Stochastic Background Search with ALLEGRO and LIGO Science Data

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on behalf of the LIGO Scientific Collaboration

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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
- Software Injections

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 $\tilde{Q}(f) \propto \frac{f^{-3}\Omega_{GW}(f)\gamma_{12}(f)}{P_1(f)P_2(f)}$
  (Initial analyses assume $\Omega_{GW}(f)$ constant across band)
- Optimally filtered cross-correlation method has Ω_{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 ± 1

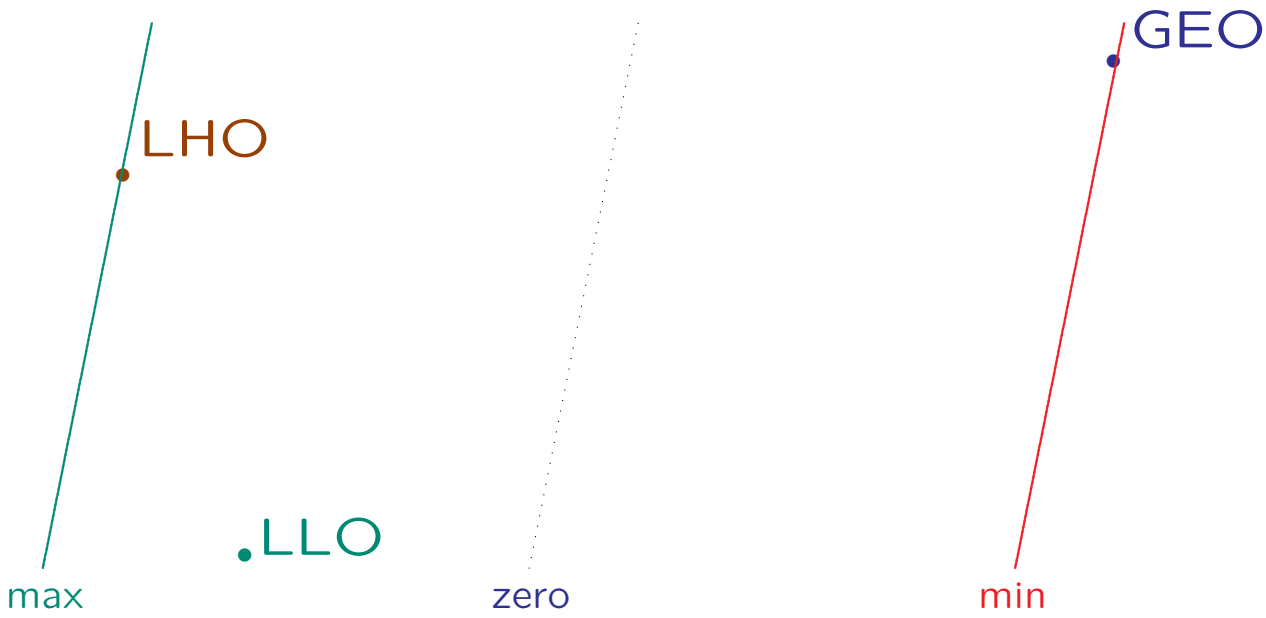
Overlap Reduction Function

$$\gamma_{12}(f) = d_{1ab} d_2^{cd} \frac{5}{4\pi} \iint_{S^2} d^2\Omega \; P^{\mathrm{TT}\,ab}_{\quad cd}(\hat{\Omega}) e^{i2\pi f \hat{\Omega}\cdot\Delta\vec{\mathbf{x}}/c}$$

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

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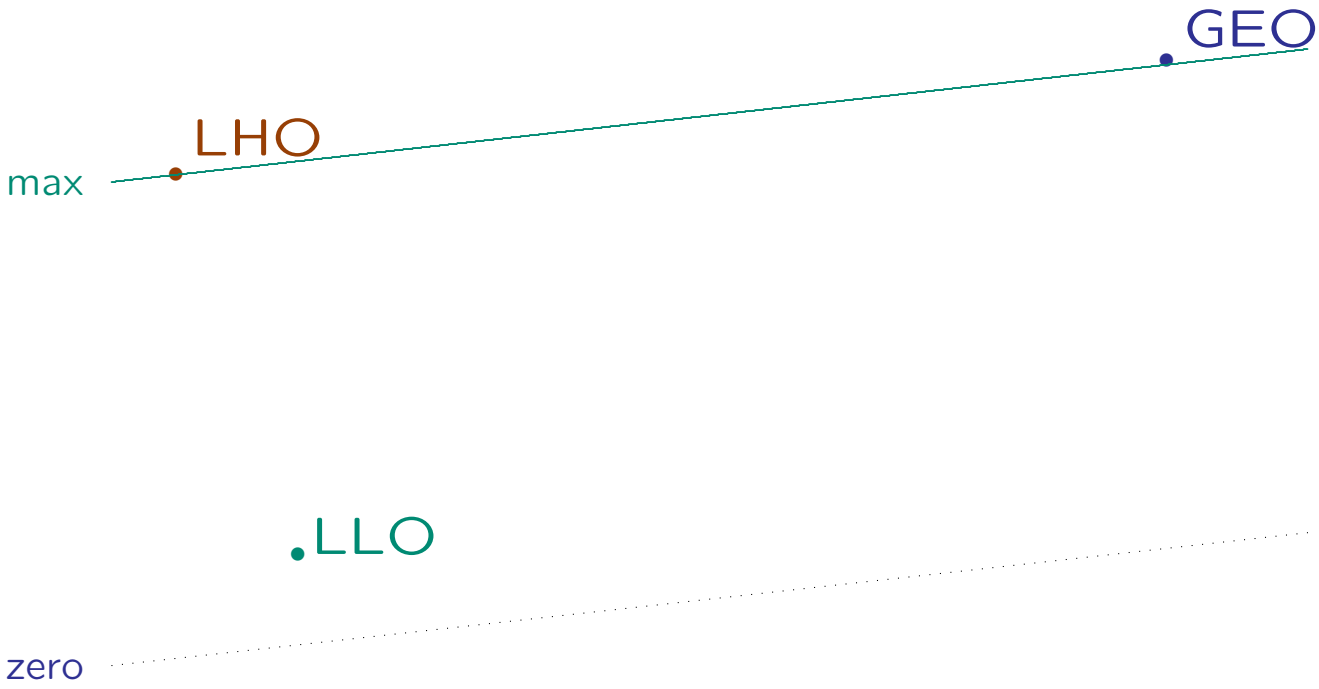
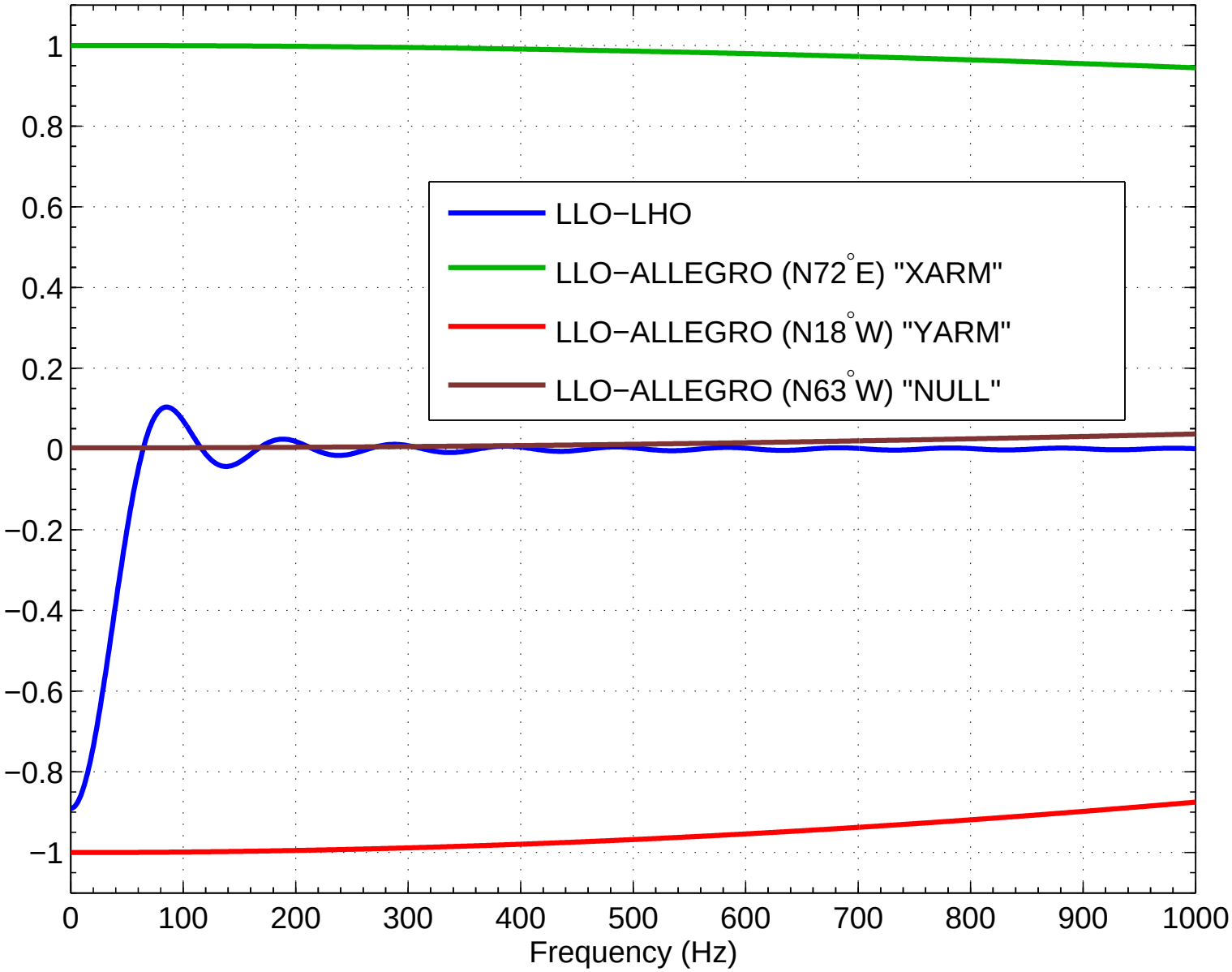


This wave (same λ) drives LHO & GEO in phase


Overlap Reduction Function
LLO−LHO
LLO−ALLEGRO (N72°E) "XARM"
LLO−ALLEGRO (N18°W) "YARM"
LLO−ALLEGRO (N63°W) "NULL"
1
0.8
0.6
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
0
100
200
300
400
500
600
700
800
900
1000
Frequency (Hz)

LLO-ALLEGRO Correlations

- Only $\sim$40 km apart $\rightarrow$ $\gamma(900\,\mathrm{Hz}) \approx 95\%$ 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
    $\longrightarrow$ can "cancel" out CC noise by subtracting results
  - NULL orientation has no expected GW signal
    $\longrightarrow$ "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 Hz $\rightarrow$ 4096 Hz
  ALLEGRO data heterodyned at 899 Hz & sampled at 250 Hz
  Time domain resampling undesirable: $2^9/5^3$ sampling ratio
  $\rightarrow$ work in freq domain w/overlapping frequencies

- Uncalibrated ALLEGRO data have sharper spectral features
  $\rightarrow$ Work w/calibrated heterodyned strain "$h(t)$" for ALLEGRO

- Calibrating ALLEGRO data is major undertaking
  (Coherent analysis requires more precise calibration than before)

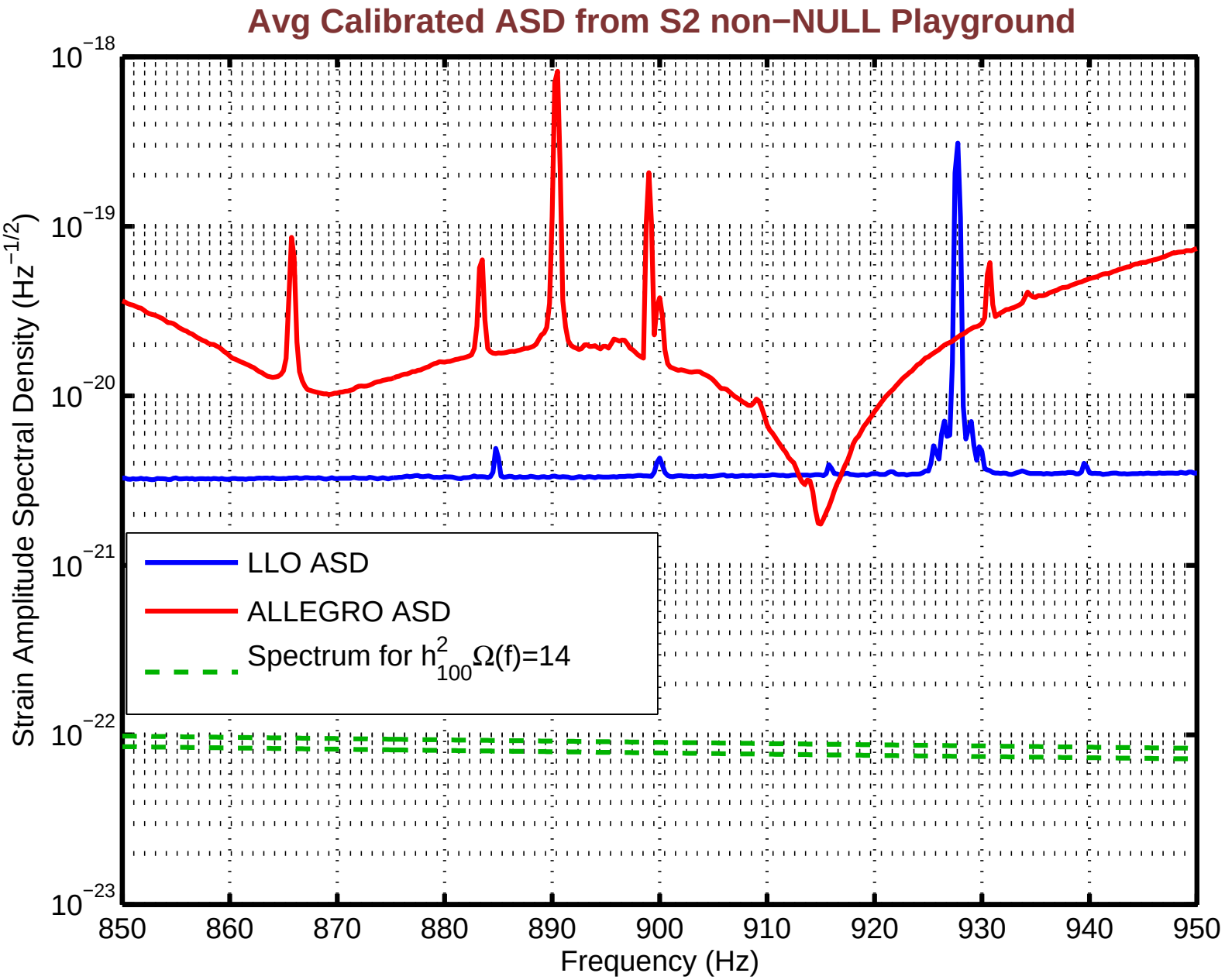
LLO-ALLEGRO data from LIGO S2 Run

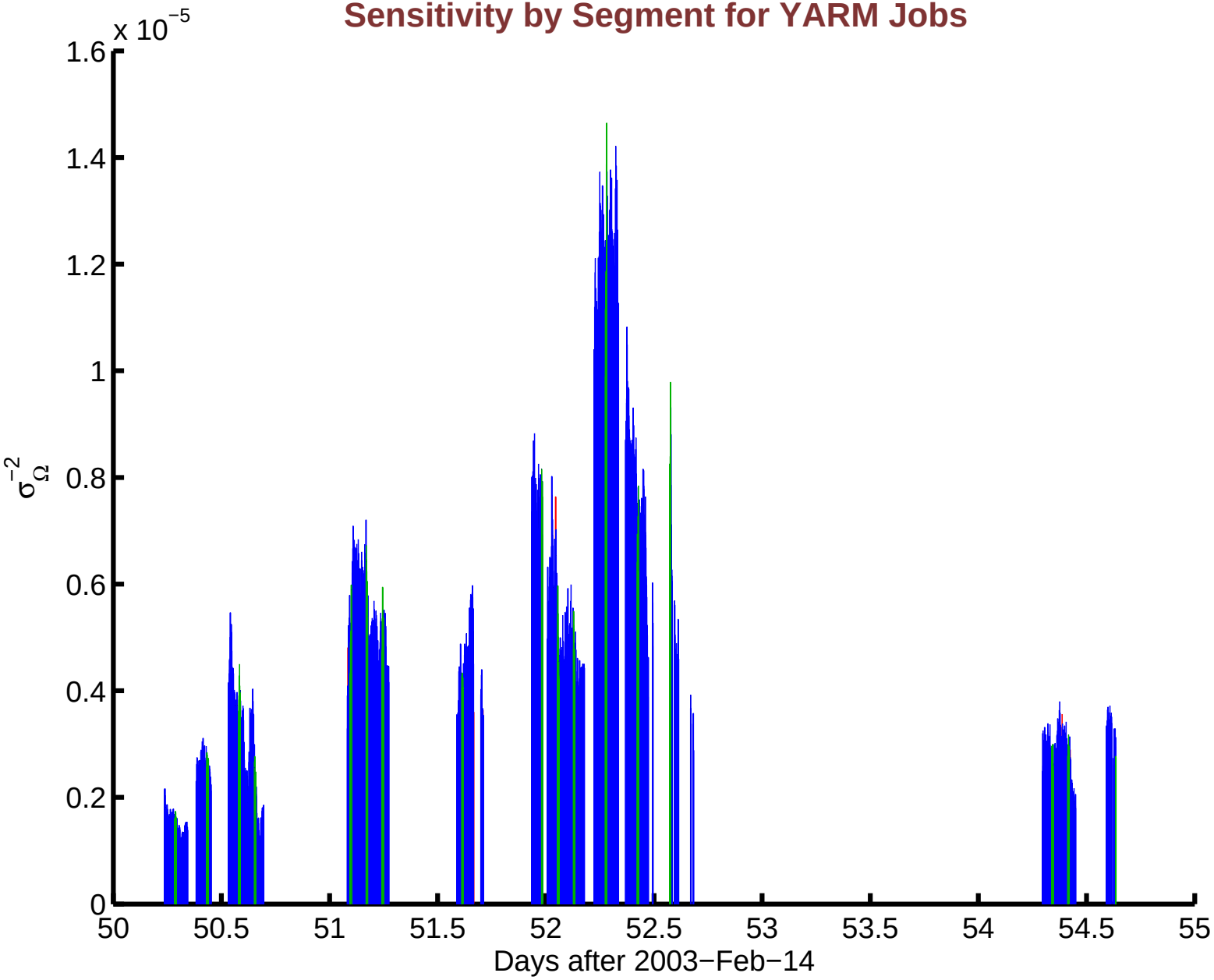
- Analysis uses sliding PSD estimator & σ ratio cut
  non-overlapping Tukey windows

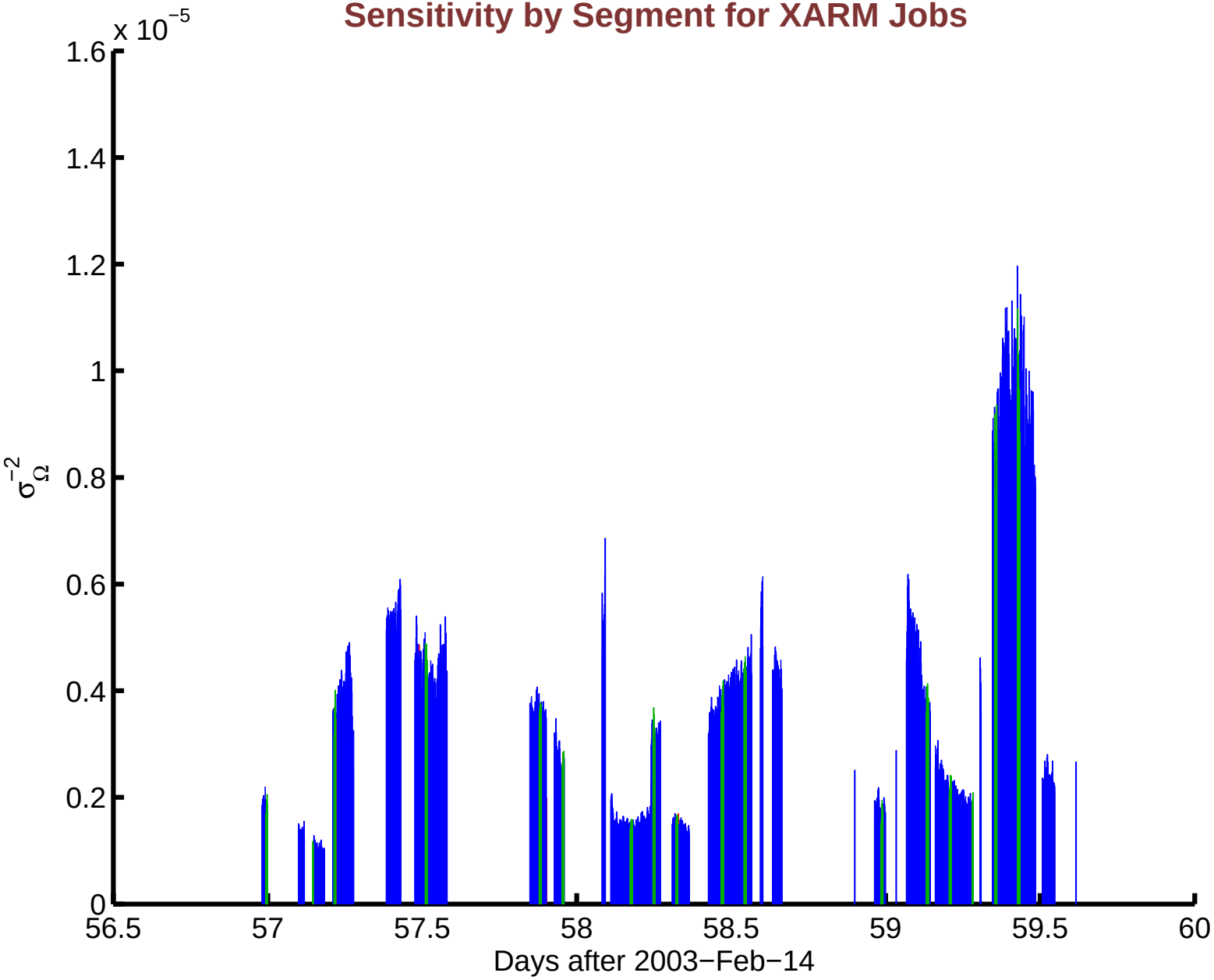
- $\sim 10\%$ of data set aside as "playground"

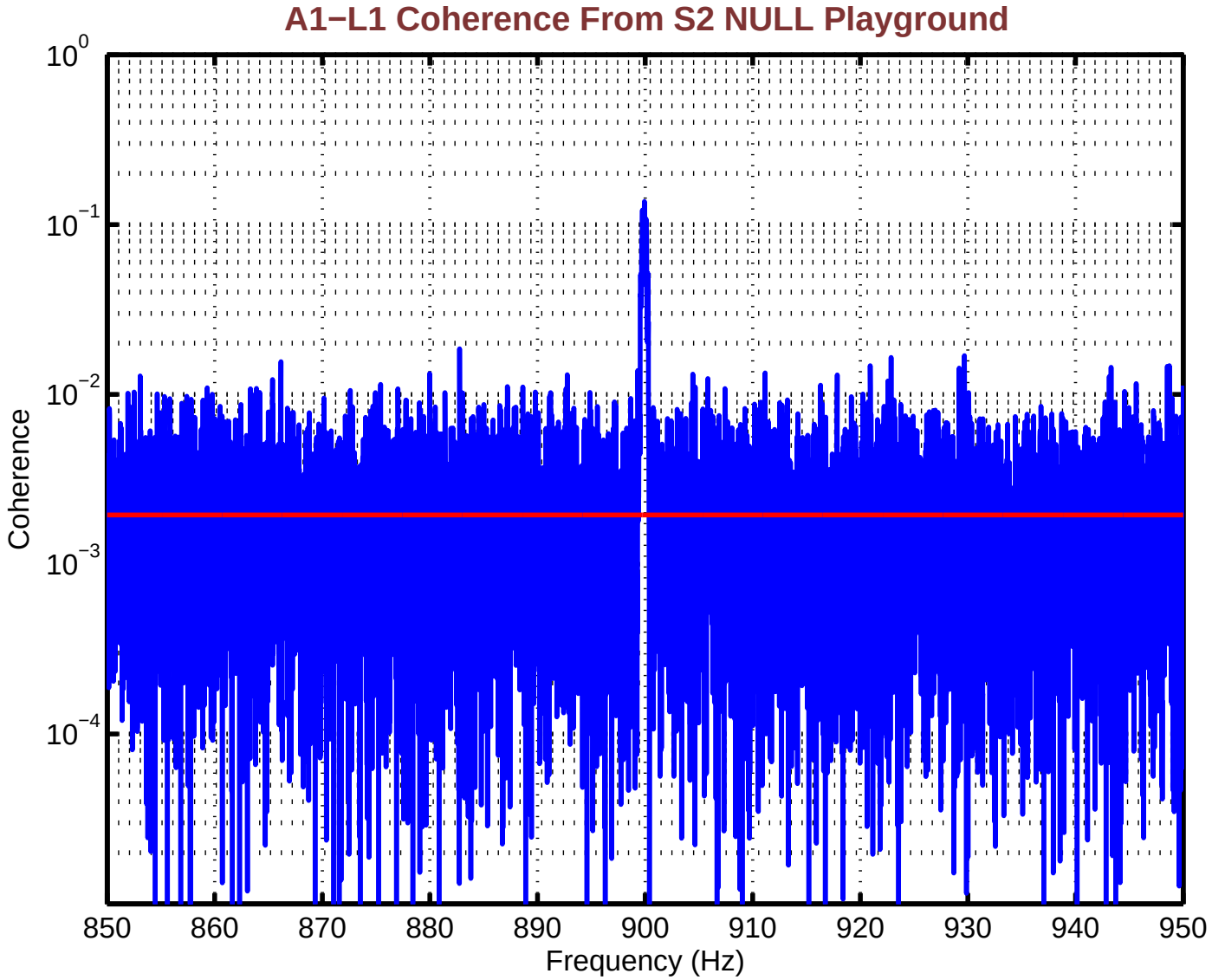
- Non-PG data divided into 60s segments; 3 orientations:
  - "NULL" ($0.028 < \gamma(f) < 0.034$): 3328 min after cuts
    "off-source" data useful for data quality & cross-checks
  - "YARM" ($-0.89 > \gamma(f) > -0.91$): 1654 min after cuts
  - "XARM" ($0.95 < \gamma(f) < 0.96$):] 1547 min after cuts

- Projected $h_{100}^2\Omega$ sensitivity using YARM & XARM data: $\sim 10 - 20$

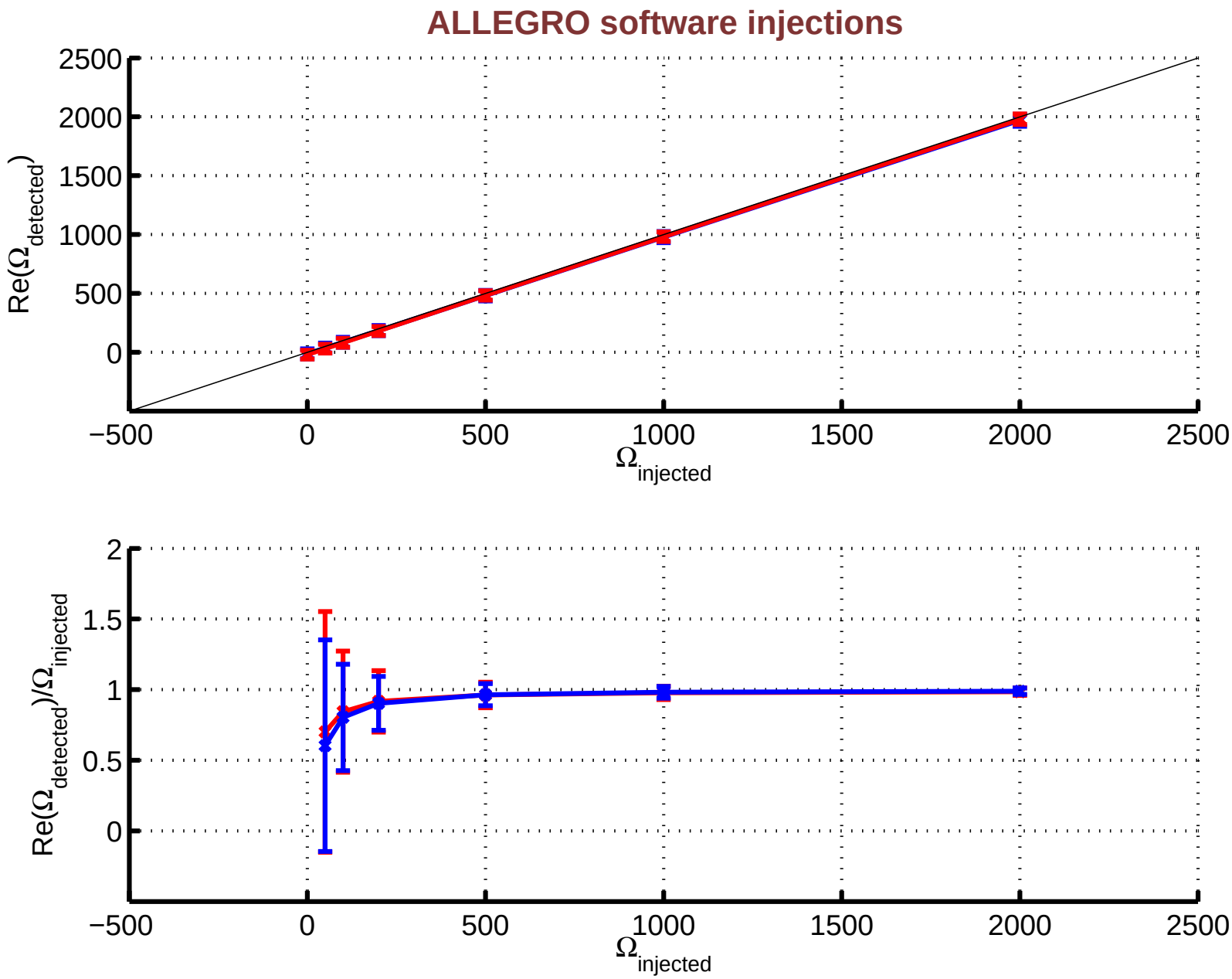

Avg Calibrated ASD from S2 non−NULL Playground
Strain Amplitude Spectral Density (Hz$^{-1/2}$)
10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
850
860
870
880
890
900
910
920
930
940
950
Frequency (Hz)
LLO ASD
ALLEGRO ASD
Spectrum for $h^2_{100}\Omega(f)=14$


Sensitivity by Segment for YARM Jobs
x 10^−5
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
σ_Ω^−2
50
50.5
51
51.5
52
52.5
53
53.5
54
54.5
55
Days after 2003−Feb−14


Sensitivity by Segment for XARM Jobs
x 10^-5
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
σ_Ω^-2
56.5
57
57.5
58
58.5
59
59.5
60
Days after 2003−Feb−14



Note 900 Hz power line harmonic


ALLEGRO software injections
2500
2000
1500
1000
500
0
Re(Ω_detected)
−500
0
500
1000
1500
2000
2500
Ω_injected
2
1.5
1
0.5
0
Re(Ω_detected)/Ω_injected
−500
0
500
1000
1500
2000
2500
Ω_injected

LLO-ALLEGRO: Summary

- First stochastic measurement correlating bar w/ifo data
- Probes higher frequency band than LLO-LHO: $\sim 850 - 950\,\mathrm{Hz}$
- 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 gr-qc/0506025
- Analyzing S2 data; S4 analysis to come
- Analysis extracts simulated signals (software injections)
- Expected S2 sensitivity from $\sim 54\,\mathrm{hrs}$ of data $h_{100}^2 \Omega_{\mathrm{GW}}(f) \sim 10 - 20$ or $\sqrt{S_{\mathrm{GW}}(f)} \sim 10^{-22}\,\mathrm{Hz}^{-1/2}$ (ALLEGRO calibration corrected; 25% systematic Ω uncertainty remains)