Searches for Stochastic Gravitational Waves with LIGO and Virgo data

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Abstract

LIGO and Virgo, the world's two km-scale gravitational-wave observatories, entered a data-sharing arrangement in Spring, 2007. We review projected sensitivities to a stochastic background (once Virgo reaches design sensitivity) which have been reported in conjunction with a joint analysis of simulated data.[1] We then describe the analysis that can be performed using the current data, taken in coïncidence during LIGO's 5th and Virgo's 1st Science Run.

Stochastic Background Sensitivity

A stochastic GW background can be defined by the correlations it generates in a pair of detectors:

$$\langle \tilde{h}_1^*(f)\, \tilde{h}_2(f') \rangle = \frac{1}{2}\delta(f-f')\, \gamma_{12}(f)\, S_{\mathrm{gw}}(f)\,. \qquad (1)$$

$S_{\mathrm{gw}}(f)$ is the 1-sided PSD it would generate in an IFO w/$\perp$ arms; $\gamma_{12}(f)$ describes the observing geometry & is given for an isotropic background by

$$\gamma_{12}(f) = d_{1ab}\, d_2^{cd}\, \frac{5}{4\pi} \iint d^2\Omega_{\hat{n}}\, P^{\mathrm{TT}\hat{n}ab}_{cd}\, e^{i2\pi f \hat{n}\cdot(\vec{r}_2-\vec{r}_1)/c} \qquad (2)$$

where

$$d^{ab} = (u^a u^b - v^a v^b)/2 \qquad (3)$$

is the detector tensor & $P^{\mathrm{TT}\hat{n}ab}_{cd}$ is a projector onto traceless symmetric matrices transverse to $\hat{n}$.

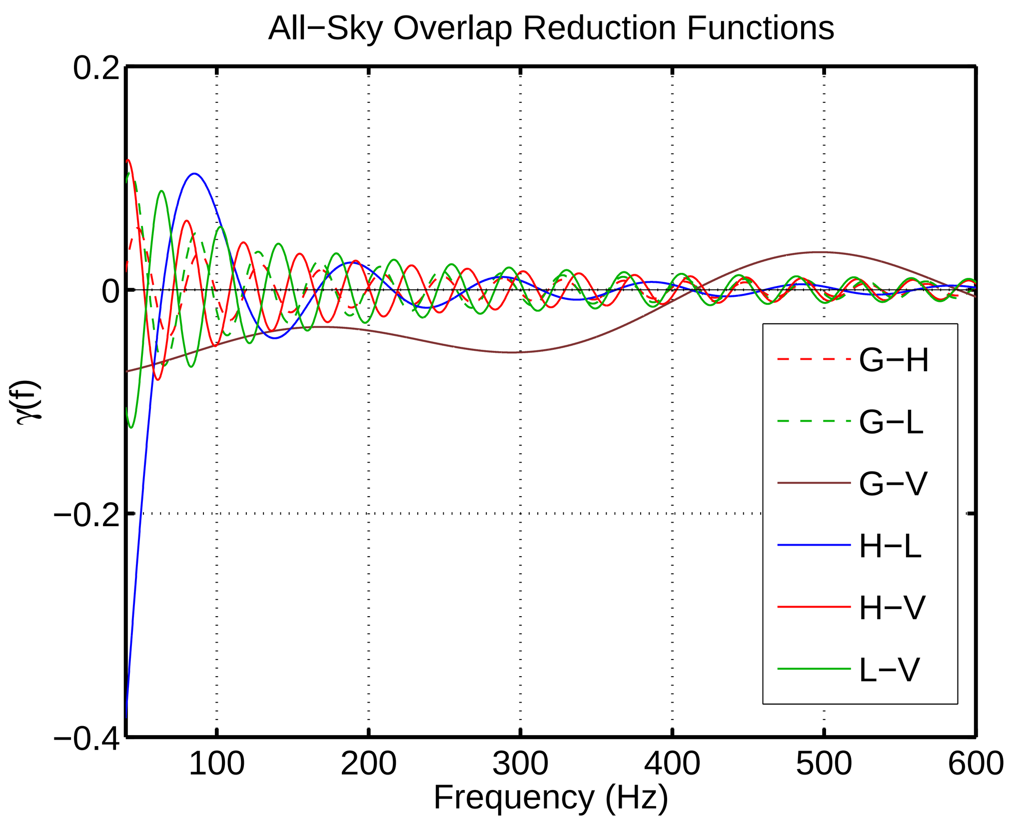

Figure 1: *Overlap reduction functions for combinations of GEO-600 (G), LIGO Hanford (H), LIGO Livingston (L) & Virgo (V)*

Its high-f limiting form is for $f \gg 1/(2\pi T_{12})$

$$\gamma_{12}(f) \longrightarrow 5 d_{1ab}\, P^{\mathrm{TT}\hat{s}_{12}ab}_{cd}\, d_2^{cd}\, \mathrm{sinc}(2\pi f T_{12}) = \frac{\gamma_{12}^{\mathrm{env}}}{f} \sin(2\pi f T_{12}) \qquad (4)$$

Envelope $\gamma_{12}^{\mathrm{env}}/f = (5 d_{1ab}\, P^{\mathrm{TT}\hat{s}_{12}ab}_{cd}\, d_2^{cd})/(2\pi f T_{12})$ suppressed by increasing light-travel time T_{12} but also by geom projection through TT plane for separation direction $\hat{s}_{12}$.

	G-H	G-L	G-V	H-L	H-V	L-V
$1/(2\pi T_{12})$ (Hz)	6.3	6.3	49.8	15.9	5.8	6.0
$\gamma_{12}^{\mathrm{env}}$ (Hz)	3.0	4.3	-17.2	-1.7	5.0	-5.9

Table 1: *Inverse light-travel times for pairs of detector sites, along with coëfficient of $1/f$ envelope in limiting form (4). Although LLO-LHO are $3\times$ closer than LLO-Virgo and LHO-Virgo pairs, projection effects make LIGO-Virgo pairs more favorable at higher frequencies.*

Sensitivity also influenced by shape of $S_{\mathrm{gw}}(f)$ & noise PSDs $P_{1,2}(f)$. For optimal cross-correlation search of duration T,

$$\mathrm{SNR}^2 = 2T \int_0^\infty [S_{\mathrm{gw}}(f)]^2\, \mathcal{I}_{12}(f)\, df \qquad (5)$$

where we've defined the sensitivity integrand

$$\mathcal{I}_{12}(f) = \frac{[\gamma_{12}(f)]^2}{P_1(f)\, P_2(f)} \qquad (6)$$

Now we can apply this to specific noise PSDs. . .

Sensitivity at Design

Put in design sensitivity PSDs[2, 3, 4]. Consider contributions of data from both LHO IFOs by using $P_{\mathrm{H}}(f)^{-1} = P_{\mathrm{H1}}(f)^{-1} + P_{\mathrm{H2}}(f)^{-1}$.

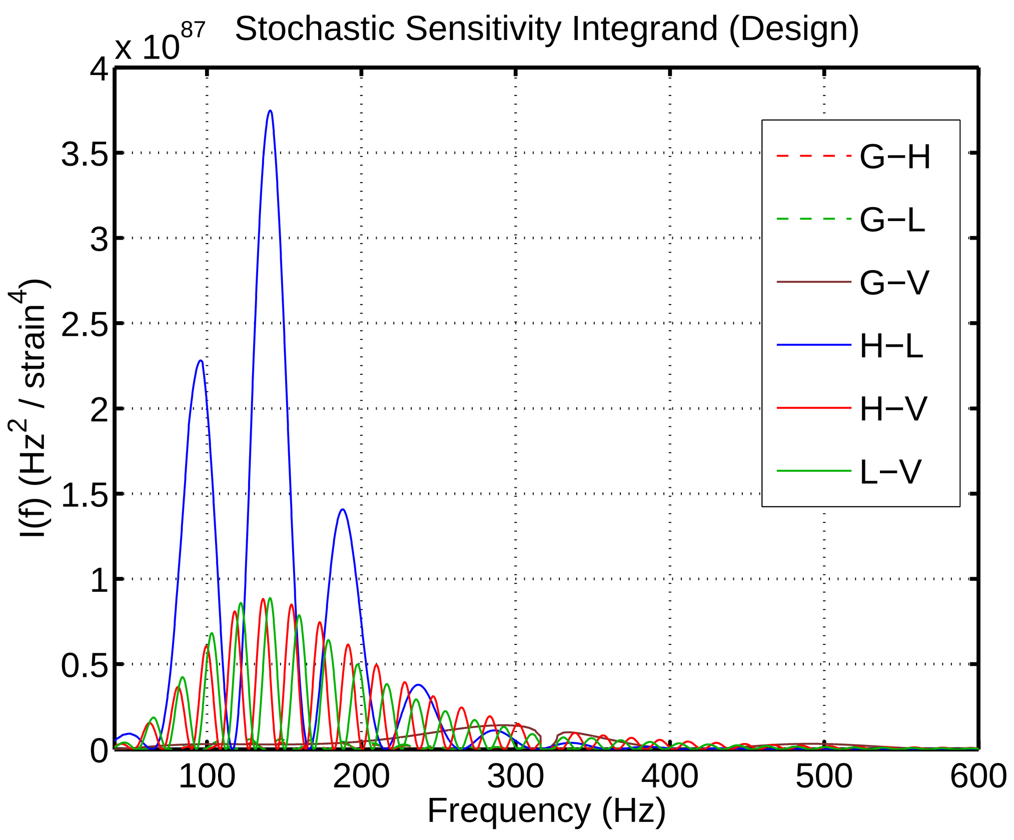

Figure 2: *Sensitivity integrands $\mathcal{I}_{12}(f)$ at design sensitivity.*

Construct networks of detector sites; L-V and H-V pairs enhance network above ~ 200 Hz. G-H and G-L don't help as much because GEO is less sensitive, but G-V adds to full network.

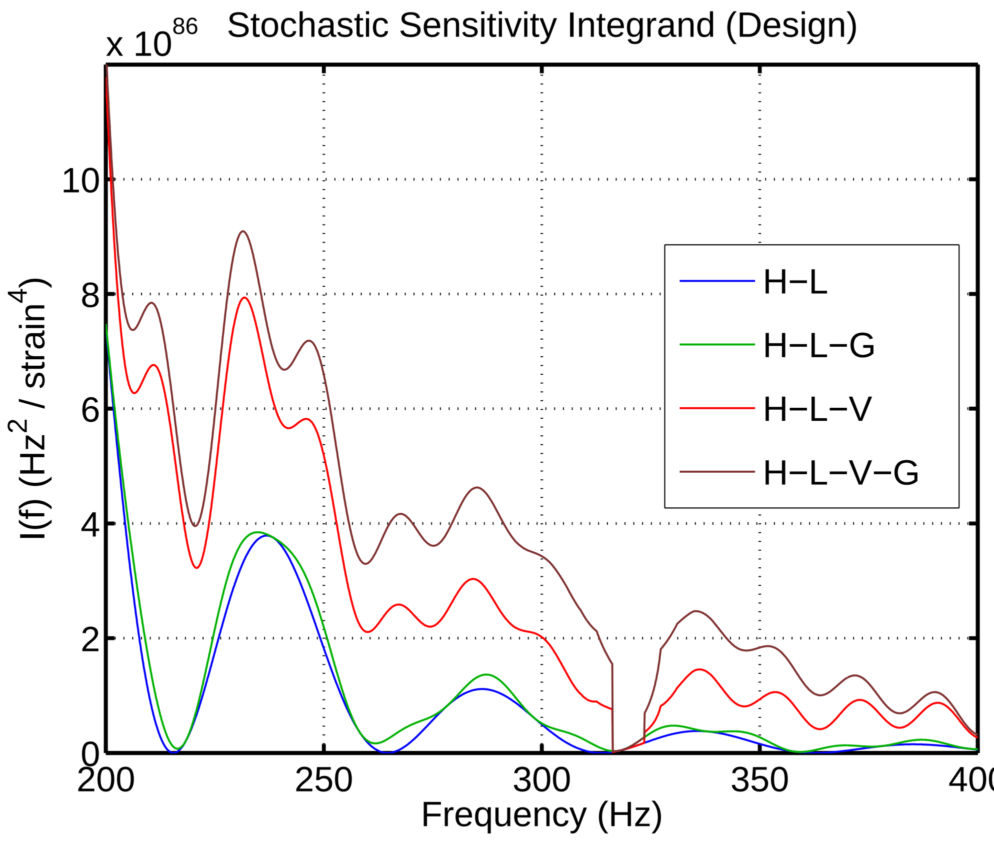

Figure 3: *Combined sensitivity integrands for detector networks at design sensitivity. Note effect of Virgo violin resonance above* 315 Hz.

A simulation project[1] has considered H-L-V network at design sensitivity. In it, we injected scaled-up astrophysically-inspired signals (with peak strength around 400 Hz) into simulated LIGO and Virgo data, which was recovered at an appropriate strength in each instrument pair.

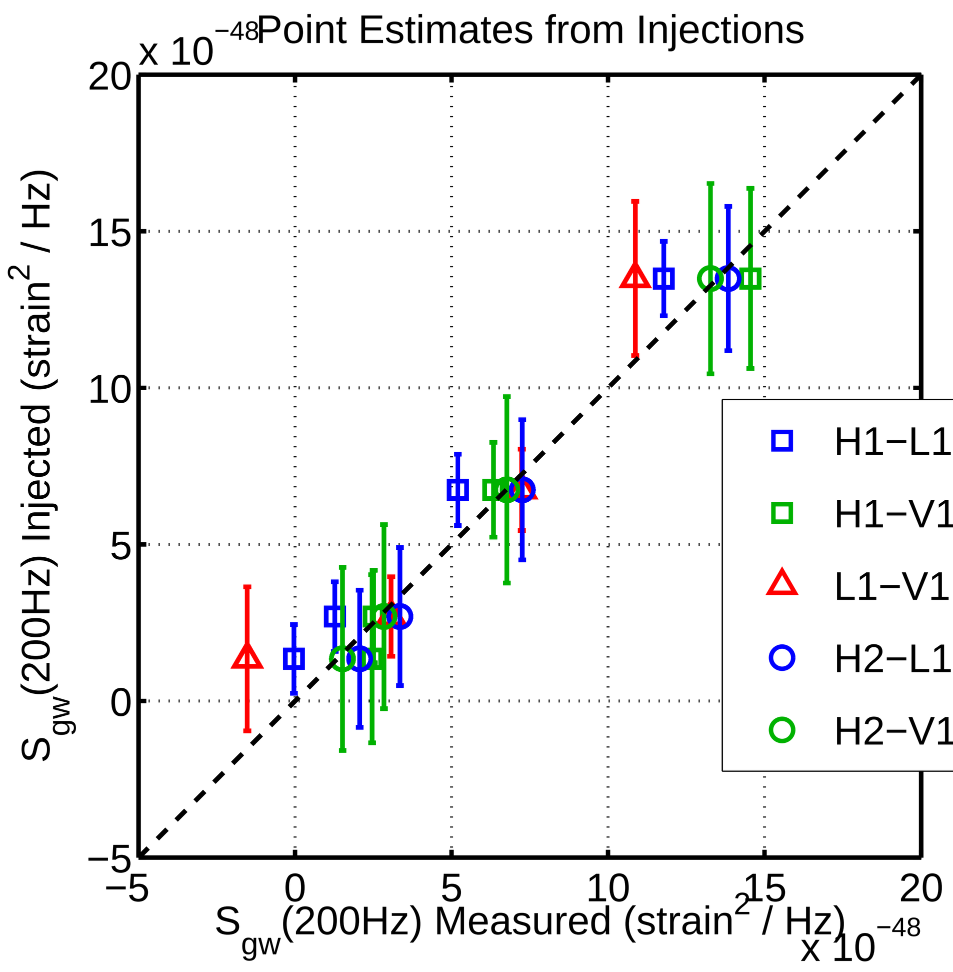

Figure 4: *Results of the simulation project described in [1].*

At design sensitivity, LIGO-Virgo pairs, and also Virgo-GEO, will significantly improve isotropic stochastic sensitivity above ~ 200 Hz.

Prospects with S5/VSR1 Sensitivities

In the current LIGO S5 run, LIGO is at its design sensitivity.[2] GEO has not yet achieved design sensitivity, so GEO pairs don't add appreciably to S5 sensitivities. Virgo is closest to its design sensitivity at high frequencies. In the short term, the greatest relative contribution will be for $f \gtrsim 800$ Hz. We thus concentrate attention there.

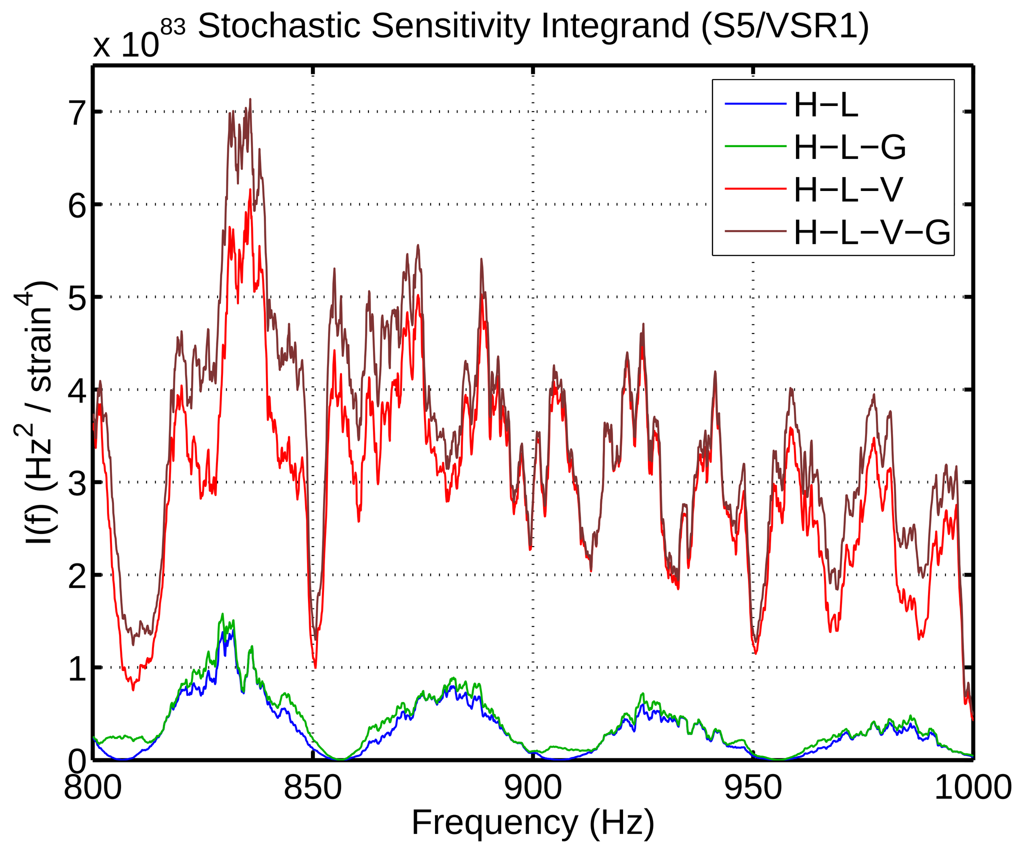

Figure 5: *Network sensitivity integrands from representative S5/VSR1 times, in the frequency band most favorable for pairs involving Virgo. The sensitivity integrand has been smoothed with a 2 Hz boxcar filter to improve visibility.*

Including Virgo-LIGO pairs in the analysis now (S5/VSR1) can make a significant impact at high frequencies. Although the short-term benefit is modest (a slight improvement on the limit set with S4 LLO-ALLEGRO measurements[6]), it will give us practical experience to be applied when Virgo achieves design sensitivity and lower frequencies ($200\,\mathrm{Hz} \lesssim f \lesssim 400\,\mathrm{Hz}$) become accessible.

Summary

Despite their geographical separation, projection effects make LLO-Virgo and LHO-Virgo pairs more favorable for higher-frequency stochastic GW correlations than LLO-LHO. Once Virgo achieves its design sensitivity, it will add significantly to the sensitivity of the global network to an isotropic stochastic background with support above ~ 200 Hz. Analysis of simulated data has illustrated the practical application of this method. The Virgo-GEO pair can likewise play a significant role at these frequencies.

In the current run (S5 for LIGO; VSR1 for Virgo), the frequencies at which Virgo is closest to its design sensitivity are higher than those targeted in the simulation. LIGO-Virgo pairs can make an immediate impact above ~ 800 Hz, and the LSC & Virgo plan to perform a joint cross-correlation analysis to improve limits at these frequencies. The experience gained will also be of use in subsequent observations at the frequencies which will become available with future improvements in Virgo sensitivity.

References

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