Update on Monitoring Bicoherence

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First Order Statistics

- 1D Statistics:
  - » Correlation: $C_{xy}(t) = \int_{-\infty}^{\infty} x(\tau)\, y(t+\tau)\, d\tau \quad \Leftrightarrow \quad X(f)\, Y^{*}(f) = S_{xy}(f)$
  - » Power Spectral Density: $C_{2x}(t) \quad \Leftrightarrow \quad X(f)\, X^{*}(f) = S_{2x}(f)$
  - » Coherence: $C_{xy}(f) = \dfrac{S_{xy}(f)}{\sqrt{S_{2x}(f)\, S_{2y}(f)}}$
    - – Tells us power and phase coherence at a given frequency

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Second Order Statistics

- 2D Statistics:
  - Bicumulant:

$$C_{xyz}(t,t') = \int_{-\infty}^{\infty} x(\tau)\, y(t+\tau)\, z(t'+\tau)\, d\tau \quad \Leftrightarrow \quad X(f_1)\, Y(f_2)\, Z^*(f_1+f_2) = S_{xyz}(f_1,f_2)$$

  - Bispectral Density:

$$C_{3x}(t) \quad \Leftrightarrow \quad X(f_1)\, X(f_2)\, X^*(f_1+f_2) = S_{3x}(f_1,f_2)$$

  - Bicoherence:

$$\mathrm{C}_{xyz}(f) = \frac{S_{xyz}(f_1,f_2)}{\sqrt{S_{2x}(f_1)\, S_{2y}(f_2)\, S_{2z}(f_1,f_2)}}$$

    - Tells us power and phase coherence at a coupled frequency

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Why Higher Order Statistics?

- For a Gaussian process: $C_{nx}(t) = 0, \text{ for } n > 2$
- For independent processes:

$$z(t) = x(t) + y(t), \quad C_{nz}(t) = C_{nx}(t) + C_{ny}(t) \xrightarrow{n>2} C_{ny}(t)$$

- Allows for isolation of nonGaussian processes
  - » Visual check of frequency coupling and phase noise
  - » Statistical test for the probability of gaussianity and linearity
  - » Iterative process to reconstruct nongaussian signal from the higher order cumulants

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Monitor Versions: MatLab tools

- Vijay's tool:
  - Calculates auto-bicoherence
  - Monitors integrated auto-bicoherence over specified frequency area
  - Allows one to see evidence of bilinear couplings if noise low
  - No background monitoring or multiple calculations per data block.
  - Does not calculate cross-bicoherence (limits full diagnosis of noise problem)
  - Vijay, the code author and primary user, has taken another job.

- MatLab HOSA toolbox
  - Calculates auto- & cross-bicoherence
  - Graphical smoothing
  - All MatLab's advantages
  - No easy integration with DMT
  - No easy integration with background monitoring
  - Normalization **was** not equivalent to our tools

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Monitor Versions: BicoMon (Background Monitor)

- Current Version (Exists. Written since August Meeting)
  - Monitor integrates bicoherence over specified frequency ROI
  - Calculates bicoherence for multiple channel combinations
  - Integrates bicoherence over multiple specified ROI
  - Integrates bicoherence over entire unique area (Gaussianity)
  - Trends Data and sends to DMTviewer.
  - Resolved the unique channel problem with DMT
  - Included proper decimation with filtering rather than rebinning
  - Tests for Operational State

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Configuration File

Calculation Parameters

Measurement Parameters

```
3  30

C 2   H1:LSC-AS_Q                          16384
      H1:SUS-ITMX_OPLEV_PERROR  2048
      256     1.0          0.5           64

M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_ALL          0  0 0
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_2_2      60  2 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_10_2     60 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_38_2     60 38 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_60_50_2     60 50 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_2_2    120  2 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_10_2   120 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_38_2   120 38 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_120_50_2   120 50 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_2_2    180  2 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_10_2   180 10 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_38_2   180 38 2
M  Bico:H1:AS_Q-ITMX_OPLEV_PERROR_180_50_2   180 50 2

C 2   H1:LSC-AS_Q                          16384
      H1:SUS-ITMY_OPLEV_PERROR  2048
      256     1.0          0.5           64

M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_ALL          0  0 0
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_2_2      60  2 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_10_2     60 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_38_2     60 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_60_50_2     60 50 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_2_2    120  2 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_10_2   120 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_38_2   120 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_120_50_2   120 50 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_2_2    180  2 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_10_2   180 10 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_38_2   180 38 2
M  Bico:H1:AS_Q-ITMY_OPLEV_PERROR_180_50_2   180 50 2

C 1   H1:LSC-AS_Q                          16384
      256     1.0          0.5           64

M  Bico:H1:AS_Q_ALL            0   0 0
M  Bico:H1:AS_Q_120_2_2      120   2 2
M  Bico:H1:AS_Q_120_10_2     120  10 2
M  Bico:H1:AS_Q_120_38_2     120  38 2
```

Monitor Versions: BicoViewer (Foreground Monitor)

- Plots Bicoherence (auto- or cross-) & PSD's of input channels
- Proper decimation & Optimized windowing
- User selects:
  - Channels
  - Frequency Range and Resolution
  - Data Span
  - Data Overlap
- Outputs GIF files of the plots
- Vectorized FFT routines for speed
- Heterodyning
- Strip Chart for Monitoring Bicoherence of certain ROI
- Output calculation parameters as configuration for BicoMon

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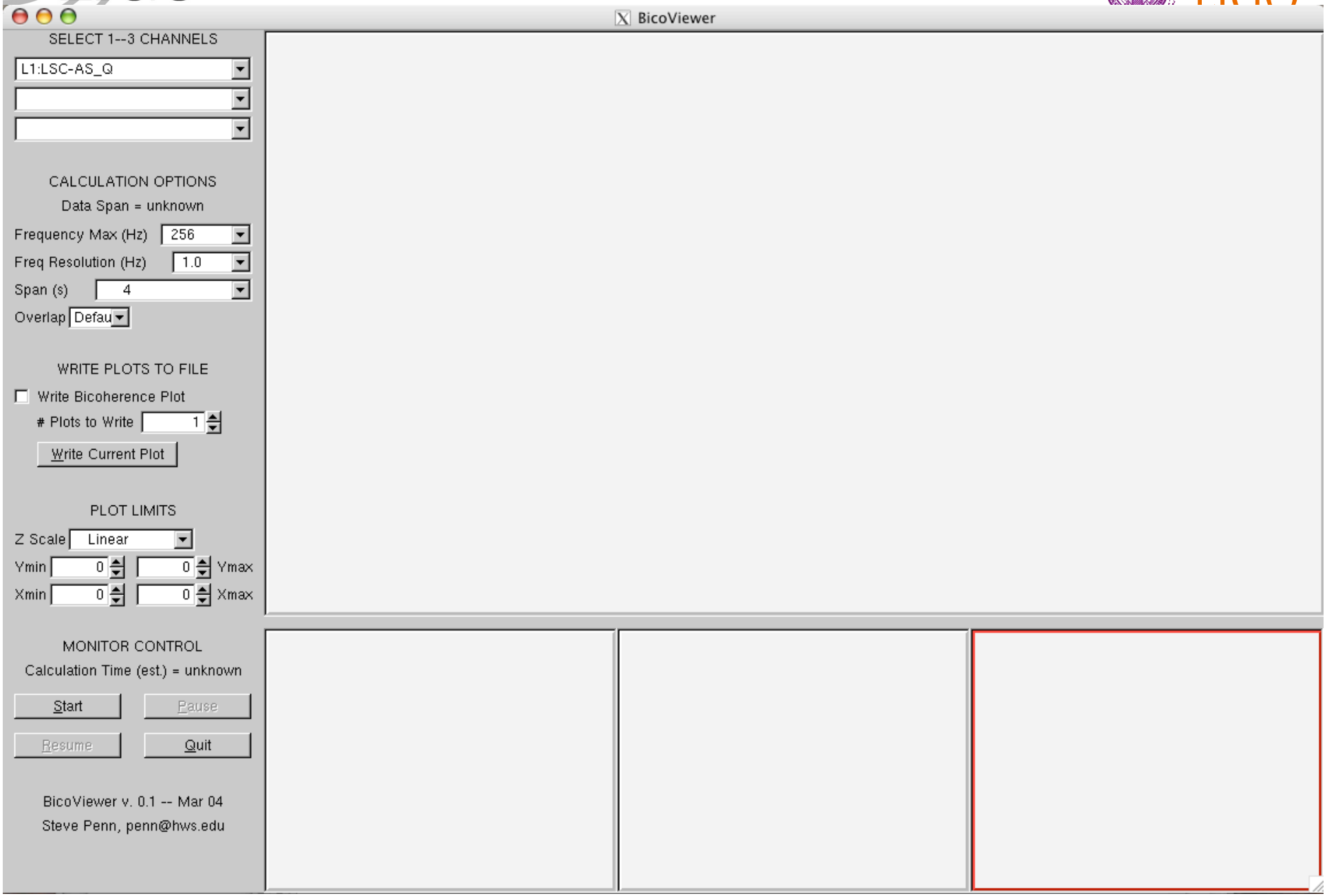
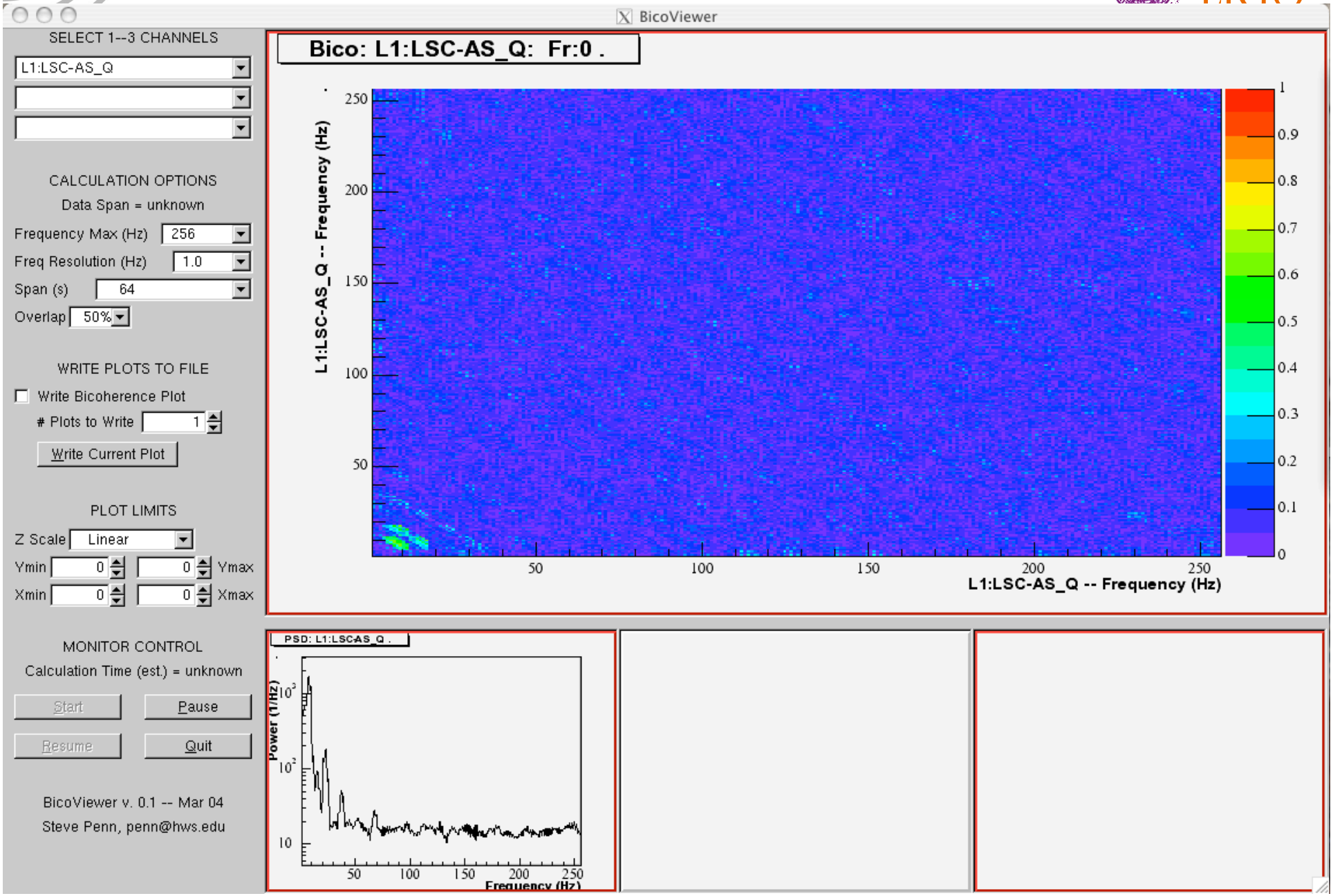

BicoViewer
SELECT 1--3 CHANNELS
L1:LSC-AS_Q
CALCULATION OPTIONS
Data Span = unknown
Frequency Max (Hz) 256
Freq Resolution (Hz) 1.0
Span (s) 4
Overlap Defau
WRITE PLOTS TO FILE
Write Bicoherence Plot
Plots to Write 1
Write Current Plot
PLOT LIMITS
Z Scale Linear
Ymin 0 0 Ymax
Xmin 0 0 Xmax
MONITOR CONTROL
Calculation Time (est.) = unknown
Start
Pause
Resume
Quit
BicoViewer v. 0.1 -- Mar 04
Steve Penn, penn@hws.edu


BicoViewer
SELECT 1--3 CHANNELS
L1:LSC-AS_Q
CALCULATION OPTIONS
Data Span = unknown
Frequency Max (Hz) 256
Freq Resolution (Hz) 1.0
Span (s) 64
Overlap 50%
WRITE PLOTS TO FILE
Write Bicoherence Plot
Plots to Write 1
Write Current Plot
PLOT LIMITS
Z Scale Linear
Ymin 0
Ymax 0
Xmin 0
Xmax 0
MONITOR CONTROL
Calculation Time (est.) = unknown
Start
Pause
Resume
Quit
BicoViewer v. 0.1 -- Mar 04
Steve Penn, penn@hws.edu
Bico: L1:LSC-AS_Q: Fr:0 .
L1:LSC-AS_Q -- Frequency (Hz)
L1:LSC-AS_Q -- Frequency (Hz)
PSD: L1:LSC-AS_Q .
Power (1/Hz)
Frequency (Hz)

LIGO

HWS LIGO

BicoViewer

SELECT 1--3 CHANNELS

L1:LSC-AS_Q

CALCULATION OPTIONS

Data Span = unknown

Frequency Max (Hz) 256

Freq Resolution (Hz) 1.0

Span (s) 64

Overlap 50%

WRITE PLOTS TO FILE

Write Bicoherence Plot

Plots to Write 1

Write Current Plot

PLOT LIMITS

Z Scale Linear

Ymin 0 0 Ymax

Xmin 0 0 Xmax

MONITOR CONTROL

Calculation Time (est.) = unknown

Start Pause

Resume Quit

BicoViewer v. 0.1 -- Mar 04

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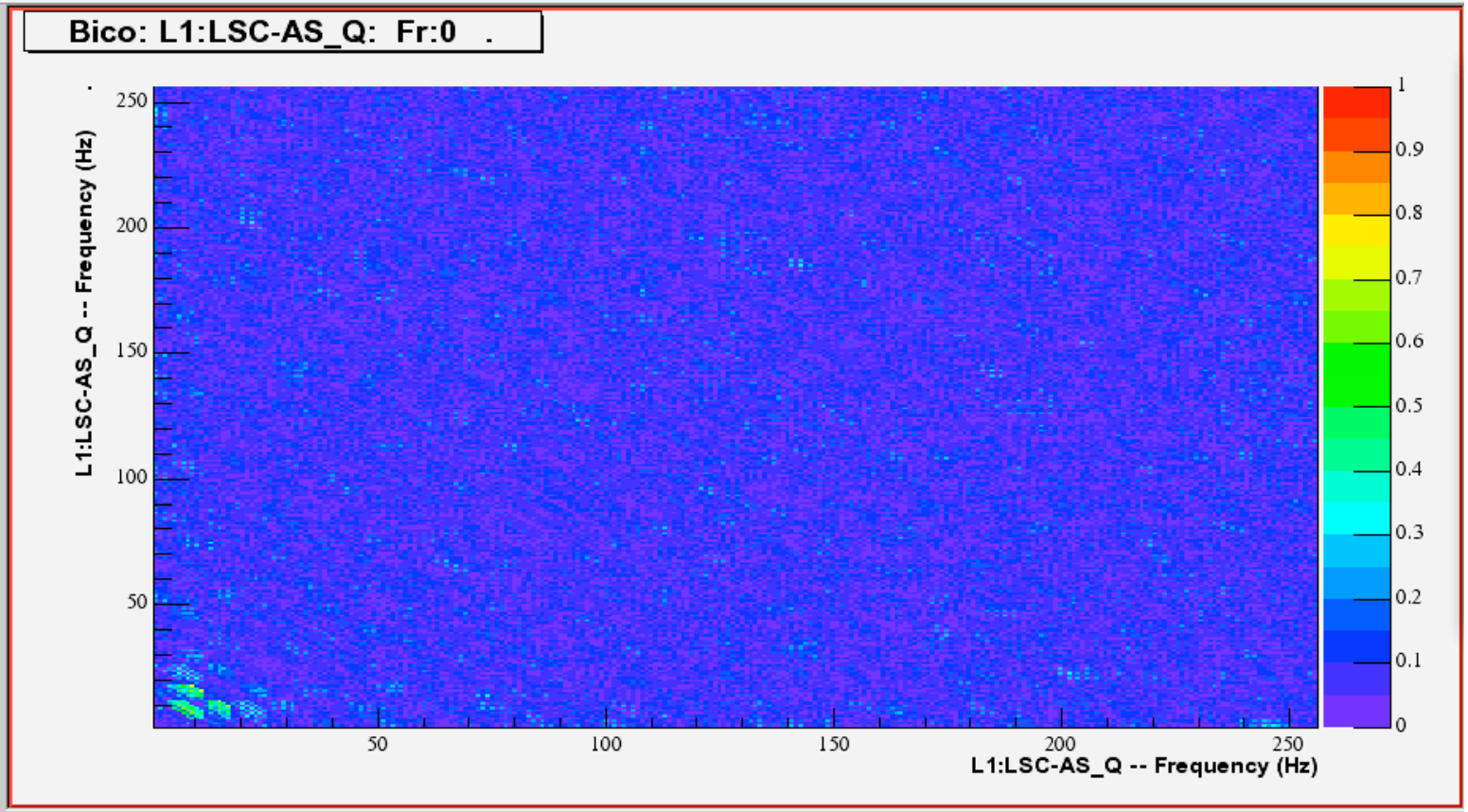

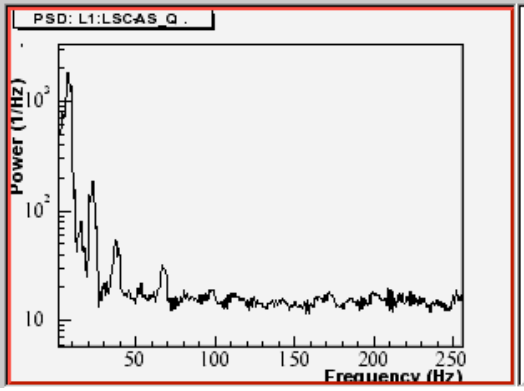

Online Demo

Conclusions

- Bicoherence monitors could be a useful tool for analyzing data for glitches, gaussianity, upconversion, and chirps.
- We are now at sensitivity where up-converted data can be seen
- BicoMon operational.
- BicoViewer works (beta test stage).
- Now that the IFO is at/near a sensitivity to see bicoherence, we need people to use monitor and make bicoherence an analysis tool on par with PSDs or coherence.

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