LIGO

Implementation of LIGO's Triggered Burst Search

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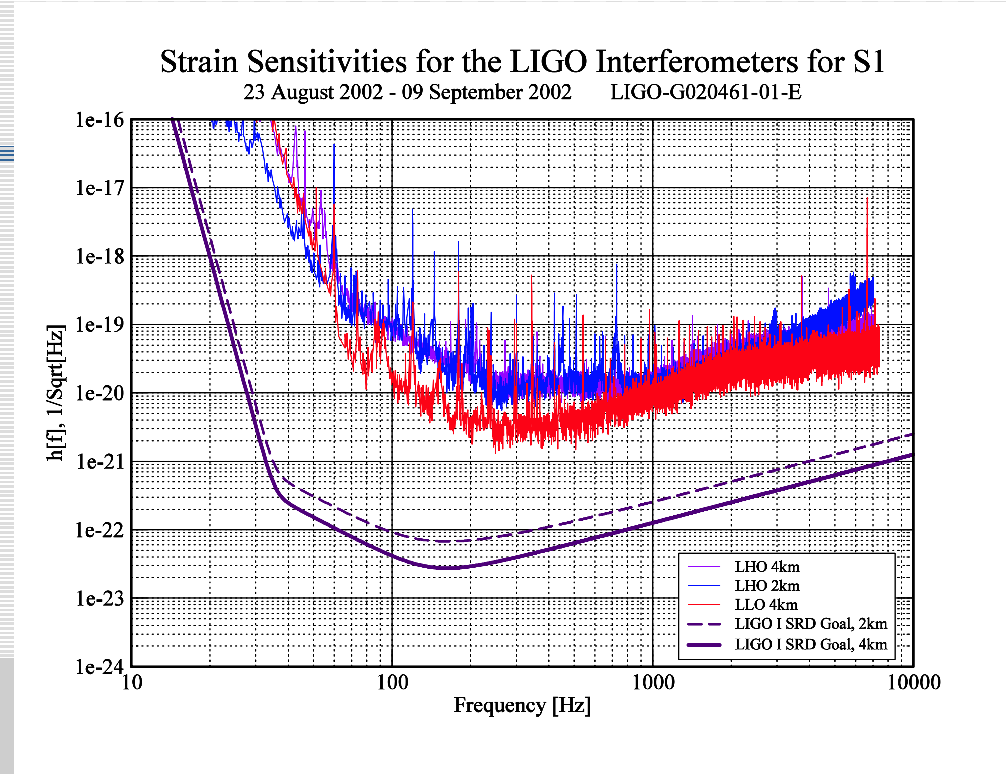
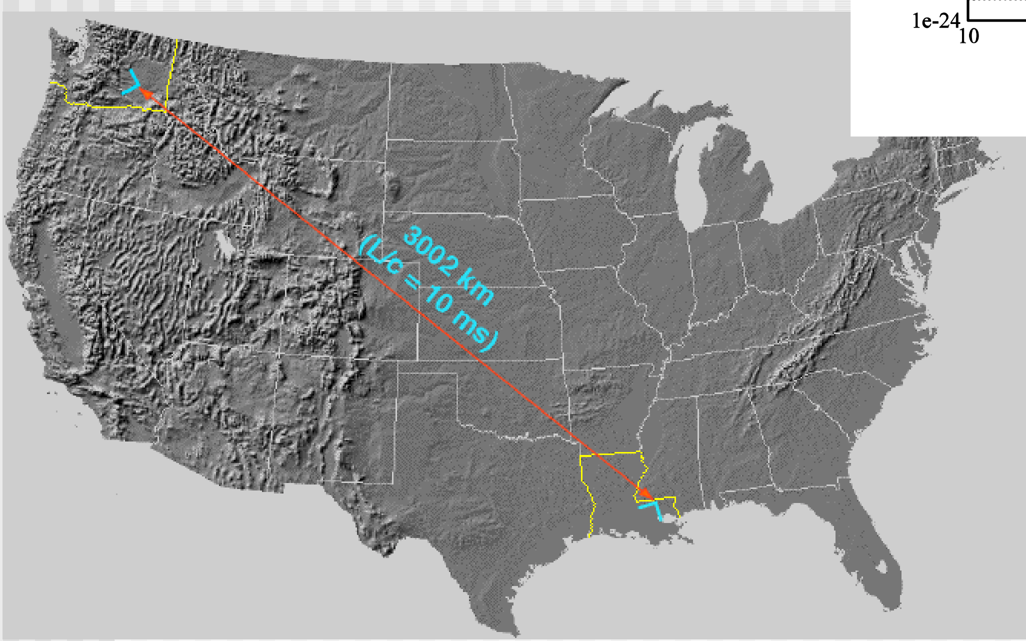
Reed College, Portland, OR

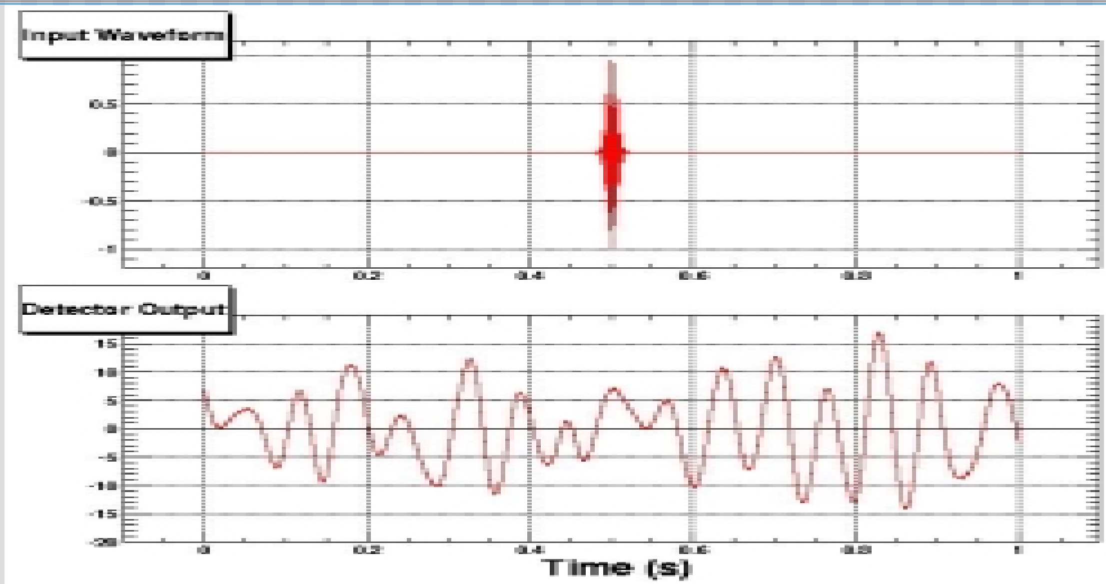
LIGO in Brief





LIGO interferometers (IFOs) measure gravity waves in strain (h) – *the amplitude of perturbation about Minkowski spacetime*

Triggered Burst Search: Motivation



Gravity Wave Bursts (GWBs) are by definition unmodeled!!

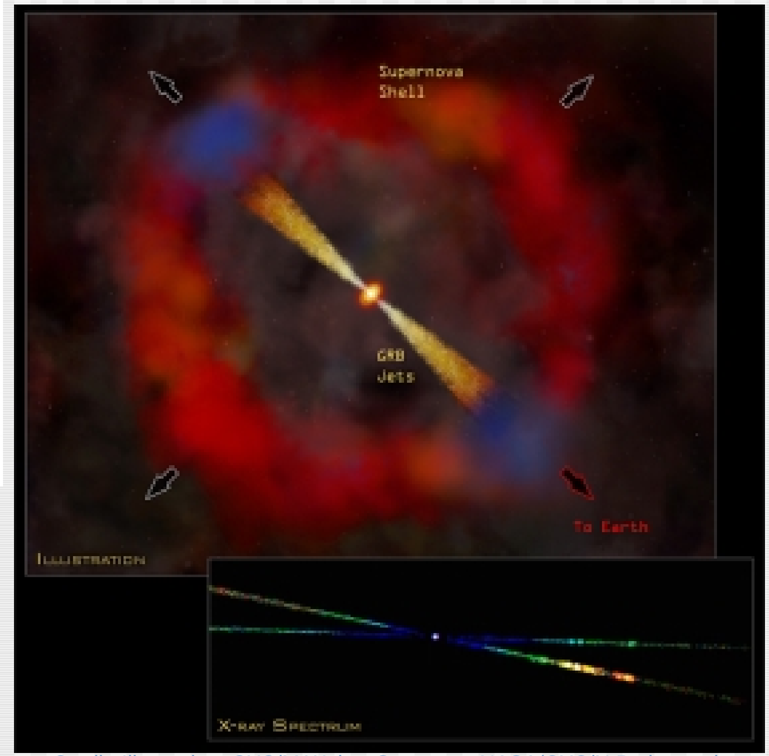
Question:

How can we use what we know[†] (astrophysics) to look for things we don't know (GWBs)?

Answer:

We can use astrophysical "triggers" to point out likely times for GWB events

GRB020813 Illustration

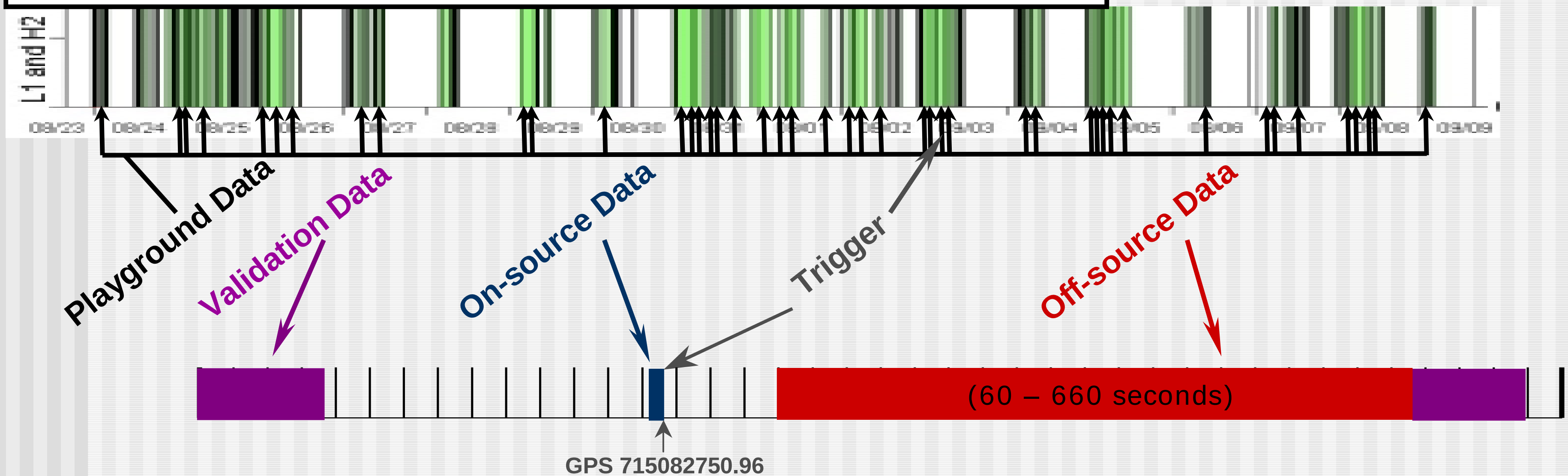


Credit: Illustration: CXC/M.Weiss; Spectrum: NASA/CXC/N.Butler et al.

† or what we think we know

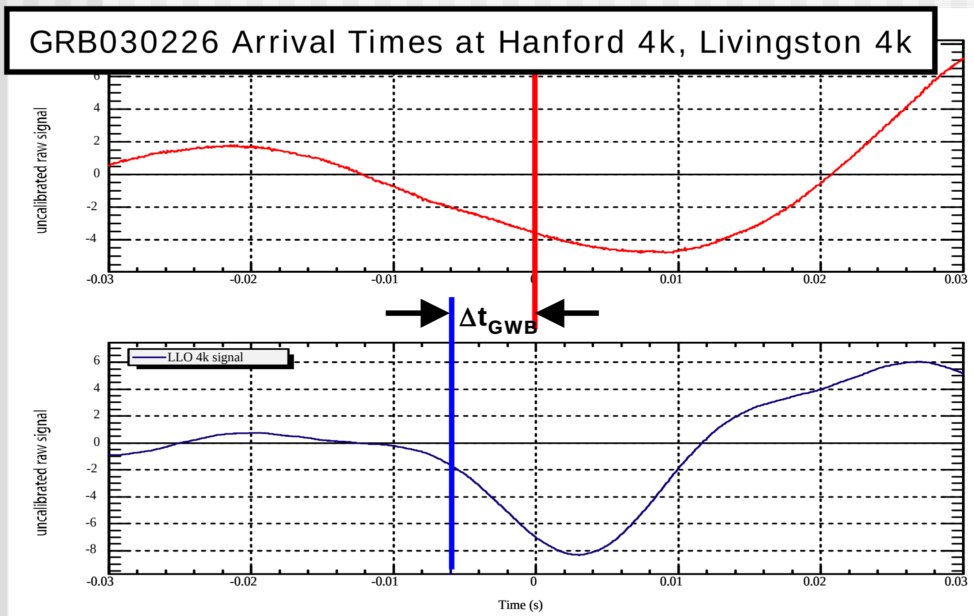
Triggered Burst Search: Overview

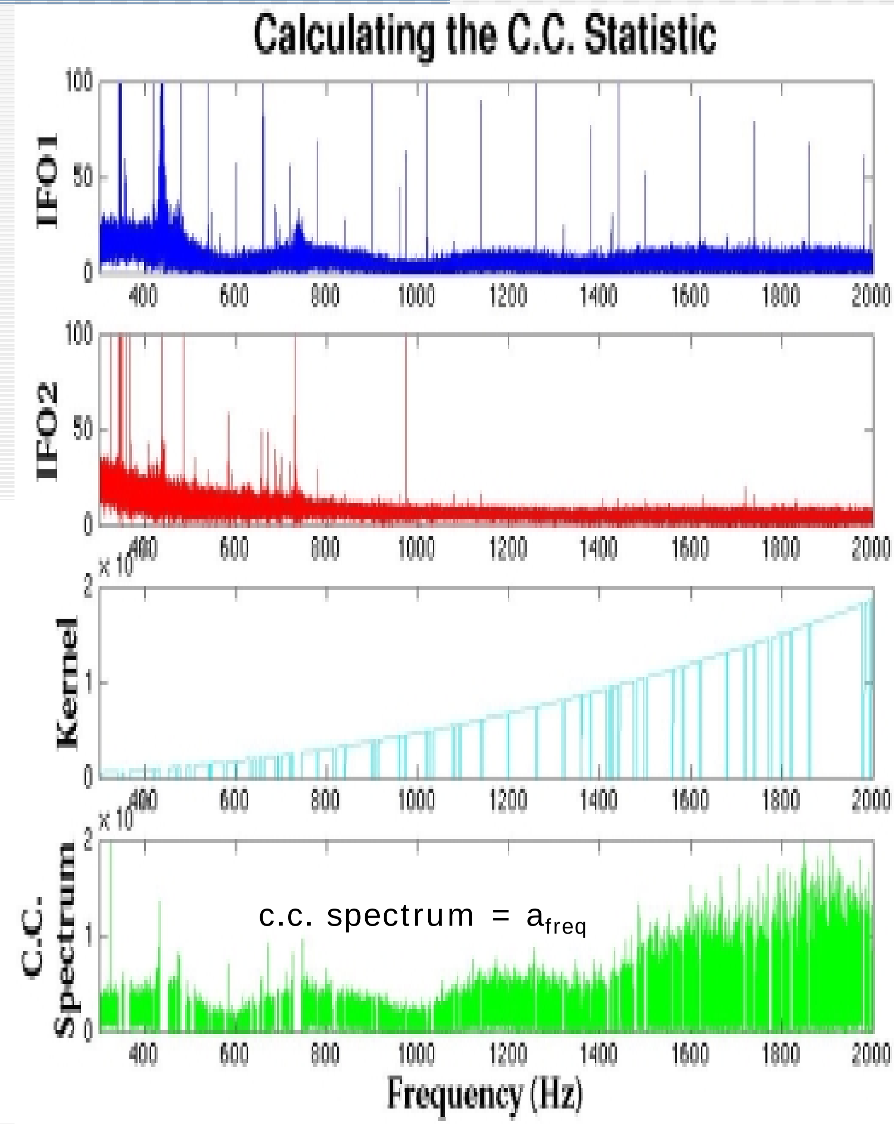
How do we use astrophysical triggers?



- Trigger time distinguishes “on-source” data from “off-source” data for each IFO.
- “On-source” Data: GWB likely
  - GWB arrives before trigger
  - GWB duration is short (~1ms), but exact arrival time is uncertain!
- “Off-source” Data: GWB **not** likely
  - Well past any model-predicted GWBs
  - Close to trigger time to ensure IFO hasn’t changed
- How can we use the fact that LIGO has three similar interferometers?

1. Filter the data for each IFO
2. Translate source directions to Δt_{GWB}
3. Shift data by Δt_{GWB}
4. FFT & cross-correlate
5. "c.c. statistic" – Σa_{freq} over some frequency band
6. Compare the c.c. statistic for "on-source" data vs. "off-source" data





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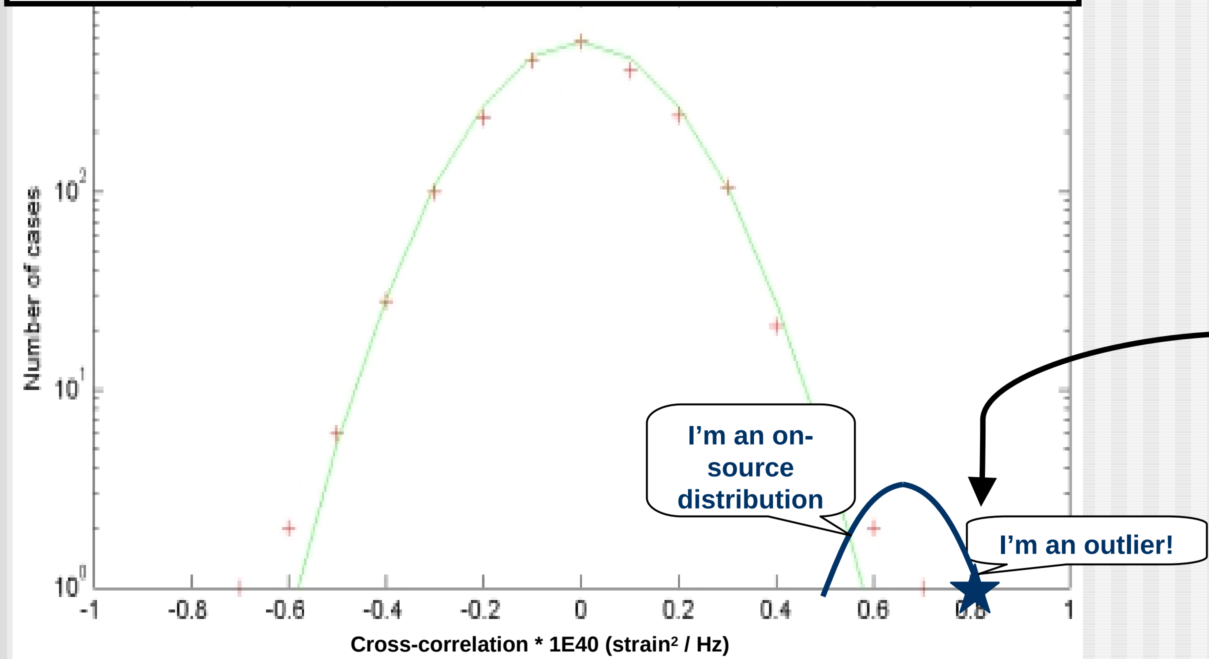
Sensitivity of the Technique

Expected sensitivity using “off-source” c.c. distribution at a random time over frequencies (200-600Hz):

(95% confidence) ~ √(1.65σ) = 5.18E-21 (strain/√Hz)

“Off-source” distribution of c.c. statistics
(mean = -0.001313, std. dev. = 1.62932E-41)

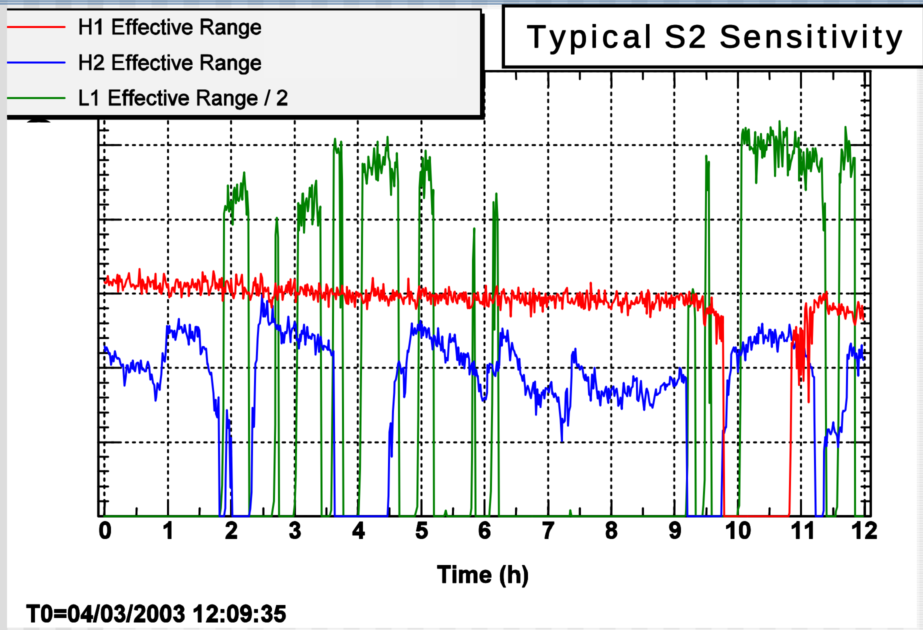


Positive GWB signal would compare as an outlier (single trigger case),

OR

as a distribution with **+**-shifted mean (multiple trigger case)

Current Analysis Issues

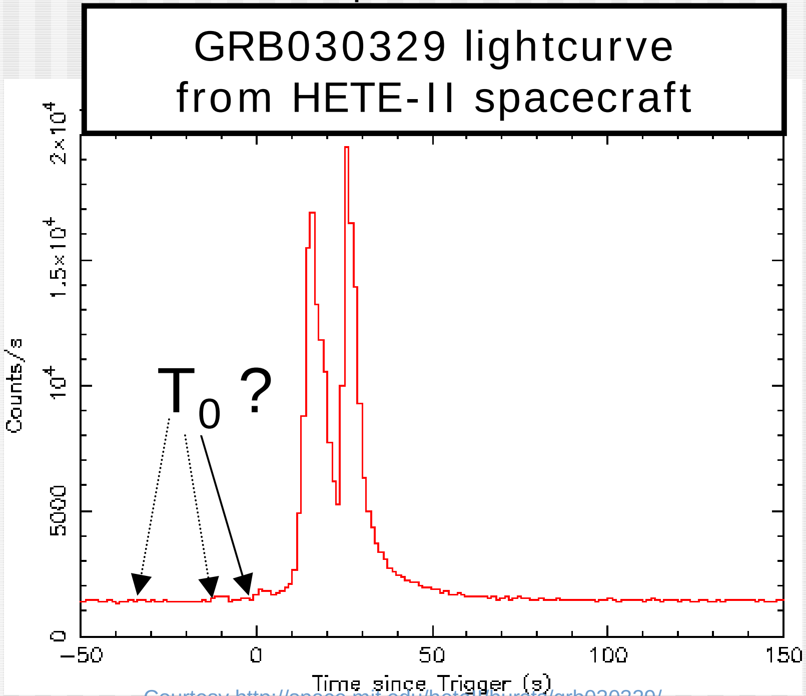


Issues which cannot be controlled:

- stability/ sensitivity of the two-IFO system

Variations within trigger sources:

- GWB duration
- GWB source direction/polarization ("antenna pattern")
- GWB source frequencies



Courtesy http://space.mit.edu/hete/bursts/grb030329/

Issues for improving the method:

- Combining single-event results
- Meeting conditions for a multi-trigger analysis
- Dealing with unknown GWB arrival times/durations
- Evaluating tolerance to non-stationarity
- Combining 3+ detectors
- Incorporating current models/classes of models

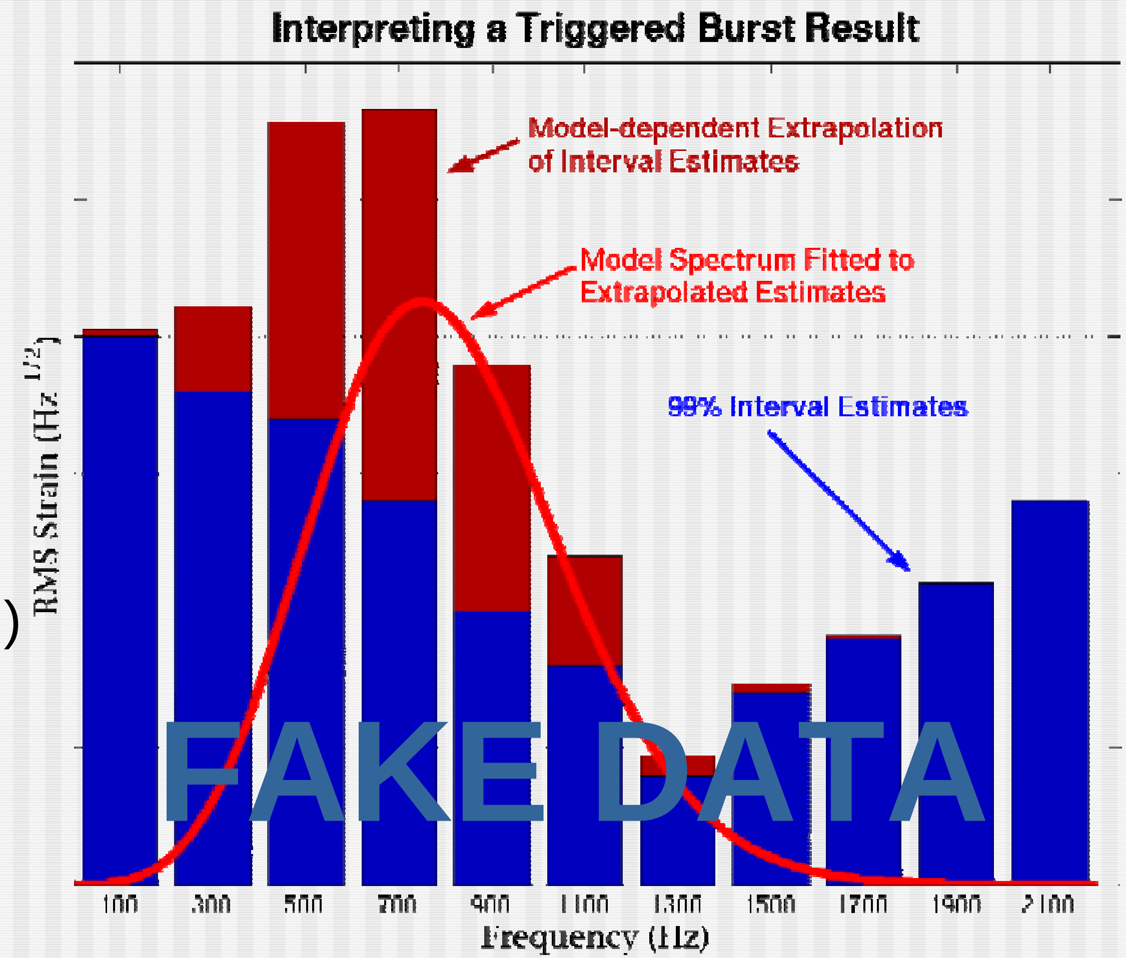
Summary

- Detecting GWB sources can be optimized using astrophysical triggers
- Cross-correlating data from two similar detectors elicits the coherent GWB signal
- Comparing “on-source” and “off-source” c.c. statistics yields the GW strain associated with a trigger
- Obtaining the associated GW strain can test models of GRB phenomena

Possible questions:

- How to deal with differences in IFO response functions
  - Scaling factor proportional to the average calibration difference
- Can you weight the strain with the observed distance to get energy at the source?
  - Possibly
- How can you test specific models of GRBs?
  - Slides 11,12
- What are antenna patterns, and why should they look like that?
  - Slide 13
- What are some models of GRBs?
  - Slide 14
- What are the causes for non-stationary frequencies?
  - Slide 15, but no pictures!
- Why is stationarity/Gaussianity important?
  - Slide 16
- What is the size of burst we injected on slide 3?
  - h_{peak} =9.5E-19
- How sensitive to error boxes for the sources?
  - Depends on the difference in light travel time; approx. 60μsec intervals
- Response time of the IFO to the GW?
  - On the order of μsecs

Interpreting Model-Dependency



- Final result is an estimate of the observable band-limited rms strain (h_{rms}) associated with the trigger
- Apply to an approximate waveform to test models
- Need to account for missing non-stationary frequencies!

Incorporating Model-Dependency

Various Options:

- Divide triggers into groups with similar characteristics
- Use a model-dependent “kernel” in cross-correlation
- Tune to different integration lengths, arrival times

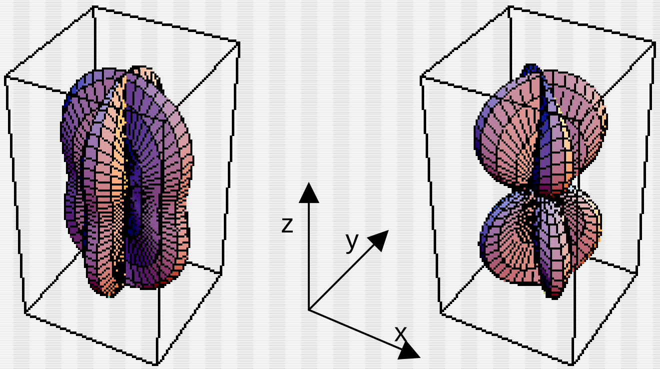
Pictures:

- 4-spectra plot with IFO1, IFO2, kernel, cross-correlation

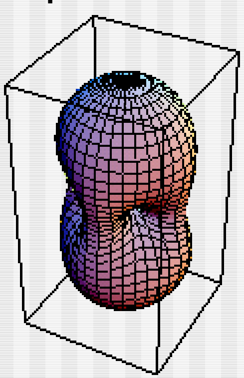
LIGO's Antenna Patterns

- Polarization-dependent
- Optimally sensitive to GWs propagating normally to detector
- Minimally (but not always zero!) sensitive in the plane of the detector
- Zero sensitivity in the plane of the detector, 45° between the arms

two polarizations: '+' and '×'



unpolarized



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GRB Models

Methods to produce GRBs:

- “Exploding Fireball”
- “Black Hole/Magnetic Torus”
- “Cannonball”

GRB progenitors:

- Hypernovae
- Merging of a binary system

Sources of non-stationarity

Figures:

- Violin mode resonances
- Some servo filter response functions

- Mechanical thermal resonances (suspending wire, internal modes of the optics)
- Servo resonances
- 60Hz electronics noise
- Acoustic coupling to the laboratory

Why Gaussianity is Important

- Gaussianity yields predictable statistics
- Gaussianity implies stationarity on a given timescale
- Gaussianity allows several triggers to be combined for better certainty

Gaussianity before and after data conditioning