Status of the Hough CW search code
- Plans for S2 -

A.M. Sintes,

B. Krishnan, M.A. Papa

Universitat de les Illes Balears, Spain

Albert Einstein Institut, Germany

Universitat de les Illes Balears

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Outline

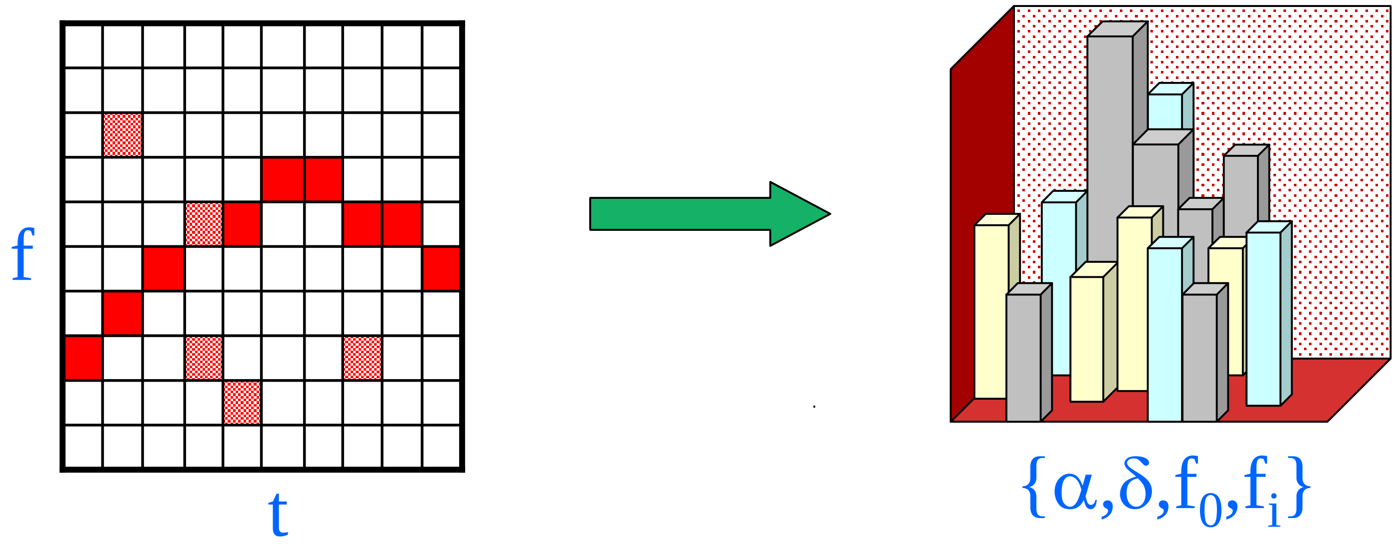
- The hierarchical Hough search. Pipeline for S2
- Statistics of the Hough maps. Frequentist analysis
- Code status
- Results on simulated & H1 data

The concept of the Hough transform

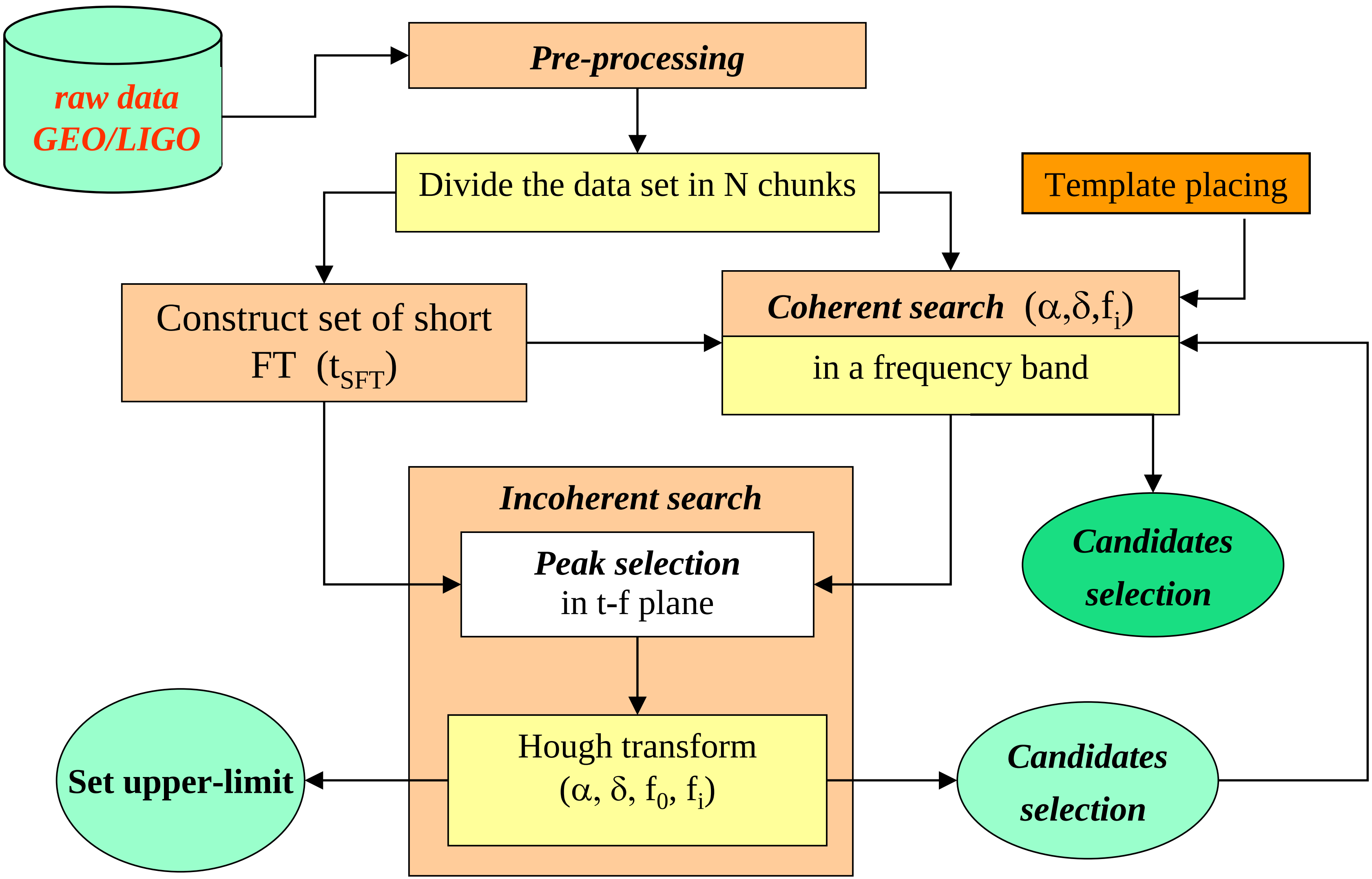
– The idea is to perform a search over the total observation time using an incoherent (sub-optimal) method:

We propose to search for evidence of a signal whose frequency is changing over time in precisely the pattern expected for some one of the parameter sets

– The method used is the **Hough transform**



Hierarchical Hough transform strategy



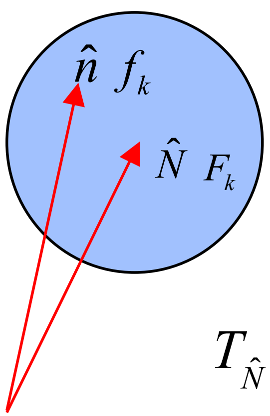
The time-frequency pattern

- SFT data

$$f(t) - f_0(t) = f_0(t)\frac{\vec{v}(t)}{c}\cdot\hat{n}$$

- Demodulated data

$$f(t) - F_0(t) = \vec{\xi}(t)\cdot(\hat{n} - \hat{N})$$



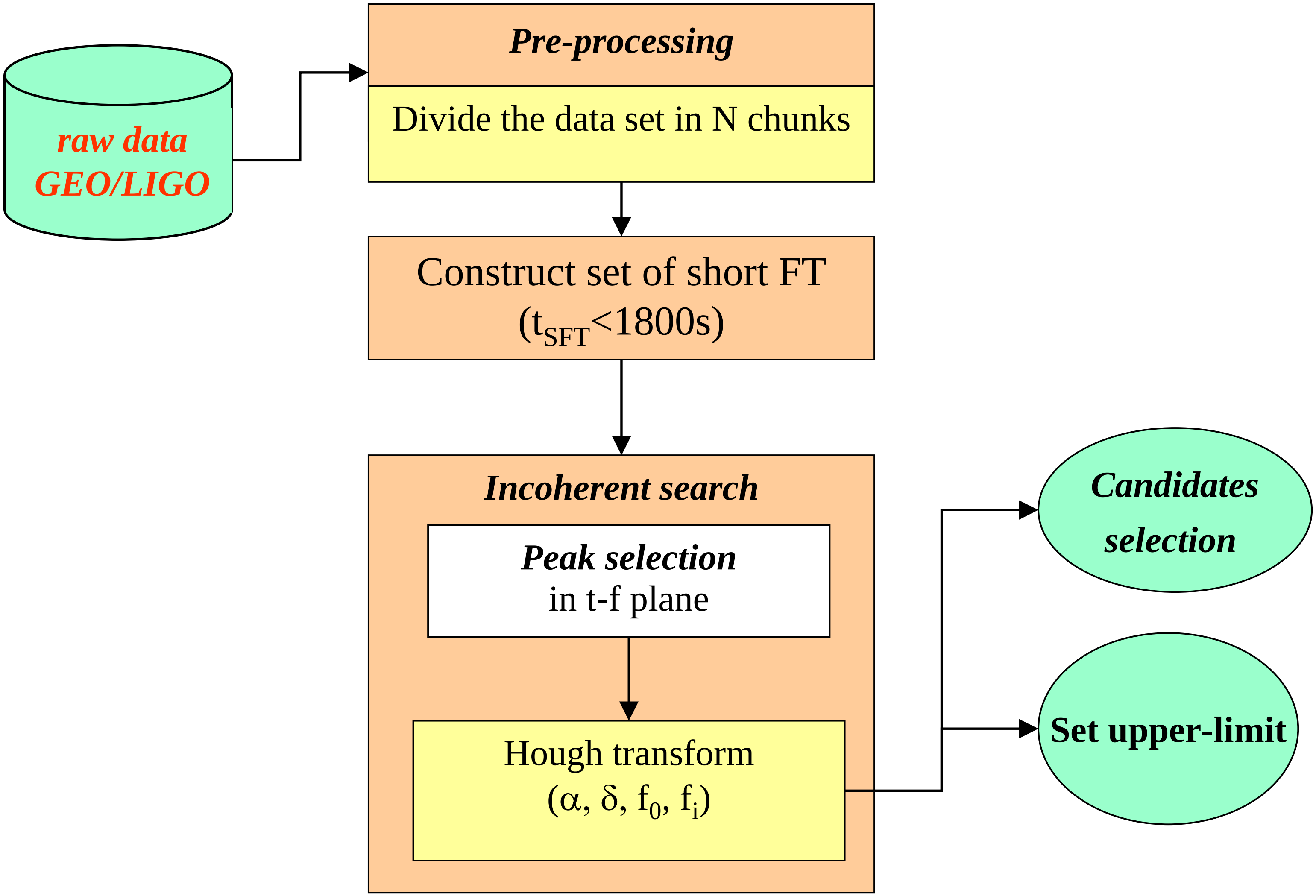
$$F_0(t) \equiv f_0 + \sum_k \Delta f_k \left[\Delta T_{\hat{N}}(t)\right]^k \qquad \Delta f_k \equiv f_k - F_k$$

$$T_{\hat{N}}(t) = t + \frac{\vec{x}(t)\cdot\hat{N}}{c} + \cdots$$

Time at the SSB for a given sky position

$$\vec{\xi}(t) = \left(F_0(t) + \sum_k F_k\left[\Delta T_{\hat{N}}(t)\right]^k\right)\frac{\vec{v}(t)}{c} + \left(\sum_k kF_k\left[\Delta T_{\hat{N}}(t)\right]^{k-1}\right)\frac{\Delta\vec{x}(t)}{c}$$

Incoherent Hough search: Pipeline for S2



Peak selection in the t-f plane

- Input data: Short Fourier Transforms (SFT) of time series
  (Time baseline: 1800 sec, calibrated) $\tilde{x}(f) = \tilde{n}(f) + \tilde{h}(f)$
- For every SFT, select frequency bins i such

$$\rho_i = \frac{|\tilde{x}(f_i)|^2}{\langle|\tilde{n}(f_i)|^2\rangle} = \frac{|\tilde{x}(f_i)|^2}{S_n(f_i)T_{SFT}}$$

exceeds some threshold ρ_0

➔ time-frequency plane of zeros and ones

- $p(\rho|h, S_n)$ follows a χ^2 distribution with 2 degrees of freedom:

$$\langle\rho_i\rangle = 1 + \frac{|\tilde{h}(f_i)|^2}{S_n(f_i)T_{SFT}} \qquad \sigma_\rho^{\ 2} = 1 + \frac{2|\tilde{h}(f_i)|^2}{S_n(f_i)T_{SFT}}$$

- The false alarm and detection probabilities for a threshold ρ_0 are

$$\alpha(\rho_0|S_n) = \int_{\rho_0} p(\rho|0, S_n)\,\mathrm{d}\rho = e^{-\rho_0}, \quad \eta(\rho_0|h, S_n) = \int_{\rho_0} p(\rho|h, S_n)\,\mathrm{d}\rho$$

Hough statistics

- After performing the HT using N SFTs, the probability that the pixel $\{\alpha,\delta,f_0,f_i\}$ has a number count n is given by a **binomial distribution:**

$$P(n\,|\,p,N) = \binom{N}{n} p^{n}(1-p)^{N-n}$$

$$\langle n \rangle = Np\,, \quad \sigma_n^{\,2} = Np(1-p)$$

$$p = \begin{cases} \alpha & \text{signal absent} \\ \eta & \text{signal present} \end{cases}$$

- The Hough false alarm and false dismissal probabilities for a threshold n_0

$$\alpha_H(n_0,\alpha,N) = \sum_{n=n_0}^{N} \binom{N}{n} \alpha^{n}(1-\alpha)^{N-n}$$

➔ Candidates selection

$$\beta_H(n_0,\eta,N) = \sum_{n=0}^{n_0-1} \binom{N}{n} \eta^{n}(1-\eta)^{N-n}$$

Frequentist Analysis

- Perform the Hough transform for a set of points in parameter space $\lambda=\{\alpha,\delta,f_0,f_i\}\in \mathbf{S}$, given the data:

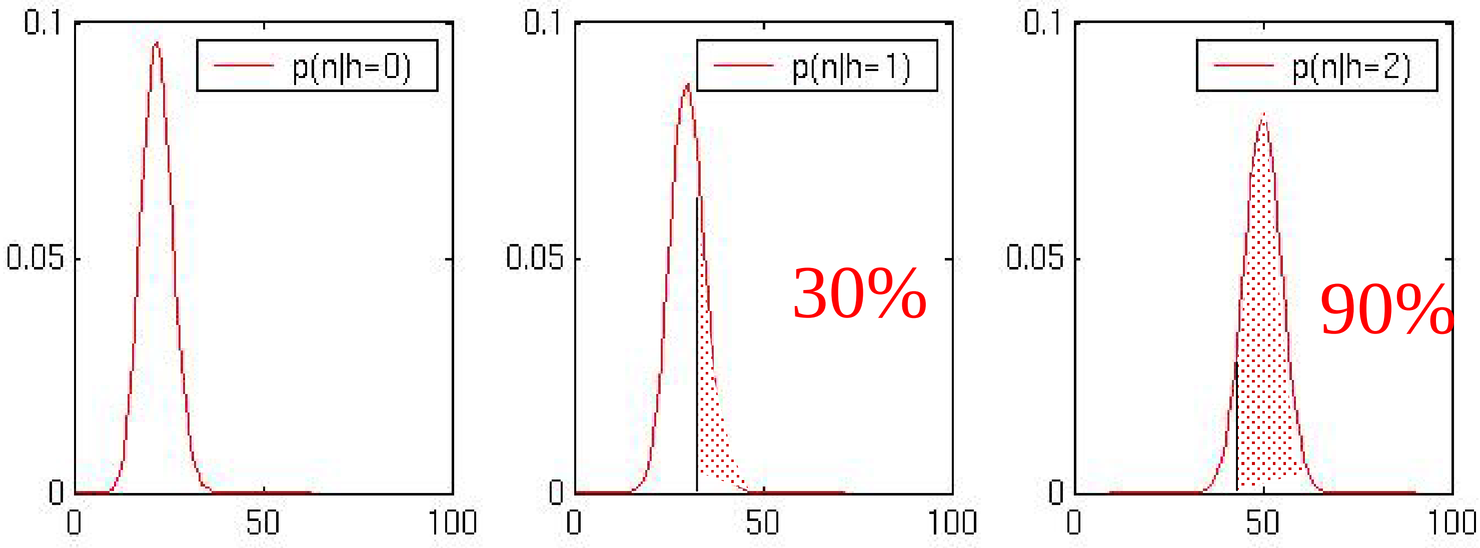
$$\textbf{HT: S} \rightarrow \textbf{N}$$

$$\lambda \rightarrow n(\lambda)$$

- Determine the maximum number count n*

$$n^* = \max (n(\lambda)) : \lambda \in \mathbf{S}$$

- Determine the probability distribution $p(n|h_0)$ for a range of h_0



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- The 95% frequentist upper limit $h_0^{95\%}$ is the value such that for repeated trials with a signal $h_0 \geq h_0^{95\%}$, we would obtain $n \geq n^*$ more than 95% of the time

$$0.95 = \sum_{n=n^*}^{N} p\left(n|h_0^{95\%}\right)$$

•Compute $p(n|h_0)$ via Monte Carlo signal injection, using $\lambda \in \mathbf{S}$, and $\phi_0 \in [0,2\pi]$, $\psi \in [-\pi/4,\pi/4]$, $\cos\iota \in [-1,1]$.

LIGO

Code Status

GEO 600

- ✓ Stand-alone search code in final phase
- ✓ Test and validation codes (under CVS at AEI)
- ✓ Hough routines are part of the LAL library:

Bookmarks Location: http://www.lsc-group.phys.uwm.edu/cgi-bin/cvs/viewcvs.cgi/lal/packages/houghpulsar/src/?cvsroot=lal

Members WebMail Connections BizJournal SmartUpdate Mktplace

Powered

View

lal/packages/houghpulsar/src

Current directory: [lal] / lal / packages / houghpulsar / src

Files shown: 9

File	Rev.	Age	Author	Last log entry
ConstructPLUT.c	1.8	4 weeks	sintes	bug fixed at bin zero
DriveHough.c	1.3	4 months	sintes	new functionality
HoughMap.c	1.2	4 months	sintes	new functionality
Makefile.am	1.4	4 months	sintes	new functionality
NDParamPLUT.c	1.2	2 months	sintes	changed
ParamPLUT.c	1.4	2 months	sintes	changed
PatchGrid.c	1.4	4 weeks	sintes	improved bin counting for non-demod. case
Peak2PHMD.c	1.4	4 months	sintes	new functionality
Stereographic.c	1.2	4 months	sintes	new functionality

Code Status II

✓ Auxiliary functions C-LAL compliant
(under CVS at AEI to be incorporated into LAL or LALApps):

- Read SFT data
- Peak Selection (in white & color noise)
- Statistical analysis of the Hough maps
- Compute <v(t)>

➢ Under development:

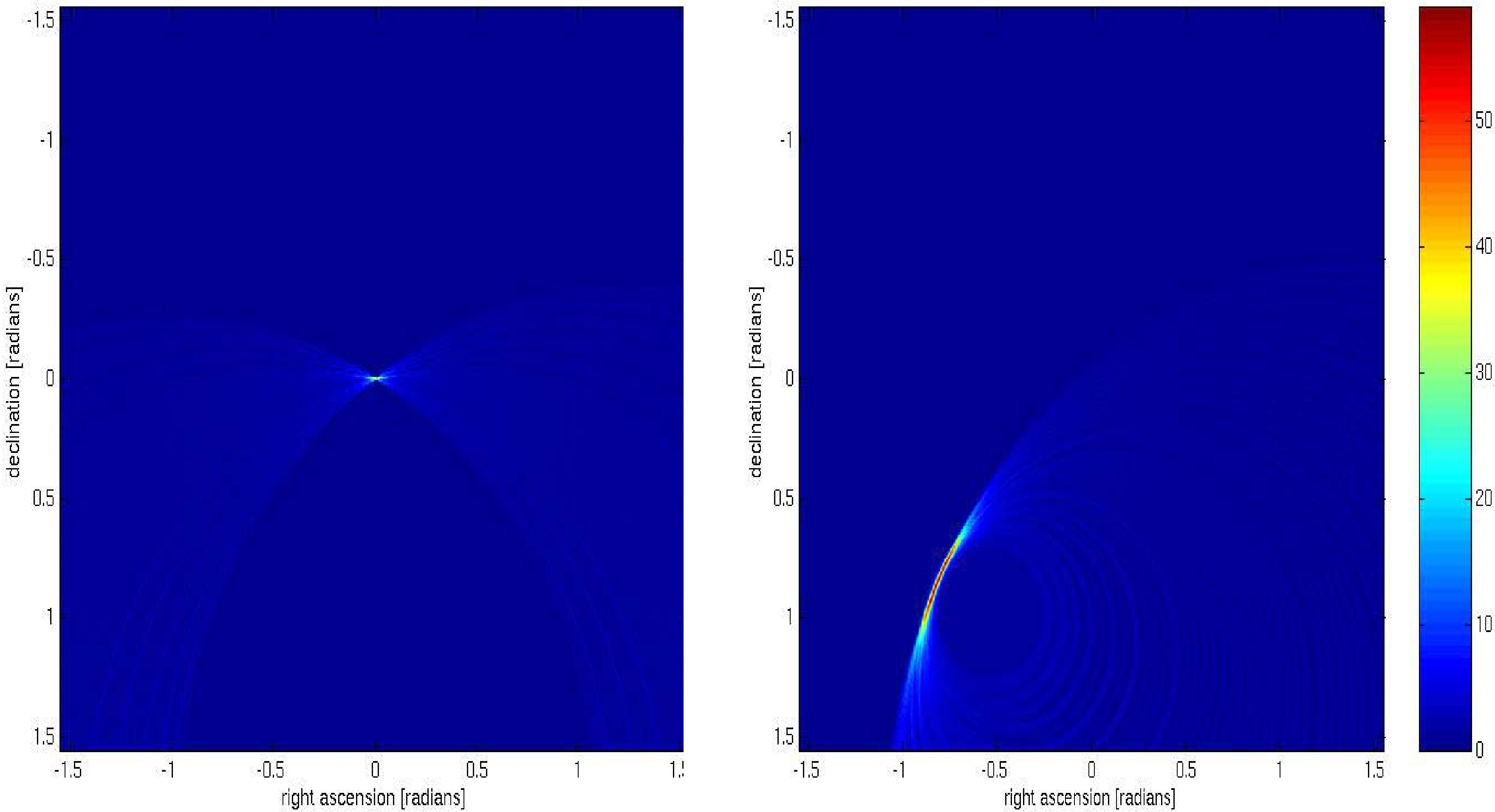
- Implementation of an automatic handling of noise features. Robust PSD estimator.
- Monte Carlo signal injection analysis code.
- Condor submission job.
- Input search parameter files

S2 Numbers

- T_{obs} = 59 days
- SFTs of T_{SFT}~ 30 minutes
- $N \equiv T_{obs}/ T_{SFT}$ = 2832 (max)
- $\Delta f = 1/ T_{SFT} = 5.55 \times 10^{-04}$ Hz
- $\Delta f_1 = 1.09 \times 10^{-10}$ Hz/s
  - Because of memory allocation (on a single node): for f_0 ~ 300Hz, sky patch ~ 1radx1rad, ~10^4 different sky locations.
  - Driver code automatically updates LUTs in the search band. A search over 500 different f_0 can be performed using the same LUT

Validation code

-Signal only case- (f_0=500 Hz)



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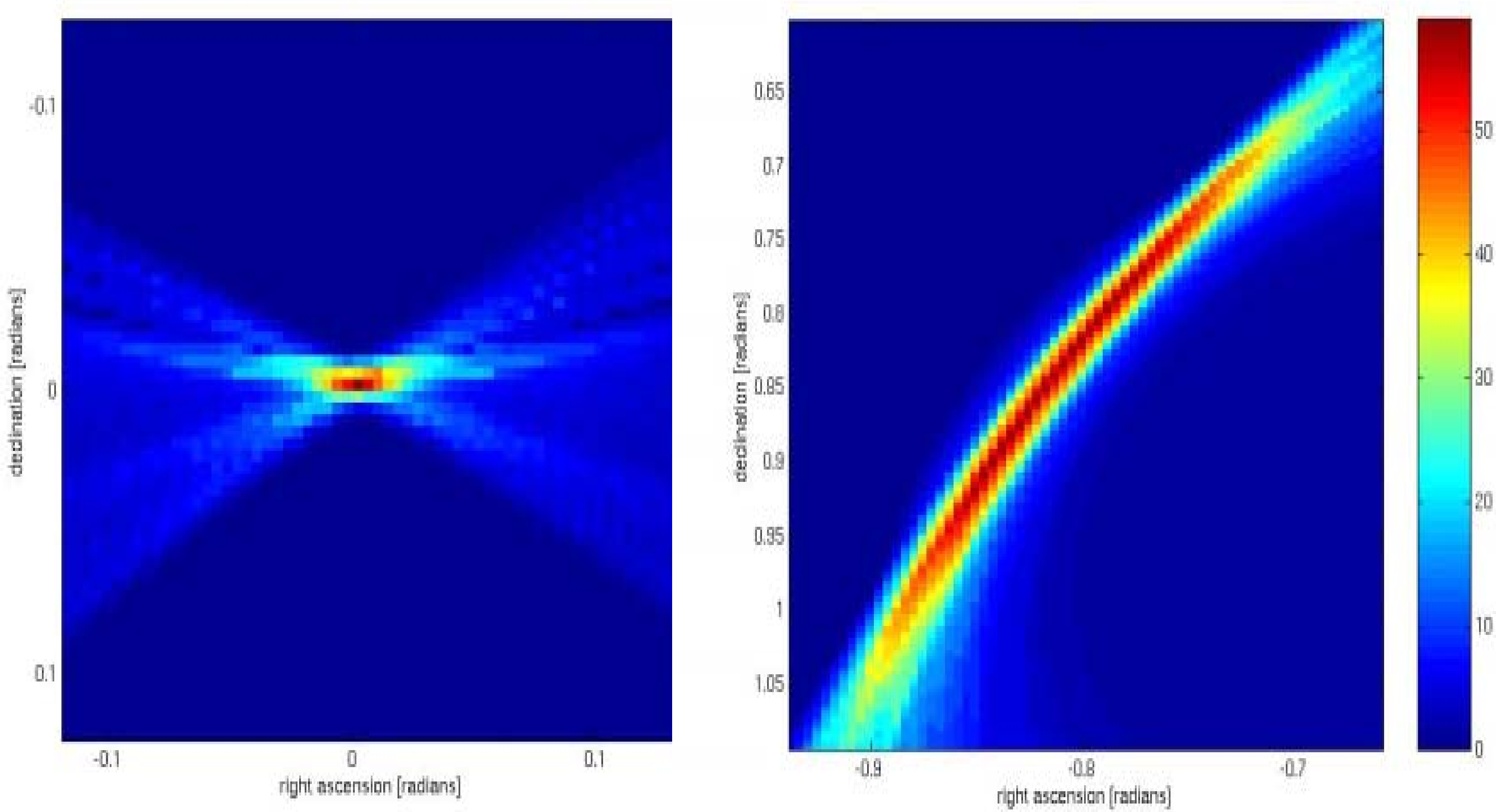
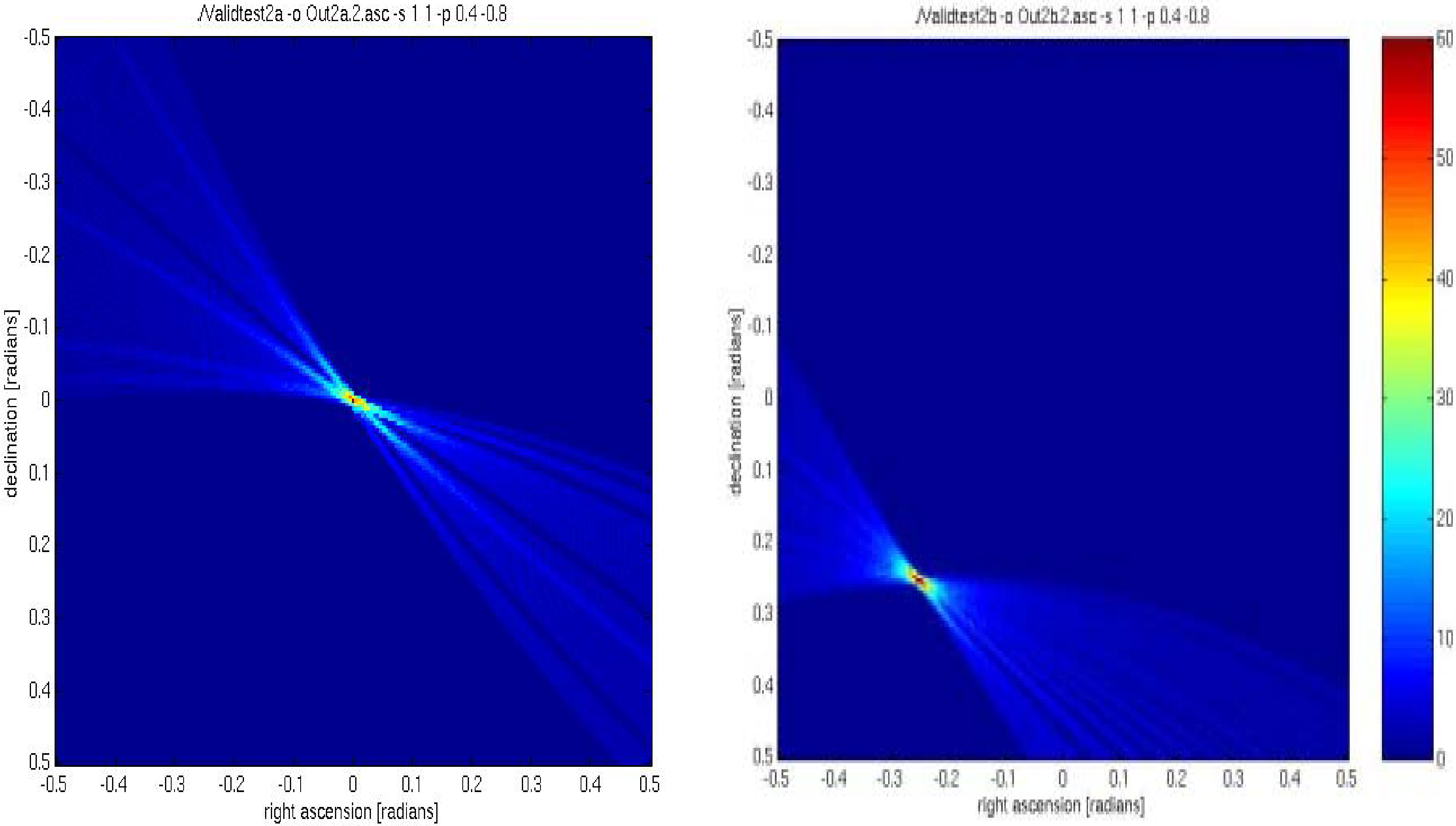
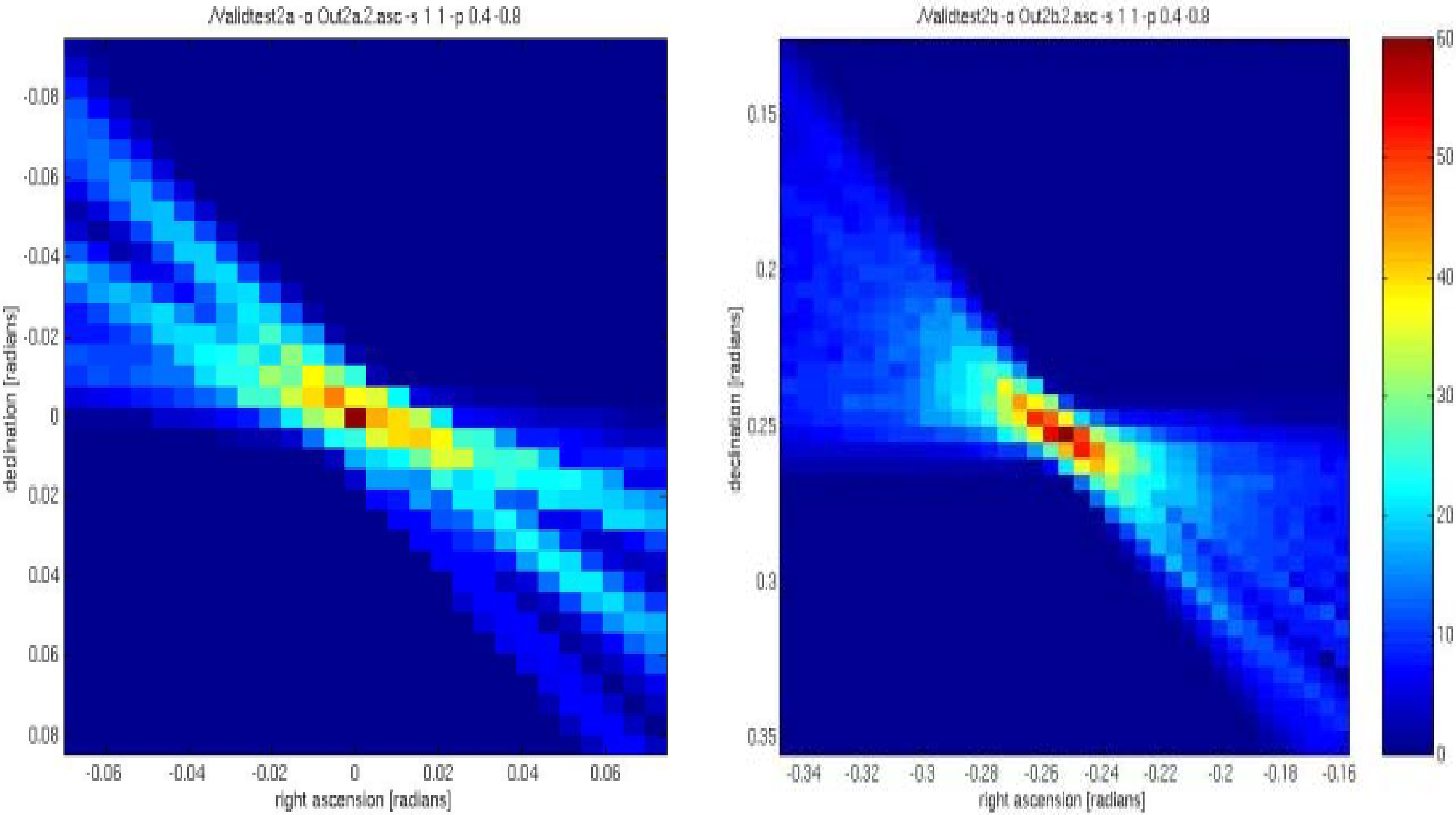


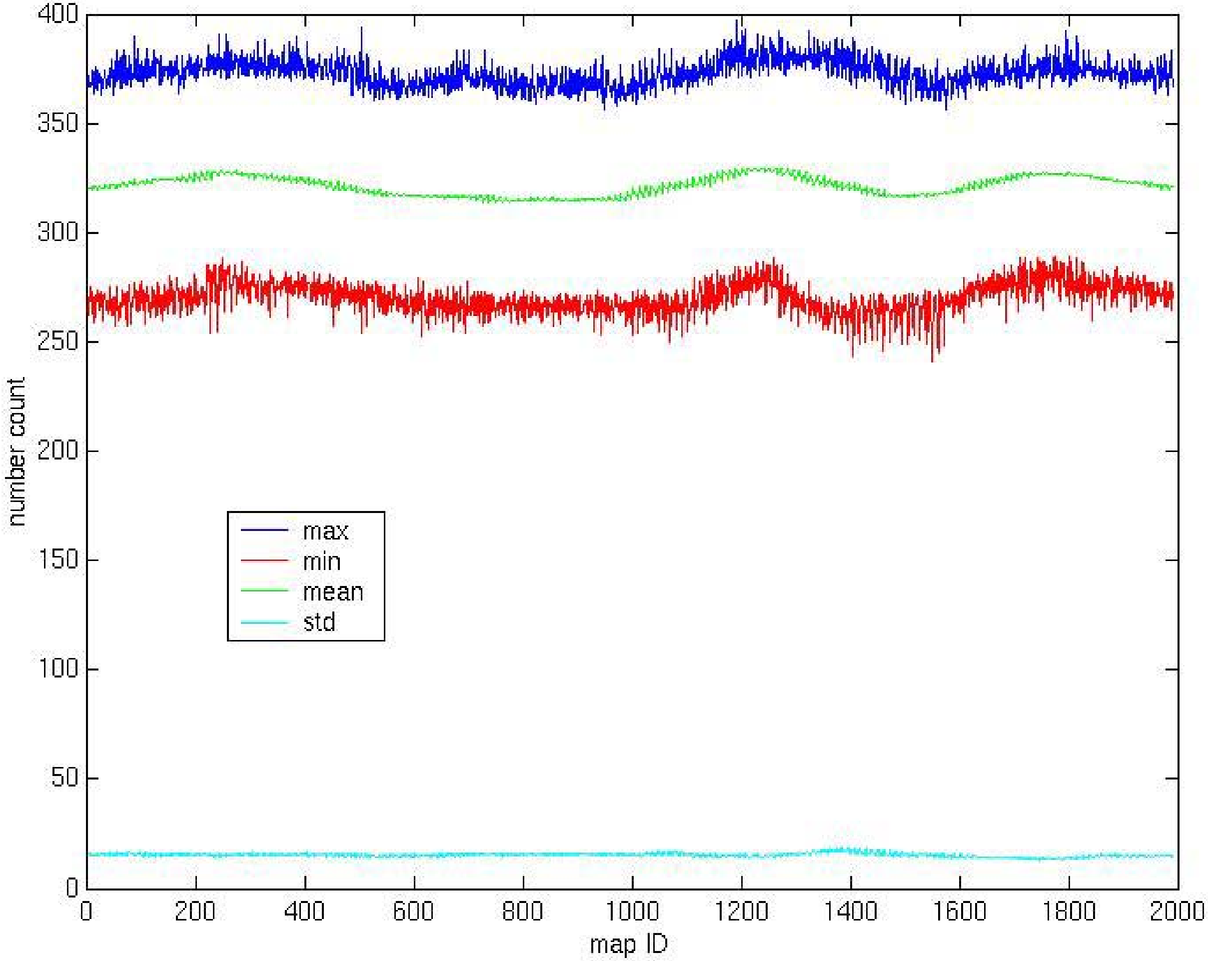
Signal only case II



Signal only case II



Results on simulated data



Statistics of the Hough maps

f_0~300Hz

t_{obs}=60days

N=1440 SFTs

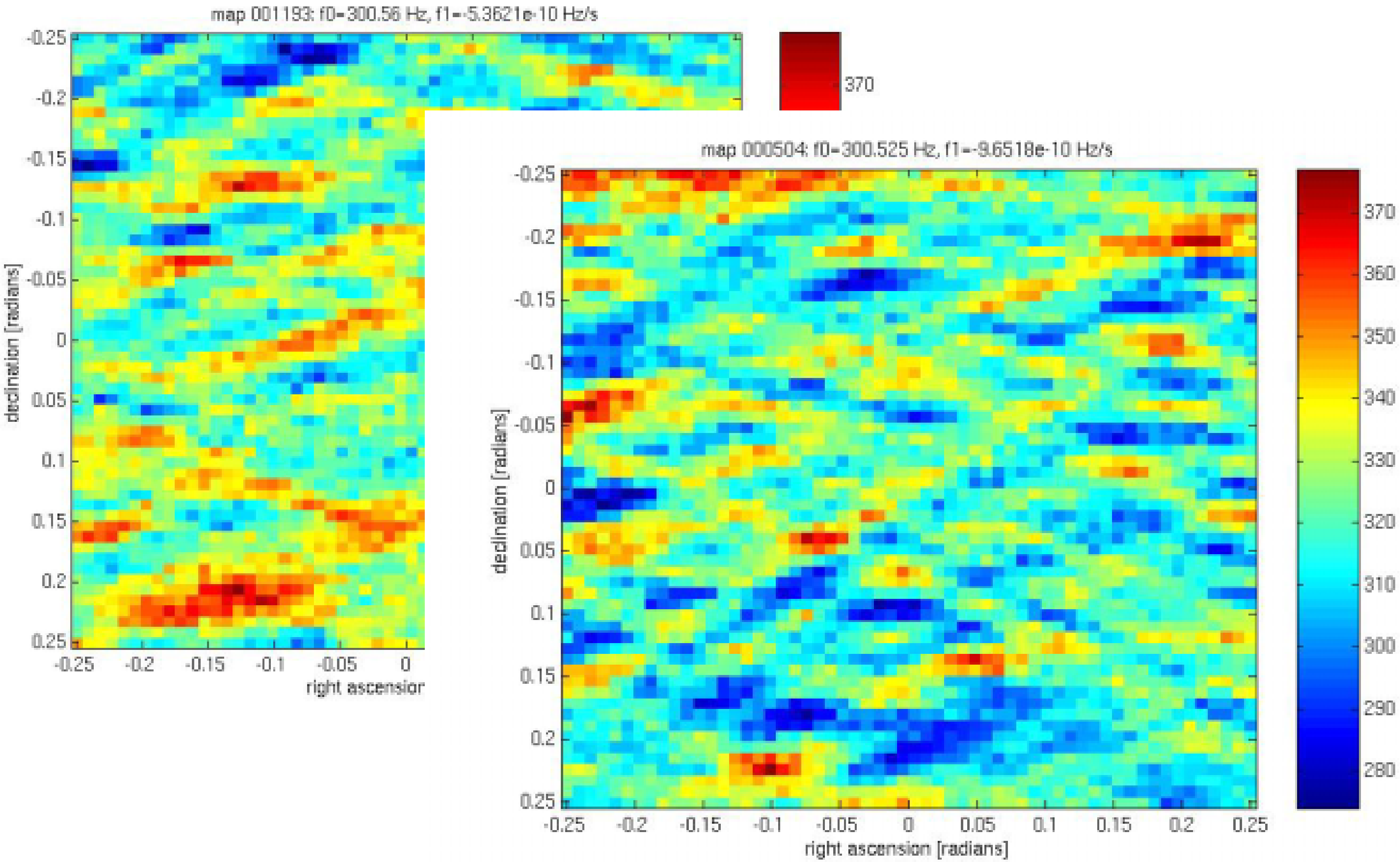
t_{SFT}=1800s

α=0.2231

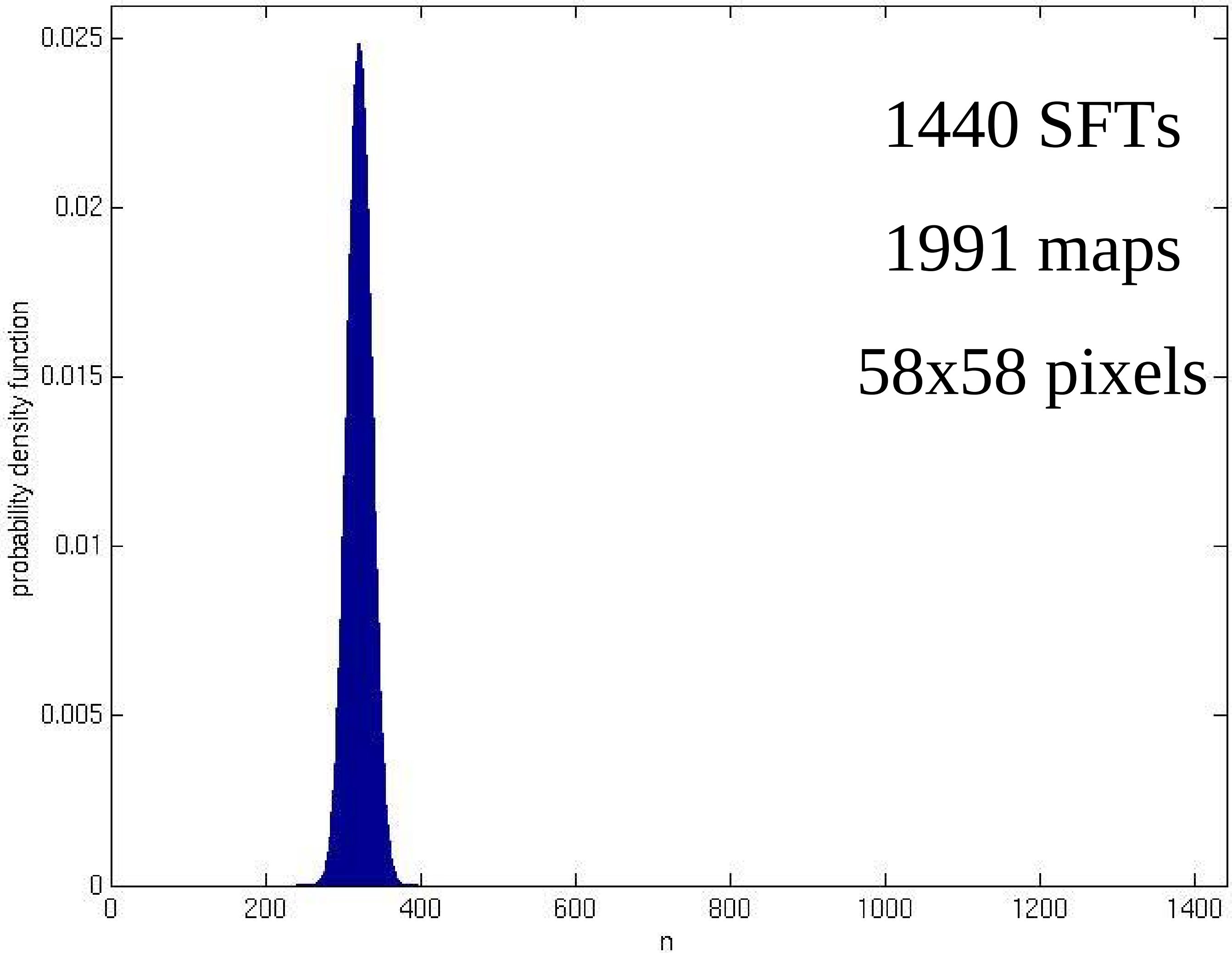
$<n> = N\alpha=321.3074$

$\sigma_n=\sqrt{(N\alpha(1-\alpha))}=15.7992$

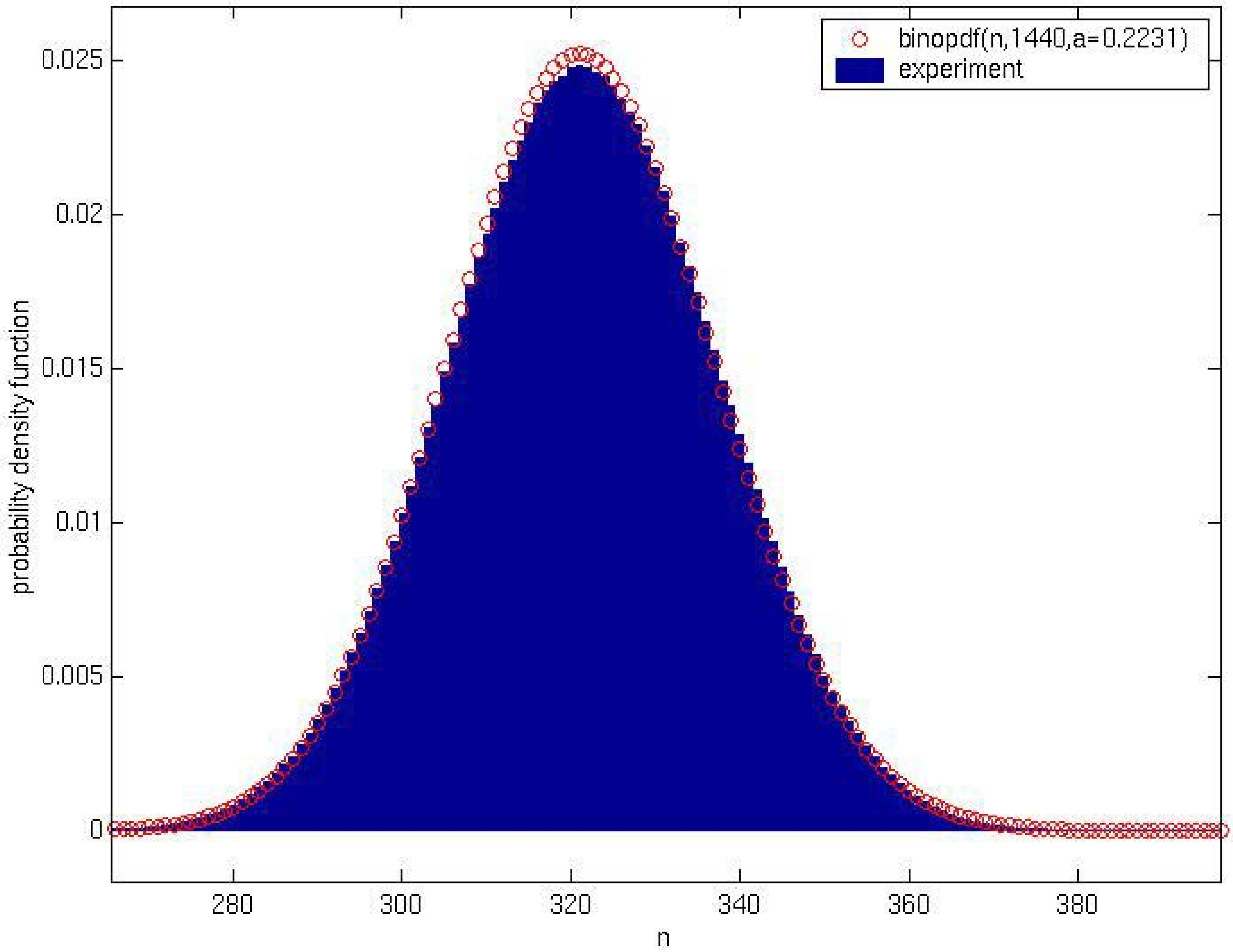
Noise only case



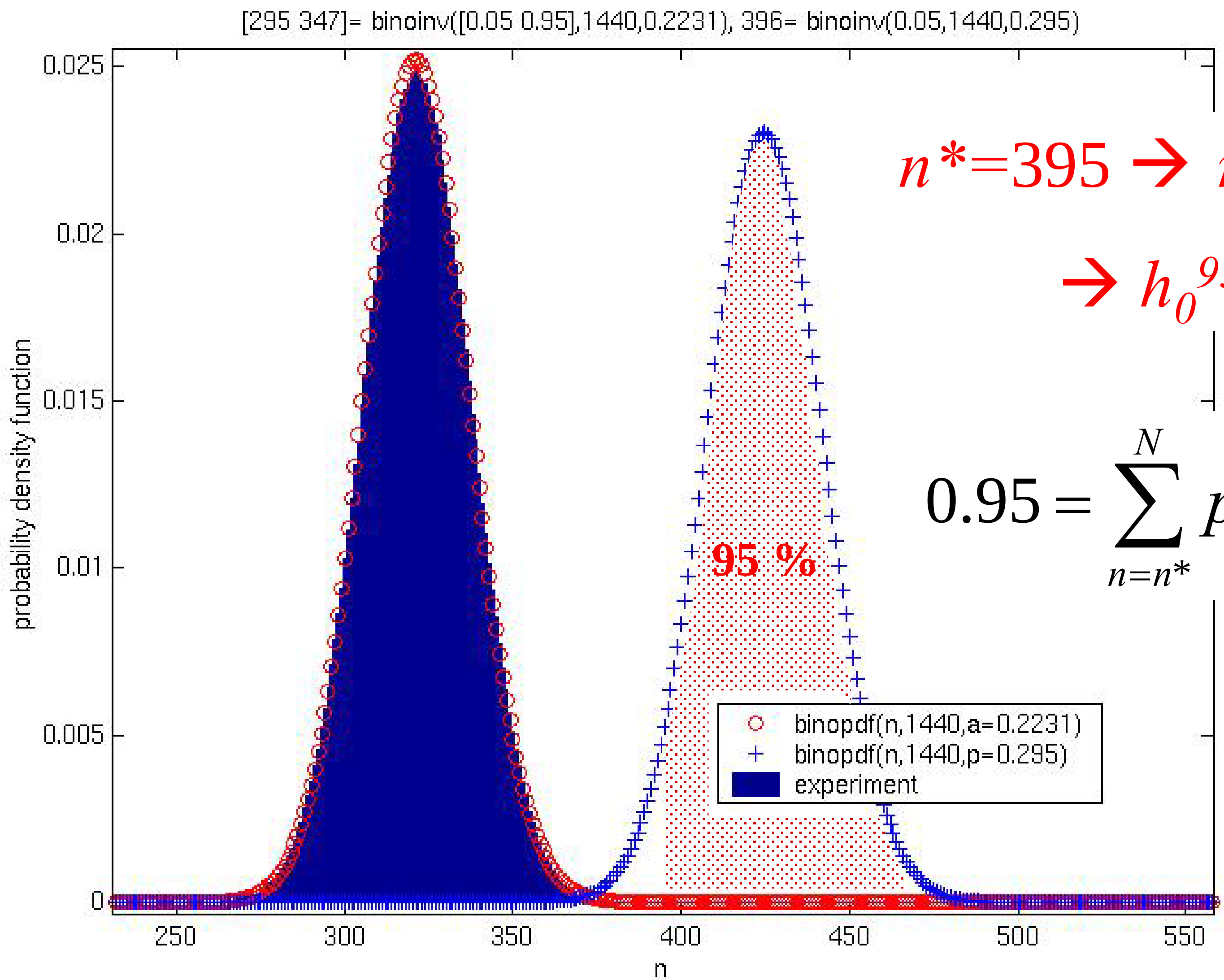
Number count probability distribution



Comparison with a binomial distribution



Set of upper limit.
Frequentist approach.

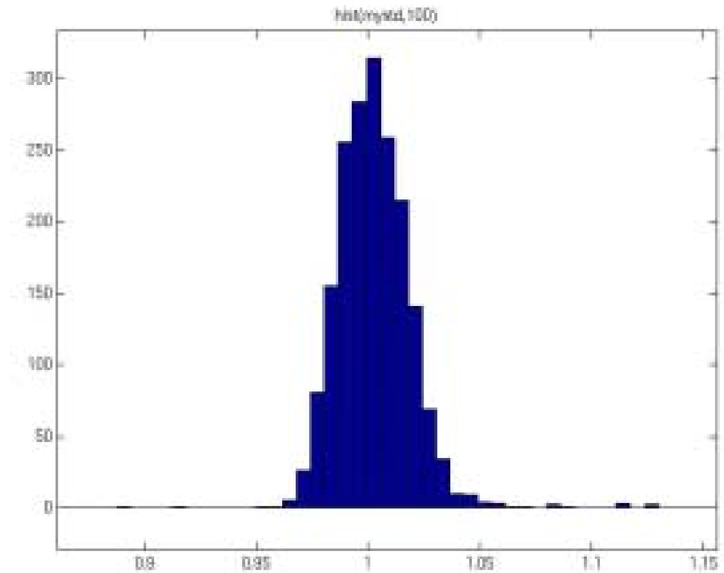


$n^*=395 \rightarrow \eta=0.295$

$\rightarrow h_0^{95\%}$

$$0.95 = \sum_{n=n^*}^{N} p\left(n|h_0^{95\%}\right)$$

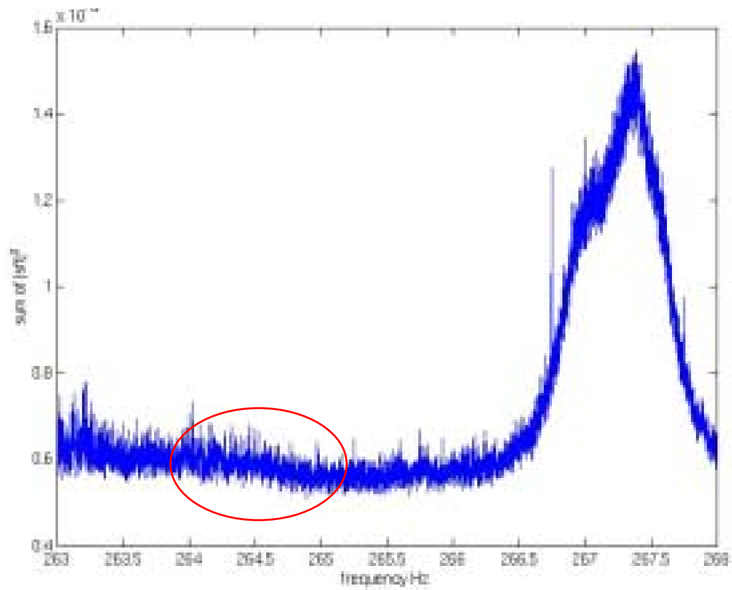
H1 Analysis – the SFTs

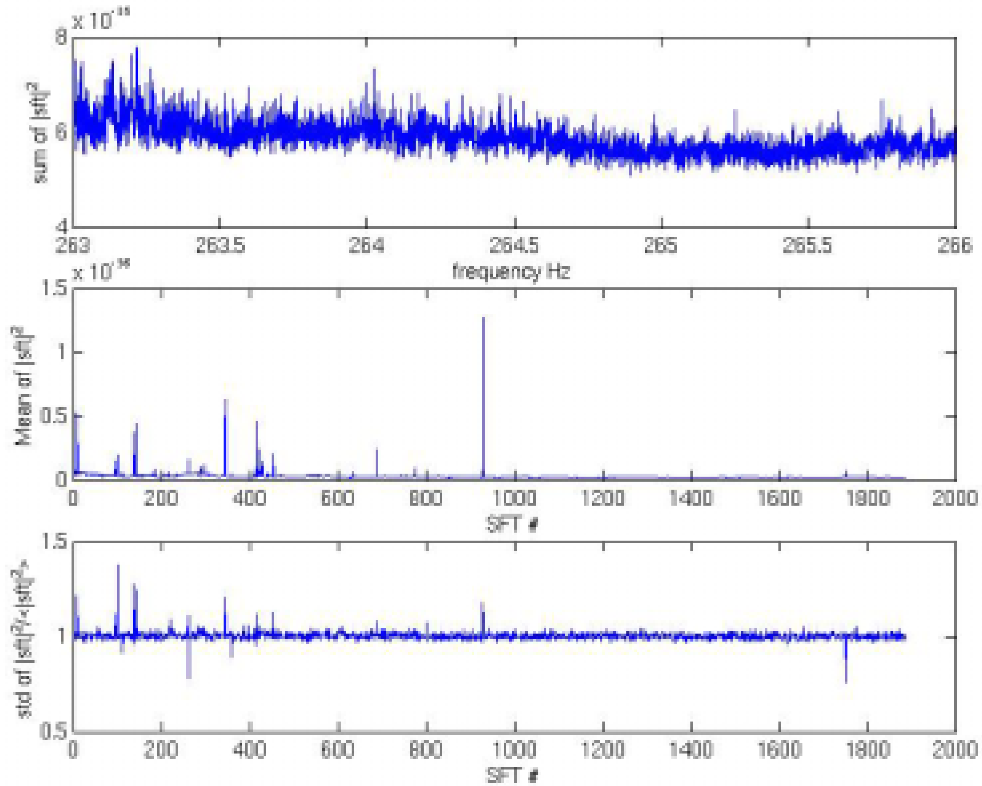


1887 Calibrated SFT's H1

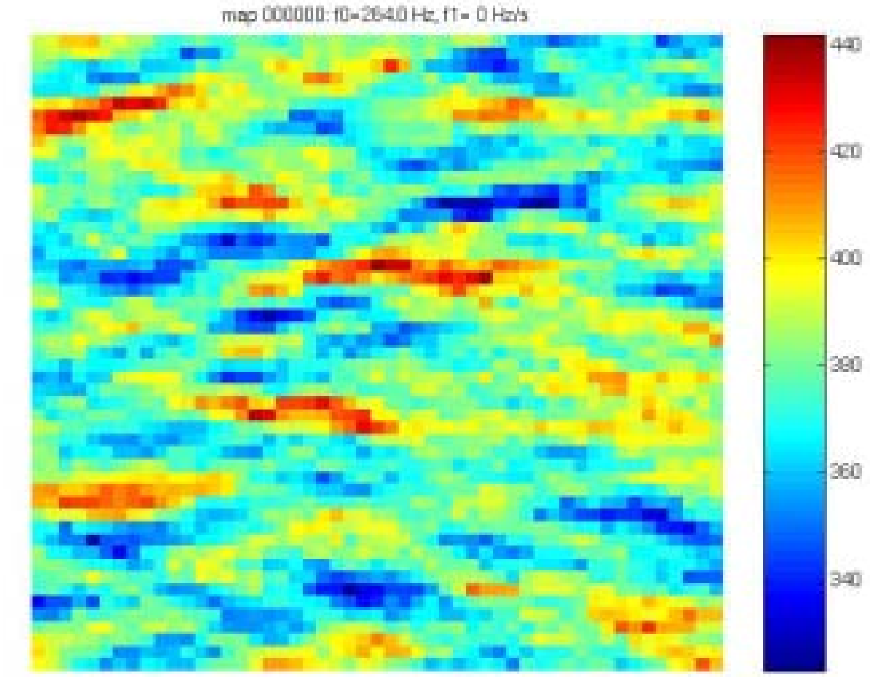
T_{SFT} = 1800s, Band : 263-268 Hz

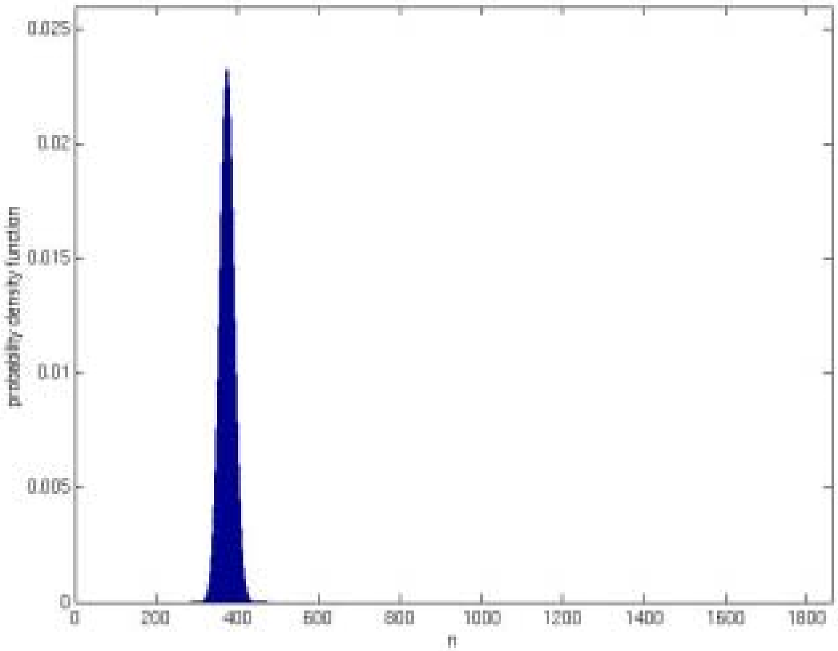
26 SFT, σ≤0.95 or σ≥1.05

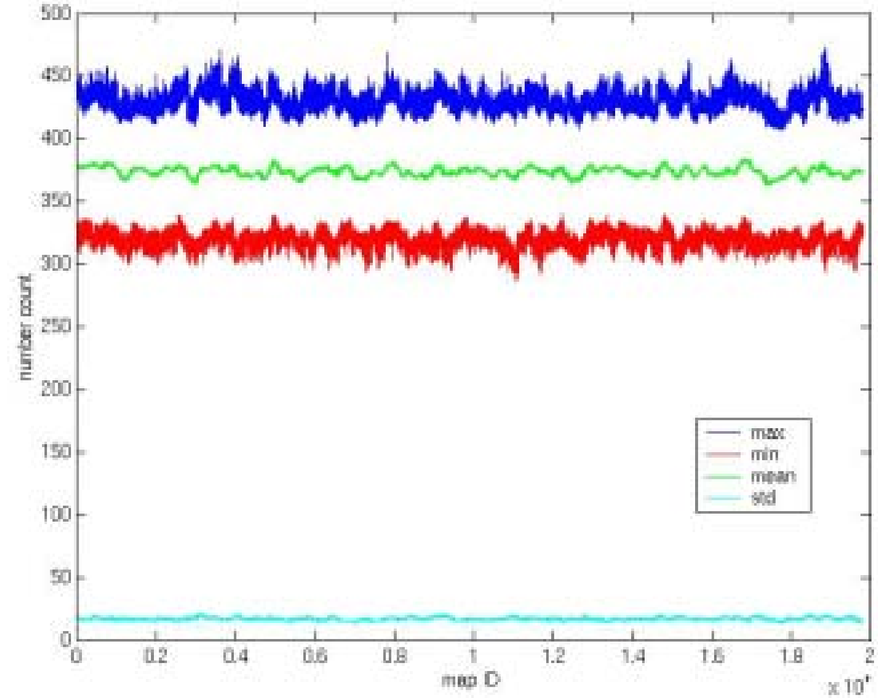




H1 Results
264-265 Hz







N=1861 SFTs

α=0.2019

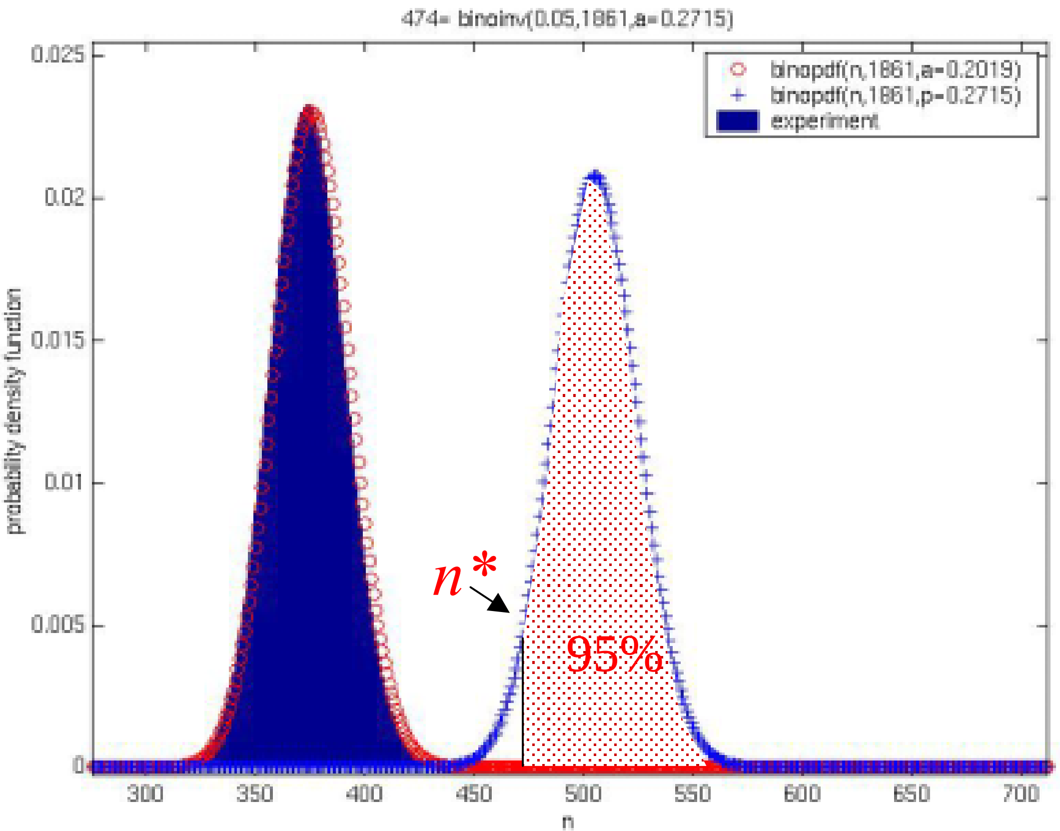
←Mean number count=373.8130

$<n> = N\alpha$=375.7294

$\sigma_n = \sqrt{(N\alpha(1-\alpha))}$=17.3168

H1 Results 264-265 Hz

"upper limit estimate"



Loudest event n*=473

95 % upper limit

$n^*=473 \rightarrow \eta=0.2715$

$$\frac{|\tilde{h}(f_i)|^2}{S_n(f_i)T_{SFT}} \approx (0.46)^2$$

$$\sqrt{S_n(f_i)} \approx 5.5\times 10^{-22} / \sqrt{Hz}$$

$$4|\tilde{h}(f_i)|^2 \approx \frac{3}{50} h_0^2 T_{SFT}^2$$

$\rightarrow h_0^{95\%} \sim 5\text{x}10^{-23}$?

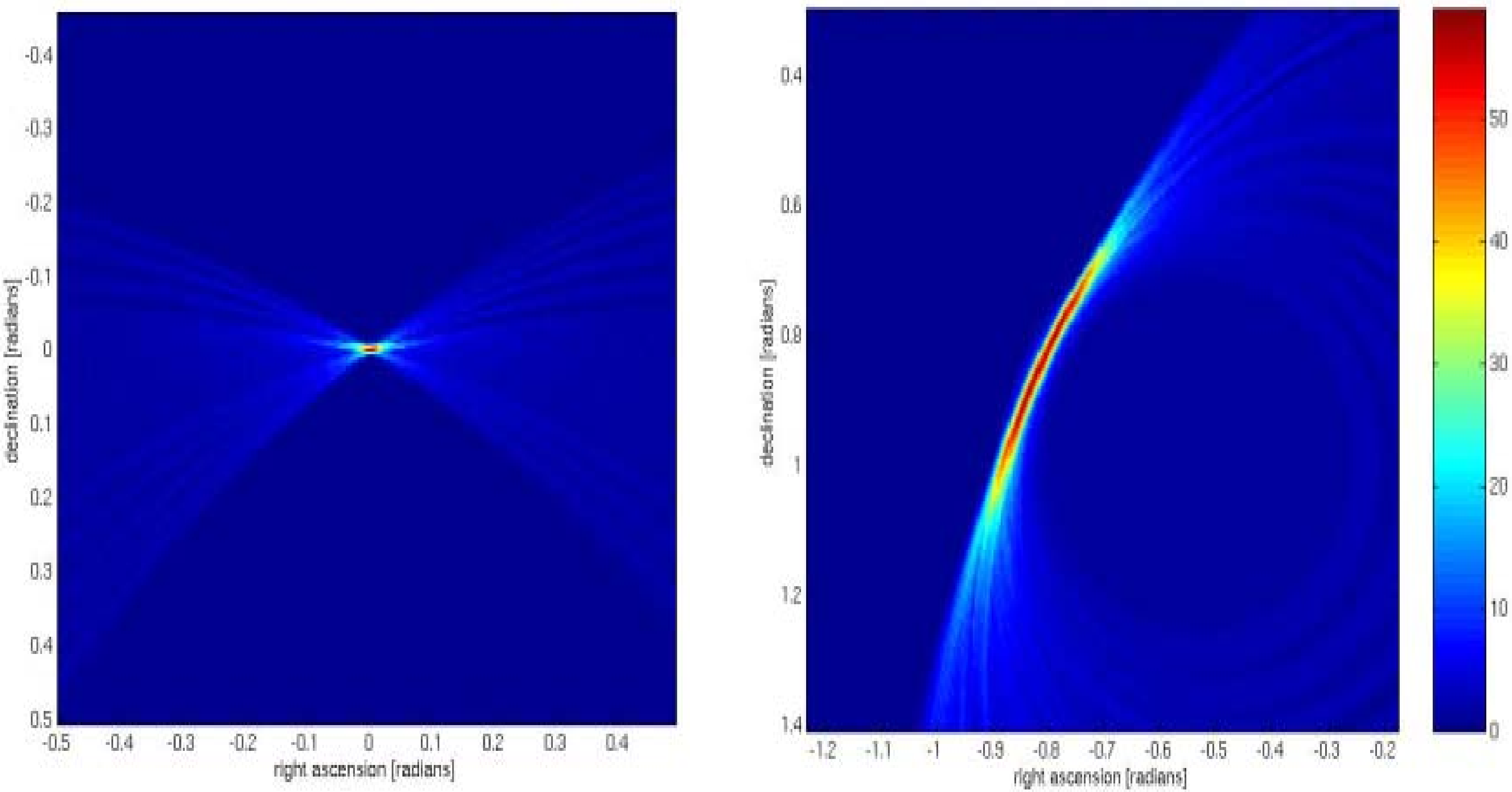
Very preliminary

Computational Engine

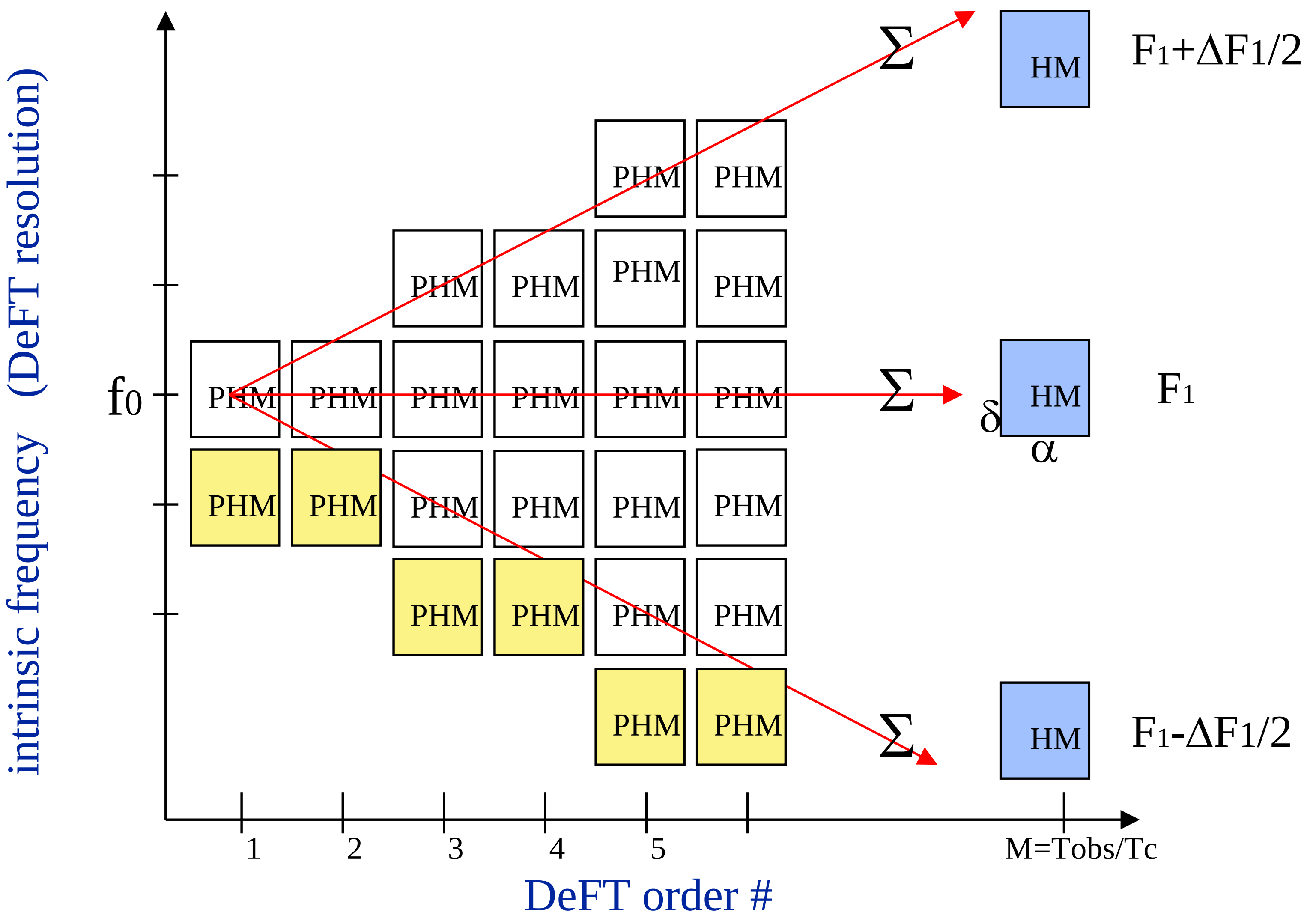
Searchs offline at:

- Medusa cluster (UWM)
  - 296 single-CPU nodes (1GHz PIII + 512 Mb memory)
  - 58 TB disk space
- Merlin cluster (AEI)
  - 180 dual-CPU nodes (1.6 GHz Athlons + 1 GB memory)
  - 36 TB disk space
- CPUs needed for extensive Monte-Carlo work

Signal only case



The cone of PHM



Signal model and parameters

$$h(t) = F_+(t)\, h_+(t) + F_\times(t)\, h_\times(t)$$

$$(\alpha,\delta), f_0, f_1, h_0, \iota, \psi, \phi_0$$

$$\left.\begin{aligned} &F_+(t,\psi) \\ &F_\times(t,\psi) \end{aligned}\right\}$$

beam-pattern functions and depend on the relative orientation of the detector w.r.t. the wave. They depend on ψ and on the amplitude modulation functions a(t) and b(t) that depend on the relative instantaneous position between source and detector.

$$\left.\begin{aligned} h_+(t) &= h_0 \frac{1+\cos^2\iota}{2} \cos \Psi(t) \\ h_\times(t) &= h_0 \cos\iota \sin\Psi(t) \end{aligned}\right\}$$

the two independent wave polarizations.

$$\Psi(t) = \phi_0 + \Phi(t)$$

the phase of the received signal depends on the initial phase and on the frequency evolution of the signal. The latter depends on the spin-down parameters and on the Doppler modulation, thus on the frequency of the signal and on the instantaneous relative velocity between source and detector.