A Coherent Network Burst Analysis

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Overview

- **Eyes open search**
  - Capable of detecting unknown and unanticipated waveforms
- **Innately distinguishes between gravitational waves and glitches**
  - Networks of three or more detectors over-determine the two strain polarizations for an assumed gravitational wave direction
    - Can construct $N-2$ *null streams* **exactly** orthogonal to the strain without **any** knowledge of the waveform
  - Anything affecting a null stream is **not** the postulated gravitational wave
    - A very powerful veto
- **Needs 3+ instruments**
  - Each with different locations and orientations
  - Such as H1, L1 and one of Virgo, GEO or TAMA

Null streams

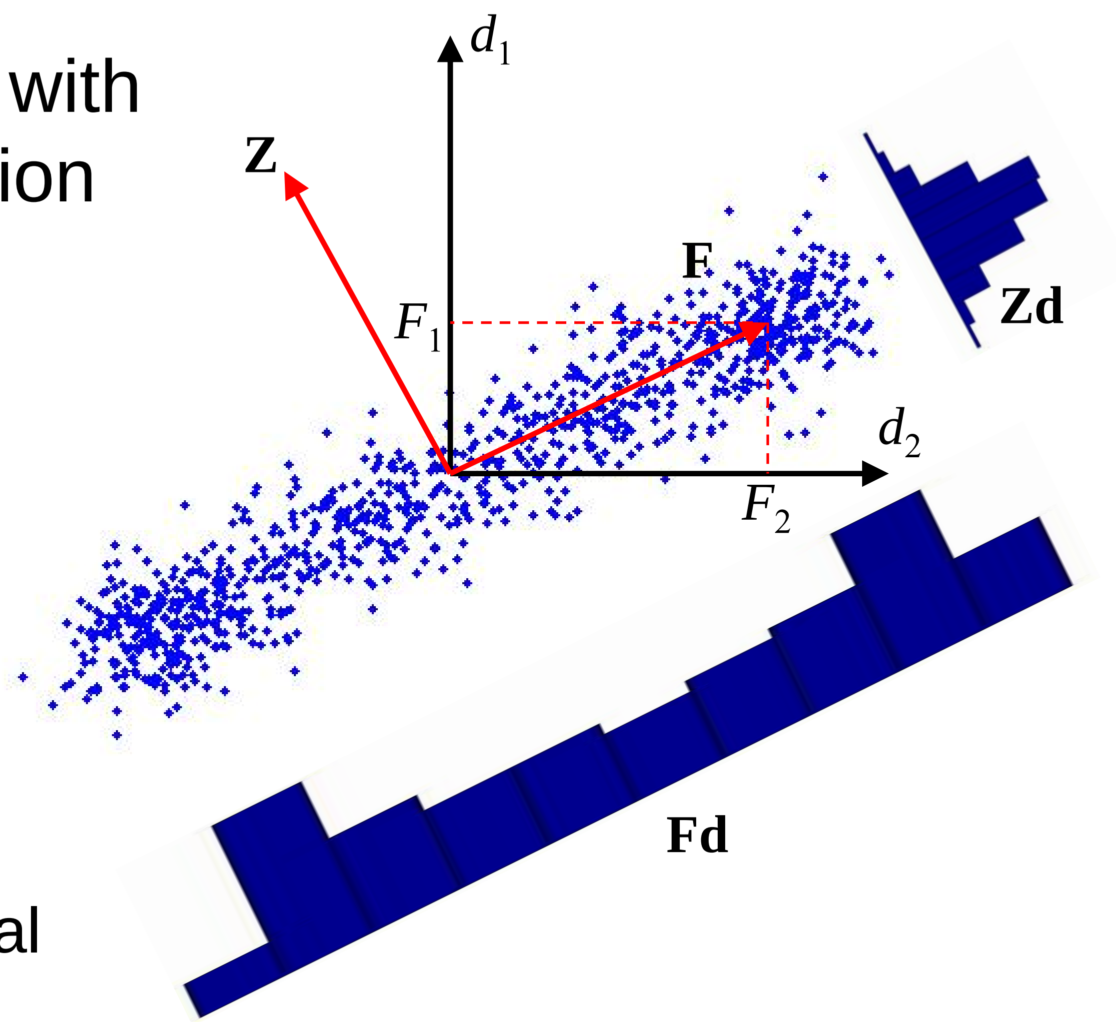
- The whitened output d_i of N detectors can be modelled by
  - Antenna patterns F_i
  - Strain h
  - Amplitude spectrum σ_i
  - White noise n_i
- The $N-2$ linear combinations $(\mathbf{Zd})_j$ are orthogonal to strain and each other

$$\begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_N \end{bmatrix} = \begin{bmatrix} F_1^+/\sigma_1 & F_1^\times/\sigma_1 \\ F_2^+/\sigma_2 & F_2^\times/\sigma_2 \\ \vdots & \vdots \\ F_N^+/\sigma_N & F_N^\times/\sigma_N \end{bmatrix} \begin{bmatrix} h^+ \\ h^\times \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

$$\begin{aligned} \mathbf{Z}^T &\equiv \operatorname{null} \mathbf{F}^T \\ \mathbf{Zd} &= (\mathbf{ZF}) \cdot \mathbf{h} + \mathbf{Zn} \\ &= 0 \cdot \mathbf{h} + \mathbf{Zn}, \end{aligned}$$

Null stream visualization

- Consider analogy with one fewer dimension
  - Detectors d_1, d_2
  - One polarization
  - Sensitivity F_1, F_2
  - Large strain h
- Null stream $\mathbf{Z}$ is orthogonal to $\mathbf{F}$
  - $\mathbf{Zd}$ is white
  - $\mathbf{Fd}$ estimates signal

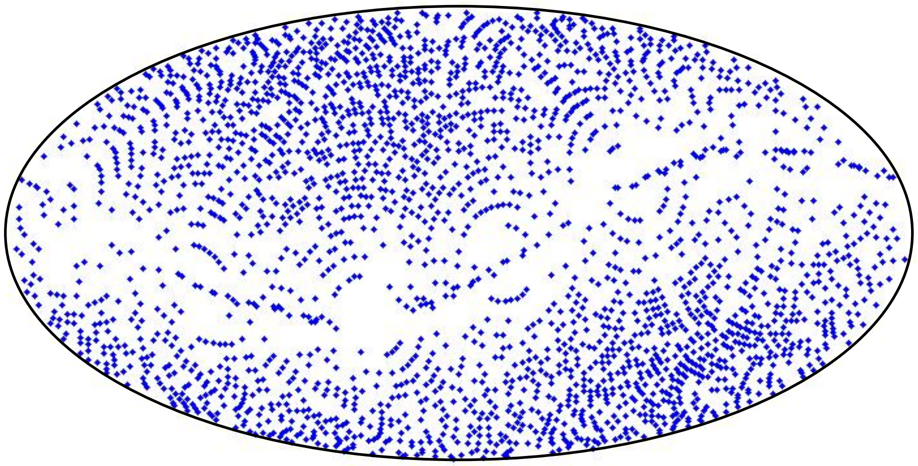


Directions

- Every direction Ω on the sky has different
  - Null stream coefficients $\mathbf{Z}$
  - Delays Δt_i for detector at $\mathbf{x}_i$

$$c\Delta t_i = -\mathbf{x}_i \cdot \Omega$$

- Sample the sky with some limited mismatch
  - Template placement problem
  - Affected by network geometry



- Mollweide plot of 0.6 ms resolution map for HLV
  - Near-optimal
  - Low density on plane of HLV baselines

Null stream test

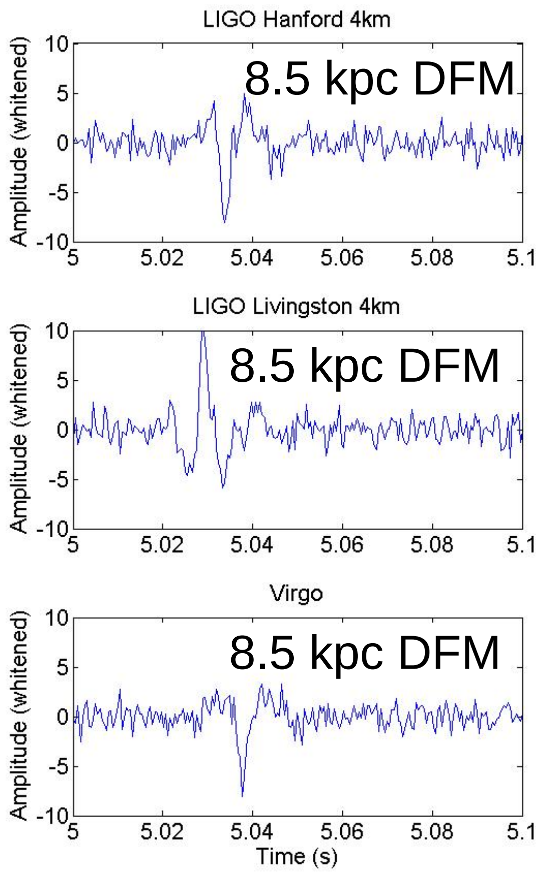
"Is the data consistent with noise plus a gravitational wave from some direction?"

is equivalent to

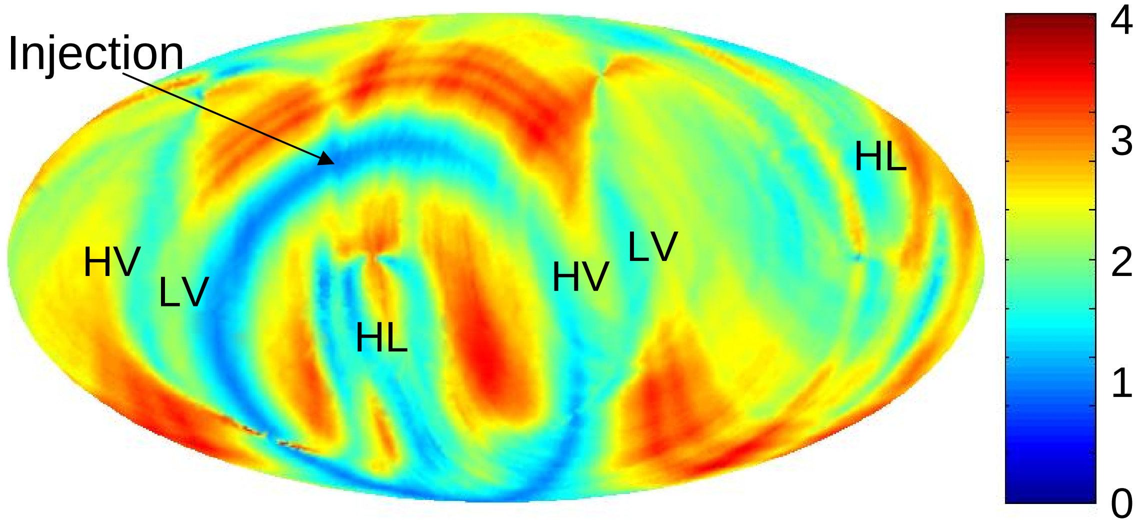
"Are the null streams for that direction consistent with noise?"

- Use a χ^2 test
  - Test that the total energy E_{null} of the null streams is consistent with white noise

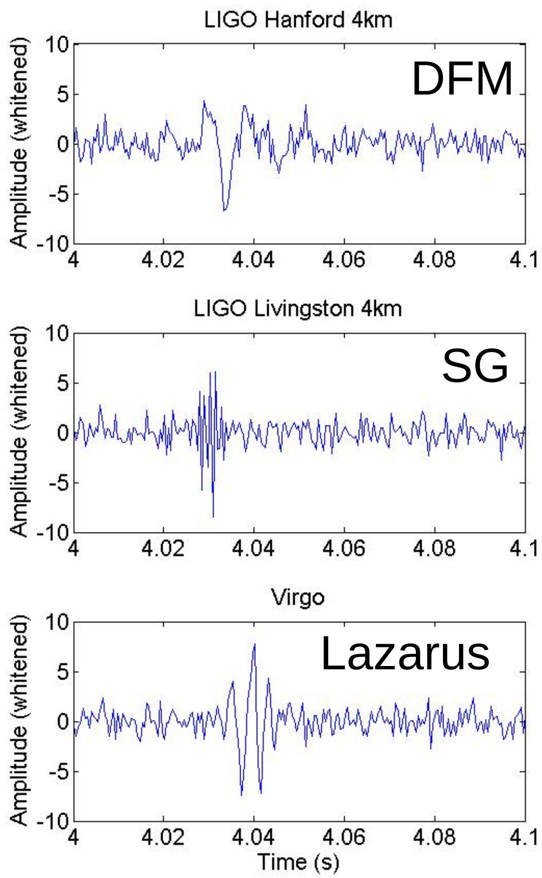
Signal injection



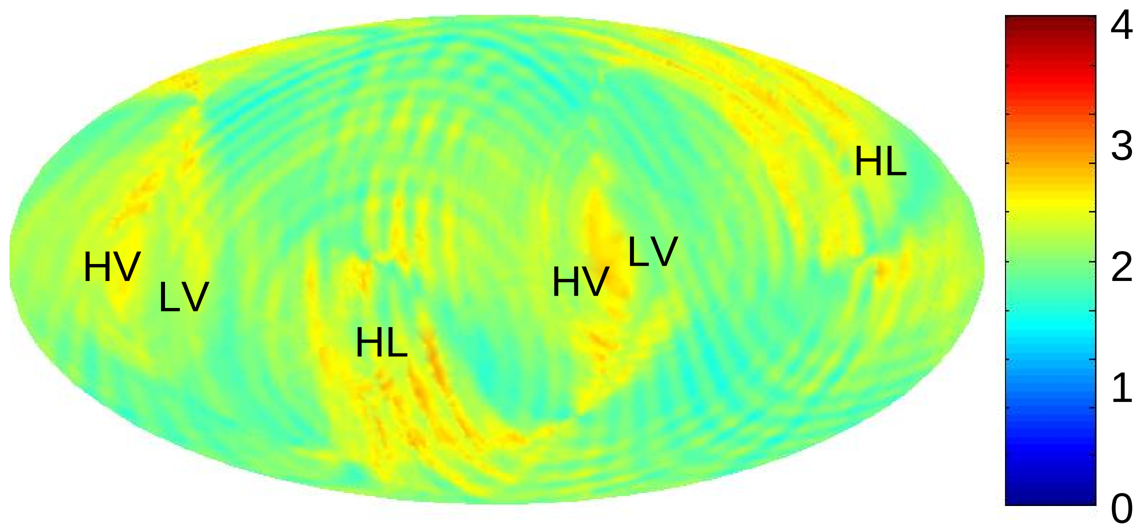
- Inject a gravitational wave
- Null stream energy consistent with noise at correct direction
  - Signal cancels out



'Glitch' injection



- Inject three different waveforms (a 'glitch')
  - Consistent times, energies
- Nowhere consistent with noise

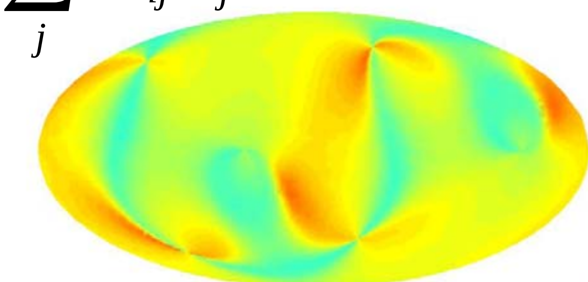


Components

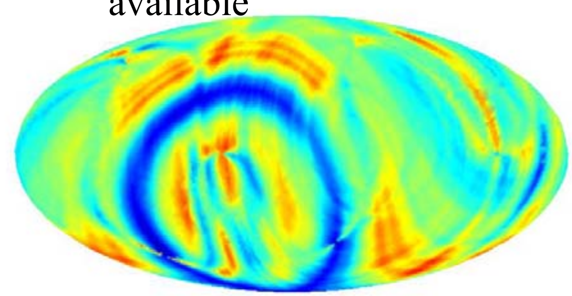
- Null stream energy E_{null} may be split into two parts
- Available energy $E_{\text{available}}$
  - "Diagonal" terms
  - Weighted sum of detector energies
  - Broad features on sky map
- Correlation energy $E_{\text{correlation}}$
  - "Off-diagonal" terms
  - Weighted sum of pair-wise detector correlations
  - Fringes on sky map

$$E_{\text{null}} = \sum_i^{N-2} \sum_j^{N} \sum_k^{N} Z_{ij} Z_{ik} d_j d_k$$

$$E_{\text{available}} = \sum_i^{N-2} \sum_j^{N} (Z_{ij} d_j)^2$$

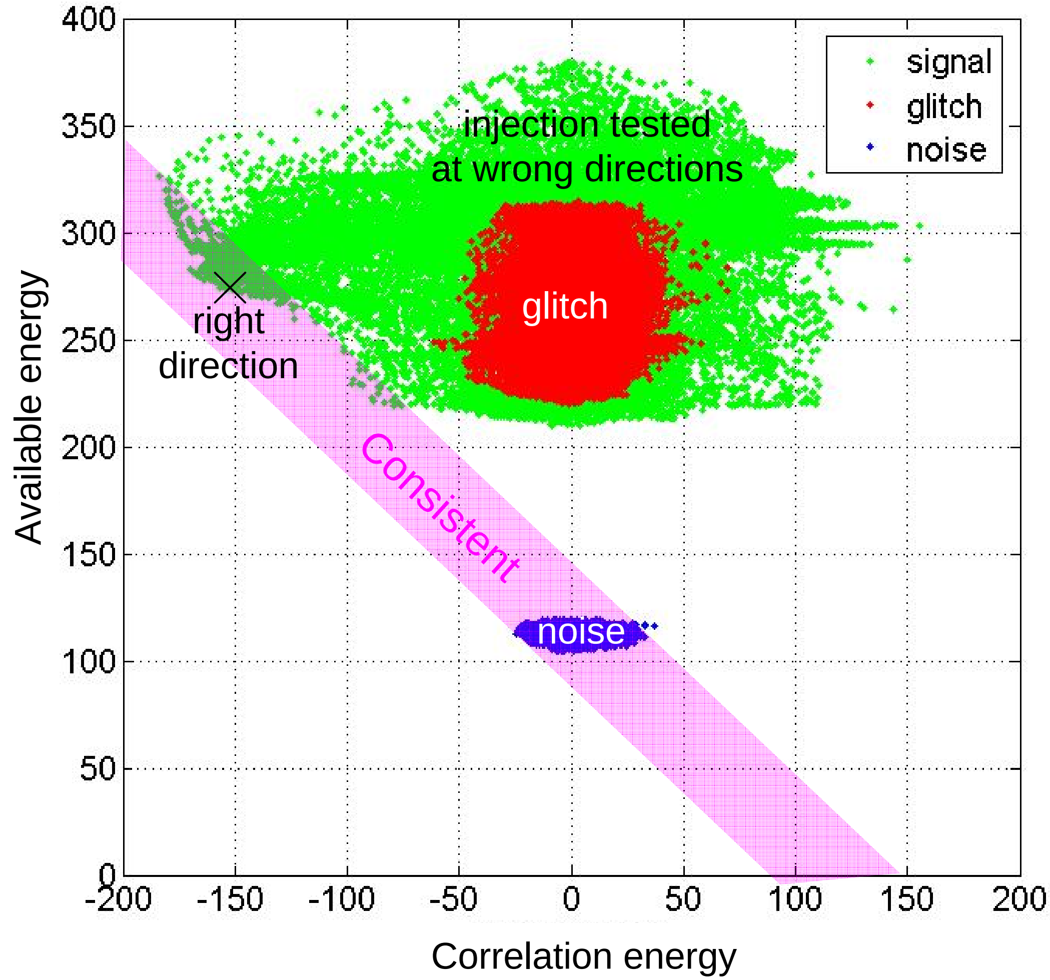


$$E_{\text{correlation}} = E_{\text{null}} - E_{\text{available}}$$



Available and correlation energies

- **Energy** in the detectors boosts up the plot
- **Correlation** in the detectors broadens across the plot
- **Cancellation** when
  - Consistent with gravitational wave
  - Right direction on sky

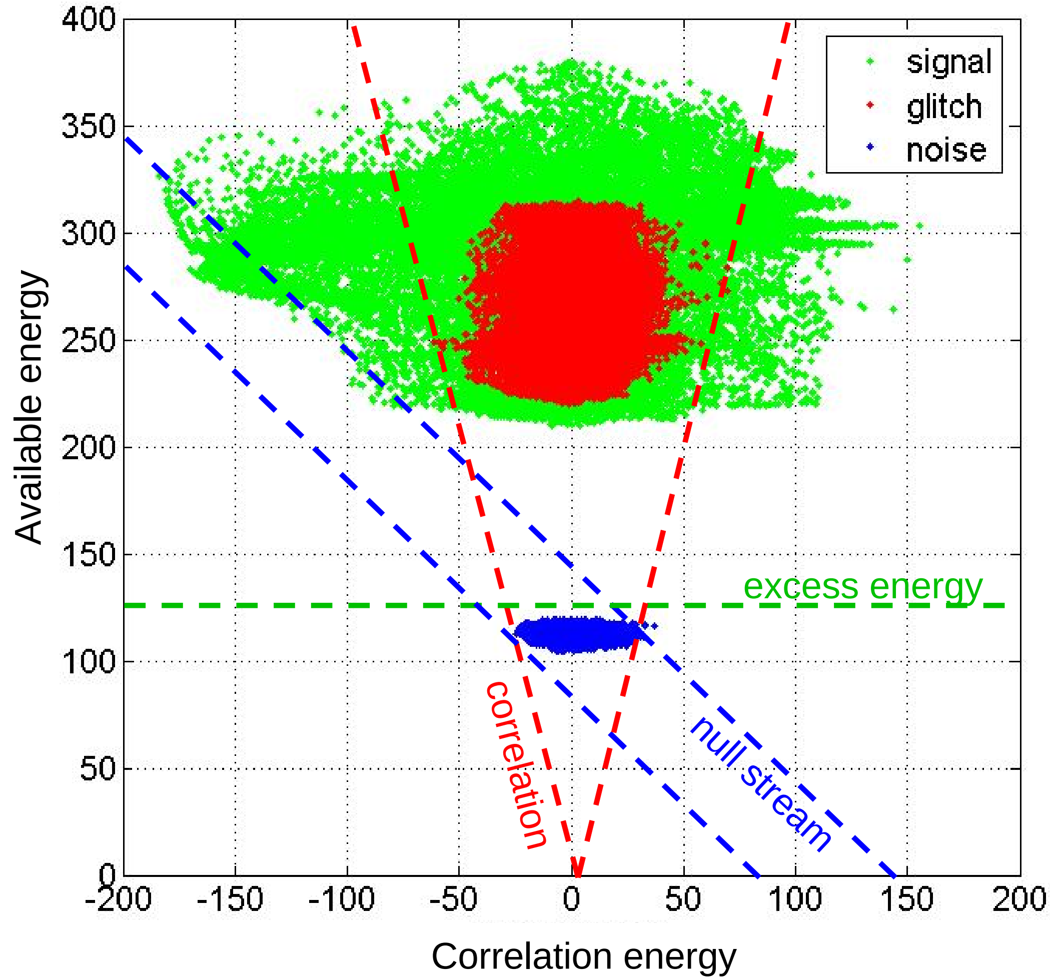


Characterization

- How does it compare to existing methods?
  - Will reject energetic and even correlated glitches
  - Won’t reject a gravitational wave
  - Won’t reject background noise and small glitches
  - **Complementary to existing tests**
- To form a search, must combine it with some other test(s)
  - **What is the population of small glitches that pass the null test, and how can we eliminate them?**

A possible search strategy

- Use excess energy to trigger
- Require correlation
- Use the null stream to identify gravitational wave candidate events



Real world problems

- **Nonstationarity,**
- **Calibration errors**

  and

- **Direction mismatch**
  - Null stream will not exactly cancel signal, so there will be residual excess energy
- **Computational cost**
  - May be practical as triggered search only
- **Duty cycle**
  - Requires at least three different sites taking data
- **Glitch population**
  - How correlated?

Future directions

- Performing large scale Monte-Carlo simulations
  - MATLAB pipeline
    - lsc-soft/matapps/src/searches/burst/coherent-network
  - Test against real glitches
  - Compare with other tests
- Preferentially detect “physical” waveforms?
  - Maximum entropy methods?
- More work on statistics
  - Bayesian interpretation?
  - Pattern recognition on sky maps?