Occultation based astrometry

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General considerations

- Occultations have traditionally been concerned with measuring sizes and shapes for airless bodies
- It has always been true that an occultation provides information about the relative position of the star and asteroid
- Now, with the Gaia catalog, we know where the star is and can transfer that to the asteroid
- There are interesting connections with distance and scale on the value of the astrometry

Constraints

- If the orbit uncertainty is too large, occultations become serendipitous events
- A single chord observation provides astrometry good to the angular size of the object
- Conservative estimates of uncertainties are an impediment to occultations
- Real deployments depend on understanding the orbit fit which usually means understanding how the data are weighted

Quantitative estimates of astrometric errors

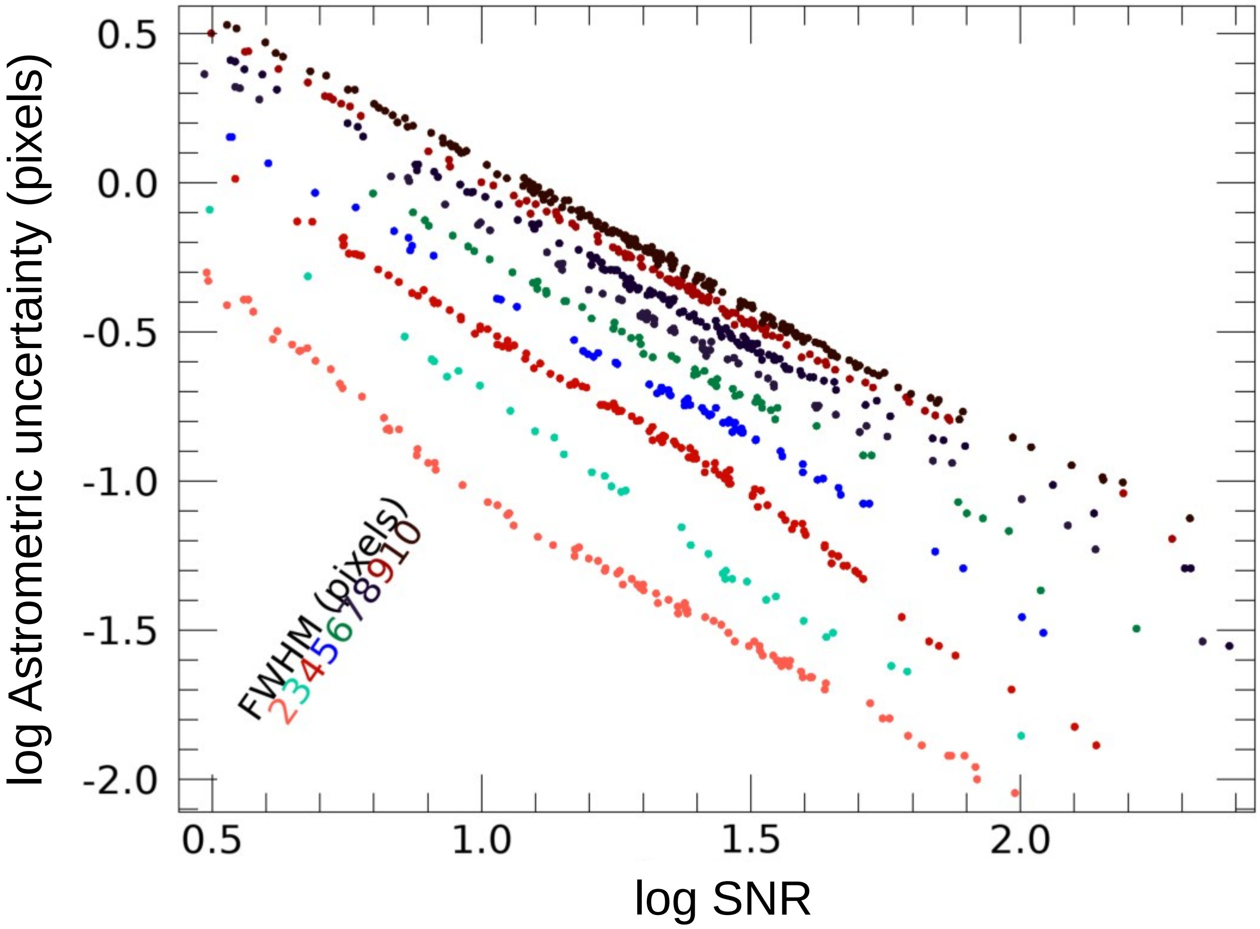
Astrometric error can be characterized by two parameters: FWHM and SNR.

Each point in the plot is the average of a 10,000 sample for a given FWHM and SNR.

Smaller than 2? stop it! You're undersampled.

Larger than 10? Try binning or wait for a better night, behavior asymtotes anyway.

Each set of a fixed FWHM can be represented well enough with a polynomial. Use 2-d interpolation to get a smooth result in between.



Derived uncertainty trends

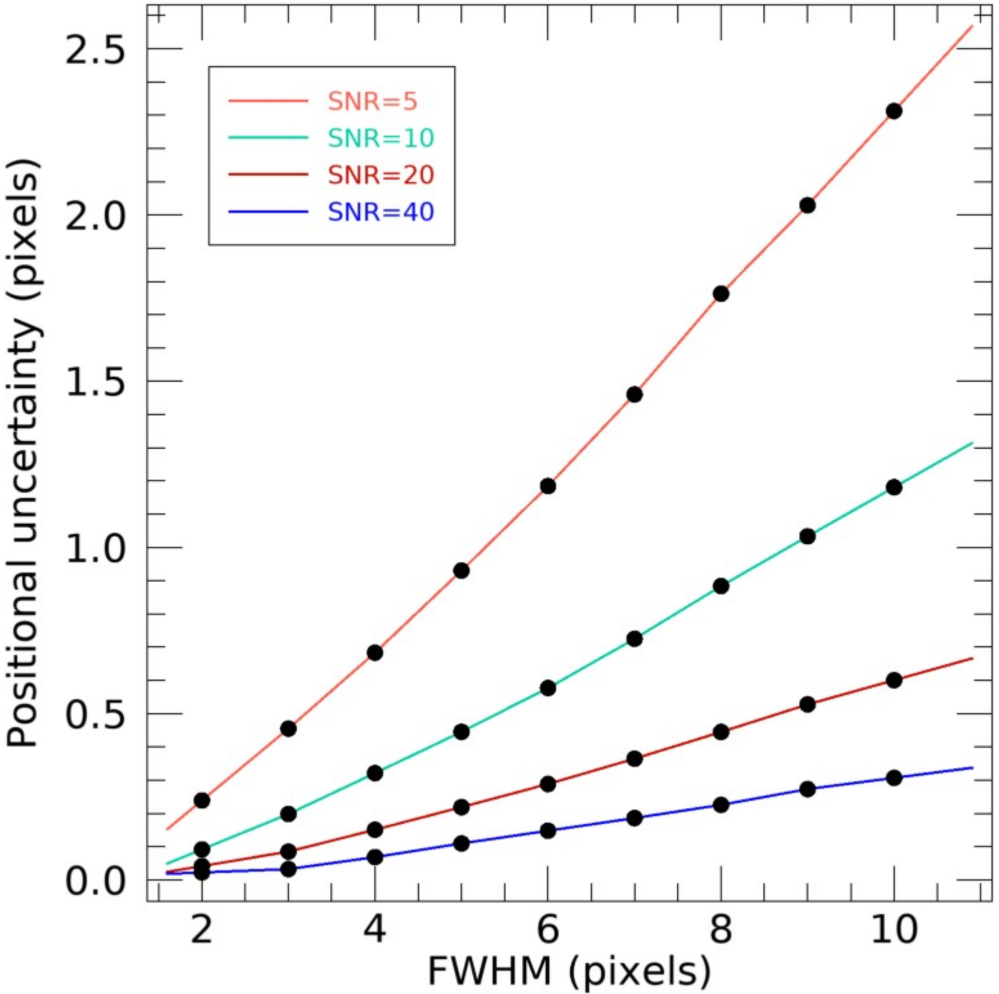
Trends match intuition.
  Better image quality = better astrometry.
  Better SNR = better astrometry.

This range is where noise and sampling dictate result. Outside of this range other systematics likely more important.

The polynomials can be effectively applied to every source in your image for a fully weighted astrometric solution and then on to your target.

The worst problem is that you don’t actually know the SNR very well at low signal. When taking a set of low signal measurements, you might be better off with an average SNR and compute an average astrometric uncertainty to apply to the set.

submitted to PSJ, in revision now



Angular and spatial scale vs. distance

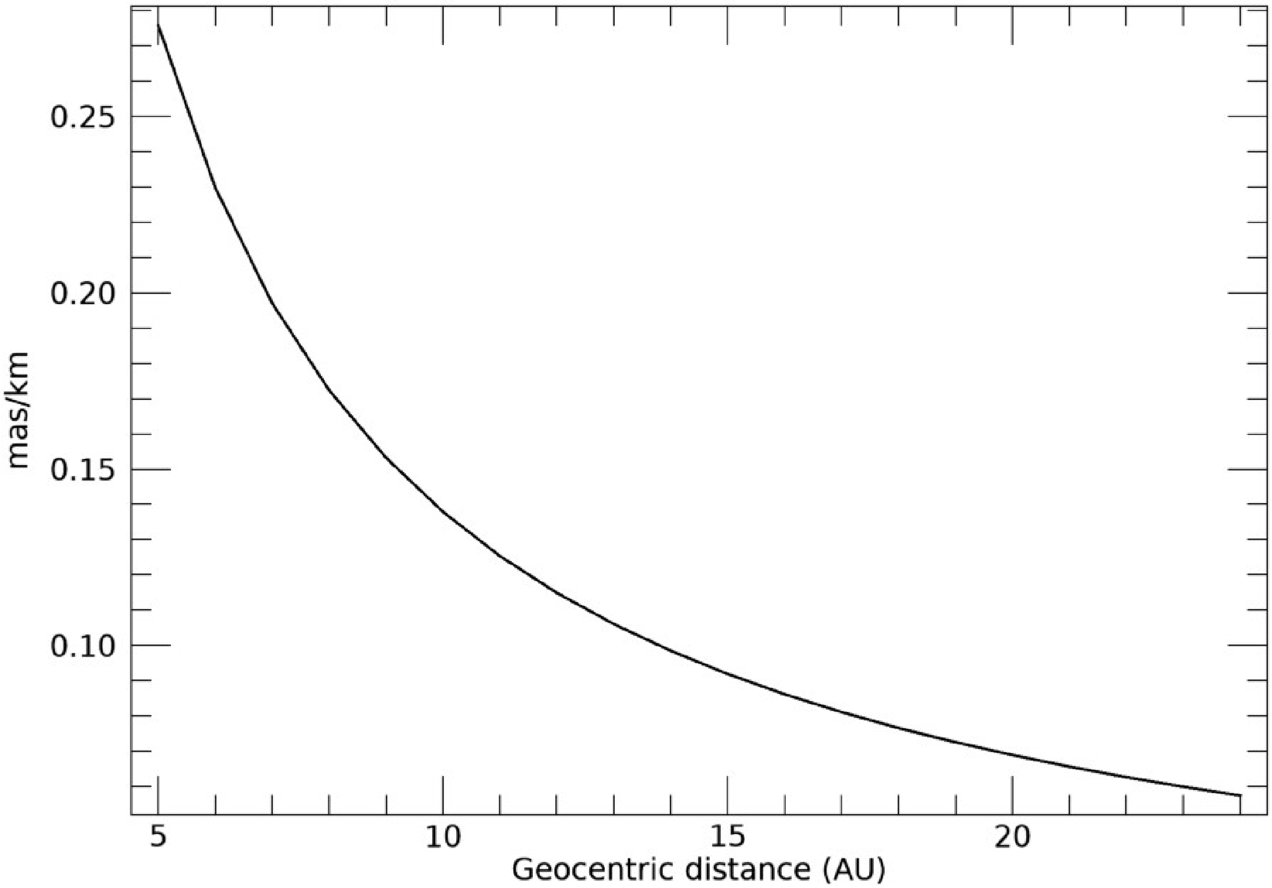
How does astrometric precision map to object size?

Beyond ~12AU, occultaiton astrometry limited by Gaia catalog.

NEA case: divide D and Δ by the same factor.

Below the black line is where occultations improve over traditional astrometry.

For D=1km NEA at 0.2 AU, 8 mas, at 1 AU, 100’s of microarcsec.



Spatial scale vs. distance

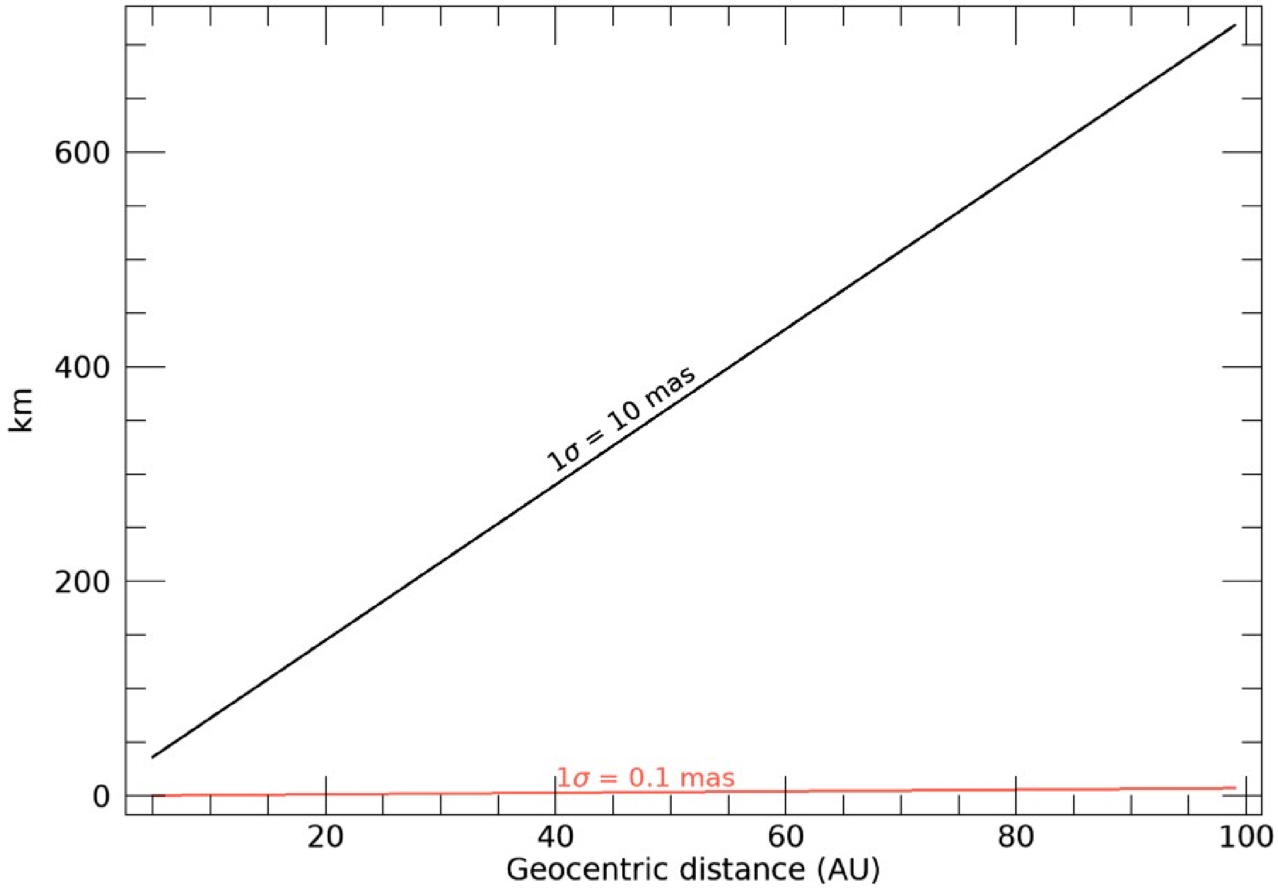
How does astrometric precision map to object size?

Upper line is for a very good orbit, lowest line is the Gaia catalog precision (best case).

NEA case: divide D and Δ by the same factor.

Below the black line is where occultations improve over traditional astrometry.

For D=1km NEA at 0.2 AU, 8 mas, at 1 AU, 100's of microarcsec.



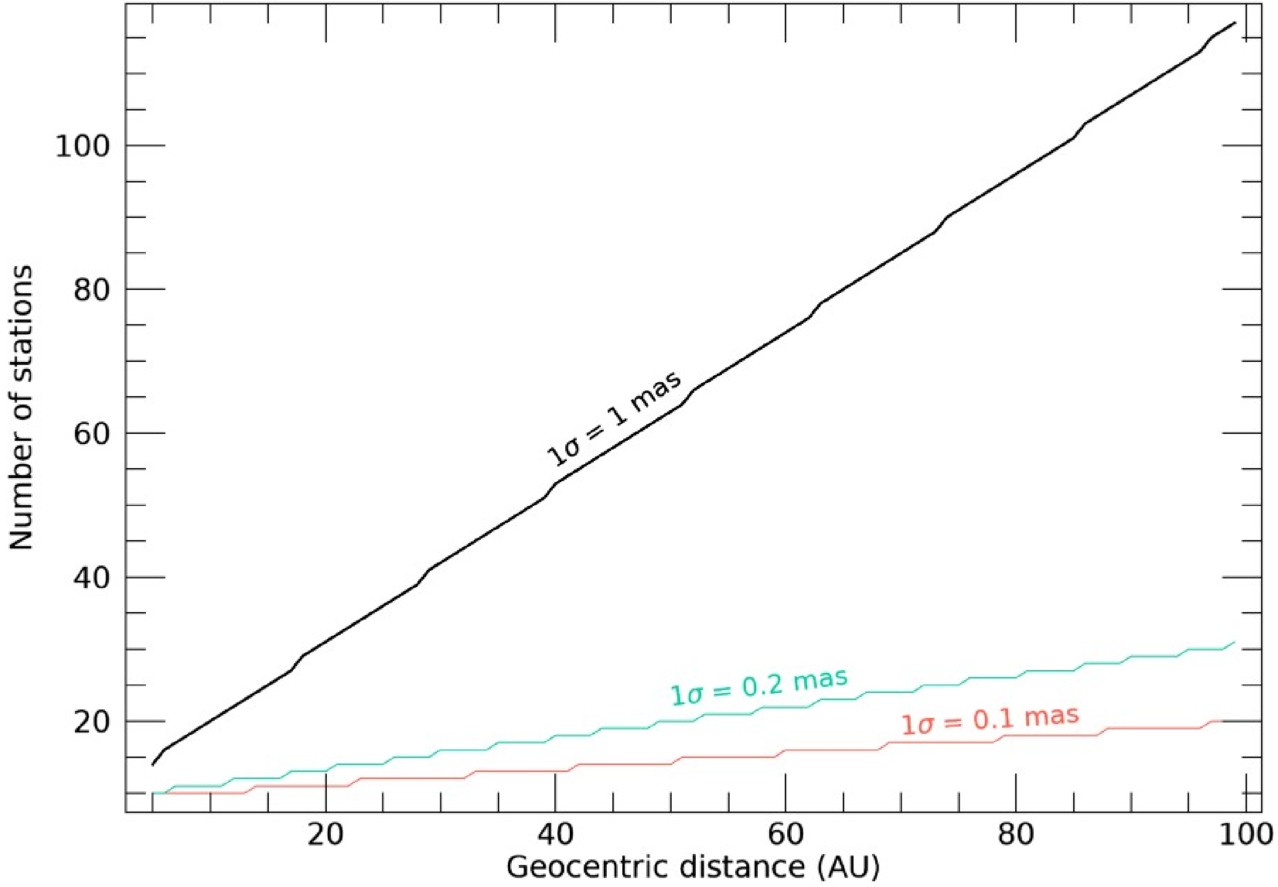
Prediction uncertainty and effort

Standard case of a D=100 km object for distant objects

How many stations are required to ensure two chords?

Upper line is for a very good orbit, lowest line is limited by Gaia catalog precision

NEA case: divide D and Δ by the same factor. For D=1km NEA, the plot range is from 0.2 to 1 AU.



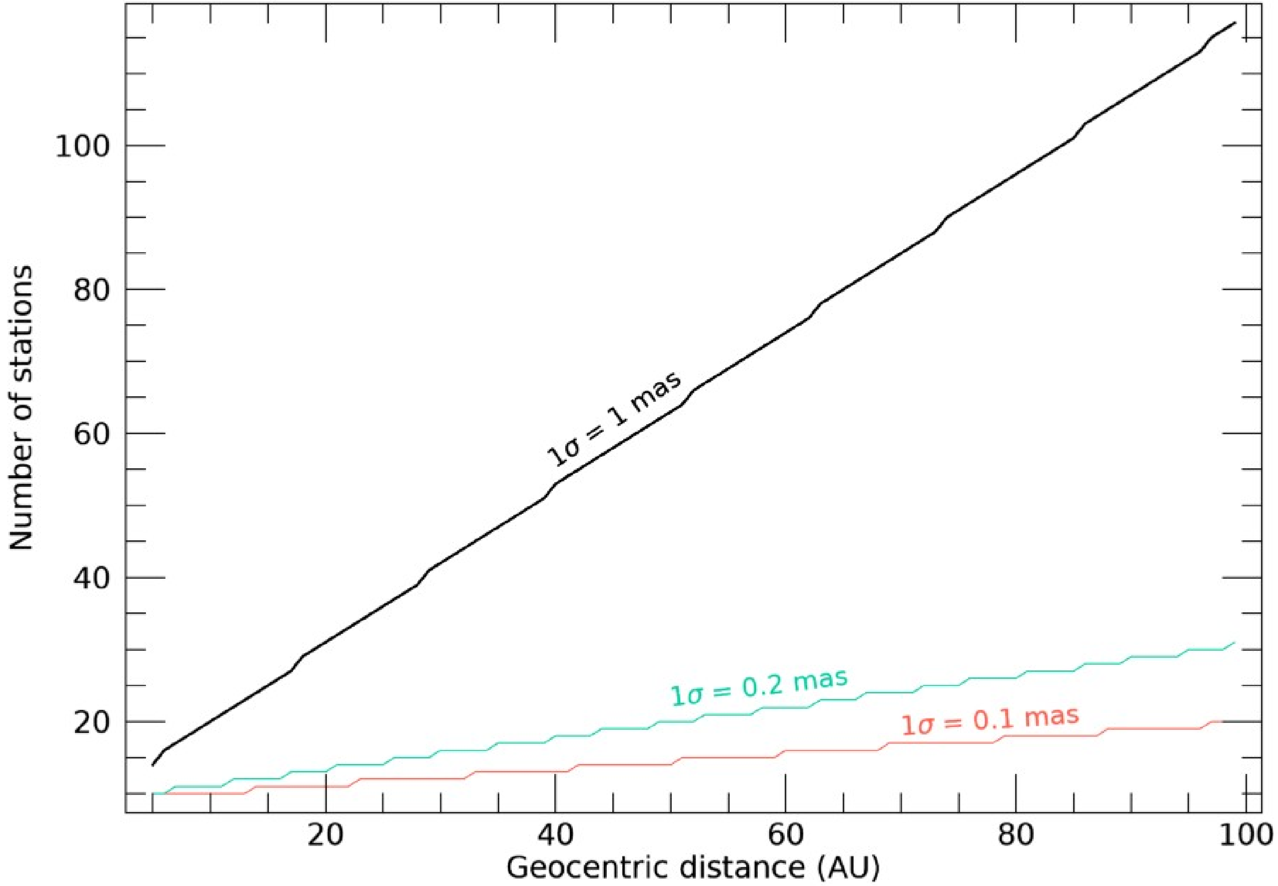
Example NEA case 1

D=1 km object, Δ=0.2 AU

σ = 10 mas, Nsta = 300
impractical

σ = 1 mas, Nsta = 30
astrometric event

σ = 0.2 mas
good for size and shape



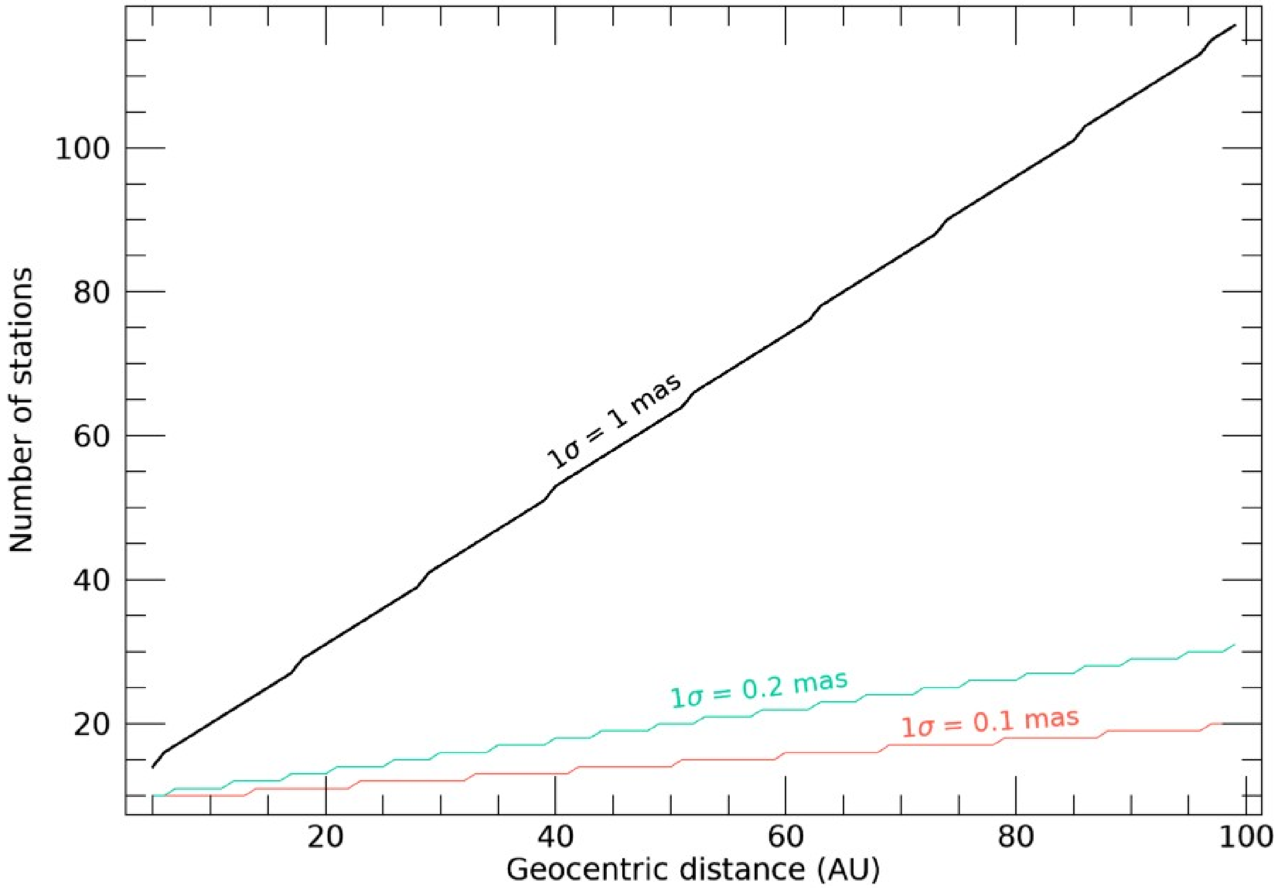
Example NEA case 2

D=1 km object, Δ=1.0 AU

σ = 10 mas, Nsta = 1500
impractical

σ = 1 mas, Nsta = 150
impractical

σ = 0.2 mas, Nsta = 30
good for astrometry



Positional uncertainty from occultations

- Different uncertainty regimes
  - sparse data
  - good sampling
  - dense sampling
- Rigourous uncertainties are nearly impossible
  - non-gaussian uncertainty clouds are common
  - Full-fidelity reporting not supported by ADES

Sparse data

- Consists of 1, maybe 2 positives
- Forced to use circular or elliptical shapes
  - negatives can rule out circular case
  - albedo constraints can limit size (1% albedos?)
- Formal uncertainties can be calculated but have no more or less validity than limits
  - shapes for small bodies can be nearly arbitrary
- If angular size of body is small (<1-200 μas), uncertainty may be dominated by star position

Good sampling

- Uncertainties will be small and the goal is to establish resonable limits
- Circular or elliptical fits have limited value
- Smooth hulls can help
  - model with random and uniform errors
- 3-D shape model with combined occultation and lightcurve data can be very effective

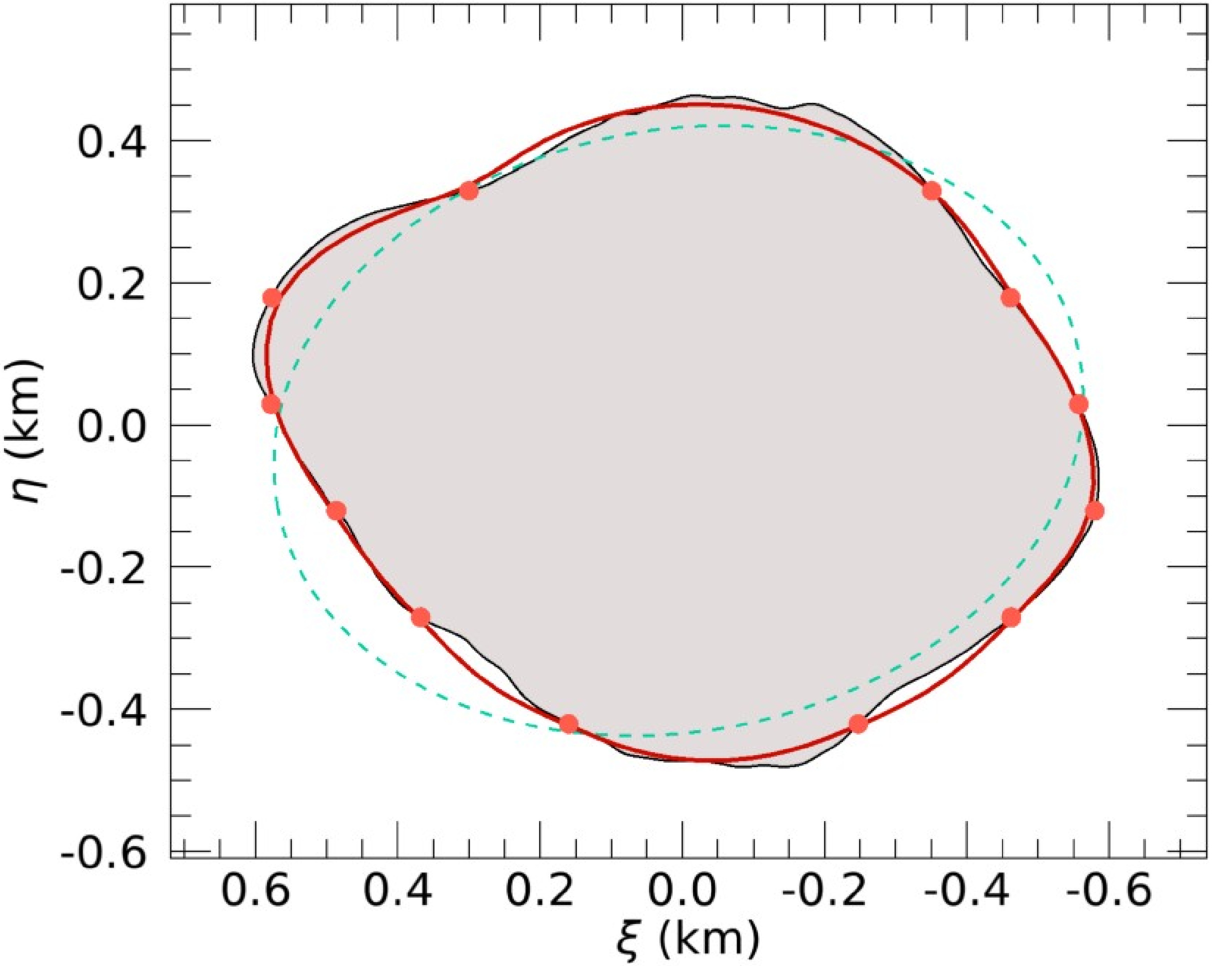
Uncertainties with good sampling

Timing uncertainties can be modeled as random errors, these are one dimensional

Negative constraints, or lack thereof, modeled with uniform uncertainty

Resulting PDF is usually non-gaussian and best handled with a discrete cloud

Converting cloud to a gaussian covariance is useful but incurs loss of information

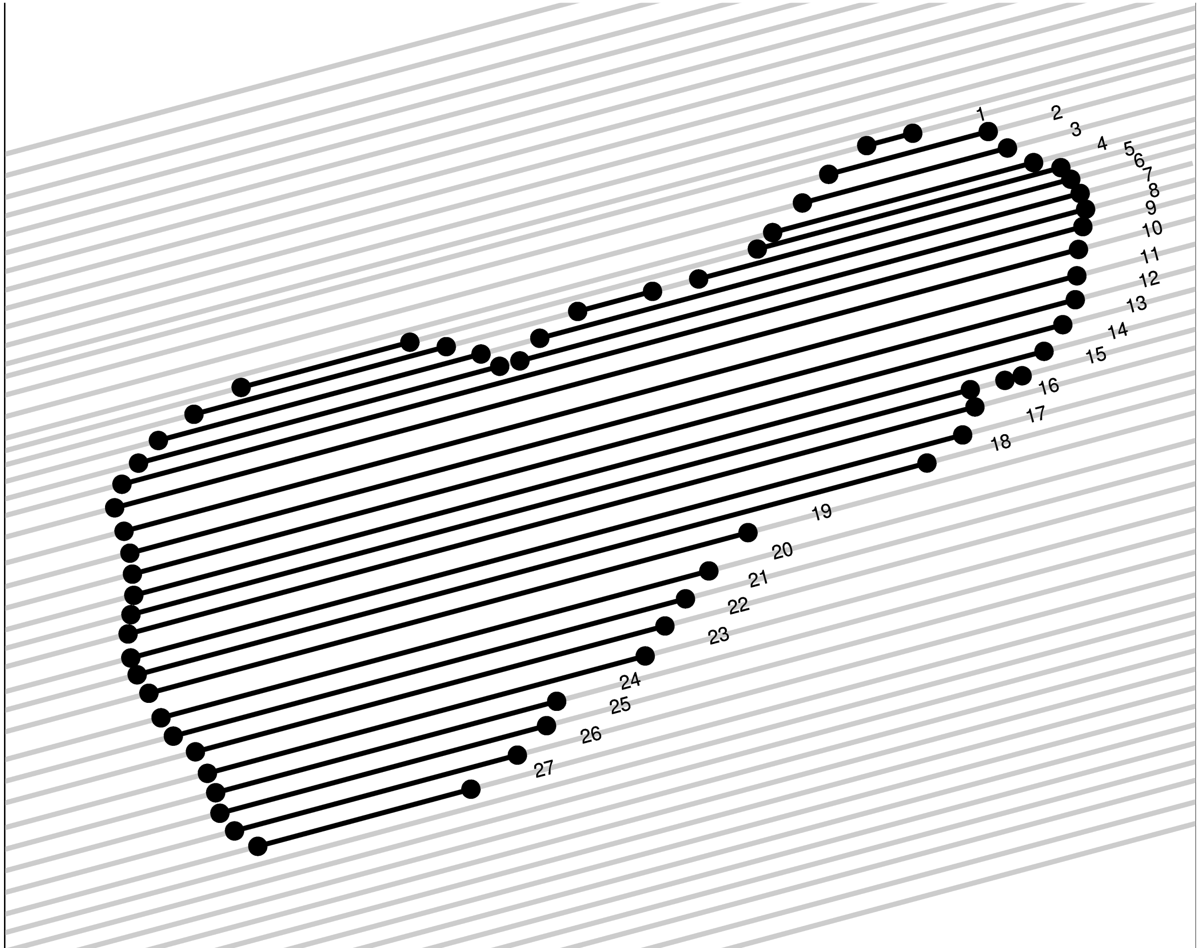


Uncertainties with dense sampling

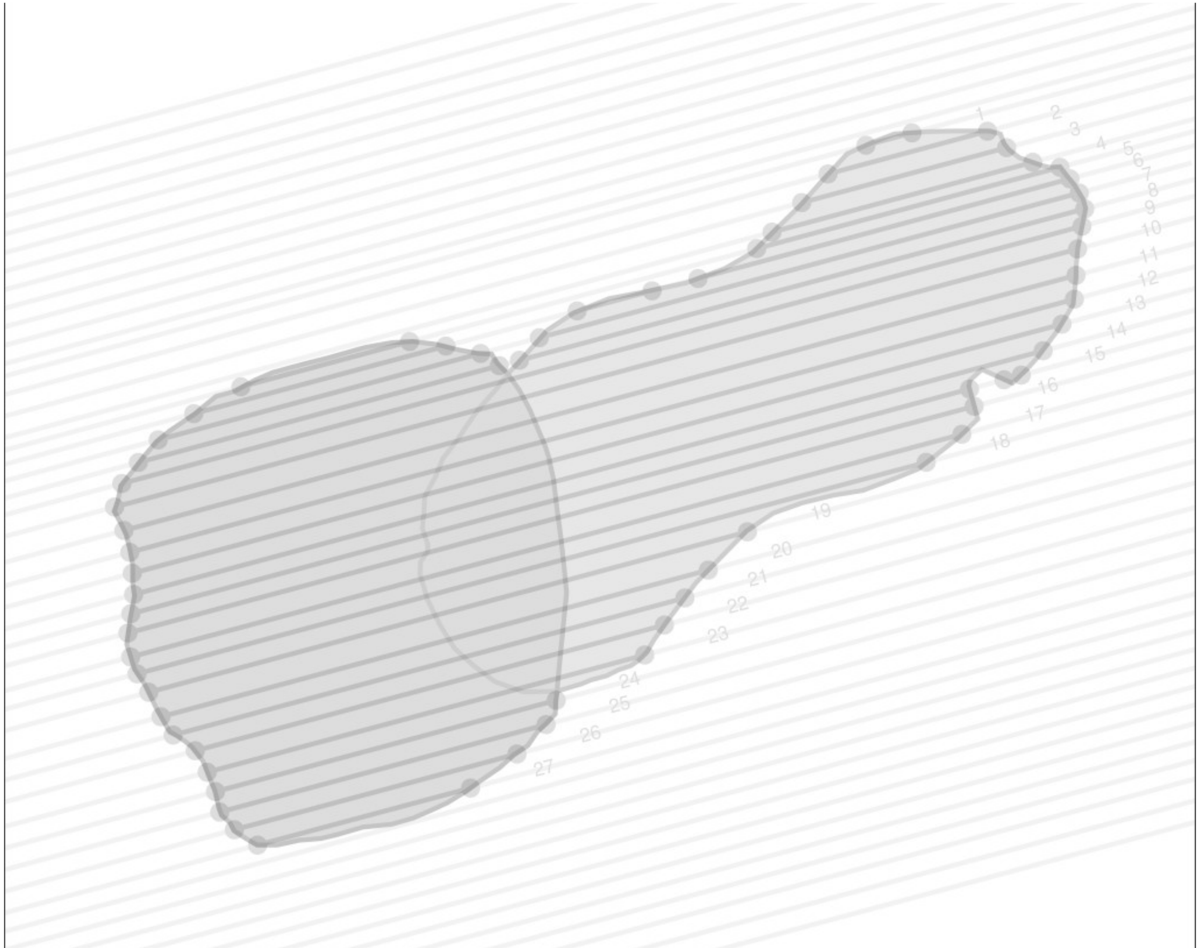
- Uncertainties of the body center are likely to be well less than star uncertainties
- How to relate center-of-body to center-of-mass?
- What else don't you know?

Uncertainties with dense sampling

FAKE!



Uncertainties with dense sampling



Idealize NEA strategy

- Most effective with lots of warning on PHA
  - strategy depends on goal: astrometry or shape?
- Good baseline orbit with traditional astrometry
- Campaign 1: pick an event to get best chance of one chord, improve orbit
- Campaign 2: shape (do soon after #1), astrometry (pick optimal time after #1)
- Campaign 3-N: until goal is reached