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Investigating the noise floor of VLBI source positions

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Outline

- ICRF2 noise floor (TN35).
- Noise floor computed with the Allan variance:
  - 2017a GSFC solution.
  - Allan variance and noise type determination.
  - Difficulties.
- Results for 2017a GSFC solution.
- Future evaluations.

ICRFs evolution

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Parameter	ICRF1 (1997) Replace FK5 optical frame	ICRF2 (Jan 1, 2010)	ICRF3 (2018)
Observation Dates	08/1979 – 07/1995 (16 years)	08/1979 – 03/2009 (29.5 years)	08/1979 – 2018 (~38.5 years)
# Observations	1.6M S/X group delays	6.5M S/X group delays	~15M S/X + X/Ka and K delays
# Defining Sources	212	295	200-300
Total Sources	608	3414	4400+ S/X -band 675 X/Ka -band 800 K-band
Noise Floor	~250 µas	~40 µas	20-30 µas
Axis Stability	~20 µas	~10 µas	<10 µas

ICRF2 noise floor

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- TN35: Noise floor calculated by decimation test (DSM).
  - gsf08b solution.
  - All experiments ordered chronologically and divided into two sets selected by even or odd session (experiments with the same core network of observing stations).
  - Declination and right ascension noise computed for each 15° declination band in each solution (derived from differences between positions in the two decimation solutions).

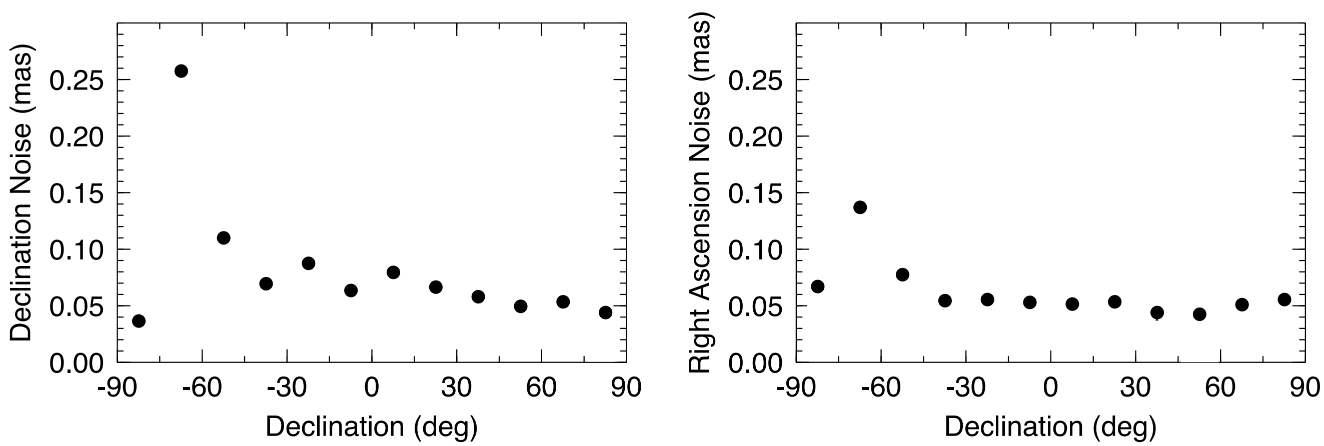

Figure 19: Declination and Right Ascension noise for each 15 degree declination band in each solution derived from differences between positions in the two decimation solutions

ICRF2 noise floor

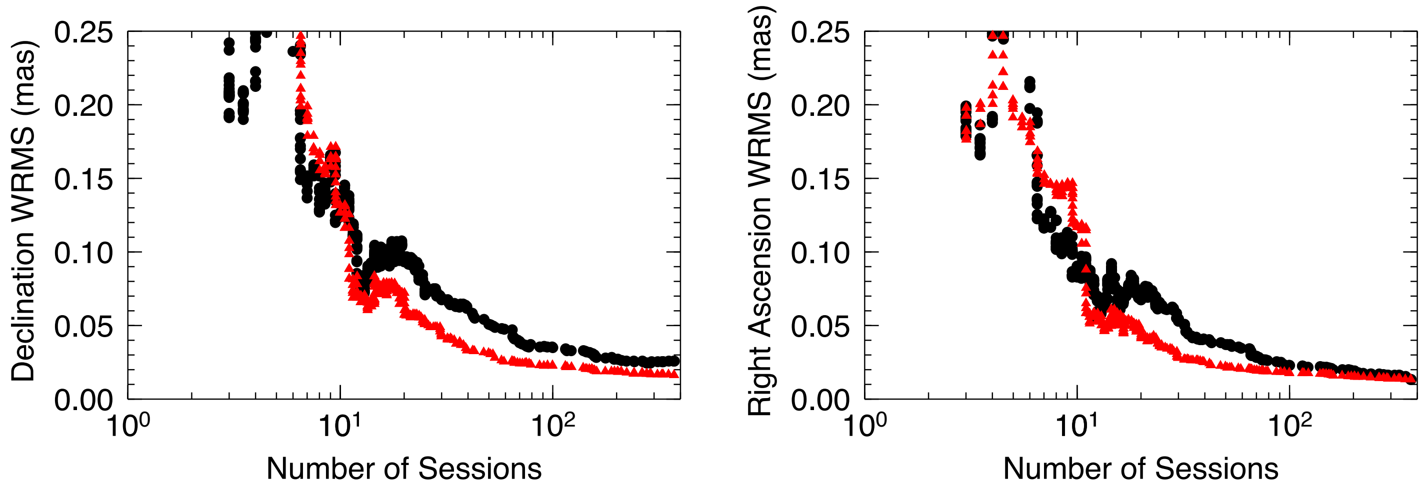

Figure 21: Wrms noise (solid circles) for subsets of 50 sources in each solution as a function of the minimum number of sessions a source was observed. The median formal uncertainty (red triangles) in each subset is shown for comparison. These were derived from differences between positions in the two decimation solutions.

- Noise floor of 15 μas in Right Ascension and 25 μas in Declination.
- As an upper limit, chosen noise floor of 40 μas.

Data studied in this work
Latest GSFC solution

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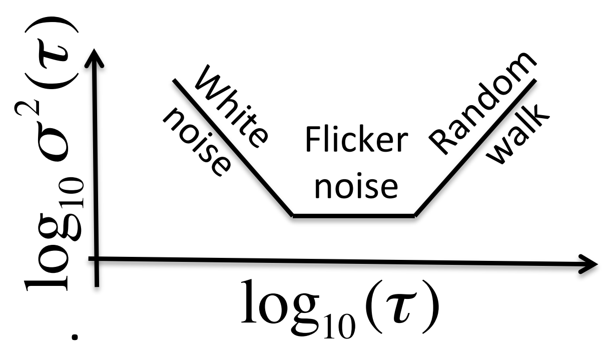
- Goddard VLBI source time series file gsf2017a.ts
  https://gemini.gsfc.nasa.gov/solutions/2017_astro/2017a_ts.html
- Generated on 14 April 2017.
- Databases from August 03, 1979 through March 27, 2017, for a total of 5696 sessions.
- Includes all of the VCS1-6, VCS-II, and UF001 A-D VLBA sessions.
- VLBI time series positions for 4241 sources. Some of these are with only one epoch.

Determination of the noise floor – The Allan variance

- The Allan variance is a statistical tool that gives level and type of noise of time series.
- If $(x_i)_{i=1,n}$ are the measurements and τ the sampling time, the Allan variance is:

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

- Cons: it has to be applied to regularly spaced time series.
- The type of noise is determined by the slope of the curve $\log_{10}$(Allan variance) = f($\log_{10}$(sampling time)).



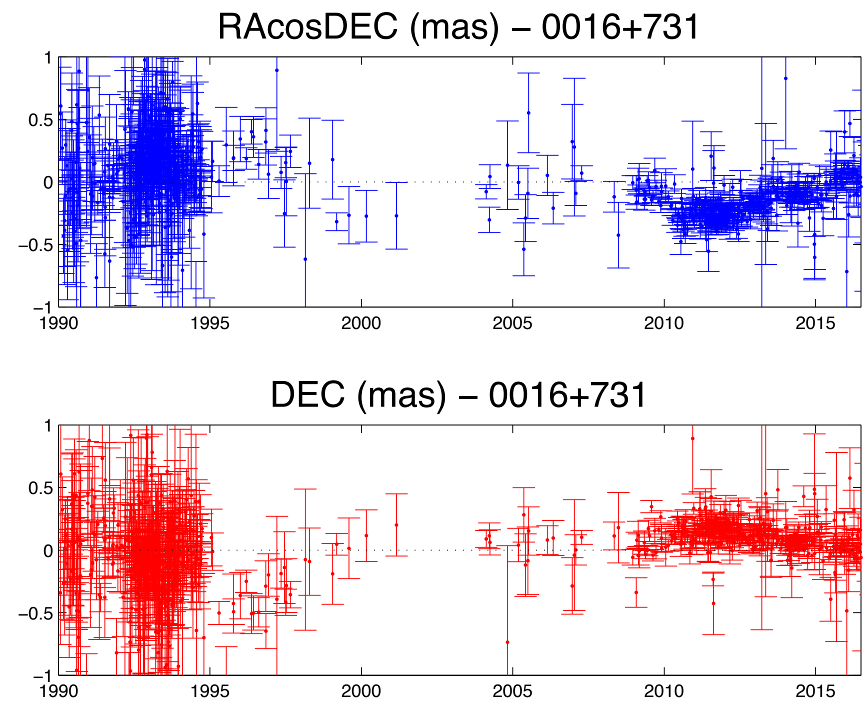
Determination of the noise floor – Difficulties (1)

- Real data:

  Sources not observed regularly

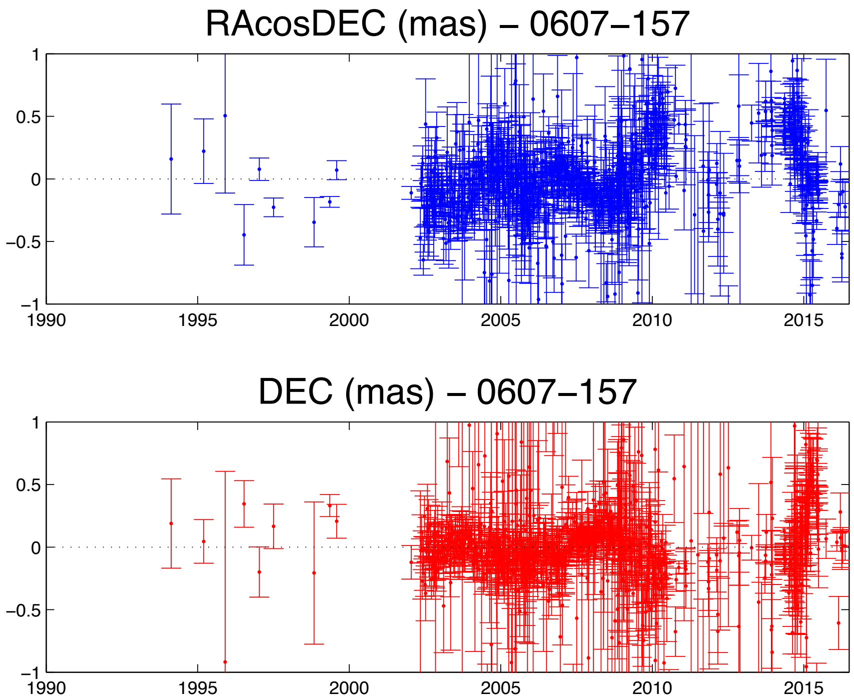
  => difficulties in statistical determination due to:
  - Gaps in between observations;
  - Number of observations.
- Averaging:

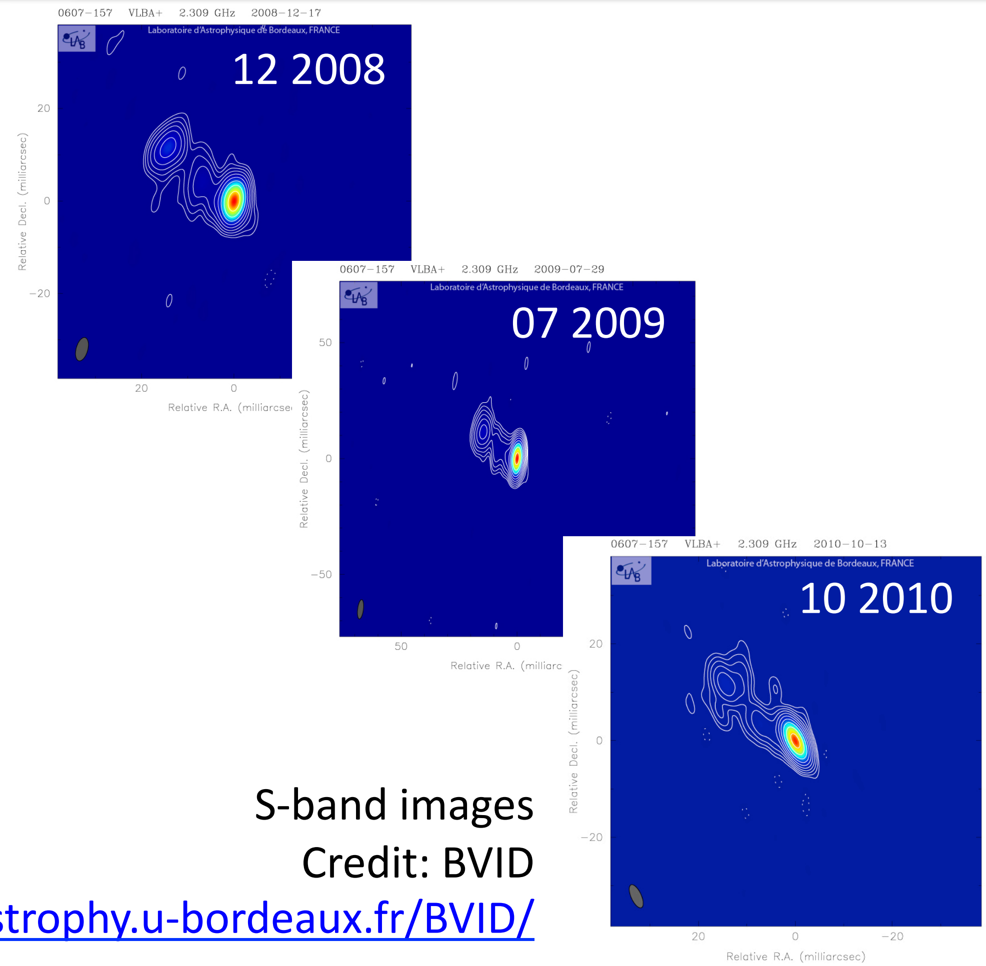
  Yearly, 30-day and 10-day.



Determination of the noise floor – Difficulties (2)

- Real data: Structure

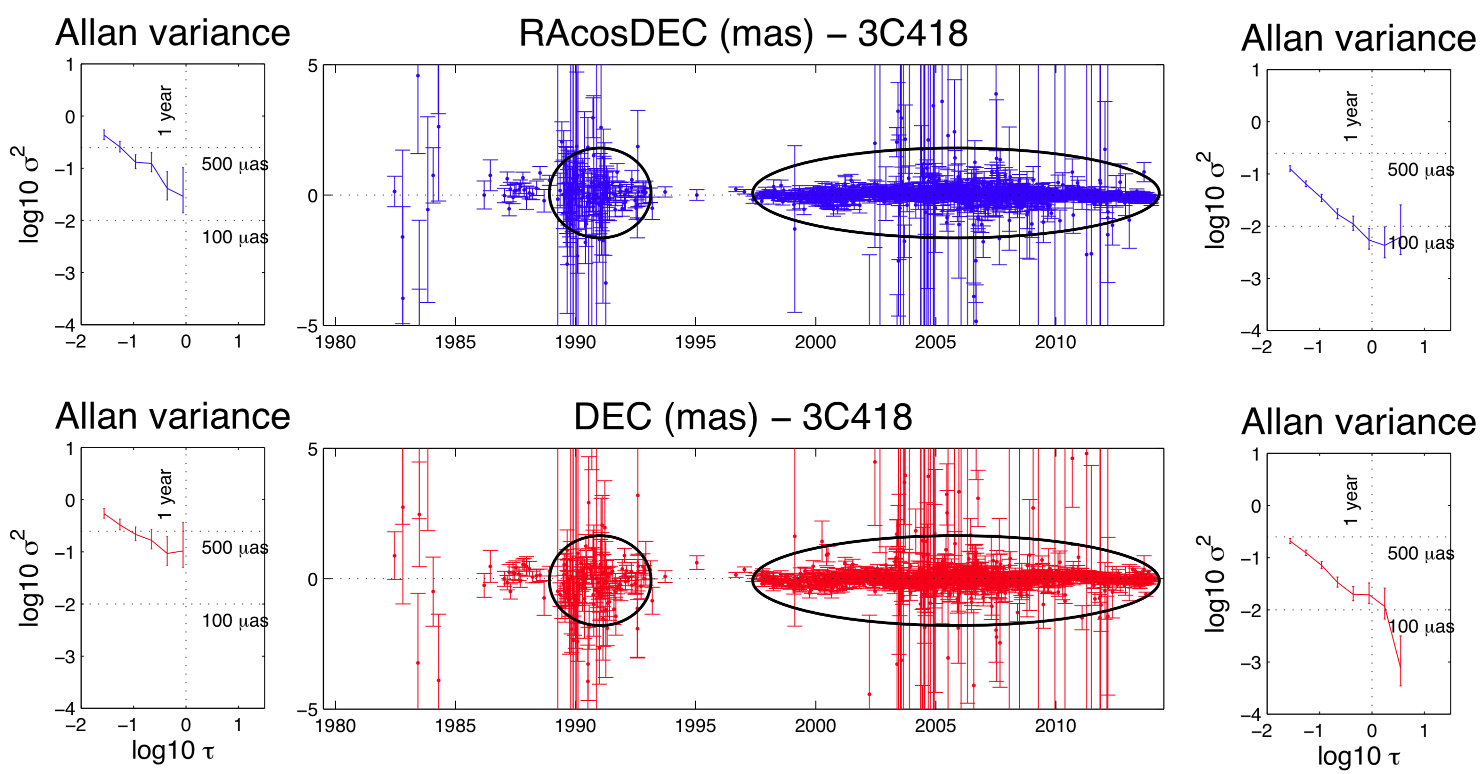




S-band images
Credit: BVID
http://www.astrophy.u-bordeaux.fr/BVID/

Determination of the noise floor – Difficulties (3)

- Real data: Homogeneity (cf. 2014 IVS GM poster)



Determination of the noise floor – Selection by level of noise

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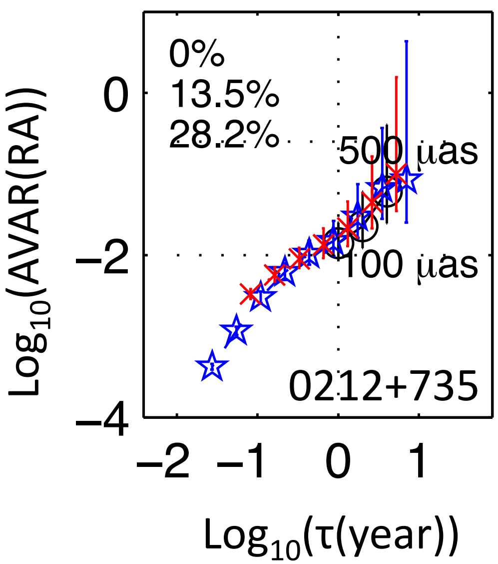
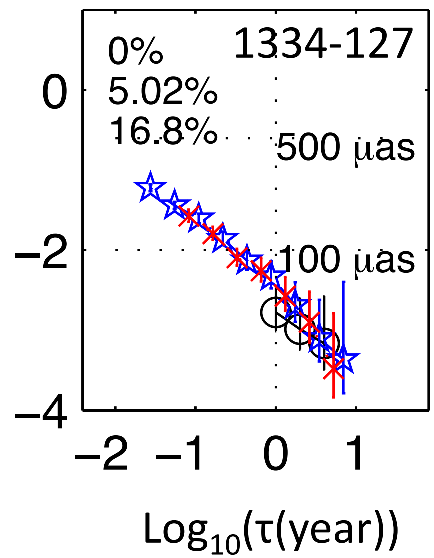
Random walk

Too much structure to determine the noise of the source.



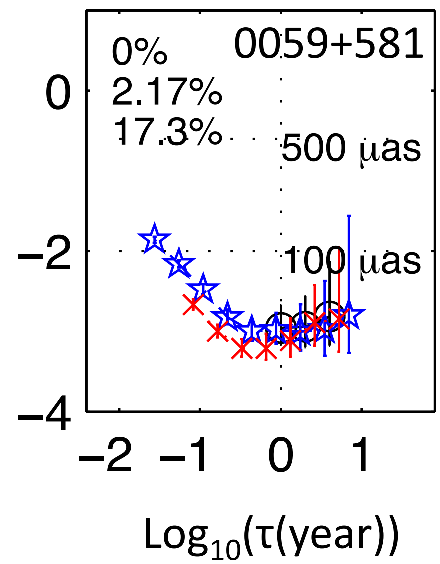
White noise

The quality of the data is improving with time.



Flicker noise

The quality of the data is stabilized at a certain level of noise.



Determination of the noise floor – Source selection

GSFC 2017a: 4241 sources

Keep sources with 10 or more observations

766 sources

Keep sources with good history (observed after 1995, more than 5 years, more than 2 observations per session, more than 1 session per year, less than 3 years in between two observations, less than 50% of gaps filled)

175 sources

Visual check of the homogeneity of the time series

164 sources

Eliminate 9 sources (random walk)

Flicker noise: 91 sources

White noise: 66 sources

Determination of the noise floor – Results

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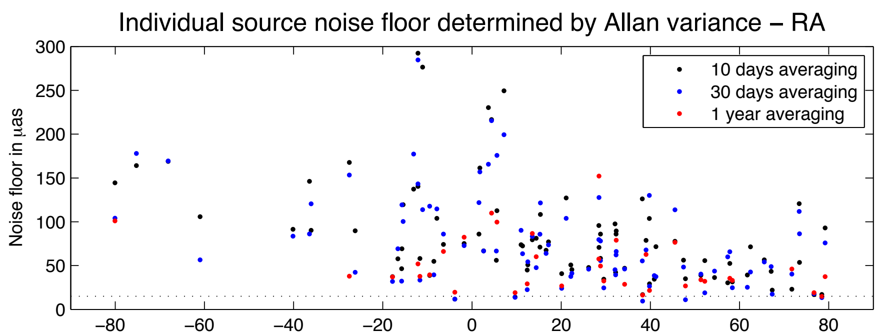
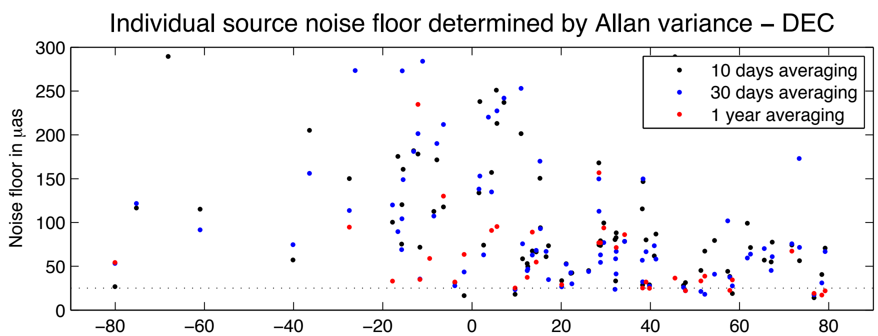
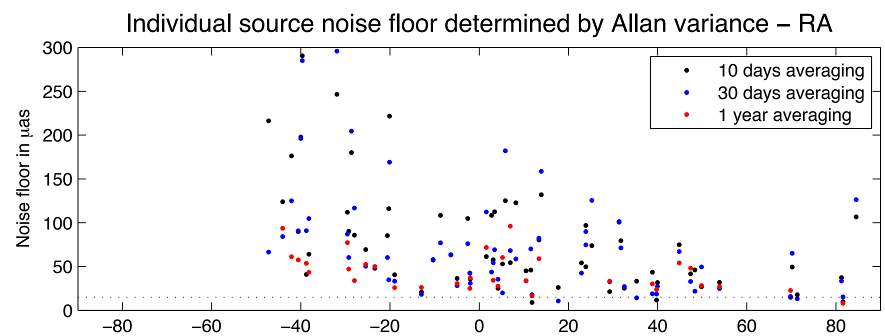
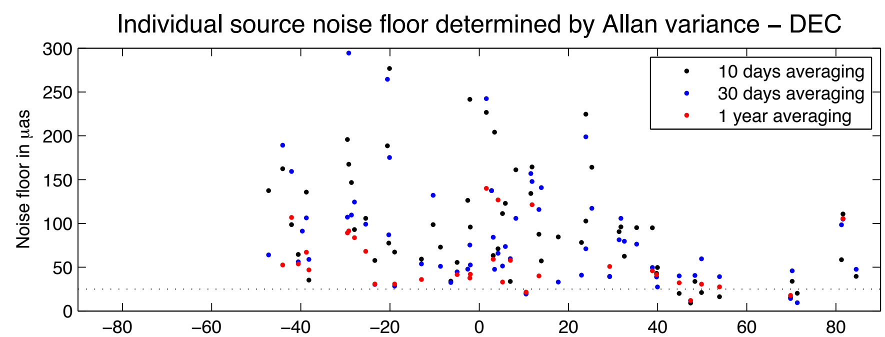
Set of Flicker Noise sources





Set of White Noise sources





=> Noise floor as low as 5 µas.

Determination of the noise floor – Results

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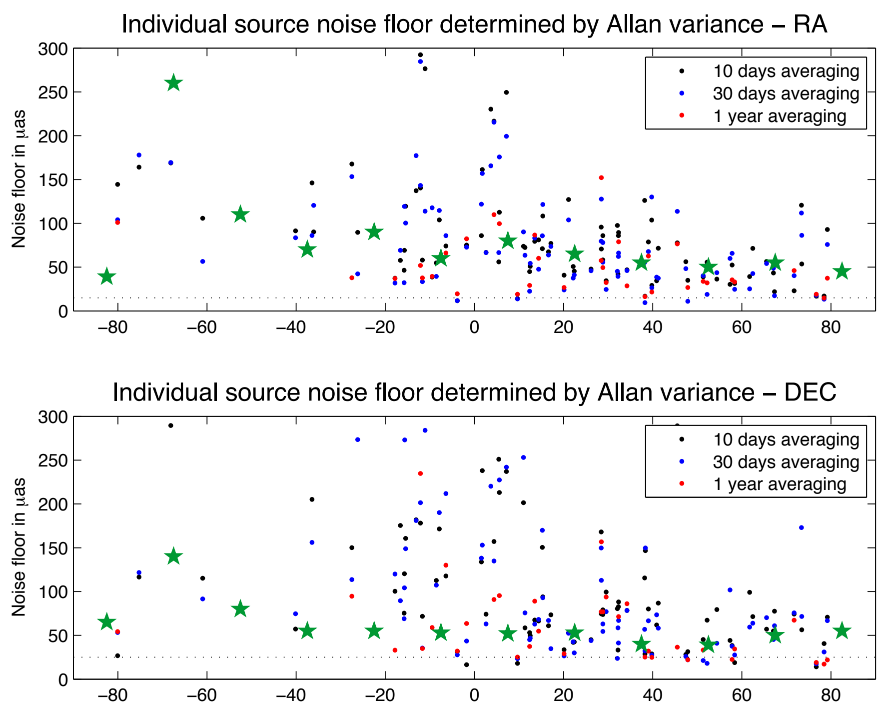
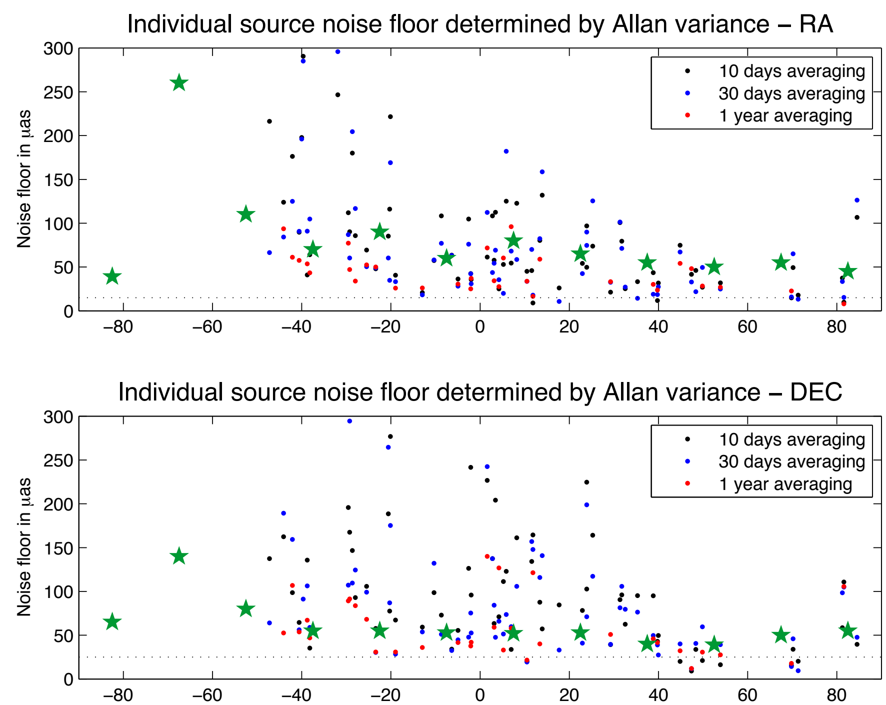
Set of Flicker Noise sources



Set of White Noise sources



Green ★ : ICRF2 noise floor - average on sources in 15° declination bands.

Attention! This method uses ALL "good" sessions, contrary to the decimation test.

Conclusions and next questions

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- Some of the sources have a noise floor as small as 5 µas.
- The noise floor increases when the declination decreases.
- Very few sources in the deep south (< -50°). Their flicker noise may be due to the small number of observations.

Next steps:

- Use this method of noise floor determination by the Allan variance with the ICRF2 data (2009) and compare.
- For the ICRF3: different analysis centers will submit their ICRF solutions.

  Different software packages, different models, different methods of data elimination…

$\Rightarrow$ Different noise floors depending on the solution;

$\Rightarrow$ Combined noise floor?