Summary of Detection Checks

Peter Saulson, 15 February 2005

	Burst	Inspiral	CW	Stochastic
Software check	yes	yes	yes	yes
Statistical confidence	yes	yes	yes	yes
Coincidence	crucial	crucial	yes	yes, by pairs
Signal character	Signals from multiple ifos must match each other.	Signal must match a modeled binary.	modulation	smoothness
Veto (instrumental, environmental)	Temporal coincidence with another channel	Temporal coincidence with another channel	Known line, or cross-correlation with another channel	Known features
Repetition/Stationarity	?	?	yes	yes
Data Integrity	yes	yes	yes	yes
Instrumental Integrity	HW injection, and ifo state at time of event	HW injection, and ifo state at time of event	HW injection	HW injection
Optional external information	External trigger	External trigger	Known source	?

Members of the Detection Committee from the various Search Groups provided very thoughtful documents outlining how their groups would test an apparent detection for the "ring of truth". In the table above, I've risked oversimplification to shoehorn those individual lists into a set of common categories. I think this is useful, to get beyond the differences in style of the different original documents, and to see the extent to which there is common ground among the different searches. (It also helps to see where there are unavoidable differences.) In the following, I go through each category of check, explaining briefly how it applies to each of our searches.

Software check: All of our search software is already subject to careful review. We would almost certainly want to look again for any possible bugs that might explain a detected signal. In many cases, we would also want to check that different analysis methods gave similar results. (In the case of transients, it would be feasible to inspect by hand the interval in which the signal is found, thus allowing many analysis methods to come into play.)

Statistical confidence: The unusualness of a candidate signal is the fundamental indicator of a possible detection, in all searches. *But we have no consensus on how unusual a signal should be before we say we've detected something.* Other considerations: How is the probability distribution or background established? Are the

results robust against small changes in algorithm, data selection, etc.? Checks of these questions will be important in establishing the reality of a signal.

Coincidence: All of our searches will take advantage, in some combination, of having the LIGO and GEO interferometers online for the search, but each takes advantage differently. The transient searches use temporal coincidence as a foundation of recognizing a potential signal. The stochastic search needs two data streams to compute the correlation that is the indication of a signal; additional coincidence tests come from using multiple pairs of interferometers. The CW search can in principle recognize a signal in a single interferometer; looking in multiple interferometers will still be a crucial confirmation, however.

Signal character: The inspiral search requires that the detected waveform exactly match a calculated waveform for some physically plausible binary. (This gets harder for black hole binaries, but should still be possible.) The CW search requires that the detected waveform is consistent with a simple signal (e.g., a perfect sinusoid, or one that has a very slowly varying frequency) that has been modulated in amplitude and phase in a manner consistent with a particular position on the sky. The burst search, by assumption, can't require a match with any particular waveform; however, it can insist that the outputs of all interferometers be consistent with a single pair of waveforms $h(t)$ for the plus and cross polarizations, for some position on the sky. (The waveform must precisely match in H1 and H2.) The stochastic search can insist that the spectrum of the ostensible background be smooth, and not dominated by the kinds of narrow lines that would be indicative of some kinds of instrumental cross-correlation.

Vetoes: The inspiral and burst searches are carrying out extensive studies looking for other channels (either environmental or instrumental) in which transients predict/explain transients in the gravitational wave output of the interferometer. Insisting that no such signals are present (above an appropriate threshold) will be an important part of ensuring that a candidate GW signal is real. The CW search keeps track of lines that are instrumental in origin, so that they won't be mistaken for signals from pulsars. The stochastic search is looking for ways to distinguish instrumental correlations from those induced by a gravitational wave background; narrow spectral features are assumed to be instrumental in origin, for example.

Repetition/Stationarity: The stochastic and CW searches can require that a real signal be present permanently, and so can examine a later data set to check an apparent detection in an earlier data set. They can also check the accumulation of signal-to-noise in their search, to see that it is consistent with a steady signal, not one that comes and goes (with any pattern or none at all.) The transient searches will likely first encounter just a single signal strong enough to detect (although there is some study in the Burst Group of "distributional analysis" that looks at how to detect an ensemble of weak signals.) *Are we prepared to go public with a detection of a single transient signal?*

Data integrity: Any detection claim will need to be checked against the possibility that signals were actually being injected (either planned, accidentally, or surreptitiously.) We

will also need to do our best to ensure against data corruption or tampering. (Checking in multiple copies of the same data is one possible way; are there others?) These questions focus on a particular time for the case of transient signals, but apply to a long interval for the searches for steady signals.

Instrumental integrity: Any detection claim needs to be based on a justified belief that the instruments were working properly. For steady signals, this mostly means that the calibration is well understood, for example checked using hardware injections. For transient signals, the questions focus especially on the time near the putative signal: Were the interferometers in their nominal operating conditions at the time? Was the environment quiet? These judgments involve considerable expertise, and will probably need to be made by a team of instrument experts.

Optional external information: We need to be prepared to discover gravitational waves in the absence of any other observations of the source. But in some cases other kinds of observational evidence may be available, and could certainly help in making a convincing case that the gravitational waves were real. The burst search has developed a special pipeline to focus on times when external triggers (e.g. from gamma ray bursts) are available, and has also subscribed to a variety of sources for such triggers. An electromagnetic transient at the time of a binary coalescence could also be convincing (and would certainly be interesting.) One track of the CW search involves known pulsars; besides the convincing match in frequency and sky position, one could imagine follow-up studies that matched frequency evolution (either steady or glitchy) between the radio pulsar and the GW signal. It is not clear that there is any analog of these activities for the stochastic search.

Relation to theoretical expectations: We wouldn't want to claim a detection that violated known laws of physics. But we also wouldn't be in this business if we weren't at least somewhat optimistic about the possibility that we might come across a phenomenon that was not yet predicted or observed in some other way. There is a school of astronomical thought (attributed to Lyman Spitzer) that says one should not believe an observation that doesn't have at least one possible theoretical explanation. *We need to think about how to appropriately link any detection to astrophysical theory and to potential corroborating observations.*

Thoughts on process for approving a detection claim
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After reviewers approve, they should join Detection Committee (and UL Chairs) for a second review. Nature of review is to check that all "scientific checks" have been done properly, and give answers that strongly point to detection. We want to be sure beyond a reasonable doubt that the claim is correct. Our ideal is a "gold plated" signature.

Scientific checks:

1. correctness of software
2. statistical confidence
3. understanding of the instruments
4. ability to rule out non-GW explanations
5. cleanliness of data and signatures
6. use of follow-up LSC gravitational wave observations
7. connection with astrophysical theory
8. (checks with other gravitational wave detectors, and other astronomical observations)

Detection Committee approval is needed on the first seven criteria before any outside communication, and in particular before seeking "outside" GW or other astronomical data to follow up. ("Outside" means not engaged in an ongoing collaborative search for the signal class in question. So GEO is not outside on any search. On basis of present MOU, TAMA would be definitely outside for stochastic and periodic, inside on burst or inspiral.) Requests for information should be made discreetly, and without any expressed or implied belief in the reality of any signals at the time of the request. Requests for data should be broad enough so that the precise nature of candidate signals can't be determined from the request itself. (e.g., for impulsive signals, more data than just the time of the candidate burst signals should be requested.)

We would want to ensure that instrument experts have given up on the plausibility of an instrumental explanation for the apparent signal. This may require assembling a tiger team to check for possible instrumental effects.

A detection involves different kinds of statistics than does setting an upper limit. Parameter estimation will come to the fore for the first time, so special review will be required for the correctness of any statements made about the characteristics of the signal.

Any indications of possible detections should be a regular part of communications by the Search Groups to the rest of the LSC at the data analysis sessions at LSC meetings.

Formal presentation of the case for a detection must be made at an LSC meeting, and approved by the LSC, before any announcement is made to scientists outside of the LSC. A paper should be presented to the LSC in advance for its approval. The paper is really required here, because upon approval we will need to be ready to communicate clear and

complete details to the outside world. (This does not apply to a first request for corroborating data, so long as that request can be made in a discreet way.)

Upon approval by the LSC of a detection claim, we should communicate it to our GWIC colleagues before an announcement to the general public. We need to allow sufficient time for a thoughtful response. (How long is that?)

If there are substantive comments from GWIC, the Spokesperson should ask the Search Group to address them. In particular, if there are any other relevant observations beyond those sought previously, their results need to be taken into account.

Once all comments have been addressed, a paper should be posted on gr-qc and simultaneously submitted to an appropriate letters journal for prompt publication. The author list should be the full standard LSC observational papers author list, plus the names of any other outside scientists whose contributions made a substantial impact on the paper.

We need to consider the possibility of time pressure for good scientific reasons. For example, we might receive a supernova alert or GRB alert, and the announcement of a gravitational wave detection might influence the planning of subsequent observations by outside astronomers. Could we do carry out this procedure in a rapid fashion for a first detection, or only subsequent ones?