Searching for Alternative GW Bursts

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Workshop on Gravitational Wave Tests of Alternative Theories of Gravity in the Advanced Detector Era

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Outline

- Philosophy
- How GW burst searches are done
- Ways that burst searches can test alternative theories of gravity
- Questions

GW Burst Search Philosophy

We're listening to the whole sky – who knows what's out there?

Models are OK, but don't put *too* much faith in them!

Goal: be able to detect *any* signal

… if it has sufficient power within the sensitive frequency band

… and is "short"

… allowing for alternative theories of gravity (ATGs) ???

An ATG could affect:

- What specific signals are received from a given source
  - Dynamics of the source
  - Coupling to GW modes
  - Signals measured by detectors
- What astrophysical systems will produce detectable signals
- What data analysis methods are suitable

GW burst search methods

Types of GW Burst Searches

Modeled burst search

Targets:

- Black hole ringdown
- Neutron star ringdown
- Cosmic string cusp
- Parabolic encounter

Can use matched filtering

Issues generally similar to CBC searches (see later session)

Generic burst search

Targets:

- High-mass binary BH merger
- Core collapse supernova
- Signals deviating from model expectations
- Other unexpected or unmodeled sources

Use robust detection methods that do not rely on having a model of the signal

“Excess Power” Burst Search Methods

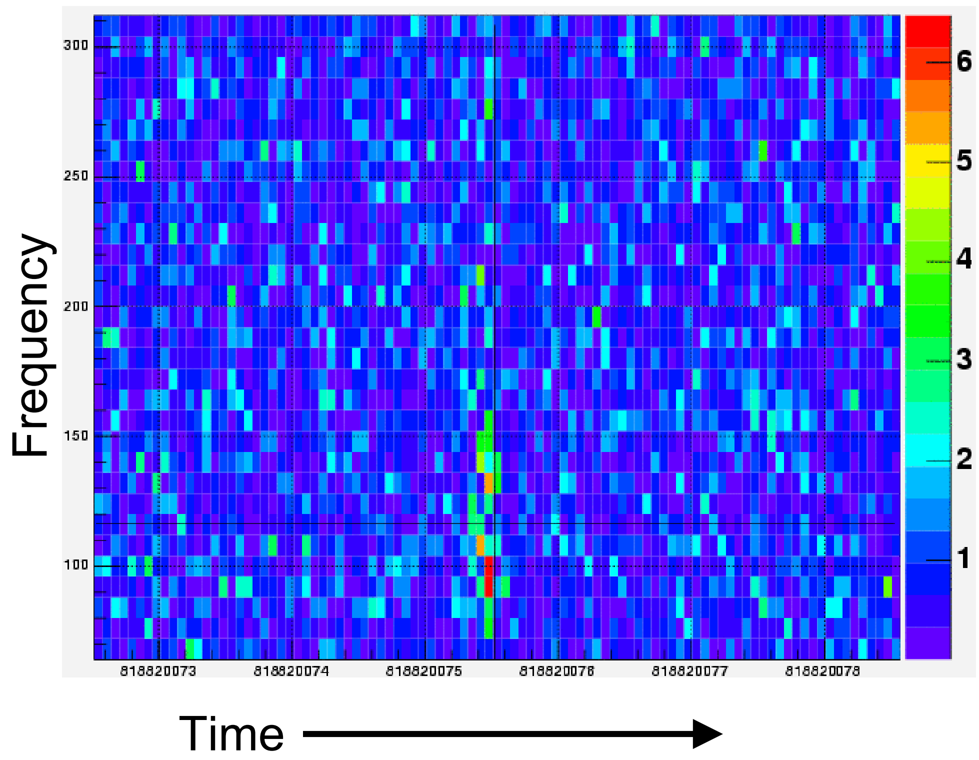
Decompose data stream into time-frequency pixels

Fourier components, wavelets, “Q transform”, etc.

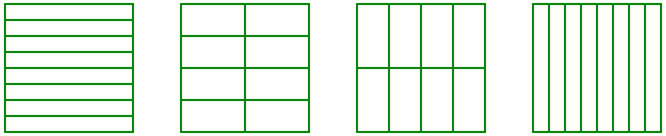
Several implementations of this type of search

Normalize relative to noise
as a function of frequency

Look for “hot” pixels or clusters of pixels

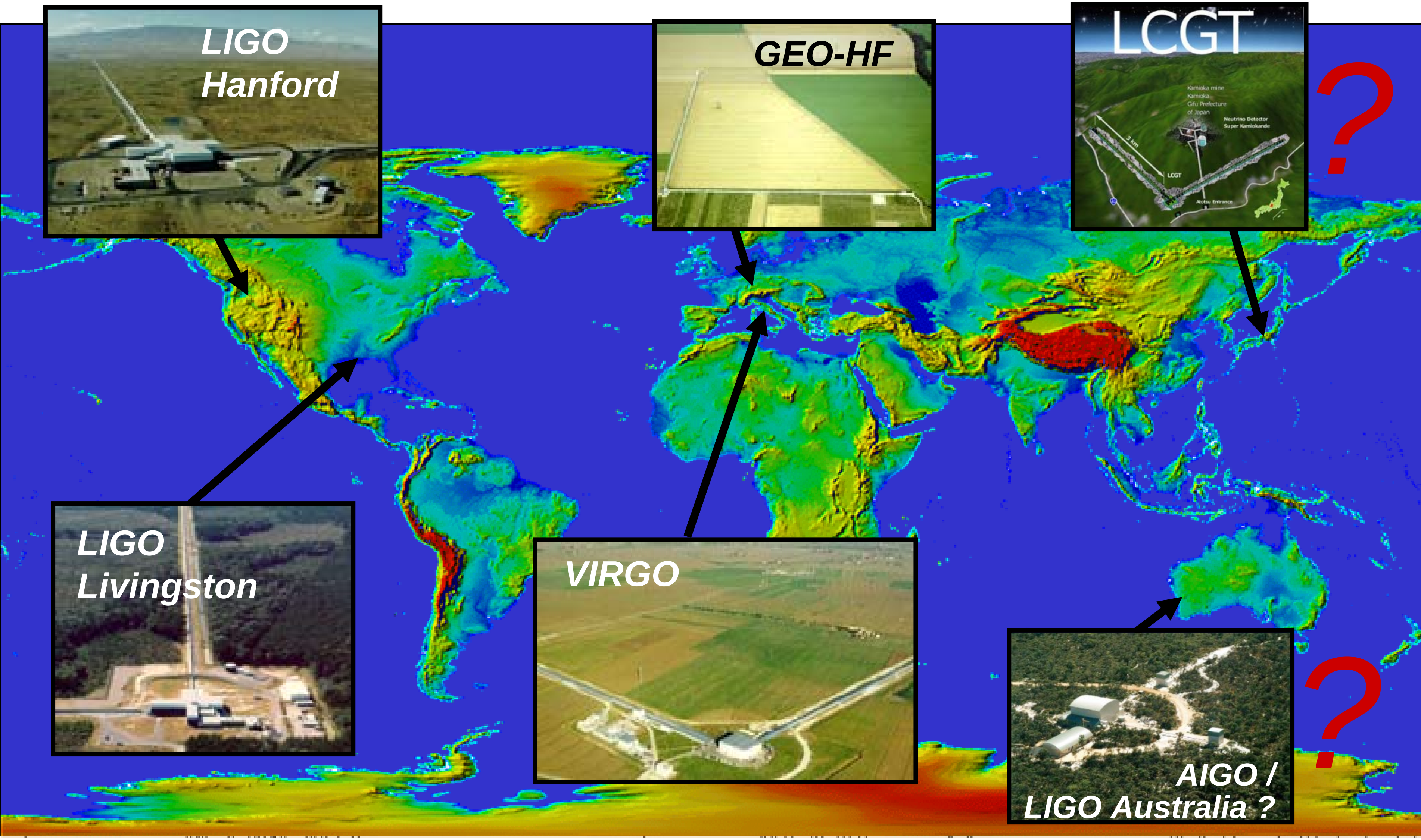


Can use multiple (Δt,Δf) pixel resolutions



…

The Advanced Detector Network



Signal Consistency Tests

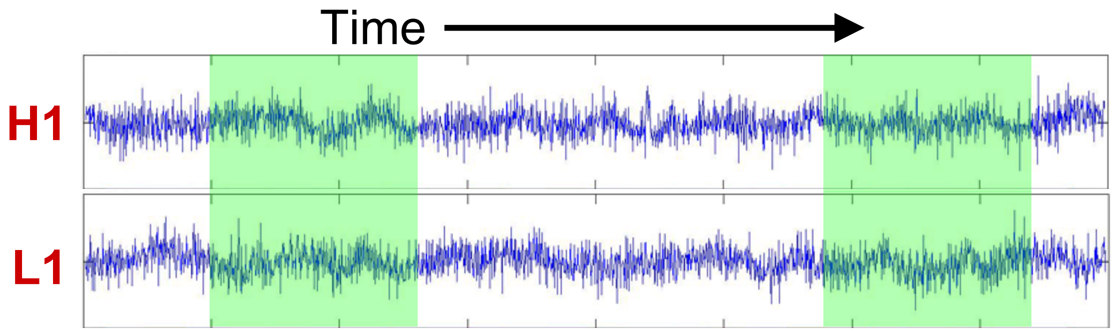
Crucial since a GW burst may look just like an instrumental glitch !

Coincidence

Require signals in different detectors to have compatible times, frequencies, amplitudes and/or other waveform properties

Cross-correlation

Look for same signal buried in two data streams



Checks for consistent waveform shape, regardless of relative amplitude

Integrate over a time interval comparable to the target signal

Signal Consistency Tests

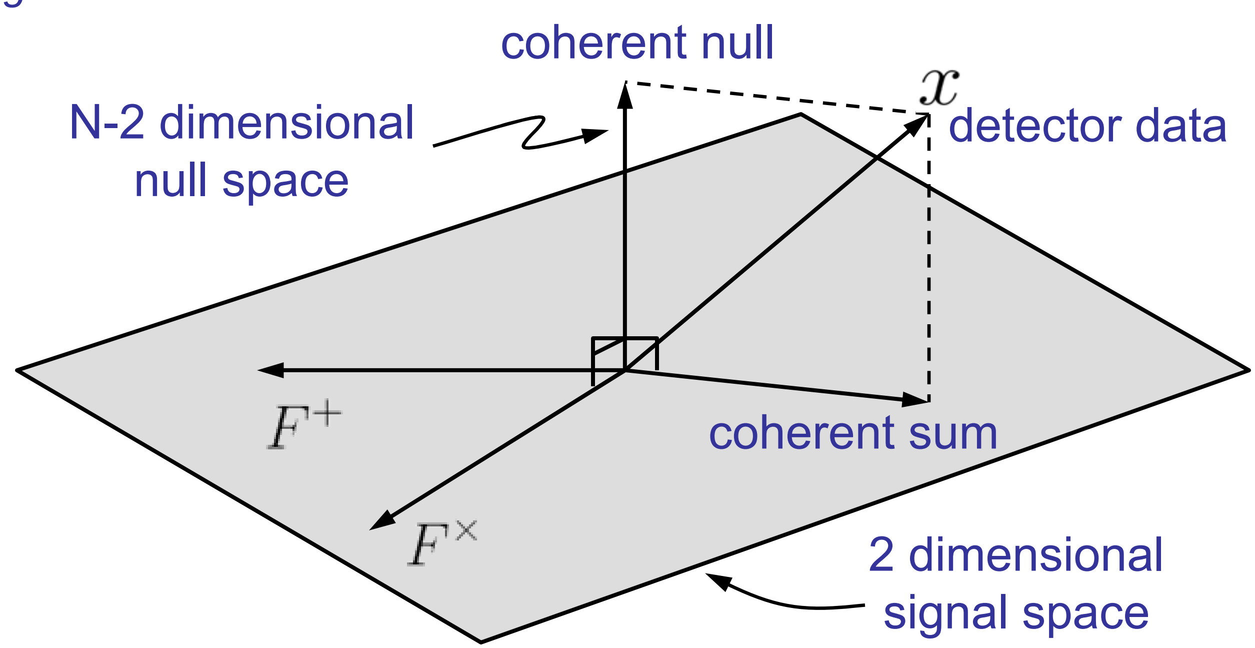
Coherent Analysis

$$\begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_N \end{bmatrix} = \begin{bmatrix} F_1^+ & F_1^\times \\ F_2^+ & F_2^\times \\ \vdots & \vdots \\ F_N^+ & F_N^\times \end{bmatrix} \begin{bmatrix} h_+ \\ h_\times \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ \vdots \\ n_N \end{bmatrix}$$

data = *response* x *signal* + *noise*

Coherent sum:
Find linear combinations of detector data that maximize signal to noise ratio

Null sum:
Linear combinations of detector data that cancel the signal provide useful consistency tests.



Big Caveat for Coherent Burst Searches

If general relativity is correct:

Each detector measures a linear combination of $h_+(t)$ and $h_\times(t)$

$\Rightarrow$ Data from 2 sites can uniquely determine $h_+(t)$ and $h_\times(t)$ for an arbitrary signal, *in the absence of noise and if the arrival direction is known*

$\Rightarrow$ Data from 3 or more sites *over-determines* $h_+(t)$ and $h_\times(t)$ if the arrival direction is known

Can treat this as a maximum likelihood problem

Maximize over arrival directions

Regulator can penalize physically unlikely signal hypotheses

If general relativity is *not* correct:

Use an alternative coherent search, or live with degraded sensitivity, or just rely on a non-coherent search

Ways that burst searches can test for ATGs

Wave Propagation Speed

In ATGs, GW speed may be different from speed of light

Can be slower or faster !

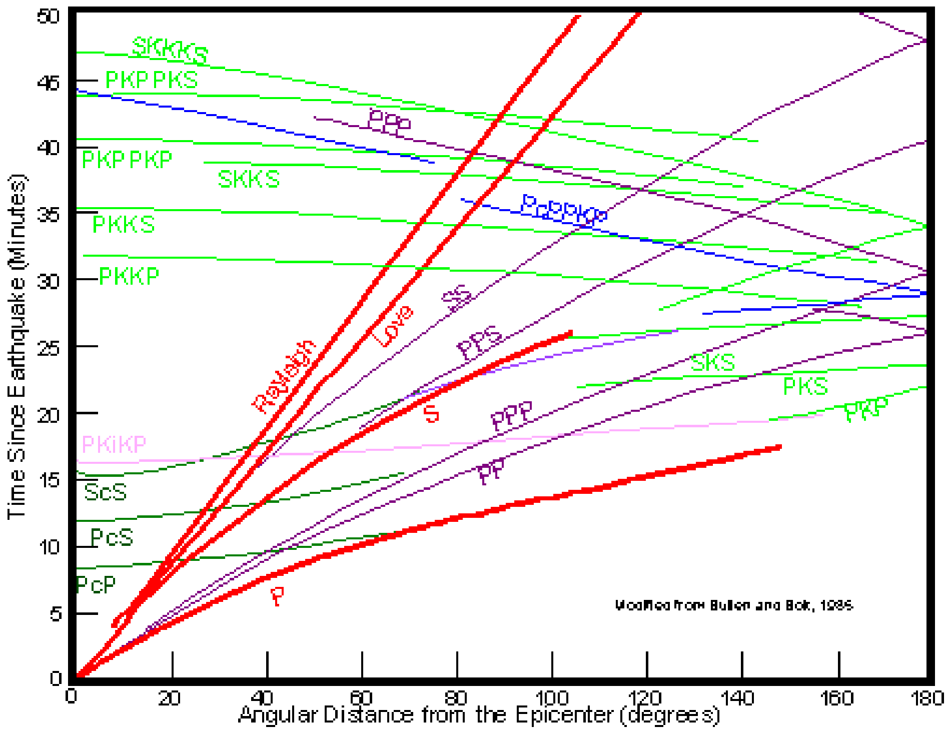
Most obvious test: compare timing of GW signal and EM or neutrino signal from a GRB or supernova

(See next session)

Possible test with untriggered burst search: look for different polarization modes arriving at different times

In some ATGs, different modes travel at different speeds

If speeds are known, provides an absolute distance measure



Extra Polarization Modes

In principle:

A theory with N modes can be ruled out using a network of $N+1$ detectors

Assumes that arrival direction is known

and that at least $N+1$ modes are actually excited

In practice:

If arrival direction isn't known, need at least $N+1$ detectors just to suppress glitches

Extra modes need to have decent SNR to be identifiable

Source Dynamics

Need a good source model to identify a *quantitative* change

Not available for most burst sources

Another possibility: *qualitative* change in signal received

Especially if little or no signal was expected

Example: spherical stellar core collapse (?)

Questions

How well can "standard" burst searches detect GWs in ATGs?
Is there value in performing a non-coherent search?
Should alternative coherent methods be developed?

Can GWs really travel faster than light?
Should we be doing searches for multiple modes arriving at different times?

What source dynamics excite what extra modes?
In particular, stellar core collapse
What ATGs could lead to surprisingly large signals?

What can/should we take from the theoretical literature?
Most interesting theories to test? (or most feasible...)

How strong is the motivation for an Australian detector in terms of better capabilities for ATG searches?