

Observing QSOs and ICRF sources with Gaia

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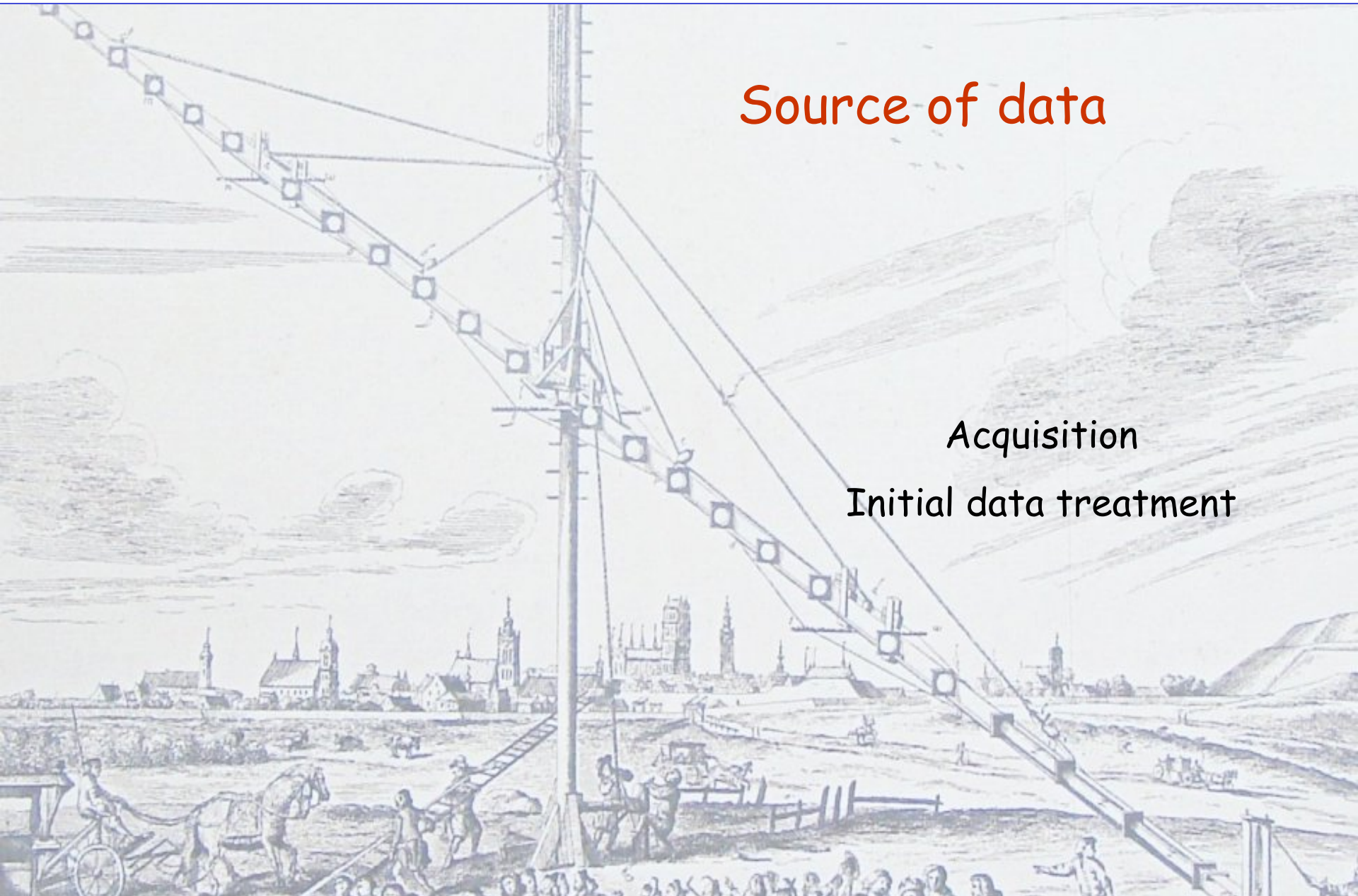
UNS/CNRS /Observatoire de la Côte d'Azur

- Source of data
- ICRF Sources
 - single observations
 - normal points
- QSOs
- Conclusion

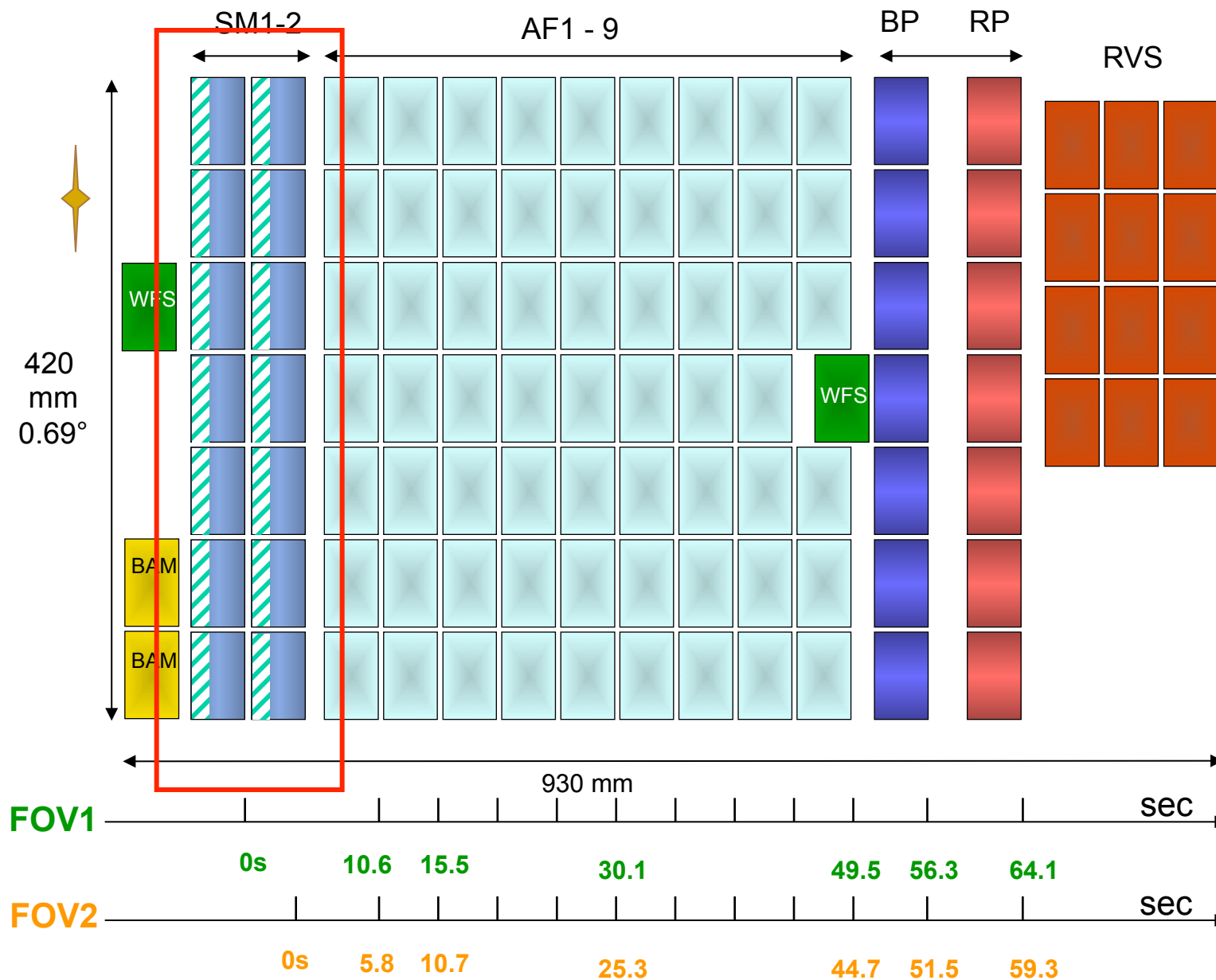
Source of data

Acquisition

Initial data treatment



Focal Plane Assembly



- Purpose Detect sources
allocate windows for Astro and Photo observations
- Integration time ~ 2.7 s
- Binning $2 \times 2 \rightarrow 120 \times 360$ mas²
- Selection cut at $G = 20.7$ mag
- limitation sources $< 1''$
optimised for point sources
- Centroiding $< 1/10$ th of a pixel
- Attitude Smoothed on-board attitude
 ~ 50 mas precision, 50 mas systematic

No Global Astrometry, No Attitude solution

- Explore the Initial Data Treatment to evaluate :
 - the on-board detection performances
 - the IDT astrometry
 - Precision, accuracy, frame orientation, magnitude dependence
 - the completeness level
- Sources
 - ICRF to assess external **accuracy** thanks to their perfect astrometry
 - Asteroids, satellites
 - QSOs, Galaxies, lenses → see Gaia Image of The Week
- Warning : no direct science purpose.
 - Just sanity checks, validation, learn data properties
 - Issue warnings in case problems are spotted
 - No use of the accurate astrometric measurements

- Gaia observations records over 9 months
- Main period considered in this report
 - Runs 270 - 515 ~ 25/09/14- 02/06/2015 ~ 8 months NSL
 - 1 run is about 1 day of observations, but not systematically
- Data extracted in each file:
 - TransitId, α , δ , G , V_{AL} (then OBMT, FOV ...)
- Each data set is 0.5 to 2 GB with 50 to 150 Mio transits
 - Largest Run 478 650 Mio transits (13 GB)
- There are ~ 20 billions transits over the period
 - ICRF = 2 every 10^6 on the average

- For all the sources transit times are precomputed
 - Gaia Orbit, Scanning law, source coordinates
 - Instrument nominal parameters
 - Period of time $t_{\text{beg}} \dots t_{\text{end}}$
- Each record contains
 - OBMT at AF1 transits, α , δ , FOV, VPU, ACpixel, Gmag
- Records are strictly in chronological order
 - Used for binary search of records at a given time
- 8 months of Gaia data yields:
 - 3414 ICRF source \sim 42,000 transits
 - 185,000 LQAC sources \sim 2,200,000 transits

- Accuracy of the predicted transits
 - The true attitude is very close to the Nominal Scanning Law
 - An infinitesimal rotation of about $25''$ is applied
- Illustration on the least observed ICRF sources

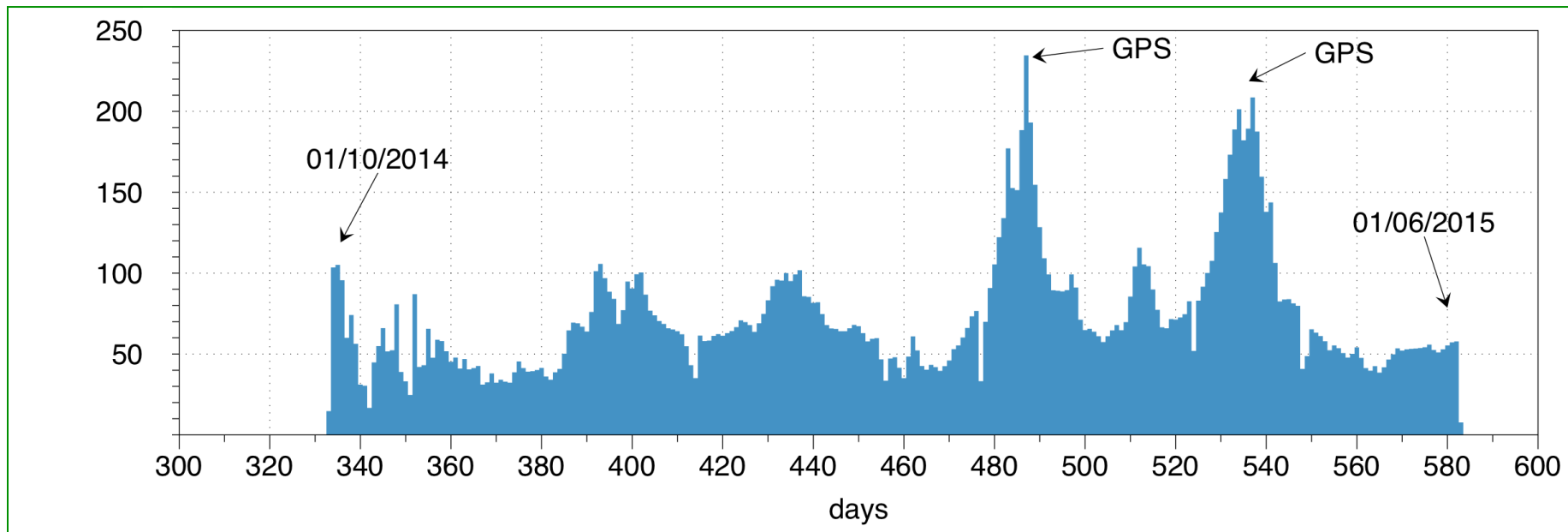


Predicted time TCB	Observed transits TCB	Diff. s
2015-01-24T01:08:17.42755	2015-01-24T01:08:17.428	0.001
2015-01-18T18:39:27.14306	2015-01-18T18:39:27.141	-0.002
2015-02-12T02:16:16.51519	2015-02-12T02:16:16.518	0.003
2014-12-25T06:45:52.74921	2014-12-25T06:45:52.748	-0.001
2015-01-17T06:42:56.35489	2015-01-17T06:42:56.354	-0.001

1 ms = 60 mas in scan !

- About 9 months of data collection
- Typically 50 Mio observations/day

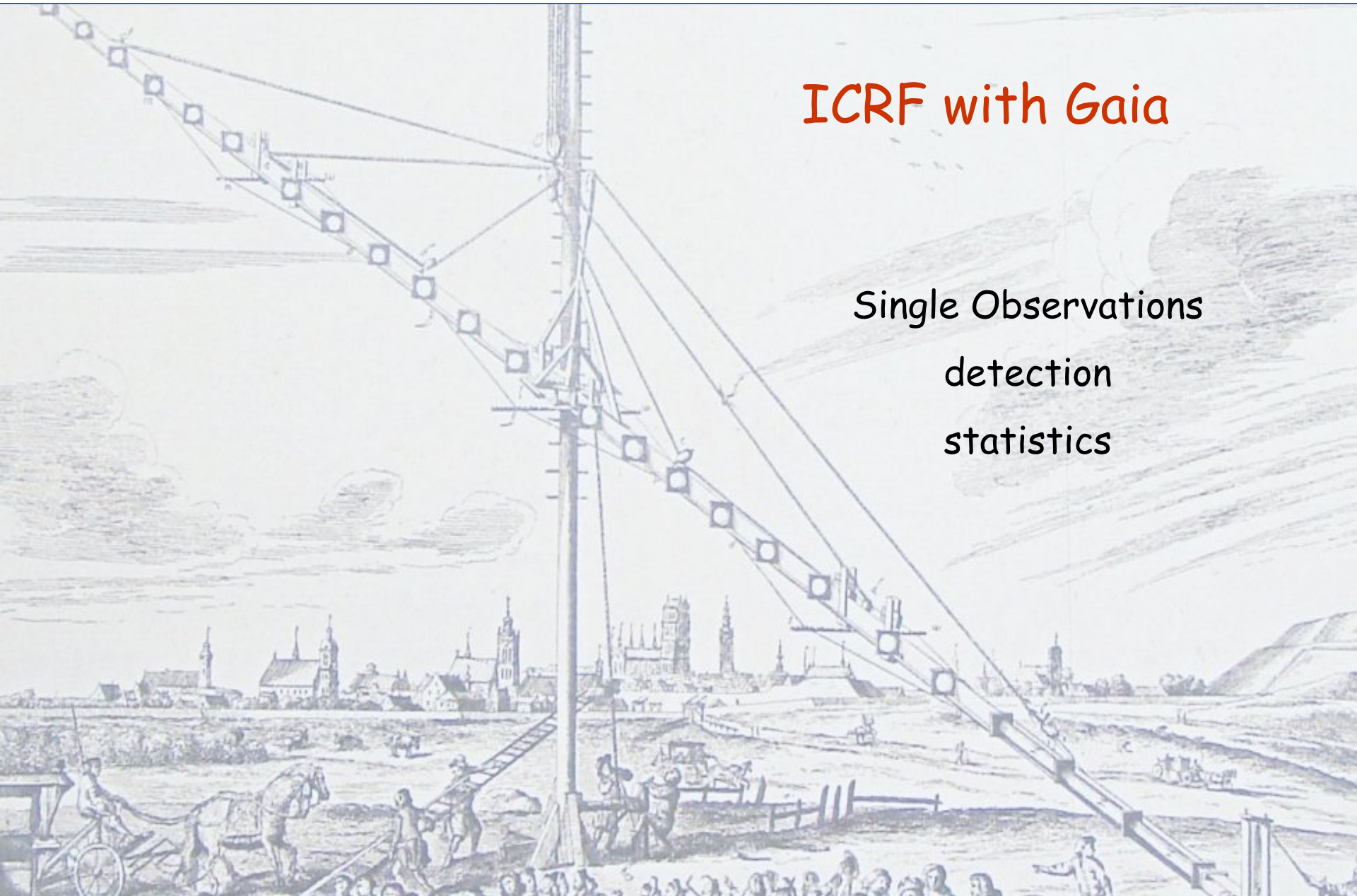
10^6 transits



Number of observations per day

ICRF with Gaia

Single Observations
detection
statistics

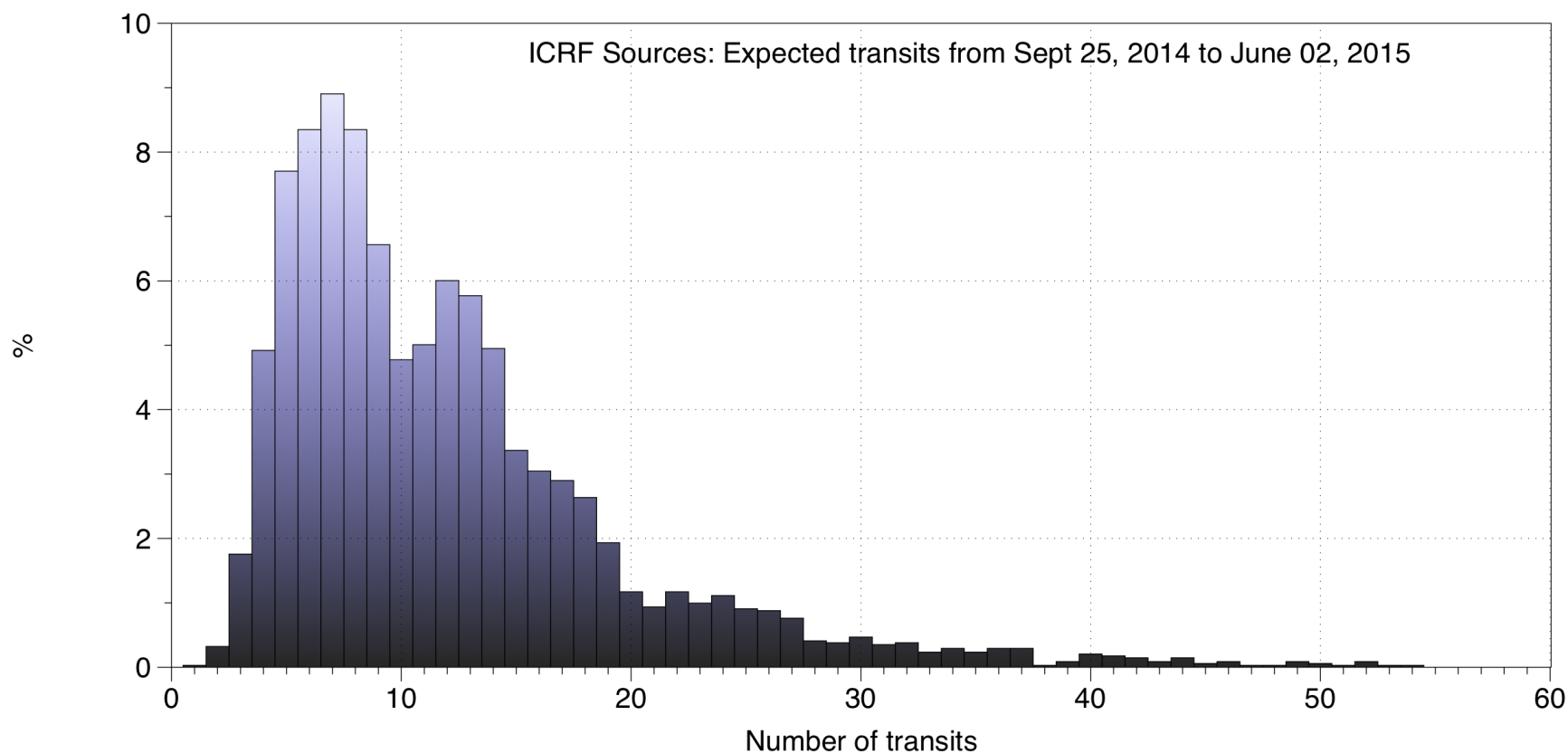


- Single observation:
 - One passage in a FOV
 - one detection
 - 2.7 s of exposure on one CCD
 - one SM measurement
- Combined observations
 - a normal point for the position with $n_{\text{obs}} \geq 4$
 - robust estimate with the median
 - precision from the interdeciles range ($9^{\text{th}} - 1^{\text{st}}$) and small sample correction

• Number of sources	3414	
- Expected detections over the period	3414	
• all sources directions scanned at least once		
• Sources detected at least once	2705	
- Never detected	709	
		3414
• Among the 2705 observed sources		
- Good sources (all $\rho < 300$ mas)	2625	
- Multi-imaged	30	
- Anomalous positions (many $\rho > 300$ mas)	50	
		2705

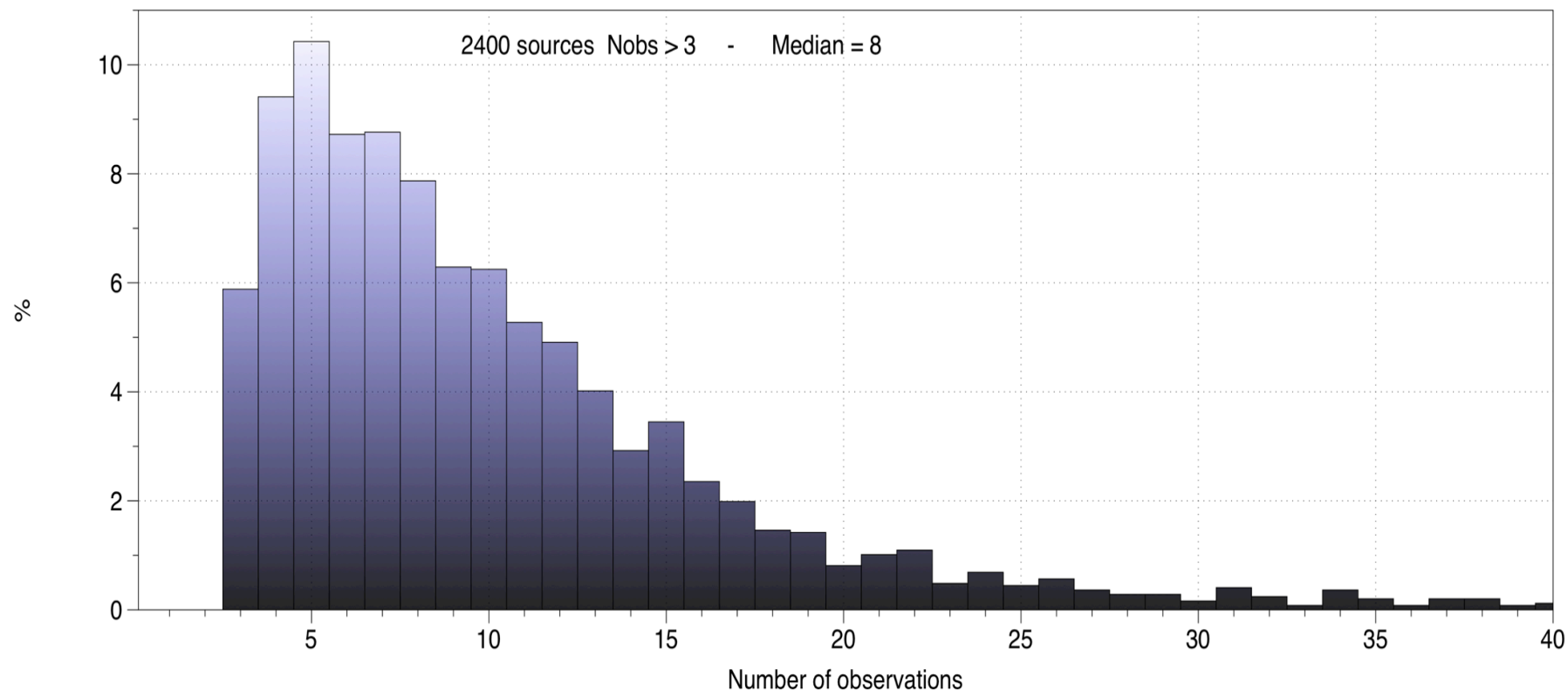
$$\rho = (\Delta\alpha_*^2 + \Delta\delta^2)^{1/2}$$

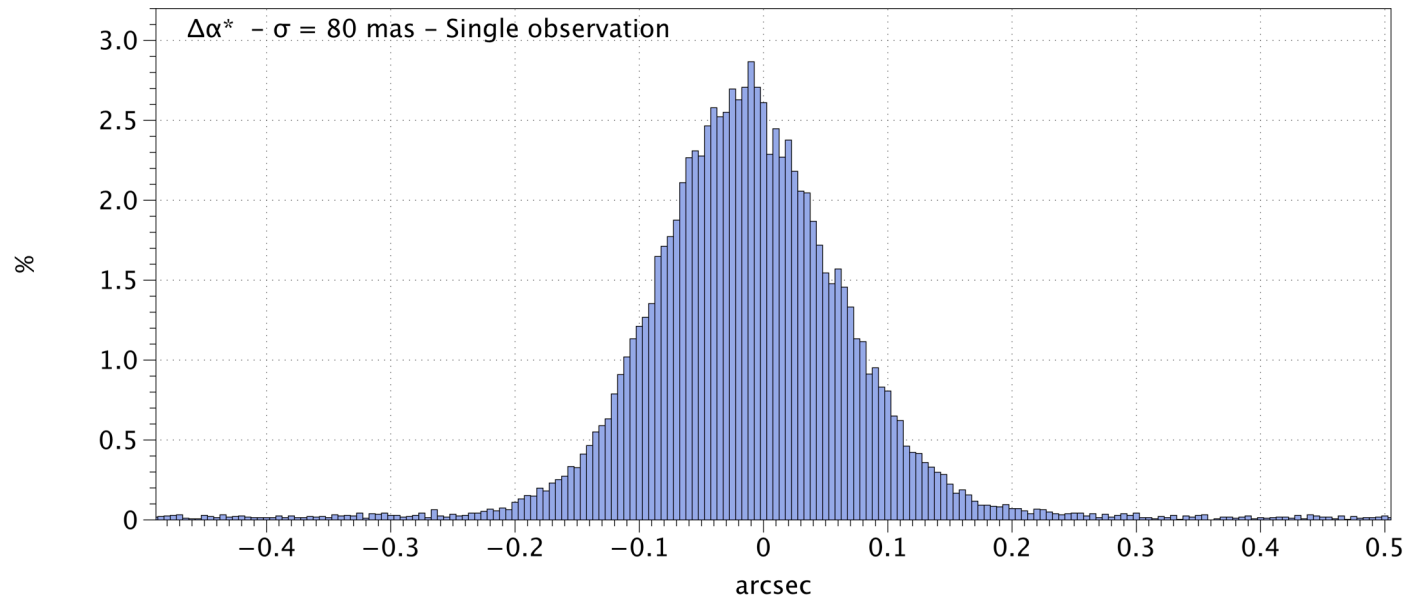
- Number of sources in the predictor 3414
- Expected detections over the period 3414
 - 241 sources predicted with $\text{nobs} < 5$
 - Median = 10, Average = 12.3



- Number of sources 2400

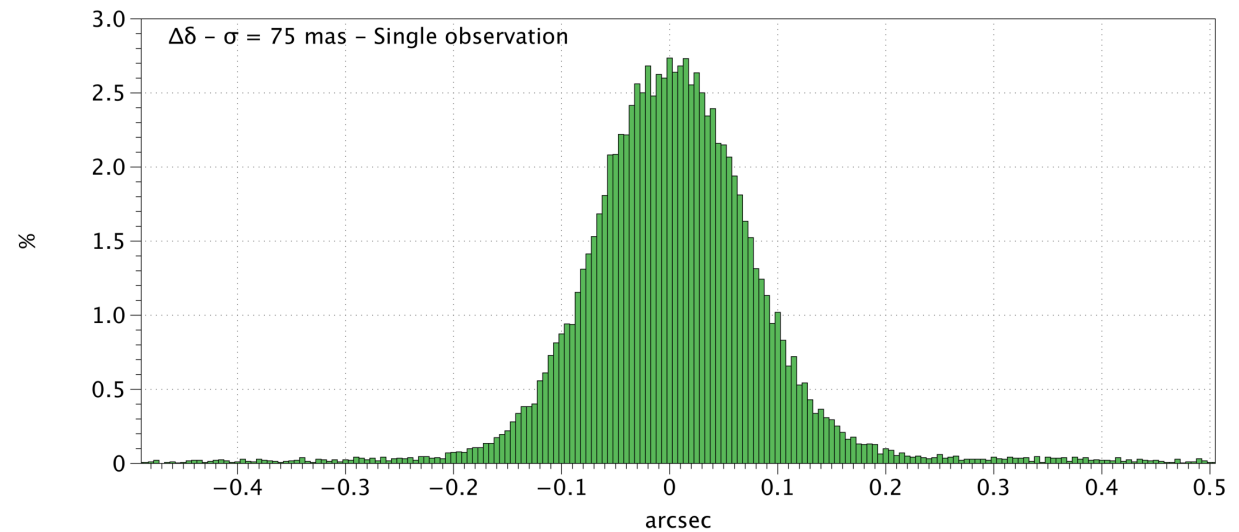
- 2400 good sources with Nobs ≥ 3
- median = 8 average = 10.2



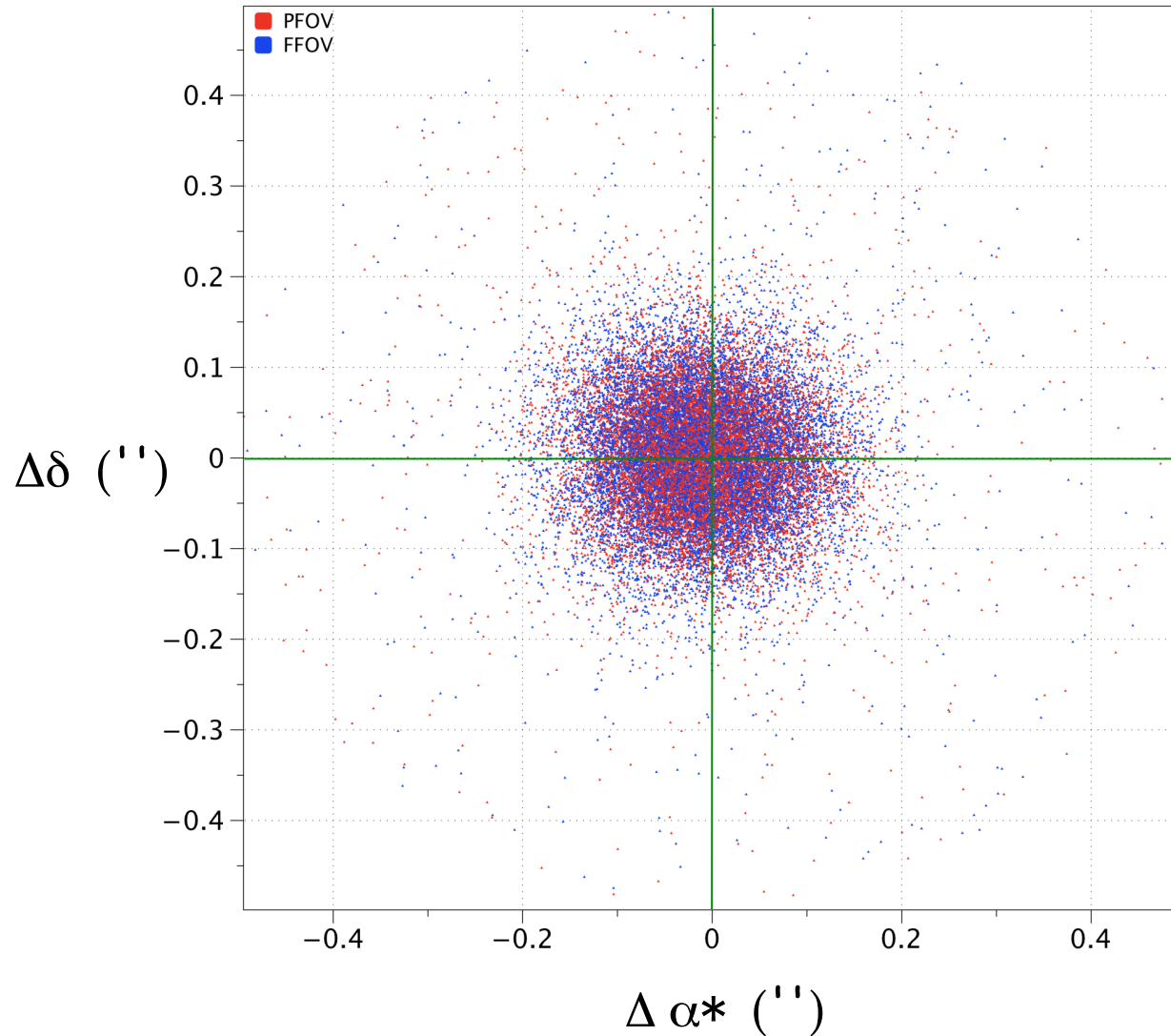


$\sigma \sim 75 \text{ mas}$

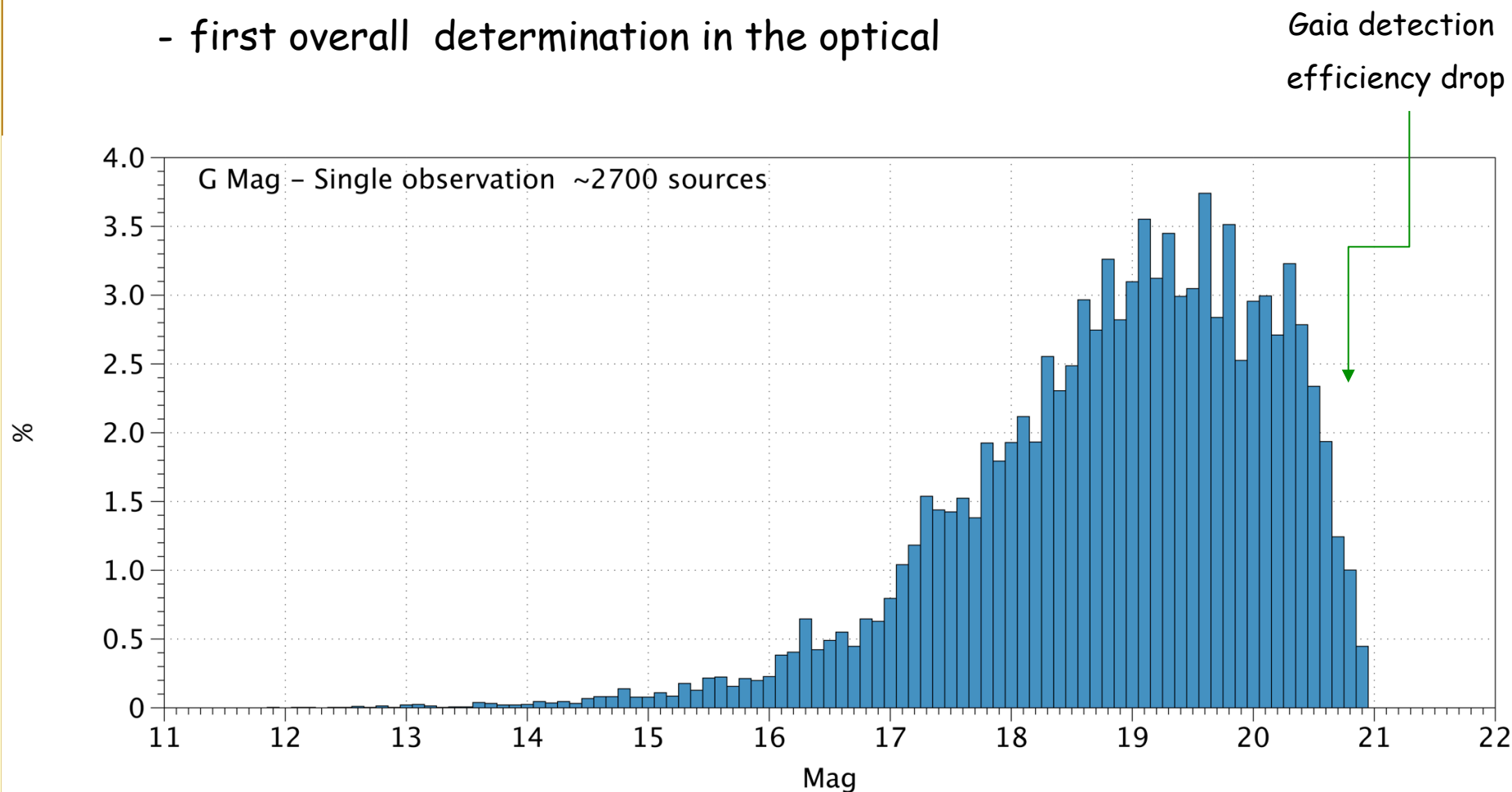
$\Delta\delta (")$



- Slight bias in RA ~ 12 mas

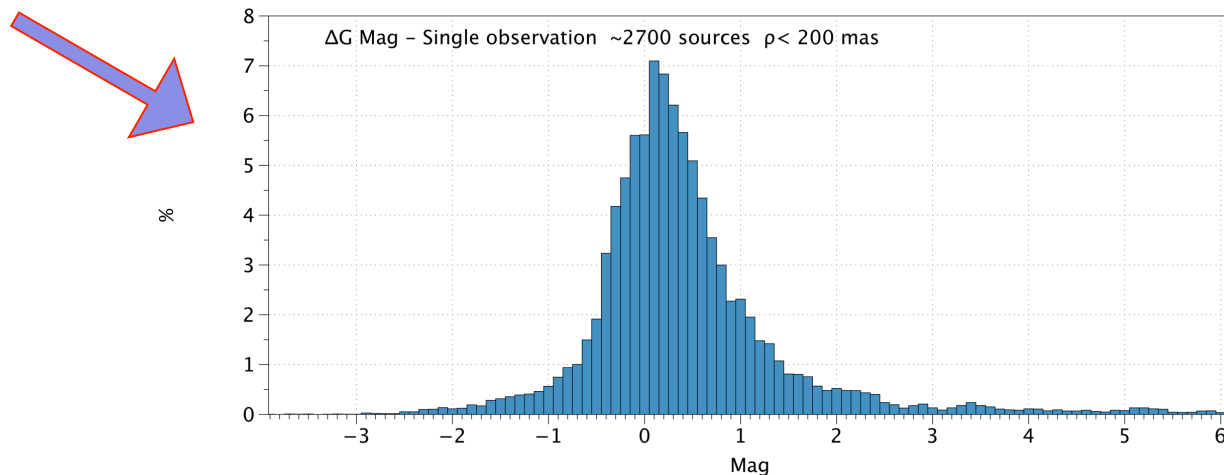
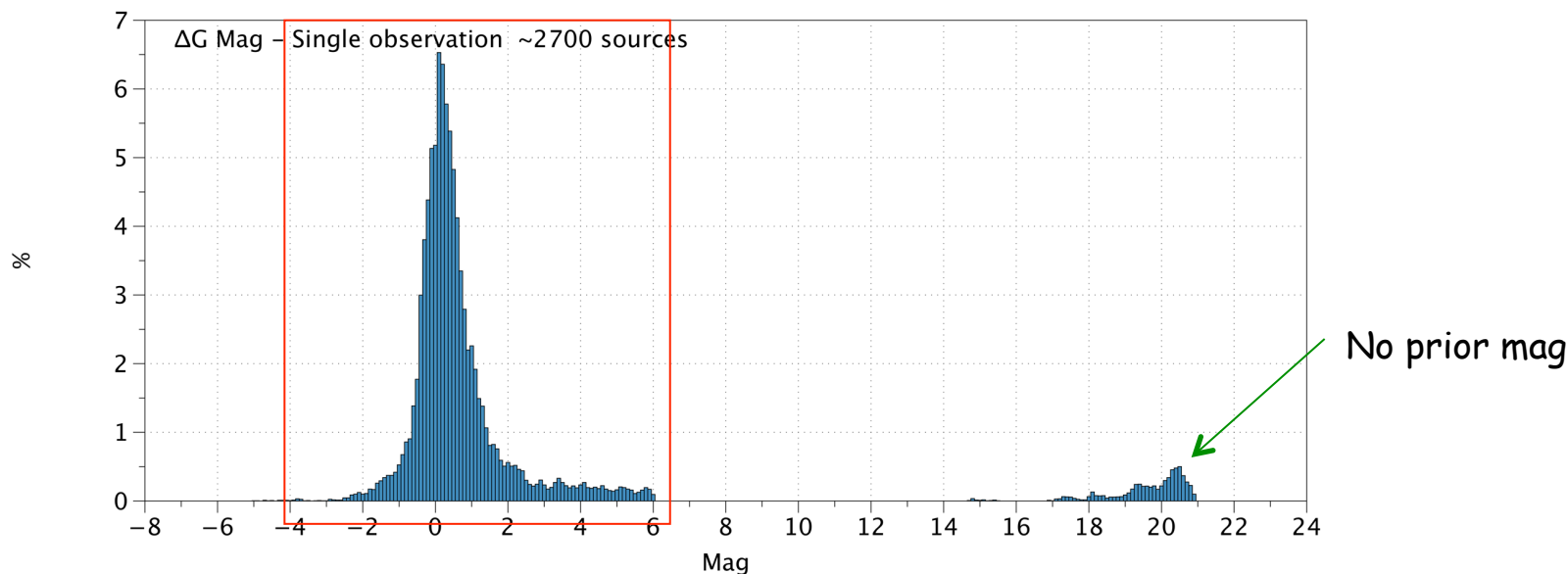


- *G* magnitude estimated for the 2700 detectable sources
 - Single observation distribution
 - first overall determination in the optical



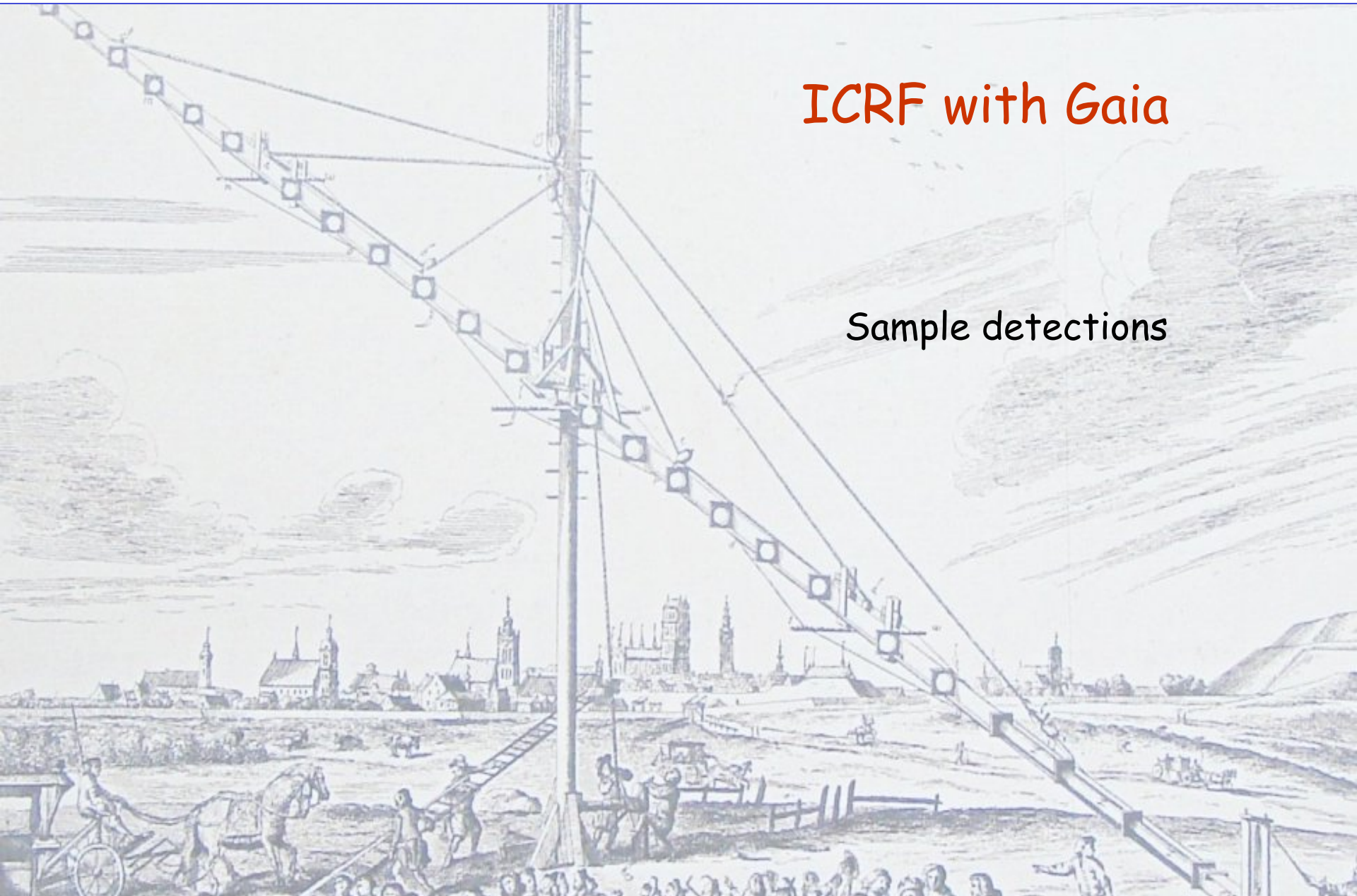
- ΔG magnitude estimated for 2700 sources

- Ground based estimates based on heterogeneous data

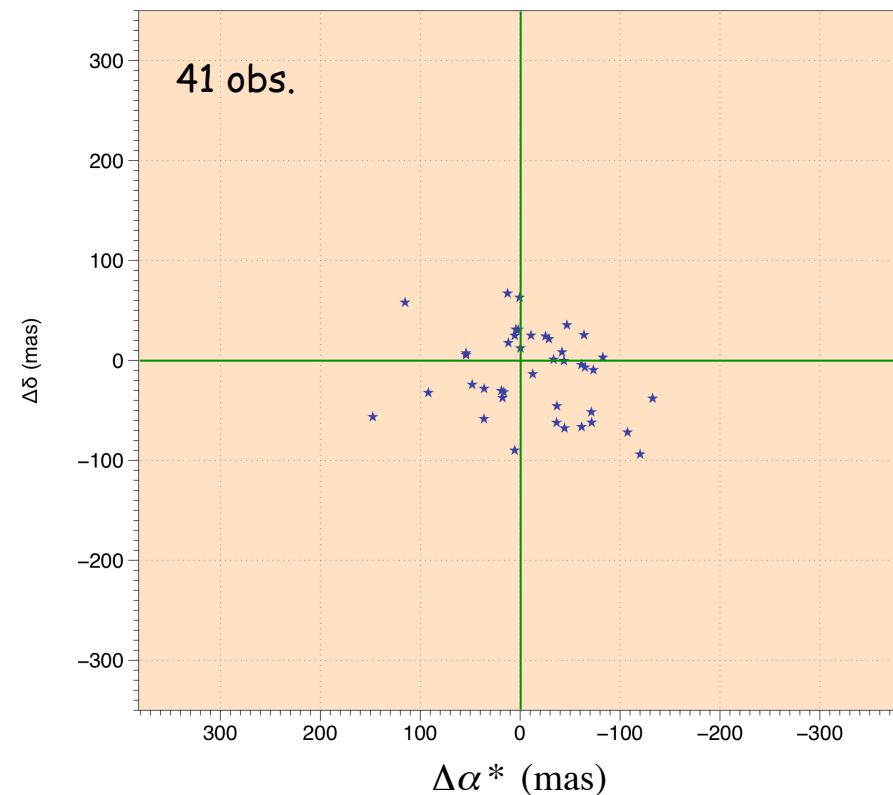
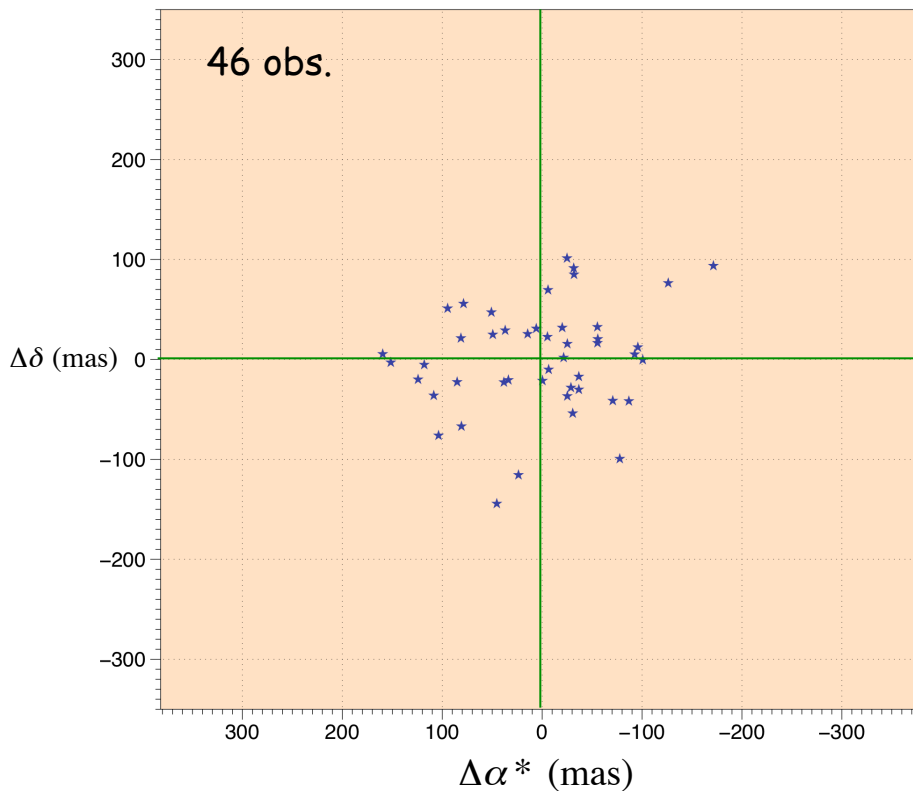


ICRF with Gaia

Sample detections

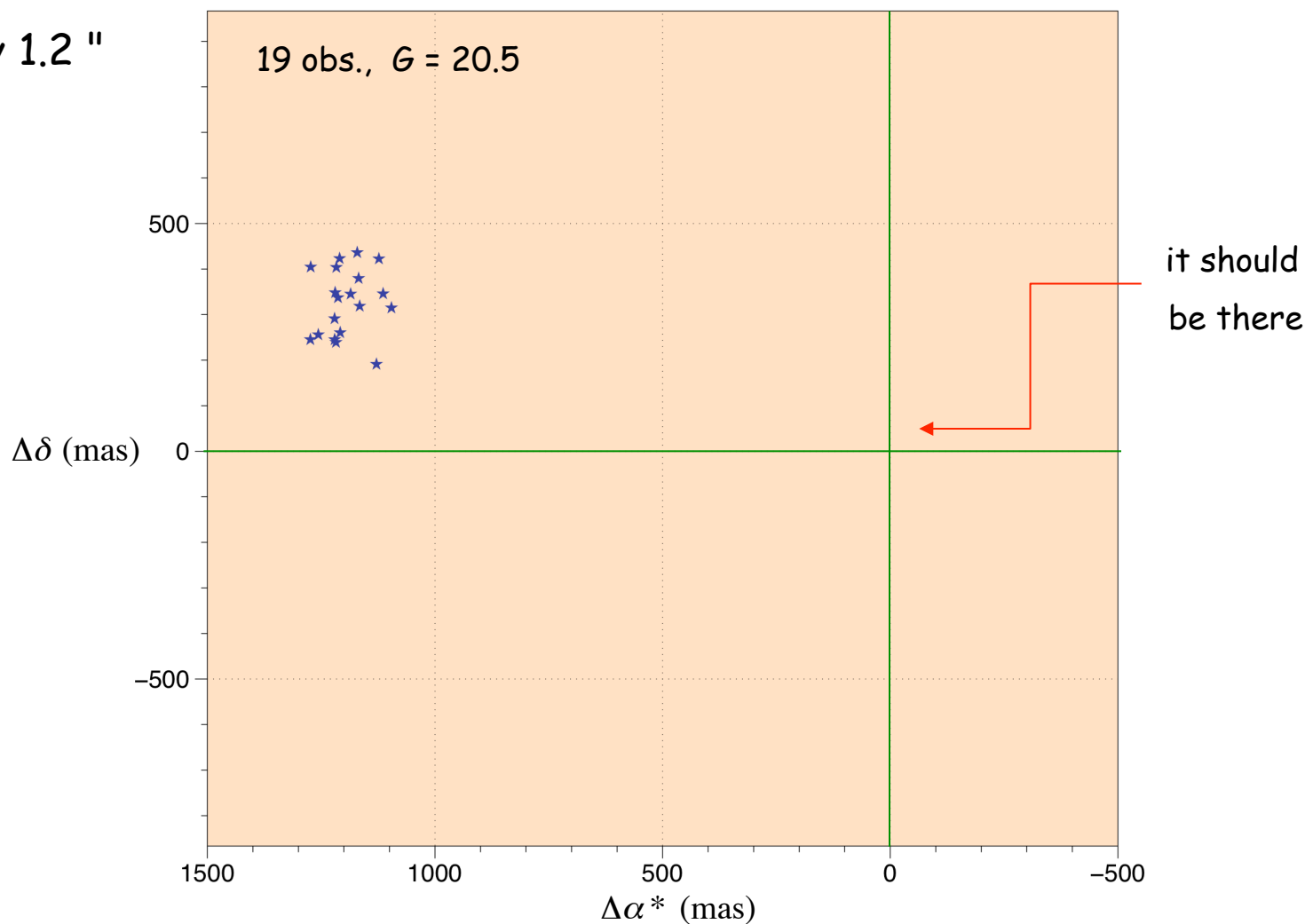


- Two sources, repeatedly observed, no outlier, well centred
 - points are single observation positions
 - $\sigma \sim 70$ mas

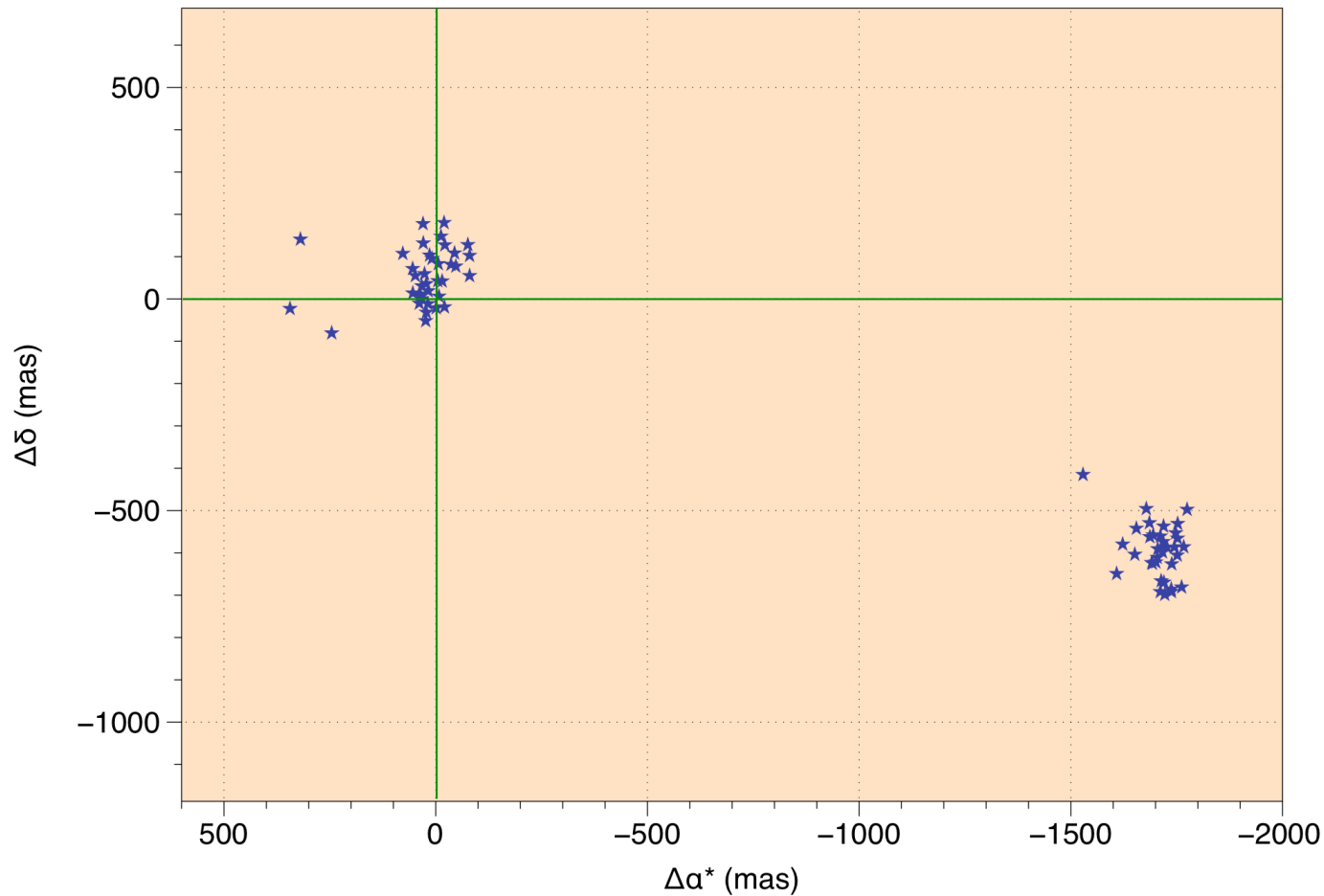


- One source, repeatedly well observed, but this is not the ICRF target

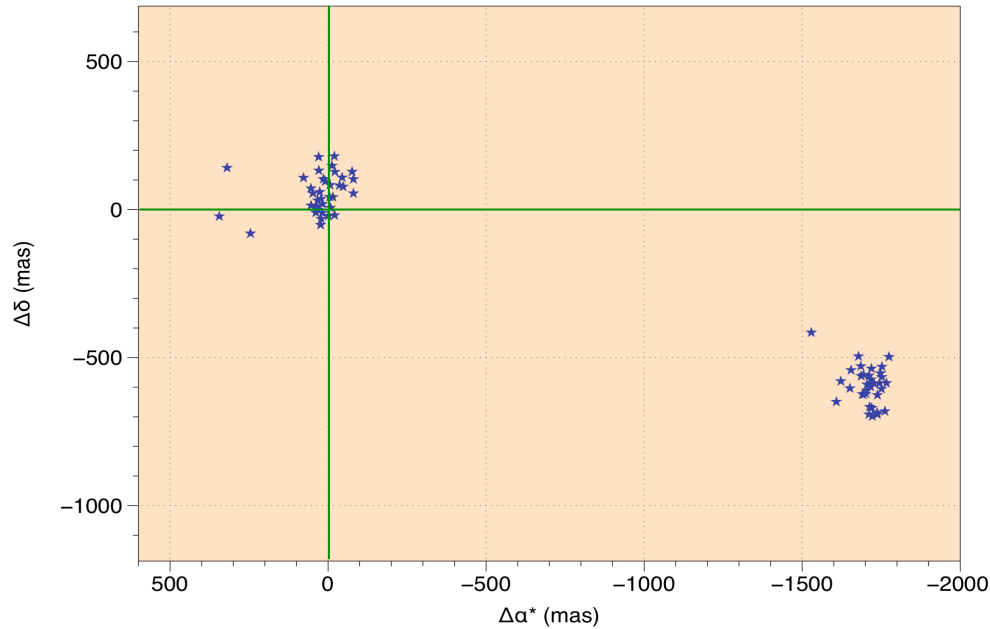
- off by 1.2 "



- About 30 sources appear 'compound'
 - Usually with two components $\rho \sim 1 - 2''$
 - Exceptionally with 3

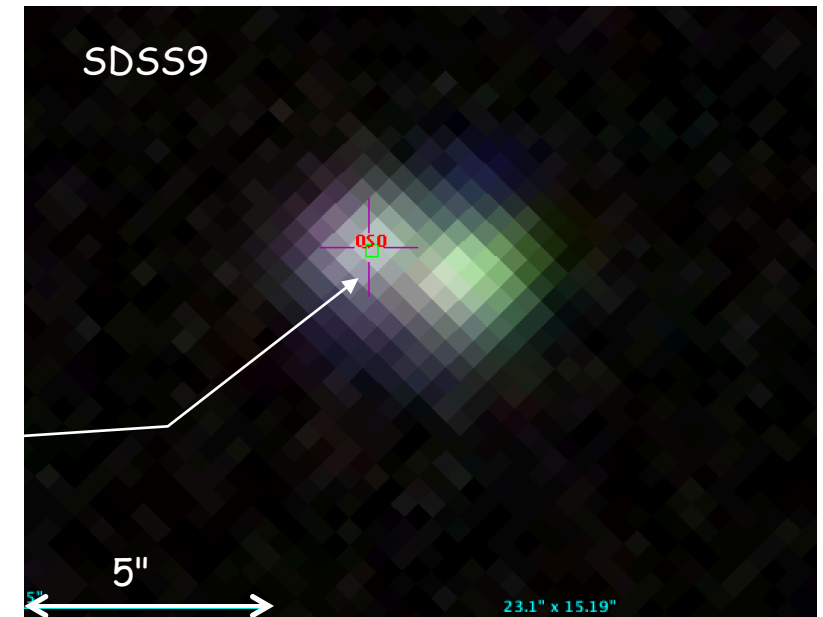


- No known as a lens
 - Check with Aladin

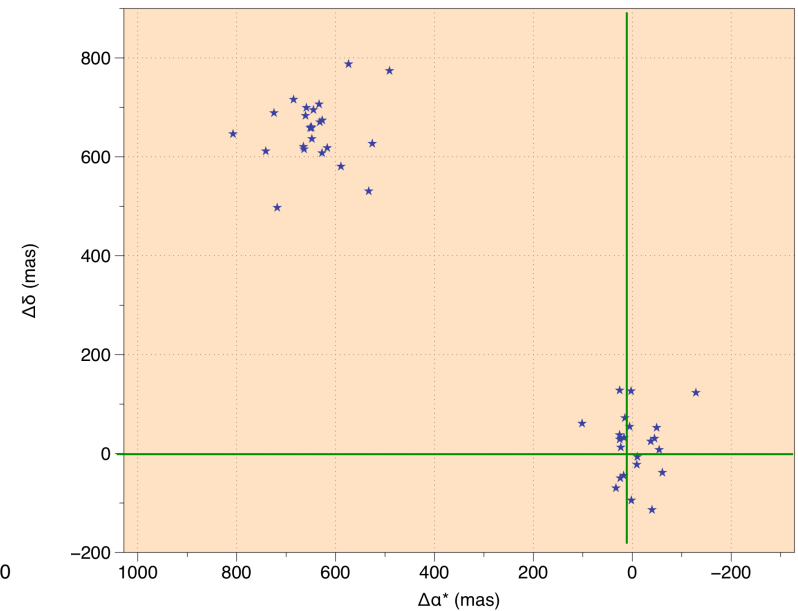
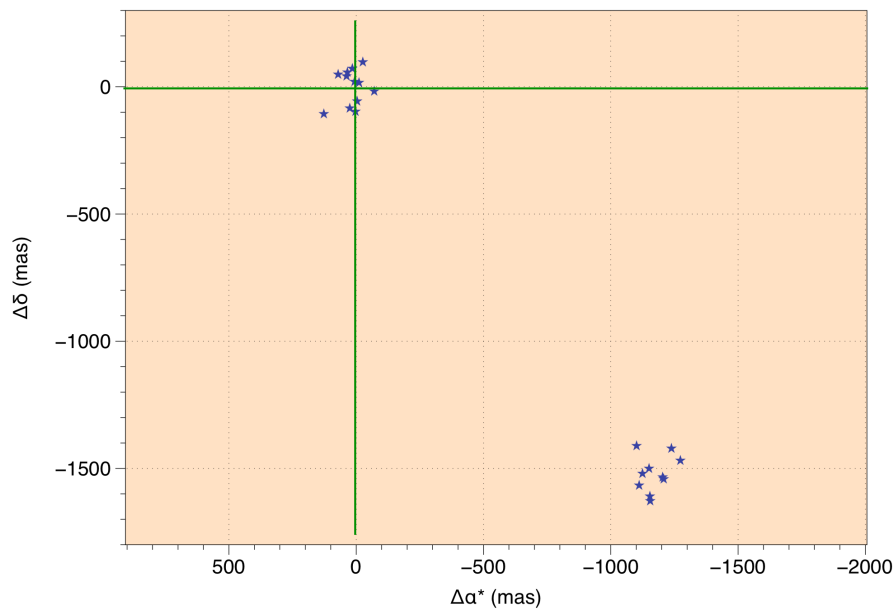
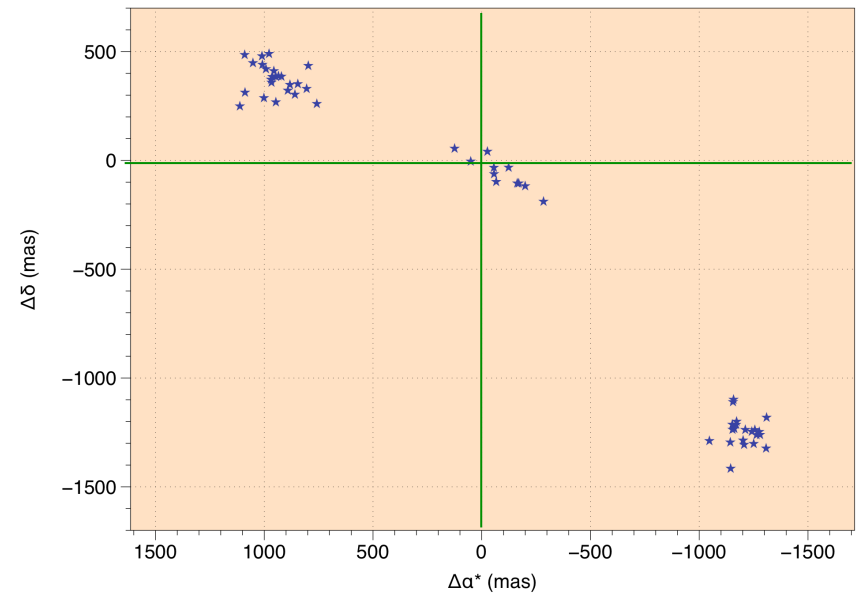
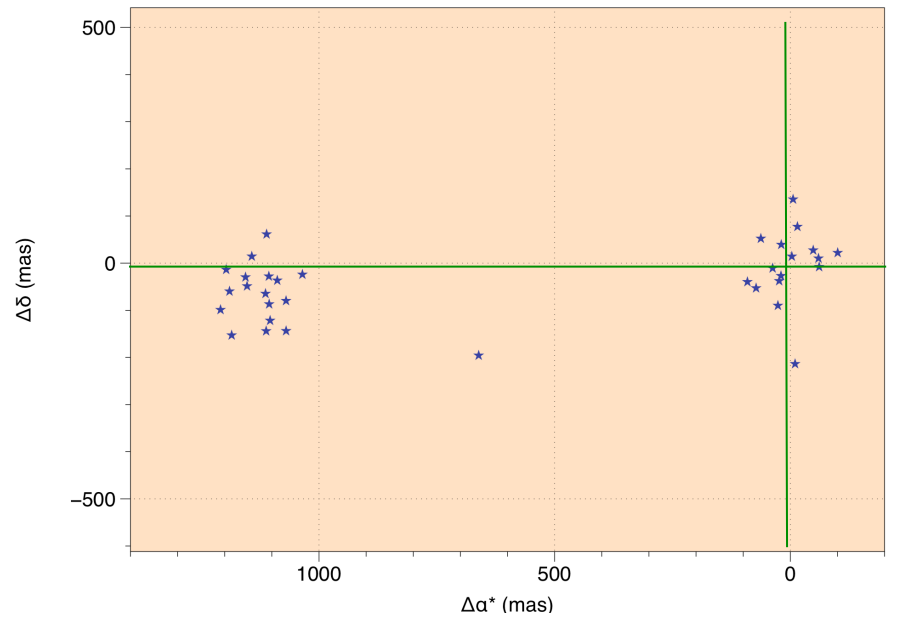


ICRF position

Nature unknown → wait for spectrophotometry



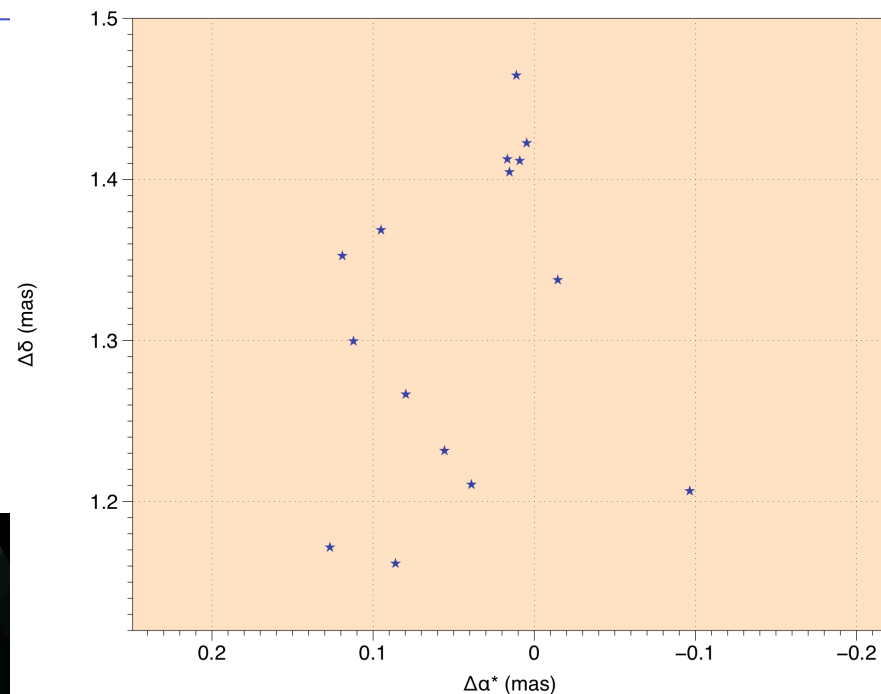
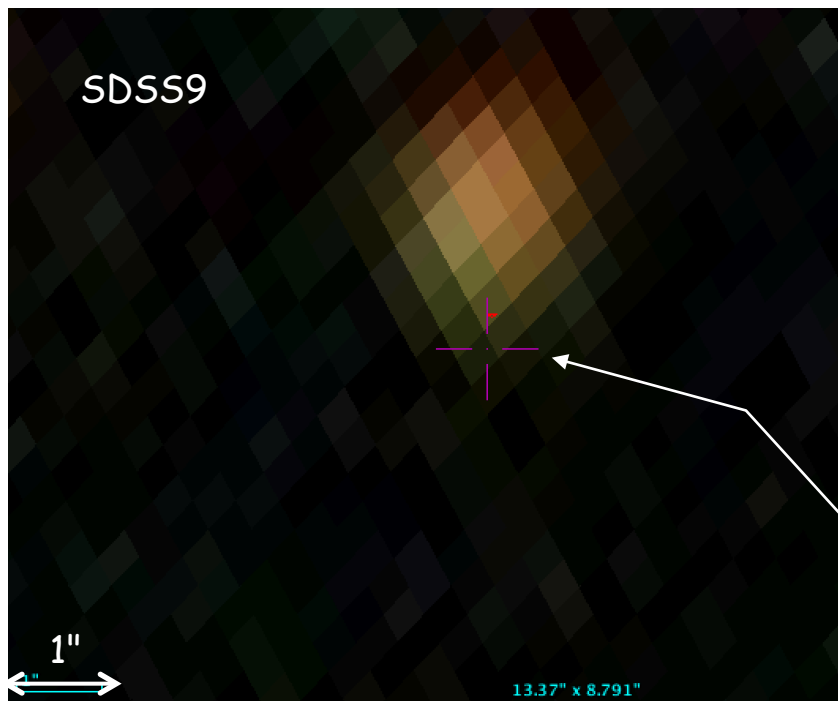
Double or multi-imaged ICRF sources



Wrong identification or solution

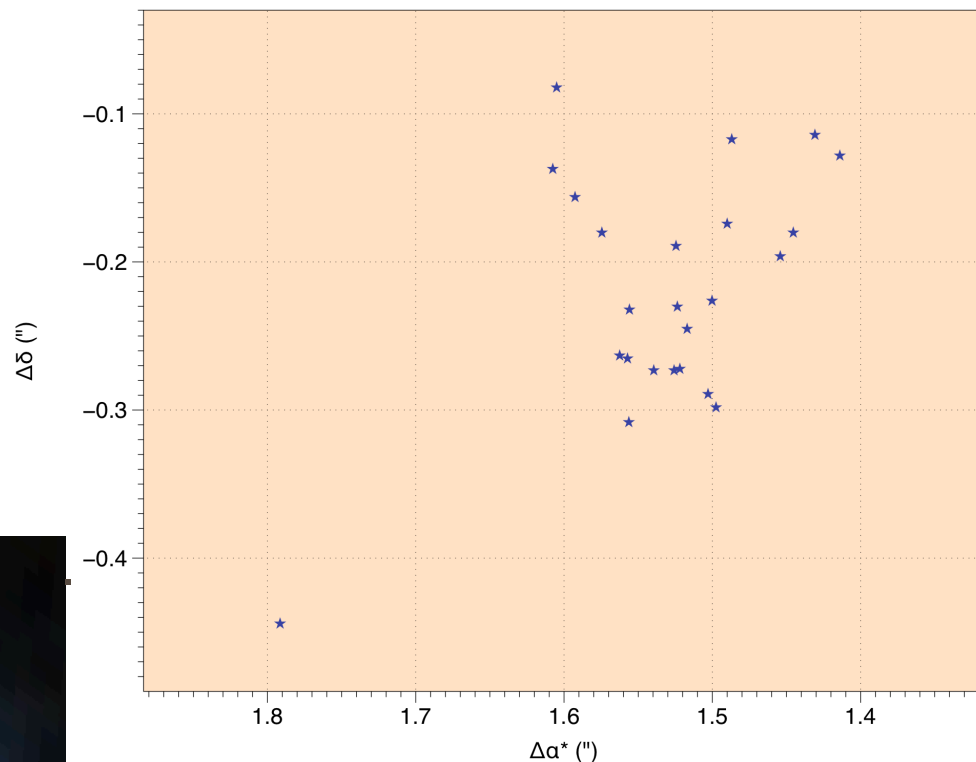
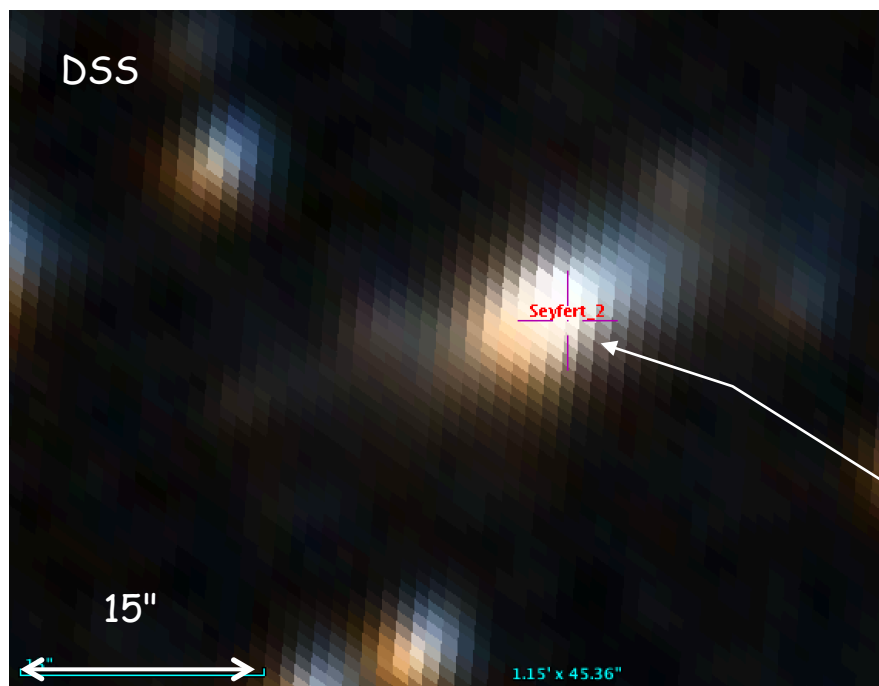
- Wrong position

- normal scatter
- $\Delta\alpha^* \sim 0''$ $\Delta\delta \sim +1.2''$
- Check with Aladin :
 - bright optical source nearby
 - $\Delta\alpha^* \sim 0''$ $\Delta\delta \sim +1''$



- Wrong position

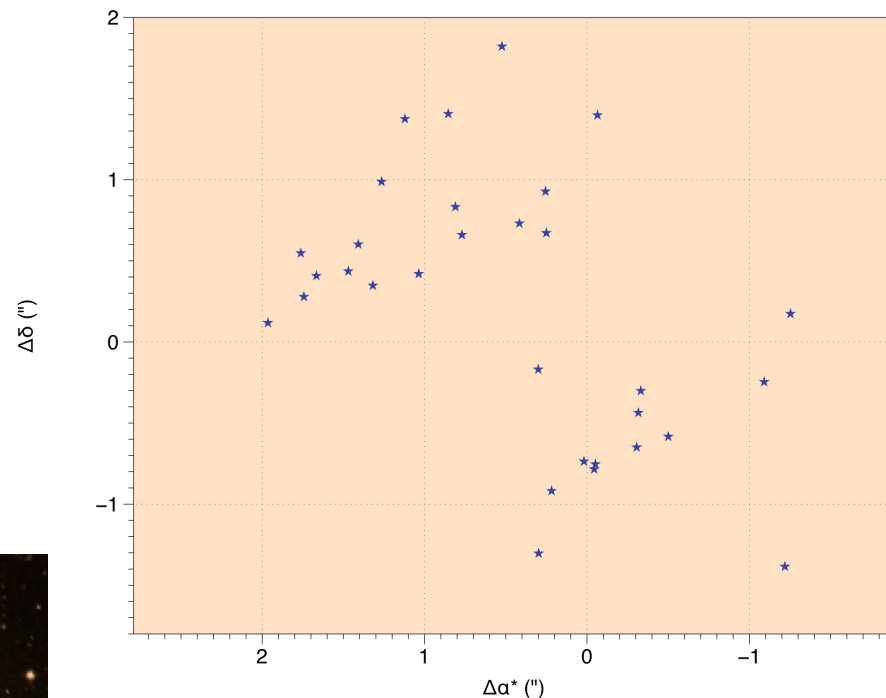
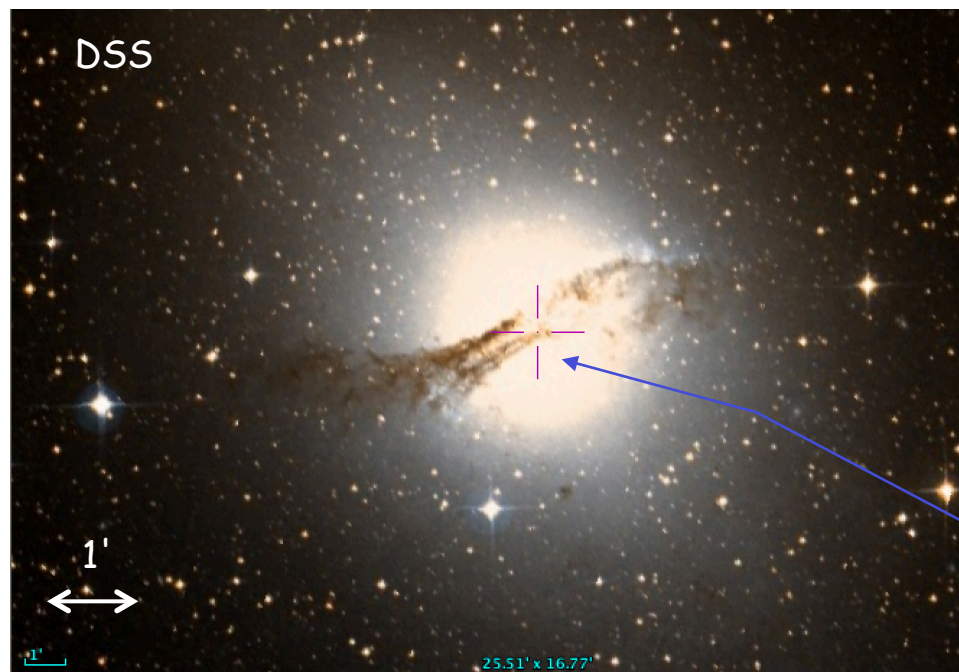
- offset 1.5 " and -0.2"
- medium scatter
- Check with Aladin :
 - bright galaxy



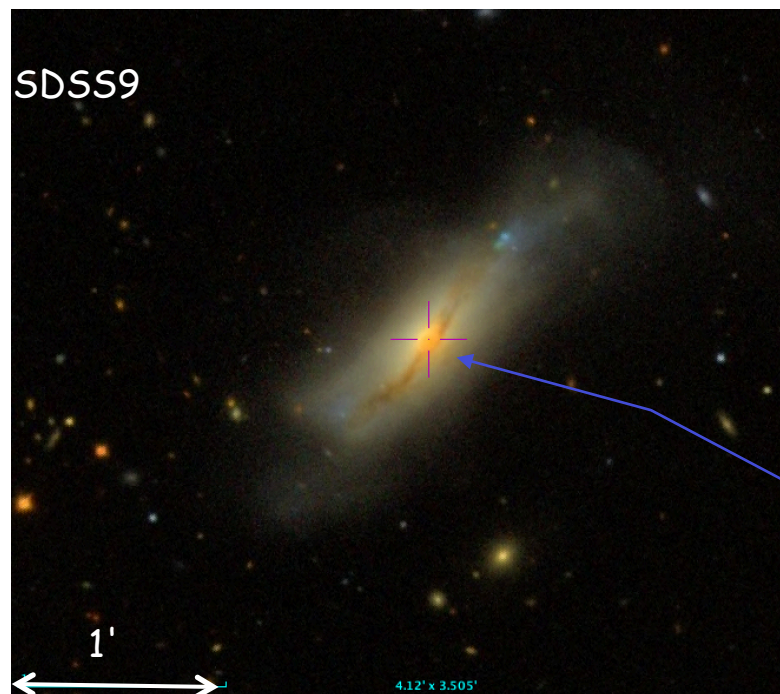
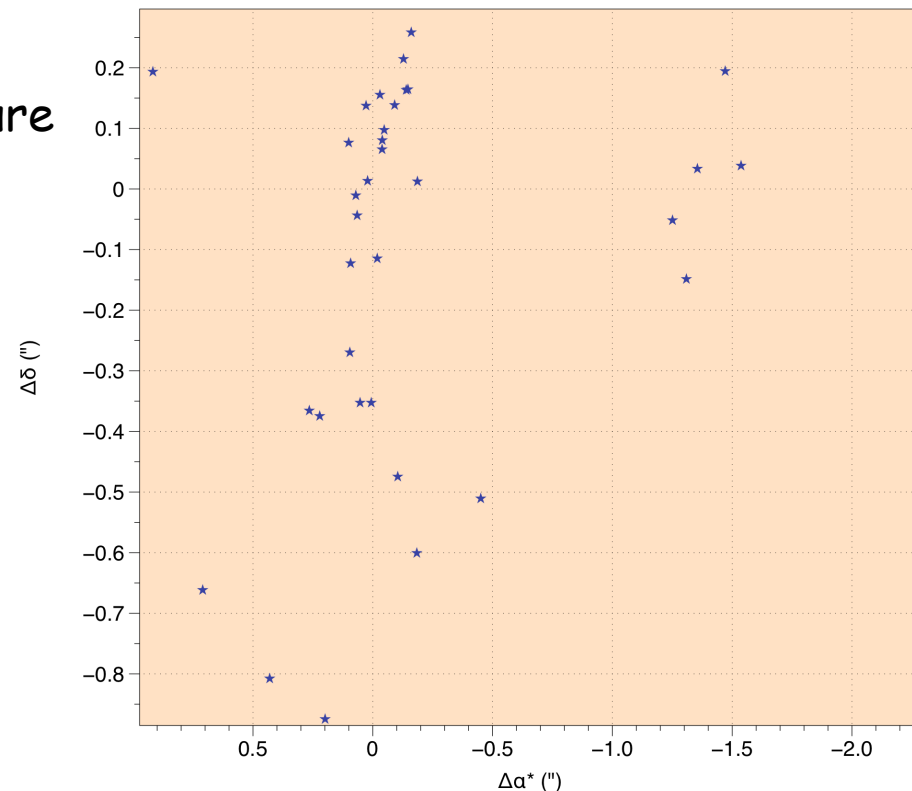
ICRF position

- Wrong position

- Very large scatter, $> 1''$
- false detections
- Check with Aladin :
 - Large and bright galaxy

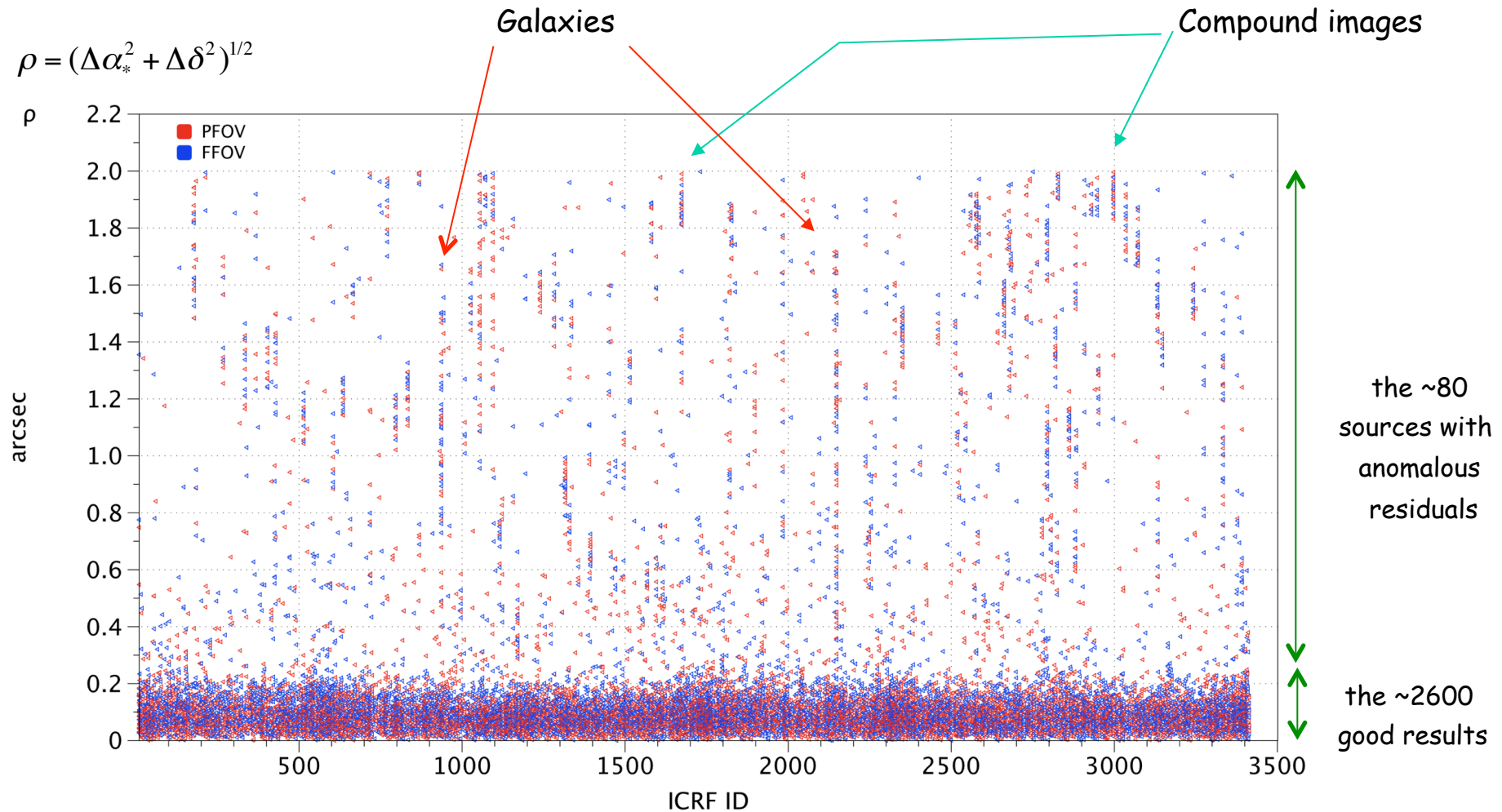


- Wrong position
 - Very large scatter, strange structure
 - false detections
- Source at the centre of a bright galaxy

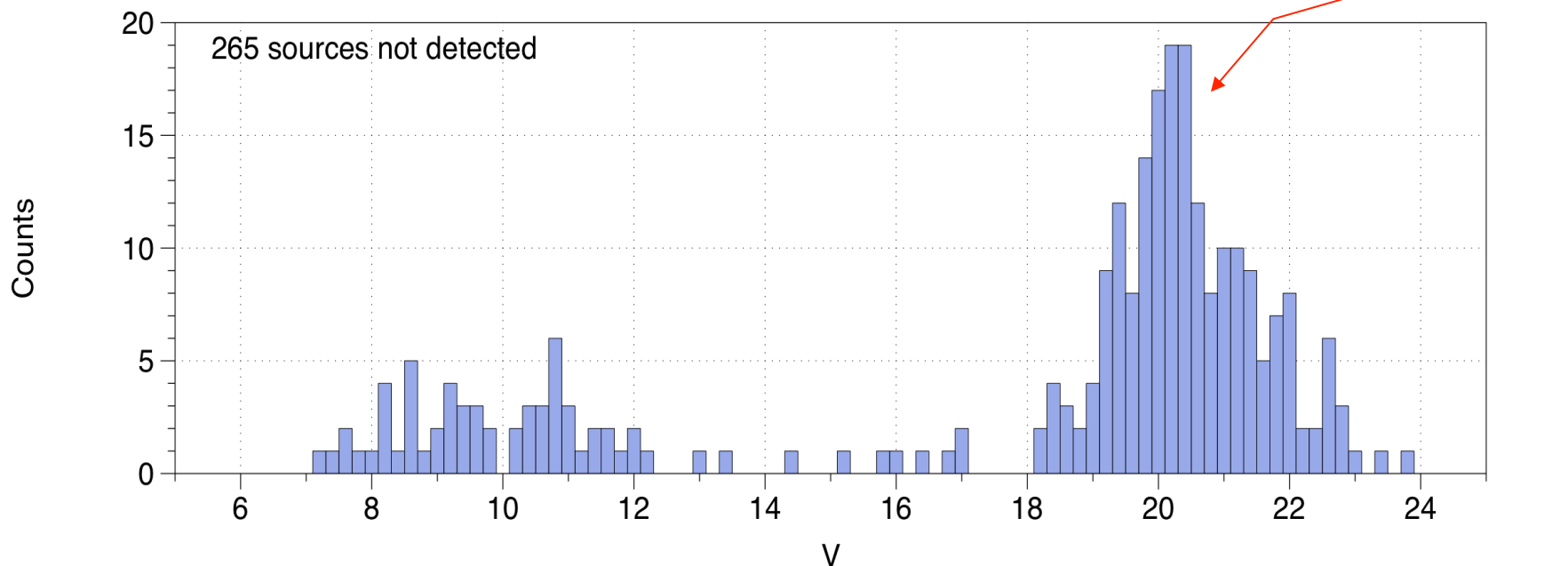


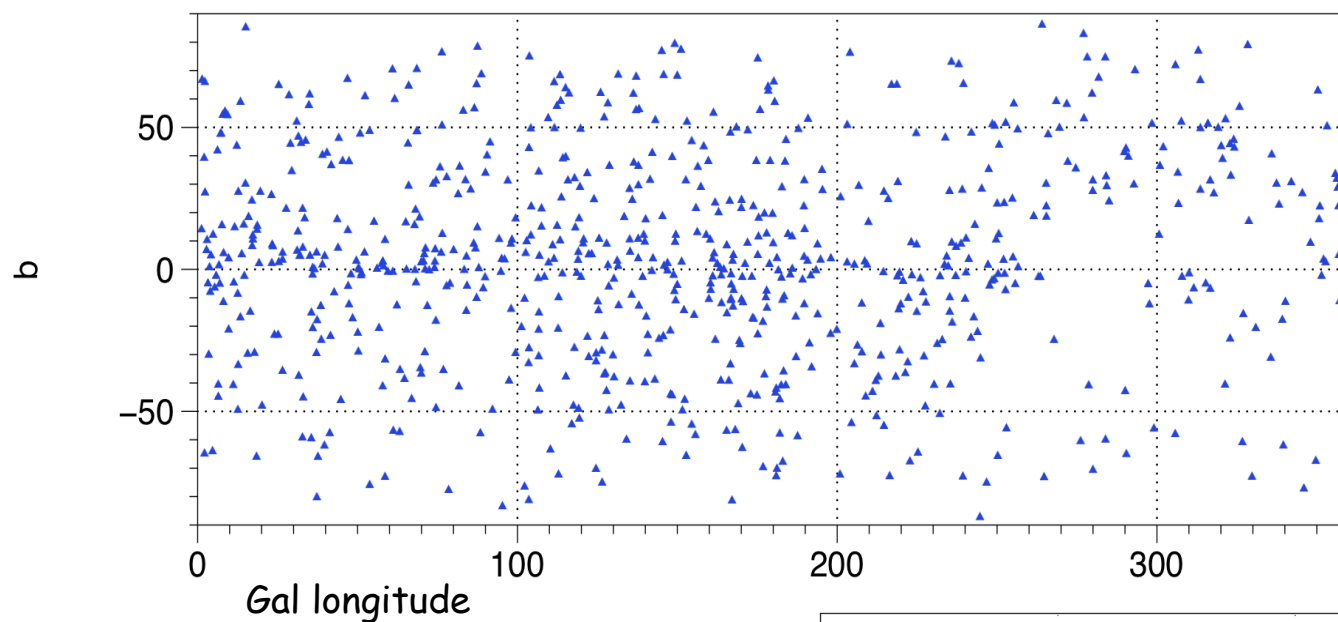
- Overall plot of $\rho = (\Delta\alpha_*^2 + \Delta\delta^2)^{1/2}$ for single observations

- the plot one should never show for good communication !



- Among the 709 never detected
 - 444 have no available magnitude (out of 700)
 - 265 with an estimated magnitude from the ground
 - Generally faint sources, but not always
 - A group of bright sources → magnitude of the galaxy
 - Galactic plane screening

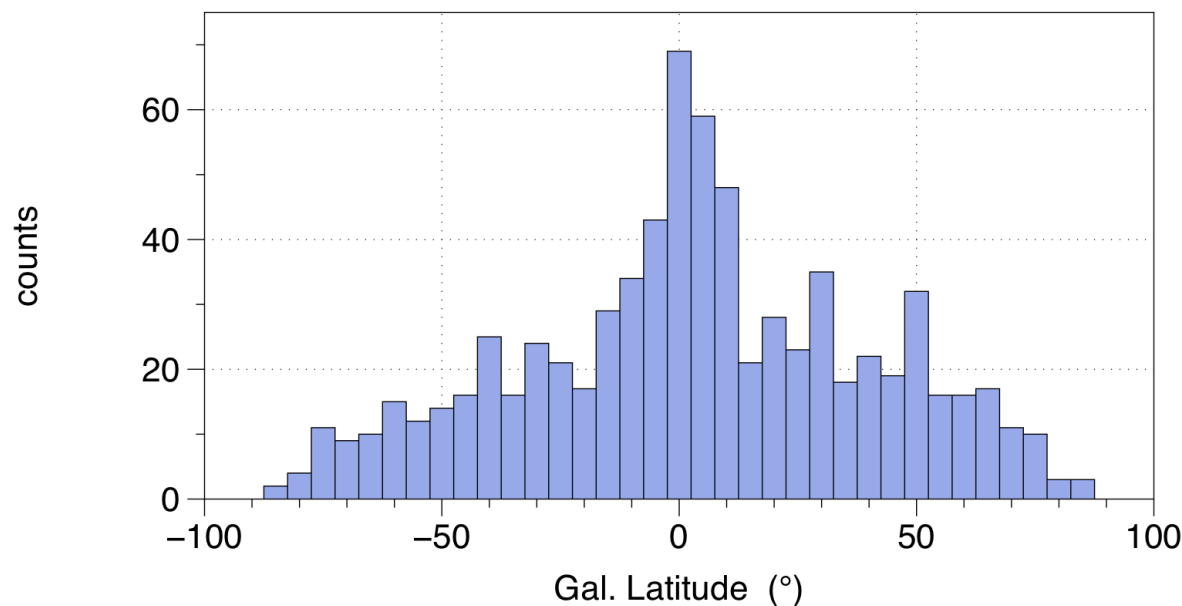




small concentration
in the galactic plane,
hardly discernible

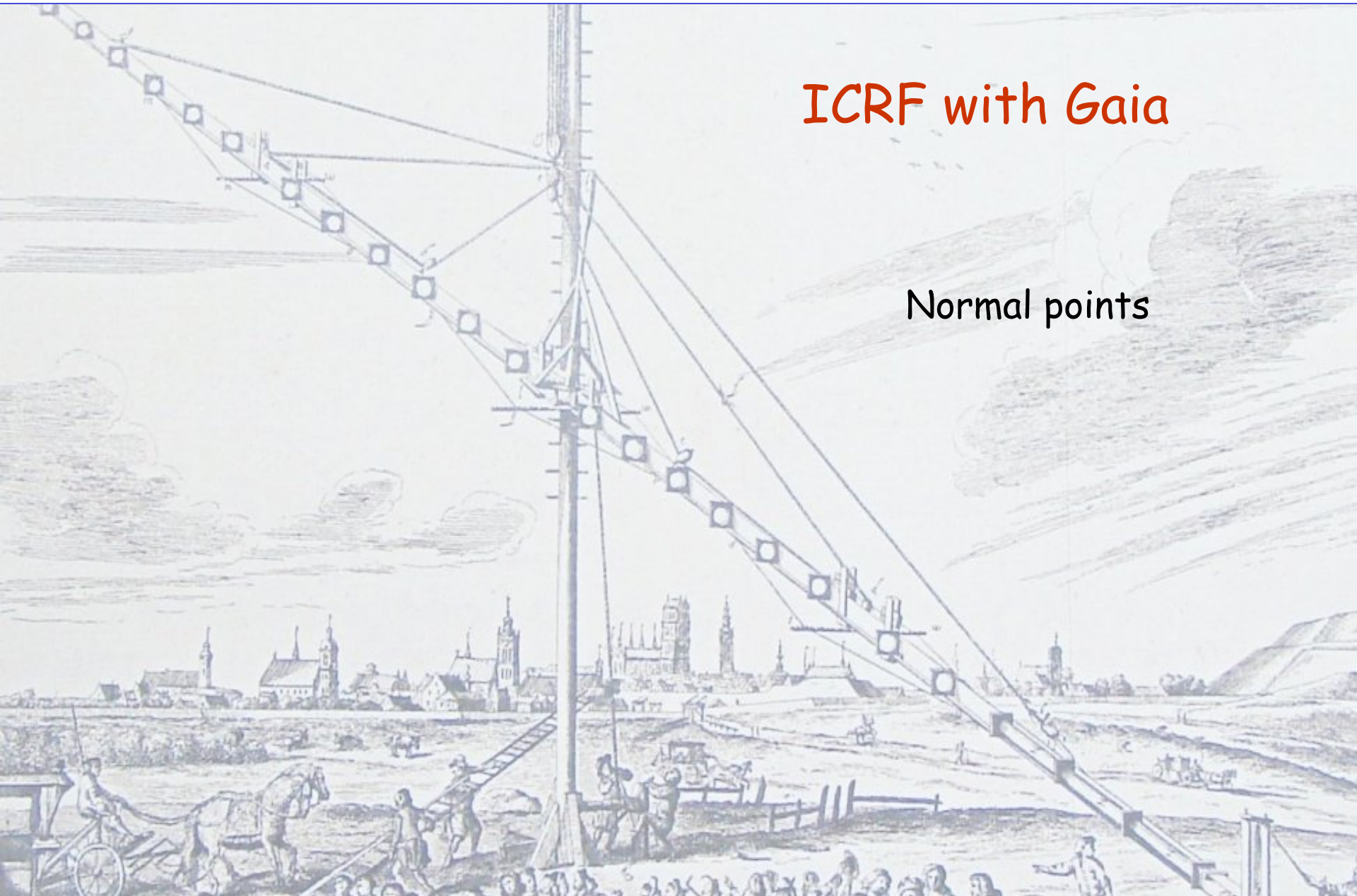
- but conspicuous
with a histogram

~ 100 sources screened



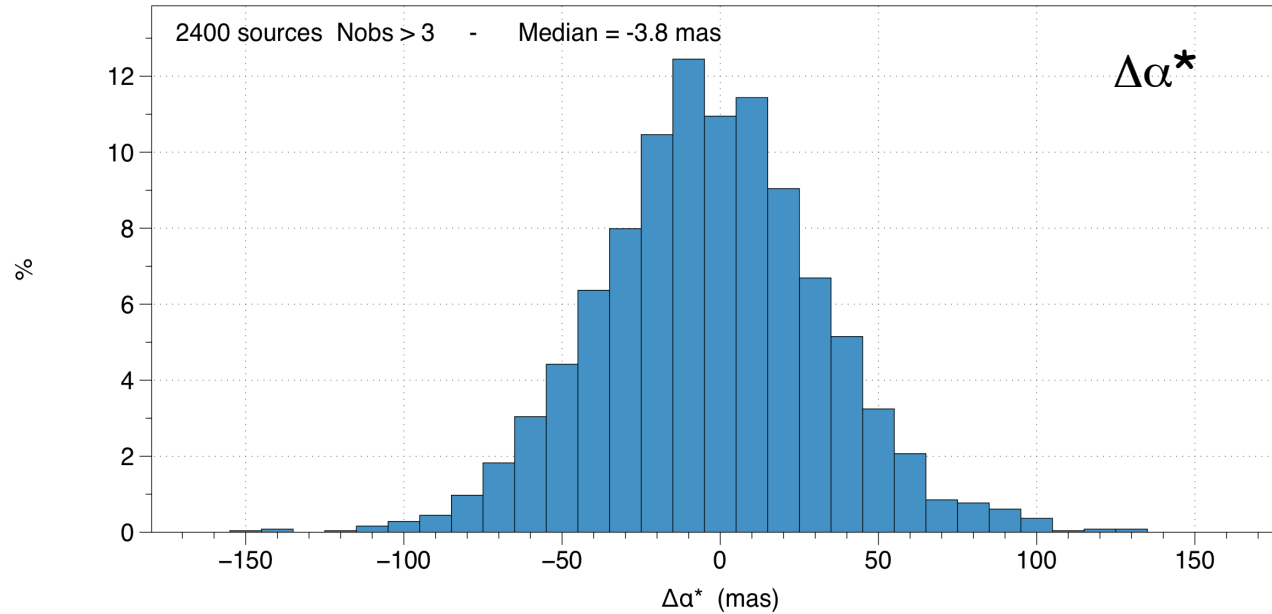
ICRF with Gaia

Normal points

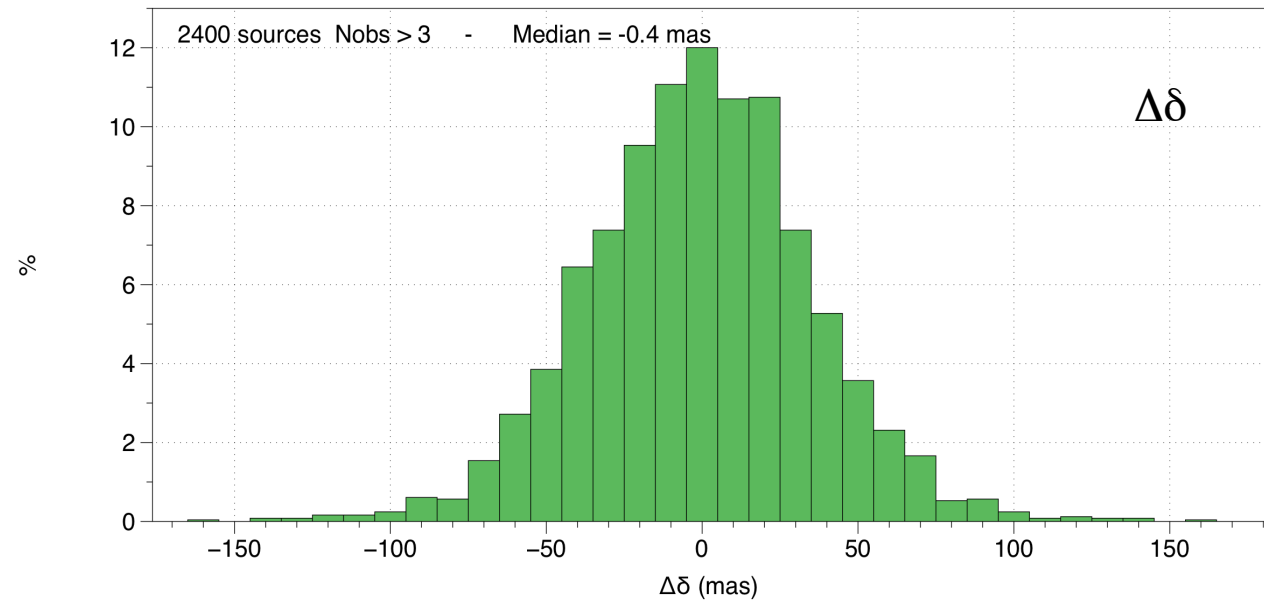


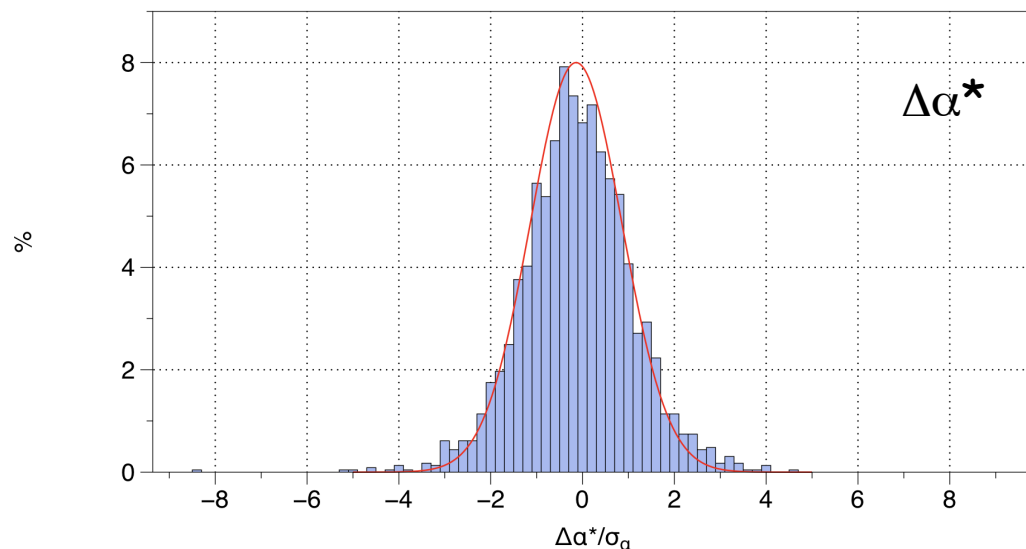
- Between 4 and 30 observations
 - 2400 sources
- Median of the positions, no global astrometry, no attitude reconstruction
- Nothing to do with Gaia astrometric accuracy (100 times better !)
 - But looks already better than FK5 !
- One single systematic (empirical) correction of 25 mas amplitude with period 59 days (Gaia spin precession ?)

Results tell more about Gaia Initial data treatment performances than about ICRF sources in the optical domain



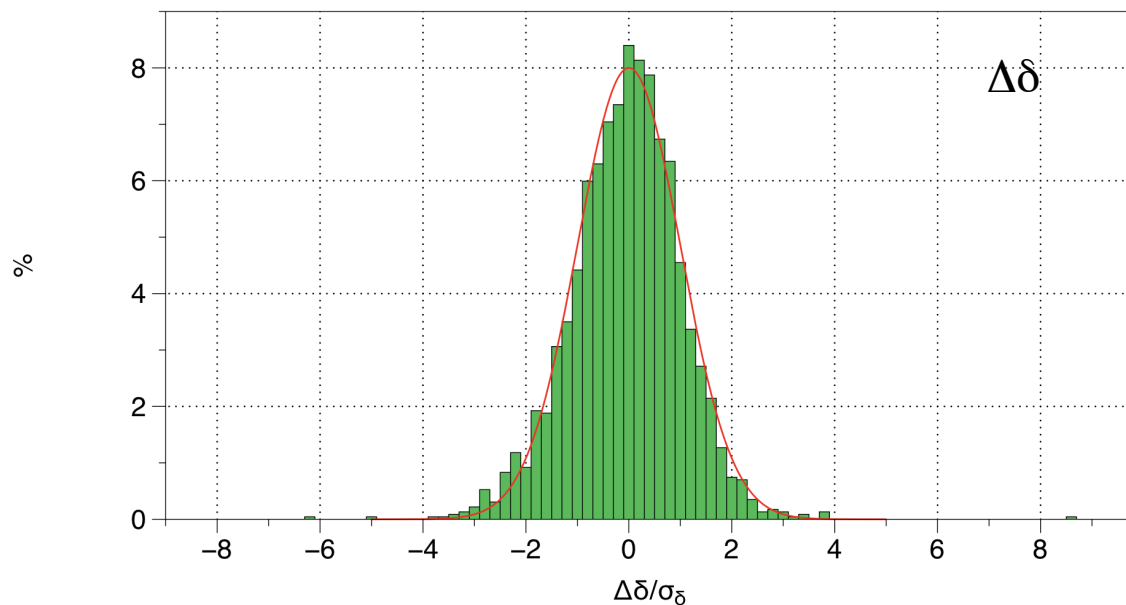
$\sigma \sim 35$ mas



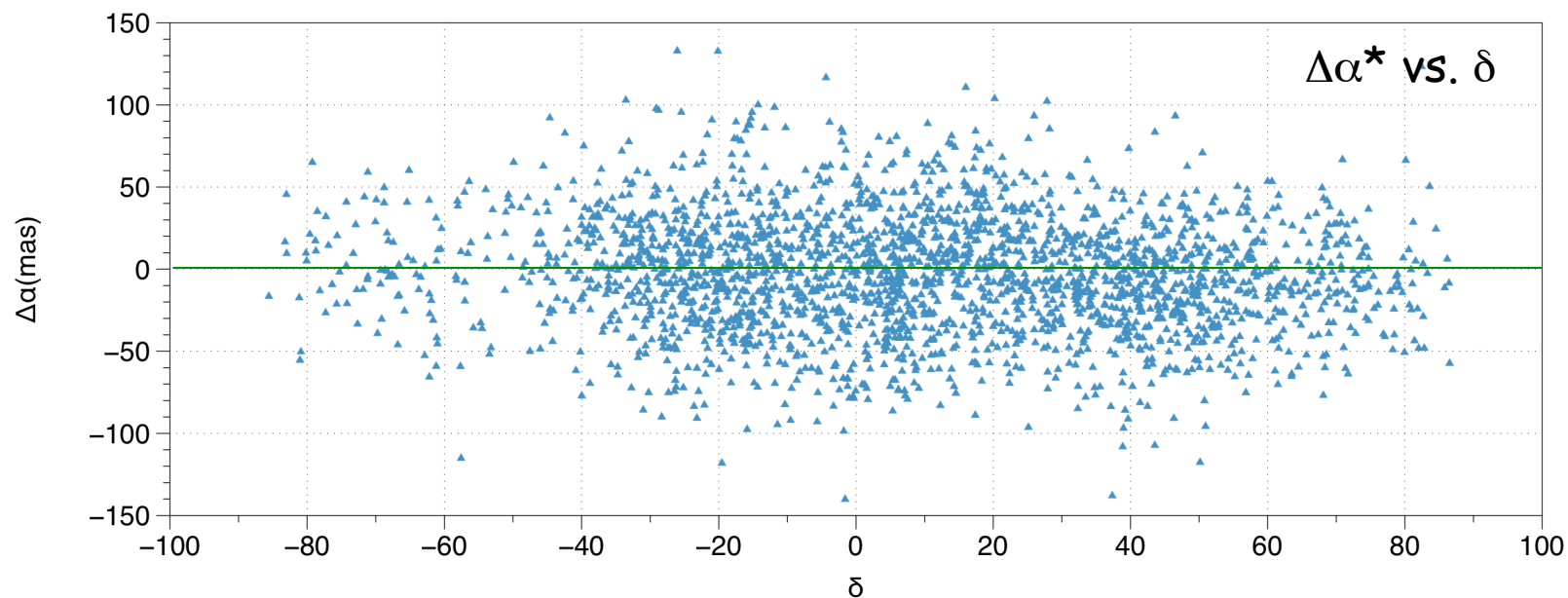
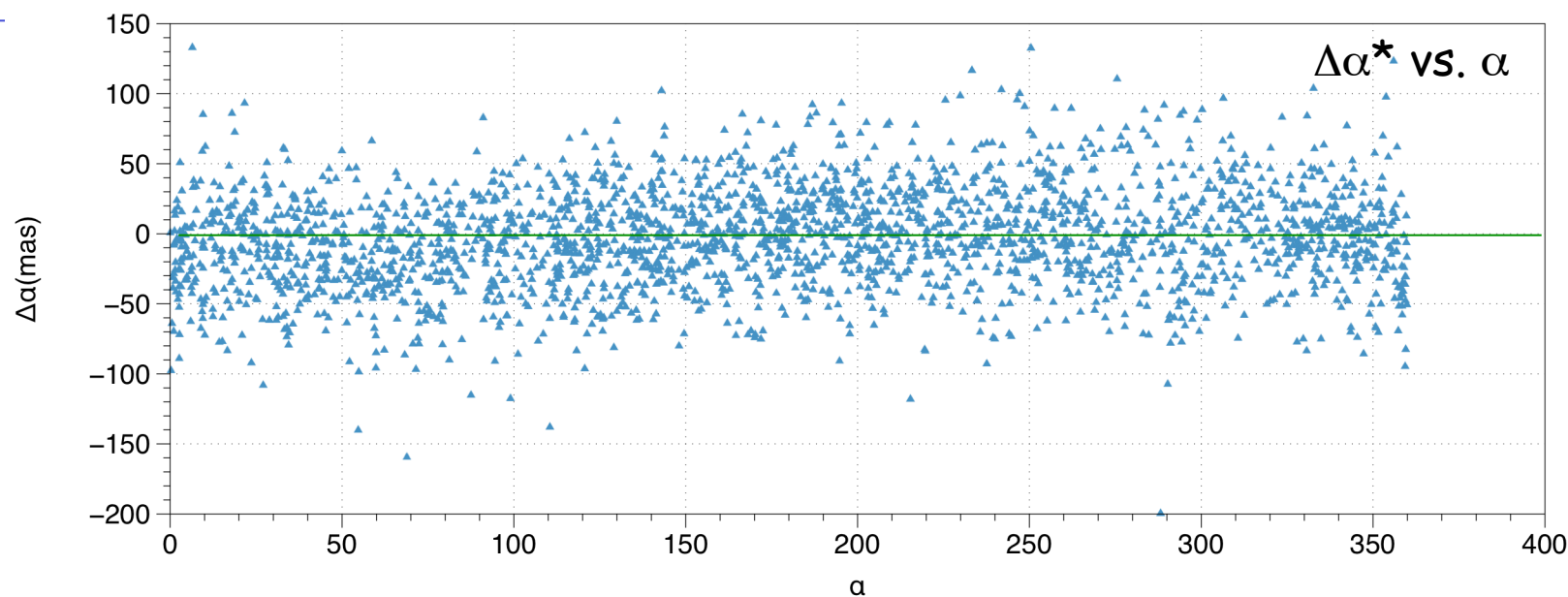


20 mas system error added
SD based on scatter only
Robust estimate for small samples

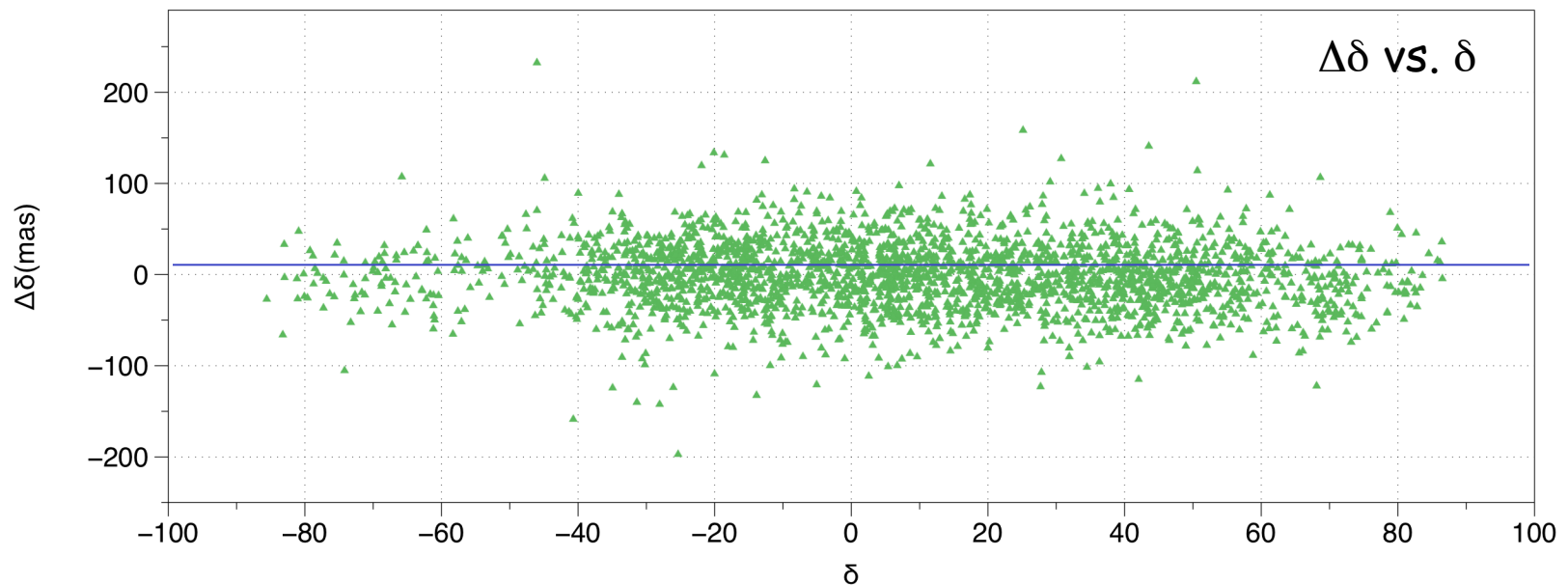
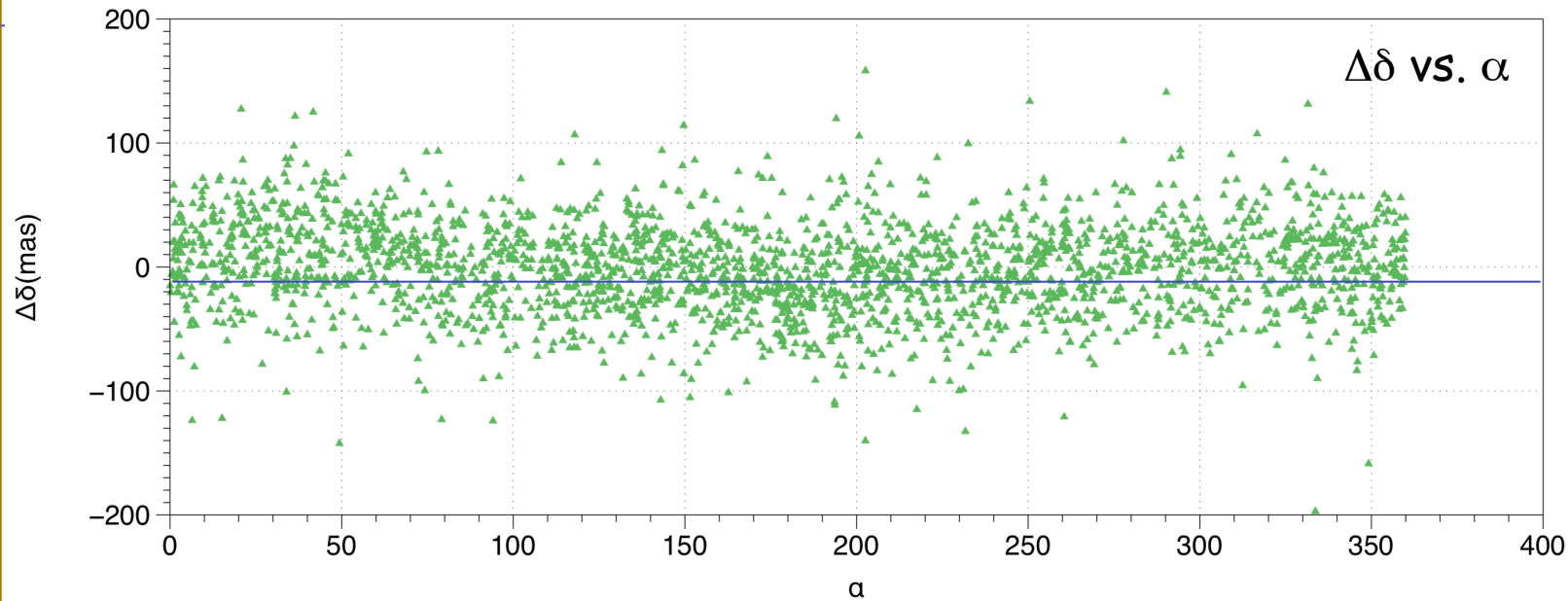
— $N(0,1)$

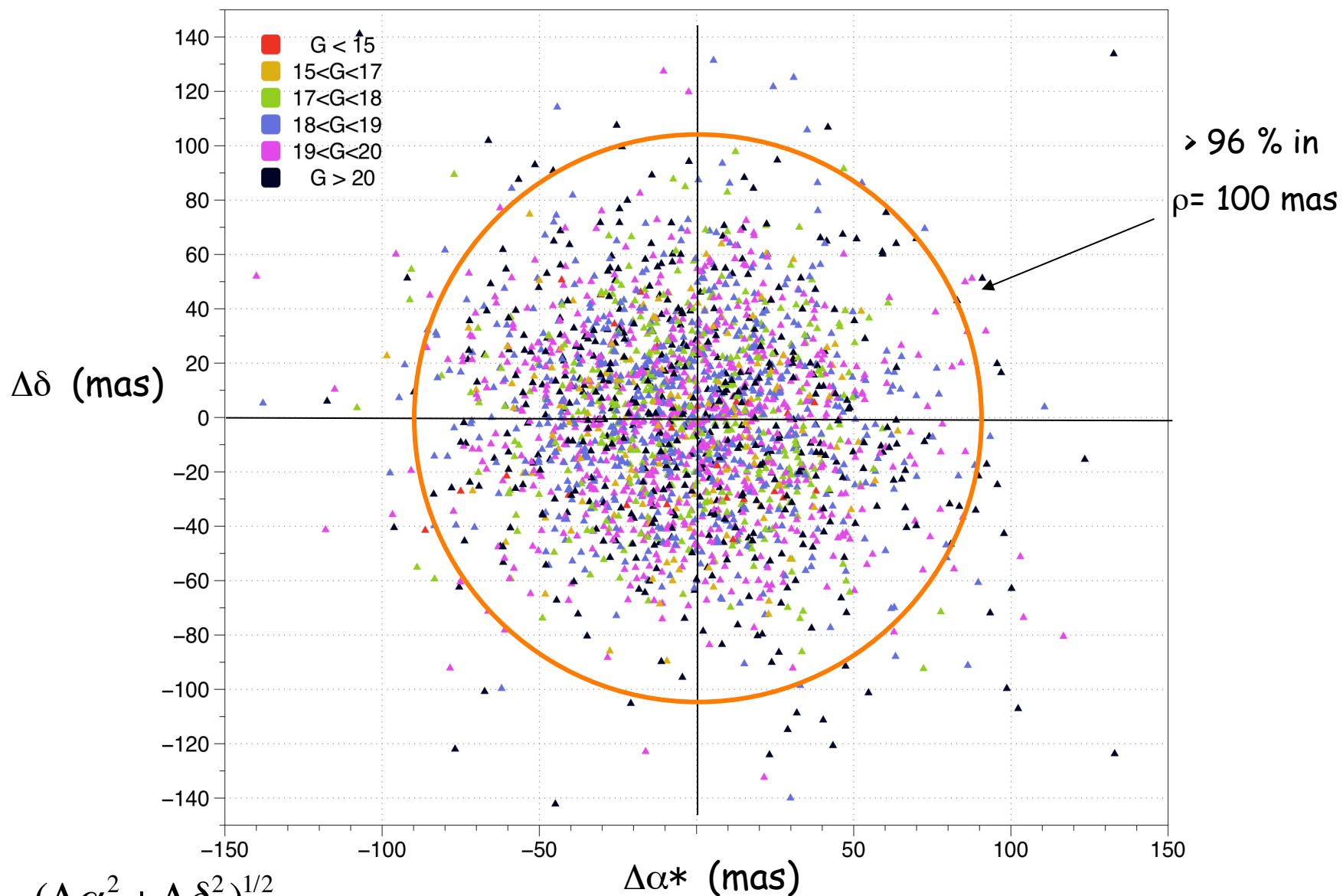


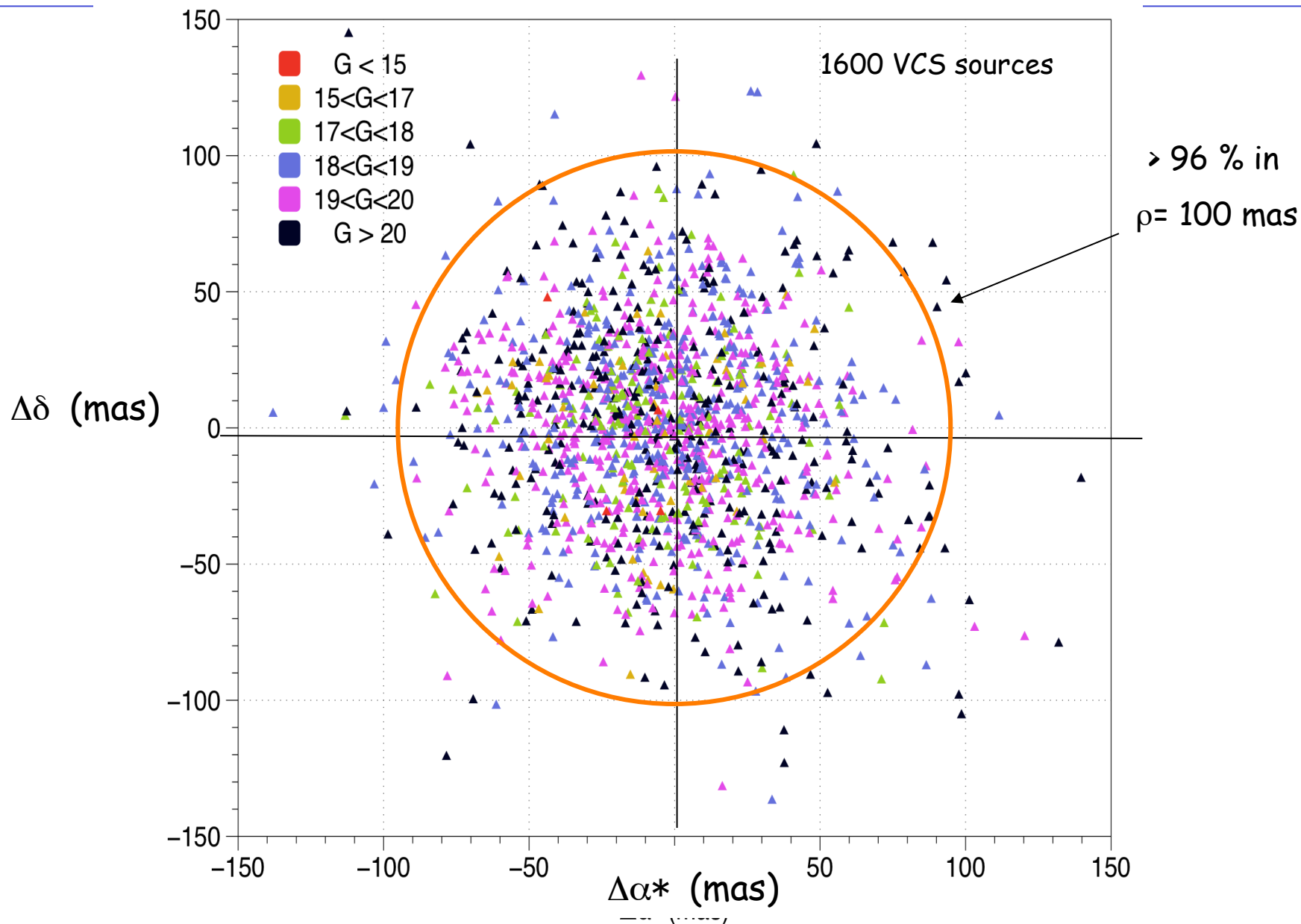
ICRF: Combination of observations



ICRF: Combination of observations



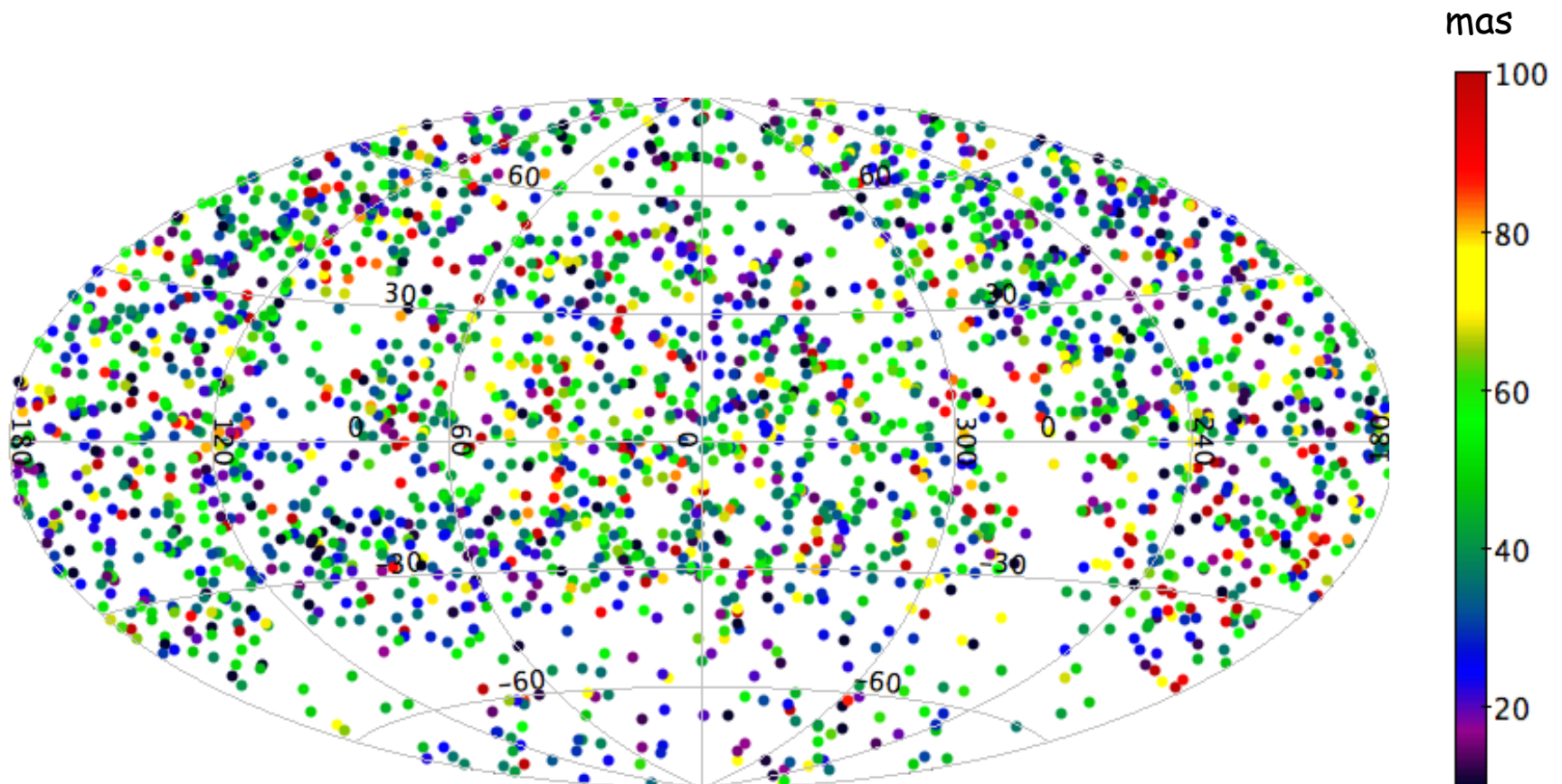




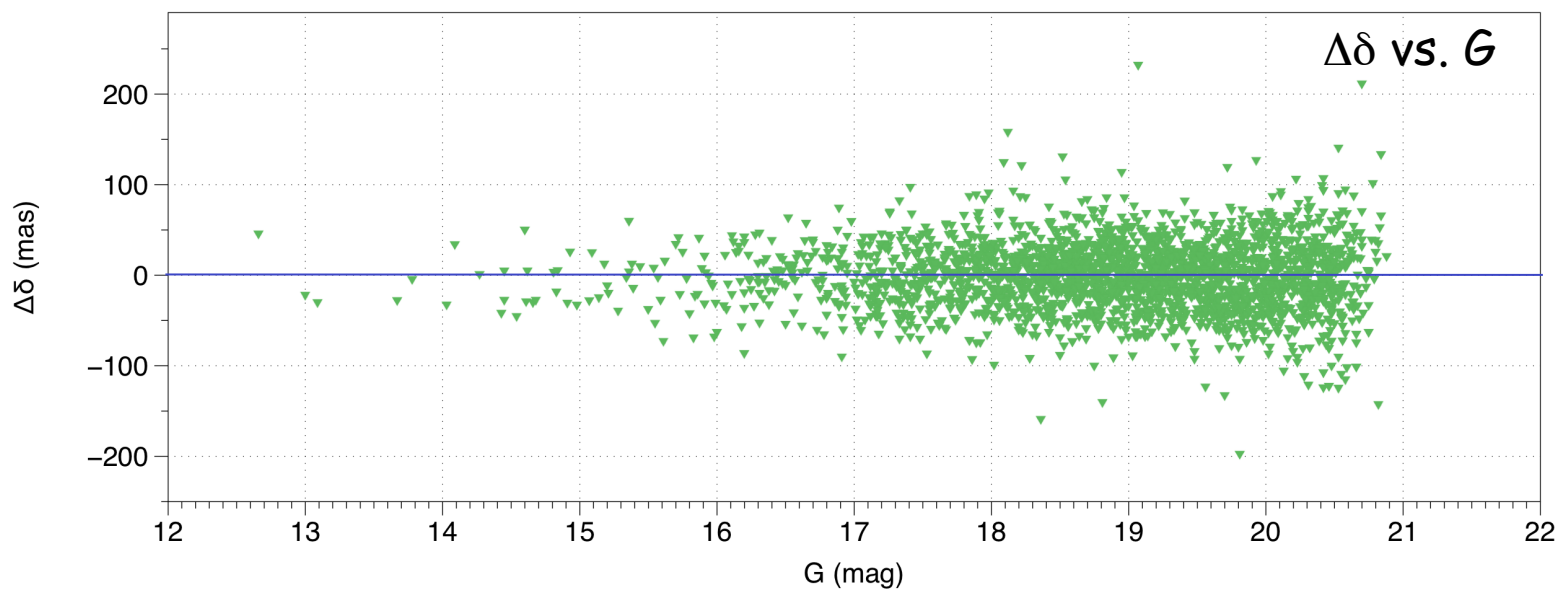
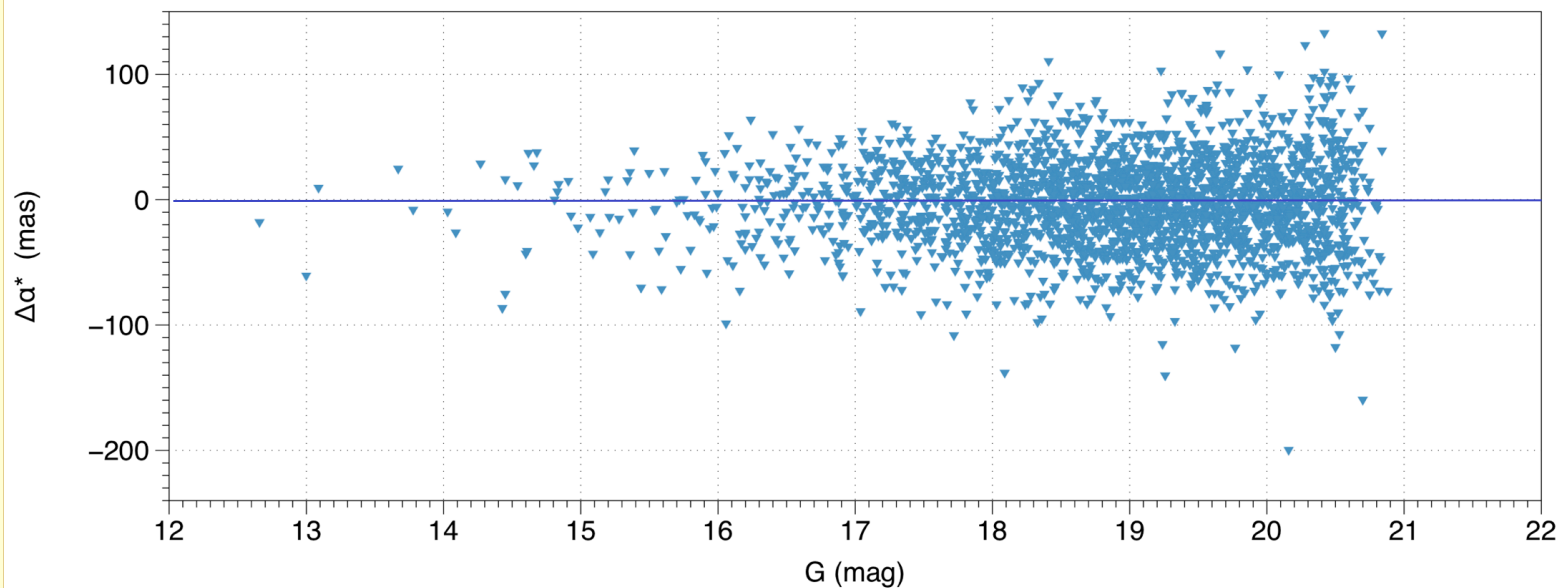
- Equatorial coordinates

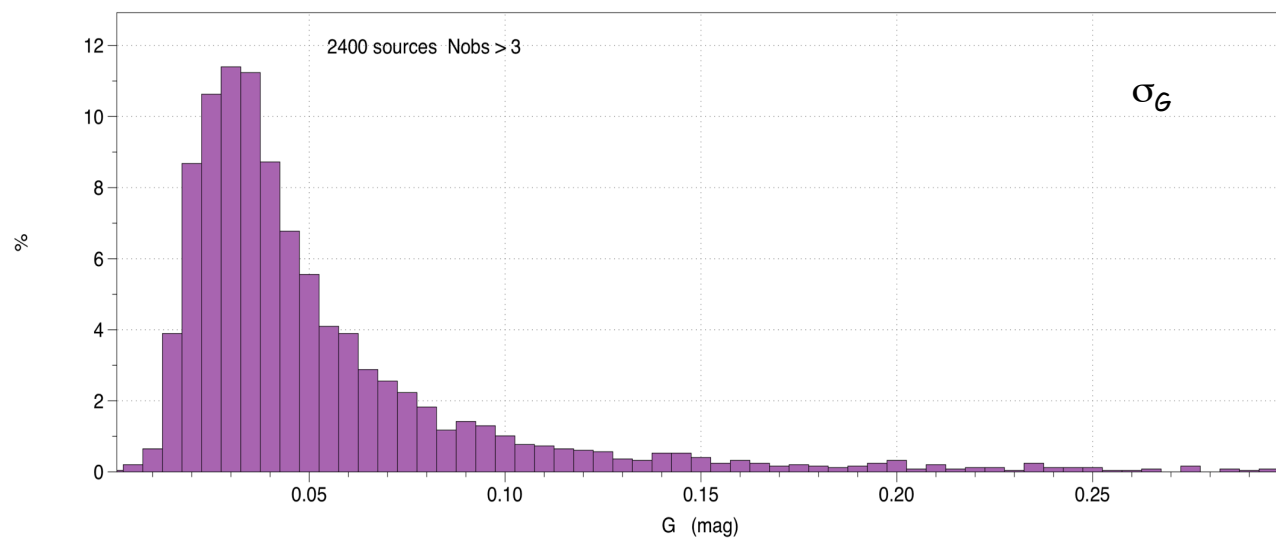
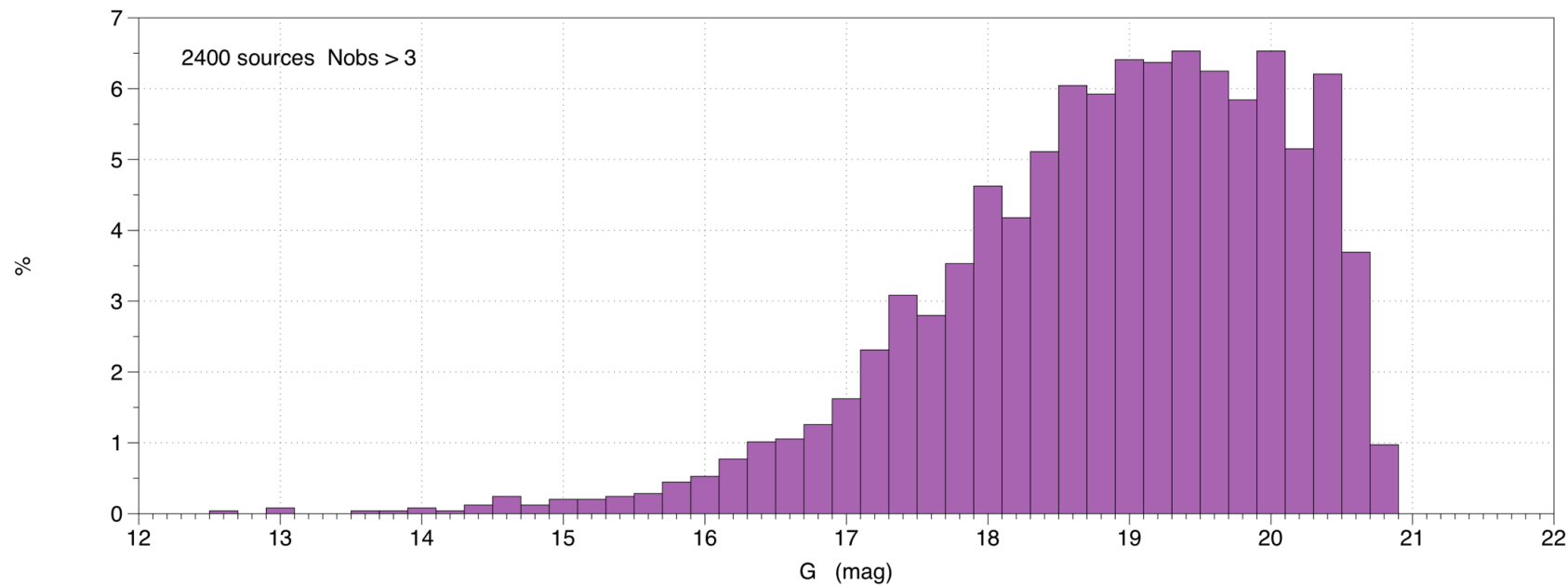
- no outstanding features
- the empty zone is the galactic plane

$$\rho = (\Delta\alpha_*^2 + \Delta\delta^2)^{1/2}$$

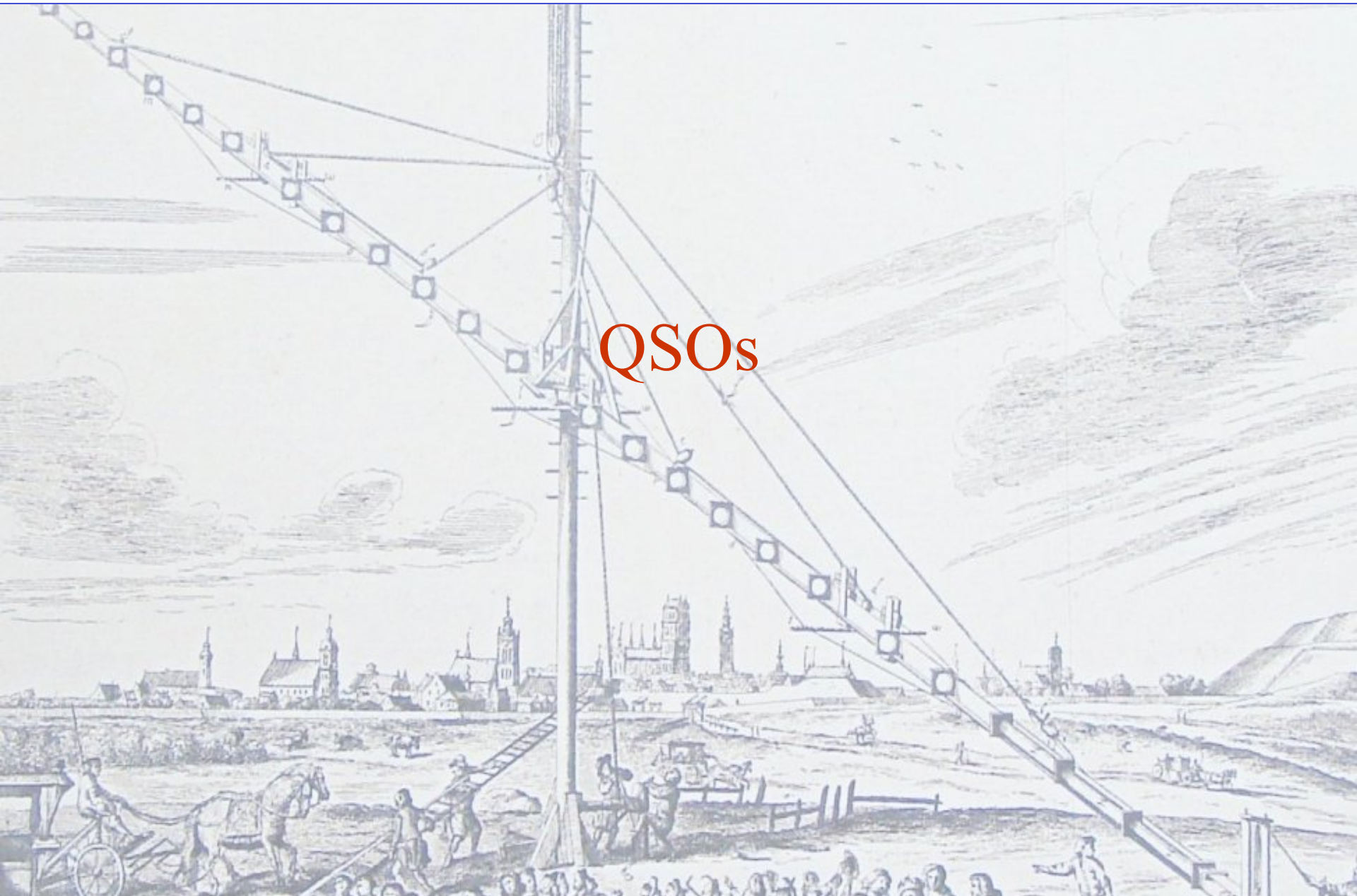


ICRF: Combination of observations



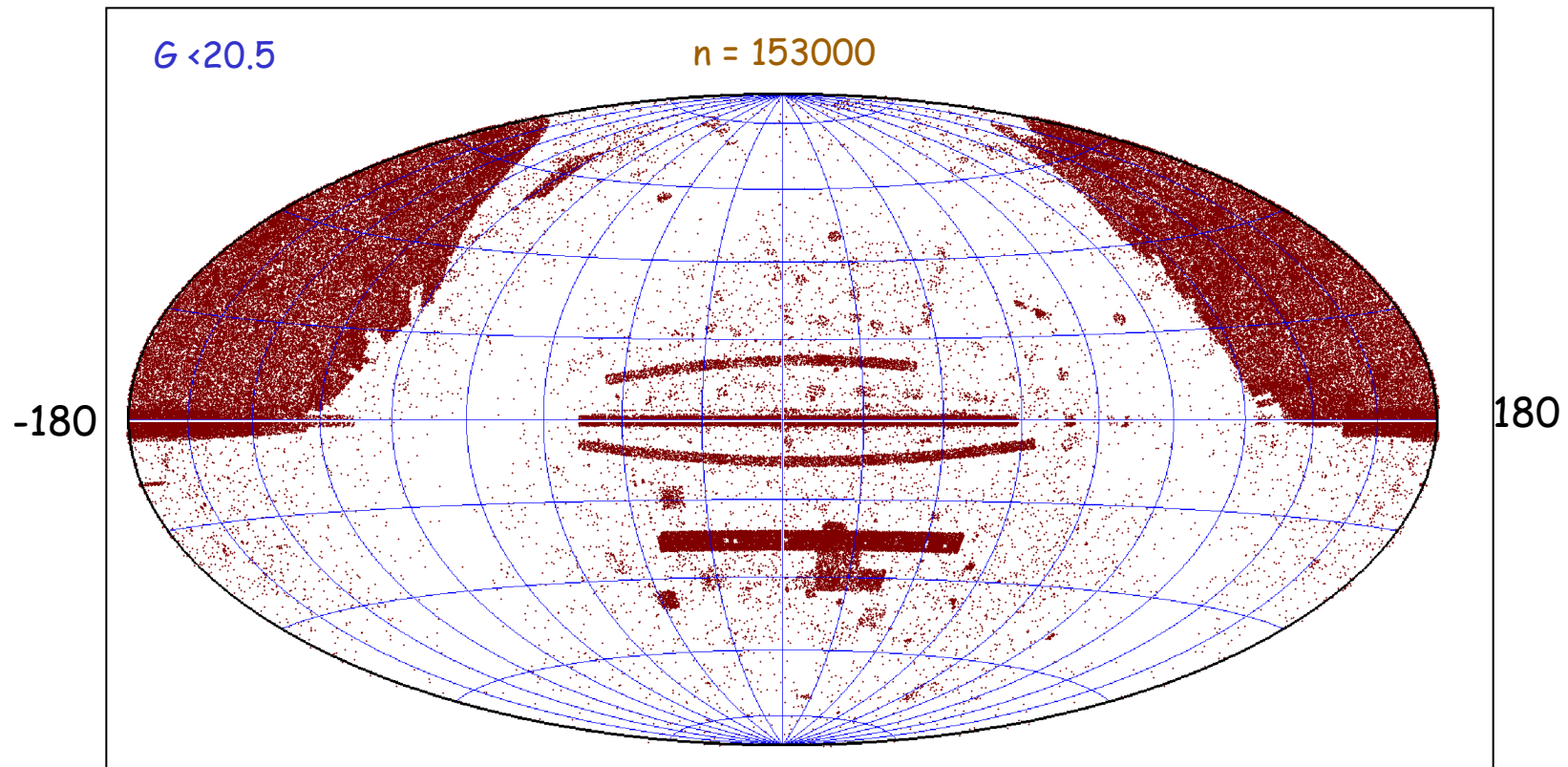


- Within the IDT (Gaia daily routine processing) validation we have already established:
 - that 2700 ICRF sources will be regularly observed with Gaia
 - 700 are too faint or within an extended source not detectable
 - The visual magnitude has been estimated consistently for the first time
 - The crude astrometry produces positions to 30 mas precision
 - systematic effects are probably of comparable magnitude
 - this won't be much improved with more observations with this technique
 - this is already better than FK5
 - Gaia global astrometry of the first release should be at least 10 times better
 - only 2% of the sources are problematic at IDT ACCURACY LEVEL
 - more could be at higher accuracy



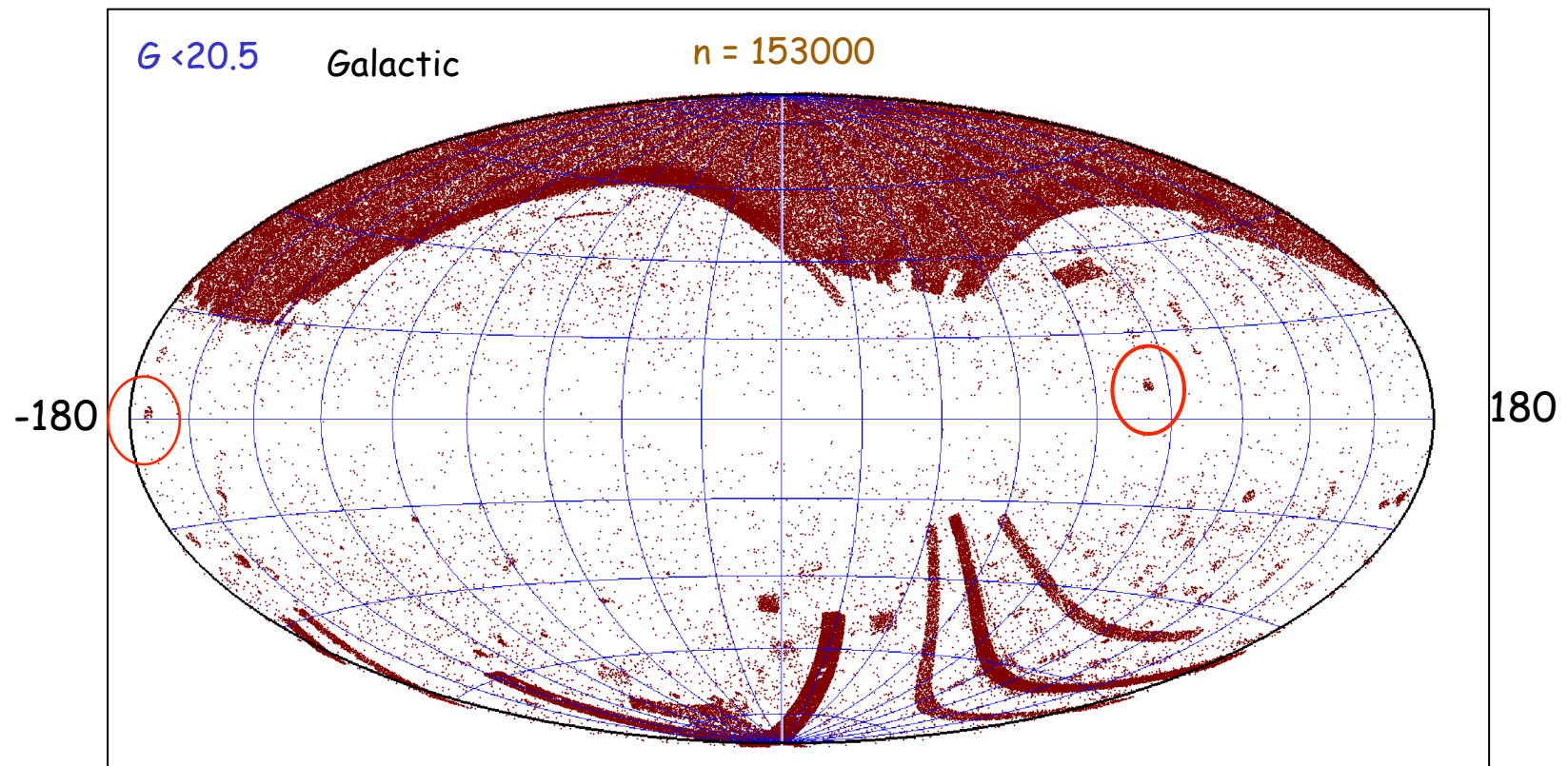
QSOs

- Catalogue LQAC (Souchay et al, 2012)
 - 185,000 entries with at least one magnitude
 - Plots in equatorial coordinates for $G < 20.5$



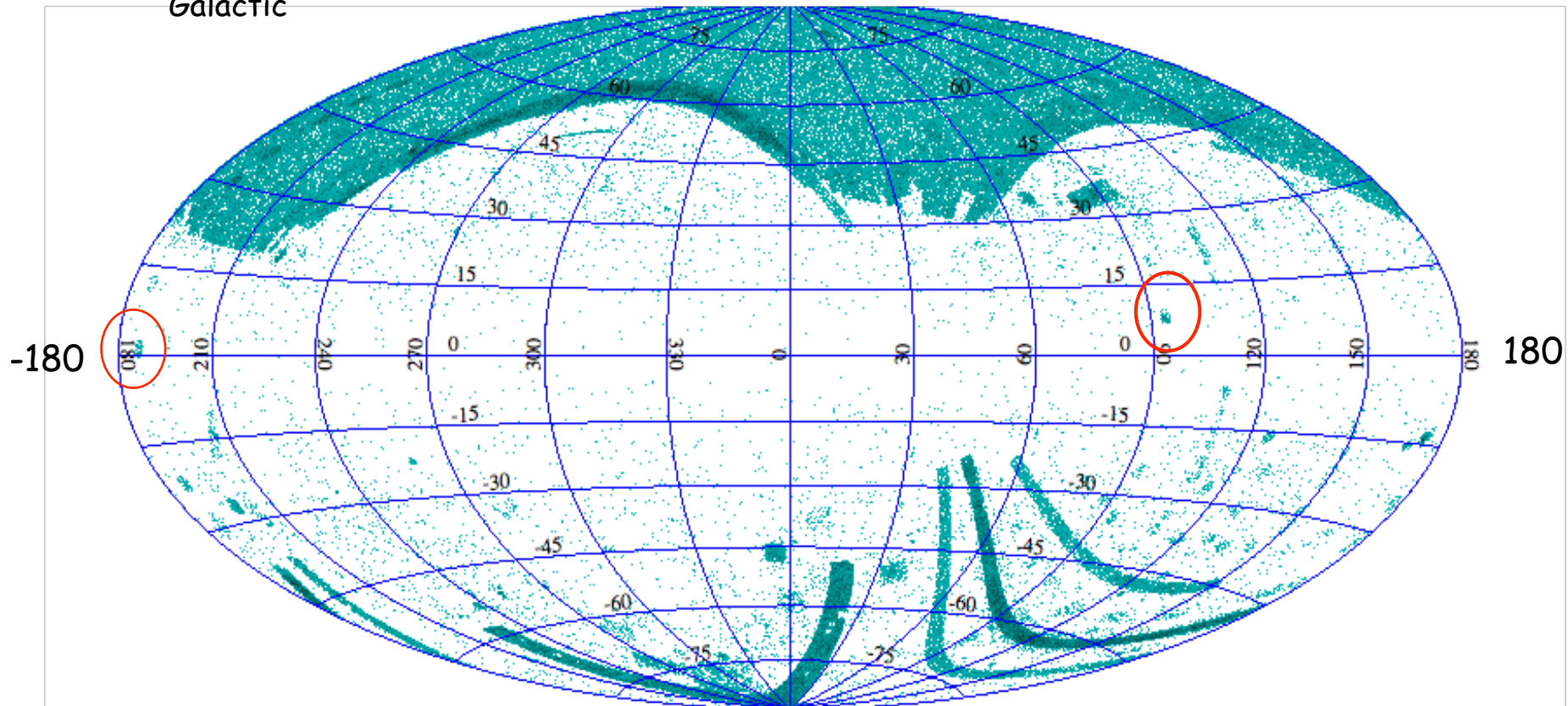
- Number of entries in the LQAC 185,400
- Number of entries never in the Gaia FOVs 0 ← Predicted
- Number of sources detected 164,000 (88.6%)
 - with 5+ observations 140,000
 - with 10+ observations 62,000
- Out of the 140,000 with 5+ observations
 - very good solutions, no outliers, clustered 120,000
 - good solutions, < 20% outliers 15,000
 - bad solutions, large scatter 600
 - Two point sources or double imaged ~ 400
 - Three point sources or three images ~ 30
 - Four point sources or four images 2-3

- Catalogue LQAC (Souchay et al, 2012)
 - Plots in galactic coordinates

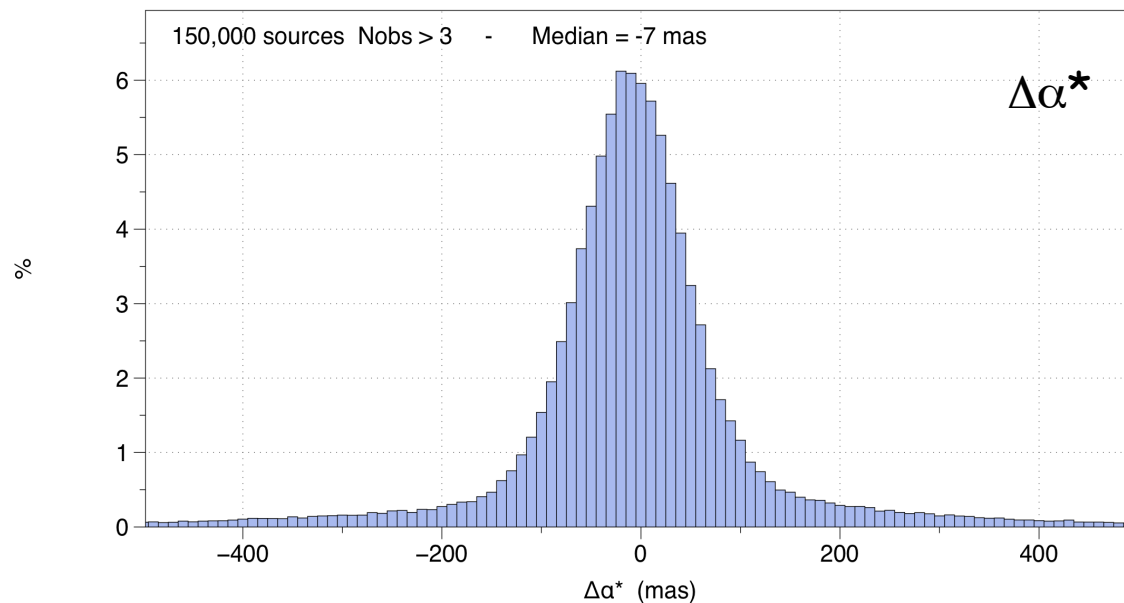


- Gaia detected sources from LQAC (with nobs ≥ 2)
 - Plots in galactic coordinates
 - QSOs detected even at $b < 10^\circ$

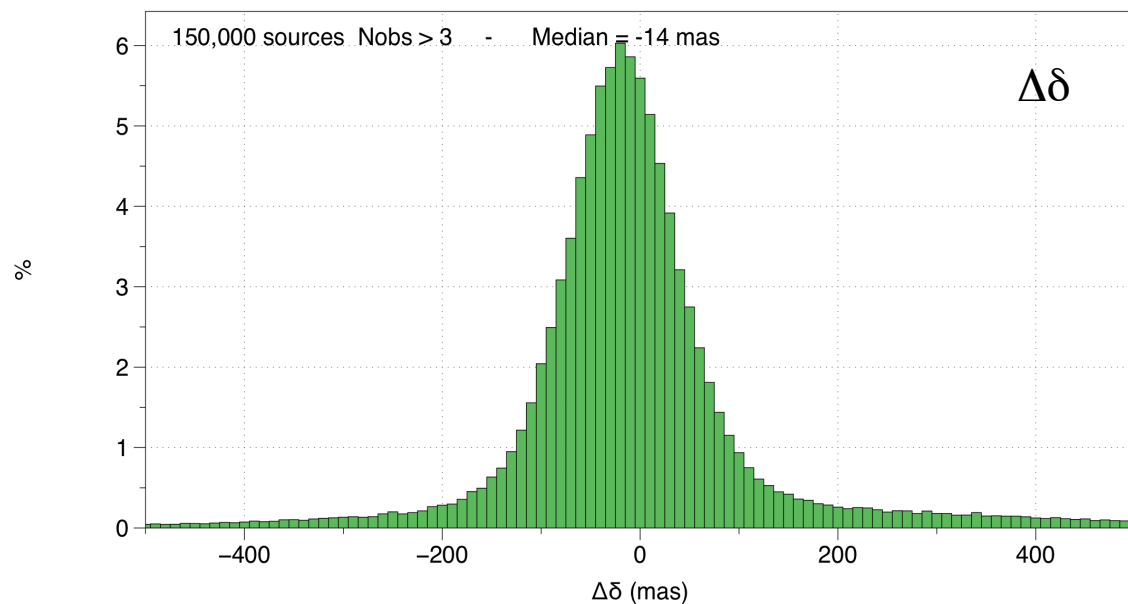
Galactic



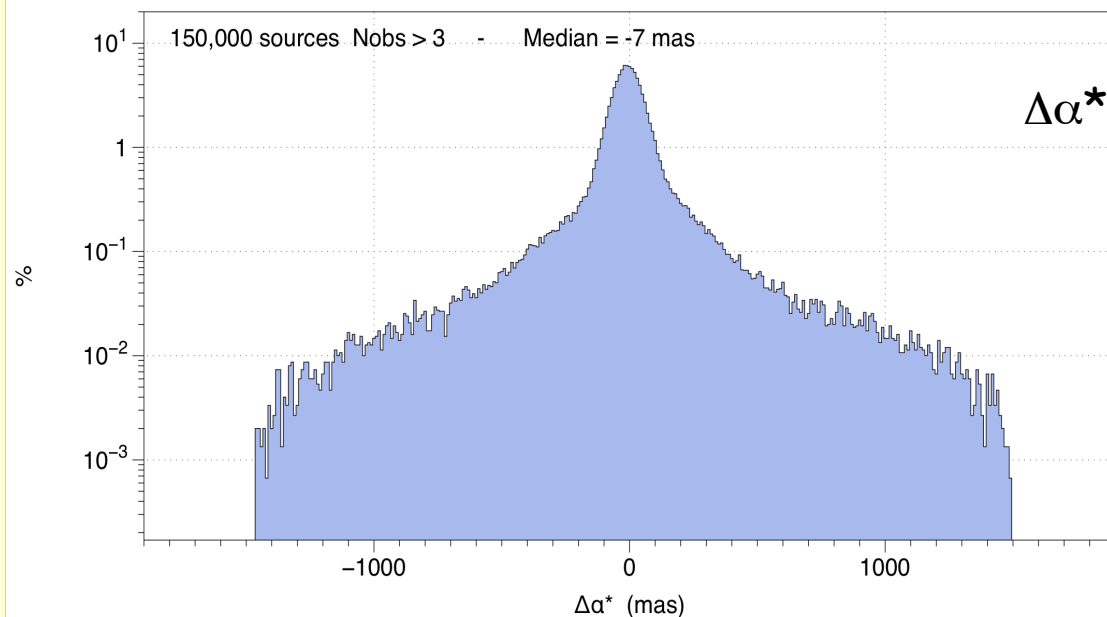
QSOs: Combination of observations



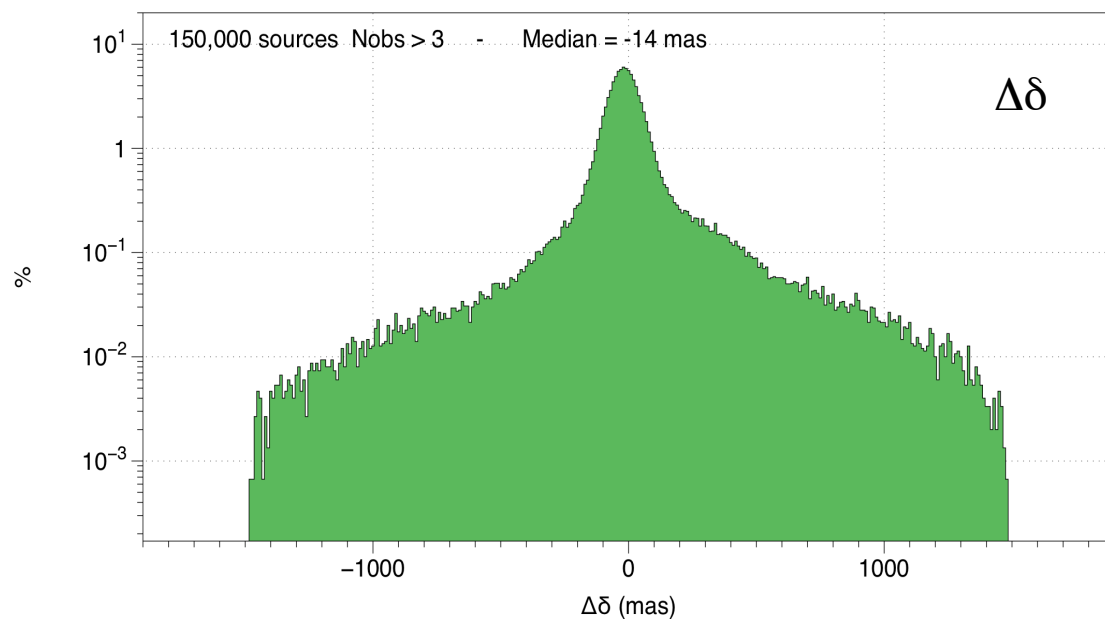
- From ICRF $\sigma \sim 30$ mas
- The width (~ 100 mas) of the distributions comes primarily from the error in the catalogue positions
- Extended tails



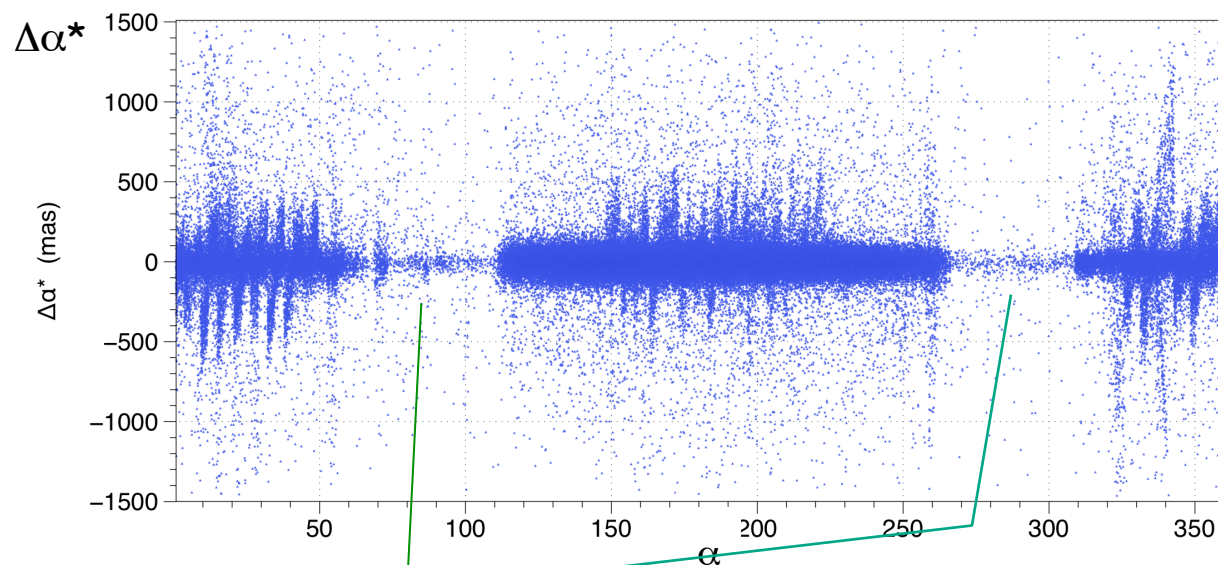
QSOs: the tails with O-C in log scale



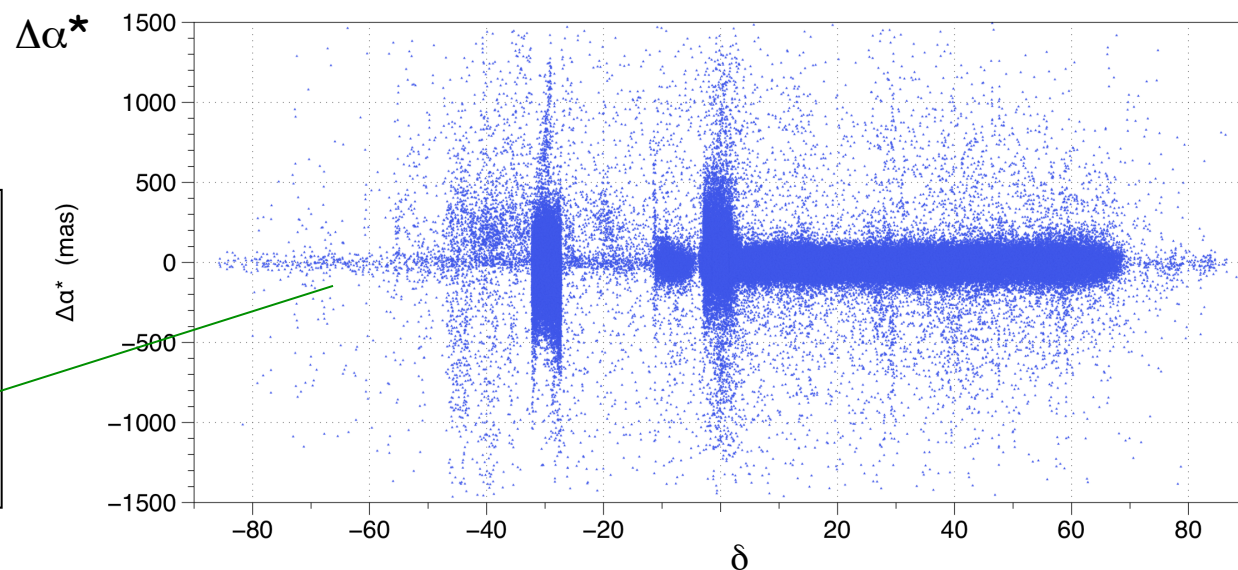
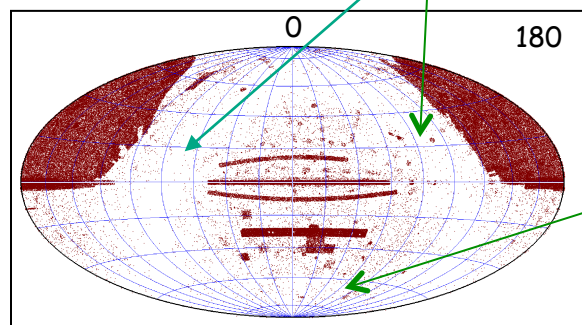
- The cut at 1500 mas is arbitrary



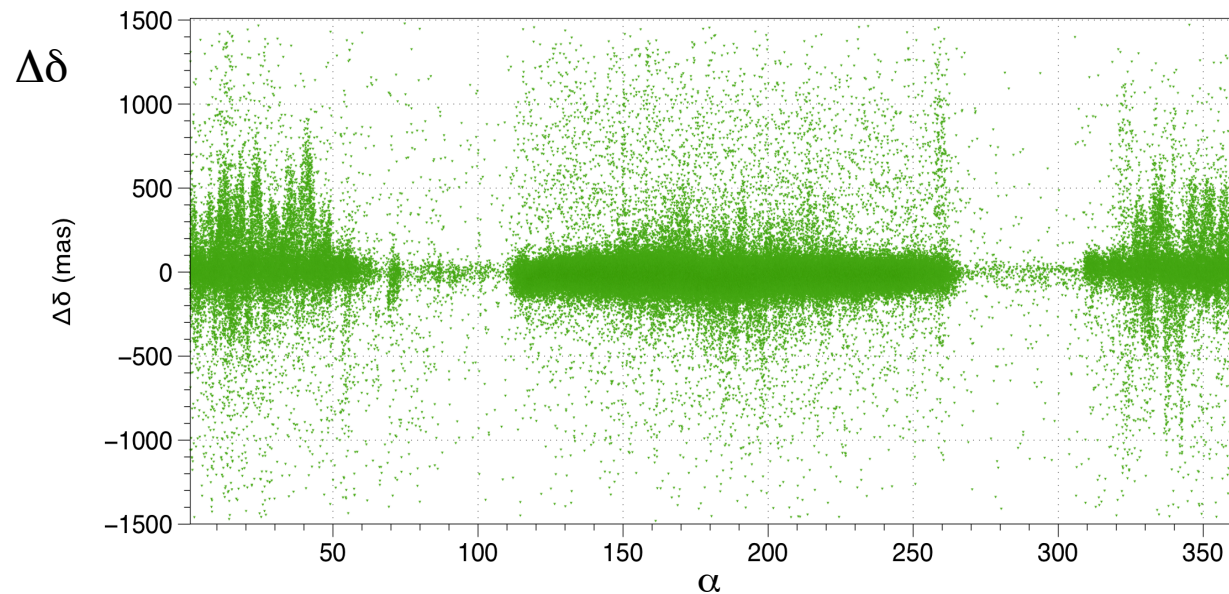
QSOs: $\Delta\alpha^*$ vs. α and δ



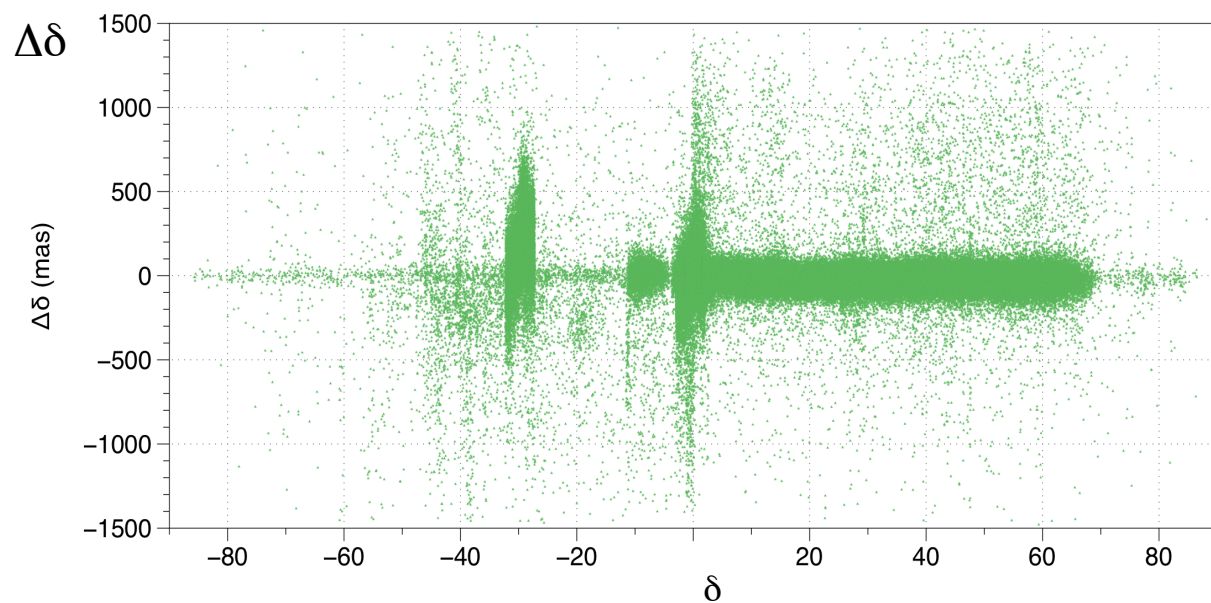
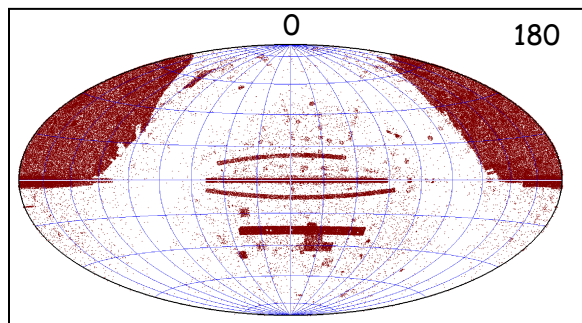
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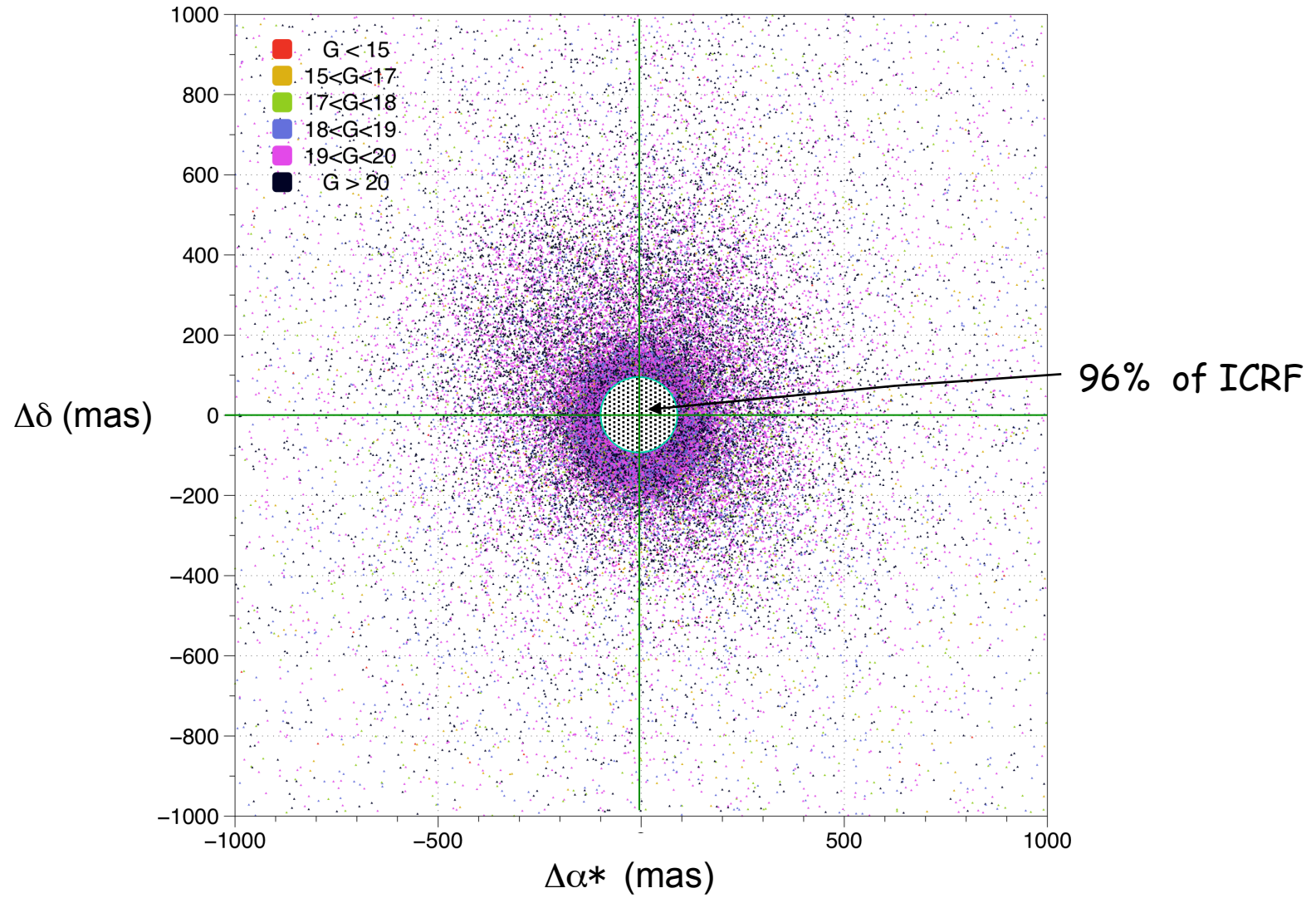


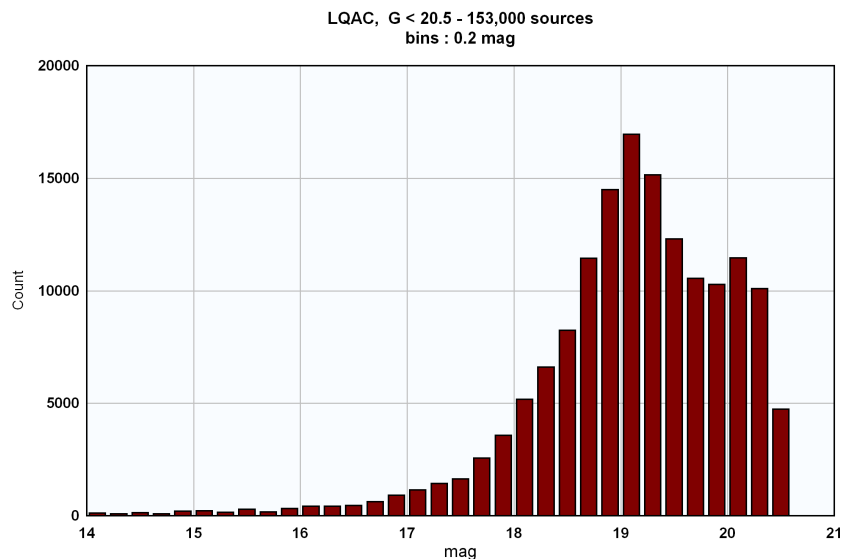
QSOs: $\Delta\delta$ vs. α and δ



- The cut at 1500 mas is arbitrary

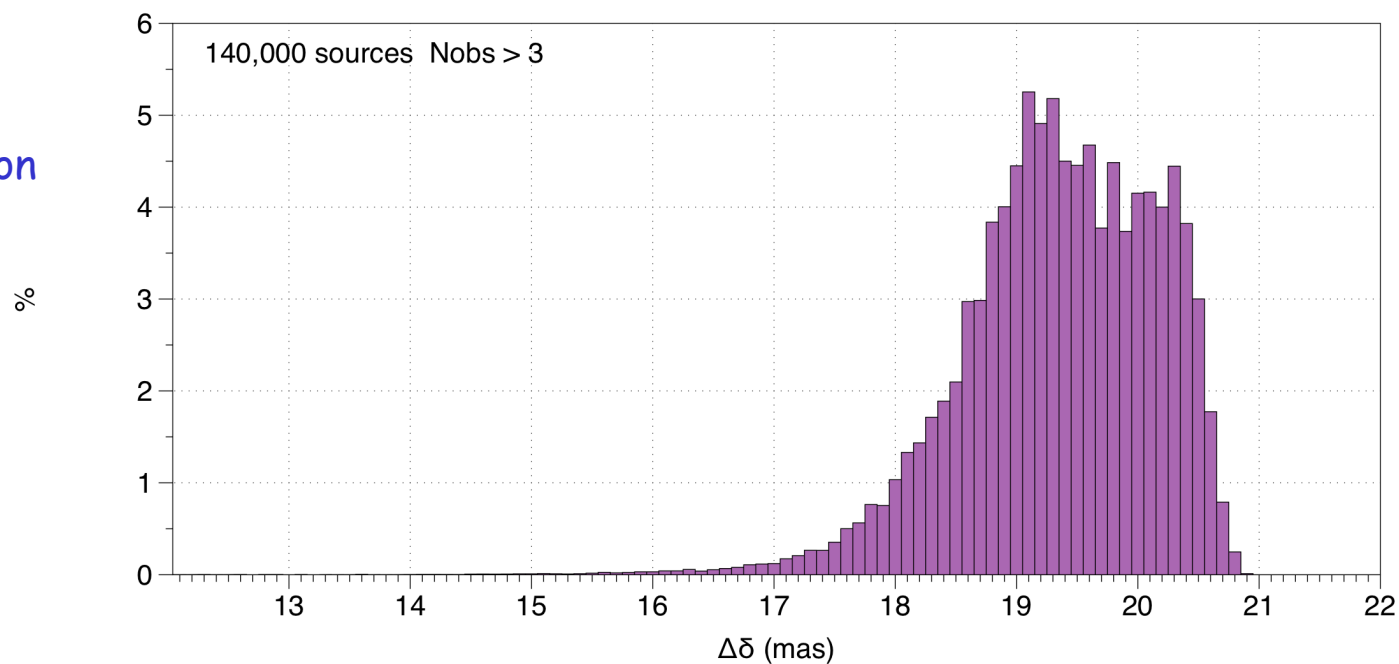


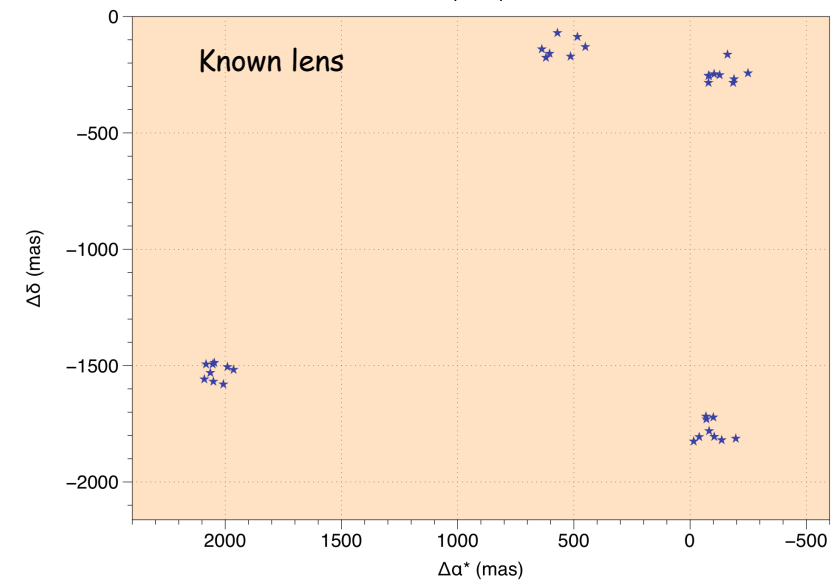
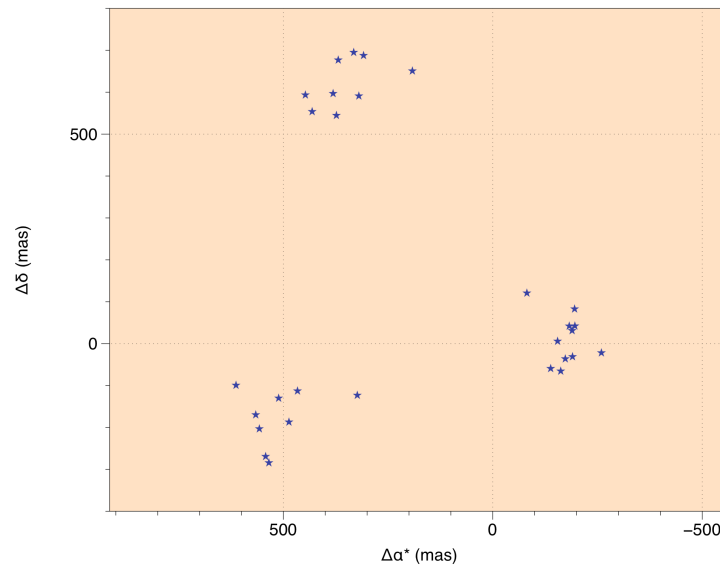
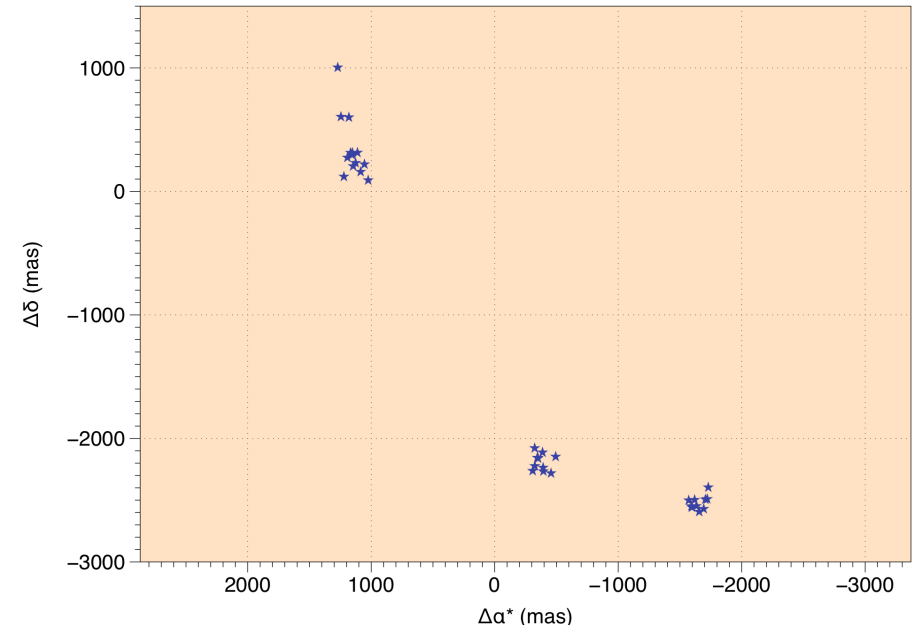
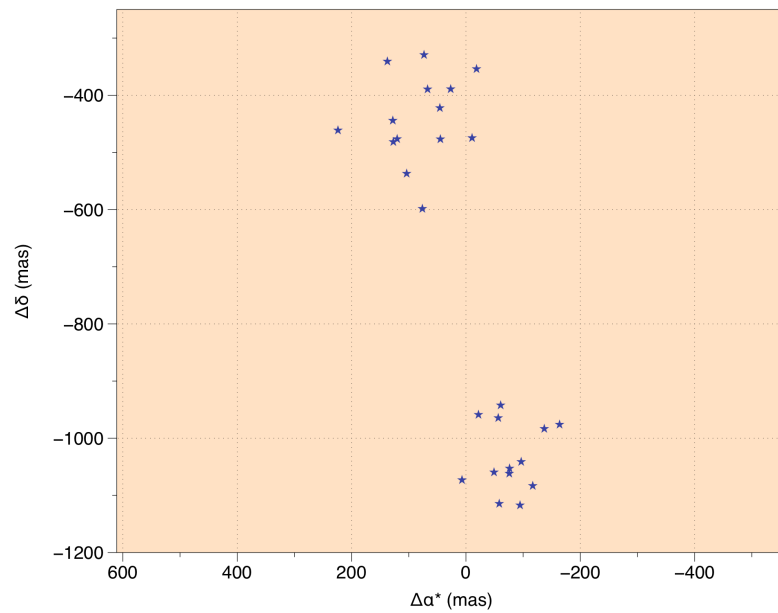




Prior distribution

Gaia distribution





- The QSOs in general are detected to $G = 20.7$
 - $< 12\%$ of the known QSOs are not detected by Gaia
 - QSOs are detected without apparent loss at very low galactic latitudes
- The IDT astrometry is already better than the best compilations
- The spatial resolution allows us to identify about 500 multi-imaged QSOs
- The statistics of detections provides the first realistic estimate of the detection probability of Gaia above $G = 20$