Time-dependent Selection of an Optimal Set of Sources to Define a Stable Celestial Reference Frame

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Agenda

- The 295 ICRF2 defining sources are a good compromise of statistical stability, good sky distribution and number of sources selected.
- The selection of a set of stable sources is not unique. It depends on the analysis strategy.
- Statistical study over the last ten years shows a better stability (network improvement).
- The VLBI sources time series noise is not a stationary process.

  Towards a statistical determination of sessions scheduling.

The Second Realization of the International Celestial Reference Frame - ICRF2 - Sources map

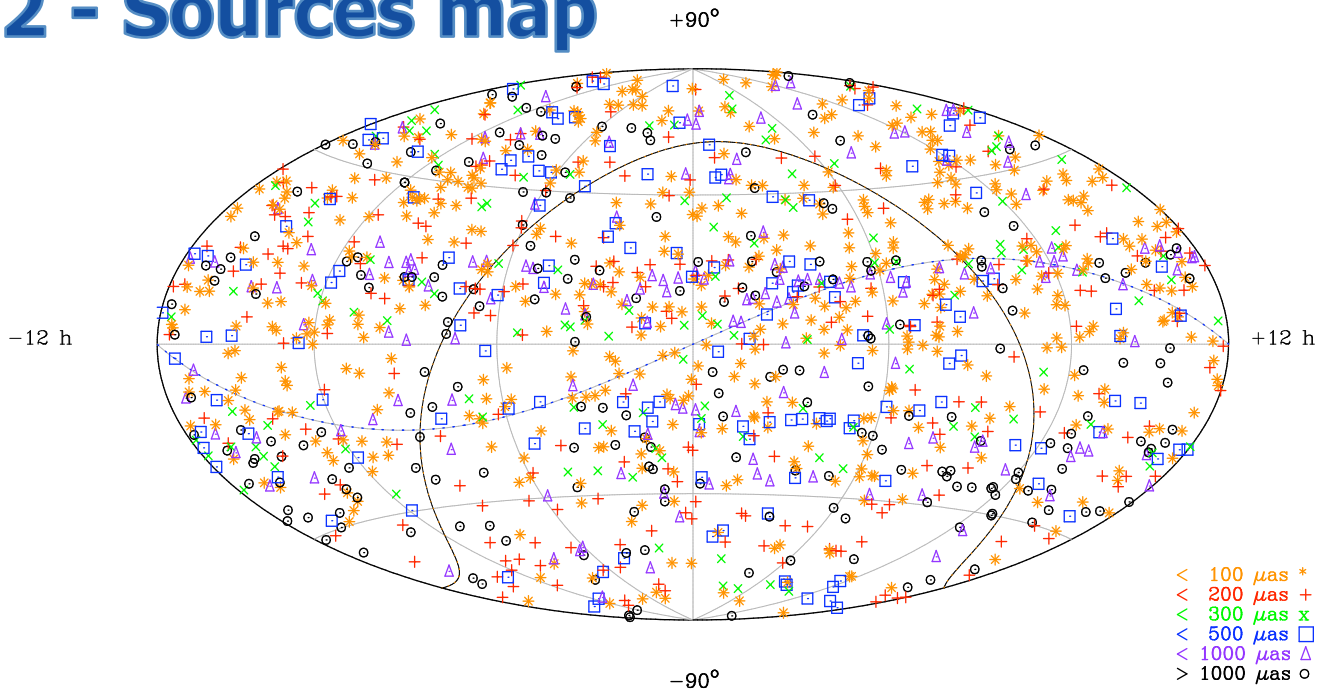


Fig. 42.— gsf008a distribution of 1448 multi-session sources (at least 2 observing sessions). The un-inflated 1-σ formal declination errors are color coded according to the legend in the figure. The median $\sigma_\delta = 175$ μas. The center is $(\alpha, \delta) = (0, 0)$. The Galactic plane is the roughly Ω-shaped line surrounding the center. The ecliptic plane is the dashed line. The single-session survey sources used to densify are shown in the next figure, Figure 43.

Statistical study of ICRF2 sources

- Analyzed data:
  - Time series of ICRF2 sources positions:
    - GSF005a (GSFC solution);
    - AUG24 (GSFC solution including more sessions);
    - OPA (Observatory of Paris solution).
  - Periods:
    - 1989.5 to present;
    - 1999.5 to present.
- Method used: the Allan variance.

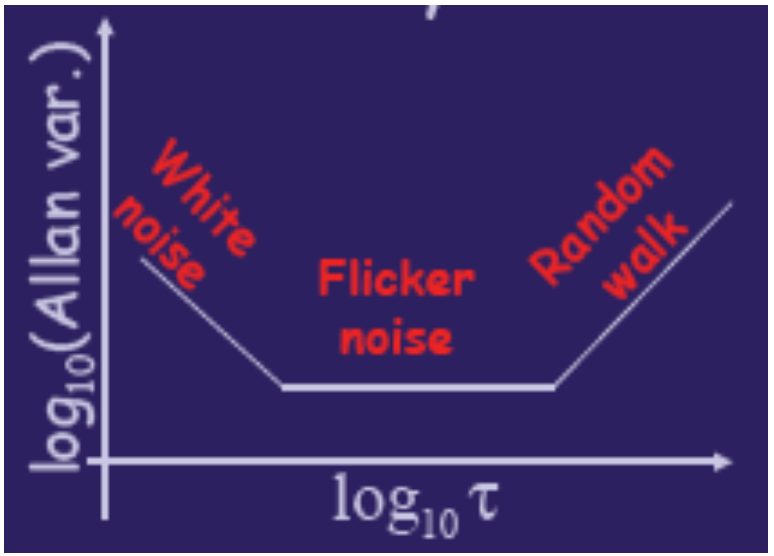
Allan Variance

- If (x_i) are the measurements and T the sampling time:

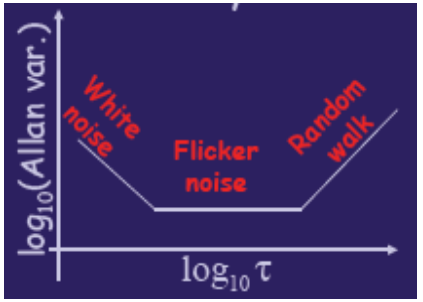
$$\sigma^2(T) = \frac{1}{2} < (\bar{x}_{i+1} - \bar{x}_i)^2 >$$

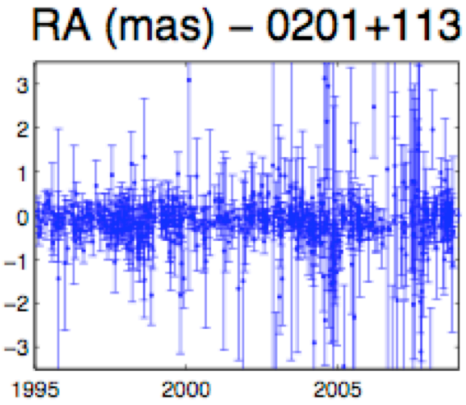
- By analogy with PSD:

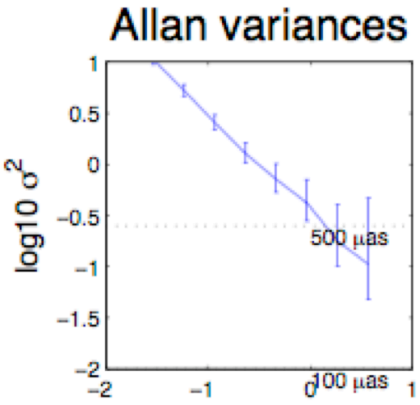
The slope of the Allan variance curve indicates the type of noise.



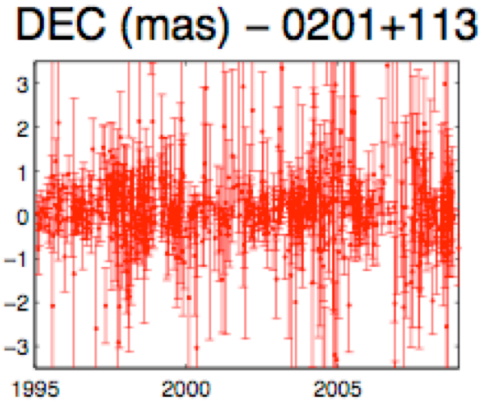
Allan Variance

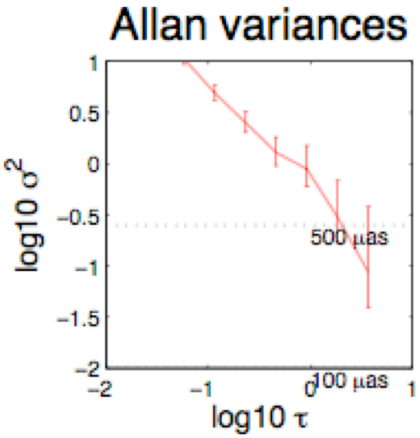






White noise



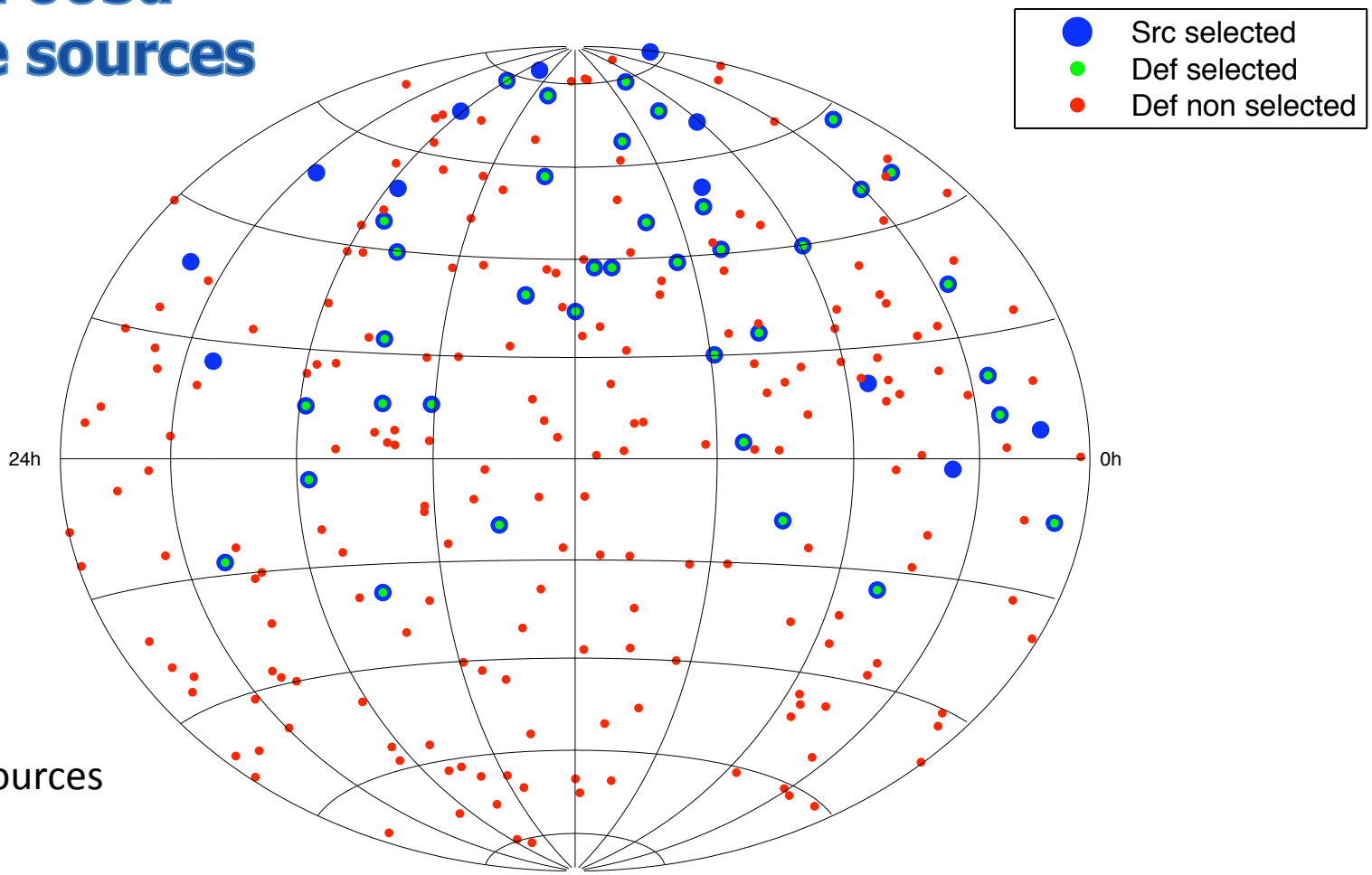


White noise

Stability index of ICRF2 sources

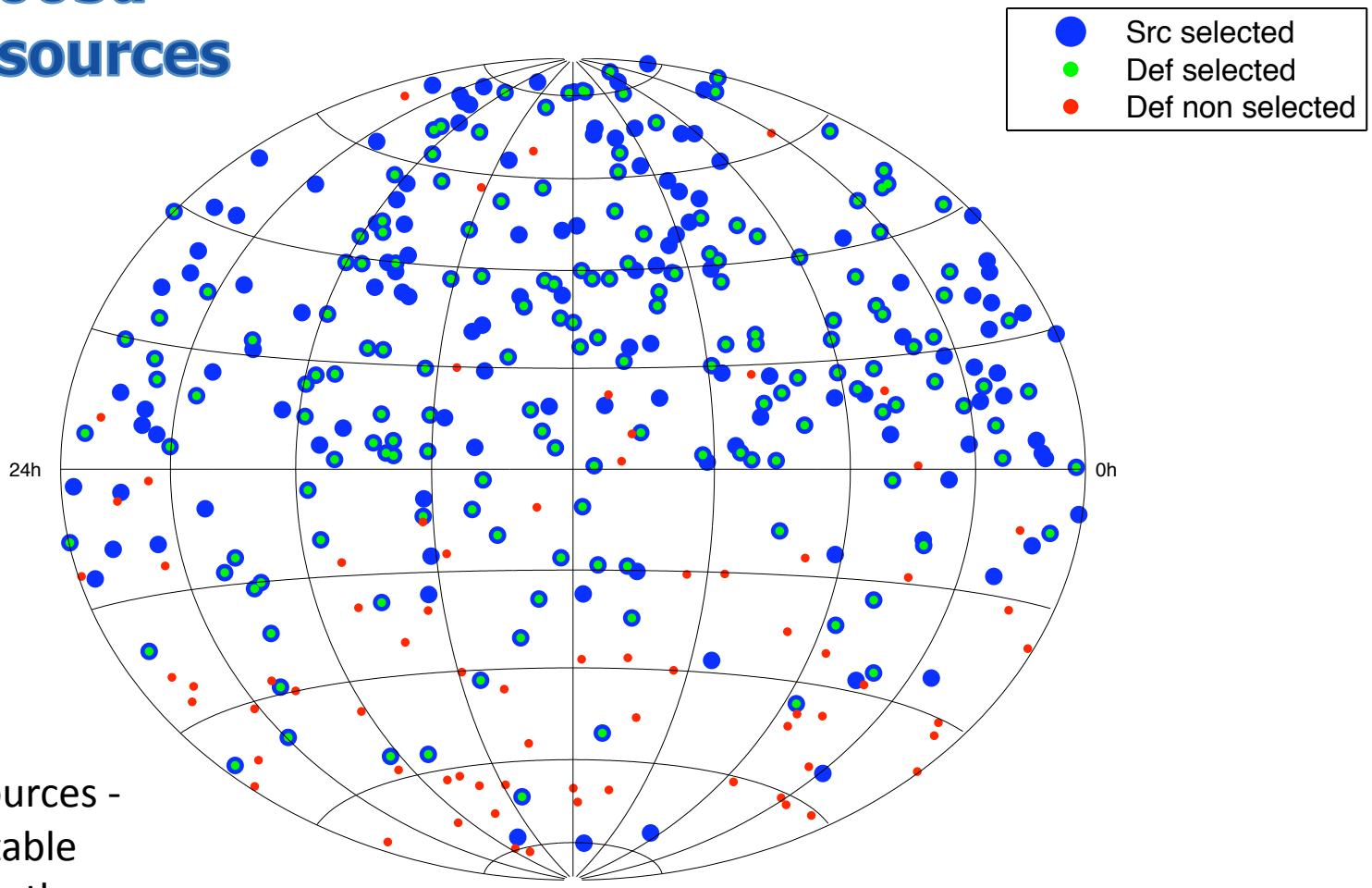
- A stability index is calculated as a combination of normalized values of the drift and the Allan variance at one-year sampling time, on both coordinates (right ascension and declination).
- The sources are sorted depending on the stability index from the most stable to the less stable (from 50 sources, 10 sources are added at every iteration).

GSF005a stable sources



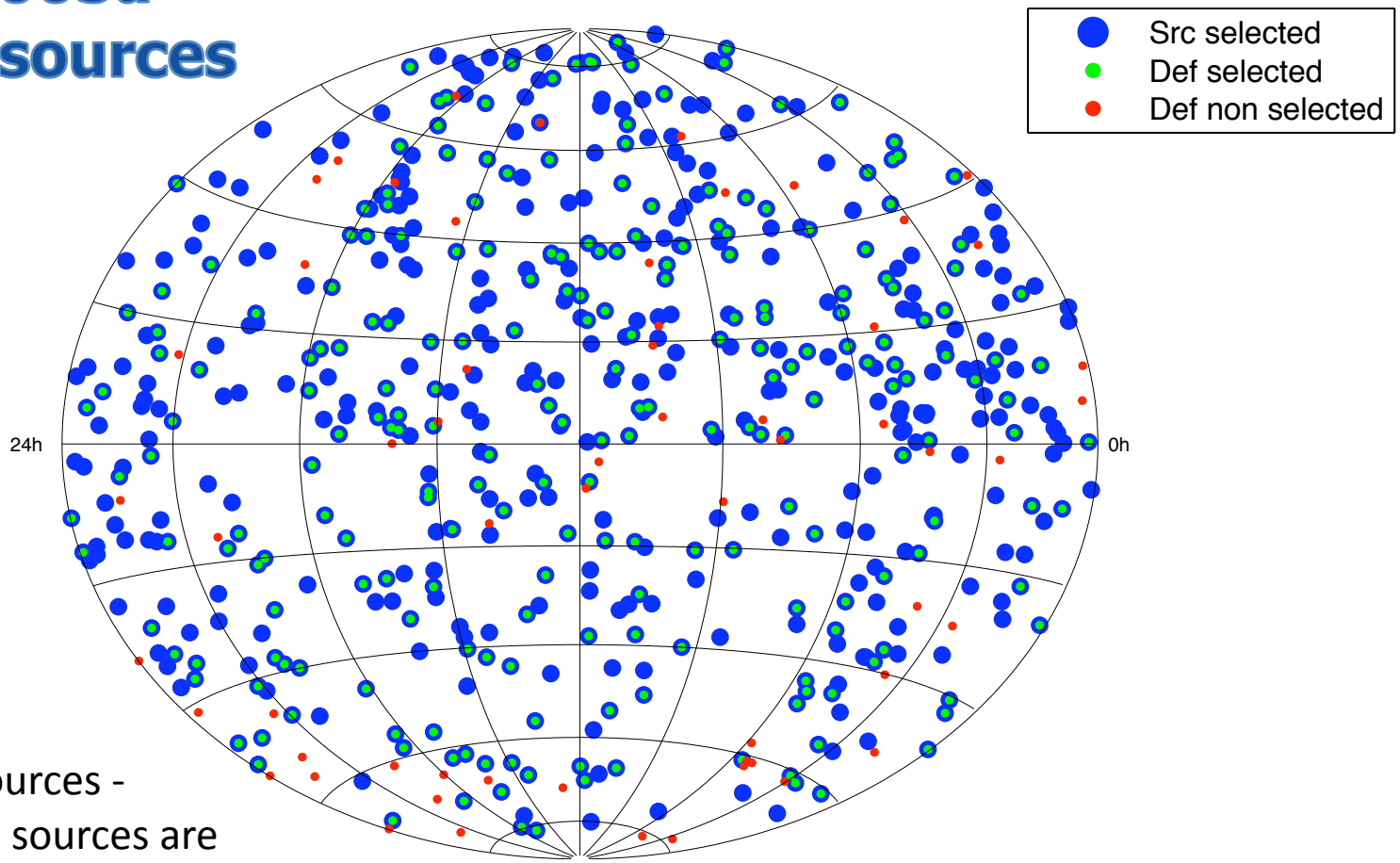
50 stable sources

GSF005a stable sources



260 stable sources - 80% of the stable sources are in the North Hemisphere.

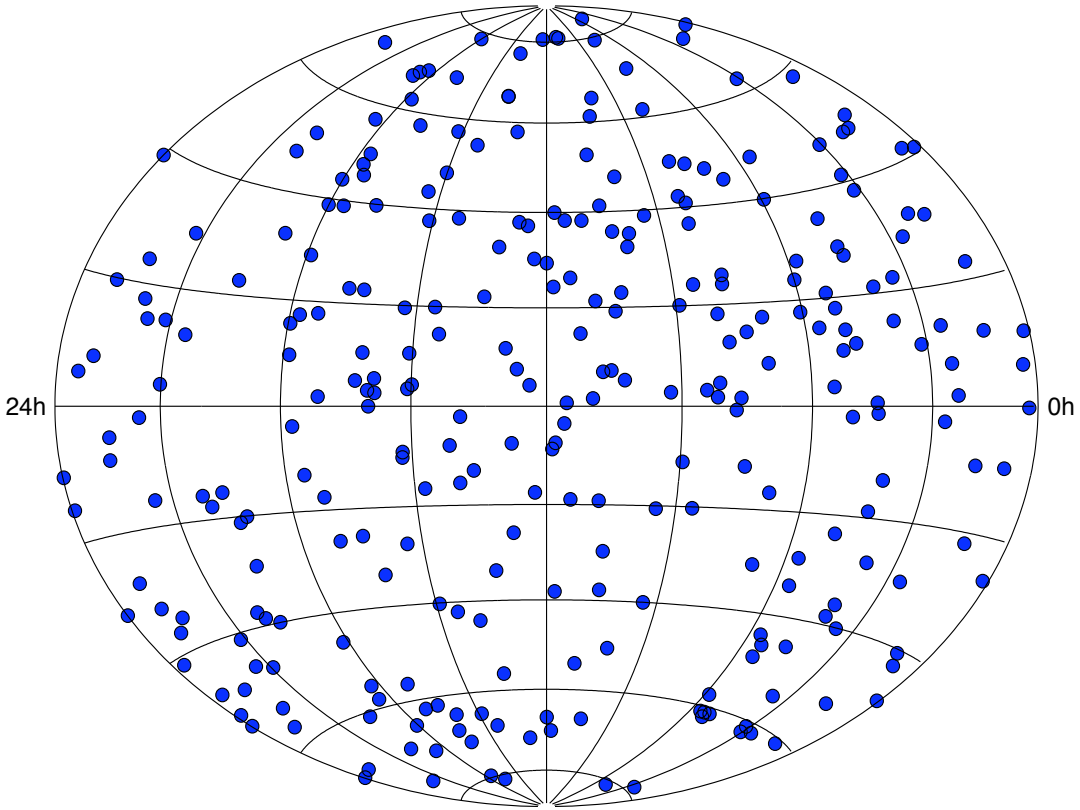
GSF005a stable sources



519 stable sources -
~ 60 defining sources are not studied (short time series). Densification of the sky coverage.

ICRF2 : 295 defining sources

- Even distribution over the sky => study in four parts of the sky (the partition is function of the declination);
- Quality of the observations => positional stability of RA and DEC (WRMS, χ^2, formal errors);
- Compactness of the source => source structure index.



ICRF2 : 295 defining sources

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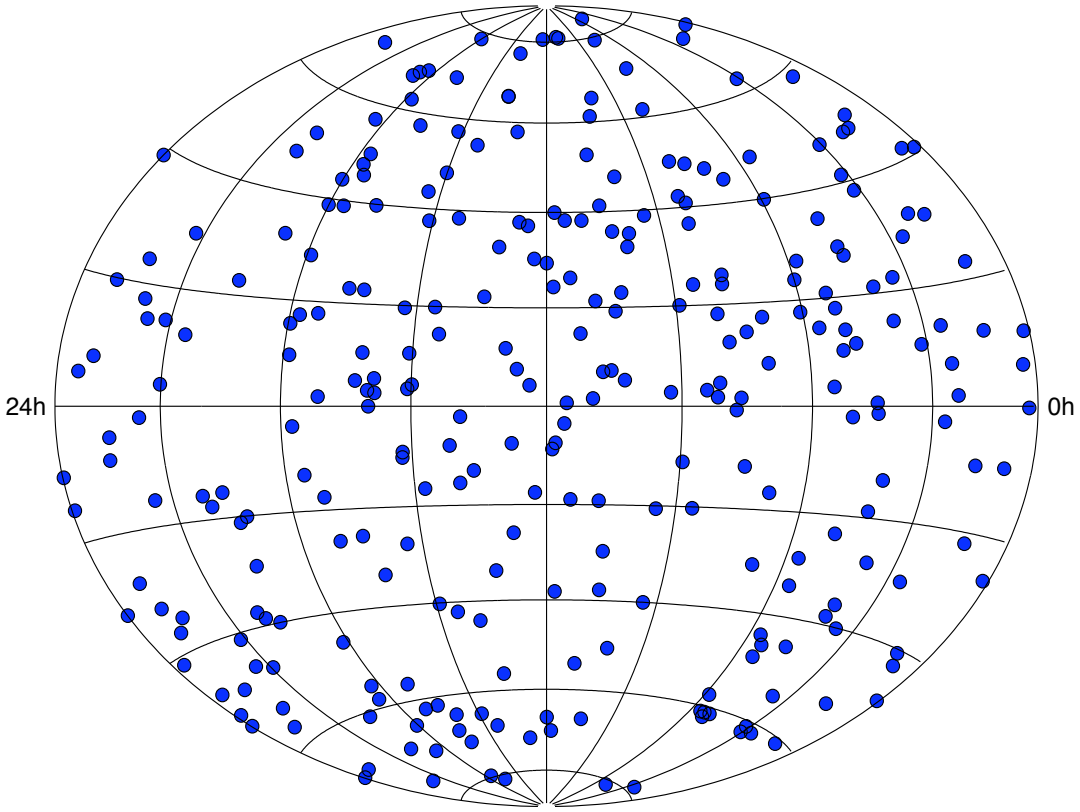
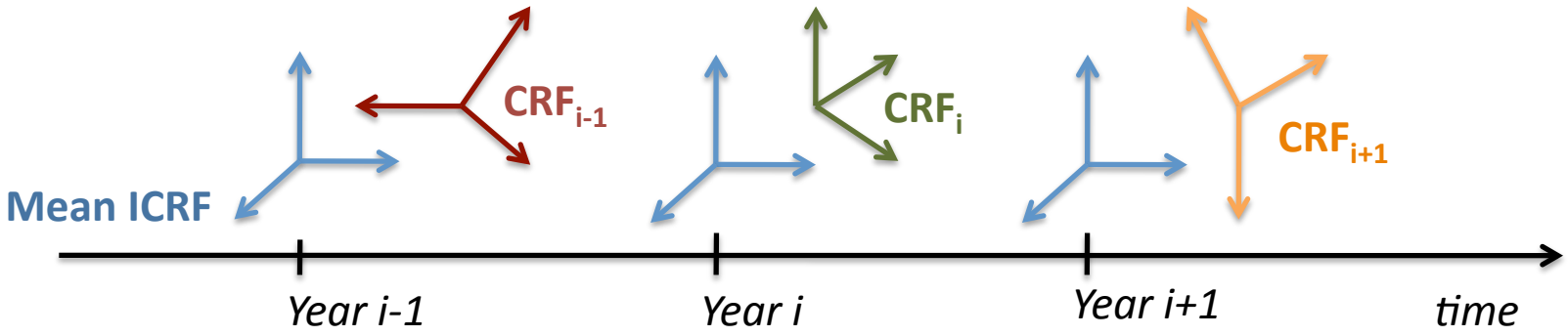


Stability test on ICRF2



$$\begin{cases} (\alpha_m - \alpha_i)\cos\delta_m &= A_1(i)\tan\delta_i\cos\alpha_i + A_2(i)\tan\delta_i\sin\alpha_i - A_3(i) \\ \delta_m - \delta_i &= -A_1(i)\sin\alpha_i + A_2(i)\cos\alpha_i + dz(i) \end{cases}$$

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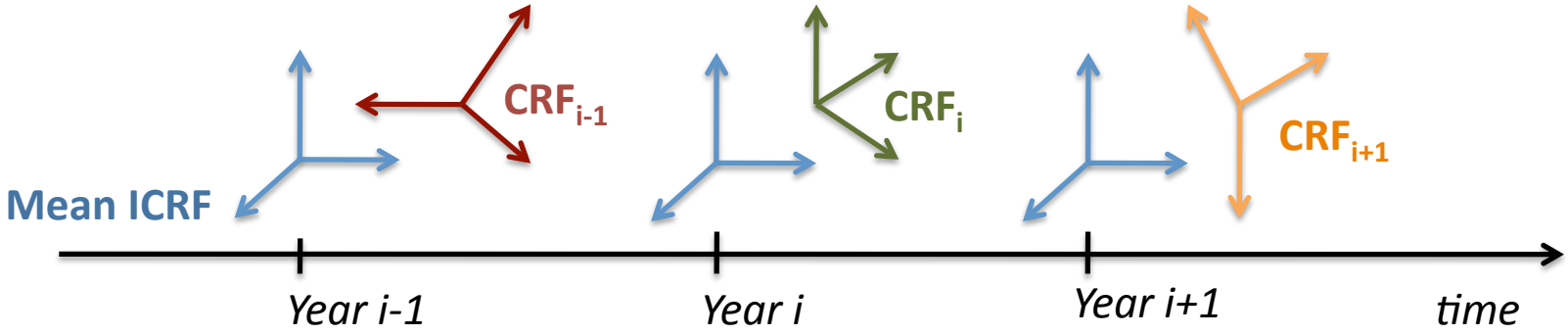

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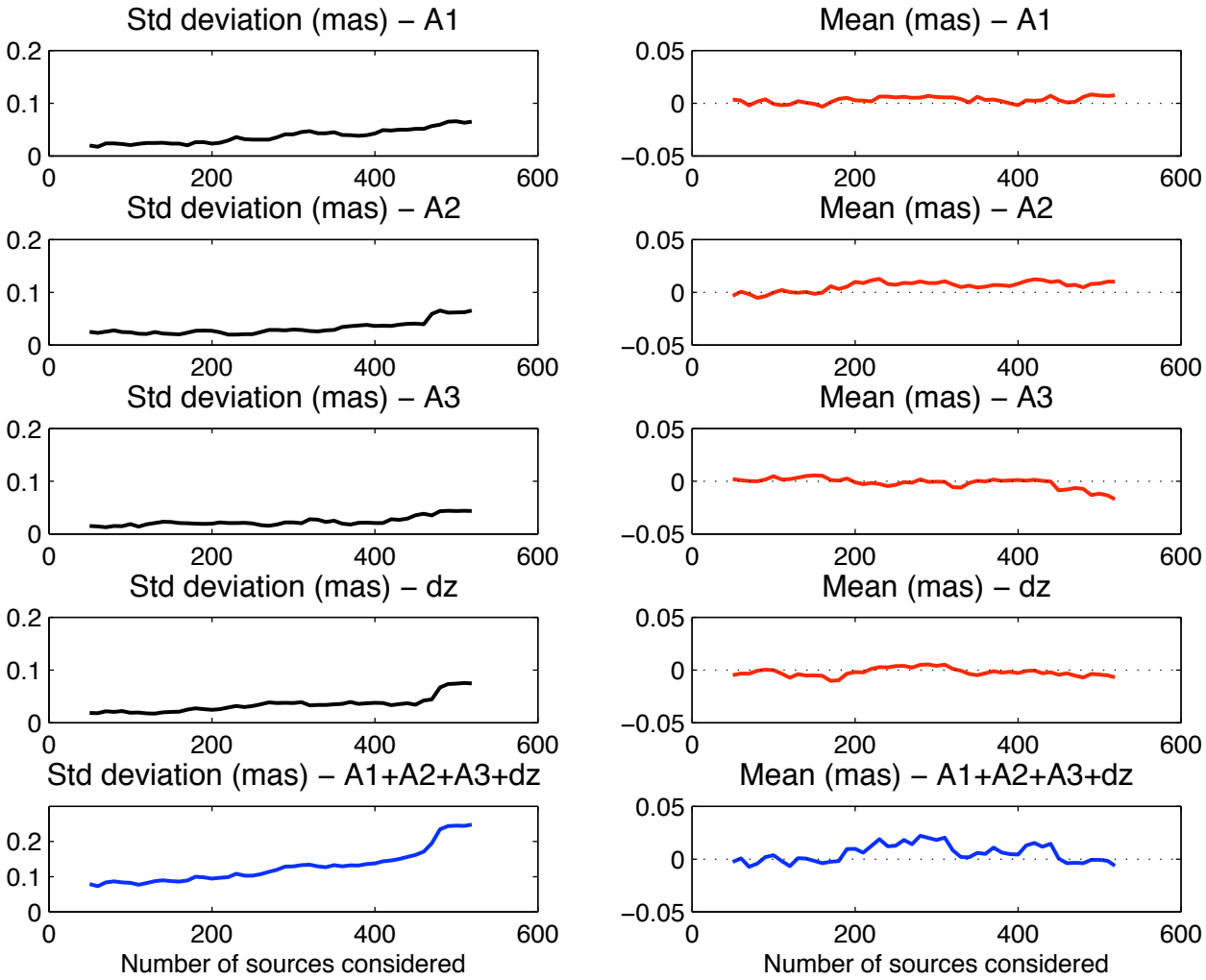
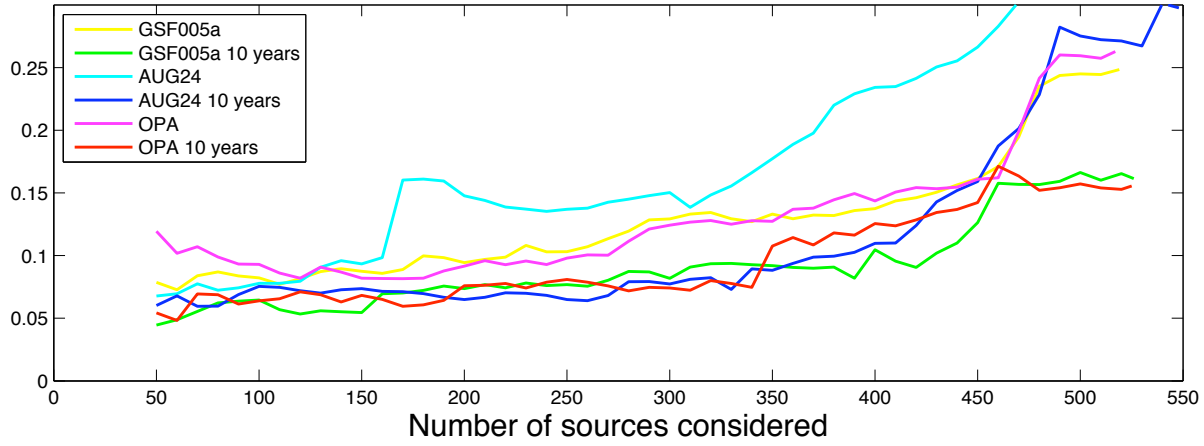
- (A1,A2,A3,dz) as an indicator of the Celestial Reference Frame stability:
  Each parameter is calculated yearly over the period studied for each subset obtained. The standard deviation and the mean are then computed for each parameter. We access then the stability of the CRF as a function of the number of sources (subsets of increasing number of stable sources) by the sum of each parameter.

Stability test on ICRF2

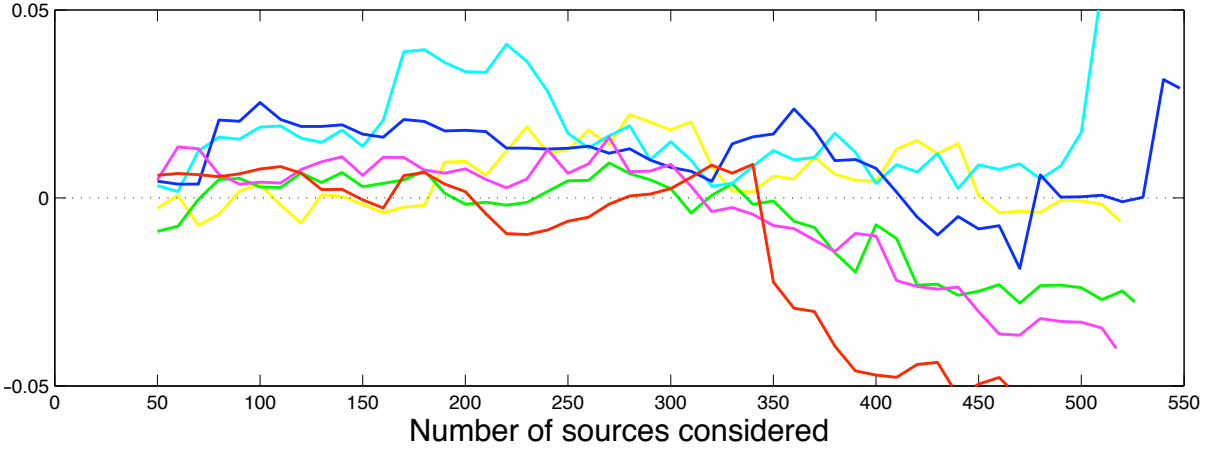


Stability test on ICRF2

Std deviation (mas) – A1+A2+A3+dz



Mean (mas) – A1+A2+A3+dz



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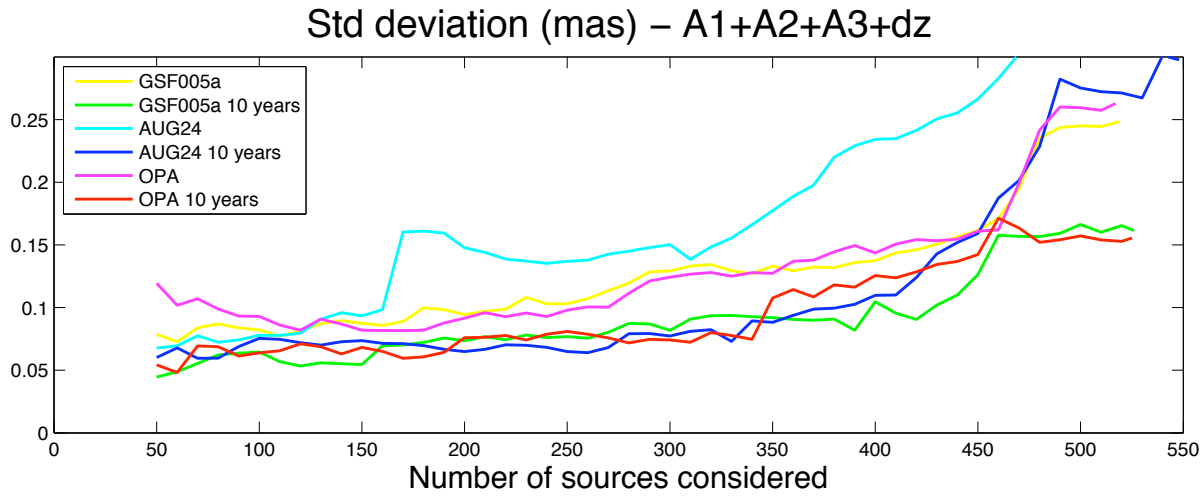

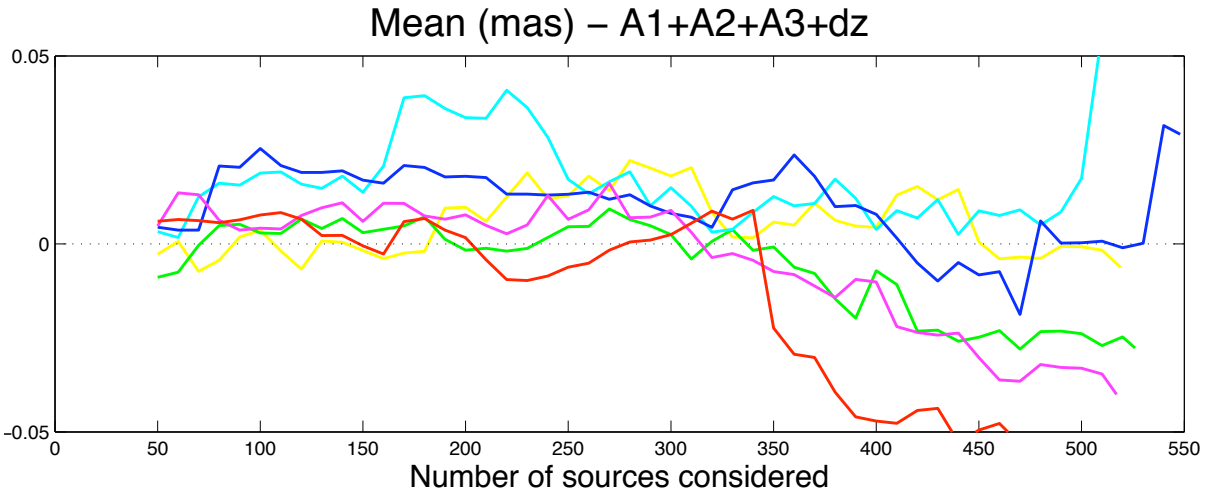

The selection of a set of stable sources is not unique. It depends on the analysis strategy.

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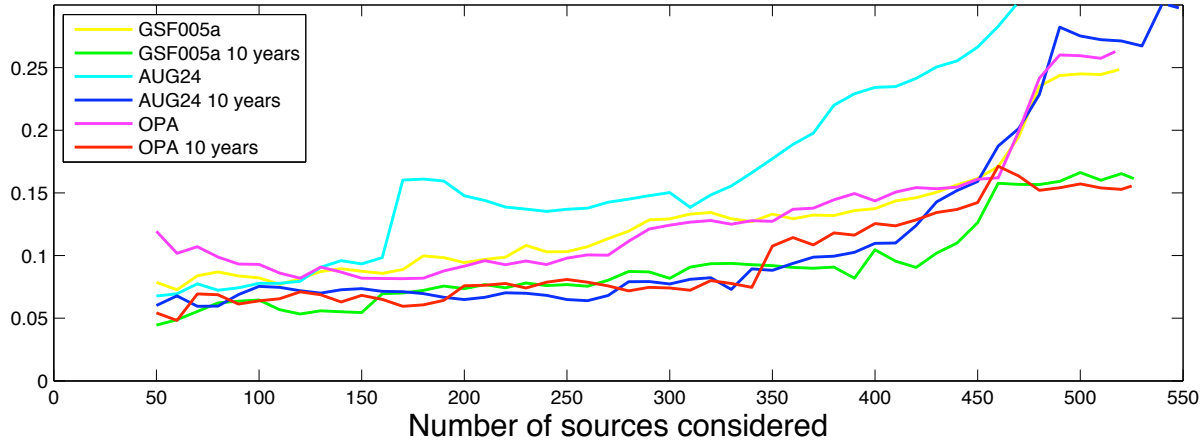

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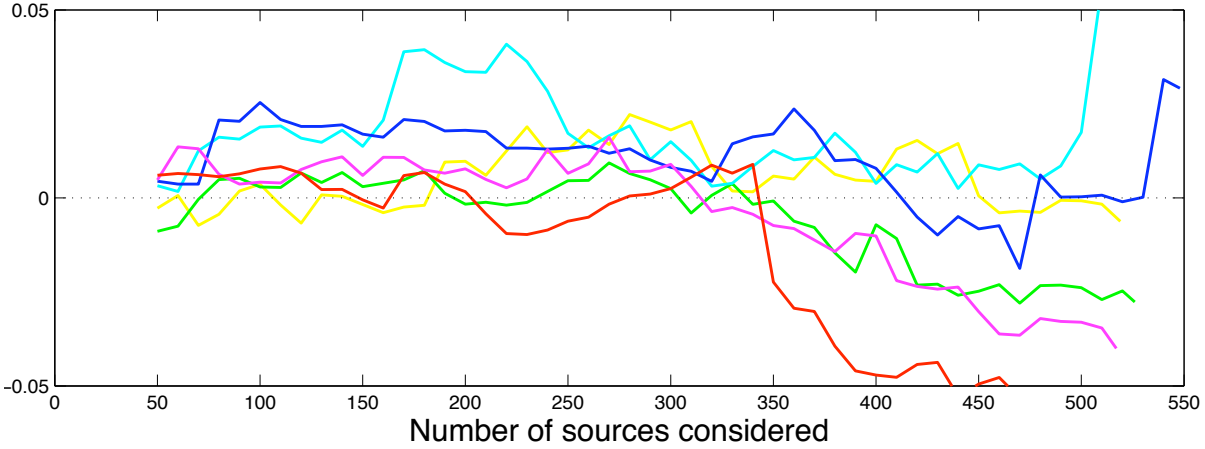

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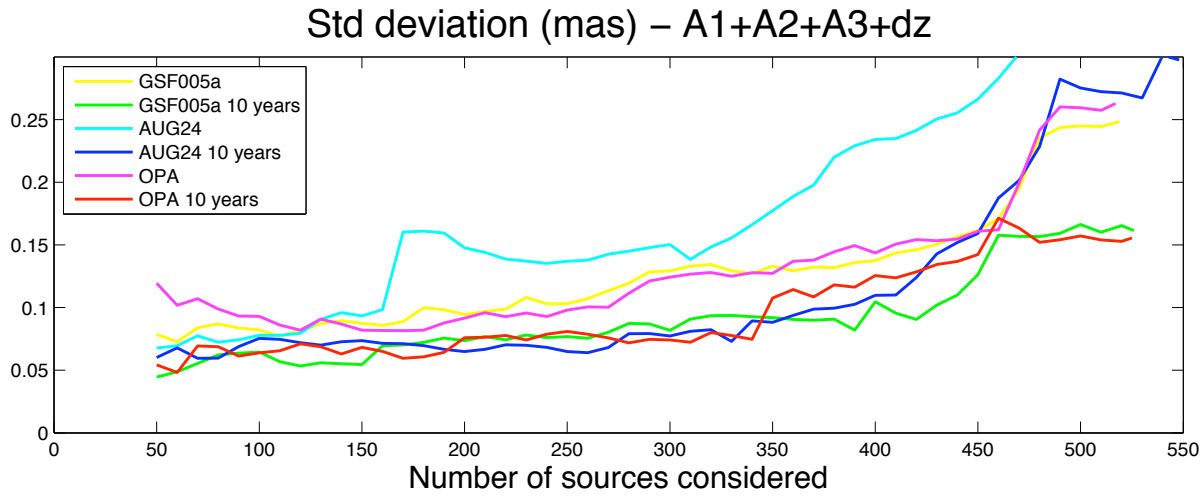
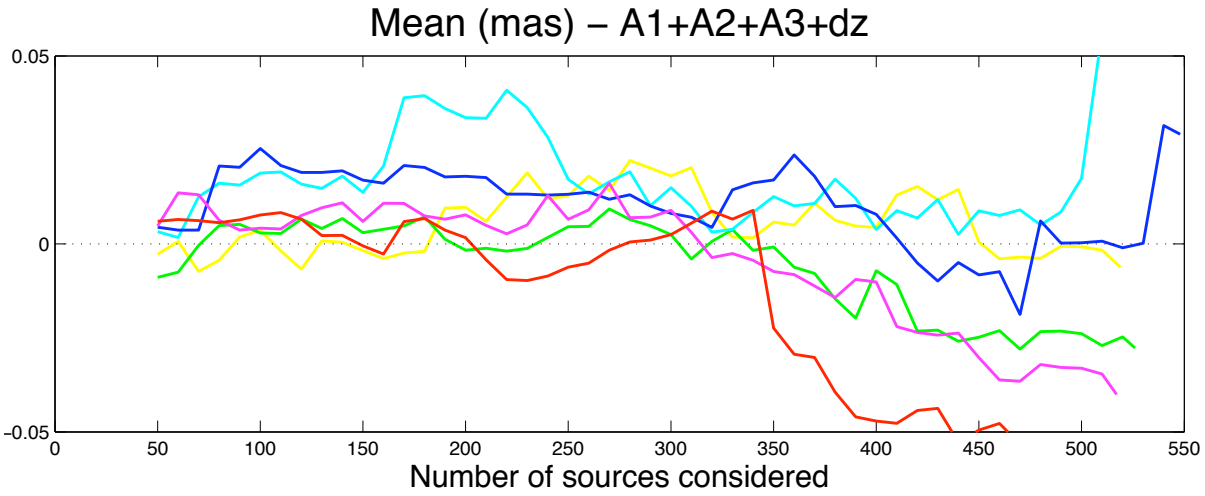


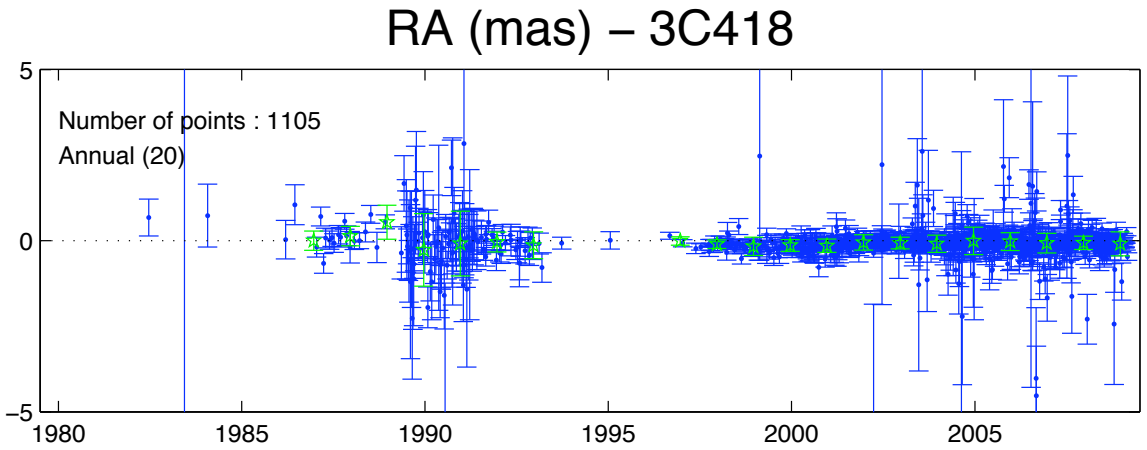


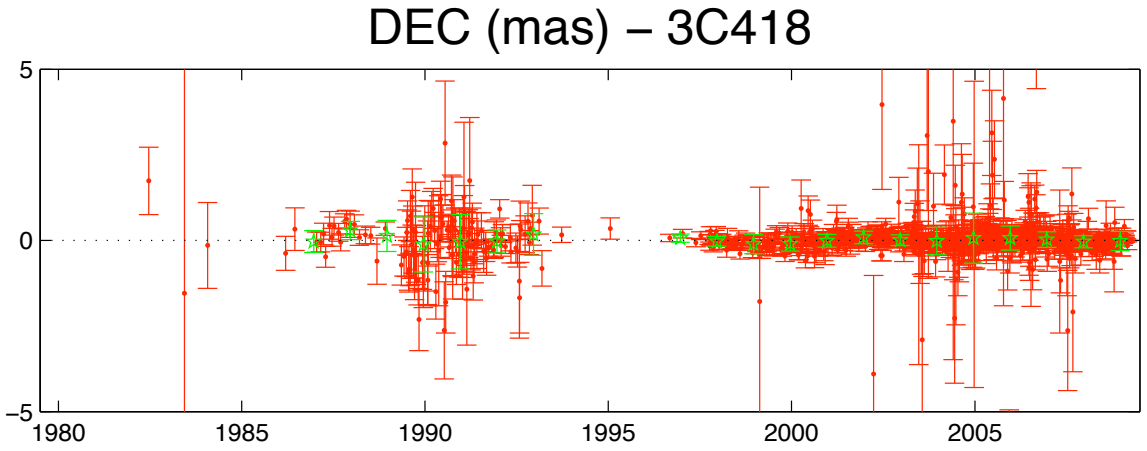
Improvement of the network over the last ten years.

Drawbacks of this method of analysis

- Stationary noise – BUT: Has a source the same behavior with time? No: strategy analysis, geometry of the observations, change in the instruments,…
- One-year average – Already smoothing time series. What is hidden behind that? Can we decrease the sampling time to obtain more points in the Allan variance plot to obtain a more precise determination of the slope?

Stationary assumption





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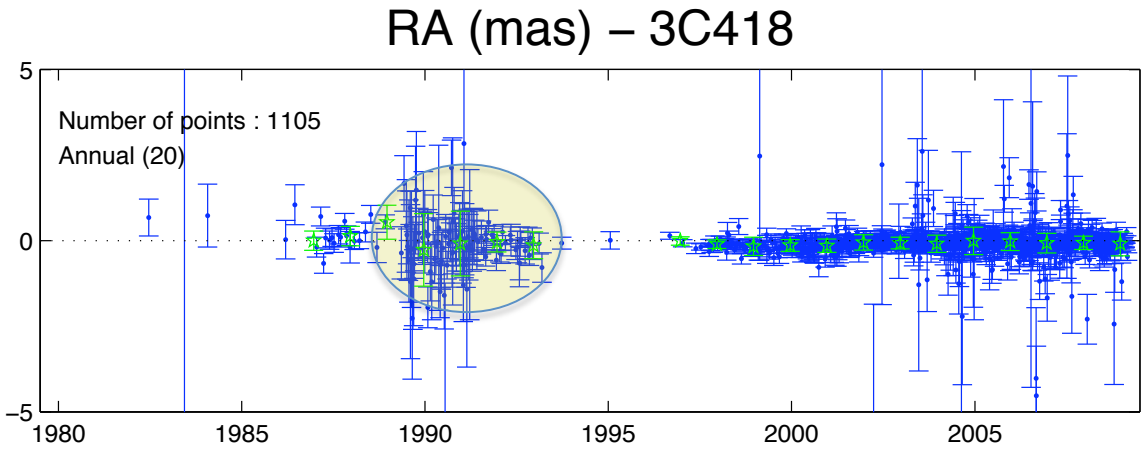
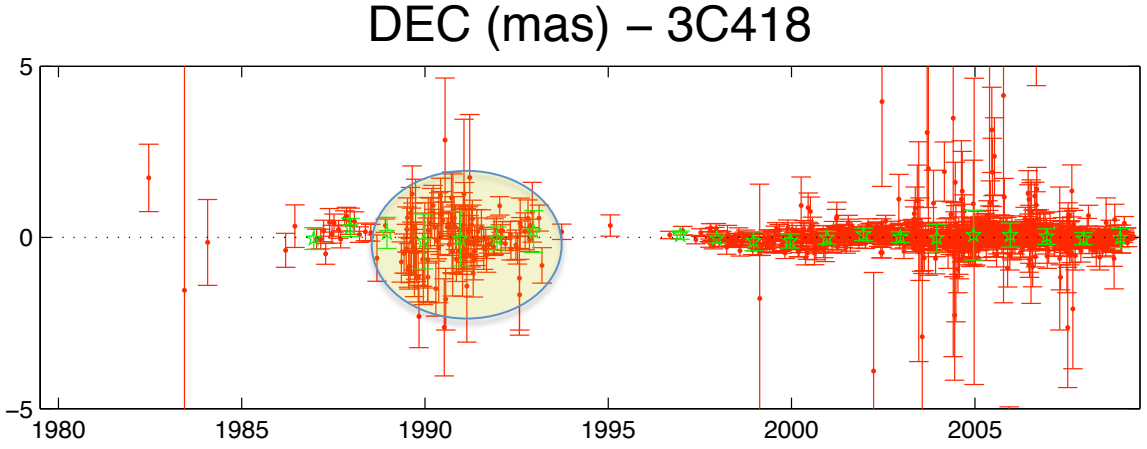
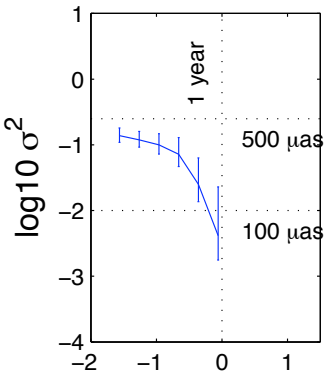


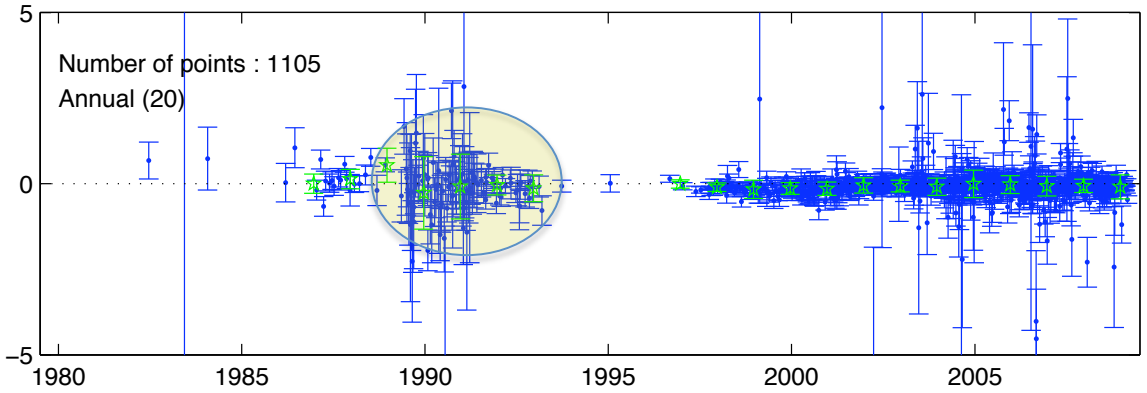


Stationary assumption

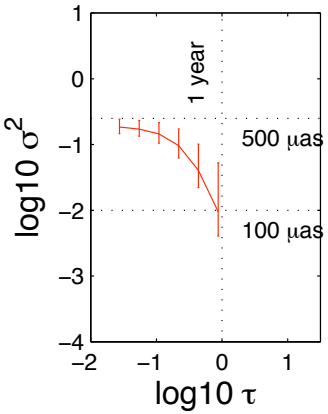
Allan variance



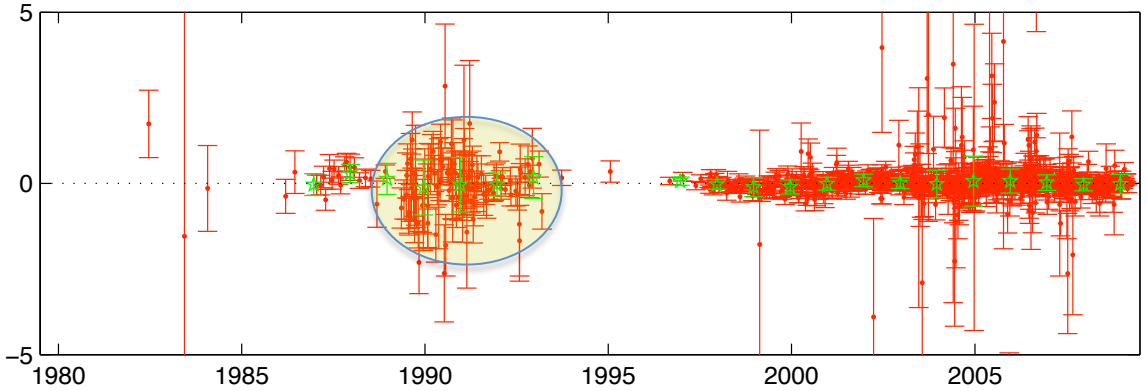
RA (mas) – 3C418



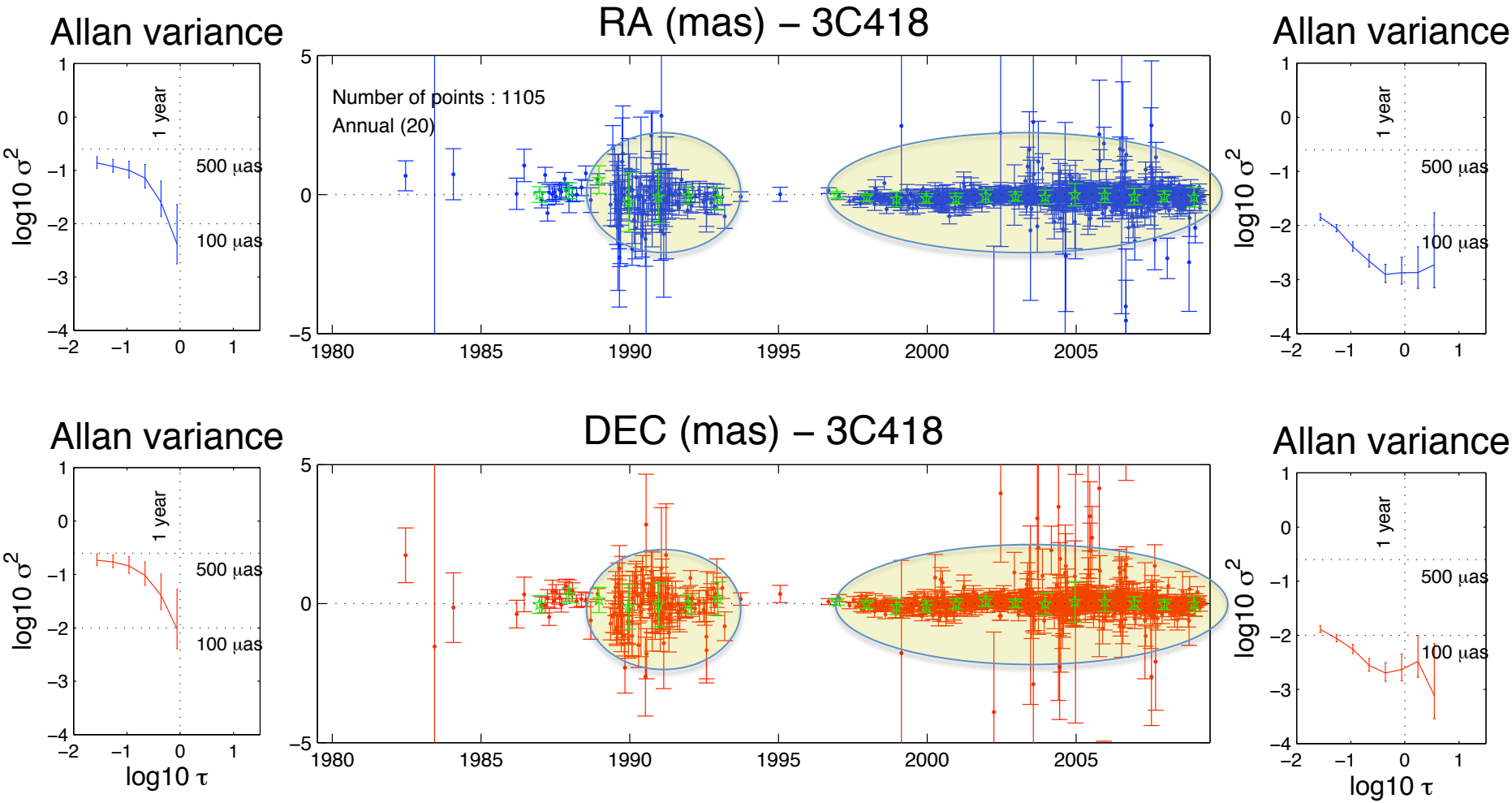
Allan variance



DEC (mas) – 3C418



Stationary assumption

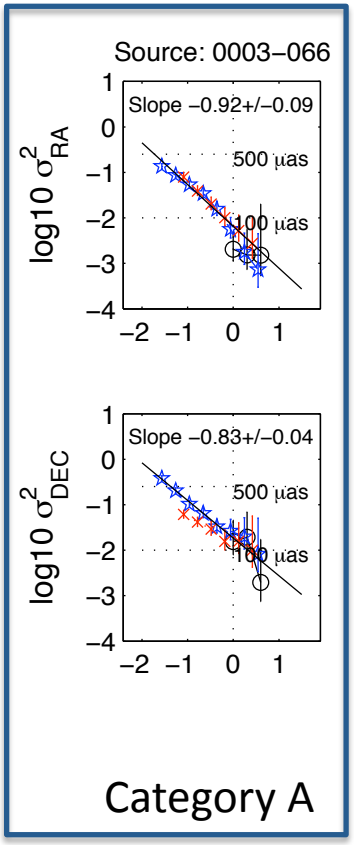


Alternate analysis method (1)

- The processing consists on:
  - An usual cleaning and elimination step (short time series);
  - Divide time series depending on observation frequency (gap);
  - Compute average time series of one-year, 30-day and 10-day (to assure robustness);
  - Allan variance computed on each time series.
- Classification in three categories depending on the type of noise (white noise, flicker noise, random walk).

Alternate analysis method (2)

- Three categories depending on the type of noise:
  - **Category A:** White noise;
  - Category B: Flicker noise or threshold;
  - Category C: Apparent motion.



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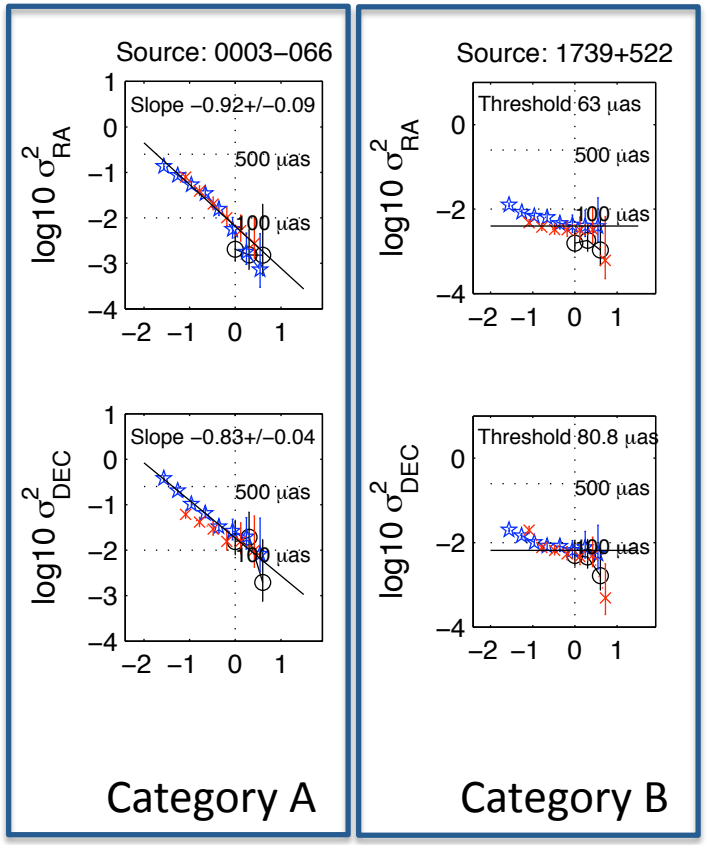

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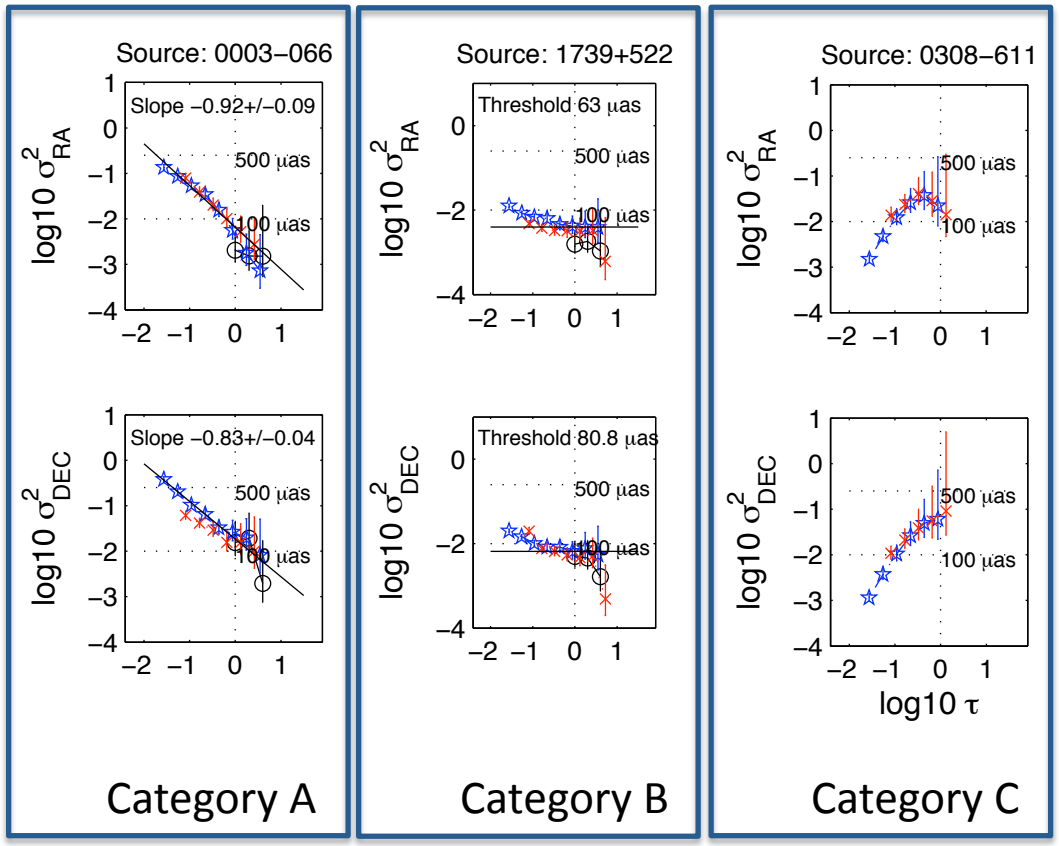
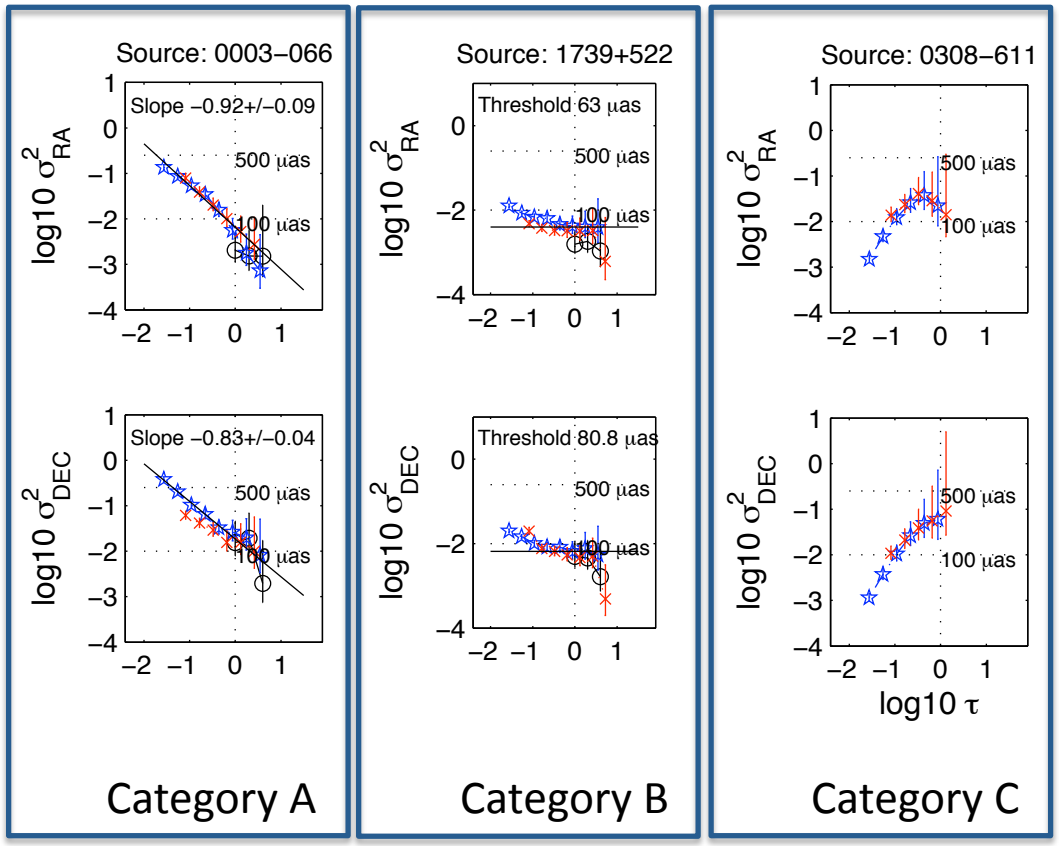


Alternate analysis method (2)

- Category A:
  The quality of the data is improving with time;
- Category B:
  The quality of the data is stabilized at a certain level of noise;
- Category C:
  This is impossible to have a clear conclusion due to some "signal" in the time series.



Conclusions

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- Statistical study over the last ten years shows a better stability (network improvement).
- The VLBI sources time series noise is not a stationary process.

  Statistical determination of sessions scheduling.

References

- 2001, A&A: “Stability of the extragalactic VLBI reference frame” - A.-M. Gontier, K. Le Bail, M. Feissel, T. M. Eubanks;
- 2003, A&A: “Selecting stable extragalactic compact radio sources from the permanent astrogeodetic VLBI program” - M. Feissel-Vernier;
- 2006, A&A: “Analysis strategy issues for the maintenance of the ICRF axes” - M. Feissel-Vernier, C. Ma, A.-M. Gontier, C. Barache;
- 2009, A&A: “On radio source selection to define a stable celestial frame” - S. Lambert, A.-M. Gontier.

Thank you for your attention.