Searches for stochastic gravitational waves in LIGO and VIRGO data

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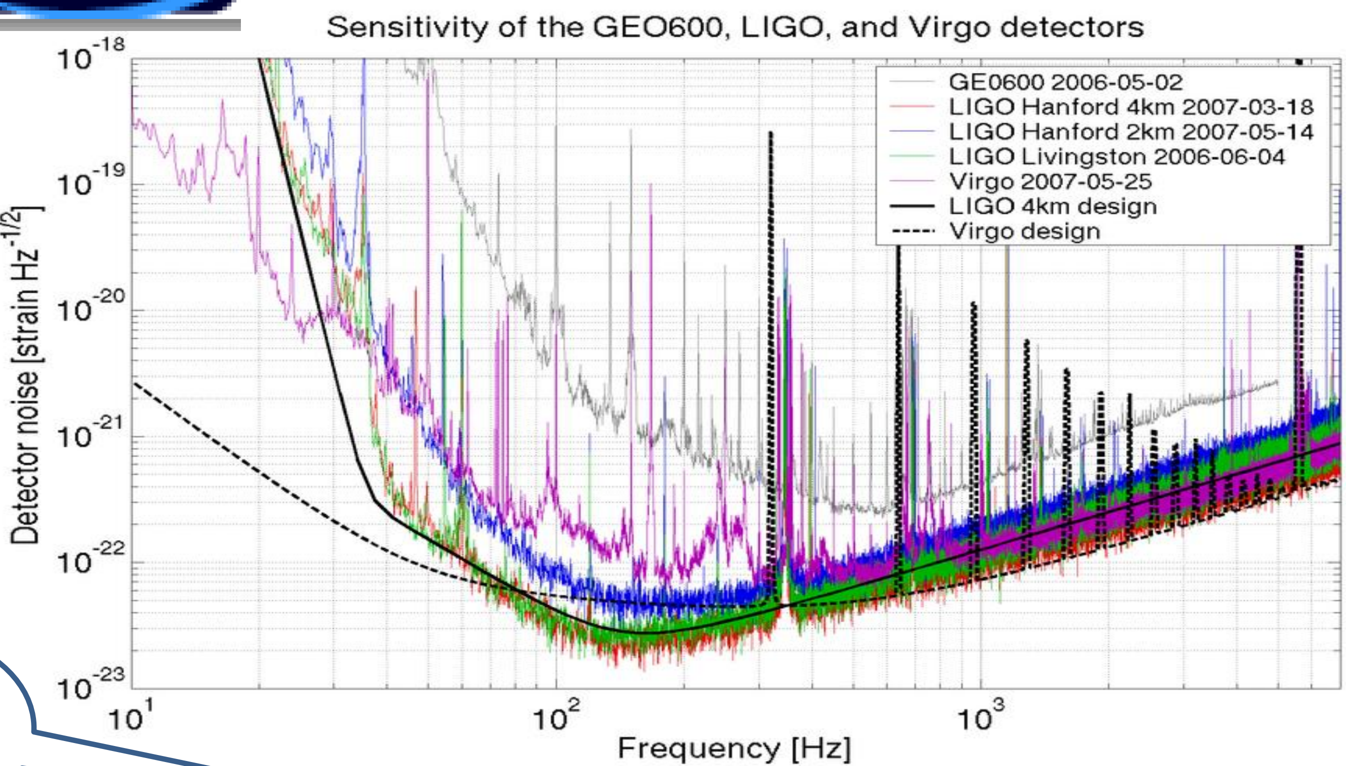
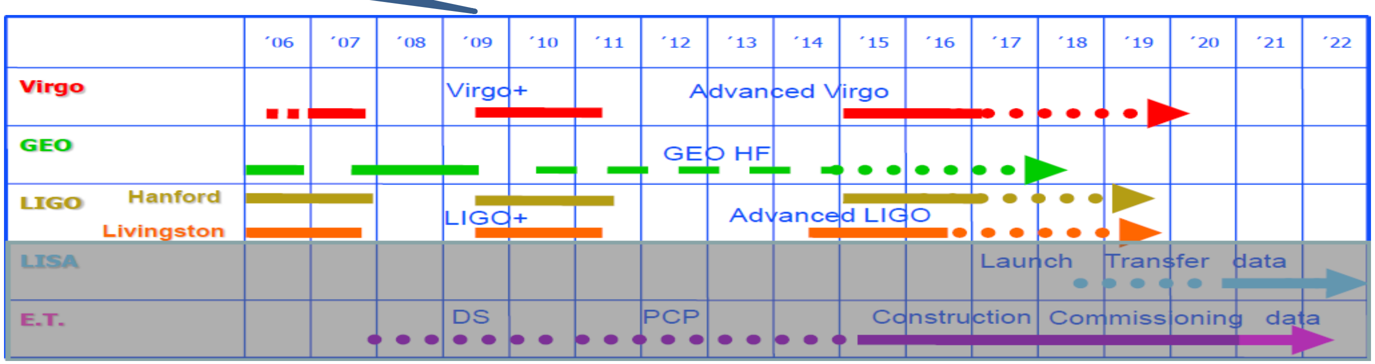
LIGO-G0900680-v1

Network of Gravitational-wave Interferometric Detectors



New data taking has just started

TIMELINE



Stochastic gravitational wave signals

Cosmological processes

- Inflation -- flat spectrum (Turner)
- Phase transitions -- peaked at phase transition energy scale (Kamionkowski)
- Cosmic (super)strings -- gradually decreasing spectrum (Damour & Vilenkin)
- Pre big-bang cosmology -- rising strength with f (Buonanno et al.)

Astrophysical Foregrounds

- Incoherent superposition of many signals from various signal classes (Ferrari, Regimbau)
  - Coalescing binaries
  - Supernovae
  - Pulsars
  - Low Mass X-Ray Binaries (LMXBs)
  - Newly born neutrons stars
    - Normal modes - R modes
  - Binary black holes
  - Black hole ringdowns

Stochastic Background of Gravitational Waves

- Energy density:

$$\rho_{GW} = \frac{c^2}{32\pi G} < \dot{h}_{ab}\, \dot{h}^{ab} >$$

- Characterized by log-frequency spectrum:

$$\Omega_{GW}(f) = \frac{1}{\rho_c} \frac{d\rho_{GW}(f)}{d\ln f}$$

- Related to the strain power spectrum:

$$S(f) = \frac{3H_0^2}{10\pi^2} \frac{\Omega_{GW}(f)}{f^3}$$

- Strain scale:

$$h(f) = 6.3 \times 10^{-22} \sqrt{\Omega_{GW}(f)} \left(\frac{100\ \mathrm{Hz}}{f}\right)^{3/2} \mathrm{Hz}^{-1/2}$$

Data analysis method

- Cross–correlation estimator

$$Y = \int_{-\infty}^{+\infty} df\ \tilde{s}_1^*(f)\ \tilde{s}_2(f)\ \tilde{Q}(f)$$

- Optimal filter (maximizes the signal-to-noise ratio)

$$\tilde{Q}(f) = \frac{1}{N}\ \frac{\gamma(f)\ \Omega_t(f)}{f^3\ P_1(f)\ P_2(f)}$$

- Template

$$\Omega_t(f) = \Omega_\alpha (f/100\ \mathrm{Hz})^\alpha$$

- Normalization

$$< Y >= \Omega_\alpha T$$

- Variance of Y

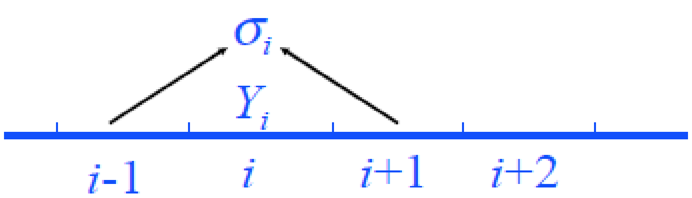
$$\sigma_Y^2 \approx \frac{T}{2} \int_0^\infty df P_1(f) P_2(f) |\tilde{Q}(f)|^2$$

Analysis Details

- Data divided into 60-sec segments:
  - » Y_i and σ_i calculated for each interval i.
  - » Weighed average performed.

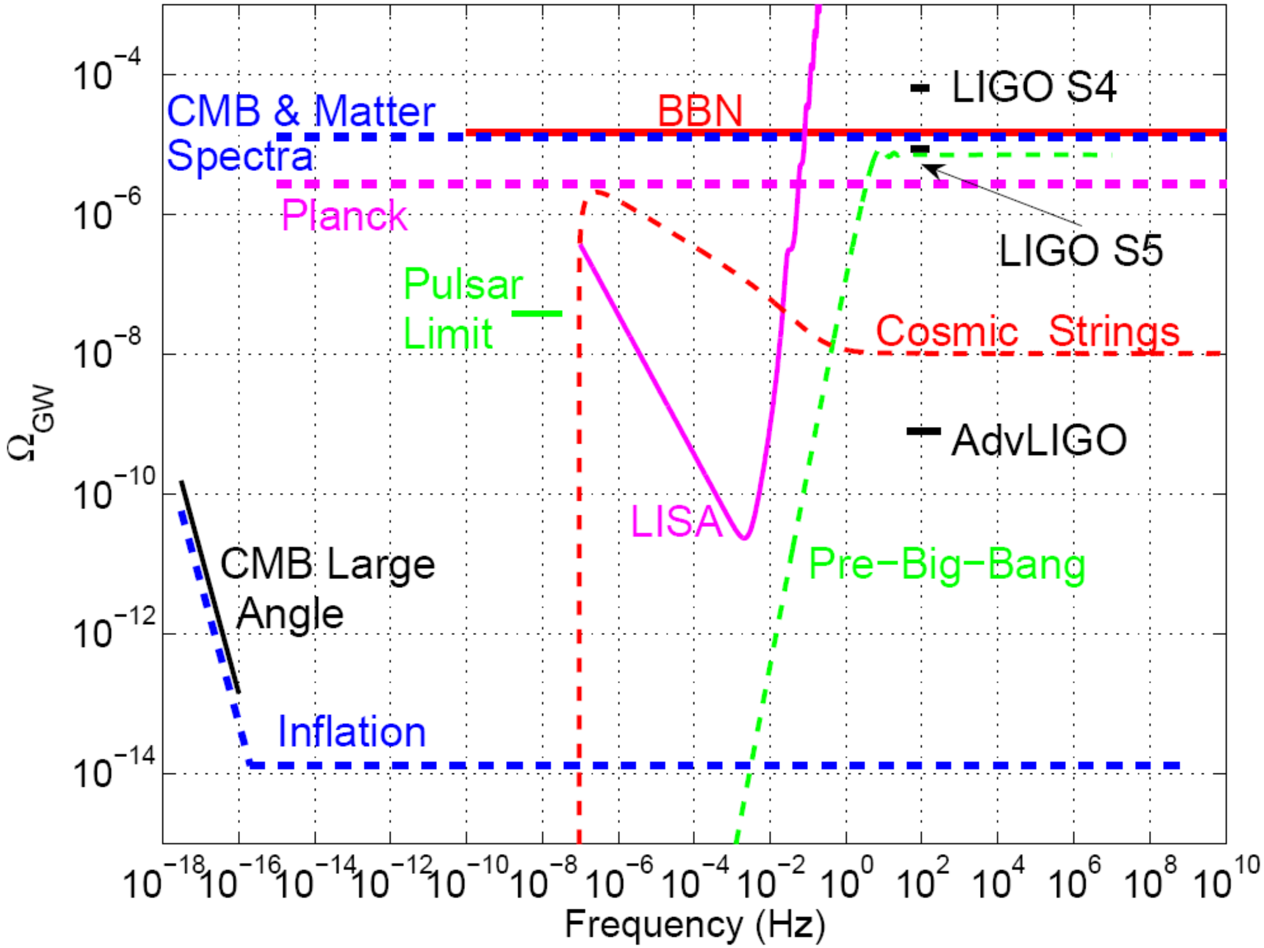
$$Y_{\rm opt} = \frac{\sum_i \sigma_i^{-2} Y_i}{\sum_i \sigma_i^{-2}} \qquad \sigma_{\rm opt}^{-2} = \sum_i \sigma_i^{-2}$$

- Sliding Point Estimate:
  - » Avoid bias in point estimate
  - » Allows stationarity cut



- Data quality cuts set blindly:
  - » Stationarity cut: $|\sigma_{i\pm1} - \sigma_i| / \sigma_i < 20\%$ (removed 4-5% of data)
  - » Reject data segments known to have problems (digitizer saturations, unreliable calibration, glitches etc).
  - » Residual distribution is gaussian.

Panorama of sources and detectors



Preliminary S5/VSR1 result - 90% confidence upper limit:

$$\boxed{\Omega_{0,\,\mathrm{LIGO}} < 9.0 \times 10^{-6}}$$

Indirect BBN and CMB Bounds

- Big-Bang Nucleosynthesis model and observations constrain the total energy at the time of BBN:

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

- CMB and matter power spectra also limit the total GW energy:

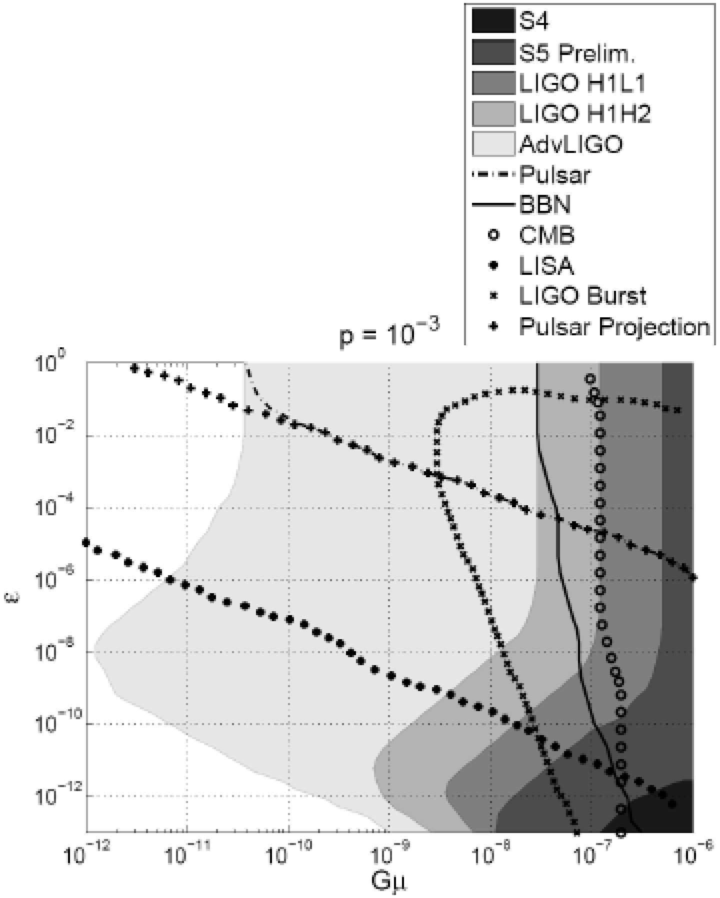
$$\int \Omega_{\mathrm{GW}}(f)\, d(\ln f) < 1.3 \times 10^{-5}$$

- In the LIGO band and for frequency independent spectrum:
  - » BBN: $\Omega_0 < 1.1 \times 10^{-5}$
  - » CMB: $\Omega_0 < 9.2 \times 10^{-6}$
- Preliminary result just surpasses these bounds.
  - » An important LIGO milestone!
  - » Expect further improvements when including the rest of S5 data.

•Inclusion of VIRGO data from the VSR1 run will further improve these bounds

Cosmic (Super)Strings: Burst and Stochastic

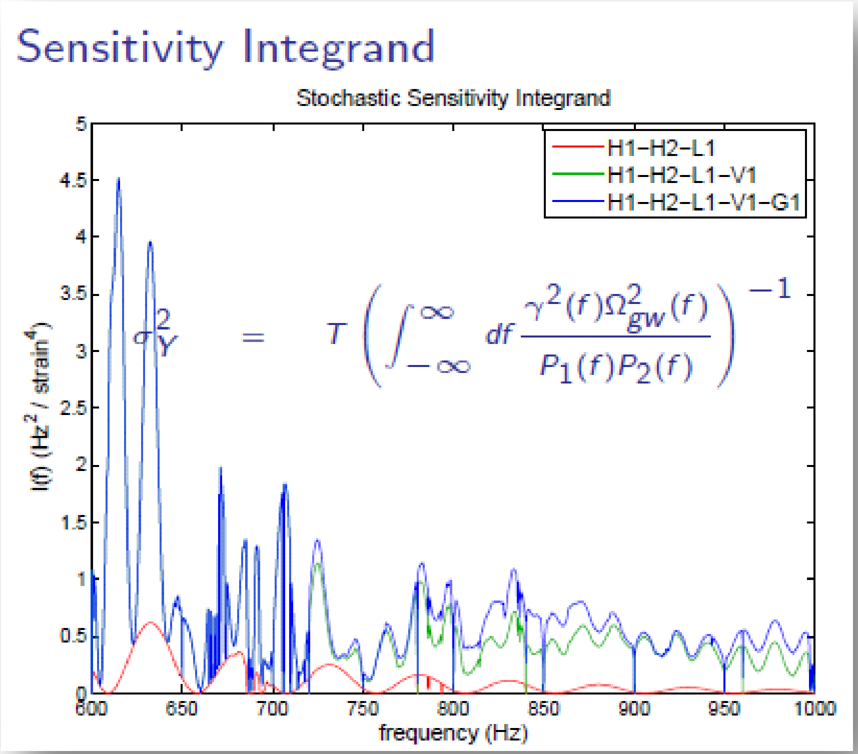
- Cosmic Strings:
  - » Topological defects from phase transitions in early universe.
  - » Fundamental strings.
- Cosmic string cusps, Lorentz boosted toward Earth produce bursts of GWs.
- Integrating over the whole network gives a stochastic background.
- Model parameters (small loop scenario)
  - » Loop-size parametrized by: $10^{-13} < \varepsilon < 1$
  - » String tension: $10^{-12} < G\mu < 10^{-6}$
  - » Reconnection probability: $10^{-3} < p < 1$
- Preliminary S5 stochastic result and S4 burst result (arXiv:0904.4718) probe this parameter space.



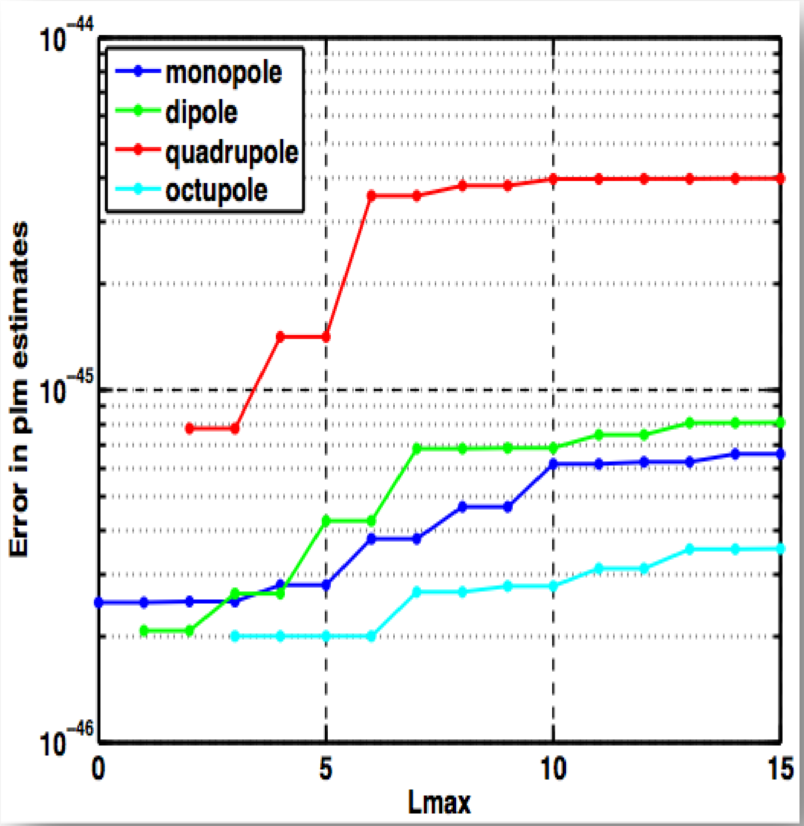
VIRGO joins the search

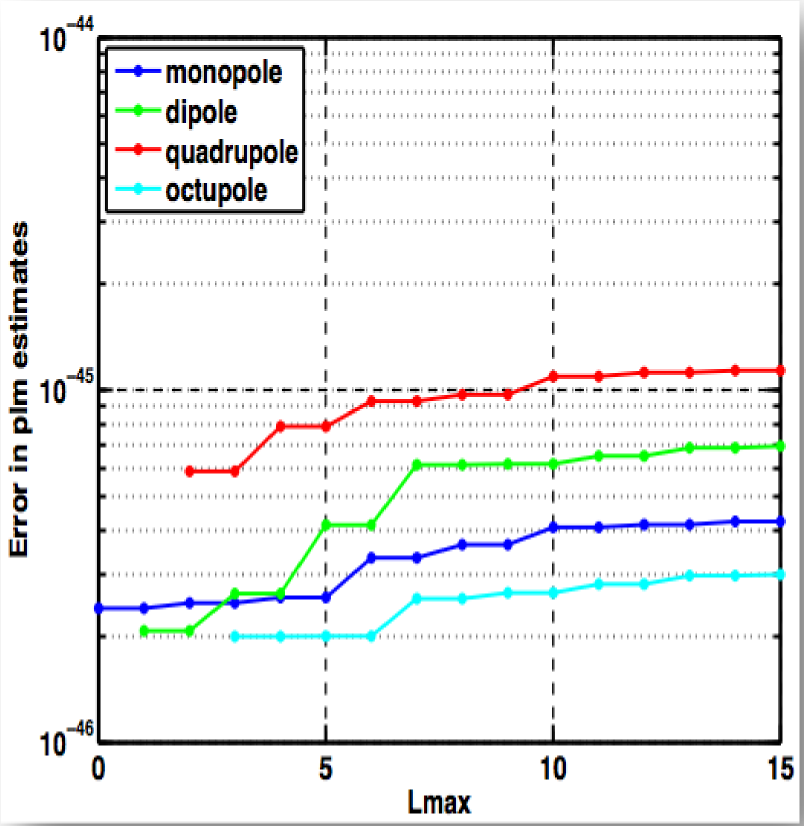
- VIRGO will contribute to isotropic search. With many detectors:
- Contributions mainly in the high frequency region (owing to coherence effects)
- Sensitivity integrand (S5/VSR1 sensitivity): contribution to SNR in the frequency domain
- Work in progress

$$\frac{1}{\Omega_{gw}^2} = \sum_{\text{pairs } i,j} \left(\frac{1}{\Omega_{gw}^{(i,j)}} \right)^2$$



Including VIRGO in stochastic targeted searches





The errors in the estimate of the power in a given spherical harmonic depends on the number of Y_{lm} included. The plots show how the error grows with the value of the largest l included for selected angular contributions, with (right) and without (left) VIRGO included.

Cosmography with advanced GW detectors

- Advanced detectors will be sensitive to compact binary coalescences (CBCs) at cosmological distances

- Position and luminosity distance to CBC can be measured with sufficient accuracy to determine the Hubble constant and even the accelaration of the universe (Schutz 1986)

- Advanced detectors will be able to determine the absolute luminosity distance to an accuracy of 10–30% for NS-NS and NS-BH binaries out to 600 and 1400 Mpc, respectively (Samaya Nissanke et al. 2009)

- Advanced detectors will provide an excellent probe of the relatively nearby (z = 0.3) universe's expansion, independent of the cosmological distance ladder, and thus complementing other standard candles

CONCLUSION:

Gravitational wave observations open a new window on the Universe