

Occultations and Binaries

Extra science from Gaia

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Occultations - Figure of Merit

- $Q = 2\sigma\Delta/D$
 - Dimensionless characterization of probability of successful observation ($[\sigma]=\text{radians}$; $[\Delta,D]=\text{km}$)
- $N_T = 3(Q+1)$
 - Number of telescopes needed to get three chords across diameter of object.
 - $Q=0$, no error, you know where to be

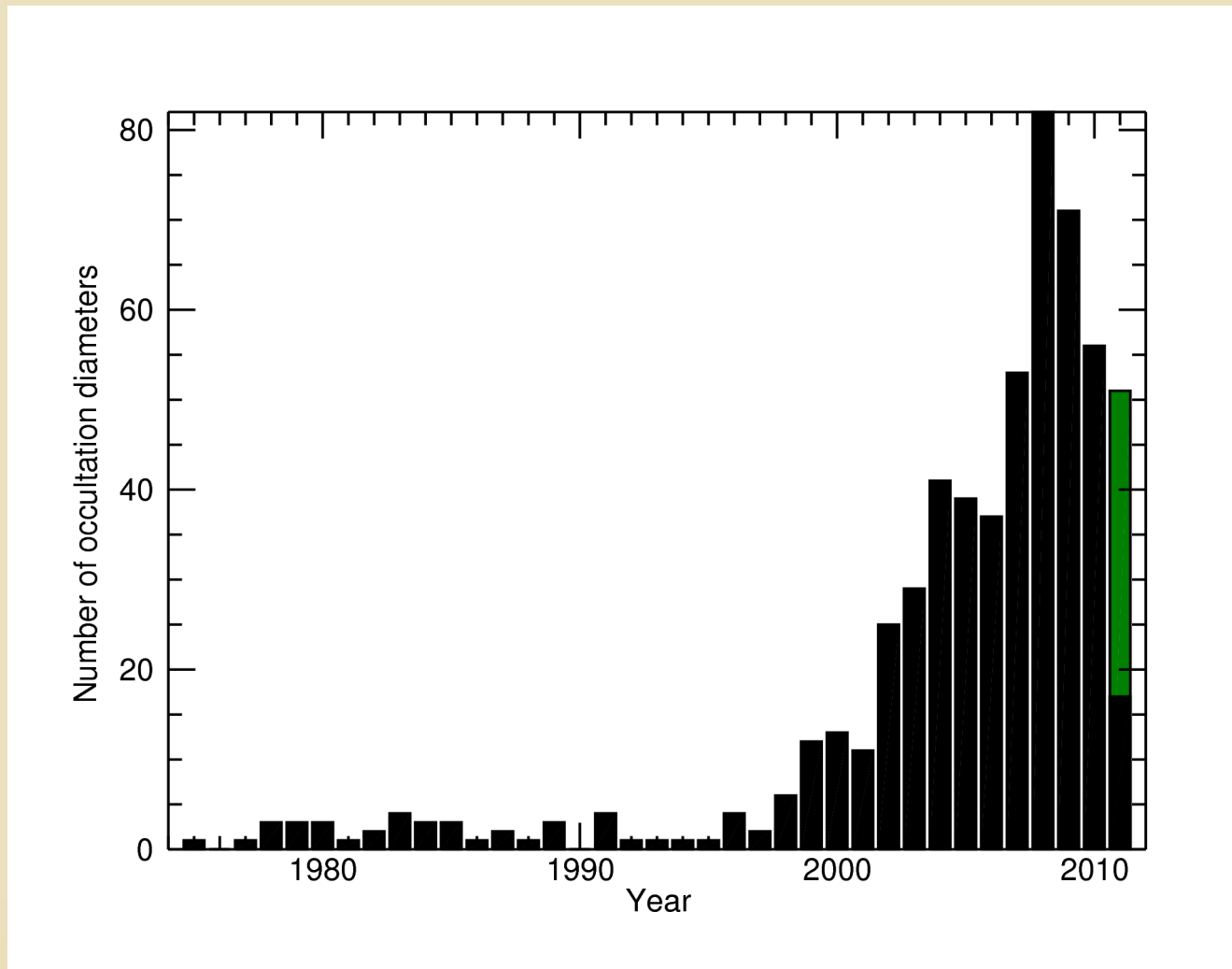
Importance of positional accuracy

- Baseline: $\sigma = 1''$, $\Delta=1$ AU, $D=100$ km; $Q=14.5$
- Main belt: $\Delta=3$ AU, $\sigma = 0.01''$; $Q=0.4$, $N_T=4$
- Outer: $\Delta=30$ AU, $\sigma = 0.001''$ for $N_T=4$
 - $\sigma = 0.01''$; $Q=4$, $N_T=40$ (fixed network)
- Distant
 - $\sigma = 0.1$ mas $\rightarrow \Delta=300$ AU
 - $\sigma = 0.01$ mas $\rightarrow \Delta=3000$ AU

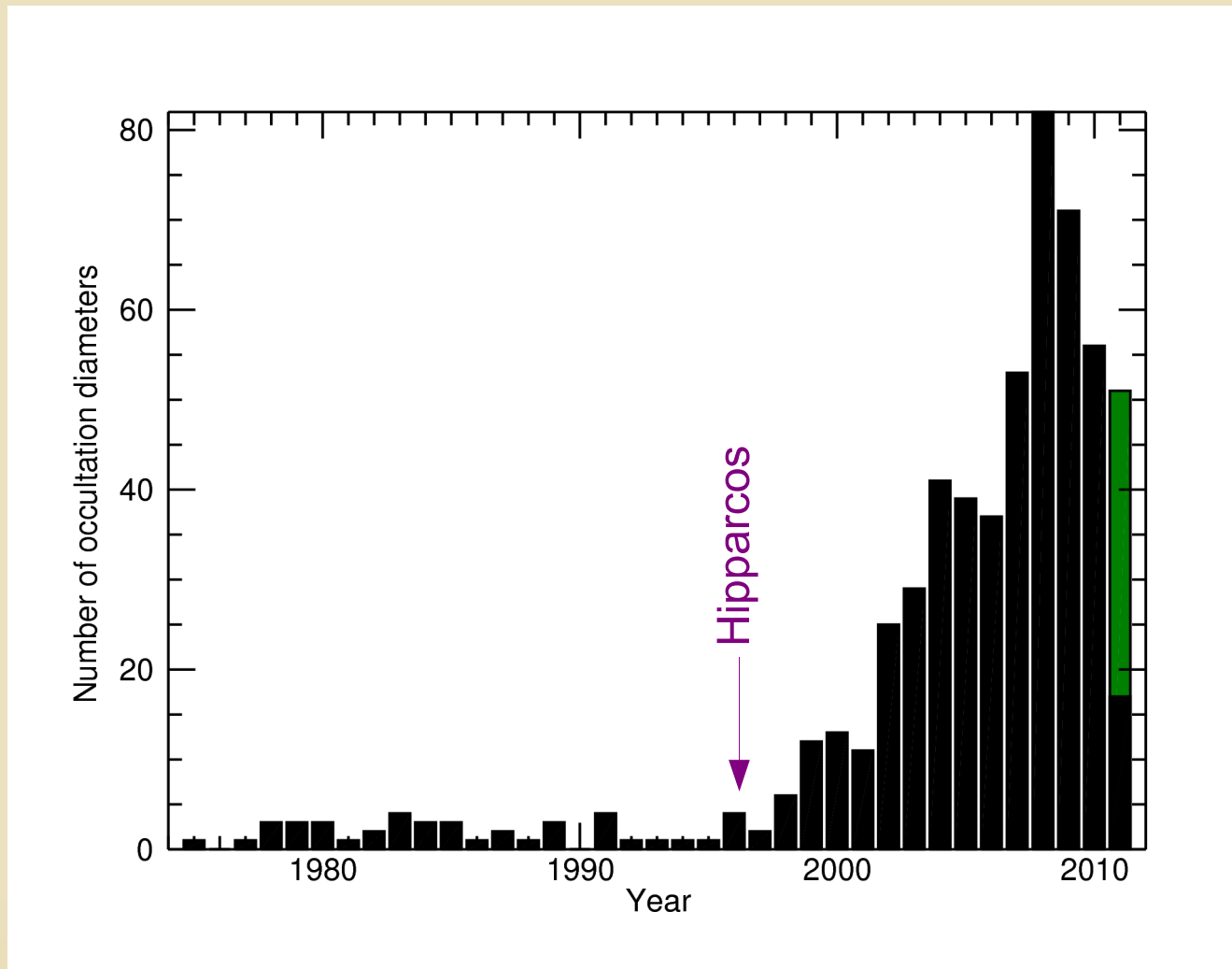
Occultation Observation Type

Type	Fixed	Portable	Network
Low-Q (Jupiter, Titan, some asteroids)	Good for large objects, target of opportunity	Excellent – high density sampling	Useful but can't pick events
Modest-Q (Pluto, Triton, most main-belt asteroids)	Excellent, Rare, easy to do	Good – requires large effort	Excellent – need decent target sample
High-Q (average TNOs, small asteroids, NEOs)	Very low return, rarely worth effort	Poor – effort too large	Good – need large target sample
$Q \sim \infty$ (small TNOs)	Not useful	Not useful	Possible with very large sample

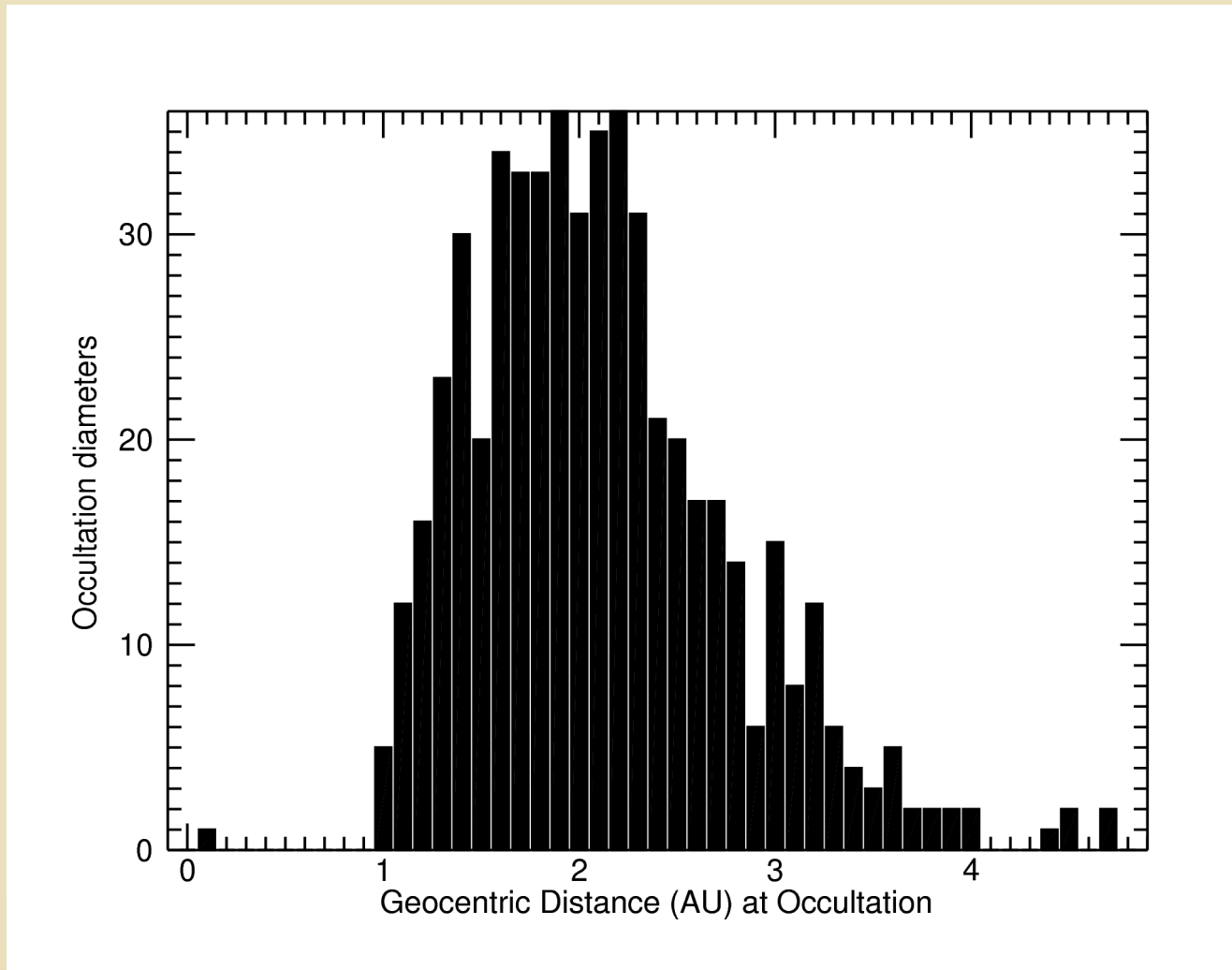
Asteroid occultations vs. time



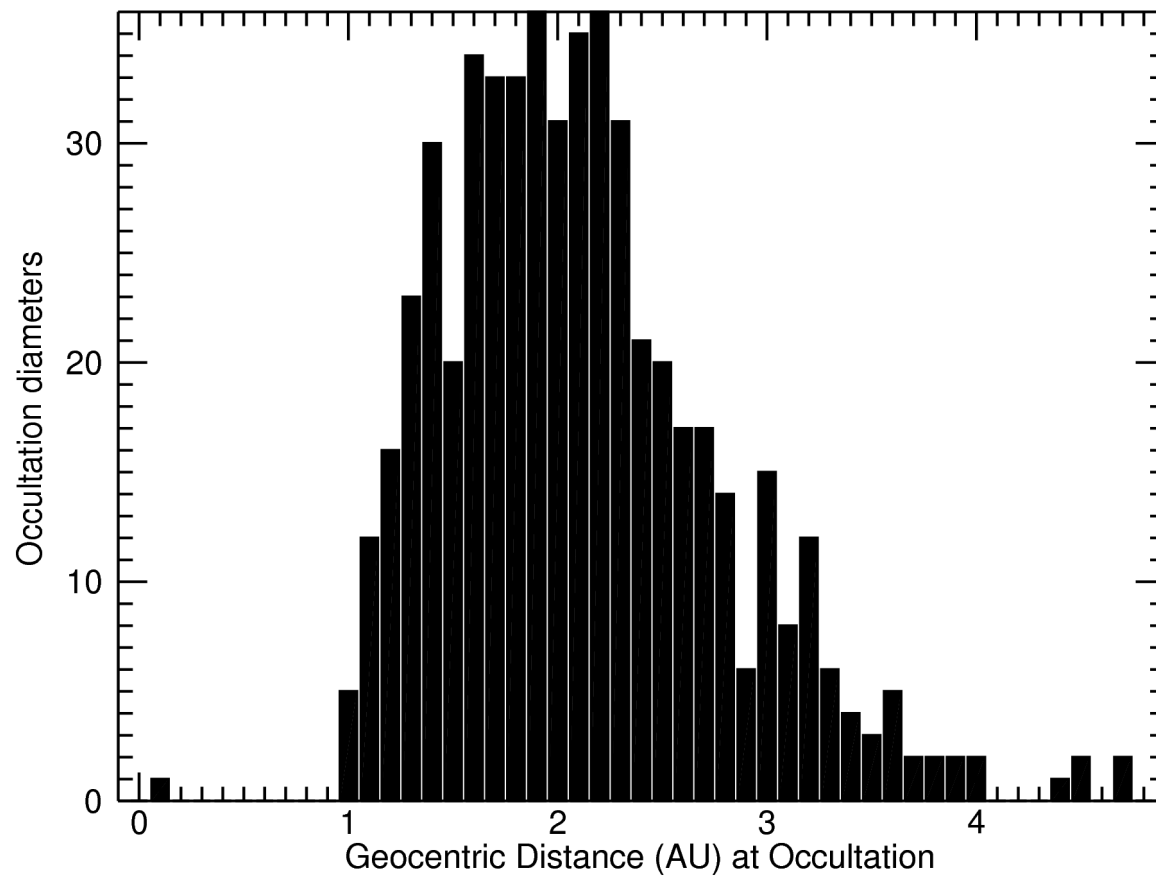
Asteroid occultations vs. time



Asteroid occultations vs. distance



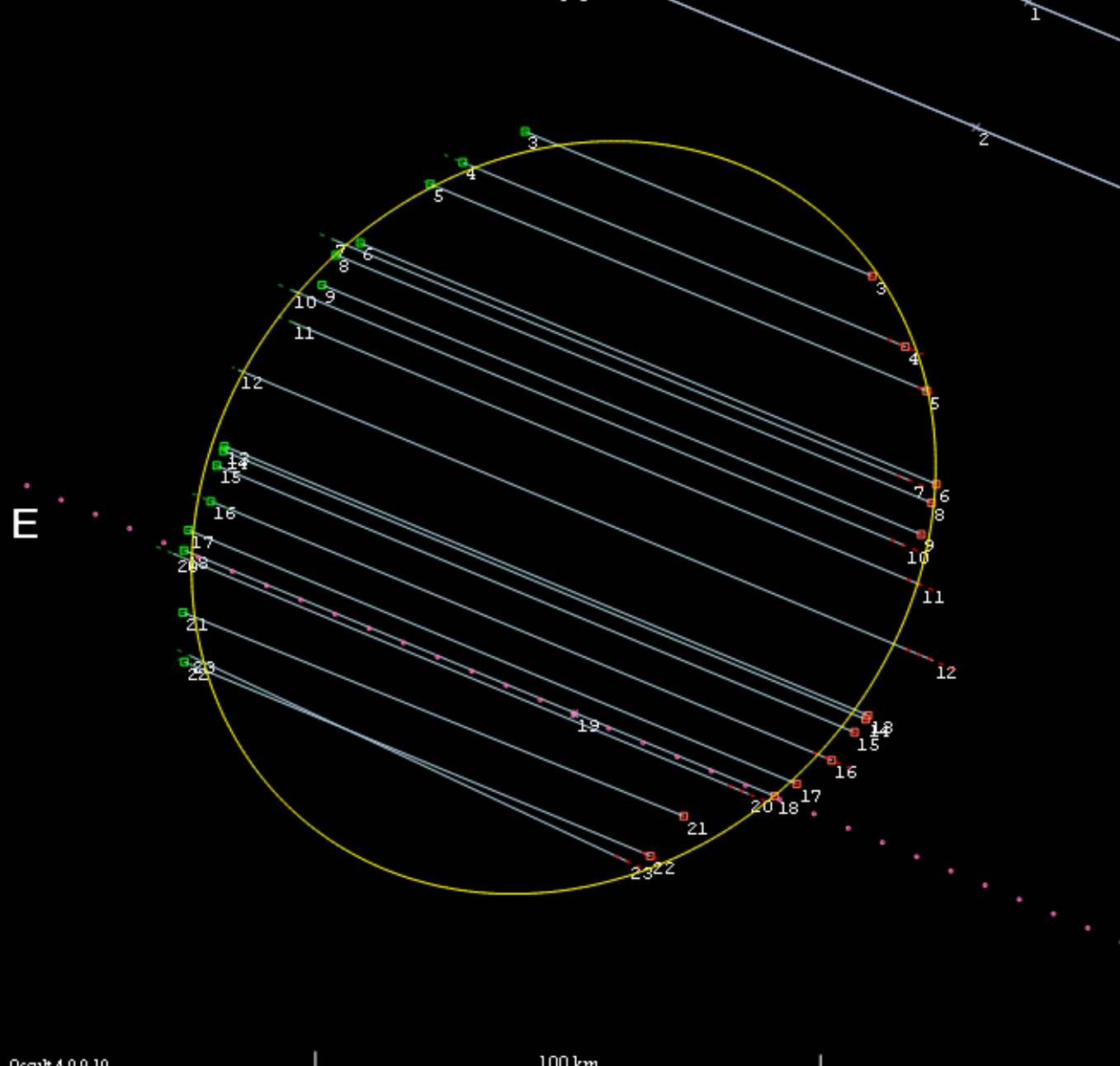
Asteroid occultations vs. distance



4+ TNOs
Chiron
Pluto
Triton

Example result

(212) Medea 2011 Jan 8 $158.1 \pm 2.0 \times 137.7 \pm 0.8$ km, PA -42.4 ± 2.7
 Geocentric X -1081.3 ± 0.4 Y 785.3 ± 0.5 km



Find best fit

Center X 0.0
 Center Y 0.0
 Major axis (km) 0.0
 Minor axis (km) 0.0
 Orientation 0.0

a/b=1.15
dM=-0.15

Double star
 Sepn (masec) 0.0
 PA of 2nd 0.0

Both Primary Secondary

Circular Include Miss events

Plot scale Quality

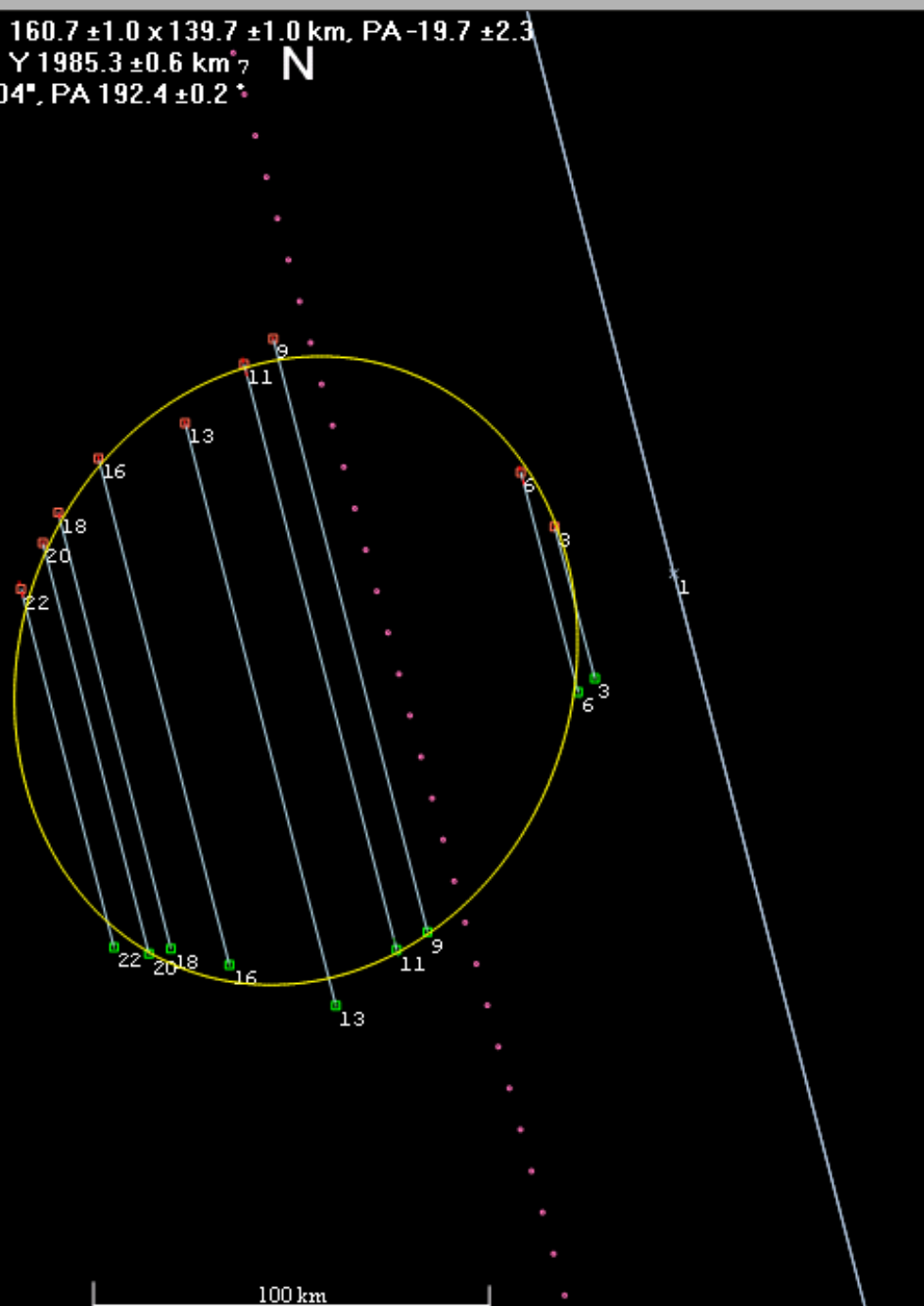
RMS fit 0.0 ± 2.9 km

- 1(M) H Yoshihara, Soja, Okayama, Japan
- 2(M) A Matsui, Ueda, Nagano, Japan
- 3 Y Ikari, Moriyama, Shiga, Japan
- 4 A Asai, Inabe, Mie, Japan
- 5 H Watanabe et al, Inabe, Mie, Japan
- 6 H Tomioka, Hitachi, Ibaraki, Japan
- 7 A Hashimoto, Chichibu, Saitama, Jap.
- 8 Y Nakamura, Kameyama, Mie, Japan
- 9 T Ito, Suzuka, Mie, Japan
- 10 O Ninomiya, Kariya, Aichi, Japan
- 11 R Aikawa, Sakado, Saitama, Japan
- 12 S Uehara, Tsukuba, Ibaraki, Japan
- 13 K Kitazaki, Musashino, Tokyo, Japan
- 14 S Uchiyama, Kashiwa, Chiba, Japan
- 15 H Takashima et al, Kashiwa, Chiba, .
- 16 M Owada, Morimachi, Shizuoka, Japan
- 17 H Suzuki, Hamamatsu, Shizuoka, Japan
- 18 M Uchiyama, Owase, Mie, Japan
- 19(P) Prediction
- 20 Y Sugiyama, Hiratsuka, Kanagawa, Ja
- 21 T Poon et al, Hokoon Science Centre
- 22 M Ida, Mihama, Mie, Japan
- 23 Ted Swift, CA

Example result

(790) Pretoria 2009 Jul 19 $160.7 \pm 1.0 \times 139.7 \pm 1.0$ km, PA -19.7 ± 2.3
 Geocentric X -4299.1 ± 0.6 Y 1985.3 ± 0.6 km
 Double : Sep 0.1448 ± 0.0004 °, PA 192.4 ± 0.2 °

E



Find best fit

Center X 16.8 0.0
 Center Y -133.4 0.0
 Major axis (km) 160.7 0.0
 Minor axis (km) 139.7 0.0
 Orientation -19.7 0.0
 a/b=1.15
 dM=-0.15

Double star
 Sepn (masec) 144.8 0.0
 PA of 2nd 192.4 0.0
 Both Primary Secondary

Circular Include Miss events

Plot scale Quality Excellent

RMS fit 0.0 ± 3.4 km

- 1 (M) R Suggs/B Cooke, Huntsville, AL
- 2 S Degenhardt, Lewisburg, TN
- 3 S Messner, Northfield, MN
- 5 S Degenhardt, Shelbyville, TN
- 6 S Degenhardt, Shelbyville, TN
- 7 (P) Predicted Centerline w/Time
- 8 R Suggs, Chickamauga, GA
- 9 R Suggs, Chickamauga, GA
- 10 D Dunham, Silver Point, TN
- 11 D Dunham, Silver Point, TN
- 12 R Venable, Five Point, GA
- 13 R Venable, Five Point, GA
- 15 R Venable, Hawkinsville, GA
- 16 R Venable, Hawkinsville, GA
- 17 R Venable, Empire, GA
- 18 R Venable, Empire, GA
- 19 R Venable, Chester, GA
- 20 R Venable, Chester, GA
- 21 D Dunham, Lawnville, TN
- 22 D Dunham, Lawnville, TN

Star = 9.9, $\Delta m = 3.5$

Current challenges

- Small objects
 - Small region of action, difficult if not impossible to get shapes with multiple chords
- Distant objects
 - Large objects can be done with large effort
 - Medium objects require different observing strategy (RECON)
 - Both star and object not well enough known

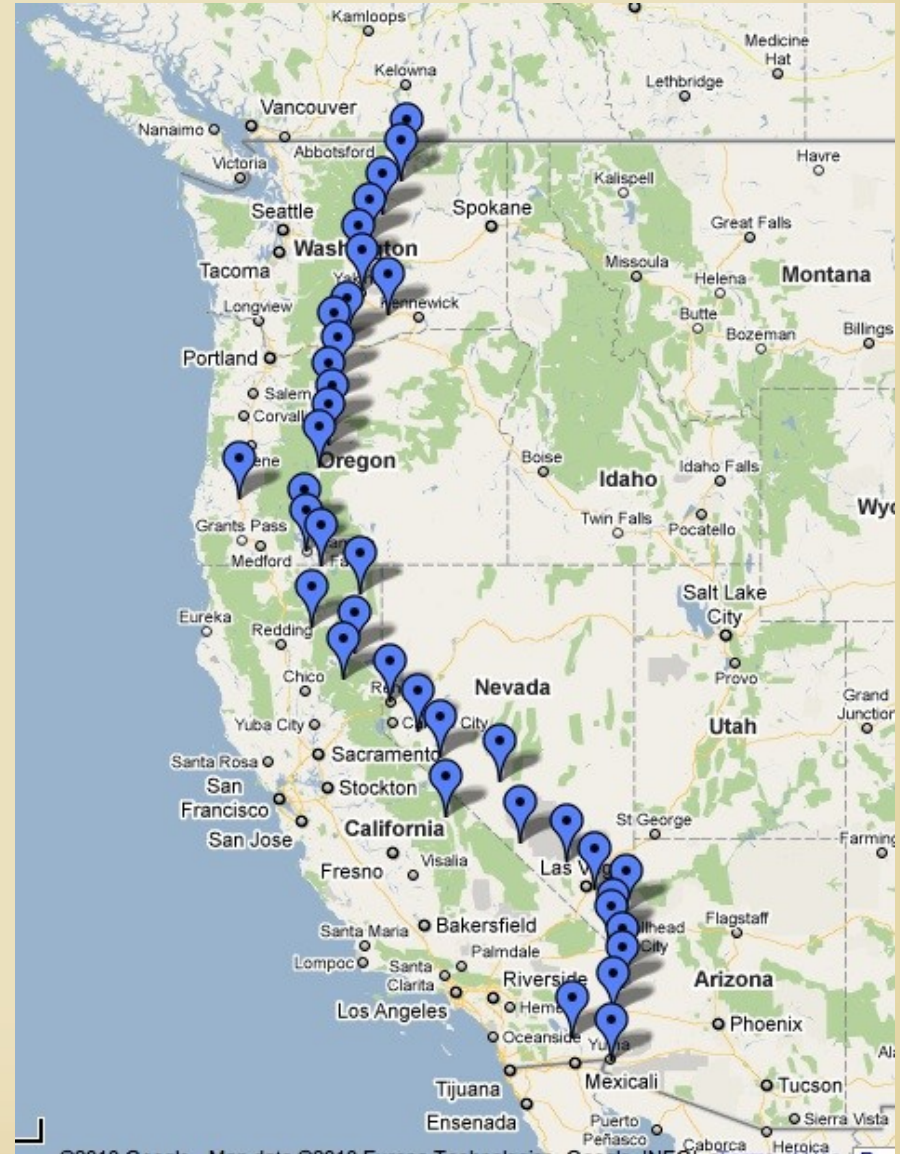
Classical TNOs

- Low- e and low- i , $a \sim 43\text{AU}$
- “100km” class object
- Most were not-detectable with Spitzer
 - Implies, cold, high-albedo, smaller size
- Highest rate of binaries ($\geq 10\%$)
- Least disturbed remnant of solar system formation
- *Second New Horizons* destination

RECON

Research and Education Cooperative Occultation Network

- Targeting 100-km class TNOs
- $V < 13$ (at limit gives size good to 10%)
- Fixed network of 28cm telescopes
- simple instrument (no computer)
- \$5,300 per system (off-the-shelf hardware), includes telescope
- 40 stations, 1800 km spread, 48 km mean spacing
- Staffing with educators and students, rural communities
- Works for Q up to 12 (can constrain tight binaries on low- Q events)



Additional Considerations

- Small or distant objects will be routine
- Prediction effort is simplified
 - Catalog search for target stars
 - Object astrometry directly tied into catalog
- No proper motion catalog degradation
 - Predictions no longer time dependent
 - Deployment can be planned well in advance
 - No more last-minute border crossings
 - More credibility for large telescope requests

Binaries

- Key to formation and evolution models
- Discovery
 - Rate of duplicity, "size" ratio (statistical result is good)
- Orbits
 - System mass, component masses, aggregate orbital properties (a, e, i)
- Mutual events, albedos, shapes, tidal evolution, densities

Gaia related issues

- Look for co-moving sources
 - Quick release needed to enable followup and more detailed characterization
- Look for departure from normal PSF that repeats within scan
 - Need to eliminate background star confusion
 - This will be a result from entire mission
- Astrometric deviations will indicate unseen companion