Visualising gravitational-wave event candidates with the

Coherent Event Display

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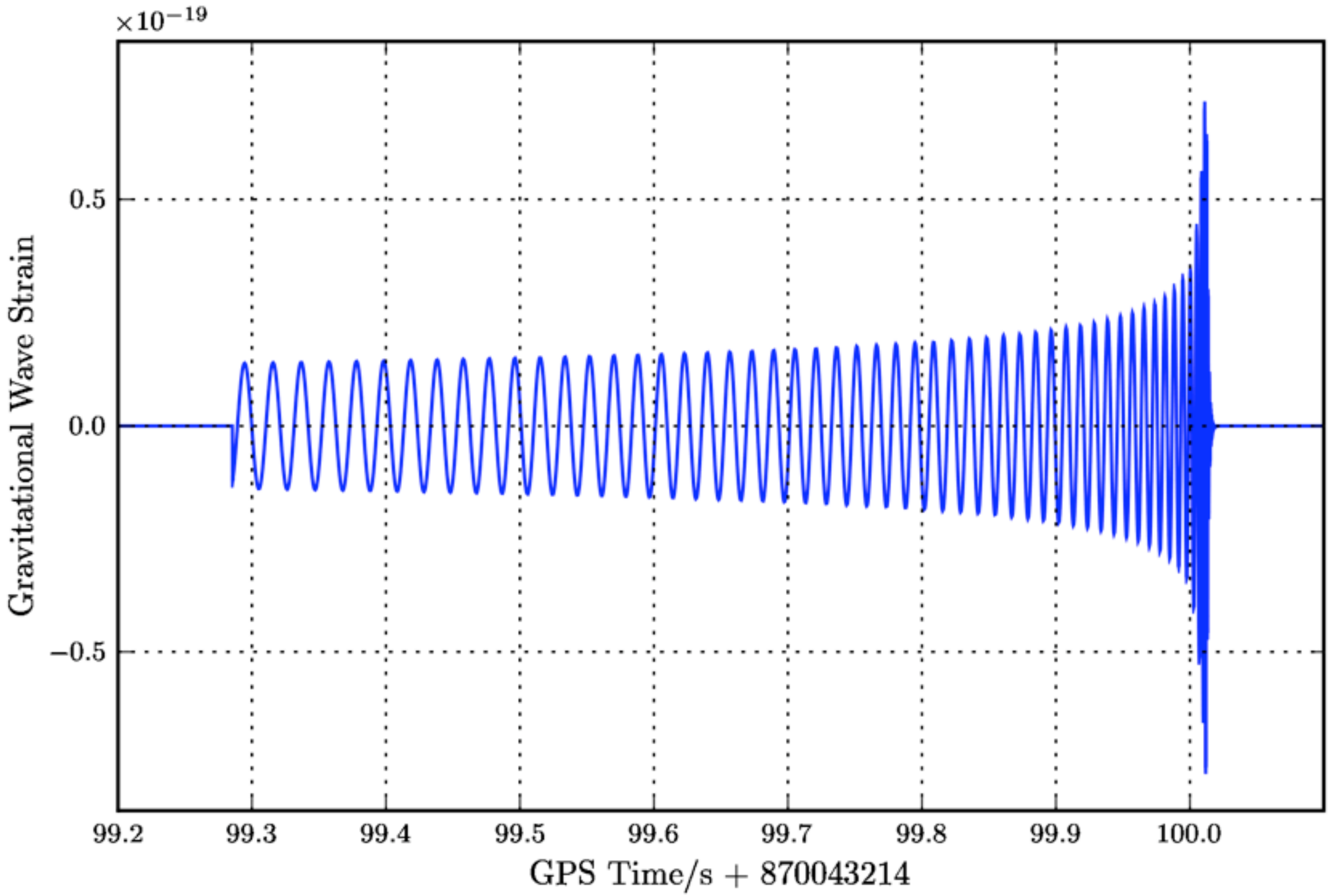
Abstract

A worldwide network of gravitational-wave detectors is now operating with unprecedented sensitivity. It is, therefore, becoming increasingly important to visualise event candidates from search pipelines using these detector networks. The Coherent Event Display has been developed with the goal of providing a simple and easy to use tool for performing follow up analyses of burst gravitational-wave event candidates. In this poster we present how the Coherent Event Display can be used for reconstructing gravitational-wave events, and present examples from the analysis of simulated signals using multiple detector networks.

Justification

- World-wide network of gravitational-wave detectors now online: LIGO (H1, H2 & L1), GEO, VIRGO
- Visualise event candidates from search pipelines running on data from these detector networks
- Targeted at transient gravitational-wave events, such as Supernovae, GRBs, BH Mergers, etc...
- Follow up tool for coherent analysis
- Produces a web page containing reconstructed event parameters, time-frequency maps, likelihood time-frequency maps, reconstructed detector responses, and skymaps of various coherent statistics
- Use the Coherent WaveBurst [1, 5] Algorithms

Example: Hybrid Numerical Relativity Binary Black Hole Merger Injection



Mass Ratio: 1.2

Total Mass: 18 $M_{\odot}$

Distance: 1 Mpc

Waveforms can then be scaled prior to being injected into the data to simulate different distances

See [2, 3, 4] for further details on these Hybrid NR Waveforms

Example: Hybrid NR Injection

Coherent WaveBurst Event Summary Page

- Job Parameter Table
- Event Parameter Table
- Network Data Matrix
- Time-Frequency Maps
- Likelihood Time-Frequency Map
- Reconstructed Detector Responses
- Skymaps
- Event Parameters (XML File)
- Configuration File
- Parameter File
- Documentation

NR Hybrid waveform scaled to a distance of 25 Mpc

Job Parameter Table

GPS Segment Time (s)	870043214
UTC Segment Time	Aug 01 2007 22:40:00 UTC

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Event Parameter Table

IFO	L1	H1	H2
Time Lag (s)	0.000	0.000	0.000
GPS Start Time (s)	870043313.906	870043313.906	870043313.906
GPS Stop Time (s)	870043314.016	870043314.016	870043314.016
GPS Central Time (s)	870043313.987	870043313.980	870043313.980
Central Time (s)	99.987	99.980	99.980
Event Duration (s)			0.109375
hrss	3.81e-22	2.57e-22	2.57e-22
Null	7.77e+00	9.41e+00	1.32e+01
Noise	2.97e-23	2.36e-23	6.45e-23
SNR	1.81e+02	1.34e+02	3.61e+01
Rank SNR	1.02e+02	7.98e+01	2.72e+01
Rank Significance	4.67e+01	3.56e+01	9.52e+00
Gaussian Significance	7.75e+01	5.47e+01	9.51e+00
Geometric Significance			3.22e+00
Likelihood			3.21e+02
Phi (degrees)			154.50
Theta (degrees)			109.50
Size			10
flow (Hz)			64.00
fhigh (Hz)			256.00
Central Frequency (Hz)			125.12
Bandwidth (Hz)			192.00
Resolution (Hz)			128
F+	5.32e-01	-1.18e-01	-1.18e-01
Fx	-3.02e-01	4.05e-01	4.05e-01
Normalisation Factor			1.00e+00
Pearson's Correlation Coefficient			7.91e-01
Network Correlation Coefficient			8.51e-01
Correlated Energy			1.73e+02
Effective Correlated Energy			1.50e+02
Energy Disbalance	3.88e+00	-6.90e+00	3.02e+00

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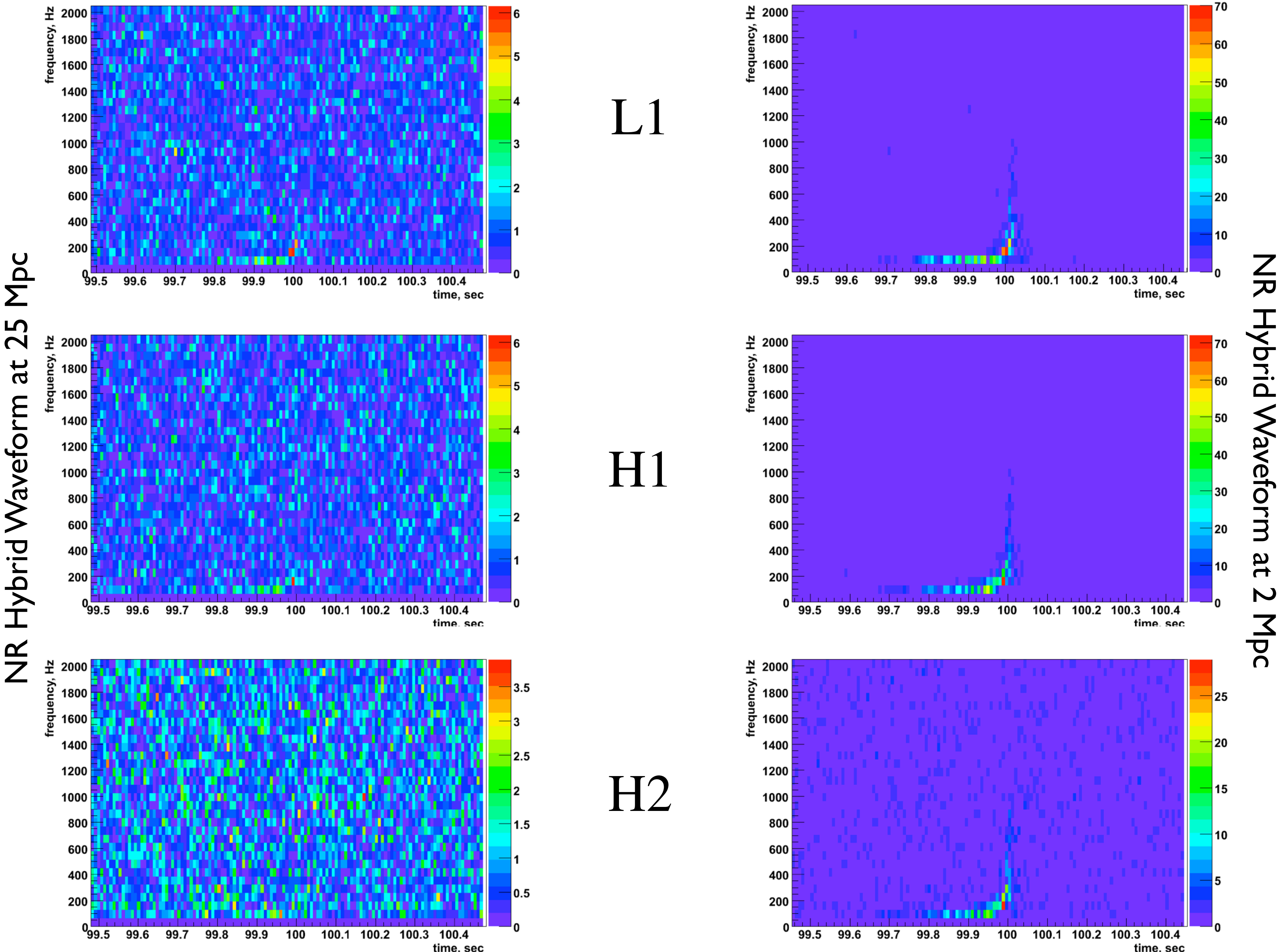
Time-Frequency Maps

The Coherent WaveBurst algorithms use wavelet transformations to produce data in the time-frequency domain. These are referred to as time-frequency maps and they show the wavelet coefficients normalised by the noise RMS as a function of time and frequency. They are then combined in order to produce a coherent statistic, the likelihood, which is then used for event selection.



NR Hybrid Waveform at 25 Mpc
NR Hybrid Waveform at 2 Mpc
L1
H1
H2
frequency, Hz
time, sec

Likelihood

- Likelihood for Gaussian noise is given by

$$\mathcal{L} = \sum_{i=1}^{N} \sum_{k=1}^{K} \frac{1}{2\sigma_k^2} \left[x_k^2[i] - \left(x_k[i] - \xi_k[i] \right)^2 \right]$$

- Detector response

$$\xi_k[i] = F_{+k} h_+[i] + F_{\times k} h_\times[i]$$

- The likelihood is also a measure of the detected energy

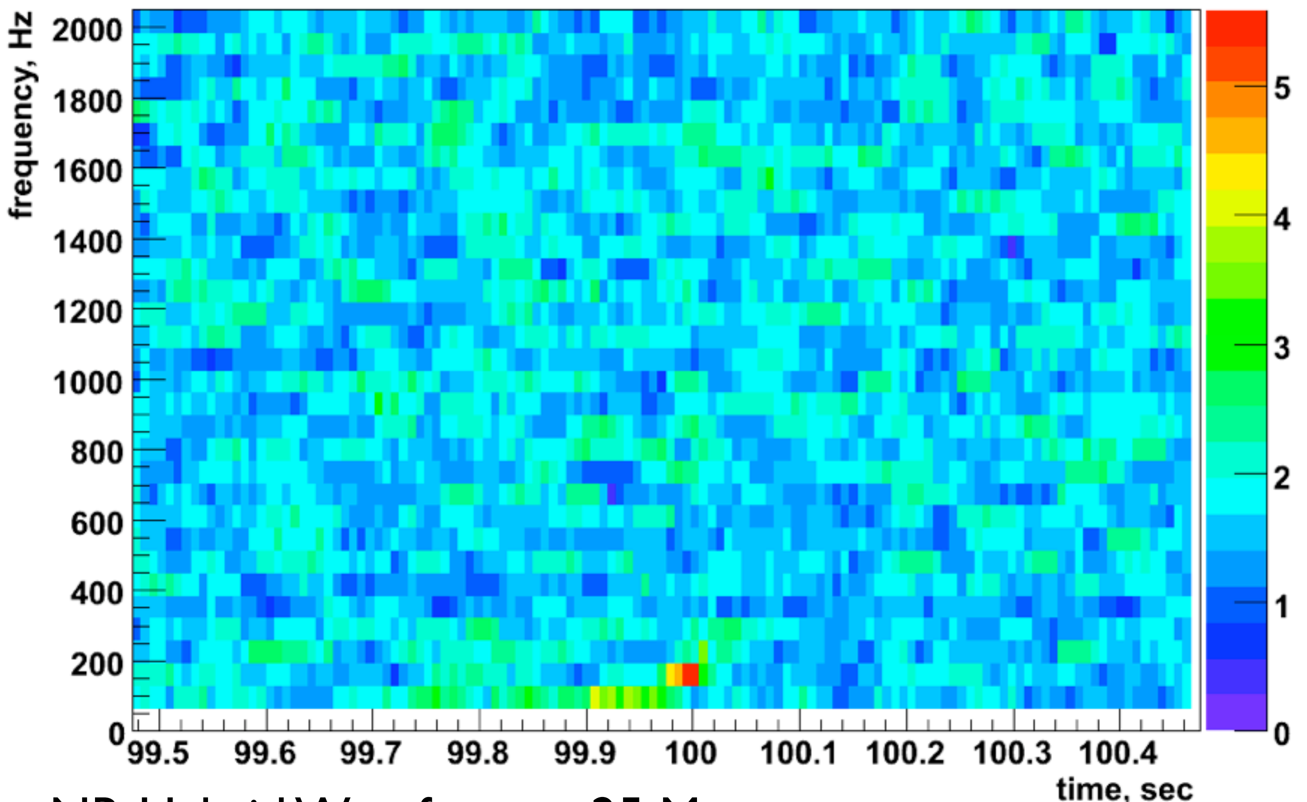
$$2\mathcal{L} = E - \mathrm{Null}$$

detected (signal) energy

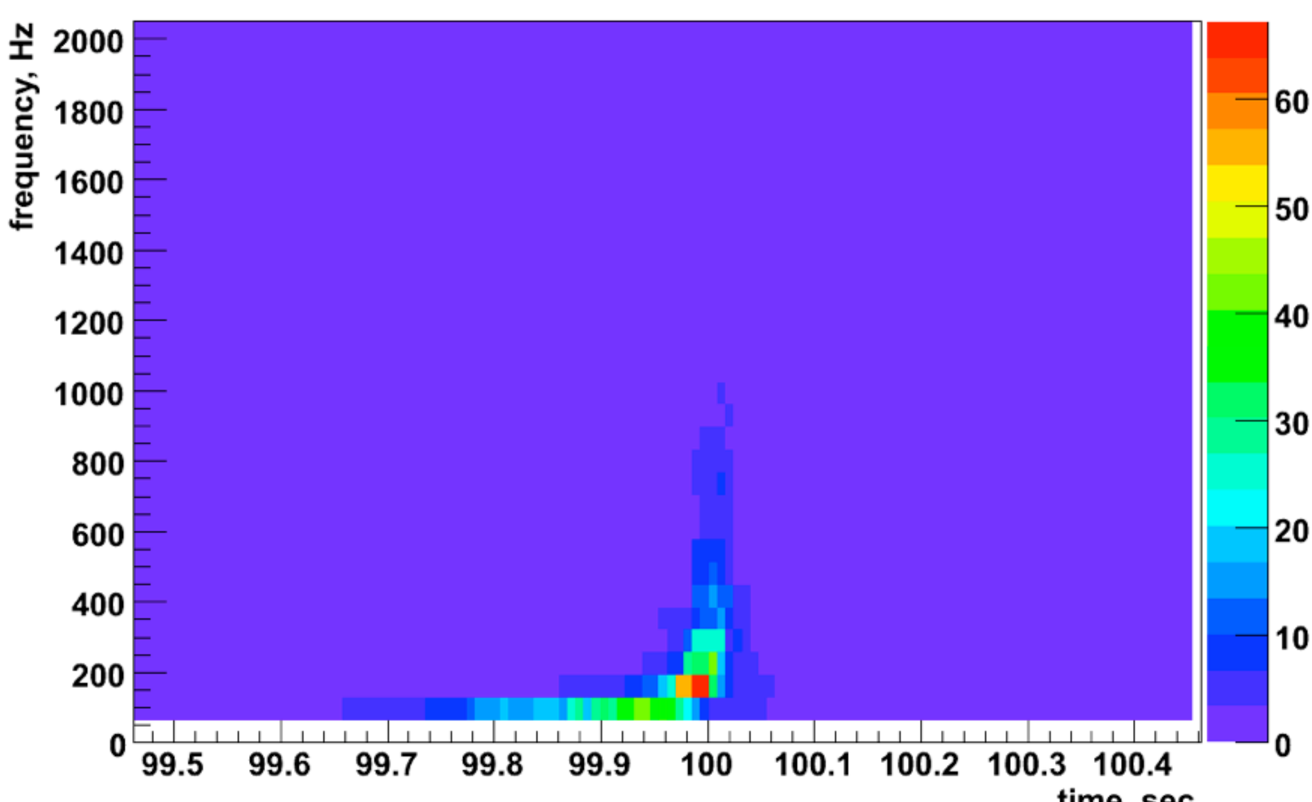
total energy

noise (null) energy

Likelihood Time-Frequency Map



NR Hybrid Waveform at 25 Mpc

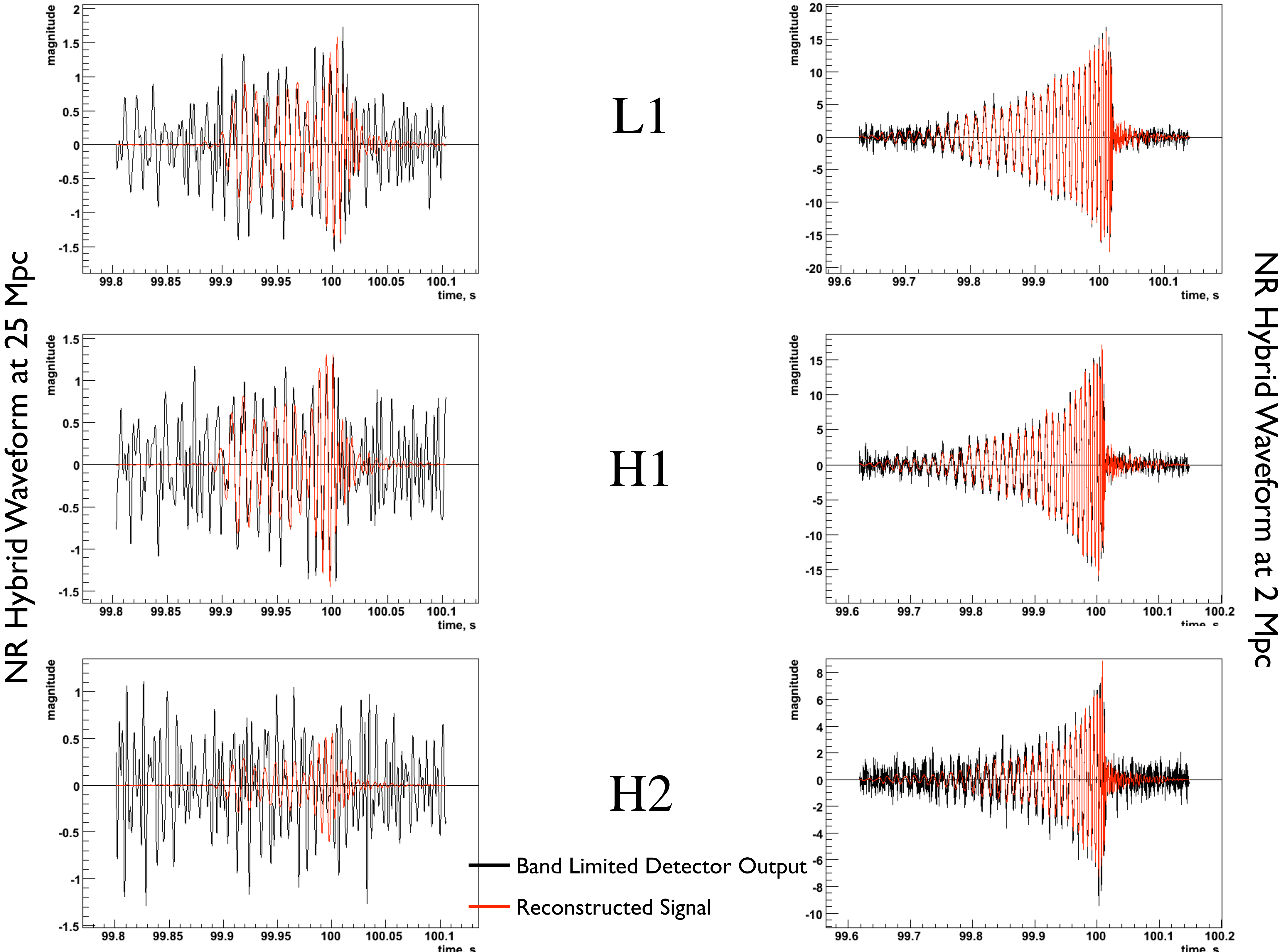


NR Hybrid Waveform at 2 Mpc

Reconstructed Detector Responses

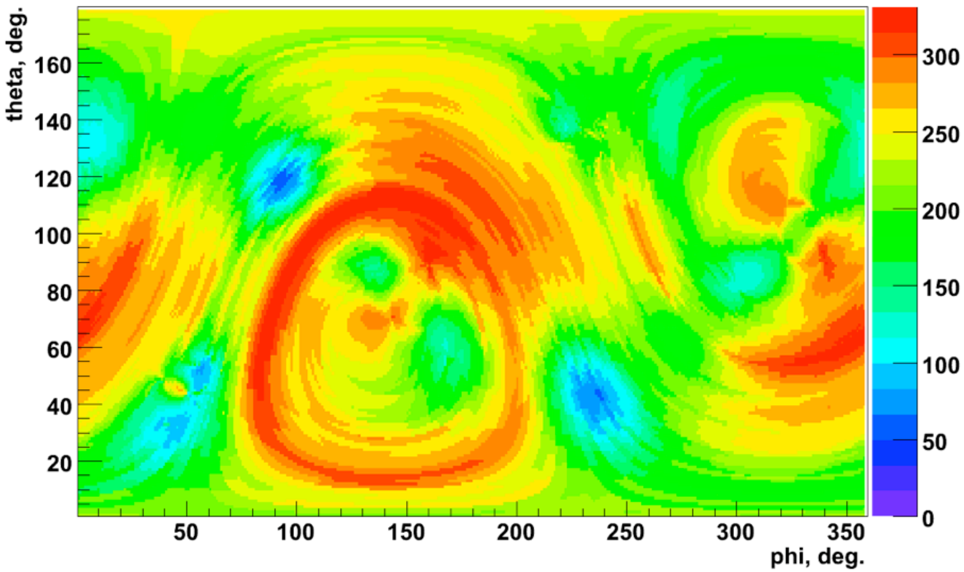
The Coherent WaveBurst algorithms can produce reconstructed detector responses and gravitational-wave waveforms from the likelihood functional. These reconstructed waveforms and detector responses can then, potentially, be to source models for extraction of source parameters, if such models are available.

SkyMaps

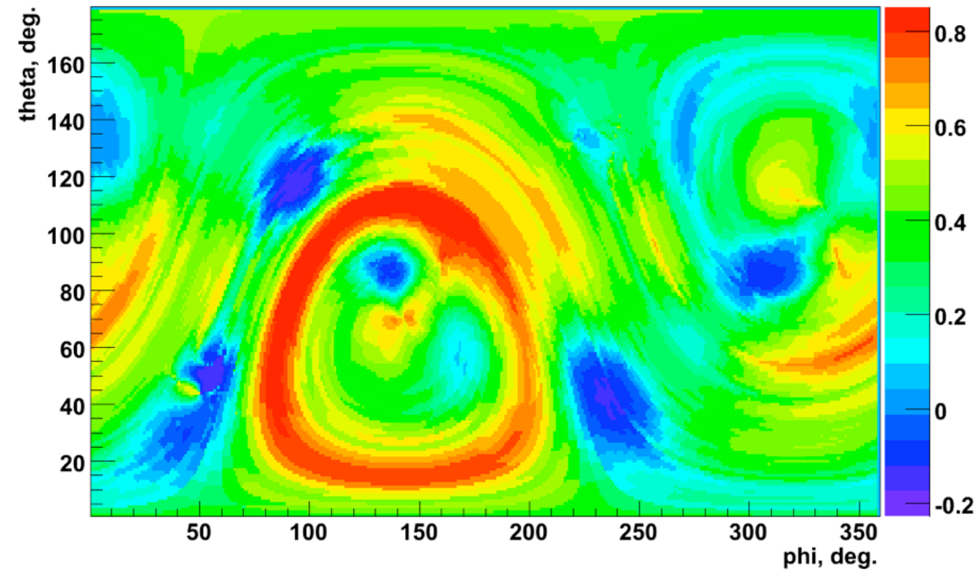


NR Hybrid Waveform at 25 Mpc
NR Hybrid Waveform at 2 Mpc
L1
H1
H2
Band Limited Detector Output
Reconstructed Signal
magnitude
time, s

Likelihood

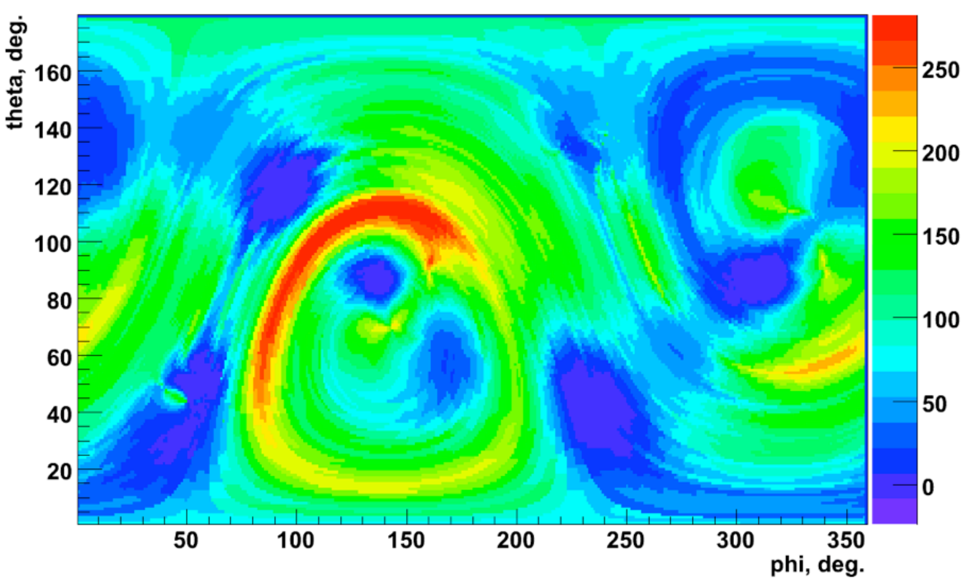


Correlation Statistic

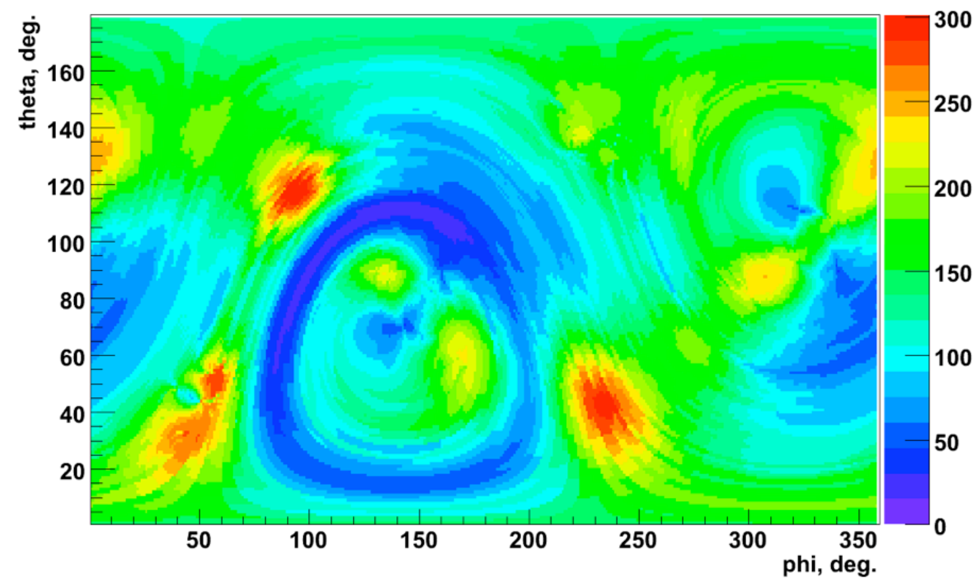


NR Hybrid Waveform at 25 Mpc

Sky Statistic



Null Energy



Correlation Statistic

- The detected energy is the sum incoherent and coherent energy

incoherent coherent

$$2\mathcal{L} = \sum_{mn} C_{mn} \langle x_m x_n \rangle = E_{m=n} + E_{m \neq n}$$

- The incoherent and coherent energies are then used to form the network correlation, which is used for post-production selection of triggers

$$C_{\rm net} = \frac{E_{m \neq n}}{\text{Null} + E_{m \neq n}}$$

Alignment & Sensitivity

- Two important network parameters that measure the alignment and sensitivity of the network to the two components of the incident gravitational-wave

$$\mathrm{SNR}_{\mathrm{total}} = 2g\left(\left\langle h_1^2\right\rangle + \epsilon\left\langle h_2^2\right\rangle\right)$$

network sensitivity

network alignment

Sensitivity to plus polarisation

$$g = g_r + |g_c|$$

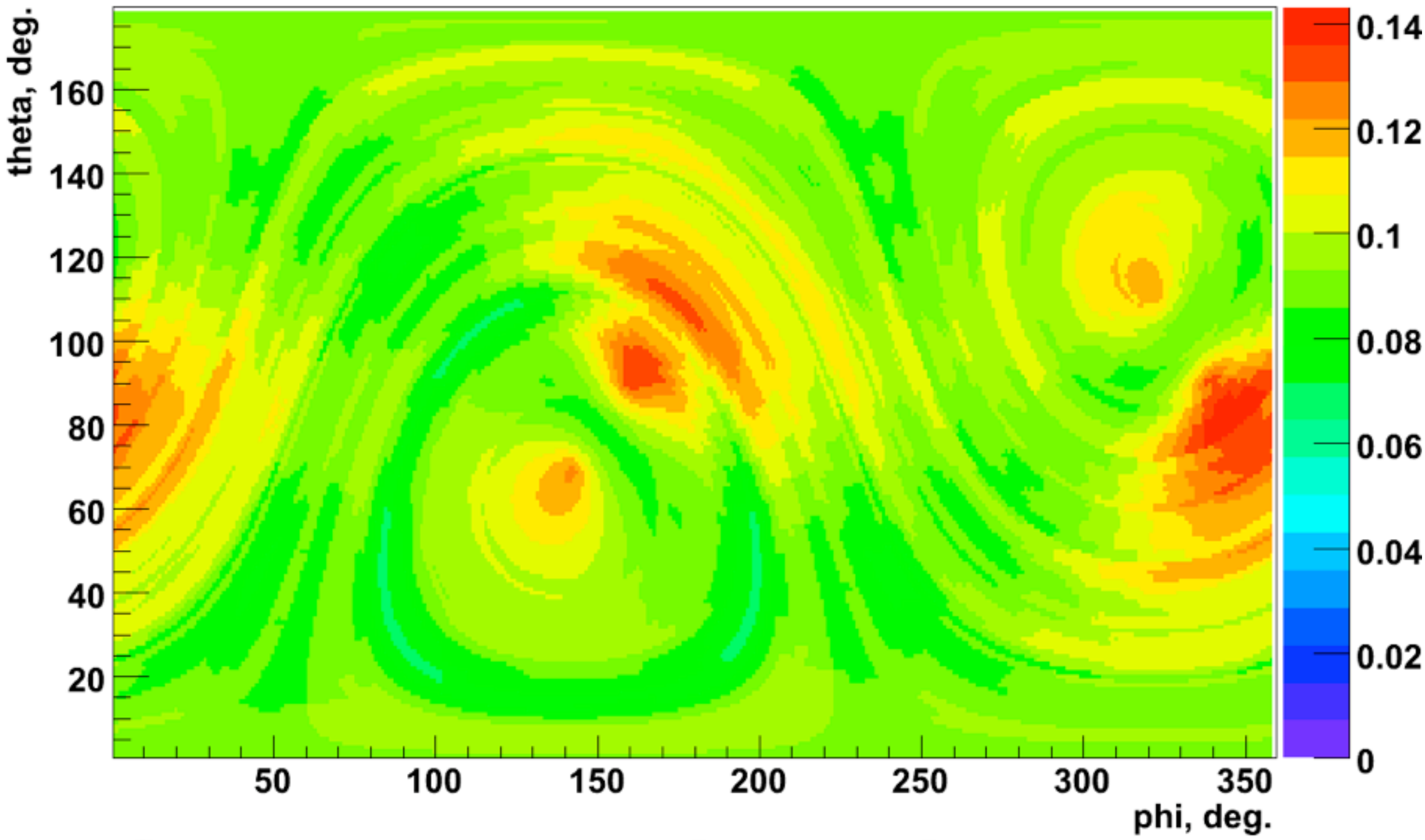
$$\epsilon = \frac{g_r - |g_c|}{g_r + |g_c|}$$

Sensitivity to cross polarisation

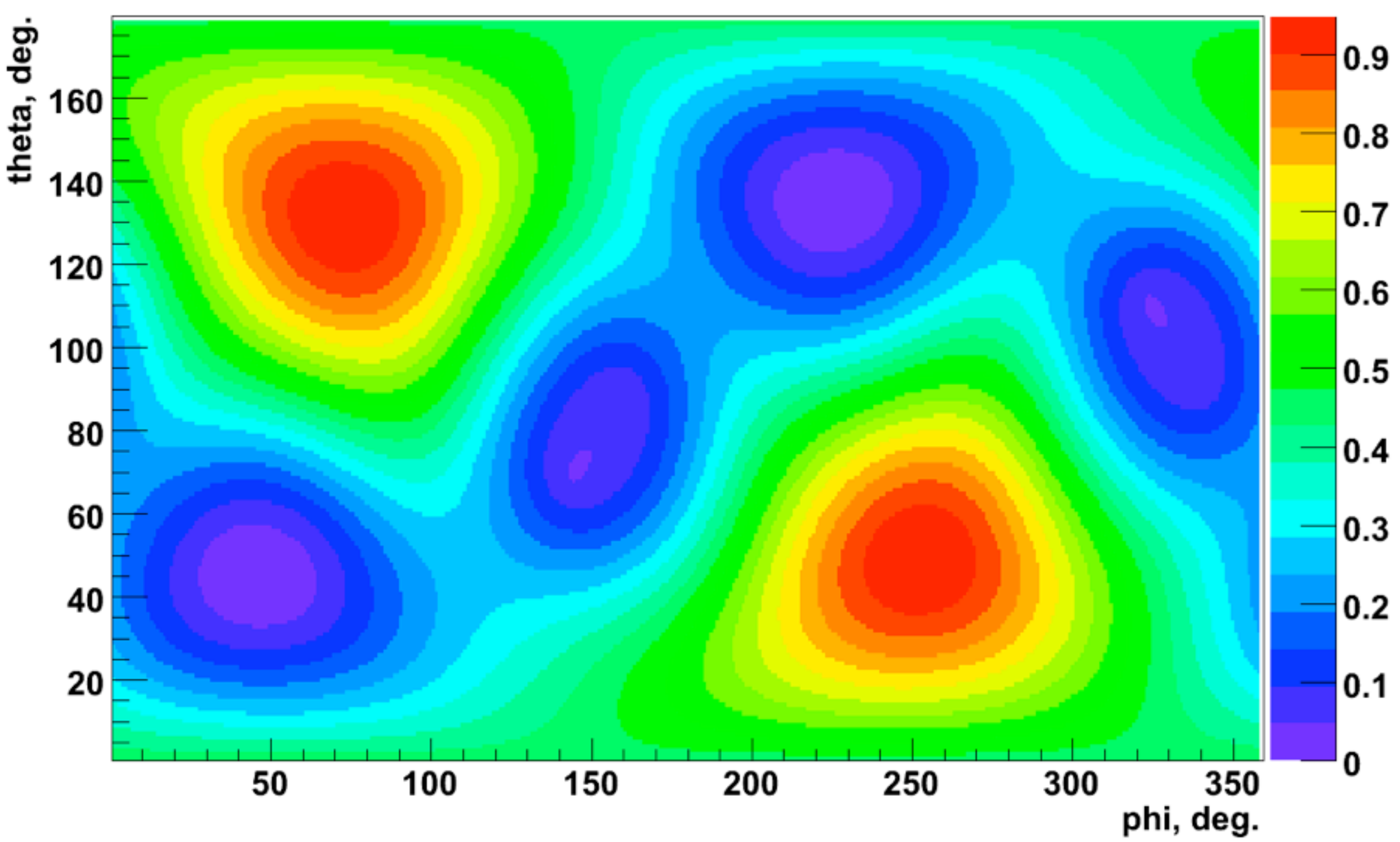
- Network antenna patterns

$$g_r = \sum_{k=1}^{K} \frac{F_{+k}^2 + F_{\times k}^2}{4\sigma_k^2} \qquad g_c = \sum_{k=1}^{K} \frac{\left[F_{+k} + iF_{\times k}\right]^2}{4\sigma_k^2}$$

Sensitivity to cross polarisation



Sensitivity to plus polarisation



NR Hybrid Waveform at 25 Mpc

Conclusions

- Coherent tool for gravitational-wave event candidate visualisation and follow up analysis
- Based upon the Coherent WaveBurst algorithms
- Currently supports all 2, 3, 4, and 5 detector network combinations of LIGO, GEO, and Virgo

References

1. Constraint likelihood analysis for a network of gravitational wave detectors, S. Klimenko et al, PRD 72: 122002, 2005

2. Phenomenological template family for black-hole coalescence waveforms, P. Ajith et al, CQG 24:S689, 2007

3. Data formats for numerical relativity waves, D. Brown et al, arXiv:0709.0093, 2007

4. Incorporating Numerical Relativity Waveforms into Gravitational Wave Data Analysis, Lucía Santamaría et al, GWDAW-12

5. Coherent burst searches for GW from compact binary objects, S. Klimenko et al, GWDAW-12