Status of the Searches for Stochastic Gravitational-Wave Backgrounds Using LIGO and VIRGO Data

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1. Overview of searches for isotropic stochastic backgrounds
2. H1-L1 Isotropic search
3. LIGO-Virgo isotropic search

Isotropic stochastic backgrounds

- Stochastic background described in terms of GW spectrum

$$\Omega_{\mathrm{GW}}(f) = \frac{f}{\rho_{\mathrm{c}}} \frac{d\rho_{\mathrm{GW}}}{df},$$

where $d\rho_{\mathrm{GW}}$ is the energy density of gravitational radiation in the range f to $f + df$ and ρ_{c} is the critical energy density of the Universe.

[Allen & Romano 1999]

- Usually use model (esp. $\alpha = 0, 3$)

$$\Omega_{\mathrm{GW}}(f) = \Omega_{\alpha} \left(\frac{f}{f_R} \right)^{\alpha}$$

- Cross-correlate data from two detectors, $\tilde{s}_1$, $\tilde{s}_2$

$$Y = \int \tilde{s}(f)_1^* \tilde{s}(f)_2 \tilde{Q}(|f|) df \quad \sigma_Y^2 \approx \frac{T}{2} \int df P_1(f) P_2(f) |\tilde{Q}(f)|^2,$$

where $\tilde{Q}(|f|)$ is optimal filter function...

Isotropic stochastic backgrounds

Optimal filter function

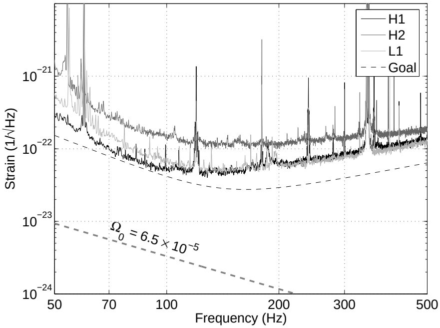
$$\tilde{Q}(|f|) = \lambda \frac{\gamma(|f|)\Omega_{\mathrm{GW}}(|f|)}{|f|^3 P_1(|f|) P_2(|f|)}$$

- $\gamma(f)$ is overlap reduction function
- $P_i(f)$ is noise power spectral density of instrument $i = 1, 2$
- λ chosen such that $< Y >= \Omega_\alpha T$
- Split time series into segments, find Y_I in each segment, use weighted mean Y_{opt} and variance σ^2_{opt} to estimate Ω_α

$$Y_{opt} = \frac{\sum_I \sigma_I^{-2} Y_I}{\sum_I \sigma_I^{-2}} \qquad \sigma_{opt}^{-2} = \sum_I \sigma_I^{-2}$$

Current results

- S4 ($\approx$ 1 month of data over 51-150 Hz)
  N.B. use $h_{100}^2 = 0.72$



Earlier results

- S1 90% upper limit
  $\Omega_0 < 44.4$
  [Abbott et al. 2004]
- S3 90% upper limit
  $\Omega_0 < 8.4 \times 10^{-4}$
  [Abbott et al. 2005]

S4 result [Abbott et al. 2007a]

- $\Omega_0 = (-0.8 \pm 4.3) \times 10^{-5}$
- 90% upper limit
  $\Omega_0 < 6.5 \times 10^{-5}$

H1-L1 search - some details

- Data from November 2005 to January 2007
- 40 - 500Hz frequency band with 0.25 Hz resolution
- 50% overlapping, 60 sec segments, with Hann windowing
- Sliding point estimate (PSDs evaluated using two neighbouring segments)
- Notched coherent frequency bins and some times (≈ 1000 s) based on coherence studies

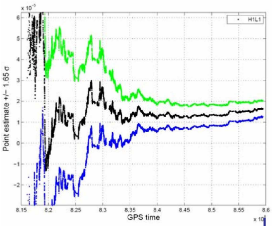
$$\Gamma(f) = \frac{|\tilde{s}_1^* \tilde{s}_2(f)|^2}{P_1(f)P_2(f)}$$

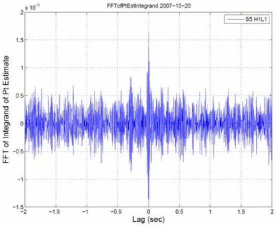
- Applied stationarity cut for $\Delta\sigma = |\sigma_{Y_I} - \sigma'_{Y_I}|/\sigma_{Y_I} > 0.2$, losing about 4.5% of the segments
- Model $\Omega_{\rm GW}(f) = \Omega_0$
- v3 calibration

H1-L1 software injections

- Check that data-quality cuts do not affect recovery of injected signal
- Performed on S5 H1L1 data up to January, with time offset.
- Inject frequency independent signal with $\Omega_0 = 3.8 \times 10^{-5}$
- Two injections with same parameters but different random seed

Recovered values
$\Omega_0 = (3.16 \pm 0.44) \times 10^{-5}$
$\Omega_0 = (4.09 \pm 0.44) \times 10^{-5}$





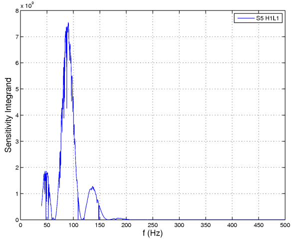
H1-L1 expected sensitivity up to January 2007

Sensitivity integrand

$$\mathrm{SNR}^2 = \frac{< Y >^2}{\sigma_Y^2} \propto \int_0^\infty [\mathcal{S}(f)]^2 \mathcal{I}_{12}(f) df$$

$\mathcal{S}(f)$ is PSD of GW signal

$$\mathcal{I}_{12} = \frac{[\gamma_{12}(f)]^2}{P_1(f) P_2(f)}$$



Overall error bar on Ω_0

$$\sigma \approx 5 \times 10^{-6}$$

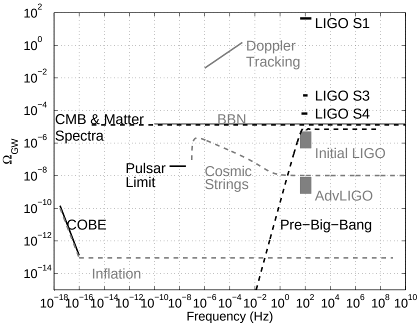
- over 41–176 Hz
- assuming $h_{100} = 0.72$

Cosmological landscape

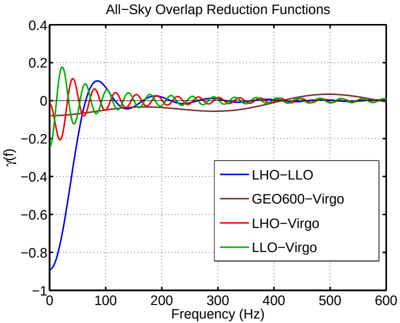
- Big Bang Nucleosynthesis (BBN) bound constrains total energy carried by GW at time of nucleosynthesis (above $\approx 10^{-10}$ Hz)

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

- Assume
  - all GW energy concentrated in 41 – 176 Hz band
  - GW spectrum is $\Omega_{GW}(f) = \Omega_0$
- Leads to limit $\Omega_0 < 1.0 \times 10^{-5}$
- The S5 result *could* place a stronger limit than this



Adding Virgo to the network

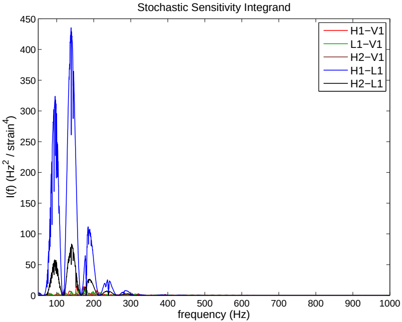


- Overlap reduction function of LIGO-Virgo does not drop off as fast as LLO-LHO – of benefit at high frequencies
- H1-H2 correlated noise needs different treatment
- GEO-Virgo – high noise floor in GEO decreases sensitivity

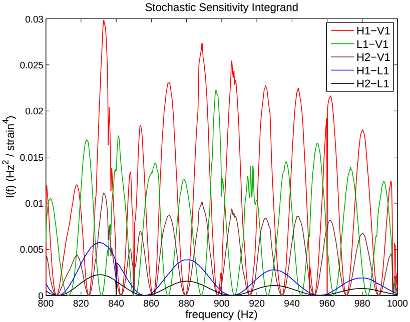
First LIGO-Virgo search

- Data Sharing May - October 2007
- 800 - 1000 Hz frequency band with 0.25 Hz resolution
- 50% overlapping, 60 sec segments, with Hann windowing
- Sliding point estimate (PSDs evaluated using two neighbouring segments)
- Model $\Omega_{\rm GW}(f) = \Omega_3 \left(\frac{f}{900 Hz}\right)^3$
- Preliminary sensitivity from first week of shared data...
- v3 calibration

Sensitivity of first week of shared data - individual pairs

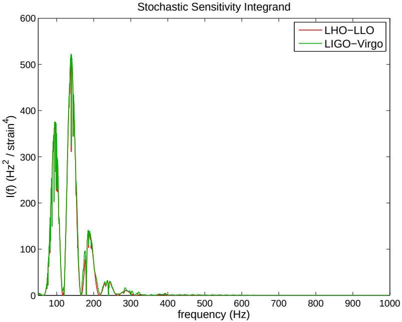


At low frequencies, dominated by LIGO-LIGO pairs

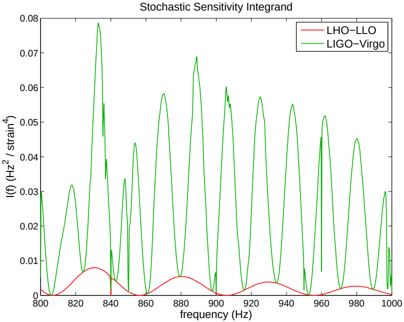


LIGO-Virgo pairs do not drop off as steeply with frequency – dominate at high frequencies

Sensitivity of first week of shared data - combined pairs



At low frequencies, dominated by LHO-LLO (i.e. H1-H2-L1)



At high frequencies, combined LIGO-Virgo more sensitive (i.e. H1-H2-L1-V1)

Sensitivity of first week of shared data

Error bars on Ω_3 over 800–1000 Hz ($h_{100} = 0.72$)

Network	First week σ	Predicted σ over 10^7 s
LLO-LHO	3	0.5
LIGO-Virgo	1	0.2

Allegro error bar on Ω_0 over 850–950 Hz

$$\sigma = 0.48$$

[Abbott et al. 2007b]

Conclusion

- Sensitivity of S5 is expected to be be an order of magnitude better than S4
- Software injections show initial validation
- First LIGO-Virgo analysis is underway, demonstraing the benefit of adding Virgo at high frequencies

References

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