Denoising cosmic rays radio signal using Wavelets techniques

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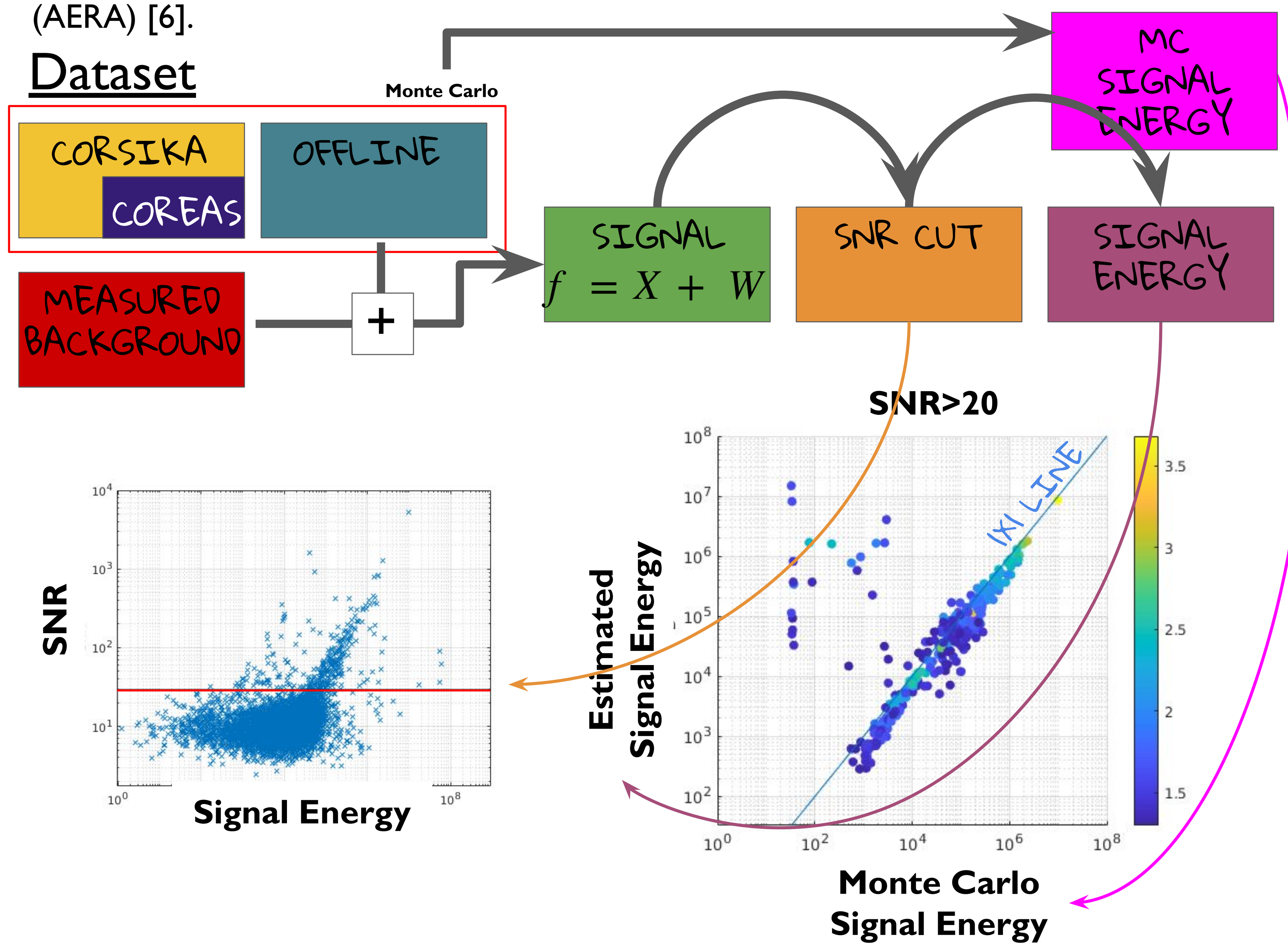
Introduction & challenge

Radio-detection of a cosmic ray is a modern, well established, and low-cost technique that uses antennas to detect the electromagnetic component of the air shower.
The community expects improvements on the accuracy of the primary particle energy, mass, and arrival direction [1]. **The challenge:**

Background reduction be it Gaussian or Impulsive

This work presents the Stationary Wavelet Transform (SWT) efficiency, for denoising cosmic-ray induced radio signals of a simulated dataset of realistic events using the Offline [5] reconstruction framework to apply the antenna and analog chain response and measured background from the Auger Engineering Radio Array (AERA) [6].

Dataset



An overall hard cut on data is roughly above the red line (**SNR** >20), where it is expected a linearity between the **SNR** of the trace and its energy. Such events roughly have a compatible reconstruction with the Monte Carlo signal energy.

Can we improve the SNR of the signal with the wavelet technique?

Wavelets

The *wavelet transform* computes the correlation between a signal *f* and the orthogonal basis of a *wavelet mother* [4].

$$\langle f, \varphi_{n,j} \rangle = \int f(t)\, \varphi_{n,j} \mathrm{d}t$$

where *f* is given by the pure signal (X) plus noise (W).

And the wavelet mother on a discrete domain is defined as

$$\varphi_{n,j} = \frac{1}{\sqrt{2^j}} \varphi\left(\frac{t - n2^j}{2^j} \right)$$

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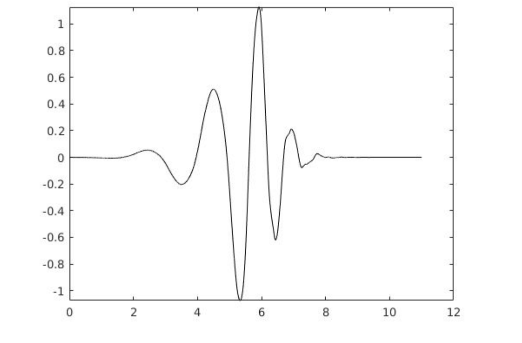
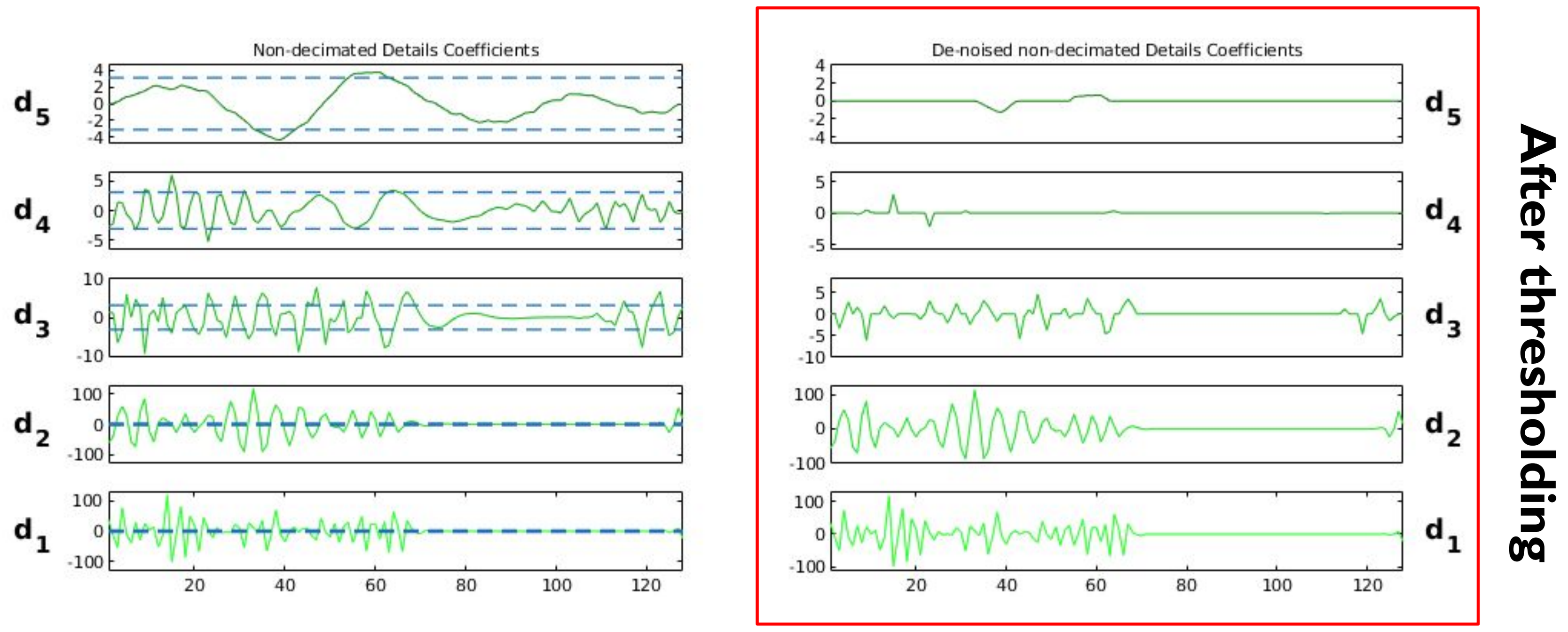


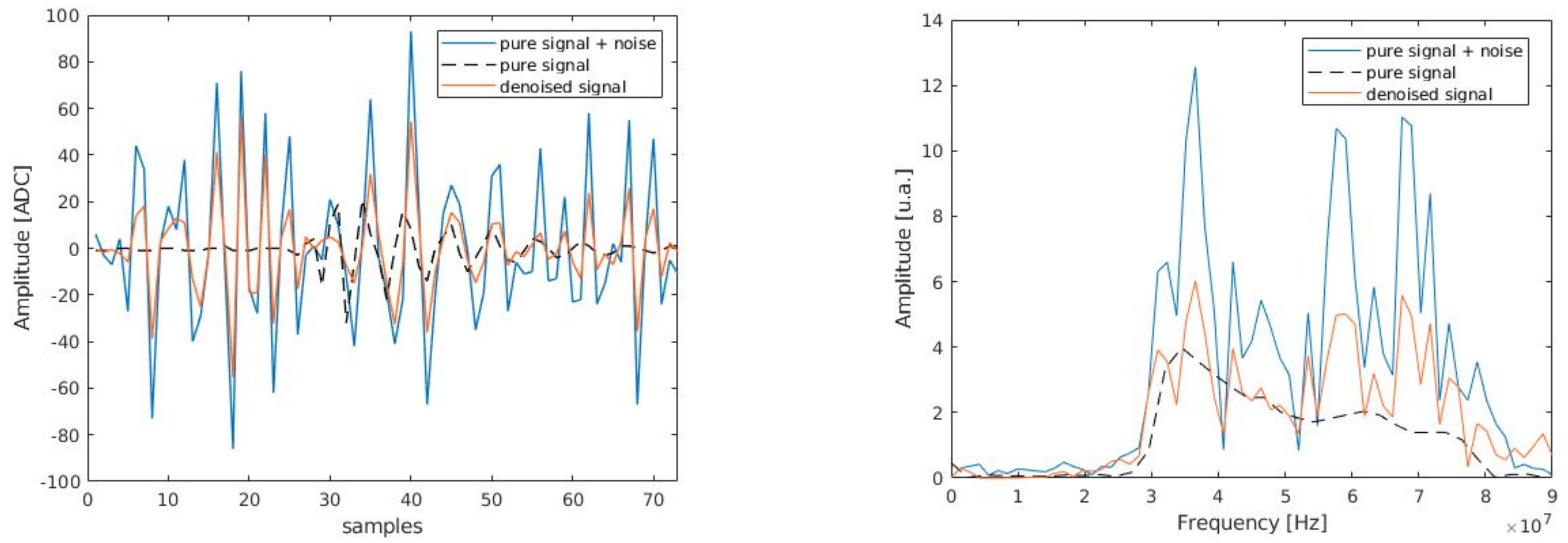
This correlation is given by coefficients, where each level represents a different "wavelength" of the wavelet mother and we may apply a threshold in each level.



Applying the threshold function on the coefficients we may reconstruct the signal again

$$f(t) = \sum_{j,n} d_j \langle f, \varphi_{n,j} \rangle \varphi_{n,j}$$

where d_j is a threshold function called *soft threshold* [4].

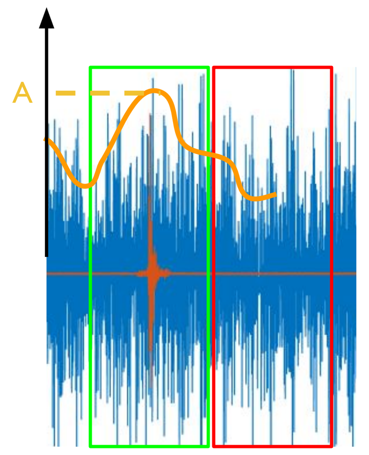


AERA signal-to-noise ratio (SNR)

The SNR definition in the AERA experiment is

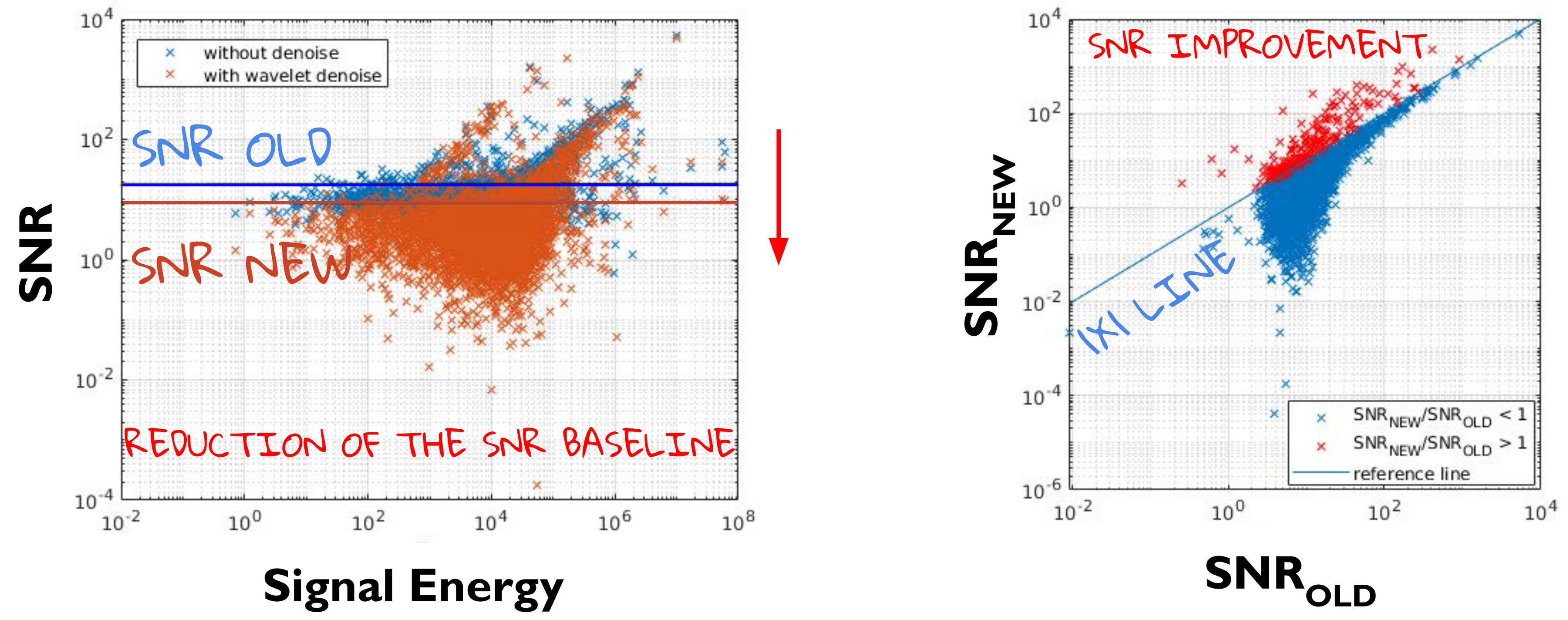
$$SNR = \frac{A^2}{RMS^2_{bck}}$$

where A is the maximum value of the Hilbert Envelope in the "signal window" and $\mathbf{RMS}_{bck}$ is the *root-mean-square* of the "background window"

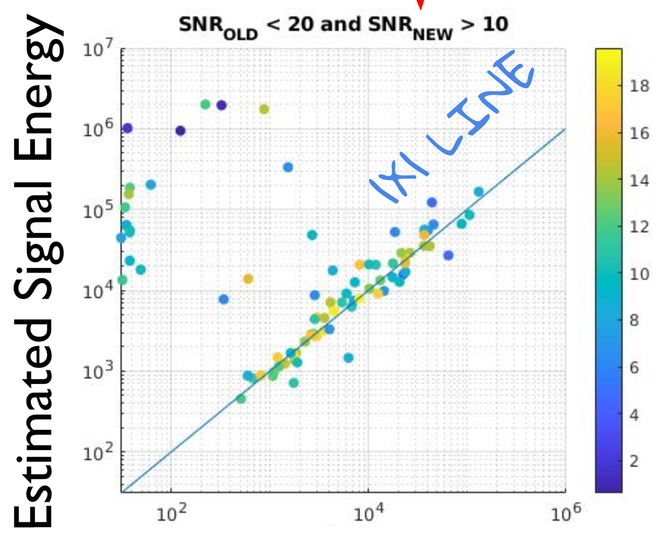


Results

Improvement is in the selection of traces based on their **SNR**. This analysis looks explicitly for traces with improved **SNR**.



This dataset consists in 344 simulated showers, which had 14239 valid traces. Using the $\mathbf{SNR}_{old}$>20 criteria we select 677 reliable traces, using the wavelet method with r > 1. $\mathbf{SNR}_{new}$>10 and $\mathbf{SNR}_{old}$<20 we recover 86 additional traces. This implies an improvement of **~13%** of the number of reliable traces. Those recovered traces have roughly a correct estimation of the signal energy of the radio signal.



Acknowledgments

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References

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