Global Second and Third Order Correlations in Physical Environment Monitors

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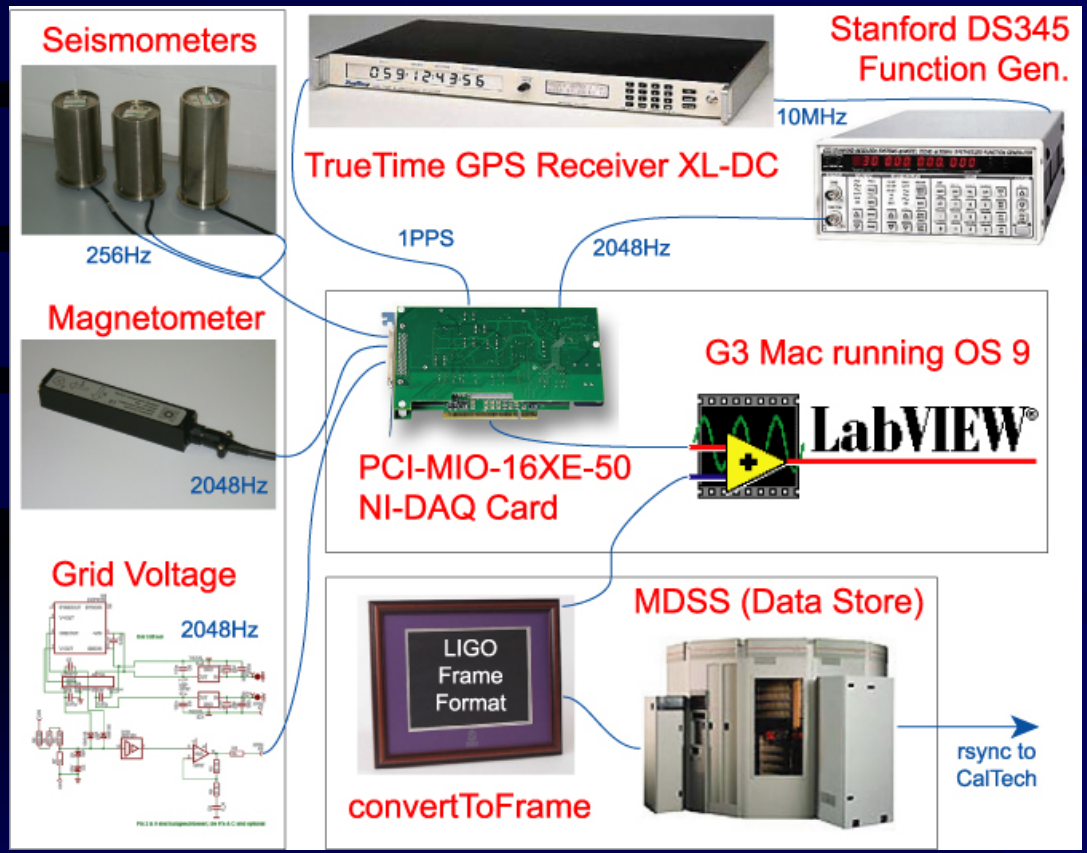
LIGO-G030364-00-Z

Motivation

- A desirable assumption is that GW detectors are subject to uncorrelated background noise
  - true for “local” noise sources eg footsteps
  - what about “global” noise sources?
- Task: investigate global-scale sources
  - seismic, **magnetic**
- Tools: PEM data, noise analysis techniques
- This talk: sanity checking, frequency lines
  - make sure we understand analysis techniques

ACIGA Physical Environment Monitor (PEM) Data



- ACIGA part of international PEM data exchange
- PEMs and datalogger at ANU, Canberra
- GPS-synch'd
- Data merged at CalTech with PEM from LLO, LHO, Virgo, (GEO)

2nd and 3rd order spectral analysis

- For time series x(t) with FT X(f), define:
- Power spectrum (2nd):

$$S_{2x}(f) = X(f)X^*(f)$$

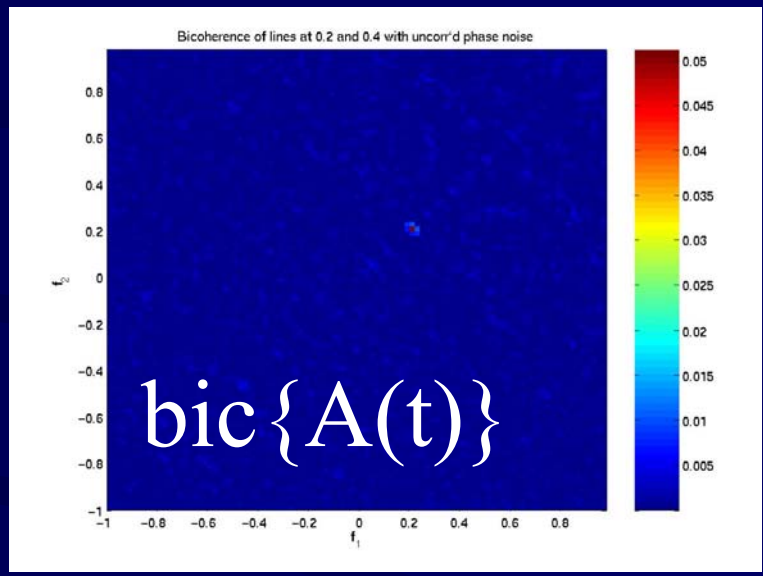
- Bispectrum: (3rd, function of 2 frequencies)

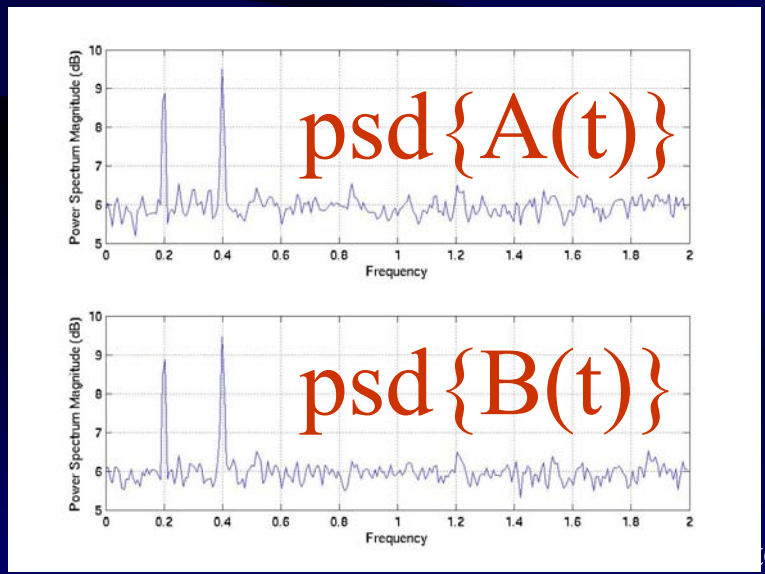
$$S_{3x}(f_1, f_2) = X(f_1)X(f_2)X^*(f_1 + f_2)$$

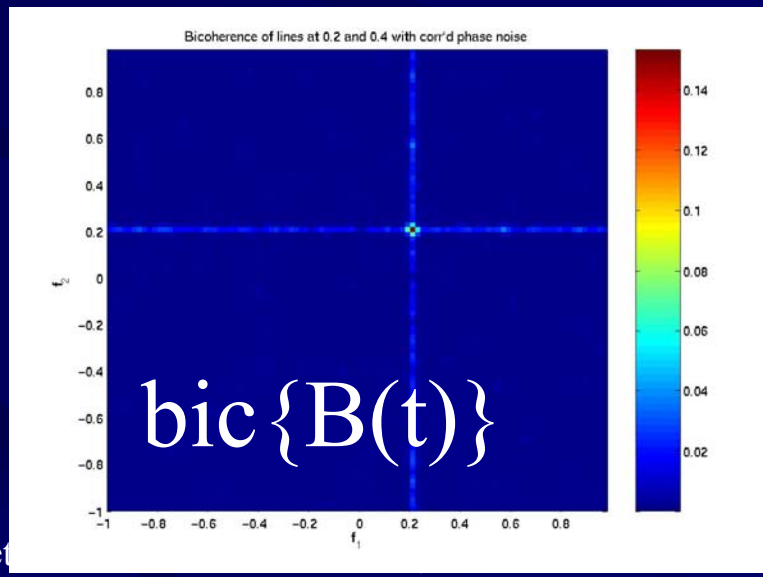
- **Bicoherence** = normalised bispectrum
- Similarly define cross-spectra, 2+ inputs

Self-bicoherence example

- Consider the time-series:
  - A(t) has lines at f (=0.2) and 2f (=0.4) with uncorrelated phase noise
  - B(t) has lines also at f and 2f with correlated phase noise

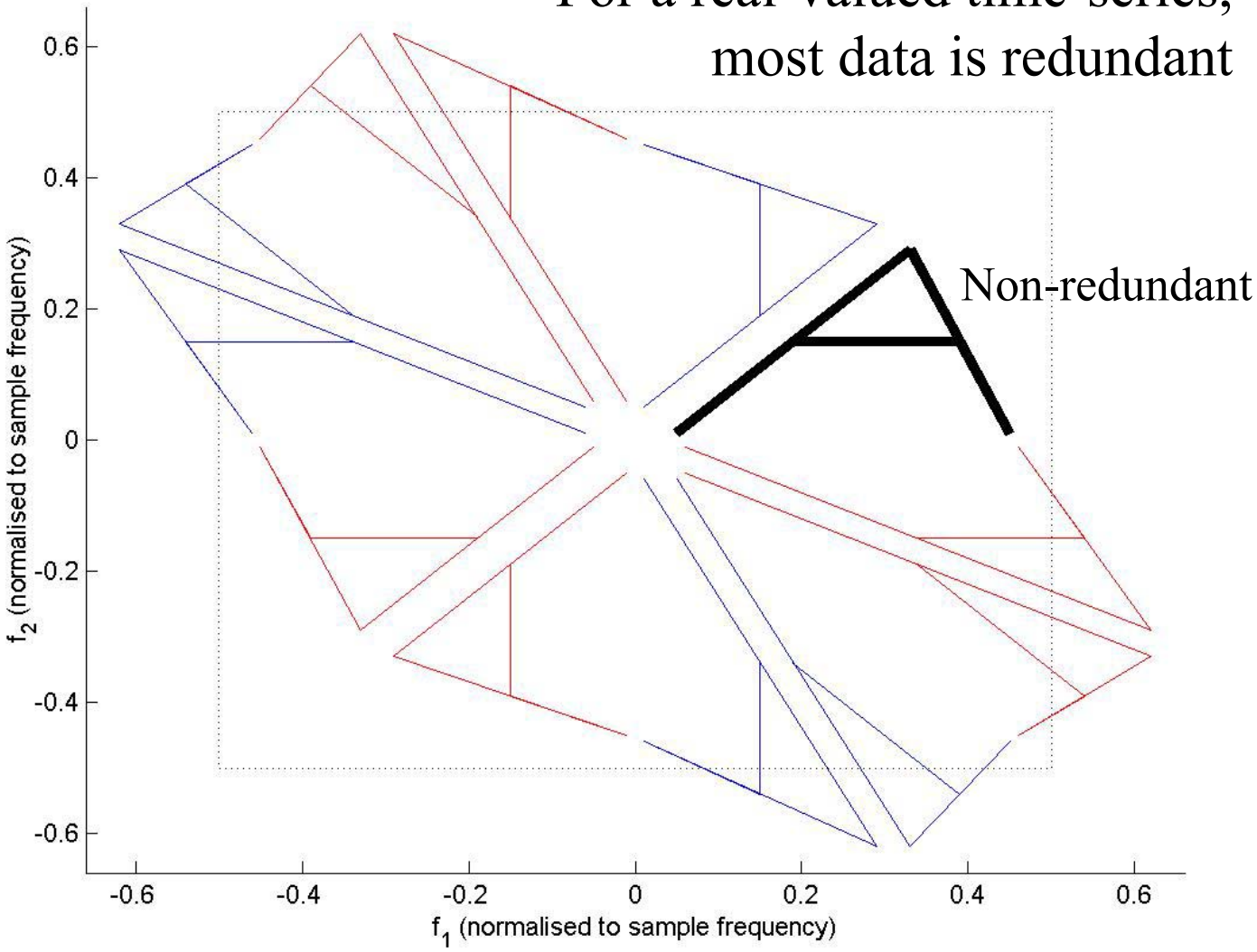






Bicoherence plot symmetry

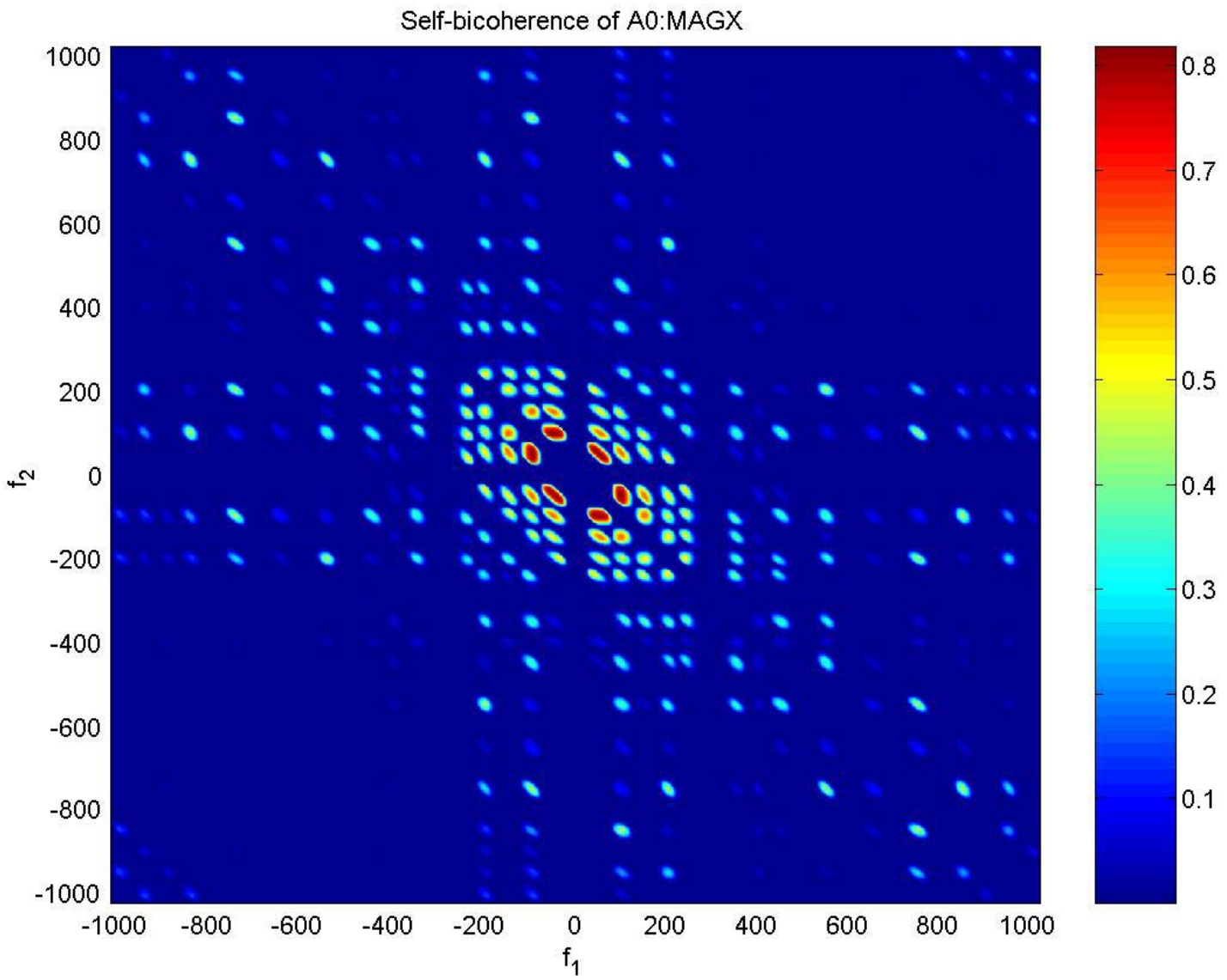
For a real-valued time-series,
most data is redundant



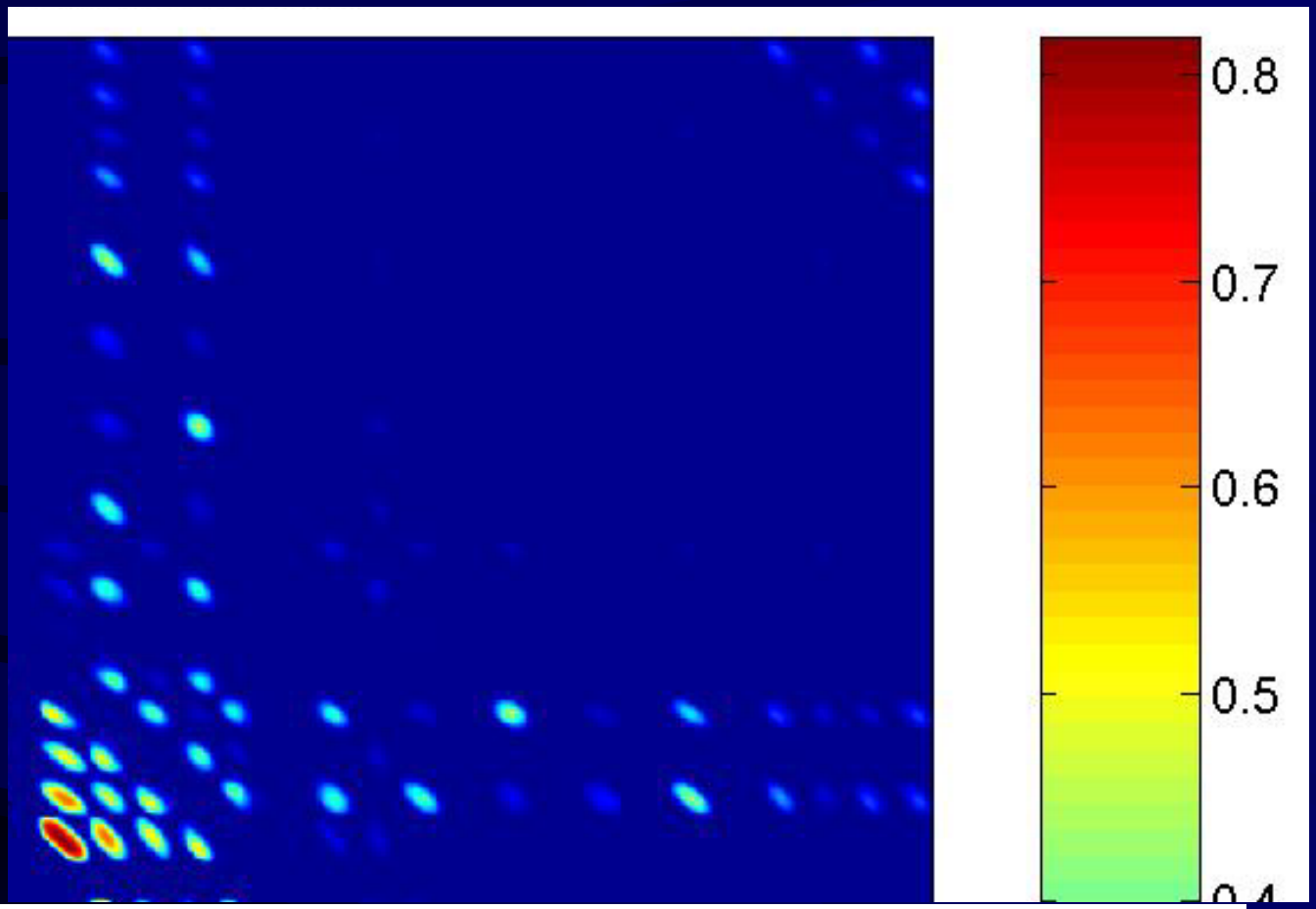
Case Study: Bicoherence of PEM channels

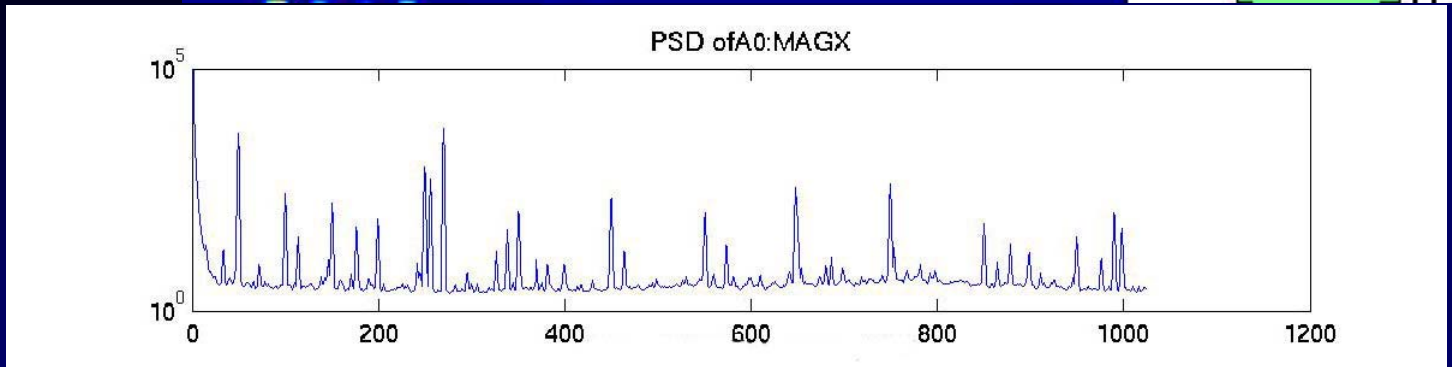
- Data from LLO, LHO and ACIGA
  - magnetometer channels
  - GPS Time: 731000000-731004000
  - during S2 (mid March)
  - 5 * 800 second data sets
    - for this talk, we'll show the first 800sec only

A0:MAGX Self-bicoherence

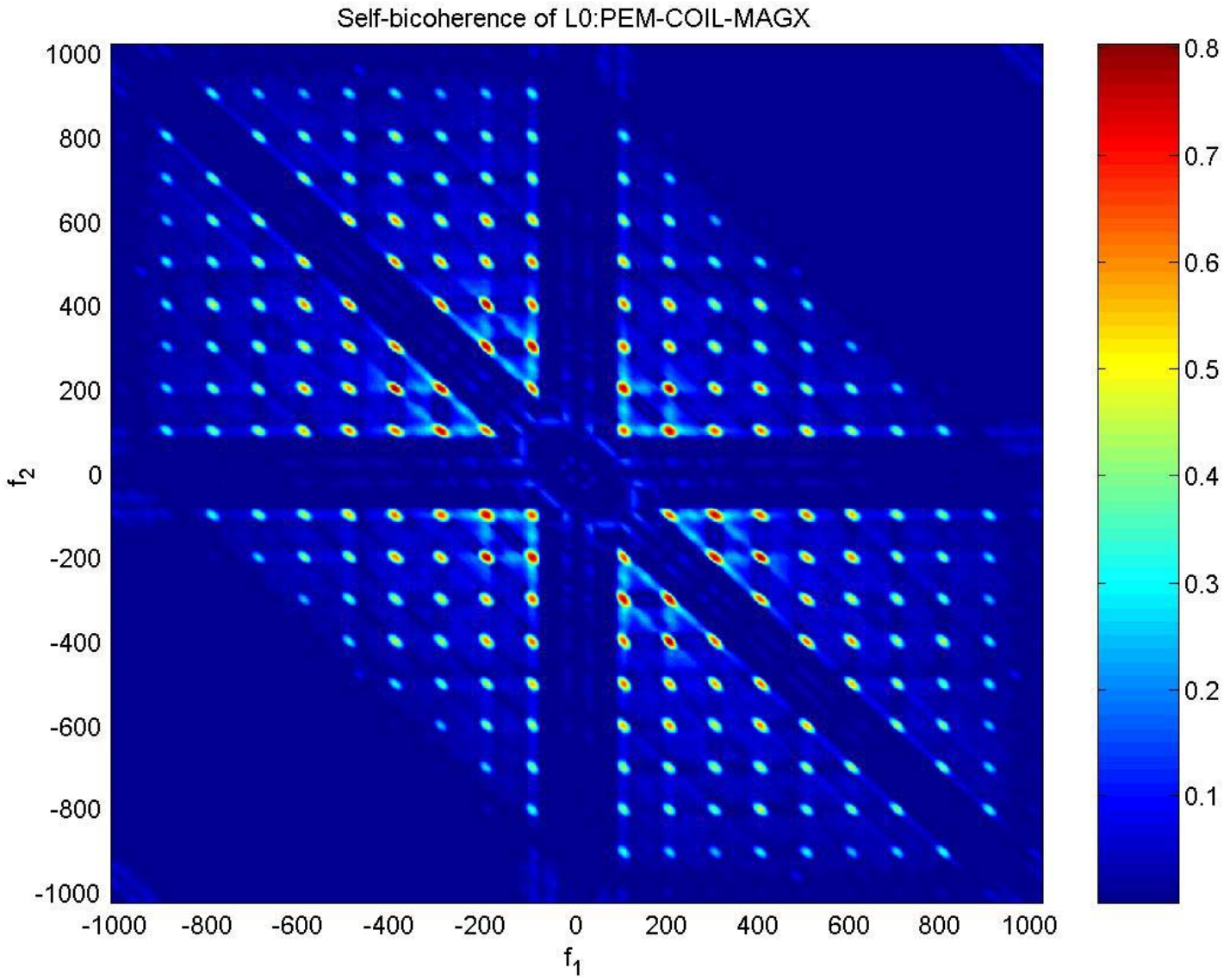


A0:MAGX Self-bicoherence

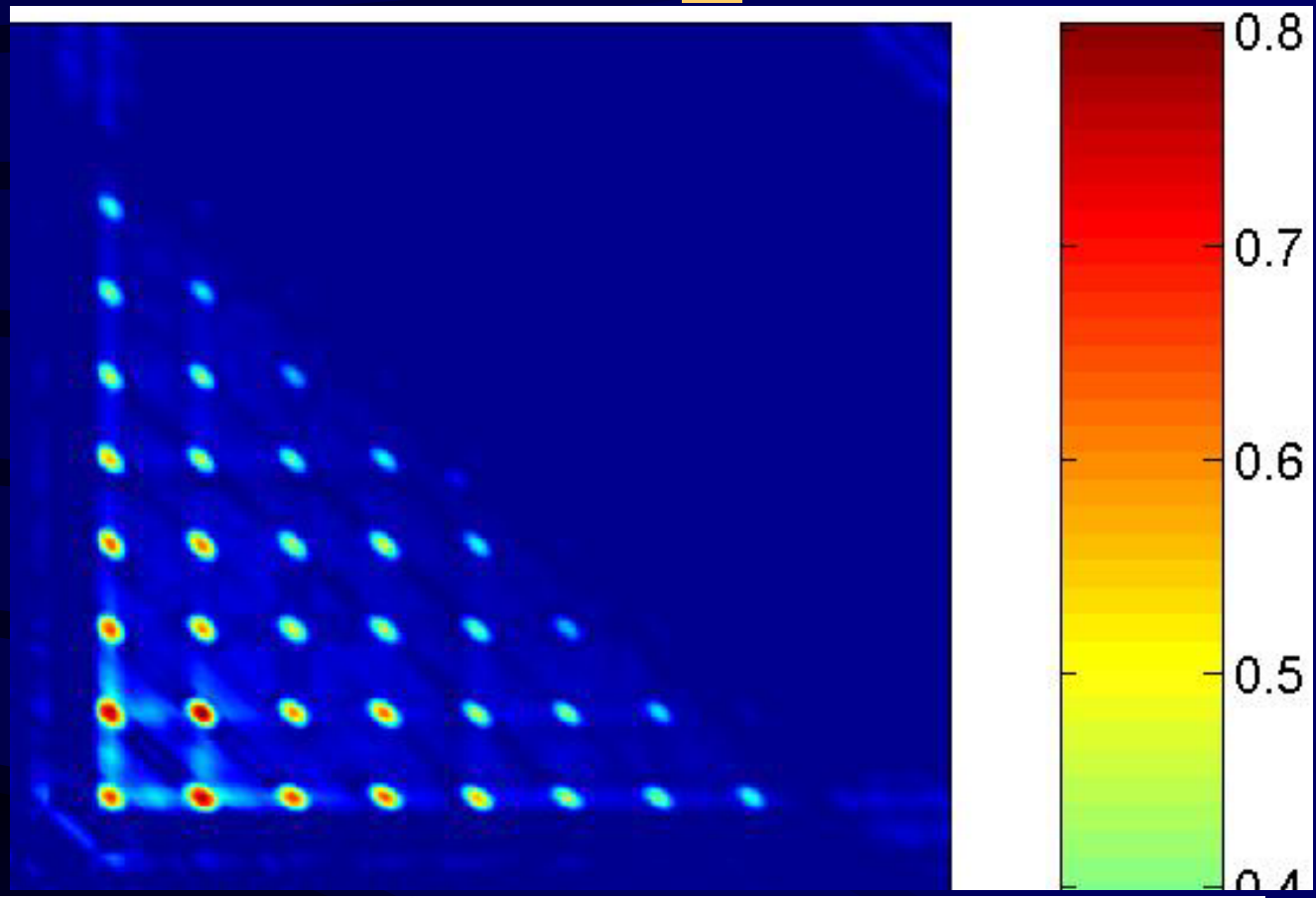


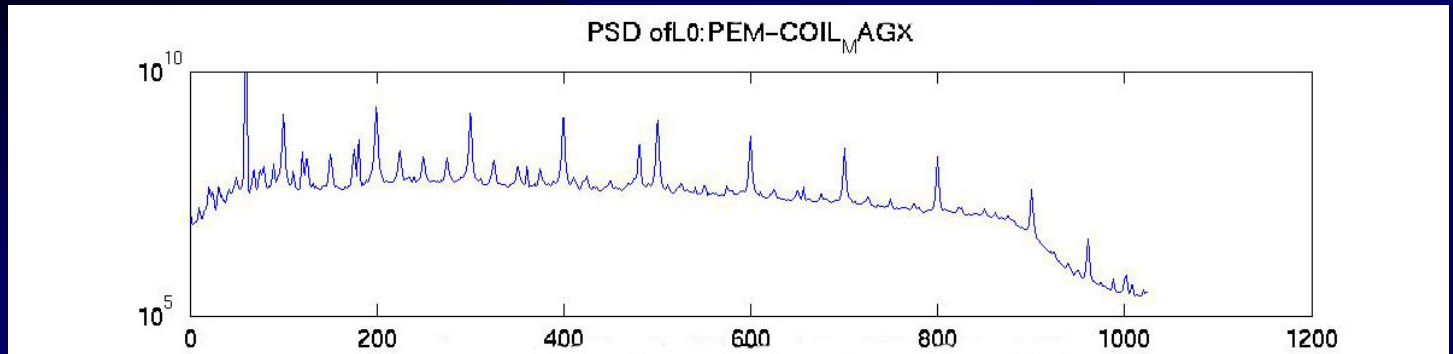


L0:PEM-COIL_MAGX

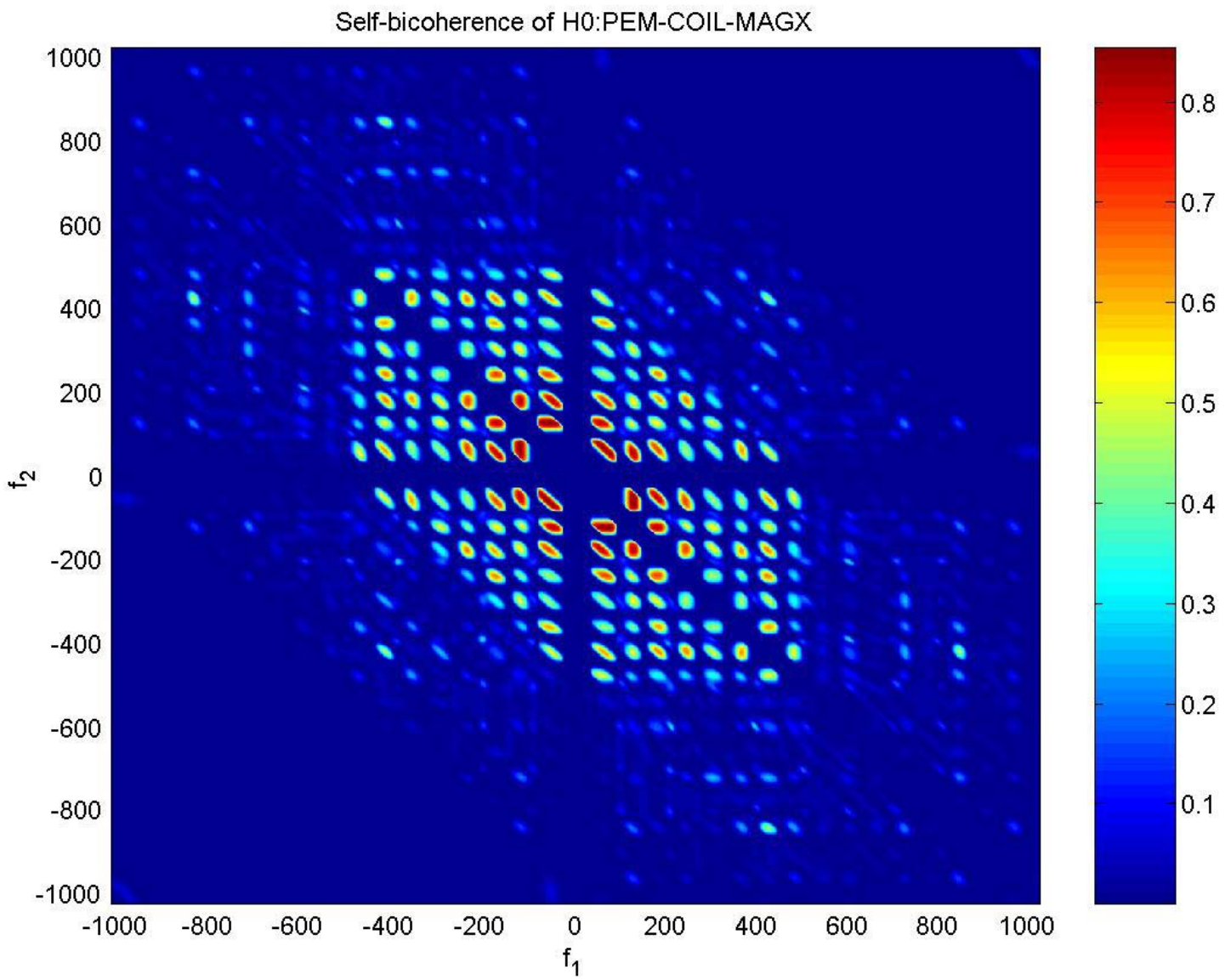


L0:PEM-COIL_MAGX

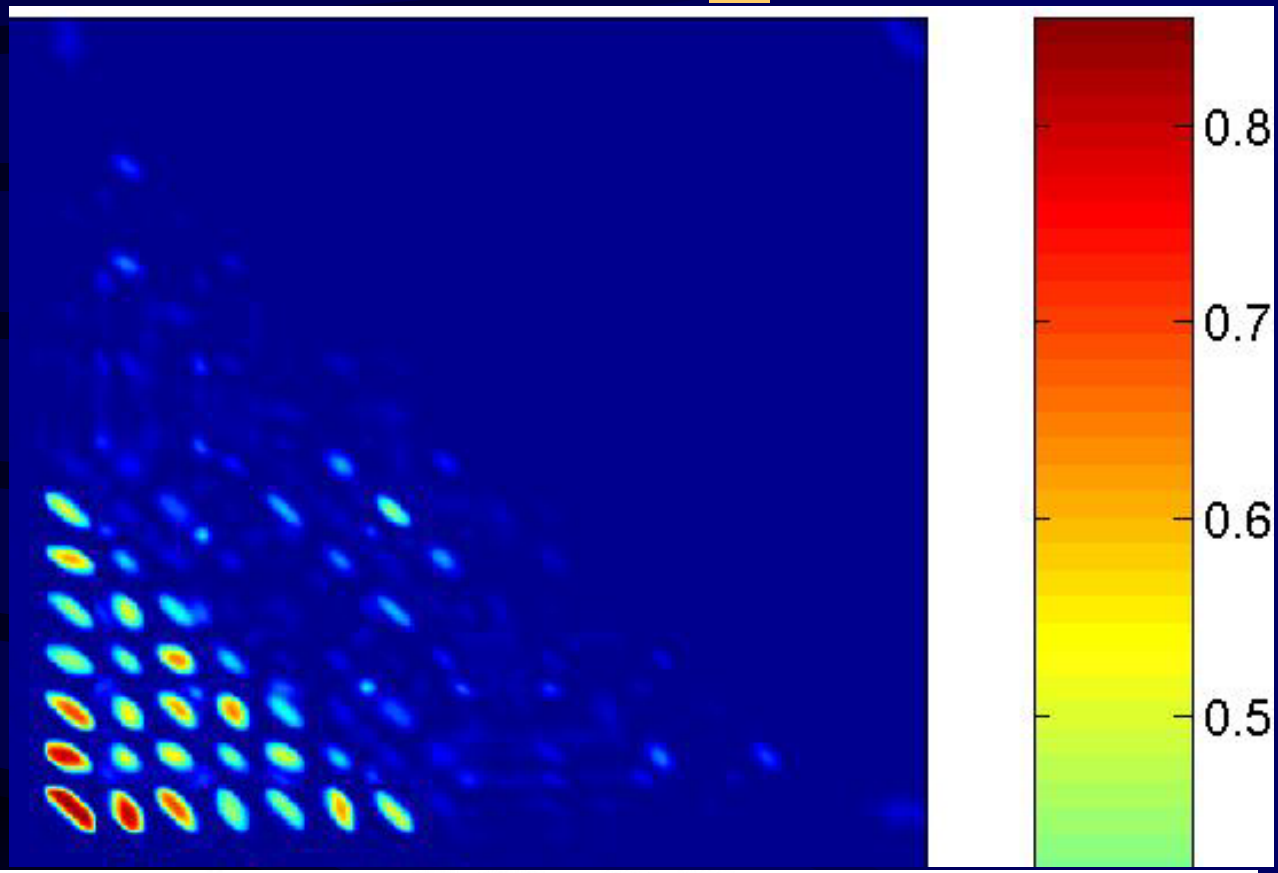


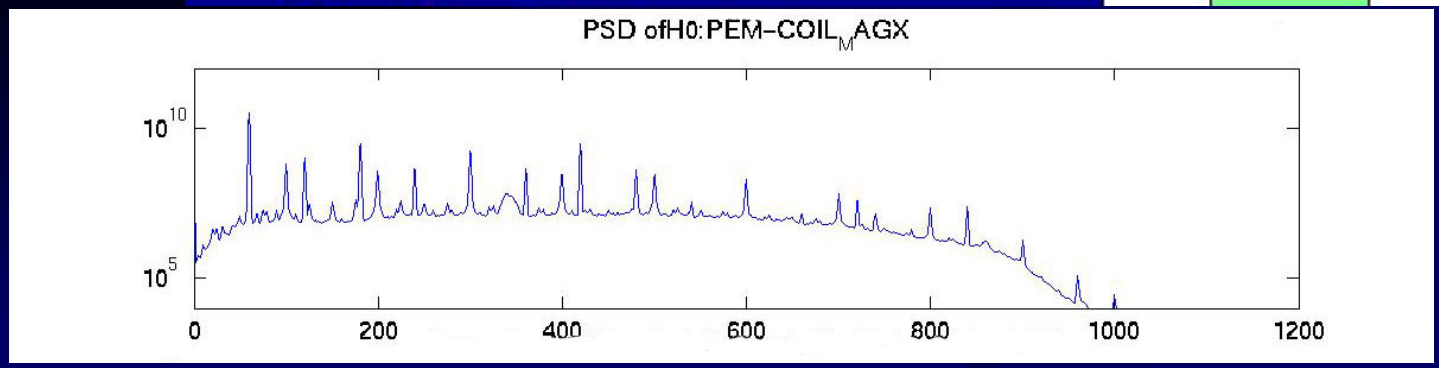


H0:PEM-COIL_MAGX



H0:PEM-COIL_MAGX

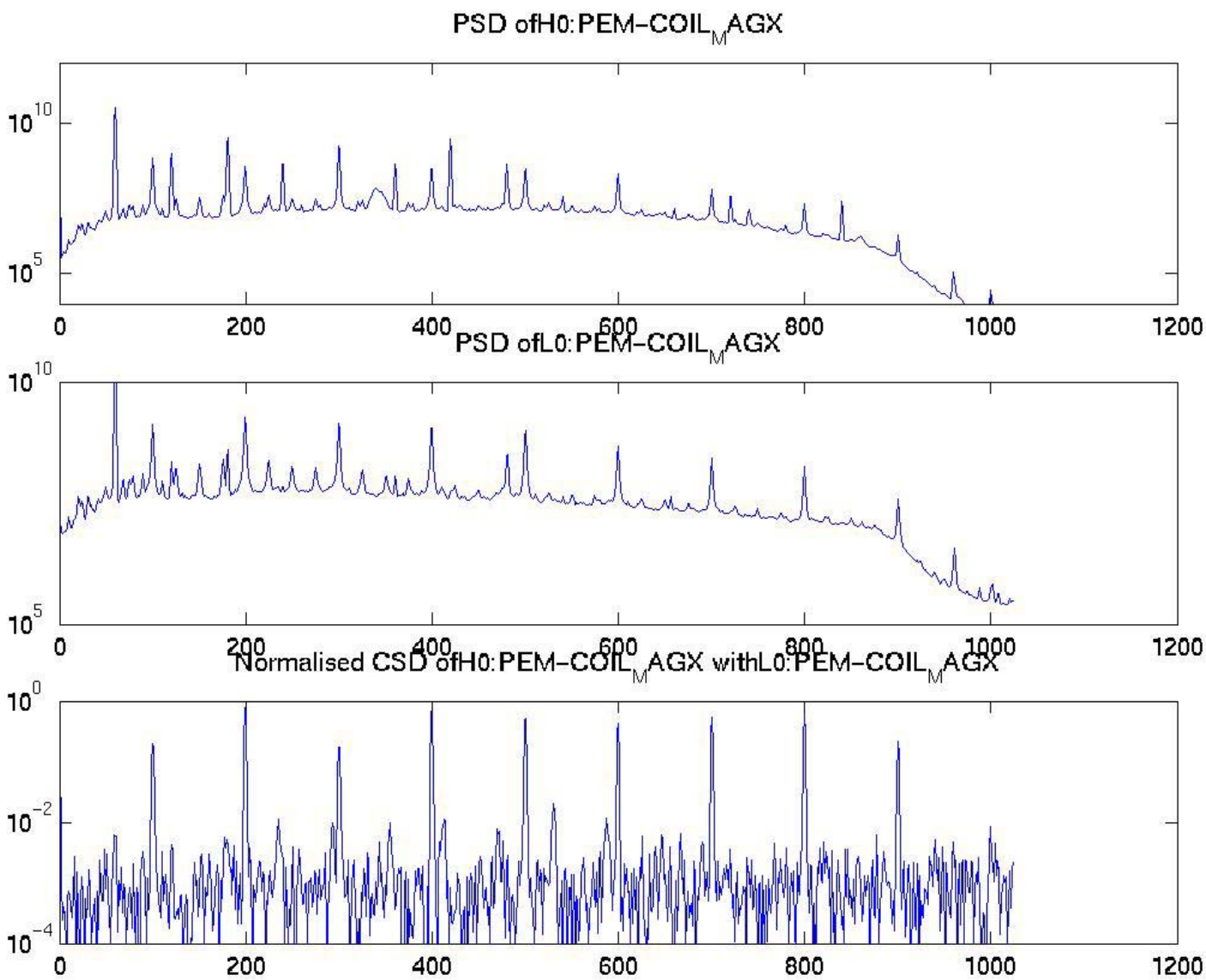




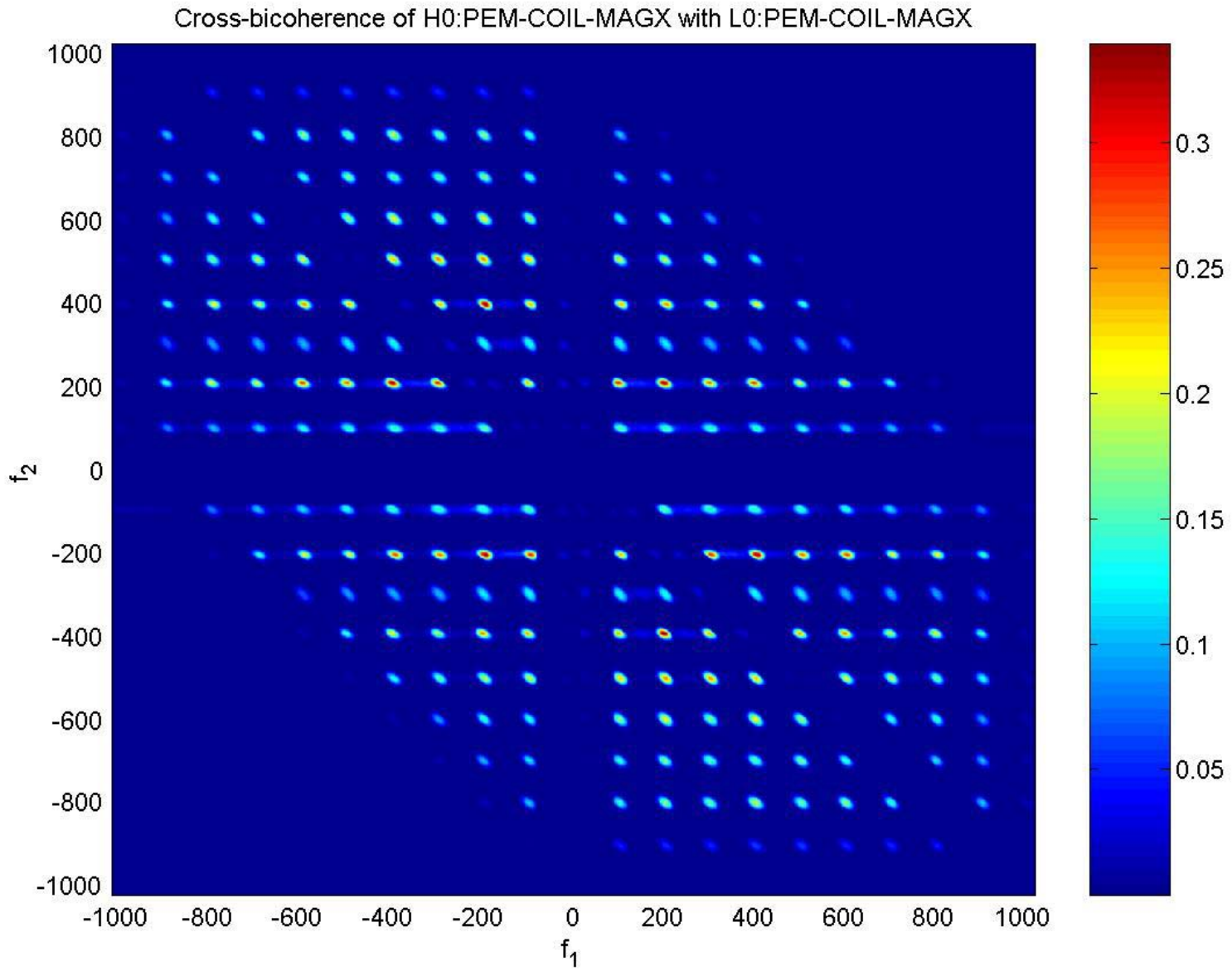
So far …

- Power lines "bicoherent"
  - ACIGA at 50Hz and harmonics
  - LHO at 60Hz and harmonics
- LLO has bicoherent n*100Hz lines
  - already discovered in **coil** magnetometer channels by Schofield et al, S1 Intersite Report
- Next, cross-coherences (2^{nd} order) and cross-bicoherences (3^{rd} order)…

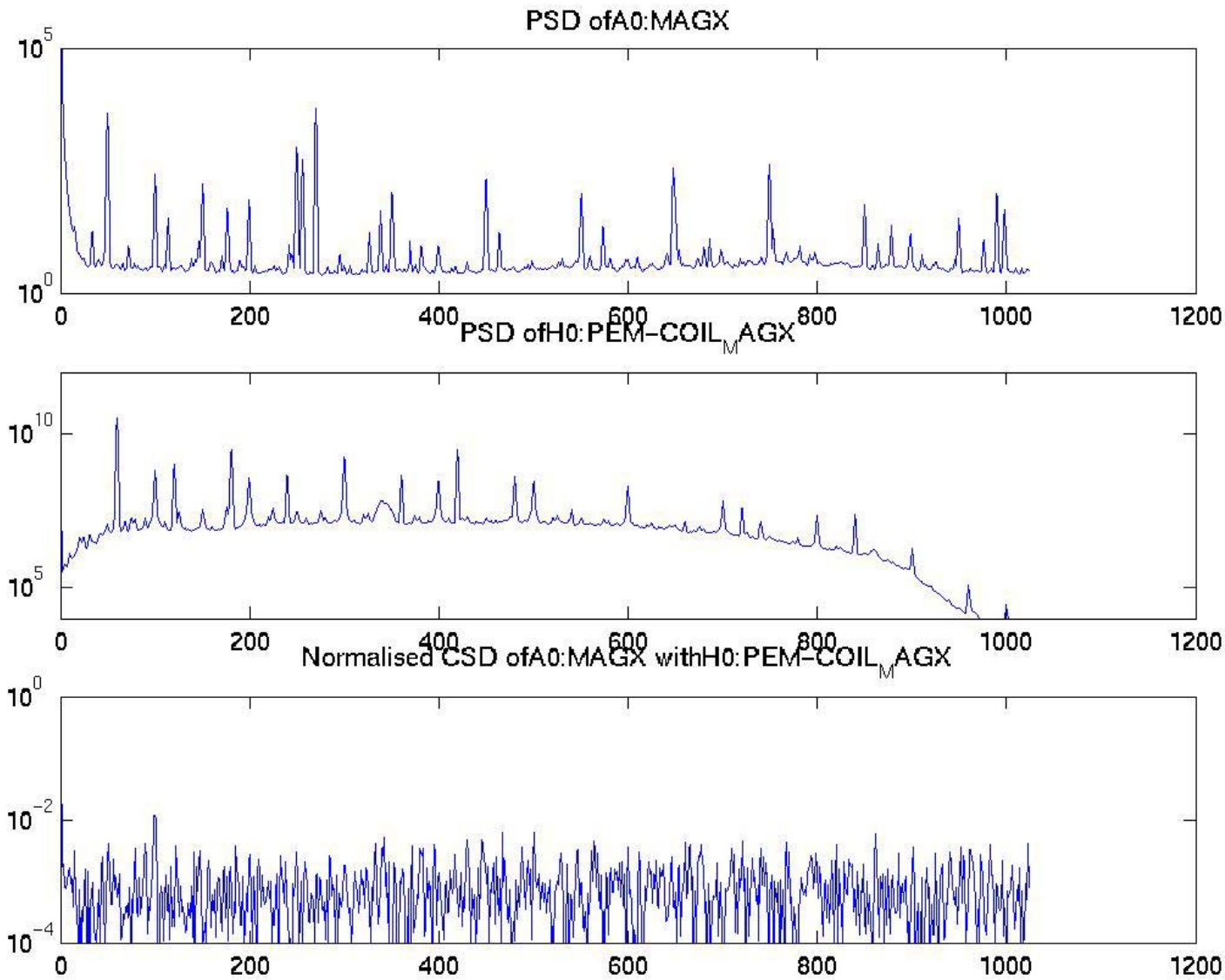
cohere(H0,L0)


PSD ofH0:PEM-COIL_MAGX
10^10
10^5
0
200
400
600
800
1000
1200
PSD ofL0:PEM-COIL_MAGX
10^10
10^5
0
200
400
600
800
1000
1200
Normalised CSD ofH0:PEM-COIL_MAGX withL0:PEM-COIL_MAGX
10^0
10^-2
10^-4
0
200
400
600
800
1000
1200

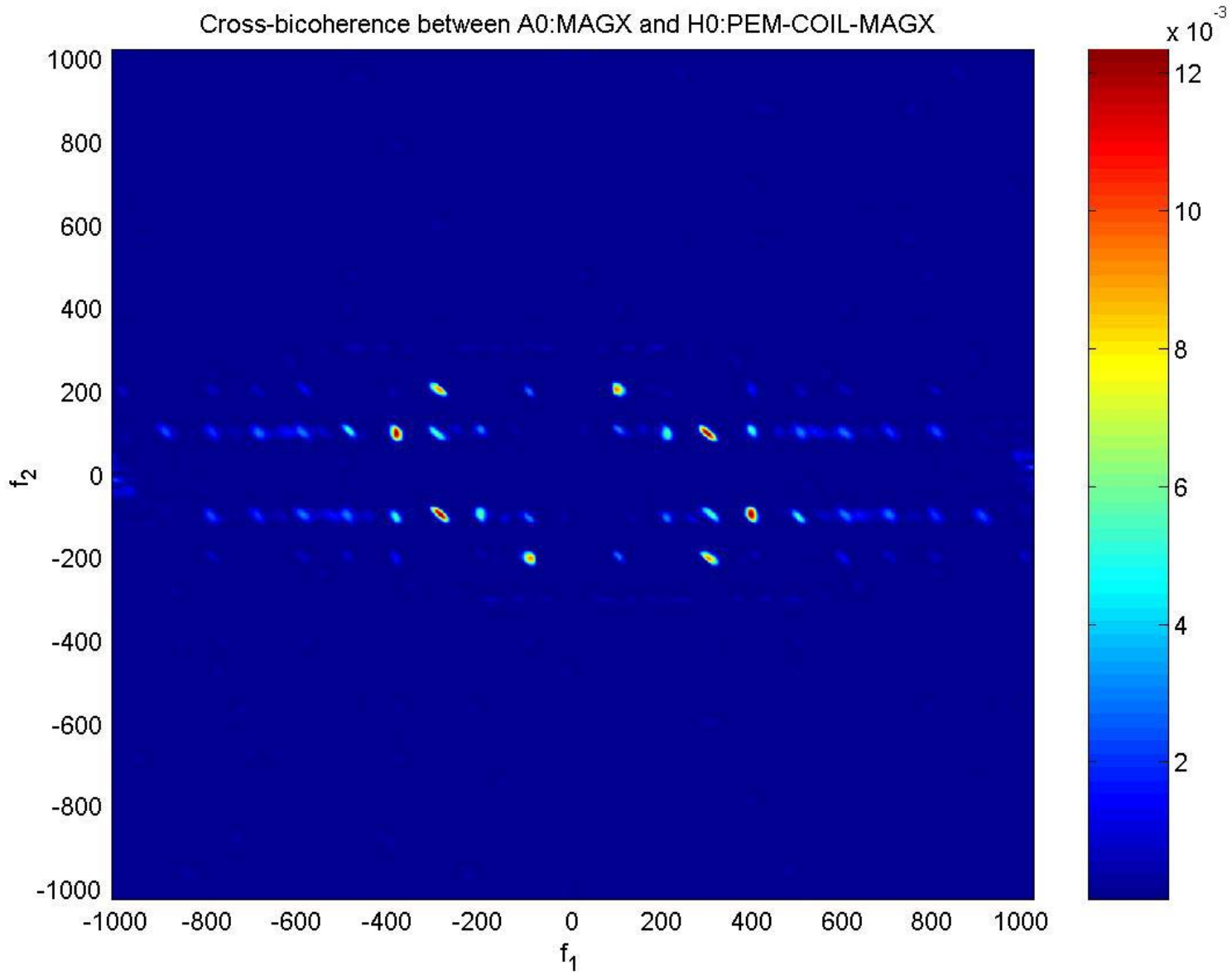
X-bicohere(H0,L0,L0)



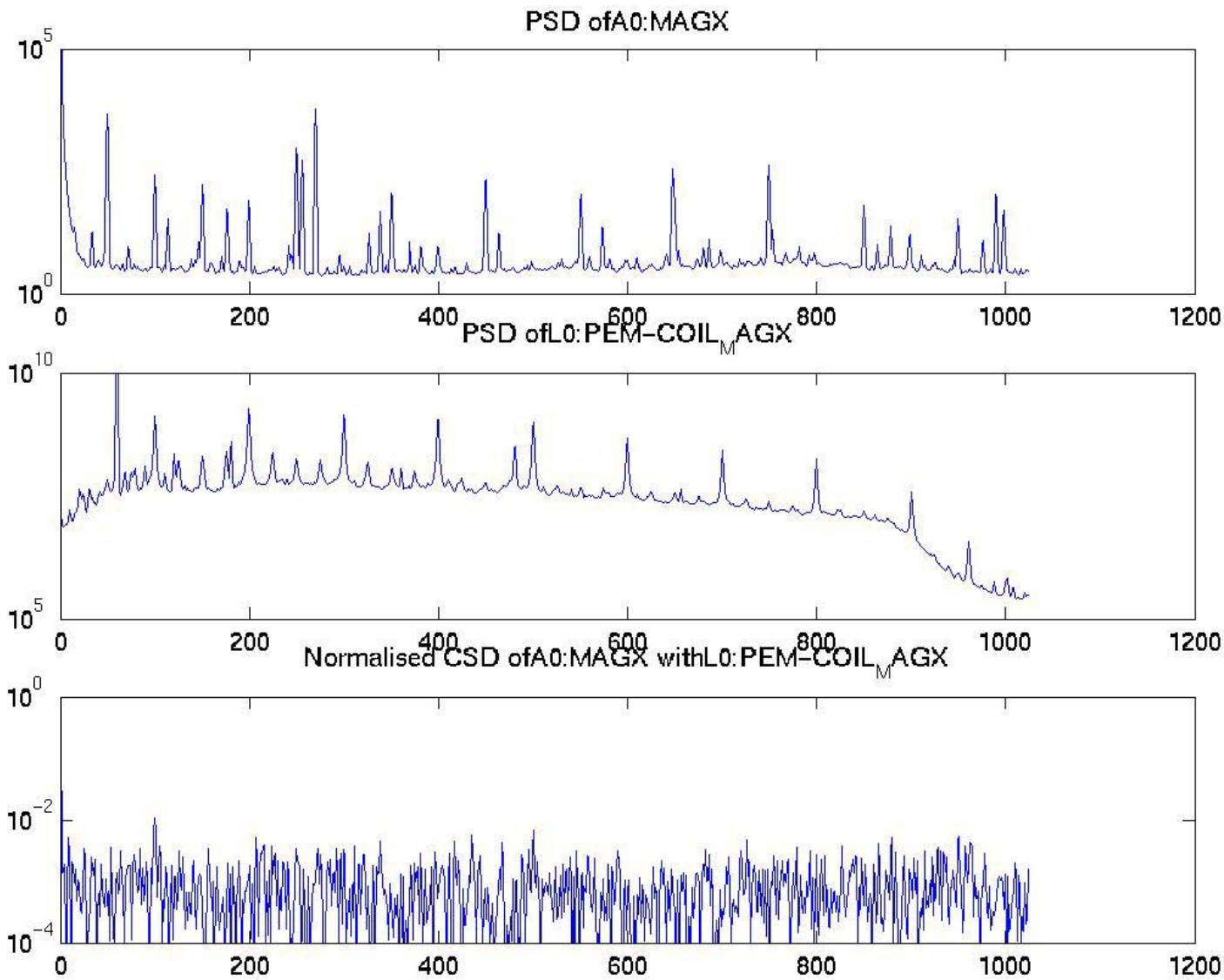
cohere(A0,H0)


PSD ofA0:MAGX
10^5
10^0
0
200
400
600
800
1000
1200
PSD ofH0:PEM-COIL_MAGX
10^{10}
10^5
0
200
400
600
800
1000
1200
Normalised CSD ofA0:MAGX withH0:PEM-COIL_MAGX
10^0
10^{-2}
10^{-4}
0
200
400
600
800
1000
1200

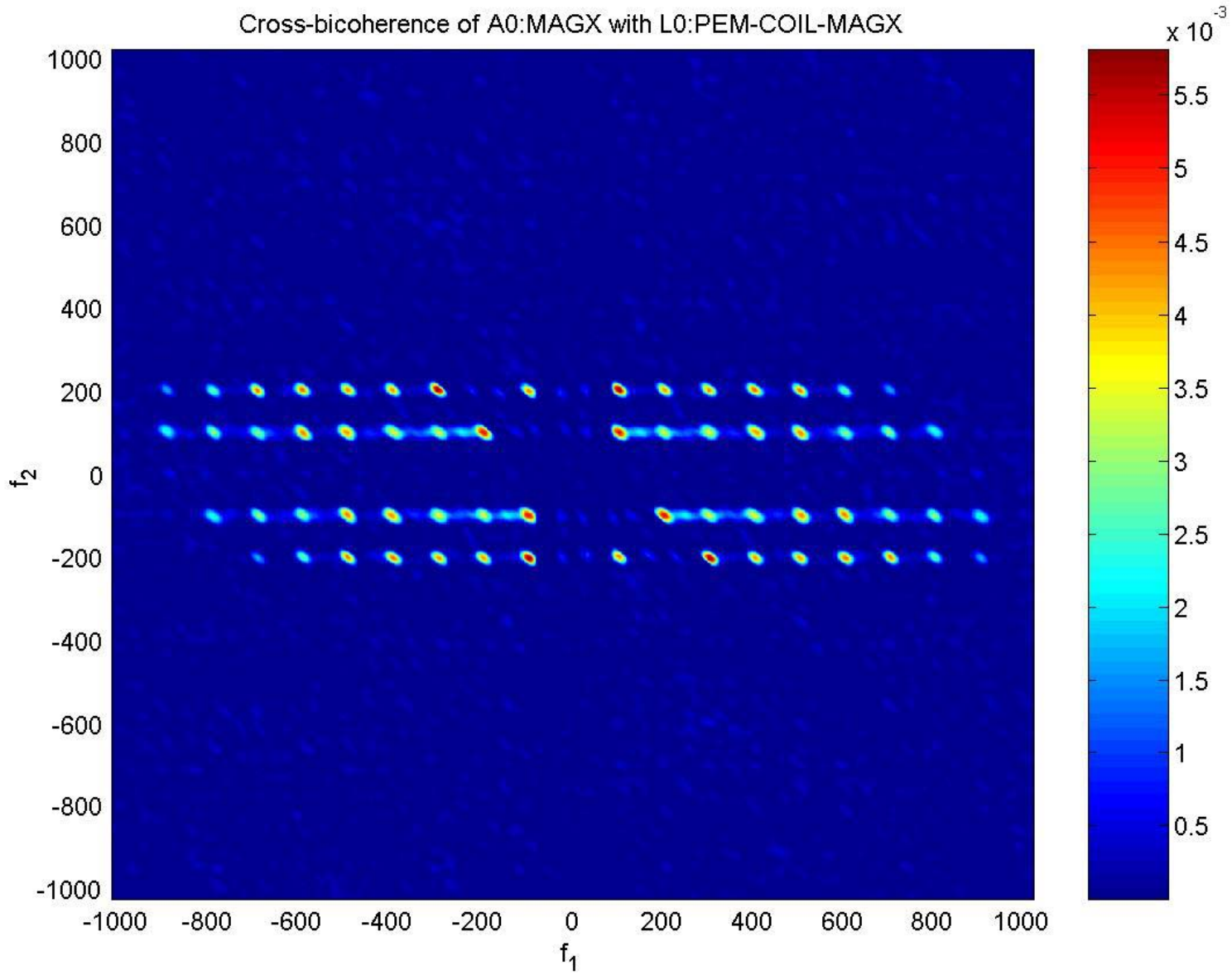
X-bicohere(A0,H0,H0)



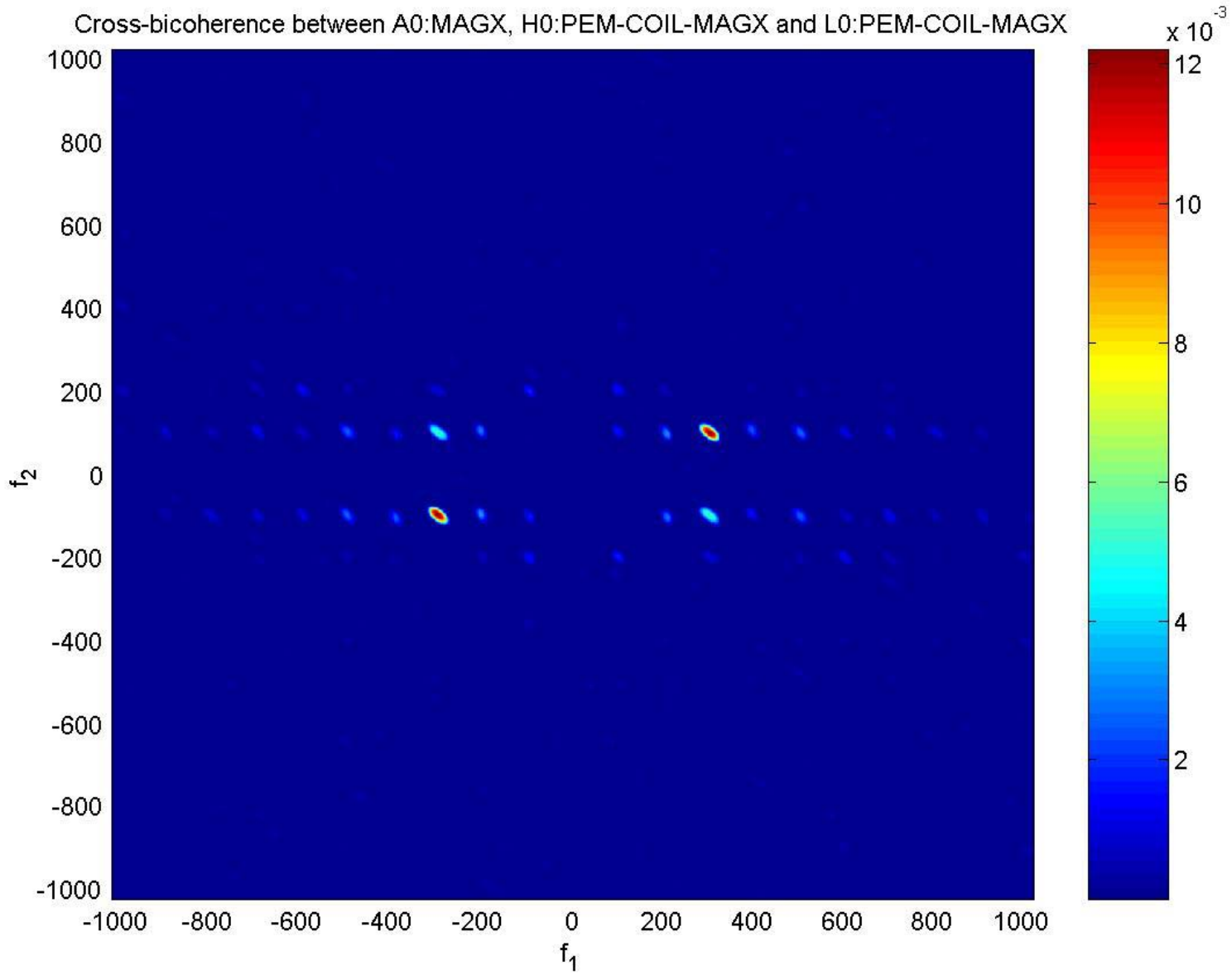
cohere(A0,L0)


PSD ofA0:MAGX
10^5
10^0
0
200
400
600
800
1000
1200
PSD ofL0:PEM-COIL_MAGX
10^{10}
10^5
0
200
400
600
800
1000
1200
Normalised CSD ofA0:MAGX withL0:PEM-COIL_MAGX
10^0
10^{-2}
10^{-4}
0
200
400
600
800
1000
1200

X-bicohere(A0,L0,L0)



triple-bicohere(A0,H0,L0)



Summarising…

- Bicoherence analysis has some merit
  - Difference shown between coherent and incoherent cases, not black and white
  - *Any* good clocks can generate "coherence"?
- Correlations between ACIGA and LIGO just above noise floor at 100Hz
  - LIGO 100Hz lines due to technical glitch
- No other apparent mag. correlations between ACIGA and either LLO or LHO

Why use bicoherence?

- 2^{nd} order statistics do not completely describe a random process
  - eg PSD ~ $|FT\{x(t)\}|^2$ throws away phase info
- Bispectrum and bicoherence (= normalised bispectrum) can give information about coherence between *different frequencies*
  - eg harmonics from common source
- HYPOTHESIS: a bicoherence plot will show significant power at (f_1,f_2) if the corresponding psd shows lines at f_1, f_2, *and* $f_1 + f_2$, *and* these frequency lines are correlated.