Gaia

impact on asteroidal occultations

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Murrumbateman
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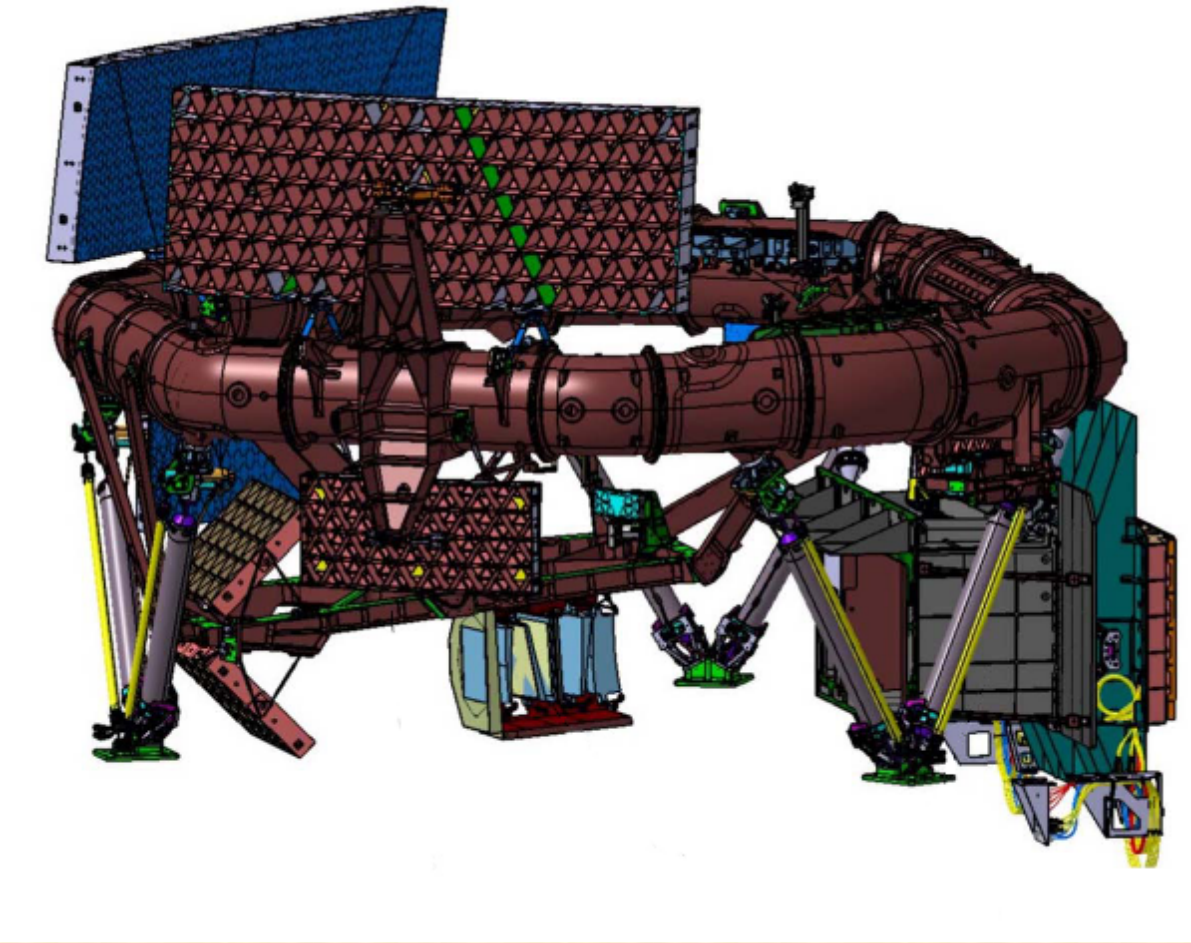
Current situation

A number to remember. *For Main Belt asteroids,* ***1mas*** *equates to about* ***2km*** *on the Earth*

- Typical uncertainty in star position 50mas
- Typical uncertainty in asteroid position 150mas
- For any one event, there is little basis to attribute the path shift between the star or the asteroid. That is, with the current accuracy of star catalogues and asteroid ephemerides, we cannot improve predictions based on recent observations

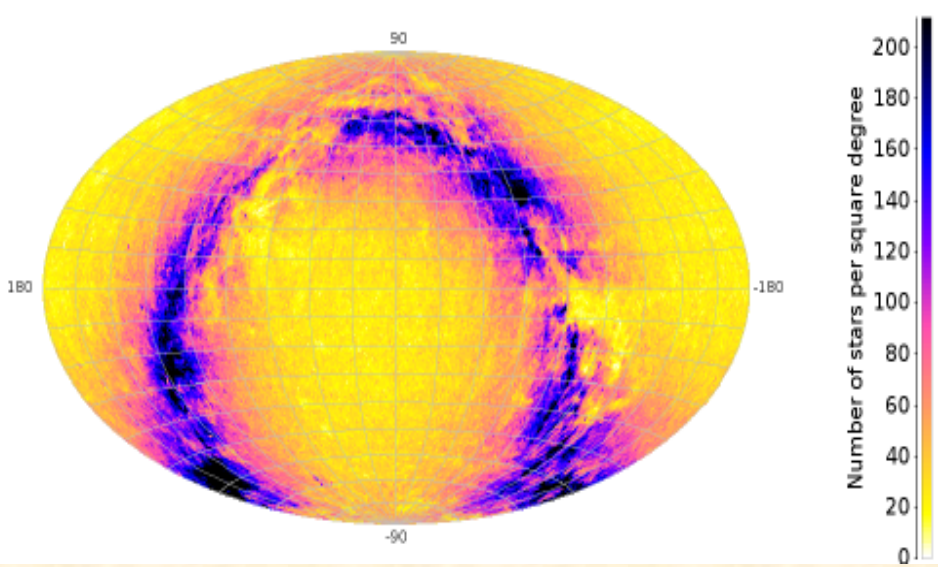
GAIA spacecraft

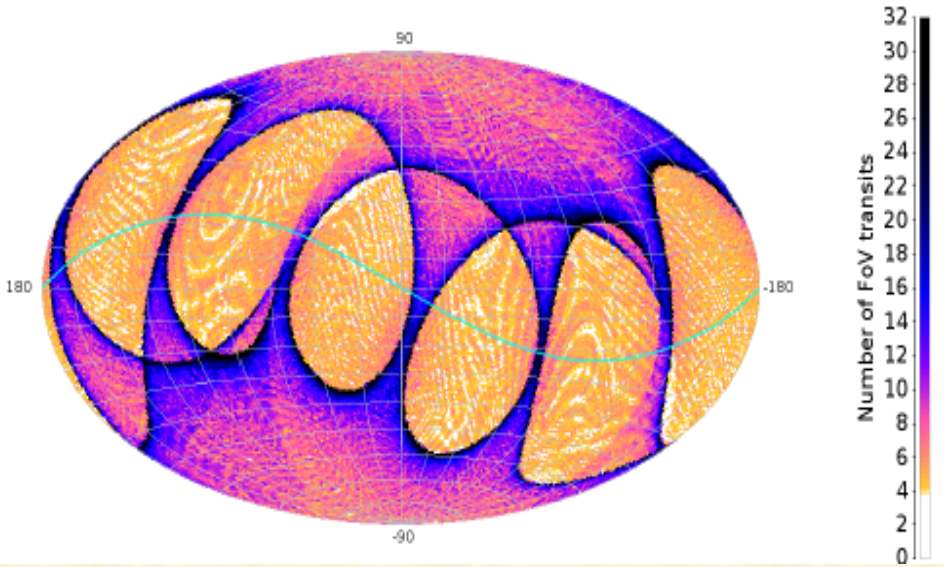


The CCD detectors are saturated at mag 12. However they can measure to mag 3, and expect to be able to measure all 243 stars brighter than 3.

Gaia scanning pattern

- Left – global star distribution
- Right – number of observations in a 6-month period



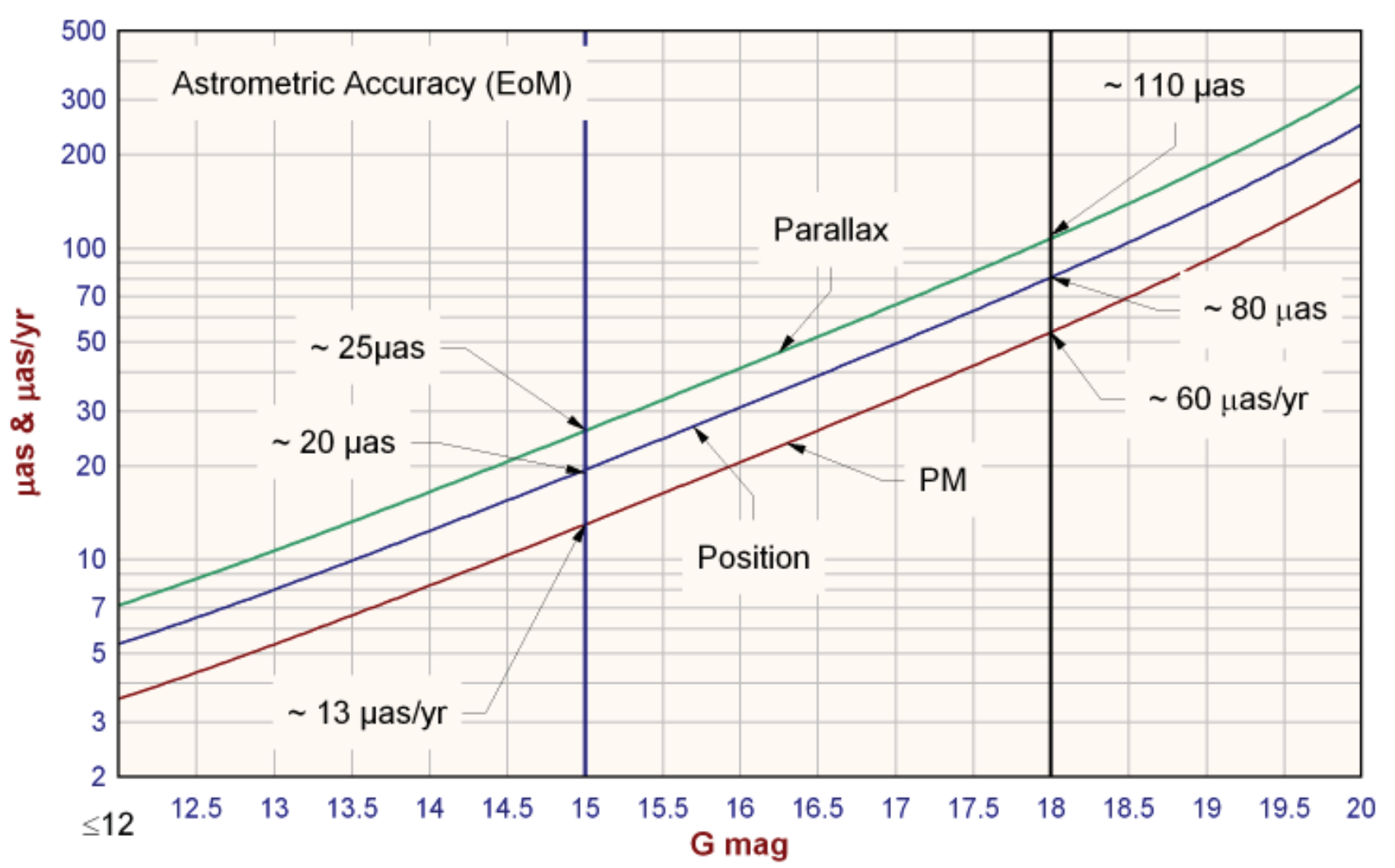


Gaia impact – star positions

Gaia will produce the following:

- μ-arcsec positions, proper motions & parallaxes down to mag ≈20 (∩1 billion stars)
- Radial velocities and spectral types – stars down to mag ≈16 (∩150 million stars) {yes – it has a spectroscope…!}
- Element abundances for stars brighter than 11
- Positions and orbits of asteroids and TNOs, to ∩mag 20

Astrometric accuracy against magnitude – final catalogue



Gaia impact - variables

Multi-epoch photometry for everything brighter than mag 20. Detects variability on time scales between seconds and ∿5 years. Estimated total variables ~18 million, including:

- 5,000,000 'classic' Cepheids
- 3,000,000 eclipsing binaries, with precise physical and orbital parameters for ∿10,000
- 300,000 with rotationally induced variability
- 250,000 Miras and SR variables
- 60,000 - 240,000 δ Scuti variables.
- 70,000 RR Lyrae
- 20,000 supernovae

AAVSO Index catalogue has a mere 342,000 entries

Gaia impact - doubles

Estimated results:

- 700,000 radial velocity orbits
- 800,000 radial velocity + astrometry orbits
- 2,000,000 astrometry orbits
- 4,000,000 non-linear-proper-motion systems
- 40,000,000 resolved binaries
- Resolve all binaries with separations >20mas which have a moderate magnitude difference.

Washington Double Star catalogue: 135,000 pairs

USNO 6th Interferometric catalogue: 83,000 pairs

Gaia data release #1/3

First release: ∿Sept 2016

- Positions (α, δ) and G magnitudes for all stars with acceptable formal standard errors on positions.
- Five-parameter astrometric solution - positions, parallaxes, and proper motions - for stars in common between the Tycho-2 Catalogue and Gaia will be released. [The Tycho-Gaia solution]

Second release: ∿Aug 2017

- Five-parameter astrometric solutions of objects with single-star behaviour
- Integrated Blue Photometer (BP) & Red Photometer (RP) photometry,
- Mean radial velocities will be released for objects showing no radial-velocity variation

Gaia data release #2/3

Third release: ≀Aug 2018 (TBC)

- Orbital solutions, together with the system radial velocity and five-parameter astrometric solutions, for binaries having periods between 2 months and 75% of the observing time
- Object classification and astrophysical parameters, together with BP/RP spectra and/or RVS spectra they are based on,
- Mean radial velocities will be released for those stars not showing variability and with available atmospheric-parameter estimates.

Fourth release: ≀Aug 2019 (TBC)

- Variable-star classifications will be released together with the epoch photometry used for the stars.
- Solar-system results will be released with preliminary orbital solutions and individual epoch observations.
- Non-single star catalogues will be released.

Gaia – Final data release (2022)

- Full astrometric, photometric, and radial-velocity catalogues.
- All available variable-star and non-single-star solutions.
- Source classifications (probabilities) plus multiple astrophysical parameters (derived from BP/RP, RVS, and astrometry) for stars, unresolved binaries, galaxies, and quasars.
- An exo-planet list.
- All epoch and transit data for all sources.
- All ground-based observations made for data-processing purposes.

Issues

For the 1st release:

- Proper motions & parallaxes for stars brighter than ~11.5 will be available in the Tycho-Gaia catalogue (which will be part of the 1st release) 
- For fainter stars - positions  , but no proper motions or parallaxes 
- No entries for stars that show evidence of a companion 

For stars in Tycho-Gaia solution

Astrometric standard errors

Mag.	Number[a]	Position [μas]	Parallax [μas]	Prop. motion [μas yr^{-1}]
Subset *Tycho* without HIPPARCOS				
6–7	411	244	399	198
7–8	8072	198	348	264
8–9	63 630	191	327	403
9–10	257 243	230	407	680
10–11	686 866	329	601	1145
11–12	993 139	379	722	1522
≥12	302 511	349	702	1615

for events within 2 years of Gaia epoch positional uncertainty at mag 6 ∿0.5mas; at mag 9 ∿1.1mas; at mag 12 ∿3.5mas

Remember: for a main belt asteroid, 1mas ≈ 2km

For all other stars

- Either adopt UCAC4 proper motions, or derive proper motions using imaging-epoch positions from UCAC4 [or PPMXL for faint stars?]
- Typical uncertainties in UCAC4 (@~2000)

  Mag ⤵12 20mas Mag ⤵15 50mas
- Given the 15 year interval from UCAC to Gaia, this translates to a proper motion uncertainty of

  Mag < 12 1.3 mas/yr Mag ~ 15 3.3 mas/year

➡ for events within 2 years of Gaia epoch, positional uncertainty at mag 12 ⤵3mas; at mag 15 ⤵7mas

Remember: for a main belt asteroid, 1mas ≈ 2km

Star uncertainties: Long-term

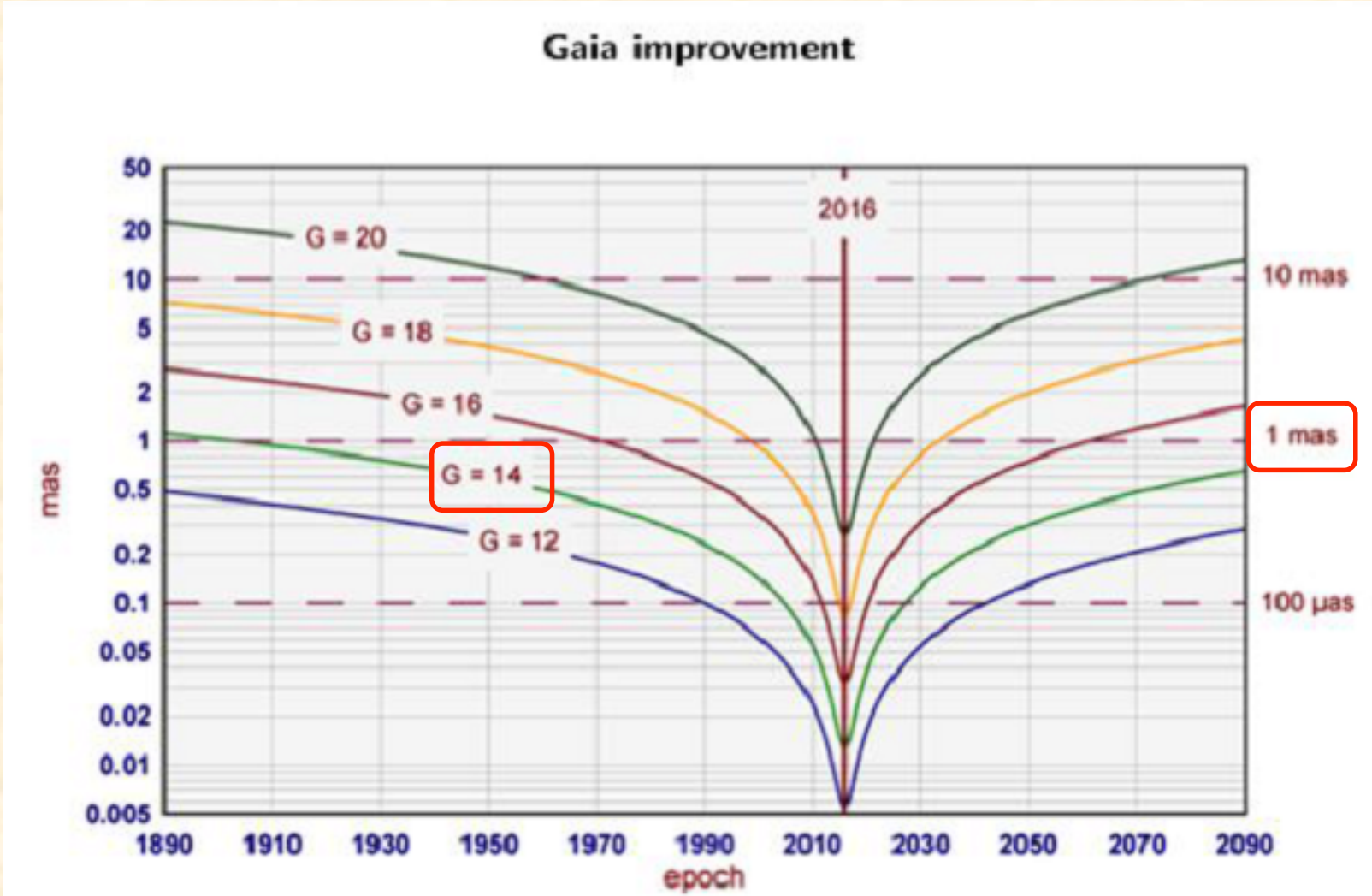


Figure 13: Error propagations of Gaia.

Summary for stars

Gaia 1st release will provide star positions with uncertainties within 2 years of Gaia epoch, of:

mag 6 ≀0.5mas mag 9 ≀1.1mas

mag 12 ≀3mas mag 15 ≀7mas

For stars brighter than ≀13, the uncertainty in path location due to the star will be <10km. At mag 9 it will be a mere 2km

- We will need to consider automating the derivation of proper motions using UCAC4
- Gaia 2nd release will have proper motions, and will considerably reduce the uncertainties

Situation for asteroids 1/3

- Asteroid orbits – not available until 4th release Aug 2019
- Past occultations provide accurate offsets from stars. Numbers are:

<10mas	650
<20mas	920
<50mas	1864

Providing proper motions are available, can derive Gaia-based positions of the asteroid. If there are enough observations of an asteroid, the orbit could be updated

Situation for asteroids 2/3

The remainder of this discussion excludes TNO asteroids

- **Data release #1** – no GAIA proper motions

∴ 'old' positions remain limited by the accuracy of the old catalogue

- However observations made within last few years will be less affected by proper motion issues

∴ opportunity to improve current predictions by using astrometry from asteroidals made in last 1 to 3 years...

Situation for asteroids 3/3

- **Data release #2** – has GAIA proper motions

∴ 'old' positions limited only by the accuracy of the relative astrometry derived from an occultation. Can use our backfile of astrometry from occultations to improve the orbits

Full improvement for asteroids will not come until data release #4 (2019)

Immediate situation for asteroids 1/2

- For main-belt asteroids: positional O-C's likely to change slowly over a period of months

→an observed offset from a recent occultation will provide a reliable indicator of the offset for the next event

→observations from several previous events will provide a trend that can be extrapolated

Immediate situation for asteroids 2/2

- Need to encourage observations of as many events as possible – even if probability of an occultation is small – to establish the recent offsets of asteroid ephemerides
- For stars brighter than mag 12, should be able to have combined uncertainty of star and asteroid <10mas

⇒ that is, a path uncertainty <20km

Asteroids – USNO FASTT

The US Naval Observatory ***F****lagstaff* ***A****strometric* ***S****canning* ***T****ransit* ***T****elescope* (*FASTT*) is a completely automated 20-cm transit telescope utilizing scan-mode CCD cameras

- USNO FASTT telescope may be able to provide astrometry of selected asteroids using the Gaia reference frame
- This might provide the most reliable source of asteroid positions before the release of the Gaia asteroid orbits
- Will need to establish arrangements to obtain astrometry of 'desired' asteroids

Long-term situation for asteroids

- Path predictions will be accurate to about 1km
- Will be able to plan an event with certainty (apart from the weather)
- Focus will move from observing anything that happens nearby, to efforts to study particular asteroids
- Will need to develop capability to incorporate shape model predictions to predict path edge locations

Other issues for asteroids (1)

- Will need to identify asteroids that we should focus our attention. Issues such as:
  - Binary asteroids
  - Asteroids with shape models
  - Asteroids having some other characteristic of importance. (Eg a member of certain classes of asteroids – whether that be based on composition, orbit type, or some other consideration)

Other issues for asteroids (2)

- Also need to think about the frequency of events involving a selected asteroid.
- For example, do we focus on asteroids when they move through star-rich regions of the sky – such that we get numerous events over a few months at different rotational orientations, which we can then match to shape models.

Overall summary

- Gaia Release #1 will largely eliminate the star position as a cause of uncertainty.
- The position of the asteroid will be the greatest source of uncertainty until Gaia release #4. However in the right circumstances the uncertainty in the path location could be less than 20km
- We will need to develop a strategy for selecting events we want to focus on.

The future for asteroidal occultations is exciting….

Any questions?!