A dedicated antenna array for radio detection of Extended Air Showers

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((1)+ (2)+ (3) ? CODALEMA collaboration)

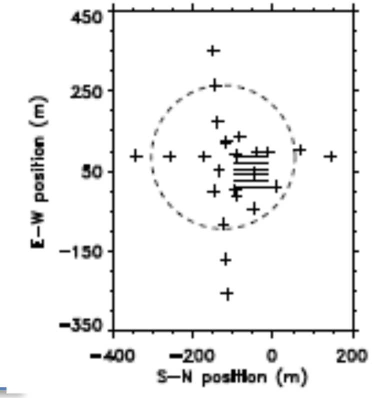
outline

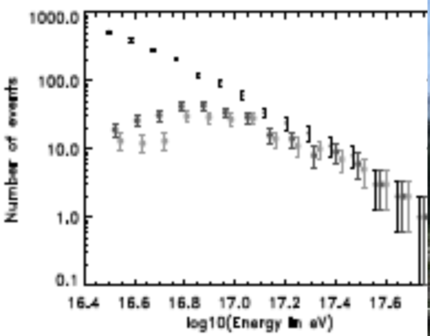
- why a new antenna array ?
  motivations and rationale.
- operated since mid 2013 in "SD triggered mode"
  ~1000 radio events from 80000 SD triggers.
- prototype for an EAS self detecting radio system (in progress):
  operation in **self detecting** mode
  (continuous sky survey + on line recognition scheme)

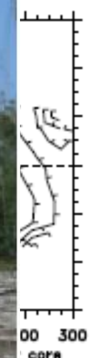
PROCEEDINGS OF THE 31st I 1

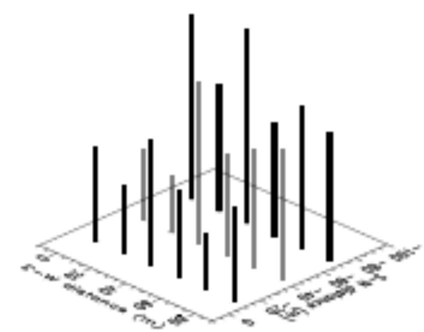
Radio signatu the

Alain Lecache



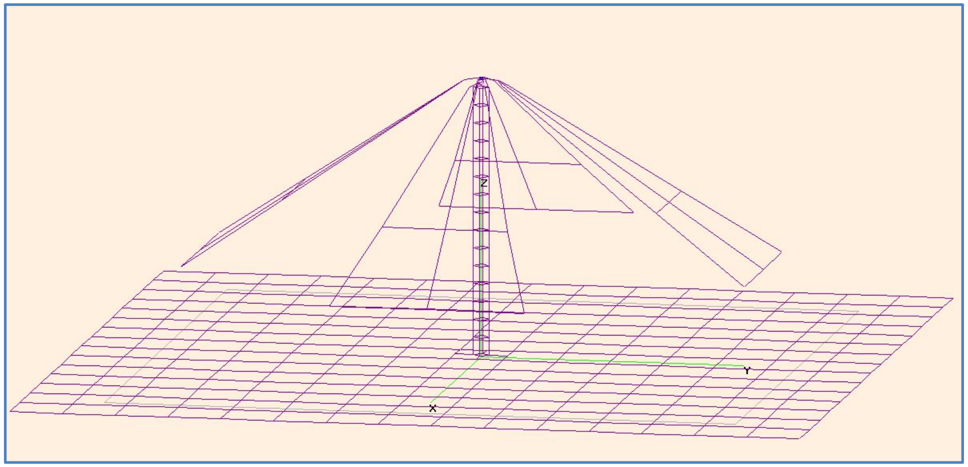


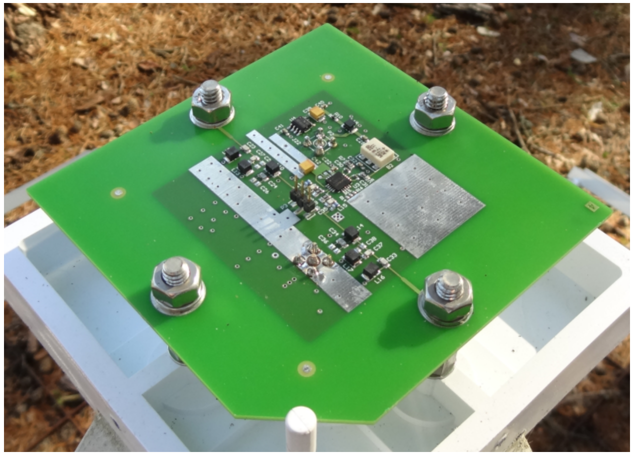


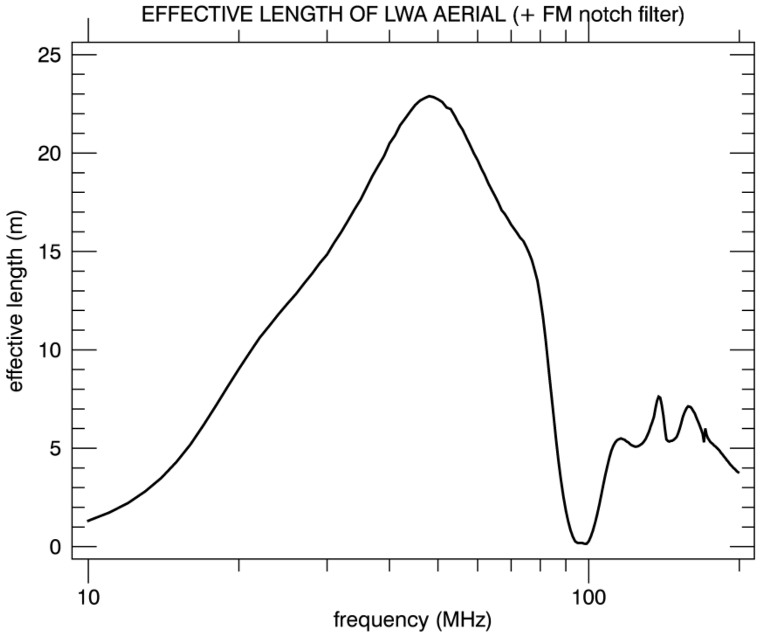


Antenne LWA
(thick V-shaped active dipolar antenna)

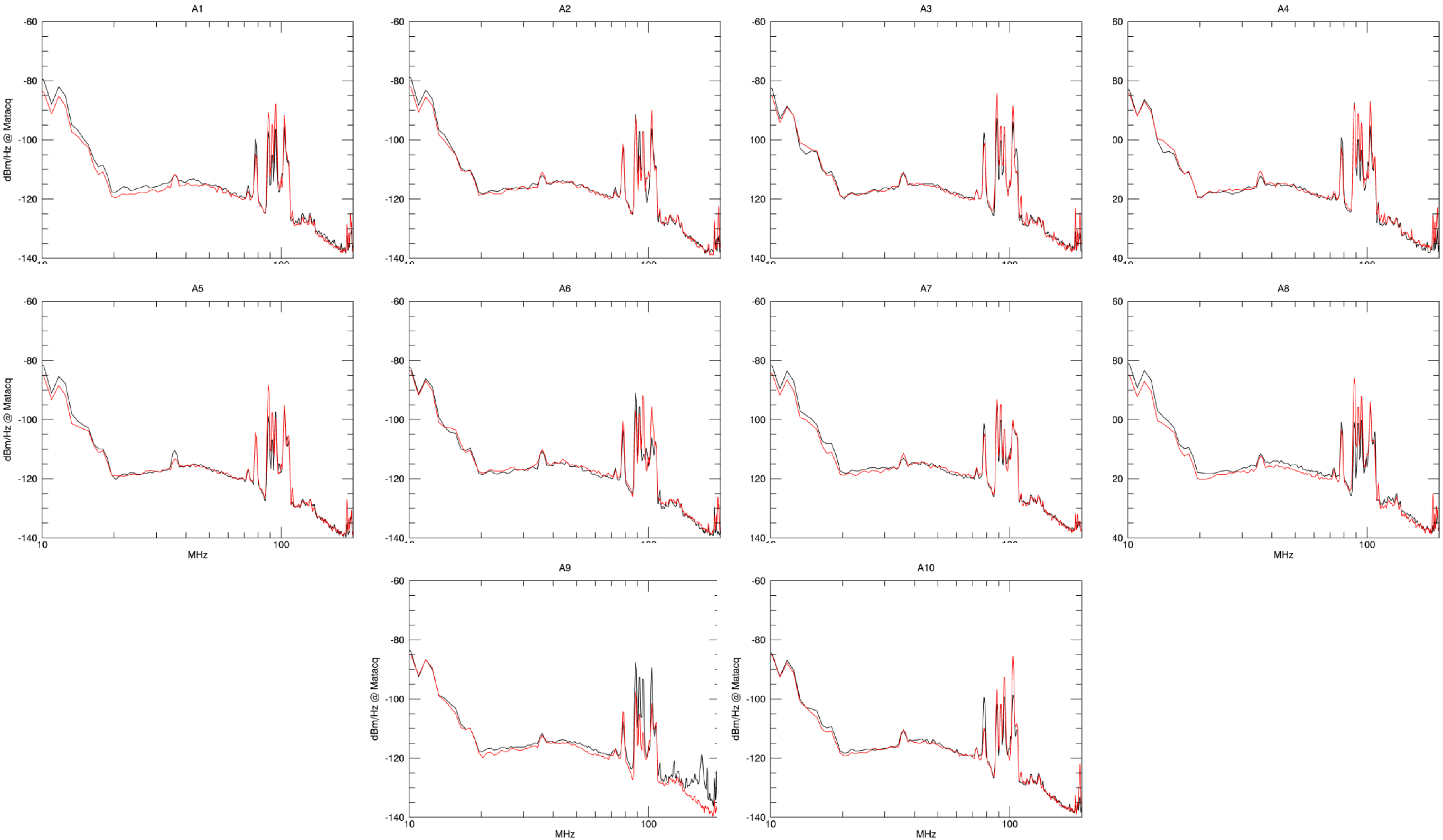
Realisation and modeling of LWA antennas (LWA aerial + "lonamos" LNA)



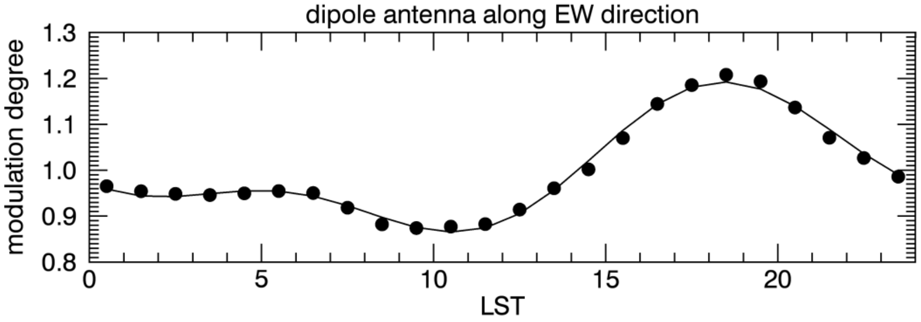


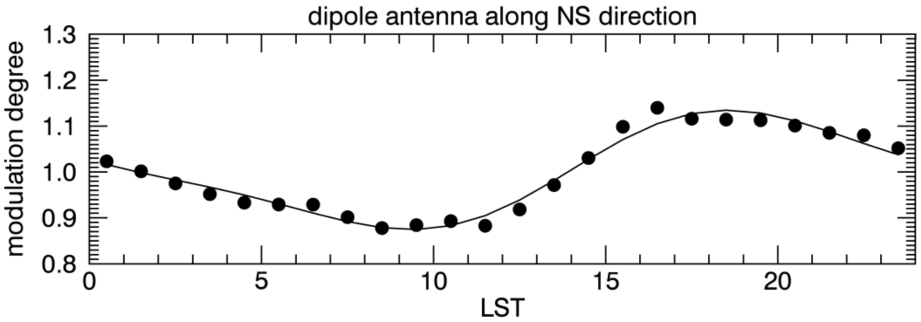


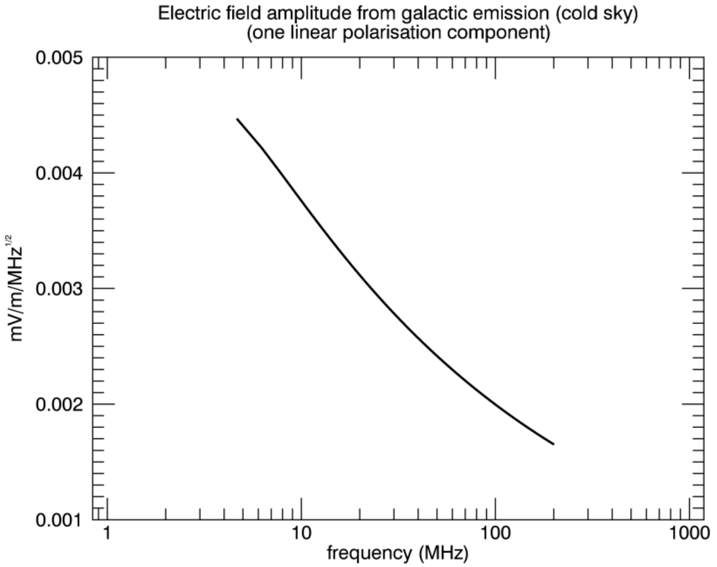
Exceptional quality of the obtained antenna matching



Response to galactic radio emission







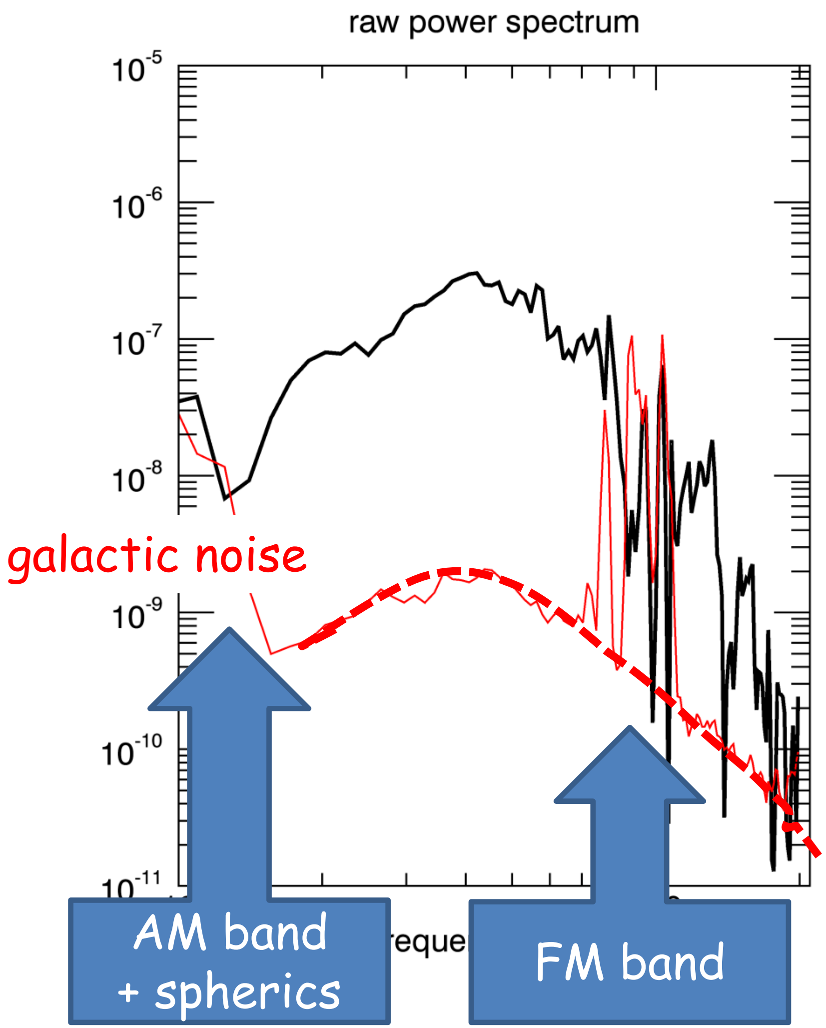
Electric field noise at the antenna induced by (cold) galactic emission (uniform brightness and spectrum in $\nu^{-2.55}$, e.g. Cane,1979) :

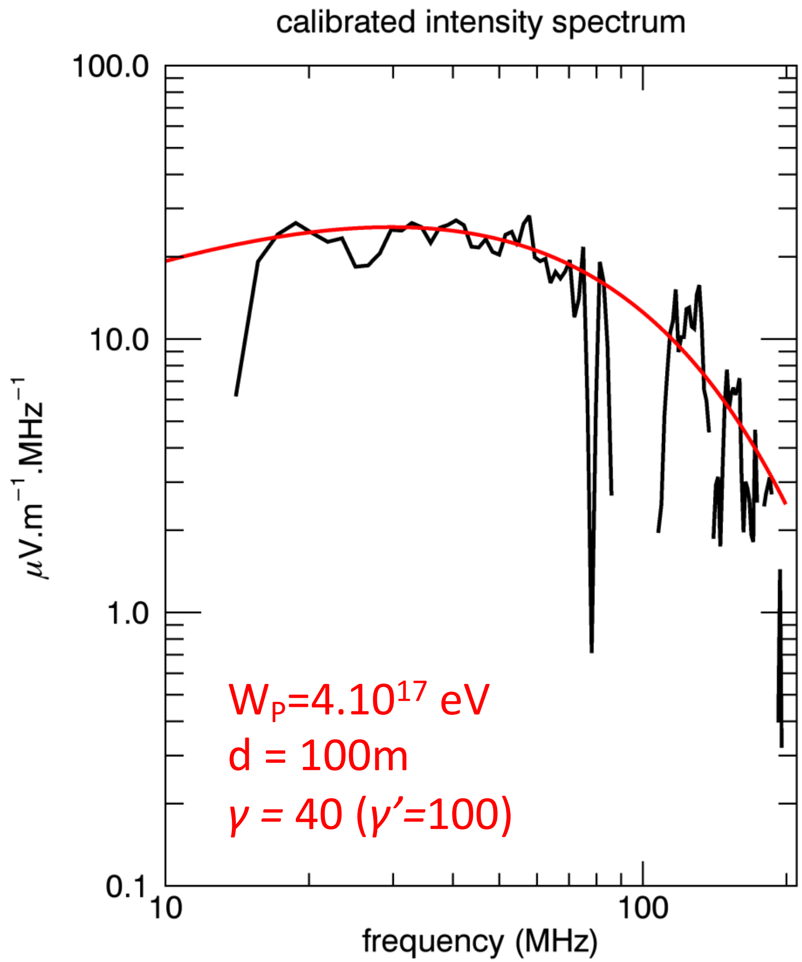
$$E_\nu = 3.12 \left(\frac{\nu_{MHz}}{20}\right)^{-0.28} \qquad \mu V.m^{-1}.MHz^{-1/2}$$

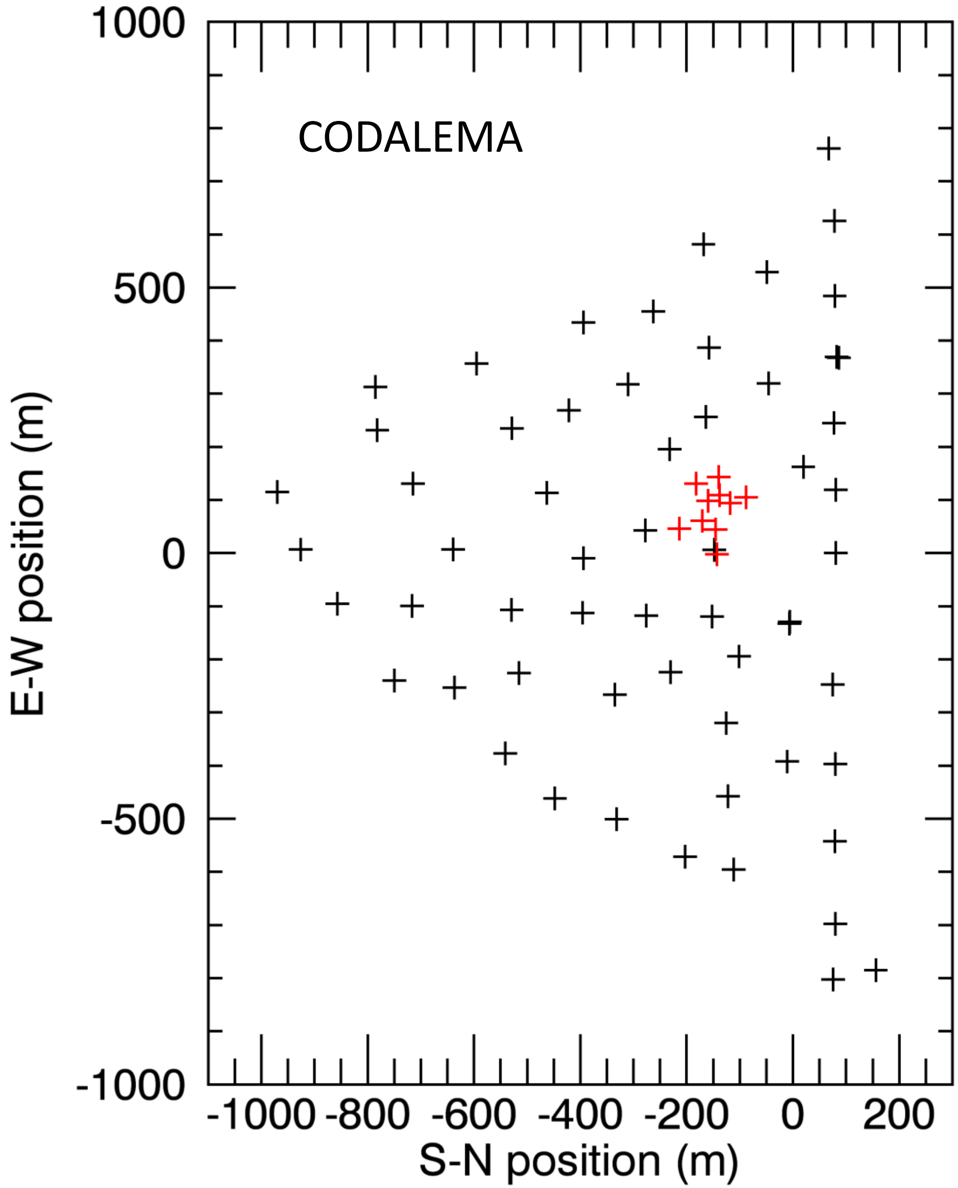
Equivalent discrete signal amplitude (in time window Δt) :

$$E_\nu = 0.098 \left(\frac{\nu_{MHz}}{20}\right)^{-0.28} \sqrt{\Delta t_{ns}} \qquad \mu V.m^{-1}.MHz^{-1}$$

EAS radio event amplitude spectrum

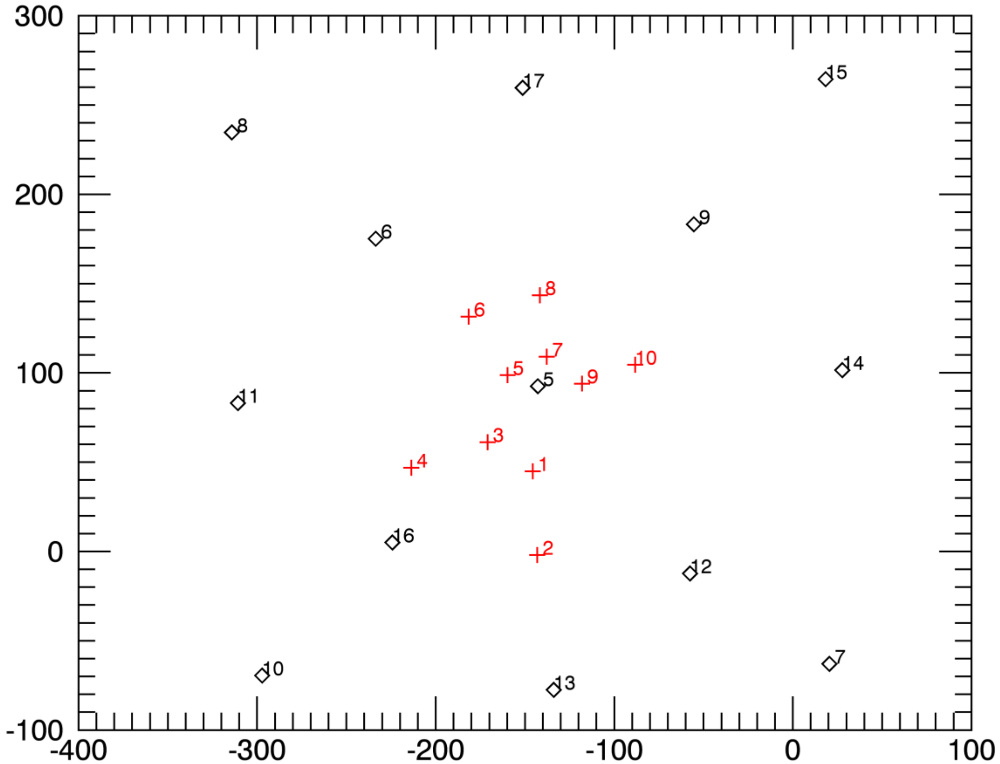






Compact Array implantation inside CODALEMA instrument in Nançay

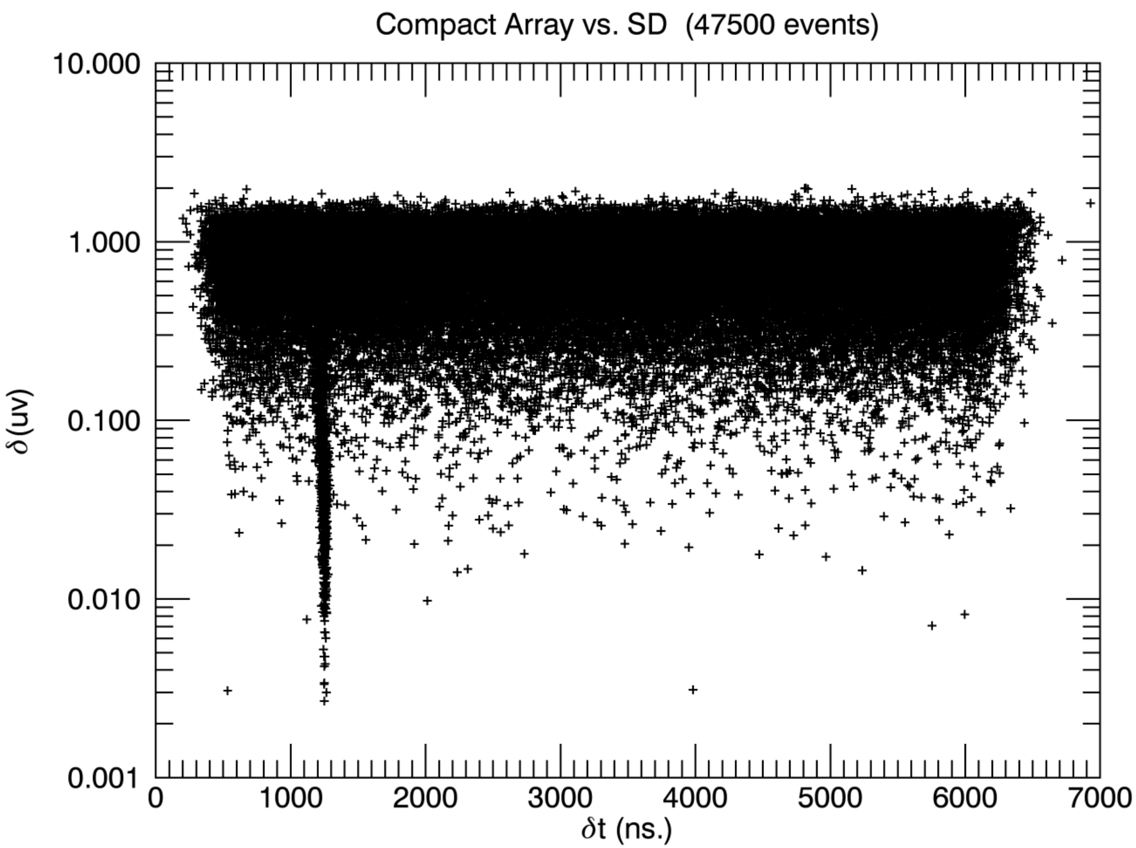
Compact antenna array and SD detectors



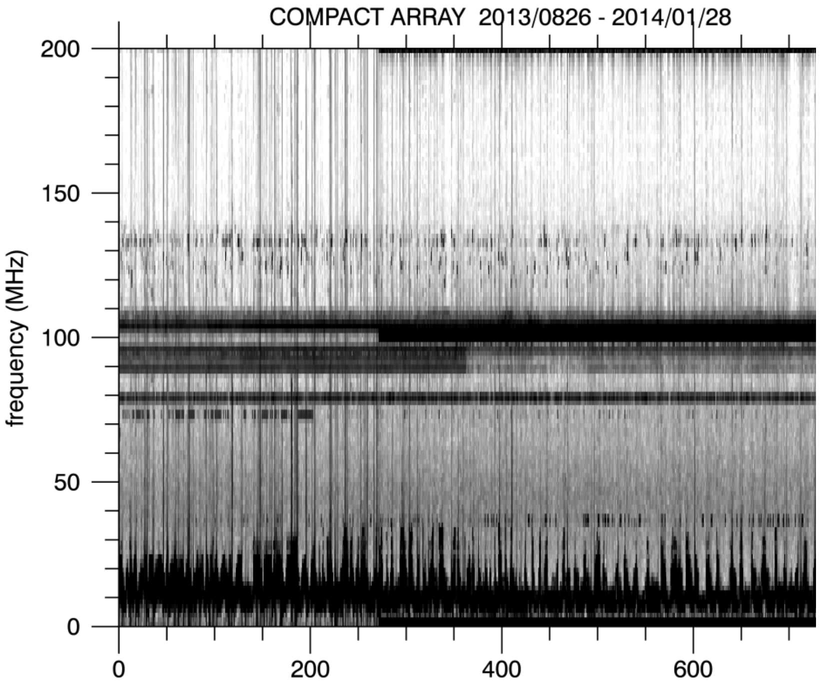
The CODALEMA Compact Array instrument

- 10 antennas in dual linear horizontal polarisation, distributed over a square of 150m x 150m (24 to 146m spacing)
- two observing modes:
  - SD triggered:
    - 20 channels, 6 μs snapshot
    - ADC 400 MHz, bandwidth: 10-200 MHz
  - self detecting mode (development in progress)
    - continuous sampling of (up to) 8 channels, in circular polarisation (linear output added in quadrature)
    - ADC 100 MHz, bandwidth: 50 MHz (2nd Nyquist band)
    - real-time software (using GPU 5 Tflops)

Search for coïncidences with SD events (time and direction)

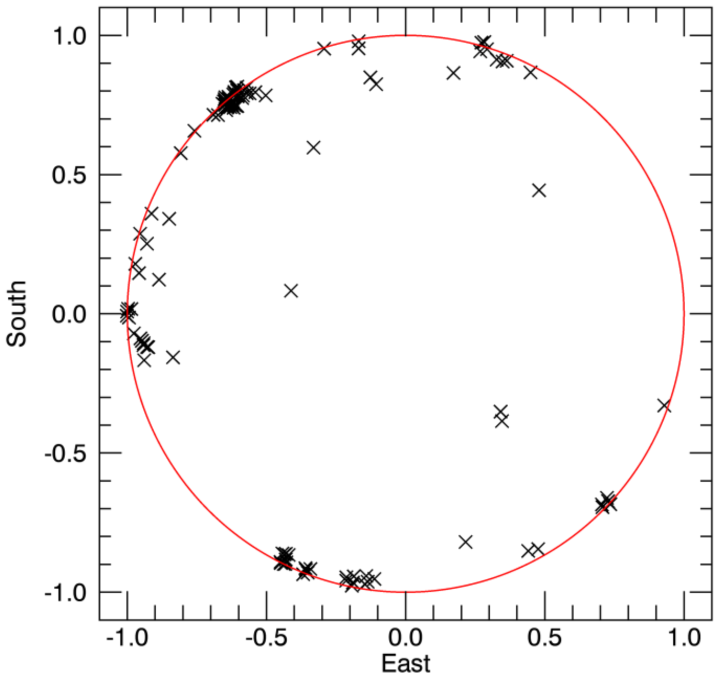


impulsive RFI environment (in Nançay)



~Time (spaning about 6 months)

Some identified recurrent RFI sources

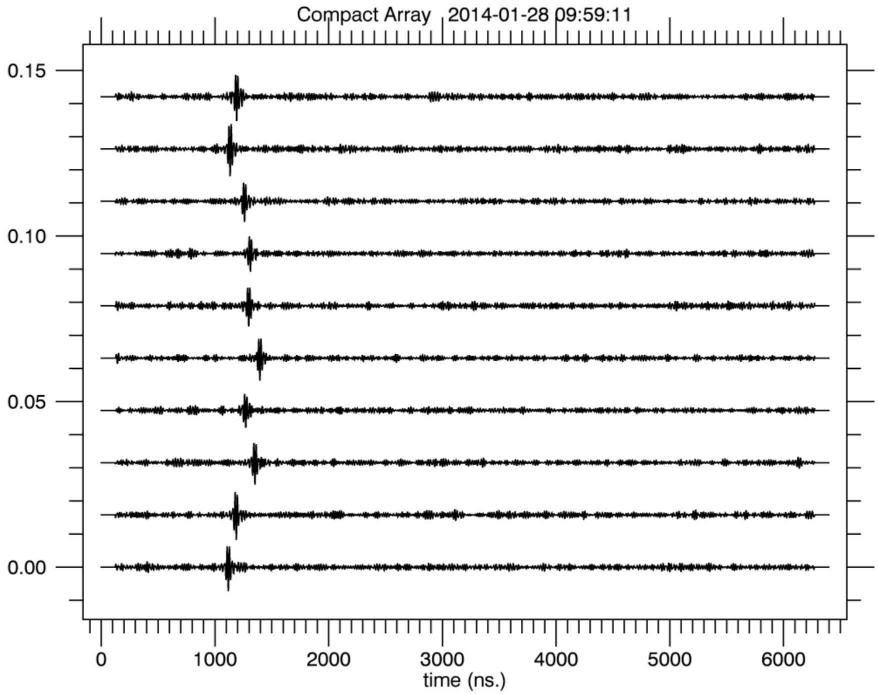


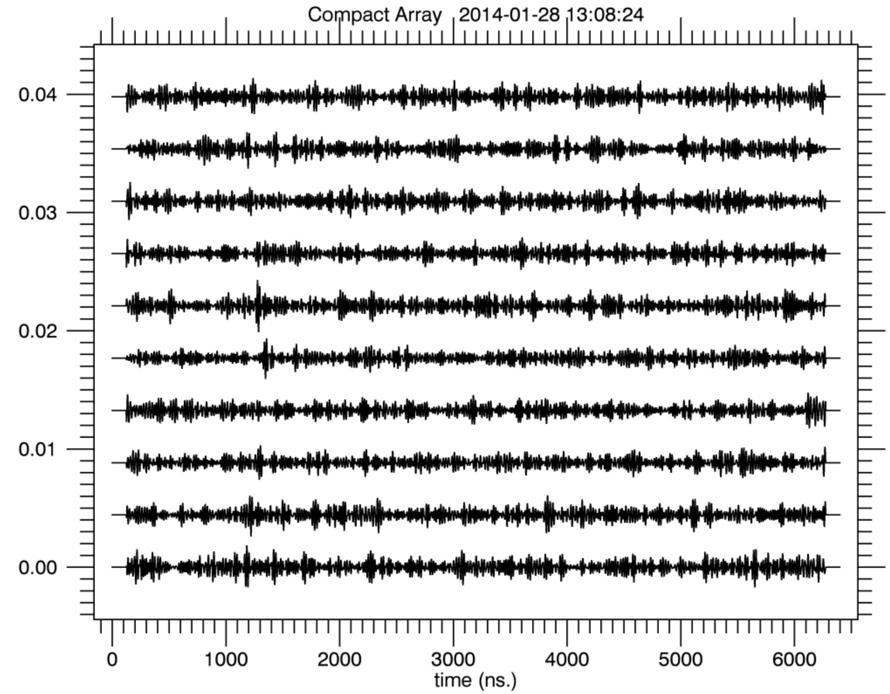
in Nançay - a « clean » environment -, one get ~100 radio pulses per second (in average) above 5 x galactic background …

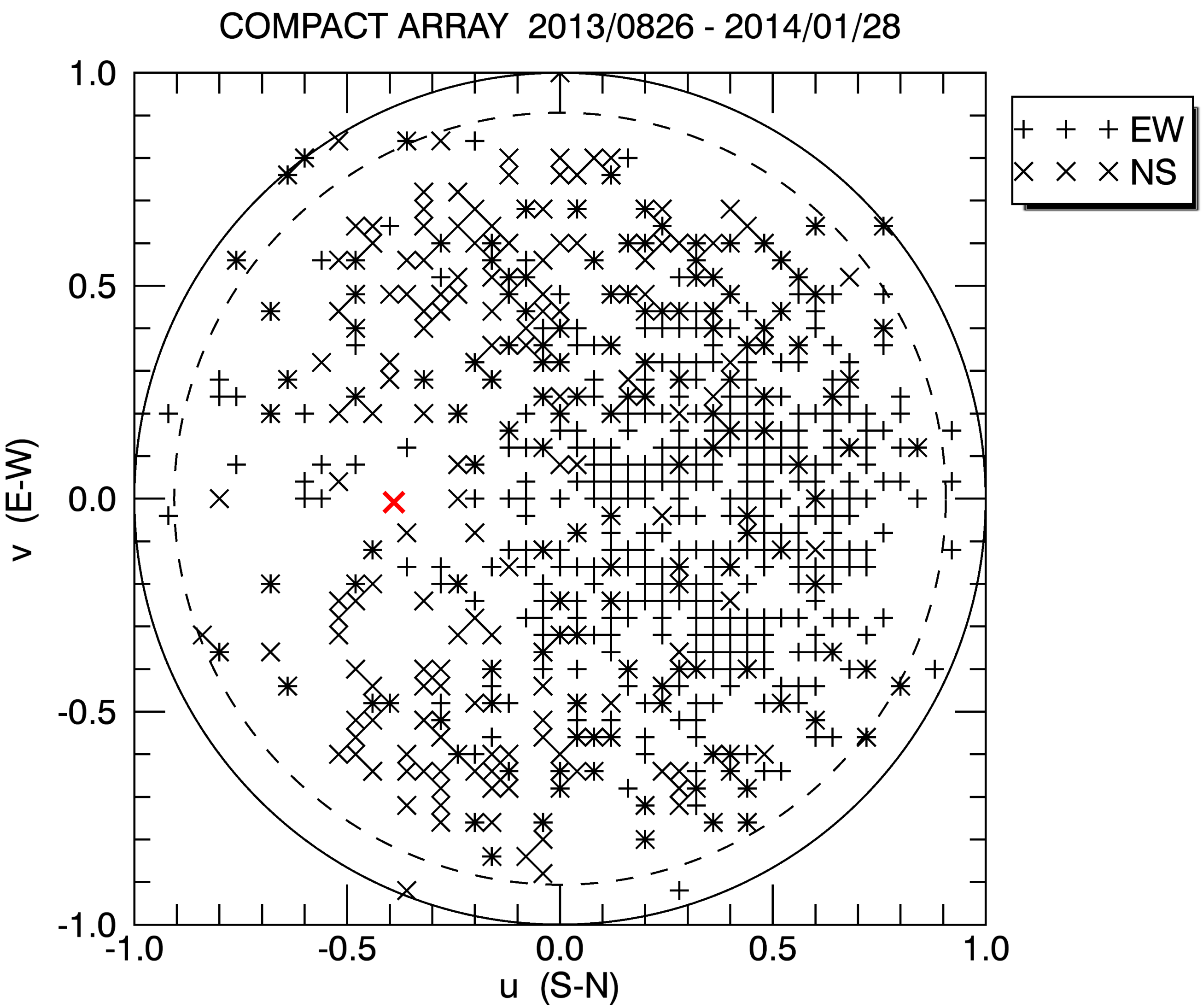
The sensitivity problem

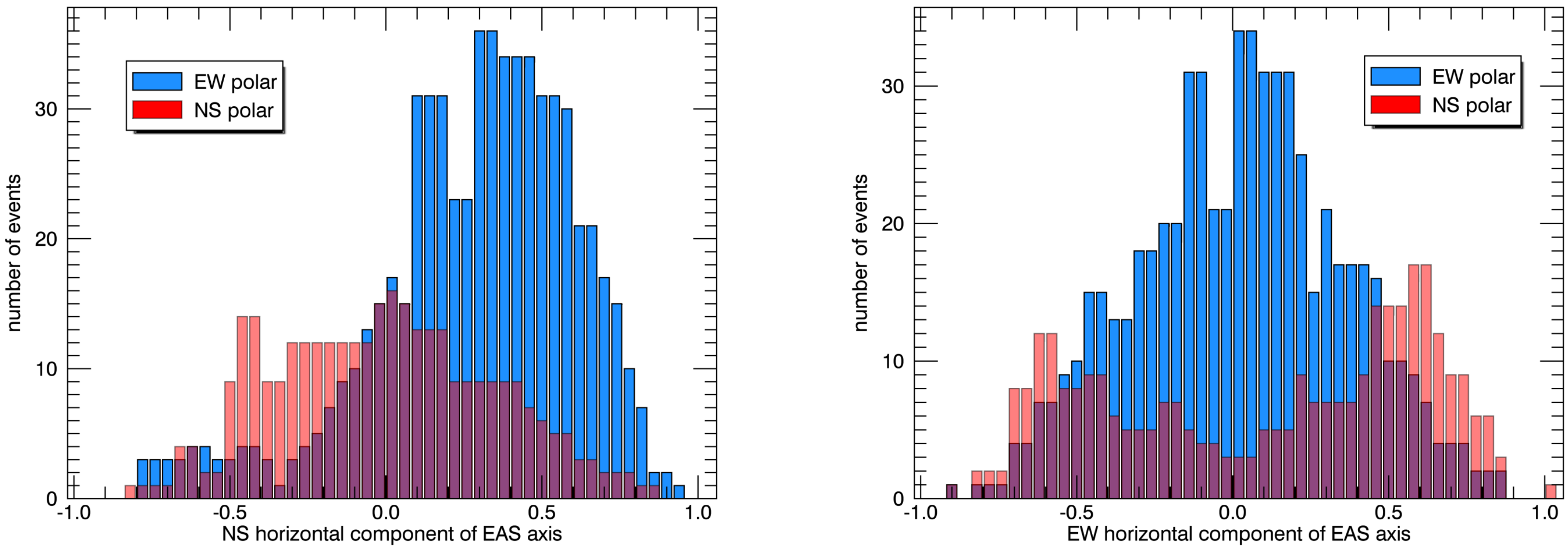
an « easy » event

this one is much more difficult to detect …






COMPACT ARRAY 2013/0826 - 2014/01/28
1.0
0.5
0.0
-0.5
-1.0
v (E-W)
-1.0
-0.5
0.0
0.5
1.0
u (S-N)
EW
NS


EW polar
NS polar
number of events
NS horizontal component of EAS axis
EW horizontal component of EAS axis
-1.0
-0.5
0.0
0.5
1.0
0
10
20
30

Antenna theory

Antennas in radio astronomy and telecom are most often described by **power** related quantities (gain & directivity, beam pattern, Stokes parameters, etc…)

They also can be described by (far) **field** related quantities, all of them being expressed in terms of **antenna effective height** (Sinclair, 1950)

$$\vec{h}(\vec{k}) = \frac{1}{I_0} \int \vec{j}(\vec{r}) e^{-i\vec{k}\vec{r}}\, d\vec{r}$$

where :
$$\begin{cases} \vec{j}(\vec{r}) \equiv \text{antenna current density on the antenna} \\ \vec{k} \equiv \text{wave vector} \\ I_0 \equiv \text{driving current} \end{cases}$$

$\vec{h}$ is a constant real vector in the quasi-static frequency range (short dipole of length $L = 2\|\vec{h}\|$) but, in general, **is <u>complex</u> and depending on <u>both</u> frequency and direction** (Macher, PhD, 2008).

Electric field orientation (i.e. polarisation)

The antenna can be modeled as (actually is !) a linear filter of which the impulse response is the antenna effective height:

$$V(t) = (\vec{\boldsymbol{h}} * \vec{E})(t) = \int \vec{\boldsymbol{h}}(t - t') * \vec{E}(t')dt'$$

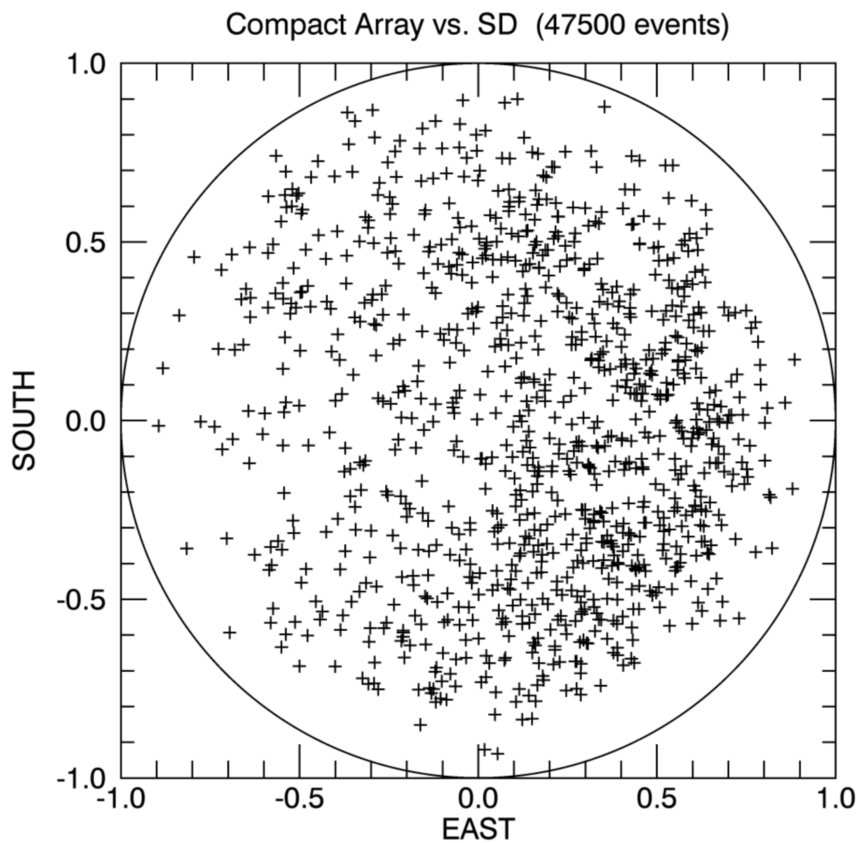
or, in frequency domain :

$$V(\omega) = \vec{\boldsymbol{h}}(\omega)\vec{E}(\omega)$$

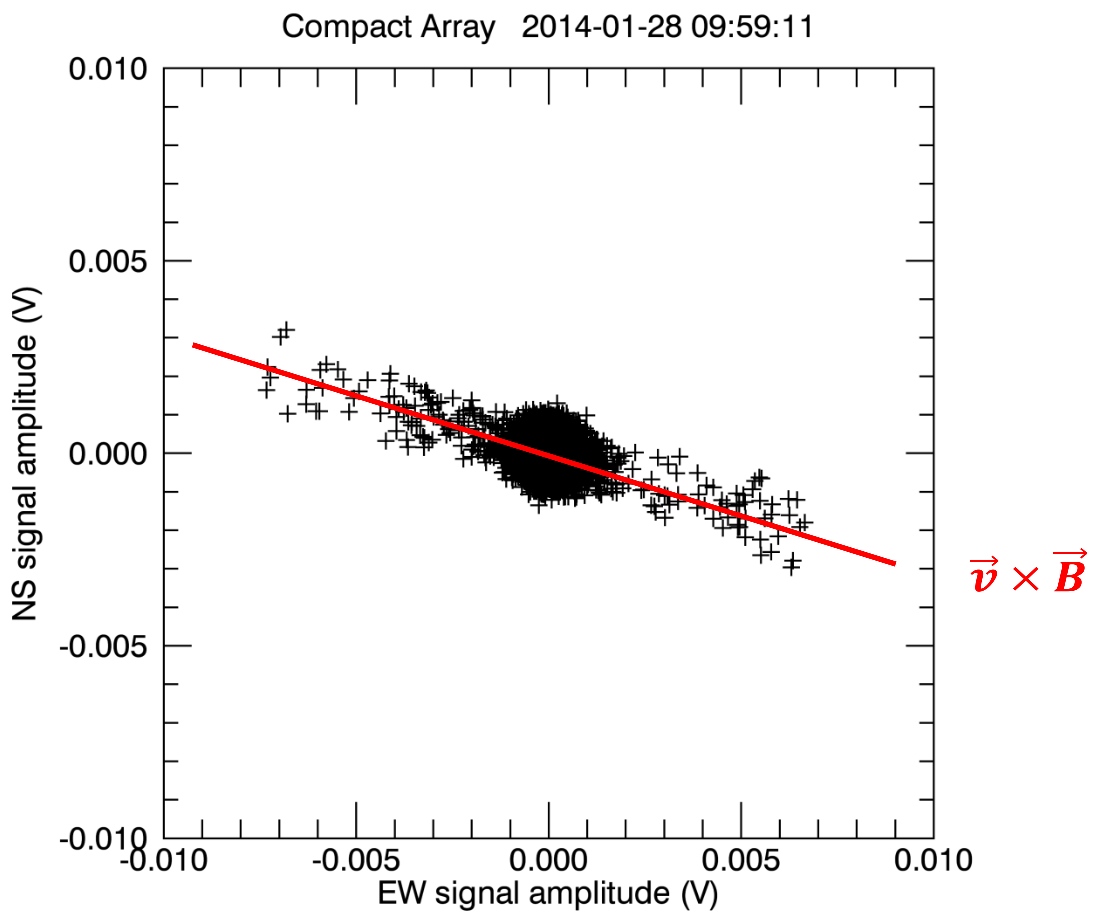
assuming identical antennas along EW and NS directions (i.e. same $\vec{\boldsymbol{h}}$ within a 90° rotation around vertical axis):

$$V_{EW} = h\, E \sin\alpha$$
$$V_{NS} = h\, E \cos\alpha$$

$$\boxed{\alpha = \tan^{-1} V_{EW}/V_{NS}}$$

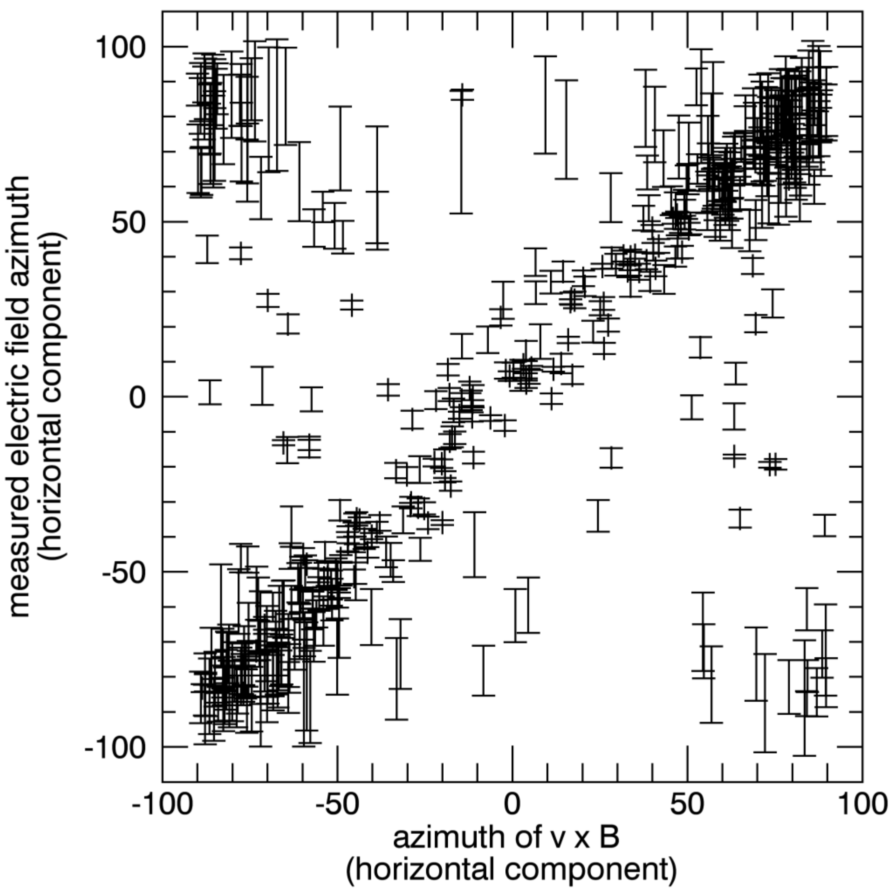

Compact Array vs. SD (47500 events)
1.0
0.5
0.0
-0.5
-1.0
SOUTH
-1.0
-0.5
0.0
0.5
1.0
EAST

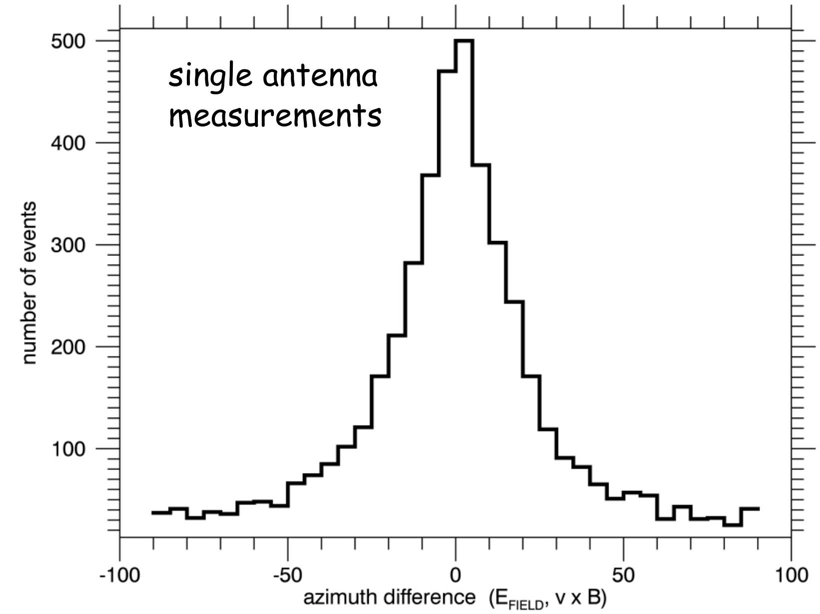
Electric field orientation

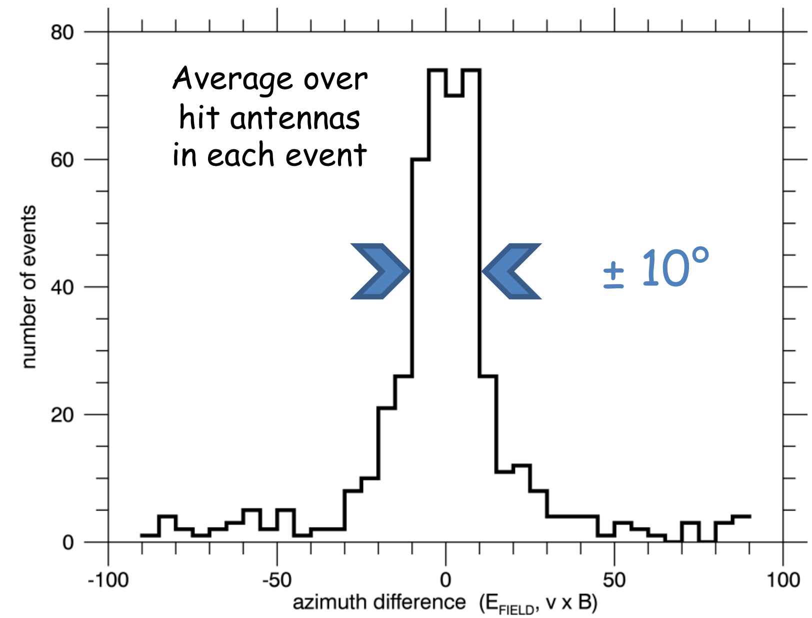


Measured vs. predicted polarisation for "charge separation" mech. : $\vec{E}_{\parallel} \parallel (\vec{v} \times \vec{B})_{\parallel}$

~400 processed events







Solving the sensitivity problem

Beamforming of N antennas :

individual waveforms : $\{x_j(t)\}_{j=1..N}$

synthesize : $y(t) = \sum_{j=1}^{j=N} x_j\left(t - \tau_j\right)$

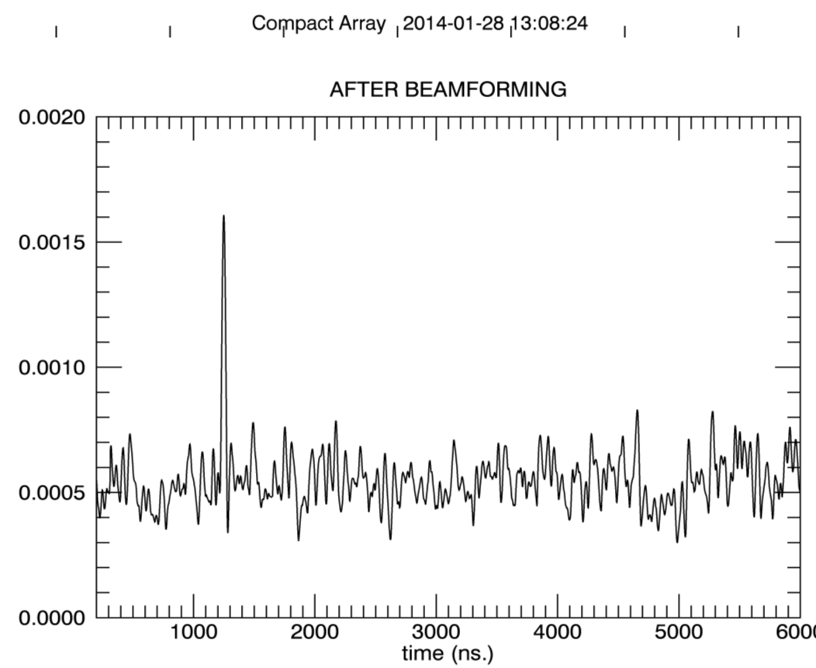
where : $\tau_j = \left(\vec{u} \cdot \vec{r}_j\right)/c$

in Fourier domain : $Y(\omega) = \sum_{j=1}^{j=N} X_j(\omega)\, e^{i\omega\tau_j}$

$\rightarrow$ SNR increased by a factor $\sqrt{N}$

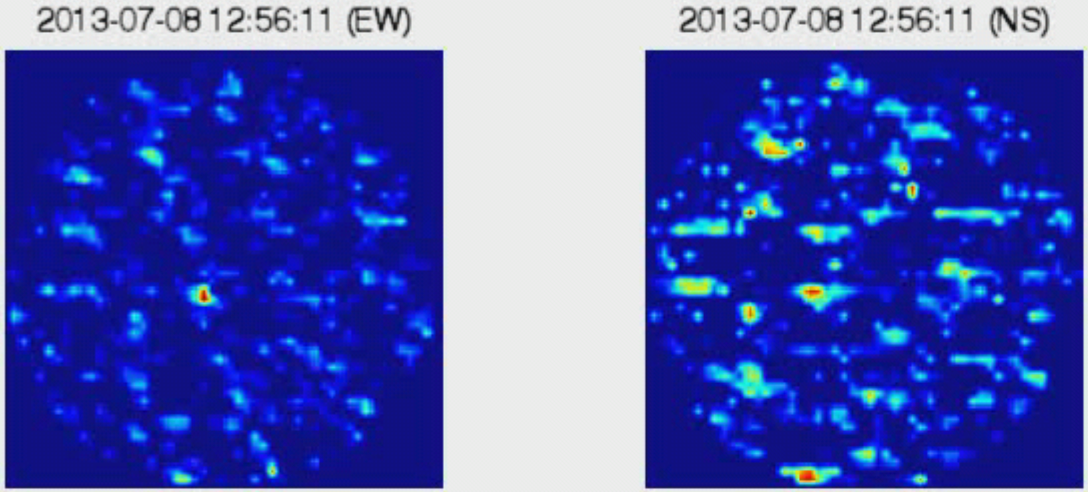
time (ns.)

this one is much more difficult to detect …



Possible self detection scheme:

- in order to avoid (natural and man made) transient noise: i.e. lightnings, electric/electronic devices, etc…
- continuous sampling (F_S=100 MHz, BW=50 MHz) of selected antenna output, stored in a ring buffer (F_S=100 MHz, BW=50 MHz)
- pre-conditioning:
  - Fourier transform each channel
  - additional band pass filtering as needed
  - synthesize circularly polarised channel (by using complex analytic representation of each pair of linear channel (software) or by using a wideband quadrature hybrid circuit (hardware).
  - compute signal envelop
- for each successive time-window corresponding to the array time aperture (500 ns.):
  - generate ~2000 beams in sky (~2° apart) via beamforming.
  - search for beam(s) containing signal above some intensity threshold
  - TBD: additional criteria (e.g. rise time, known RFI direction, etc…)
- feasibility ?
  - 8 channels x 100 Msamples/sec. ~ 1 Gsamples/sec.
  - using CPU+GPU :
    - software presently developed on NVIDIA C1060, 0.6 Tflops
    - final version will use NVIDIA K20, 5 Tflops


2013-07-08 12:56:11 (EW)
2013-07-08 12:56:11 (NS)