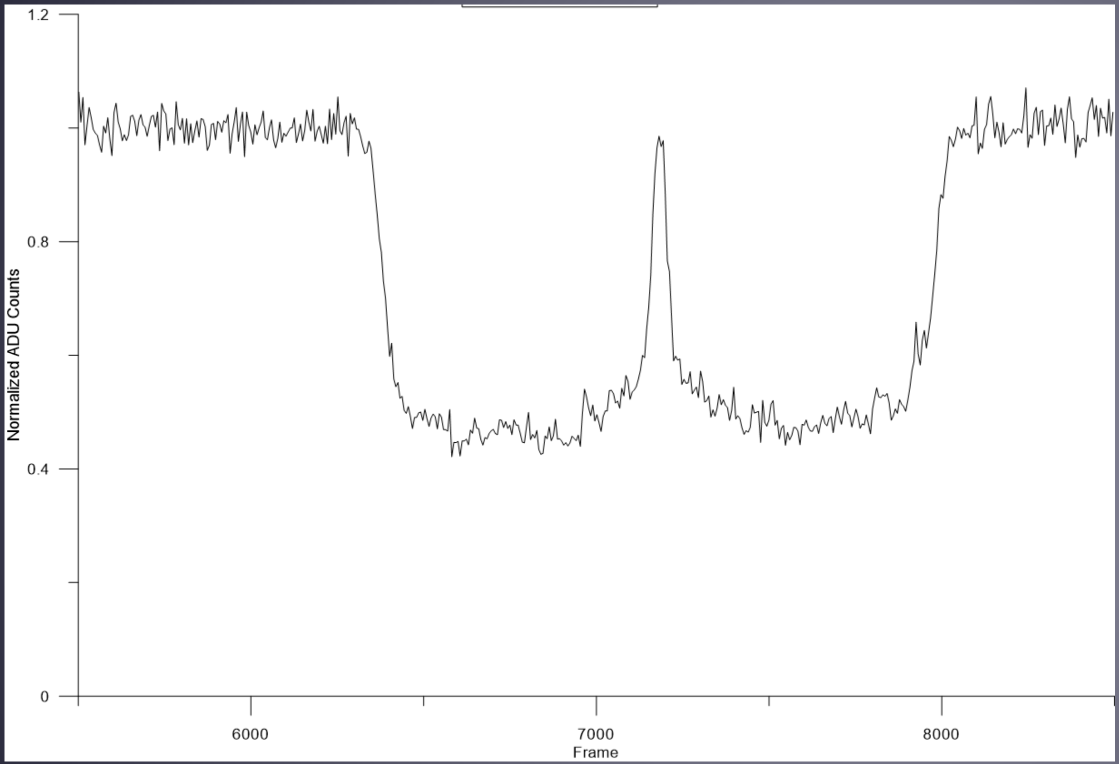
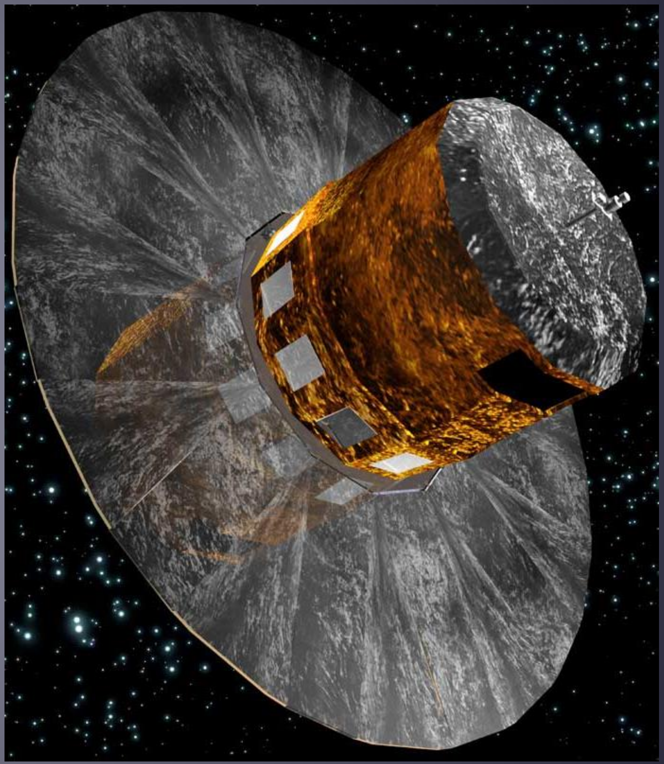
A new approach to stellar occultations in the Gaia era





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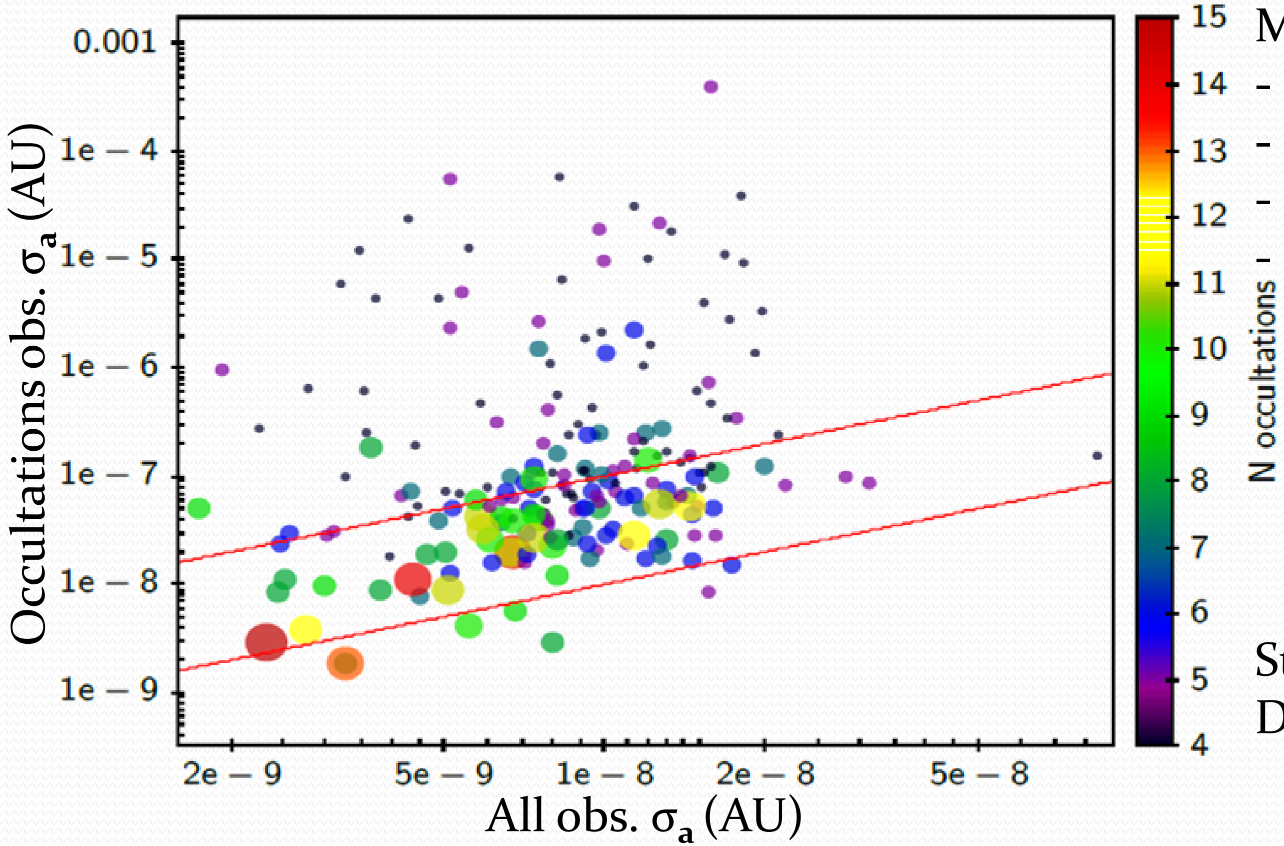
The challenges today

- Improve asteroid orbits by combining Gaia and Earth-based astrometry:
  - Resulting in improved predictions;
  - Difficult due to systematic errors in old catalogues;
  - Work in progress (with Federica Spoto and Paolo Tanga).

- Exploit systematically to obtain astrometry (at Gaia level) from the ground:
  - Science goals: support detection of subtle dynamical effects (Yarkovsky).

- Advantage: with DR2 the error on the star position becomes negligible.

Occultations vs. other archive astrometry



Other astrometry from MPC:

- CCD Imaging;
- Space Telescopes;
- Photography;
- Radio Imaging.

Stellar astrometry from DR1.

Spoto et. al (2017):

Occultations of Gaia stars by asteroids: accuracy on orbits can be as good as all other MPC archive data (decades of observations) combined (Gaia not included).

Gaia – DR2 Results

- Asteroids: > 14 000 with epoch measurements;

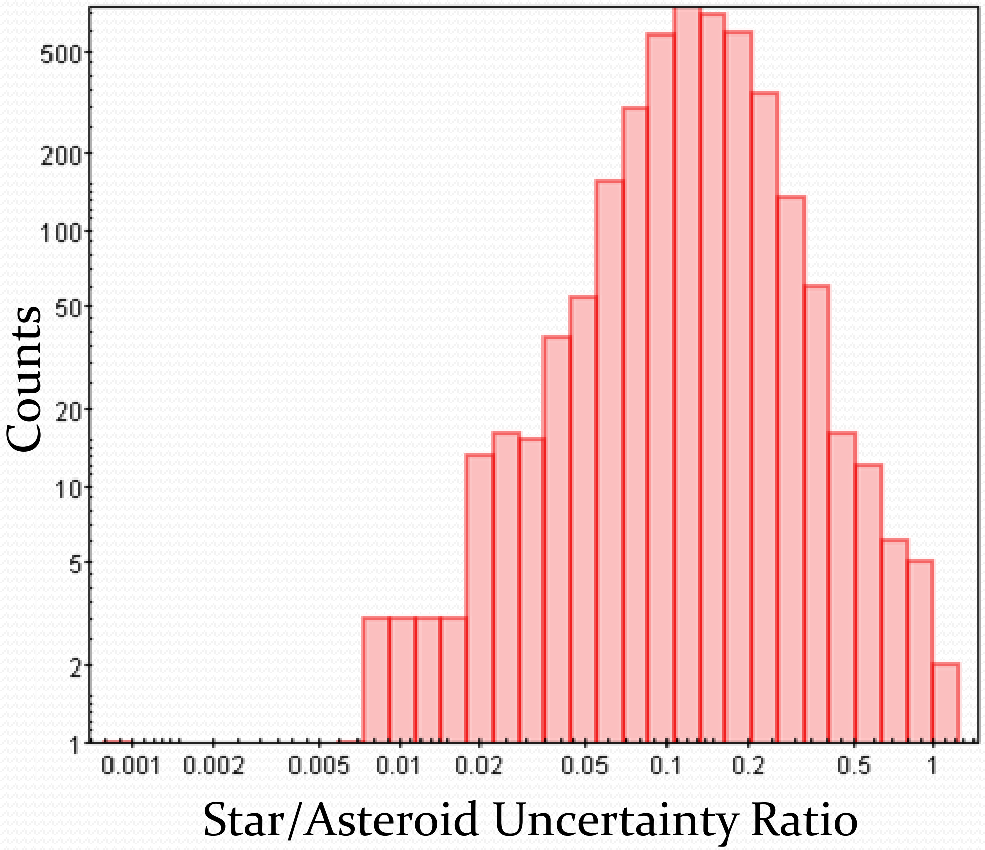
- Stars: Up to mag 14 with sub-mas position and proper motion uncertainties.

Data product or source type	Typical uncertainty
Five-parameter astrometry (position & parallax)	0.02–0.04 mas at $G < 15$ 0.1 mas at $G = 17$ 0.7 mas at $G = 20$ 2 mas at $G = 21$
Five-parameter astrometry (proper motion)	0.07 mas yr^{-1} at $G < 15$ 0.2 mas yr^{-1} at $G = 17$ 1.2 mas yr^{-1} at $G = 20$ 3 mas yr^{-1} at $G = 21$

Gaia – Impact on Predictions

- Star uncertainty used to be major factor when making predictions;
- With GDR2, millions of targets suddenly have sub-mas error margins;
- Amount of viable event predictions “explodes”: Calern for 1 year: ~250 events with >10% probability, without accounting for asteroid orbit improvement;
- New strategies needed to observe them, such as robotic telescopes.

Stars no longer contribute to error

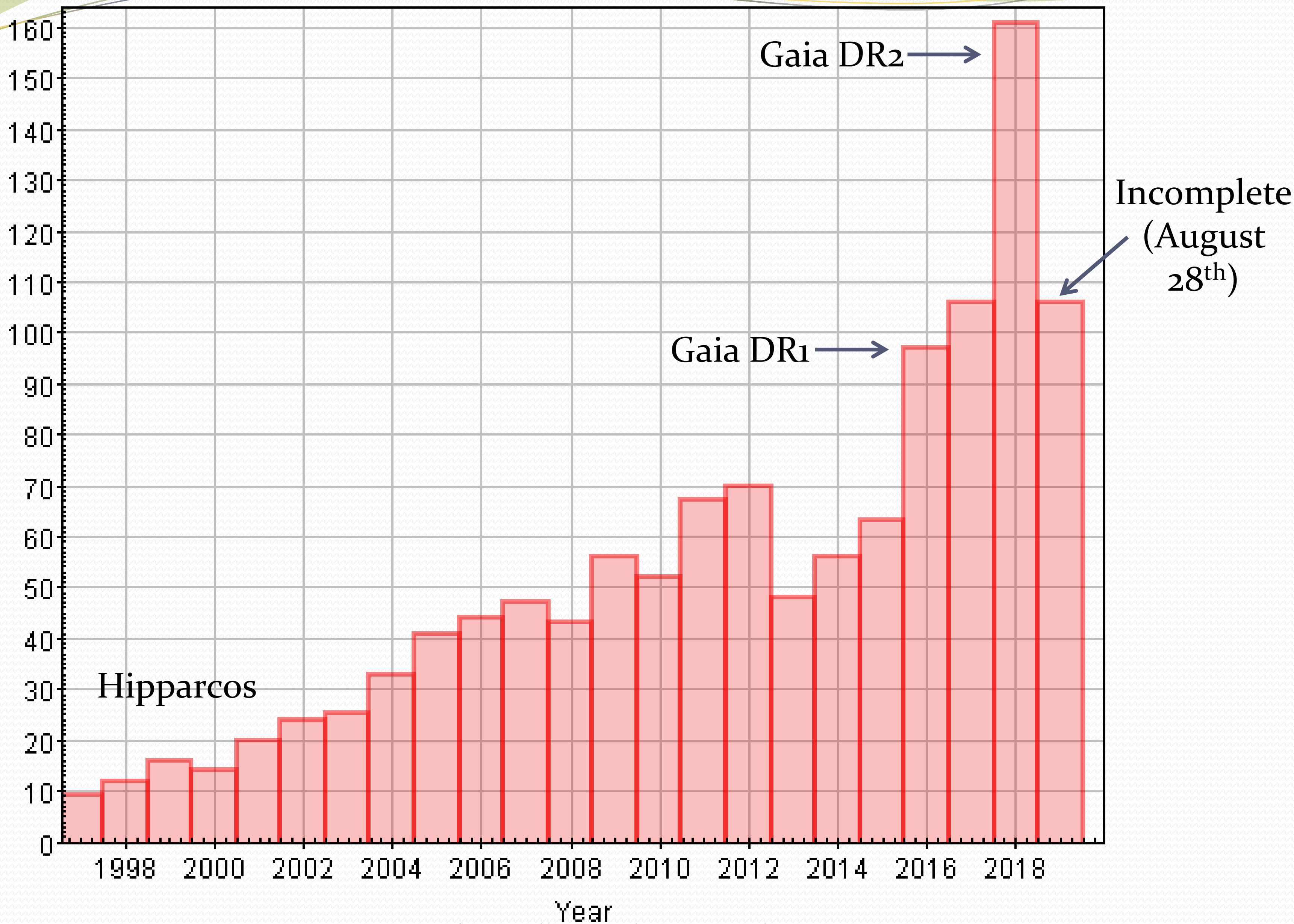


Sources:

- Star uncertainty: Gaia DR2;
- Asteroid uncertainty:
  - ephemeris (JPL Horizons);
  - With current orbits (no Gaia observations).

Star uncertainty usually 3-20x smaller than asteroid's.

History – Events by Year



Gaia – DR3 and Beyond

- Early GDR3: end of 2020;

- Asteroids: ~100 000, with epoch astrometry, some with orbital solutions, shape and spin models and a few low resolution spectra;

- Stars: improved astrometry (34 months of data vs 22 in GDR2);

- Beyond GDR3: Future releases depend upon mission extension (2022, possibly up to 2024).

Context for this Work

- Gaia decreases uncertainties to the point where viable events outgrow manpower available;
  - In particular, smaller asteroids can be observed with bigger frequency;
  - Automated data reduction and regression systems become necessary.

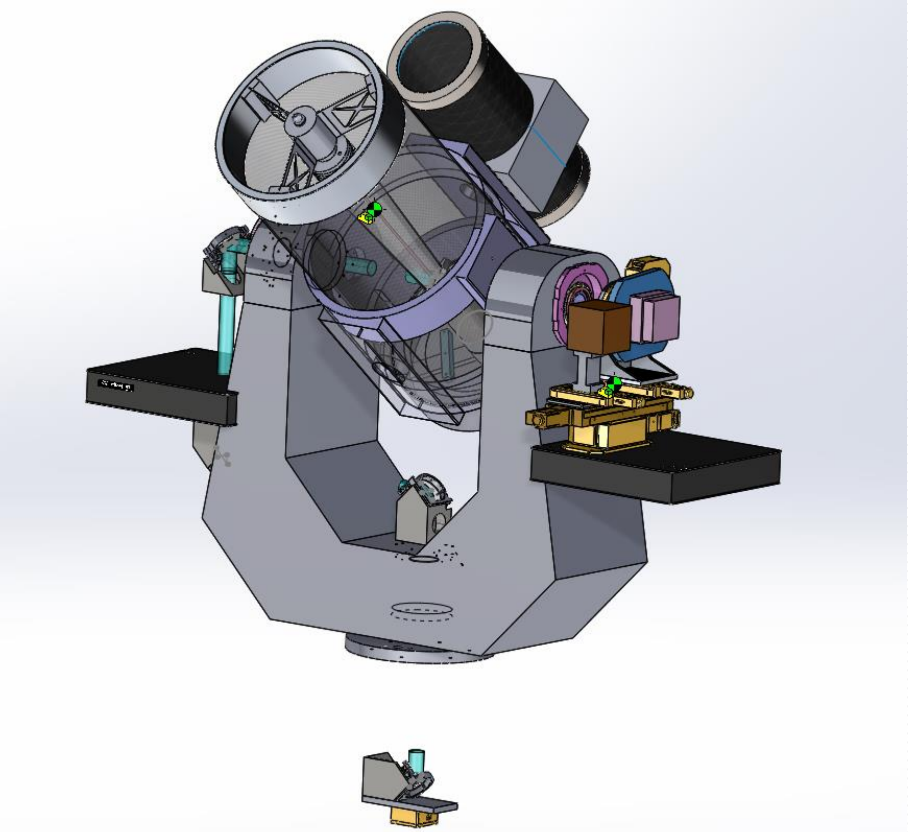
- Probabilistic approach to whether or not an occultation happened instead of "yes"/"no" system (confidence level);

- Goal – build an automated pipeline for the data reduction:
  - Based on a realistic telescope + detector system.

UniversCity Robotic Telescope

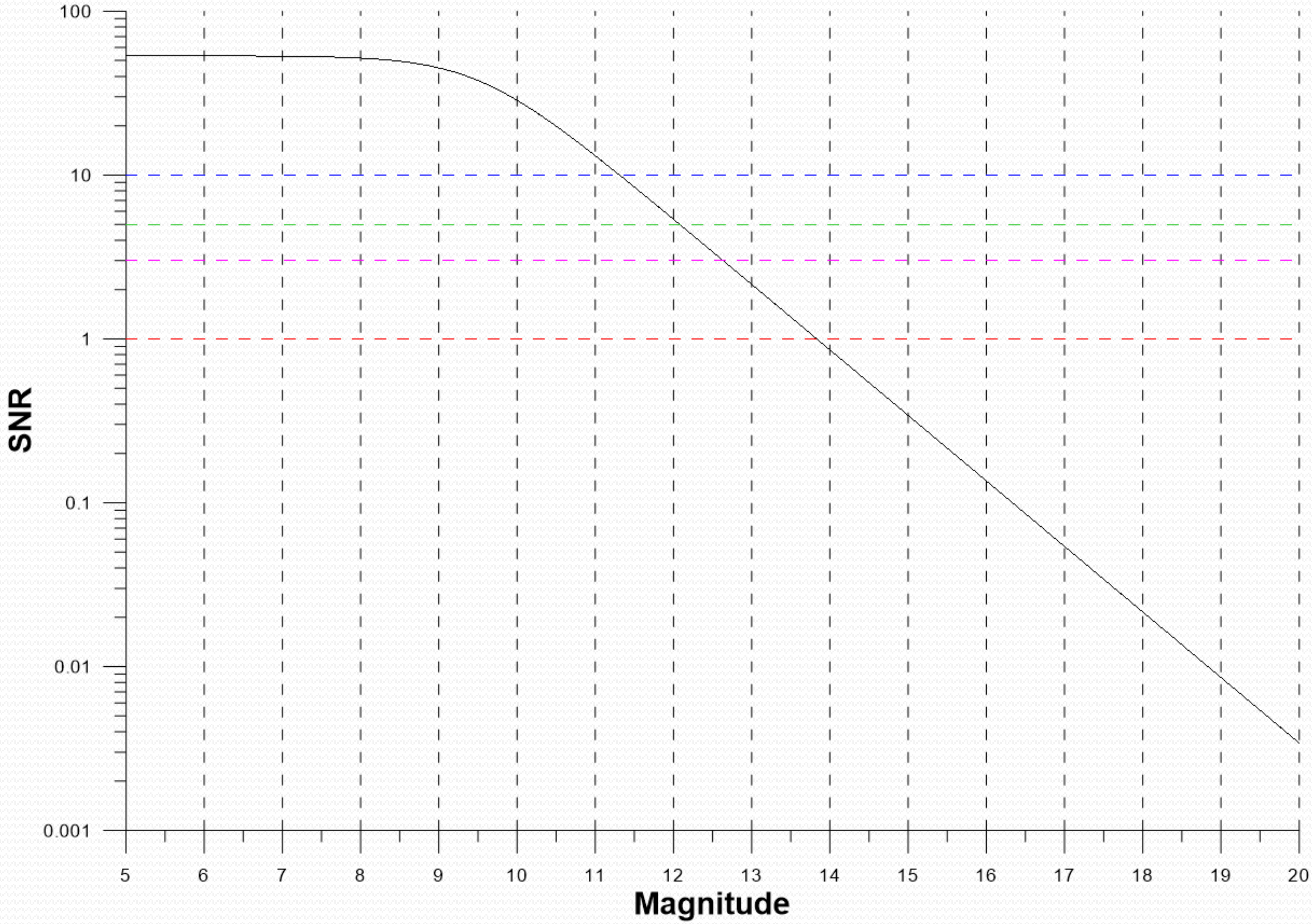
- Telescope prototype used for this study:
  - UniverCity 50 cm robotic telescope at Calern Observation site, near Nice;
  - First light : end of 2019.

- Will allow several observations per week without human intervention.



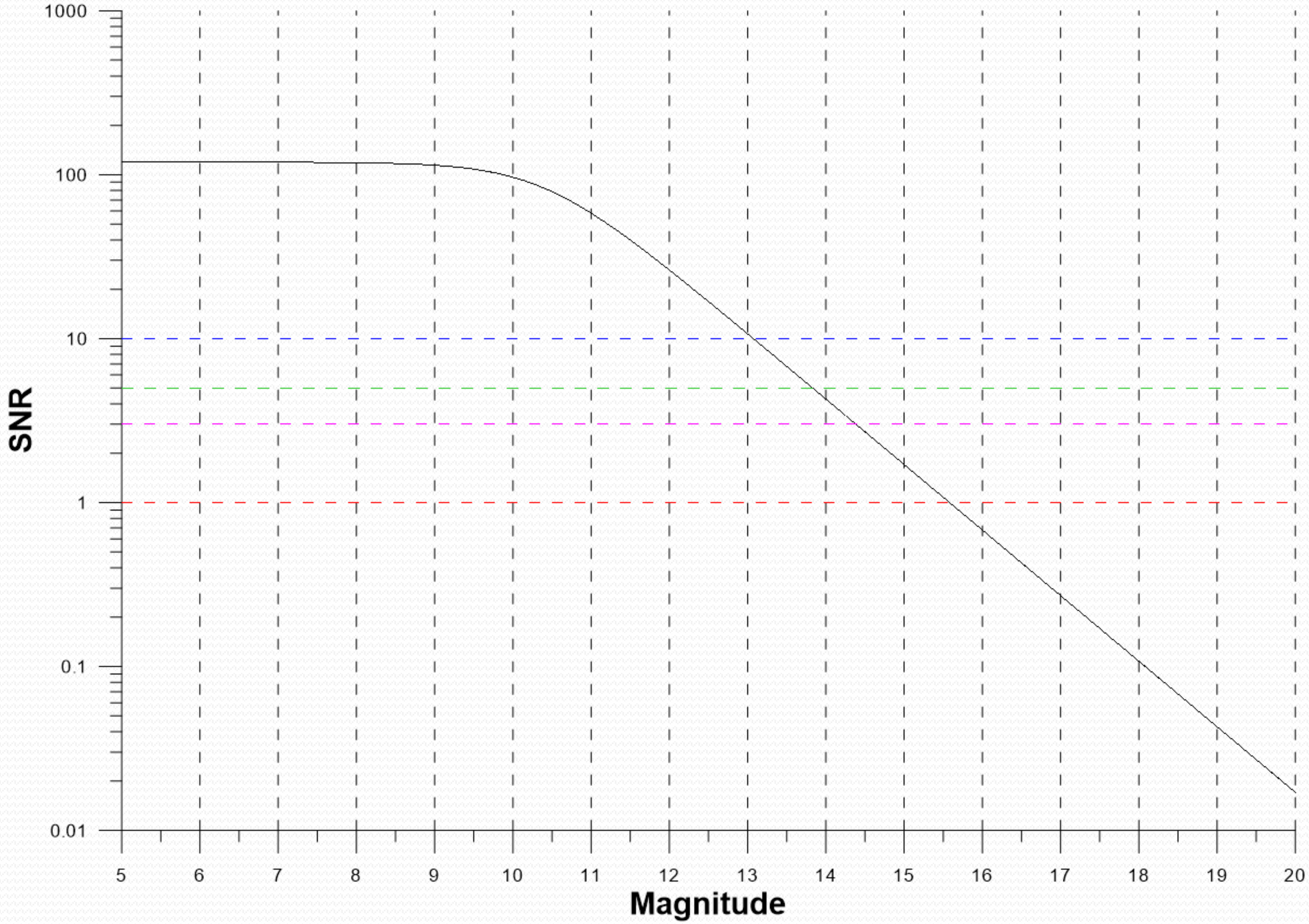
UniversCity's Limitations

- Exposure time 0.1 s: limiting magnitude ~12.5 (SNR~3).



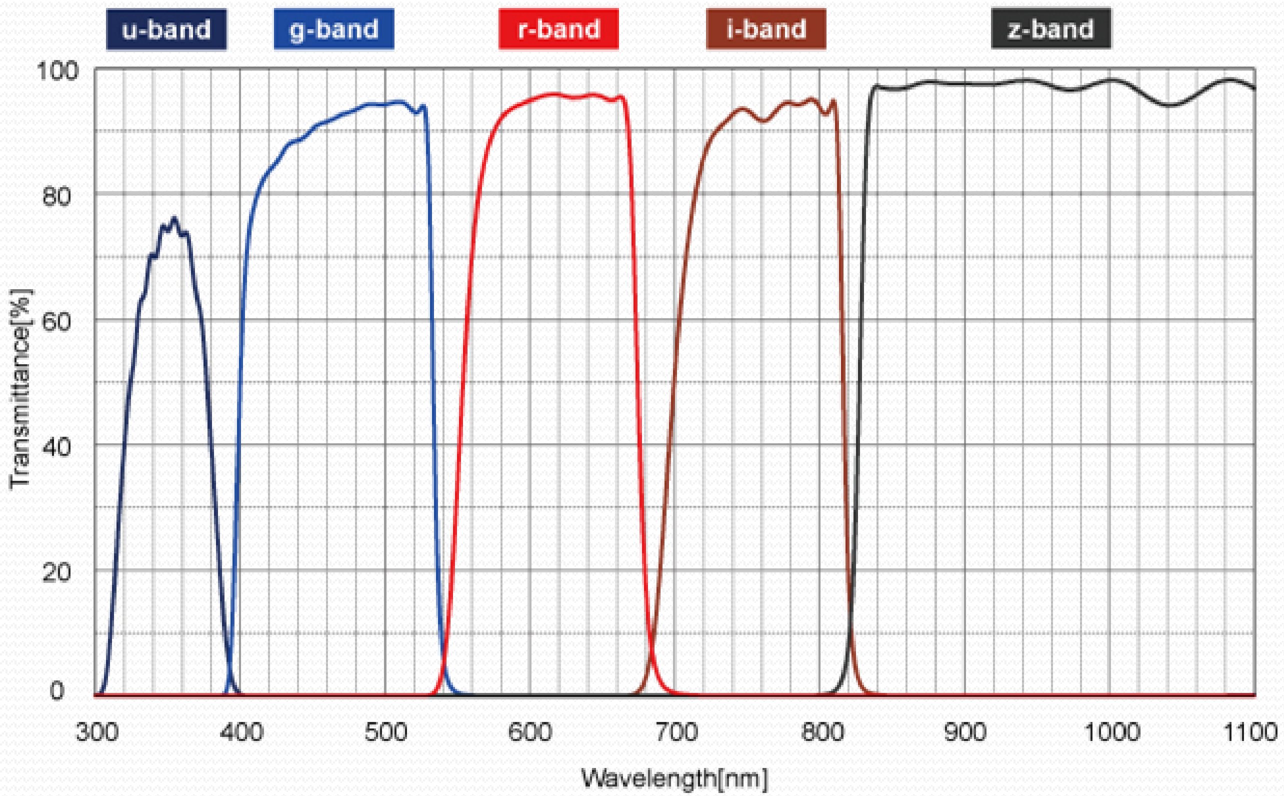
UniversCity's Limitations

- Exposure time 0.5 s: limiting magnitude ~14.5 (SNR~3).



UniversCity's Limitations

- Noise estimates based on previous observations with C2PU telescope;
- Limiting magnitude likely conservative, due to use of filter in those observations (SDSS i', 700-850 nm).



Occultation Model

$$\boxed{F(t) = F_0 - A * S(\mu; \sigma; \omega)}$$

F(t) -> Lightcurve function;

S(μ, σ, ω) -> Supergaussian, square-like function if σ is very small;

F_0 -> Combined flux (Star + Asteroid) outside occultation (constant);

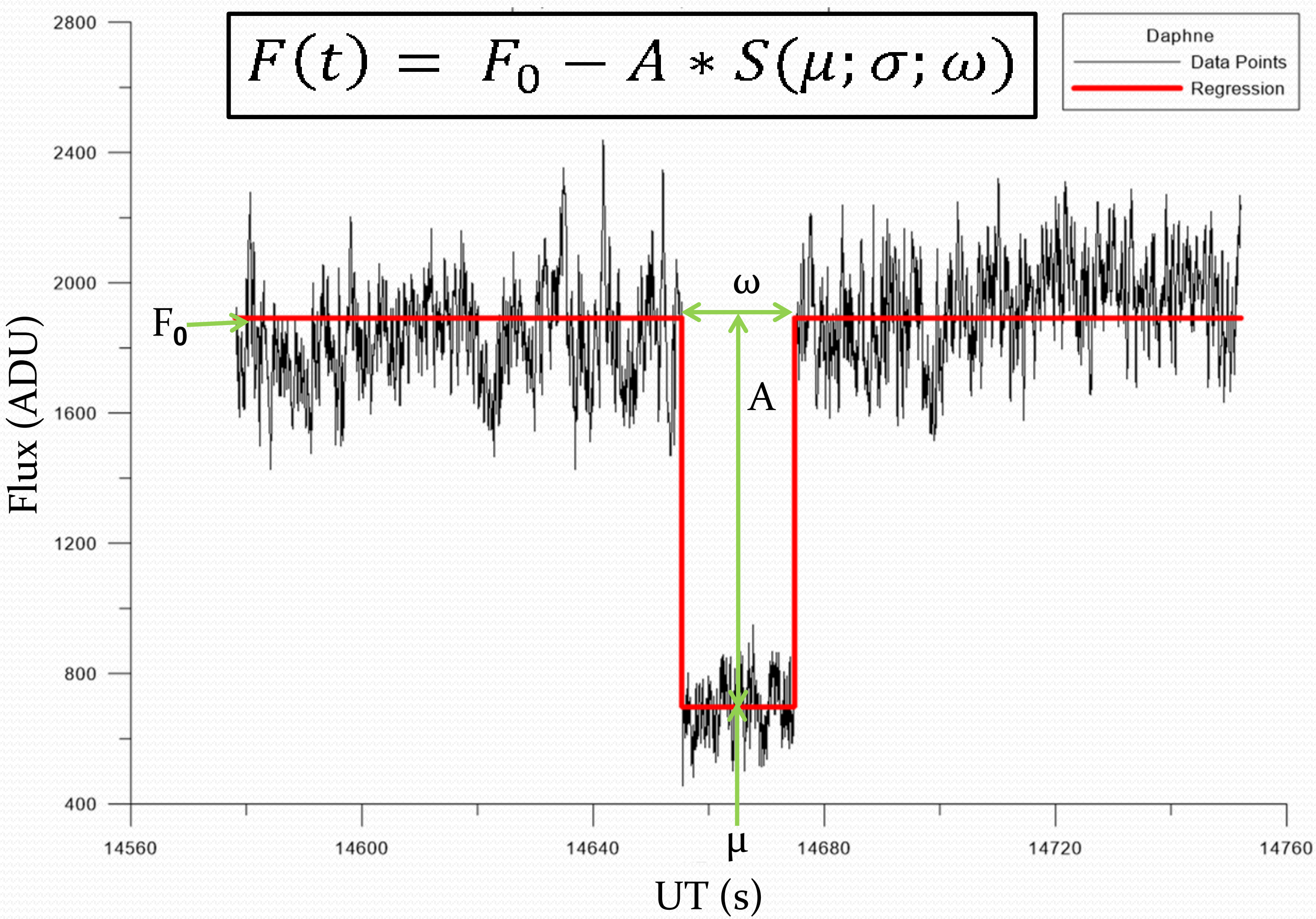
A -> Drop caused by occultation (constant);

4 parameter regression (fixed σ);

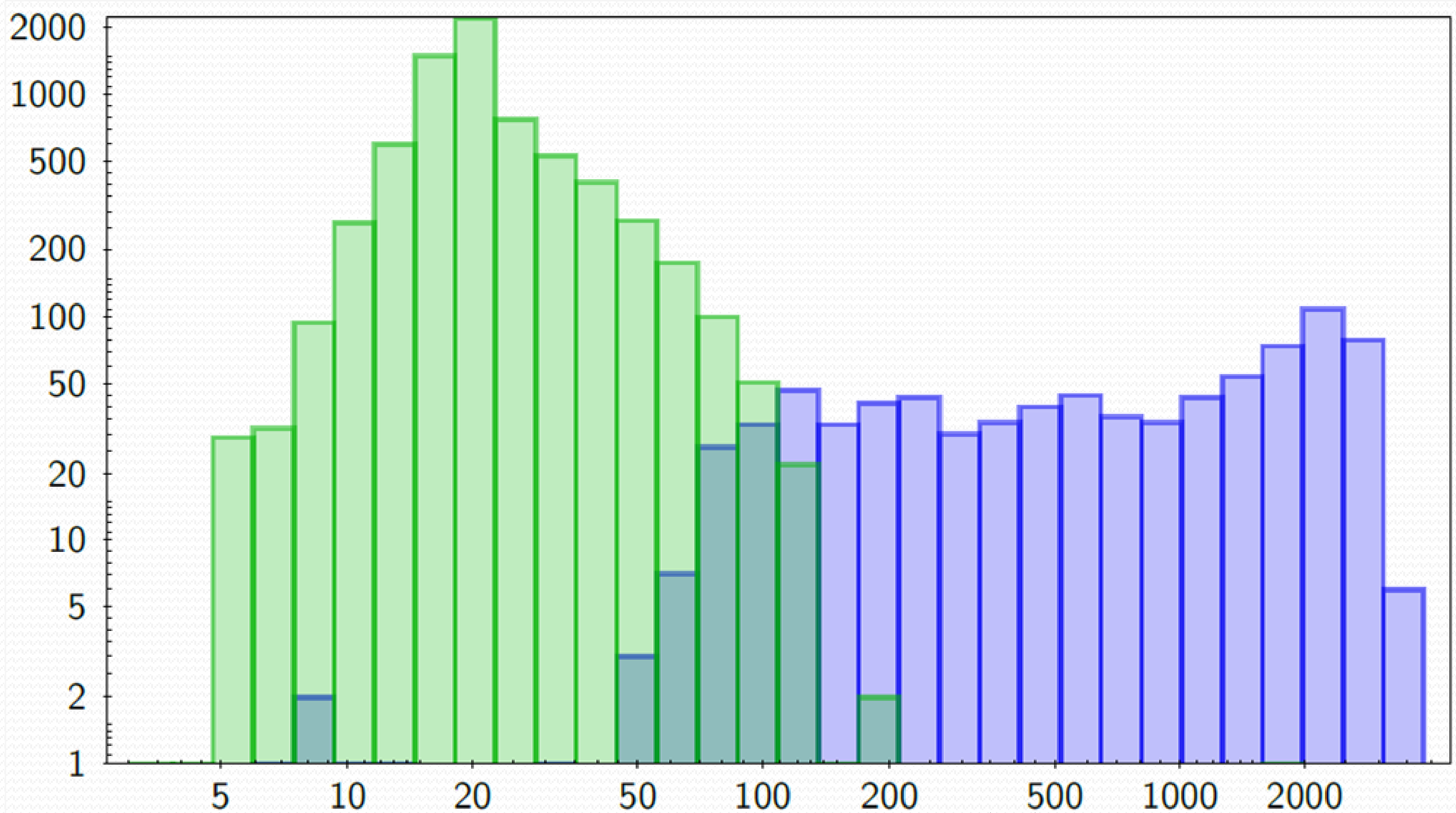
No Occultation Model (Control)

$$\boxed{F(t) = F_0}$$

Regression: Example



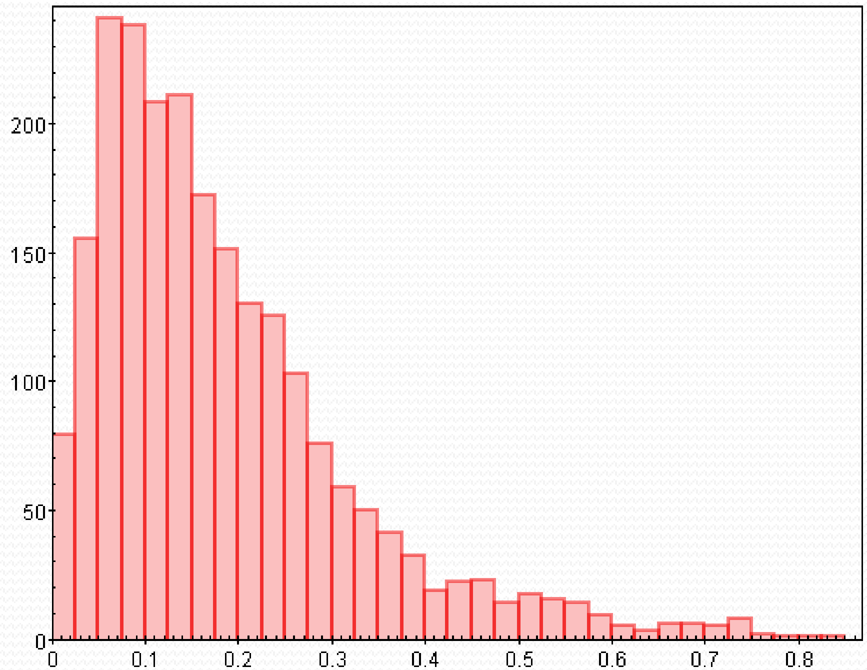
Results – centre epoch and confidence



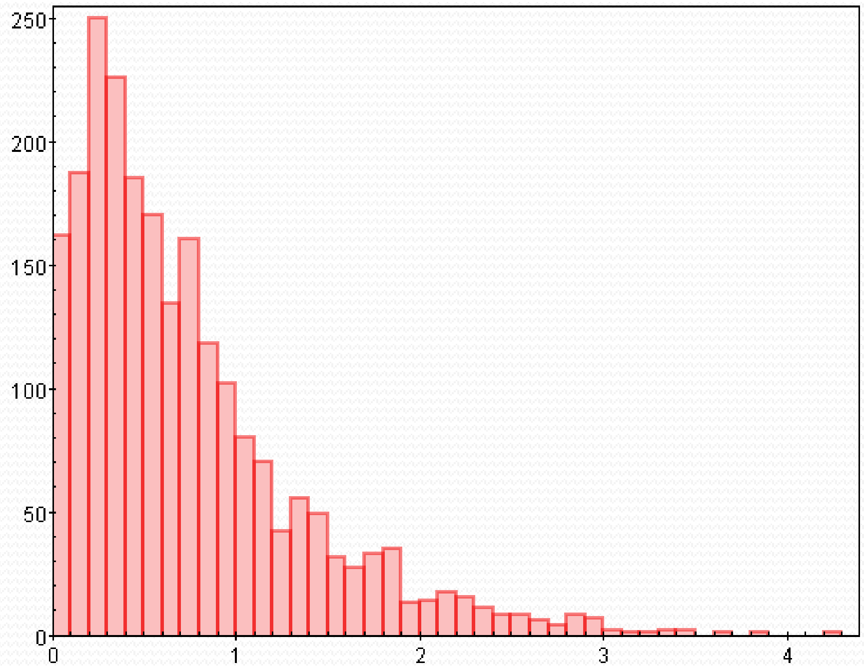
Centre Epoch Precision (%)
Green – Statistically significant regressions.
Blue – Non-statistically significant regressions.
Precision on Centre Epoch (units of sampling time).

Results – Astrometry

Expected along-track uncertainty on the chord position.



uncertainty (mas)



asteroid/star Uncertainty Ratio

Typical values : proper motion 10-15 mas/s in the Main Belt;
2700 predicted events for Calern, Nice (1-year period) → DNR, apparent motion;
Requirements of magnitude, drop and duration similar to those simulated.

Conclusions

- For a 50 cm telescope the practical limit is at least V~12.5 with 0.1 s exposure and 14.5 with 0.5 s;
- Bayesian Inference Method performs better than classical Least Squares Fit for these data;
- Minimum duration limit ~2 samples during occultation;
- Typical uncertainty:
  - Centre Epoch: ~20% of sample time → 0.1-0.2 mas;
  - Duration: 5-10% of chord → 1-2 km for a 20 km asteroid.

Perspectives

- Use of Universcity soon and of its 35 cm prototype (at OCA) now;

- Take into account orbital uncertainty in the statistics of predictions;

- Exploit improved orbits with asteroid astrometry in GDR2;

- Study impact of future data releases of Gaia, in particular orbital solutions and shape models.

Thank you!