Searches for the Stochastic Gravitational-Wave Background with Advanced LIGO and Advanced Virgo Detectors

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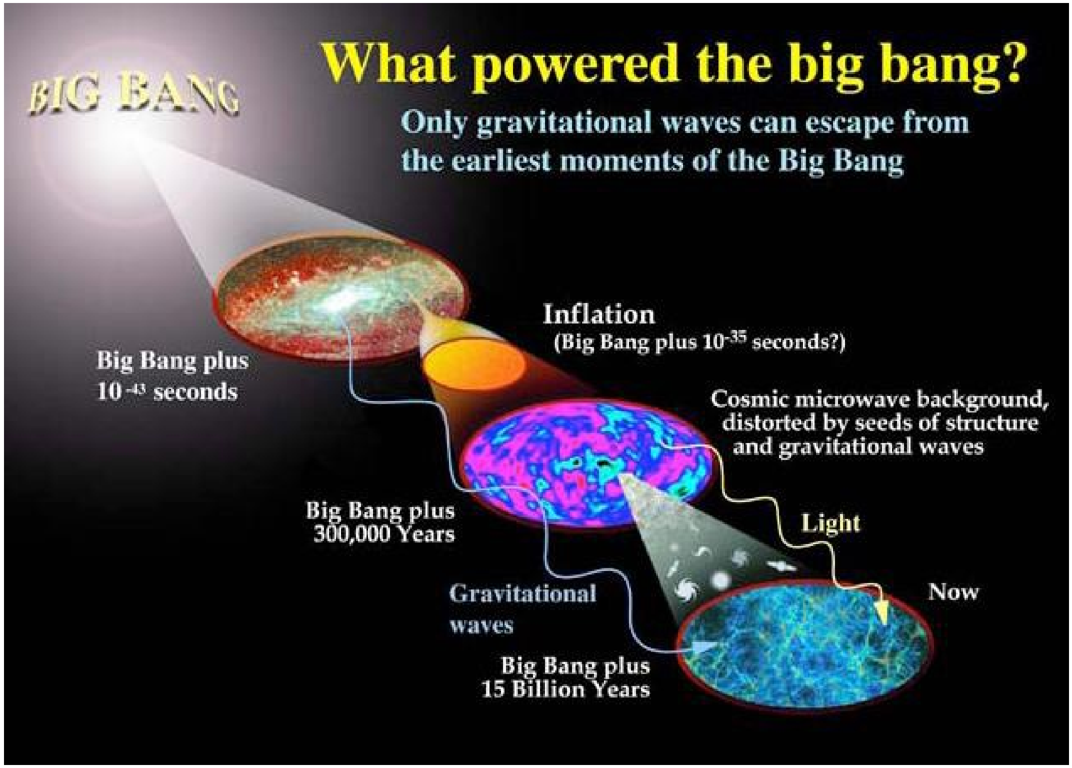
Outline

- Introduction
- Isotropic search
- Directional search

GW = Gravitational wave

Stochastic background

- Incoherent superposition of many unresolved GW sources
- Cosmological (eg. inflation, cosmic strings) and astrophysical (eg. compact binary coalescences, neutron stars, supernovae)



➔ *With observation claimed by BICEP2, appears possible to study physics of very early times and very high energies*

Advanced LIGO and Advanced Virgo

- Advanced LIGO [1] and Advanced Virgo [2] expected to achieve four orders of magnitude improvement in sensitivity to GW energy density at 100 Hz
- Expected to be sensitive to frequencies down to 10 Hz
- Studies different region of frequency space from LISA/eLISA, provides complementary information for constraining GW models



Isotropic search

- Looks for isotropic stochastic background from cosmological and astrophysical sources
- Cross-correlates data streams from different detectors to look for correlated signal within detector noise

Isotropic search: detection strategy

Cross-correlation estimator

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

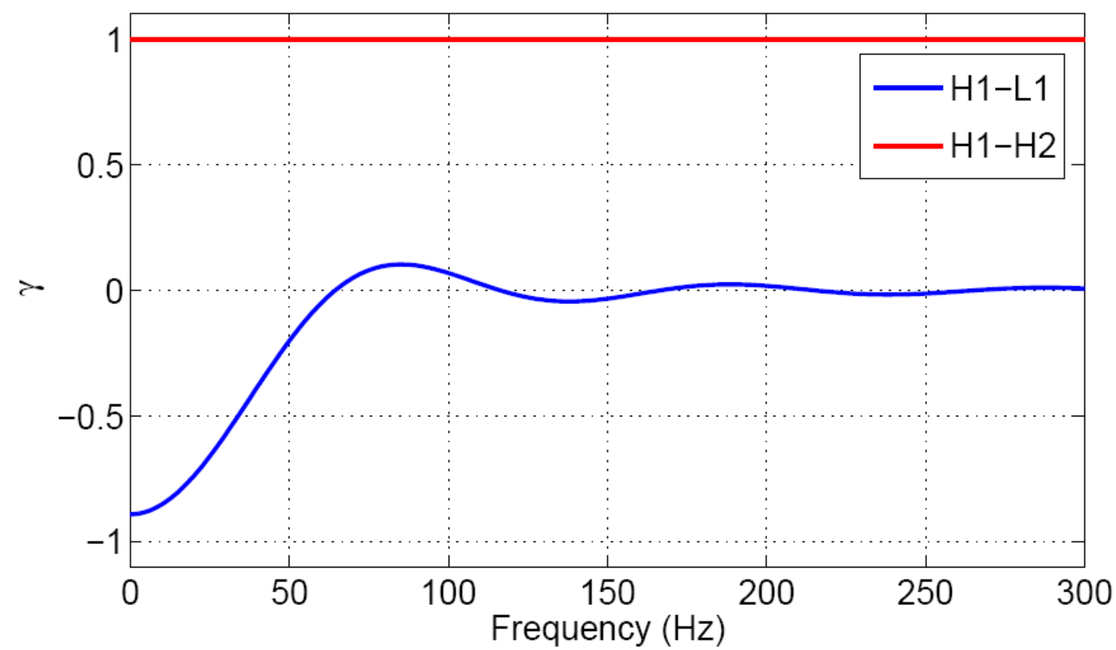
Assumed GW spectrum

$$\Omega_{\rm GW}(f) = \Omega_\alpha \left(\frac{f}{f_{\rm ref}}\right)^\alpha .$$

Variance

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

Overlap reduction function



Optimal filter

$$\tilde{Q}(f) = \lambda \frac{\gamma(f)\Omega_{\rm GW}(f) H_0^2}{f^3 P_1(f) P_2(f)}$$

λ such that:

$$\langle \hat{Y} \rangle = \Omega_\alpha$$

Isotropic search

- Mature and long-established analysis
- Has already set the best direct upper limits with initial LIGO and Virgo data [3,4]

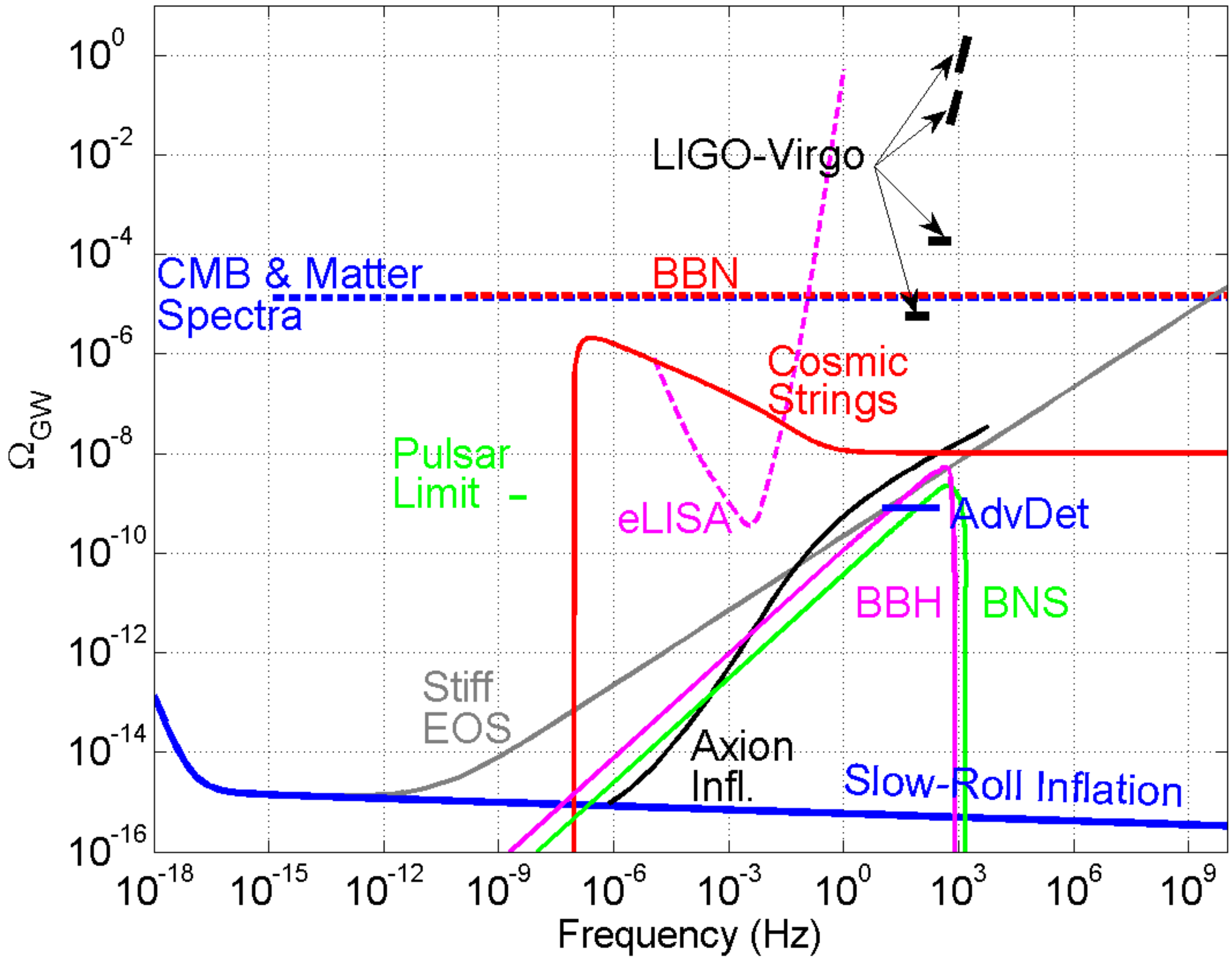
Isotropic search: latest results

- Latest results from 2009-2010 LIGO and Virgo data (paper being submitted soon!):
  - Find no evidence for isotropic stochastic GW background

PRELIMINARY

Frequency (Hz)	f_{ref} (Hz)	α	95% CL upper limit on Ω_α	Previous limits
41.5-169.25	-	0	5.6 x 10^{-6} 38% <------->	7.7 x 10^{-6}
170-600	-	0	1.8 x 10^{-4}	-
600-1000	900	3	0.14 x2.5 <-------->	0.35
1000-1726	1300	3	1.0	-

Isotropic search: latest results, cont.



PRELIMINARY

Directional search

- Looks for anisotropic stochastic background from aggregate of astrophysical sources dominated by strongest members
- Uses cross-correlated data to create sky maps of gravitational wave power
- Time delay between detectors used to measure location of signal on sky, Earth rotation breaks degeneracies for permanent signals

Directional search: detection strategy

- Energy density:

$$\Omega_{\rm GW}(f) \equiv \frac{f}{\rho_c}\frac{d\rho_{\rm GW}}{df} = \frac{2\pi^2}{3H_0^2} f^3 \int_{S^2} d\hat{\Omega}\, \mathcal{P}(f,\hat{\Omega})$$

- Point source (radiometer) search:

$$\mathcal{P}(\hat{\Omega}) \equiv \eta(\hat{\Omega}_0)\, \delta^2(\hat{\Omega},\hat{\Omega}_0)$$

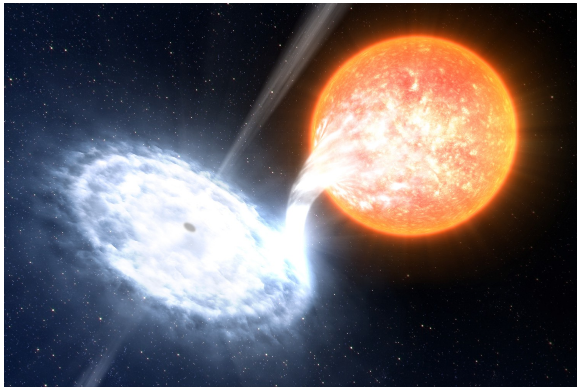
- Spherical harmonic decomposition (similar to CMB analyses):

$$\mathcal{P}(\hat{\Omega}) \equiv \sum_{lm} \mathcal{P}_{lm} Y_{lm}(\hat{\Omega})$$

Directional search

- Useful in disentangling different sources of background
- Mature analysis, published results [5,6]
- Narrowband radiometer useful for point sources when significant uncertainty in phase evolution of neutron star signal (such as Sco X-1)

Directional search: improvements to narrowband radiometer



- Bin size as a function of frequency
  - Sco X-1 modulation from binary motion [7]:

    $\Delta f = (0.133 \pm 0.017\ \text{Hz})\ (f / 500\ \text{Hz})$

    - At $f = 40$ Hz, $\Delta f = 0.0106 \pm 0.0013$ Hz. Standard ¼ Hz bin size much larger than necessary
    - At $f = 1726$ Hz, $\Delta f = 0.4591 \pm 0.0587$ Hz. Standard ¼ Hz bin size contains at most half of the signal
- Overlapping bins
  - If signal of SNR = 5 falls on border of two adjacent frequency bins, the signal would show up as SNR = 2.5 in each of the bins

Directional search: improvements to narrowband radiometer, cont.

- Use improved code in mock data challenge for comparison of Sco X-1 analysis methods
- Analyze 2009-2010 LIGO/Virgo data with improvements
- Vetted code in place for Advanced LIGO and Advanced Virgo

Conclusions

- Expect four orders magnitude improvement in sensitivity at 100 Hz with aLIGO and aVirgo, sensitive down to 10 Hz
- Isotropic search: new results from 2009-2010 data
- Directional search: planned improvements to narrowband radiometer to be implemented for advanced detectors
- Certain astrophysical and some alternative cosmological backgrounds may be within reach of aLIGO and aVirgo

References

[1] G. M. Harry and LIGO Scientific Collaboration, Classical and Quantum Gravity 27, 084006 (2010).

[2] Virgo Collaboration, Advanced Virgo baseline design (2009), URL https://tds.ego-gw.it/itf/tds/file.php?callFile=VIR-0027A-09.pdf.

[3] B. P. Abbott et al., Nature 460, 990 (2009).

[4] J. Abadie et al., Phys. Rev. D 85, 122001 (2012).

[5] J. Abadie et al., Phys. Rev. Lett. 107, 271102 (2011).

[6] B. Abbott et al., Phys. Rev. D 76, 082003 (2007).

[7] C. Messenger, LIGO Document T1000195-v3 (2010).