The High-Frequency Stochastic Search (S4)

An Update for the March 2007 LSC Meeting

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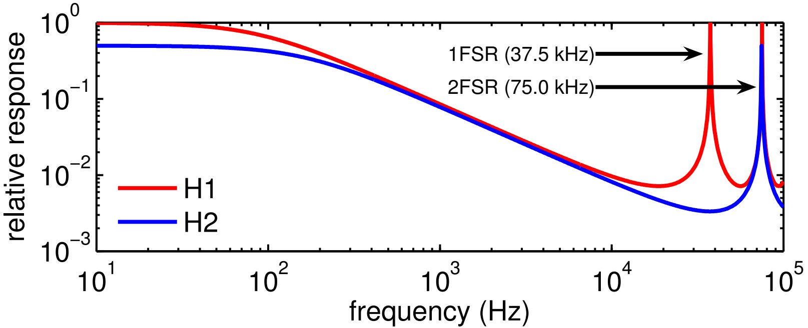
Motivation

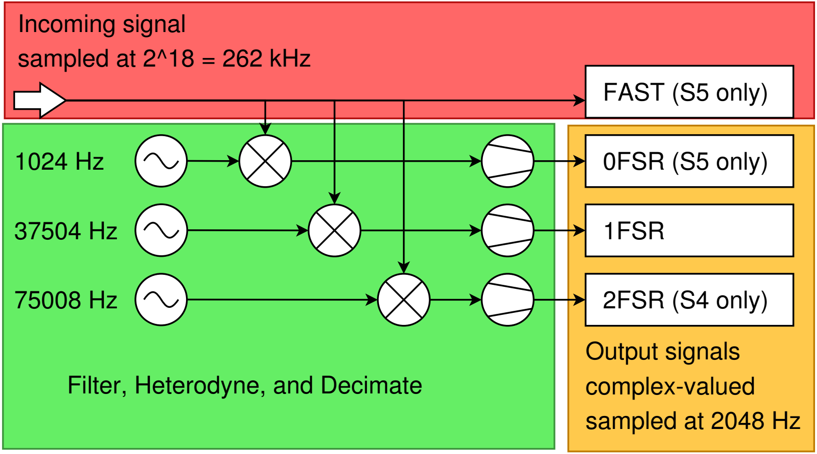
- Interferometers have increased sensitivity at the free spectral ranges of the arms–as good as at DC!



- We conduct a coherent all-sky search at 37.5 kHz and 75 kHz using `H1-H2`.

Data Acquisition

The fast DAQs (`h{1,2}adcufast`) provide 2048 Hz swaths of bandwidth centered at 1FSR and 2FSR, downshifted to zero Hz.

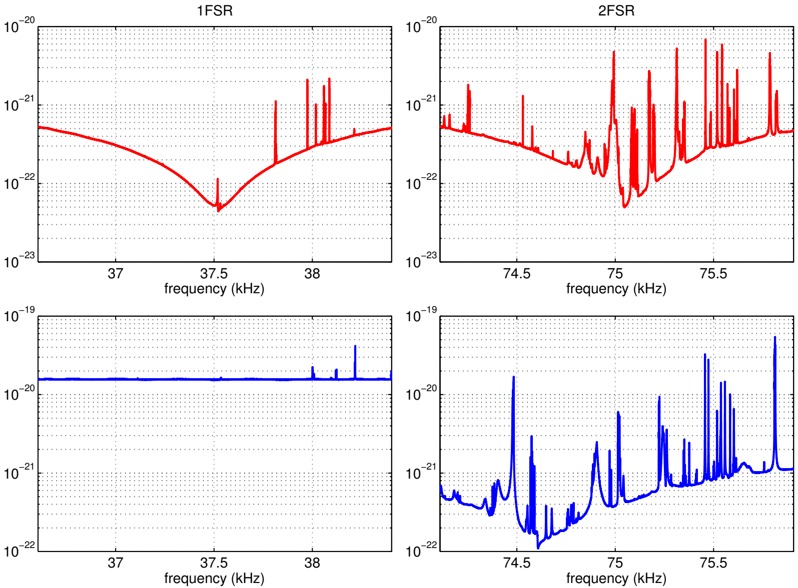


Calibration

- Calibration based on two measurements (before and after the run) of calibration lines in the `FAST` channel.
- We use the standard interferometer model with appropriate additions for our channels.
- (Direct excitation at 37 kHz is problematic.)
- Final results are scaled by antenna pattern integrated over all angles, relative to low frequency.

See also "Introduction to Calibration at the FSR" (T070044), "Geometric Acceptance at FSR" (T070043), and Stefanos' talk at DetChar.

Spectra


1FSR
2FSR
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-19}
37
37.5
38
74.5
75
75.5
frequency (kHz)

Analysis Method

We conduct a standard cross-correlation search.

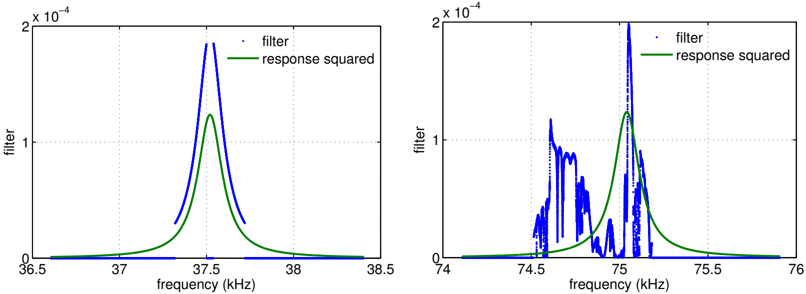
$$
\begin{aligned}
x_1(f) &= s(f) + n_1(f) \\
x_2(f) &= s(f) + n_2(f)
\end{aligned}
$$

$$\langle {x_1}^* x_2 \rangle = |s(f)|^2$$

Frequency bins are weighted via a filter Q, giving one *statistic*, Y_I, for each 256 second interval:

$$
\begin{aligned}
Y_I &= \int Q(f) x_1(f)^* x_2(f) df \\
{\sigma_I}^2 &\approx \int Q(f)^2 |x_1(f)|^2 |x_2(f)|^2 df
\end{aligned}
$$

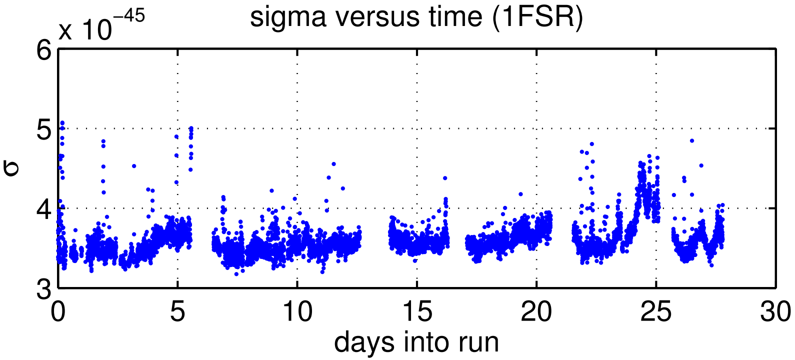
Choice of filter



The theoretical form of the optimal filter is the squared response of the instrument divided by the product of the PSDs of the channels. For 1FSR, we take the PSD to be completely uniform but notch the "double cavity pole". For the 2FSR filter, we use the PSD as averaged over the entire run.

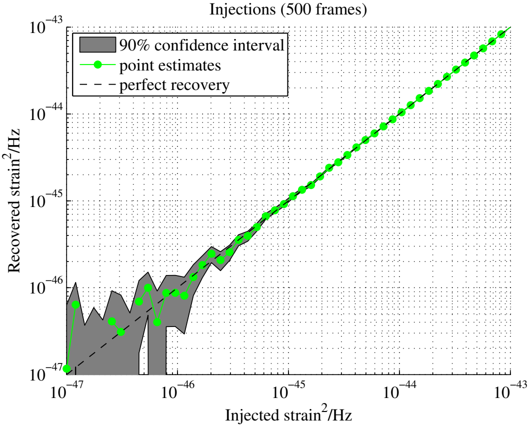
Data cuts

1. We apply data quality flags to get a list of "good times."
2. We use only frames that fall entirely within these intervals.
3. We currently do no cuts based on σ_I.



Validation: Injections

We use our own software, written in Matlab. It is relatively concise ($\approx$ 2000 lines). The code may be found in Matapps CVS under `src/searches/stochastic-fsr`. The software is validated via software injections.



Timing: How synched are H1 and H2?

A relative time shift τ between H1 and H2 introduces a phase $\phi = 2\pi f \tau$ into our measurement:

$$\begin{aligned} x_1(f) &= s(f) + n_1(f) \\ x_2(f) &= e^{i\phi}\left[s(f) + n_2(f)\right] \end{aligned}$$

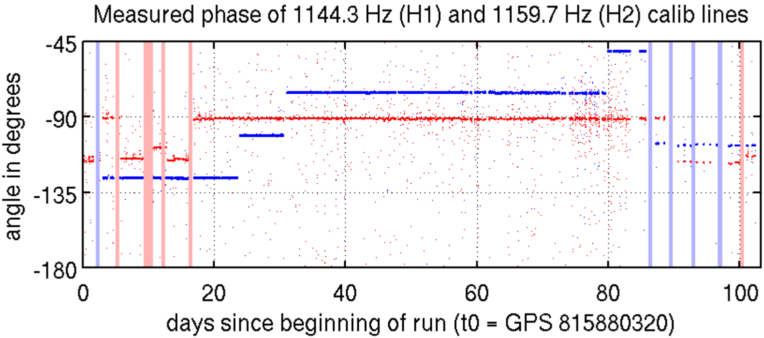
$$\langle {x_1}^* x_2 \rangle = e^{i\phi} |s(f)|^2$$

Because of the high frequency under consideration, we're much more sensitive to timing shifts τ than the low frequency search.

- To investigate, we examine `0fsr` channel in S5...

Timing investigation (S5 data)

To check the timing, we used the `0fsr` channel to look at the calibration lines at the beginning of S5.



- Jitter is less than one microsecond RMS. No problem.
- We also find discrete jumps in phase!
- Most associated with DAQ reboots.

Timing: marginalization

Neither `OFSR` nor the full bandwidth fast channel were archived during S4, so we can't look for relative timing information.

1. One approach would be to assume no discrete phase jumps between reboots (or something similar). Marginalize over phase within these segments, combine segments incoherently (using Bayesian likelihoods).
2. The more conservative approach is to not use any inter-frame phase information, and instead combine all of the statistics incoherently. *We adopt this approach.*

- This increases our (strain) upper limit by a factor of ≈ 2.5.

Results

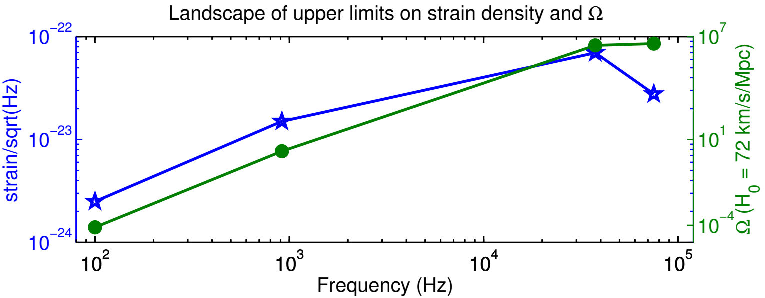
Performing an incoherent combination (using Bayesian likelihood) of our 6017 statistics Y_I with associated sigmas σ_I, we obtain 90% upper limits on gravitational wave strain of:

$$\boxed{\begin{array}{l} |h_0|_{\rm rms}(f = 37.5\ {\rm kHz}) < 6.97 \times 10^{-23}/\sqrt{\rm Hz} \\ |h_0|_{\rm rms}(f = 75.0\ {\rm kHz}) < 2.77 \times 10^{-23}/\sqrt{\rm Hz} \end{array}} \tag{1}$$

In terms of Ω, these limits are:

$$\boxed{\begin{array}{l} \Omega_{\rm GW}(f = 37.5\ {\rm kHz}) < 3.10 \times 10^{6} \\ \Omega_{\rm GW}(f = 75.0\ {\rm kHz}) < 3.92 \times 10^{6} \end{array}} \tag{2}$$

Conclusion



1. Heterodyne channels calibration currently under review (Rick Savage *et al*)
2. S4 Paper currently under review (Warren Anderson *et al*)
3. Web page with our notes: `http://web.pas.rochester.edu/~tobin/ligo/fsr`

Bonus slide: Optimal (coherent) combination

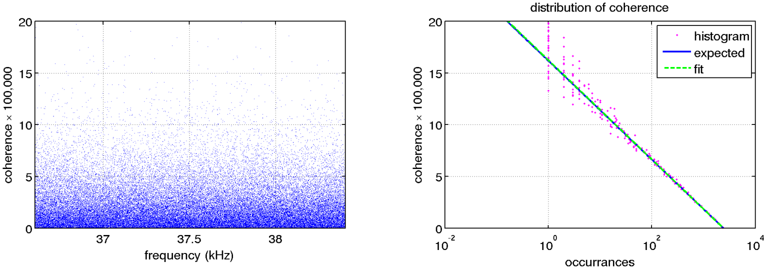
Individual statistics can be combined optimally to get a final answer:

$$
\begin{aligned}
Y &= \left(\frac{1}{\sum 1/{\sigma_I}^2}\right) \sum_{I=0}^{N} \frac{Y_I}{{\sigma_I}^2} \\
\sigma^2 &= 1 \Big/ \left(\sum_{I=0}^{N} \frac{1}{{\sigma_I}^2}\right)
\end{aligned}
$$

See also "Another view of the Optimal Filter" (`T069245`).

Bonus slide: Diagnostics: Coherence

Coherence at 1fsr: (2fsr is similar.)



We find no statistically significant coherence. No lines are apparent. (Plot shows $1/(32\ \mathrm{s}) = 0.03\ \mathrm{Hz}$ resolution.)

- ...But timing problems could make this a false negative.
- ...But S5 coherence measurements also show no coherence.