Status of the LIGO-ALLEGRO Stochastic Background Search

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on behalf of the LIGO Scientific Collaboration

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Corrected version using v1.5 ALLEGRO calibration
Outline

I Background/Motivation for LLO-ALLEGRO Search
- Overlap Reduction Function
- LLO-ALLEGRO Pair (proximity, overlap modulation)
- Technical Considerations (sampling, heterodyning, calibration)

II Status of S2 Analysis
- Data Volume by Orientation
- Data Quality
- Expected Sensitivity
Sensitivity to Stochastic GW Backgrounds

- Optimally filtered CC statistic

\[ Y = \int df \tilde{s}_1^*(f) \tilde{Q}(f) \tilde{s}_2(f) \]

- Optimal filter \( \tilde{Q}(f) \propto f^{-3} \Omega_{GW}(f) \gamma_{12}(f) \)

  \[ \frac{P_1(f)P_2(f)}{P_1(f)P_2(f)} \]

  (Initial analyses assume \( \Omega_{GW}(f) \) constant across band)

- Optimally filtered cross-correlation method has \( \Omega_{GW} \) sensitivity

\[ \sigma_\Omega \propto \left( T \int \frac{df}{f^6} \frac{\gamma_{12}^2(f)}{P_1(f)P_2(f)} \right)^{-1/2} \]

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

\[ \gamma_{12}(f) = d_{1ab} d_{2cd} \frac{5}{4\pi} \int \int_{S^2} d^2 \Omega \ P^{TT}_{ab}(\hat{\Omega}) e^{i2\pi f \hat{\Omega} \cdot \Delta \vec{x}/c} \]

Depends on alignment of detectors (polarization sensitivity)
Frequency dependence from cancellations when \( \lambda \lesssim \) distance
\( \rightarrow \) Widely separated detectors less sensitive at high frequencies

This wave drives LHO & GEO out of phase

LHO

GEO

max

zero

min
Overlap Reduction Function

\[ \gamma_{12}(f) = d_{1ab}d_{2cd} \frac{5}{4\pi} \int \int_{S^2} d^2 \Omega \ P_{TT}^{ab}(\Omega) e^{i2\pi f \hat{\Omega} \cdot \Delta \vec{x}/c} \]

Depends on alignment of detectors (polarization sensitivity)
Frequency dependence from cancellations when \( \lambda \lesssim \) distance
→ Widely separated detectors less sensitive at high frequencies

This wave (same \( \lambda \)) drives LHO & GEO in phase
Overlap Reduction Function

Frequency (Hz)

LLO−LHO
LLO−ALLEGRO (N72° E)
Overlap Reduction Function

- LLO–LHO
- LLO–ALLEGRO (N72° E) "XARM"
- LLO–ALLEGRO (N18° W) "YARM"
- LLO–ALLEGRO (N63° W) "NULL"
LLO-ALLEGRO Correlations

- Only $\sim 40$ km apart $\rightarrow \gamma(900\,\text{Hz}) \approx 95\%$ for best alignment
  Sensitive in different freq band from LLO/LHO pair

- Unique experimental technique: rotate ALLEGRO to callibrate cross-correlated noise (Finn & Lazzarini)
  - XARM & YARM orientations have opposite GW sign
    $\rightarrow$ can “cancel” out CC noise by subtracting results
  - NULL orientation has no expected GW signal
    $\rightarrow$ “off-source” measurement of CC noise

- Currently analyzing S2 (2003 Feb 14-Apr 14) data; ALLEGRO was offline for S3 (2003 Oct 31-2004 Jan 9), now running again; Further work planned for S4 & beyond
LLO-ALLEGRO: Technical Considerations

- **LIGO** data digitally downsampled $16384\text{ Hz} \rightarrow 4096\text{ Hz}
- **ALLEGRO** data heterodyned at $899\text{ Hz}$ & sampled at $250\text{ Hz}$
- Time domain resampling undesirable: $2^9/5^3$ sampling ratio → work in freq domain w/overlapping frequencies

- Uncalibrated **ALLEGRO** data have sharper spectral features → Work w/calibrated heterodyned strain “$h(t)$” for **ALLEGRO**

- Calibrating **ALLEGRO** data is major undertaking
  (Coherent analysis requires more precise calibration than before)
  See [McHugh talk](#) for more details
LLO-ALLEGRO data from LIGO S2 Run

- Analysis uses sliding PSD estimator & $\sigma$ ratio cut non-overlapping Tukey windows

- $\sim 10\%$ of data set aside as “playground”

- Non-PG data divided into 60s segments; 3 orientations:
  - “NULL” ($0.028 < \gamma(f) < 0.034$): 3328 min after cuts
    “off-source” data useful for data quality & cross-checks
  - “YARM” ($-0.89 > \gamma(f) > -0.91$): 1654 min after cuts
  - “XARM” ($0.95 < \gamma(f) < 0.96$): 1547 min after cuts

- Projected $h_{100}^2\Omega$ sensitivity using YARM & XARM data: $\sim 14$
Avg Calibrated ASD from S2 Playground

Frequency (Hz)
Strain (Hz\(^{-1/2}\))
LLO ASD
ALLEGRO ASD
Spectrum for Ω(f)=14
Sensitivity by Segment for YARM Jobs

Days after 2003−Feb−14

$\sigma_\Omega^2$ vs. Days after 2003−Feb−14

$1.6 \times 10^{-5}$
LLO-ALLEGRO: Summary

- First stochastic measurement correlating bar w/ifo data
- Probes higher frequency band than LLO-LHO: $\sim 850 - 950$ Hz
- Rotation of ALLEGRO modulates stochastic response (data taken in 3 orientations during S2)
- Freq-domain method seems to solve sampling rate issues
  $\exists$ more careful analytic demonstration
- Analyzing S2 data; next coincident run is S4
- Expected S2 sensitivity from $\sim 54$ hrs of data $h_{100}^2 \Omega_{GW}(f) \sim 14$