Improved Hough Search for S4

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Outline

- Overview of S2 analysis
- Improvements for S4
- Preliminary S4 results

Review of S2 Hough analysis

- Start with 1800s SFTs for each detector
- Select frequency bins by setting threshold on normalized power – gives time-frequency collection of 0s and 1s
- For N SFTs, the final number count for a given parameter space point is $n = \sum_{i=1}^{N} n_i$ where n_i is 0 or 1
- For each i we pick bin where the signal would be located

Review of S2 Hough analysis

- Using 0s and 1s leads to gain in computational efficiency by allowing us to know before hand which templates would be triggered by a given frequency bin in a SFT
- Nominal sensitivity for given FA and FD assuming a perfectly matched template averaged over sky, orientations and polarization angles:

$$h_0 = 5.34 \frac{S^{1/2}}{N^{1/4}} \sqrt{\frac{S_n}{T_{SFT}}} \qquad S = erfc^{-1}(2\alpha_H) + erfc^{-1}(2\beta_H)$$

Review of S2 Hough analysis

- S2 analysis covered 200-400Hz, over the whole sky, and 11 values of the first spindown with a resolution of $(T_{obs}T_{SFT})^{-1} \approx 10^{-10}\,Hz/s$
- Three IFOs analyzed separately
- Upper limits obtained by signal injections

Detector	**L1**	**H1**	**H2**
Frequency (Hz)	200-201	259-260	258-259
$h_0^{95\%}$	**4.43×10^{-23}**	4.88×10^{-23}	8.32×10^{-23}

Improvements for S4

- Still work with 1800s SFTs (no demodulations)
- Take into account that the SFTs have different noise floors and the signal amplitude changes in time – SNR changes across SFTs
- Give more weight to SFTs having greater SNR
- Number count is not an integer anymore

$$n = \sum_{i=1}^{N} w_i n_i \qquad \sum_{i=1}^{N} w_i = N$$

Improvements for S4

- Using the weights does not lead to any loss in computational efficiency or robustness
- Weighing method was initially suggested by C.Palomba and S.Frasca at GWDAW-2004
- Has been generalized to the Multi-IFO case
- No decision yet on whether S4 Hough search should use Multi-IFO or not

Improvements for S4

- No intention to present at APS meeting
- Aim to include in S4 paper on semi-coherent searches
- Basic single-IFO search code and method has been reviewed
- However results and multi-IFO code have not yet been reviewed

Improvements for S4

- Improved Sensitivity: $$h_0 = 3.83\, S^{1/2} \left(\frac{\|w\|}{w \cdot X} \right)^{1/2} \sqrt{\frac{\langle S_n \rangle}{T_{SFT}}}$$
- Assumes template is perfectly matched to signal, and average over all pulsar orientations and polarization angles (but not over sky-positions)
- $X_i = \langle S_n \rangle \frac{a_i^2 + b_i^2}{S_n^{(i)}}$
- Optimal choice of weights is: $w_i \propto \frac{a_i^2 + b_i^2}{S_n^{(i)}}$
- Optimally weights should be calculated at same sky-location as signal

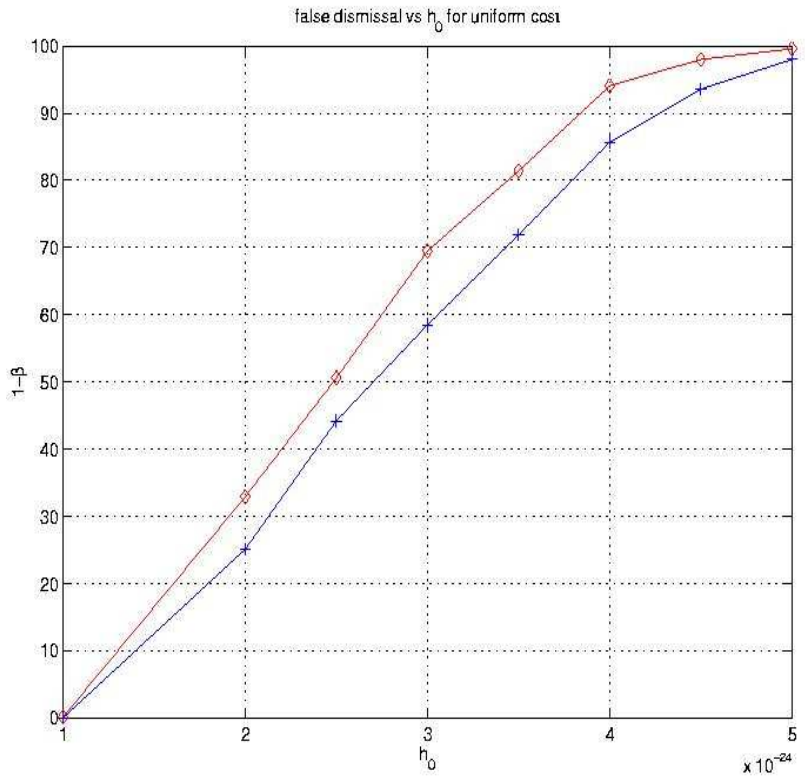
Improvements for S4

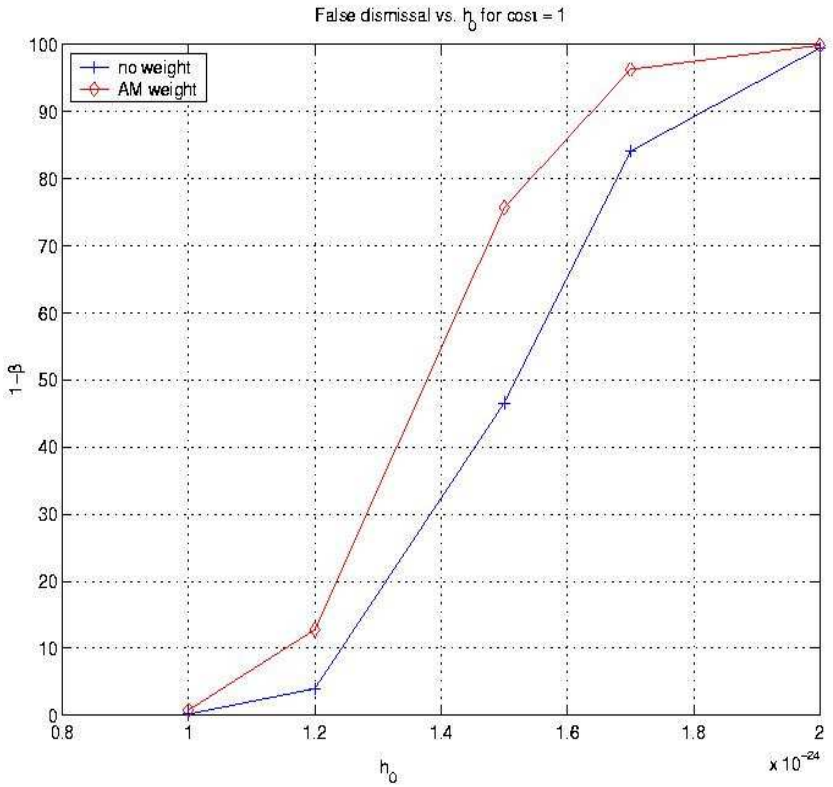
- Gain in sensitivity is large if standard deviation of SFT noise floors is large or if signal amplitude changes rapidly across SFTs
- Mean number count is unchanged due to normalization of weights: $\langle n \rangle = N\,\alpha = Ne^{-\rho_{th}}$
- Standard deviation always increases: $\sigma = \|w\| \sqrt{\alpha\,(1-\alpha)}$
- Number count threshold for a given false alarm:

$$n_{th} = N\,\alpha + \sqrt{2\,\|w\|^2\,\alpha\,(1-\alpha)}\,erfc^{-1}\,(2\,\alpha_H)$$

Improvement in detection efficiency

- Signal injections in fake data, 250-260Hz, random sky-position and polarization angles. Number count threshold set for $\alpha_H = 10^{-10}$





Improvement in detection efficiency

- Improvement in sensitivity at 90% effciency is roughly 10% in signal amplitude for a perfectly matched template
- The gain depends on pulsar orientation
- Will be somewhat degraded when searching in a sky-patch because of a mismatch and also because we will use a single set of weights for the whole skypatch (calculated at the center)

Preliminary S4 Results

- Search frequency band 100-1000Hz
- All sky search
- Sky is broken up into 92 patches typically about 0.4 rad x 0.4 rad wide
- 11 values of spindown at resolution of

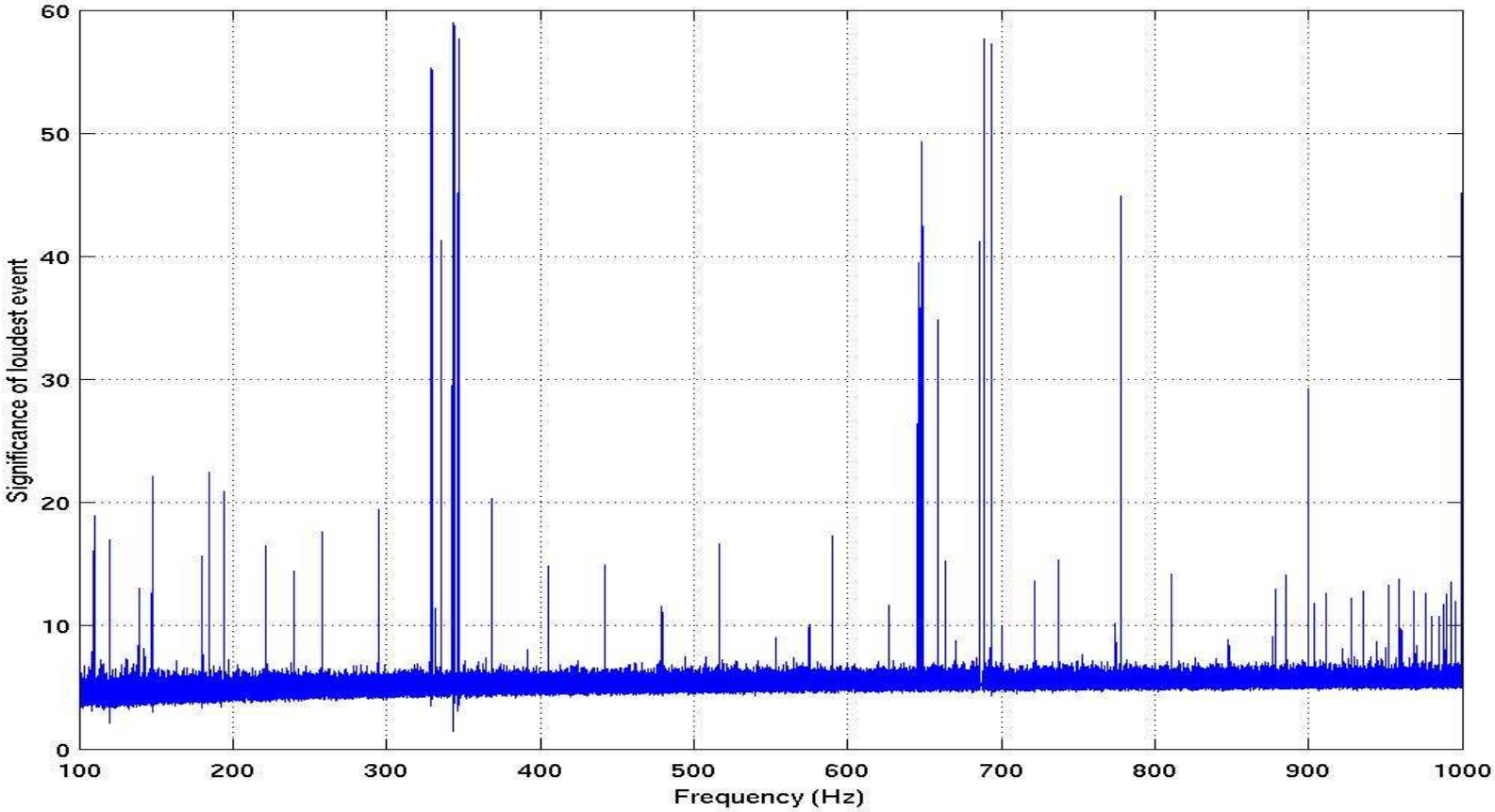
$$(T_{obs}\,T_{SFT})^{-1} \approx 2.2 \times 10^{-10}\ Hz/s$$

Preliminary S4 Results

- Line cleaning used to remove known narrow spectral lines
- Monte-Carlo injections will use the same line removal consistently
- Line cleaning method (same as used by stack-slide) was initially developed for S2 hough analysis but not used in the final S2 search for simplicity

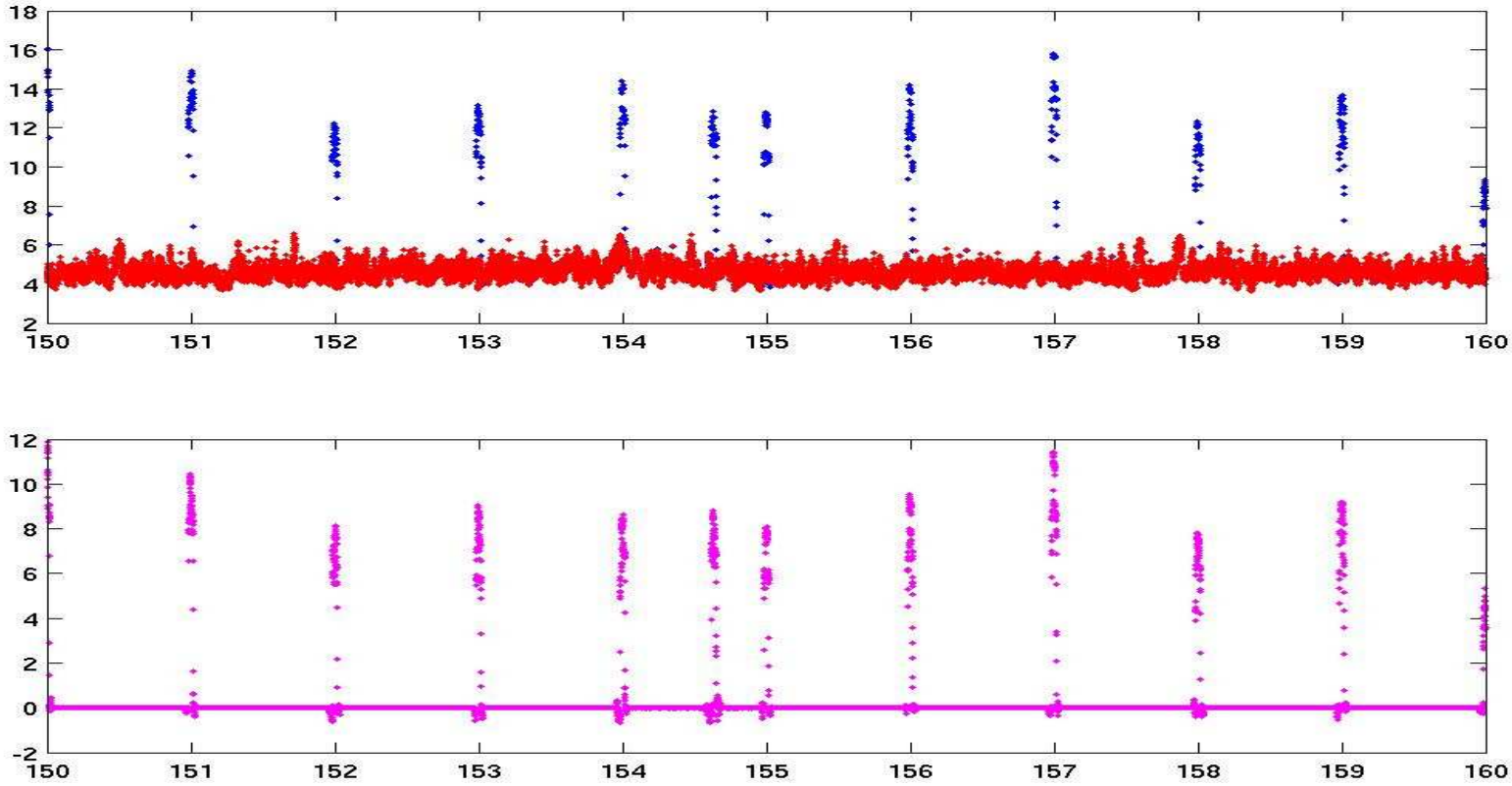
Preliminary S4 Results

- L1 most significant events: (n-mean)/std



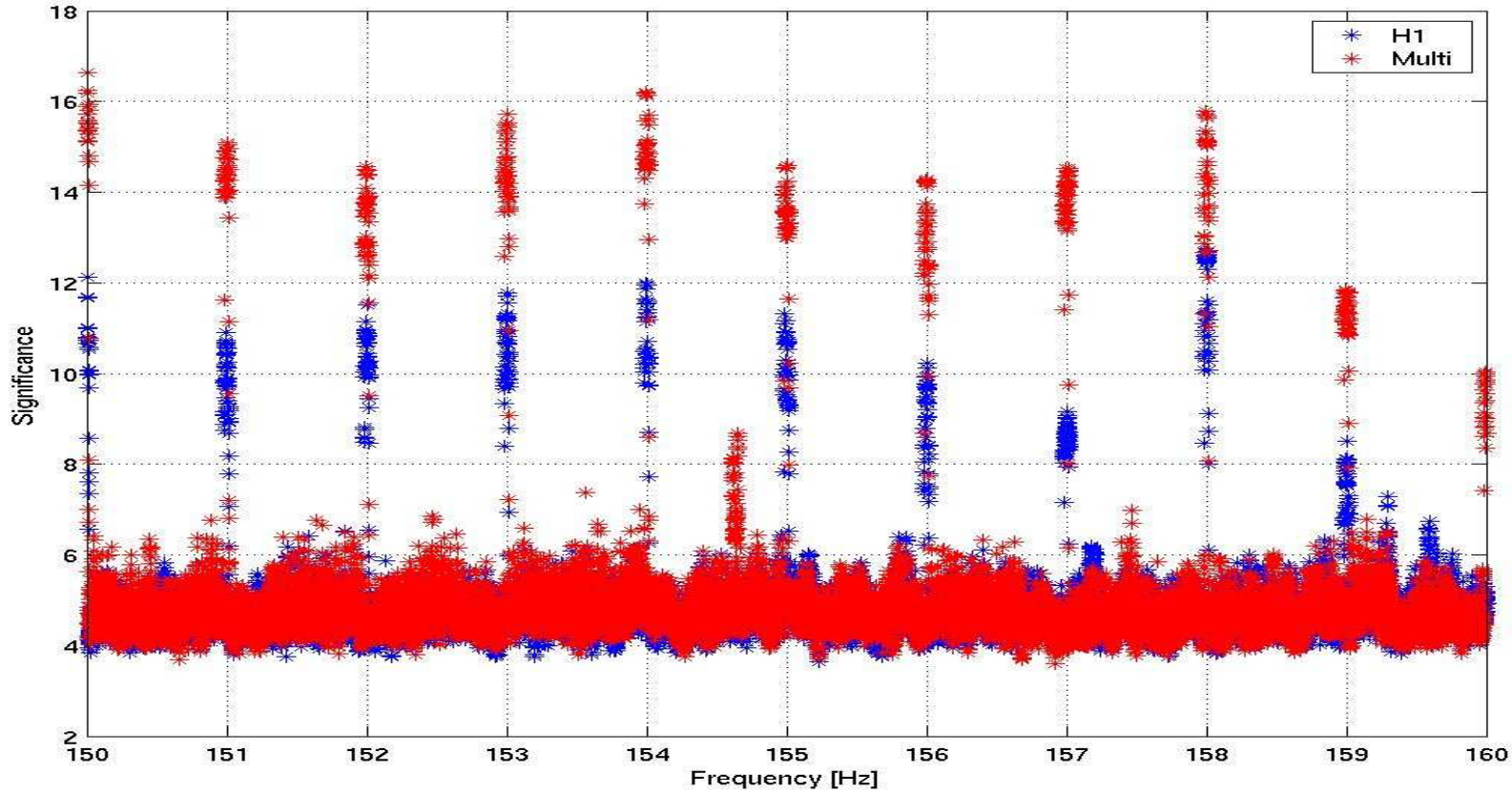
Preliminary S4 Results

- Effect of line cleaning (for L1)



Preliminary S4 Results

- Multi-IFO search 150-160Hz compared with H1

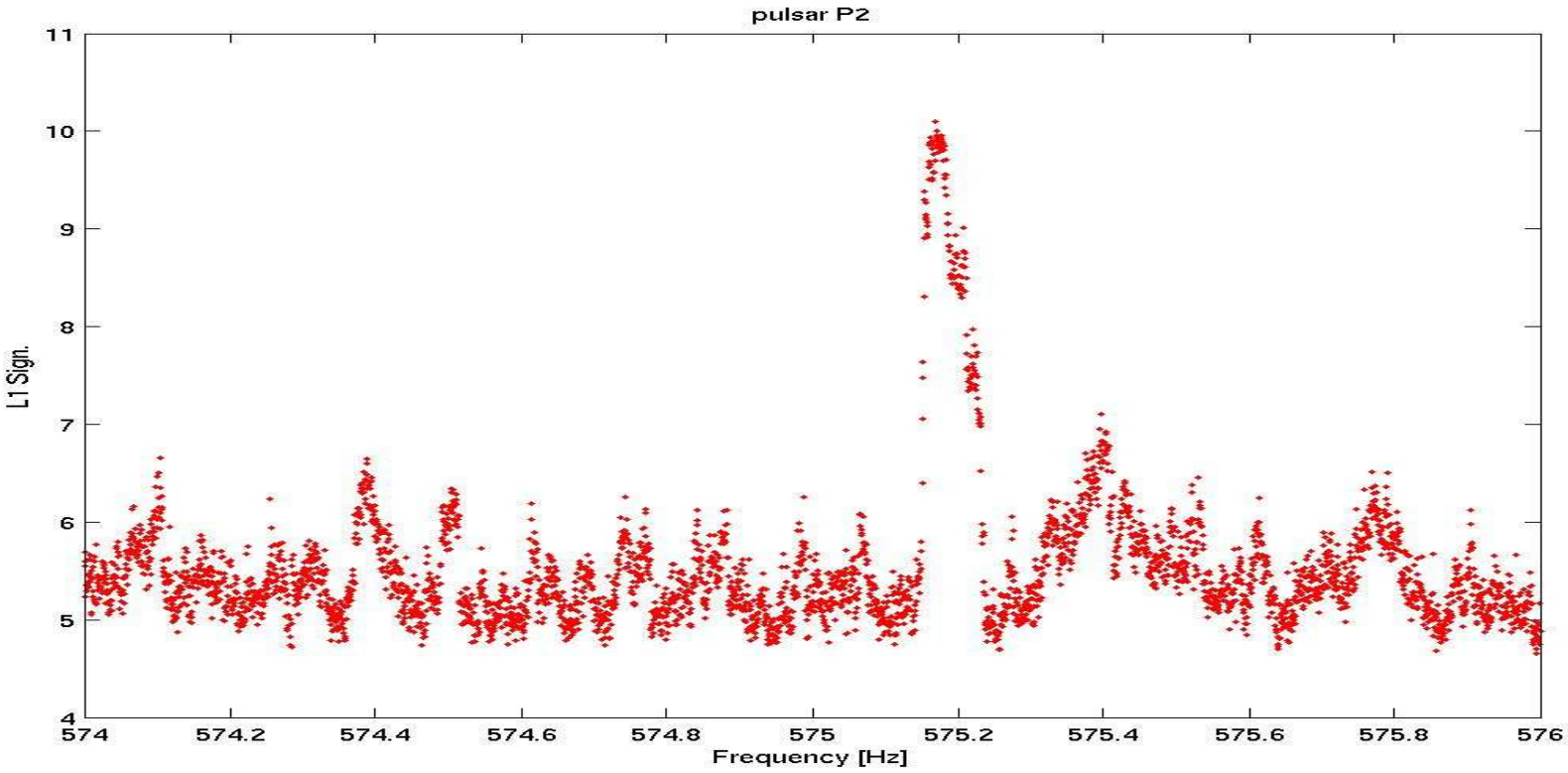


Preliminary S4 Results

- 1Hz lines are present in both L1 and H1 but not in H2
- However, H2 has higher noise and thus contributes less to total number count and thus multi-IFO search gives more significance to 1Hz lines

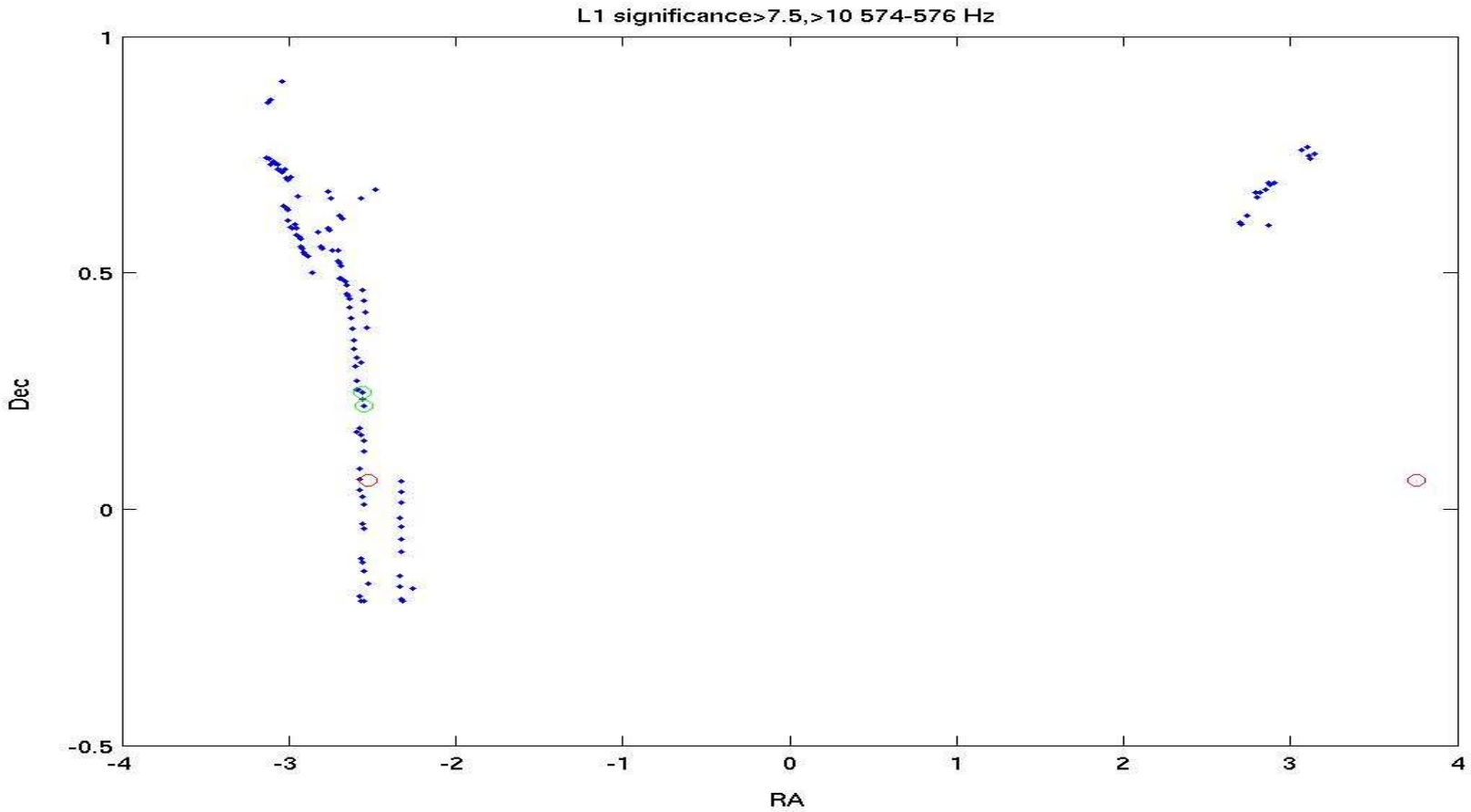
Preliminary S4 Results

- Injected pulsar P2 (f = 575.1636Hz, delta = 0.060 rad, alpha = 0.653 rad, h_0 = 8.49e-24)



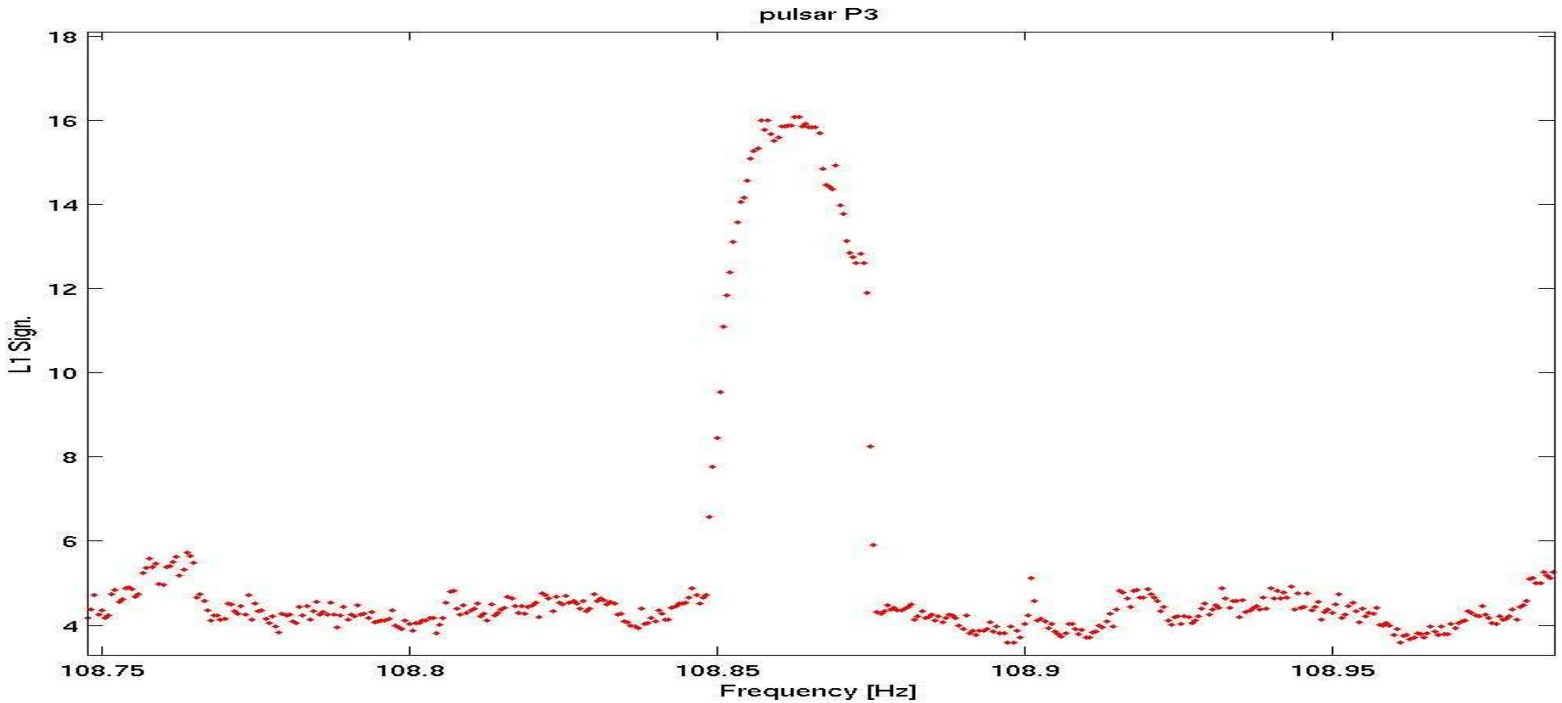
Preliminary S4 Results

- P2: sky-locations of most significant events



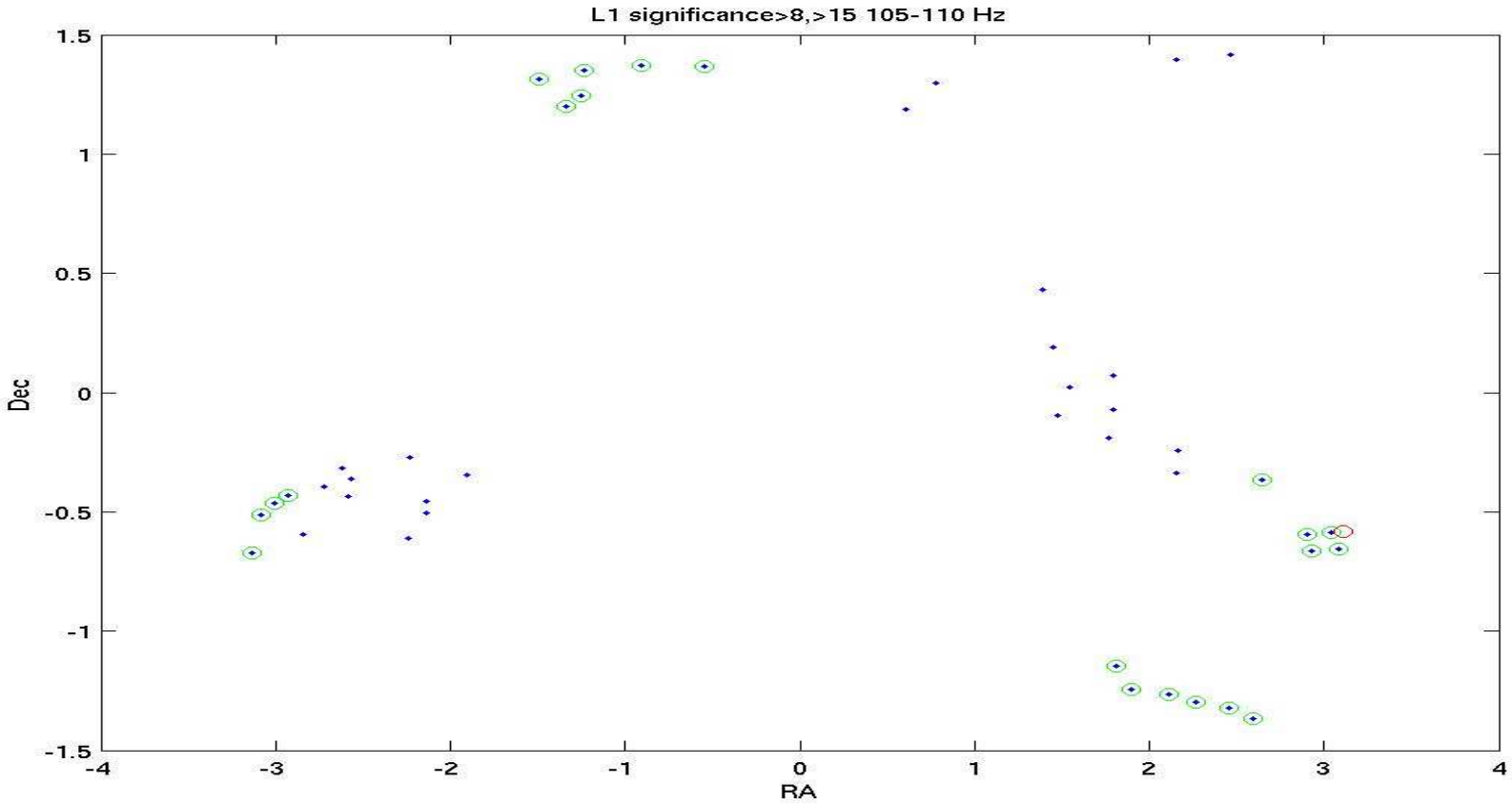
Preliminary S4 Results

- Injected Pulsar P3 (f = 108.857 Hz, delta =-0.5836 rad, alpha = 3.113rad, h_0 = 6.16e-23)



Preliminary S4 Results

- P3: sky-location of most significant events



In progress...

- Monte-Carlo code for setting upper limits in development in accordance with the modified search
- More validation of new Hough code and
- Comparison with Power-Flux and Stack-Slide have to be redone
- Ongoing development of Hough on F-statistic segments from multiple IFOs