Known source detection

Hardware & software injections

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4-May-2010

Outline of the procedure

(by Matlab, starting from our Short FFT database)

- Extraction of the band in a (single) sbl file
- Simulation of the two basic linear polarization signals (stored in sbl files)
- Reconstruction of the uniformly subsampled signal for the data, with correction of Doppler, Einstein effect and spin-down for the three signals (for data and simulations) – using the new resampling procedure
- Cleaning
- Parameter estimation.

Analyzed data

- Three hardware injections:

  Pulsar_2, Pulsar_3, Pulsar_4

- Three software injections, same as hardware, but 1 Hz more

- About 12 days of VSR2-v1 data (22-Sep -> 3-Oct)

New function pss_fd_resamp
(used by pss_bandrecos_strob)

- Our sfdb data have, for each sft, the position and velocity of the detector in SSB of the center sample
- The data are oversampled in order to have at least 8 samples for source period
- From these data we compute for each (high frequency) sample the SSB position (by interpolating with a 3rd degree polynomial)
- Also the Einstein effect and the spin-down are converted in delay and then in position
- The resampling is done very easily

Resampling procedure

The idea of resampling is the construction of a new time abscissa:

$$t' = t + \Delta t_{Dop}(t) + \Delta t_{SD}(t) + \Delta t_{Einst}(t)$$

with

$$\Delta t_{Dop}(t) = \frac{\Delta D(t)}{c} \qquad \Delta t_{SD}(t) = \frac{1}{\omega} \cdot \left(\frac{d_1}{2} \cdot t^2 + \frac{d_2}{6} \cdot t^3 \right) \qquad \Delta t_{Einst}(t) = -\int_0^t \Delta z(t) \cdot dt$$

Where D is the distance from the source, d_1 and d_2 are the first 2 spin-down parameters and z the gravitational redshift.

The strobo function

The function that does the resampling is easily

```
function [out iout]=strobo(x,tt,dtout)
tt=tt/dtout;
tt1=floor(tt);
ii=find(diff(tt1));
out=x(ii+1);
iout=round(tt(ii(1)));
```

where **x** are the oversampled data, **tt** is the new time abscissa t' and **dtout** is the output sampling time (1 s).

out are the output samples and **iout** the discrete abscissa

Programs and times (on my workstation)

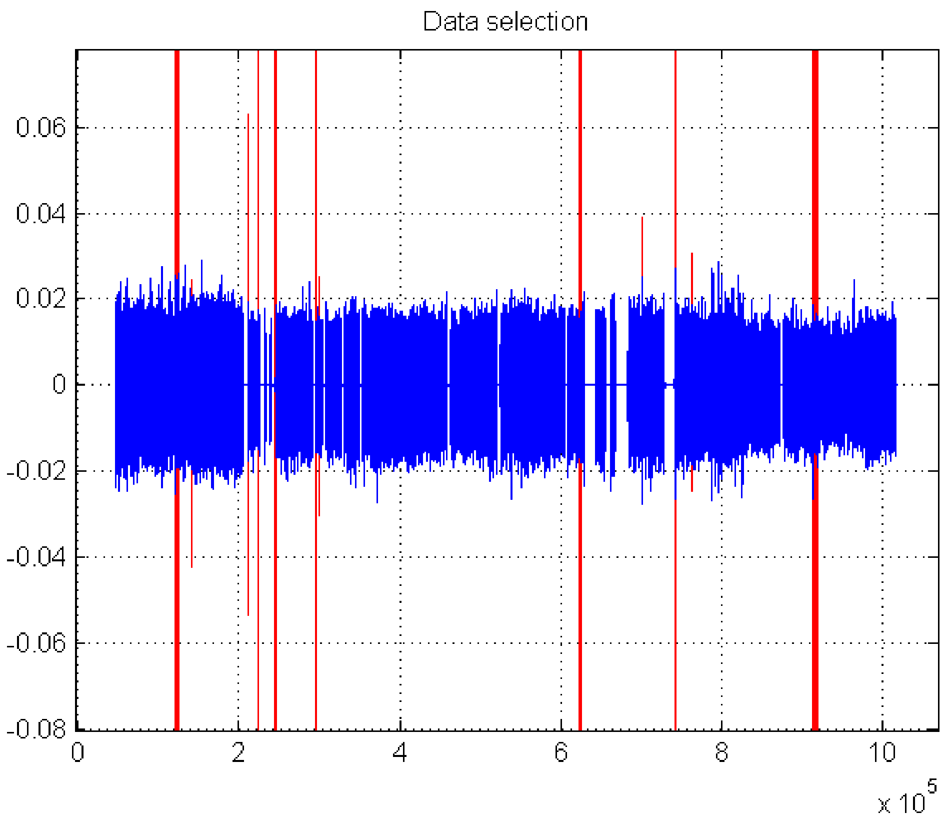
What	Function	Time
Band extraction	sfdb09_band2sbl	0.85 h
Simulation (1 signal)	sfdb09_band2sbl	0.85 h
Reconstruction(1 signal)	pss_band_recos_strob	0.85 ~ 2.28 h
Estimation	ana_kpsour	few seconds

The times are intended to process about 12 days.

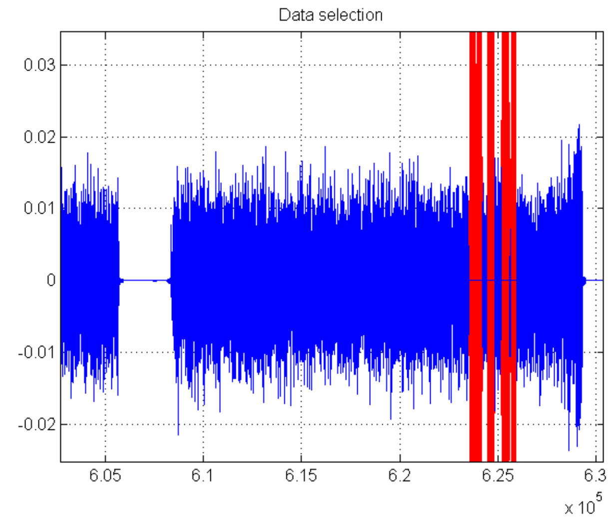
The resampling procedure is about 100 times slower than the preceding ones (pss_band_recos1 and pss_band_recos2), but

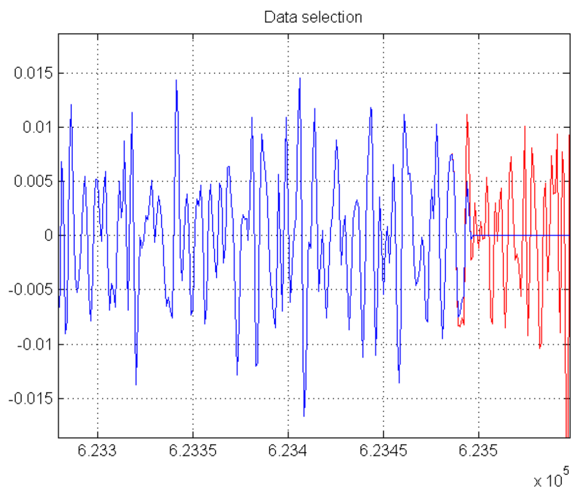
a) is much more precise
b) it is not limited to a very narrow band

Reconstructed data (pulsar_3)

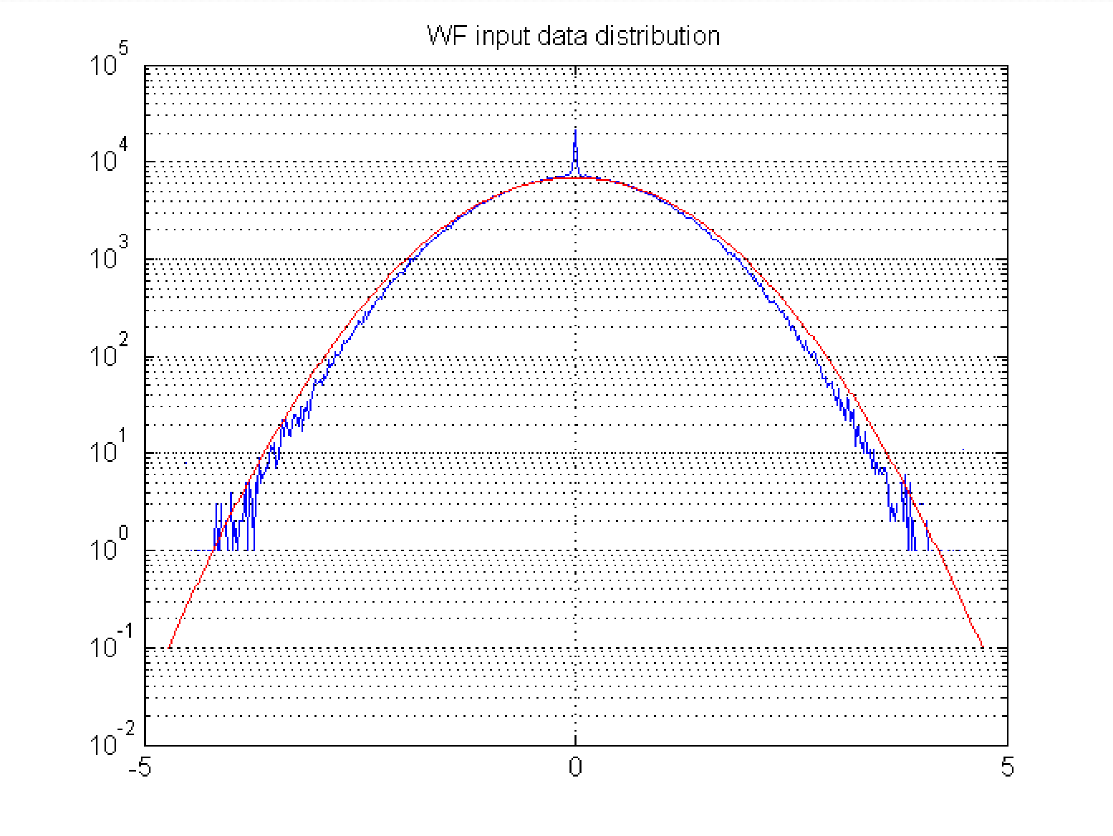


abscissa in s

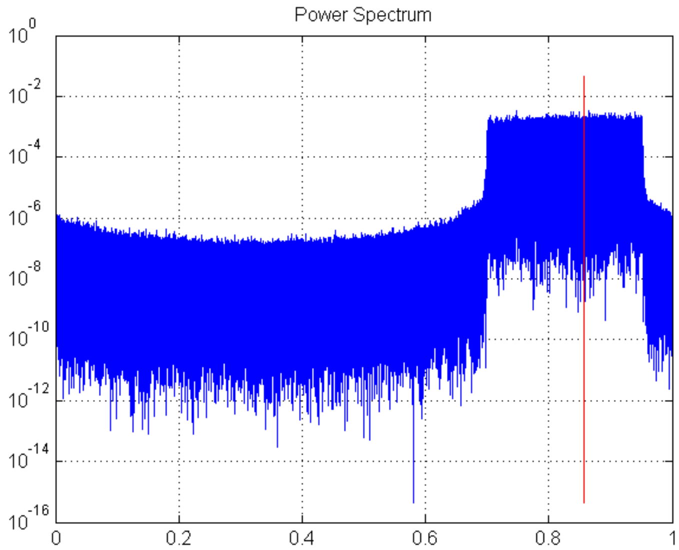


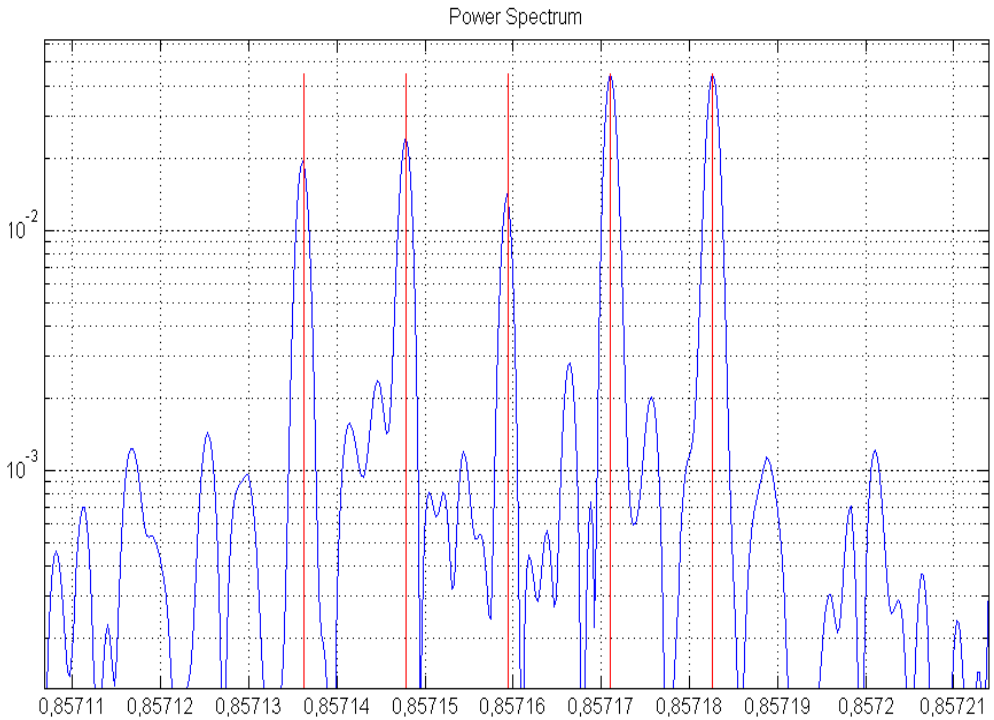


Data distribution

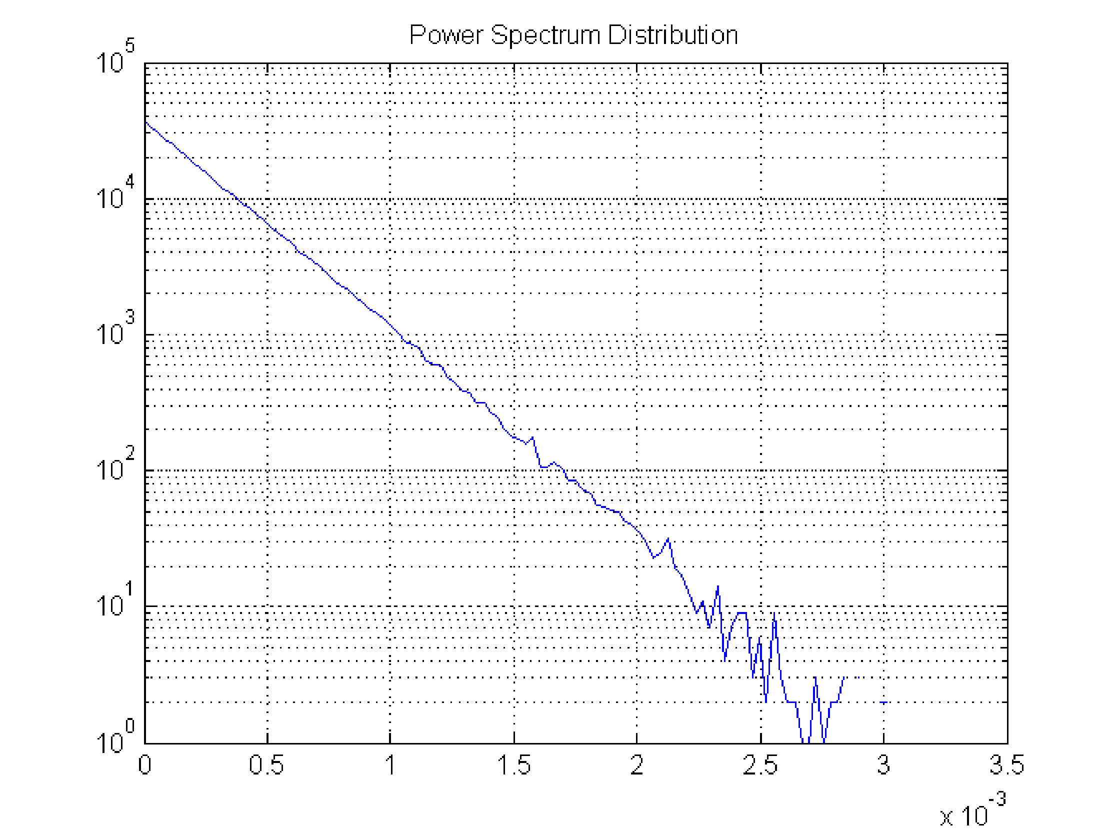


Spectrum of reconstructed data

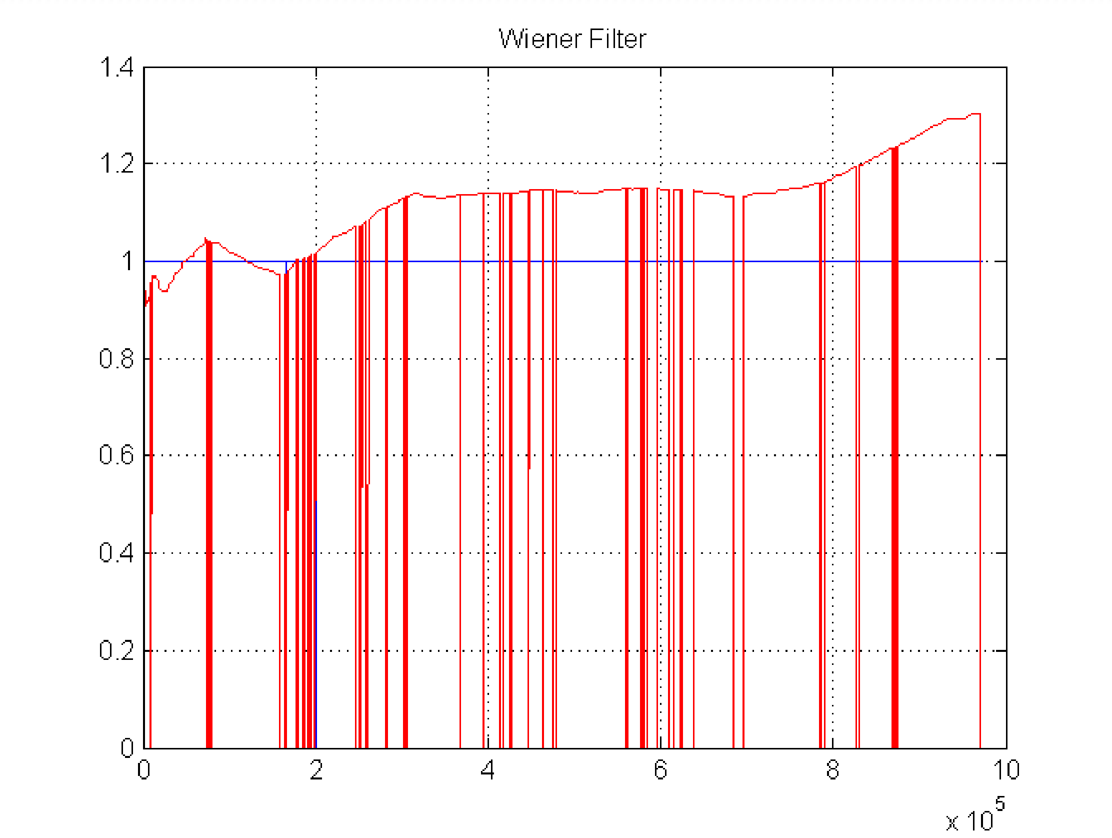




Power spectrum distribution (in the band)



“Wiener filter”



Parameter estimation: definitions

The parameters are h (the amplitude), η and ψ (polarization parameters).

If the polarization ellipse has semi-axes a and b, with the convention to put b positive if the circular part is L (CCW) and negative if it is R (CW), the two polarization parameters are $\eta = \frac{b}{a}$ and the linear polarization angle ψ.

What is a 5-vect ?

A 5-vect is a 5 component complex vector that contains the whole information regarding the detection of the gravitational periodic signal. The 5 components are the Fourier components of the Doppler and spin-down corrected sampled data at the angular frequencies $\omega_0-2\Omega$ $\omega_0-\Omega$ ω_0 $\omega_0+\Omega$ $\omega_0+2\Omega$ (Ω is the sidereal angular frequency).

A “data” 5-vect has 10 degrees of freedom, a “signal” 5-vect has 4 degrees of freedom.

The operations on the time series (filtering, simulations,…) can be done on the 5-vect, obtaining practically the same results, with much higher efficiency.

Many equations regarding the 5-vect are formally identical to that regarding time series.

What is coherence

$$c = \frac{|g\mathbf{S}|^2}{|\mathbf{X}|^2}$$

S is the signal 5-vect, g is the (complex) estimated amplitude, **X** is the data 5-vect

$$c = \left|\left(\tilde{\mathbf{X}} \cdot \tilde{\mathbf{S}}\right) \cdot \tilde{\mathbf{S}}\right|^2 = \left|\tilde{\mathbf{X}} \cdot \tilde{\mathbf{S}}\right|^2$$

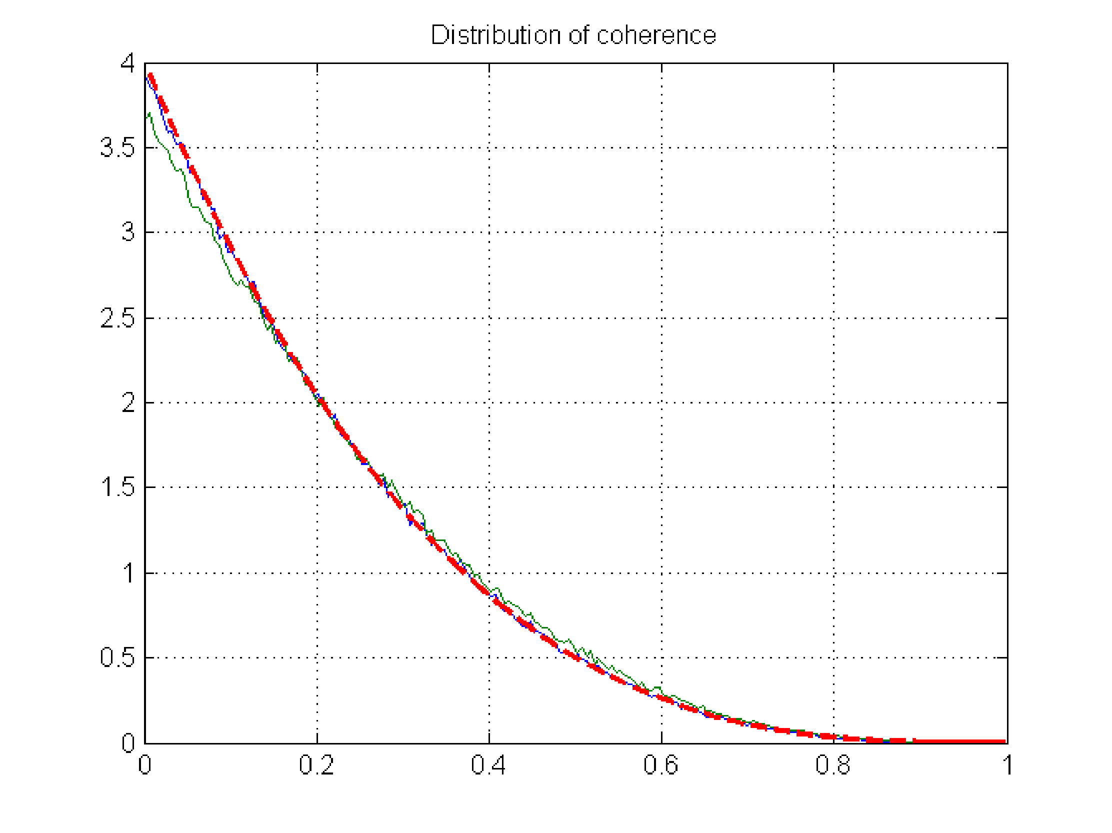
the tilde indicates the normalization; note that it is independent on the amplitude of **X** and **S**

Here are the distributions (are both beta) in case of no signal, for the 2 dof and the 4 dof

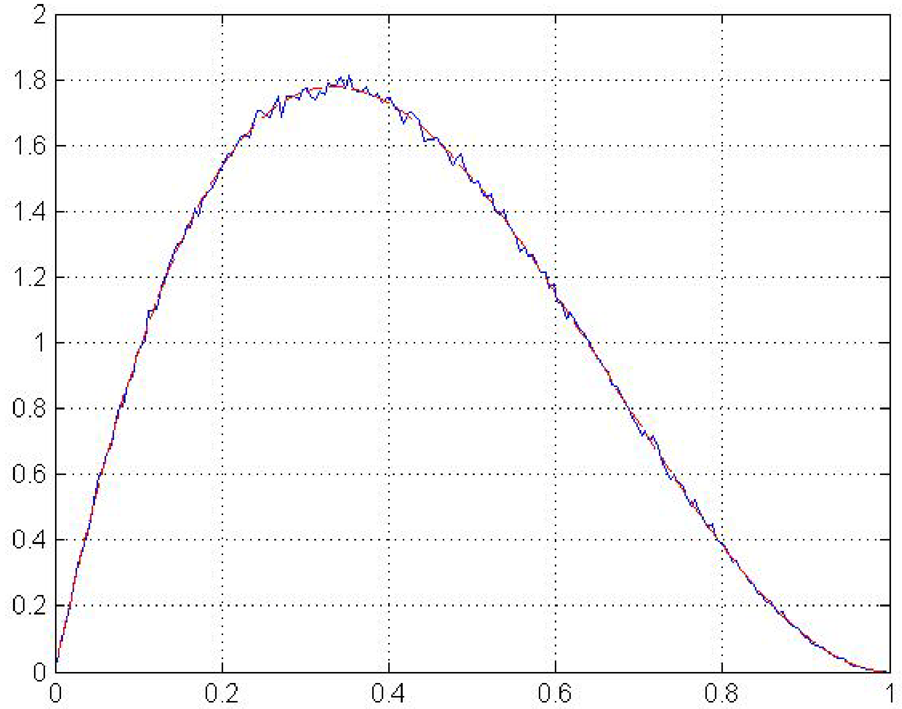
$$f(x) = 4 \cdot (1 - x)^3$$

$$f(t) = 12 \cdot t \cdot (1 - t)^2$$

2-dof coherence distribution
(in case of only noise)



4-dof coherence distribution
(in case of only noise)



Parameter estimation

(on 12 days starting at 22 September)

	Pulsar_2s	Pulsar_2	Pulsar_3s	Pulsar_3	Pulsar_4s	Pulsar_4
Frequency	576.163573	575.163573	109.857159	108.857159	1404.163331	1403.163331
Spin-down	-1.37E-13	-1.37E-13	-1.46E-17	-1.46E-17	-2.54E-08	-2.54E-08
alpha	215.26	215.26	178.37	178.37	279.99	279.99
delta	3.44	3.44	-33.44	-33.44	-12.47	-12.47
Threshold	0.06	0.06	0.03	0.03	0.06	0.06
h0 inj	5.28E-24	5.28E-24	8.30E-24	8.30E-24	2.76E-23	2.76E-23
h0 found	**5.23E-24**	**5.42E-24**	**8.03E-24**	**7.55E-24**	**2.99E-23**	**2.64E-23**
ratio f/i	**0.99**	**1.03**	**0.97**	**0.91**	**1.08**	**0.95**
eta inj	0.997	0.997	0.160	0.160	-0.515	-0.515
eta found	**0.865**	**0.983**	**0.183**	**0.178**	**-0.422**	**-0.358**
psi inj	77.292	77.292	25.439	25.439	-37.124	-37.124
psi found	**72.835**	**1.954**	**25.681**	**26.949**	**-31.844**	**-32.937**
SNR	**11.6**	**14.0**	**27.4**	**19.8**	**22.9**	**20.2**
coherence	**0.988**	**0.997**	**0.999**	**0.997**	**0.975**	**0.978**

Parameter estimation: new h-rec

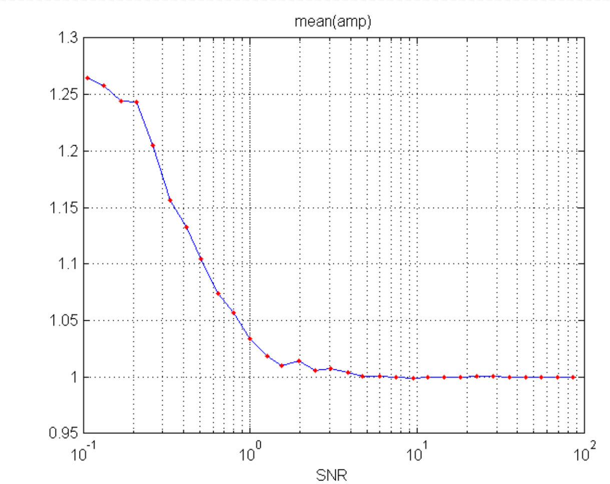
(on 12 days starting at 22 September)

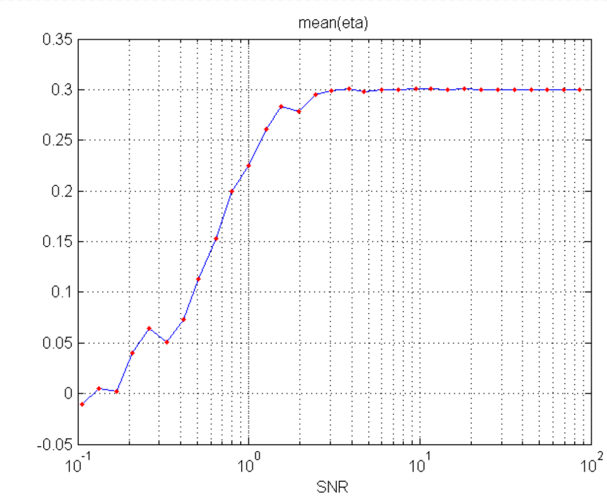
VSR2 v1 - v3												
	Pulsar_2s		Pulsar_2		Pulsar_3s		Pulsar_3		Pulsar_4s		Pulsar_4	
Frequency	576.163573		575.163573		109.857159		108.857159		1404.163331		1403.163331	
Spin-down	-1.37E-13		-1.37E-13		-1.46E-17		-1.46E-17		-2.54E-08		-2.54E-08	
alpha	215.26		215.26		178.37		178.37		279.99		279.99	
delta	3.44		3.44		-33.44		-33.44		-12.47		-12.47	
Threshold	0.05		0.06		0.04		0.04		0.06		0.06	
Noise level	**1.25E-22**	**1.30E-22**	**1.05E-22**	**1.10E-22**	**8.90E-23**	**9.13E-23**	**1.20E-22**	**1.23E-22**	**1.82E-22**	**1.93E-22**	**1.81E-22**	**1.92E-22**
h0 inj	5.28E-24		5.28E-24		8.30E-24		8.30E-24		2.76E-23		2.76E-23	
h0 found	**5.24E-24**	**5.30E-24**	**5.42E-24**	**5.61E-24**	**8.03E-24**	**8.08E-24**	**7.55E-24**	**7.43E-24**	**2.99E-23**	**2.96E-23**	**2.64E-23**	**2.83E-23**
ratio f/i	**0.99**	**1.00**	**1.03**	**1.06**	**0.97**	**0.97**	**0.91**	**0.90**	**1.08**	**1.07**	**0.95**	**1.02**
eta inj	0.997		0.997		0.160		0.160		-0.515		-0.515	
eta found	**0.853**	**0.924**	**0.984**	**0.926**	**0.183**	**0.174**	**0.178**	**0.187**	**-0.422**	**-0.382**	**-0.358**	**-0.320**
psi inj	77.292		77.292		25.439		25.439		-37.124		-37.124	
psi found	**72.184**	**44.668**	**1.110**	**69.486**	**25.674**	**25.375**	**26.949**	**26.938**	**-31.844**	**-29.341**	**-32.937**	**-30.889**
SNR	**13.7**	**13.8**	**16.7**	**17.1**	**33.1**	**33.6**	**23.7**	**23.6**	**27.9**	**23.6**	**24.6**	**22.6**
coherence	**0.985**	**0.984**	**0.997**	**0.995**	**0.999**	**0.999**	**0.997**	**0.996**	**0.975**	**0.963**	**0.978**	**0.966**

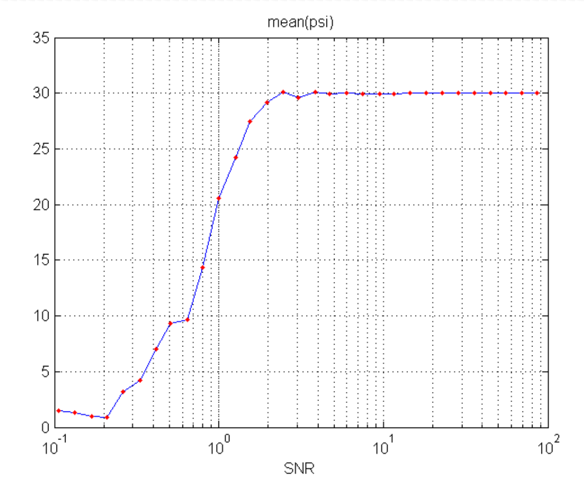
		v3/v1		**v3/v1**		**v3/v1**		**v3/v1**		**v3/v1**		**v3/v1**
Noise ratio		**1.04E+00**		**1.04E+00**		**1.03E+00**		**1.02E+00**		**1.06E+00**		**1.06E+00**
Signal Ratio		**1.01E+00**		**1.04E+00**		**1.01E+00**		**9.84E-01**		**9.91E-01**		**1.07E+00**
SR/NR		**9.74E-01**		**9.93E-01**		**9.81E-01**		**9.62E-01**		**9.36E-01**		**1.01E+00**
SNR		**1.009302**		**1.025365**		**1.016109**		**0.995369**		**0.84684**		**0.91886**

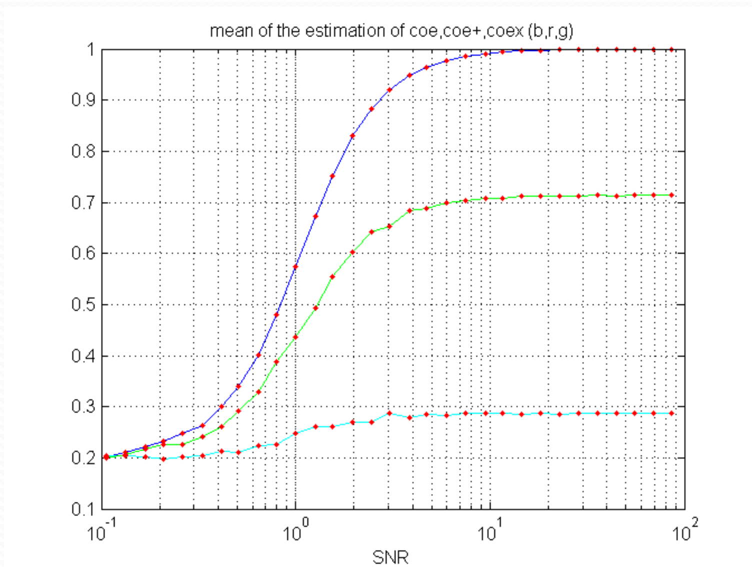
Mean of the estimators

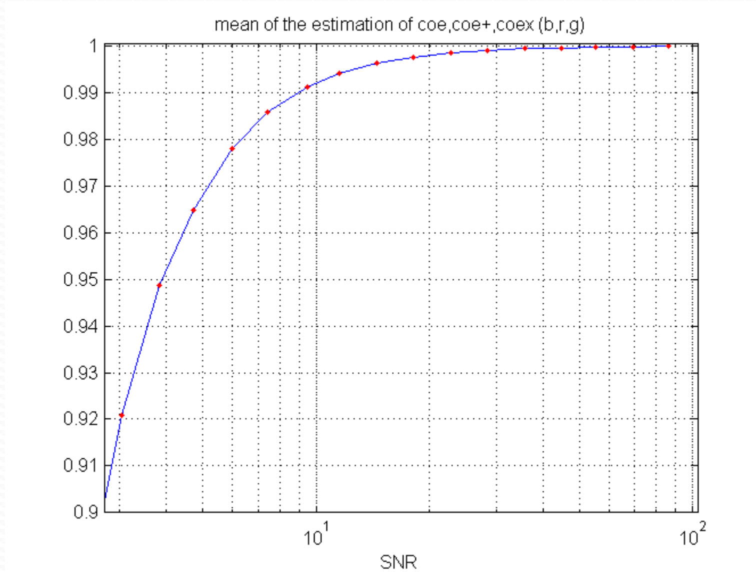
(Virgo & Vela with η=0.3, ψ=30º - stationary gaussian noise)





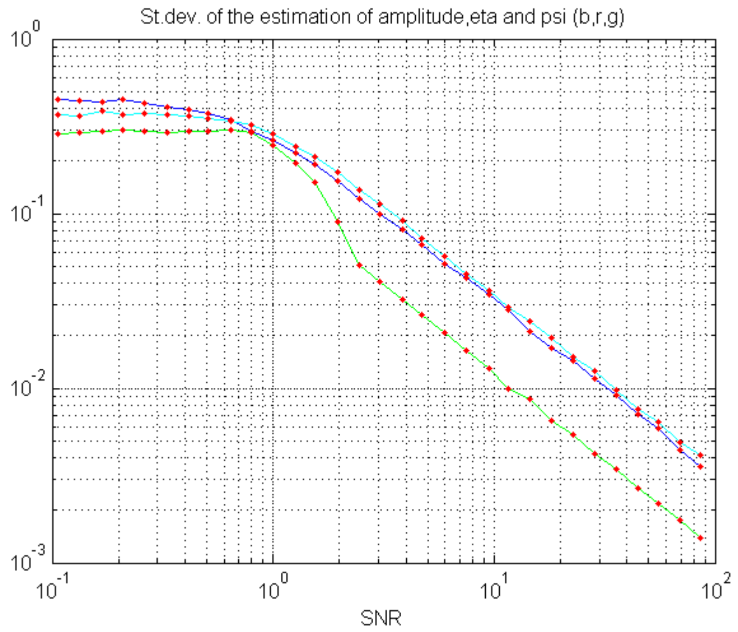


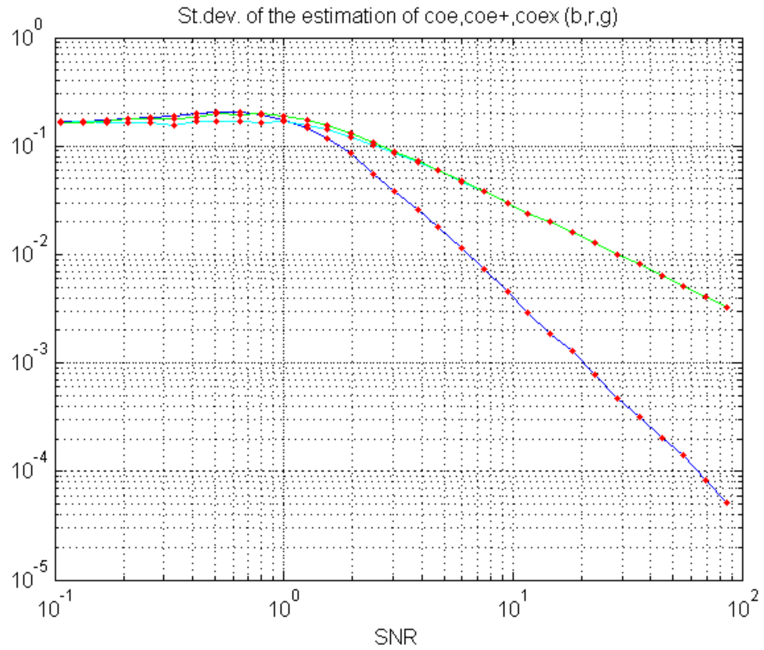




Standard deviation of the estimators

(Virgo & Vela with η=0.3, ψ=30° - stationary gaussian noise)





Bias correction: just a check:

use the software injection to “correct” the hardware injections

	Bias or factor		Corrected values		Bias or factor		Corrected values		Bias or factor		Corrected values	
h	9.92E-01	1.00E+00	5.46E-24	5.60E-24	9.67E-01	9.74E-01	7.80E-24	7.63E-24	1.08E+00	1.07E+00	2.43E-23	2.64E-23
eta	-0.144	-0.073	1.000	0.998	0.023	0.014	0.155	0.173	0.093	0.133	-0.451	-0.454
psi	-5.108	-32.624	6.218	12.110	0.235	-0.064	26.714	27.002	5.280	7.783	-38.217	-38.672
			Residual error				Residual error				Residual error	
h			0.034	0.059			-0.060	-0.080			-0.119	-0.046
eta			0.003	0.001			-0.005	0.013			0.064	0.061
psi			18.926	24.818			1.275	1.563			-1.093	-1.548

Conclusions

- The correction of the Doppler, Einstein and spin-down is very good
- The estimated parameters are not completely satisfactory, there are biases due to the holes and Wiener correction that cause the non-orthogonality of the signal 5-vects
- We are working to reduce these biases.