Searching for a Stochastic Background of Gravitational Waves with LIGO

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Stochastic GW Background

- Random background of grav waves (like CMBR in E&M)
- Produced in early universe (cosmological) and/or by many unresolved sources (astrophysical)
- Strength defined by $\Omega_{\mathrm{GW}}(f) = \frac{1}{\rho_{\mathrm{crit}}} \frac{d\rho_{\mathrm{GW}}}{d \ln f} = \frac{f}{\rho_{\mathrm{crit}}} \frac{d\rho_{\mathrm{GW}}}{df}$
- Search with cross-correlation; given detector outputs $h_1 = s_1 + n_1$ & $h_2 = s_2 + n_2$, expect noise n_1 & n_2 be uncorrelated, leaving

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

Sensitivity to Stochastic GW Backgrounds

- Optimally filtered CC statistic

$$Y = \int df\, \tilde{h}_1^*(f)\, \tilde{Q}(f)\, \tilde{h}_2(f)$$

- Optimal filter

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

- Optimally filtered cross-correlation method sensitive to

$$\Omega_{\mathrm{GW}} \propto \left(T \int \frac{df}{f^6} \frac{\gamma_{12}^2(f)}{P_1(f)P_2(f)} \right)^{-1/2}$$

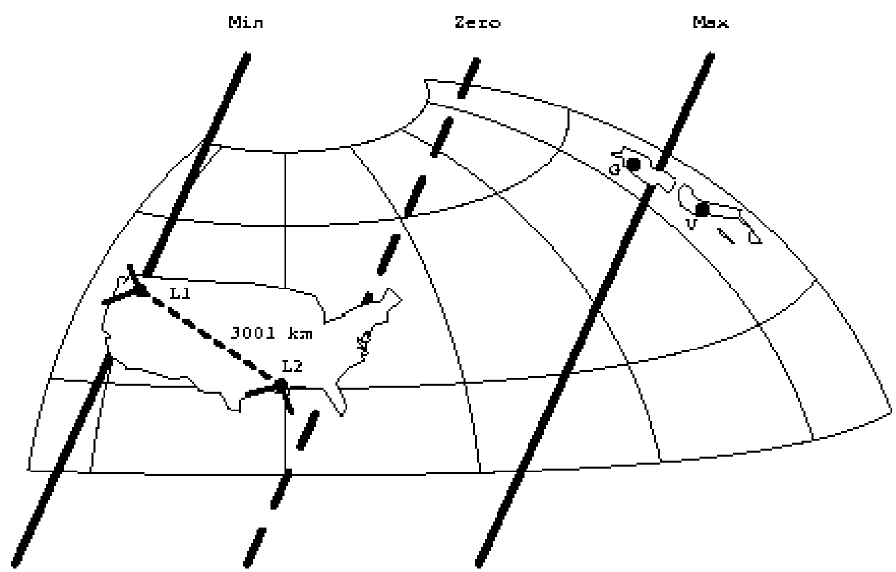
- Significant contributions when
  - detector noise power spectra $P_1(f)$, $P_2(f)$ small
  - overlap reduction function $\gamma_{12}(f)$ (geom correction) near ± 1

Overlap Reduction Function

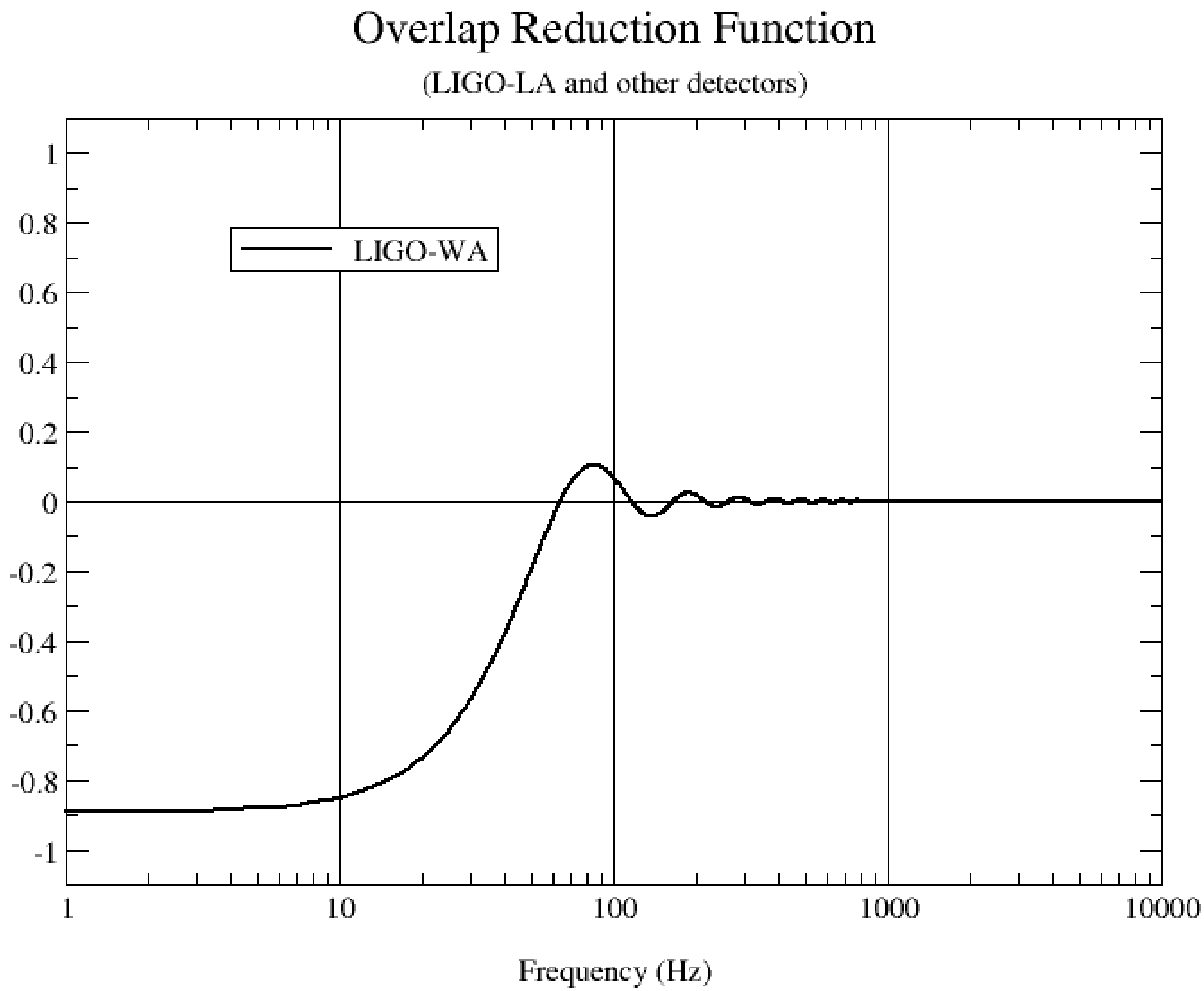
Depends on alignment of detectors (polarization sensitivity)

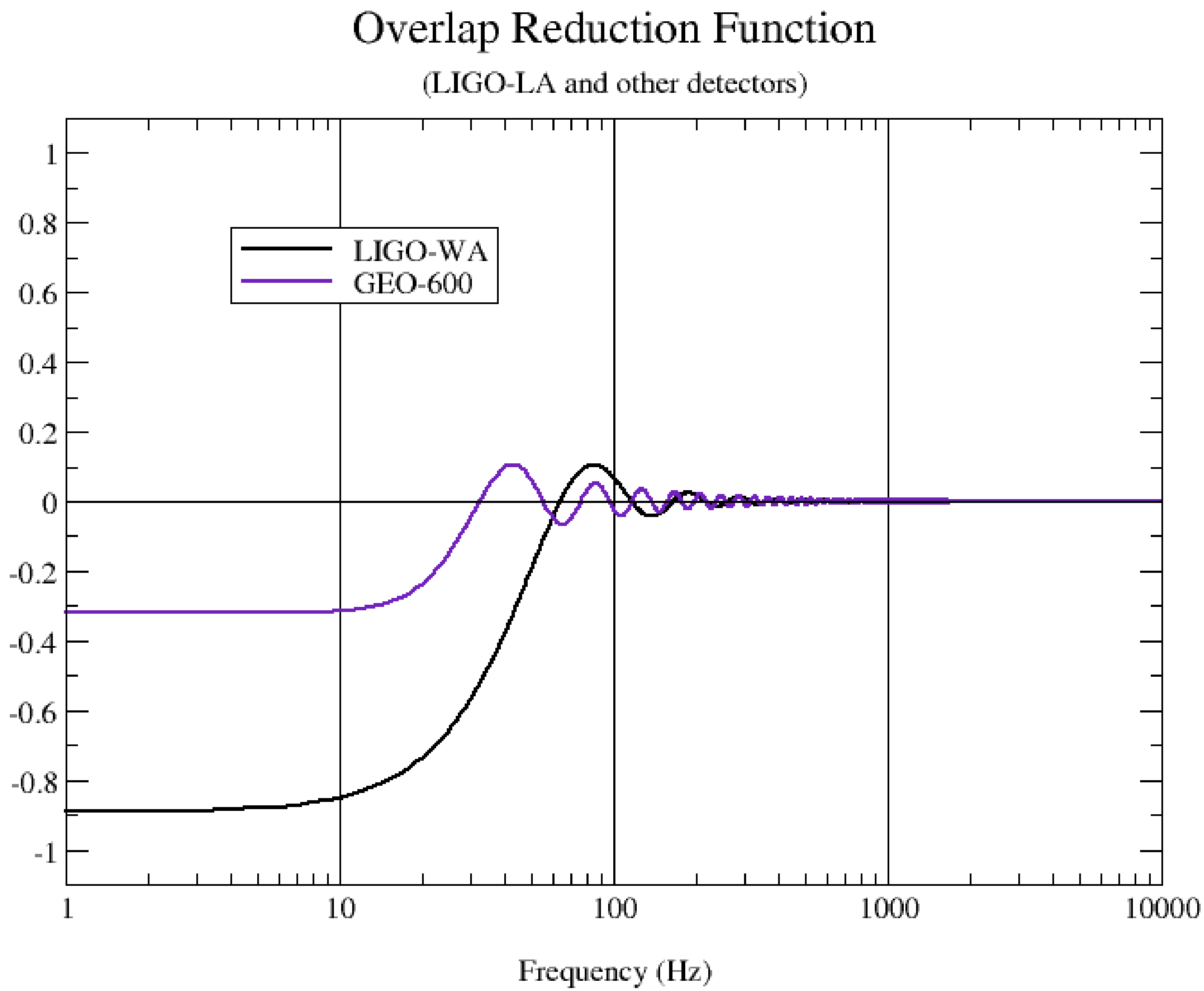
Frequency dependence from cancellations when $\lambda \lesssim$ distance

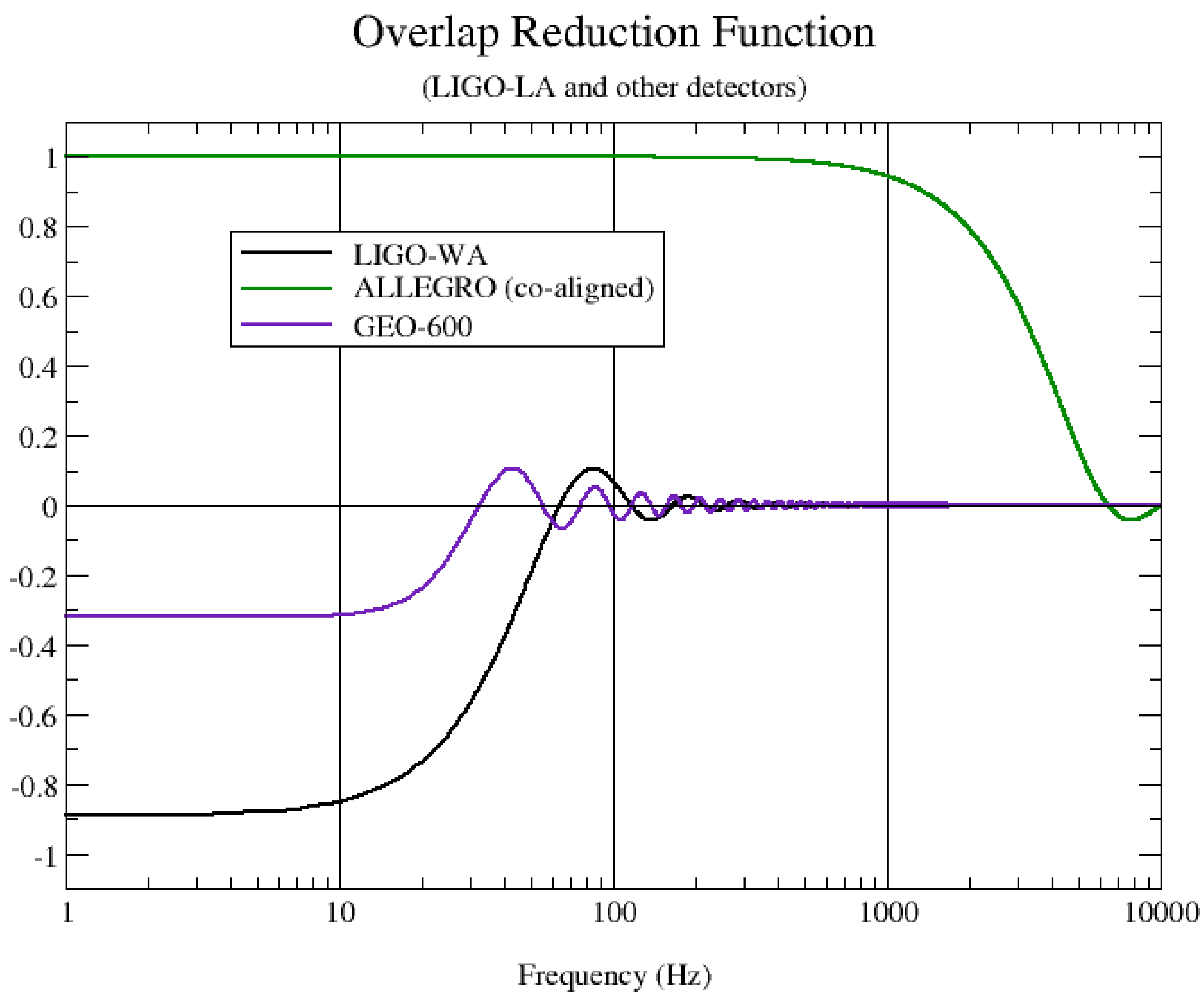
$\longrightarrow$ Widely separated detectors less sensitive at high frequencies

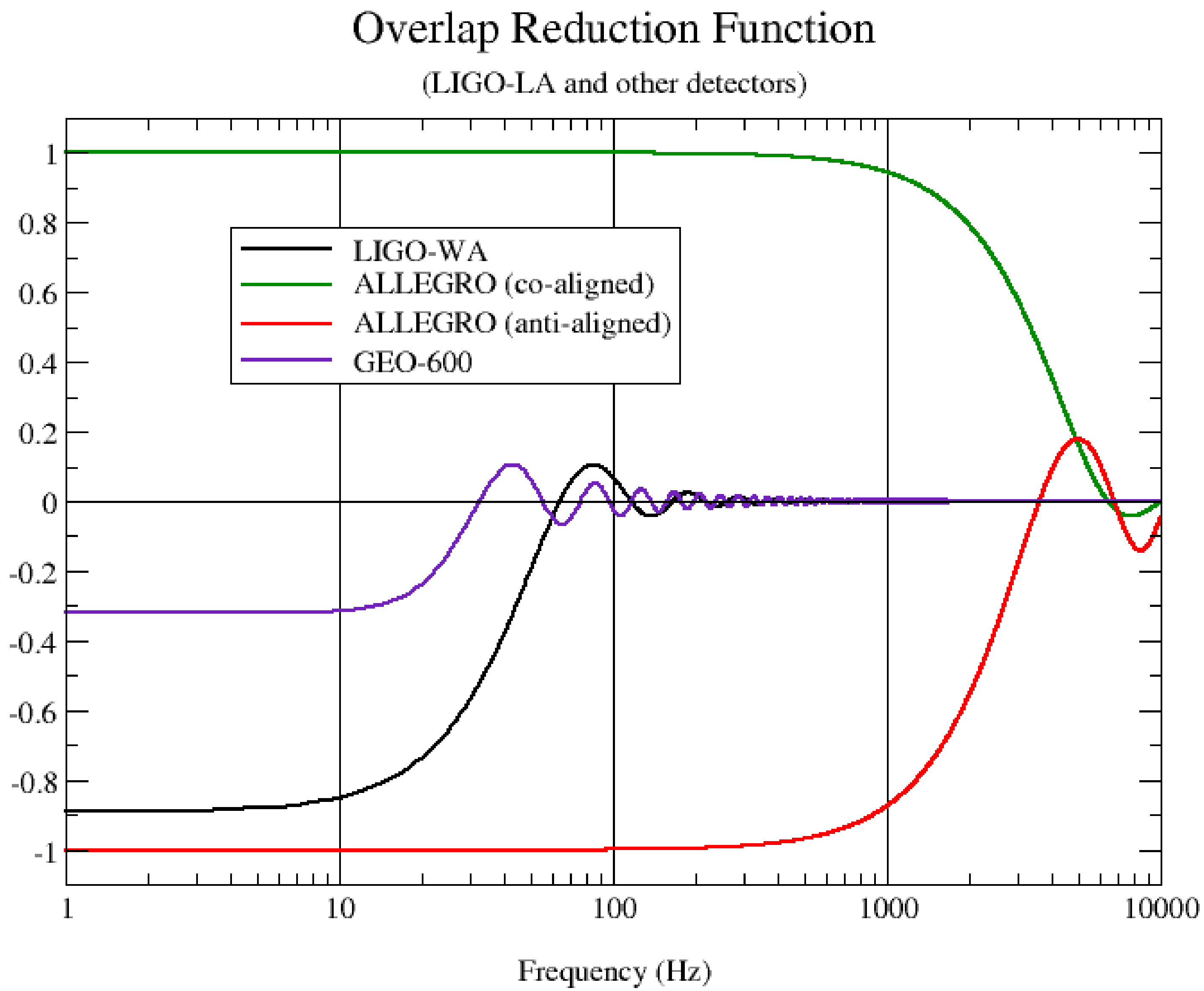


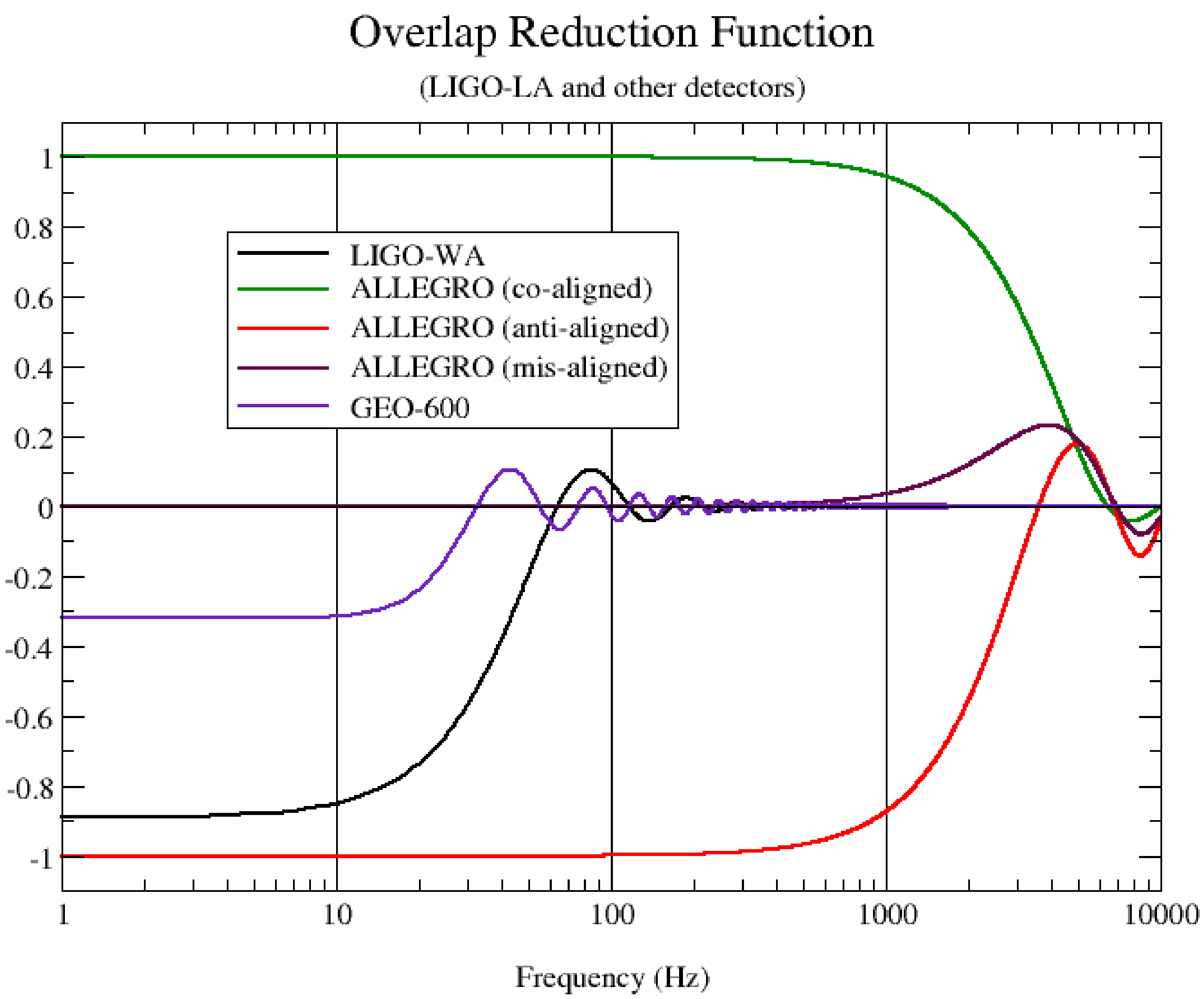
(figure from Allen & Romano PRD, gr-qc/9710117)


Overlap Reduction Function
(LIGO-LA and other detectors)
LIGO-WA
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
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)


Overlap Reduction Function
(LIGO-LA and other detectors)
LIGO-WA
ALLEGRO (co-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)


Overlap Reduction Function
(LIGO-LA and other detectors)
LIGO-WA
ALLEGRO (co-aligned)
ALLEGRO (anti-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)


Overlap Reduction Function
(LIGO-LA and other detectors)
LIGO-WA
ALLEGRO (co-aligned)
ALLEGRO (anti-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)

Previous Results

- Current best upper limit: correlation between EXPLORER & NAUTILUS bars (Astone et al, 1999): $\Omega_{\mathrm{GW}}(907\,\mathrm{Hz}) \leq 60$
- Upper limit from single bar (Astone et al, 1996): $\Omega_{\mathrm{GW}}(907\,\mathrm{Hz}) \leq 100$
- Correlation between Garching & Glasgow prototype IFOs (Compton et al, 1994): $\Omega_{\mathrm{GW}}(f) \lesssim 3 \times 10^5$
- Correlation between 70 hrs of LIGO Hanford & Livingston engineering (E7) data (Tech Doc LIGO-T020115-00-Z): $\Omega_{\mathrm{GW}}(f) \lesssim 8 \times 10^4$

SB Searches with LIGO Science Data

- LLO/LHO sensitive to $\Omega(40\,\mathrm{Hz} \lesssim f \lesssim 300\,\mathrm{Hz})$
- S1 Run (2002 Aug 23-Sep 9): 100+ hrs of coïncident data currently being analyzed.
- Preliminary results (See Lazzarini, LIGO-G030003-04-E @AAAS) $\longrightarrow$ S1 upper limit should beat EXPLORER–NAUTILUS limit
- S2 Run (2003 Feb 14-Apr 14): 4x obs time @ 10x amp sens: expect factor of 200 improvement in upper limit
  Back-of-the-envelope estimate is $\Omega_{\mathrm{GW}}(f) \lesssim 10^{-2}$

Other Detector Combinations

- LIGO Hanford site has 2km & 4km interferometers:
  colocation means $\gamma(f) = 1$: more sensitive, wider bandwidth
  however, correlated noise may be a problem
  Status: included in S1 analysis
- LLO & ALLEGRO resonant bar detector 40 km apart:
  gives measurement @ $\sim 900\,\mathrm{Hz}$
  & rotating ALLEGRO modulates GW resp to sep from corr noise
  Status: last coïncident data was from E7 (analysis coming soon)
  ALLEGRO hoping to be online again by end of S2
- LIGO & GEO-600 (Hannover, Germany)
  separation reduces stochastic GW sensitivity (lower $\gamma(f)$)
  useful for probing transatlantic environmental correlations
  Status: S1 data; analysis pipeline under construction

Summary

- To detect a stochastic GW background, look for a **cross-correlation** among detectors

- Maximize signal-to-noise using an **optimal filter**

- LIGO Livingston (LLO) & Hanford (LHO) data being correlated to improve **upper limits**

- Other detector combinations being studied: LHO4km/LHO2km, LLO/ALLEGRO, LLO/GEO-600

Members of LSC Stochastic Sources Upper Limits Group

B. Allen, W. Anderson, S. Bose, N. Christensen, E. Daw, M. Díaz, R. Drever, L. S. Finn, *P. Fritschel*, J. Giame, W. Hamilton, I. S. Heng, R. Ingley, W. Johnson, W. R. Johnston, E. Katsavounidis, S. Klimenko, M. Landry, A. Lazzarini, M. McHugh, S. Mukherjee, T. Nash, A. Ottewill, P. Pérez, *J. Romano*, T. Regimbau, K. Riles, J. Ringland, J. Rollins, B. Schutz, A. Searle, A. Sintes, C. Torres, C. Ungarelli, E. Vallarino, A. Vecchio, **JTW**, B. Whiting, R. Weiss