Search for Stochastic Background of Gravitational Waves with LIGO

(LIGO-G080290-00-Z)

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Sources of Stochastic Gravitational waves

- Cosmological origin (inflation, pre-big-bang, phase transitions, cosmic strings)

- Astrophysical origin (unresolved binaries, neutron star instabilities, LMXBs)

- Assume it's isotropic, unpolarized, stationary and gaussian

  - isotropic, in analogy to Cosmic Microwave Background Radiation

  - unpolarized, if stochastic in nature no preferred polarization is expected

  - stationary, Gravitational-Wave characteristic period << age of universe

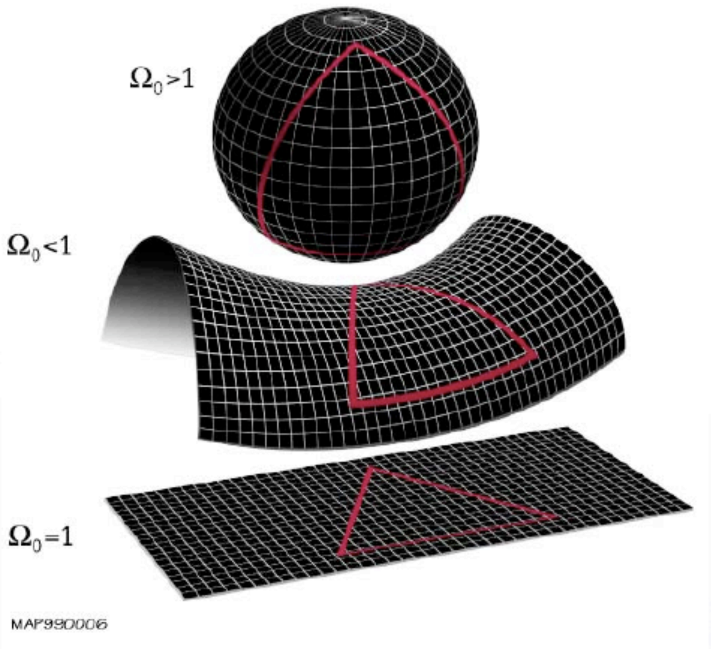
  - gaussian, can be justified by the central limit theorem

Stochastic Background Characterization

- Described in terms of the GW spectrum by:

$$\Omega_{gw}(f) := \frac{1}{\rho_{crit}} \frac{d\rho_{gw}}{d\ln f} \equiv \frac{f}{\rho_{crit}} \frac{d\rho_{gw}}{df}$$

via its contribution to Ω (=ρ/ρc), where Ω is the average density of the universe divided by the critical energy density required for the universe to be flat (zero curvature) and Ωgw the energy density due to a gravitational-wave background



- Equivalent strain power (for interferometer with orthogonal arms)

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

Data analysis Cross-correlation Statistic

- Cross-correlate two signals from a pair of detectors

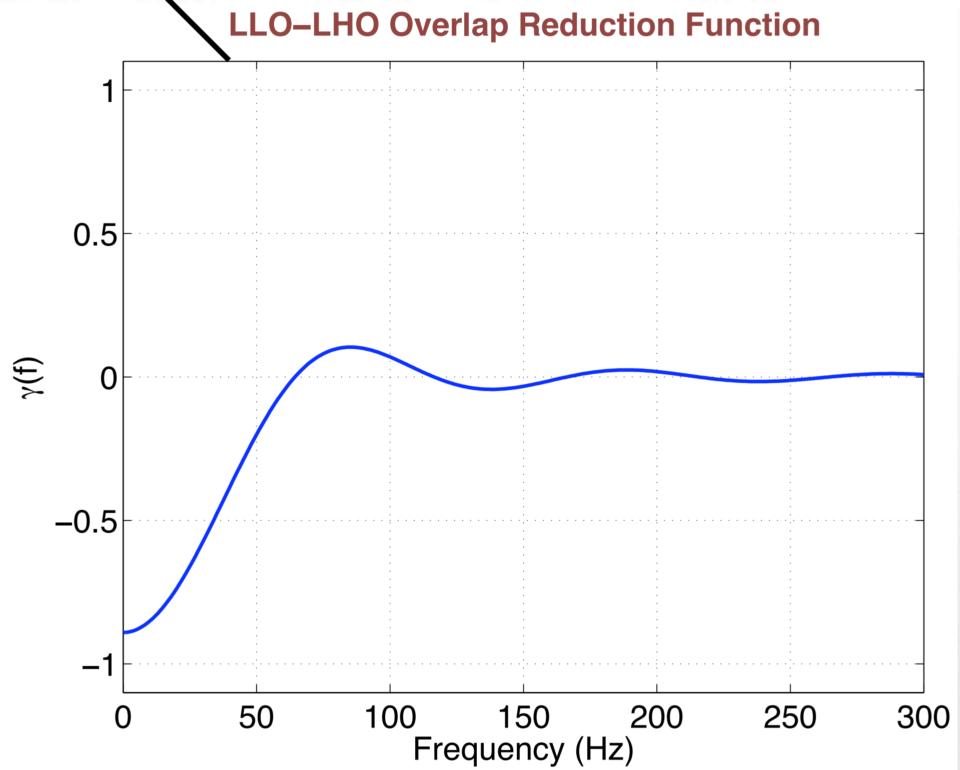
$$\langle \tilde{s}_1(f)^* \tilde{s}_2(f) \rangle = \gamma(f) S_{gw}(f)$$

- Point estimate of $\Omega_{gw}(f)$

$$\hat{\Omega} = \int df \, \tilde{s}_1^*(f) \, \tilde{Q}(f) \, \tilde{s}_2(f)$$

$$\tilde{Q}(f) \propto \frac{\gamma(f)}{f^3 P_1(f) P_2(f)}$$

Optimal filter



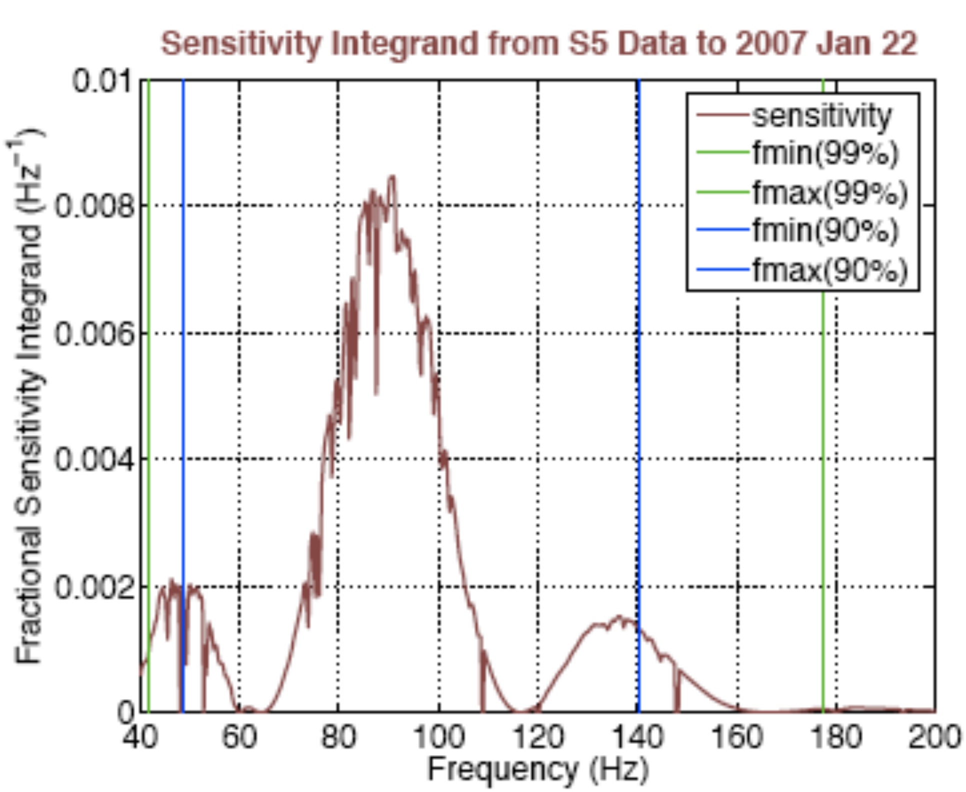
- Error bar estimate

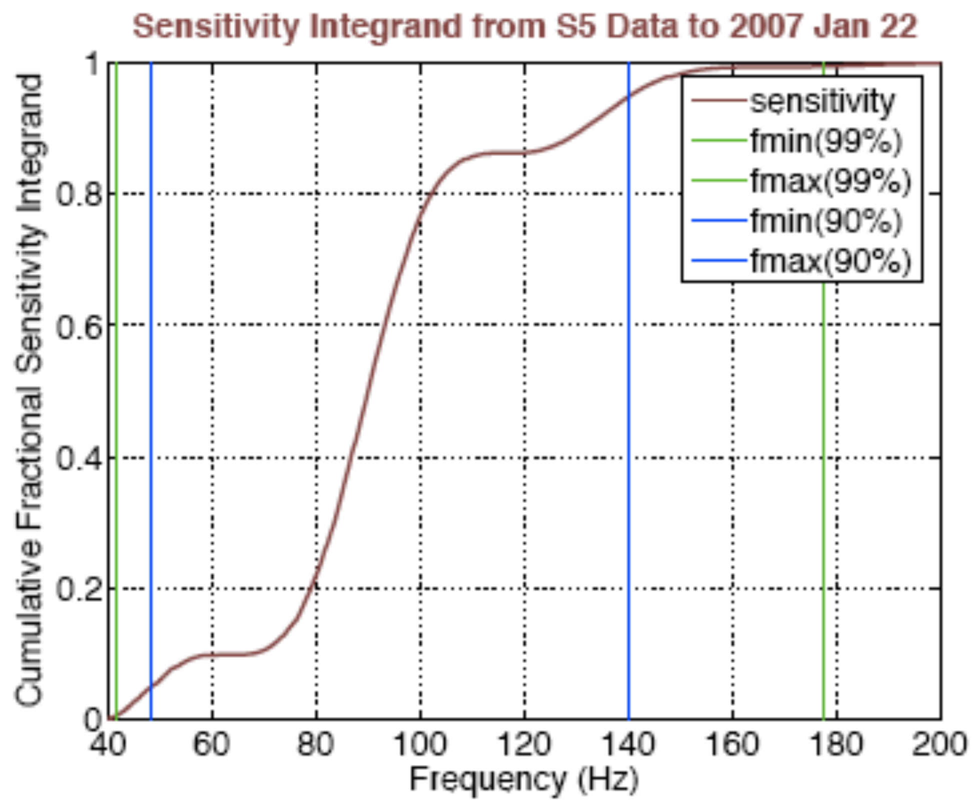
$$\sigma \propto \left(T \int df \, \frac{[\gamma(f)]^2}{f^6 P_1(f) P_2(f)} \right)^{-1/2}$$

S5 Data

- S5 run started November 4 2005 for LIGO Hanford Observatory (H1 4-km IFO and H2 2-km IFO) and November 14 2005 for LIGO Livingston Observatory (L1 4-km IFO)
- S5 run ended September 30 2007 (~1year in triple coincidence)
- Preliminary Results span ~ 140 days effective observing time for H1-L1 coincident data (up to January 22 2007)
- Preliminary Calibration up to January 22 2007 is used
- Data until January 22 spans ~ 1/2 of total available observing (H1-L1) coincident time in S5

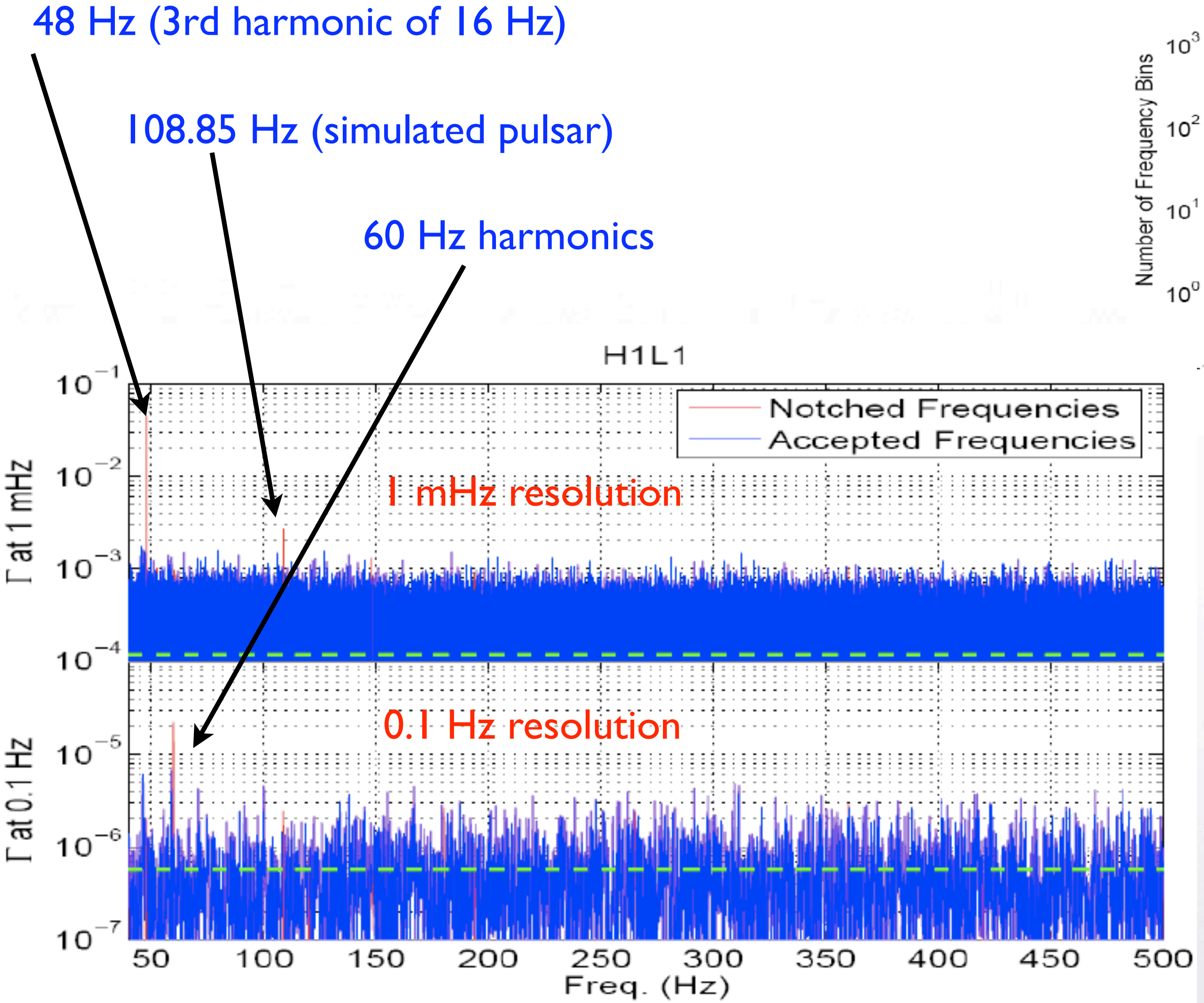
Selected frequency range

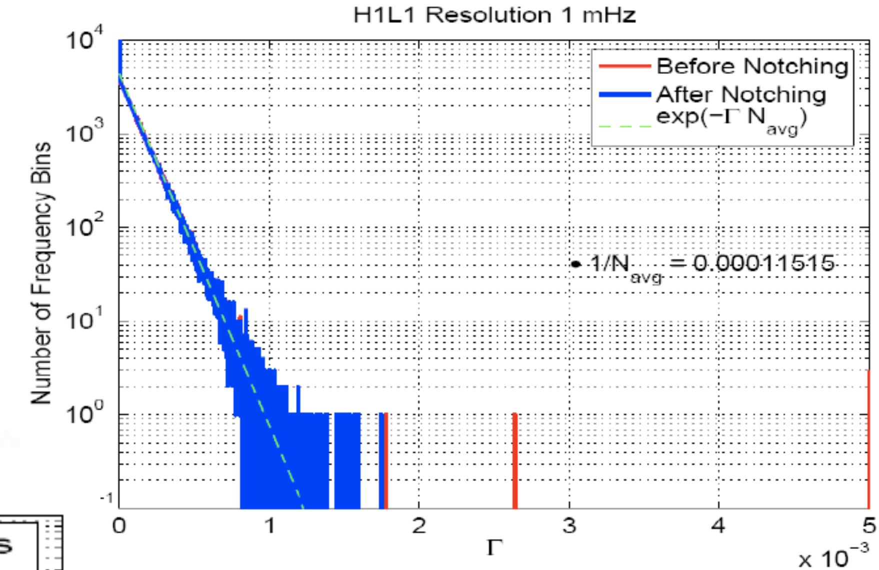




- 90 % of sensitivity in 48.5 Hz < f < 140.25 Hz
- 99 % of sensitivity in 41.5 Hz < f < 177.5 Hz (used in analysis)
- sensitivity integrand from σ^{-2}

Instrumental correlations
H1-L1 Coherence

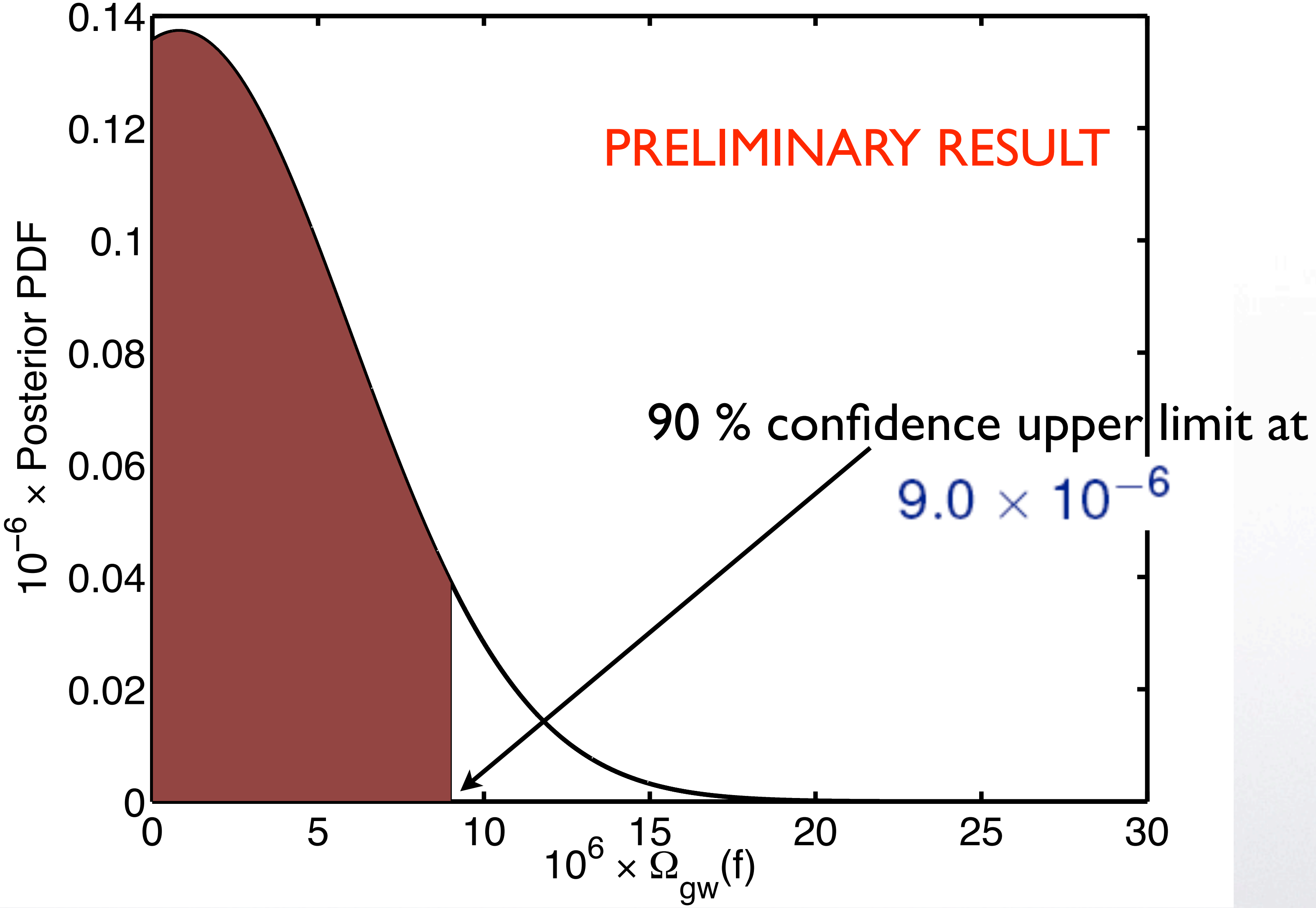




Preliminary H1-L1 result

- Assume constant $\Omega_{gw}(f)$ in 41.5 Hz < f < 177.5 Hz
- Point estimate $\hat{\Omega} = 1.0 \times 10^{-6}$ $\sigma = 5.2 \times 10^{-6}$ (null result)
- Construct Bayesian posterior probability density function (PDF) using S4 posterior as prior
- Marginalize over calibration uncertainty (with a Gaussian prior)
  (7% statistical, 10% systematic for H1, 6% statistical for L1)

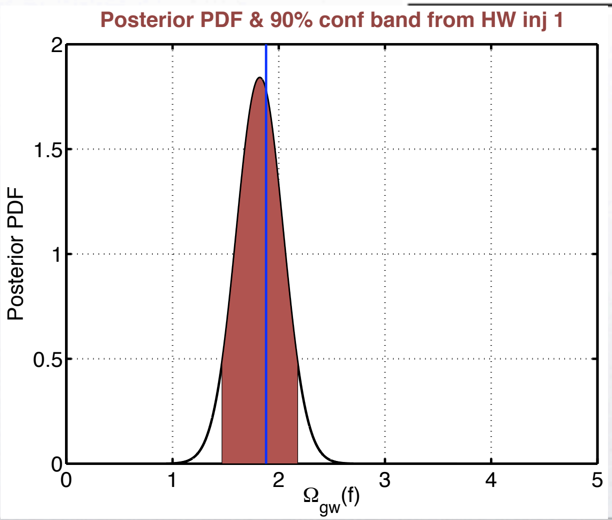
Posterior PDF & 90% conf band from S5 Data to 2007 Jan 22

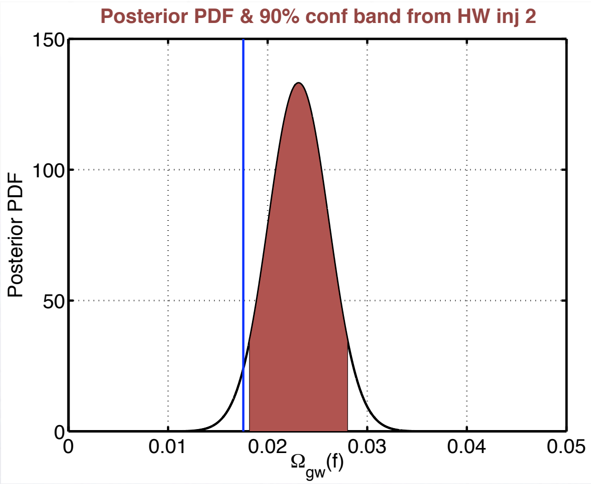


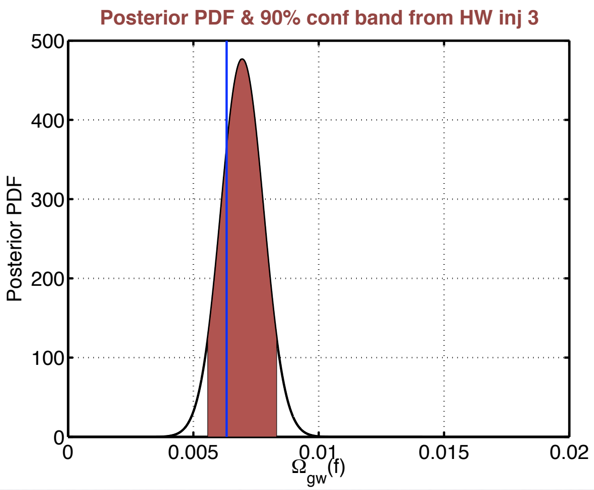
Injections

- Software injections can be recovered at a level of $\Omega_{gw}(f) \sim 4 \times 10^{-5}$
- 3 different hardware injections during S5

	inj 1	inj 2	inj 3
T_{eff} (min)	12.9	29.3	215.5
Ω_{gw}^{inj}	1.88	1.76×10^{-2}	6.3×10^{-3}
$\hat{\Omega}$	1.82	2.31×10^{-2}	6.9×10^{-3}
σ (statistical)	0.05	0.13×10^{-2}	0.2×10^{-3}
σ^{cal}	0.21	0.27×10^{-2}	0.8×10^{-3}







Big-Bang Nucleosynthesis

- BBN occured shortly after Big-Bang and constrains the energy density of gravitational waves present at the time of nucleosynthesis

- BBN limit on <u>total</u> contribution from GW background:

$$\int \Omega_{\rm GW}(f)\, d(\ln f) < 1.1 \times 10^{-5}\, (N_\nu - 3)$$ or

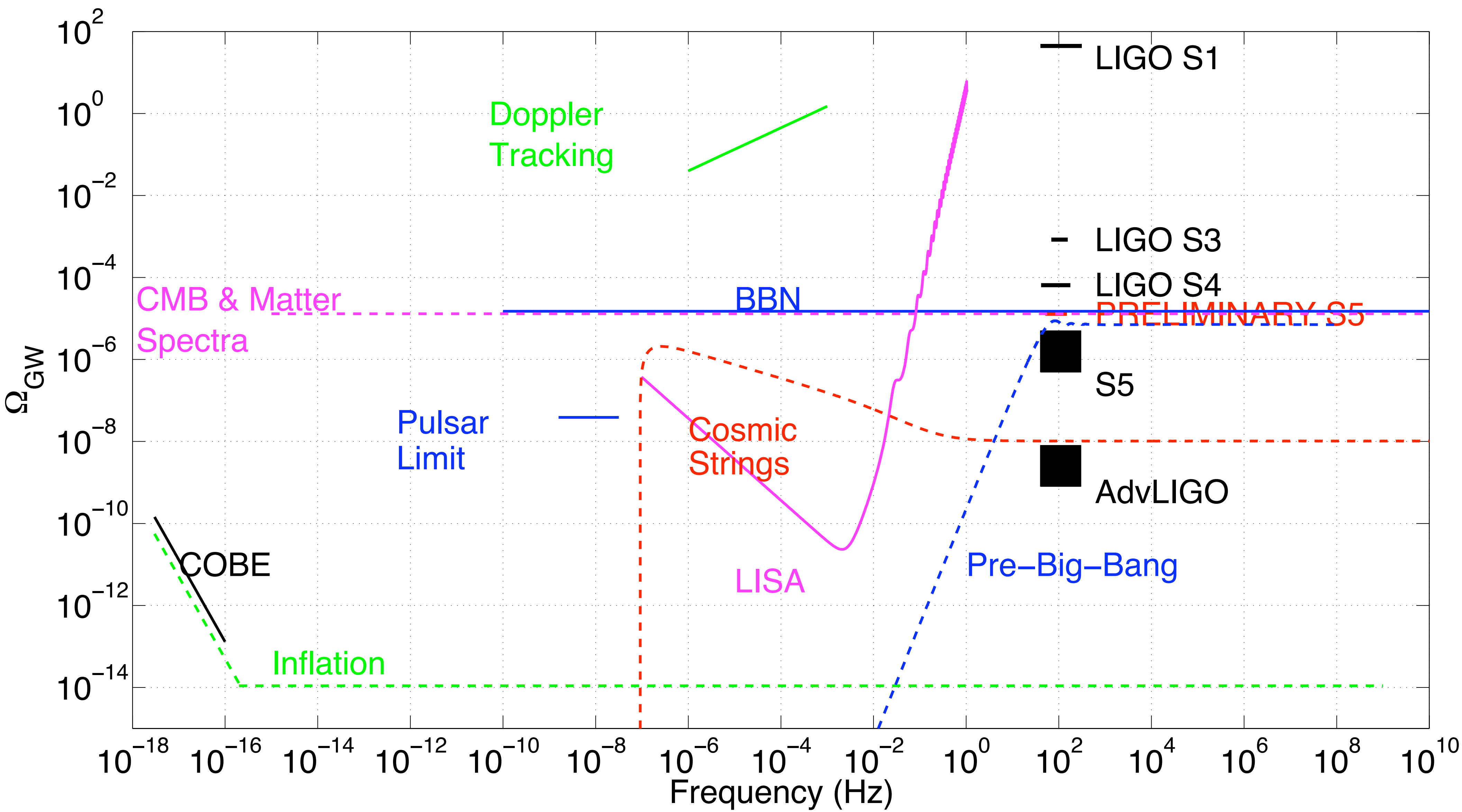
$$\int \Omega_{\rm GW}(f)\, d(\ln f) < 1.5 \times 10^{-5}$$

- In our region of interest (41.5 Hz < f < 177.5 Hz): $\Omega_{gw}(f) = 9.0 \times 10^{-6}$

or $\Omega_{gw}^{tot} = \int \frac{df}{f} \Omega_{gw}(f)$, $\Omega_{gw}^{tot} = 1.3 \times 10^{-5}$ (preliminary result)

comparable to BBN limit

Theoretical models and Upper Limits



Summary

- LIGO S5 H1-L1 stochastic result until January 22 2007
- ~ 1/2 of coincident observing time used
- Preliminary result on $\Omega_{gw}(41.5\,\mathrm{Hz} < f < 177.5\,\mathrm{Hz}) \lesssim 9.0 \times 10^{-6}$ comparable to BBN limit
- S5 Sensitivity and duty cycle improved after January 22
  - Expect factor of 1.7x improvement from DECREASE in sensitivity for full S5 H1- L1 data
  - Total observing time in S5 is 2x the time spanned until January 22
    - leads to 1.4x improvement (scales as 1/Sqrt[T])
  - Expect overall improvement of 1.7 x 1.4 = 2.4 decrease in error bar from all S5 data