Source Characterization by the Allan Variance

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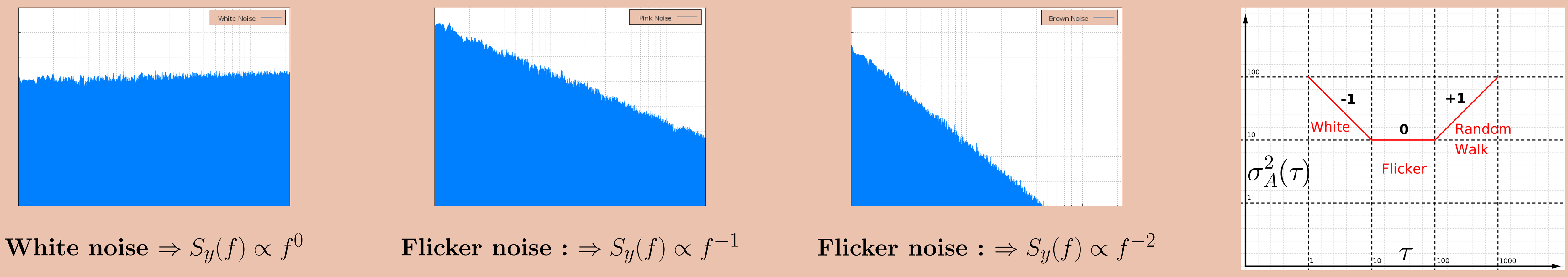
Abstract : *Until now, the main criteria for selecting geodetic sources were based on astrometric stability and structure at 8 GHz [4]. But with more observations and the increase of accuracy, the statistic tools used to determine this stability become inappropriate with regards to sudden motions of the radiocenter. In this work, we propose to replace those tools by the Allan Variance [1], first used on VLBI sources by M.Feissel-Vernier [3], which lead to a new classification of sources in three groups according to the shape of the Allan Variance. In parallel, we combine two catalogues, the Large Quasar Astrometric Catalogue [7] and the Optical Characteristics of Astrometric Radio Sources [5], in order to gather most physical characteristics known on those VLBI targets. By doing so, we may reveal a physical criteria that may be useful in the selection of new targets for the futur VLBI observations.*

Allan Variance

Let $y(t)$ be a continuous time function. Given a time scale τ, samples can be computed using $\overline{y_k} = \overline{y(t_k)} = \frac{1}{\tau}\int_{t_k}^{t_k+\tau} y(u)du$. In the case of VLBI data $\overline{y_k}$ were obtained by averaging observations inside a sliding window of width τ. The **Allan Variance** [1] is a statistic tool that can **study the dispersion of a signal between peers** :

$$\sigma_y^2(\tau) = \frac{1}{2}\left\langle(\overline{y}_{k+1}-\overline{y}_k)^2\right\rangle \qquad (1)$$

Rather than study the dispersion around the mean, like with the true variance, we study the variation between two successive samples given a time sampling $k\tau$. VLBI time series can show several type of noise from white noise (or thermal noise) to coloured noise, such as flicker noise (random jump at random time) and random walk noise. Those noises **differ in their spectral density** $S_y(f)$ by different exponent in power law which lead to **different behaviour of the Allan Variance**.

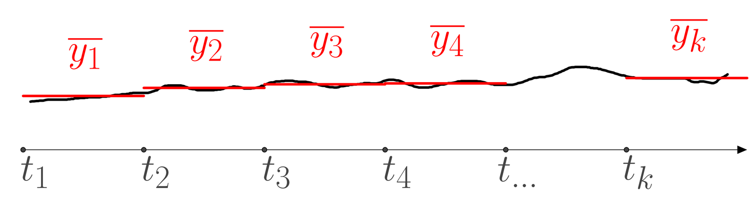


White noise $\Rightarrow S_y(f) \propto f^0$ **Flicker noise :** $\Rightarrow S_y(f) \propto f^{-1}$ **Flicker noise :** $\Rightarrow S_y(f) \propto f^{-2}$

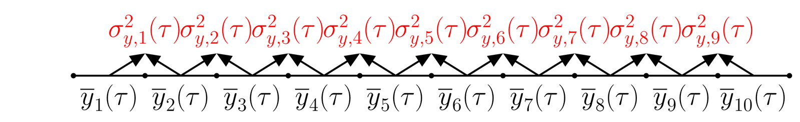
In our work, we used the modified Allan variance with the particularity that we do not fill the observation gap present in most of the time series.

Allan Variance in picture

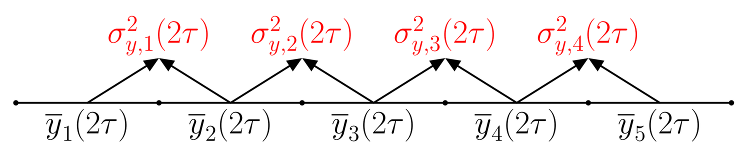
1. Regular sampling of the function with a minimal time-scale τ



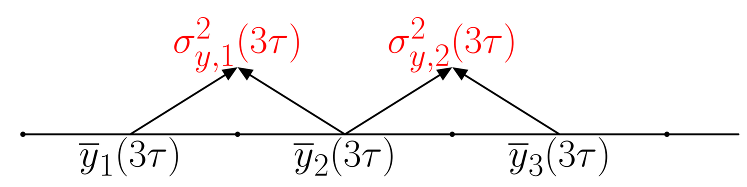
2. Apply the Allan Variance equation



3. Increase the time-scale $\tau \to 2\tau$ and apply the Allan Variance again



4. Increase and apply ...



New Source Classification from Time series

To the aim of studying the stability of VLBI radio sources, we work on the coordinates time series of those sources. We used CALC/SOLVE to analyse all the available VLBI non-intensive session on the IVS website. We applied a special treatment to our analyse. We got **time series from 11 different solutions** where 9/10 of the number of sources are estimated globally and 1/10 locally. This repartition is applied to defining sources and standard sources separately in order to keep the No Net Rotation (NNR) constraint on 9/10 of the ICRF2 defining sources.

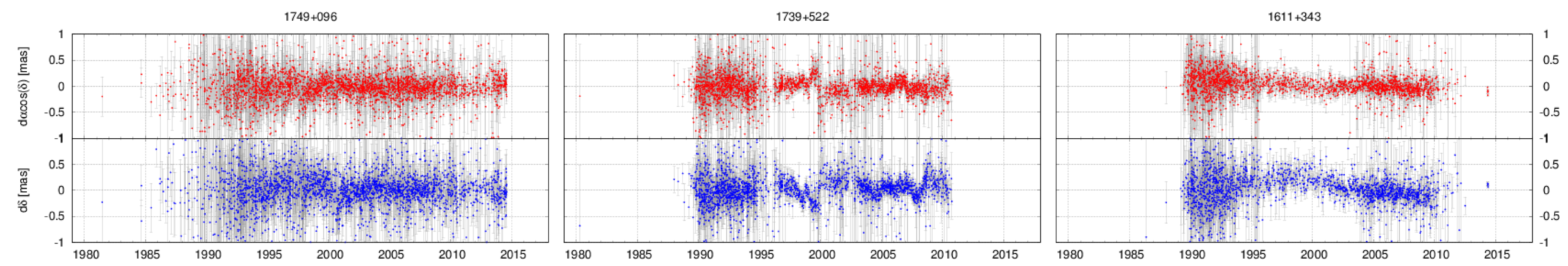


Fig. 5: Examples of radio sources coordinates time series from CALC/SOLVE VLBI analysis. On the upper graph, $d\alpha\cos(\delta)$ with respect to the temporal mean position. On the lower graph, $d\delta$ with respect to the mean position

We applied the Allan Variance on **VLBI sources present in more than 100 sessions** after removing the outliers. Then we defined three new status given the shape of the Allan Variance on $d\alpha\cos(\delta)$ and $d\delta$. For each status, sources are sorted by the quadric sum of minimums of Allan variance on both coordinates.

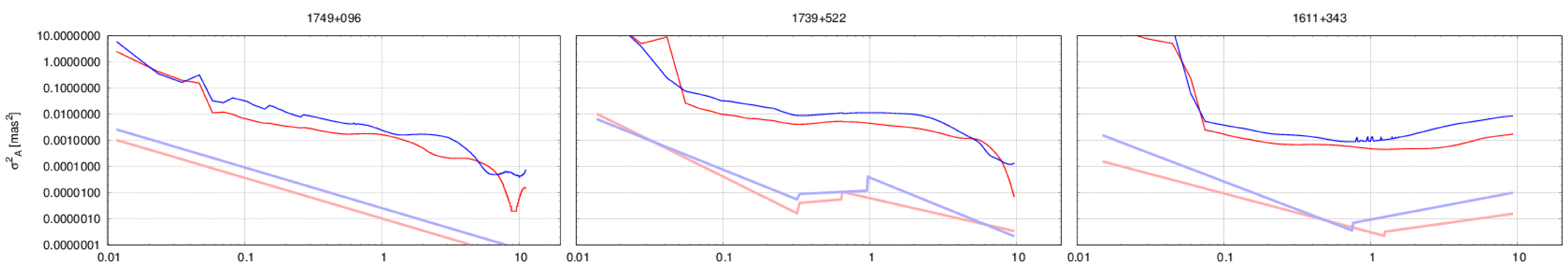
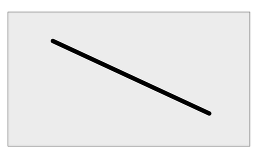
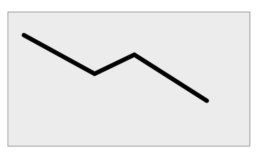
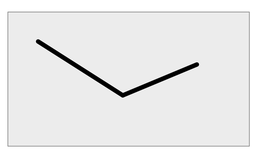


Fig. 6: Allan Variance in $d\alpha\cos(\delta)$ in red and $d\delta$ in blue of the previous sources and their linear piece-wise adjustment. From left to right : Allan 0 example, Allan 1 example, Allan 2 example.

 Allan0 Good Sources

 Allan1 Medium Sources

 Allan2 Bad Sources

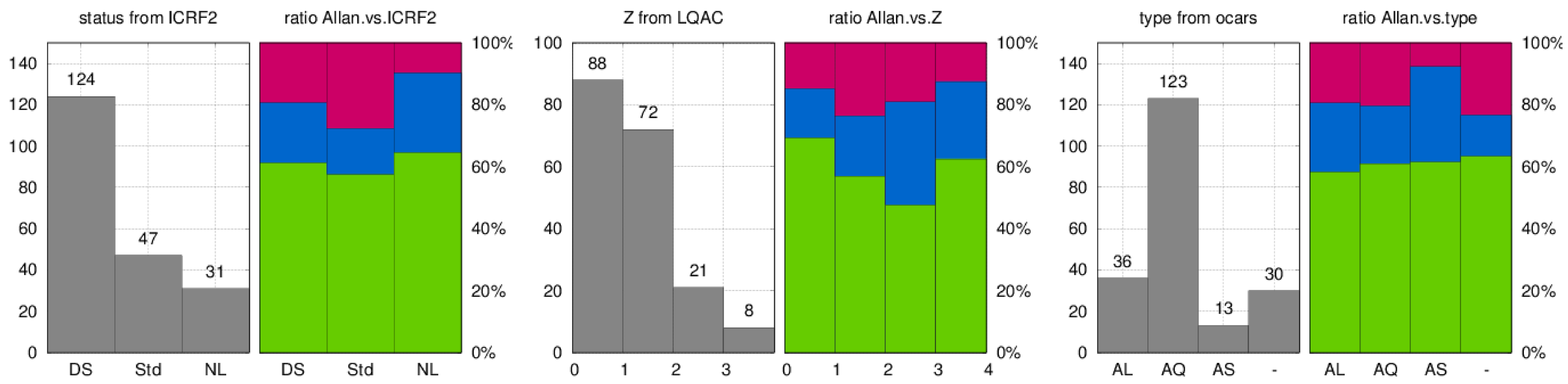


Fig. 7: Repartition of this new classification with respect to the previous one (ICRF2), the redshift and the type of source. Only Sources with more than 100 observing sessions is included. DS = defining sources, Std = Standard sources, NL = Non linear sources ; AL = Blazar, AQ = quasar, AS = Seyfert

Physical characteristics

In parallel, we took several characteristics of VLBI Radio sources from catalogues.

- LQAC3 : The LQAC is a compilation of several surveys, such as radio-interferometry surveys, SDSS, etc... It brings a powerful table resuming radio and optical characteristics of quasars such as coordinates, redshift, magnitude, radio flux, etc... [7]
- OCARS : The OCARS is a compilation of catalogues and it brings optical characteristics of VLBI radio sources such as redshift and magnitude. It also brings a classification of VLBI sources by type of the AGN. [5] http ://www.gao.spb.ru/english/as/ac_vlbi/ocars.txt

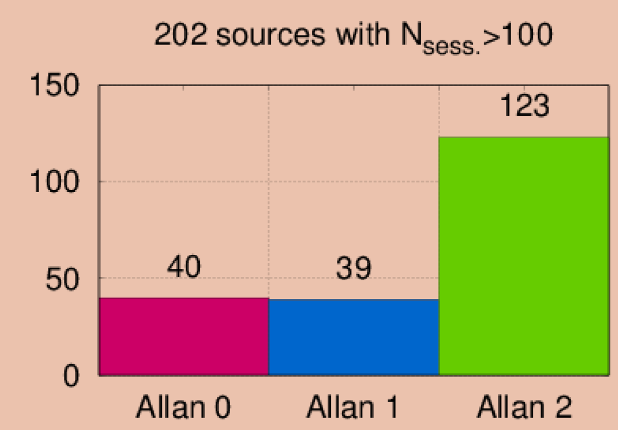


Fig. 9: Number of sources with more than 100 observing in each category of our new classification with respect to stability

Conclusion

This new classification seems not in agreement with the repartition DS/Std/NL of the ICRF2. This can be an effect of the new sessions from 2010 to 2016, or it can show that one or the other method is not relevant to determine the stability of a radio-source. Allan Variance should be test on the ICRF2 data to conclude. On another hand, we see that stability with respect to Allan Variance do not show dependance on the type of the AGN, i.e. on different orientations of the sources with respect to the line of sight [2, 8]. There may have a dependance on redshift with an optimum around 1 but it is difficult to conclude.

This work introduces a new method to classify VLBI sources by mean of the Allan Variance. We do not succeed in finding a common physical characteristics for stable sources but the stability of the sources may be strongly link to what happen around the black hole(s), resulting to (multiple-)core emission or (multiple-)jet emission as it is show by the work of Roland, J., see [6] for an example. The next step is to study the effect of this classification on referential frame and it is the topic of my speech in this meeting.

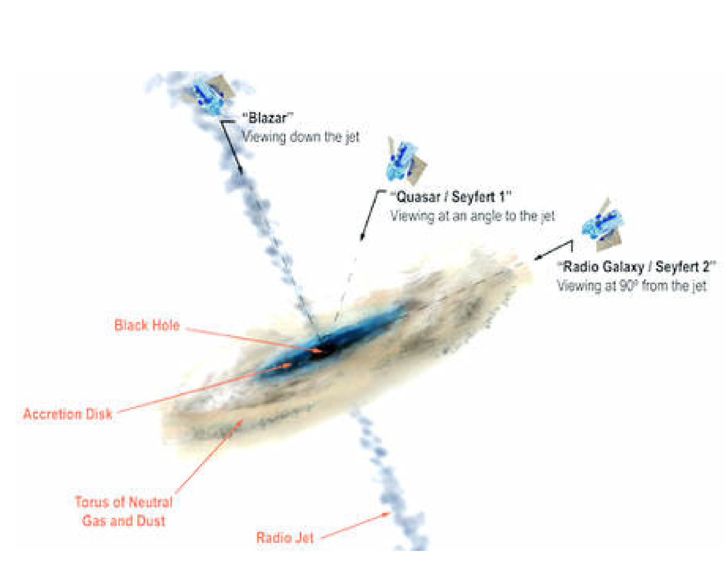


Fig. 8: Unified theory of the AGNs [2, 8]

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