Coherent network analysis technique for discriminating GW bursts from instrumental noise

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in collaboration with

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Motivation

- Null stream formalism tests network data for consistency with gravitational waves
  - Y. Gürsel and M. Tinto, Phys. Rev. D **40**, 3884 (1989)
  - Closely related to likelihood analysis of Klimenko et al (2005).

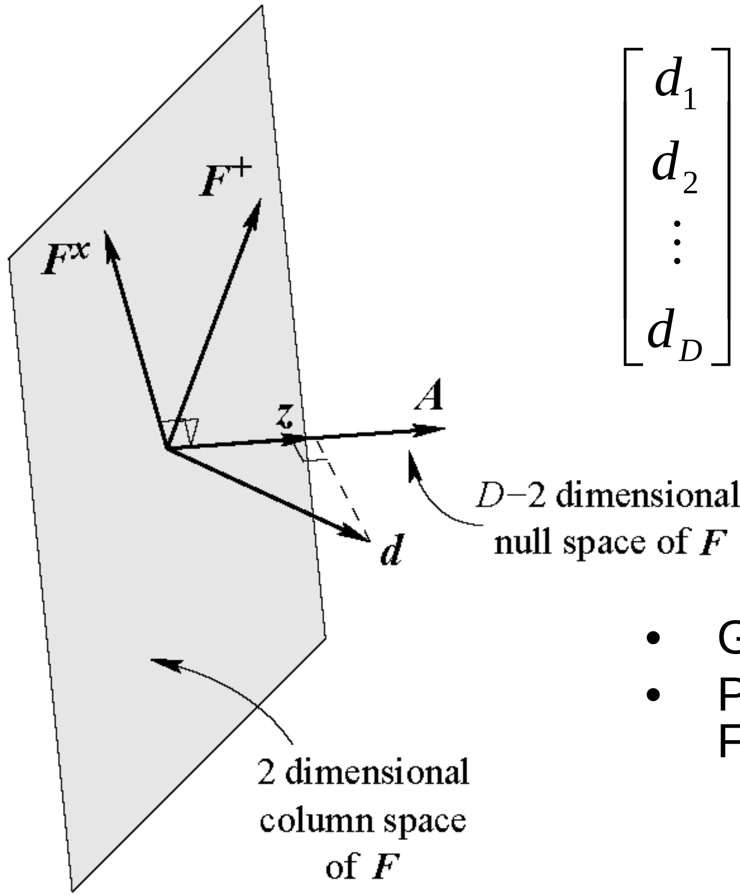
- Real interferometers have populations of *glitches*, bursts of excess power not due to gravitational waves
  - Can fool null-stream analysis.

- *Extension of null stream technique to veto these glitches on the basis of their inconsistency with gravitational waves.*

- Related to, but separate from, problems of
  - transient detection
  - source localization
  - waveform extraction.

Null Streams

- Consider output of network of detectors at one time / frequency bin:



$$\begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_D \end{bmatrix} = \begin{bmatrix} F_1^+(\Omega)/\sigma_1 & F_1^\times(\Omega)/\sigma_1 \\ F_2^+(\Omega)/\sigma_2 & F_2^\times(\Omega)/\sigma_2 \\ \vdots & \vdots \\ F_D^+(\Omega)/\sigma_D & F_D^\times(\Omega)/\sigma_D \end{bmatrix} \begin{bmatrix} h^+ \\ h^\times \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_D \end{bmatrix}$$

noise-weighted antenna response varies with sky position, frequency

whitened noise

- GWB only couples in through F^+/σ, F^x/σ.
- Project network data vector orthogonally to F^+/σ, F^x/σ (“null stream”).
  - Transient disappears in null stream *if the transient is a GWB from the assumed sky position.*

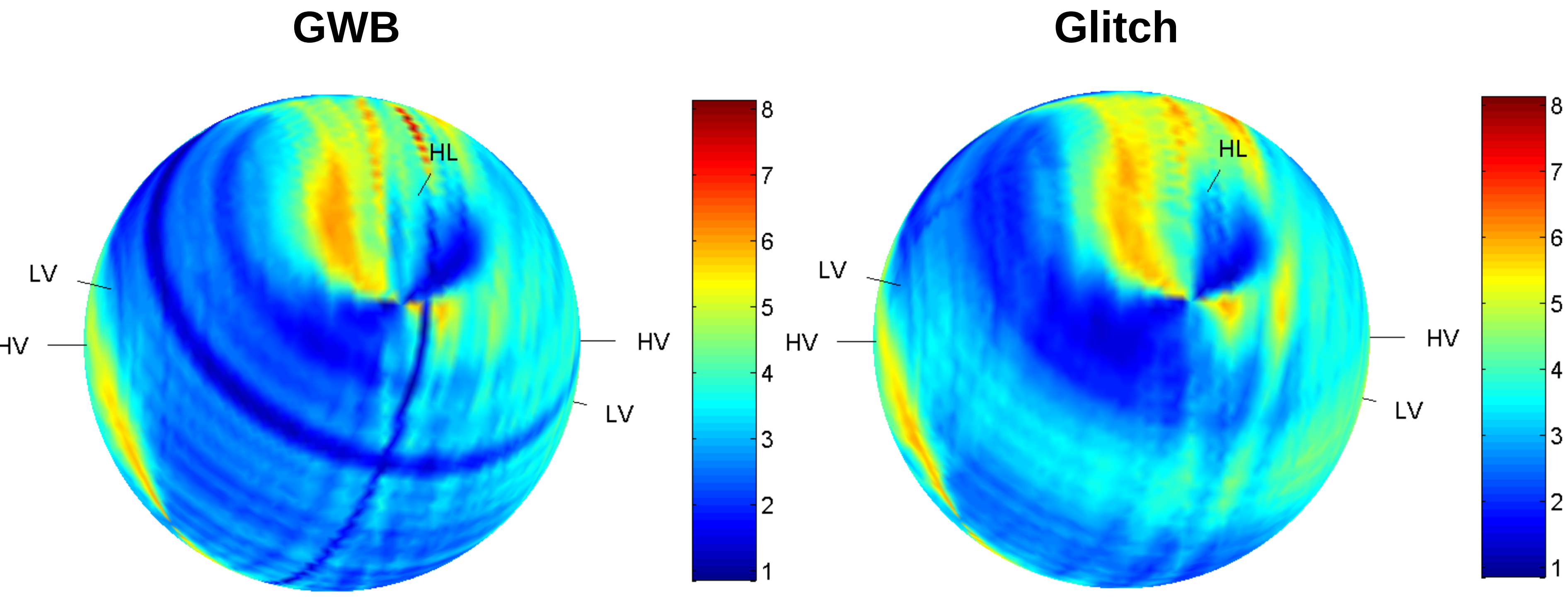
GWBs vs Glitches

- GWB: Cancel out transient signal by forming null stream.
- Glitch: Independent signals – can’t cancel significant portion of energy.
- Energy measures:

$$E_{null} = \begin{bmatrix} d_1^* & d_2^* & \cdots & d_D^* \end{bmatrix} \begin{bmatrix} Q_{11} & Q_{12} & & Q_{1D} \\ Q_{21} & Q_{22} & & Q_{2D} \\ & & \ddots & \vdots \\ Q_{D1} & Q_{D2} & \cdots & Q_{DD} \end{bmatrix} \begin{bmatrix} d_1 \\ d_2 \\ \vdots \\ d_D \end{bmatrix}$$

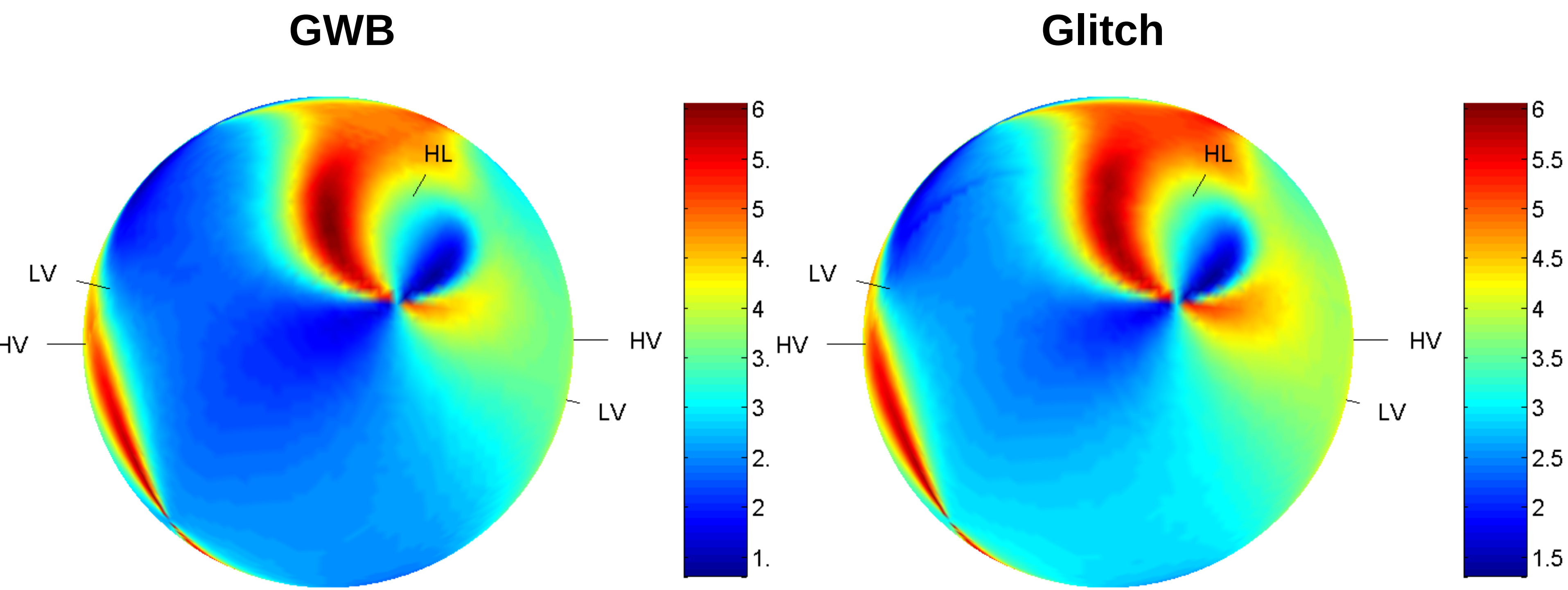
- E_{inc} := Autocorrelation terms (“incoherent energy”). Amount of energy expected in null streams for uncorrelated transient (glitch).

Sky Maps: Null Energy / DOF



- GWB and glitch constructed to have same time delays, size in each IFO.
- Null energy maps very similar.
- χ^2 ~1 somewhere for both GWB and glitch.

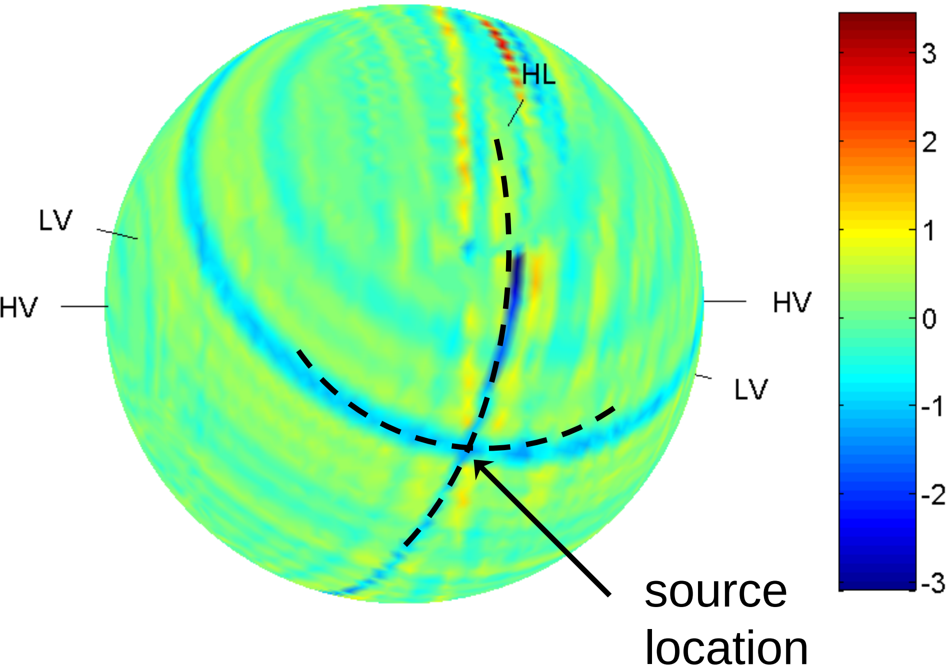
Sky Maps: Incoherent Energy / DOF



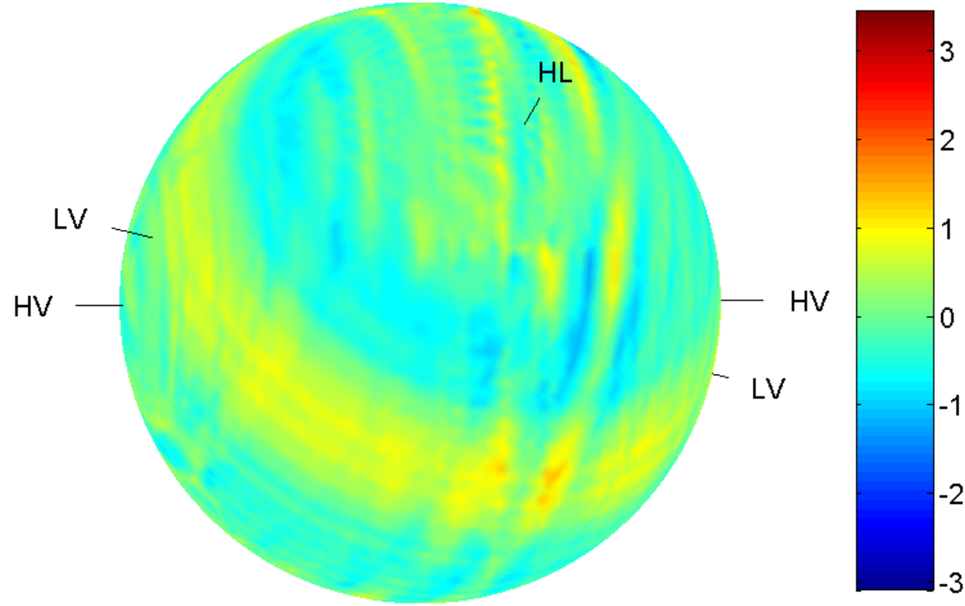
- Incoherent energy maps almost identical.
- E_{inc} structure reflects network geometry, not signal.

Sky Maps: (E_{null} – E_{inc}) / DOF

GWB



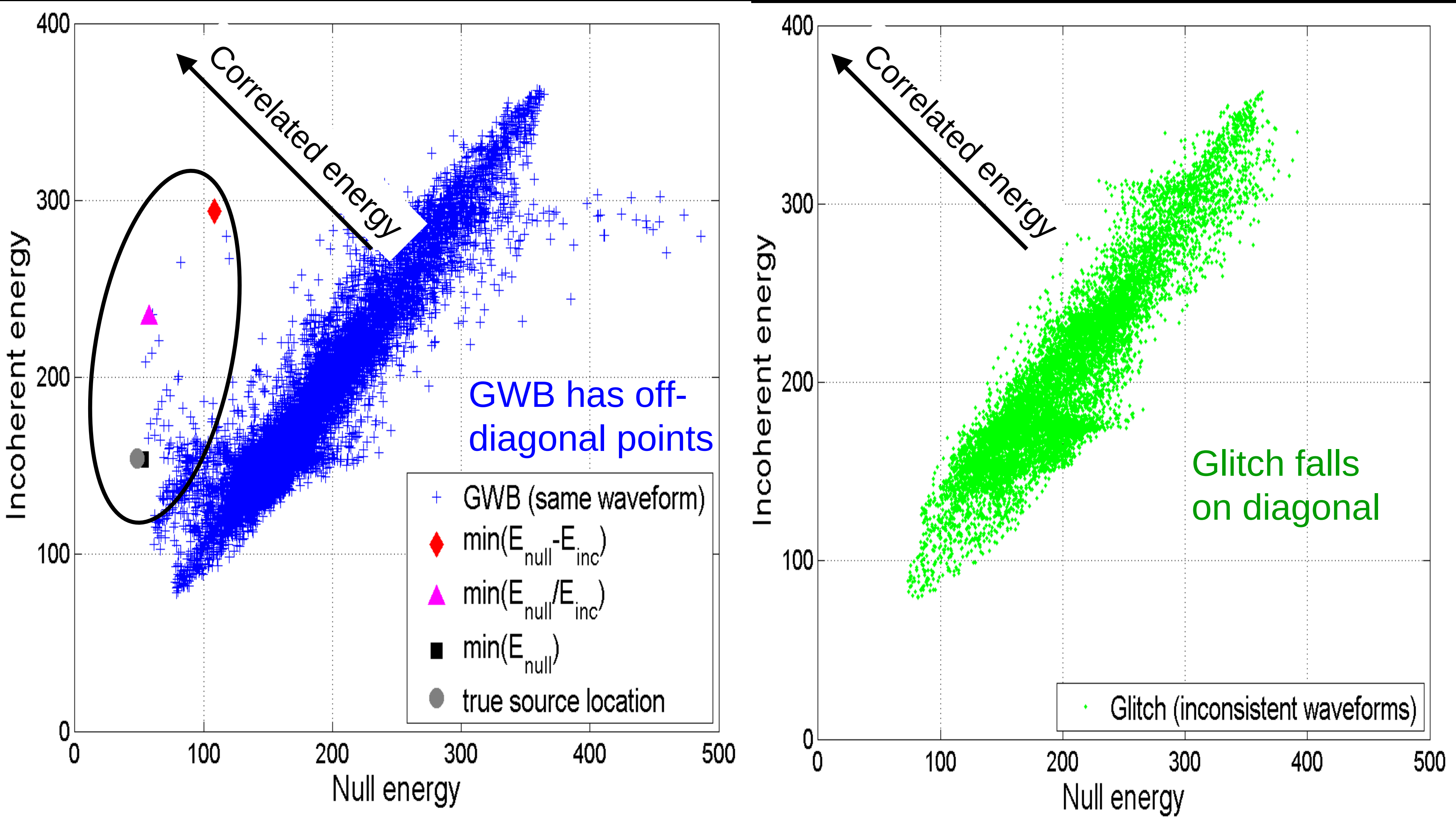
Glitch



- Removing E_{inc} makes signal interference fringes, source location clearer.
- Glitch has no strong interference fringes.

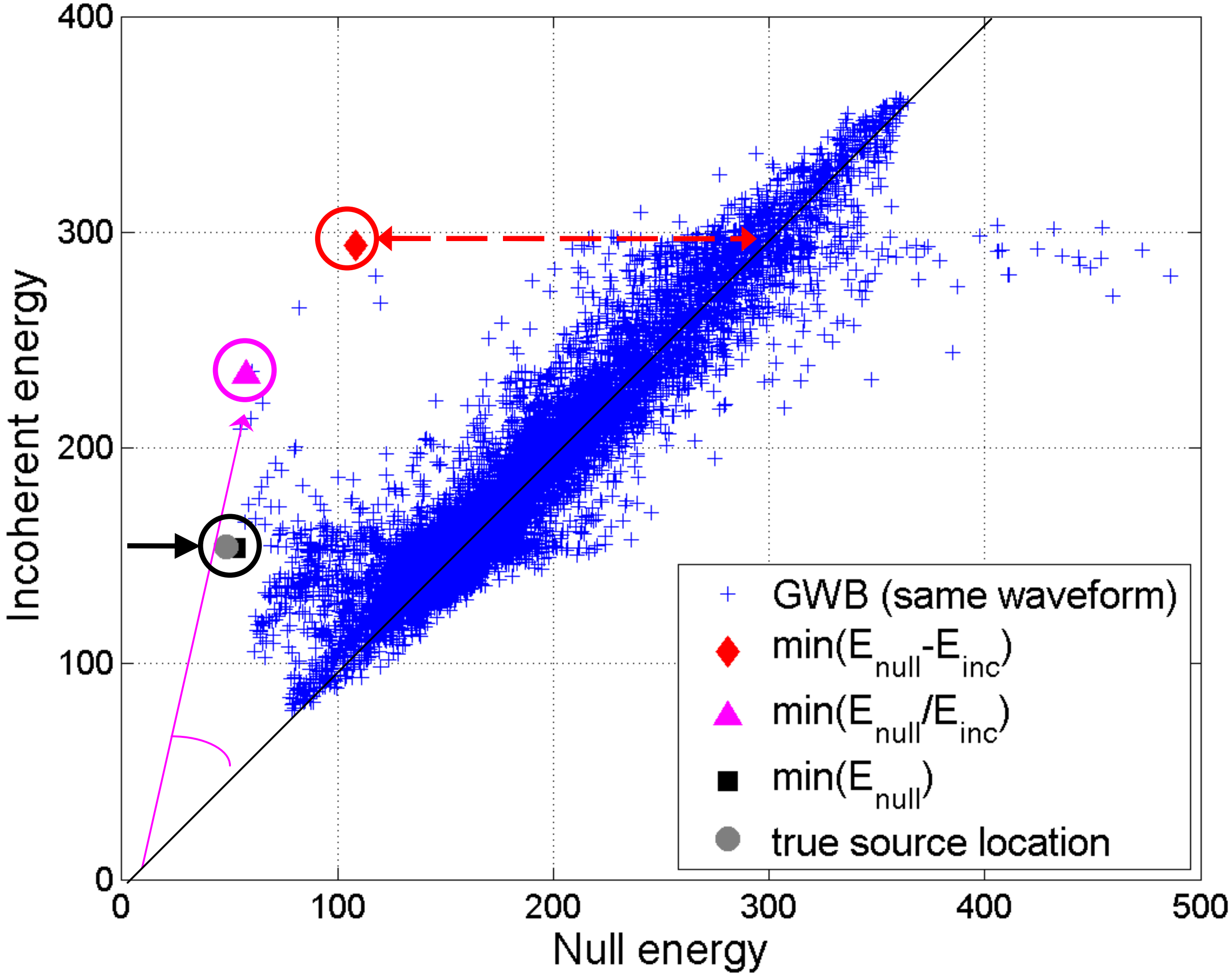
GWB vs. Glitch

- H1-L1-V1 network
- 10^4 sky positions in each plot
- use DFMs for GWBs *and* glitches



Measures of Correlation

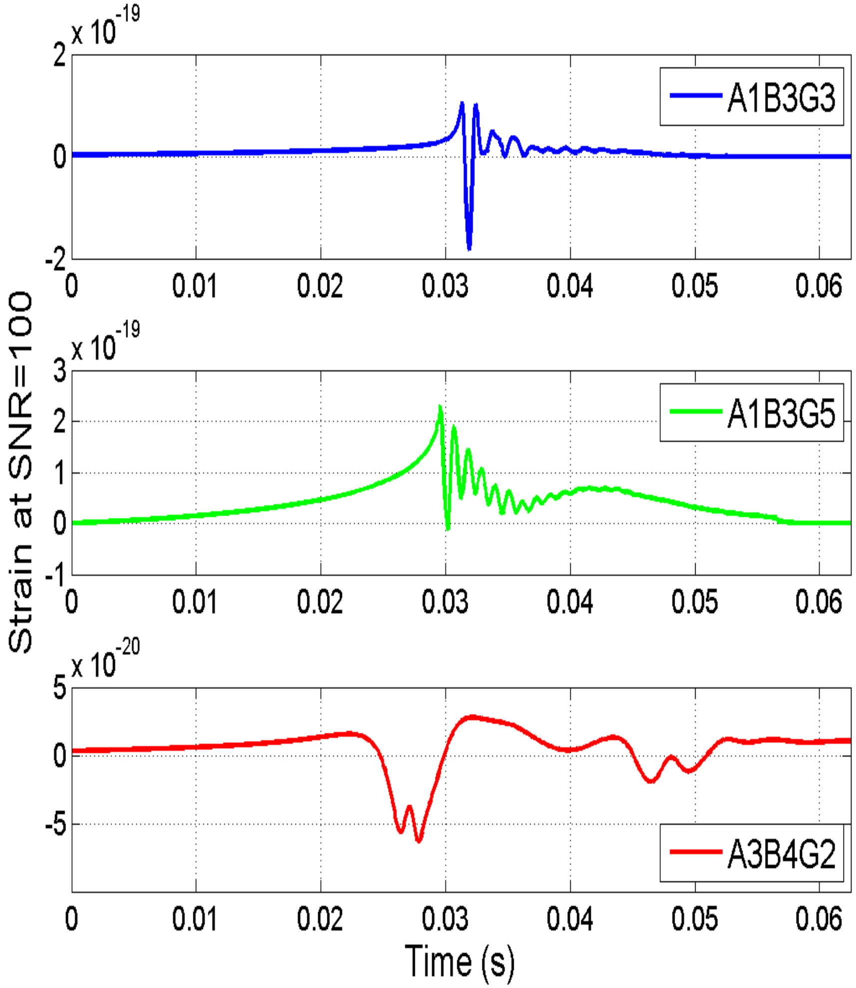
- **E_{null} - E_{inc}**
  "total amount of energy cancelled in null stream"
- **E_{null} / E_{inc}**
  "fraction of energy left in null stream"
- **E_{null}**
  original Gursel-Tinto null energy



New Since GWDAW

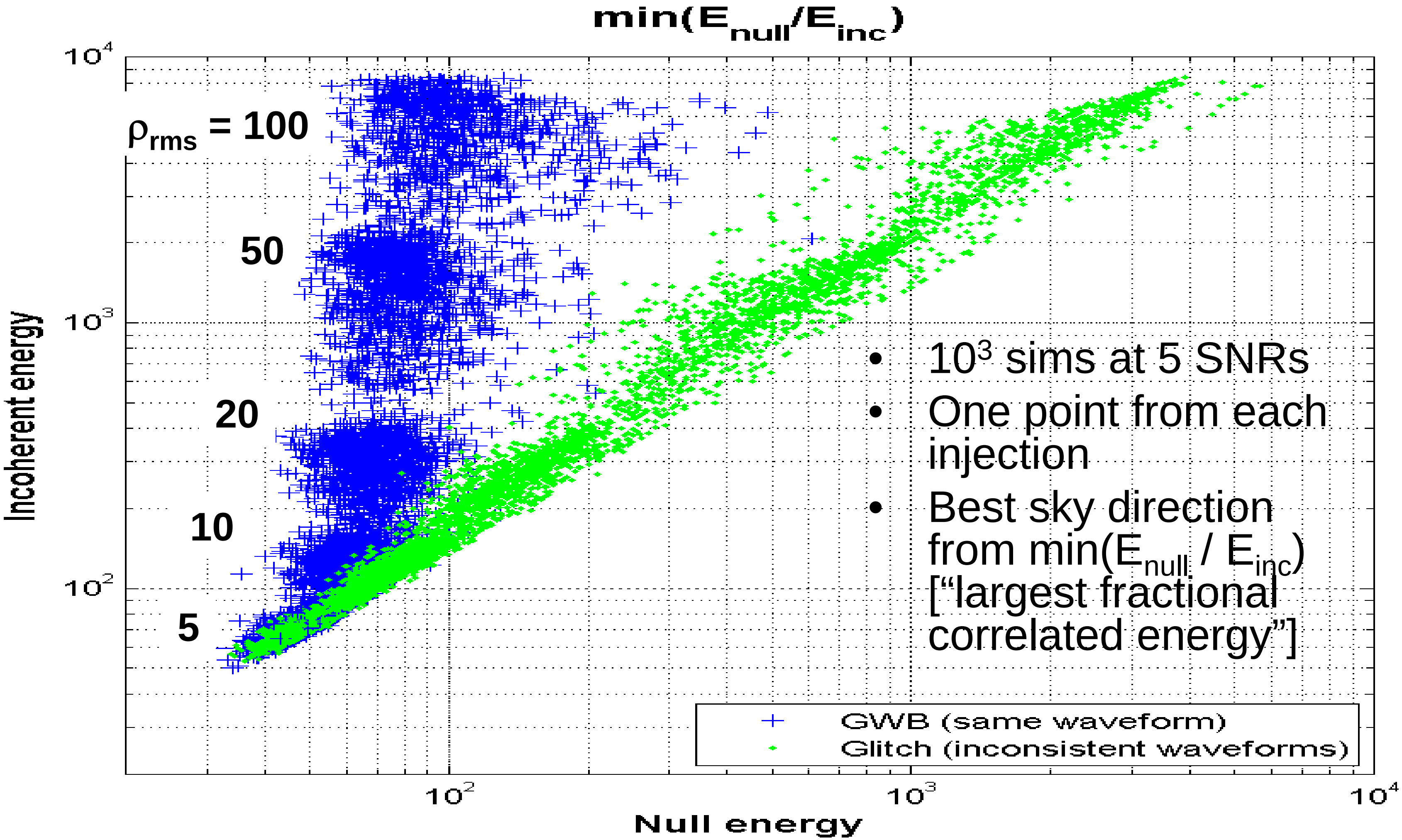
- At GWDAW:
  - Preliminary results for GWBs vs. “pathological” glitches with same time delays, SNRs.
  - H1-L1-Virgo network @ design sensitivity
- Code improvements
  - better whitening, implement data overlapping
- More simulations
  - 10^3 GWBs and glitches at each of 5 SNRs.
- Testing more statistics
  - $E_{null} - E_{inc}$ “total amount of energy cancelled in null stream”
  - E_{null} / E_{inc} “fraction of energy left in null stream”
  - E_{null} original Gursel-Tinto null energy

Waveforms: 3 DFMs (supernovae)



- Simulating a GWB:
  - Pick one DFM and add to all three IFO data streams
- Simulating a glitch:
  - Add different DFM to each IFO data stream
  - Pathological glitches! Use same time delays, amplitudes as GWB.
- Shows method does not require that GWBs “look different” from glitches.

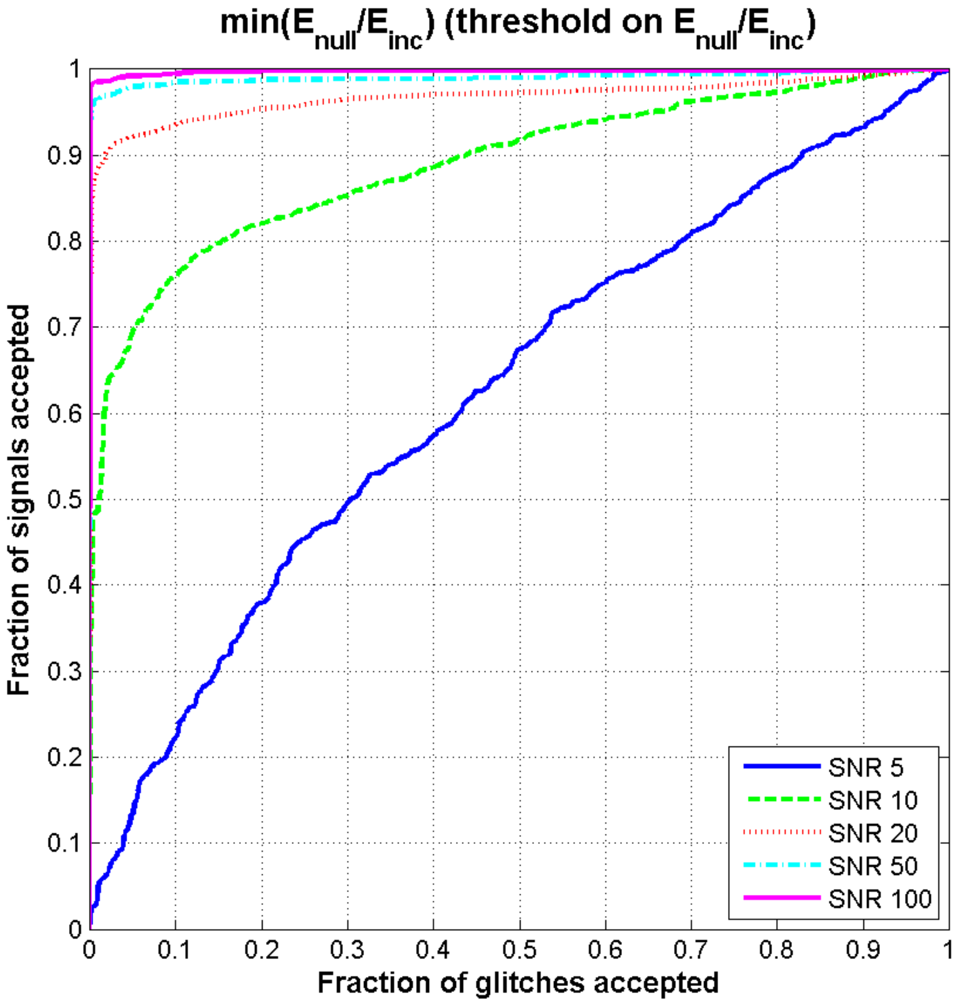
GWBS vs. Glitches: Most Correlated Positions

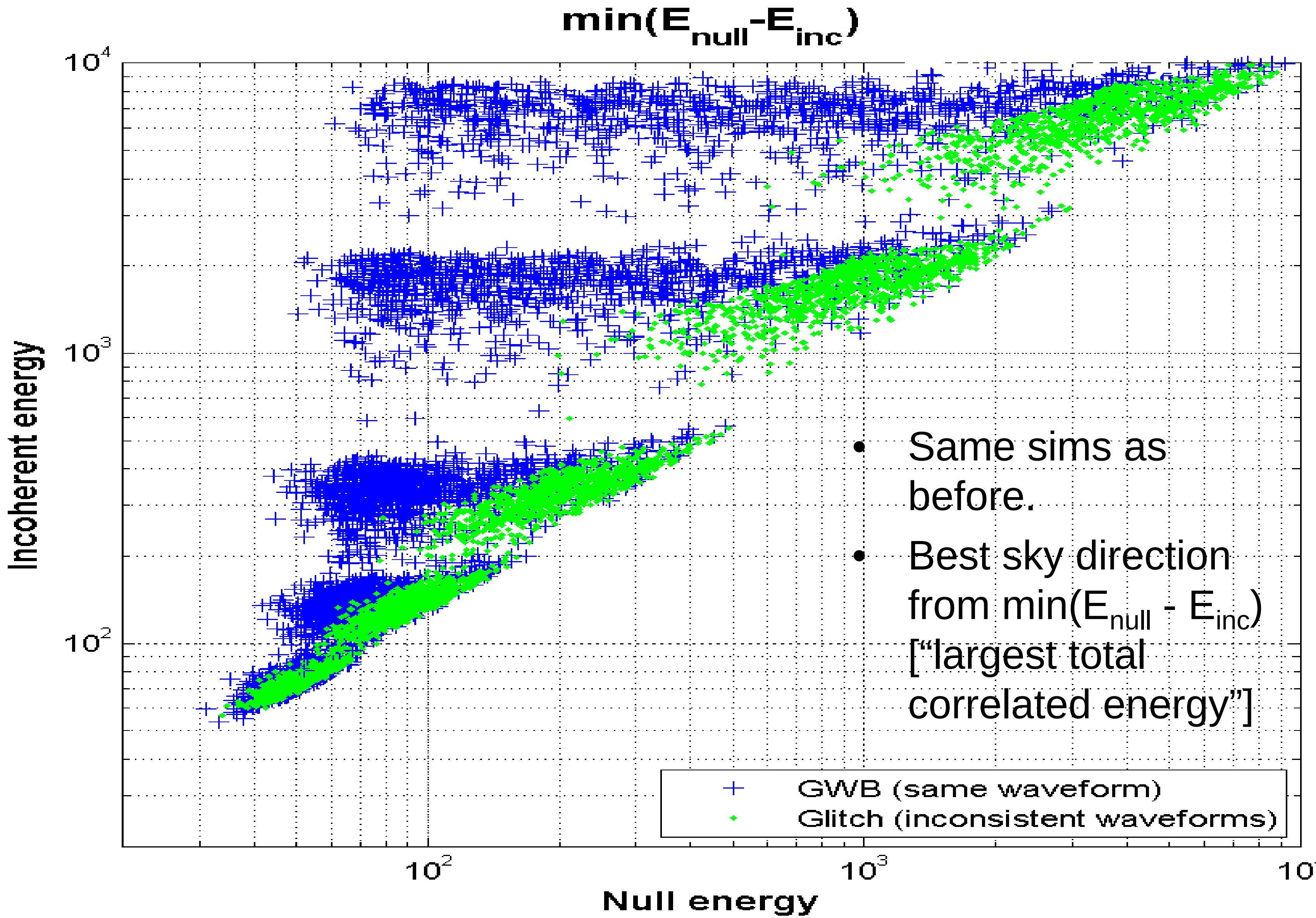


- 10^3 sims at 5 SNRs
- One point from each injection
- Best sky direction from $\min(E_{null} / E_{inc})$ ["largest fractional correlated energy"]

ROC: Distinguishing GWBs from Glitches

- Test efficacy vs SNR of signal.
  - For comparison, WaveBurst in S3 had 50% detection efficiency for SNR > 15-20.

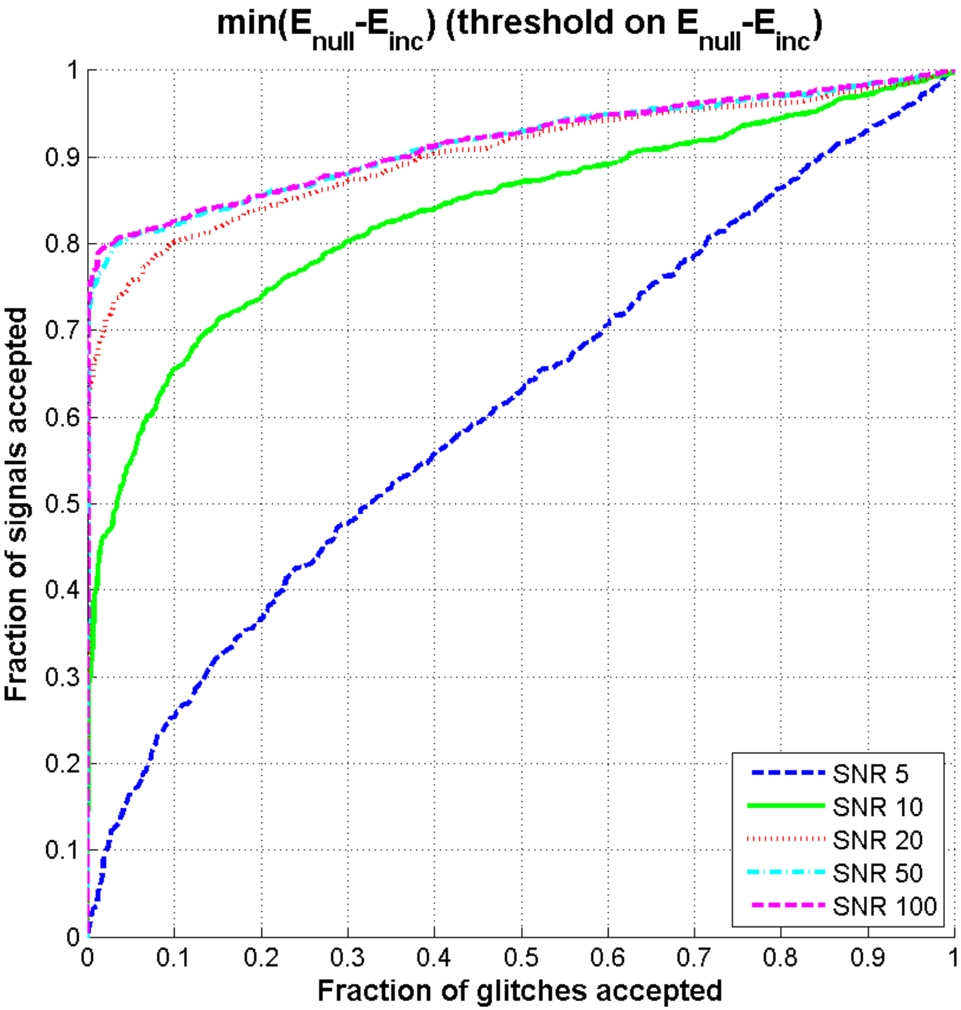


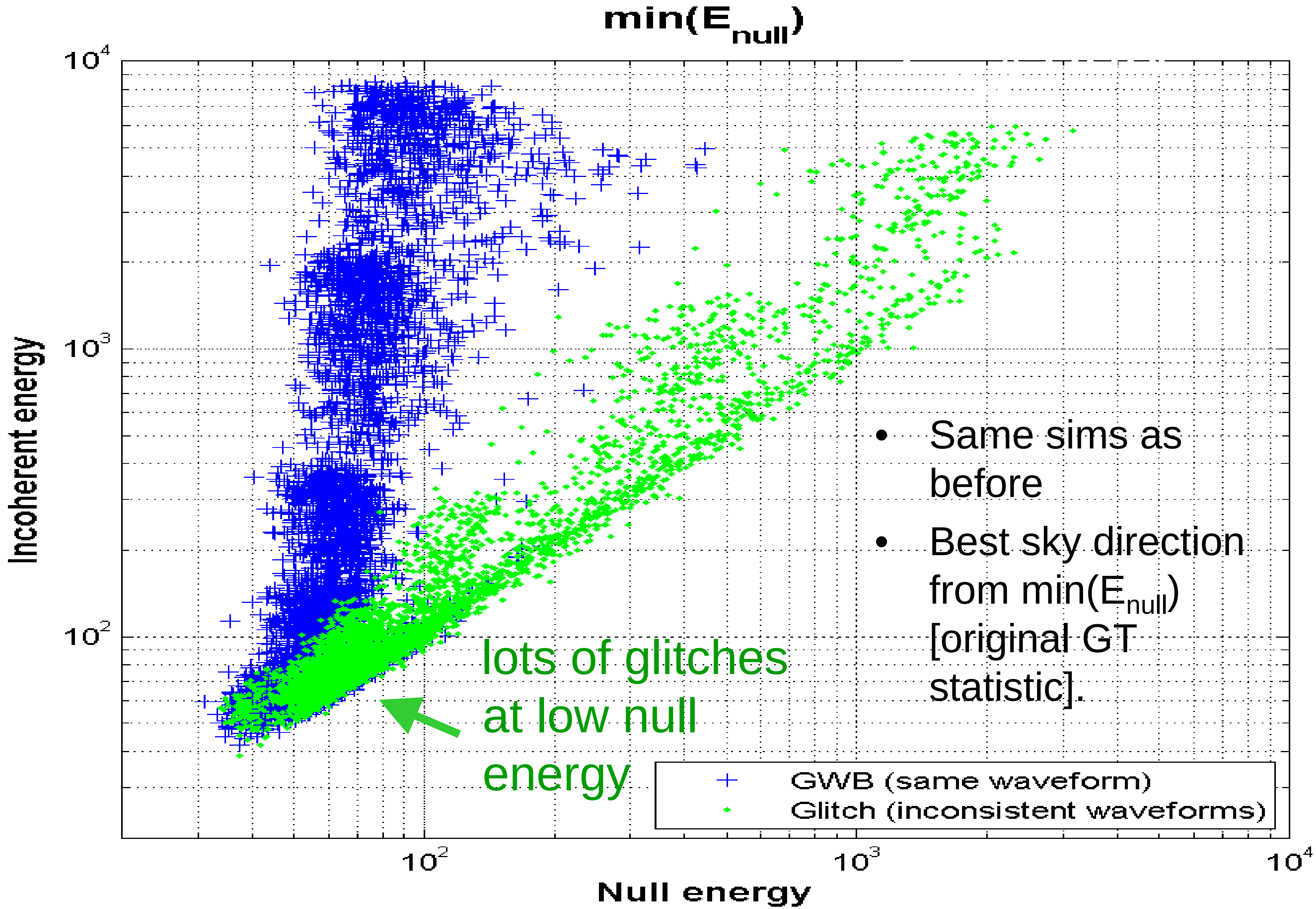


- Same sims as before.
- Best sky direction from min(E_{null} - E_{inc}) ["largest total correlated energy"]

Energy Difference: $E_{null} - E_{inc}$

- Not as good as fractional energy E_{null}/E_{inc}.

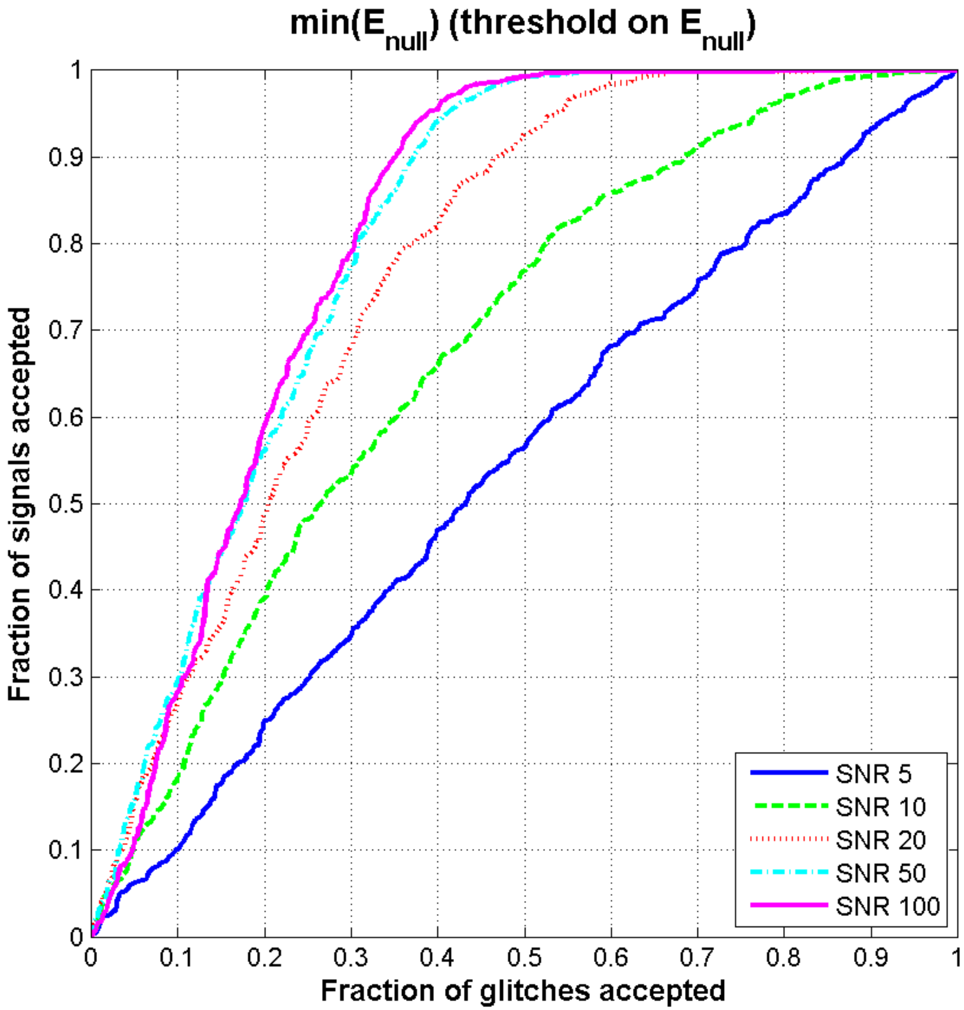




- Same sims as before
- Best sky direction from min(E_{null}) [original GT statistic].

Using only Null Energy (GT)

- Very poor at discriminating GWBs from glitches.



Conclusions

- Generalized Gursel-Tinto null stream technique to arbitrary detector networks.
  - Formally equivalent to likelihood procedure of Klimenko et al. (2005).
- Added second energy measure: "incoherent energy" E_{inc}.
  - Based on energy expected in null stream for *uncorrelated* signals (as opposed to GWBs)
- Fractional energy cancelled in null stream looks promising for discriminating GWBs from glitches.

To Do List

- Paper will be out to LSC this week
  - target journal PRD
- Apply to real data (LIGO-GEO / LIGO-Virgo)
- Source localization and waveform extraction tests
  - SURFs from 2005 & 2006