The Search for a Stochastic Gravitational Wave Background

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LIGO

Characterization of a Stochastic Gravitational Wave Background

- **Assuming SGWB is isotropic, stationary, and Gaussian the strength is fully specified by the energy density in GWs**

$$\Omega_{gw}(f) = \frac{1}{\rho_{critical}} \frac{d\rho_{gw}}{d(\ln f)}$$

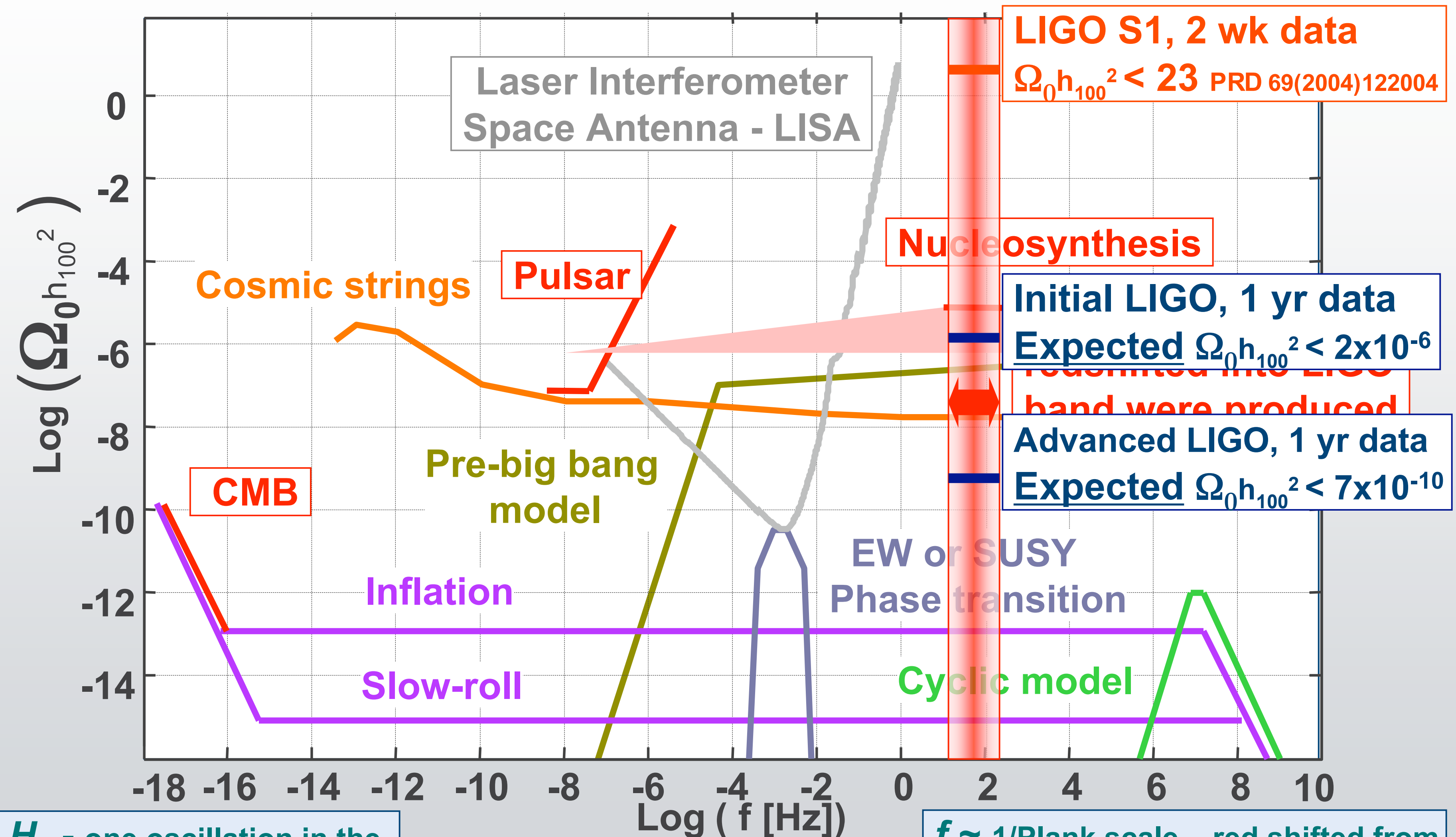
- **$\Omega_{gw}(f)$ in terms of the strain power spectrum, $S_{gw}(f)$:**

$$S_{\rm gw}(f) = \frac{3H_0^2}{10\pi^2} f^{-3}\Omega_{\rm gw}(f)$$

- **Strain amplitude scale:**

$$h(f) = S_{\rm gw}^{1/2}(f) = 5.6\times10^{-22}\, h_{100}\sqrt{\Omega_0}\left(\frac{100\rm Hz}{f}\right)^{3/2} {\rm Hz}^{1/2}$$

LIGO Predictions and Experimental Limits



f ~ H_0 - one oscillation in the lifetime of the universe

f ~ 1/Plank scale – red shifted from the Plank era to the present time

Data Analysis Strategy

- **Assume that detector noise $n_i(t)$ dominates the output, $P_i(f)$ - noise power spectrum**
- **Cross-correlate outputs from two interferometers $s_i(t) = h_i(t) + n_i(t)$**
- **Operator $\tilde{Q}(f)$ weights the cross-correlation to maximize the signal-to-noise ratio of the $\Omega_{gw}(f)$ measurement**
- **Overlap reduction function $\gamma(f)$ accounts for separation and angle between two detectors**

$$Y = \iint dt_1 dt_2\ s_1(t_1) Q(t_1 - t_2) s_2(t_2)$$

$$\overline{Y} = \frac{T}{2} \int df\, \gamma(f) S_{gw}(f) \tilde{Q}(f)$$

$$\sigma_Y^2 \approx \frac{T}{4} \int df\, P_1(f) \left|\tilde{Q}(f)\right|^2 P_2(f)$$

$$\tilde{Q}(f) \propto \frac{\gamma(f) S_{gw}(f)}{P_1(f) P_2(f)}$$

Signal

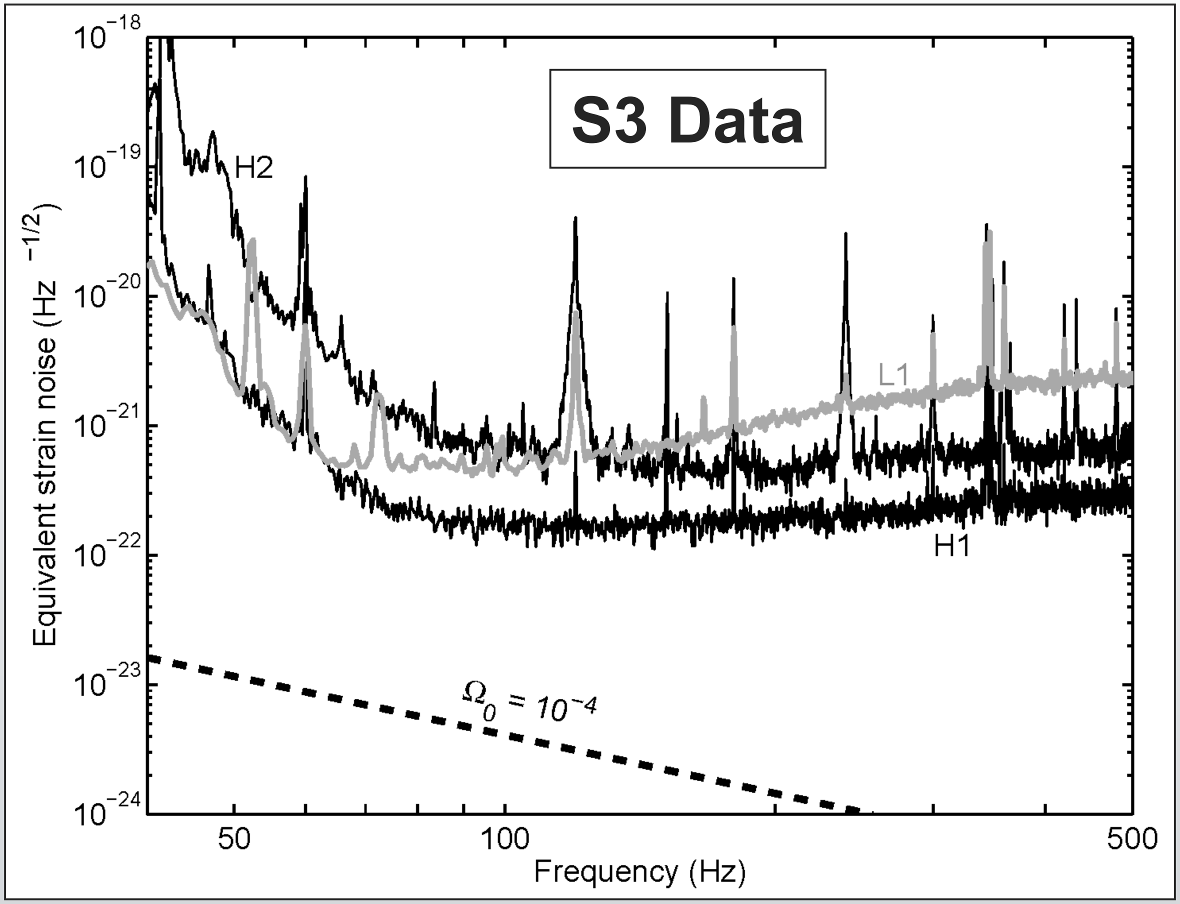
Noise

Allen, Romano, PRD59 (1999)

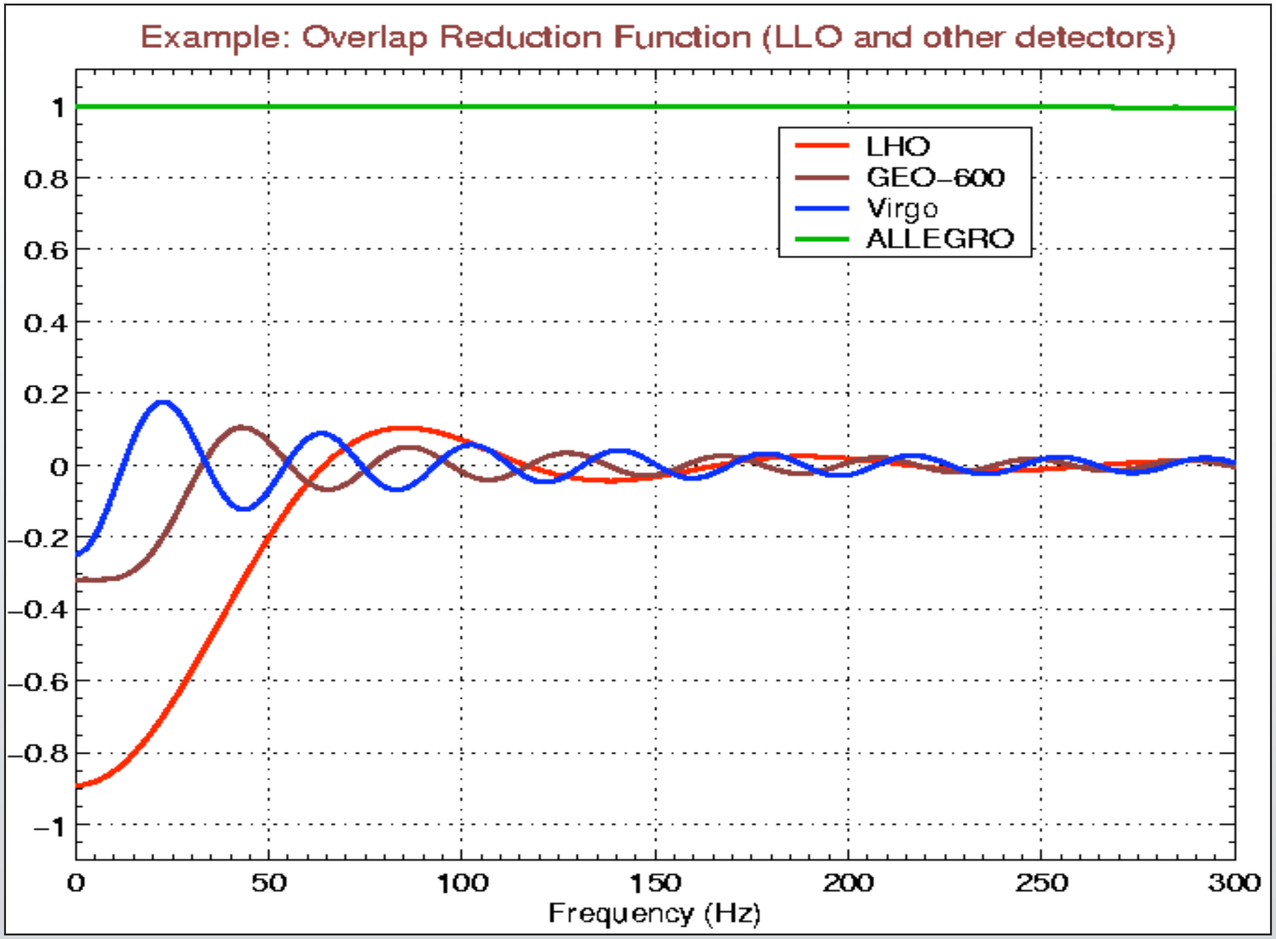
$S_{gw}(f) \propto 1/f^3$ *for* $\Omega_{gw}(f) = \Omega_0 =$ *const*

Strain Noise Spectral Densities

- **S2 and S3 runs have comparable observation time (387 and 350 hours respectively) but S3 sensitivity is an order of magnitude better than S2.**

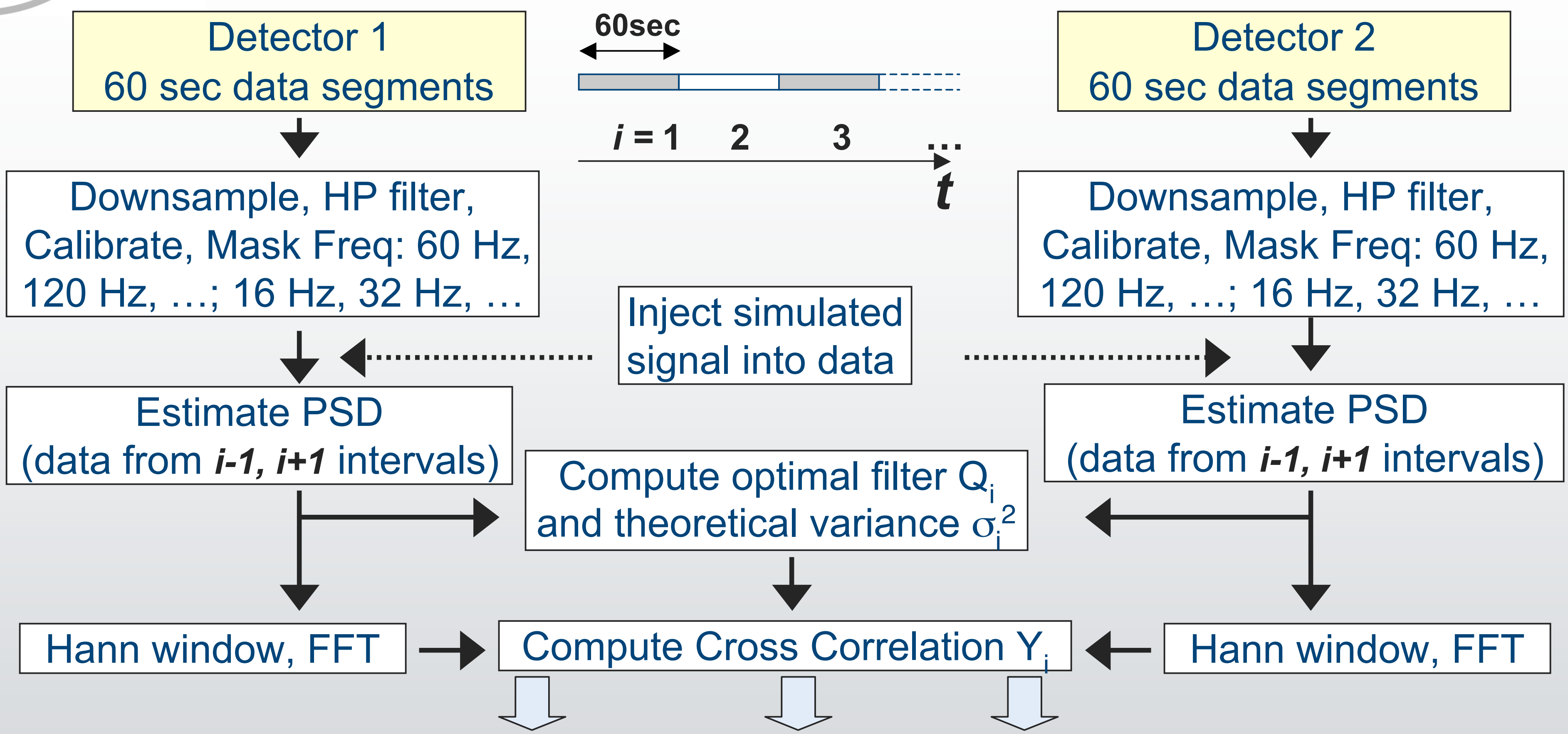


Overlap Reduction Functions Between L1 and Other Detectors



Flanagan, PRD48, 2389 (1993)

Data Analysis Flow



$$Y_{\mathrm{opt}} = \frac{\sum_i \sigma_i^{-2} Y_i}{\sum_i \sigma_i^{-2}}$$

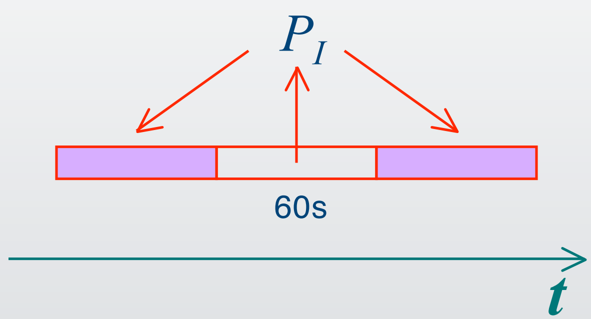
$$\sigma_{\mathrm{opt}}^{-2} = \sum_i \sigma_i^{-2}$$

$$\Omega_0 h_{100}^2 = Y_{\mathrm{opt}} / T$$

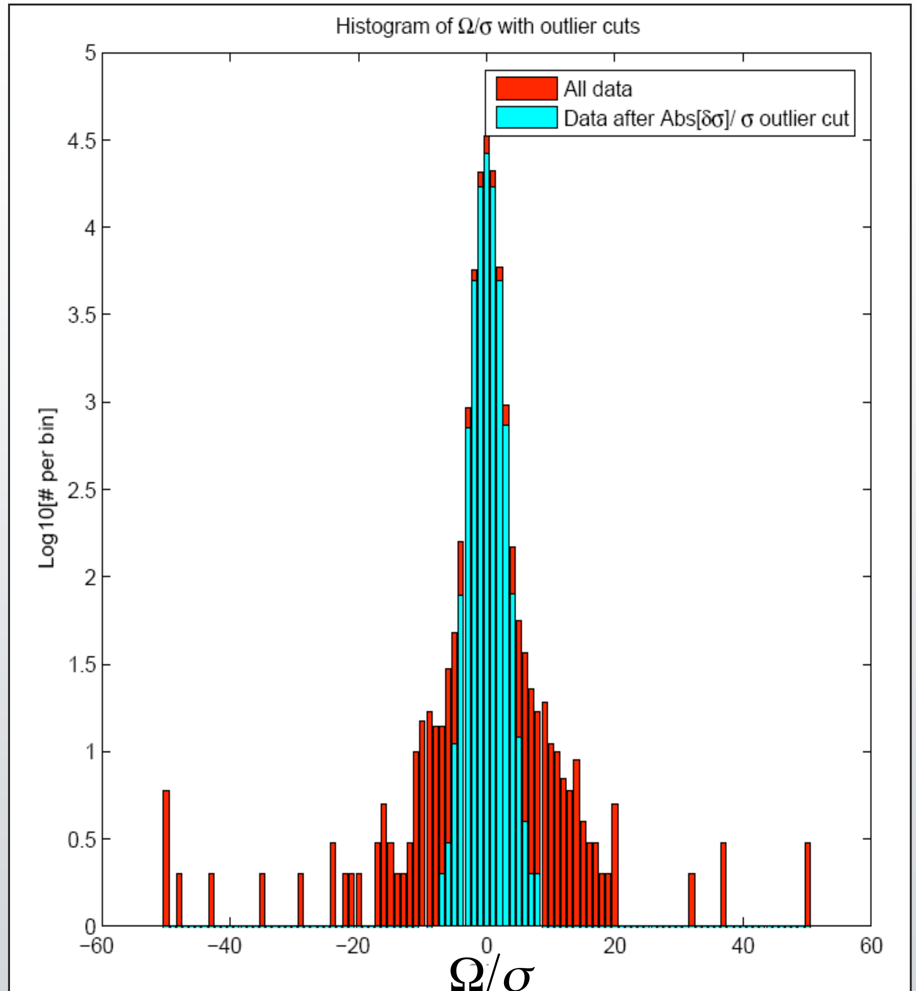
$$\hat{\sigma}_\Omega = \sigma_{\mathrm{opt}} / T$$

Dealing with Non-stationary Noise

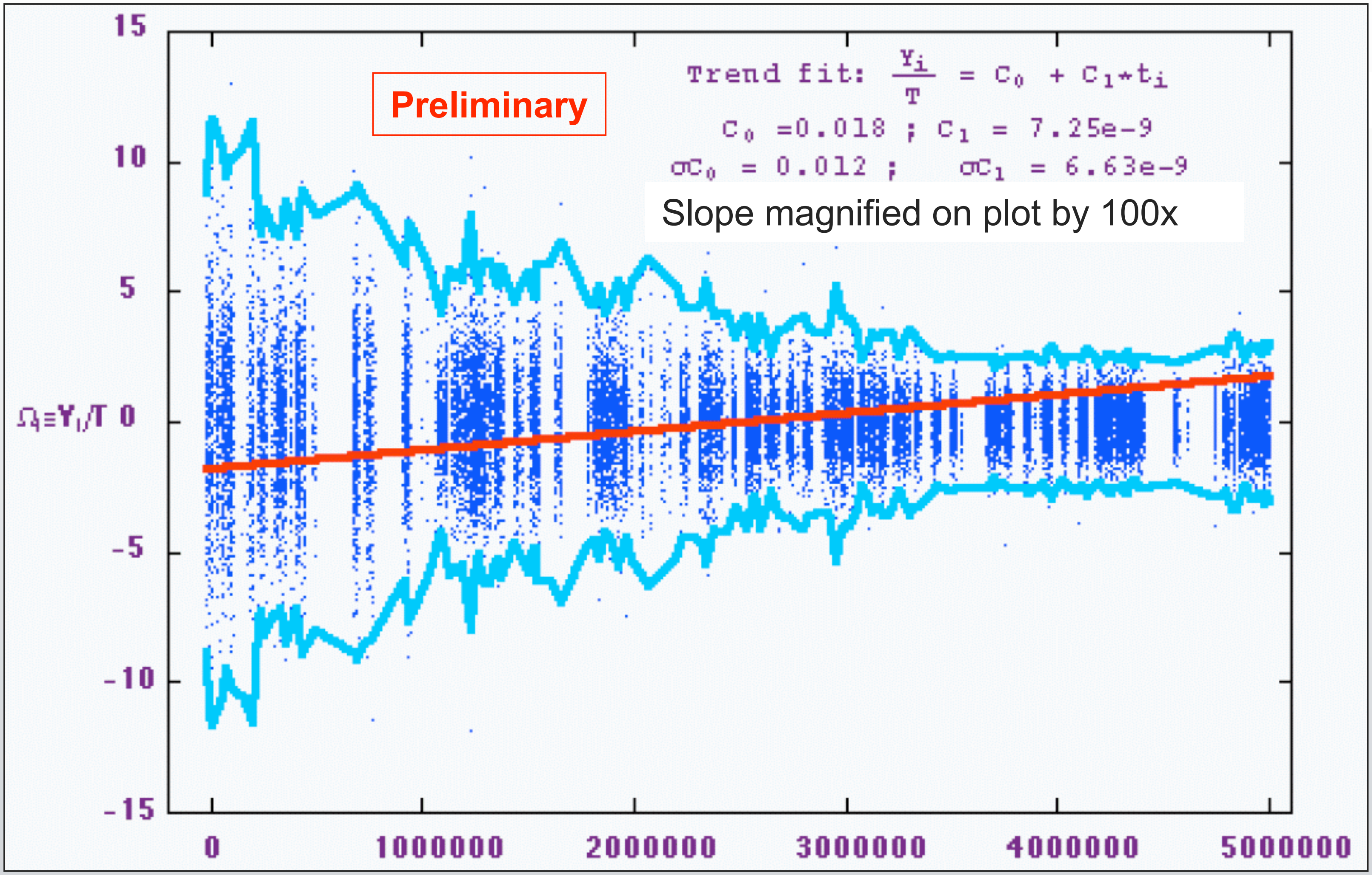
- **Sigma-integrand is proportional to 1/(P1*P2)**
- **P1, P2 estimated using data outside of 60s interval being analyzed, to avoid bias in cross-correlation**



- **Problems with PSD estimators when the noise is non-stationary over this time period**
- **Compare this PSD to that computed with data in the interval; reject interval if they don't agree within 20%**

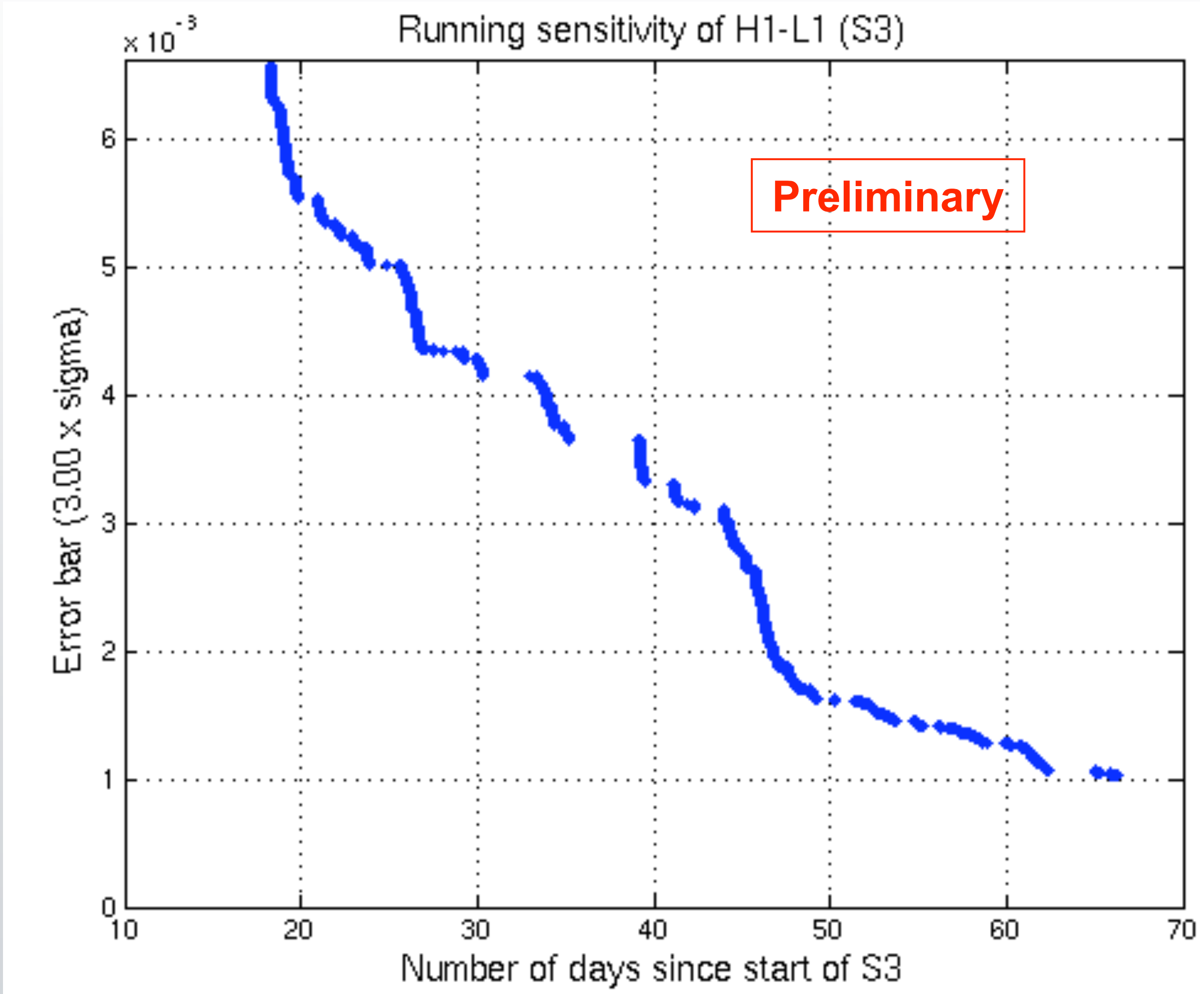


S2 Results: H1-L1 CC statistic trend



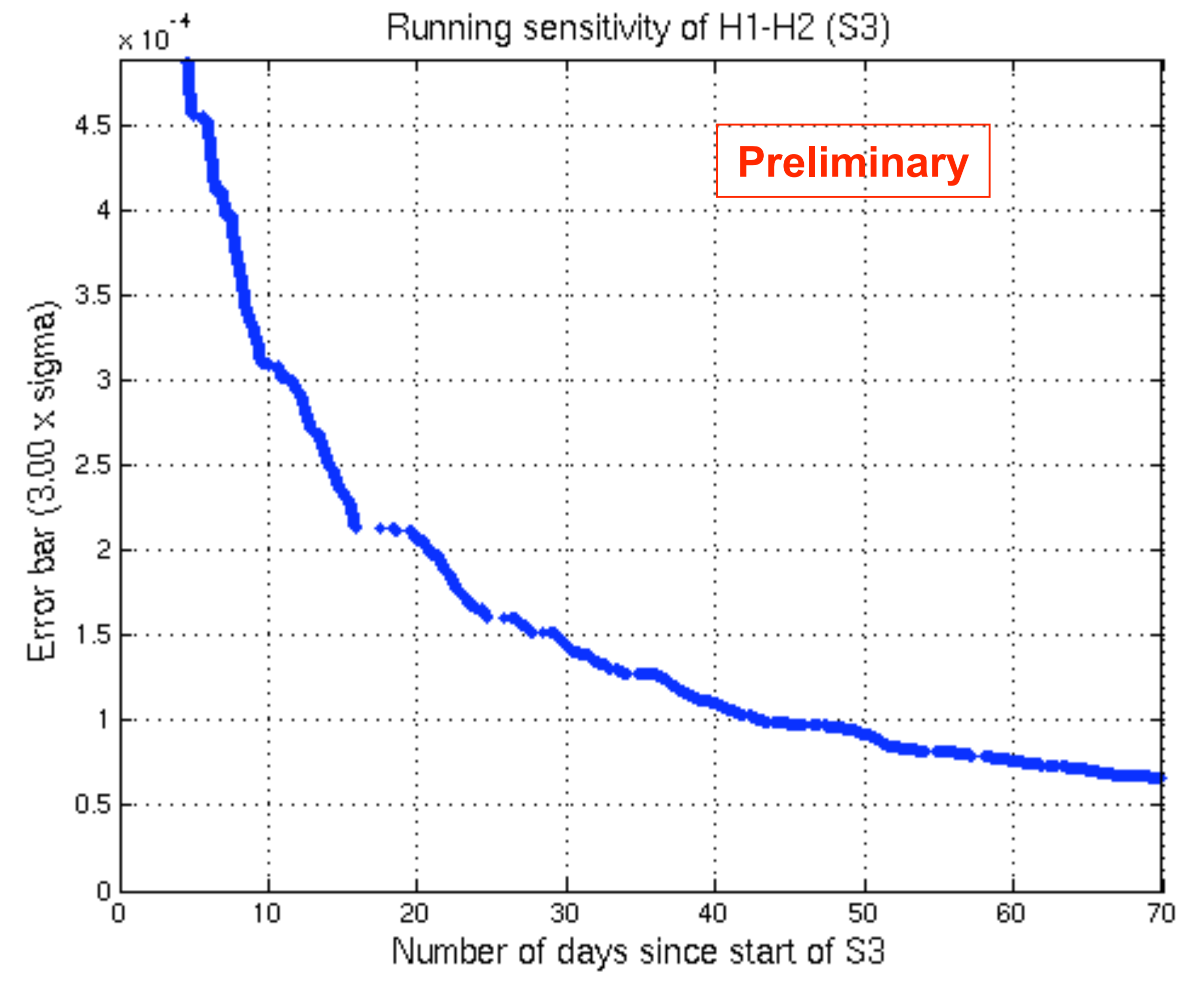
S3 Sesitivity: H1-L1

Error-estimate (+3σ) plotted for the H1-L1 pair as a function of run time.



S3 Sensitivity: H1-H2

Error-estimate (+3σ) plotted for the H1-H2 pair as a function of run time.



LIGO

LIGO Results on $\Omega_0 h_{100}^2$

LIGO run	H1-L1, H2-L1	H1-H2	Frequency Range	Observation Time
S1 PRD 69(2004)	< 23 +/- 4.6 (H2-L1)	Cross-correlated instrumental noise found	40-314 Hz	64 hours (08/23/02 – 09/09/02)
S2 Preliminary	< 0.018 +0.007- 0.003 (H1-L1)	Cross-correlated instrumental noise found	50-300 Hz	387 hours (02/14/03 – 04/14/03)
S3 In progress		Trying to account for instrumental noise in bounding Ω_{gw}	50-250 Hz (H1-L1) 70-220 Hz (H1-H2)	350 hrs (H1-L1) 550 hrs (H1-H2) (10/31/03 – 01/09/04)
S4 Starting Analysis				447 hrs (H1-L1) 510 hrs (H1-H2) (02/22/05 – 03/24/05)

Summary

- The current best IFO-IFO upper-limit is from S1: $\Omega_0 h^2 < 23 +/- 4.6$
  - S2 result: 0.018 (+0.007- 0.003) PRELIMINARY
  - The S3 data analysis is in progress.

- H1-H2 is the most sensitive pair, but it also suffers from cross-correlated instrumental noise.

- Also working on:
  - Set limits for $\Omega_{gw}(f) \sim \Omega_n (f/f_0)^n$
  - Targeted searches

- Expected sensitivities with one year of data from LLO-LHO:
  - Initial LIGO $\Omega_0 h^2 < 2\times10^{-6}$
  - Advanced LIGO $\Omega_0 h^2 < 7\times10^{-10}$