LIGO data and the Stochastic Gravitational Wave Background

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GRAVITATIONAL WAVES

What are gravitational waves? A change in the space-time metric. In the weak field approximation:

$$\Box h_{\mu\nu} = -(16\pi G/c^4)\, T_{\mu\nu}$$

Generated by catastrophic events such as supernova collapse, binary star or black hole mergers; emitted by non-axisymmetric, rotating astrophysical bodies (i.e. pulsars).

Possibly produced in the early universe and manifested today as a stochastic background (c.f. microwave background)

Estimate of the amplitude (strain) of gravitational waves at the earth (strain density in the frequency domain)

$$h(f) \sim 10^{-23}/\sqrt{\text{Hz}}$$

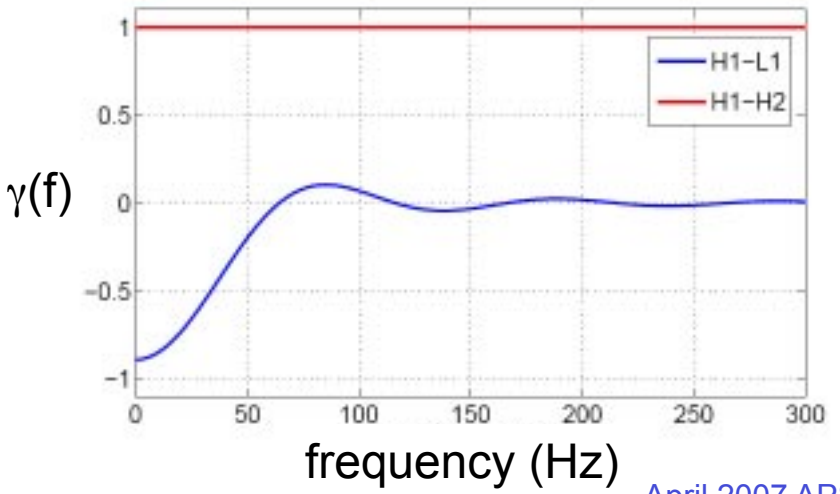
THE HANFORD AND LIVINGSTON LIGO INTERFEROMETERS

Stochastic Background

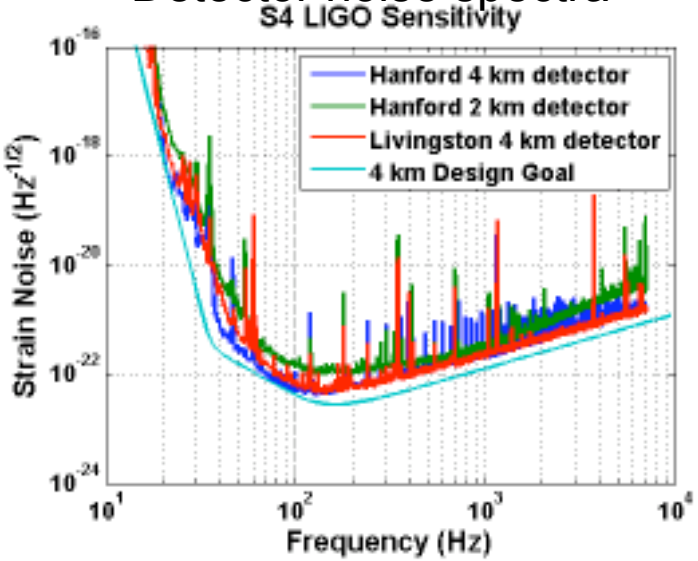
- Cross-correlate two data streams s_1 and s_2
- For isotropic search optimal statistic is

$$Y = \int_{-\infty}^{+\infty} df\, \tilde{s}_1^*(f) \frac{\gamma(|f|)\tilde{S}_{\rm GW}(f)}{N f^3 P_1(f) P_2(f)} \tilde{s}_2(f)$$

"Overlap Reduction Function"
(determined by network geometry)



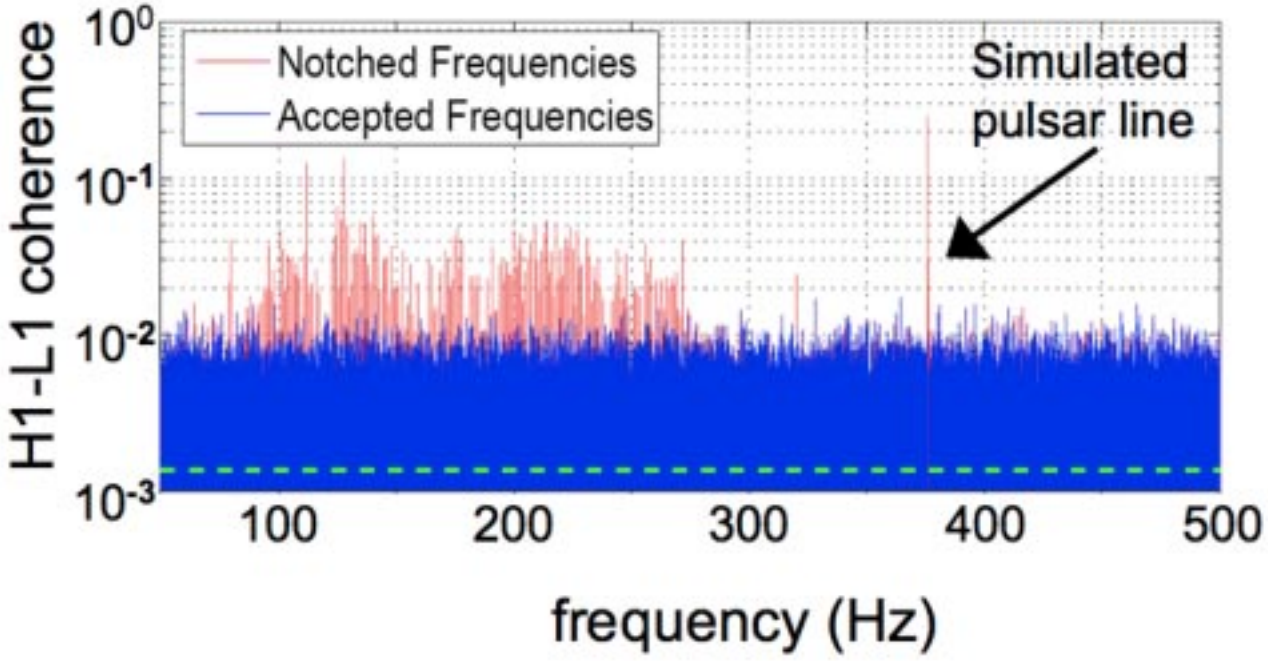
Detector noise spectra



Technical Challenges

- Digging deep into instrumental noise looking for small correlations.
- Need to be mindful of possible non-GW correlations
  - » common environment (two Hanford detectors)
  - » common equipment (could affect any detector pair!)

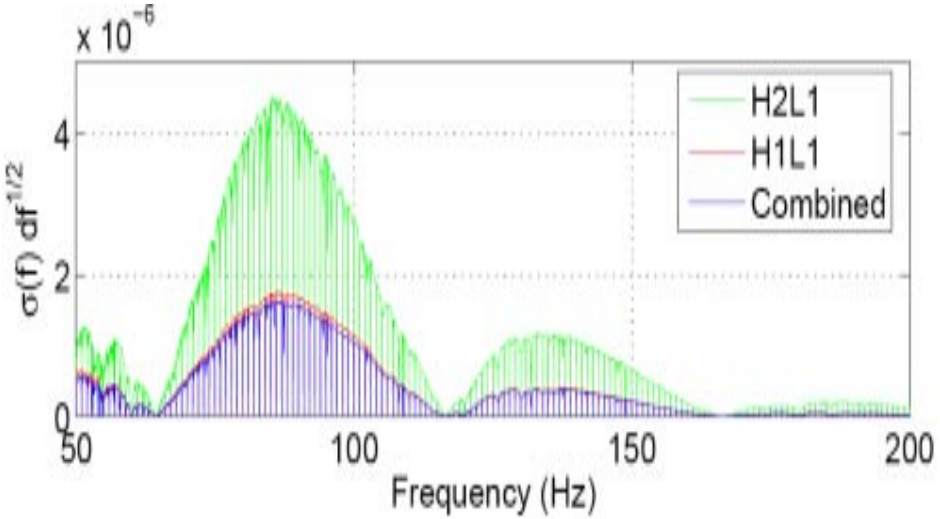
- Example:
  - » Correlations at harmonics of 1 Hz.
  - » Due to GPS timing system.
  - » Lose ~3% of the total bandwidth (1/32 Hz resolution).



S4 Analysis Details

- Cross-correlate Hanford-Livingston
  - » Hanford 4km – H1
  - » Hanford 2km – H2
  - » Livingston – L1
  - » Weighted average of two cross-correlations (new in S4).
  - » Do not cross-correlate the Hanford detectors.

S4: Sensitivity vs Frequency



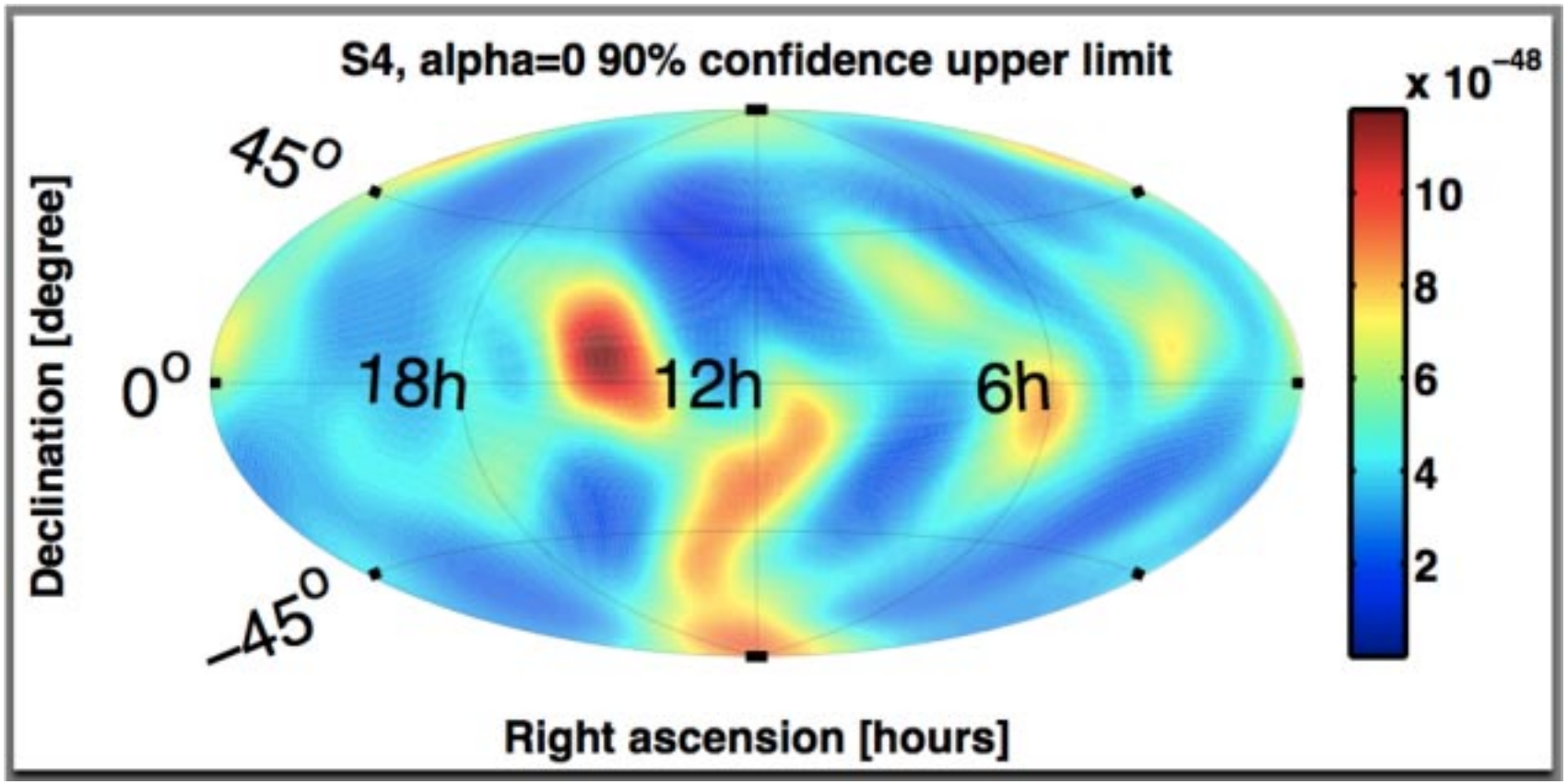
- Data quality:
  - » Drop segments when noise changes quickly (non-stationary).
  - » Drop frequency bins showing instrumental correlations (harmonics of 1 Hz, bins with pulsar injections).

S4 Analysis Results

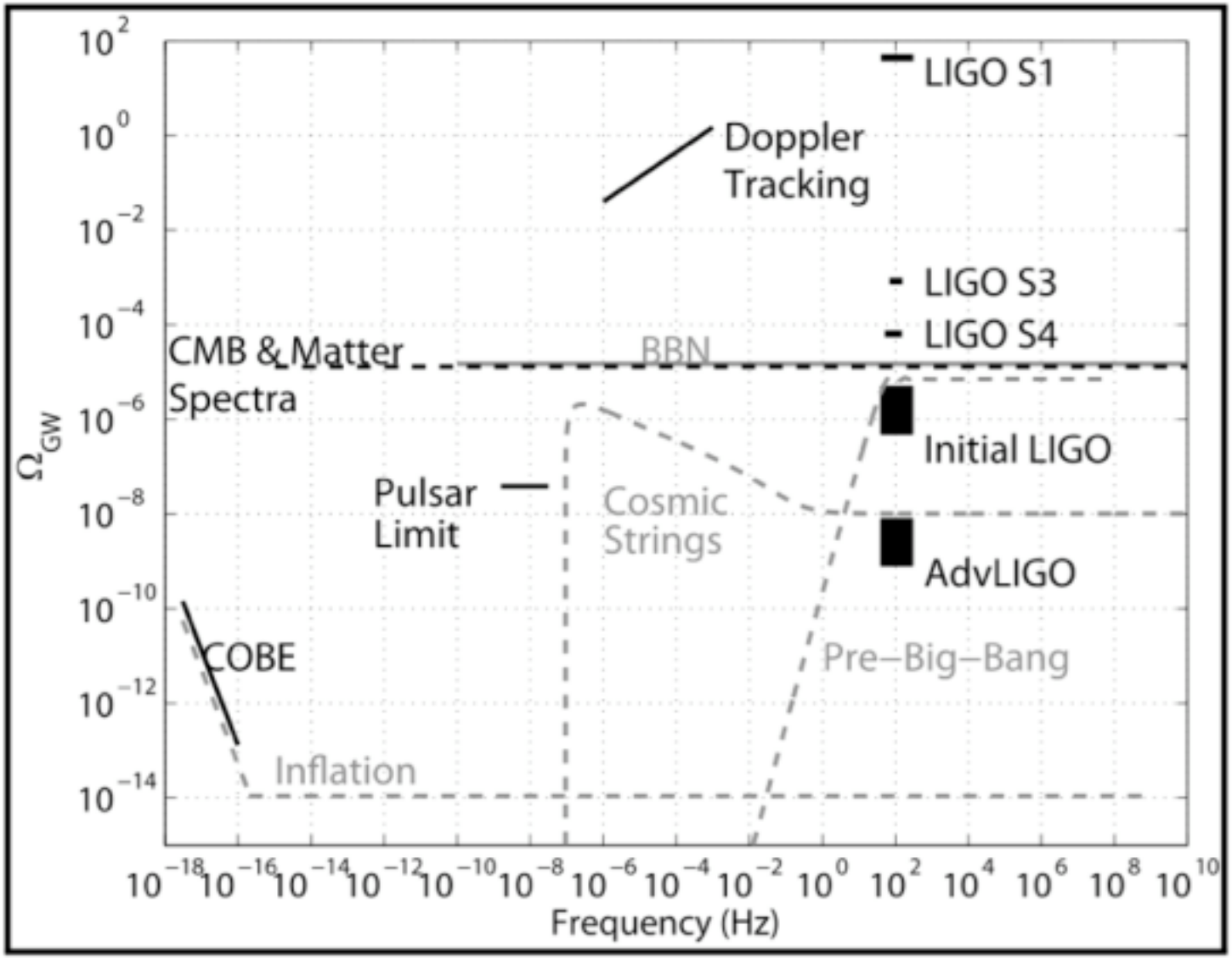
- Bayesian UL: $\Omega_{90\%} = 6.5 \times 10^{-5}$
  - » Uses S3 posterior distribution for S4 prior.
  - » Marginalized over calibration uncertainty with Gaussian prior (5% for L1, 8% for H1 and H2).
  - » ~10^{10} improvement over first interferometer result
  - » ~10^{6} improvement over first LIGO result
- What does immediate future hold?
  - » Better S5 result (run finishes within months)
  - » Possible H1-H2 result (works in the pipeline)
  - » Unique result at higher frequencies (FSR at 37.5 kHz)
  - » More detail at low frequencies (see next slide)

Radiometer: first upper-limit sky-map

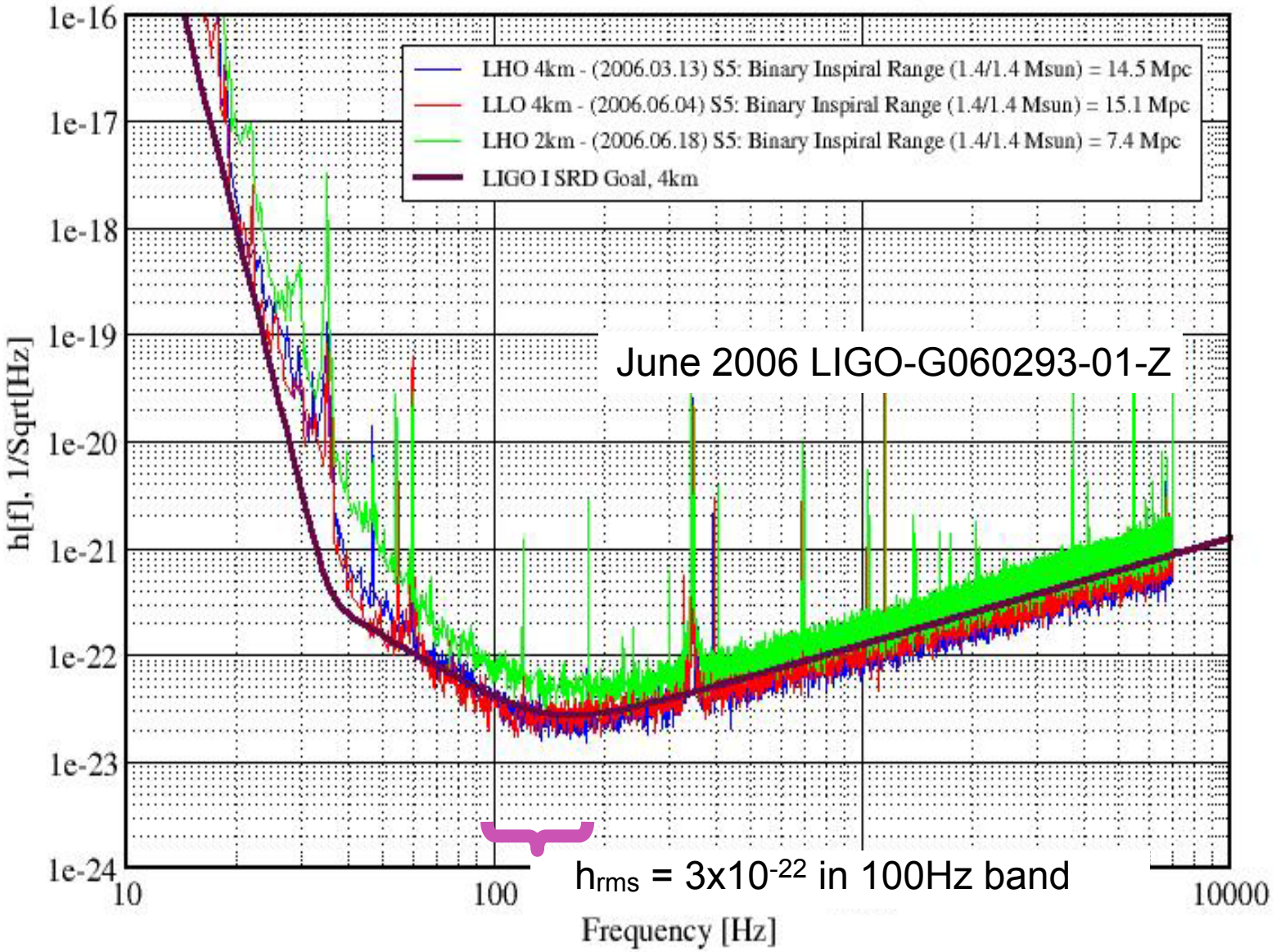
- Upper limit map on point sources with a broadband, flat strain power spectrum $S(f) \sim f^{\alpha}$ with $\alpha = 0$.



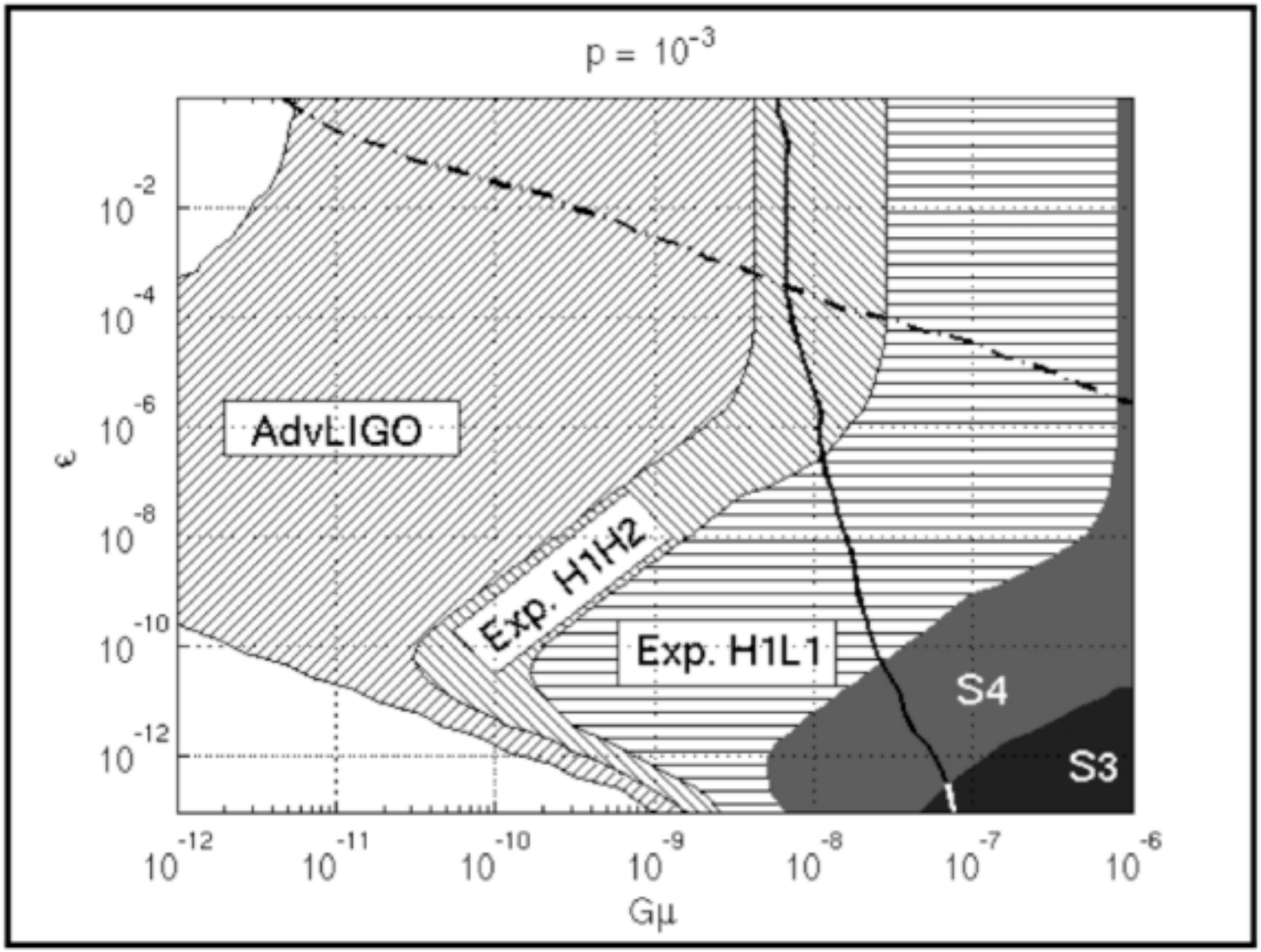
Predictions and Limits



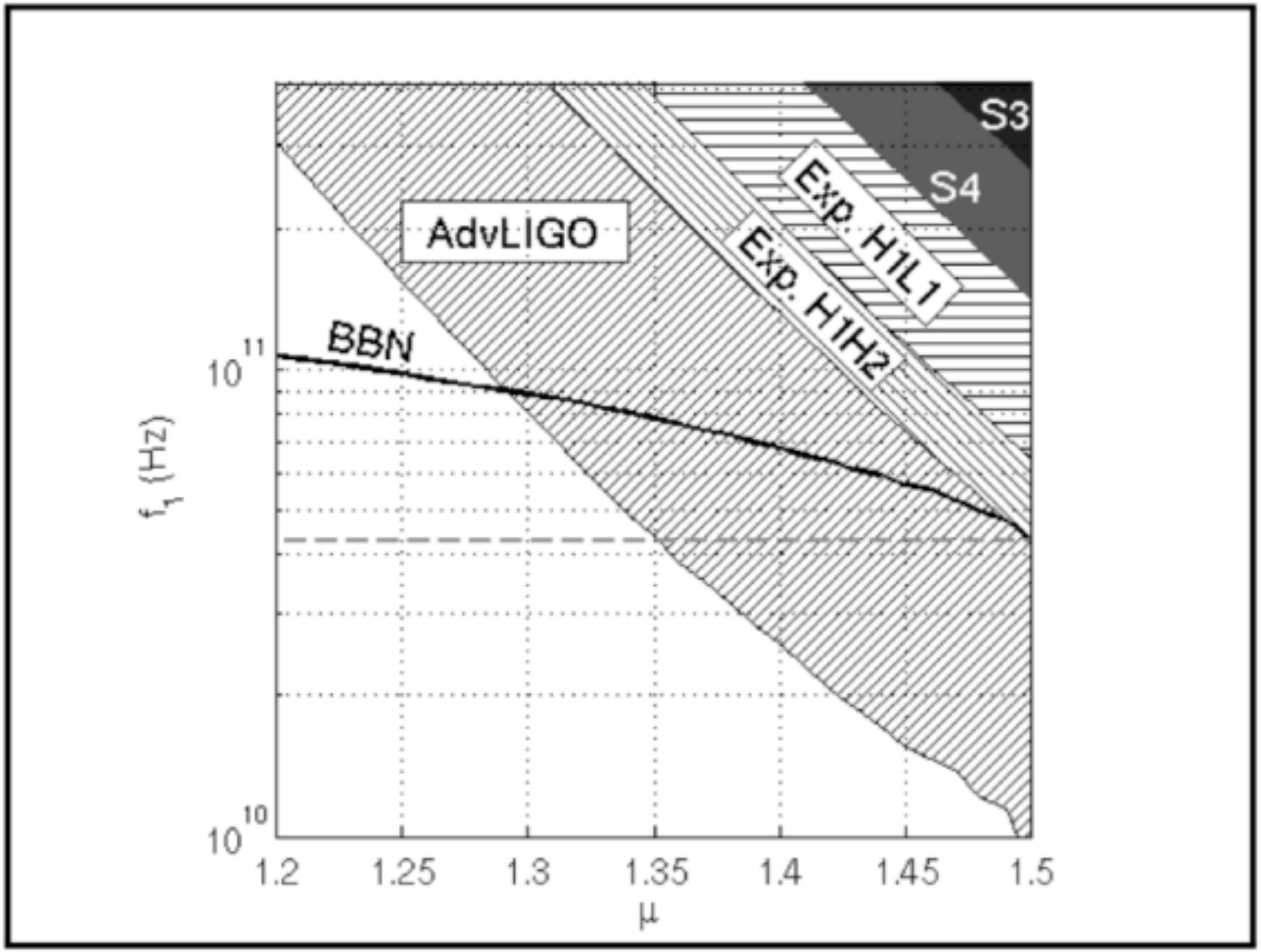
S5 Science Run: Nov '05 -…



Constraining cosmic strings



Constraining pre-big bang models



What does future hold?

- More theoretical suggestions for potential sources
  - » (may even be astrophysical rather than cosmological)
- Better sensitivity in current band (S5, Enhanced LIGO)
- New sensitivity at higher frequencies (AdLIGO, AdVirgo)
- New instruments in other bands (LISA)
- New limits from other sources (Pulsar timing)

What do we hope to gain?

- More insight into the early universe
- New insight into the early universe
- Better insight into the early universe
- Unique insight in to the early universe
- Constrain theory of the early universe