Plans of the POLGRAW group for an all sky search of the VSR1 data

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On behalf of the POLGRAW –VIRGO group

Introducing the POLGRAW group

POLGRAW group is a new member group of the VIRGO project

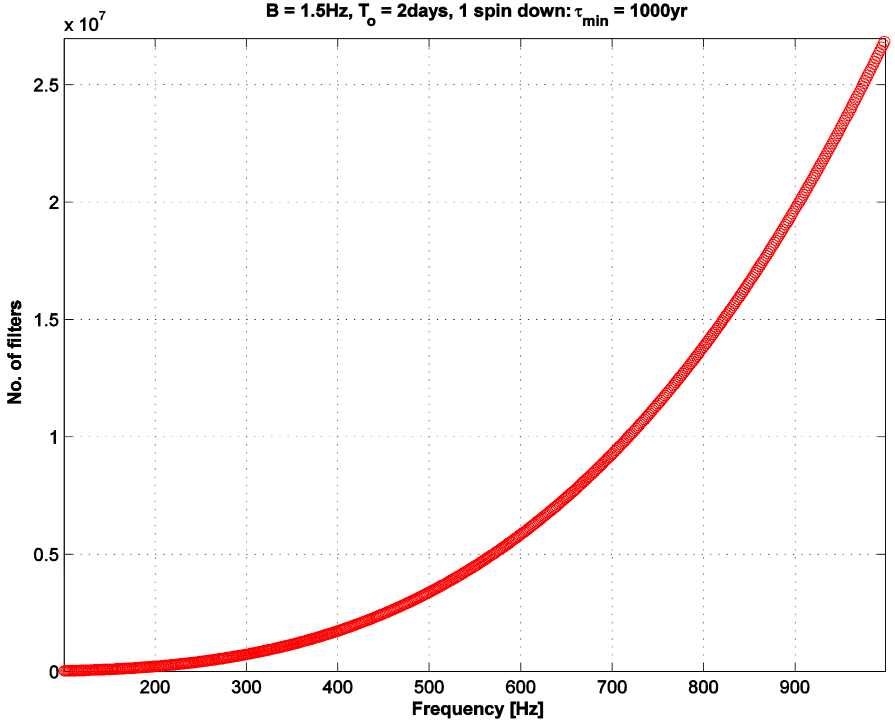
Members of POLGRAW contributing to CW data analysis

Andrzej Królak
Robert Budzyński
Kazimierz Borkowski
Piotr Jaranowski
Witold Kondracki
Maciej Piętka

Continuation of the collaboration with the ROG group on search for CW sources in bar data

Search of the VSR1 **data** using the $\mathcal{F}$-statistic

We assume that SFT data base is in place together with software that extracts the data of given observation time (T_o) and bandwidth (B) .



Parameters of the search

T_o = 2 days , B = 1.5Hz
1 spin down, T_{min} = 1000yr

1 filter = 1 F-statistic for 2^{19} bins

Computational time

Optimal grid *MM = √3/2*

Band [100Hz – 1KHz] - Nof = 5.6×10^9

We need 100 cores to do 5×10^7 templates in 2 days

We need **10 000** cores to analyze VSR1 in „real time"

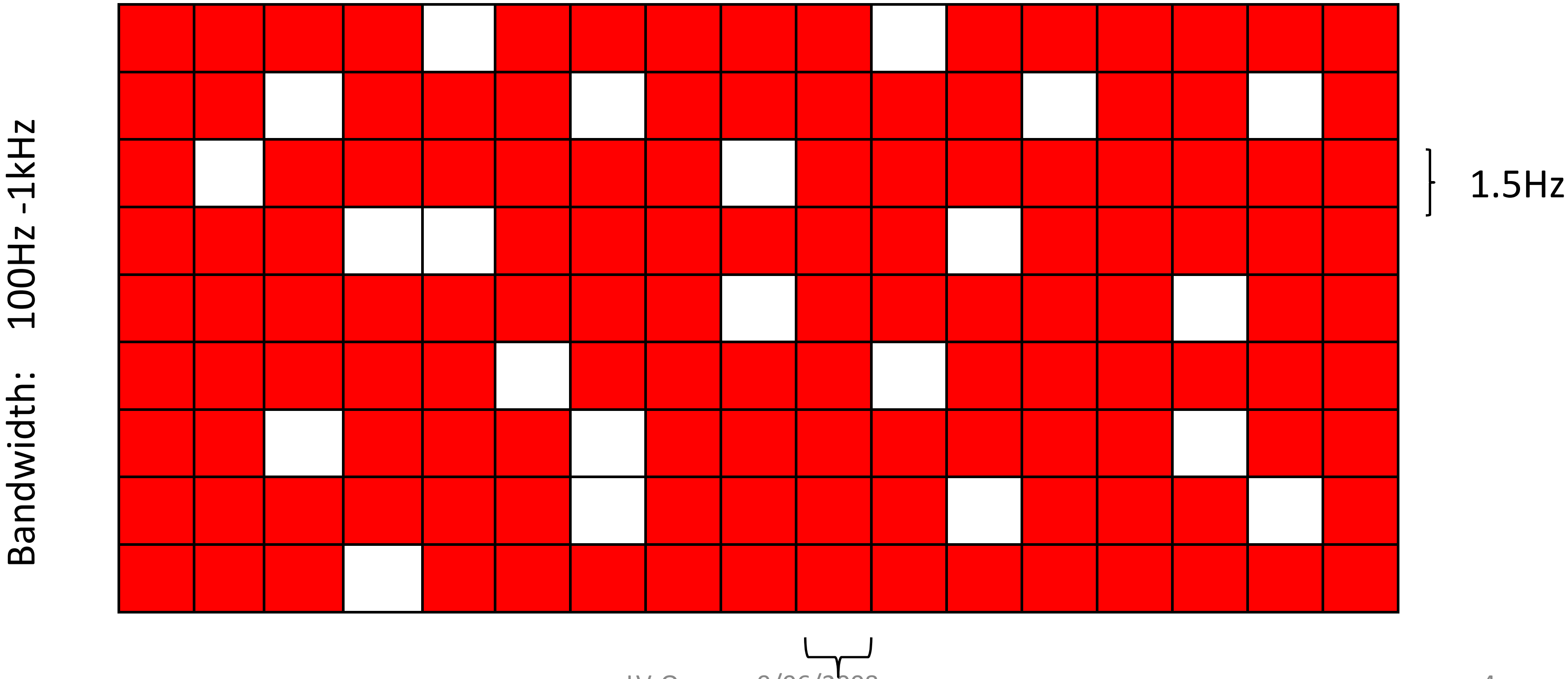
Not all the data are good. Analyze only very good data. This saves computational time and effort to interpret the results.

Realistically with available resources we can do 1000 2-day sequences out of 20000 (this requires 500 cores running continuously for 4 month).

VSR1

$h \leq 10^{-22}$ /√Hz

Time: 18/5/2007 - 1/10/2007 (136 days)



Verification PRocedure

1. Coincidence analysis of candidates in various data stretches

Collaboration with LSC - E@H codes

(Theoretical analysis in progress: Fisher matrix as a metric or L_1-norm distance to define coincidence cells)

2. Analysis of SNR gain with the increase of the observation time (go from 2 to 4 days)

(Theoretical analysis in progress: F-test and its generalizations)

Coincidences analysis

L_1-norm distance : (CQG **25** (2008) 015005)
(Has a certain probabilistic interpretation.

$$d_L(p,q) = \int_X |\, p(x) - q(x)\,| dx \,/\, 2$$

In Gaussian case we have:

$$d_L(\theta_M,\theta_N) = erf\left[\sqrt{(s(\theta_M)-s(\theta_N)\,|\,s(\theta_M)-s(\theta_N))}\,/(2\sqrt{2})\right]$$

Parameters of an candidate from
the Mth sequence

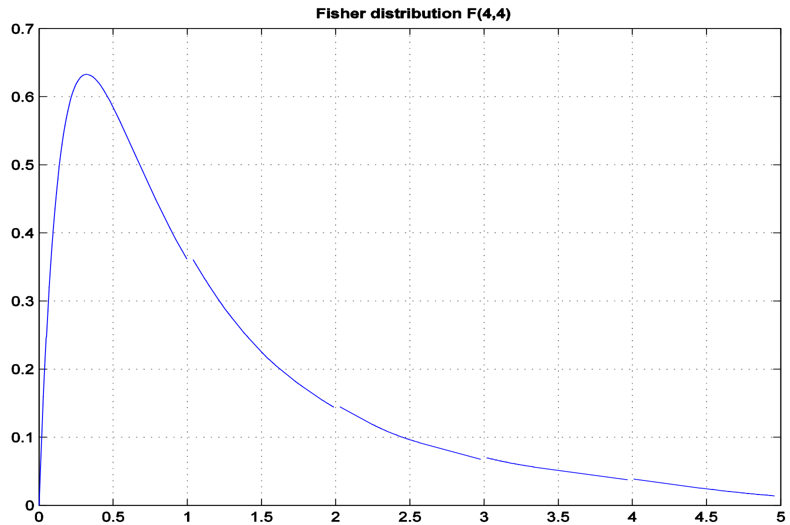
From F-statistic to F-test

$$F_{candidate} = \frac{\mathcal{F}_{4\,days}}{\mathcal{F}_{2\,days}}$$

Central χ^2 with 4 degrees of freedom

If 4 days and 2 days data independent F has Fisher F –distribution F(4,4)

F-test - null hypothesis: data only noise



Testing the Codes: real Data

Test of procedure with 6-day stretch of narrowband data

a. Search 3 2-day sterches
b. Coincidences
c. SNR gain in a 4-day stretch disjoint form the 2-day one

Make injections!

Suggestion:

Do the same for LIGO data with 6-day stretch with the same starting time and bandwidth as the VSR1 one.

Create data Base of Candidates

Data base entries:

Frequency, spin down, sky position, amplitudes, SNR

GPS time of the first sample taken

Detector

$\mathcal{F}$-statistic: maximum likelihood detection

C=0 if T_o = integer no. of days

$$\mathcal{F}(x;\xi) = \frac{2}{S_0}\frac{V\left|F_u\right|^2 + U\left|F_v\right|^2 - 2\Re(CF_u F_v^*)}{D}$$

$$D = UV - C^2 \qquad U = \frac{1}{T_o}\int_0^{T_o} u^2 dt$$

$$F_u = \int_0^{T_o} x(t)\, u(t;\xi)\exp[-i\phi(t;\xi)]\, dt$$

Linear phase model

Linear model for an all sky search: neglect componet of the vector $\mathbf{r_d}$ perpendicular to the ecliptic

$$\phi_{\mathrm{lin}}(t) = \sum_{k=0}^{s} \omega_k \frac{t^{k+1}}{(k+1)!} + \alpha_1\mu_1(t) + \alpha_2\mu_2(t),$$

where α_1 and α_2 are new constant parameters,

$$\alpha_1 := \omega_0(\sin\alpha\cos\delta\cos\varepsilon + \sin\delta\sin\varepsilon),$$

$$\alpha_2 := \omega_0\cos\alpha\cos\delta,$$

Grid of templates

Expectation value

$$E_1[\mathcal{F}] = 1 + \frac{d^2}{2} C(\tau_k)$$

$$\mathcal{C}(\tau_k) \approx \langle \cos[\tau_k m_k(t)] \rangle^2 + \langle \sin[\tau_k m_k(t)] \rangle^2$$

Hyperellipse → $\tilde{\Gamma}_{ij}\tau^i\tau^j = 1 - MM^2$ ← Minimal match

Find a grid (lattice) so that each point of the grid belongs to at least one hyperellipse ← Covering problem

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$$N_{filters} = \frac{V_{parameter\_space}}{V_{grid\_element}}$$

How to reduce the computational time?

$$F_u = \int_0^{T_o} x(t)u(t;\chi)\exp - \imath[\omega_1 t^2 + \omega(t + Doppler\,(t;\chi))]dt$$

Resampling

(interpolation) $\longrightarrow$ $t_b = t + Doppler\,(t;\chi)$

$$F_u = \int_0^{T_o} x(t_b)u(t_b;\omega,\chi)\exp(-\imath\,\omega_1 t_b^{\,2})\exp(-\omega\, t_b)d\,t_b$$

Use FFT to compute F_u

THE Two resampling methods

1. Nearest neighbor interpolation
   (Stroboscopic resampling)

   5% rms error

2. Two step method
   (Fine resampling)
   a. Fourier interpolation
   b. Spline interpolation

   0.1% rms error

Resampling

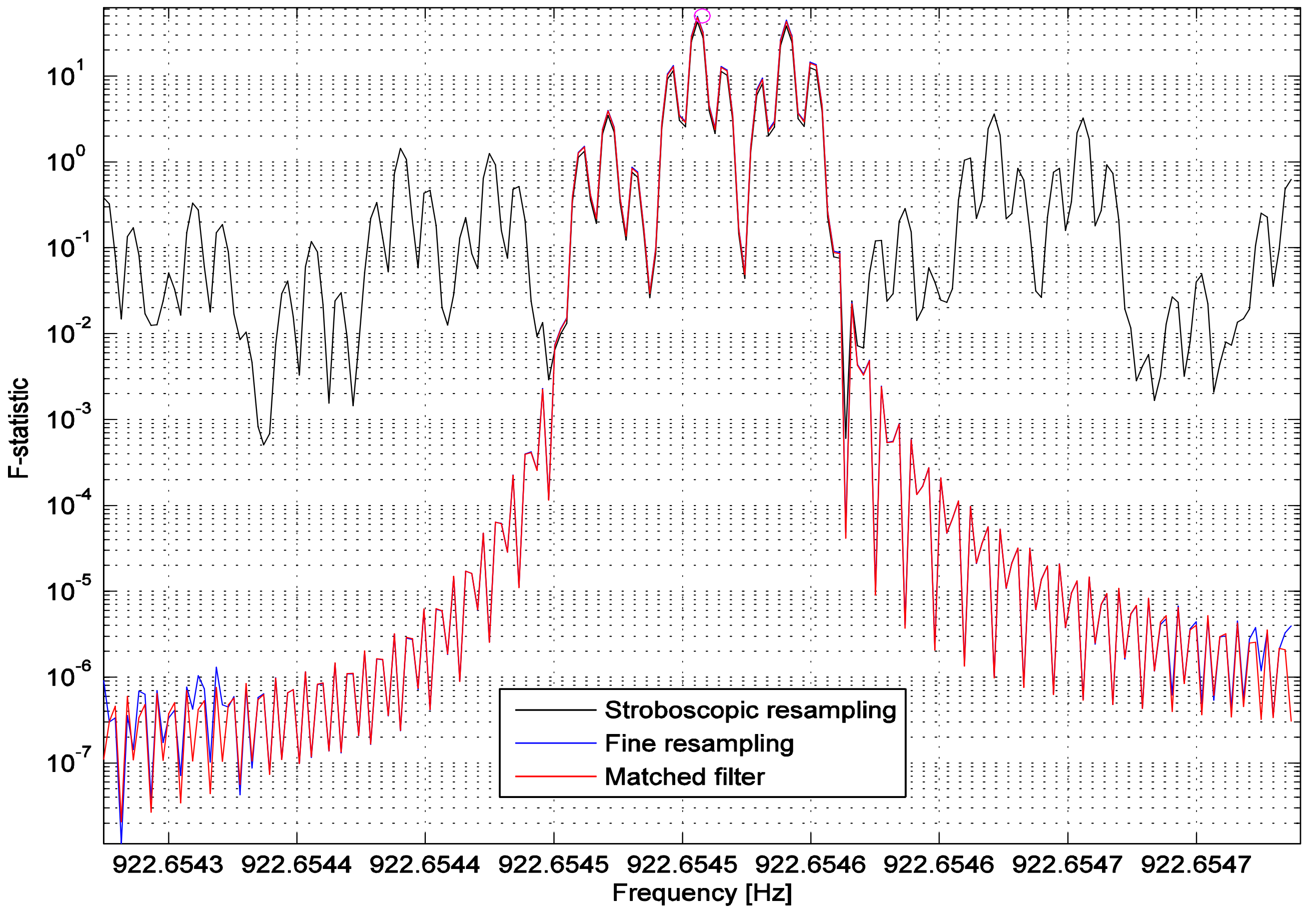


FIG. 4: Comparison of the two interpolation methods and the perfect matched-filtering. We see that the two-step interpolation method that uses Fourier and spline interpolation very accurately reproduces the perfect matched filter.

Lattices with constraints

1. We want to use the FFT. Hence the nodes of the lattice must coincide with the Fourier frequencies.

Constraint no. 1. *One vector of the lattice has to be parallel to the frequency axis and the frequency component must be equal to the Fourier frequency.*

2. We want to minmize the number of times we have to perform resampling.

Constraint no. 2. *Another vector of the lattice has to be perpendicular to the sky plane.*

Generator matrix

$$\begin{array}{cccc} & & sky & \\ \omega & \dot{\omega} & \alpha_1 & \alpha_2 \end{array}$$

$$M = \begin{pmatrix} \pi & 0 & 0 & 0 \\ b_1 & b_2 & 0 & 0 \\ c_1 & c_2 & c_3 & c_4 \\ d_1 & d_2 & d_3 & d_4 \end{pmatrix}$$

Our code has three **DO** loops (over A, B, $\dot{\omega}$). The innermost being over $\dot{\omega}$. Thus we move in turn along vectors **d**, **c**, **b**. As $b_3 = b_4 = O$, when we move along the **b** direction, the sky position does not change. So we *need to resample only once for all the spin downs.*

As $a_2=a_3=a_4=O$ and $a_1=\pi$ we *obtain by FFT the F-stat at lattice points for the whole bandwidth*.

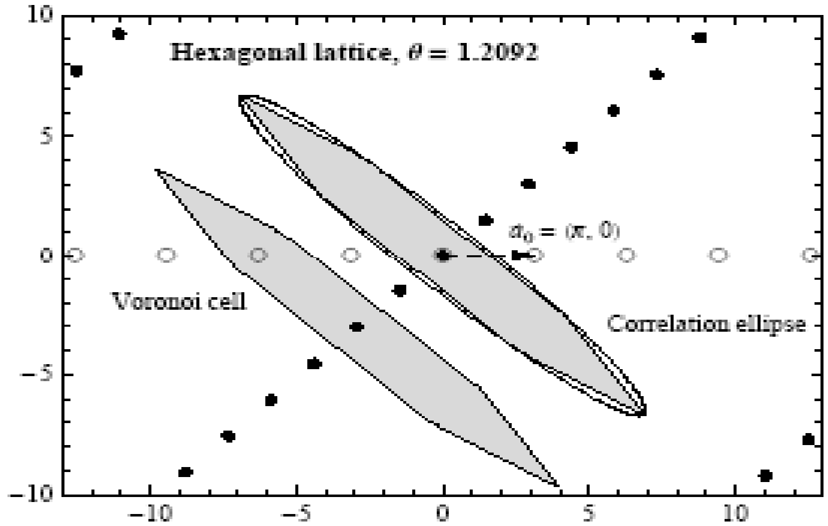
Constrained grids: NAUTILUS search case

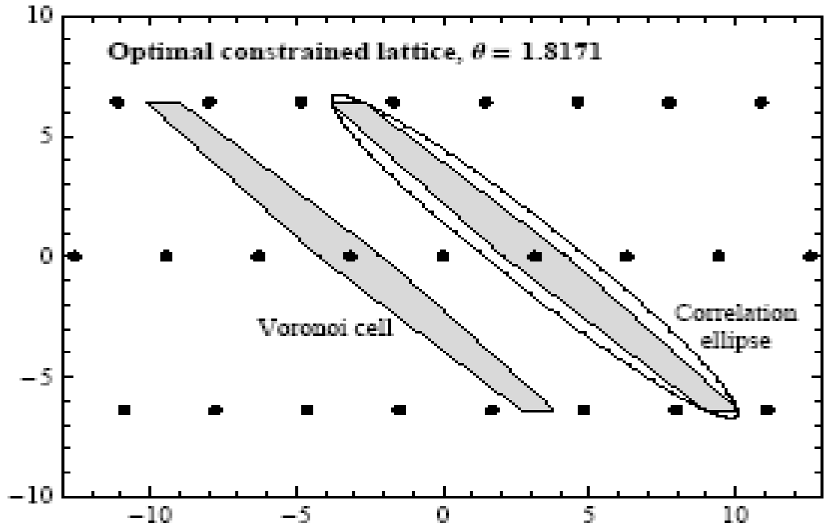
MM = $\sqrt{3}/2$ To = 2 days NUTILUS bar position

All sky 1 spin down

Lattice	Thickness: thinnest lattice	Thickness: constrained lattice	No. Of filters
CUBIC	4.9	5.6	58 million
A*4	1.8	2.1	22 million

Constrained grid in 2 dimensions





Testing the Codes: Monte Carlo simulation

500 runs
Signals with randomly chosen parameters added to white Gaussian noise.
Amplitude scaled so that each signal has **SNR = 8.5.**

Threshold (2 F) = 40
Hence the false dismissal probability = 8.6567e-003 (4 signals for 500 runs)

A. Fine resampling

2 signals missed

B. Stroboscopic resampling

followed by a refined search

3 signals missed

Monte Carlo simulation: parameter estimation