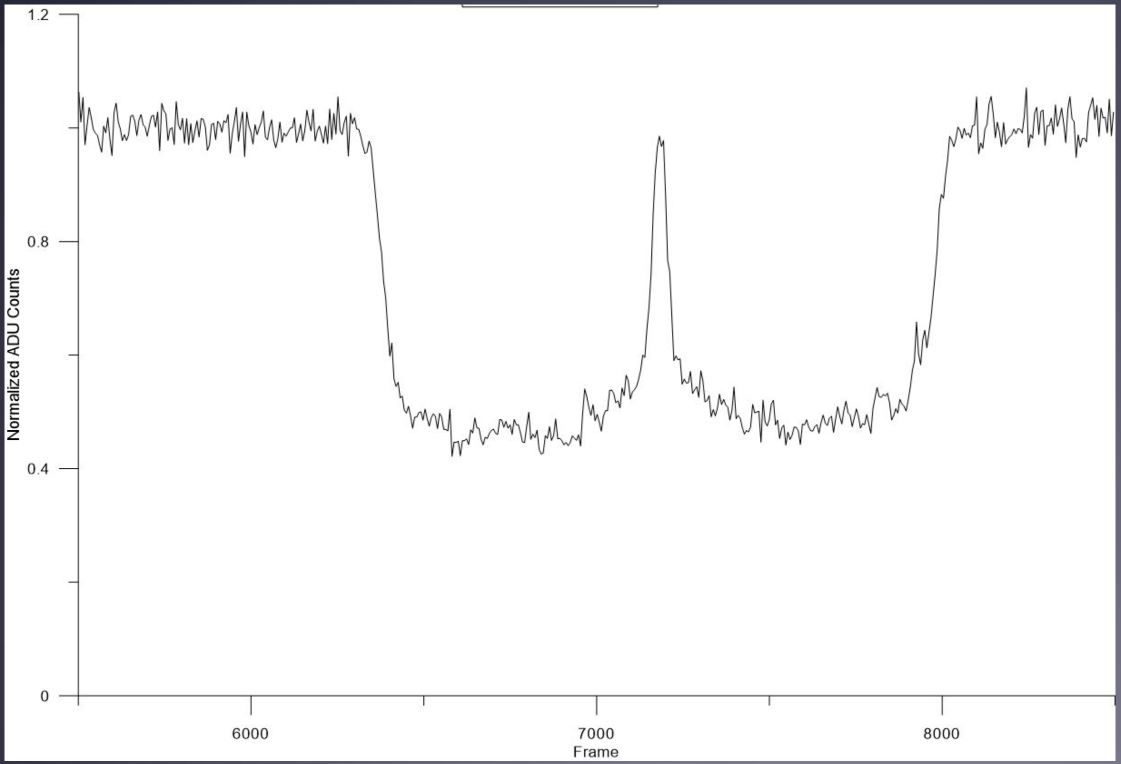
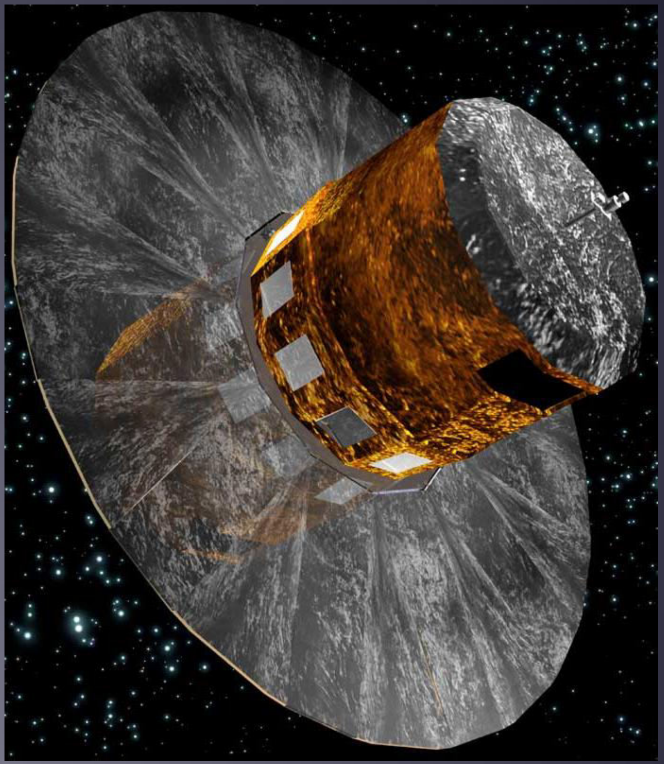
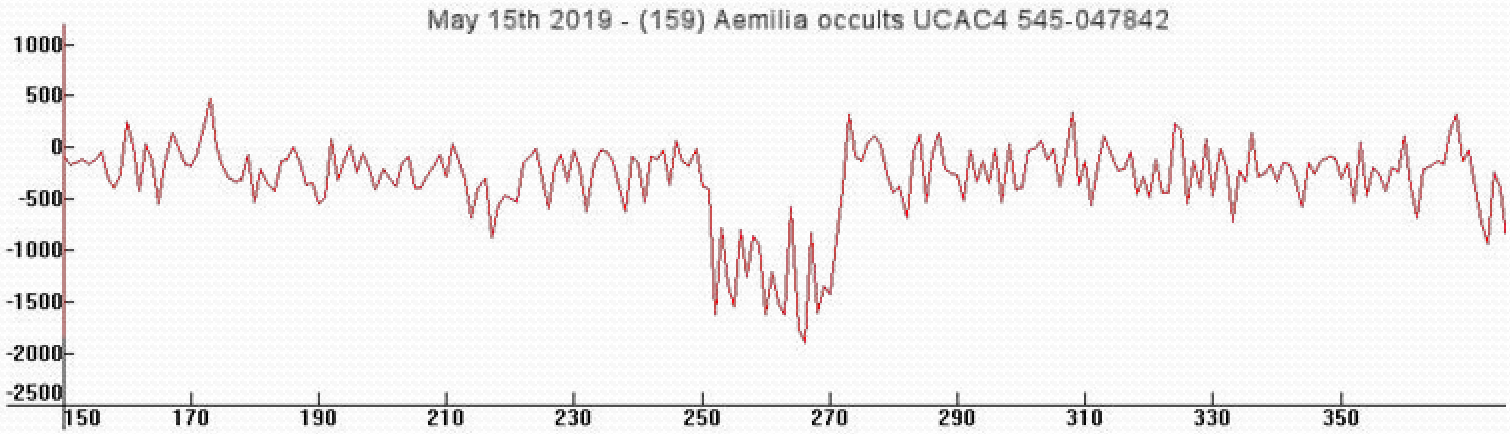
# A new approach to stellar occultations in the Gaia era

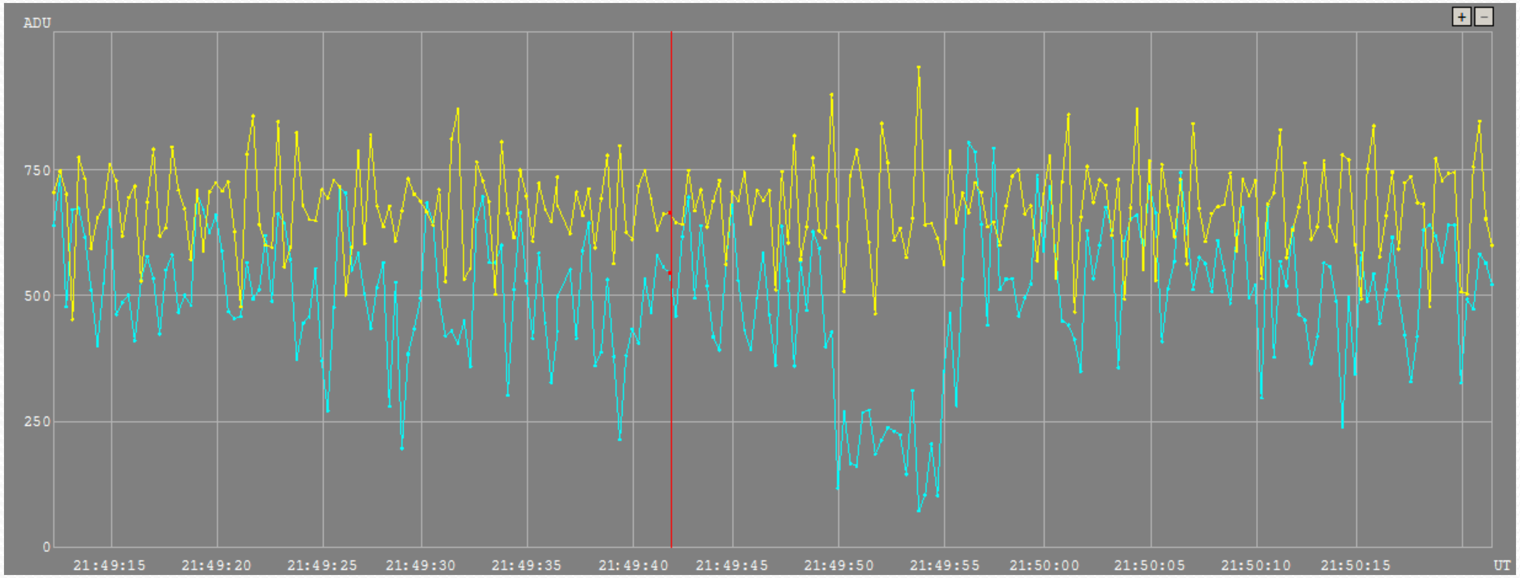


2019/05/16 – Journées de la SF2A
João Ferreira (Observatoire de la Côte d'Azur & IA-Lisboa)
Paolo Tanga (Observatoire de la Côte d'Azur, Nice and Gaia Mission)
Pedro Machado (IA-Lisboa)

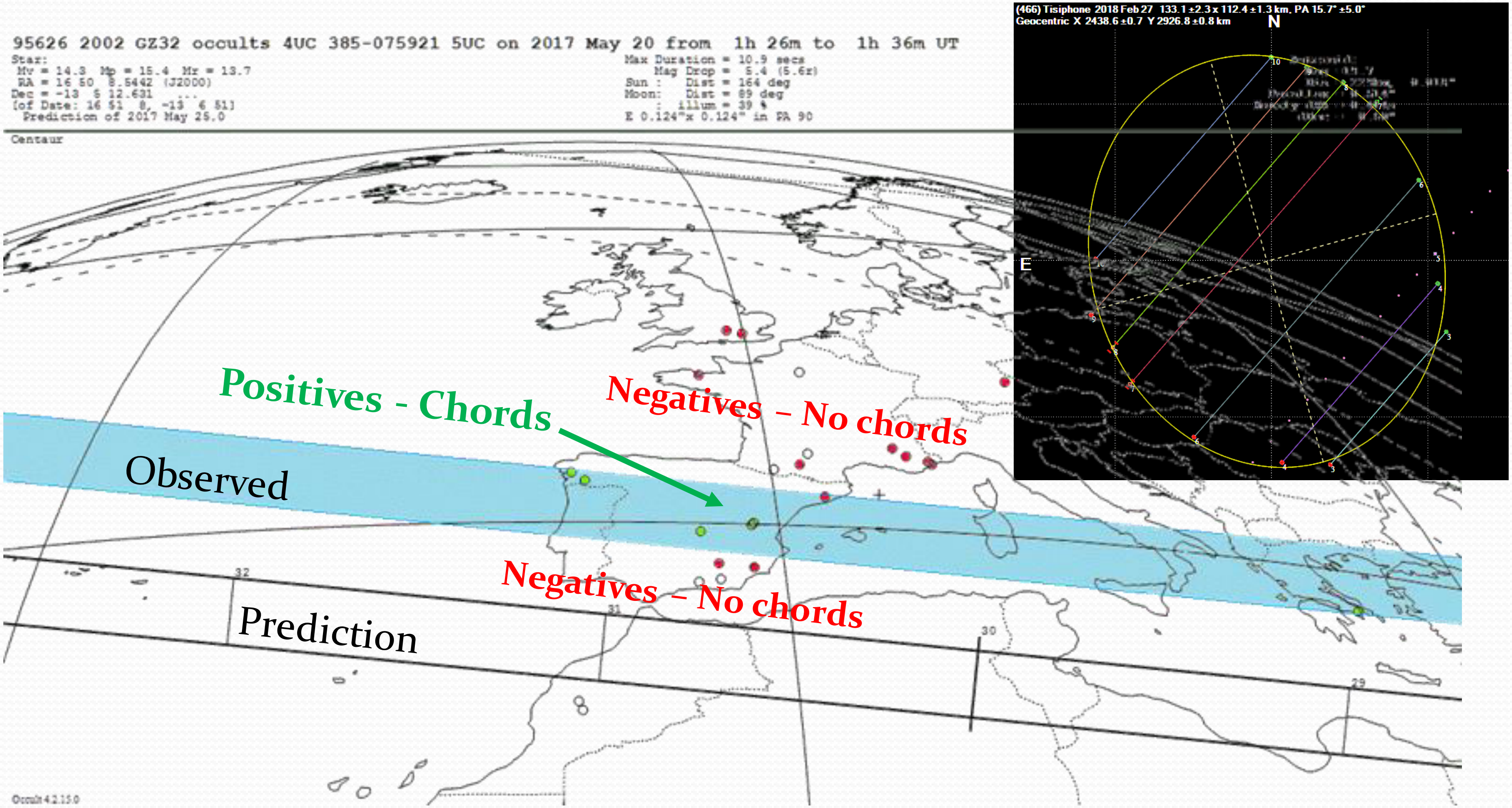
# (159) Aemilia occultation – OCA, 2019/05/15-16




Thanks to: Matthieu Conjat (AIMA Development)

# How do occultations measure size and shape?




Multiple observations allow the measurement of several sections (“chords”) of an object.

With multiple chords, it becomes possible to model the shape of an asteroid.

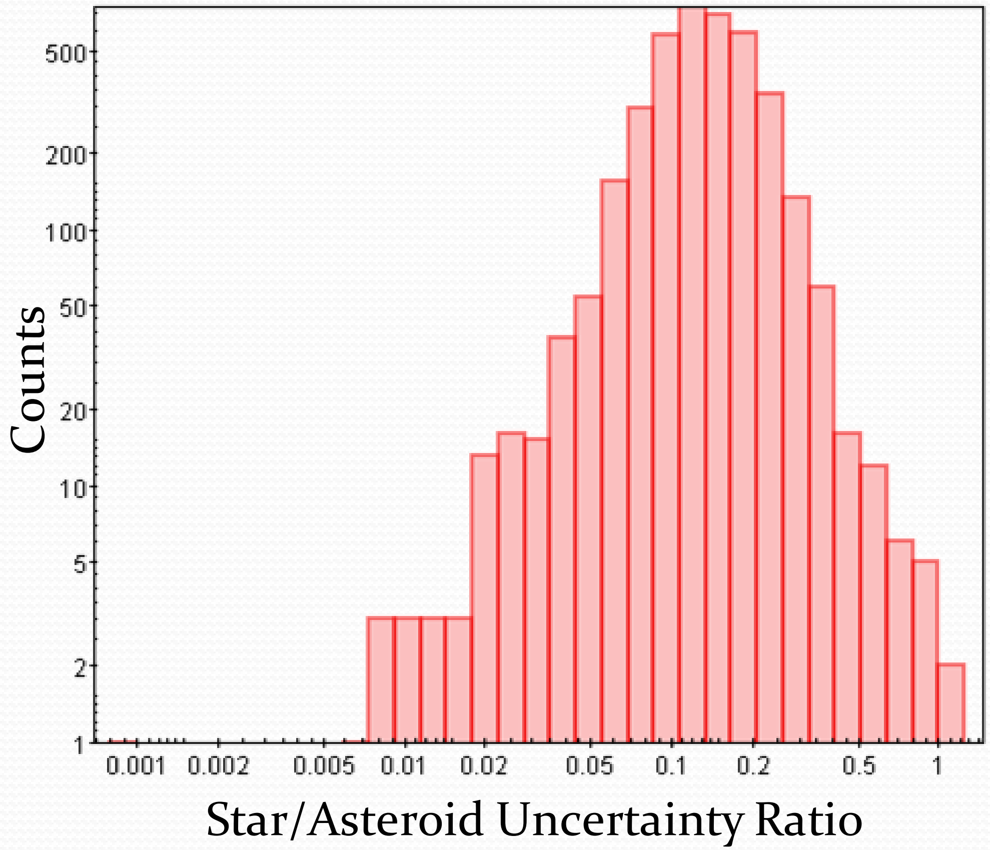
# The challenges today

- 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.

# Stars no longer contribute to error

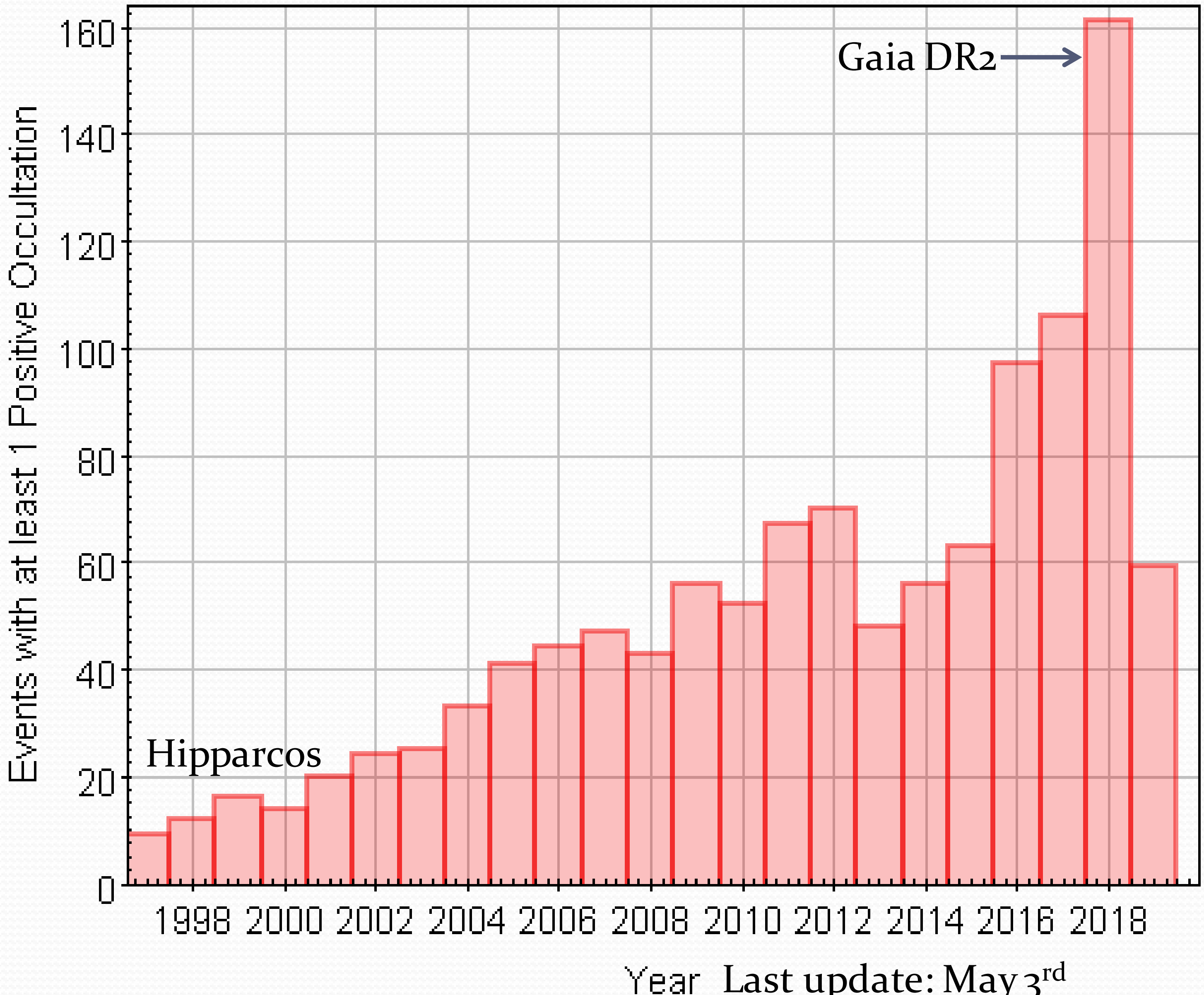



Sources:

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

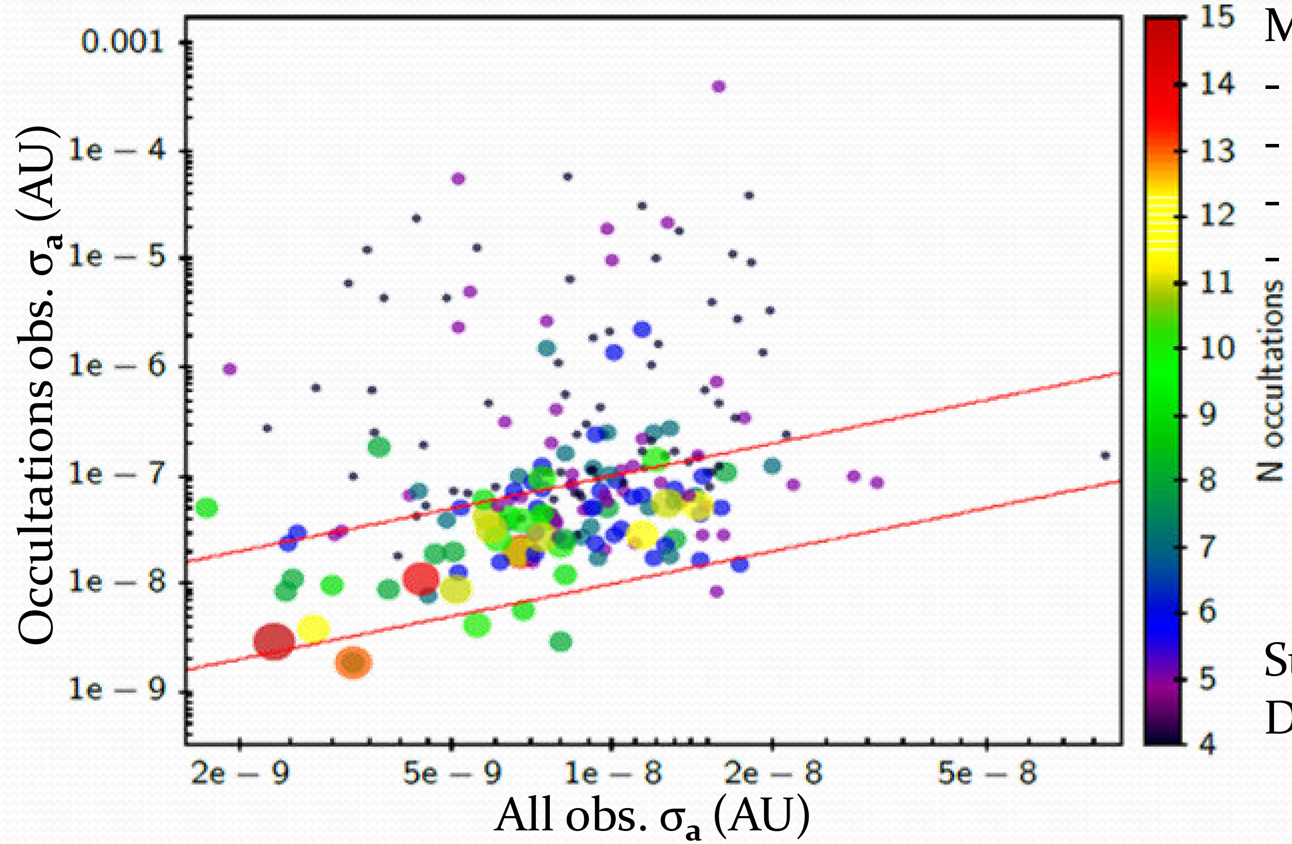
Star uncertainty usually 3-20x smaller than asteroid's.

# History – Events by Year




Last update: May 3rd

# 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).

# 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.

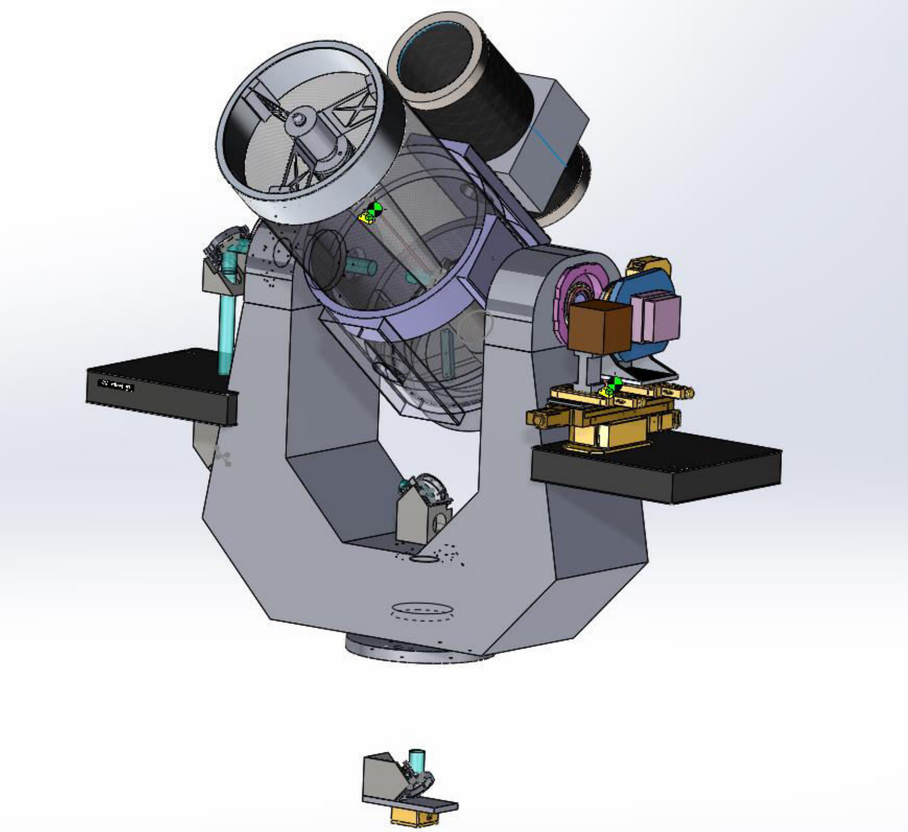
- Probabilistic approach to whether or not an occultation happened instead of “yes”/“no” system (confidence level);

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

# UniversCity Robotic Telescope

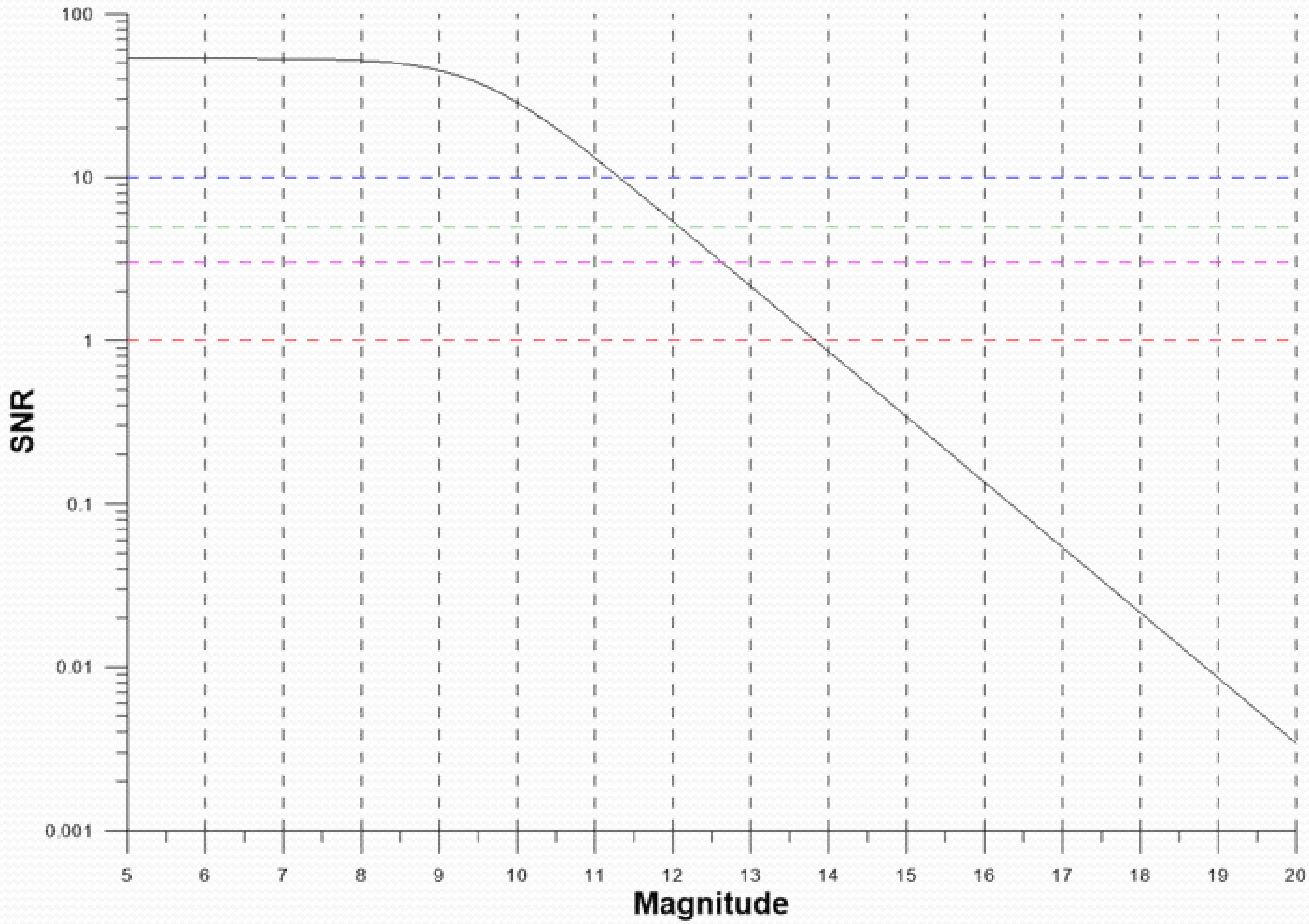
- Telescope prototype used for this study:
  - UniverCity 50 cm robotic telescope at Calern Observation site, near Nice;
  - First light : end of 2019.

- Will allow several observations per week without human intervention.



# UniversCity's Limitations

- Exposure time 0.1 s, limiting magnitude ~13 (SNR~3).
- With 0.5 s, this level is reached at ~14.5.



# Occultation Model

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

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);

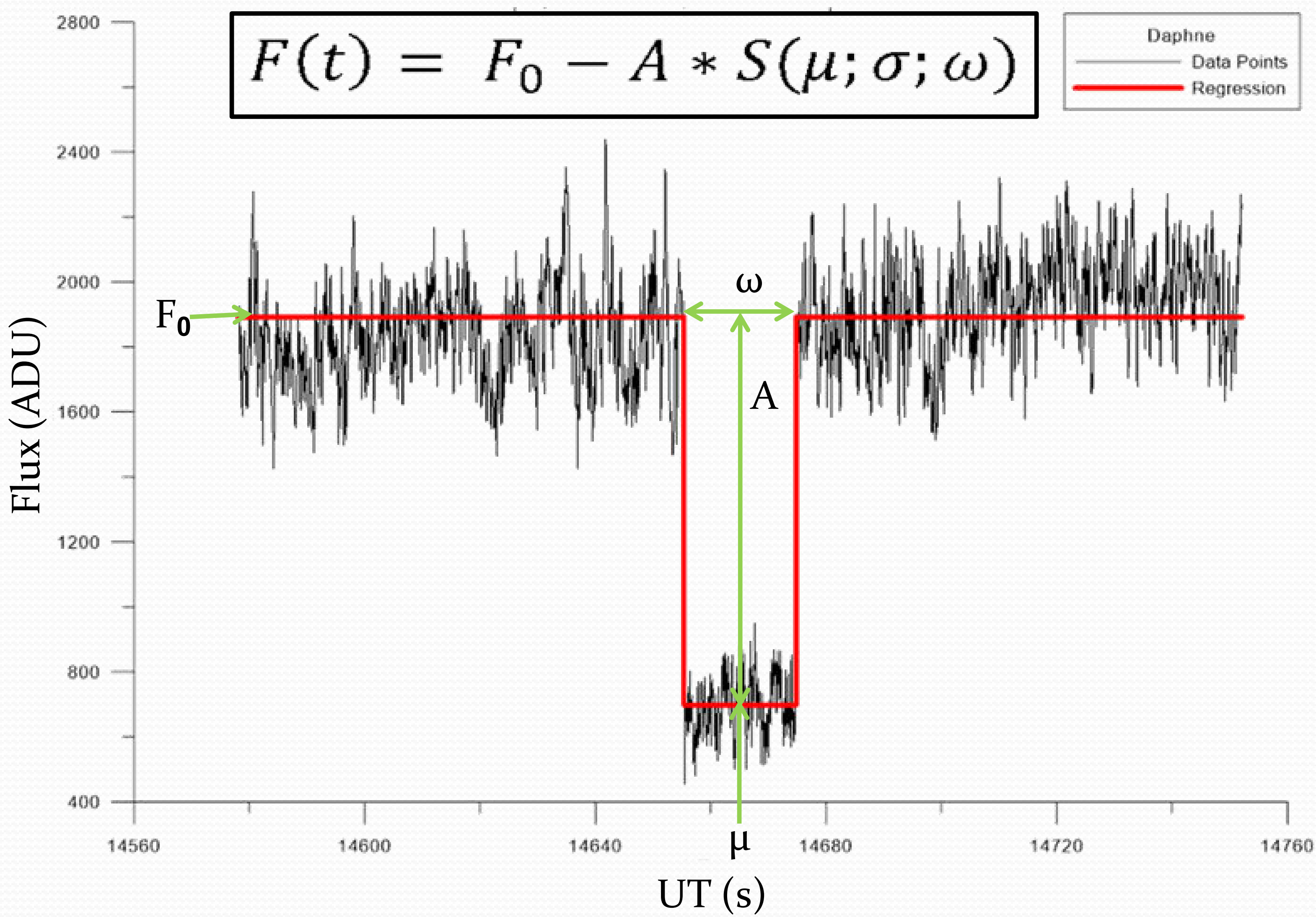
A -> Drop caused by occultation (constant);

4 parameter regression (fixed σ);

# No Occultation Model (Control)

$$F(t) = F_0$$

# Regression: Example



# Method: exploring the limits

- Simulations (~8 000):
  - Exposure time: 0.1s;
  - star magnitude: 11.5-13.5;
  - wide range of drop (0.3-1.0 mag) and duration (2-10 points);
  - Realistic parameters for telescope/camera/atmosphere efficiency;
  - Major noise sources: scintillation and readout;
  - Secondary: photon, background and dark current.

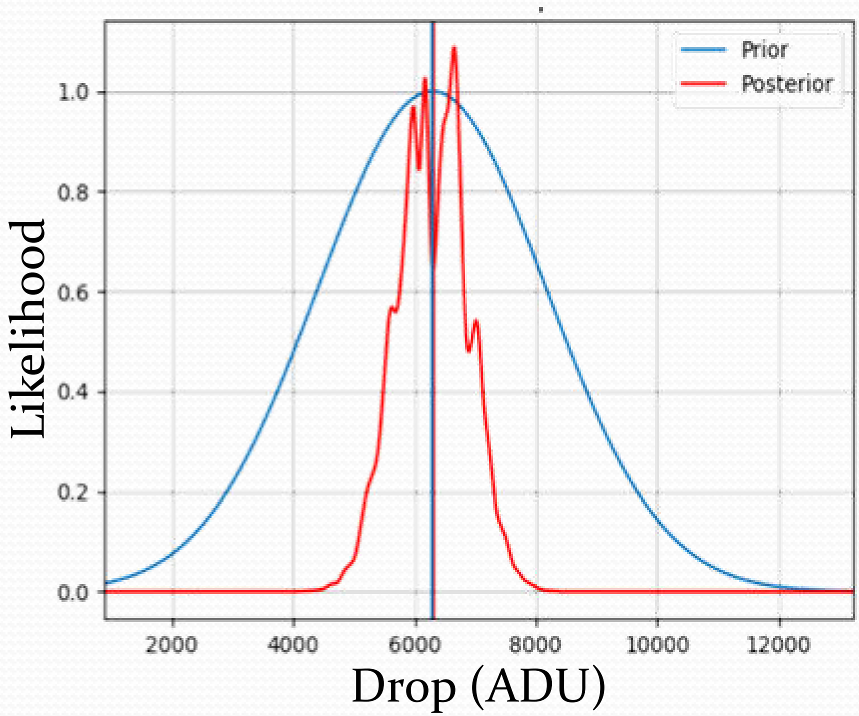
- Data reduction:
  - regression system based on a Bayesian Inference Method (BIM).

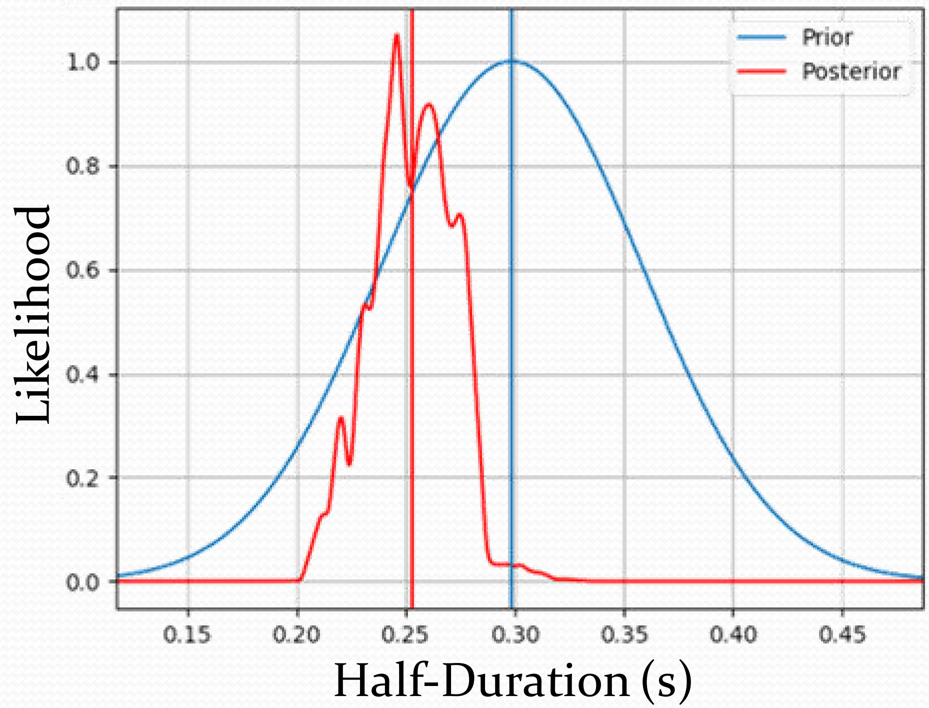
# Priors

- Uniform or gaussian for all parameters;
- Gaussian priors fit better with real uncertainties;
- 1-σ intervals:
  - 10% for combined asteroid + star flux;
  - 40% for Drop;
  - 20% for Duration;
  - 2.0 seconds for Centre Epoch.
- Uniform priors were 0.5-1.5x the input values (except Centre Epoch, with interval of 6 seconds).

# Simulation Results with BIM

Marginal distributions after BIM (Intermediate case, Drop and Duration).



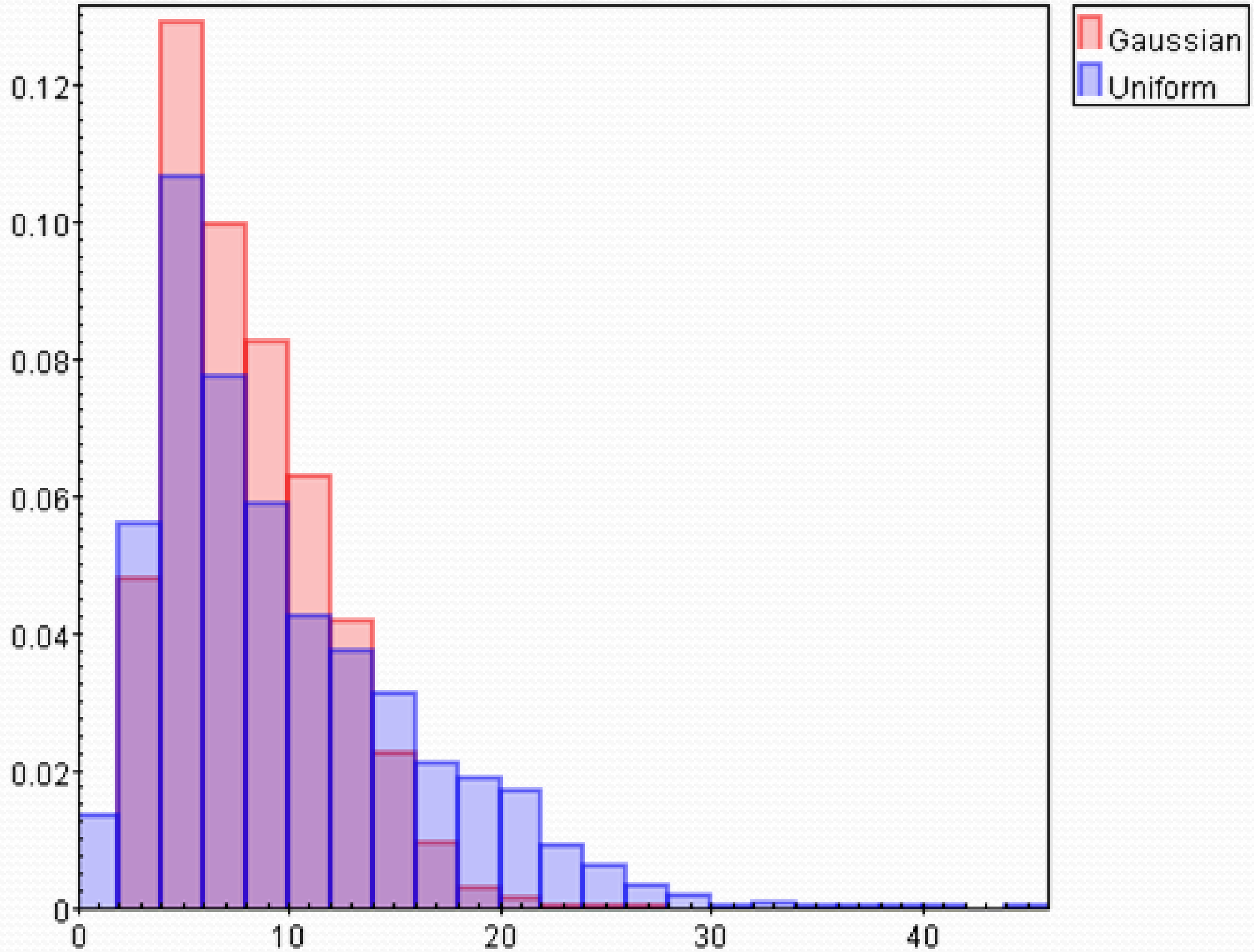




Other results from BIM:

- Bayesian Evidence for both models;
- Confidence level of occultation model by comparing evidences;
- Median and variance for all 4 parameters.

# Results – Duration

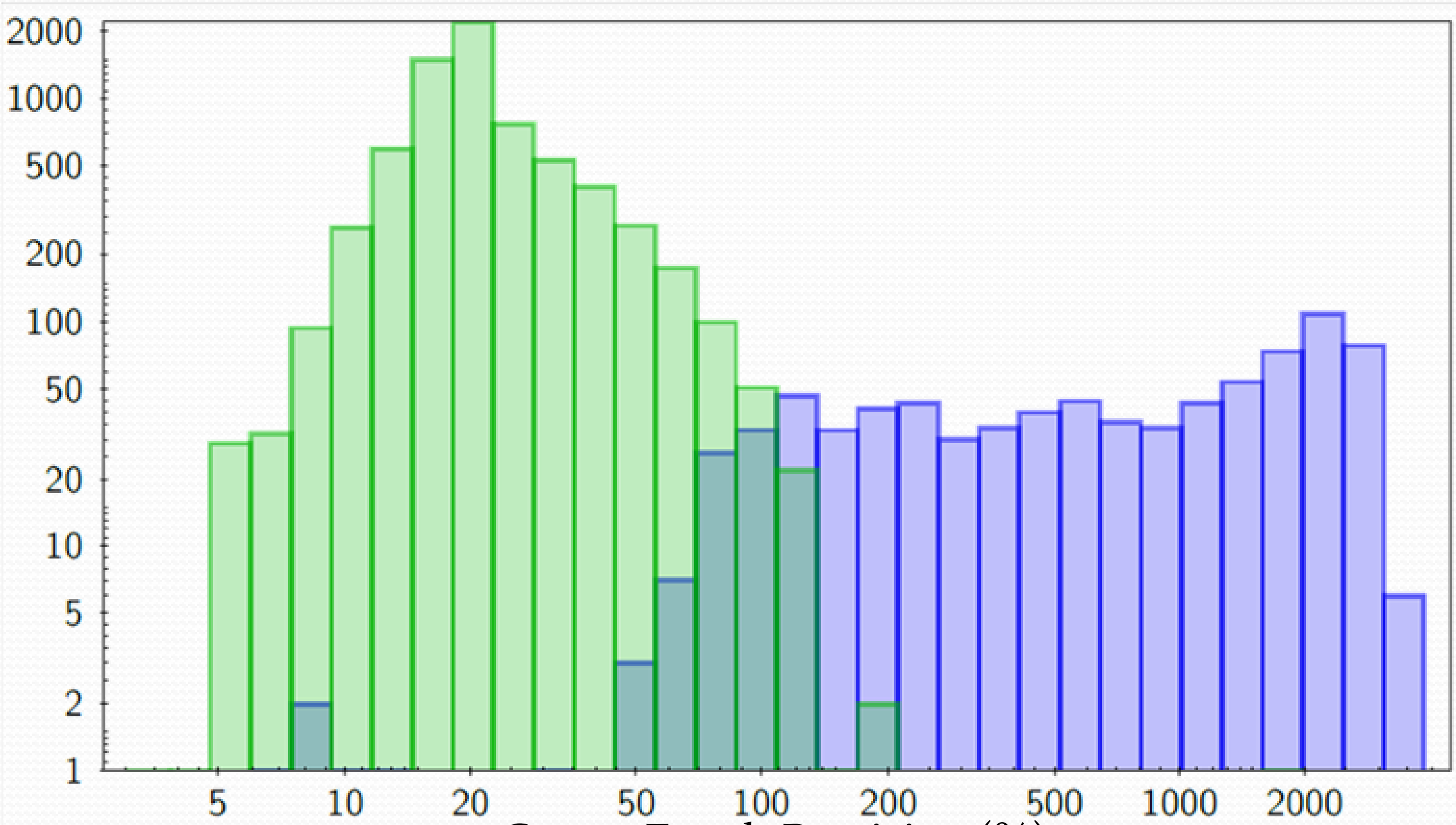
Red – Gaussian Priors. Blue – Uniform Priors.




Duration Precision (%)

In % of duration.

# Results – centre epoch and confidence



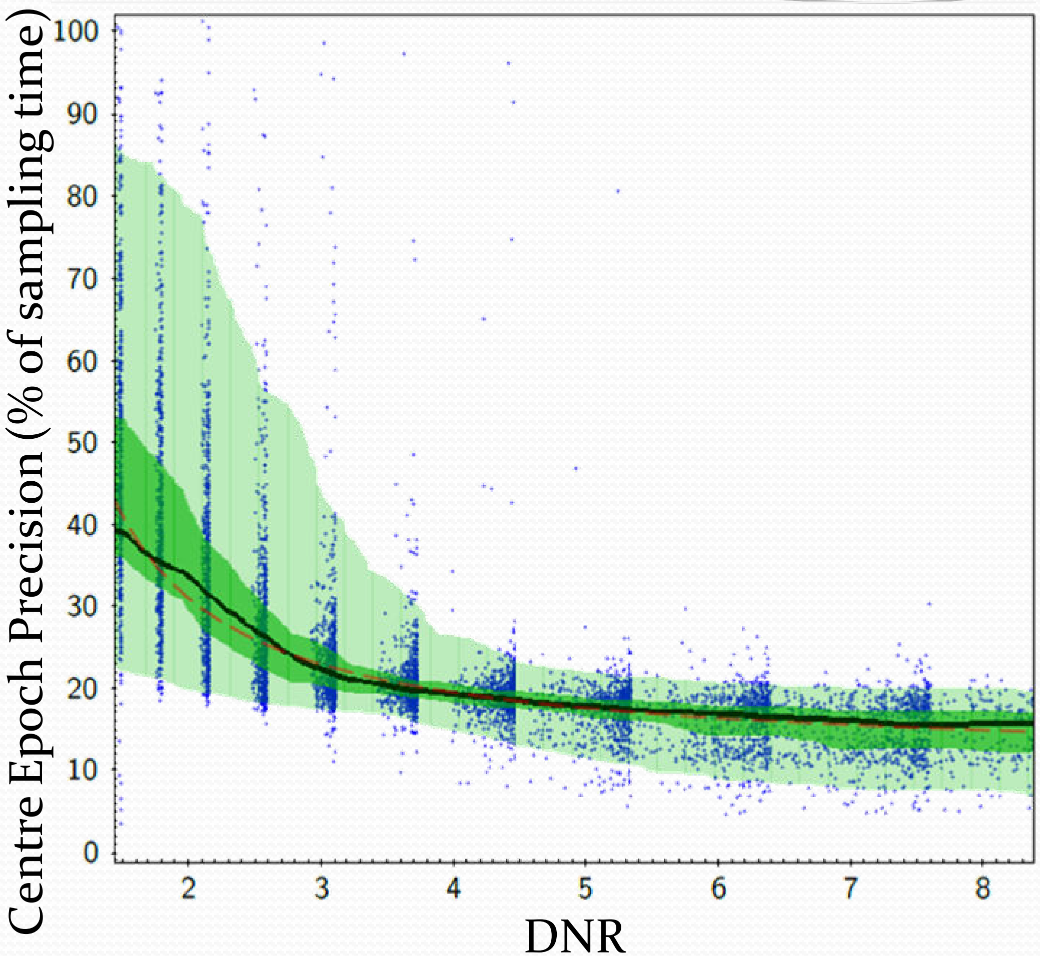

Centre Epoch Precision (%)

Green – Statistically significant regressions.

Blue – Non-statistically significant regressions.

Precision on Centre Epoch (units of sampling time).

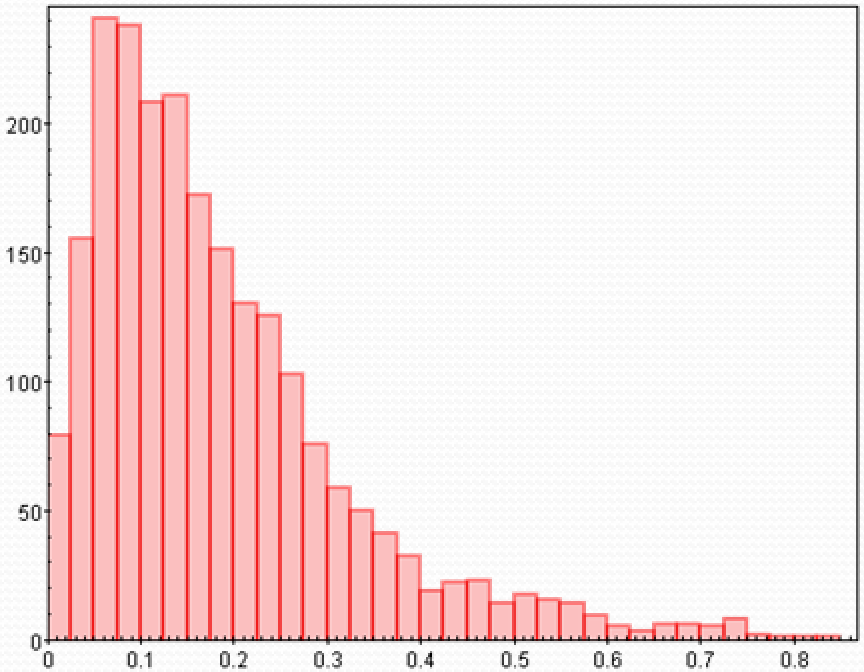
# Results – centre epoch vs DNR



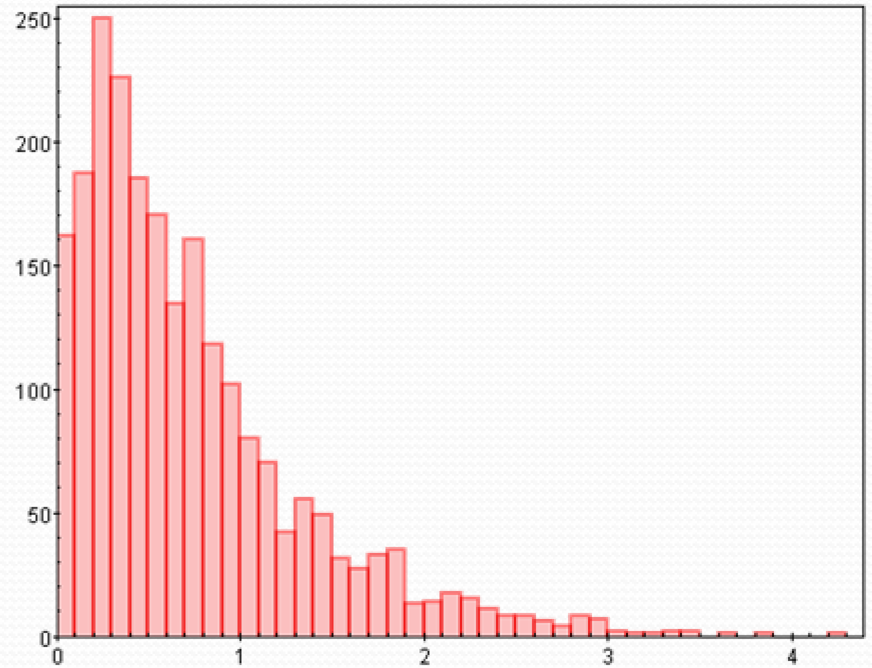

$$DNR = \frac{F_0 - A}{\sqrt{\sigma_{F_0}^2 + \sigma_A^2}}$$

# 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 V~13.5 with 0.1 s exposure;
- 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:
  - Take into account orbital uncertainty in the statistics of predictions;
  - Exploit improved orbits with asteroid astrometry in DR2.

# Thank you!