Progress on Stochastic Background Search Codes for LIGO *

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Outline

I Techniques for Detecting a Stochastic Background

- Cross-Correlation Statistic
- Optimal Filter
- Overlap Reduction Function

II Plans for & Status of LIGO Analysis

- E6 Upper Limits Run & Mock Data Challenge
- Implementation in LIGO Data Analysis System
- LHO/LLO & LLO/ALLEGRO correlations

I. Techniques for Detecting a Stochastic Background

Stochastic Background

Assume cosmological in origin, thus isotropic, unpolarized, gaussian, & stationary.

Describe i.t.o. GW contribution to $\Omega = \frac{\rho}{\rho_{\mathrm{crit}}}$:

$$\Omega_{\mathrm{GW}}(f) = \frac{1}{\rho_{\mathrm{crit}}} \frac{d\rho_{\mathrm{GW}}}{d \ln f} = \frac{f}{\rho_{\mathrm{crit}}} \frac{d\rho_{\mathrm{GW}}}{df}$$

Note $\rho_{\mathrm{crit}} \propto H_0^2$, so $h_{100}^2 \Omega_{\mathrm{GW}}(f)$ is independent of

$$h_{100} = \frac{H_0}{100\,\mathrm{km/\,s/\,Mpc}}$$

How to Tell Stochastic Signal from Random Noise

- Need correlations among detectors
  - Detector 1: $h_1 = s_1 + n_1$, Detector 2: $h_2 = s_2 + n_2$

- Assume noise uncorrelated with signal & between detectors

- Cross-correlation:

$$\langle h_1 h_2 \rangle = \langle n_1 n_2 \rangle + \langle n_1 s_2 \rangle + \langle s_1 n_2 \rangle + \langle s_1 s_2 \rangle$$

  only surviving term is from stochastic signal

Optimally Filtered Cross-Correlation Statistic

$$Y_Q = \int dt_1\, dt_2\, h_1(t_1)\, Q(t_1 - t_2) h_2(t_2)$$
$$= \int df\, \tilde{h}_1^*(f)\, \tilde{Q}(f)\, \tilde{h}_2(f)$$

Combine detector outputs using an *Optimal Filter* to maximize signal-to-noise ratio:

- Signal $\equiv$ mean of cross-correlation statistic $Y \propto T$
- Noise $\equiv$ variance of cross-correlation statistic $Y \propto \sqrt{T}$

Optimal Filter

$$\tilde{Q}(f) \propto \frac{f^{-3}\Omega_{\mathrm{GW}}(f)\gamma_{12}(f)}{P_1(f)P_2(f)}$$

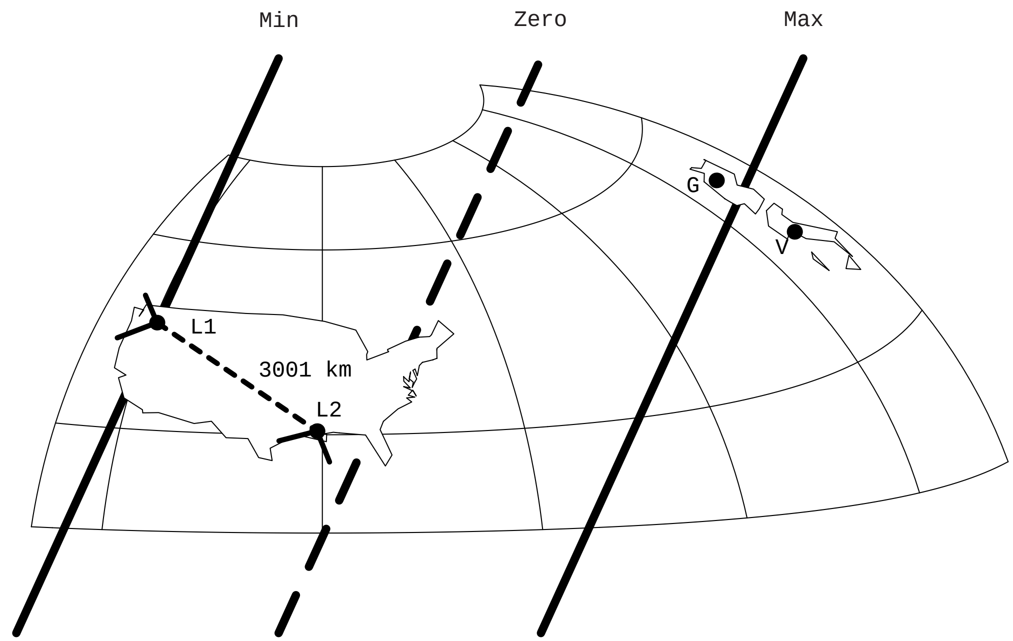
- Enhanced by signal $f^{-3}\Omega_{\mathrm{GW}}(f)$
  $\longrightarrow$ depends on target signal model

- Suppressed by noise $P_1(f)$,$P_2(f)$

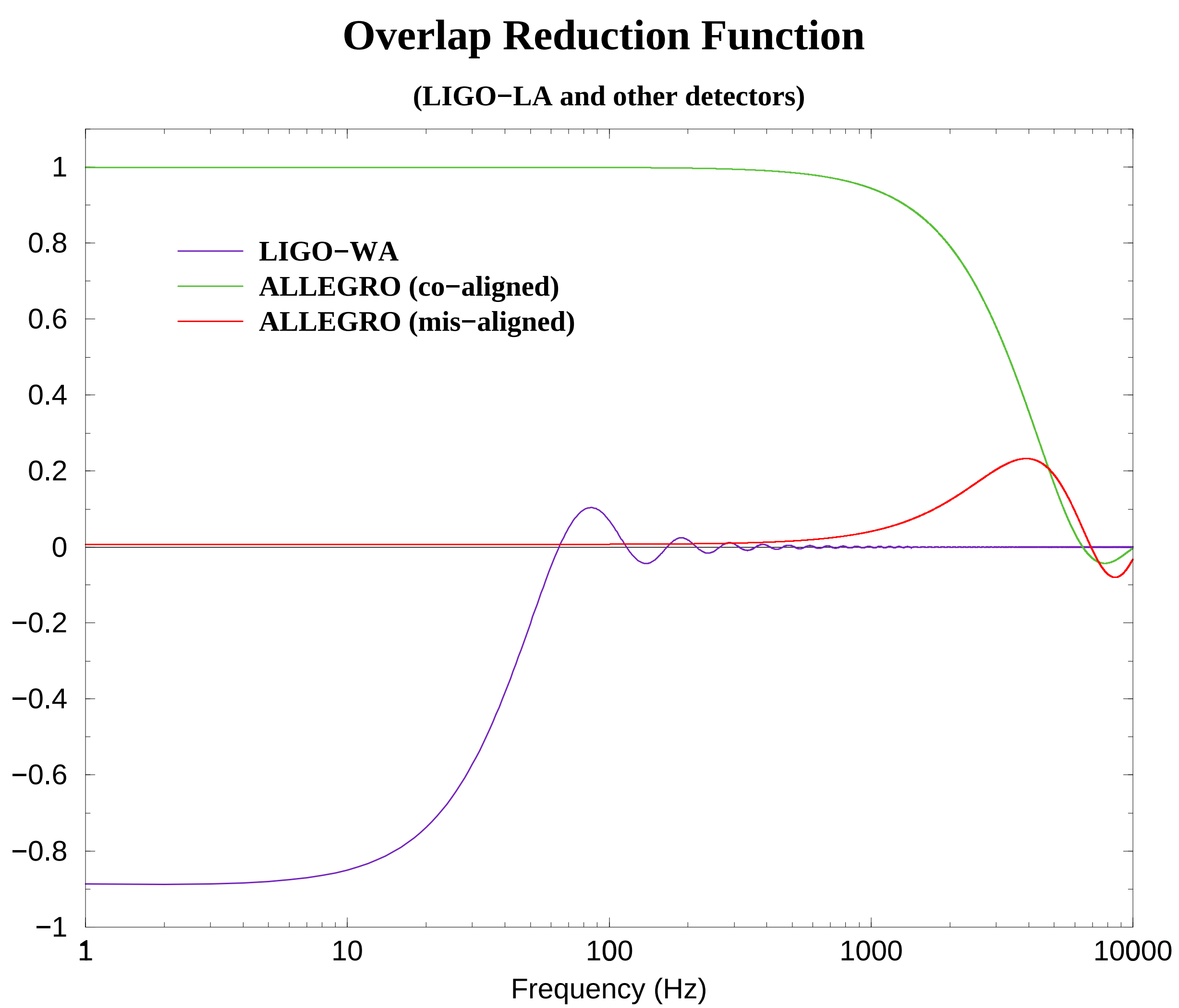
- Geometry via overlap reduction fcn $\gamma_{12}(f)$

Overlap Reduction Function

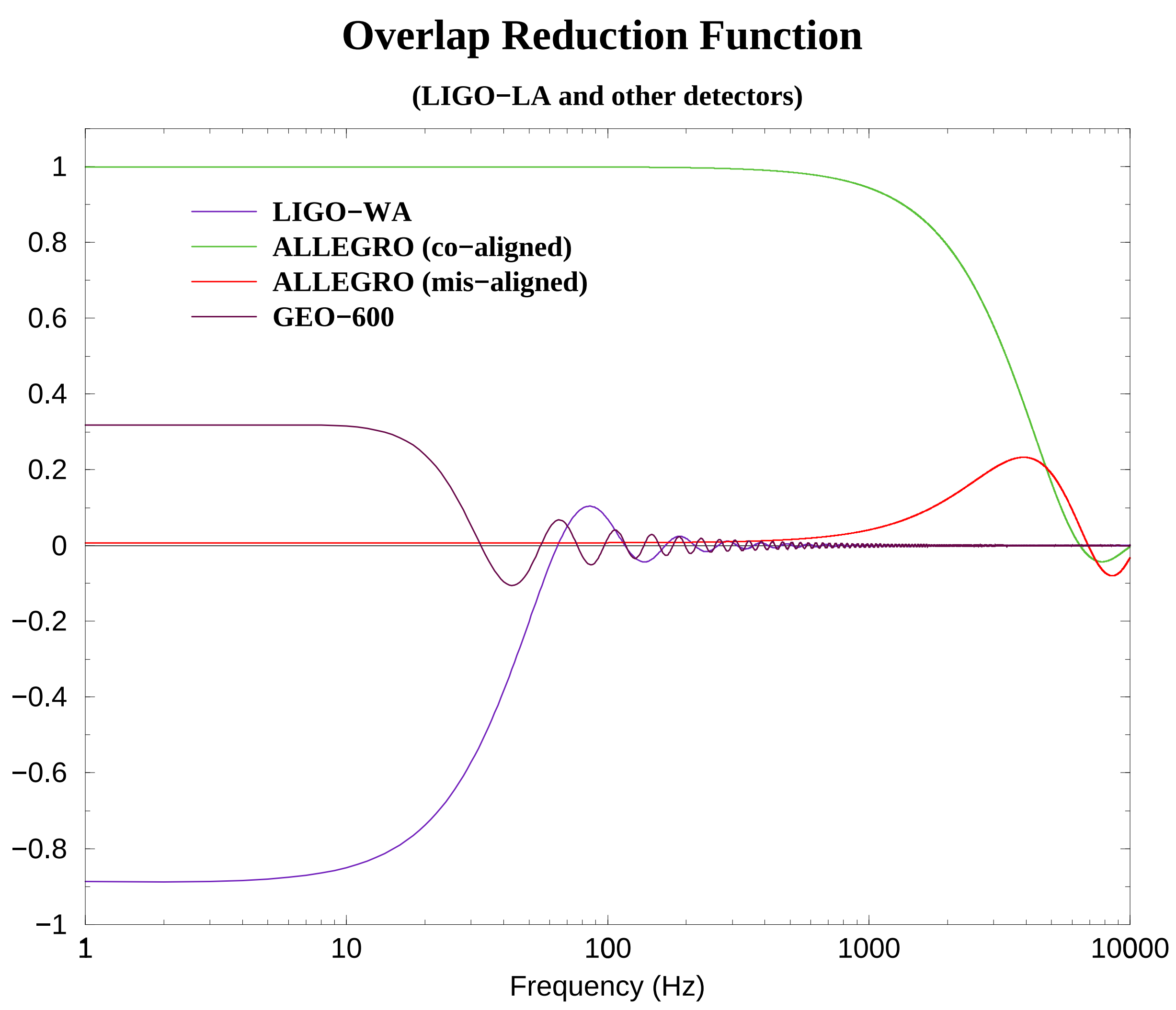
Depends on distance between & relative alignment of detectors



(figure from Allen & Romano, gr-qc/9710117)



Overlap Reduction Function
(LIGO−LA and other detectors)
LIGO−WA
ALLEGRO (co−aligned)
ALLEGRO (mis−aligned)
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1
10
100
1000
10000
Frequency (Hz)


Overlap Reduction Function
(LIGO−LA and other detectors)
LIGO−WA
ALLEGRO (co−aligned)
ALLEGRO (mis−aligned)
GEO−600
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1
10
100
1000
10000
Frequency (Hz)

II. Plans for & Status of LIGO Analysis

LIGO Timetable (in reverse)

- Fall 2002: Science Run Begins

- October 2001: E6 Engineering Run: ~ 2 weeks of coïncident data from LIGO-Hanford (LHO) & LIGO-Livingston (LLO);
  Upper Limits analysis;
  Coöperation with GEO-600 & ALLEGRO

- September 2001: Stochastic Mock Data Challenge

Plans for E6

1. Set Upper Limit on Stochastic Background by Correlating LLO & LHO

- Use Optimally-Filtered Cross-Correlation Statistic (Look for $\Omega_{\mathrm{GW}}(f)$ =const)

- Perform Analysis within LIGO Data Analysis System (LDAS) with codes from the LAL algorithm Library

- LHO/LLO Overlap Reduction Function kills correlations above ∼300Hz; most information from 50–250Hz

2. Set Upper Limit on Stochastic BG by Correlating LLO & ALLEGRO

- ALLEGRO bar detector (Louisiana State Univ.) sensitive in narrow frequency band around 900Hz
- Overlap Reduction Function not a problem b/c ALLEGRO & LLO only ~40km apart
- Sensitive to correlations in different frequency band from LLO/LHO pair
- Test bar/interferometer collaboration model (using LDAS/LAL)

Mock Data Challenge (Sept 4–10)

- Test data analysis code & LDAS pipeline

- Tests planned for both Livingston/Hanford & Livingston/ALLEGRO correlations

- Algorithm code written & being tested; controlling "search engines" under construction

- Use both simulated signals & data from earlier engineering runs

Summary

- To detect a stochastic GW background, look for a **cross-correlation** among detectors
- Maximize signal-to-noise using an **optimal filter**
- First big test: use E6 engineering data to set **upper limits**
- Preliminary test: Stochastic **Mock Data Challenge**

References

1. B. Allen, Les Houches lecture; gr-qc/9604033
2. B. Allen & J. D. Romano, PRD **59**, 102001 (1999); gr-qc/9710117
3. Stochastic Upper Limits Page: http://feynman.utb.edu/∼joe/research/stochastic/upperlimits/
4. Stochastic Code Development Page: http://oates.utb.edu/LAL-stochastic/
5. Finn & Lazzarini gr-qc/0104040