-up observations.

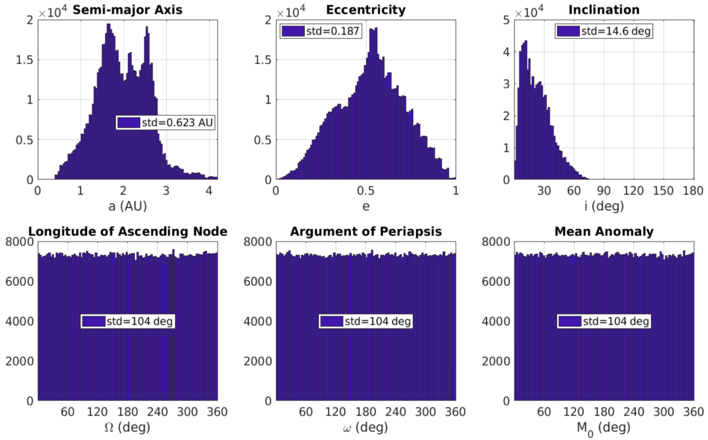
Methodology (I), Orbit determination sensitivity study using simulation

We use simulation to study the orbital determination sensitivity as function of the astrometry, arc length, number of observations, and the distance of close approach, as well as parallax from two observatories or earth rotation.

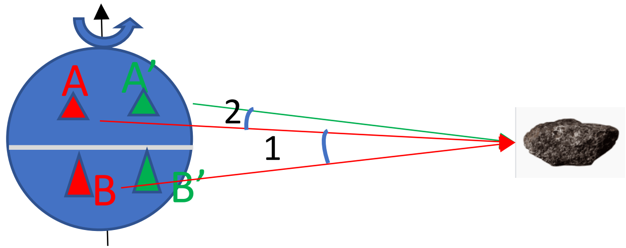
a) We use the Granvik NEO database to simulate more than 1500 observation scenarios

b) We use Monte Carlo simulation to derive orbital parameter uncertainties by injecting random measurement noises.

c) We study the capability of cataloging a NEO by estimating the density of NEOs down to 10 m (~10^8) in orbit parameter space (a, e, i, Ω, ω) and then quantify the volume of uncertainty from the simulation to estimate chance of confusion with another NEO.



Granvik's orbital parameter distribution



parallax: 1) formed between observatories (A,B)
2) between (A, A') same observatory different time

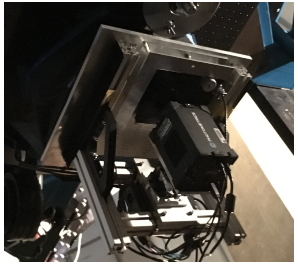
Methodology (II), perform NEO follow-up observations to use real data validate the simulation

We acquire NEO observational data with our instrument at the Pomona College's 40-inch telescope and use the synthetic tracking technique to achieve accurate NEO astrometry.

a) Synthetic tracking advances NEO astrometry from accuracy of 100 mas to 10 mas level by 1) avoiding trailing loss, 2) centroiding using compact PSFs, 3) keeping atmospheric effect and telescope jitter effect common between target and reference objects.

b) We compare the orbital parameters, estimated using a few of our measurements over short arcs, with the JPL Horizons orbital parameters to validate our simulation results.

https://tmf.jpl.nasa.gov



Photometrics Prime 95B CMOS camera

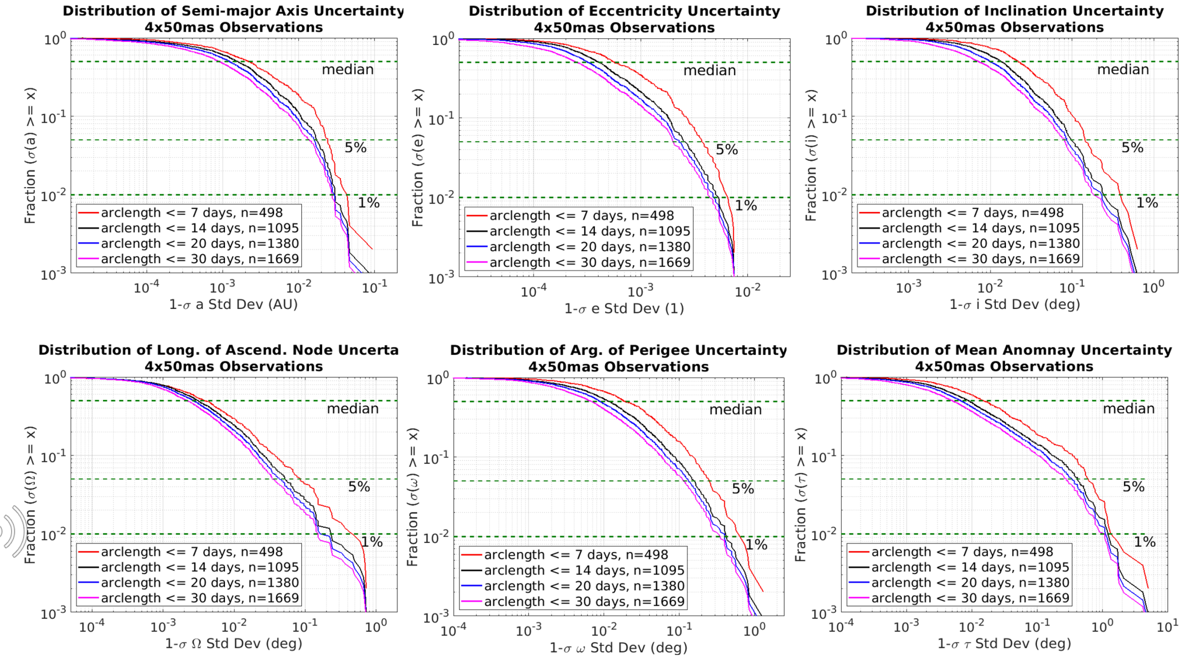
Results (I), Orbital parameter uncertainty distributions

Orbital parameter uncertainties are quantified as standard deviations from the Monte Carlo simulation. Distributions of the Six orbital parameter determined based on 4 measurements of 50 mas accuracy over more than 1500 observation scenarios are displayed.

Four curves are for different maximum arc length. Among1669 cases with arc length < 30 days, 498 (30%) has arc length of 7 days or shorter.

Shorter arcs have larger uncertainties.

The distribution is wide; median, and top 5% and 1% values are marked.

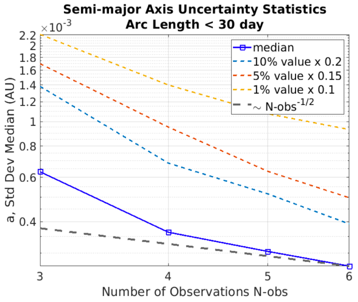


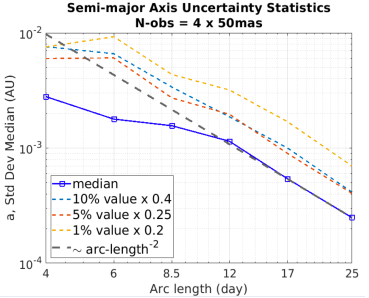
Results (II), Orbital parameter uncertainty dependency

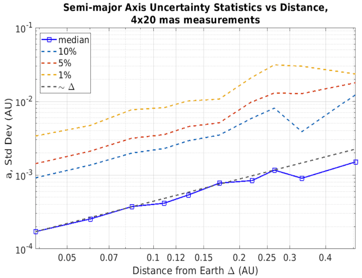
The median and top 10%, 5%, and 1% values are examined as function of astrometric accuracy, number of observations, length of arc, distance of approach, and parallax.

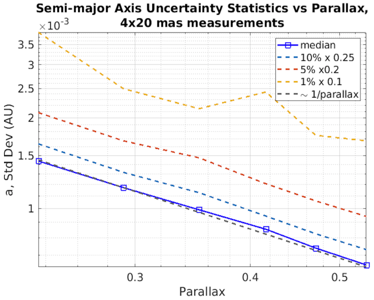
The uncertainties of estimated orbital parameters

- are linearly proportional to the astrometric accuracy ε
- decrease faster than the inverse of the square root of the number of observations, N_{obs}
- decrease with the increase of the arc length T_{arc}
- increase with the distance of close approach Δ
- decrease with parallax (measure of diversity in hour angles and latitudes of observatories.



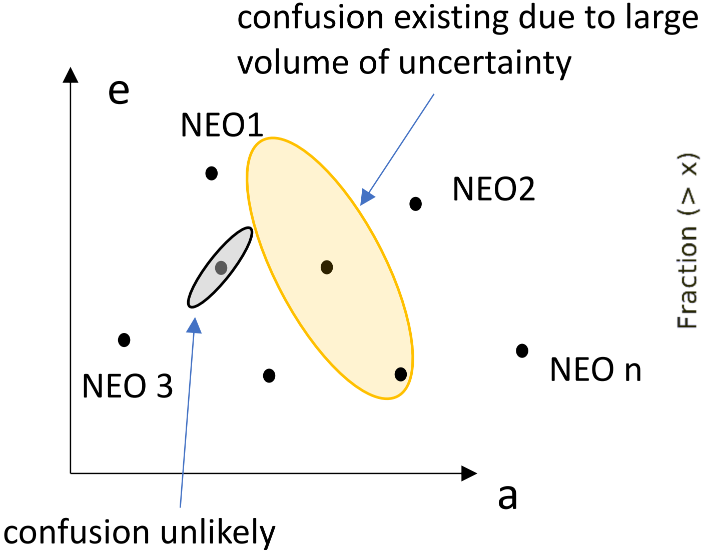


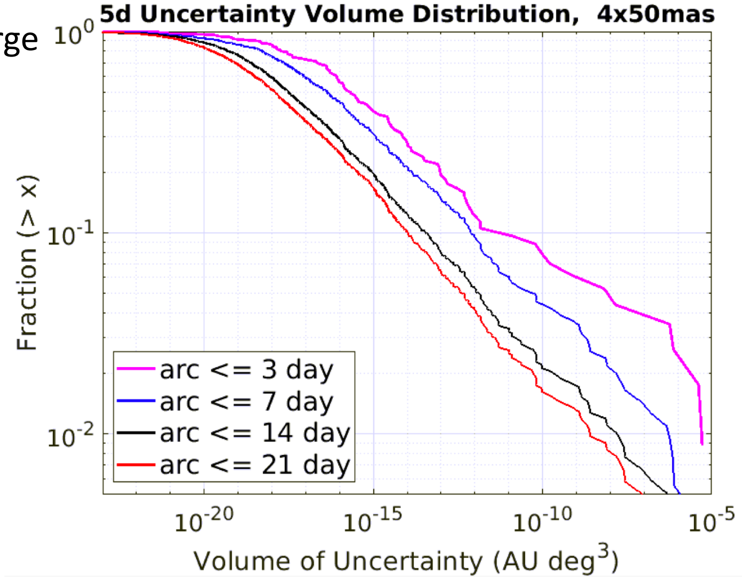




Results (III), probability of confusion

It is useful to view each NEO as a point in 5d space spanned by (a, e, i, Ω, ω) determining the shape of its orbit. With the Monte Carlo simulation results, the estimated orbital parameters will be dots around the point of the true orbit. The distribution of the dots around the true orbit allows us to estimate a volume of uncertainties for different confidence levels. We estimate the density of NEOs down to size of 10 m in 5d space ~ 76 NEO per AU deg^3.





Volume of uncertainty at confidence level ~ 1e-4 the largest < 1e-5 AU deg^3, even for arc length as shorter than 3 days, highly unlikely to have confusion for density 76 per AU deg^3

Results(IV), NEO follow-up observations

We have regularly performed NEO follow-up observations using the Pomona College's 40-inch telescope since the beginning of this fiscal year.

- We have reported more than 2000 highly accurate NEO astrometric measurements to the Minor Planet Center.
- We helped 40 NEOs get their provisional designations.
- We have compared orbital parameters estimated using our measurements over arc length of 5 days or less with the orbital parameters from JPL Horizons based on much longer records and found the differences are consistent with our simulation.

Acknowledgements

We thank our collaborator, Prof. Philip Choi at Pomona College, and his observation team, including Kutay Nazlie, Nez Evans, for taking experimental data and helping improve instrumentation and operation. The software controlling Photometrics camera was originally developed by Russell Trahan at JPL under a contract with the Air Force. Heath Rhoades at the Table Mountain Facility of JPL, Anthony L. Grigsby, and Hardy Richardson at the Pomona college provide constant support for the instrumentation. We thank Paul Chodas at JPL for advice on using he JPL Horizon System. Discussions with T. Ely, J. Lazio, T. J. Martin-Mur, W. Owen, R. Preston, and S. Shakland are helpful. We appreciate the support from our line management and our group members. We used Gaia DR2 catalog.

This work was prepared at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Thank you!

Publications and References

Publications

[A] Chengxing Zhai, Michael Shao, Navtej Saini, Russell Trahan, Philip Choi, "Near-Earth-Object Orbit Determination using Accurate Astrometry and Parallax," *50th DPS Meeting*, Knoxville, TN, Oct 21-26, 2018.

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