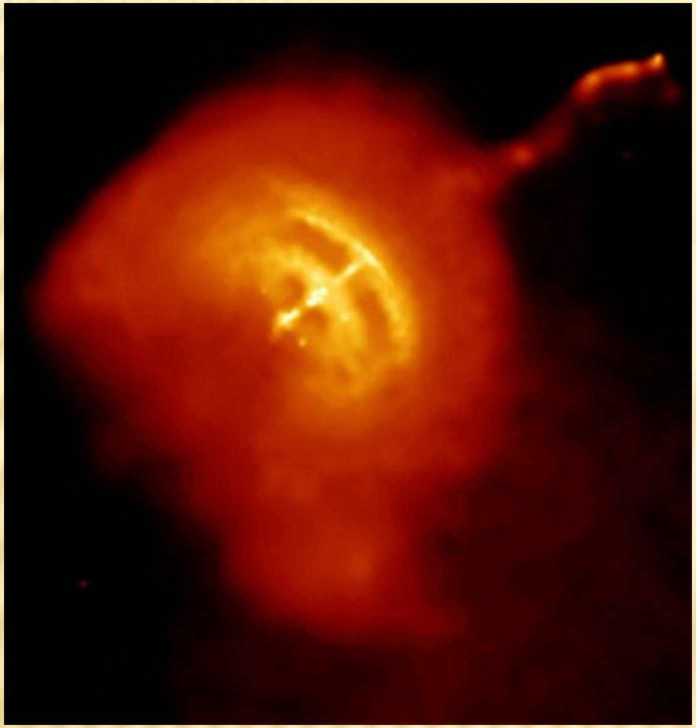
THE SEARCH FOR VELA PULSAR IN VIRGO VSR1 DATA

S.Frasca on behalf of LSC-Virgo collaboration

New York, June 23rd, 2009

G0900712-v1

THE VELA PULSAR



Right ascension: 8h 35m 20.61149 s
Declination: -45º 10' 34.8751 s
Period: ~89.36 ms
Distance: 290 pc

Glitch occurred between day 24 July and 13 August of 2007

Ephemerides supplied by Aidan Hotan and Jim Palfreyman using the Mt. Pleasant Radiotelscope (Hobart, Tasmania) (period 25 Aug – 6 Sept)

Spin-down limit: 3.3e-24
Presumed ψ=131º, ı=61º (ε=0.51)

G0900712-v1

THE DATA USED

- The selected Virgo data are from 13 Aug 2007 6:38 to the end of the run (1 October)
- Ephemerides, given for the period 25 August – 6 September, were extrapolated

- The same data have been used also for a similar search by the POLGRAW group led by A.Krolak

THE SOURCE AND THE ANTENNA

For a gravitational wave described by

$$\mathrm{h}(t) = h_0 \cdot \left(\mathrm{e}_{\oplus} \cdot \kappa_+ + \mathrm{e}_{\otimes} \cdot \kappa_\times \exp\left(j\varphi \right) \right) \cdot \exp\left(j\omega_0 t \right)$$

$$\kappa_+^2 + \kappa_\times^2 = 1$$

where the two κ are real positive constants. The response of the antenna is

$$h(t) = h_0 \cdot \left(A_+ \cdot \kappa_+ + A_\times \cdot \kappa_\times \exp\left(j\varphi \right) \right) \cdot \exp\left(j\omega_0 t \right)$$

with

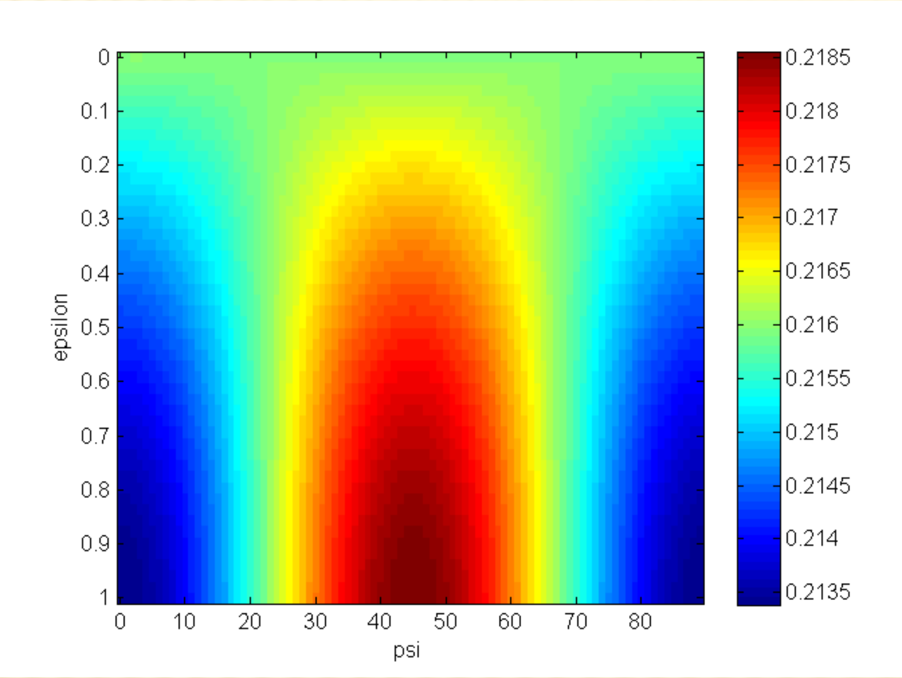
$$A_+ = a_0 + a_{1c} \cdot \cos\left(\Omega \cdot t\right) + a_{1s} \cdot \sin\left(\Omega \cdot t\right) + a_{2c} \cdot \cos\left(2 \cdot \Omega \cdot t\right) + a_{2s} \cdot \sin\left(2 \cdot \Omega \cdot t\right)$$
$$A_\times = b_{1c} \cdot \cos\left(\Omega \cdot t\right) + b_{1s} \cdot \sin\left(\Omega \cdot t\right) + b_{2c} \cdot \cos\left(2 \cdot \Omega \cdot t\right) + b_{2s} \cdot \sin\left(2 \cdot \Omega \cdot t\right)$$

where the constants *a* and *b* depend on the position of the source and of the antenna.

So the whole information on a signal (and on the noise) is in 5 complex numbers.

THE SOURCE AND THE ANTENNA

Energy of the wave that goes into the antenna, for all types of waves from Vela



If we describe the wave with an elliptical polarization of semi-axes *a* and *b* normalized such that $\sqrt{a^2+b^2}=1$ we have (being $a \geq b$)

$$\varepsilon = a - b$$

ψ is the polarization angle of the linearly polarized part.

G0900712-v1

SCHEME OF THE PROCEDURE

- Create the (cleaned) SFT data base (after this step all the analysis is done on a workstation with Matlab)
- Extract a 0.25 Hz band
- Reconstruct the time signal with the Doppler and spin-down correction
- Eliminate bad periods and disturbances
- Apply the “Noise Wiener filter”
- Simulate four basic signals
- Apply the 5 components matched filter
- Find the best source for the data
- Enlarge the analysis to the near frequencies

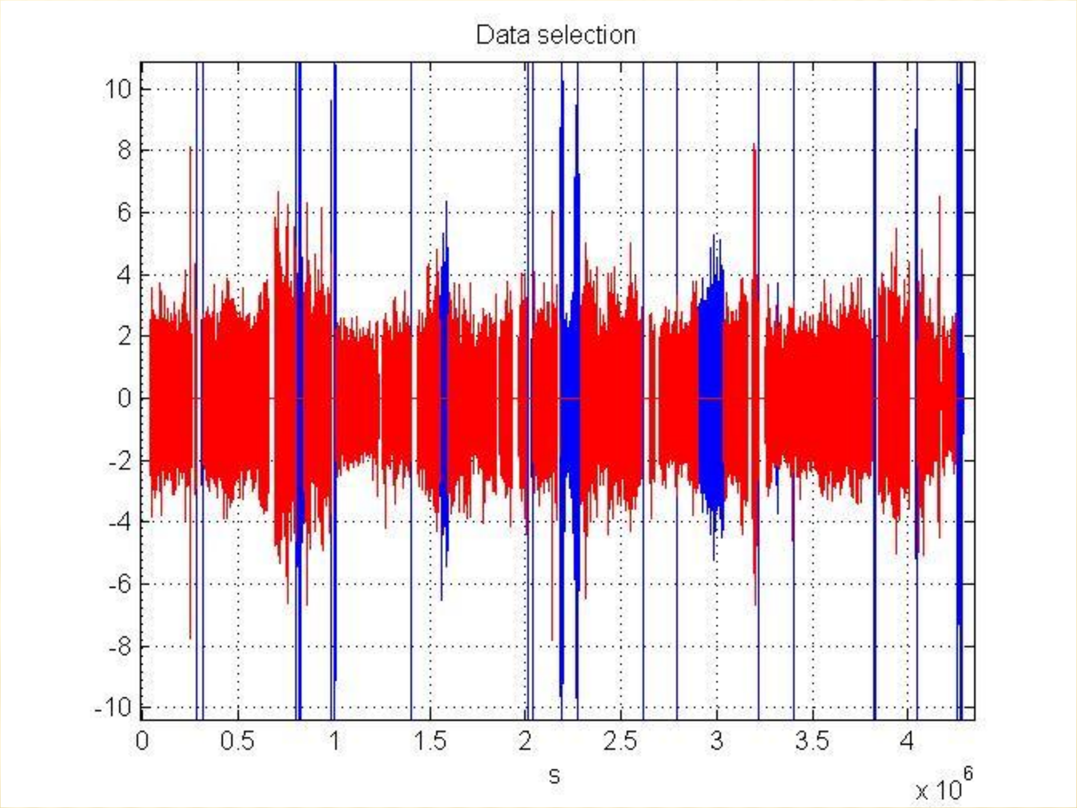
THE SFT DATA BASE

- Our Short FFTs are computed on the length of 1024 s and interlaced
- In our period we have about 7000 FFTs
- **Our h data are multiplied by 10^{20}**

BAND EXTRACTION AND TIME DATA RECONSTRUCTION

- The data of the SFTs in the band 22.25~22.50 are extracted in a single file of about 15 MB
- From these we reconstruct a time series with 1 Hz sampling time (and zero where there are holes), correcting for the Doppler effect and the spin-down. We obtain data with “apparent frequency” 22.38194046 Hz.

DATA SELECTION



"NOISE WIENER FILTER"

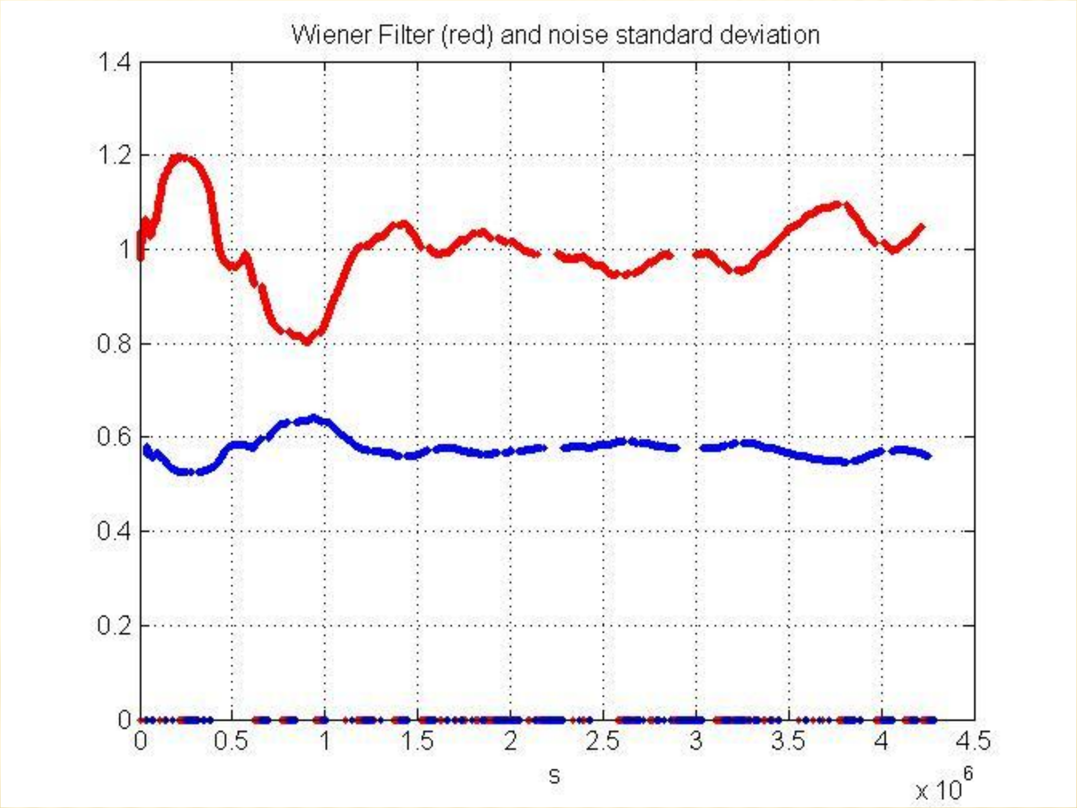
- The data are not stationary, so the sensitivity of the antenna is not constant in the observation period. To optimize for this feature we introduced the "Noise Wiener Filter" as

$$W(t) = \frac{T_0}{\int_0^{T_0} \frac{1}{\sigma^2(t)} \cdot dt} \cdot \frac{1}{\sigma^2(t)}$$

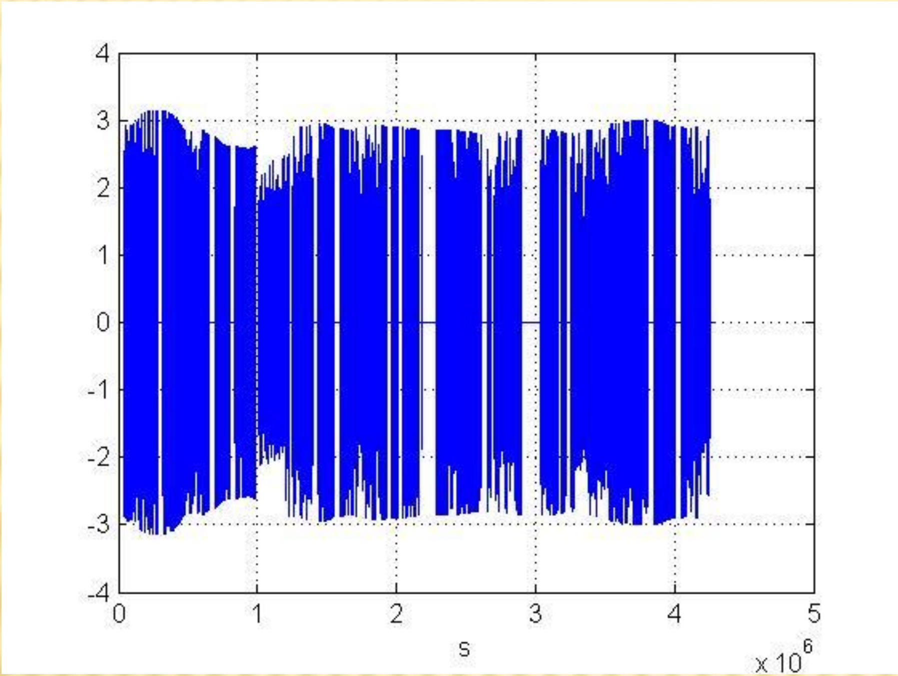
where $\sigma^2(t)$ is the slowly varying variance of the data.

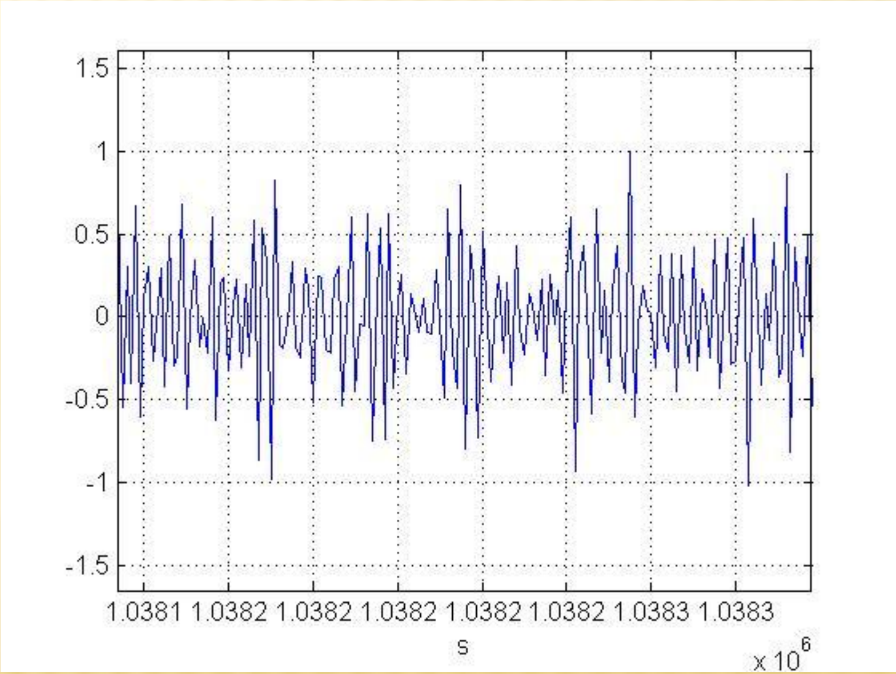
W(t) multiplies the time data.

NOISE WIENER FILTER

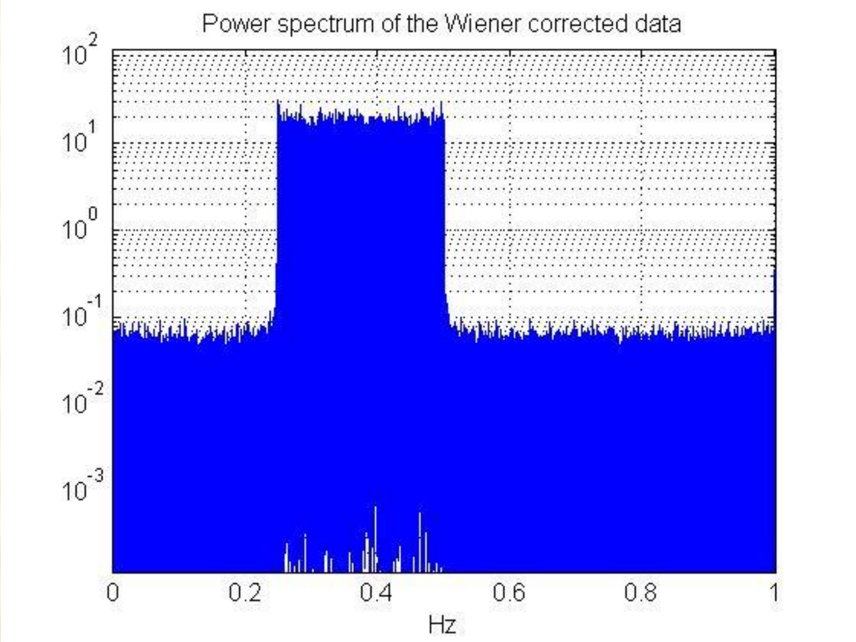


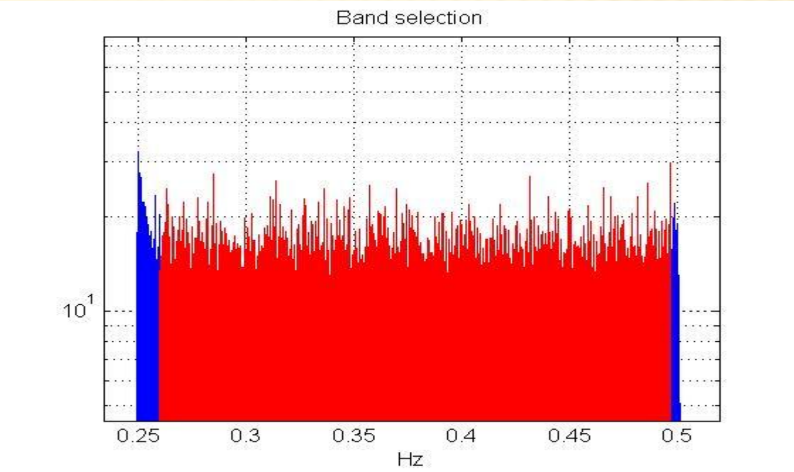
WIENER FILTERED DATA (CLIPPED)

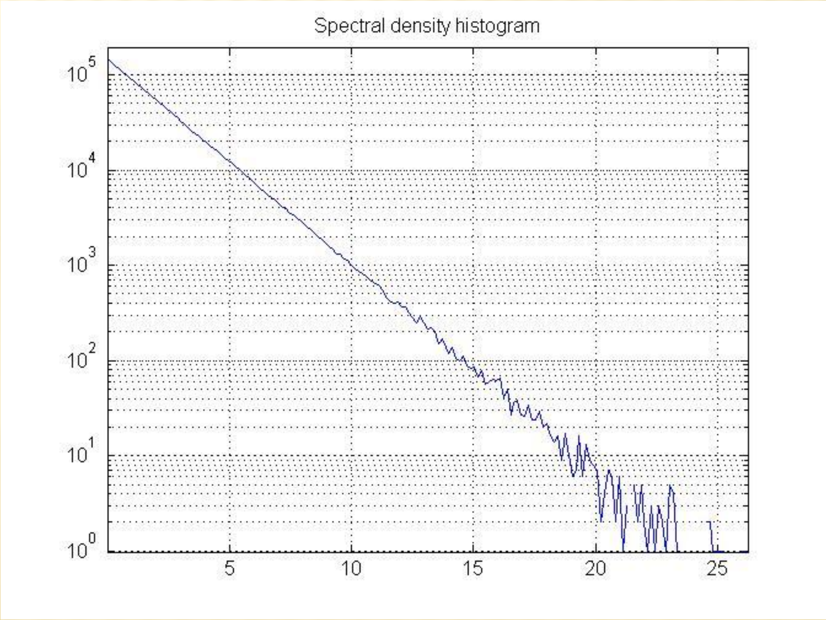




SPECTRUM OF THE SELECTED DATA
(AFTER THE NWF)







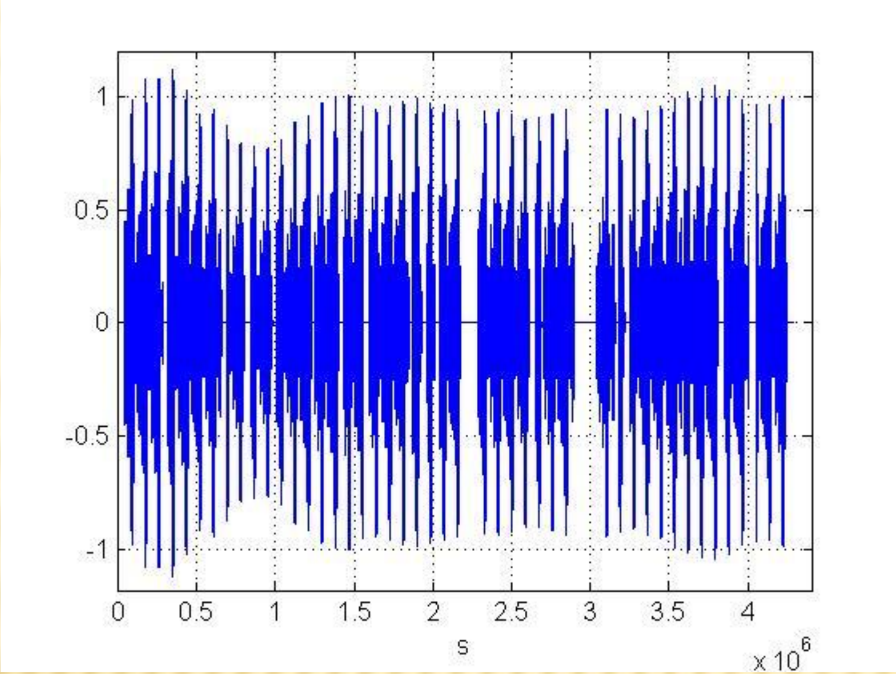
Full band (1 Hz), selected part and histogram of the Wiener filtered data power spectrum.

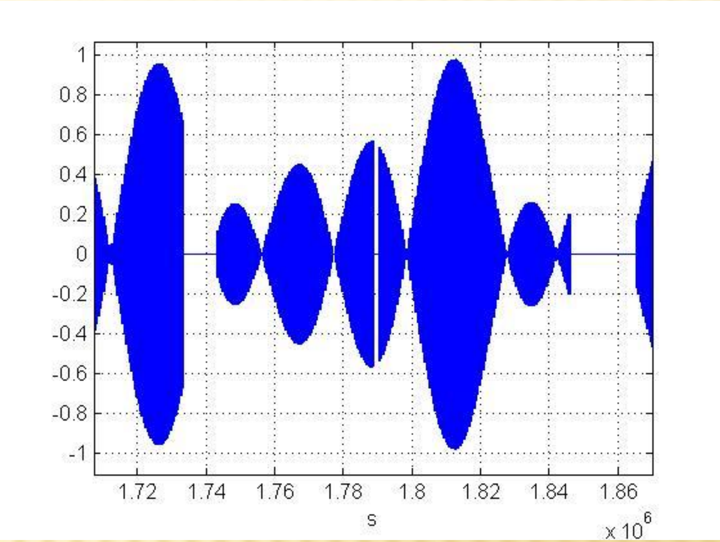
Spectrum : $\mu = 2.0063$, $\sigma = 2.0070$
selected about 2 million spectral data (resolution=2)

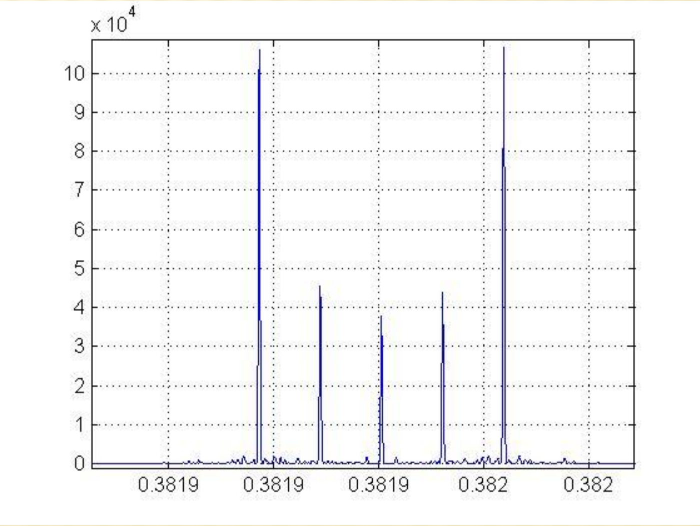
THE SIGNAL AND THE SIMULATIONS

- The same band extraction function is used to simulate the basic signals from Vela.
- The same Doppler and spin-down correction, the same cuts and the same Wiener filter, that we applied to the Virgo data, have been applied to the signals data.
- The simulated signals were the 2 linearly polarized signals and the 2 circularly polarized signals in both left and right rotation.
- The amplitude was $h_0=10^{-20}$.

SIMULATED SIGNALS
(LINEARLY POLARIZED SIGNAL, Ψ=0)







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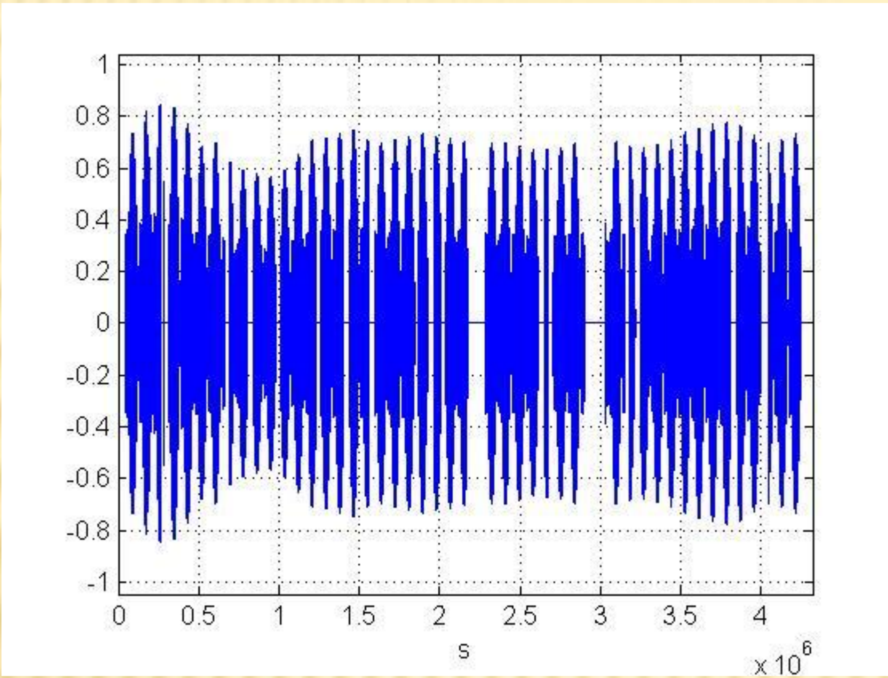
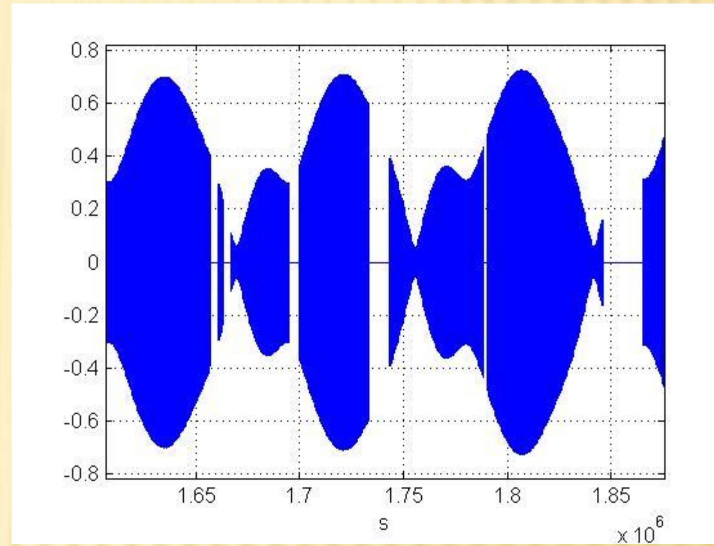
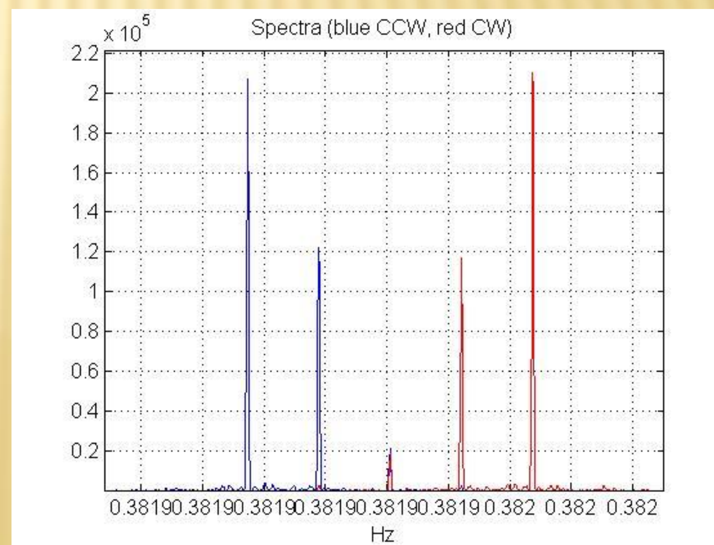
SIMULATED SIGNALS
(CIRCULARLY POLARIZED SIGNAL)







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THE MATCHED FILTER

- As it is well known, the signal contains only the 5 frequencies f_0, $f_0 \pm F_s$ and $f_0 \pm 2F_s$, where f_0 is the (apparent) frequency of the signal and F_s is the sidereal frequency. So we can consider only the components of the signal and of the noise at that frequencies, that means 5 complex numbers. For two signal that differ only in phase, these 5 numbers are all multiplied for the same complex coefficient $e^{j\varphi}$.
- The basic idea of the 5-components matched filter is that the best way to detect a signal **s** (bold means a quintuplet of complex numbers) in a signal+noise combination

$$\mathbf{d} = A\,\mathbf{s} + \mathbf{n}$$

we do the estimation of the complex number $A = A_0\, e^{j\varphi}$ as

$$\hat{A} = \boldsymbol{d} \cdot \frac{\boldsymbol{s}'}{|\boldsymbol{s}|^2}$$

where **s**' is the complex conjugate.

We obtain the 5-components for any signal from the simulated basic signals, that has been treated exactly as the data.

It is convenient to consider the squared value of the estimated A_0; in this case, in absence of signal, we have an exponential distribution.

G0900712-v1

THE COHERENCE

- For each evaluation of the matched filter we compute also the squared coherence of the estimated signal with the data as

$$c = \frac{\left|A \cdot s\right|^2}{\left|d\right|^2}$$

where s and d are the signal and data quintuplets, as in the previous slide.

APPLICATION OF THE 4 BASIC MATCHED FILTERS

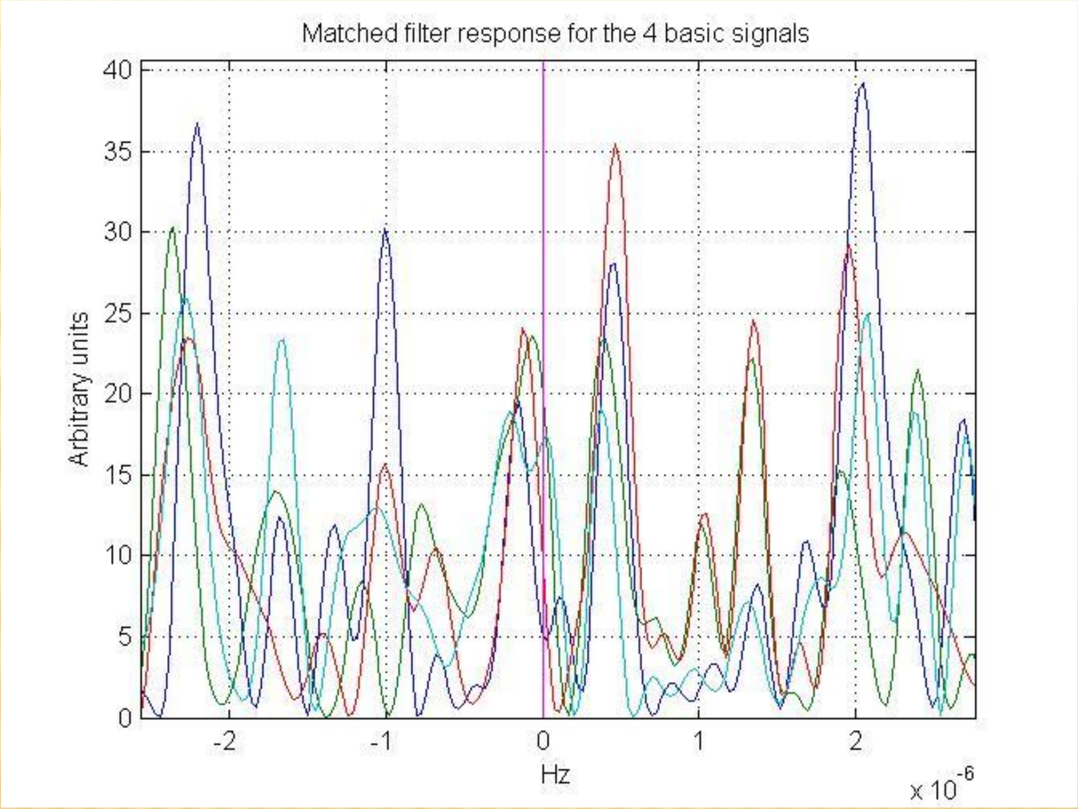
Squared output of the matched filter applied to the data and to all the signals

	Lin0	Lin45	CircCCW	CircCW	data
Lin0	1	0.002	0.454	0.454	
Lin45		1	0.550	0.550	
CircCCW			1	0.004	
CirdCW				1	
Data					1

Coherences for the above filters

	Lin0	Lin45	CircCCW	CircCW	data
Lin0	1	0.002	0.478	0.476	
Lin45		1	0.526	0.524	
CircCCW			1	0.005	
CirdCW				1	
Data					1

APPLICATION OF THE 4 BASIC MATCHED FILTERS: BACKGROUND



Blue: Linear ψ=0
Green: Linear ψ=45
Red: Circular CCW
Cyan: Circular CW

Mean Std Signal

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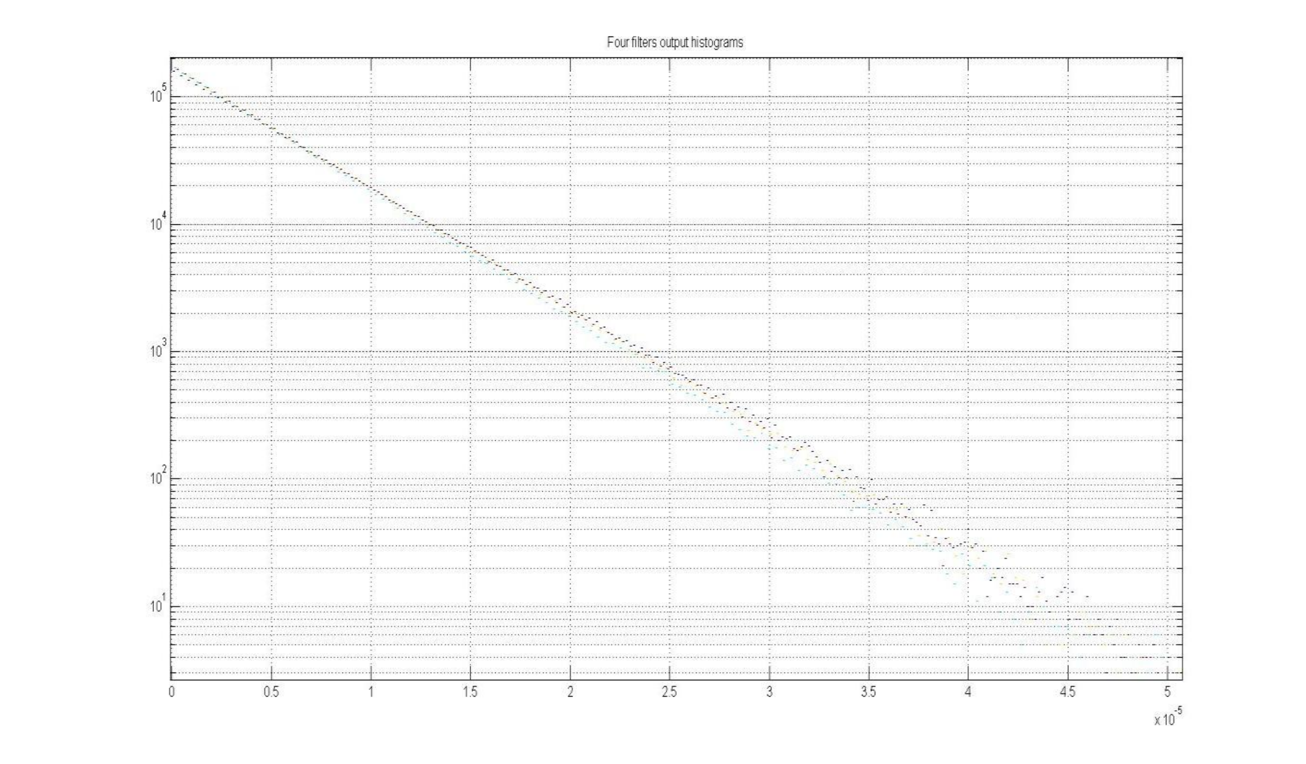
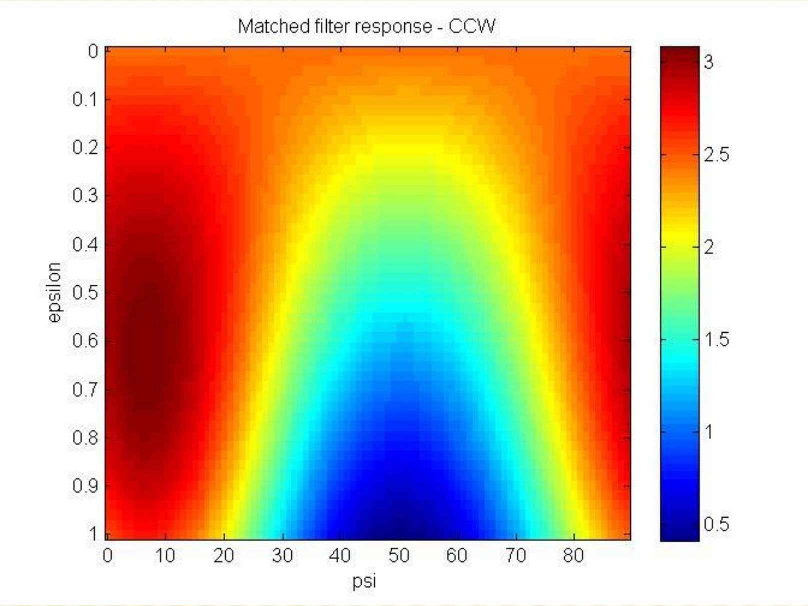
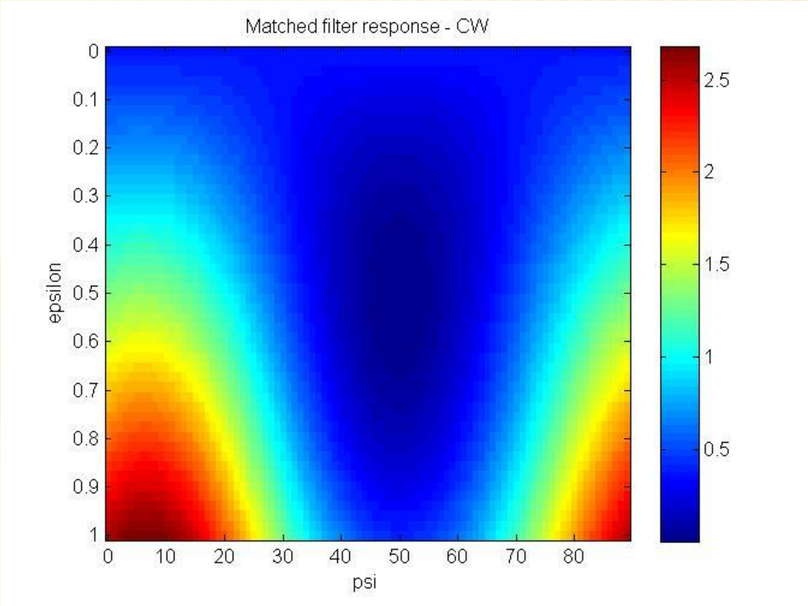
APPLICATION OF THE 4 BASIC MATCHED FILTERS: BACKGROUND



Histograms of the squared modulus of the 4 matched filters applied to the sub-band.

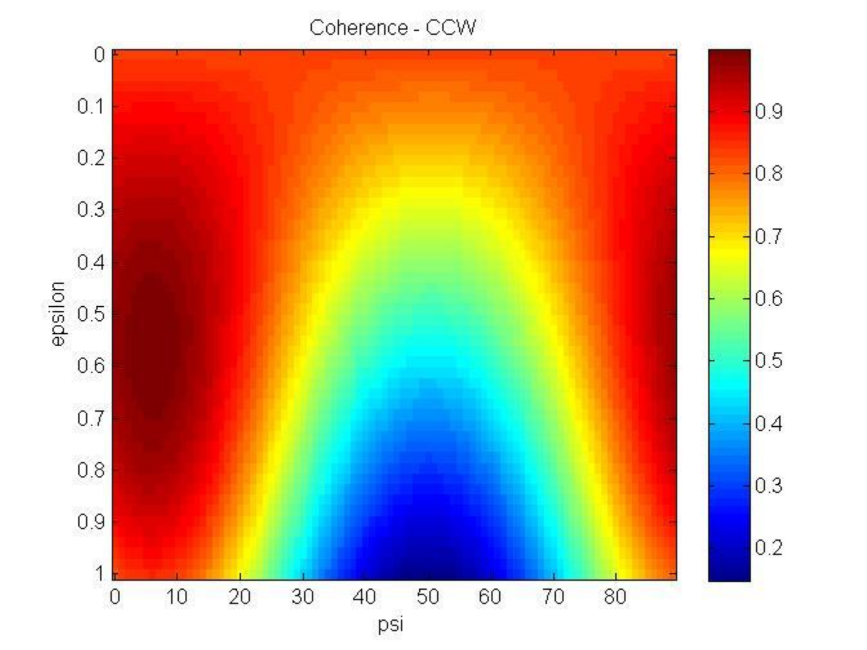
APPLICATION OF THE 4 BASIC MATCHED FILTERS: RESULTS FOR ALL THE SIGNALS

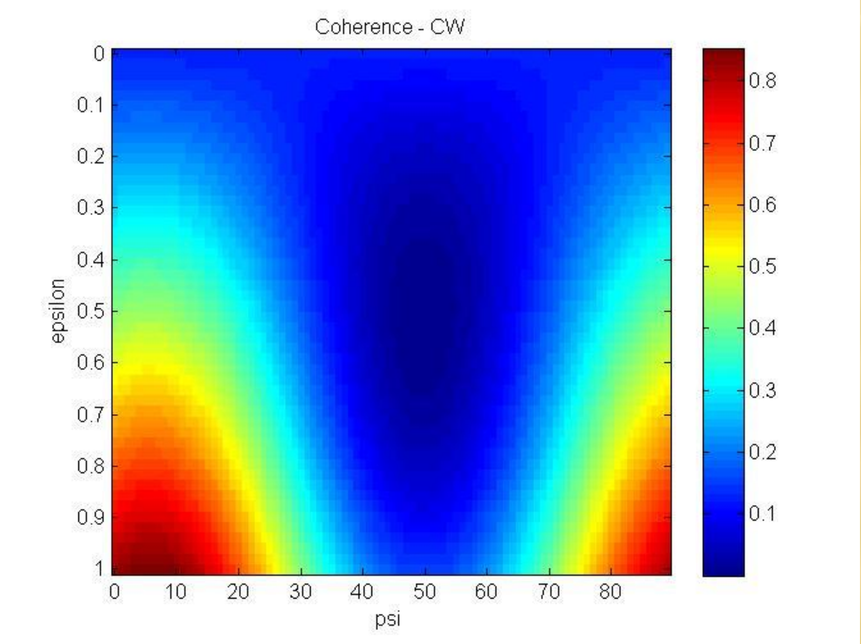




Fake signal

APPLICATION OF THE 4 BASIC MATCHED FILTERS: COHERENCE FOR ALL THE SIGNALS





Fake signal

For the maximum, the coherence is about

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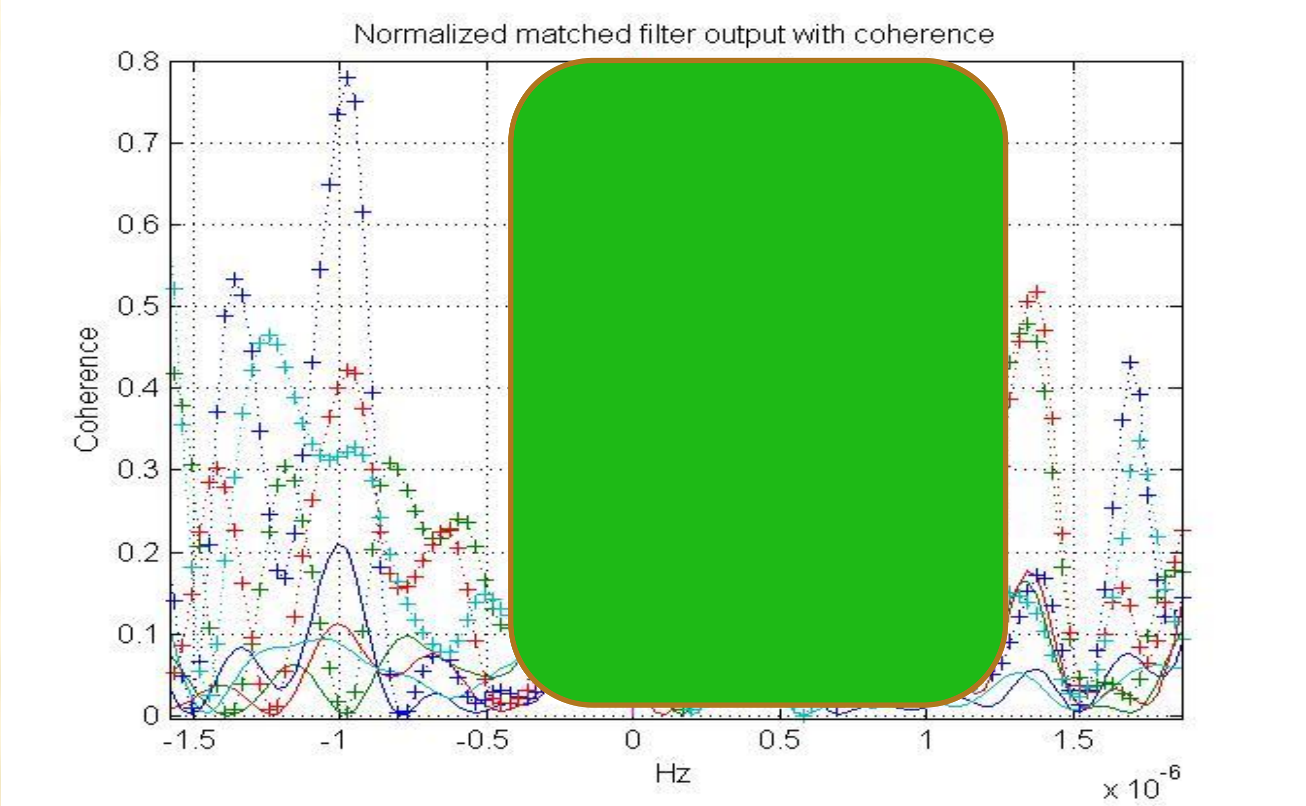
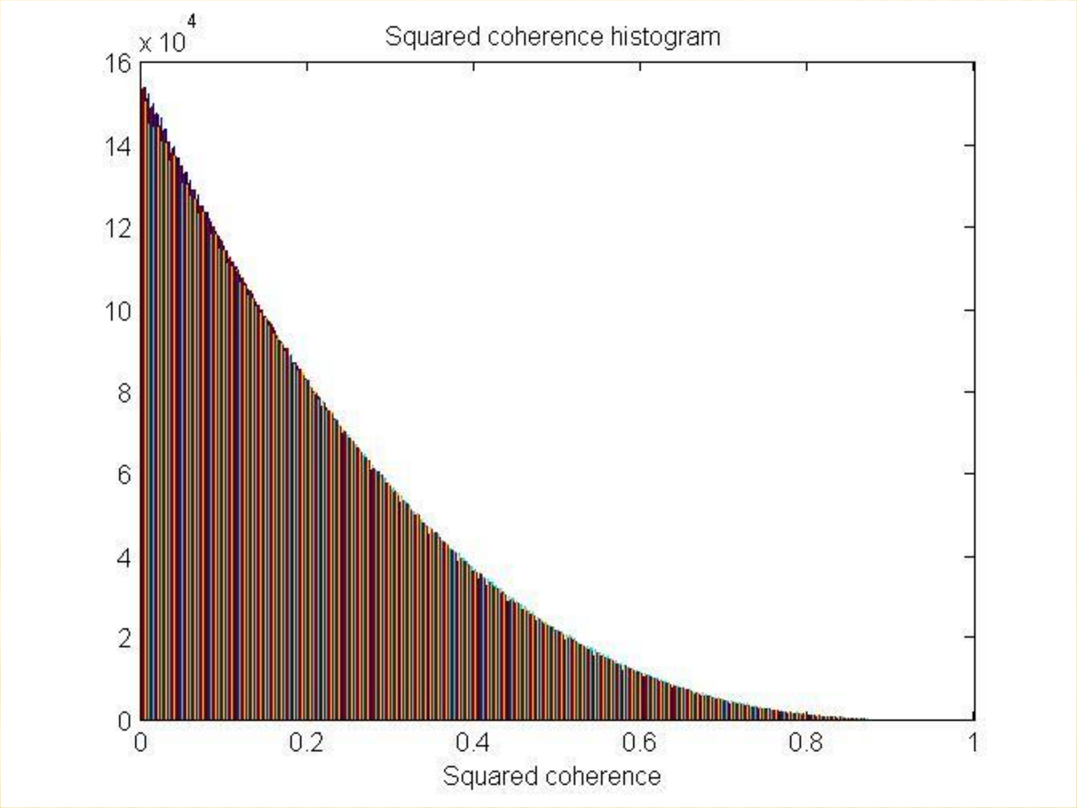
BROWSING AROUND
(ABOUT 8 MILLION FREQUENCIES IN 0.24 HZ)



Coherence (crosses) with normalized quadratic response of the 4 matched filters

COHERENCE DISTRIBUTION



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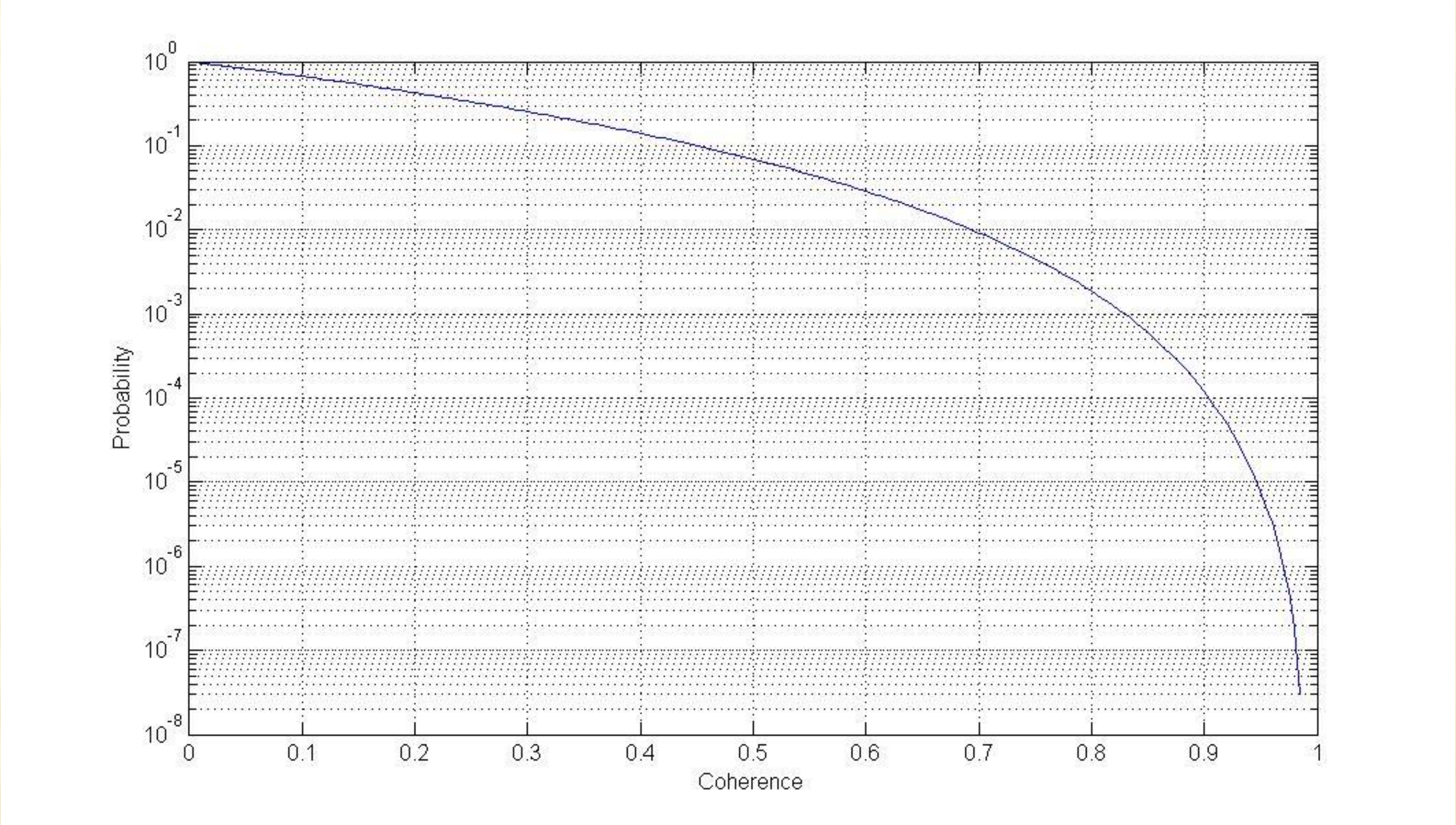
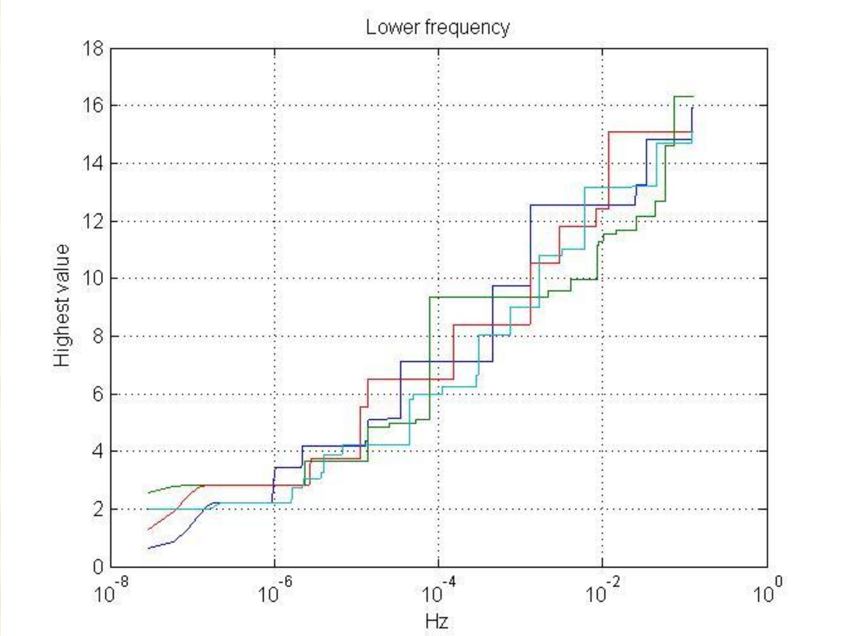
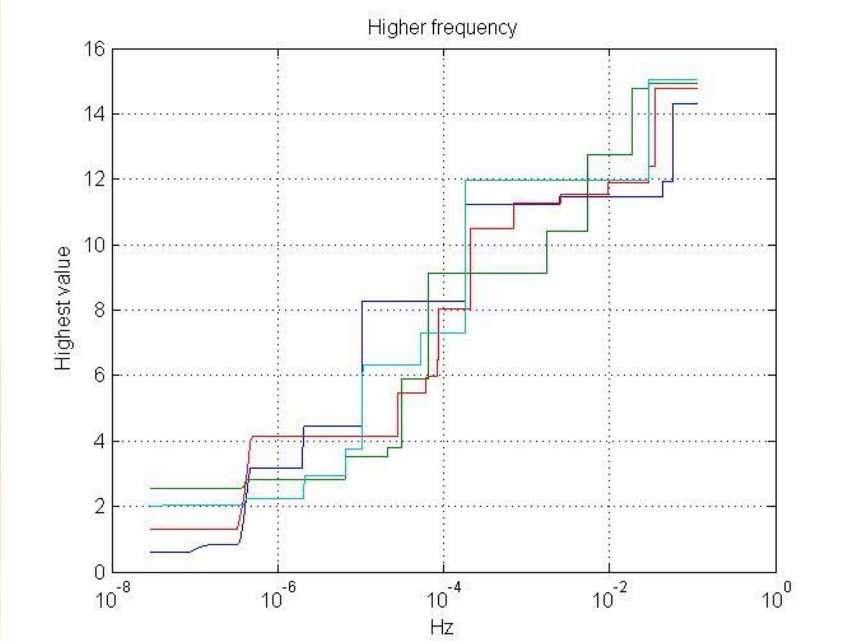
COHERENCE PROBABILITY



Probability to have a coherence bigger than a certain value.

BROWSING AROUND





The graph shows the maximum of the normalized absolute square of the 4 basic matched filters applied at frequencies near the apparent frequency. The abscissa is the distance from the apparent frequency.