



Looking for Gravitational-Wave Bursts Using a Network of Detectors

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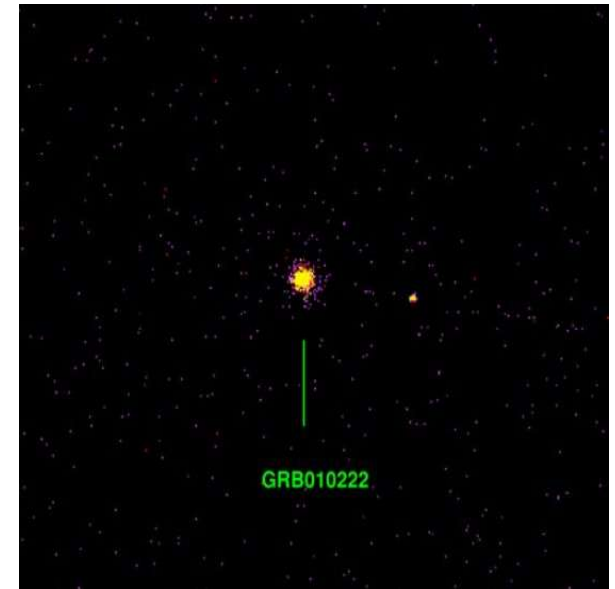
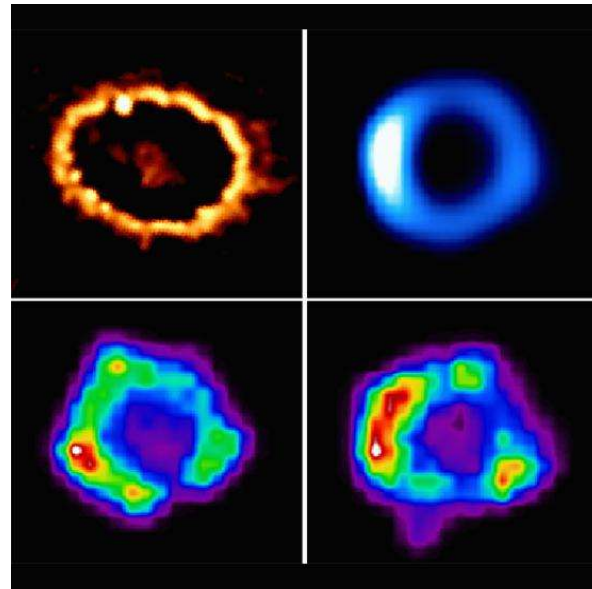
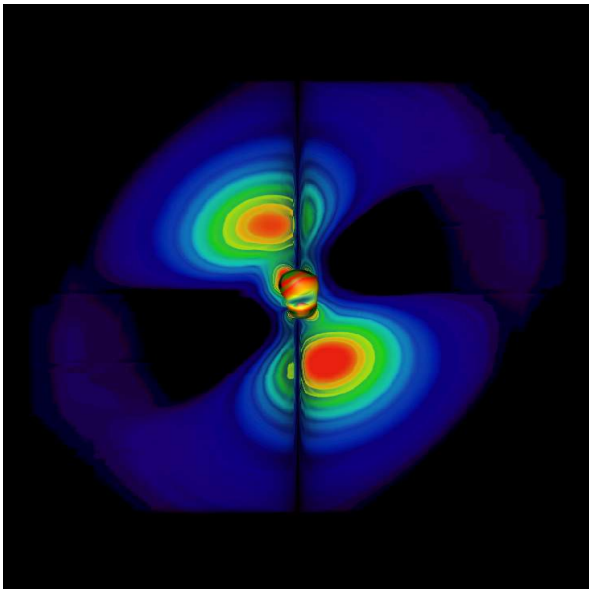
work done in collaboration with
L. Wen, I. S. Heng and B. F. Schutz



Overview

- Expected burst sources.
- DA strategies in burst search.
- Vetoes.
- The Null-stream.
- A veto strategy using Null-stream
- Implementation – 2 detectors.
- Implementation – 3 detectors .
- Open Issues.

Possible Burst sources



BH mergers, Supernovae, GRBs ..



Data analysis from Burst sources

Lots of unknown physics
**We don't know
what are we looking for!**

No reliable models of the
expected waveforms

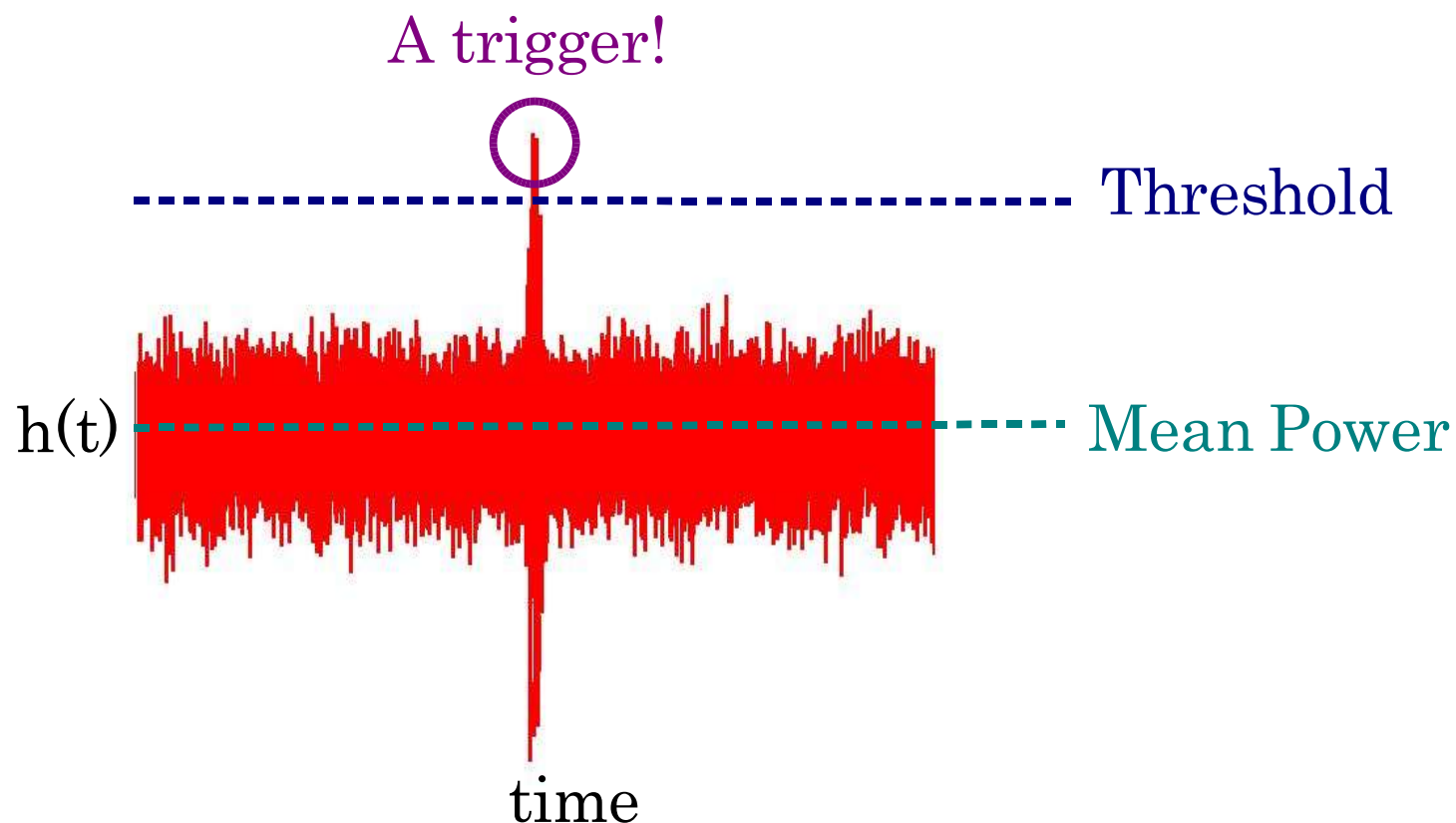


Data analysis from Burst sources

Hardest data analysis problem;
simplest of methods!

**Look for
short-lived excess power
in the data**

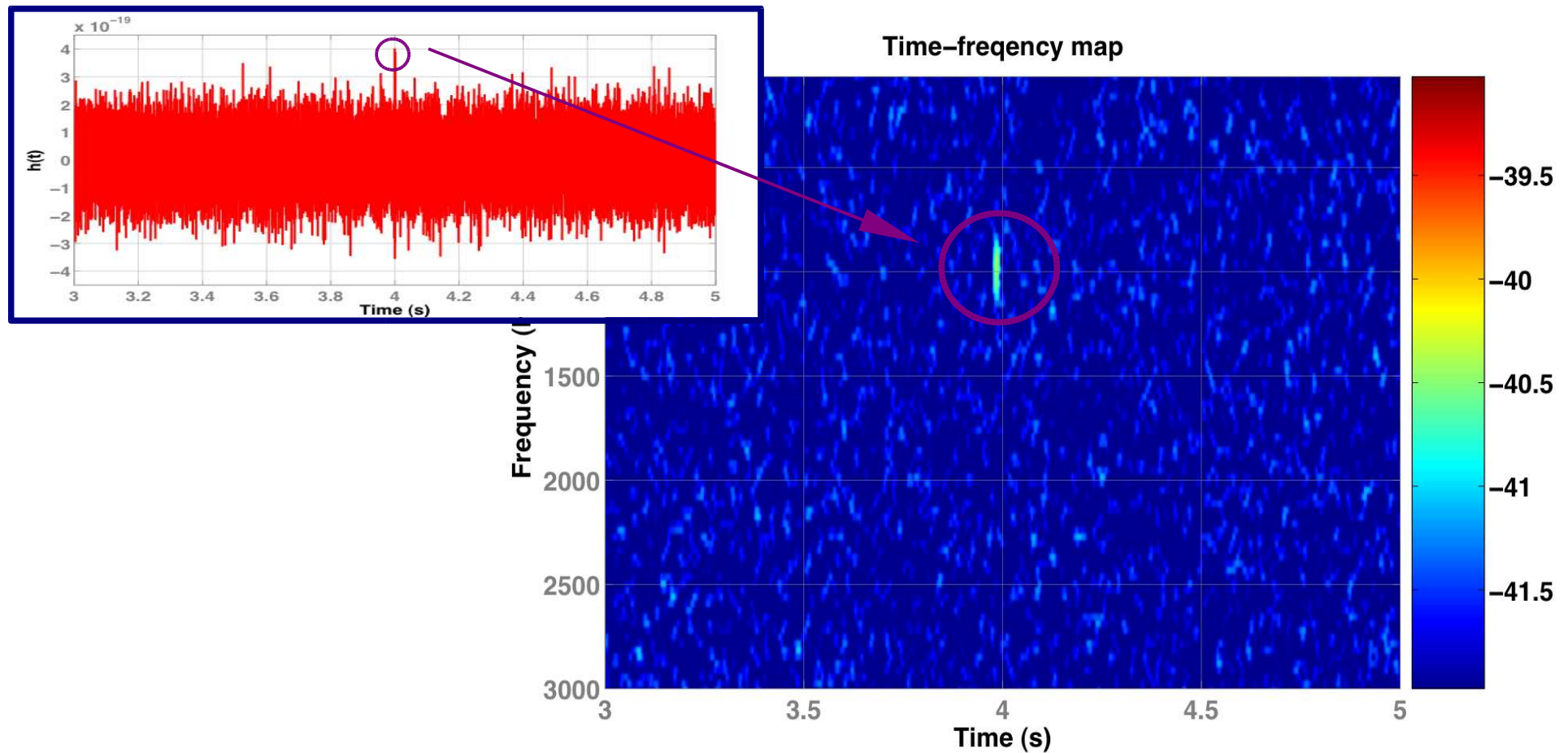
A Simplistic *ETG*



Suggested Refs:

- W Anderson et al PRD 63 (2001) 042003
- J Sylvestre PRD 66 (2002) 102004
- S Klimenko et al CQG 21 (2004) S1819-S1830
- R Balasubramanian et al CQG 22 (2005) 3015-3028

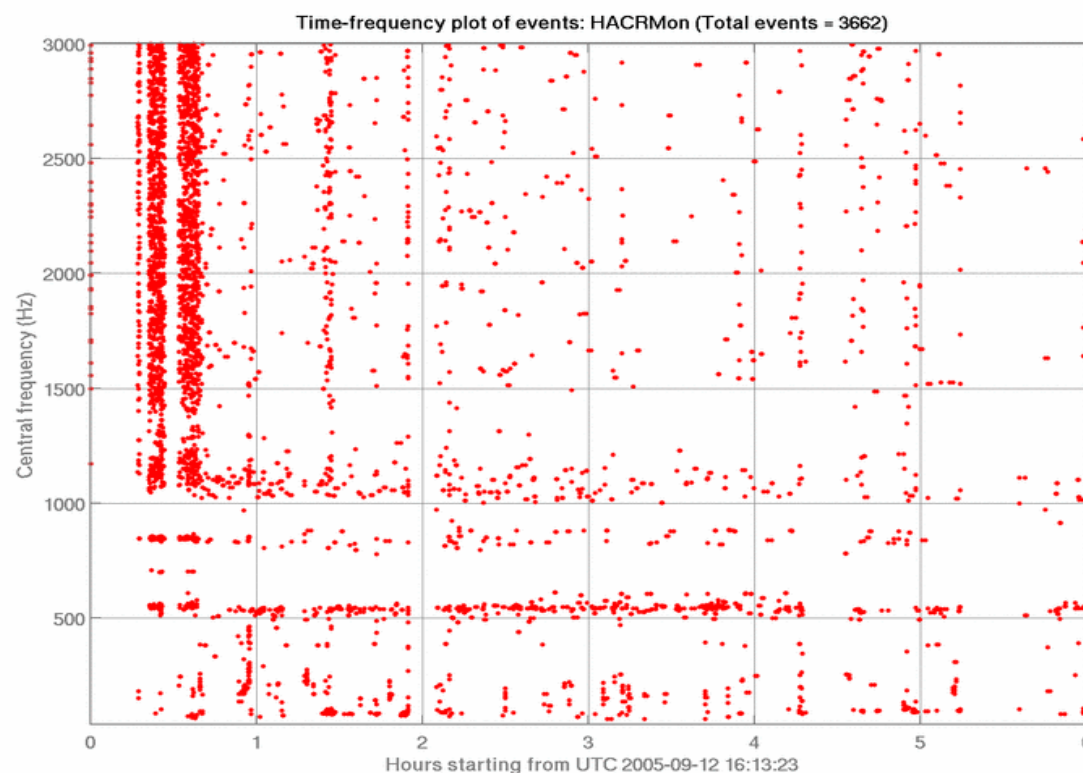
Time-frequency detection algorithms



Look for short-lived excitations in the TF map constructed from the the data

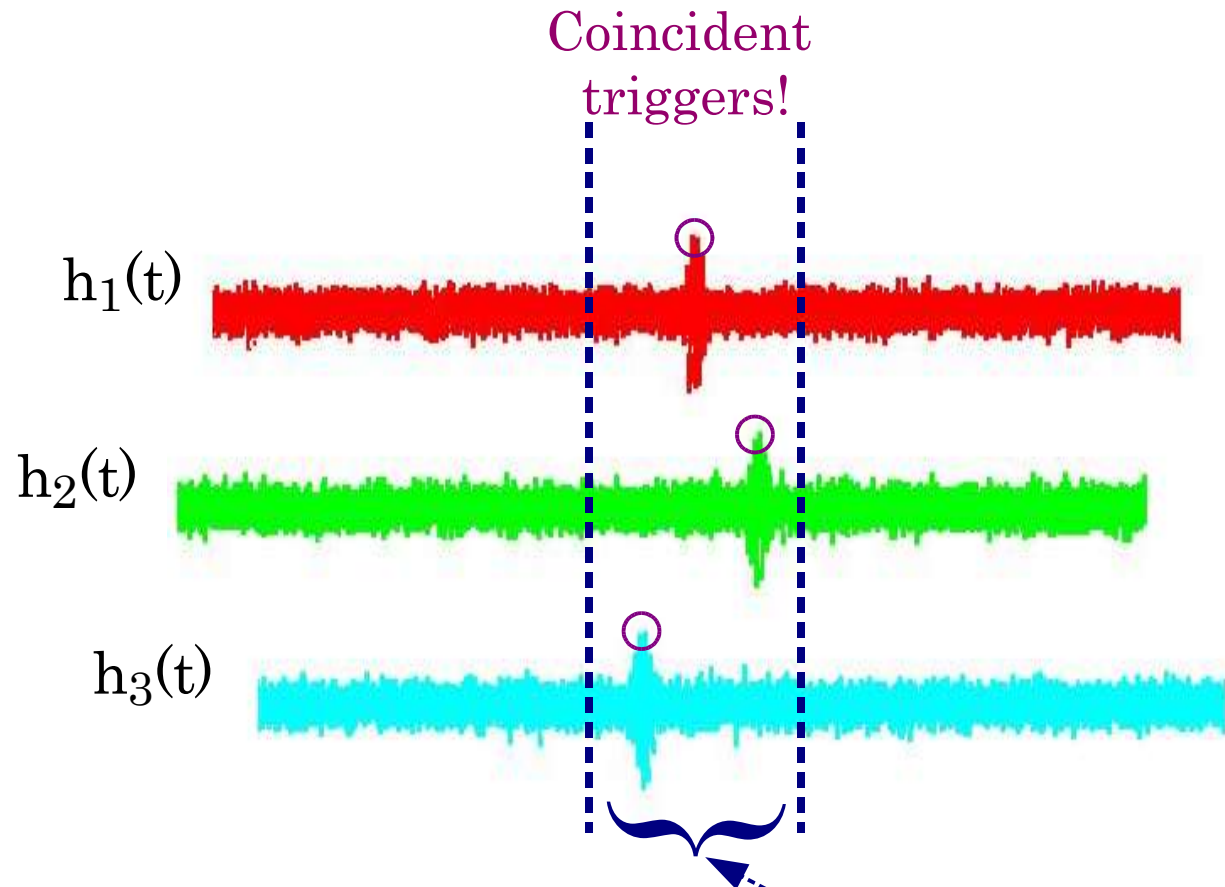
Time-frequency detection algorithms

We detect too many bursts!



Lots of spurious instrumental bursts will be triggered

Possible way out Coincidence Analysis



Require that triggers from multiple detectors should be coincident (within a time-window)



Vetoos

How to deal with coincident instrumental bursts?

Need reliable methods to distinguish between
coincident instrumental bursts and actual GW triggers;
popularly known as **Vetoos**

We develop a veto strategy that relies
on the physical properties of GWs;
but not relying on the prior knowledge of the waveforms

Suggested Refs:

- K. Kötter et al CQG 20 (2003) S895.
- A. Di Credico CQG 22 (2005) S1051.
- L. Cadonati CQG 21(2004) S1695.
- M. Hewitson et al CQG (2005) In press.



Null-stream

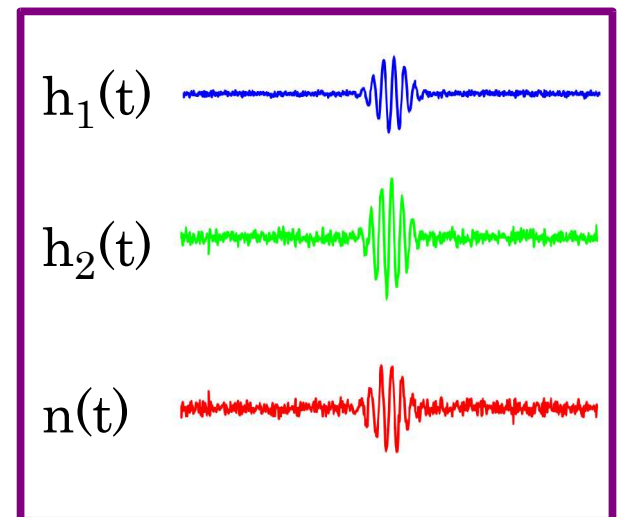
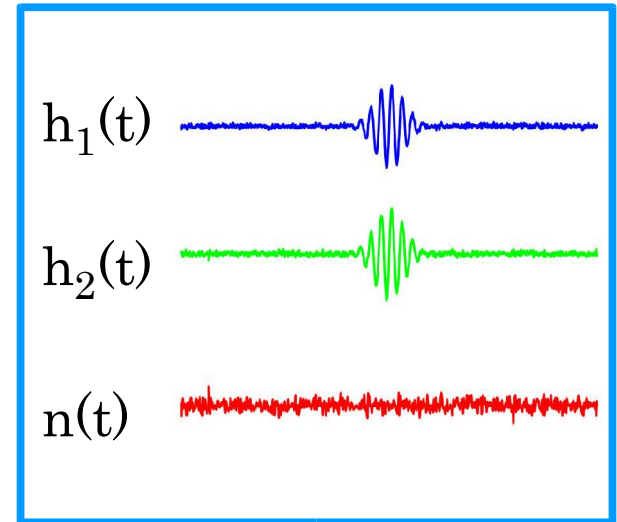
- Given the time series data from n detectors, one can find a particular linear combination, the 'null-stream', which contains no trace of the GWs [Gürsel and Tinto, 1989].
- Simplest case of two co-located detectors:

- If $h_1 = \overset{\text{noise 1}}{\underbrace{n_1(t)}} + \overset{\text{GW}}{\underbrace{\hat{h}(t)}}$, $h_2 = \overset{\text{noise 2}}{\underbrace{n_2(t)}} + \overset{\text{GW}}{\underbrace{\hat{h}(t)}}$

- Null-stream: $n(t) = h_1(t) - h_2(t)$

Null-stream Veto

- The null-stream can be used to distinguish between actual GW events and spurious events in a triggered search.
- If the coincident triggers correspond to ..
 - An actual GW burst: Burst signal will cancel out in Null-stream; null-stream will contain only noise.
 - Spurious instrumental bursts: Burst signals will not cancel out in the null-stream; null-stream will contain some excess power.
- This can be tested with a given false alarm rate.





Construction of the Null-stream statistic

- Let $N_k = \text{FFT}\{n(t)\}$, $x_k = \text{Re}[N_k]$ and $y_k = \text{Im}[N_k]$
- Construct two reduced normal variables

$$\hat{x}_k = \frac{x_k - \bar{x}_k}{\sigma_{x_k}}, \quad \hat{y}_k = \frac{y_k - \bar{y}_k}{\sigma_{y_k}}$$

- The statistic

$$S = \sum_k \hat{x}_k^2 + \hat{y}_k^2$$

will follow a Gamma distribution in the case of real GW triggers.
Parameters of the expected distribution can be estimated from the noise.

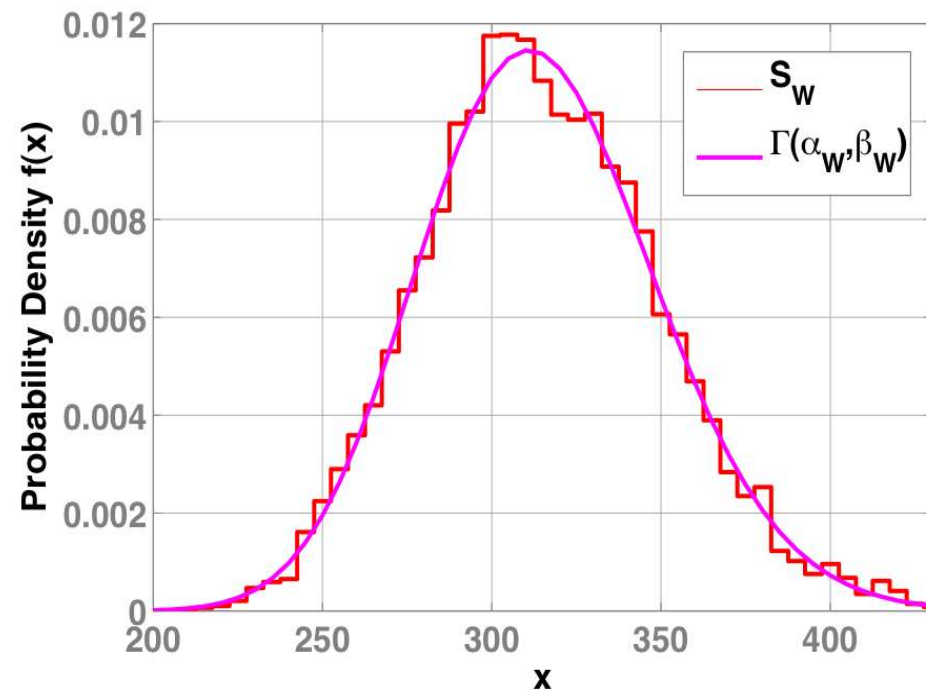
Assumption The frequency components (FFT) of the null stream, N_k , are normally distributed in the absence of any bursts. This is true if the frequency components of $h_1(t)$ and $h_2(t)$ are normally distributed.

How valid are your assumptions?

H1-H2 Network

- Two co-located LIGO-Hanford detectors form the simplest network.
- We construct the null-stream statistic from arbitrary segments of H1-H2 null-stream.

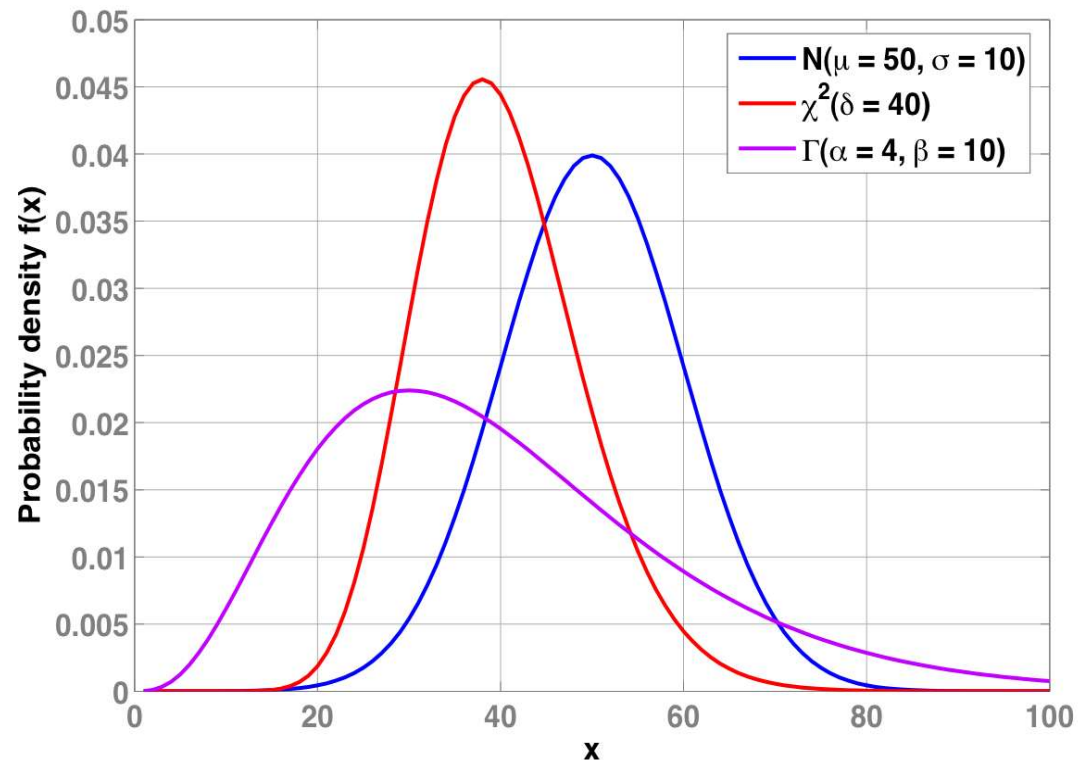
If the constructed statistic at the time of a coincident trigger is not part of a similar distribution, veto the trigger.





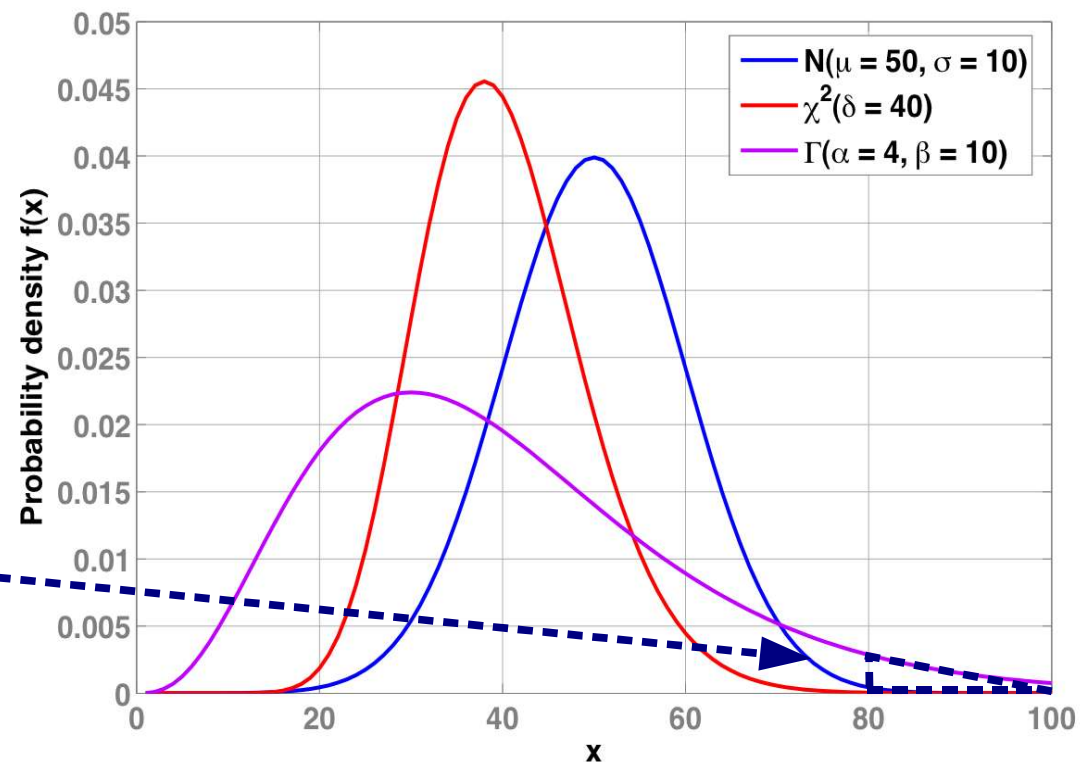
A time-out Statistical hypothesis testing

- Impossible to say that a certain random variable x is drawn from a particular distribution $f(x)$; the same variable can be drawn from many distributions.
- Can only say that x is not drawn from $f(x)$.



A time-out Statistical hypothesis testing

- Choose a threshold x_t .
- If $x > x_t$, $x \notin f(x)$.
- But there is always a false-rate in the test.
- In the figure:
 - $x = 80 \notin N$ and χ^2 (low false-rate)
 - $x = 80 \notin \Gamma$ (high false-rate)





Veto Algorithm

- Take a set of coincident triggers.
- Construct null-stream.
- Construct null-stream statistic S .
- Calculate the parameters of the expected Gamma distribution from the noise.
- Decide a false-veto rate W .
- Calculate the threshold γ_{thresh} corresponding to W . (assuming a Gamma distribution).
- If $S > \gamma_{\text{thresh}}$, veto the trigger.



Performance

How does the veto method perform?

Define two figures of merit:

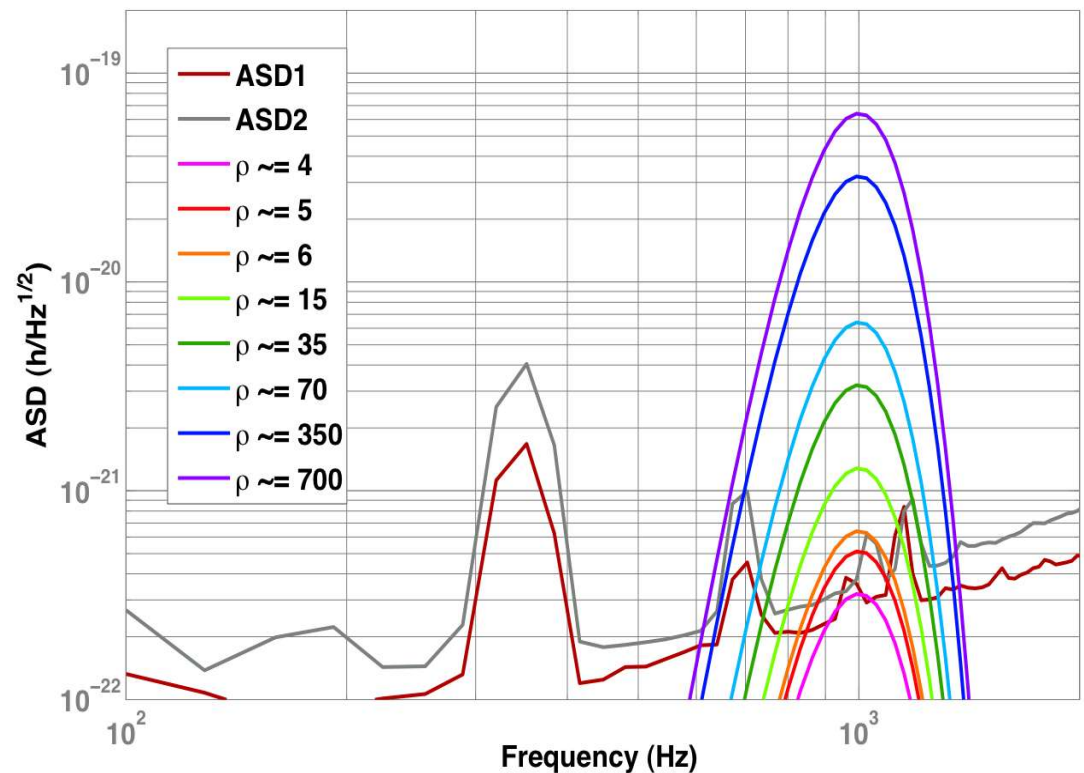
False-rate fraction of actual GW events that are accidentally vetoed.

Efficiency fraction of spurious instrumental triggers that can be vetoed with a given false-rate.

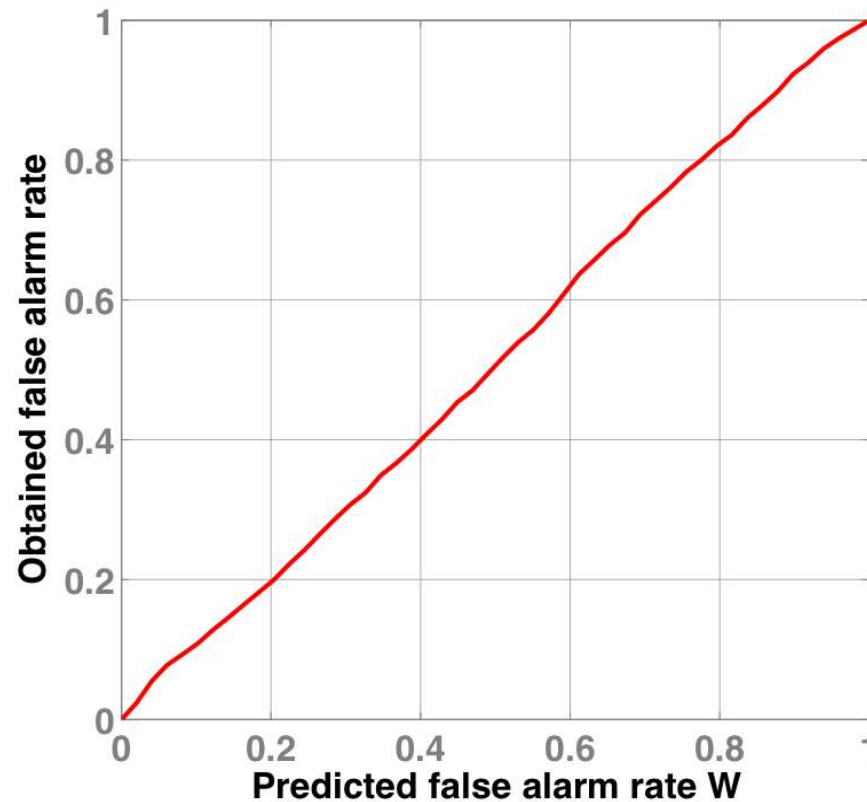


Estimating false-rate & efficiency: Software injections

- **GW-like injections:** Two copies of the same sine-Gaussian waveforms are injected into H1-H2 data. Fraction of vetoed events is the false-rate.
- **Instrumental bursts-like injections:** Random SGWs are injected into two data streams. Fraction of vetoed events is the efficiency.

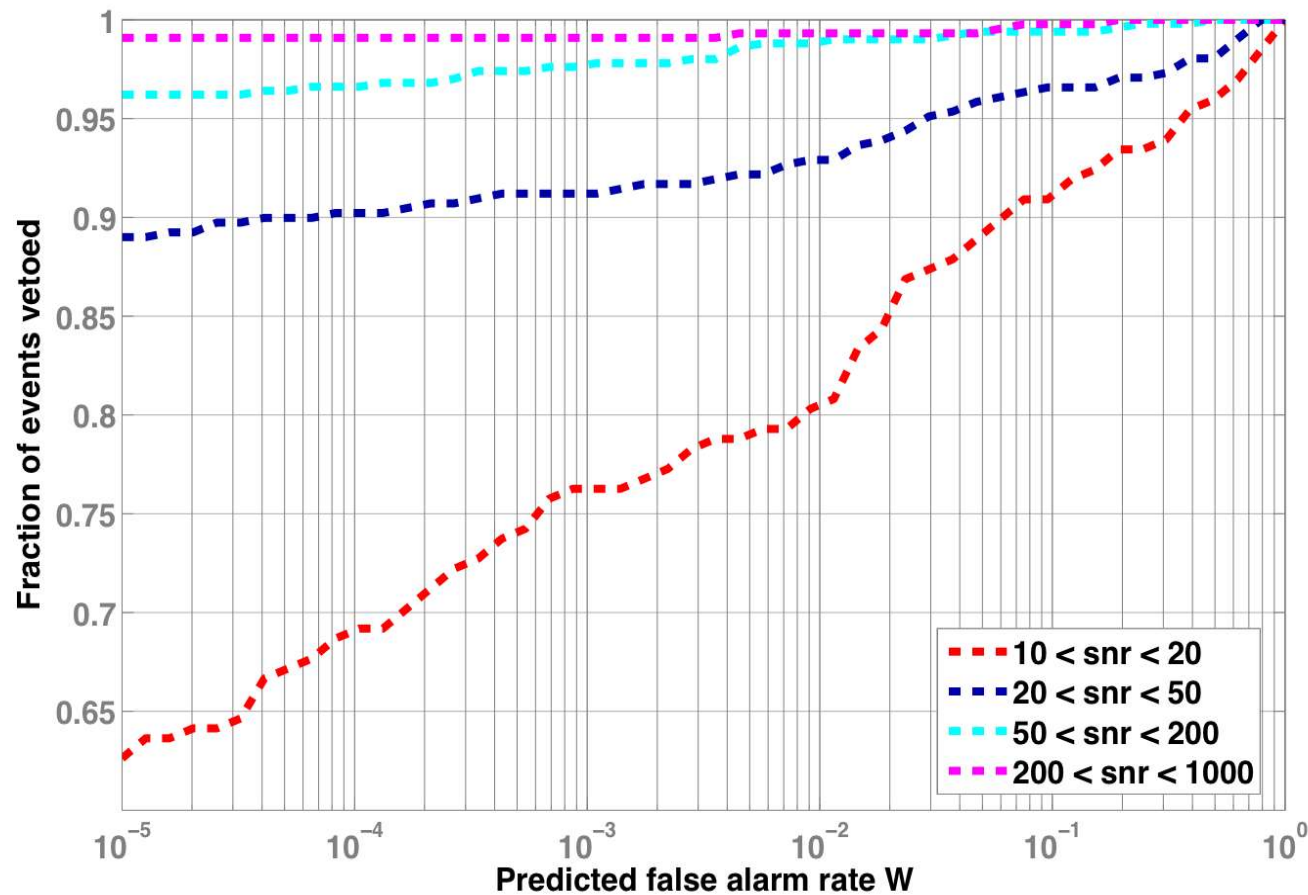


Estimated false-rate Vs. Predicted false-rate From **GW-like injections**



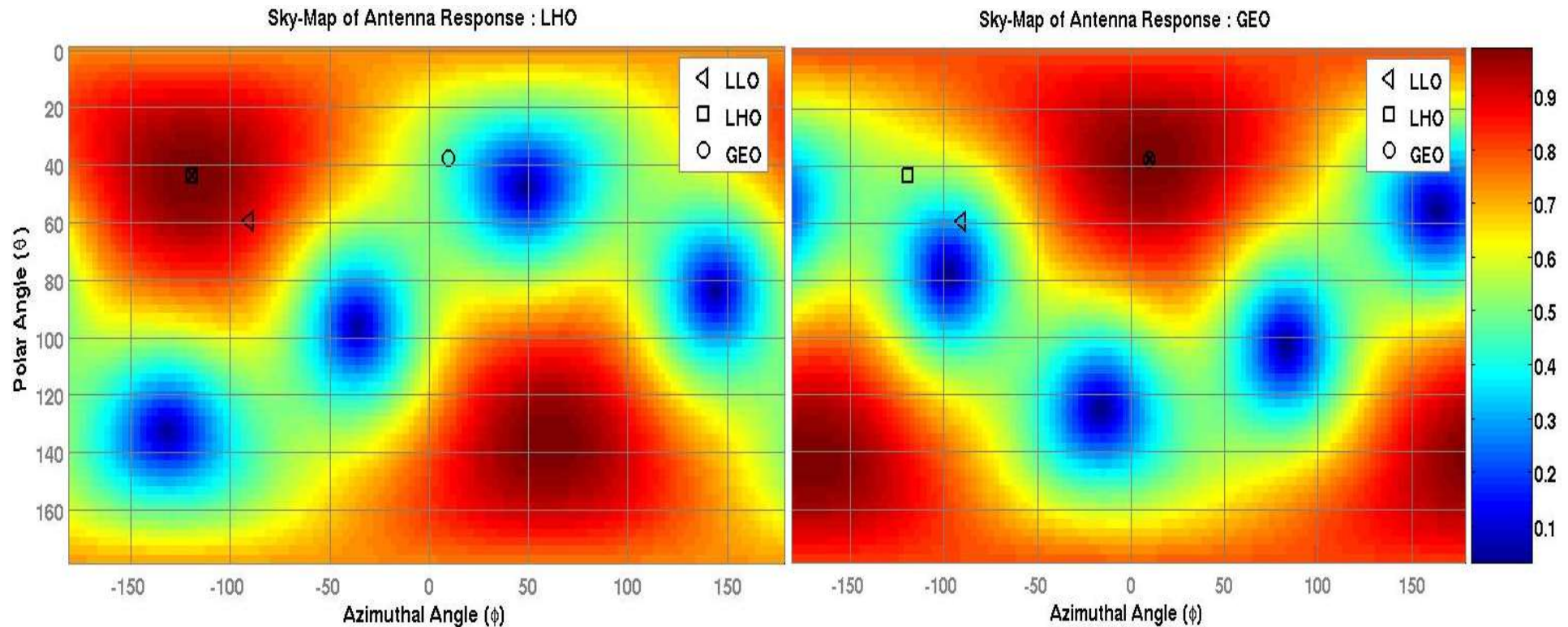
Estimated false-rate is in good agreement with
the predicted rate

Veto efficiency Vs false-rate From IB-like injections



Possible to achieve 80% efficiency
with 1% false-rate for signals with $\text{snr} > 10$

3 Detector Network



In case of widely-separated detectors,
 Null-stream is a function of the antenna responses,
 and hence, the source position.

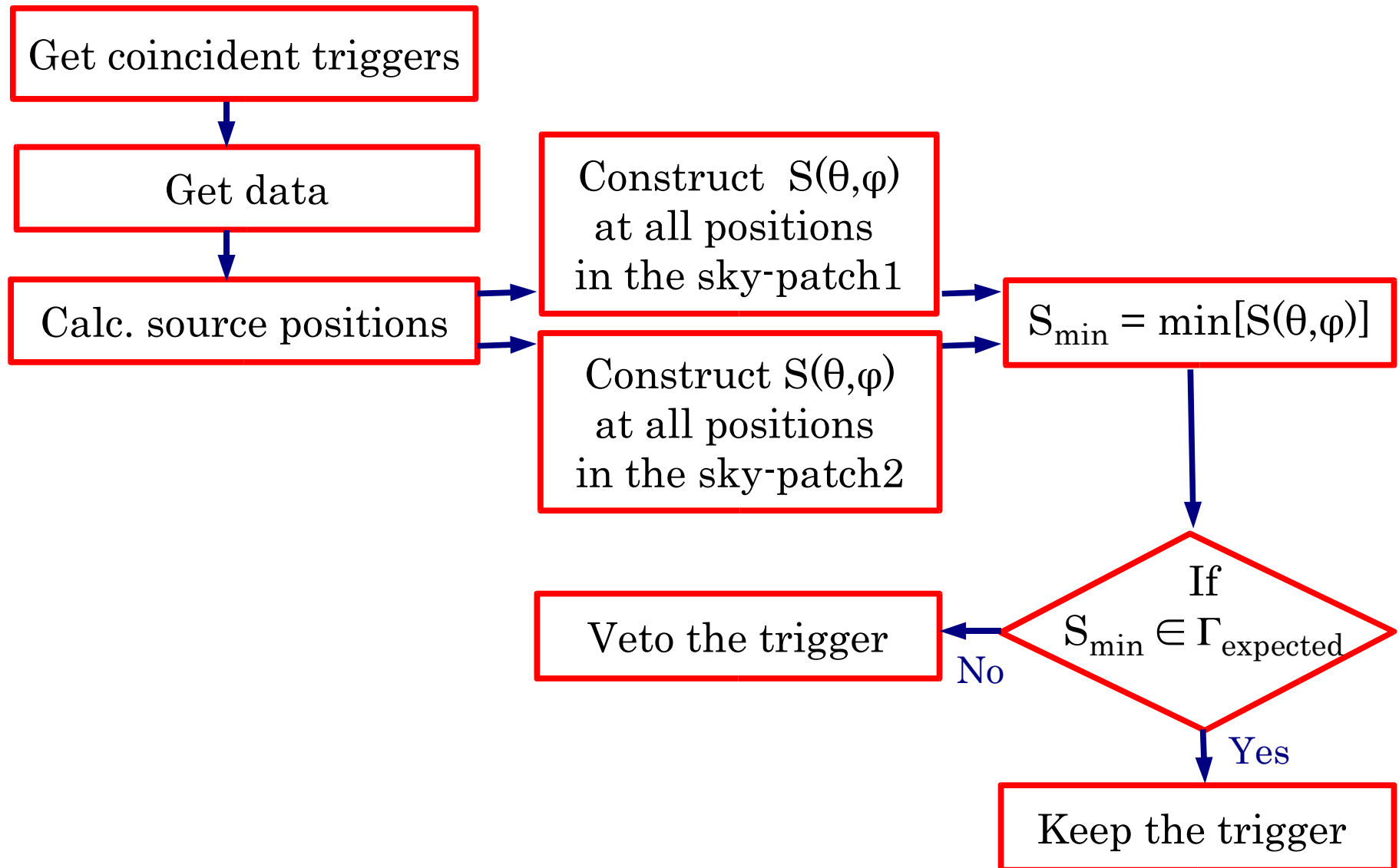
$$n(t, \theta, \phi) = A_{23}(\theta, \phi) h_1(t) + A_{31}(\theta, \phi) h_2(t + \tau_{12}) + A_{12}(\theta, \phi) h_3(t + \tau_{13})$$



3 Detector Network

- GW signal coming from a particular source will reach different detectors at different times.
- From the time-delay between coincident triggers, the source position can be re-constructed.
- Three detectors \rightarrow Two independent time-delays \rightarrow Two possible sky-positions (one of them being the actual position).
- Time-delays inferred from the triggers are not perfect; ETGs have errors \rightarrow reconstructed source position will have errors; but one can identify two 'sky-patches' .
- Null-stream is constructed at all sky-positions in the above patches.
- In the actual source position, all the GW signals will be canceled in the null-stream.

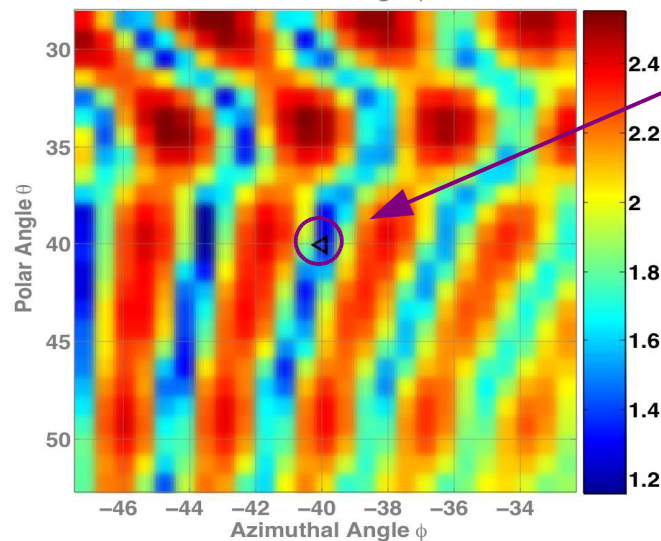
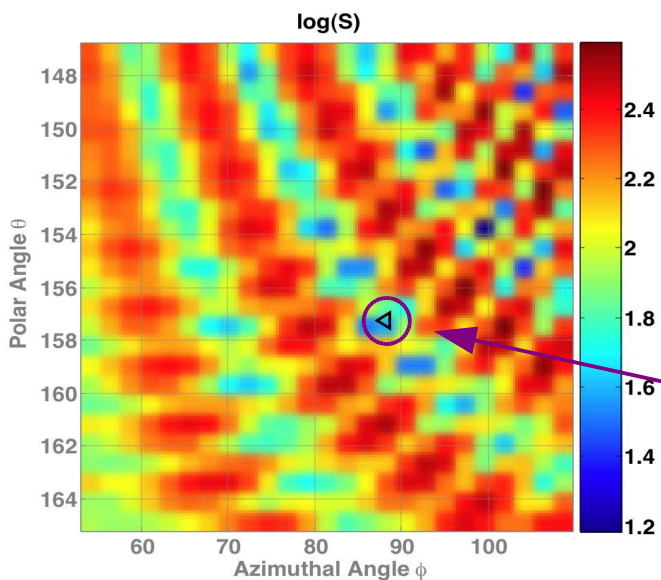
3 Detector Null-stream Veto Pipeline



LIGO-GEO Network Simulations

SG $\rho = 14$ Injection ($\theta = 40, \phi = -40$)

Sky-map of the Null-stream statistic



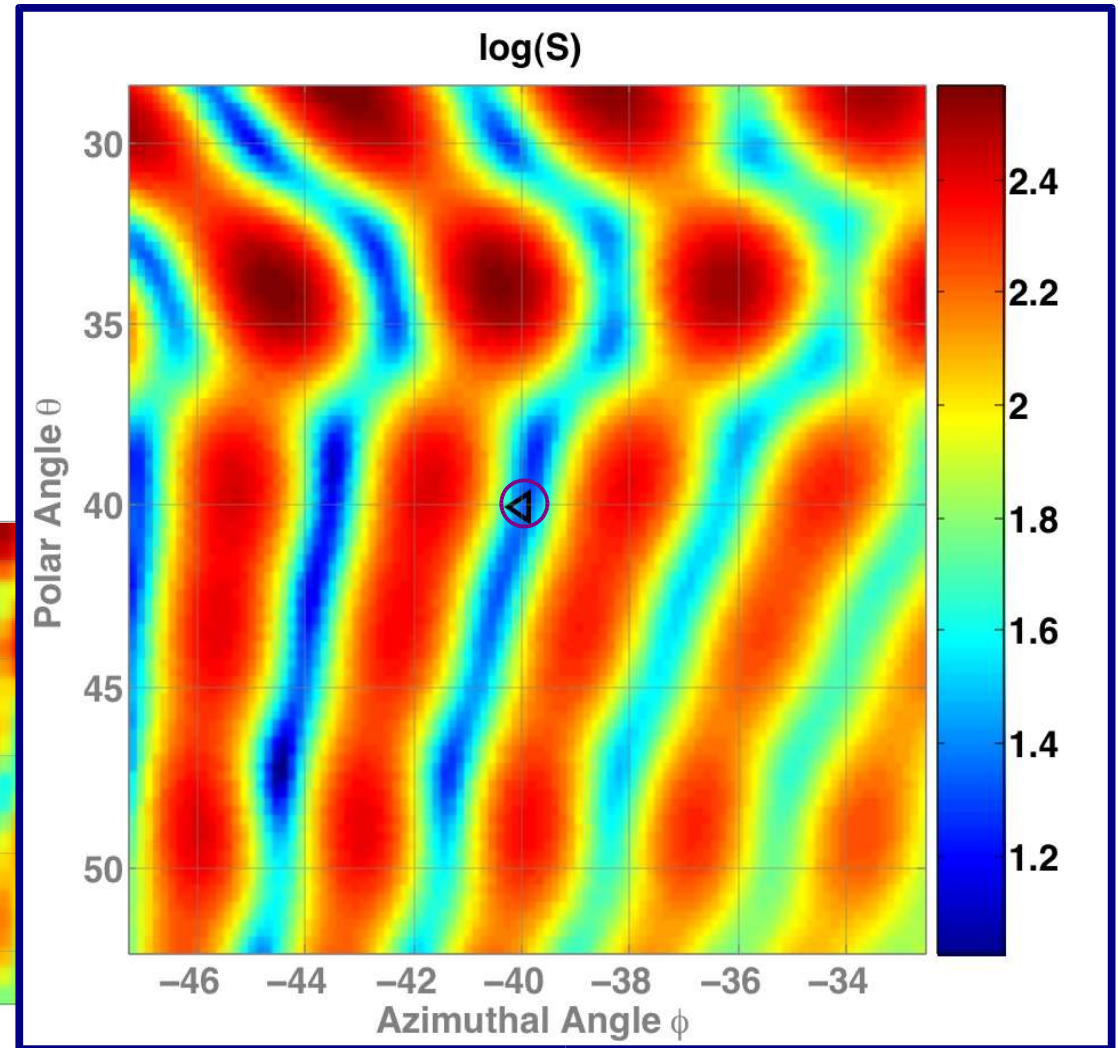
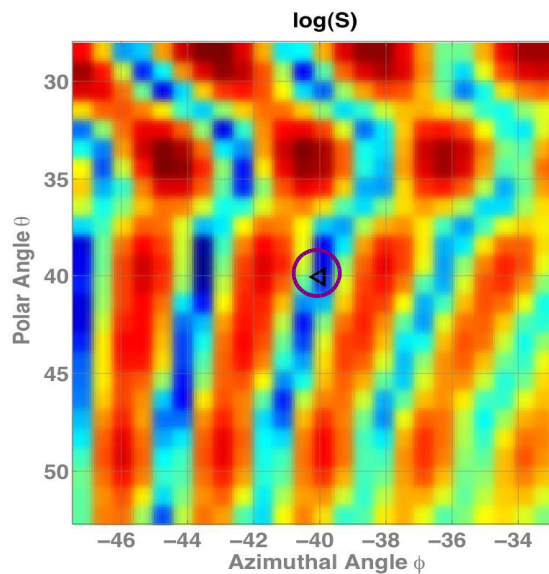
Source-positions estimated from the time-delay information

Coarse search

LIGO-GEO Network Simulations

SG $\rho = 14$ Injection ($\theta = 40, \phi = -40$)

Sky-map of the
Null-stream statistic



Coarse search

Fine search



Open issues

- **Computational power**
 - Intelligent hierarchical searches.
- **Calibration errors**
 - 'Residual signal' in the null-stream, null-stream is not 'perfect'.
 - Estimate the 'residual signal part' in the null-stream statistic and subtract that from the constructed statistic.
 - Full-correction requires prior knowledge of the signal.
 - Can be partly corrected. Laid out and tested a formulation in the H1-H2 search.
- **Possible non-stationarities**
 - Method breaks down.



Work in progress!