Bilinear Coupling Investigations.

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- Identify Bilinear Couplings in LLO s2 data.
- Track bicoherence over long stretches ~4-5hr for certain frequencies which are identified.
- How is Bicoherence affected by transients?
- Does bilinearity change with different noise levels(inspiral range)?
- Which couplings are “glitchy “ during the course of a long lock, for different instrument sensitivity?

Definition of Bicoherence

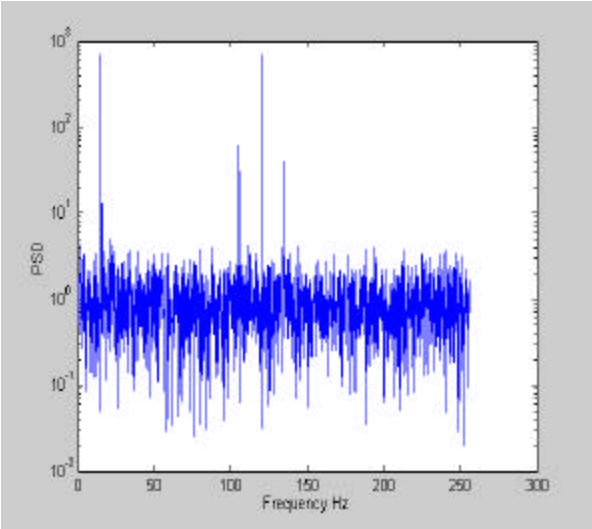
$$b(k,l) = \frac{< X_k X_l X_m^* >}{\sqrt{|X_k X_l|^2 |X_m|^2}}$$

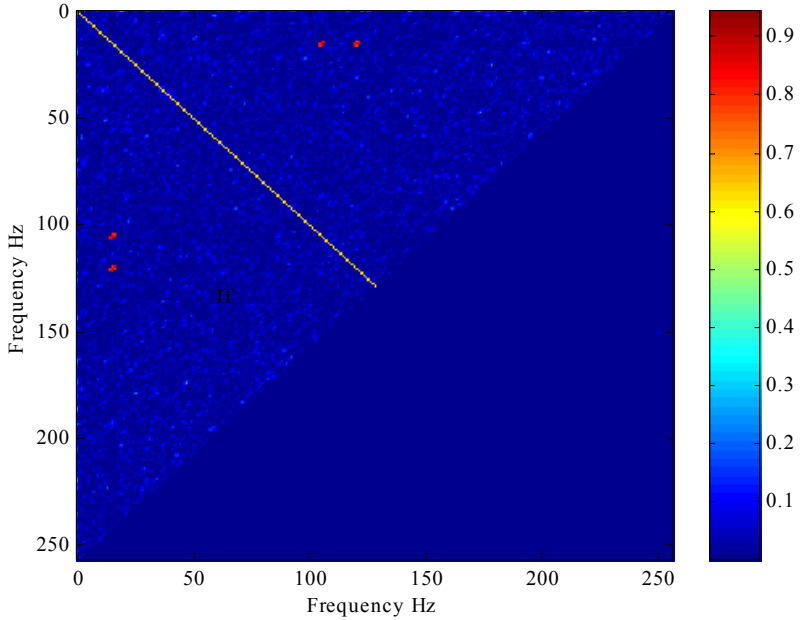
Bicoherence => degree of coherence between k, l and m = k+l

$$e^{if_1} e^{if_2} e^{-i(f_1+f_2)}$$

$$|b|^2 = \frac{P_m^{upconv}}{P_m^{upconv} + P_m^{noise}}$$

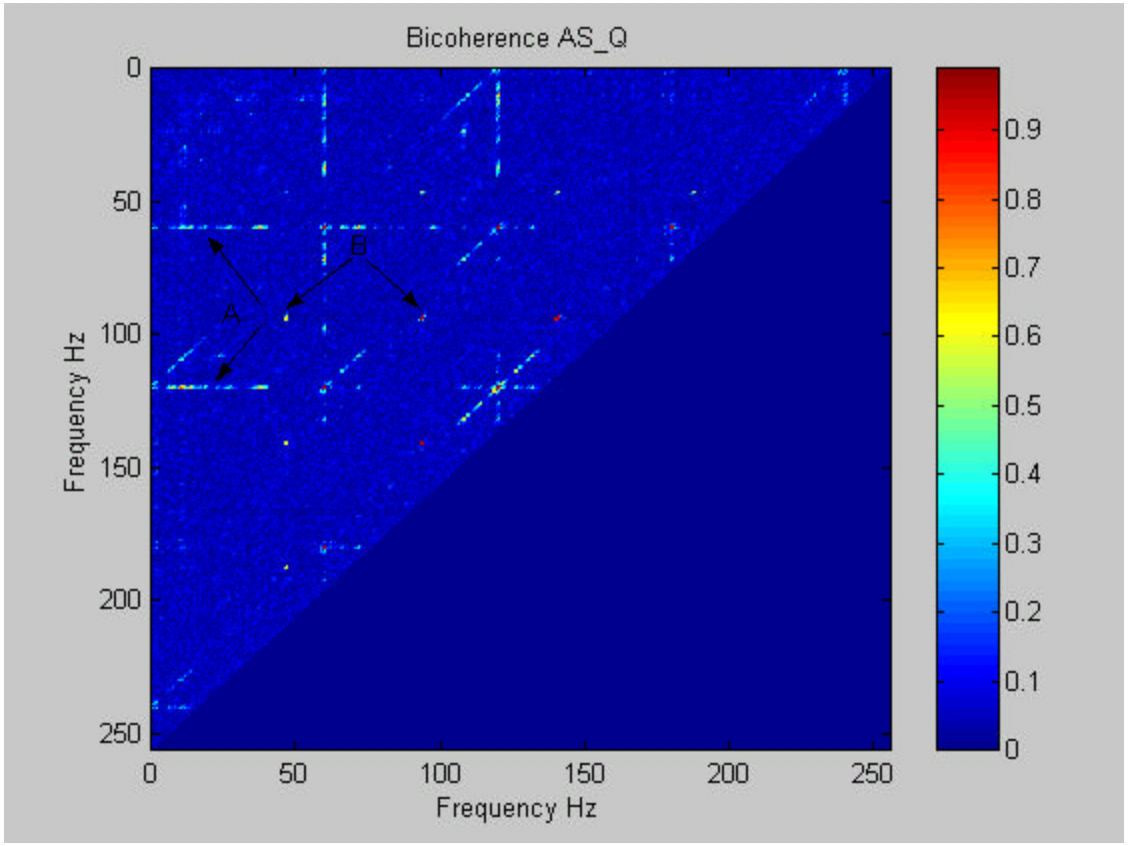
Y=y1 + y2 + y1*y2 +noise, 15Hz, 120Hz
15+105=120; 15+120=135





Identification of Bilinear Couplings

Bicoherence→ c^2 2 deg. freedom



Main Features:

A. Low frequency mirror Suspensions, stack modes, vibrational modes, pump vibrations upconverted by line harmonics.

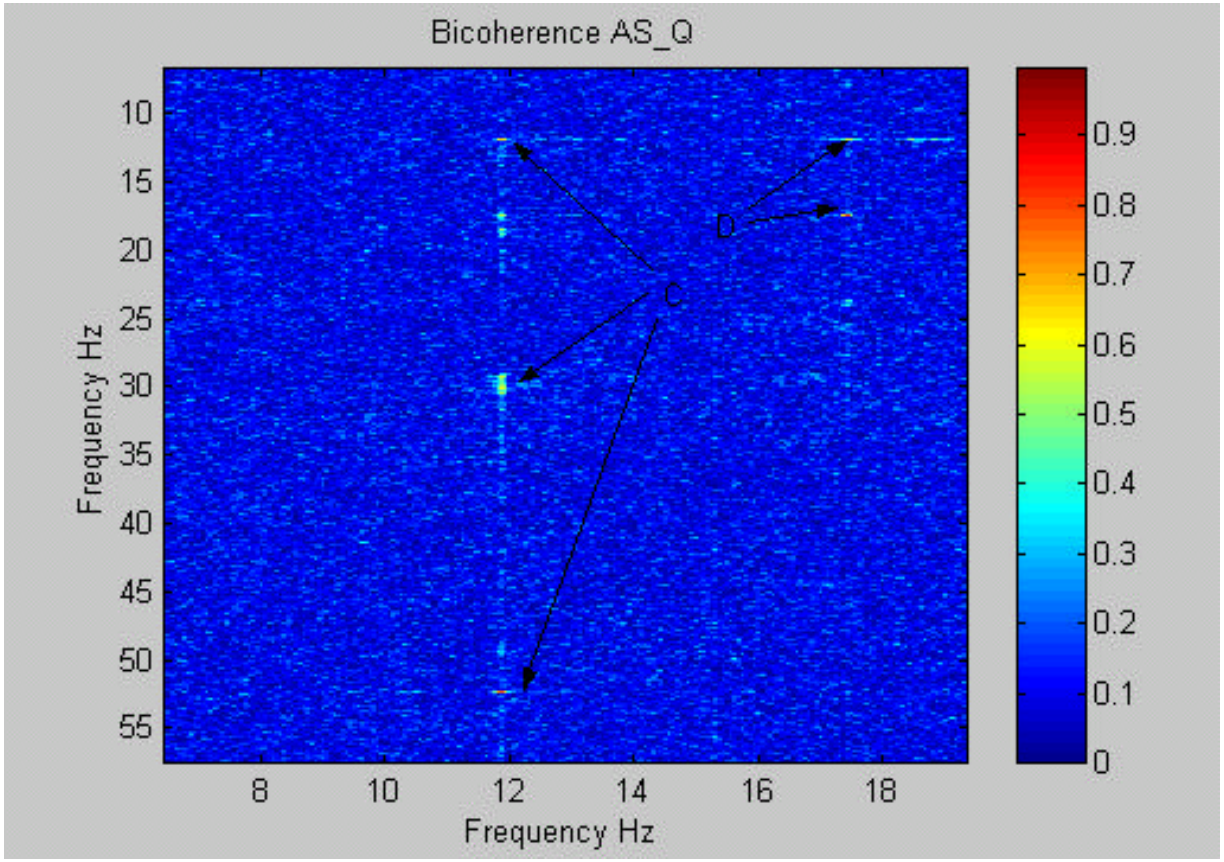
B. Optical lever pitch, L1:SUS-ETMY_OPLEV_P

C: Most bilinear couplings occur at low frequencies.

A. Nonlinearity in electronics? Cross-Bicoherence with MC transmitted light shows 60, 120Hz contribution. Intensity fluctuations * length fluctuations?

B. Optical lever laser oscillation ~47Hz, 94, 141 188 .. Laser not centered exactly on QPD?

Identification of Bilinear Couplings



High Resolution Plot

C. 11.9Hz **vertical** mode
ETM, ITM coupling

1. **Self-Coupling**
   11.9Hz+11.9Hz
2. 17.4Hz **L1:IOO-M1_P**
(Persicope Mirror guides light into Mode Cleaner)
   17.4Hz+11.9Hz
3. 29.8Hz **Pump Vibrations**
   29.8Hz +11.9Hz
4. 52.3Hz **Calibration Line**
   52.3Hz + 11.9Hz

D. **Self-Coupling**
17.4Hz + 17.4Hz

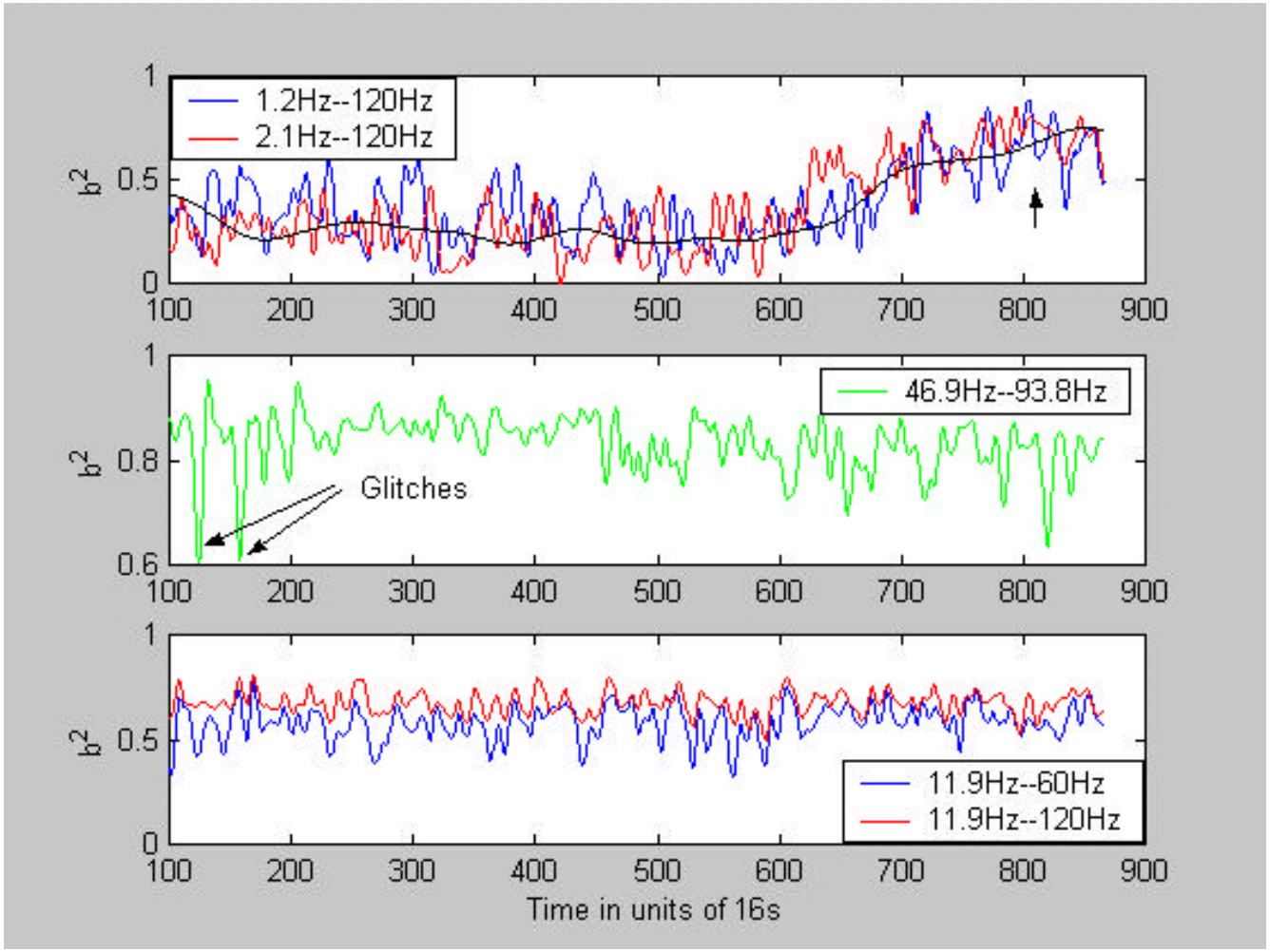
C. Vertical Mode couples into beam if center of mass of mirror is slightly displaced, longitudinal motion * transverse motion. Ex. Calibration line.

D. Vibrations of Periscope mirror phase modulates light entering MC(rf sidebands on Modulation sidebands and Carrier) AS_Q is demodulated beat ➔ 17.4Hz+17.4Hz ??

Other Couplings? **Need to model/experiment these effects.**

Tracking Bicoherence for pairs of Identified frequencies

Compute Bicoherence at (f1-f2) for T=64s , overlap=16s, frequency resolution=.1Hz



Increase in bilinear coupling at low freq at end of locked stretch

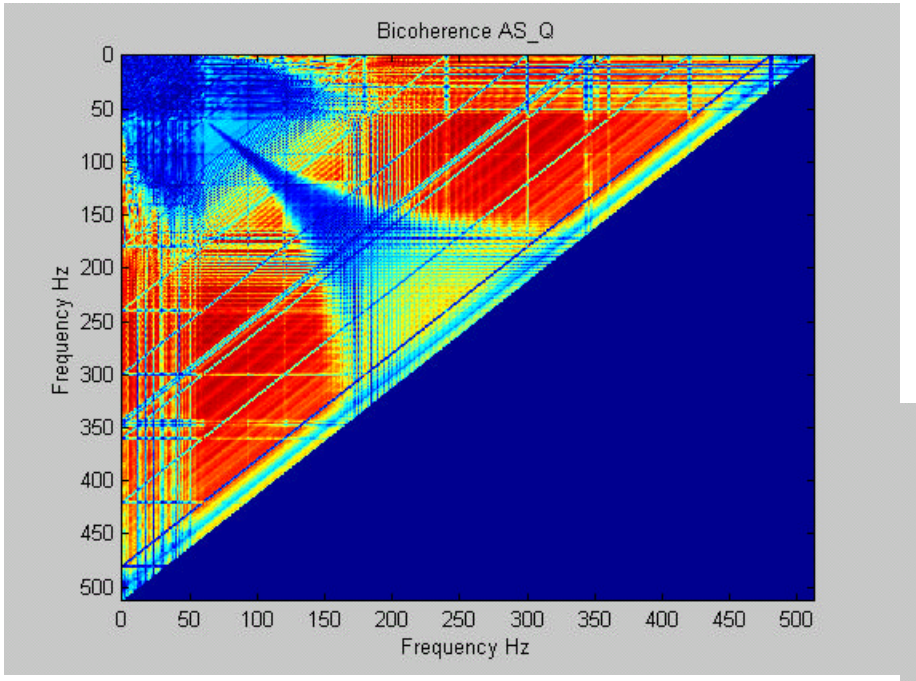
Glitches influence Bilinear coupling

Most prominent is the upconversion of 11.9Hz line.

Study Bicoherence Trend → increase/decrease upconversion → coupling + veto ?

How do transients affect Bicoherence?

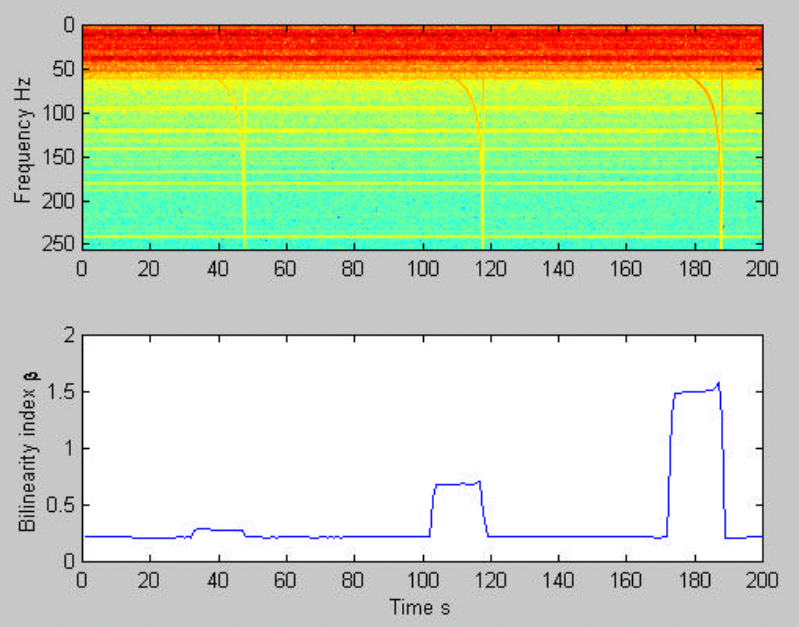
Transients introduce several frequencies over short time scale, which, over a window appear to be correlated ➔ Non-zero Bicoherence
Example: Injections, What does an inspiral look like?



Compute Average Bicoherence: Sum of Bicoherence over all frequency pairs, L
Measure of Bilinearity in data.

$$b = \frac{\sum_{L} b^2(k,l)}{L}$$

Compute Bic over a sliding window of 16s.

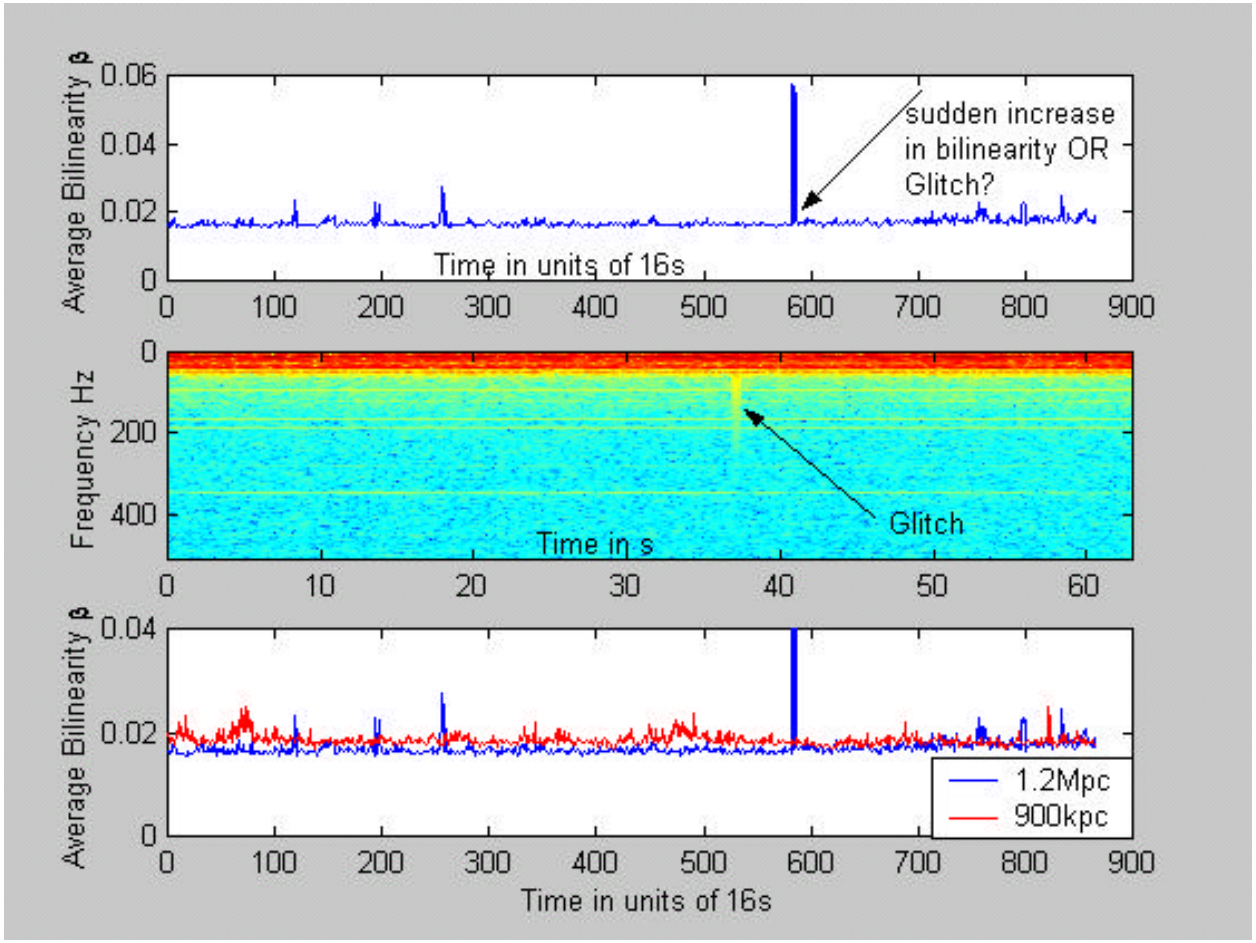


Need to differentiate between Transient and bilinear coupling

Tracking Average Bilinearity for long stretches.

$$b = \frac{\sum_{L} b^2(k,l)}{L}$$

Although average bilinearity index indicates degree of coupling of different frequencies, non-Gaussian noise will add a constant value to it.



Effect of Glitches:

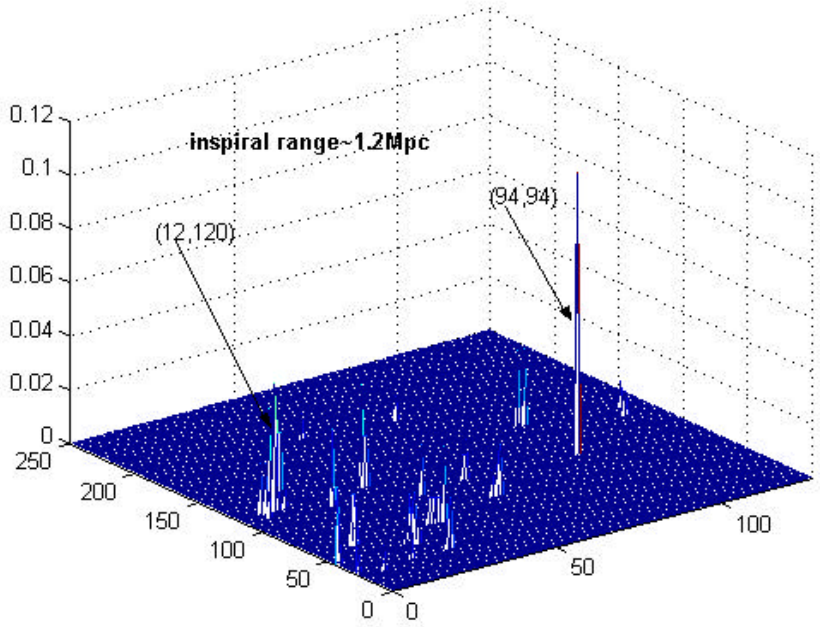
1. Change bilinear couplings.

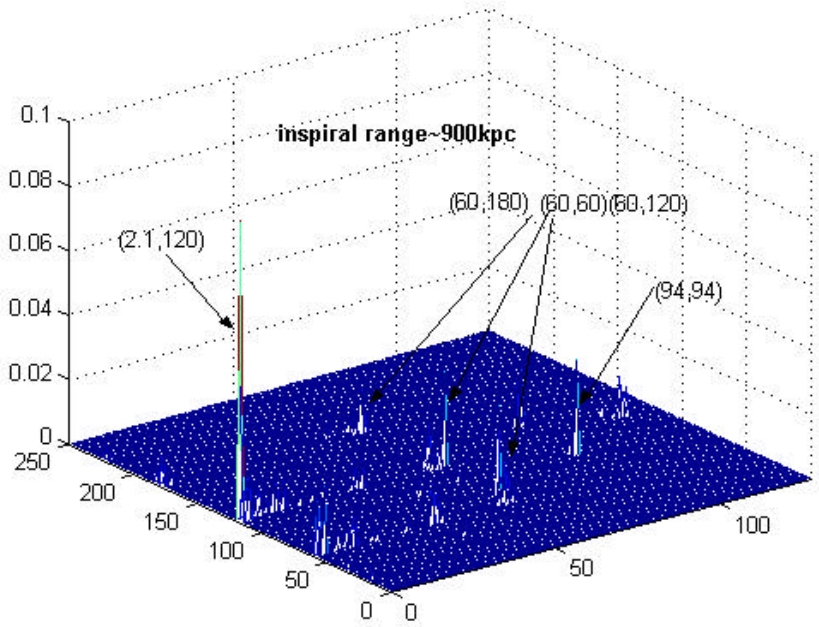
2. Populate several frequency bins with energy→ over short time scales appear correlated.

Lower noise =>
1. lower average bilinearity(less glitchiness)
2. Sharper features in bicoherence.

Tracking Bilinear Glitching

Compute Bic1 64s window → slide window 16s →Compute Bic2 64s window
If |Bic1- Bic2| > 20% → write (f1,f2) to text file.
→ 2D histogram of bilinear "Glitching"→ relative probability of occurance of (f1,f2)





Similar histograms for different inspiral ranges < 1Mpc indicate
Lower sensitivity → larger glitchiness in (60*n, 60*n) Hz.

Summary and Conclusions

- Identified some of the bilinear couplings. Coupling mechanisms need to be investigated more thoroughly → simulation? Experiment?.

- Individual variations in Bicoherence trends --- the effects of glitches on Bicoherence -- Histograms of glitchiness help in study of noise couplings. Need to integrate this with BicoMon.

- Work in progress with Steve Penn on background monitor for computing bicoherence trends. Selection of frequency pairs by BicoMon.

- Would it help to whiten data before computing Bicoherence? Low frequencies swamped by noise.Simulations suggest that there is a small increase in Bicoherence after whitening data. Whitening produced by linear prediction.