A Coherent Network Burst Analysis

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on behalf of

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Outline

- Basic concept of coherent burst searches
- Null streams, time delays and signal reconstruction
- Features of a sky map of null stream power
- Pros and cons relative to existing methods
- Anticipated real world problems

LIGO

Concept

- Networks of 3+ distinct observatories contain redundant GW information
  - » **Can exactly remove GWB strain** by making an appropriate linear combination of time-shifted detector outputs
  - » Uncorrelated noise (e.g., glitches) cannot be so removed.

- Suggested references:
  - » Gursel & Tinto, PRD **40** 3884 (1989).
  - » Flanagan and Hughes, PRD **57** 4566 (1998).
  - » Anderson, Brady, Creighton, and Flanagan, PRD **63** 042003 (2001).

Null Streams

- Output of N white-noise detectors: **d = F h + n**, where

$$\mathbf{d} = \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_N \end{bmatrix}, \quad \mathbf{F} = \begin{bmatrix} F_1^+ & F_1^\times \\ F_2^+ & F_2^\times \\ \vdots & \vdots \\ F_N^+ & F_N^\times \end{bmatrix}, \quad \mathbf{h} = \begin{bmatrix} h^+ \\ h^\times \end{bmatrix} \text{ and } \mathbf{n} = \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

  - » Antenna responses F vary with sky direction
- There are N-2 independent linear combinations of the d_j which contain no GW signal.

$$\mathrm{I}_i = \sum_j \mathrm{K}_{ij} \mathrm{d}_j = \sum_j \mathrm{K}_{ij} \mathrm{n}_j , \quad i \in \{1,\ldots,N-2\}$$

$$\text{where:} \quad \sum_j \mathrm{K}_{ij} \mathrm{F}_j^+ = 0, \quad \sum_j \mathrm{K}_{ij} \mathrm{F}_j^\times = 0,$$

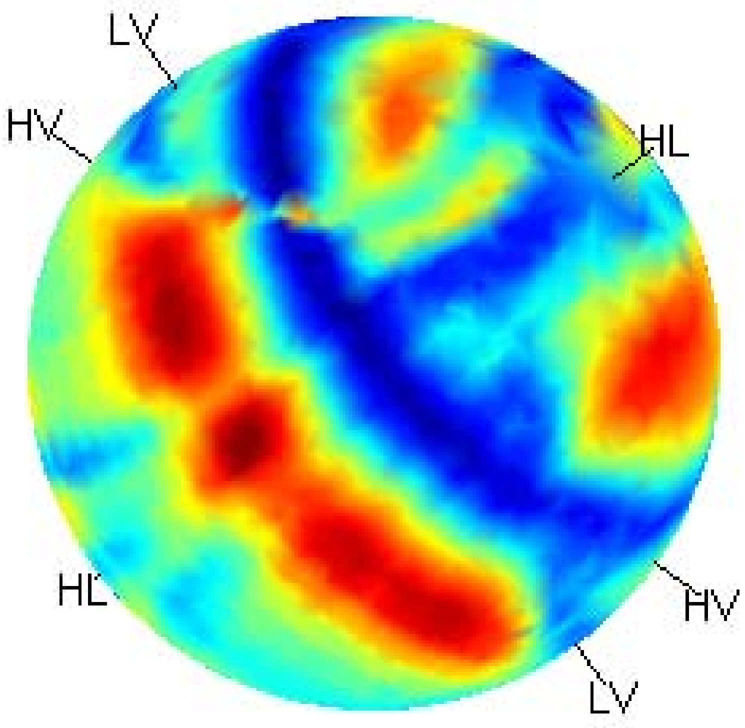
- Power in these null streams is χ^2 distributed (N-2)*length(d) degrees of freedom *if we pick the correct sky position*.

Sky Map of Null Power

- If a signal is present, only the null streams for the correct direction on the sky cancel out the excess power
  - » If noise glitch, then *no* sky position cancels excess power.
- The correct location is a global minimum (in high SNR limit)
- DFM supernova example

  blue: low power (signal cancelled)

  red: high power (signal not cancelled)



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- The correct location is a global minimum (in high SNR limit)
  - » Rings are due to correlations in pairs of detectors

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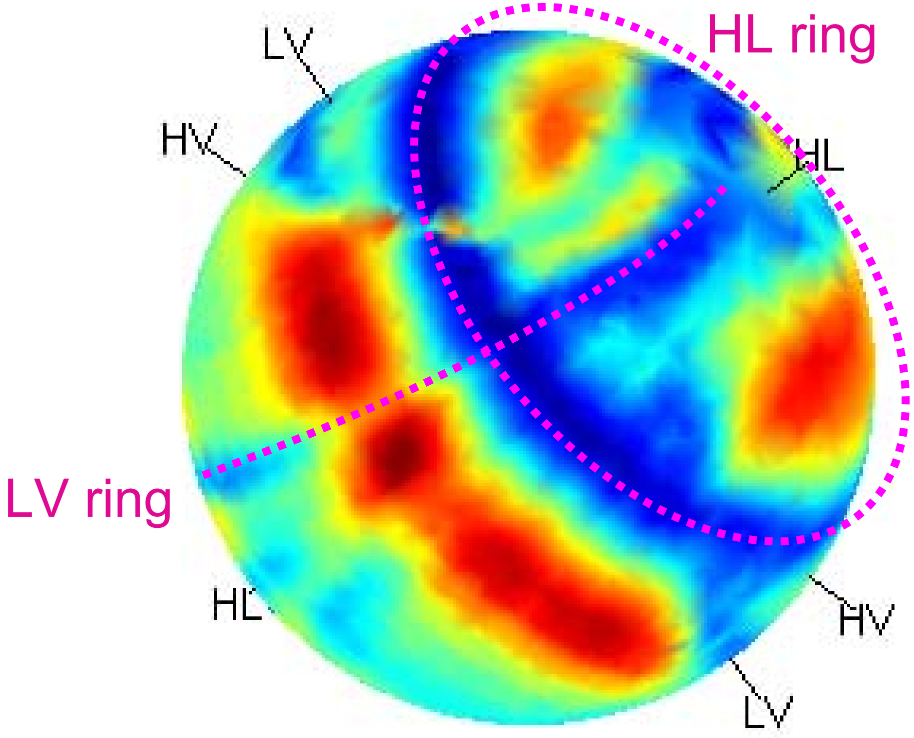


Significance

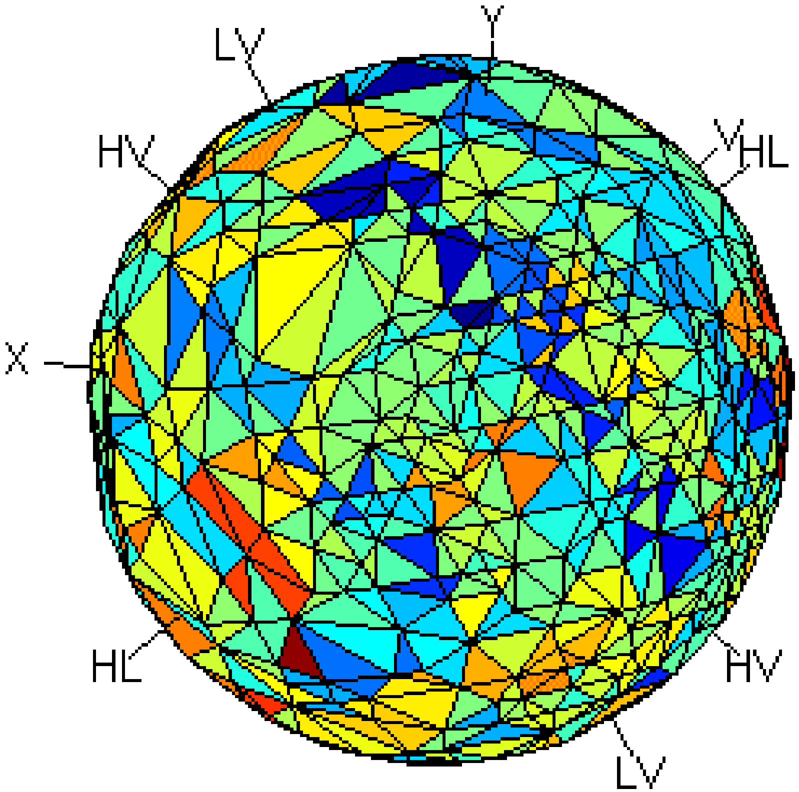
- Excess power in the null stream
  - » Something in the data that is neither
    - – White noise
    - – A gravitational wave signal from that direction
  - » If excess power for all directions at some time, a time-coincident glitch has been found and can be considered a veto for other analyses
- No excess power in the null stream
  - » Data could be
    - – White noise
    - – A gravitational wave signal from that direction
  - » There are locations on the sky where glitches in any one or two detectors do not produce any null power.
    - – Developing thresholding technique to compute significance as a function of sky position.

Time Delays

- Null stream coefficients K_{ij} are only valid for one particular direction
  - » Direction Ω in Earth-based coordinates
- Data from detector at a location x must be delayed by

$$\Delta t = -c^{-1} x \cdot \Omega$$

- Directions for an all-sky search chosen to not exceed allowed mismatch at maximum frequency of analysis
  - » Equivalent to mismatch in Δt
  - » Currently done by decimation
  - » Density varies with detectors
  - » >10^3 directions for <1ms error



Signal Recovery

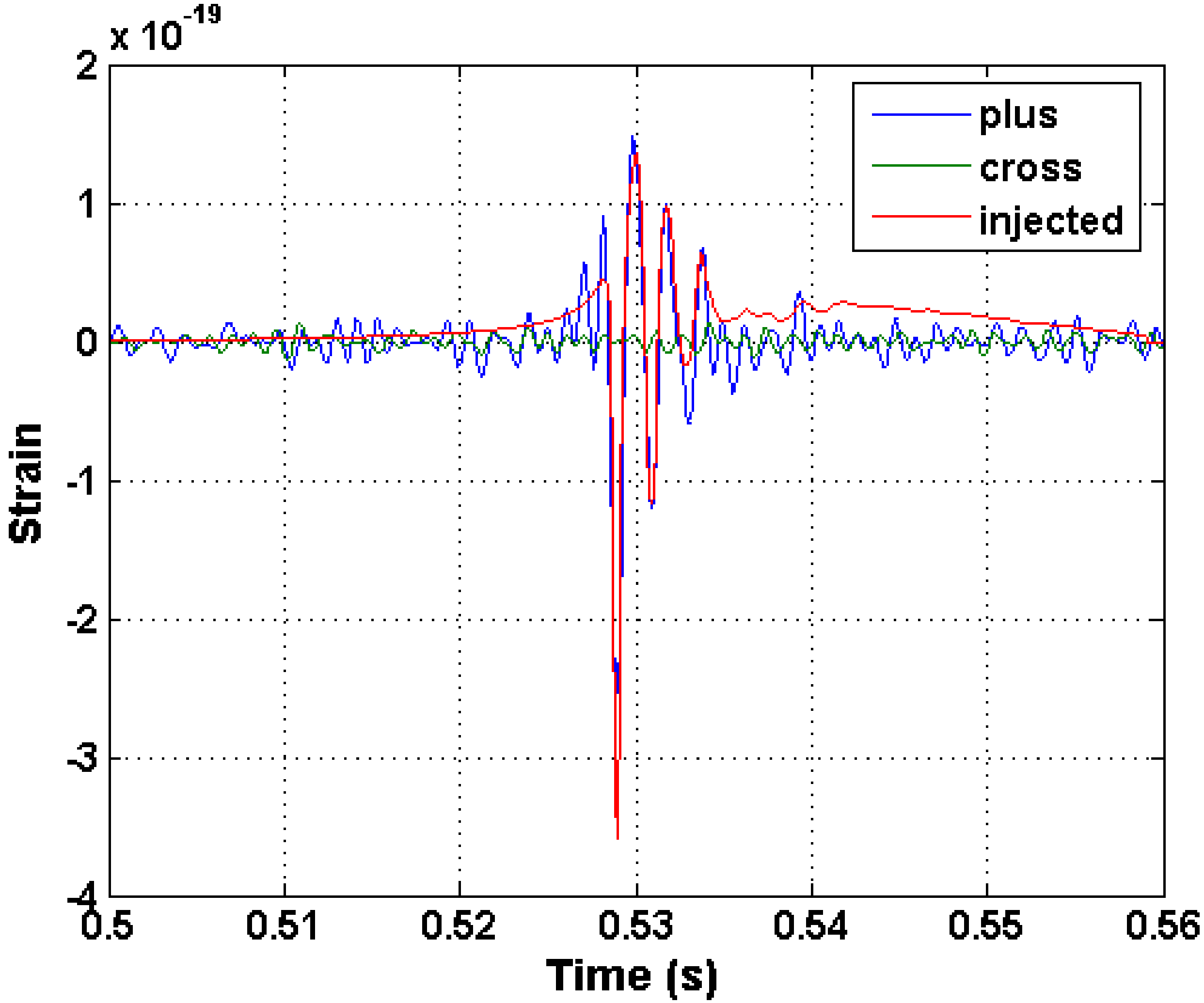
- Given sky location, can estimate GWB signal as h_+, h_x that maximizes likelihood Λ:

$$\Lambda \equiv -\ln P(\vec{d} \,|\, h_+, h_\times, \theta, \varphi) \approx -\frac{1}{2}\sum_a \sum_f \frac{\left| d_a(f) - \left[F_a^+ h_+(f) + F_a^\times h_\times(f) \right] \right|^2}{S_a(f)}$$

- Maximizing Λ gives linear system of equations for h_+, h_x in terms of data d. Can solve explicitly for general network:

$$0 = \frac{\partial \Lambda}{\partial h_+^*}, \quad 0 = \frac{\partial \Lambda}{\partial h_\times^*} \quad \Rightarrow \quad \begin{array}{l} h_{+,\times}^{\mathrm{best}} = \sum_a V_a^{+,\times} d_a \\ V_a^{+,\times} = V_a^{+,\times}[S_a(f), F^+(\theta,\phi), F^\times(\theta,\phi)] \end{array}$$

Signal Recovery



Recovered signal is noisy, band-passed version of injected signal.

Simulated signal has h_x=0.

Ringing is due to a sharp cut-off in the frequency integral.

Implementation

- Almost ready for large-scale Monte-Carlo simulations
- MATLAB, available from lsc-soft/matapps
- Much slower than real time (many directions on sky)
  - » Triggering on incoherent null power would make much faster

Pros and Cons

- Eyes open search
  - Unknown or unanticipated waveforms
- Innately distinguishes between gravitational waves and glitches
  - A powerful veto for other methods

- Less sensitive than matched filtering
- Needs 3+ instruments
  - Not co-located
  - LIGO + Virgo or GEO
- Computationally expensive

Some Real World Problems

- Sensitivity
  - » Requires significant excess power
- Nonstationary noise
  - » Will hurt analytic thresholds
- Calibration errors
  - » Null stream will not exactly cancel, so there will be residual power.
- Matching time-frequency bands:
  - » Run over a nested grid of time and frequency bands like Q-pipeline to avoid drowning signal in out-of-band noise
- Finite sampling of the sky
  - » Must look for white noise + allowed mismatch
- Computational cost
  - » Can be run as a triggered search, as statistical test threshold requires excess power in detectors
- Population of correlated glitches?