

Regularized coherent network analysis pipeline for triggered searches

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Burst Triggered Search



- Gamma ray burst, Neutrino burst, X-ray burst from transient astronomical events
- The time and sky location of these events can be estimated by other astronomical observations such as HETE, SuperKamiokande, Chandra etc.

Triggered search already going

- GRB - Cross Correlation method ----- S. Mohanty's talk
- SGR - Excess Power method ----- L. Matone's talk

Our approach ----- regularized coherent network method

Outline

- Data Conditioning
- Event Selection based on regularized coherent network analysis
- Analysis
 - Detection Efficiency
 - Accuracy of waveform estimation

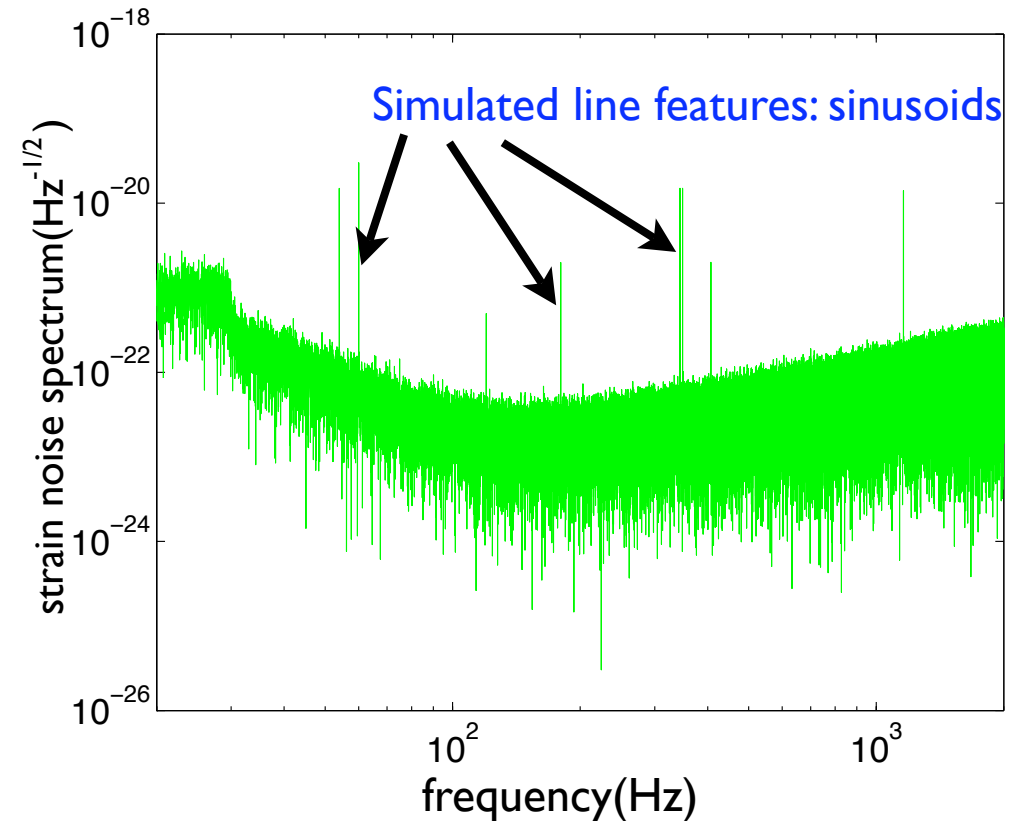
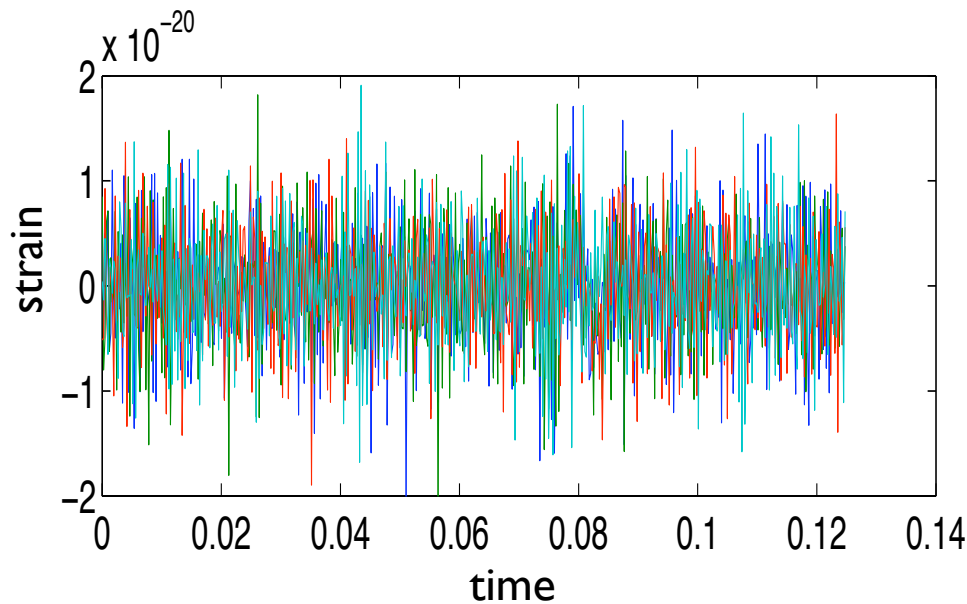
Data
Conditioning

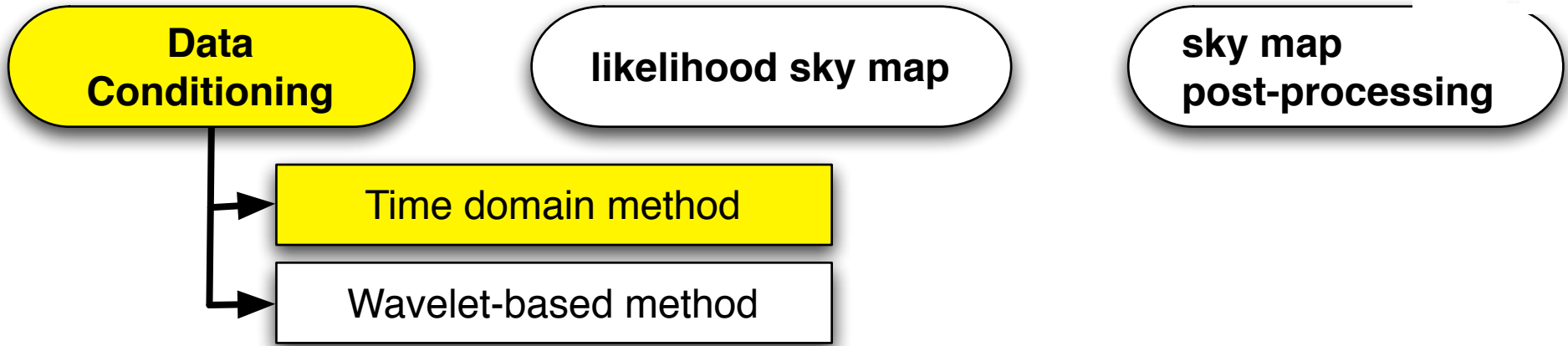
likelihood sky map

sky map
post-processing

4 data at H1-H2-L1-GEO with same simulated detector noise(right figure).
A burst signal is injected.

Band-pass filtered(64-2000Hz) signals

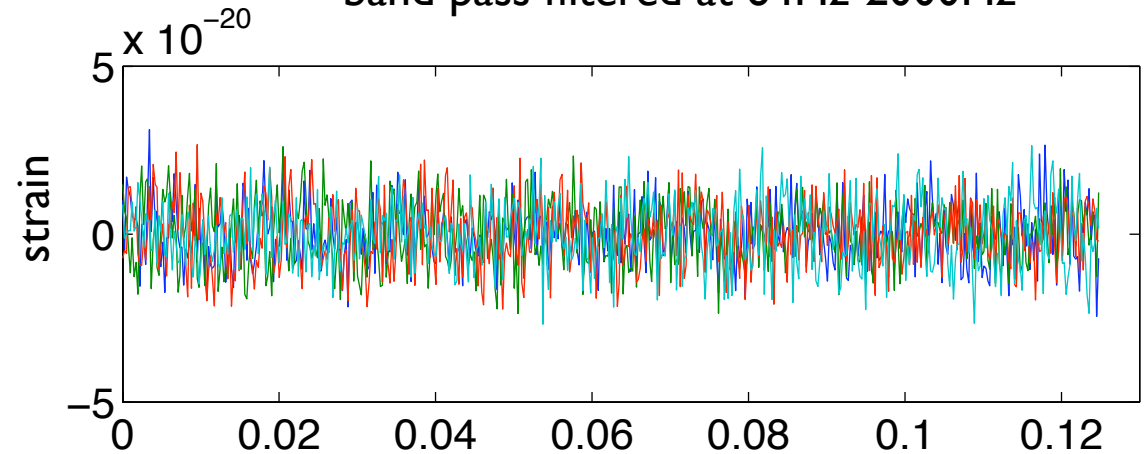




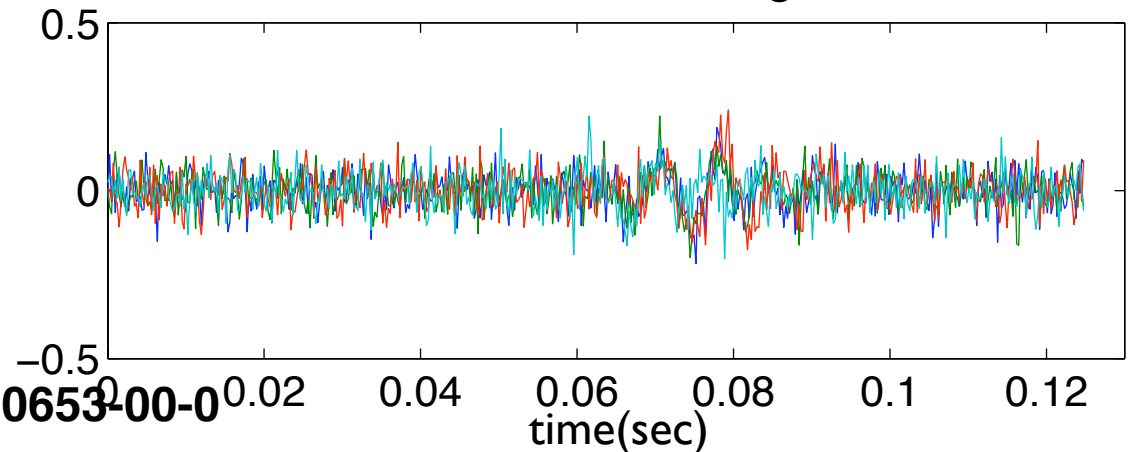
Time domain method

- Time domain noise floor whitening
S. Mukherjee CQG 21 (2004) S1783
- Remove lines by Median Based Line Tracker
S. Mohanty CQG 19 (2002) 1513

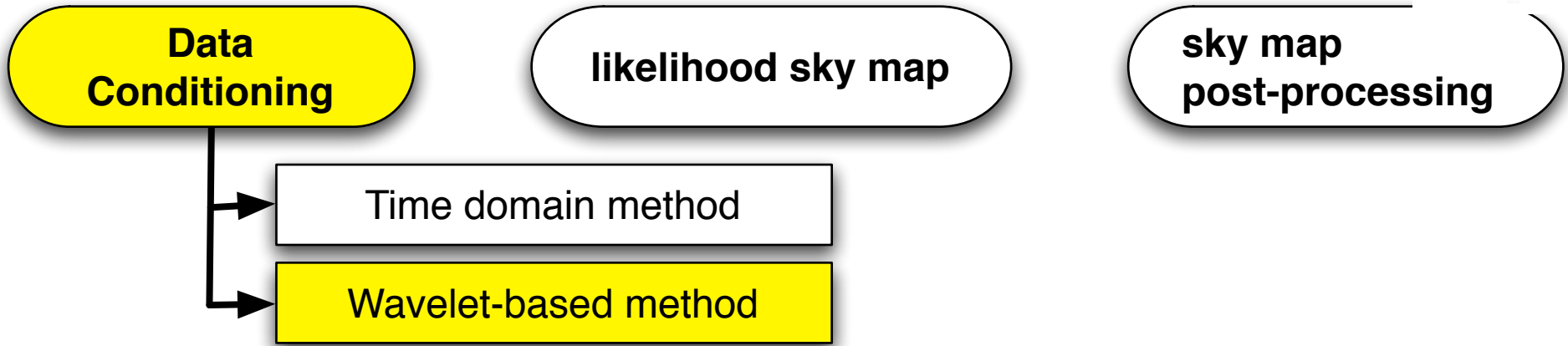
band pass filtered at 64Hz-2000Hz



after conditioning

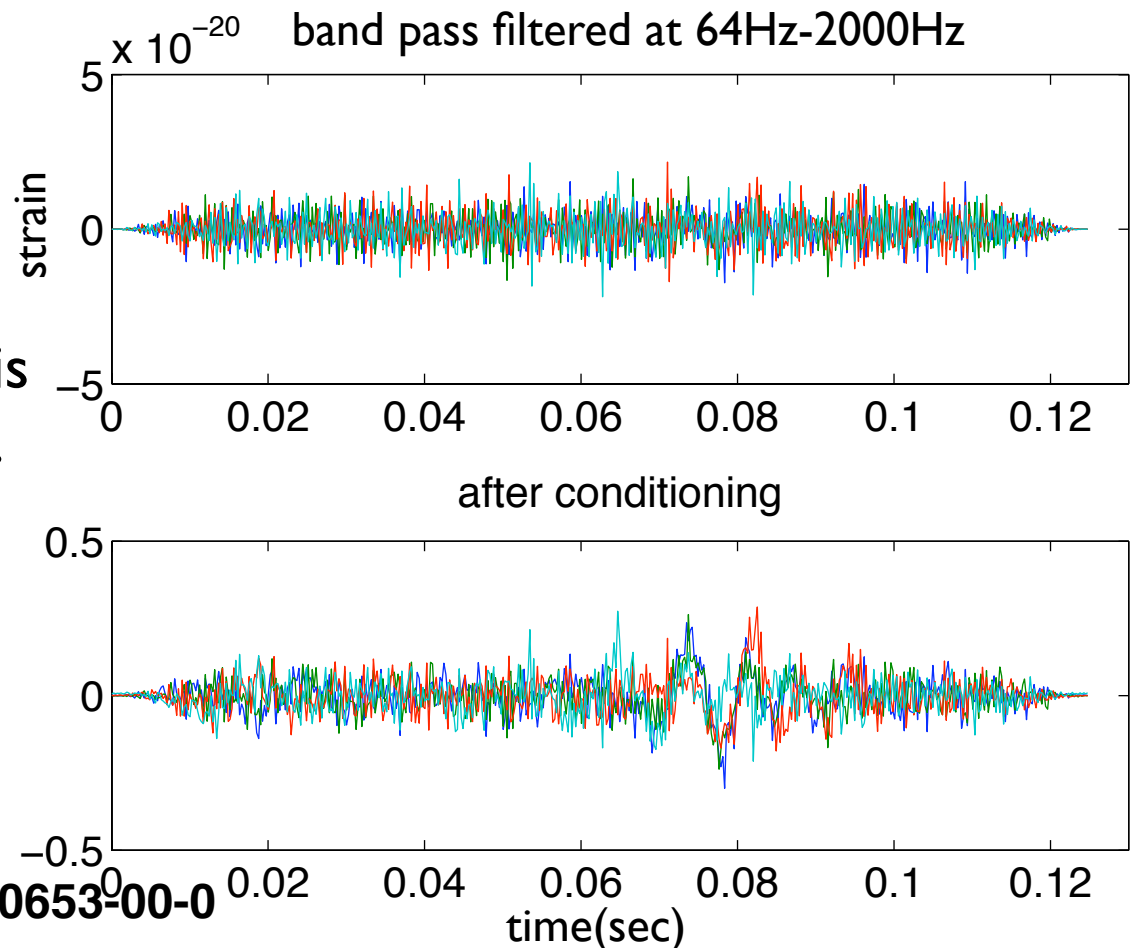


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Wavelet-based method

- Select frequency region to analyze by nulling around lines
- In frequency region, spectrum is estimated by wavelet de-noising.
- Whiten data using estimated spectrum



Data Conditioning

likelihood sky map

sky map post-processing

Detector output

$$\begin{bmatrix} x_1(t) \\ \vdots \\ x_k(t) \end{bmatrix} = \begin{bmatrix} F_{+,1}(\theta, \phi) & F_{\times,1}(\theta, \phi) \\ \vdots & \vdots \\ F_{+,k}(\theta, \phi) & F_{\times,k}(\theta, \phi) \end{bmatrix} \begin{bmatrix} h_+(t) \\ h_{\times}(t) \end{bmatrix} + \begin{bmatrix} \eta_1(t) \\ \vdots \\ \eta_k(t) \end{bmatrix}$$

rank deficiency

Ill-posed problem

1. Data is divided into chunks



2. generate skymap at each chunk



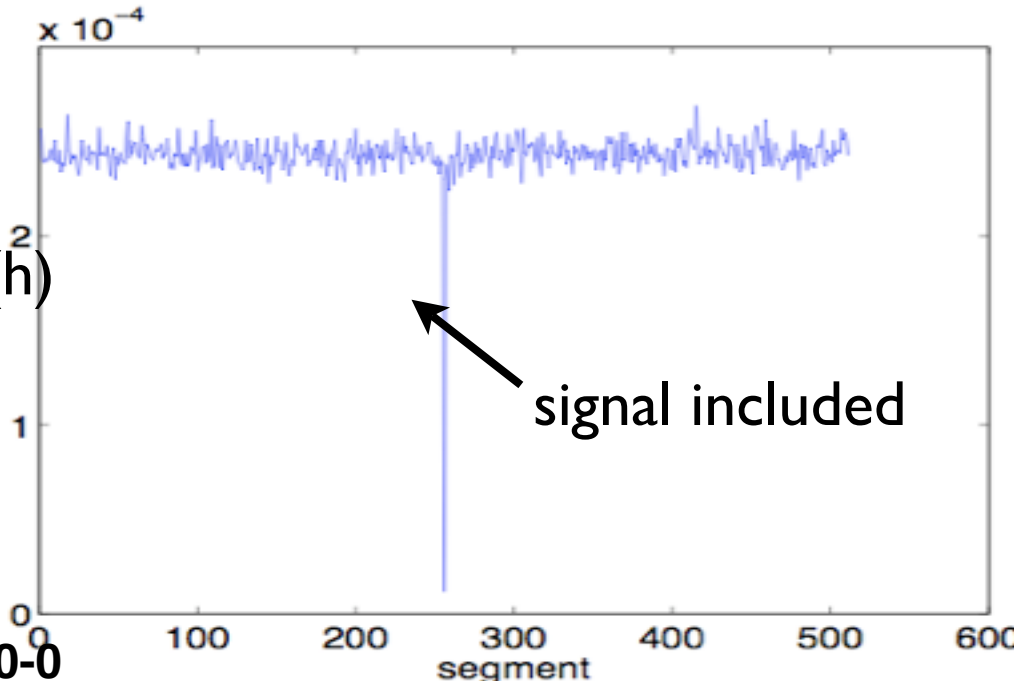
One Solution-- Tikhonov regularization

M. Rakhmanov CQG 23 (2006) S673

$$L_g = ||\mathbf{x}(t) - \mathcal{F}(\theta, \phi)\mathbf{h}(t)||^2 + g\Omega(\mathbf{h})^2$$

$$R = x^T Q x$$

R@source location



Data Conditioning

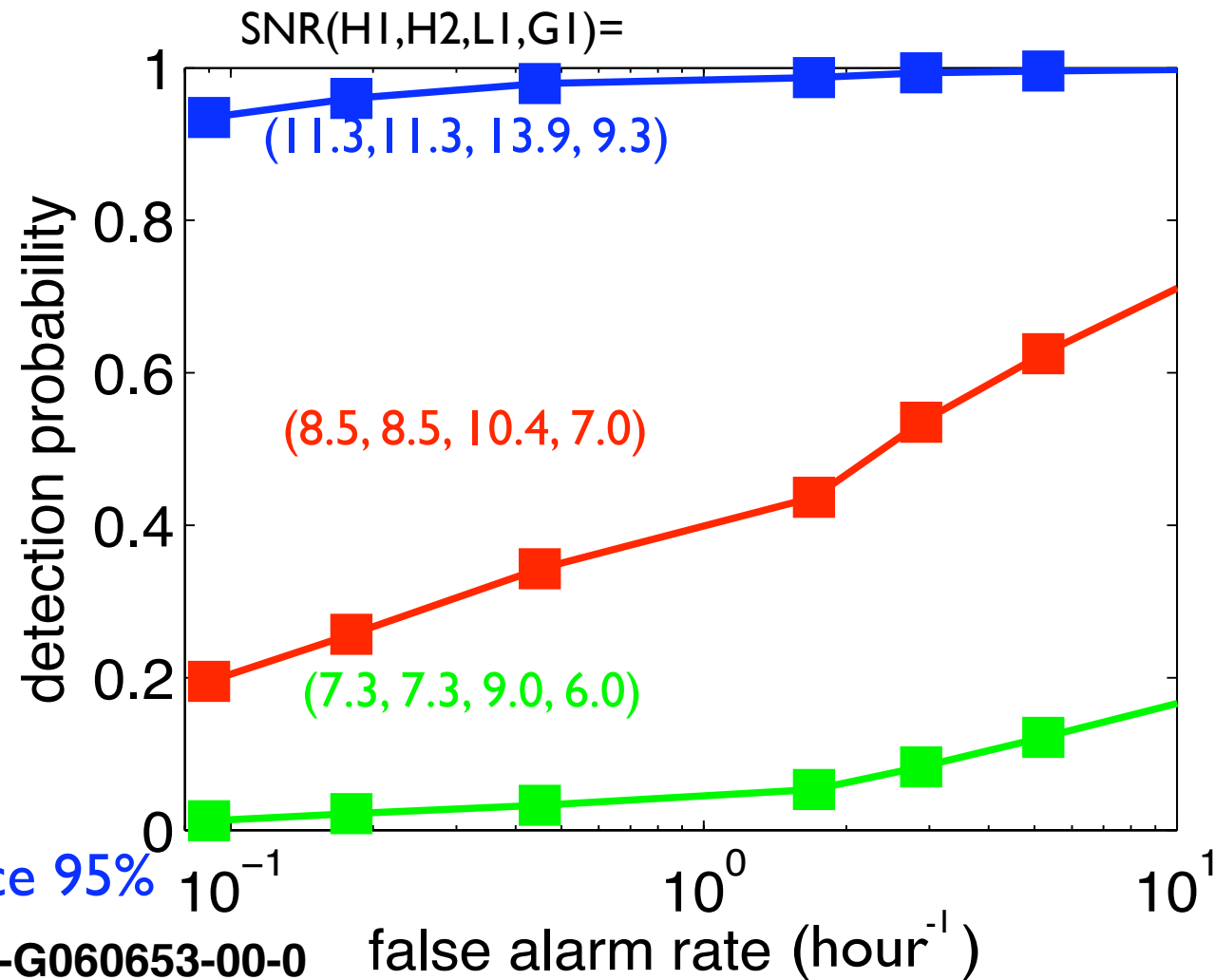
likelihood sky map

sky map post-processing

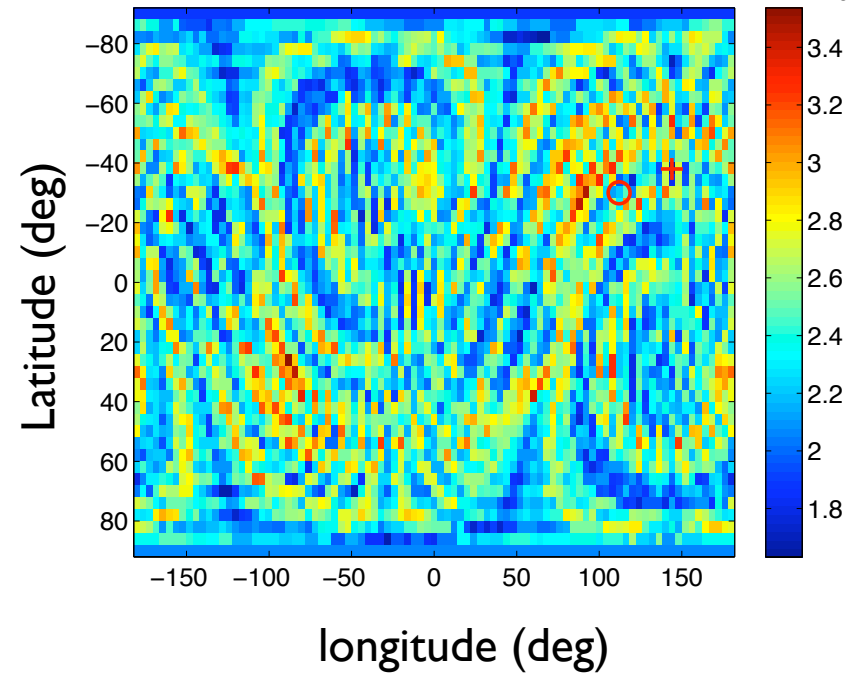
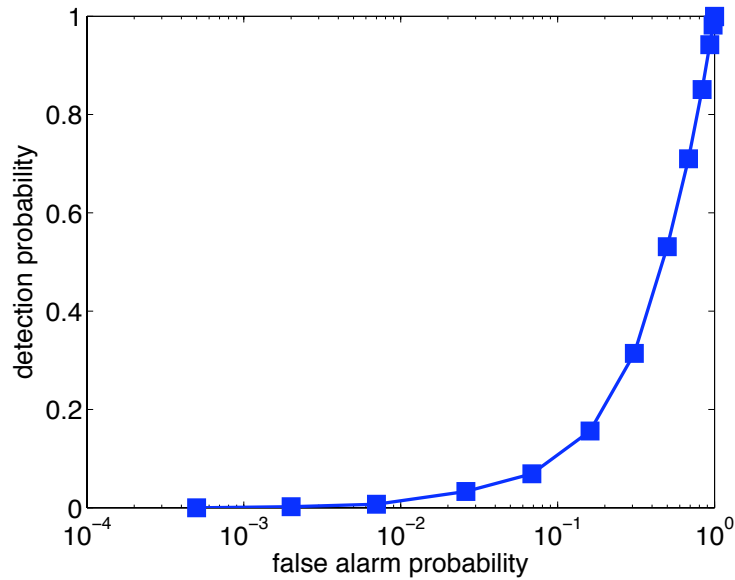
Simulation

- 5000 trials in which a burst is in the simulated noise (sampling rate = 4096Hz)
- The burst: black hole merger
- 5000 trials in noise data

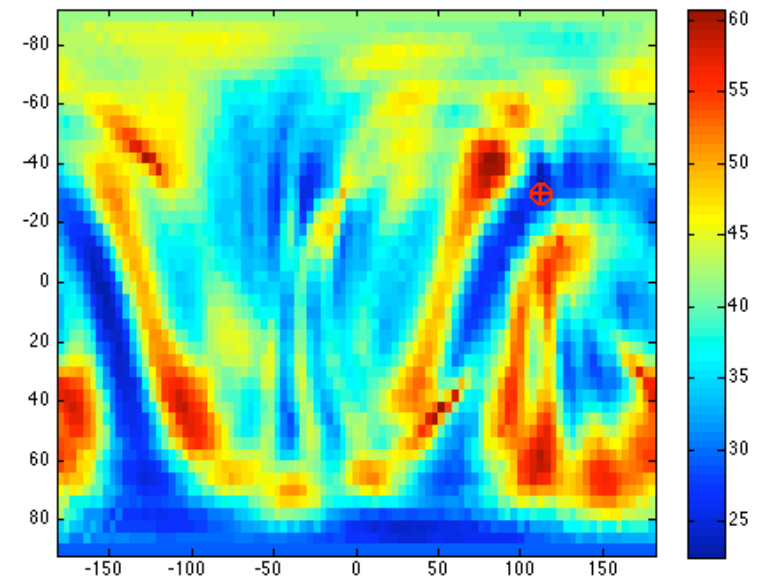
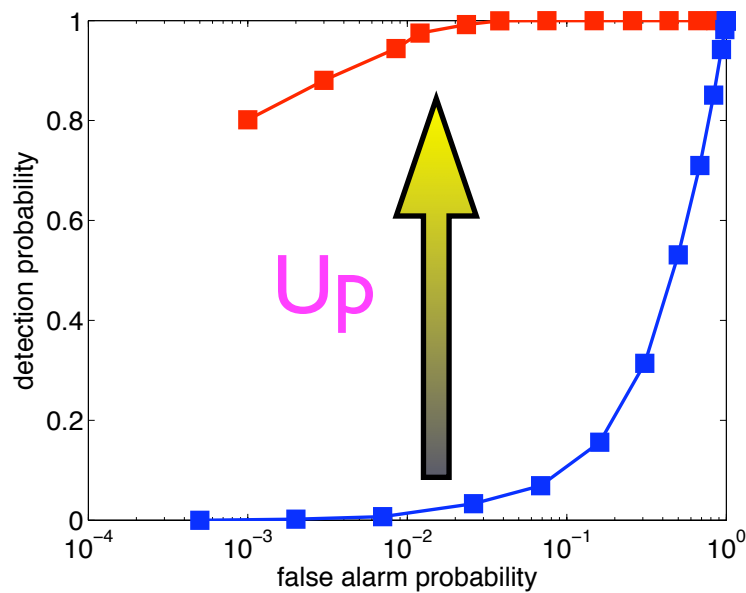
Receiver Operating Characteristic Curve



**Without
DC**



**With
DC**



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CGWA

Data Conditioning

sky map whitening

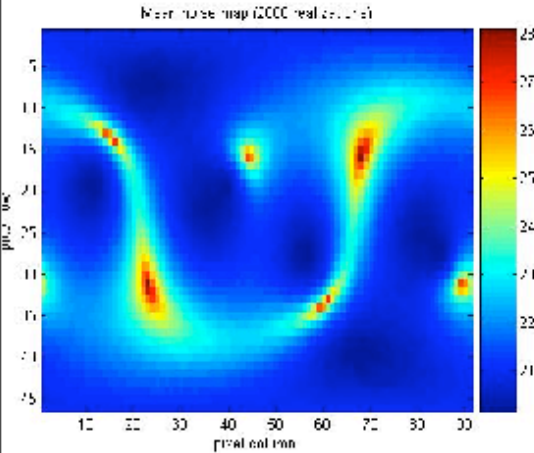
likelihood sky map

sky map post-processing

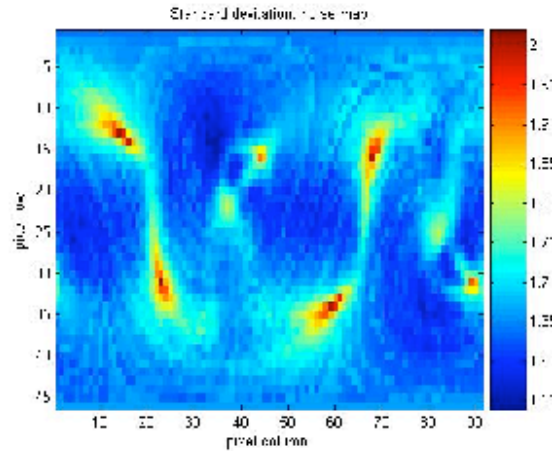
PENNSTATE



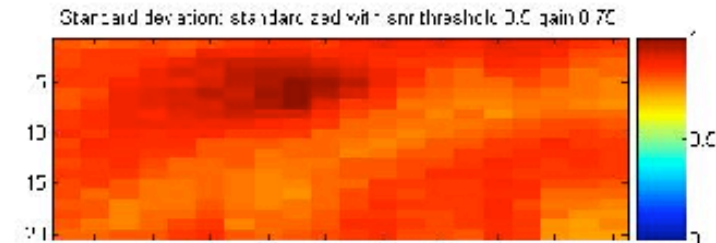
mean noise map



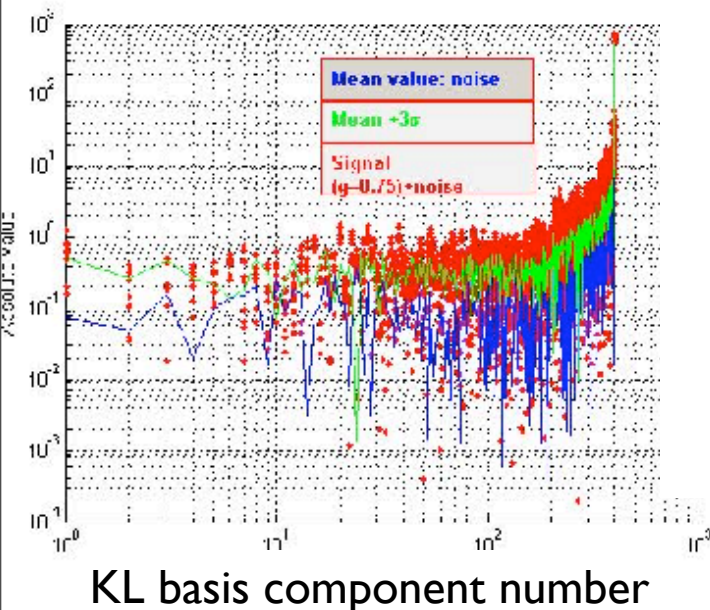
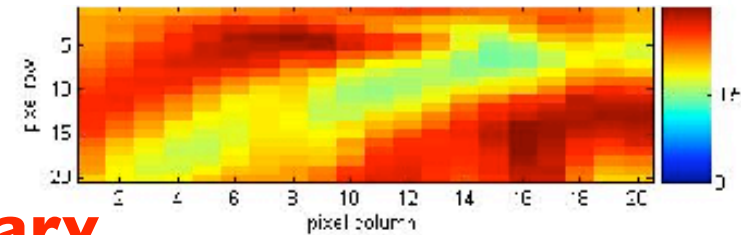
standard deviation:noise map



standard deviation:after standardized



standard deviation:raw sky map



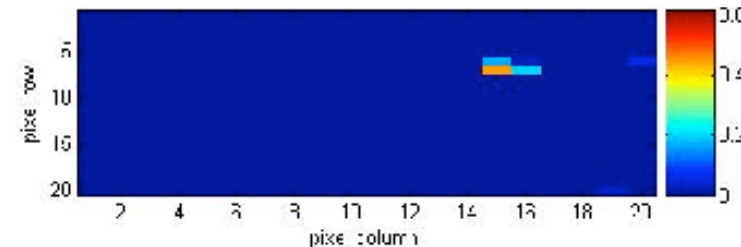
Preliminary

- Submap around known sky location
- Estimate noise only pixel-to-pixel covariance matrix
- Obtain eigenvectors: **Karhunen-Löve basis**
- Select KL basis components \triangleright specified "snr" level

location of minimum after standardized



location of minimum before standardized

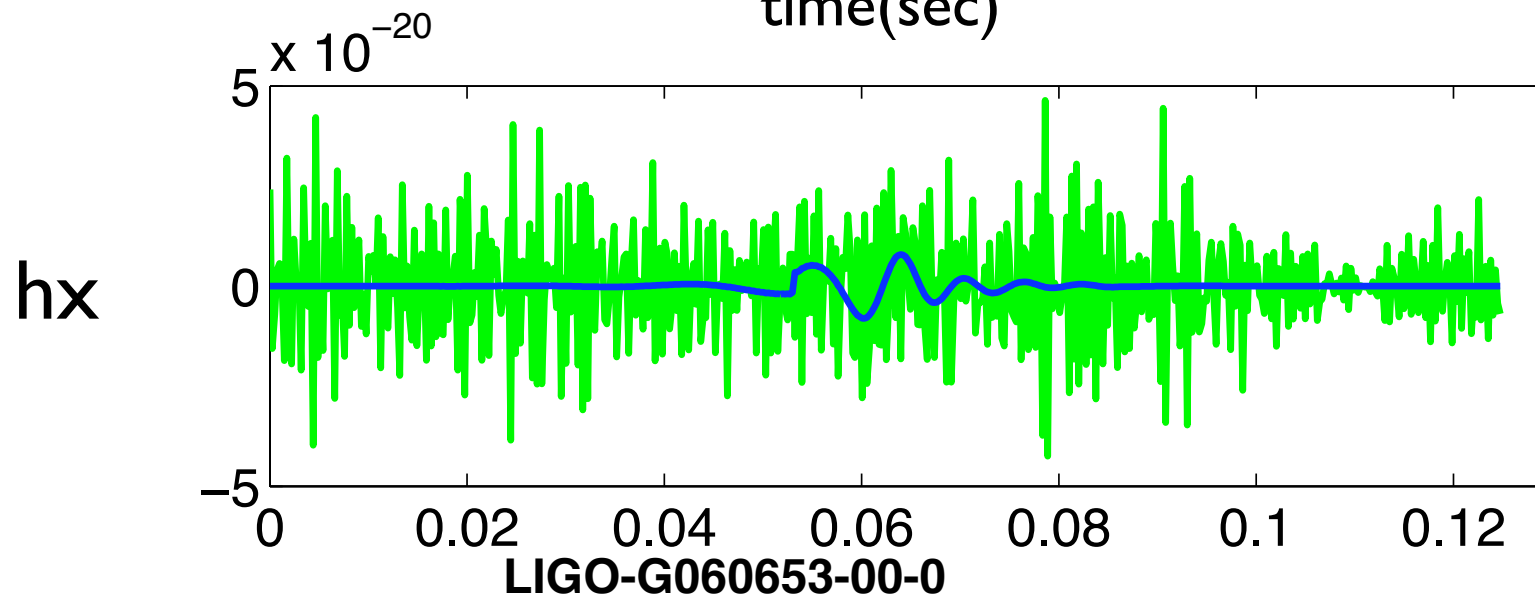
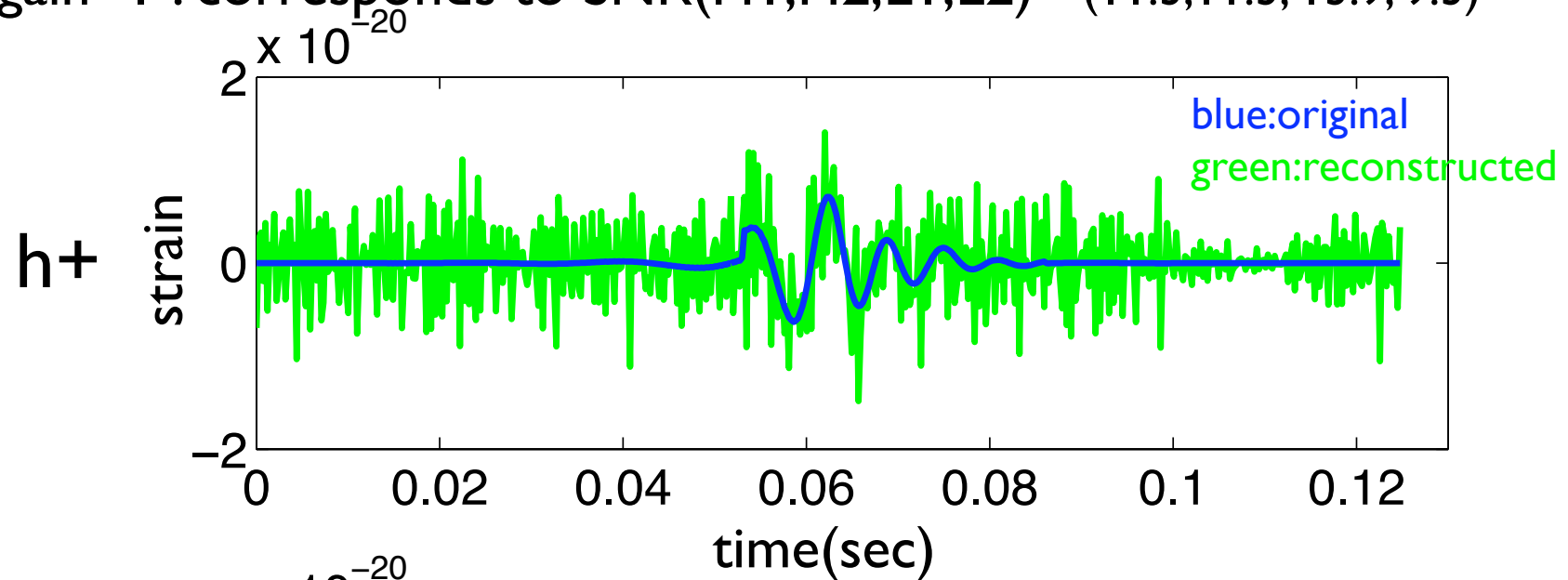


Data
Conditioning

likelihood sky map

sky map
post-processing

signal gain=1 : corresponds to $\text{SNR}(H1,H2,L1,L2) = (11.3, 11.3, 13.9, 9.3)$

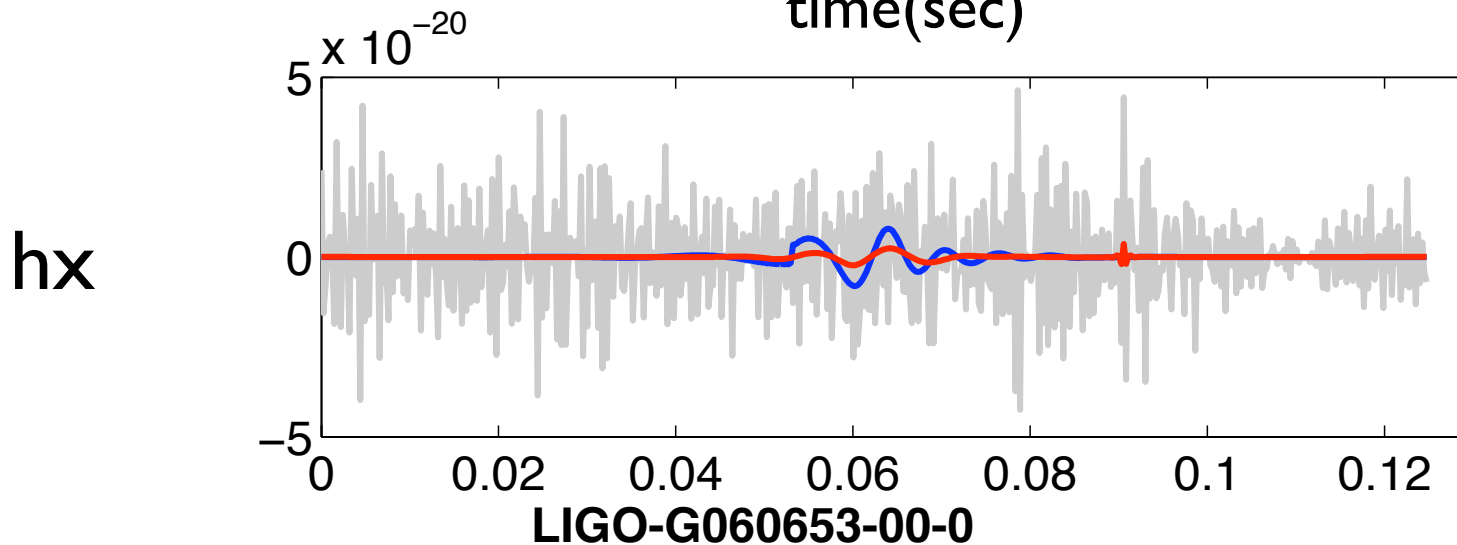
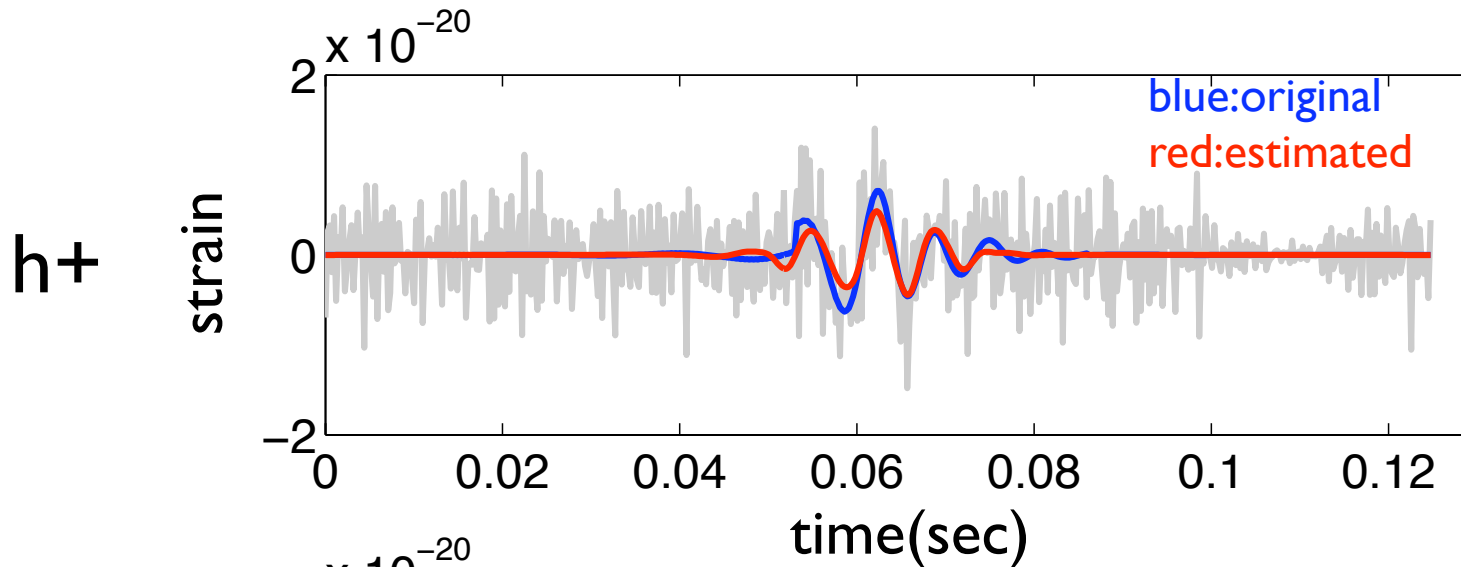


Data Conditioning

likelihood sky map

sky map post-processing

To de-noise, wavelet-based waveform estimation method is used (red)
 Hayama, Fujimoto **CQG 23 (2006) S9**

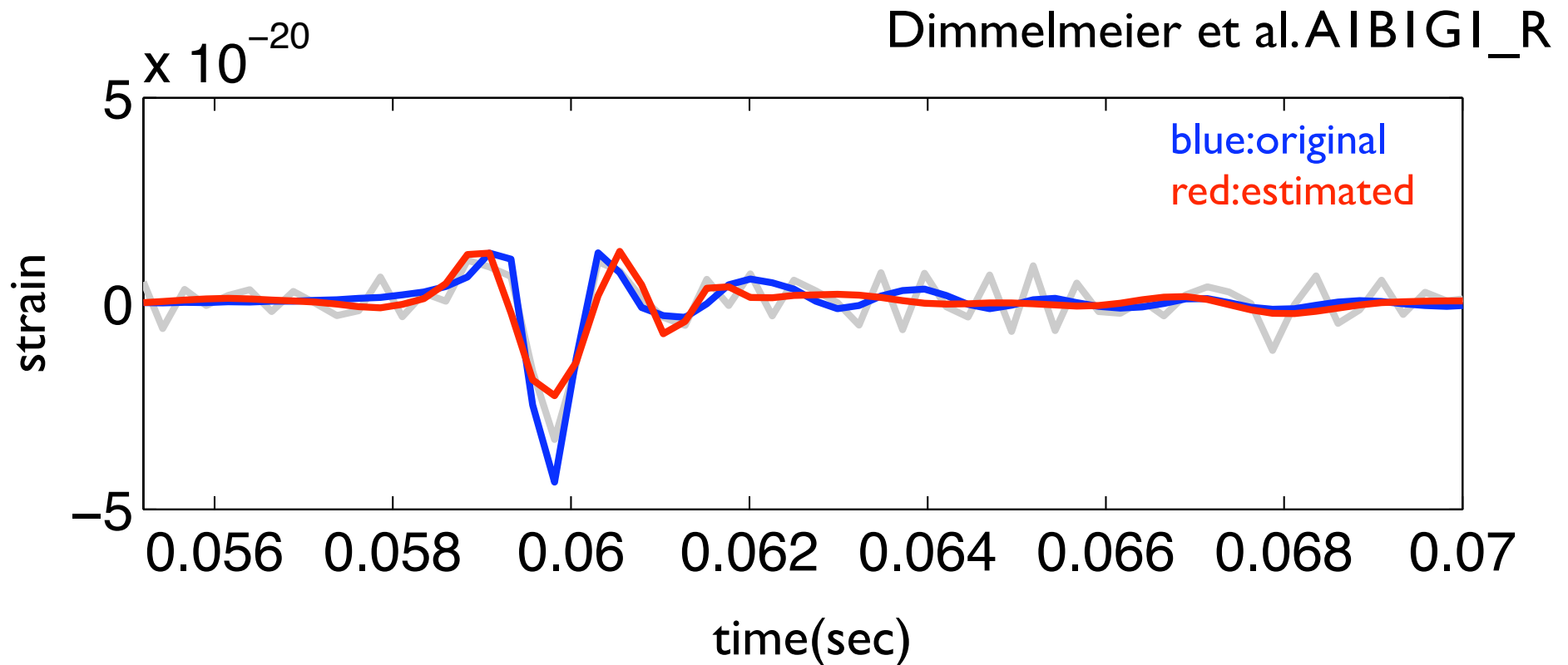




Accuracy of Waveform Estimation



Using HI-LI-VIRGO.... these detectors have comparable sensitivity
Supernova signal at (l 12, -30) at 2kpc distant from Earth
SNR(HI,LI,V)=(11.1, 14.0, 3.5)



h waveform(duration=14msec) of the burst from 2kpc at (l 12,-30) can be estimated within MSE of 0.3

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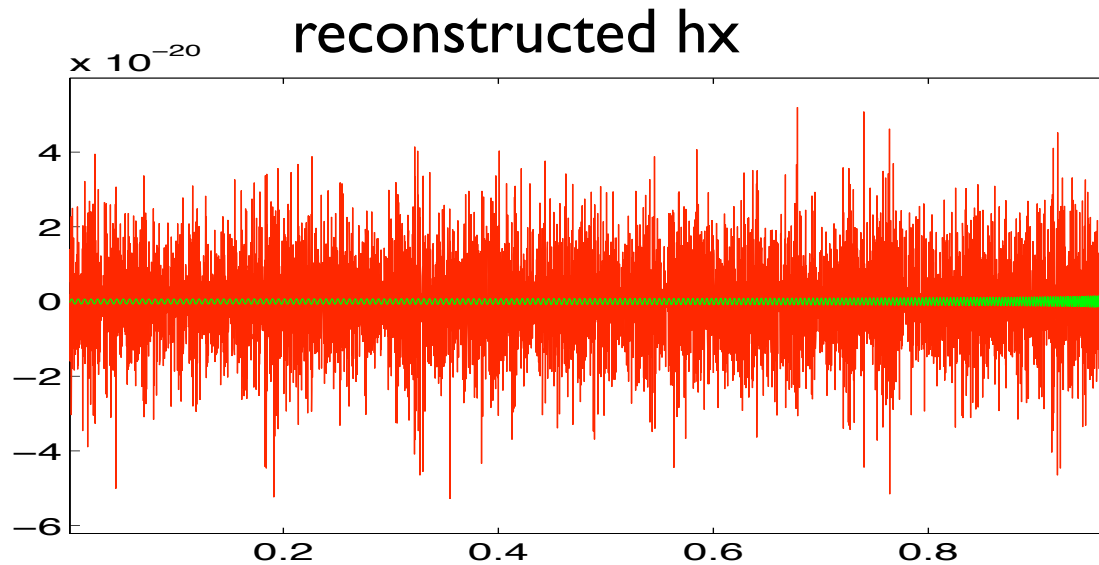
Reconstruction of Inspiral signal



Idea: Join continuous reconstructed h^+ , h_x segments

----->> we can get arbitrary signal's h^+ , h_x time series.

Example : Inspiral signal(IM-IM), 1Mpc



Matched filter on h^+ , h_x

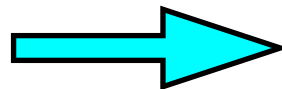
Theoretical SNR

H1:16.6

H2:16.6

L1:17.8

GEO:4.5



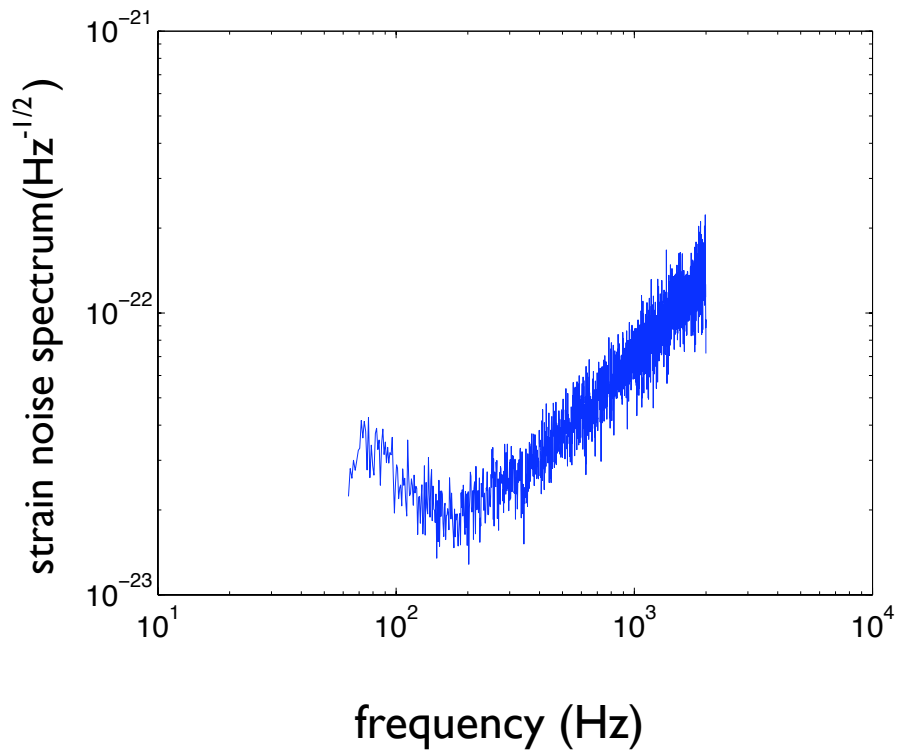
SNR (with rough spectrum estimation)

H_p :7.8

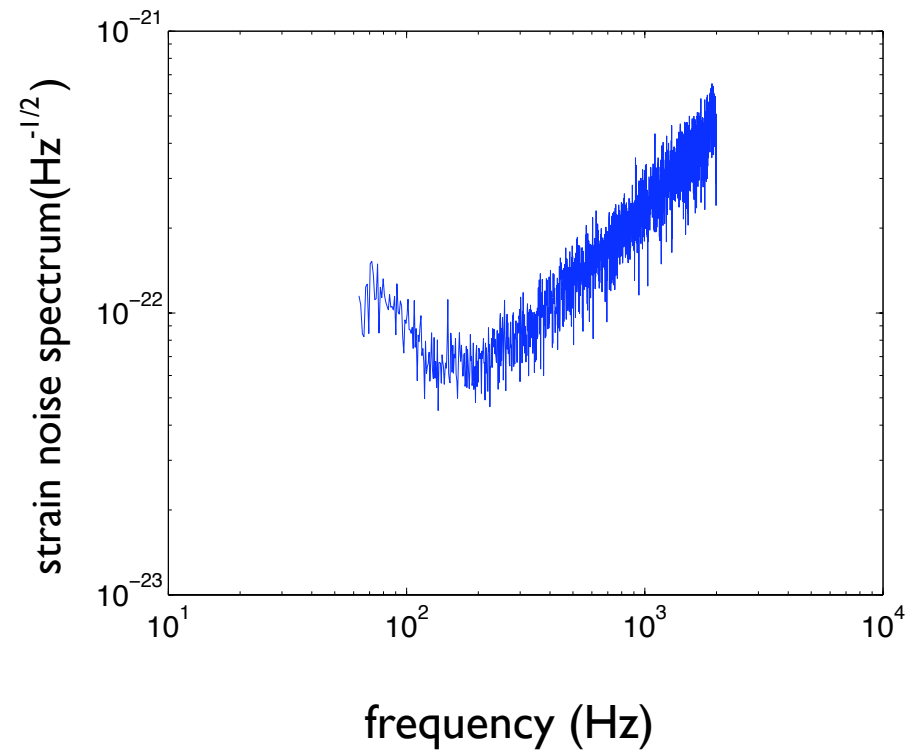
H_c :3.2

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h_+



h_x



- Regularized coherent network analysis pipeline for triggered search has been developed
- From the pipeline, we get not only a detection statistic but also the reconstructed polarization waveforms.
- Using wavelet-based waveform estimation, we showed accuracy of estimated waveform
- We can get h_+ , h_x time series for any given direction on the sky and can search for signals other than bursts.(e.g. template based search)
- In progress: application to real data

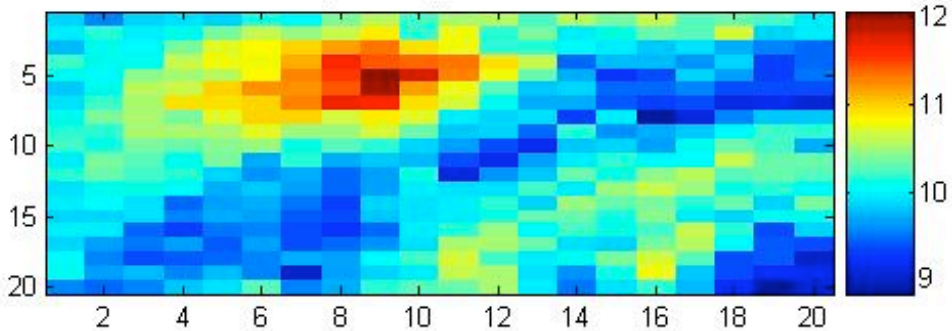
Data
Conditioning

likelihood sky map

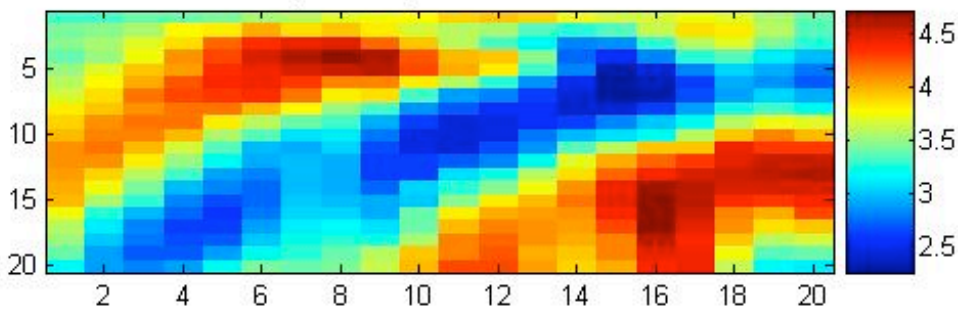
sky map
post-processing

Standard deviation of skymap

Stdev(Noise+sig) : standardized

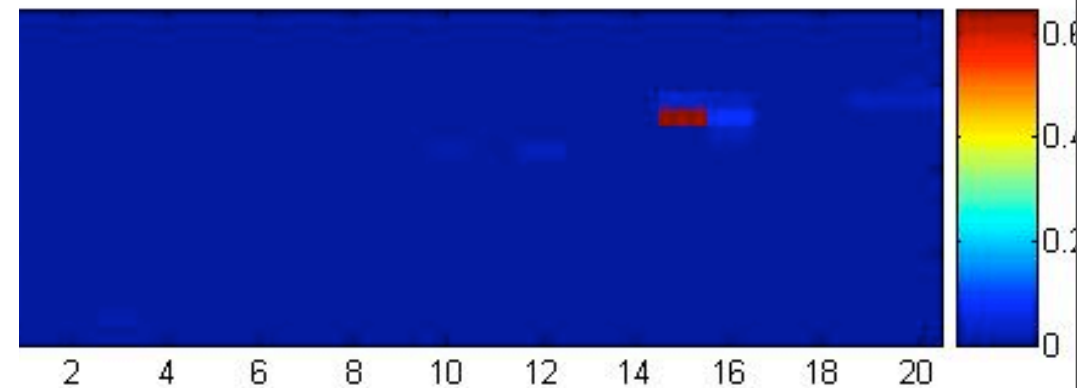


stdev(Noise+sig) : not standardized

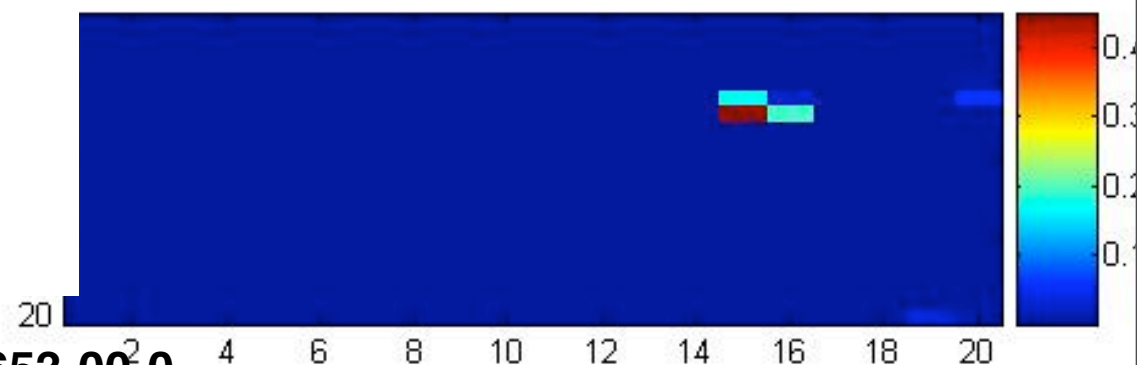


Location of minimum R

location of minimum: standardized



location of minimum: not standardized

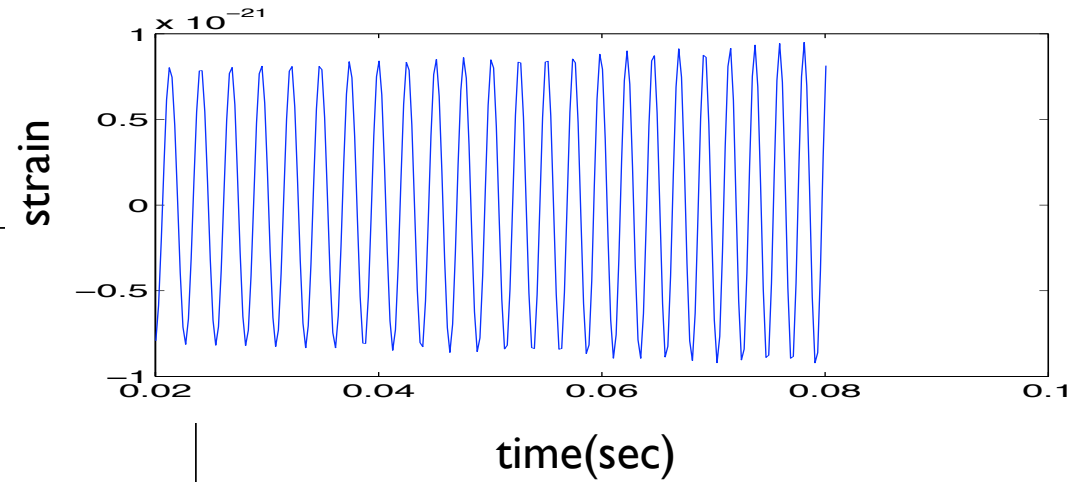
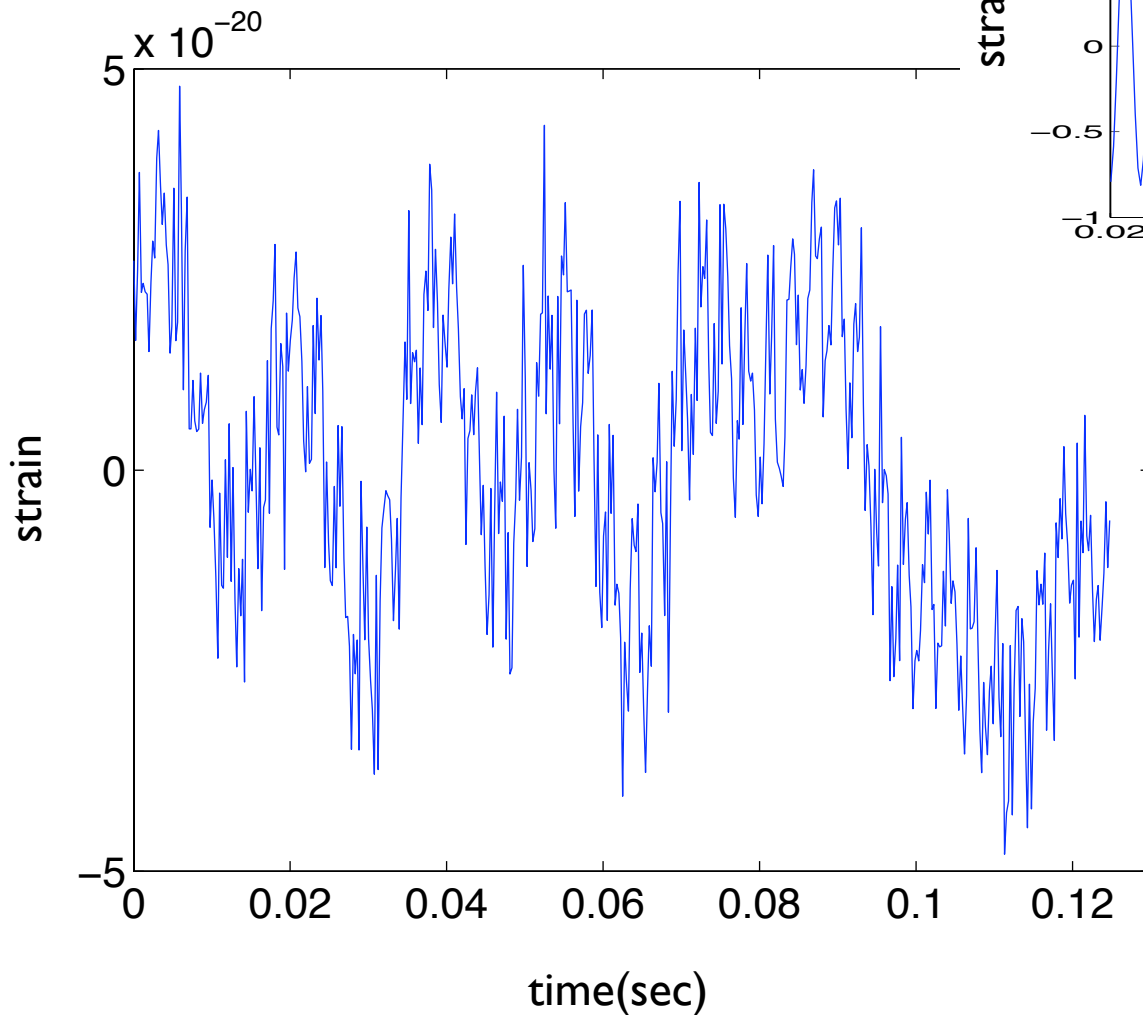




Reconstruction of Inspiral signal

Waveform

SNR:8.65



SNR
H1:4.34
H2:8.65
L1:8.6
GEO:1.83

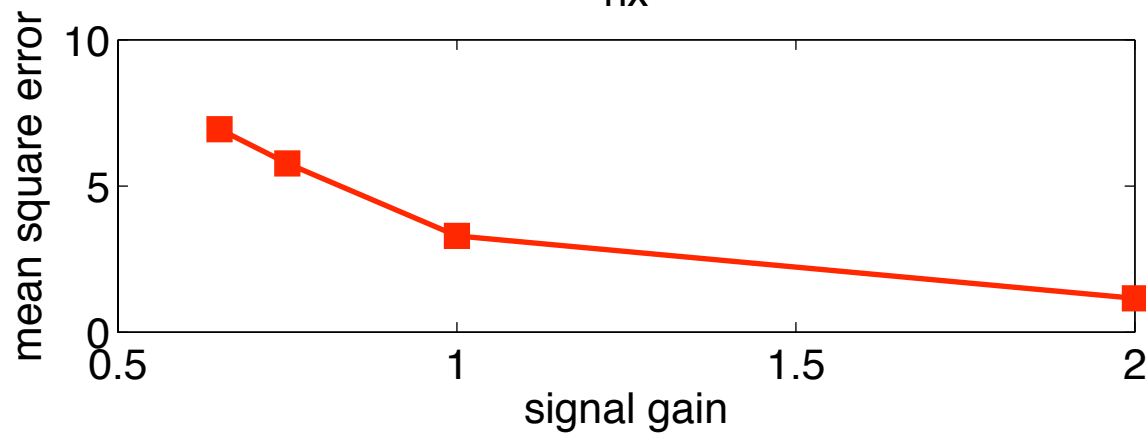
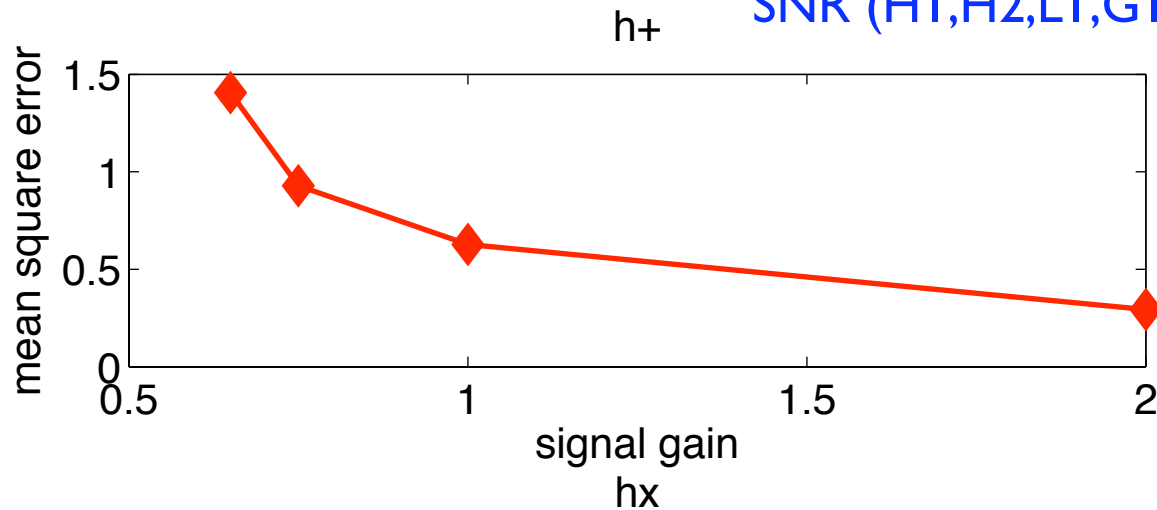


Accuracy of Waveform Estimation

Averaged mean square error normalized signal energy as a function of signal gain.

of trials at each SNR is 1000.

signal gain=1 corresponds to
SNR $(H_1, H_2, L_1, G_1) = (11.3, 11.3, 13.9, 9.3)$





Detection Efficiency

Data Conditioning

Event Selection

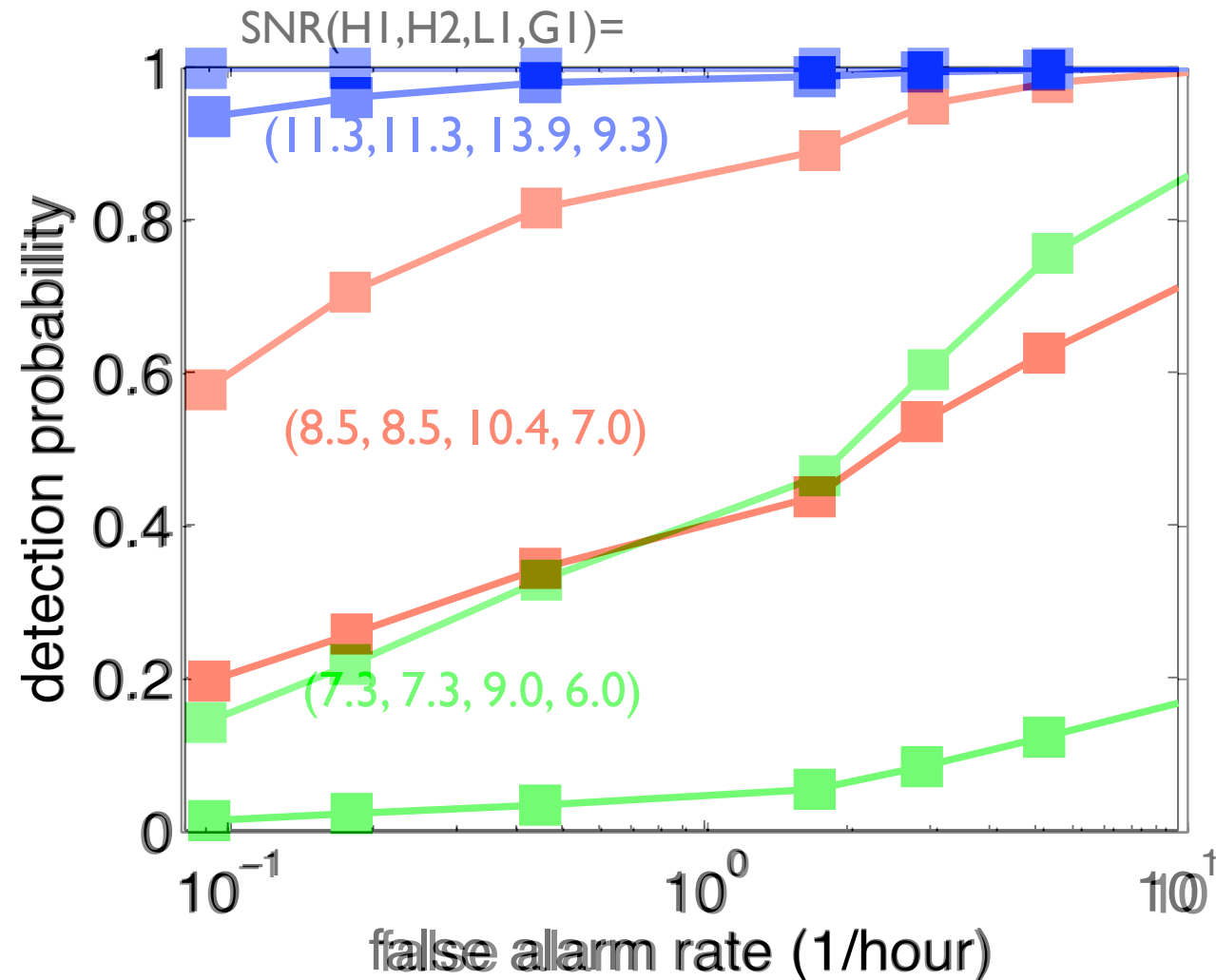
Detection Efficiency
Event Reconstruction

Detection probability vs
False alarm probability ??

↓
Receiver Operating
Characteristic Curve

To obtain ROC, the numerical simulation consists of 5000 trials in which the burst is in simulated LIGO noise, and 5000 trials in only noise.

Comparison of trigg and untrigg





Detection Efficiency

Data Conditioning

Event Selection

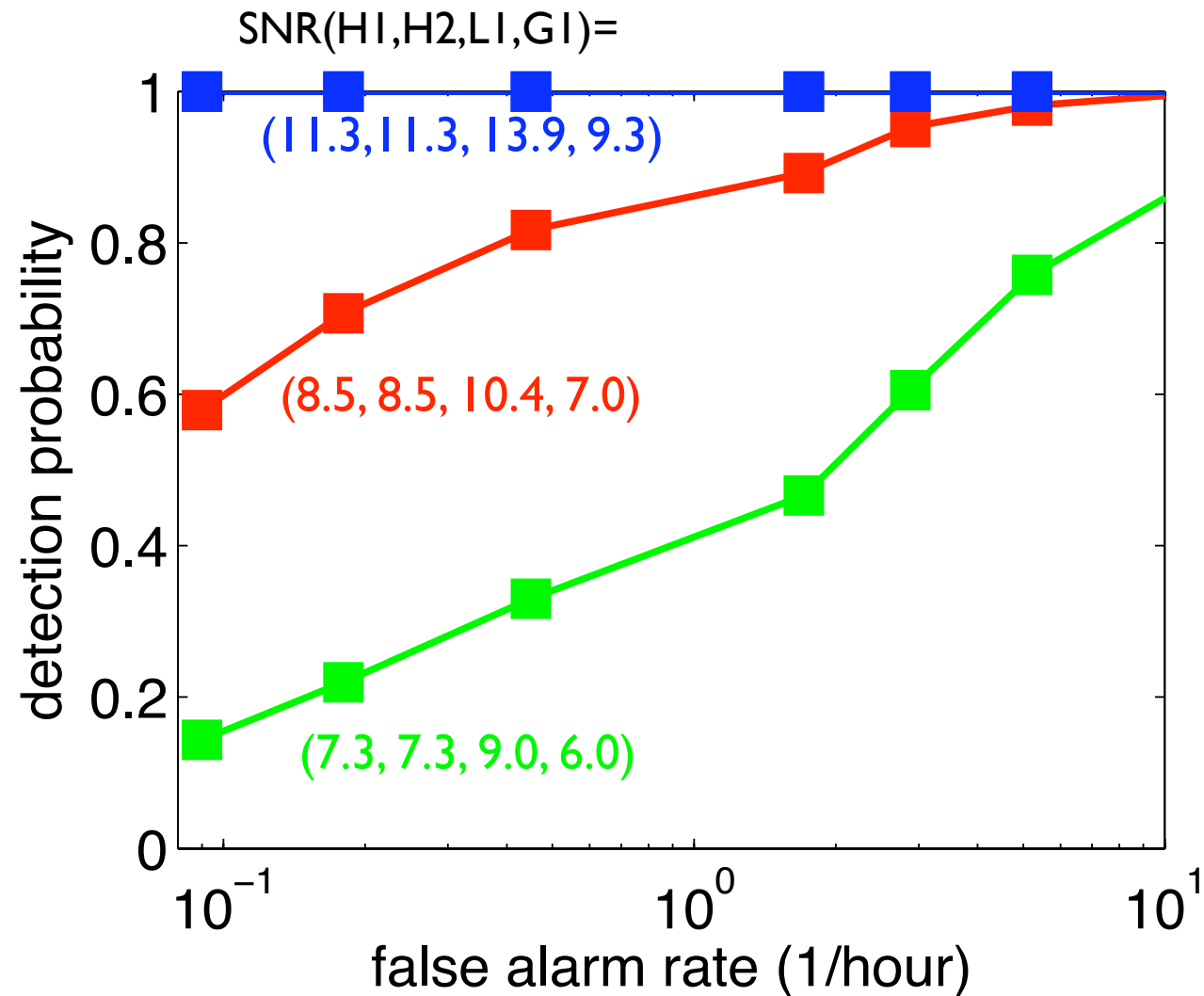
Detection Efficiency
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Detection probability vs
False alarm probability ??

Receiver Operating
Characteristic Curve

To obtain ROC, the numerical simulation consists of 5000 trials in which the burst is in simulated LIGO noise, and 5000 trials in only noise.

Untriggered Search





Regularized coherent network analysis pipeline

Data
Conditioning

Event Selection

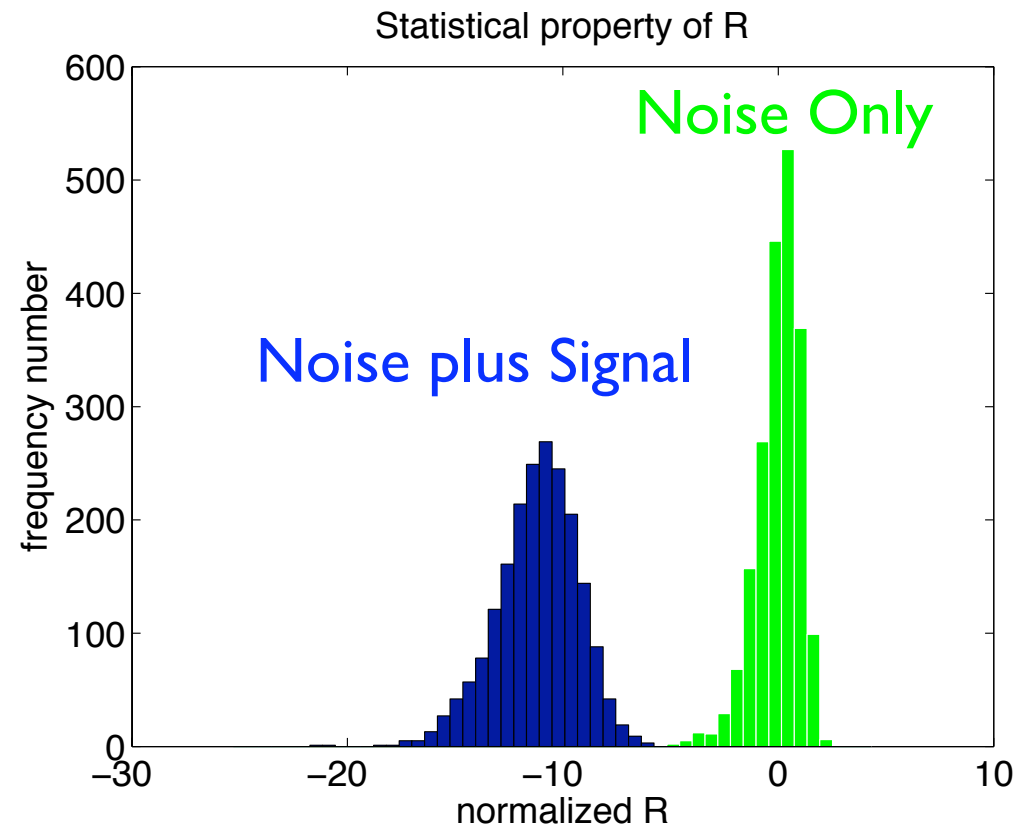
Detection Efficiency
Event Reconstruction

Statistical Property of R

SNRs of signal at each detectors are
(H1,H2,L1,G1)= (11.3,11.3, 13.9, 9.3)

Histograms are normalized by mean and variance of R of noise only data

For event selection,
Threshold of detection is decided to satisfy adequate false alarm rate and detection probability



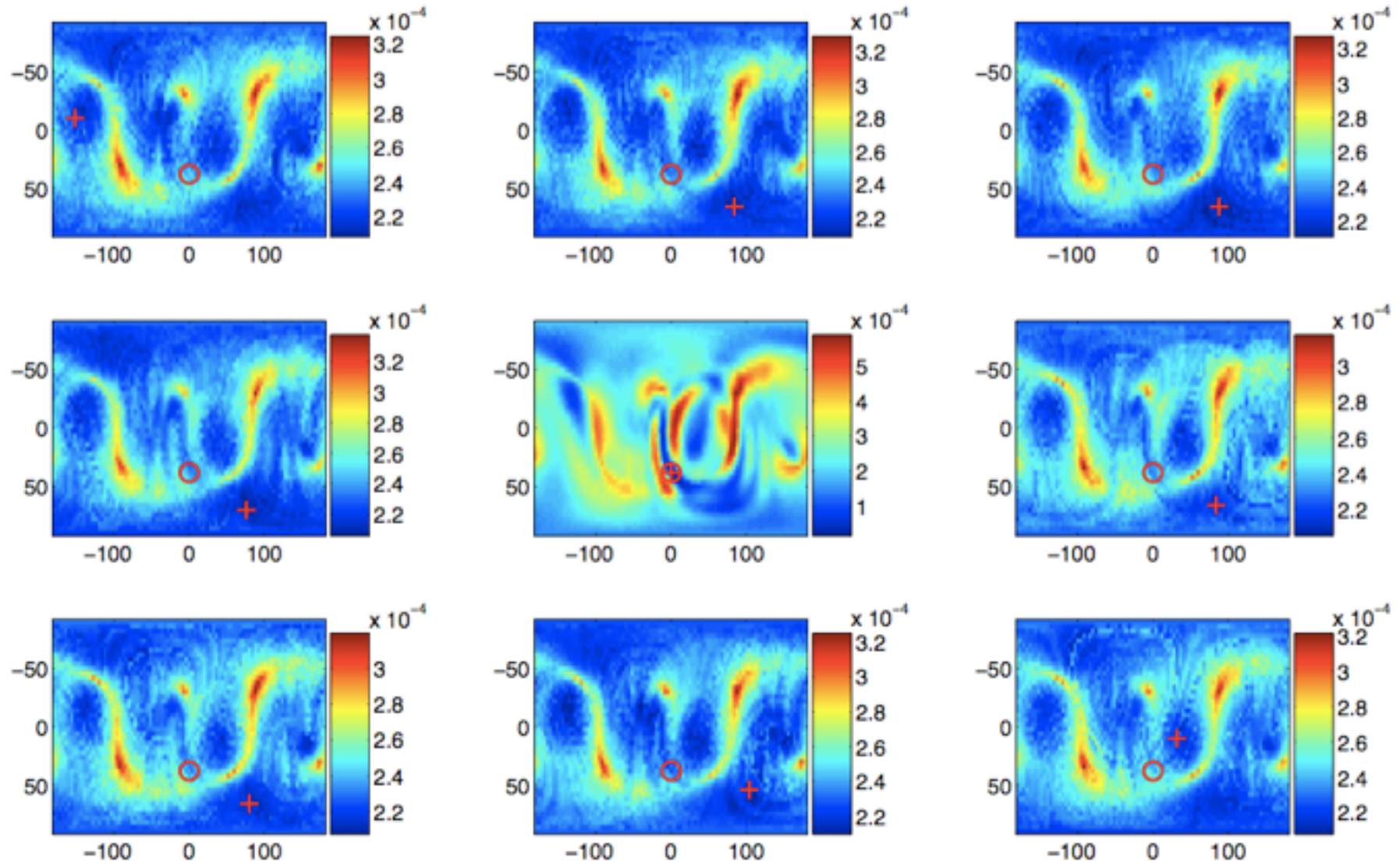
Regularized coherent network analysis pipeline

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Detection Efficiency
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Reconstructed sky maps around the true segment (Center)

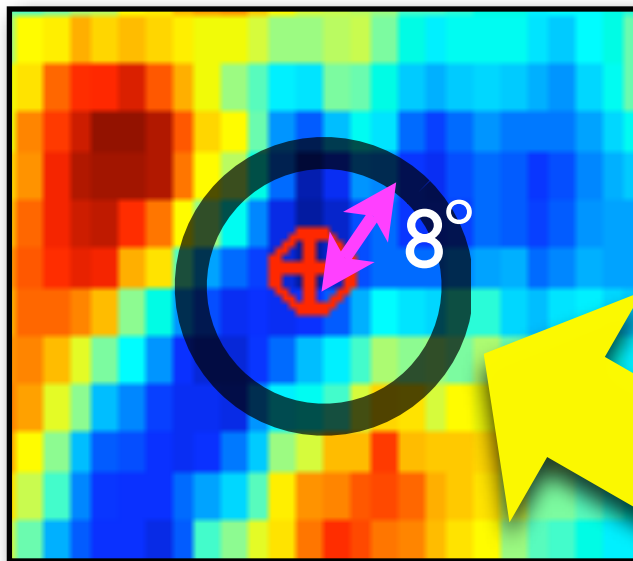


Efficiency of Source Location

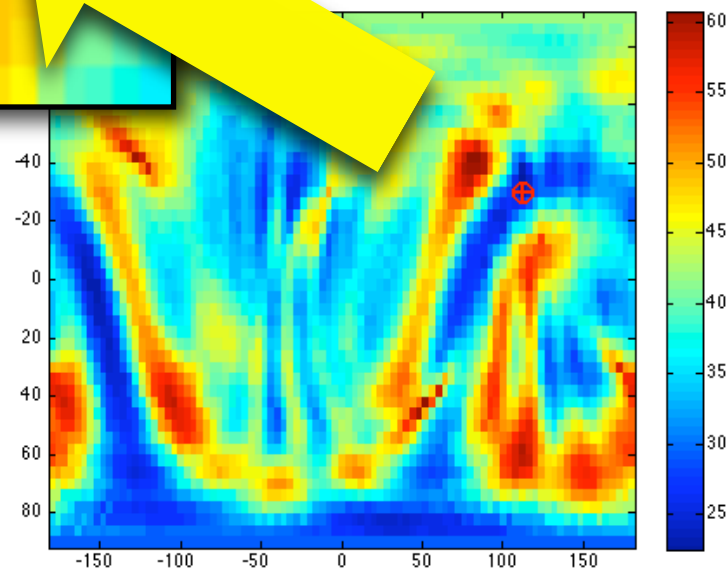
Data
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Detection Efficiency
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Fraction of signals detected
within 8 of their true
position ??



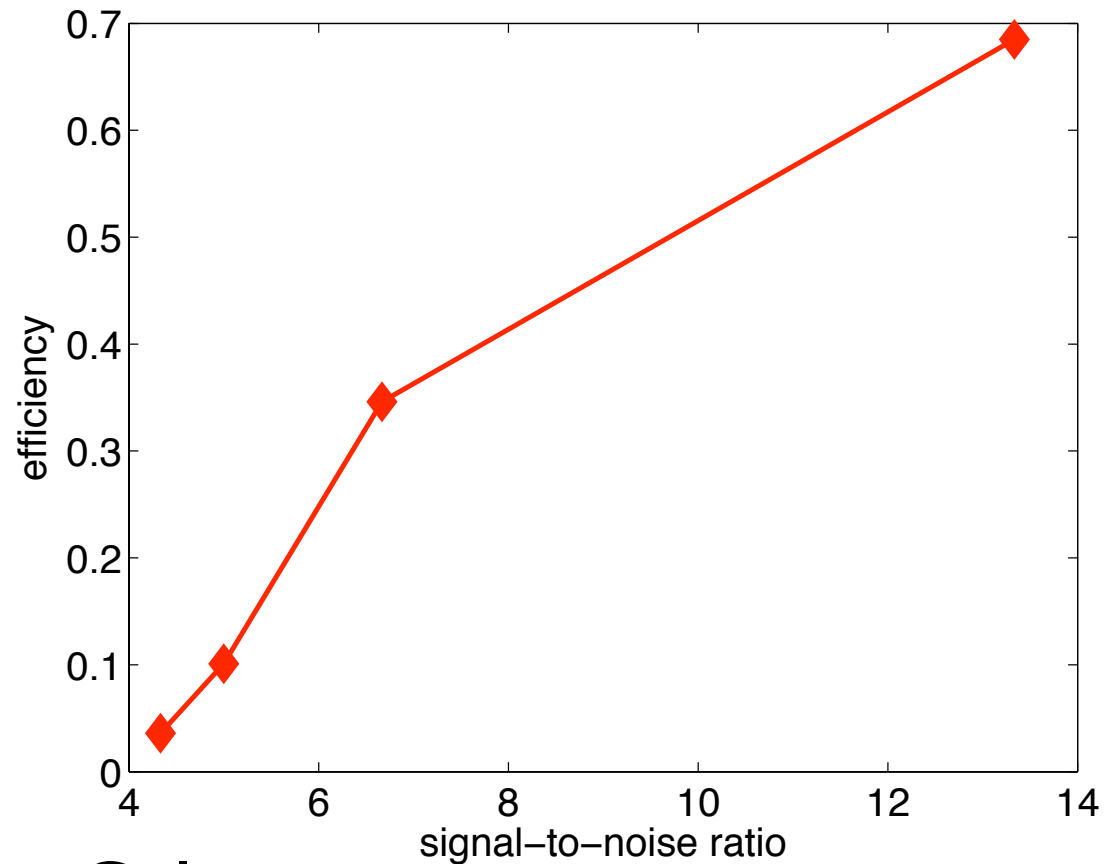
Efficiency of Source Location

Data
Conditioning

Event Selection

Detection Efficiency
Event Reconstruction

of trials at each SNR is
1000



Location of supernova from Galactic center
can be estimated within error of pm 8 at
efficiency 0.6 !

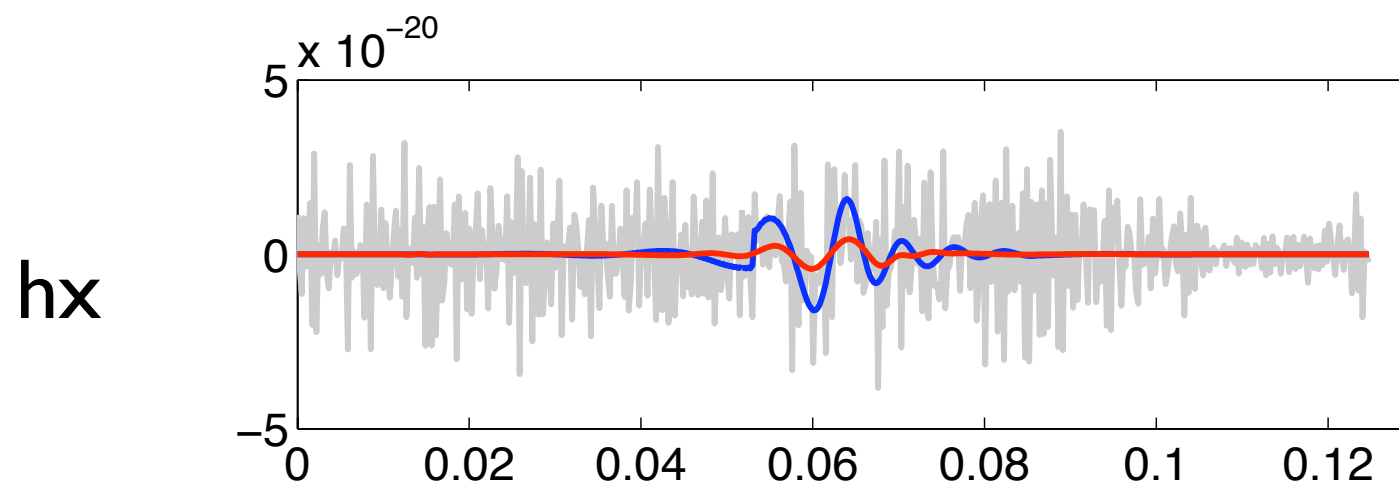
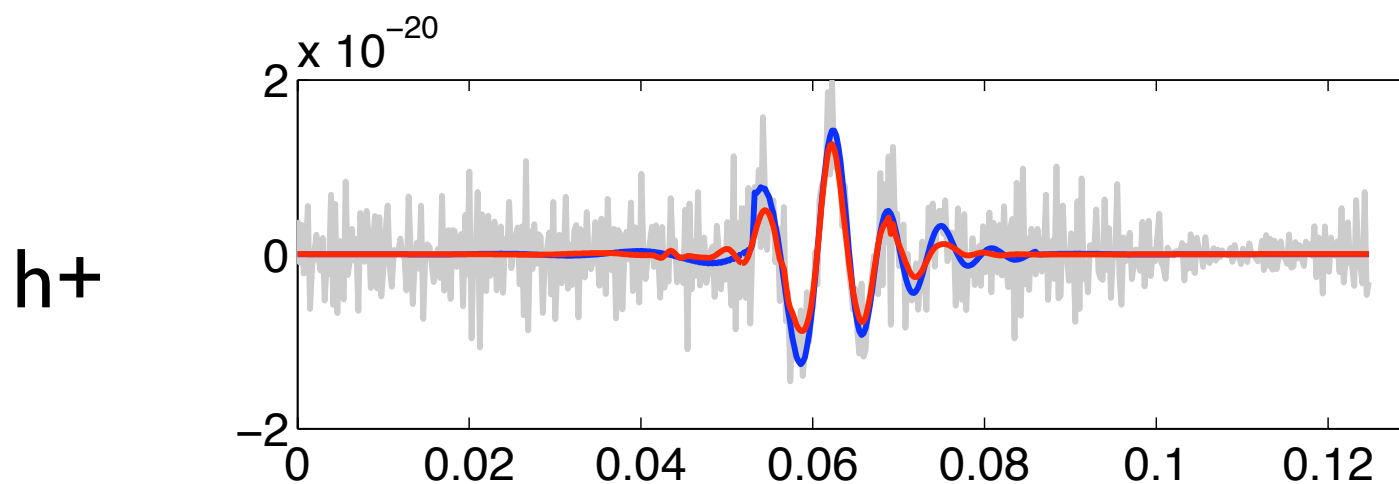
Accuracy of Waveform Estimation

Data
Conditioning

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Detection Efficiency
Event Reconstruction

In case of gain = 2



Regularized coherent network analysis pipeline

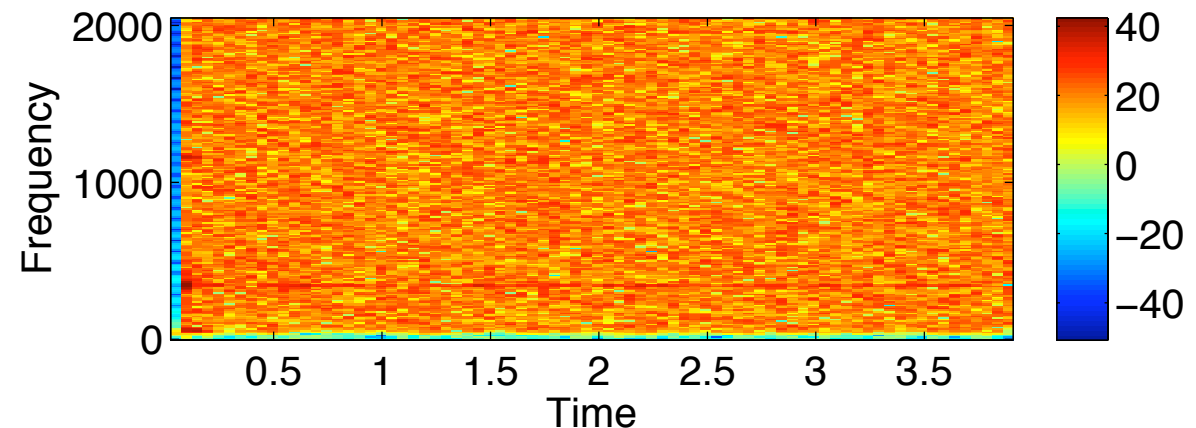
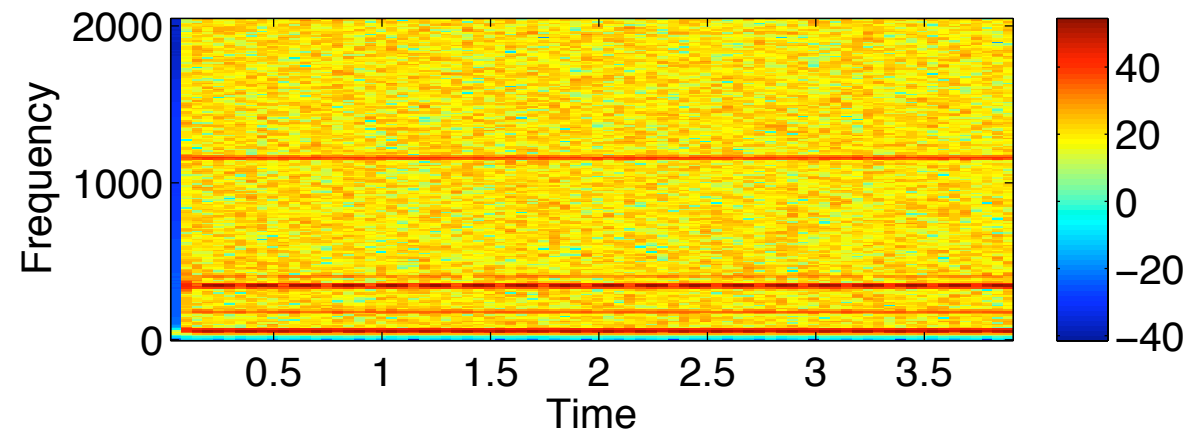
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Regularized coherent network analysis pipeline

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Event Reconstruction

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S. Mohanty CQG 19 (2002) I513

