**New Folder Name** WAVE BURST EXPERIMENTS

# COINCIDENCE GRAVITATIONAL WAVE BURST EXPERIMENTS WITH WIDE-BAND DETECTORS OF DIFFERING SENSITIVITY

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## ABSTRACT

We investigate the effective sensitivity of coincidence experiments done with three wide-band gravitational wave detectors of differing sensitivity, with optimum choices of thresholds for the detectors within a constraint of a maximum allowable chance coincidence rate arising from Gaussian noise. In a typical example, degrading the amplitude sensitivity of one detector in a triple coincidence experiment by a factor of 2 reduces the effective sensitivity of the whole experiment by a factor of only 1.25 when thresholds are optimized.

## 1. Introduction

The possibilities of coincidence experiments involving two or more wide-band gravitational wave detectors have made it important to estimate the effective sensitivity of gravitational wave burst experiments involving detectors of differing individual sensitivity. We consider here simple threshold-crossing coincidence experiments, in which coincidences are sought between times when the detector outputs cross preset thresholds. The choice of thresholds in such experiments is arrived at by balancing detection efficiency against the rate of chance crossings due to noise, but the optimization may not be immediately obvious if the detectors are not of equal intrinsic sensitivity. We consider some simple cases, and determine the loss in effective sensitivity in a threefold coincidence experiment as the sensitivity of one of the detectors is reduced, with the thresholds kept optimized. In general it is advantageous to choose a low threshold, and correspondingly high singles rate, for the least sensitive detector. The resulting accidental coincidence rate is kept down mainly by the lower rate of singles from the more sensitive detectors.

This work is relevant to one aspect of the detection strategy in the LIGO Project[1]. LIGO will carry out gravitational wave burst searches with systems comprising three laser interferometer gravitational wave detectors in which one of the interferometers has shorter arm length than the other two. This paper quantifies the loss in sensitivity obtained with three such detectors operating in coincidence compared with that from three detectors of equal arm lengths, when the dominant background is Gaussian noise. LIGO will have a full length and a shorter-arm detector at one site, and a full-length detector at a distant site, thus giving the geographical isolation between coincidence detectors essential for discrimination against local disturbances, along with economy in co-locating one pair of detectors which may share common vacuum pipes. Such a system can give information on the dependence of test mass motion on test mass separation. This provides a specific signature for gravitational wave signals and improved discrimination against many possible disturbing phenomena. The detector with shorter arms will in most cases have poorer gravitational-wave

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strain sensitivity than the others. For similar detectors with equal laser power, and arm lengths in the ratio 1:2, the ratio of sensitivities can be 2:1 when the dominant noise source is thermal or other stochastic noise affecting the test masses. If photon shot noise is the dominant factor in a broad-band interferometer the sensitivity ratio with light recycling limited by mirror losses will be $\sqrt{2}$:1, while if there is no recycling the sensitivity can be independent of arm length if the storage times in the arms are sufficiently long.

## 2. Experiments Compared

We compare two experiments:

(a) A triple coincidence experiment performed with three detectors of equal sensitivity, two located at one site and the third at another, similarly oriented, site; and

(b) A similar experiment to (a), but with one of the detectors at the first site replaced by one of lower intrinsic sensitivity.

We explore the effective coincidence sensitivity of the experiment as a function of the detector thresholds to find an optimum combination of thresholds consistent with some practical constraints. Here we take the "effective sensitivity" of an experiment to be the amplitude of gravitational wave burst which, with optimum polarization and direction of propagation, has a 50% probability of being detected.

We have adopted two constraints on accidental rates:

(1) a maximum coincidence accidental rate arising from detector noise, which we take as 0.1 coincidences per year to enable a low rate of events to be significant;

(2) an upper limit to the single threshold-crossing rate of any one detector, which we choose to keep below 1% the probability that a threshold crossing occurs within a coincidence resolving time of a previous threshold crossing by the same detector.

The accidental rates depend on the resolving times used. For local coincidences between the two detectors at one site a short resolving time can be used, and we take for this a value equal to half the dominant period of the impinging gravitational wave. For coincidences between detectors on different sites, the resolving time must be extended to allow for differences in the arrival times of the gravitational wave of up to the light travel time between the sites. Here we extend the resolving time by 14.5 msec, corresponding to a representative distance between sites of 4500 km.

We have made two further simplifying assumptions here. We do not take into account any possible use of amplitude correlations beyond simple threshold crossings. Use of more detailed amplitude correlation might improve effective sensitivity slightly, but is unlikely to affect significantly the comparisons involving near-threshold events being made here. Further we deal with a situation in which the significant detector noise can be assumed Gaussian. Some gravitational wave detectors do give a pulse height distribution which includes an excess of relatively rare large pulses, but this would require detailed spectral information for analysis, and is not likely to significantly alter the comparisons made here.

## 3. Results

A summary is given in the accompanying Table, for several situations.

We assume, for clarity, that gains of the individual gravitational wave detectors are adjusted so that a gravitational wave burst gives an equal output amplitude from each. We denote the rms noise level from the higher-sensitivity detectors under these conditions by $\sigma_0$, and the (larger) noise level from the detector of lower sensitivity in each case by $\sigma_1$, integrated over the relevant bandwidths. We represent the effective sensitivity of the coincidence experiments by the corresponding output amplitude from an individual detector, denoting this by $S_0$ for the cases of equal detectors, and by $S_1$ for the corresponding experiments with one lower-sensitivity detector.

| Detector Sensitivity Ratio $\sigma_1/\sigma_0$ | Bandwidth (Hz) | Effective Sensitivity | | Sensitivity Reduction $S_1/S_0$ |
|---|---|---|---|---|
| | | 3 High Sensitivity Detectors $S_0/\sigma_0$ | 2 High Sens. Dets., 1 Low Sens. Det. $S_1/\sigma_0$ | |
| 1.414 | 1000 | 5.5 | 6.0 | 1.09 |
| | 200 | 5.3 | 5.8 | 1.09 |
| | 30 | 5.0 | 5.6 | 1.12 |
| 2.0 | 1000 | 5.5 | 6.9 | 1.25 |
| | 200 | 5.3 | 6.8 | 1.28 |
| | 30 | 5.0 | 6.8 | 1.36 |
| 2.0 ( Thresholds equal ) | 1000 | 5.5 | 7.7 | 1.41 |

We give results for three bandwidths using a Gaussian filter for the bursts and assuming that in each case the predominant gravitational wave frequency is equal to the bandwidth. For each situation we have explored a wide range of sets of detector thresholds consistent with the constraints above, and for each set solved for the amplitude of gravitational wave burst which has a 50% likelihood of being detected in coincidence. Since the resulting systems of equations are transcendental, we obtained the solutions numerically. We give in the Table the optimum sensitivities found. For comparison, we also give in the bottom row sensitivities which would be obtained if the thresholds were not optimized in this way, but were instead made equal in all of the individual detectors, ignoring the differences in their noise levels. This latter choice, which has been used in discussions of detector networks[2] gives in most cases sensitivity close to the optimum found here, the largest difference found corresponding to less than 13% difference in amplitude sensitivity.

The results in the last column of the Table are probably the most significant ones. Here the fractional changes in overall amplitude sensitivity incurred by reducing the intrinsic sensitivity of one of the detectors are listed. Over the range of conditions assumed, the general finding is that the effective fractional reduction in overall amplitude sensitivity is by a factor of about a quarter to a third of the fractional change of sensitivity of the single detector which caused it.

## 4. Acknowledgements

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## 5. References

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